Title: eWater Source and Community of Practice for Integrated Water Resource Management

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Abstract – Mathematical models for Integrated Water Resources Management (IWRM) have traditionally been designed for scientific exploration of a limited set of hydrologic processes.

Water management organisations are however increasingly concerned with holistic decision-making for short-term operations and long-term planning of both water quantity, water quality and ecosystem health, integrated across urban and rural catchments.

Systems Thinking is a technique to understand complex dynamic interdependent systems based on feedback and iteration rather than a fixed concept of what level of detail is required.. Certain stages are tiered to allow decision-maker to identify, screen, prioritise and evaluate risks and options, before deciding whether more detailed risk assessments and options appraisals are required.

In order to fully address IWRM goals, the eWater Source framework introduces the ability to approach river basin management from a Systems Thinking perspective, progressively building complexity as it is required and can be justified in terms of supporting good decisions.

Keywords – Integrated River Basin Management, Integrated Water Resources Management, Systems Thinking.

Introduction

Management of water has become an increasingly complex issue and it is no longer sufficient to justify decisions on the basis of incomplete science or limited process descriptions in simulation tools. Water managers need new generation tools that allow integration across multi-sectoral, hydrological and governance domains. Time scales for decisions are often driven by broader socio-political agendas and it is impractical to delay while additional costly and time-consuming data collection campaigns are undertaken, to be followed by even more modelling. Decision-makers also recognize that to investigate each part of the process with equal detail can be a very long and expensive exercise and may not ultimately better inform the decision, despite the best intentions.

The Systems Thinking approach argues that the only way to fully understand why a problem or element occurs and persists is to understand the parts in relation to the whole, which is in direct contrast to the scientific reductionist approach (Wikipedia, 2012). Application of Systems Thinking in an IWRM context implies that an adaptive framework is necessary where all the physical and governance arrangements are available but complexity is matched to the sensitivity of outcomes. The concept of adaptive complexity supports this approach to decision-making where models are matched to the level of information and outcome as shown below in figure 1.

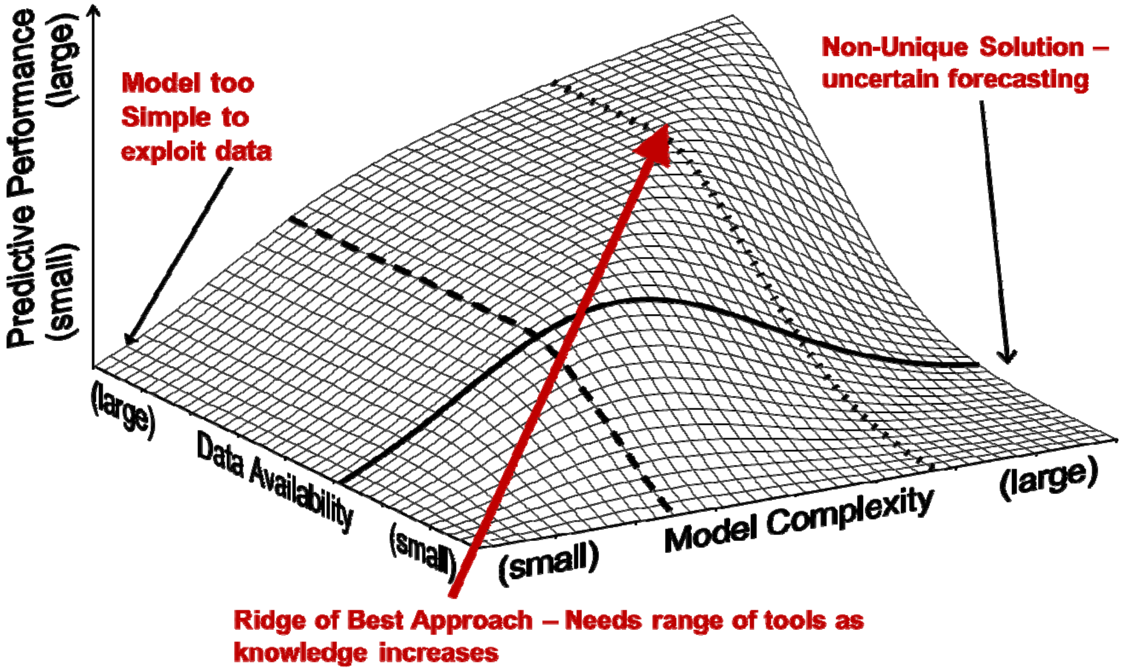

Figure 1. Concept of Adaptive Complexity (Adapted from Grayson, R., and Bloschl)

A further trend which has emerged in recent years is that of complex models underpinning Decision Support Systems however again this important arena has become mired in the need to address more and more data, and often becoming more like Data Support Systems (Carr, 2012) where the true costs of maintenance are not exposed until the knowledge in the original group of trainees is lost through organizational change.

