CENTRE FOR WATER RESEARCH: LEADING EDGE TECHNOLOGY WINS INTERNATIONAL PROJECTS

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Abstract

The Centre for Water Research at the University of Western Australia has for decades been developing technologies for the adaptive management of natural river basins and the water bodies. The methodology consists of building an objective function that identifies a sustainable goal for the domain under consideration, a relational data base management system that is used to control the data flow and schedule from field sensors and model output, a suite of 3D hydrobiological models and a web interaction tool. These technologies are in use in projects in Singapore, Japan, Israel, Saudi Arabia, Germany, UK, Italy, the US, Canada, Brazil, Argentina, Venezuela and Colombia.

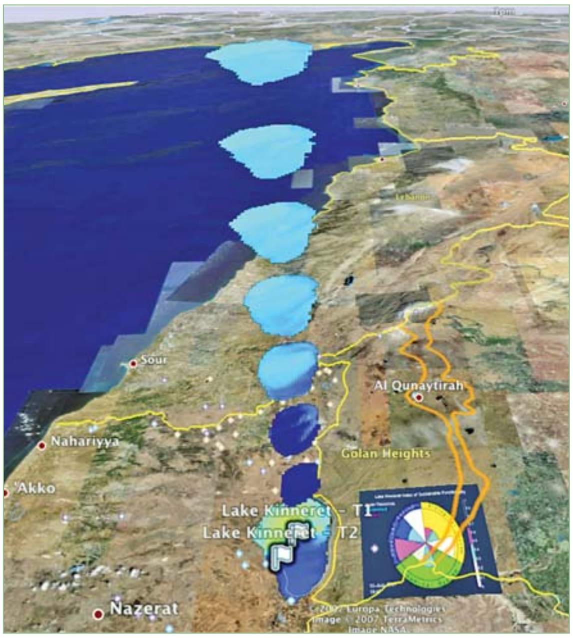

Figure 1. Model output embedded into Google Earth for viewing data from Lake Kinneret (Israel) in the context of the surrounding landscape. Sheets are chlorophyll at 5 m depth intervals from the top to the bottom layer. A colour-coded representation of the measured gradient is used. The schematic adjacent to the lakes is the real time ISF graph.

Introduction

Over the last 25 years researchers at the Centre for Water Research (CWR) have developed a deep understanding of the hydrobiological processes operating in natural systems; catchments, rivers, lakes, wetlands, estuaries and coastal regimes, backed up by the development of real-time hardware and software.

Research at CWR focuses on the optimisation of water quality, carbon sequestration, aesthetic value and human satisfaction while maintaining design water yields, power generation, flood protection and protein yield in natural systems. The interaction of multi-parameters and stakeholder interests can be captured and optimised by setting up an objective function called the Index of Sustainability or ISF (Imberger *et al.* 2007). This is used to control actions with a software suite called Aquatic Realtime Management System (ARMS) that acts both as a data base controller and an action scheduler (Ewing *et al.* 2004).

Australian technology being applied in thirteen overseas countries.

The ISF is a single number that may be used as an objective function in an optimisation scheme; the objective of an operator strategy should be to maximise the ISF for that particular domain. Since the stakeholders' weightings will change with time, the domain will evolve to reflect their priorities. A domain and its stakeholders may then be deemed to be acting sustainably: "if the domain can absorb the impact of development actions without loss of functionality" (Imberger *et al.* 2007). This objective function is particularly useful as it allows a concrete way to adaptively manage a domain in the face of development and climate change.

The Models

In principle ARMS (http://www.cwr.uwa.edu.au/services/models. php?mdid=1) can be used to schedule any suite of models and databases, but ARMS and the CWR suite of models are optimised to function together. CWR models fall into two categories. First, are the hydrodynamic driver models such as DYRESM (Yeates and Imberger 2004), DYRIM (Devkota and Imberger 2004) and ELCOM (Hodges *et al.* 2000) that allow for the transport and mixing of mass, momentum and energy in water bodies at desired environmental scales (i.e. from hydrologic flows, to rivers, flood plains, wetlands, lakes, estuaries and coastal seas); in brief water bodies at environmental scales. Second, is a universal ecological model CAEDYM (Hipsey *et al.* 2006) that, when coupled to one of the above hydrodynamic drivers, accounts for the transfer of mass among the ecological state variables that are relevant to that water body and to the questions under examination by the models.

The objective is to develop an open source set of models for the modelling of water from the rain to dispersion in the coastal regime.

