WASTE NOT, WANT NOT – USING WASTE HAY TO IMPROVE PIT LAKE WATER QUALITY

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ABSTRACT

Pit lakes can present a significant financial, environmental and reputation risk to the company responsible for their management and all stakeholders. If the pit lake is acidic, the stakes are higher. A novel field scale trial, involved the placement of spoilt hay bales into an acidic pit lake, located in the Pilbara region of Western Australia. The aim of the trial was to test whether waste hay would improve lake water quality by promoting the growth of sulfate-reducing bacteria.

Two pit lakes (West and East; pH 3.6 and 5.8, respectively; >1000 mg/L SO_4, depth <10 m, area <1.5 ha, age 5 years) were used for the trial, which ran from August 2015 to March 2016 in both the treated (West) and untreated (East) lakes. Approximately 19 t of waste hay was added to West Lake to create a layer approximately 0.3 m thick across the sediment. Water quality parameters (nutrients, select metals, pH, ORP, conductivity, SO_4 and Cl) were monitored at surface and bottom of the water column, throughout the trial using a combination of grab samples and continuous in-situ monitoring. Data were described over time.

Both lakes were thermally stratified with differences of 3-4 °C over 5 m however, salinity stratification was less obvious. The sulfate to chloride ratio remained constant in the surface water of the East Lake, but there was an indicative decrease in sulfate concentrations (from approximately 10,000 to 8,000 mg/L) and the sulfate to chloride ratio in the West Lake bottom water. Results suggest the deposition of hay had some impact on the quality of deeper (benthic) lake waters, in particular for promoting reducing conditions. The dissolved oxygen concentration in bottom waters decreased from >4 mg/L prior to hay deposition to <3 mg/L.

Waste hay could provide a local source of material for pit lake remediation. However, future trials should focus on assessing the long-term effects of the remediation beyond the 7-month trial, and adding multiple treatment and control lakes.

1.0 INTRODUCTION

Pit lakes can form in open cut mining pits, which extend below the pre-mine water table. Once dewatering ceases, groundwater, surface water and direct rainfall contribute to the formation of a pit lake. As a result of current open cut mining practices extended well below the water table, the quantity and size of potential pit lakes have increased over the last decade.

Pit lakes can present a significant financial, environmental and reputation risk to the company responsible for their management and all stakeholders. This is particularly relevant for pit lakes that are expected to generate Acid and Metalliferous Drainage (AMD). Backfill plans exist for many of these potential pit lakes, however, backfill may need to be done post-closure which may involve rehandling. In some cases pit backfill costs can be over $300 million, therefore, there may be significant advantages to mining companies by not backfilling pits deemed to have a low risk to the environment (McCullough et al. 2013).

2.0 BIOREMEDIATION

Sulfur Reducing Bacteria (SRB) have the potential to remediate AMD as sulfate is converted to sulfide under reducing conditions, using labile organic carbon substrates as electron donors. This process under low redox conditions forms amorphous FeS and FeS_2, removing the elevated acidity, sulfate and associated metals from pit lake water and therefore breaking the acid generating cycle (Castro and Moore 2000). SRB activity can be initiated by the addition of organic materials. However, the success of SRB-based bioremediation is largely determined by the suitability of the material (Neculita et al. 2007). Effective SRB-based bioremediation requires highly labile organic material for sufficient reactivity and must have efficient longevity to sustain the bacterial reduction over a long time frame. Additionally, the organic materials produce anaerobic conditions and facilitate growth of facultative anaerobic bacteria which helps break down recalcitrant organic materials into more labile forms (Wendt-Potthoff and Neu 1998).

