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A decision support system for water management in Thomson Reservoir, Victoria

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Abstract: The Aquatic Real-time Management System (ARMS), which incorporates data acquisition, data visualization and, 3D hydrodynamic modelling was used to optimise field sampling and run scenario forecasting as part of a comprehensive limnological study of Thomson Reservoir, the largest storage in the Melbourne Water supply system (Victoria, Australia). The 3D Estuary, Lake and Coastal Ocean Model (ELCOM) was coupled with ARMS to support operational and planning decisions over short and long timescales. The system can address, in particular, key issues related to:

- Melbourne Water's drought management policy
- Environmental flows
- Management of the overall supply system

Part of the drought management policy requires allowing the Thomson Reservoir to re-fill over a projected period of 8 to 10 years by lowering abstraction from the reservoir as a metropolitan desalination plant comes online. Construction of the desalination plant is due to begin in mid-2009 and finish at the end of 2011 and will yield an estimated 150 GL per year. The constant addition of a large volume of desalination water into the current supply network will significantly alter the way the supply network is utilised, having impacts on individual reservoirs. ARMS allows the end-user to view reservoir data in real-time, and investigate management strategies through scenario forecasting of alternative operating regimes under changing reservoir conditions during drought.

Building the ARMS for Thomson Reservoir included ELCOM calibration and validation against Lake Diagnostic System (LDS) data and profiles obtained during an intensive 4-day field sampling campaign. ELCOM can be dynamically coupled with the Computational Aquatic Ecosystem Dynamics Model (CAEDYM), a process-based ecological model that simulated the key biogeochemical processes influencing water quality. CAEDYM was not used in this study.

ELCOM has previously been configured for Cardinia, Sugarloaf, Silvan and Upper Yarra reservoirs in the Melbourne supply system, and ELCOM-CAEDYM modelling is proposed for Greenvale Reservoir this year. Once these reservoirs are integrated into ARMS the system could be applied as a system-scale monitoring and management tool that has the capacity to balance key stakeholder, environmental and economic interests through better real-time knowledge and management scenario forecasting.

Keywords: *Aquatic Real-time Management System (ARMS), water management, Thomson Reservoir, Estuary, Lake and Coastal Ocean Model (ELCOM).*

1. INTRODUCTION

1.1. General

Approximately 90 percent of Melbourne's drinking water comes from pristine catchments. There are over 157,000 ha of catchment reserved for harvesting water. Melbourne Water manages nine major reservoirs, which provide Melbourne with a storage capacity of 1,773,000 ML of water. Not only are these reservoirs important for supplying water for human consumption, agriculture, horticulture and viticulture, they must be carefully managed to provide sufficient environmental release to sustain biodiversity.

Current drought conditions and an expanding population have applied pressure to the Melbourne supply system. As a response, the Victorian State Government released the "Our Water Our Future" plan in 2004, (updated in 2007), to diversify and boost water supplies through the construction of a desalination plant, upgrading irrigation in the Food Bowl (northern Victoria), and expanding the Victorian Water Grid to connect Melbourne's supply system with the desalination plant, among other initiatives. The Melbourne Water 2007/2008 Sustainability Report (Melbourne Water, 2008) lists one of its challenges for the upcoming year as "carefully managing and conserving existing water sources until new ones come online". This challenge complements the broader Victorian State Government plan to diversify and boost supplies.

