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Statistical analysis and modelling of the manganese cycle in the subtropical Advancetown Lake, Australia

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ABSTRACT

Study region: Advancetown Lake, South-East Queensland (Australia).
Study focus: A detailed analysis of available meteorological, physical and chemical data (mostly coming from a vertical profiler remotely collecting data every 3 h) was performed in order to understand and model the manganese cycle. A one-dimensional model to calculate manganese vertical velocities was also developed.
New hydrological insights for the region: The soluble manganese concentration in the hypolimnion is dominantly dependent on the dissolved oxygen level, pH and redox potential, which determine the speed of the biogeochemical reactions between different manganese oxidation states. In contrast, the manganese level in the epilimnion is mainly affected by the transport processes from the hypolimnion and thus to the strength of the thermal stratification, with high concentrations recorded solely during the winter lake circulation and wind playing only a minor role. The value of the peak concentration was found to be proportional to the amount of manganese in the hypolimnion and to the temperature of the water column at the beginning of the circulation period. In case of partial circulation only, a very high peak is espected during the next full winter turnover. This issue will increase in the future due to global warming and increased number of years with partial circulations only. These findings provide water authorities with increased manganese predictive power and thus proactive water treatment management strategies.

1. Introduction

1.1. Manganese and water treatment

The chemical element manganese (Mn) comprises 0.1 per cent of the Earth's crust (Emsley, 2001) and it can be observed in oxidation states ranging from −3 to +7. The most stable valence states are +2 and +4; hence the most naturally occurring Mn forms are dissolved Mn(II) and particulate Mn(IV) (Kohl and Medlar, 2007). In lakes and reservoirs, Mn can be present in both soluble and insoluble forms; its production, suspension, precipitation, mixing and interactions with other elements are complex and generally ruled by factors such as pH, redox potential (ORP), dissolved oxygen (DO) and level of turbulence.

Abbreviations: BoM, Australian Bureau of Meteorology; DERM, Department of Energy and Resources Management of the Queensland Government; DO, dissolved Oxygen; Mn, manganese; ORP, redox potential; VPS, vertical profiling system.

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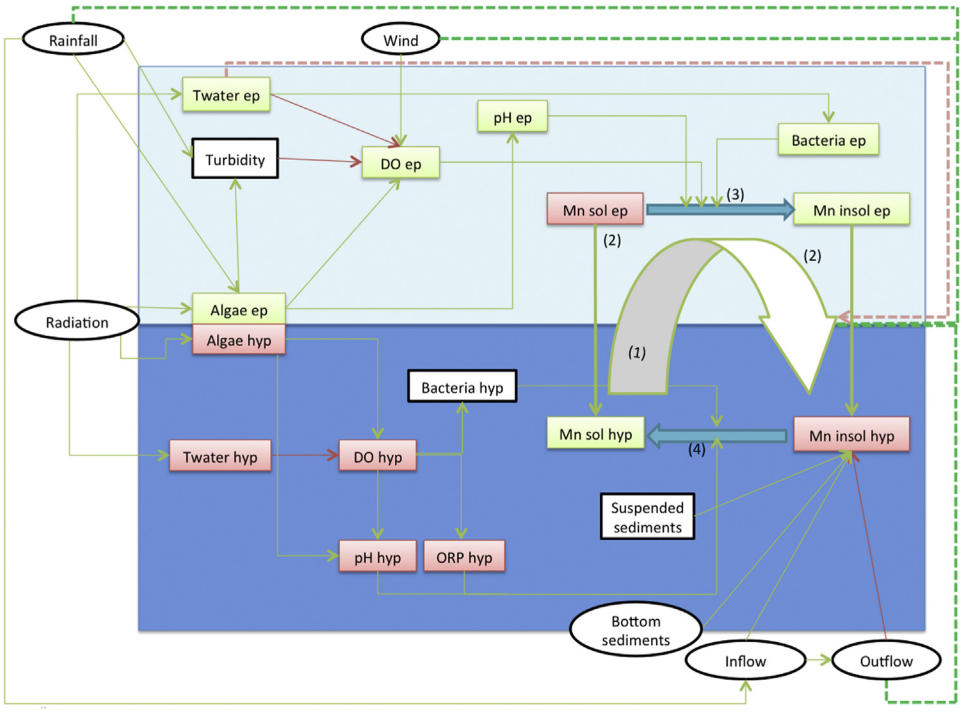

Fig. 1. Schematization of the Mn cycle in a reservoir: green connections: increase in x increases y; red connections: increase in x decreases y; dashed connections: processes affecting lake circulation; upper box: epilimnion; lower box: hypolimnion; rectangles: variables part of the cycle; ovals: external inputs; (1): lake turnover; (2): Mn precipitation; (3): Mn oxidation; (4) Mn reduction.

It has been found that Mn can potentially cause decreased IQ and neurotoxic issues at high levels (Khan et al., 2012). The Mn concentration levels in drinking water, despite being typically too low to cause health issues (although values above World Health Organisation's drinking water limits can be recorded in groundwater, see Homoncik et al., 2010), can cause aesthetical problems such as black or brown colouring or, with even higher levels, a metallic taste (Raveendraan et al., 2001). Typical standards (such as that fixed by the United States Environmental Protection Agency) for soluble Mn are 0.05 mg/L; however, recently, some water utilities have been targeting 0.015 – 0.2 mg/L to avoid any customer complaints (Kohl and Medlar, 2007), and Seqwater (the water authority that manages Advancetown Lake) require treated water manganese to be <0.02 mg/L.

A better understanding of the Mn cycle and the variables affecting it would allow the water authority to manage Mn treatment more efficiently. Although many experiments have been conducted to examine the importance of single variables such as pH or ORP, only few studies (e.g., Johnson et al., 1991) have taken into account the overall process. Remarkably, to the authors' knowledge, limited studies have quantitatively analysed the Mn behaviour during the lake natural destratification that, in monomictic lakes such as Advancetown Lake, usually occurs once per year. This event dramatically changes the lake structure, leading to an even distribution of physical and chemical parameters (Nürnberg, 1988). For this study, after an extensive data collection from several sources and over several years, the overall Mn cycle for Advancetown Lake was analysed and the main variables affecting it were detected during both the stratified and the circulating (destratified) periods. Although the study is limited to Advancetown Lake, it provides a general assessment of Mn behaviour in subtropical monomictic lakes, focusing especially on understanding and predicting the timing and peak concentrations during winter circulations.

1.2. Manganese cycle: biogeochemistry

The key processes involved in a lake's Mn cycle are summarised in Fig. 1. During the stratification season, there are evident differences in Mn concentration between the epilimnion and the hypolimnion. In the epilimnion, the incident radiation allows photosynthesis to occur and the level of DO is high, although higher water temperatures decrease its solubility. The presence of algae also means higher pH because of the removal, through photosynthetic assimilation, of acidic CO_2 forms such as HCO_3^- (Dubinsky and Rotem, 1974). Under these conditions, the soluble Mn is oxidised (Stumm and Morgan, 1981) into insoluble forms such as Mn dioxide, which precipitates downwards into the hypolimnion.

This reaction is slow for pH lower than 8.5/9 (Howe et al., 2004; Johnson et al., 1995) but with high water temperatures (with an optimum at 30 °C), bacteria play a central role in the oxidation reaction, making the reaction much faster (Johnson et al., 1995). The occurrence of Mn is largely dependent on two groups of bacteria: oxidising bacteria (which convert soluble