Following promising theoretical and laboratory research (Lund et al. 2017), the availability of hay waste from local agricultural projects provided an opportunity to test bioremediation using green waste at the field scale. The water quality results from this trial are presented in this paper. This paper is a descriptive study of water quality trends and forms part of a larger study investigating water quality statistics and the variability of microbial assemblages over time in lakes and microcosms

3.0 LOCATION

Two temporary pit lakes (referred to as East and West Lakes) that began forming in 2010 after active mining and dewatering ceased, were the focus for the trial. These lakes were located in an iron ore mine in the Pilbara region of Western Australia. The climate at the mine site is semi-arid to arid with hot summers and mild winters. Mean maximum temperatures range from 35.9-38.3 ^{o}C in summer (Dec-Feb) and 23-25.5 ^{o}C in winter (Jun-Aug). Rainfall is highly variable and characterised by periodic high intensity rainfall events occurring predominantly in summer months, followed by extended periods of drought. Mean annual rainfall is 399 mm and evaporation is generally >3000 mm annually, exceeding rainfall by an order of magnitude.

In September 2015, approximately 19 t (27 hay bales) of waste hay was added to West Lake to create a layer approximately 0.3 m thick across the sediment. East Lake was monitored however no amendments were added. The pit contained approximately 252,300 m^2 of reactive black shale surface exposures on the pit wall, and most exposures were estimated to have >0.1% sulfur. The pits were groundwater sinks and acidic lake water was most likely constrained to the base of the pit, where it was underlain by relatively impermeable Mount McRae Shale (MCS). West Lake was primarily surface water fed however, East Lake had groundwater input.

Low pH values (3.6-5.8) and elevated sulfate concentrations (>1,000 mg/L) have been recorded for the pit lake waters suggesting that the black shale pit wall exposure may have resulted in some oxidation of sulfides and formation of acidic waters within the pit lakes.

4.0 METHODS

4.1 Pit Lake Bathymetry

A remote controlled boat with a logging GPS and depth sounder was utilised to record the bathymetry of West Lake. West Lake, which was found to have a maximum depth of approximately 9.5 m in the north western pod, with depth decreasing toward the east. A bathymetric survey could not be completed for the East Lake due to presence of abandoned dewatering pipework.

4.2 Water Quality Analysis

The pH, Electrical Conductivity (EC), redox, Dissolved Oxygen (DO) and temperature of both lakes was measured in situ using a combination of Hanna Instruments, Odyssey and Hobo loggers (on thermistor strings). Samples were collected from the pit lake surface and analysed for pH, EC, Total Dissolved Solids (TDS), metals/metalloids, sulfate, chloride, acidity, dissolved organic C and nutrients once every 3 months. Two samples were collected from near the bottom of West Lake, using a low flow bladder pump (QED MP50) 0.5 m from the bottom of the thermistor string.

The dissolved oxygen sensor on the Hanna probe used the Clark cell methodology. This methodology requires a frequent calibration schedule for accurate data collection that was not adhered to for this trial. Scaling and to a lesser extent biofouling were an issue on probes, particularly in shallow waters. Cleaning was completed when the instruments were removed for calibration (as noted in Figures 1-10).

5.0 RESULTS

5.1 Logistics and Field Technology

There are a number of difficulties associated with discerning the effects of hay deposition and potential activity of SRB. Most significantly is the fact that the trial was held on an operational mine site, which created a variety of issues, such as limited access and the project being cut short due to early backfill of the pits. Six months between the deposition of hay and the completion of the trial may not be enough time to see the full *in situ* effects.

The thermistor strings were useful for collecting continuous data. However, issues with biofouling and scaling on the probes meant some probes may have been reporting incorrect data for periods of time and cleaning and calibration needed to be performed quite regularly (as indicated in Figures 1-6).

The untreated East Lake was also monitored to provide a comparison for conditions in the hay treated West Lake. However, there were differences in water chemistry and chemical responses between the West and East Lakes. The East Lake is groundwater connected and therefore far less influenced by rainfall and evaporation processes than West Lake (which has little groundwater input). This meant that East Lake data was less useful as a control for the hay trial.

5.2 Water Levels

Water level monitoring of the West Lake revealed a drop during the dry period indicating the lake level is strongly influenced by evaporation and precipitation. In contrast, the East Lake level stays more constant as groundwater inflow is roughly equal to the water lost by evaporation. This result is consistent with the variation of ~2 m in the calculated water depth above the pressure logger for the West Lake compared to <1 m for the East Lake.

