The Macraes Gold Mine Irrigation Project, New Zealand

Cathy Rufaut[1], Dave Craw[1], Erin Weightman[1], Dhana Pillai[1], Gavin Lee[2]

[1]Geology Dept, University of Otago, PO Box 56, Dunedin 9054, New Zealand

dave.craw@otago.ac.nz

[2]Oceana Gold Ltd, Macraes Flat, Otago, New Zealand

Abstract

The Macraes gold mine is in a semi-arid area and is surrounded by agricultural pasture that suffers from summer droughts. Some mine waters have elevated sulfate (>2500 mg/L) and elevated nitrate (5-20 mg/L), and treatment of these waters post-closure would be expensive. This study has trialed use of mine waters for agricultural irrigation. The trials were successful in encouraging pasture growth, although some localised precipitation of Ca-carbonates and saturation from over-irrigation caused some dieback. Summer irrigation added nutrients (S, N) to the soil, although the nutrient effects waned over subsequent winter. The irrigation approach is a potential win-win solution for the mine and surrounding farms with further long-term trials.

Keywords: Sulfate, Nitrate, Waste Rock, Irrigation, Closure

Introduction

Post-mining water management is a significant legacy issue for the mining industry. It can result in substantial and ongoing post closure costs and an inability for companies to obtain closure relinquishment. Unfortunately, in many cases poor post-mining water management has led to a 'socialisation' of the perceived negative impacts of mining and has become a poster child to those who seek to stop future mine development.

Macraes Gold Mine (Fig. 1a,b; Craw and MacKenzie 2016) is fortunate in that it does not experience acid rock drainage (ARD) issues (Mains *et al*. 2006; Craw and Pope 2017; Craw and Rufaut 2017). However the processes which drive ARD are present. Thanks to the buffering capacity of the host geology, mine water drainage has an alkaline pH, but is high in sulphate concentrations (Weightman *et al*. 2020). In addition, relatively recent analysis has determined high levels of nitrate. Current cost estimates for managing mine water during mine closure are over $4 million.

The mine area is in a semi-arid environment (Craw *et al*. 2022) that is surrounded by grazing pasture land that suffers from drought in summer months. During discussions with local farmers it was also noted that they used both nitrate and sulphate fertilizers. As a four-year collaboration with the Otago University Geology Department, the Macraes Irrigation Project began with determining source and concentrations for main dissolved elements, as well as associated mineral precipitates (Weightman *et al*. 2020). The second step was to establish pilot scale trials to determine metrics and measurements for sulphate and nitrate that quantified their impacts on the terrestrial environment (Rufaut *et al*. 2022). A third stage examined effects from direct application of untreated mine water under agricultural conditions, along with assessing the potential for change to the downstream water chemistry.

Methods

Two water discharge points were selected for detailed examination leading to irrigation trials: a silt pond that collects water from a large waste rock stack (red; Fig. 1b); and a collection point for seepages from waste rock and tailings (green, Fig. 1b). Water compositions discharging from these two sites (Fig. 1b) were well established with routine environmental monitoring by Oceana Gold Ltd (Craw and Pope 2017; Weightman *et al*. 2020). The geochemical (Fig. 2) and mineralogical nature of these discharges