1.2. Thomson Reservoir

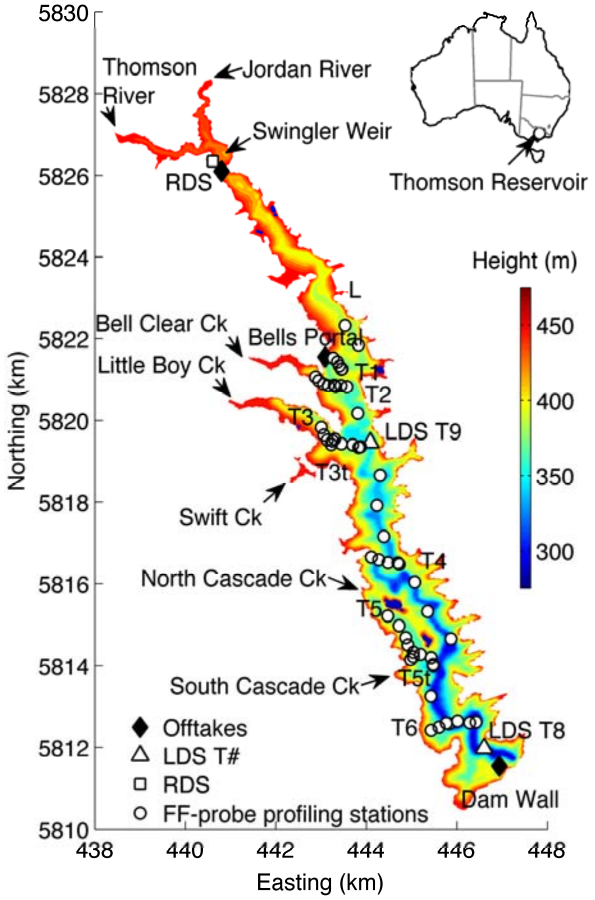

Figure 1. Thomson Reservoir bathymetry (colour is height in mAHD) showing the main inflows (Swingler Weir, Bell Clear Ck, Little Boy Ck, Swift Ck, North Cascade Ck, South Cascade Ck), outflows (Swingler Weir, Bells Portal and dam wall offtakes) and instrument deployment locations (L-FF-probe longitudinal transect, T# FF-probe cross transects).

Thomson Reservoir, located approximately 125 km east of Melbourne (**Figure 1**) is the largest storage reservoir in the Melbourne supply system and therefore plays an important role in the city's long-term water supply strategy. The reservoir has a maximum volume of 1,068,000 ML. The reservoir receives water from its local catchment (~48,700 ha), with a majority of the inflow entering via the Upper Thomson River (70000-120000 ML p.a.) and the Jordan River (20000-50000 ML p.a.). The major withdrawal from the reservoir is transfer to Upper Yarra Reservoir, which ranges between 60000 and 250000 ML p.a., whereas environmental and irrigation releases amount to 50000-100000 ML p.a. Under normal operating conditions water is transferred from Thomson Reservoir from a point mid-reservoir known as Bells Portal (**Figure 1**), which is located approximately 5 km from the entrance of the Upper Thomson and Jordan Rivers and 10 km from the dam wall. Due to the local drought conditions in recent years, the normal operating regime has been altered and water withdrawn for the Upper Yarra Reservoir now alternates between withdrawal from Bells portal (gravity-fed under normal conditions and pumped under low reservoir conditions) and withdrawal from the smaller upstream Swinglers weir, which is located at the junction of the two main rivers. Swinglers weir operated during the construction of the dam and was then drowned during filling; however, current low water levels have lead to Swinglers again operating as a spilling weir that provides a alternative location for water extraction prior to flow being released into the main body of the reservoir.

The catchment of Thomson Reservoir is partially protected, with activities such as walking, horse riding and logging permitted. It is recognized that disturbances to vegetation in the catchment, either through bushfires or forestry, can impact on water yields and quality. The potential for transfer of catchment derived contaminants from Thomson Reservoir into the Upper Yarra Reservoir and consequent contamination of the city supply is therefore a key issue when considering the management of Thomson Reservoir.

The Thomson Reservoir study provides a means to quantify the barrier capacity of the reservoir to inflow events from the local catchment, and its susceptibility to catchment-derived contamination. The project consisted of four core stages:

1. Install in-situ instrumentation and a central database system to monitor the hydrodynamics of Thomson Reservoir;
2. Construct a 3D hydrodynamic model to simulate the flow within Thomson Reservoir;
3. Undertake an inflow field experiment to further validate the 3D model and to assess the mechanisms responsible for water flux paths under weakly stratified conditions in spring; and
4. Refine the 3D model based on the experimental data and prepare the model as a real-time predictive tool for reservoir management. The model aims to provide a means to quantify the barrier capacity of Thomson Reservoir to inflow events from the local catchment, and its susceptibility to catchment-derived contamination.