5.3 Thermal Stratification

Both lakes were thermally stratified with differences of 3-4 °C over 5 m (Figures 1 and 2). However, temperature stratification disappeared in the upper 1-2 m in both lakes following rainfall events of >20 mm. No clear complete turnover of bottom and surface waters was observed.

5.4 Continuous In-Situ Water Quality

Prior to the deposition of hay, the pH at the surface of West Lake ranged from 3.3 to 3.5. There was a noticeable drop of ~0.5 pH units following the deposition of the hay in September 2015, which was followed by a gradual increase in pH (Figure 3). Following the Hanna Probe being moved to deeper waters in November 2015 in West Lake, the bottom water pH varied over of 0.7 pH unit range, in an apparent cyclic manner. This cyclical change may have been associated with recharge although it does not correlate well with rainfall data. Additionally, this cyclical pattern is only visible in the deep water which suggests that it is associated with unique processes possibly caused by the hay. From late January 2016 there was a rapid increase in bottom water pH, starting from a low of ~3.1 reaching pH 4.5 just prior to the end of the trial. The beginning of this sharp change coincided with a high rainfall event. However, the observed subsequent exponential increase in pH would not be consistent with a change due to higher rainfall. The change in pH was mirrored by a lowering of redox potential (Figure 4) and indicates that reducing conditions developed within the deeper lake waters and that these changes may have been associated with microbial (SRB) activity in the deeper waters of the lake. Similarly, DO concentrations at 4-5 m depth were close to zero for the same period (Figure 5). Slight periodic increases in bottom water DO appeared to have coincided with rainfall events and may represent the percolation of oxygenated meteoric waters into the water column. In comparison, the DO measured at 7 m in East Lake indicated fairly oxygenated waters at depth (Figure 6).

5.3 Grabbed and Pumped Water Quality

The pH measurements of surface waters from both lakes were variable and there was a considerable change in pH for both lakes between February 2015 and May 2015 (Figure 7). However, the pH of the West Lake surface water fell from around 4.8 to 3.4 and the pH of East Lake surface water rose from ~3.8 to 4.7. This difference between lakes was likely due to the higher groundwater inflow into the East Lake. The lower pH in West Lake may have been exacerbated by surface water runoff over PAF exposures in the pit wall. The salinity (EC and TDS) of water was generally higher in the West Lake and higher for bottom water compared to surface water (Figure 8). This is consistent with the higher influence of evaporative concentration in West Lake compared to East Lake. The EC does appear to fall following large rainfall events and then rise during dry periods. However, there are no obvious changes in salinity relating to hay deposition.

Major ion concentrations are mostly correlated and follow the same trend of EC suggesting they are mostly influenced by evaporative concentration during dry months and dilution following rainfall events. Decreased sulfate concentrations in West Lake deep waters (4-5 m depth) may indicate that SRB activity has occurred (Figure 9). Sulfate reduced by 2,200 mg/L despite increased chloride and salinity between November 2015 and March 2016. This suggests the changes in sulfate are not associated with normal evaporation and dilution processes because sulfate would have increased linearly with chloride (Figure 10).

Furthermore, an increase in West Lake bottom water pH from 3.5 to 4.5 was recorded. Unfortunately there is no data for bottom water prior to hay deposition and only two points overall so it is not possible to compare or observe the full extent of variation in bottom water chemistry. These changes were not observed in the surface water chemistry. Metal concentrations did not follow the same trend for sulfate in bottom waters, with a number of metals (e.g. Fe and Mn) increasing and only Cu decreasing between the two collected time points.

6.0 CONCLUSIONS

Temperature, water pH, dissolved oxygen and sulfate concentrations highlight changes in water chemistry and thermal stratification of the West Lake between anoxic deeper waters and more acidic and oxic shallow waters. Deep waters in West Lake increased in pH levels and decreased in dissolved oxygen and sulfate, most notably from late January 2016, which could be attributed to SRB activity following hay deposition. The water quality changes seen in West Lake after hay treatment were not seen in East Lake.

