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Acid sulphate soil interaction with groundwater: a remediation case study in East Trinity

A Vahedian
University of Wollongong, av325@uowmail.edu.au

S Asadzadeh Aghdaei
University of Wollongong, saa832@uowmail.edu.au

S Mahini
University of New England

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Contaminated soil and groundwater resulting from pyrite oxidation occur in coastal areas throughout the world, but do not pose an issue unless allowed to oxidise as a result of drainage or excavation. The exposure and oxidisation of these soils increase the concentration of iron and aluminium ions and cause adverse impact on flora and fauna and also water quality. Depending on the climate conditions and scale of areas contaminated by acid sulphate soil (ASS), several remediation techniques (e.g. fixed-level weirs, two-way modified floodgates, permeable reactive barriers, etc.) can be employed to increase the pH near to neutral and prevent the oxidation of pyrite and production of extra acid. A case study of the East Trinity, the east of Cairns, Queensland, Australia is presented in this study. This region episodically discharges large amounts of acid resulting in periodic fish kills. To remediate the ASS issue, a lime-assisted tidal exchange strategy had been undertaken by the local government. As a result, the quality of water improved and the pH increased from 3.5 to 6-8 and also the rate of aluminium and iron reduced to neutral values.

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Acid Sulphate Soil Interaction with Groundwater: A Remediation Case Study in East Trinity

A. Vahedian [a,*], S. Asadzadeh Aghdaei[b] and S. Mahini[c]

[a,b] *School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW, 2522,Australia*
[c] *Discipline of Civil & Environmental Engineering, University of New England, NSW, 2351, Australia*

Abstract

Contaminated soil and groundwater resulting from pyrite oxidation occur in coastal areas throughout the world, but do not pose an issue unless allowed to oxidise as a result of drainage or excavation. The exposure and oxidisation of these soils increase the concentration of iron and aluminium ions and cause adverse impact on flora and fauna and also water quality. Depending on the climate conditions and scale of areas contaminated by acid sulphate soil (ASS), several remediation techniques (e.g. fixed-level weirs, two-way modified floodgates, permeable reactive barriers, etc.) can be employed to increase the pH near to neutral and prevent the oxidation of pyrite and production of extra acid.
A case study of the East Trinity, the east of Cairns, Queensland, Australia is presented in this study. This region episodically discharges large amounts of acid resulting in periodic fish kills. To remediate the ASS issue, a lime-assisted tidal exchange strategy had been undertaken by the local government. As a result, the quality of water improved and the pH increased from 3.5 to 6-8 and also the rate of aluminium and iron reduced to neutral values.

Keywords: Acid sulfate soils and groundwater; Remediation; Lime-assisted, Weirs

1. Introduction

Acid sulphate soils (ASS) are soils or sediments containing highly acidic soil horizons or layers affected by the oxidation of iron sulphides or any sulphidic substance in the layers [1]. ASS layers are often discovered in

* Corresponding author. Tel.+6-145-111-8680
E-mail address: a.vahedian.61@gmail.com

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surface or near to the surface that the level of groundwater is shallow and frequently changes due to climate conditions [2]. Moreover, in acid sulphate soils, heavy rainfall causes drainage of acid and metal ions into groundwater and, thereby, significantly affects the aquatic ecosystems, human health and infrastructure [1]. Sulphuric acid can release heavy metal and other substances from soil and spread them into the adjacent area which may be surrounded by underground or water stream [3]. The acid runoff from these areas causes diverse range of impact on flora and fauna and also economic impacts including ecological concerns related to aquatic organism such as fish kill, destructive effect on agricultural productivity, fishery industry and tourist resources. It causes groundwater contamination, disrupts biodiversity, and causes steel and concrete infrastructure damage in the coastal area where corrosion is critical. Therefore, the rehabilitation of the affected area is necessary by using different remediation methods which is costly [4-6].