2. AQUATIC REALTIME MANAGEMENT SYSTEM (ARMS).

Stage one of the project was to install (a) in-situ instrumentation and (b) a central database system to monitor the hydrodynamics of the reservoir. These tasks are described in detail below.

2.1. Install instrumentation

An analysis of the available data streams required for model forcing reveal significant shortcomings that lead to installation of two Lake Diagnostic Systems (LDS) (Imberger 2004) that continually measure meteorological conditions and reservoir water temperature profiles and a River Diagnostic System (RDS) that measures the rate, temperature and salinity of the main reservoir inflow water. These were installed for quasi real-time data streaming to a central database within ARMS. The LDS measures in-situ water column temperature with an array of precision thermistors (accuracy 0.001 ^{o}C) and a suite of meteorological sensors mounted approximately 2 m above the surface water (air temperature, humidity, net radiation, short wave radiation, wind speed and direction). The sensors are mounted from a self-levelling surface buoy. Two LDS were installed on the reservoir in the vicinity of Bells Portal (LDS T9) near the dam wall (LDS T8) (**Figure 1**). The LDS at Bells comprised a thermistor chain and full meteorological station, while the LDS at the dam wall comprised of a thermistor chain and wind speed and direction sensors. The RDS was installed at Swingler Weir to measure inflow rate, temperature and salinity. RDS data was also transmitted into a ARMS via satellite communication.

2.2. Install a central database

Data from these instruments were collected into a central database as part of ARMS developed by CWR (Ewing et al. 2004). ARMS has been used in multiple applications for numerous agencies and comprises of a central database, a range of graphical tools that can be used to generate figures of observational data, and a suite of modelling tools to configure, run and output scenarios.

3. ESTUARY, LAKE AND COASTAL OCEAN MODEL (ELCOM)

ELCOM solves the 3D, hydrostatic, Boussinesq, Reynolds-averaged Navier-Stockes, and scalar (e.g., potential temperature, salinity or tracer) transport equations, separating mixing of scalars and momentum from advection (Hodges et al. 2000). Free-surface evolution is modelled by vertical integration of the conservation of mass equation for incompressible flow applied to the kinematic boundary condition. Scalar transport uses the conservative, flux-limiting, explicit differentiation scheme ULTIMATE-QUICKEST whereas the momentum advection is by an Euler-Lagrange scheme. Baroclinic and barotropic responses, rotational effects, wind stresses, surface thermal forcing, inflows, outflows, and transport of heat and passive scalars are included in the code. ELCOM was configured to simulate the 3D temperature, salinity (and density) and velocity fields in Thomson Reservoir using meteorological forcing, inflows and outflows. The model was initially setup and forced with high temporal resolution meteorological data collected at LDS T8 and T9, inflow data from the Swingler Weir RDS and outflow data recorded by Melbourne Water. The initial surface water level was obtained from LDS T8, while initial temperature profiles were taken from both LDS T8 and T9.The model was initially validated by way of data collected at the reservoir. A final validation was undertaken against high-resolution data collected during and intensive process-focused field sampling campaign.

4. FIELD EXPERIMENT

An inflow field experiment to further validate the 3D model and to assess the mechanisms responsible for water flux paths under weakly stratified conditions in spring was conducted from 24 to 27 November 2008, using a free falling fine-scale profiler (F-probe) equipped with sensors to measure temperature, conductivity, turbidity, dissolved oxygen and pH (Imberger and Head 1994). A Fluoroprobe attached to the F-probe to measure the concentration of four algae groups and DOC variation based on a fluorescence detection system. The combined instrument (F-probe plus Fluoroprobe) is hereafter referred to as the FF-Probe. **Figure 1** shows the ELCOM bathymetry with inflows, offtakes and the instrument deployment locations. The field data collected during the experiment showed signals of significant inflow from three creeks on the western shore of the reservoir in addition to inflow from the Upper Thomson and Jordan rivers that enters via Swinglers Weir.