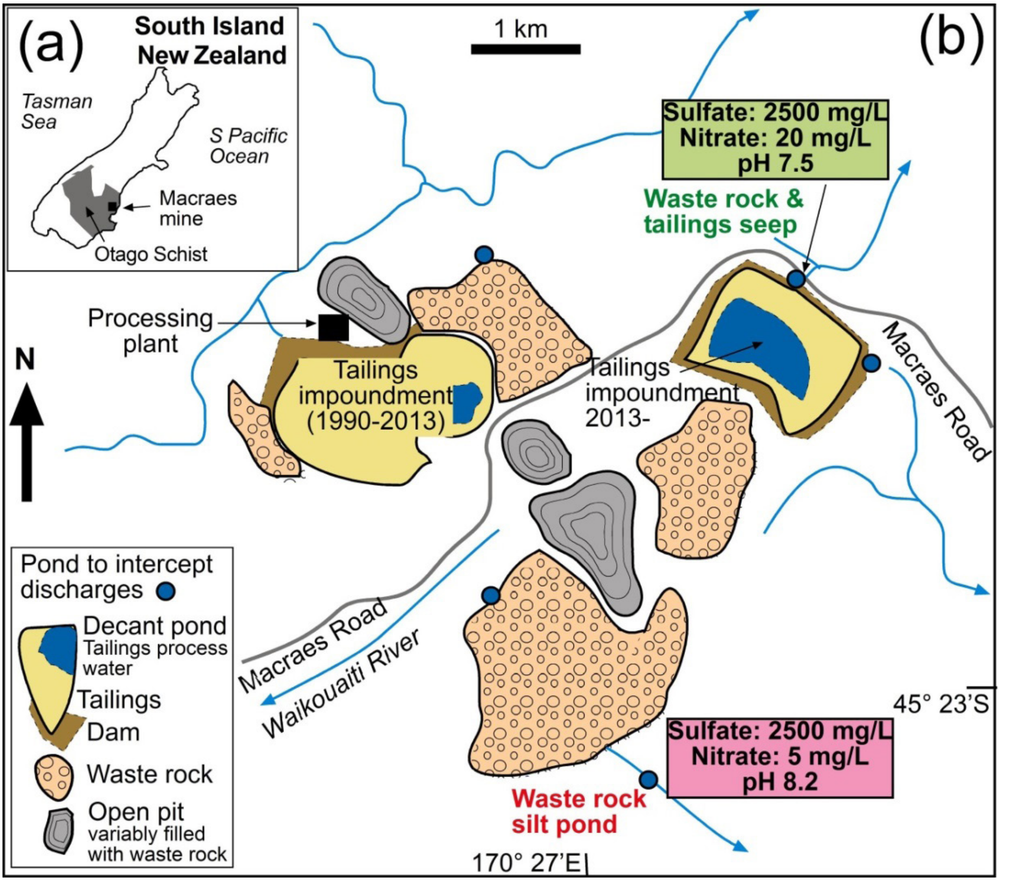

Figure 1 *VLocation and setting of Macraes gold mine in southern New Zealand (a) and the mine site (b). Two sites for irrigation trials are indicated: Site 1 waste rock water collected at a silt pond (bottom) and Site 2 sump water from waste rock and tailings (top right). Generalised water compositions are indicated.*

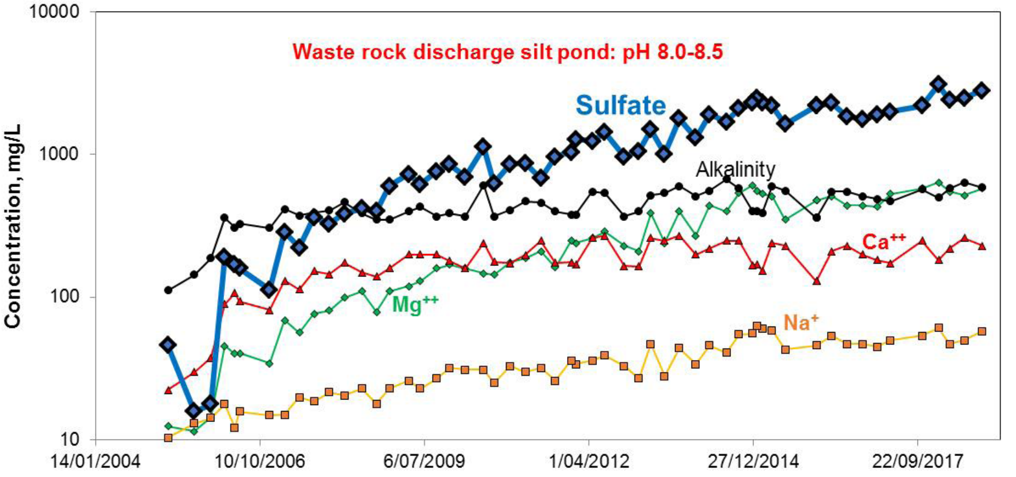

Figure 2 *Evolution of waste rock water compositions over time, as measured by routine environmental monitoring at the silt pond below a waste rock stack (Fig. 1b; bottom). Modified from Weightman et al. (2020); alkalinity is presented as* HCO_3^-.