2. Oxidation of Sulphidic Compounds

The principal sulphidic compound in acid sulphate soils is the mineral iron pyrite, FeS2, which when oxidised release large amount of iron compounds, sulphuric acid greenhouse gases, CO2 and N2O and other contaminants that cause to decrease the soil pH below 4 and in some cases below 3 [7]. Rainfall and human activities such as excavation, sulphidic sediments dredging speed up the oxidation. In dry conditions and the absence of water and oxygen, the mineral iron pyrites are stable and desire to accumulate in sediments. However, in wet conditions and the presence of oxygen ASS can completely oxidise and promote sulphide oxidation [8]. The process in the following equation shows the oxidation procedure of this mineral compound produces acid sulphuric in an aqueous environment. In this equation, each unit mole of iron pyrite produces 4 moles of acidity [9]:

$$FeS_{2(s)} + 15/4\ O_{2(g,aq)} + 7/2\ H_2O \Rightarrow Fe(OH)_{3(s)} + 4H^{+}_{(aq)} + 2SO_4^{\ 2-}{}_{(aq)}$$

3. Acid Sulphate Contamination in Groundwater and Remediation Techniques

Contamination of groundwater with sulphuric acid is often due to battery recycling or manufacturing processes [10]. The contamination involves increased sulphate and heavy metal concentrations as well as acidic water conditions. Increased water-rock interaction, especially the dissolution associated with low degree of acidity levels has the potential to significantly alter hydrogeological conditions. In addition, the heavy metals released during water-rock interactions make it even more difficult to differentiate between contaminants from primary and secondary sources. Furthermore, in dry conditions, the evapotranspiration from the groundwater is low, instead when the level of groundwater increased by rainfall, consequently the acidic oxidation products can be transported to the drains [11].

Remediation is the procedure of exchanging the existing acidified freshwater environment which progressively and cautiously managed with a tidal wetland system including:

- Hydraulic suppression of acid release from the soil and neutralizing the existing acidic water with neutralizing materials.
- Making sure of all low lying areas to keep soils wet with the regular tidal inundation, holding up the oxidation of pyrite and producing of extra acid.
- Using hydrated lime for treatment of acid drainage water in order to enhance buffering and precipitate iron and aluminium [1].

In regions which are contaminated by the oxidation of pyrite in the soil forms sulphuric acid, several low cost remediation techniques such as fixed-level weirs and modified two-way floodgates were installed. The purpose of these remediation techniques were to maintain the level of groundwater above the acid sulphate soils, restraining additional pyrite oxidation and decreasing the rate of discharge of acid to drain to prevent of creating reservoirs of acidic water by pH lower than 4.5 that discharge during low tide [12]. Moreover, Indraratna et al. [13] stated that to remediate contaminated groundwater with acid sulphate, using of permeable reactive barriers (PRBs) can be installed because of its advantages such as minimal operation and maintenance costs, no energy consumption, and minimal disruption to the existing land use. In this case, the recycling concrete plays a main role in groundwater remediation since they include the alkaline minerals and by dissolving alkaline minerals, most of metal and Aluminium ions comprised in the groundwater precipitated immediately. Hence, it significantly increases the pH of groundwater near the neutral values [13]. Furthermore, by decreasing the amount of oxygen transported to the sulphidic soil can minimise the generation of acid. The diffusion of oxygen through the air is approximately 105 times faster than through water. Therefore, to decrease the volume of oxygen transported to the pyritic layer, weirs operate as an effective method since the weirs maintain the level of groundwater above the level of sources acid sulphate [14]. One of the standard methods used to remediate groundwater which sulphate is the primary contaminant is pumping and treating. This approach is effective at controlling the contaminant plume, but is generally cost and time intensive. Electro-kinetic methods are another possible in situ alternative for remediation. However, their use would typically be restricted to very small, shallow sites with relatively high concentrations [15].

3.1. Groundwater Level Adjustment Using Weirs

The implementation of a fixed level weirs is the first management strategy that raise the level of the groundwater to saturate the pyritic soil layer, this process prevent further pyrite oxidation. After installing of the weirs, the level of groundwater was maintained above the potential acid sulphate soil (PASS) layer at most locations for the entire monitoring period. Moreover, the level of drain water also rose by more than 0.3m. Increasing in the level of drain decreased groundwater drawdown near to the drains and low hydraulic gradients established (Fig. 1). The groundwater pH changed from less than 3.5 to more than 5 from the beginning of the pre-weir monitoring and dilution by two flooding. To remove sediments that accumulate near the weir, every six months the weirs should be maintained to clear weeds and other debris from the drain [11].