The results from this trial are promising and suggest addition of hay may be capable of improving pit lake water quality. However, it is difficult to produce firm conclusions and determine the potential long term success of the remediation. Further work is required and any opportunity to implement a longer term remediation trial in existing pit lakes would be invaluable for investigating and providing techniques for remediation of acidic pit lakes.

7.0 ACKNOWLEDGEMENT

The Hamersley Agriculture Project and RTIO mine site operations were instrumental in implementing this project safely.

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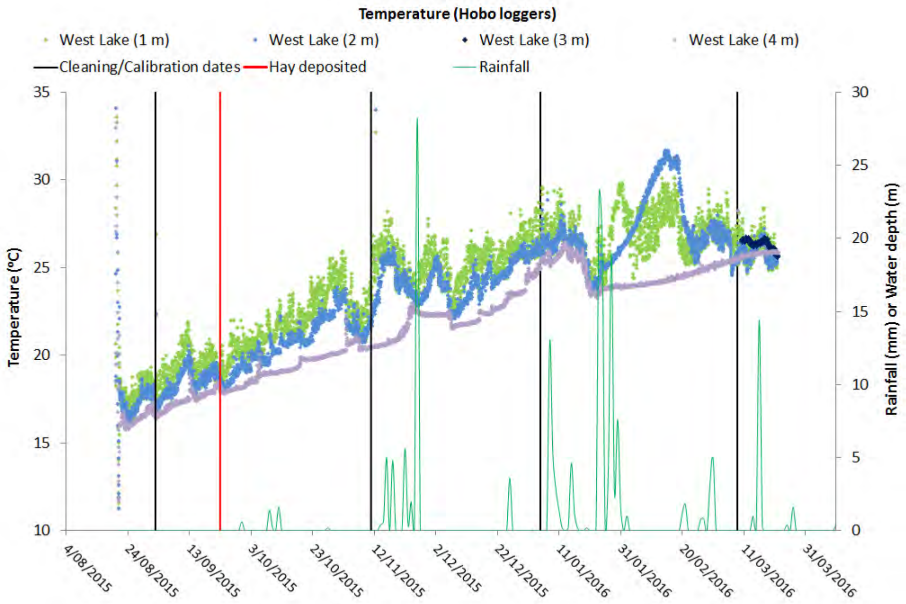

Fig. 11. Temperature within West Lake at various depths.

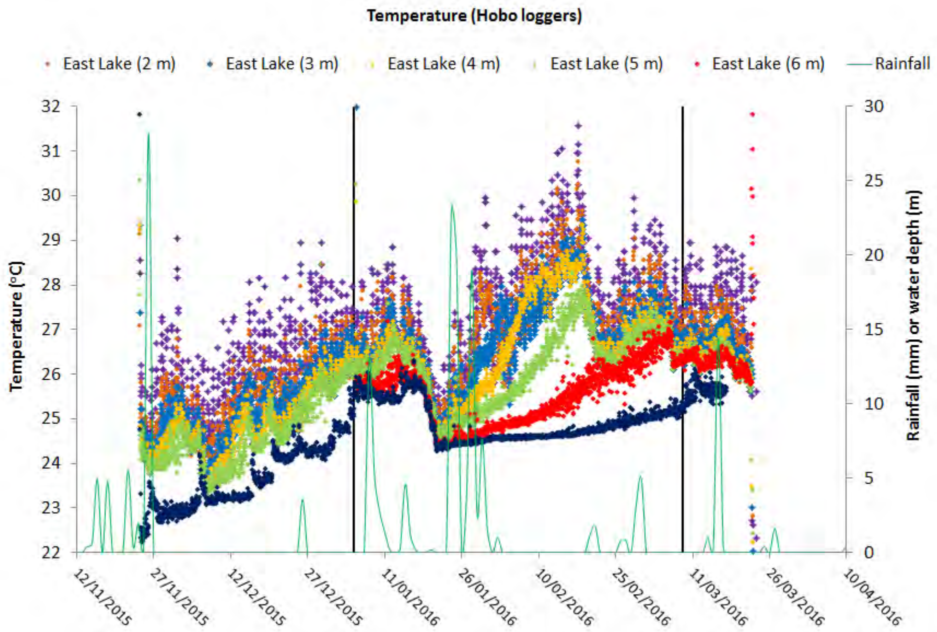

Fig. 2. Temperature within East Lake at various depths.

