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Comparing software for modelling the management rules that river operators implement

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Abstract: Hydrologists, river managers and modellers advise on how different policy, past actions or climate change scenarios affect the use and distribution of water in regulated river systems. In the Australian context, this typically involves using Integrated Quantity Quality Model (IQQM) or Resource Allocation Model (REALM) but in the future may involve using RiverManager or other software packages. This paper compares how well these packages model some of the rules that policy-makers develop and river operators implement.

The comparison centres on IQQM, REALM and RiverManager models for a regulated reach between Split Rock and Keepit dams of the Upper Namoi catchment of New South Wales, Australia. Figure 1 shows that each model predicts a similar volume of water in Keepit Dam, which demonstrates the correct modelling of operators' rules. Interestingly, each software package provides a different mechanism to describe the operators' rules and a different mechanism to solve the water distribution problem.

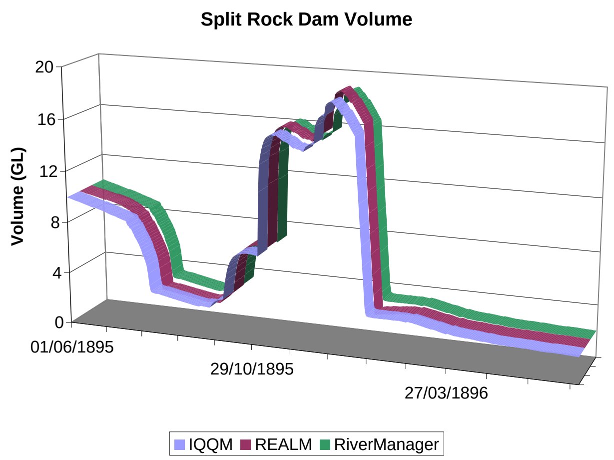

Figure 1. IQQM, REALM and RiverManager produce similar results for river flows and storage levels in the Upper Namoi scenario. The difference between the models for Split Rock Dam was a normalised root mean squared deviation of 1%.

The result of the comparison was that each software package accurately models the river flows and levels but software packages differ on other characteristics. IQQM performs faster than the other products at a daily time step. REALM is the most flexible of the models surveyed. River modellers should avoid REALM where transparency is important. RiverManager performance slows with the addition of complicated expressions. Subject to further investigation of user interface issues, IQQM is less suitable for a novice user.

This paper contributes a better understanding of software packages for modelling river management. In addition, this paper validates the correctness of the packages for modelling operator behaviour. The assessment involved only one river system and did not involve a usability study. Further comparisons between the software products in additional river systems with multiple sets of users would increase confidence in the results. We conclude that of the limited set of software packages examined, RiverManager performs well against a range of criteria, suggesting it provides a good foundation for hydrologists, river managers and modellers to model the rules that policy-makers develop and river operators implement.

Keywords: River Management, Water Sharing Plans, Regulated Rivers, IQQM, REALM, RiverManager

1. INTRODUCTION

Hydrologists, river managers and modellers advise on how different policies, actions and climates affect the use and distribution of water in river systems. They model regulated river systems using software packages that model the flow and management of rivers. In these models, the river flows and storage levels depend on the operational rules. For example, the Gwydir River (NSW) water-sharing plan requires operators to:

“ • ensure that flows into the Gwydir wetlands are at least equal to the sum of inflows from the Horton River, Myall Creek and Halls Creek, up to a maximum of 500 megalitres per day (ML/day), and

• ensure that 50% of the flows above 500 ML/day are protected for the environment.” (DIPNR, 2004)

These rules for the Gwydir River result in water flowing into the wetlands regardless of any irrigator demands or physical flow sequence. Since river flows and storage levels depend on the rules that operators follow, river managers and modellers require that software packages accurately model these rules. In addition, because there are many software packages for regulated rivers, river managers and modellers need guidance on which software packages best support their needs.

