A discussion of acid sulfate soils mapping methodology as applied in Cairns, Far North Queensland

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Abstract
This paper discusses the current methodology used by the Queensland Acid Sulfate Soils Investigation Team (QASSIT) within the QLD Department of Environment and Resource Management (DERM) to map acid sulfate soils in Queensland in a manner capable of assisting regional and local authorities to carry out land use planning, development application assessment, and similar tasks. A recently-completed mapping project in Cairns, Far North Queensland, provides an opportunity to discuss the details of the methodology, its costs and its benefits as compared with other mapping methodologies used in Australia.

Key Words
Acid sulfate soils, mapping, sampling, methodology.

Introduction

Coastal acid sulfate soils (ASS) are soils or sediments containing iron sulfides, primarily in the form of pyrite (FeS_2). They commonly form in coastal environments where a supply of iron, sulfate, and organic matter are available to bacteria in an anaerobic environment. ASS have been forming for many thousands of years and can be encountered in at least 23,000 km^2 of the Queensland coast, both at the surface and buried beneath newer soil layers (National Working Party on Acid Sulfate Soils 2000). ASS are relatively benign in their natural (wet or buried) environment but can be hazardous when disturbed, having the potential to cause widespread environmental damage via the release of acid and metals from the soil. As such they have become an issue of concern for environmental and planning authorities. QLD government State Planning Policy 2/02 (Government of Queensland 2002) makes ASS mapping a priority, and mapping projects are ongoing along the extensive QLD coastline.

Spatial Representations of Acid Sulfate Soils

Acid Sulfate Soils mapping has been undertaken in a number of Australian jurisdictions within the last 15 years. Approaches have varied in their details, but have mostly focused on representing the risk or hazard of encountering ASS at a particular point in the landscape using methods similar to the 'integrated survey' approach (Hewitt *et al.* 2008). This approach has allowed for relatively rapid identification of coastal landscapes containing ASS, since it is largely based on geology data and/or aerial photo interpretation (API) accompanied by minimal confirmatory fieldwork (Naylor *et al.* 1998; Rampant *et al.* 2003; West Australian DEC 2007). Maps produced from such programs have been reasonably successful in assisting planners with ASS avoidance and management, but are not without problems. There is some suggestion that the extent of ASS has been underestimated in some landscapes (for example, compare ASS extent estimates in Rampant *et al.* 2003 and Victorian Department of Sustainability and the Environment 2009). Additionally, the concepts of risk and hazard themselves are frequently poorly understood and communicated, leading to map misinterpretation and poor decision making (Covello and Sandman 2001).

Other programs have employed more conventional fieldwork-heavy approaches which aim to map the occurrence of and depth to ASS, using remotely sensed and other data as assistants to mapping rather than primary information sources (Hill and Edmeades, 2008; Malcolm *et al.* 2002). The 'free survey' technique (Reid 1988) has not recently been favoured in Australia but may be more appropriate for ASS maps, given the heterogeneity and unpredictability of low coastal plain deposits. Mapping in Queensland presently takes this approach, using field and laboratory data to delineate land units of a relatively homogeneous 'depth to ASS' as well as highlighting particular ASS features such as degree of oxidation (QASSIT 2002). However, free survey has its own problems, in particular the expense of field operations and laboratory analyses and the slower production pace. QLD ASS mapping is considered to be highly accurate at the scale at which it is produced (usually 1:50,000 or 1:25,000), but only limited areas of the state's coastline have been mapped at present and workers in many jurisdictions remain reliant on secondary mapping sources to estimate the extent of ASS.

Planning to Map: Data Sources and Sample Site Selection

QLD ASS mapping project planning starts with a general literature search focusing on relevant landscape processes. An understanding of how landscape processes operate in the project area is essential to successfully applying the free survey technique, as sites are chosen in part to represent particular geomorphic and soil-forming environments. Of particular relevance to ASS survey are articles on estuarine formation processes (Dalrymple *et al.* 1992; Roy 1984) and Quaternary sea-level change (Pickett *et al.* 1985; Bloom *et al.* 1974), along with standard references on soil survey and laboratory methods (Ahern *et al.* 2004; Ahern *et al.* 1998; McDonald *et al.* 1990). Locally-specific information enhances understanding of the project area. In Cairns, some geological studies were available from the Geological Survey of Queensland (Jones 1985) and the QLD Department of Mines (Willmott and Stephenson 1989). Discussion of local coastal fringe geomorphology was available in Bird (1972) and Beach Protection Authority (1984).