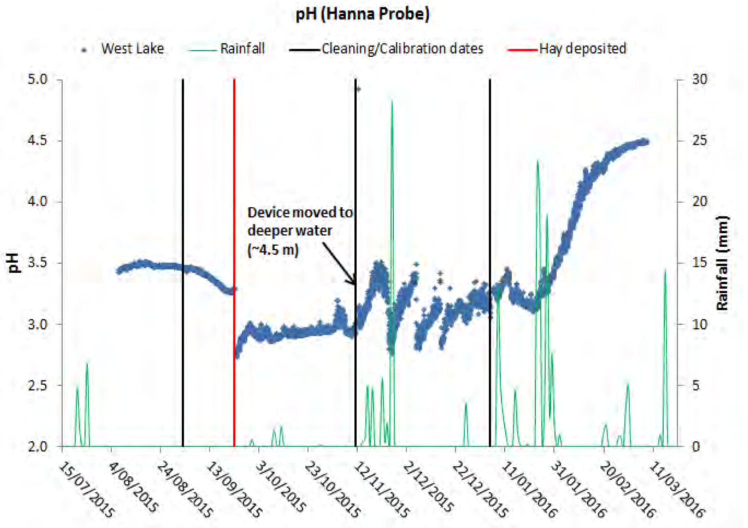

Fig. 3. pH within West Lake over the trial.

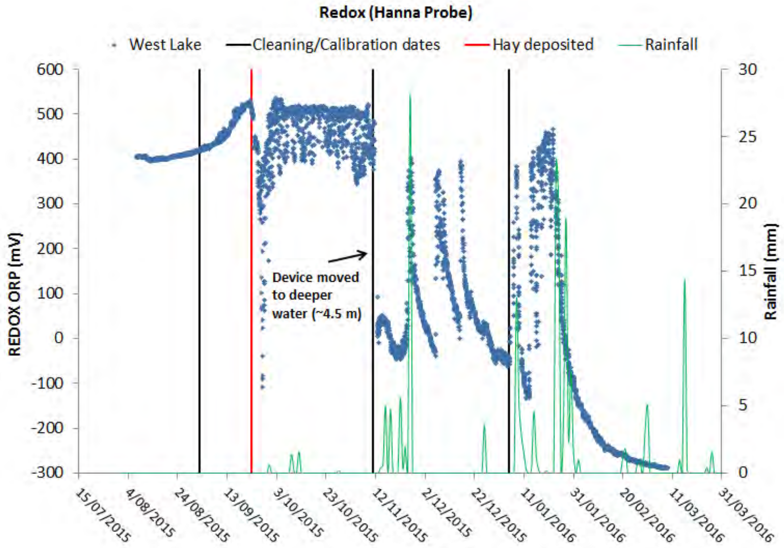

Fig. 4. Redox potential in West Lake over the trial.

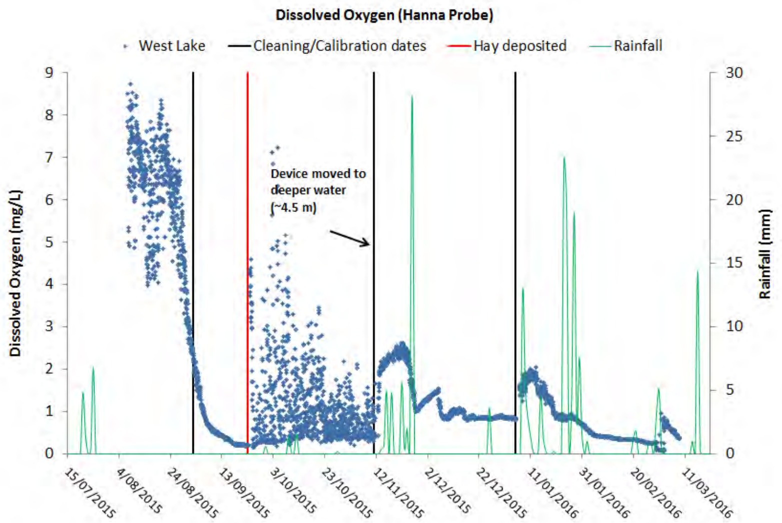

Fig. 5. DO concentration at ~4.5m depth in West Lake over the trial.