Software packages that model regulated river systems include Integrated Quantity Quality Model (IQQM) (Podger 2004, Simons et. al 1999, DLWC 1999), Resource Allocation Model (REALM) (Perera 2005, VUT et al. 2000), MIKE Basin[1], RiverWare (Zagona et. al. 1998, Zagona et. al. 2001), WathNet (Kuczera 1992) and custom tools such as BigMod-MSM[2] (Close 1986) and CALSIM (Munévar et. al. 1999), which model the River Murray in Australia and the Sacramento and San Joaquin rivers in California respectively. In Australia, the most popular software tools are IQQM and REALM, which government departments use extensively in the eastern states (CSIRO 2008). In the past, these software packages have satisfied the user community. However, they now need better support for water accounting and environmental demands, which has motivated the development of RiverManager by the eWater collaborative research centre.

Each new software package introduces a new approach for the modelling of river systems; however, there is little guidance on how the approaches compare. In the context of planning and resource allocation problems, Yeh (1985) and Labadie (2004) review algorithms for optimising the operation of multiple reservoirs. Wurbs (1993) surveys software packages and routines for solving multiple reservoir problems. Others such as Zagona (2001) and Fulp (2001) describe the implementation of particular products. There is no accepted framework, criteria or objectives for comparing river modelling software packages. Therefore, to compare the way software packages model operating rules, §2 provides a set of objectives. We compare IQQM, REALM and RiverManager models against the objectives in the Upper Namoi, Australia (see Figure 2–).

This paper provides guidance on how well IQQM, REALM and RiverManager can model operating rules in regulated river systems. It introduces a case study in the Upper Namoi in §3. The results of the assessment in §4 is that each software package accurately models the river flows and levels, but the software packages differ in the way a user constructs and sets up their model. We conclude that of the limited set of software packages examined, RiverManager performs well against a range of criteria, suggesting it provides a good foundation to model the rules that policy-makers develop and river operators implement.

2. OBJECTIVES FOR SOFTWARE IMPLEMENTATION OF OPERATING RULES

There is no accepted framework, criteria or objectives for comparing river modelling software packages (Ilich, 2008). Therefore, to compare the way software packages model operating rules, this section defines a set of objectives based on existing literature. The set of objectives is not comprehensive nor is the set of objectives ranked. The objectives are specific to the application of operating rules. Definitions of the objectives reflect the purposes of this paper and do not purport to be general definitions. The reader may judge which objectives they consider important. The objectives include accuracy, transparency, usability, performance, flexibility and validation.

1. *Accuracy*. The accuracy of a software package is the software package’s ability to produce results that enforce the rules that are in the model. For example, if a user constructs a model in a software package that has an environmental release into a wetland of 10 GL/day (gigalitres per day) then the results should reflect the 10 GL/day release into the wetland (within a reasonable tolerance). Not all software packages will promise accurate results for all models; Ilich (2008) demonstrates that particular linear programming algorithms cannot accurately resolve particular river system properties. Packages may legitimately exchange accuracy for performance.

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[1] MIKE Basin is a product of DHI Software http://www.dhigroup.com/.

[2] BigMod provides daily parametric routing. Monthly Simulation Model provides a monthly water balance model that takes into account management actions. Close (1986) attributes the model to Blainey (1970).

2. *Transparency*. The transparency of a software package is how easily someone who is unfamiliar with a model can work out why particular parts of the model are there. This objective reflects the goals of the RiverWare Policy Language (RPL). CADWES (2008) reports that one requirement behind RPL is that it should be easy to understand policy objectives and the logic of rules in models. An essential requirement of this is that the model description must be separate from the mechanics of calculating the results.

3. *Usability*. This paper uses the definition of Dumas et. al. (1999): "Usability means that the people who use the product can do so quickly and easily to accomplish their own tasks".