Key Issues and Challenges

> *There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success than to take the lead in the introduction of a new order of things.*
> Niccolo Machiavelli

South Asia and South-East Asia have major concentrations of poor people. Unresolved conflicts over water remain a significant issue which, if resolved, can deliver significant progress towards poverty reduction goals through equitable access to water.

Australia's Murray-Darling Basin process has evolved from a water governance environment which can provide many lessons for other transboundary river basins in the region, and while the Australian journey is not complete, models as the underlying technical basis for policy has emerged as a common foundation which has lead to shared understanding and ultimately agreement.

Transforming the development of water policy into a science-based evaluation regime founded on systems thinking methods will require changing how institutions develop, test and implement policy. Modelers, who have traditionally seen their role as producing the most scientifically-robust and defensible tool will also need to adjust their approach more towards providing the most appropriate methodologies to support policies.

At the high level, eWater Source has been designed and developed within Australia to provide a flexible, transparent, robust and repeatable approach to underpin a wide range of water planning and management purposes. The eWater suite have been developed over more than 25 years of combined R&D amongst Australia's leading water practitioners, researchers and decision-makers to reflect the four principles of:

1. Adaptive Complexity - Matching models, data and outcomes
2. Flexibility - No one right solution – multiple options
3. Openness New Knowledge All The Time – Open Framework
4. Defensible - Best Practice Tools and Applications

eWater tools have been used to develop water sharing plans and underpin daily river operations, as well as assessments of water quantity and quality due to changes in, i) land use and climate ii) the influence of demands (irrigation, urban, ecological) and iii) infrastructure types (control structures, weirs and reservoirs); iv) the influence of various management rules that may be associated with these; as well as v) the impacts of all of the above on various ecological indices.

The challenge is therefore to bring the policy and modeling mindsets together. To do so will require a long term commitment to capacity building which embeds the concepts and practice of systems thinking to support sustainable science-based policy development.

eWater Source - basic conceptual structure and capability:

Source is a model which combines supply, demand and management elements in a single framework. This is intended as a very brief overview of the technical aspects of Source, for a more detailed description see Carr and Podger, 2012.