5. FINAL MODEL VALIDATION AND SCENARIO SETUP AND TESTING

5.1. Experimental data

The key indicators of good model performance include its ability to accurately reproduce physical attributes such thermal structure, inflow intrusions and surface water height. Following the field experiment, inflow from the two largest (Little Boys Creek and North Cascade Creek) of the three additional inflows observed on the western shore of the reservoir were included in the model and their inflow rates estimated from a reservoir water balance. **Figure 2** shows both the observed (top panel) and simulated (bottom panel) water temperature profiles for LDS T8 for the period 18 to 28 November 2008. The simulated surface water height and water temperature output compared well with observations. **Figure 3** shows the observed and simulated salinity in a transect along the thalweg of the reservoir for day two of the field experiment (25 November 2008). Because no inflow salinity data was available during this period, the simulated inflow salinity was set to a constant 0.016 PSU as observed during the field experiment, and the initial salinity was defined using three salinity transects from the field. The figures clearly show the ability of ELCOM to replicate the main inflow intrusion from Swinger Weir (entering at the left of the transect).

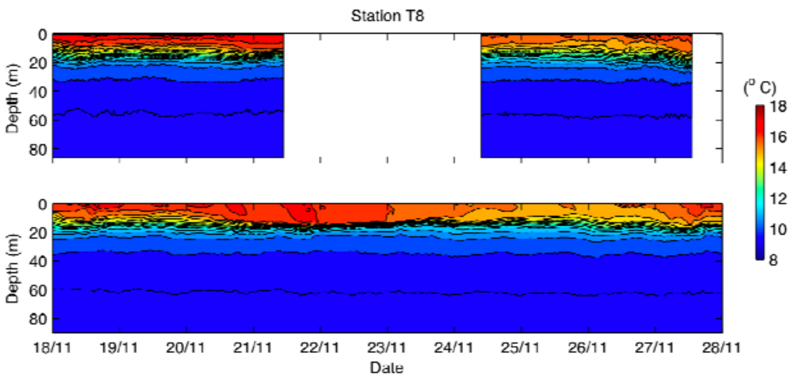

Figure 2. Water temperature time series measured at LDS T8 (top) and simulated with ELCOM (bottom). White sections indicate missing field data.

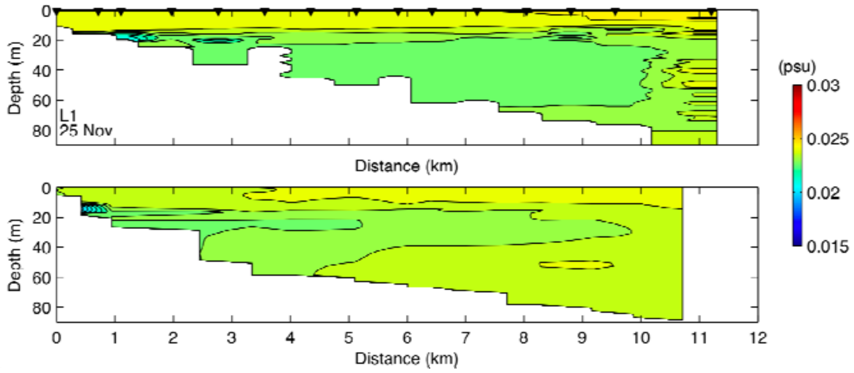

Figure 3. Longitudinal transect showing spatial distribution of field salinity (top) and simulated with ELCOM (bottom) on 25 November 2008 during the process field experiment. Profiling stations are indicated with triangles at surface level in the top panel.

5.2. Real-time prediction

Three two-week forecasting scenarios were setup in consultation with Melbourne Water. These comprised of (1) a baseline inflow scenario, where the model ran a two-week forecast using forcing data from the current day for inflow temperature and current week for meteorological forcing and withdrawal rates, (2) a large inflow scenario, where an inflow event was added to the current week's inflow rate and again run for a two-week forecast, and (3) a two-week forecast in which an alternate, temporary offtake for Bells was positioned at a deeper point slightly downstream in the reservoir and set to offtake water from closer to the surface than the existing Bells offtake.