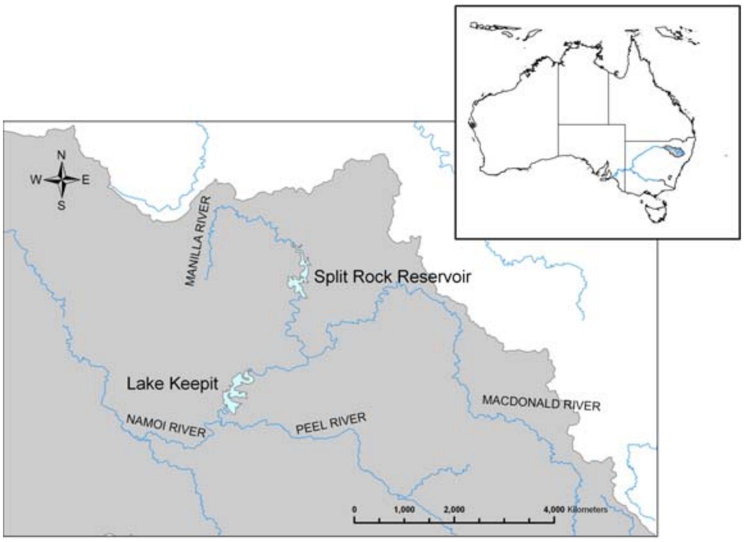

Figure 2–1. The Split Rock and Keepit Dams are on the Namoi River in the Namoi catchment (grey) of the Murray Darling Basin.

4. *Performance*. The performance of a software package relates to the additional processing time that adding a rule introduces. For example, if a model takes five minutes for the software package to run without an environmental rule and six minutes with that rule, the additional overhead is one minute. CADWES (2008) indicates that the performance of interpreting RPL must not result in unacceptable runtimes.

5. *Flexibility*. The flexibility of a software package is the variety of rules that the software package can describe. Hameed et. al. (2005) highlights the importance of flexibility. He says that IQQM must provide river modellers with the flexibility to model a wide range of rules and it must allow them to respond quickly to requests. Likewise, Close (1986) reports that river models undergo significant development and change as river modellers examine different scenarios and consider different management and operational rules and infrastructure. Note that the ability of software packages to implement rules depends both on how well they can describe rules as well as how accurately they can solve them.

6. *Validation*. Validation is how well the software package enforces physical laws, ensures that logical rules are not broken and that execution occurs as expected. For example, an ill-formed rule might result in the creation or destruction of water unless the software package has a mechanism for checking water balance. Similarly, an ill-formed rule might result in an owner's water in a reservoir exceeding their capacity unless the software package checks this.[3] Finally, the software package may allow users to enter rules that interfere with the normal execution of the software package and cause infinite loops.

This section defined a set of objectives for comparing river modelling software packages. The objectives of accuracy, transparency, usability, performance, flexibility and validation form the basis of the software package comparison in §4.

3. IMPLEMENTATION - UPPER NAMOI CASE STUDY

Implementing river models provides a basis for comparing how well software packages model operator rules. This section describes the implementation of IQQM, REALM and RiverManager river models for the Upper Namoi. While WathNet was not tested, its properties will be similar to REALM because of its lineage and the similar way it simulates river operations. Each model ran on a daily time-step for a long-term planning scenario (110 years). The case study area for the river models is a regulated part of the Upper Namoi catchment of New South Wales, Australia as shown in Figure 2–. The area contains Keepit Dam and Split Rock Dam with capacities of 426 GL and 397 GL respectively (DIPNR 2005).

The IQQM, REALM and RiverManager model inflow from the Manilla and MacDonald rivers and demands from downstream of Keepit Dam. Each model imitates the river operator's behaviour. Operators balance the reservoirs to maximise capture of runoff while meeting downstream demands. In practice, this means maintain sufficient head in Keepit Dam to release just enough water to meet downstream requirements. The river system also has a maximum flow requirement downstream of Split Rock Dam of 1500 megalitres per day and a very small minimum flow requirement between Split Rock Dam and Keepit Dam[4] (CSIRO, 2007).

[3] Continuous accounting arrangements for the River Murray (MDBC, 2006) provide an example of storage shares.
[4] The minimum flow requirement is five or six megalitres per day depending on season.