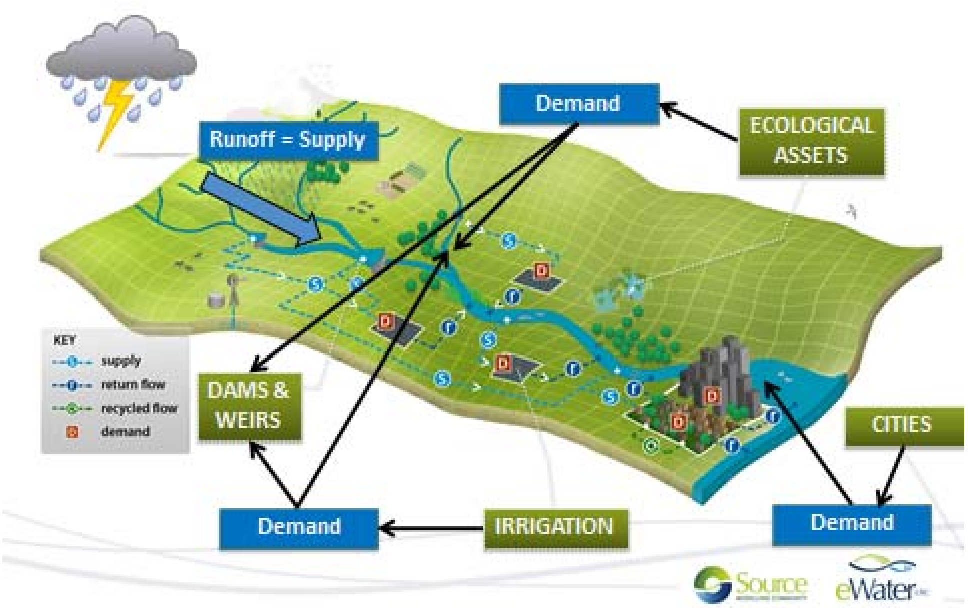

Figure 2. eWater Source

Source is built on top of a Microsoft .NET-based technology stack, with TIME as a base modelling framework (Rahman, et. al. 2003) and E2 (Argent, et. al. 2005) providing the base simulation system. The Invisible Modelling Environment (TIME) is a software development framework consisting of thousands of routines for creating, testing and delivering environmental simulation models. TIME includes support for the representation, management and visualisation of a variety of data types, as well as support for testing, integrating and calibrating simulation models.

The catchment toolset within Source consists of several elements:

- Tool for delineating catchments from DEM and assigning network elements;
- 6 rainfall runoff models (AWBM (Boughton, 2004), IHACRES (Croke et. al., 2006), Sacramento (Burnash et. al.,1973), SIMHYD (Chiew et. al., 2002), SMARG (Kachroo et. al., 1992 and Tutjea et. al., 1999), GR4J (Perrin et. al., 2003)). Ability to include new rainfall-runoff models through plugin functionality;
- Configurable for different input modes (user defined grids, sub catchment areas, lumped catchments);
- Calibration tool (pre defined objective functions, 4 optimisation procedures);
- Regionalisation methods (for ungauged catchments and different land use types); and
- Stochastic procedures (for rainfall inputs).
- Constituent export and routing methods are available to support assessment of changes in land use and climate on runoff and constituents)
- Spatial structure (Digital maps, DEMS, land use, land cover (Perrin et. al., 2003, Brown et. al., 2007));
- Constituent generation (Dry Weather Concentration, Event Mean Concentration, USLE (Wischmeier, 1972), SEDNET (eWater Toolkit, 2006 and Prosser et. al., 2001));
- Filtering (riparian filtering, farm dams; and
- In-Stream sources, sinks and decay.

River Networks in Source are schematised into a simplified node-link structure. Nodes are available for particular usage/needs and through the plugin capability, new elements can be introduced on the basis of local research or knowledge.

- Links - routing (Linear (McCarthy, 1938, Gill, 1978), non linear (Laurenson, 1959, Mein, 1974, Kousis, 2009), Piecewise linear (Close, 1996) and pure lag).
- In-stream water quality (water quality routing, in-stream constituent decay);
- Nodes for physical processes (inflow, flow observation, storages, loss, splitters and confluences for anabranches, supply point, water use and hydraulic connector for hydraulically driven flow)
- Nodes for management processes (controlled splitter, confluence for order distribution, water user, maximum order constraint, minimum flow requirements, off allocation, storages, transfer ownership and parallel arcs)

An additional feature of the Source model is that the routing and travel times in the links can be informed by more complex river routing tools such as those based on the St Venant Equations and the important parameters collated into a ‘data cube’ where the complexities of the more detailed model are parameterised into the important elements of the Source link. In this way, the Source model can utilise the detailed local scale modelling to develop a broad strategy.

Source incorporates a simplified Groundwater-Surface Water Interaction Tool (GWSWIT) (Rassam, et. al., 2012) to inform surface water modelling of the impacts of groundwater/surface water interactions. The tool accommodates (i) exchange fluxes (Magnitude and direction, along links, bank storage, groundwater pumping, irrigation recharge, diffuse recharge, evapotranspiration, floodplain inundation); (ii) SW-GW connectivity mapping (Saturated and unsaturated); and (iii) ability to import data (MODFLOW, direct field measurements and other groundwater models).

River regulation and storages in Source are defined by many different combinations and types of storages, reservoirs and weirs in regulated river systems. Reservoirs and storages can be configured as:

- Series (re-regulating through on-river or off-river storages);
- Parallel (independently, harmony operation, order splitting, access zones);
- Multiple outlets to multiple downstream paths;
- Hydraulically connected reservoirs;
- Weirs (with routing in the un-flooded upstream reaches);
- Releases and volumes may be forced with time series inputs; and
- Evaporation, rainfall and seepage fluxes directly on the reservoir surface.
- Reservoirs have the ability to accommodate ordering through rules-based or network linear programming approaches. They may also be partitioned for water ownership.