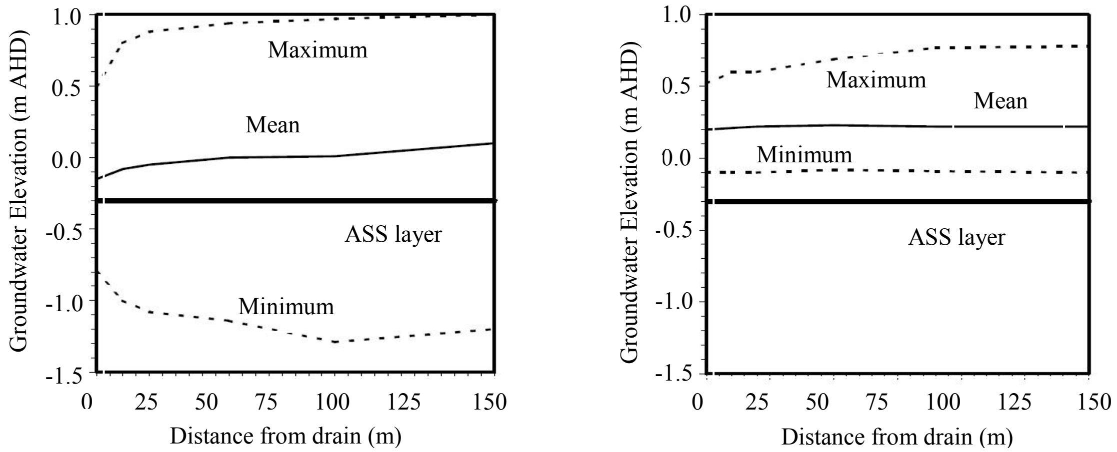

Fig. 1. Average groundwater elevation (a) before and (b) after weir installation, with the maximum and minimum groundwater elevation dashed [11].

4. East Trinity: a Case Study

4.1 Site Description

The East Trinity site is located in east of Cairns across Trinity, Queensland, Australia. The site occupies approximately 700 ha of former wetland and was drained and allocated for sugarcane production by the construction of long bund wall, a network of deep drains and several tidal floodgates where placed on the creek outlets. To facilitate cane production, a large pump was sited at the floodgates on Hills Creek to eliminate tidal water and lowering the natural water table. The main stream traversing the site is Hills Creek which has a pH lower than 4 during periods of low flow in the late dry season [1].

Soil investigation indicated that virtually the entire site below 1.5 m AHD comprises at least some actual acid sulphate soils. However, the actual acid sulphate soils are confined to the regions below the 1 m AHD surface contour, mainly below the 0.5 m AHD surface contour. In these circumstances, it is likely that the acid production and acidification at East Trinity have strongly degraded the land within the drained area and adversely affected the environment for many years to come unless remedial actions are implemented [16].

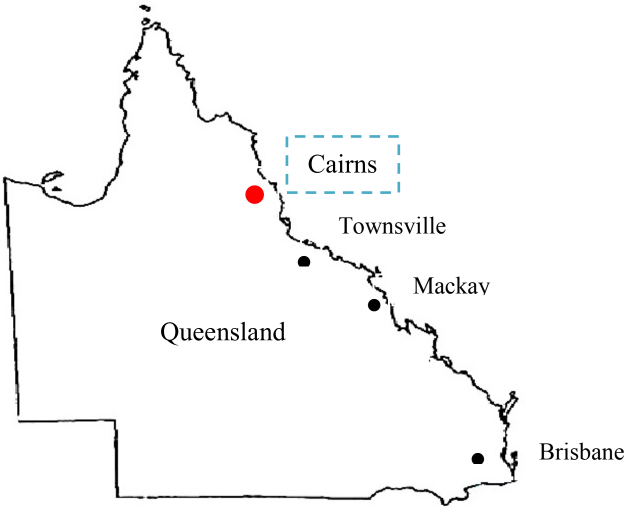

Fig. 2. Location of the East Trinity site

4.2. Remediation Strategy: Lime-Assisted Tidal Exchange

In every remediation project, the associated cost is one of the most effective factors which make a significant impact on selecting remediation approach. According to available information [15], $A 62 million expended to rehabilitate and remediate acid sulphate soils at East Trinity by conventional lime except the cost of substantial earthworks to mix and compound the lime.