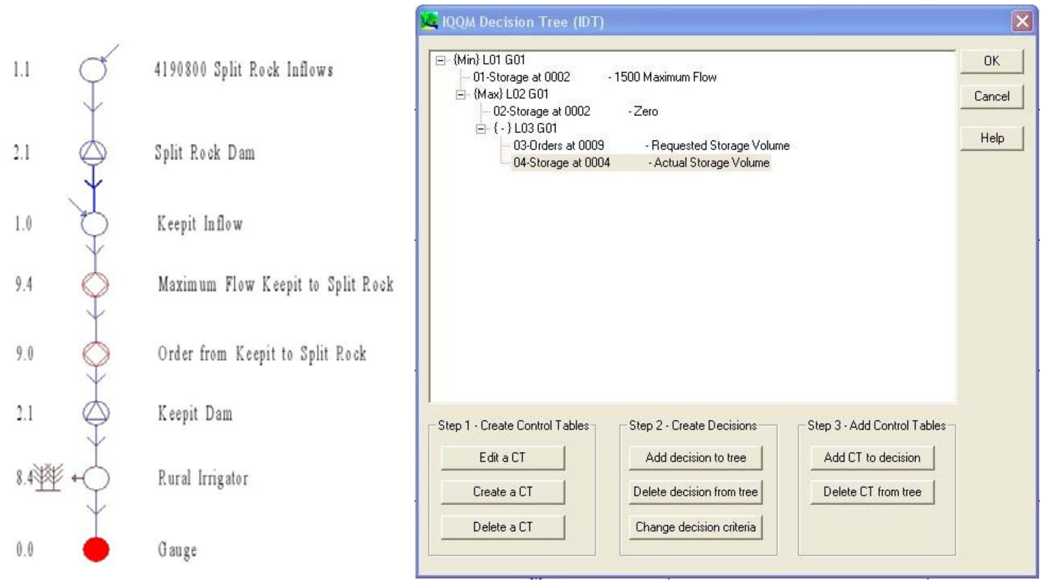

Figure 3–1. The IQQM model for the Upper Namoi has the structure shown above left with the IQQM Decision Tree shown above right.

IQQM models for this region were constructed using the GUI version 7.60.7. Two versions of the model were developed, one using IQQM's basic behaviour and one using IQQM Decision Trees (IDTs). Model developers can use IDTs to customise the models to model particular operator behaviours (Hameed et. al. 2005). The IQQM model for the Upper Namoi did not require an IDT; however, we implemented an IDT to compare the customisation abilities of IQQM. The IDT represented the operator rule that orders water from Split Rock Dam to meet Keepit Dam's downstream water requirements. The rule uses a piecewise linear function to map orders for Keepit Dam to a requirement for the Keepit Dam storage volume (e.g. if the required diversion is 3000 ML/day then the storage would need to have storage volume of 54 GL). If the actual storage volume is less than the required storage volume an order is placed up to a maximum of 1500 ML/day (see Figure 3–1).

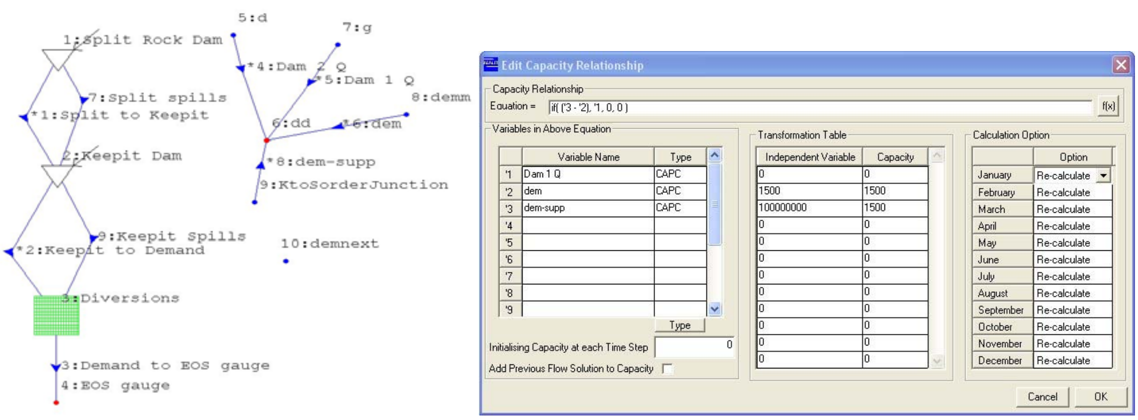

Figure 3–2. The REALM model for the Upper Namoi contains the structure shown above left with a variable carrier arc capacity shown above right.

