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An autonomous decision support system for manganese forecasting in subtropical water reservoirs

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ABSTRACT

Manganese monitoring and removal is essential for water utilities in order to avoid supplying discoloured water to consumers. Traditional manganese monitoring in water reservoirs consists of costly and time-consuming manual lake samplings and laboratory analysis. However, vertical profiling systems can automatically collect and remotely transfer a range of physical parameters that affect the manganese cycle. In this study, a manganese prediction model was developed, based on the profiler's historical data and weather forecasts. The model effectively forecasted seven-day ahead manganese concentrations in the epilimnion of Advancetown Lake (Queensland, Australia). The manganese forecasting model was then operationalised into an automatically updated decision support system with a user-friendly graphical interface that is easily accessible and interpretable by water treatment plant operators. The developed tool resulted in a reduction in traditional expensive monitoring while ensuring proactive water treatment management.

Software availability

Name of software: Hinzedam_MnModel
Developer: Charles Hacker
First available year: 2015
Software requirements: MS-Windows XP or later
Programming language: Embarcadero Rad Studio (C Builder and Delphi)
Language: English
Minimum hardware requirements: Intel Pentium II, 200 MHz, 128 MB RAM
Contact person: Edoardo Bertone

1. Introduction

1.1. Manganese and water treatment

High manganese (Mn) concentrations in drinking water reservoirs are one of the major concerns for many bulk water suppliers, since they can cause aesthetical problems such as black or brown colouring or, with very high levels, a metallic taste of the water supplied to the customers. Typical standards (such as those fixed by the United States Environmental Protection Agency) for soluble Mn are 0.05 mg/L; however, recently, some water utilities have been targeting 0.015/0.02 mg/L to avoid any customer complaints (Kohl and Medlar, 2007), and Seqwater (the main water authority in South-East Queensland, Australia) requires soluble Mn to be <0.02 mg/L in treated waters.

As a consequence, understanding the Mn cycle in a lake or reservoir is of paramount importance for the water utility, in order to potentially predict when high Mn loads will occur. Typically, in case of subtropical, warm monomictic reservoirs, which are thermally stratified for most of the year, Mn concentrations are very low in the epilimnion (i.e. the upper, warmer layer of water) (Kohl and Medlar, 2007) as soluble Mn is typically oxidized (Stumm and Morgan, 1981) due to high levels of oxygen and high pH, and the resulting insoluble form precipitates in deeper layers (Dojlido and Best, 1993). On the other hand, in the typically colder, acidic and anoxic lower layer, called the hypolimnion, the insoluble Mn is stored in the bottom with suspended sediments reduced to their soluble form. In the hypolimnion, soluble Mn concentrations

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gradually increase over the stratification season. In reservoirs such as Advancetown Lake, an offtake tower allows for raw water to be withdrawn from the most suitable depth, which on most occasions is around the midpoint of the epilimnion due to high Mn and other nutrients loads in the hypolimnion and possible high algae concentrations at the water surface. However, during winter, the stratification is broken and a full lake circulation occurs; the lake circulation leads to an almost uniform distribution of chemical and biological constituents throughout the water column, with the top layers enriched in nutrients from the hypolimnion (Nürnberg, 1988) through mechanisms such as turbulent diffusion. Thus, during this period, the soluble Mn present in high amounts in the hypolimnion evenly spreads out through the water column. Critical Mn concentrations are also detected in the epilimnion, therefore effective and timely Mn removal procedures must be implemented. In Seqwater water treatment plants (WTP), whenever the detected soluble Mn concentration exceeds 0.02 mg/L, pre-filter chlorination takes place in order to remove the excess Mn; in case of much higher Mn loads (i.e. >0.18 mg/L, but in practice based on the operators' experience), the addition of potassium permanganate hastens the oxidization and removal of Mn from the water.

Typically, in South-East Queensland (SEQ) reservoirs, Mn is monitored through weekly manual lake water samplings and subsequent laboratory analyses. In recent years, Vertical Profiling Systems (VPS) have been installed in several of the regions' water supply reservoirs. The VPS consists of a YSI Sonde suspended by a cable to a floating buoy which is automatically winched up and down the water column in order to collect a range of water quality parameters such as water temperature, dissolved oxygen (DO), pH, conductivity and redox potential, which are relayed via telemetry for the whole profile every 3 h. While the VPS has enhanced traditional water quality monitoring practices, it is not able to measure Mn concentrations, thereby still necessitating the continued costly and time-consuming manual samplings and analyses of Mn levels. Since previous studies (e.g. Calmano et al., 1993; Carlson et al., 1997; Howe et al., 2004) showed correlations between some of the parameters measured by the VPS and Mn concentrations, there is potential for the development of a Mn prediction model and a related VPS-based Decision Support System (DSS) that is able to forecast Mn concentrations a few days in the future and make a better decision for water treatment. Such a Mn DSS will significantly reduce Mn monitoring costs and also promote a more proactive water treatment management regime.

