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Informing risk and opportunity management in coal mine pit lakes via modelling experiments

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Abstract:

Thousands of abandoned or closed open-cut mines worldwide have filled with water to form pit lakes, which pose both risks and opportunities for surrounding environments and communities. These lakes may accumulate salts and other contaminants through leaching, groundwater inflows, and evaporation, and pose long-term environmental risks if discharged into surface and groundwater systems. Management approaches typically aim to minimise risk by isolating pit lakes, but there is growing interest in whether they can instead be transformed into beneficial water resources for uses such as irrigation or livestock watering. However, achieving this requires robust understanding of long-term lake water balances, water quality dynamics, and interactions with the natural (e.g., climate and groundwater systems) and engineered (e.g., catchment area) environment.

To date, most studies on the beneficial uses of pit lakes have either been site-specific (focused on modelling of a single mine) or broad qualitative reviews. As a result, little is known about the general conditions under which pit lakes could reliably provide water of sufficient volume and quality for beneficial use, or the extent to which management strategies can mitigate risks. This lack of quantitative baseline knowledge limits informed decision-making by stakeholders and regulators, particularly in mining regions where water availability is a key constraint on future development.

This study develops a numerical model of pit lake hydrology and salinity dynamics, applying it as an exploratory tool to assess risks and opportunities across a wide range of scenarios. Using the Bowen Basin coal mining region of Queensland, Australia, as a case study, we build a simplified but fully coupled pit lake - surface water - groundwater simulation model, incorporating key features characteristic of the case study, such as in-pit spoil deposition, confined and unconfined groundwater connectivity, and engineered surface catchment. Risks are quantified in terms of frequency of contaminated discharges to groundwater and surface water, while opportunities are measured through sustainable yields for livestock and irrigation water. Based on a detailed literature review, a factorial sensitivity analysis is conducted by varying key environmental and physical factors such as climate, pit geometry, and hydrogeology, and understanding their impacts on pit lake risks / opportunities. A scenario analysis is performed to assess the efficacy of potential management options on decreasing risks and facilitating opportunities, including rapid filling, water treatment, and controlled withdrawals.

Preliminary findings highlight that the engineered catchment area is the primary driver of lake water balances and long-term salinity trajectories. Management interventions can significantly reduce risks or create opportunities, but their effectiveness is highly dependent on-site context. The analysis demonstrates that regional-scale scenario modelling provides critical baseline insight into when pit lakes should be managed conservatively and when they could support beneficial uses. This approach offers a transferable framework for guiding closure planning and water resource assessments in mining regions globally.

Keywords: *Pit lake, salinity, water balance model, risk management*