The REALM model was constructed using version 5.0 of REALM. The REALM model describes the behaviour of operators using expressions on carrier arcs (VUT et. al. 2000). The objective function of the model encourages storage of water and discourages demand shortfalls. Each reservoir has a low cost arc representing the release of water for orders and a high cost arc representing the uncontrolled spilling of water. REALM predicts the flows and levels using a network linear programming solver that minimises the total cost of distributing water through the system. Figure 3–2 shows the REALM network. Both dams have release and spill arcs downstream. The release arcs have a maximum capacity that is described in storage to discharge relationships. A separate set of calculation nodes and carrier arcs calculate orders from Keepit Dam to Split Rock Dam. The extra carrier arcs define the storage to discharge relationship on Split Rock Dam (needed because the calculation of the Keepit orders occupy the Split Rock release curve), and a calculation of shortfall that triggers an order up to a maximum of 1500ML/d (see transformation table in Figure 3–2). The calculation uses a logical if statement (Figure 3–2) with numbered variables.

The RiverManager model describes the behaviour of operators using expressions and tables in a minimum flow requirement node. The RiverManager model contains piecewise linear functions, patterns and a series of functions. The piecewise linear functions describe the Keepit Dam dimensions ($keepitVolumeLookup) and release mechanisms ($combinedRelease). A pattern represents the minimum flow requirement ($minimumFlow). Figure 3–3 shows the parameterisation of the model in the expression editor. The minimum flow requirement orders water from Split Rock Dam when the storage volume that is required to meet the projected downstream demand for Keepit Dam is less than the actual storage volume.

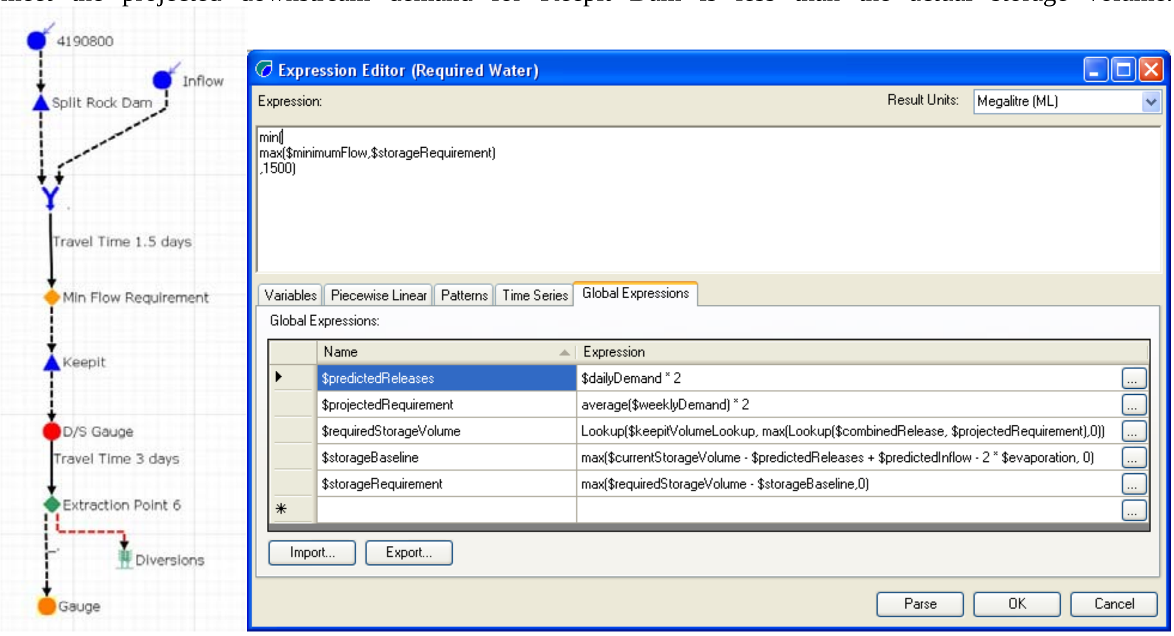

Figure 3–3. The RiverManager model uses a series of expressions to define the upstream requirement of Keepit Dam.

