

An integrated monitoring and modelling framework to predict and manage the water quality of drinking water reservoirs in Singapore

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Introduction

Singapore (population 5 million, area 712 Km²), a country with limited natural freshwater resources, is heavily dependent on catchment rainwater harvesting to generate drinking water supplies. With the development of three new drinking water reservoirs, the Marina, Punggol and Serangoon Reservoirs, the total Singapore land area utilised for rainwater harvesting will be increased to 70% over the coming years. All three reservoirs are situated in heavily urbanised catchments and receive high external pollutant loads, derived mostly from diffuse sources coupled to sudden and frequent tropical rainfall events. Apart from their primary function for raw drinking water supply, the reservoir systems are also important for flood control and recreation. Potential water quality concerns in the new reservoirs include eutrophication and nuisance algal blooms, water column turbidity and bacterial contamination.

The aim of the current study was to develop a continuous water quality monitoring and modelling framework to assist with the operational management of the newly created drinking water reservoirs and serve as an early warning system to allow predicted water quality concerns to be prevented or alleviated. The modelling framework was further applied to assess the efficacy of a number of in-reservoir and catchment mitigation scenarios for long-term water quality improvement.

Methods

A comprehensive modelling framework was developed to simulate catchment hydrology, pollutant loads, hydrodynamics and future water quality condition for each reservoir (Fig. 1). Catchment storm water runoff, river discharges and external pollutant loads from point and diffuse sources were modelled using coupled 1D-hydrological, emission and water quality models based on meteorological forcing data and an hourly model time step. Reservoir water quality, including concentrations of nitrogen, phosphorus, dissolved oxygen and chlorophyll-a, together with phytoplankton species composition, were simulated hourly using coupled 3D hydrodynamic-water quality-ecological models. The model framework was calibrated based on measurements of water velocity and water level at key inflow locations, and monthly reservoir water quality profiles at various reservoir monitoring stations. Model scenarios were applied to assess the efficacy of a range of catchment and in-lake mitigation scenarios to improve individual reservoir water quality condition with respect to recreational, drinking water and ecological targets, including load reduction, artificial aeration, and recirculation.

The complete modelling framework was coupled to an Operational Management System (OMS), developed to integrate a network of monitoring stations collecting real-time catchment (inflow discharge) and reservoir (water column dissolved oxygen, nutrient and chlorophyll-a

concentrations and temperature) data with the modelling environment (Fig.1). The OMS was configured to automatically evaluate real-time water quality trends against pre-set water quality standards and targets, import meteorological forecasts, and set up and simulate catchment and reservoir model forecasts for the coming days.

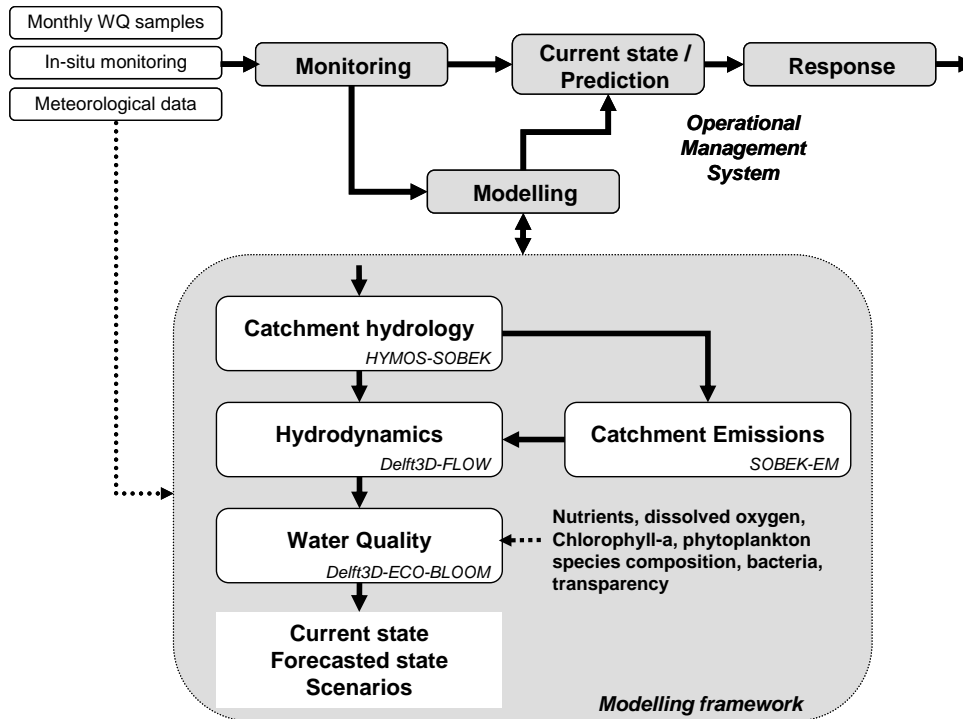


Fig. 1: Catchment and reservoir modelling framework and set-up of the Operational Management System as applied to the Marina, Punggol and Serangoon Reservoirs, Singapore.

Results

Model simulations suggest that eutrophic conditions will exist in all three future reservoir systems, with mean predicted total nitrogen and total phosphorus concentrations in the surface waters of around 0.6 and 0.06 mg L⁻¹, respectively. Trends in expected reservoir water quality are highly dynamic due to strong influences by storm water pollutant loads, which are derived mostly from diffuse catchment sources (> 90%). Expected water quality concerns include high phytoplankton biomass (> 50 ug L⁻¹) and bacterial pollution, with recreational water quality targets exceeded more than 40% of the time for some parameters and locations. The results of a range of management scenarios suggest that the expected poor water quality can be managed the majority of the time, but only in combination with comprehensive mitigation measures. A combination of external load reduction strategies, many of which have already been implemented, are most feasible for improving the long-term water quality of the Reservoirs. However, active day to day management of water quality through operational controls, for example recirculation, flushing and artificial aeration, can greatly improve local water quality condition over the short-term.

The complete OMS framework provides detailed spatial and temporal information on current and expected water quality state and developing trends, and serves as an early warning system allowing operational control measures to be implemented prior to or as water quality concerns develop. The system incorporates, visualises and integrates data-feeds from various

sources such as online monitoring platforms, historical data and model predictions, and provides comprehensive information and alerts to operational and strategic teams responsible for the day to day management of reservoir water supply and water quality. The use of the integrated 1D-3D catchment-reservoir model framework allows catchment and reservoir water quality to be understood and managed more effectively, particularly in tropical environments where discharges and diffuse loads are mostly associated with intense runoff events, which lead to sudden and rapid changes in water quality condition. Further development and testing of the OMS system for all reservoirs in Singapore is ongoing.