1.2. Existing water quality parameters prediction models and DSS

Interestingly, only few studies have been conducted to try to fully model the Mn cycle (e.g. Johnson et al., 1991). Importantly, to the authors' knowledge, no studies have attempted to predict future Mn concentrations. Several prediction models have been applied over the years for different environmental problems, but as pointed out by Maier et al. (2010), with regards to particular categories of extensively implemented models such as artificial neural networks (ANN), the vast majority of them deals with water quantity (e.g. inflow) more than water quality issues. Besides, the typically modelled water quality parameters are pH, salinity or algal growth (e.g. DeSilet et al., 1992; Bastarache et al., 1997; Zhang and Stanley, 1997; Whitehead et al., 1997; Millie et al., 2012) with limited focus on nutrients. Additionally, few studies have attempted to forecast these parameters more than one day ahead in the future. Interesting exceptions are given by Bowden (2003), which adopted an ANN to predict four weeks ahead the peak concentrations of cyanobacteria in the River Murray, Australia, and by Yabunaka et al. (1997), who forecasted algal concentrations in a Japanese lake seven days ahead. Moreover, Zhang et al. (2013) also built a Windows-based software to predict algal blooms up to five days ahead using weather forecasts. ANN-based models are now commonly found in the literature (see e.g. Zaldívar et al., 2000; Lekkas et al., 2001; Recknagel et al., 2002; Joorabchi and Zhang, 2007; Tsanin et al., 2008) but also other techniques such as regression trees have been applied (e.g. Jung et al., 2010). Traditional regression models are still relevant for many applications; for example, Giustolisi and Savic (2006) developed an innovative approach using regression models for data pre-processing and input selection. Moreover, multivariate statistical techniques are still commonly used (e.g. Sinnakaudan et al., 2006; Rocha et al., 2009) especially where there is a need to simplify the analysis of complex datasets (Shrestha and Kazama, 2007). Process-based models have been widely applied in the environmental sector whenever enough data were available. Nevertheless, attempts to model the Mn cycle, with particular focus on the rapid transport processes towards the epilimnion during the lake destratification, were not present. One of the few studies found in the literature was completed by Johnson et al. (1991), who created a mathematical model for simulating the Mn cycle in a Swiss lake. The model made use of differential equations including the main processes affecting the formation and transport of soluble and particulate Mn, such as eddy diffusion, outflow, flux from the sediment, oxidation in the water column and coagulation with subsequent sedimentation. However, because of the several inputs required, it is not ideal for short-term forecasts. Process-based models are instead better for climate change studies; an example is given by Trolle et al. (2011) who noticed increased eutrophication (and thus possible higher nutrients loads) for three different lakes when future expected air temperature increases are considered by the model.

DSS have often been created around hydrological and water quality models for different purposes, with the main goal of assisting end-users with an easy model usage and clear interpretability of the results. However, most of the created environmental DSS are used for analysis of different possible policies/choices of the decision-makers (McIntosh et al., 2011). Examples are given by the catchment modelling software proposed by Argent et al. (2009) and Stewart and Purucker (2011), where the target user is an investigator interested in characterising contamination, or by the model proposed by Soncini-Sessa et al. (2003), applied to an Italian Lake to assist the decision-maker to calculate the amount of water to be released over the next 24 h. Also, Touma (1995) developed a DSS with associated Graphical User Interface (GUI) for scenario analysis on air quality, built on a C++ environment. In other cases, the DSS was mainly designed and used within spreadsheets (e.g. Jolma et al., 1997). Often, manual input data is necessary (such as meteorological forecasts, see Zhang et al., 2013). Nevertheless, some DSS have been implemented in order to display in real-time the models results; this is the case of Quinn et al. (2005), who encapsulated a DO forecasting model into a DSS, whose features include: (1) ability to enter the continuously collected data through land line phone modem, cellular phone or satellite; (2) computer programs able to automatically retrieve data and parse them into model-friendly formats; (3) GUI, allowing mouse usage and results-related colours, to facilitate inspection of real time and forecasted data.

1.3. Project objectives

The study had three main objectives as described below:

1. **Development of seven-day ahead Mn forecasting model:** The foundation objective of the study was to forecast Mn concentrations in the epilimnion of Advancetown Lake (next to the lower intake) seven days ahead by mainly relying on real-time data collected by the VPS. If such a model can be built,