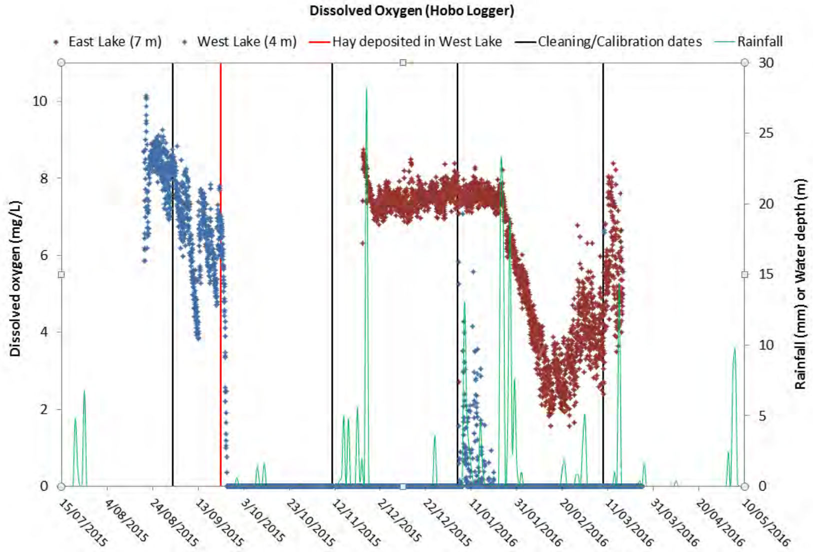

Fig. 6. DO concentrations measured at ~4m in West Lake and ~7m in East Lake over the trial.

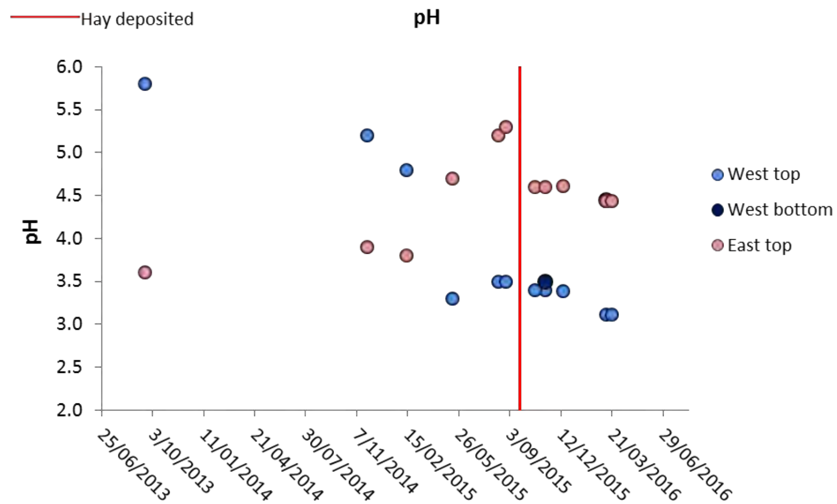

Fig. 7. The pH of surface water measured in the East and West Lakes.