CWR models differ from most other models in that they have their origins in either the larger oceanographic context or smaller mechanical fluid machinery applications. Further, by incorporating integral closure schemes, CWR models are designed to run on simple desktop computers at speeds of around 200 times real time for domains with the order of one million grid points.

In addition, over the last 5 years, CWR has developed a web visualisation tool, called OLARIS (http://rtm.cwr.uwa.edu.au/olaris/), which automatically renders the images, delivered by ARMS to the databases, on the web. OLARIS allows images to be scrolled, zoomed, overlaid and time synchronised (Figure 1). This programme is under active development to allow for personalised client visual output.

The output from the models and any current or historical field data, may be embedded automatically by ARMS into Google Earth so that all the added information in all of Google Earth's layers becomes available in a consistent way.

Instrumentation

Over the last 25 years, CWR has developed a special suite of instruments (http://www.cwr.uwa.edu.au/services/field.php?mode=list) designed to allow process measurements in natural systems. These developments are ongoing and may be categorised into four groups: (a) *in situ* devices that measure a range of variables such as inflow, outflow and meteorological forcing; (b) boat mounted profilers to enable the measurement of both microstructure-scale (~1 mm) and fine-scale (~1 cm) state variables; (c) self-learning data acquisition equipment that enables real time coupling of 3D modelling and field data acquisition; and (d) in-field real time polymerase chain reaction (PCR) for the detection of informative DNA sequences in the water. Two developments deserve a more detailed description:

The Lake Diagnostic System (LDS): The hardware of the LDS consists of a full meteorological station and chains of sensors in the water column; the chains may contain temperature, conductivity, DO, pH, but other sensors will shortly be available. The data acquisition of the LDS has 20-bit accuracy and when matched, with highly stable sensors, allows water motions to be diagnosed. For instance, temperature when measured to 0.1 milli°C allows not only temperature to be documented, but also the light extinction coefficient, turbulent mixing coefficients and even estimates of the biomass may be obtained (Imberger 2004). Data streams for the LDS go via GSM telephone or other transmission routes, in real time to ARMS, where the data are analysed to be displayed through OLARIS.

There are currently 32 LDSs in use in locations around the world including Lake Como (Italy) (Figure 2), Lake Kinneret (Israel), Deadwood Reservoir (USA) Marina Bay (Singapore), Lake Burragorang (Sydney), Prospect Reservoir (Sydney) and Upper Yarra (Melbourne), reporting real time data back to the CWR website (http://rtm.cwr.uwa.edu.au/olaris/).

Figure 2. The Lake Diagnostic System deployed in the western arm of Lake Como in front of the City of Como (Italy).

Controlled Lagrangian Drogue (CLD): In oceanography, winged glider vehicles are relatively commonplace but they are unsuitable for lake work because they fly rather fast, (close to 1 m/s), and when combined with a sensor response of a second or more they yield poor vertical spatial resolution. Furthermore, manoeuvring such vehicles in a bounded domain is difficult because of their rather long turning circles. CWR has developed a similar vehicle, but without wings (Figure 3); the CLD adjusts its depth to take advantage of the natural current system in the water column to go from station one station to another. When coupled with a real time 3D ELCOM simulation the CLD can profile the water column every two hours for a period of up to three months, traversing the lake so as to optimise the signal to noise ratio of the signals under consideration.

Examples of Overseas Projects

CWR is currently involved in about sixteen projects in twelve overseas countries. Below is a sample of four typical projects in progress or about to commence:

Managing local nutrient loads into Lake Como, Italy

The iconic Lake Como, is one of Italy's most popular resort areas, playground and home to the rich and famous. The western arm of Lake Como has had ongoing water quality problems due to nutrient effluent inflows from the Cosia River. The first reaction of the governing bodies was to mandate a clean up programme of the contributing catchments in line with the 5th European Water Quality Framework.

CWR advised the local authorities that such a reduction of nutrients would take a long time to achieve, was of questionable cost effectiveness and would, in any event, lead to a reduction of primary production and consequently a reduction in fish biomass.

Measurements had consistently shown that Lake Como proper was oligotrophic with very low levels of phosphorus and nitrogen. Thus a more sensible, cost effective and palatable solution for the local fishing industry was to disperse the nutrient rich Cosia River water into the lake proper and allow it to be taken up by the food chain. This is also a more environmentally responsible strategy as it would increase the rate of carbon sequestration. The Centre recommended a way to disperse the nutrients, and currently dispersion is being achieved with a number of impeller type pumps from ITT Flygt. The results from the pilot study of the deployment last October has verified the effectiveness of the above concept (Figures 4 & 5).