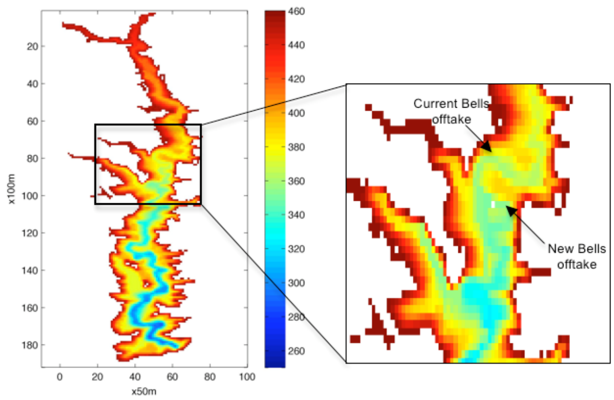

Figure 4. Thomson Reservoir bathymetry (left) showing close-up of alternate, temporary Bells offtake (right, white cell) compared with the existing Bells offtake.

Scenario (3) was set up in response to lowering of reservoir water levels over recent years to a point where abstraction from the existing Bells offtake may not be feasible in the near future. This provides a basic example of how ARMS can be used to assess available options during drought management. The results from this scenario are examined here in detail. The alternate Bells offtake was positioned such that water was withdrawn from 5m below the surface above the deepest location in the old riverbed adjacent to the existing Bells offtake (Figure 4). ELCOM was spun-up over the experimental period before a peak flow of 32.9 m^3/s was superimposed on a zero background flow with the flow temperature set to the average temperature recorded by the RDS in the last day of the record. Withdrawal and meteorological forcing data collected over the most recent week were repeated and the model run until 11 Dec 2008.

The inflow tracer concentrations from Swingler Weir and Little Boys Creek present in the offtake water from the existing and alternate offtake locations are shown in **Figure 5**. (LHS). Note that under this scenario offtake only occurred for a 24-hour period at Bells. Swingler Weir inflow (the greatest source of inflow to the reservoir) was diluted more than 10 times at the alternate, temporary offtake location, compared with more than 5 times at the existing offtake location. The increased dilution could be due to first, the more downstream location of the alternate offtake, allowing more time for the Swingler Weir inflow water to mix and dilute before entering the offtake, and second, the higher withdrawal depth of this alternate offtake which targets water from the well mixed epilimnion. The smaller Little Boy's Creek inflow (red line) was less diluted under this configuration, due to the closer proximity of the offtake to this inflow compared with the existing location. The maximum temperature of the offtake water increased from approximately 13.6 ^{o}C for the existing offtake location (scenario 2) to 15.4 ^{o}C for the alternate offtake location (scenario 3) (**Figure 5** – RHS). This was due to the different depths of the offtakes withdrawing from a thermally stratified water column. While the existing offtake withdrew water from between 381 and 383m AHD (approximately 13 to 15m below the surface water level at the time of the simulation), the alternate offtake withdrew water from a warmer, shallower region, between 5 and 8m below the surface water level.

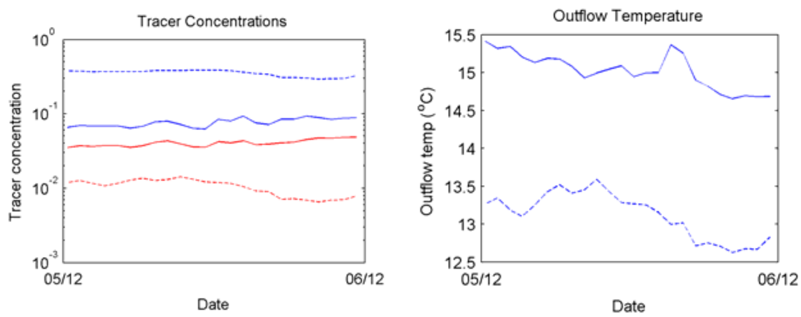

Figure 5. LHS: Concentrations of tracers T1 (Swingler Weir inflow - blue) and T2 (Little Boy's Creek inflow - red) evident in the offtake water. The dashed lines represent scenario 2, large inflow results at the existing offtake locations, while the solid lines represent scenario 3, large inflow at the alternate, temporary offtake location. RHS: Withdrawal water temperature in the offtake for (a) scenario 2 (existing offtake location, dashed blue line) and (b) scenario 3 (alternate offtake location, solid line).