were quantified with geochemical modelling and direct SEM observations of precipitates (Weightman *et al*. 2020).

Initial irrigation trials were set up to distribute water on to nearby agricultural land, to attempt to evaluate the best rates of application and potential effects on the pasture and downstream runoff (e.g., Fig. 3). Subsequently, full irrigation trials were carried out on larger areas of land and more detailed evaluation of chemical effects on pasture grasses, soil (0-30cm), and subsoil (40-60cm) was carried out. Standard vegetation and soil analyses were carried out by commercial laboratory, Hill-Labs, Hamilton New Zealand.

Initial water characterisation and irrigation trials

The waters are neutral-alkaline (pH 7.5-8.5) with high alkalinity, Ca and Mg, as well as high sulfate (Fig. 2,3). The waste rock water compositions have evolved rapidly with time to become progressively more concentrated (Fig. 2), and the waste rock & tailings seep waters have broadly similar compositions although Na contents are generally higher (300 mg/L) and pH is lower for the latter (Fig. 1b). The elevated sulfate concentrations arise because of oxidation of pyrite in the waste rocks and ore, and abundant calcite in these rocks ensures that any acidification is neutralised, with substantial increase in alkalinity (Fig. 2).

Direct field observations showed that precipitation of aragonite (Ca-carbonate), with minor gypsum (Ca-sulfate) occurs at Site 1 waste rock discharge area, and that epsomite (Mg-sulfate) also precipitates with further evaporation. At Site 2, the waste rock & tailings seep water precipitates epsomite and bloedite (Na-Mg-sulfate). Geochemical models predict that Ca-sulfate will precipitate from these water at pH <7. The soils of both sites have pH 5-7, so one aim of this project was to lower the pH of discharge waters by interaction with natural soil, to cause precipitation of Ca-sulfate and this could potentially attenuate downstream sulfate concentrations.

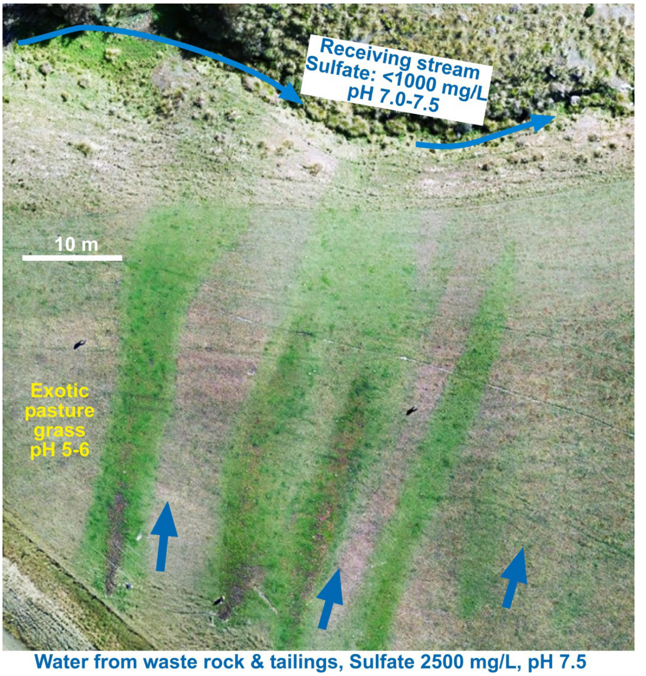

***Figure 3** Drone view of initial irrigation trial at Site 2 using water seeping from waste rock and tailings (Fig. 1b). Water was discharged at ≈10 m spaced points from a pipe leading from the seep site, with discharge rate decreasing from left to right. Dark green strips are pasture grass with growth enhanced by water addition. Dark strips at discharge points are temporary pasture dieback on saturated soils.*