Demands, Water Sharing and Ownership are configured as a demand-driven model (regulated system) or as a free-flowing river (unregulated) or as a combination of both. This is one of the most powerful features of Source where in combination with the ownership functionality allows policy-makers and managers to gain insight into reliability and security of systems within single jurisdictions and for trans-boundary policy development. In this mode Source is applicable to a wide range of water management issues such as (but not limited to) (i) urban water (time series, regression relationships, waste water reuse, alternative supplies, stormwater harvesting); irrigation demands (3 soil moisture accounting models) and (iii) environmental demands (multiple event based environmental water requirements and flow objectives)

Many regulated rivers have complex water management rules, called resource assessment systems (RAS), to share the available water resource amongst water users in a defined hierarchy. These sharing systems are increasingly being applied not only to large river systems but also urban systems. Resource assessment (resource sharing) can accommodate many policy and legal instruments which are common in Australian water management including Simple accounting, Annual accounting (with and without carry over), Continuous Accounting, Continuous sharing and Unregulated flow sharing

Source includes complex ownership systems for managing water of different stakeholders (e.g. environment, states or countries) that allow for water in the model to be subject to assignment, tracking, storage sharing (internal spilling and ceding), constraint sharing, borrow and payback between owners and multiple ownership systems.

Source includes a comprehensive Environmental Demand Model (EDM) allows the user to specify a flow rule set that will generate the water required to achieve target environmental objectives. Target river locations (eg. fish breeding habitats), river reaches (eg. a polluted zone downstream of a large city) or ecosystems (eg. floodplain wetland) are represented in Source as ‘user’ demand nodes. The EDM operates on a daily basis generating demands and extracting water to meet these demands via the water user and supply nodes. The aim of the model is to specify a flow rule set that will generate the water required to achieve predefined environmental objectives. This model can be applied in both regulated (with large dams) and unregulated systems.

There are four basic ways of customizing Source through user additions of algorithmic representations of processes occurring at a node, link, or functional unit level.

- The expression editor allows user-defined algorithms for inputting & evaluating expressions in various parts of the software. These relationships could for example represent a regression expression for sediment export from a specific research on a specific catchment.
- Custom Functions which are new functions or transformations within the expression editor based on user-written code.
- Plug-ins which are essentially new process descriptions for a part of the Source framework. Plugins can include model algorithms, user interface code, input or data input validation codes, persistence mapping files, graphics or even icon text. Plug-ins can enhance catchment, node or link models, data pre-processing tools, reporting and export tools.
- Remote running - the simulation engine can be run from the command line as a ‘slave’ within a range of larger optimisation packages, executed through a command prompt with parameters modified through the parameter browser.

Source has implemented a multi-criteria multi-objective optimisation tool based on the NSGAII algorithm (Deb, 2002) called Insight (Blackmore et. al.2009), Application of the tool requires development of objective functions (which are the trade-off metrics) and decision variables that are the parameters, which can be varied in the optimisation. The expression editor in Source is typically used to develop metrics which can inform the decision space which can be informed by both internal variables within Source or external data sources.

Best Practice Modelling

As a major provider of modelling products to the Australian Water Industry, eWater recognised its’ responsibility to foster a best practice approach. There is also now a growing expectation in Australia (and elsewhere) that there should be a consistent approach to applying models used to support water management decisions across the nation, with the aims (amongst others) of:

- Improving modeling practice;
- Evaluation of uncertainty;
- Improving decision making, including improving the use of science to improve the quality and robustness of decisions made and outcomes;
- Improving communication with end-users of model results: water managers, decision makers and the wider community; and
- Providing a process that is transparent, robust and repeatable.

To this end, eWater has developed a Quality Assurance process as a way to achieving Best Practice Modelling based on defining a wide range of user needs and modeling domains relevant to water management. A hierarchy, or family, of guidelines have been published beginning with a generic procedure to underpin delivery of quality assured, best modelling practice outcomes. This procedure then provides a framework for a consistent set of supporting domain-specific guidelines which, in turn are supported by a set of model specific guidelines.