4. RESULTS OF ASSESSMENT

This section compares IQQM, REALM and RiverManager implementations against the objectives in §2 of accuracy, transparency, usability, performance, flexibility and validation. Table 4–1 provides the results from the assessment. The assessment involved models of only one river system. Additional analysis could determine how boundary conditions, objective functions or hydrological inputs affect the results. Further comparisons of the software products in additional river systems would improve the confidence in the results.

Each model provides an accurate simulation of the operational rules for the Upper Namoi. Figure 4–1 shows a high correlation between the three models for the volume of water in Keepit and Split Rock Dams. The storage volumes are indicative of other system characteristics (levels, releases etc.). IQQM and RiverManager results differ by a normalised root mean squared deviation (NRMSD) of 3% for Keepit Dam and 1% for Split Rock Dam. REALM and RiverManager results differ by a NRMSD of 1% for Keepit Dam and less than 1% for Split Rock Dam. The software packages vary in the way they simulate the river; the differences between the results could be due to calculation of evaporation and rainfall, modelling of travel time, integral rounding in REALM or subtleties of the IQQM default operating procedure or other reasons.

The rules and expressions in IQQM and RiverManager models are more transparent than REALM. In IQQM, the node type numbers are helpful because they indicate whether nodes contain IDTs. Furthermore, the encapsulation of the IDTs makes them easy to understand. Likewise, the encapsulation in RiverManager of expressions in particular nodes for particular values is helpful (e.g., the expression editor can describe the required water in minimum flow nodes). Unfortunately, the flexible approach of REALM has the consequence that REALM models are less transparent. In particular, it is difficult to understand which carrier arcs contribute to different parts of a river simulation, even in the small Upper Namoi model. The cross-references between carrier arcs create a maze of dependencies.

Testing the usability of the IQQM, REALM and RiverManager requires a thorough usability study involving multiple participants or it requires an assessment against a carefully selected set of heuristics. In lieu of such a study, the user community may benefit from our subjective and partisan comments on the software packages. From our case study, we identified some serious user interface problems. For example, during the construction of the IQQM model, IQQM corrupted its text file when adding an IDT to the minimum flow node. The file could only be fixed by hand. Another problem was the linkage between variables and expressions in REALM. REALM uses variable numbers (e.g. '1), string connections between carrier arcs (e.g. the variable name must match a carrier arc name) and pseudonyms for variable types (e.g. ELVL, which is the storage end water levels) to link variables to expressions. These are easy to misinterpret or fail to apply correctly. In comparison, RiverManager uses variable names and full descriptions to make these links. Other features affect the user experience. The authors feel a more objective study is necessary to demonstrate or dismiss our usability concerns. Undoubtedly, REALM and RiverManager would benefit from modern syntax checking, colouring and command completion behaviours.

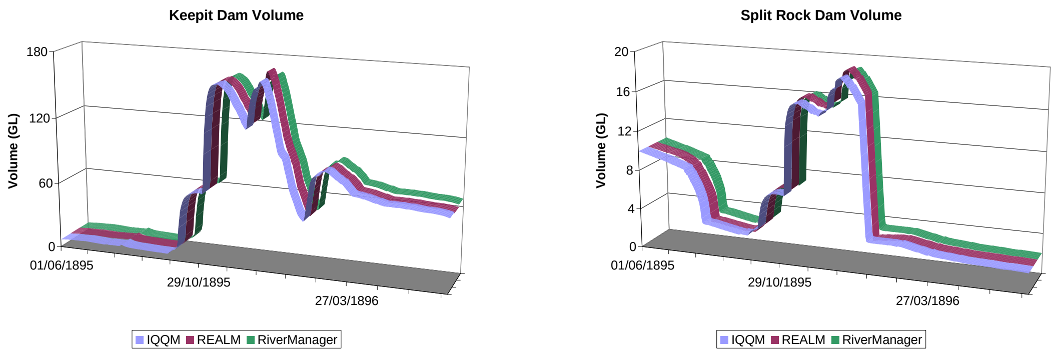

Figure 4–1. IQQM, REALM and RiverManager produce similar results for storage levels in the Upper Namoi scenario.