Initial irrigation trials distributed waters on to nearby pasture in a convenient and generalised way in order to evaluate the practicalities of irrigation and its short term effects on pasture (e.g., Fig. 3). Only minor soil gypsum was observed and instead Mg-sulfate and Ca-carbonate was found more readily on evaporation surfaces. Runoff water from Site 2 irrigated with waste rock & tailings seep water had distinctly lower sulfate concentration (Fig. 3). Application rates at Site 1 irrigated with waste rock waters from the silt pond (Fig. 1b) were initially too high, and excess water ran into the nearby stream. This site also had thin soil on basement rock, further enhancing the rate of water runoff. Irrigated pasture had healthy, green plants in contrast to drought-affected adjacent pasture at both sites (Fig. 3).

Extended irrigation trials

Irrigation trials were extended using more standardised agricultural sprinkler irrigation techniques and realistic water application rates typical for wider region. Irrigation hardware consisted of a 4-pod 63 mm pipe, with 10 m pod spacing and stock protective guards. Installed water timers delivered 3-4 mm water per day over a daily total of 1.5 – 3 hours. Daily irrigation operated alongside rain events. The water application rates used did not result in downstream runoff from Site 2 irrigated with waste & tailings water. However, some runoff re-occurred from Site 1 waste rock silt pond water.

Results showed no observed adverse effects on plants from sprinkler irrigation at the waste & tailings Site 2, nutrient contents of soil increased (Fig. 4a,d) and grass pasture species flourished in growth and biomass (Fig. 5). At Site 1 waste rock silt pond irrigation, most pasture responded well to irrigation compared to control plots, and nutrients increased (Fig. 4a,b,d) but some water pooling during irrigation caused localised (square metre scale) pasture die back in late summer (Fig. 6). Ongoing observations at these die-back spots showed foliage and soil surfaces covered in Ca-carbonate and iron precipitates as thin surface crusts. These minerals lasted through winter but became progressively less abundant. By the end of the trial, they had broken down and normal pasture regrowth was observed to be resuming.