What is in practice “best achievable, commensurate with the intended purpose” may be subject to data availability, time, budget and other resourcing constraints. Hence, what is meant by the term “Best Practice Modelling” can vary. Not only does it depend on the circumstances of the project, particularly fitness for purpose, but it also depends to a great degree on interpretation in peer review. This, in turn, will be influenced by the general state of knowledge and technology in the modelling field, which can be expected to progressively develop over time (such as new remote sensing data sources coming on line, and new computing hardware), as well as data, time, budget and resourcing constraints. These processes support the Systems Thinking Approach underpinned by the 4 principles of eWater models . Best Practice Modelling provides for a strategic approach to modelling which enables the trade-offs that may be imposed by these constraints to be better managed, and assists in identifying priorities for addressing model and data limitations.

At the time of writing, the Best Practice Guidelines high level document has been released and more than 5000+ copies have been downloaded worldwide. 12 sub-chapters have been, or are in the process of being published as shown below in Figure 4. The Best Practice Modelling Guidelines are available through the eWater Toolkit site (www.toolkit.net.au).

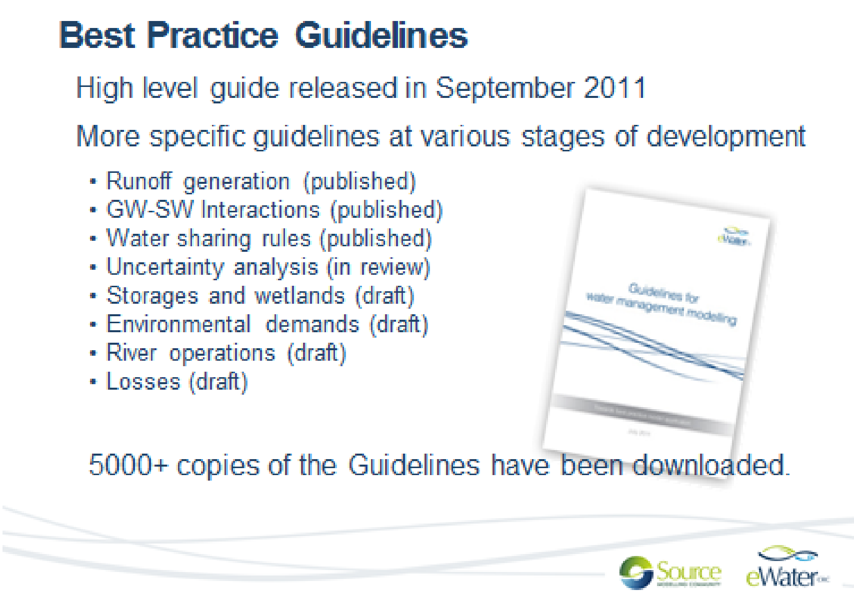

Figure 4. Best Practice Modelling Guidelines

Opportunities:

The task to develop sustainable transboundary water policy to improve equitable access to water for a wide range of users is not an easy task. Australia’s investment into tools which can implement a systems thinking approach and bring decision-makers and modellers together in a community where institutional and operational knowledge can be shared and experienced provides one pathway towards the goal. The impact would be to greatly enhance the ability of River Basin Managers to demonstrate and communicate a strong link between science and policy through advanced water modelling which is focused on the needs of the consumers of that information (i.e. planners, operators and policy makers). Both policy makers and modelers would gain a set of common tools, processes and communication workflows through a community of practice approach. The benefits could include:

- Speed up problem solving by providing a common technical platform
- Facilitate interpersonal communication and learning: All groups work with same data, platform and models
- Reveal new approaches to the formulation of problems and generate new evidence for decisions
- Encourage exploration and discovery on the part of all stakeholders
- Lower barriers to understanding by adopting an open platform approach

Questions for MDB's and DMC's

The recent signing of the India-Australia Water Science and Technology Partnership (http://www.ausaid.gov.au/HotTopics/Pages/Display.aspx?QID=1011) indicates that the willingness to explore transboundary (even states within country) policy development at a systems thinking level is tangible.

If the process is to gain momentum then what kind of structures, partnerships and resources will be required to take this forwards? How will partners come together to integrate tools and information already developed and collected into a central repository, hosted with an organization which will support and maintain it for 20+ years?

How will data integrity be assured for stakeholders to build trust as the process moves from high level gaming to more detailed local studies and data collection?

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