Site selection is further guided by a combination of aerial photography and high-resolution elevation data, which together are capable of revealing landform and vegetation patterns indicative of ASS-forming environments. High-resolution aerial photography of the Cairns area was sourced from DERM archives, with the most recent rectified mosaic produced in 2006. The oldest full-coverage aerial photography from 1952 was used for comparison purposes, as development activity in the intervening decades has obscured or removed many landform and vegetation patterns.

A recurrent problem in ASS mapping is a lack of access to high-quality elevation data. Since the QLD mapping centres on detecting depth to ASS, accurate elevations are essential for normalising data across sample sites. In addition, small changes in elevation can signify changes in the depositional environment (for instance the existence of prior stream channels and swamp basins) which often imply a change in the depth to ASS and other soil characteristics. Elevation data therefore has a role in both sample site selection and map unit boundary delineation. Coastal ASS mapping project areas in QLD are naturally low-relief and low-elevation (<10m AHD), and so contour intervals >2m have limited utility. For the Cairns mapping project, Cairns City Council provided high-resolution Light Detection and Ranging (LiDAR) elevation information, allowing production of contour lines at up to 0.25m intervals. 0.5m and 1.0m contours proved most useful during field activities, revealing useful information without adding excessive and confusing detail.

Sample site densities required to produce maps of a given scale are discussed in McKenzie *et al.* (2008). The suggested rate of 1-5 sites per km^2 for 1:50,000 scale maps was met or exceeded by the survey team in 65% of the Cairns project area, using a standard target of 4 sites per km^2. While many sample sites are located on public land, site access is still often governed by landholder permission, geography, and safety. Site density in QLD ASS mapping is generally low in highly urbanised areas, national park and similar reserves, and in areas of low-lying mangrove flats. This is not necessarily problematic when producing a planning map, although it does mean that mapping data may not be well-suited to spatial statistical analysis. Urbanised areas are already disturbed significantly by excavation and filling activities and may also have undergone neutralisation treatment in places, and so a) mapping information isn't needed as much and b) sample sites within them cannot be extrapolated from spatially in the way that 'natural' sites can be, and therefore aren't very useful. Areas of marine plants (e.g. mangroves), parks and reserves, other areas are protected by several QLD laws (e.g. the *Fisheries Act 1994*) and are therefore not under significant development pressure. Mangrove areas can also safely be assumed to contain significant ASS from the surface downwards as a natural consequence of the interaction of ASS-forming factors. The maps therefore remain useful for decision-making in a planning context despite their variable sampling intensity.

Soil Description, Field Testing and Sampling

Sampling equipment for ASS needs to extract a minimally disturbed/contaminated core large enough to describe and sample, and needs to be able to consistently reach the depth of ASS across the project area. This can be difficult to accomplish in the saturated, variable-textured sediments common to low coastal plains, but a variety of suitable machines and hand-operated samplers are available. In the case of the Cairns project, most mechanical sampling was undertaken with a GeoProbe™ model 54DT coring machine or a trailer-mounted vacuum vibro-corer. Hand sampling in difficult to access areas was undertaken using soil, sand, and tapered gouge augers. Augers were constructed to order from stainless steel, as equipment corrosion is a significant issue in ASS survey. Corrosion and sample cross-contamination is kept to a minimum by thorough cleaning at each site, using a high-pressure water sprayer. Based on QASSIT's field experience, sample site depths need to reach at least -1.0m AHD.