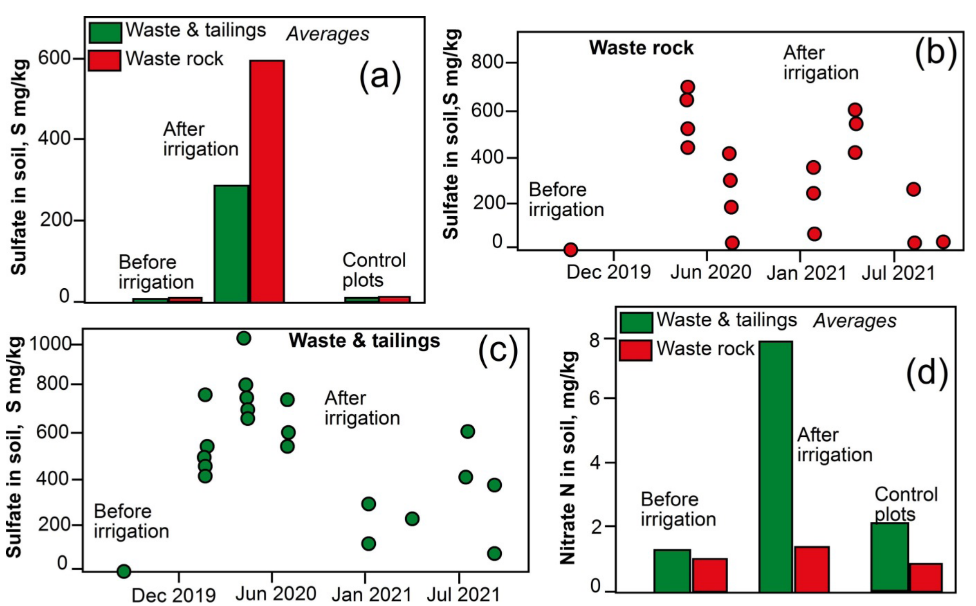

Figure 4 Soil chemical data for the two water types irrigated via agricultural sprinklers on to pasture over a 22 month period. (a) Average sulfate S before and after irrigation, compared to nearby control plots. (b) and (c) Sulfate S contents over time, showing declines after summer (Dec-Feb) irrigation periods. (d) Average soil nitrate N before and after irrigation, compared to nearby control plots.

Figure 5 *Abundant summer pasture growth in irrigated Site 2 below the waste & tailings seep site.*

Figure 6 *Summer pasture growth at Site 1 irrigated from the waste rock silt pond. Pale patches near the irrigation sprinkler developed from water ponding and Ca-carbonate and Fe oxyhydroxide precipitation on plant and soil surfaces. These mineral deposits waned over the following winter, and pasture re-grew in affected spots.*

Soil sulfate S and nitrate N contents increased substantially during the irrigation trials, although these nutrients decreased over time after irrigation ceased (Fig. 4a-d). The higher levels of S and N in the irrigated soils were typical of well-fertilised agricultural pasture. Herbage S levels slightly exceeded typical agricultural values but N levels did not.

Conclusions

For Macraes Mine, the pilot trial successfully demonstrated an ideal decrease in sulfate and nitrate concentrations from source water to the subsoil environment (down to 60 cm). Losses of sulfate and nitrate are attributed to dilution, leaching, and plant-microbial uptake for which some measured values of occurrence were obtained in the study. From an agricultural perspective, the input of dissolved sulfate and nitrate from mine water was shown to be plant-available and combined with an increase in seasonal soil moisture from irrigation, had a positive short-term benefit on grass growth and soil fertility reserves.

The Macraes Irrigation Project has the potential to be a win-win for the Mine and the local farming community. Alongside ongoing monitoring, controlled use of mine water for irrigation could provide farmers with much needed water and nutrients for pasture during dry periods. For the Mine, utilisation of mine water during post operations converts a multi-million dollar legacy issue, into beneficial post-mining land use enhancement.

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References

Craw D, MacKenzie D, (2016). Macraes gold deposit, New Zealand. SpringerBriefs in World Mineral Deposits. ISBN 978-3-319-35158-2, 130 pp.

Craw D, Pope, J. (2017). Time-series monitoring of water-rock interactions in mine wastes, Macraes gold mine, New Zealand. NZ J Geol Geophys 60: 159-175.

Craw D, Rufaut C, (2017) Geochemical and mineralogical controls on mine tailings rehabilitation and vegetation, Otago Schist, New Zealand. NZ J Geol Geophys 60: 176-187.

Craw D, Rufaut C, Pillai D, (2022) Geological controls on evolution of evaporative precipitates on soil-free substrates and ecosystems, southern New Zealand. Sci Total Environ 849: 157792.

Mains D, Craw D, Rufaut CG, Smith CMS, (2006) Phytostabilisation of gold mine tailings, New Zealand. Part 1: Plant establishment in an alkaline substrate. Int J Phytoremed 8: 131-147.

Rufaut C, Weightman E, Craw D, Pillai D, Kerr G, Scott J, (2022) Potential for pastoral irrigation using sulfate-rich waters at Macraes gold mine, southern New Zealand. Water Air Soil Pollution (in press).

Weightman E, Craw D, Rufaut CG, Kerr G, Scott J, (2020). Chemical evolution and evaporation of shallow groundwaters discharging from a gold mine, southern New Zealand. Appl Geochem 12: 1-15.