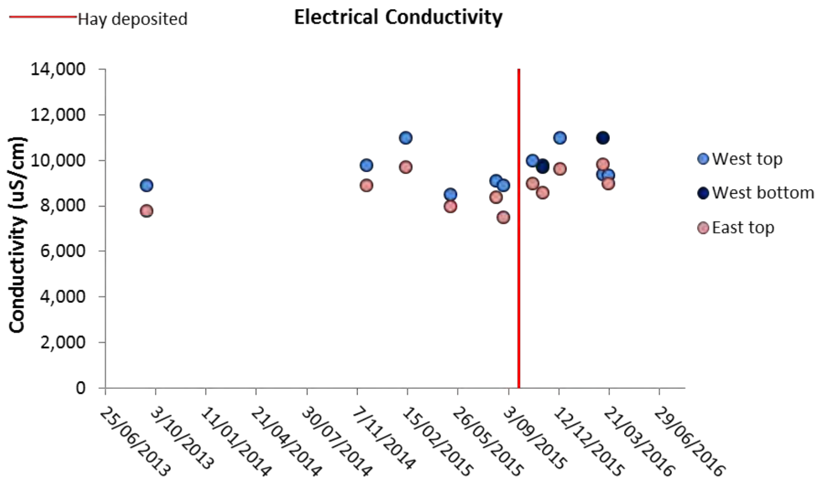

Fig. 8. The electrical conductivity of surface water measured in the East and West Lakes.

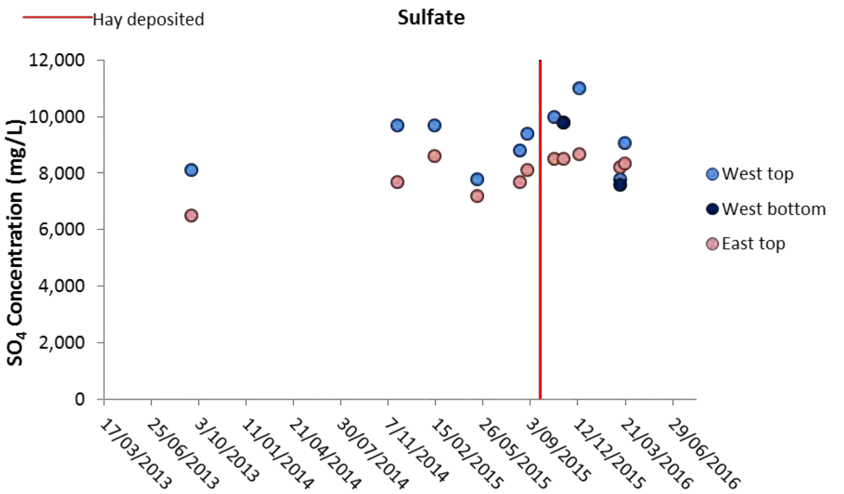

Fig. 9. Sulfate concentration of surface water measured at the West and East Lakes.

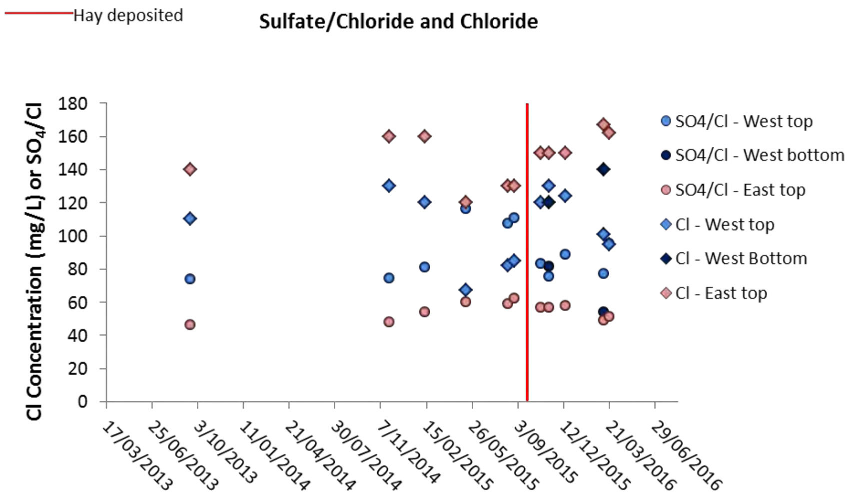

Fig. 10. Sulfate to chloride ratio and chloride concentration of surface water measured at the West and East Lakes.