6. ARMS AS A DECISION SUPPORT SYSTEM

The scenario described above provides a demonstration of how ARMS can be used to support a management decision, in this case assessing the merits of re-configuring the outlet design. Moreover, this process is not static and through ARMS the collection of model forcing data and ongoing scenarios assessment becomes an automated process that can provide a running report on the effectiveness of proposed changes. This opens the possibility for an adaptive management approach that relies on accurate forecasting on timescales of days, weeks, months or even years ahead. In this case the scenario evaluation suggests that a change in the offtake configuration will withdraw water from a different part of the storage. The preliminary scenario modelling described above indicates that both the degree of dilution of the inflow water at the offtake and the offtake water temperature vary under these different offtake scenarios. Changes to the particulate, chemical or biological loads in the withdrawal water under alternate withdrawal configurations are as yet unknown. By dynamically coupling the Computational Aquatic Ecosystem Dynamics Model (CAEDYM) (Romero et al. 2003) to ELCOM, these constituents could be modelled explicitly and withdrawal water quality predicted.

There are numerous issues associated with the current drought, including reduced reservoir inflow, altered inflow quality (due to drier run-off regions), and the potential for increased bushfire frequency and intensity. The current model can be used to model short-term scenarios associated with the altered inflow characteristics, such as the alternate offtake configuration described above. Recent bushfires in Victoria have lead to uncertainty about the response of the catchments and in turn their reservoirs to upcoming seasonal rainfall events. There is the potential for significant input of fire-related particulates that may rapidly change the ecology of the reservoir and lead to a deterioration of the water quality, as was the case in Cotter Reservoir after the Canberra bushfires of 2003 (White et al. 2006). ARMS offers a system to forecast the likely response and give fore-warning about potential hazards for water quality. With up-to-date information and detailed forecasts reservoir operators are in a position to make rapid and informed decisions that can minimize potential risks in the most cost-effective way. This, for example, may involve shifting offtake points, switching on an aerator or preparing for a change in downstream treatment regimes. Over the long-term, the effects of increased bushfire frequency on reservoir water quality could be modelled.

On the other hand, there is the long-term management scenario regarding increased inflow. Thomson Reservoir will be allowed to re-fill over a projected period of 8 to 10 years by lowering abstraction from the reservoir as a metropolitan desalination plant comes online. During this time, there will be a continual evolution of the reservoir behaviour as it the water level increases. ARMS allows scenario prediction which will be valuable in managing that change. The collection of valuable reservoir data via the LDS, and storage of this and other data in ARMS over the long-term ensures a highly detailed, growing record of key reservoir data.

7. SUMMARY

This project involved the successful development of a decision support system for Thomson Reservoir. This was achieved by:

- Installing of high resolution monitoring equipment to measure meteorological parameters, temperature and dissolved oxygen at key collection points in the reservoir;
- Setting up the Aquatic Realtime Management System with a validated hydrodynamic model that has the ability to run forecast scenarios with quasi-real-time forcing data as supplied by LDS T8, T9 and the Swingler Weir RDS;
- Undertaking a field experiment during which high-resolution spatially and temporally physical and biochemical data was collected; and
- Re-validating the model using the fine-resolution field data that was then set-up to run three scenarios.

The three scenarios serve as a demonstration of the forecasting that can be done through ARMS and should be expanded on and updated by Melbourne Water as conditions in the reservoir and operational strategies change. One scenario included an alternate temporary location for the Bells offtake, which suggested that a significant change in the offtake water characteristics could result due to the selective offtake of water higher in the water column.

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