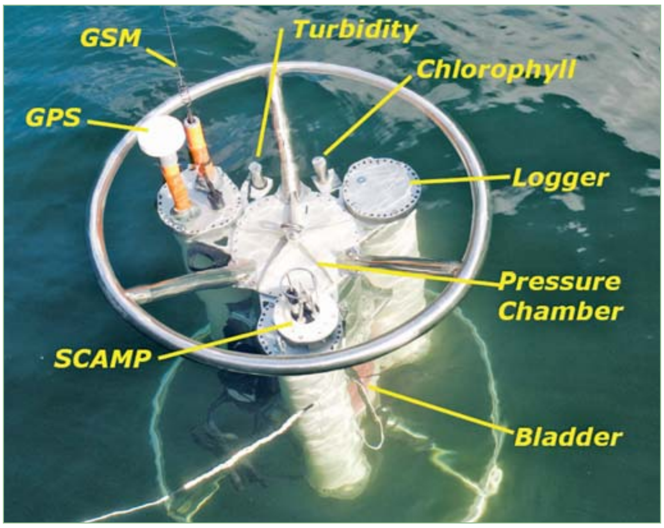

Figure 3. The CLD in the water during recent field-testing in the Swan River Estuary, Perth, Western Australia.

Multi-purpose city icon, Marina Bay, Singapore

The Marina Barrage and Reservoir project is a showcase project for Singapore and the Singapore's Public Utilities Board (PUB). The construction of a barrage across the Marina Channel will result in the formation of a freshwater system with minimal water level variations in the downtown area of Singapore. The reservoir will become the showcase water body in Singapore, incorporating water supply, flood control, recreation and a new lifestyle (Figure 6).

The project is funded by PUB and CWR is working in partnership with Nanyang Technological University (NTU) and CWR's real-time management system will be further developed for use in Marina Reservoir (which is yet to be built).

The objective is to allow the control of river diversion, pump back, lake partitioning to optimise a yet to be formulated ISF objective function. The system will also allow alarm calls, notification of the general public as to the likelihood of potential water quality problems, the expected longevity of the problems and the recommend alleviation measures. The real-time management system consists of a real-time monitoring network, integrated 3D reservoir modelling and forecasting capabilities.

Hydropower water quality optimisation, Caruachi Reservoir, Caroni River, Venezuela

The Caroni River in the north-east of Venezuela has four large hydropower and flood control structures. Together, these dams supply 85% of the power requirements of Venezuela, leaving their oil reserve free to earn foreign capital. The lakes range in size with associated residence time from a few weeks to about one year.

As stage one CWR has been commissioned to install one LDS in Caruachi Reservoir (residence time of 3 months) on the Caroni River, couple the 3D suite ELCOM-CAEDYM with the objective of reducing the very severe macrophyte outbreaks in the embayments around the perimeter (Figure 7).

In Step One, we will verify the hypothesis that the blooms that occur in embayments have a much longer residence time. In Step Two we will model the observed rate of growth of macrophytes and in Step Three we will design alleviation strategies that enhance the horizontal dispersion, thus lowering the residence time in the offending embayments. Numerous strategies will be investigated such as submerged curtains to deflect the through flow current into the embayments, local nutrient reduction, and increasing differential heating and cooling

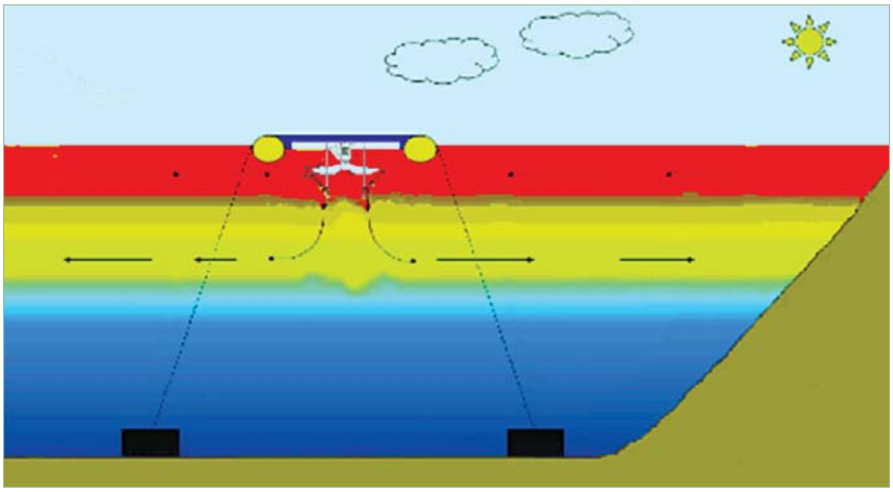

Figure 4. Schematic showing action of the vertical ITT Flygt Impeller.