The remediation procedure of lime-assisted tidal exchange required comprehensive site characterization including deep drilling, acid sulphate soil analyses, geomorphic descriptions and analyses and ground water assessment [1]. Moreover, in order to increase the oxidation of pyrite, the soil needs to be kept saturated. To cover entire areas where soil acidification has occurred by hydrated lime treated water, one or more of the Hills Creek floodgates should be opened. This method employed automatic tidal regulators (ATR) to accurately control the tidal exchange across the bund wall [2].

4.3. Monitoring

There were some key parameters measured at strategic locations including soil solution and soil redox potential, surface and groundwater quality, suspended solids and colloid and stream biota. The lime assisted tidal exchange has had a positive effect on reducing the acidity of the soil. Although, after 12 month of lime-assisted tidal exchange installation 1pH unit enhancing were observed to a depth of 1.2m below ground level, the soil solution remains acidic as well as drainage water which have been affected by acid contribution of actual ASS regions that are higher than the level of consistent inundation. Adding the hydrated lime caused to exit water form Hills Creek have been quietly maintained above pH 6 to drains and streams in the upper reaches of the Creek (Fig. 3) During tidal exchange period, the pH of the water in the creek improved from 3.5 to more neutral values (pH 6–8) [16]. Moreover, biological monitoring has shown not only that the lime-assisted tidal exchange have had no negative effects on fish communities in Hills Creek, but modest increases in species diversity and richness have been observed [17].

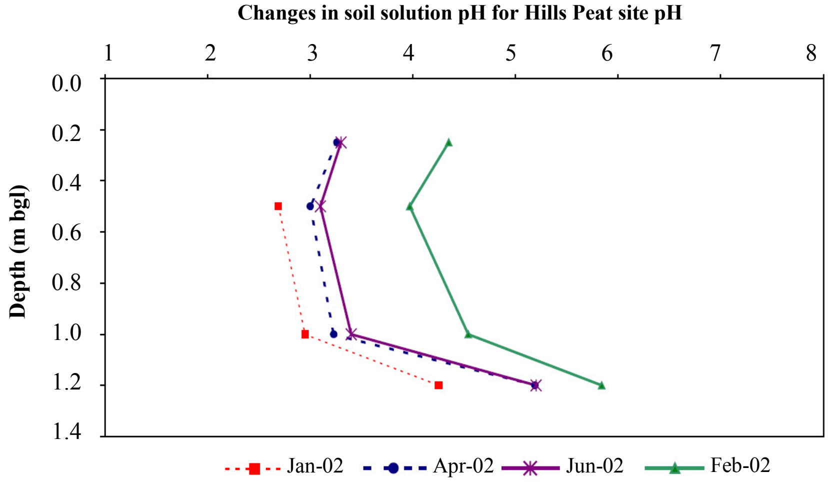

Fig. 3. Changes in soil solution pH for the Hills Peat site (elevation +0.41m AHD). January and April 02 are pre-tidal exchange data. June 02 sampled during Hills Creek floodgate replacement (tidal exchange to+0.5m AHD). February 04 data were recorded after 12 months of lime-assisted tidal exchange to +0.5m AHD [16].

5. Discussion

The increased mobility of acid sulphuric and metals constitutes the greatest threat to aquatic organism, biodiversity of environment, human health and well-being through its devastating effects on agriculture production and pollution of drinking water sources. Consideration of the adverse effects of ASS development is required also in urban areas, both in terms of the effect on the natural and the built environment.

After installation the weirs in flood mitigation drains, the elevation of the groundwater table can be manipulated. Significant rainfall increased the level of groundwater through the region where pyrite oxidation was occurred during the preceding dry period. These changes in groundwater levels can minimize the production of 'new' acid from the oxidation of pyrite by oxygen. Moreover, maintaining the drain water in high level caused lower groundwater hydraulic gradients towards the drain. Therefore reduction in the rate of the acid discharge to the drain is observed.

6. Conclusions

The East Trinity remediation case study reveals the problems within the site related to acidic soil and the high cost involved in prevention of acid intrusion into reef waters. For a comprehensive ASS remediation in Queensland, a combination of soil properties, groundwater and tidal behaviour, terrain modelling, flood modelling and engineering assessment are required. These actions are prerequisite to effective ASS remediation. In conclusion, the strategies adopted in East Trinity were able to resolve the issue of reef water contamination. However, a holistic approach is needed to successfully manage the impacts of ASS disturbances on reef water quality.

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