ASS sample site profiles are described according to MacDonald *et al.* (1990) with soil colours identified using the Munsell™ soil colour charts. This system identifies soil features in a manner consistent with other soil surveys carried out in Australia, and allows emphasis to be placed on soil diagnostic features particular to ASS (distinctive colours and mottle patterns, presence of shells and/or organic material, etc). Field tests of pH in water and pH after reaction with concentrated hydrogen peroxide are conducted according to Ahern *et al.* (1998) at 0.25m intervals down the soil profile (including at least one sample per horizon). Samples are collected at standard depths of 0.0-0.1m, 0.2-0.3m, 0.5-0.6m, 0.8-1.0m, 1.3-1.5m and every half-metre thereafter. Sample depths are adjusted when intersected by horizon boundaries, and a minimum of one sample per horizon is taken. Larger sample volumes are taken when the soil contains a high proportion of particles >2mm, since these coarse particles are discarded in the laboratory prior to grinding and analysis. Samples are stored in airtight plastic bags, accompanied by a waterproof identification tag. Bags are immediately stored in a portable fridge/freezer to minimise oxidation. In Cairns, samples were transferred to a deep-freeze unit at the end of each working day, and transported by refrigerated courier to the DERM soils laboratory in Brisbane in larger batches at the end of each sampling trip. Samples were kept frozen for no longer than three weeks before processing, although frozen storage for up to several months is possible with minimal oxidation.

Data and Laboratory Analysis, Map Construction

All samples are thawed and air-dried at 85°C for a minimum of 48 hours, which minimises oxidation during drying, before fine-grinding to 0.5mm. ASS laboratory analysis is carried out according to Ahern *et al.* (2004; now Australian Standard 4969), with soil descriptions and field pH test results being used to guide sample analysis. Soil descriptions are entered into an electronic database and used to produce a GIS-ready dataset containing key soil and site features, lab results, and location information. Sample sites are assigned map unit codes according to the protocol described in QASSIT (2002) and then overlaid on elevation and air photo data. Units of homogeneous landform, depth-to ASS, and type of ASS are delineated by hand according to the managing project officer's best judgement and geomorphological understanding of the area. Since the map units produced by this method contain a variable number of sample sites (and because of the variations in sampling intensity discussed earlier) an intensity diagram detailing the effective scale of each map unit is prepared to accompany the ASS map itself. The final mapping product for Cairns was released mid-2009 at an overall scale of 1:50,000, and is accompanied by a detailed report on the project's findings.

Towards a better ASS map?

The approach to mapping described above is considered capable of providing high-quality information well-suited to making planning decisions. Confidence in QLD's ASS mapping remains unquantified, however, due to an unfortunately persistent lack of funding for validation testing. Additionally, there have been few attempts to model or predict ASS landscapes (Hayne *et al.* 1996) in QLD, partly due to lack of funding and partly due to the difficulty of accurately modelling the extremely variable subsurface conditions common to low coastal plains. At best, one can comment that this kind of work does not appear to be standard practice anywhere else. It is possible that the accuracy of new integrated survey projects may improve somewhat (despite the lack of adequate correlative landscape models for coastal plains) thanks to availability of better-quality remotely-sensed data and improved laboratory procedures. However, no known attempts have been made to directly compare the accuracy of the free survey and integrated survey approaches to ASS mapping.

Separate to the debate about survey technique is the issue of how much and what type of information to include on ASS maps. For instance, mapping in some jurisdictions classifies ASS by the depositional environment in which it occurs before referring to other characteristics like depth to ASS. While such information is useful to soil scientists, it is debateable whether such information assists those who depend on the mapping most: planning staff, who generally have little knowledge of coastal geomorphology. At the 'regional' (~1:50,000) scales at which these maps are produced, the information may also be of little practical help to ASS management professionals. Similarly, information on ASS neutralising capacity may introduce a false sense of security when the prospect of disturbing 'self-neutralising' ASS arises, especially given the uneven spatial distribution of neutralising materials and the lower reliability of neutralising capacity analyses in the lab. Information to be included in ASS mapping products should be chosen based on ease of understanding and ability to improve management of ASS environments.

The rapid development of ASS mapping protocols in Australia in recent years raises the possibility of developing consistent national mapping standards. Issues of field and laboratory methodology, data analysis, and information representation such as those outlined in this paper will become significant points of discussion if such protocols are to be established.

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