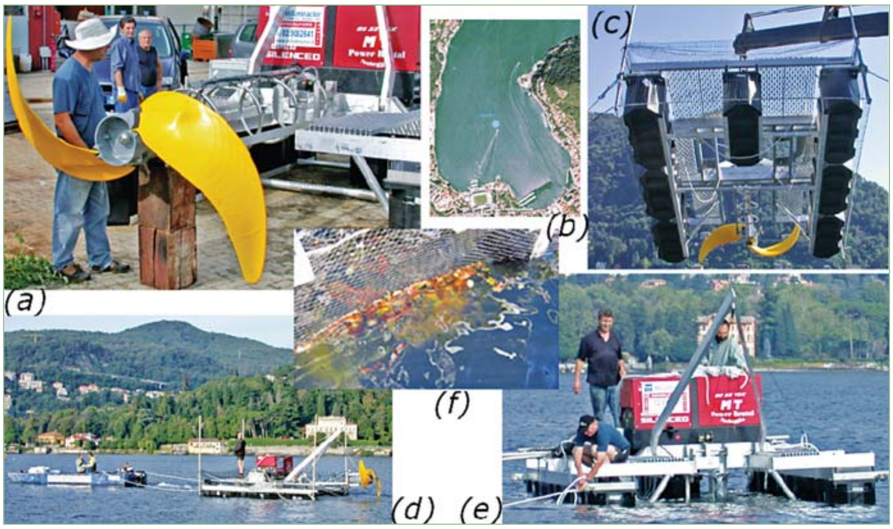

Figure 5: Various pictures of the ITT Flygt Impeller Installation in Lake Como. a) Close up of impeller before installation; b) location of Impeller in the west arm of Lake Como in front of the City of Como; c) Crane lifting pontoon containing impeller and diesel generator into water; d) Pontoon being towed out to site; e) Pontoon being anchored at site; f) leaves being drawn towards protective netting showing that surface water was being drawn into the Impeller jet and ejected vertically down towards to thermocline as shown in schematic Figure 4.

Figure 6. Artists impression of the new Marina Barrage and surrounding developments.

Cleaning up heavy metal pollution without causing algal blooms, Coeur d'Alene Reservoir, Idaho, US

Coeur d'Alene reservoir is an iconic lake that is partly managed by the Coeur d'Alene Tribal Lake Management Department. The Coeur d'Alene Tribe holds the lake sacred and has jurisdiction over waters within the Reservation boundaries of the lake. The lake is also a popular recreation and tourist attraction. The lake is replenished with water from two rivers. The St Joe enters the lake at the southern extreme and this water is mildly polluted with phosphorus and nitrogen due to agricultural activity in its catchment. The second river is the Coeur d'Alene River which drains a large catchment, historically the site of major mining activities and flows in as a slightly submerged underflow shown in Figure 8.

The catchment is an Environmental Protection Authority super-site and the water in the Coeur d'Alene is heavily polluted with heavy metals and in particular with zinc. This pollution inhibits algal growth that would otherwise be sustained by the nutrients flowing in from the St Joe River. The water, at present, is clear and of high aesthetic value even though polluted with heavy metals. CWR was commissioned to assist in the design of a metal reduction programme without inducing algal blooms in the lake. An extensive field campaign revealed the underlying physics of the two intruding rivers and the associated mixing patterns. Together with the United States Geological Survey, the CWR model CAEDYM was extended to include a full metals process description and the combined CWR model ELCOM-CAEDYM simulations were used to ascertain the likely extent of algal blooms as a result of metal clean up in the Coeur d'Alene River and corresponding different degrees of nutrient reduction in the St Joe River water.

Summary

Our methodology of field experiments, analytic and numerical modelling, and real time hybrid environments has enabled us to provide a comprehensive service to managers of multi-purpose water bodies worldwide. These services have resulted in reduction in pollution of water-ways; improved management of water resources; access to clean waterways, maintenance of strategic water resources and enabling ongoing public access to recreational facilities.

Acknowledgments

CWR was established in 1982 with funding from the State Government and the Commonwealth Government of Australia through the Special Research Centre funding scheme. This funding ceased in 1999. Our ability to maintain our international reputation has to a large extent been due to the support received through projects funded by a number of international sources and by Sydney Catchment Authority, Melbourne Water and the Australian Research Council.

Figure 7. Nuisance growth in Caruachi Reservoir.