IQQM was the fastest software package of those tested; IQQM took 11 seconds to run 110 years worth of daily data routed at six-hourly time step and did not take any longer with an IDT. Surprisingly, the REALM model performed faster with carrier arcs describing the operator rule than without carrier arcs describing the operator rule (see Table 4–1). This behaviour is due to the mechanics of the linear optimiser and the iterations needed to converge in REALM. RiverManager performance slows with the addition of expressions.

All three software packages can model a large variety of rules; from our definition, they have a high level of flexibility. REALM is the most flexible of the software packages, followed by RiverManager then IQQM. The REALM software package provides generic mechanisms that support a wide range of applications. For example, Zaman et. al. (2009) uses REALM for economic trade-offs. This is not possible in IQQM or RiverManager. IQQM is further constrained; It is not possible to replicate the expressions from the RiverManager model in IQQM because IDTs can only combine values using minimum, maximum, addition, subtraction, multiplication, division, and 'difference >= 0'.

IQQM, REALM and RiverManager validate the physical laws of the system by restricting the parameterisation of the model and assessing the model during simulation. IQQM and RiverManager software packages aim to accept models only if they describe a system that preserves water balance. REALM models will preserve water balance unless its solver fails to converge. When REALM fails to converge to a solution, REALM will add a message to the log file. In addition, IQQM and REALM report total mass balance to demonstrate that the software does not gain or lose water. REALM does not validate any logical rules. IQQM and RiverManager validate many logical rules. More work is necessary to determine the extent of IQQM and RiverManager validation.

		River Model		
		IQQM	REALM	RiverManager
Objective	Accuracy	Very high	Very high	Very high
	Transparency	High / moderate	Low	High / moderate
	Usability	*Low*	*Moderate / low*	*High / moderate*
	Performance	0:11 (0:11 without)	0:48 (0:50 without!)	0:31 (0:22 without)
	Flexibility	Moderate / high	Very high	High
	Validation	Moderate	Very low	Moderate

Table 4–1. Results of river model comparisons. Note a more detailed study is required for usability.

Table 4–1 shows the results of the assessment. Each software package accurately models the river flows and levels but software packages differ on other characteristics. IQQM performs faster than the other products at a daily time step. REALM is the most flexible of the models surveyed. River modellers should avoid REALM where transparency is important. REALM modellers must build models carefully, because they can build models that break logical rules. RiverManager performance slows with the addition of complicated expressions. Subject to further investigation of user interface issues, IQQM is less suitable for a novice user. RiverManager performs well against a range of criteria.

5. CONCLUSIONS

Hydrologists, river managers and modellers advise on how different policy, past actions or climate change scenarios affect the use and distribution of water in regulated river systems. This paper compared software packages that Australian river modellers use for modelling river systems. The comparison was limited to IQQM, REALM and RiverManager products. The assessment involved only one river system and did not involve a usability study. Further comparisons between the software products in additional river systems with more users would increase confidence in the results. River modellers would also benefit from further work that compared these software products to other frequently used products such as RiverWare and MIKE Basin.

This paper found that each software package accurately models the river flows and levels but software packages differ on other characteristics. IQQM performs faster than the other products at a daily time step. REALM is the most flexible of the models surveyed. River modellers should avoid REALM where transparency is important. RiverManager performance slows with the addition of complicated expressions. Subject to further investigation of user interface issues, IQQM is less suitable for a novice user. We concluded that of the limited set of software packages examined, RiverManager performs well against a range of criteria, suggesting it provides a good foundation for hydrologists, river managers and modellers to model the rules that policy-makers develop and river operators implement.

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