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Jorg Imberger, Director of the Centre for Water Research is an internationally recognised and respected environmental engineer who was recently elected a Fellow of the American Geophysical Union and inducted to the US National Academy of Engineering. In 2007 Jorg was awarded the ASLO A.C. Redfield Lifetime Achievement for his work in physical limnology. In 1996 he was awarded the Stockholm Water Prize and in 1995 the Onassis Prize. Jorg leads a research organisation that provides both the worldwide research community and industry with state of the art tools that has resulted in the implementation of effective and sustainable water management strategies for water bodies worldwide. **Caroline Wood** is a Deputy Director at the Centre for Water Research. Caroline is responsible for marketing, long term planning, managing international collaboration and directing high profile events. **Clelia Marti** is Manager of Field Operations at the Centre. She is responsible for overseeing all the Centre's field related projects and for overseeing the instrument development at the Centre. Contact details: Centre for Water Research, The University of Western Australia. Website: http://www.cwr.uwa.edu.au/. Email: wood@cwr.uwa.edu.au. Telephone (08) 6488 2466.

References

Devkota, B.H. and Imberger, J. 2004. Numerical simulation of river flows in a Lagangian reference frame, Shallow Flows. G.H. Jirka and W.S.J. Uijttewaal, editors. *Selected papers of the International Symposium on Shallow Flows*, June 16-18 2003, Delft, The Netherlands, A.A. Bakema Publishers, 672 pp., 535-540.

Ewing, T.C., Romero, J.R., Imberger, J., Antenucci, J.P. and Deen, A. 2004. A real-time reservoir decision support system. HYDROINFORMATICS (In 3 Volumes, with CD-Rom). *Proceedings of the 6th International Conference,* Singapore 21 - 24 June 2004 edited by S-Y. Liong, K-K. Phoon and V. Babovic, PS7B-04, Vol 2: 1123-1131.

Hipsey, M.R., Romero, J.R., Antenucci, J.P, and Imberger, J. 2006. The Computational Aquatic Ecosystem Dynamics Model (CAEDYM): a versatile water quality model for coupling with hydrodynamic drivers. *Proceedings of the 7th International Conference on Hydroinformatics, Nice, France,* 03-08 September 2006, Vol 1., 526-533

Hodges, B.R., Imberger, J, Saggio, A., and Winters, K.B. 2000. Modeling basin-scale internal waves in a stratified lake. *Limnol. Oceanogr.* 45:1603-1620.

Imberger, J., 2004. A lake diagnostic system for managing lakes and reservoirs. *Water Resources Impact*, 6(1): 7-10

Imberger, J., Mamouni, E-A.D., Anderson, J., Ng, M-L., Nicol, S. and Veale, A. 2007. The Index of Sustainable Functionality: A new adaptive, multi-criteria measurement of sustainability: Application to Western Australia. *International Journal of Environment and Sustainable Development,* in press.

Morillo, S., Imberger, J. and Antenucci, J.P. 2007. The influence of wind and lake morphometry on the interaction between two rivers entering a stratified lake. *Journal of Hydraulic Engineering,* ASCE, submitted.

Yeates, P.S. and Imberger, J. 2004. Pseudo two-dimensional simulations internal and boundary fluxes in a stratified lakes and reservoirs. *Inter. J. River Basin Management* (4):1-23.

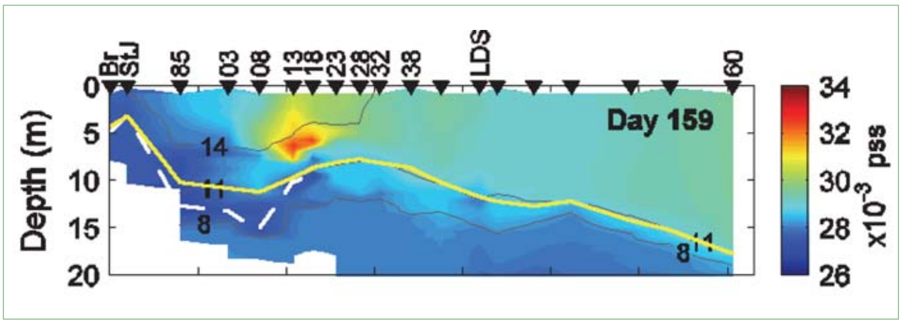

Figure 8. Longitudinal cross section from the entrance of the St. Joe River to the downstream dam wall. Grey lines are temperature contours and the colours salinity. The high concentration near station 08 is the Coeur d'Alene River underflow (Morillo *et al.* 2007).