

# Australian Hydrological Modelling Initiative: River System Management Tool (AHMI: RSMT) functionality specifications

W.D. Welsh and G.M. Podger





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CSIRO Land and Water

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# 1 Introduction

River-system models are developed and used to investigate the influence of a range of changes to river basins. These models allow managers to consider the combined effects of multiple influences, such as changes in policy, operation, climate and land-use. They are hydrologic simulation packages with mathematical representations of key aspects of physical processes and management rules that occur within river basins. For background information, see the discussions of river hydrology in Linsley et al. (1988) and Maidment (1993), and the glossary of terms and abbreviations in this report. River-system models capture water movements in a river system, and can be used for planning and evaluating proposed changes in policy and operation.

In Australia, different generic and specific models are used within the different organisations managing water resources. This makes combining individual models to represent a larger river basin, such as the Murray-Darling Basin cumbersome, as downstream models require the outputs of upstream models as inputs, and these models are often run at different time steps.

To address this issue, the eWater RiverManager tool (eWater CRC 2007, p. 4) is being developed as a common framework that will encompass and enhance the key functionalities of the three most-used river-system modelling tools in eastern Australia:

- IQQM (Simons et al. 1996; Podger and Beecham 2004; Podger 2004).
- REALM (Diment 1991; Perera et al. 2005; VU and DSE 2005a, 2005b, 2005c).
- MSM-Bigmod (Close 1996a, 1996b; Murray-Darling Basin Commission 2002).

RiverManager is being developed collaboratively by the eWater CRC partners using The Invisible Modelling Environment (TIME) (Rahman et al. 2003) and building on the E2 catchment model (Argent et al. 2007a; Argent et al. 2007b) developed by the CRC for Catchment Hydrology.

The National Water Commission (NWC) is providing funding to accelerate the development of RiverManager and to enhance uptake of the model. The product being delivered to them for this is the Australian Hydrological Modelling Initiative (AHMI) River System Management Tool (RSMT). The RSMT will model the transportation, storage and management of river water and will include ownership, multiple supply paths and storages, resource assessment and water management rules engine functions. The RSMT will be the first release of RiverManager, and it will be freely-available to non-commercial users in Australia.

Additional functionality that will be developed for RiverManager outside the timeframe for the RSMT is described in Appendix A. Some generic river management modelling concepts, including the methodologies that can be used for the operation of a river model, and modelling supply and demand in a river-system model are described in Appendix B. A comparison of REALM, IQQM, MSM-Bigmod and the RSMT is provided in Table 1.

A Groundwater–SurfaceWater Interaction Tool (GSWIT) is also being developed in the eWater CRC with supplementary funding from the NWC. The GSWIT and eWater CRC D3 project (eWater CRC 2007, p. 35) are together developing groundwater–surfacewater interaction models that will provide this functionality to the RSMT. Specifications for the GSWIT functionality are summarised in Chapter 8 and fully described in the D3/GSWIT work plan (Jolly et al. 2008).

Chapter 2 gives an overview of the development approach being used for the RSMT. Chapter 3 discusses the association between the functionalities that pre-exist in E2 and those functionalities that will be developed for the RSMT. The remaining chapters describe the river-system functionalities being developed for the RSMT.

**Table 1. Comparison of IQQM, REALM, MSM-Bigmod and RSMT river-planning models (modified from Podger 2006).**

		RSMT	IQQM	MSM- Bigmod	REALM
Time step		Any	Daily	Monthly/ Daily	Monthly/ Daily
Routing	Lag	y	y		
	Linear	y	y		
	Non-linear	y	y		
	MSM routing	y		y	
	Storage routing	y	y		
Water distribution	Optimisation	y			y
	Heuristic	y	y	y	y
Storages	Storages with spillways	y	y	y	y
	Gated storages	y	y		
	Off-river storages	y	y	y	y
	On-farm storages	y	y		
	Airspace and rule curves	y	y	y	y
	Storages in series	y	y	y	y
	Harmony operation	y	y	y	y
	Storage transfer	y	y	y	y
Supply	Order accumulation	y	y	y	y
	Order accumulation multiple paths	y	y	y	y
	Multiple supply reservoirs	y	y	y	y
	Multiple flow paths (anabranches)	y	y	y	y
	Maximum flow constraints	y	y	y	y
Water use	Town water supply	y	y	y	y
	Minimum flows	y	y	y	y
Ownership	Sharing groups (states)	y	y	y	
	Other groups	y	y		y
	Reservoir shares	y	y	y	y
	Internal spilling and ceding	y	y	y	
	Inflow and stream flow share	y	y	y	y
River operations	Re-regulation of flow	y	y		
	Flow targets	y	y	y	y
	Intra-valley transfer	y	y		
	Inter-valley transfers	y	y		y
Useability	Schematic view	y	y		y
	Time series graphing	y	y		y
	Time series analysis	y	y		
	Water management rules	y	y		y
Assessment	Resource assessment	y		y	

## 2 Methodology

The RSMT will model the transportation, storage and management of river water, and will be suitable for use with both regulated and unregulated rivers. A river is considered to be regulated where it is downstream of a major storage from which the supply of water to irrigators or other users can be controlled to enhance the water supply reliability.

The RSMT will use the E2 catchment modelling tool developed in TIME as its core. Using this framework will enable a flexible modelling approach, allowing the attributes and detail of the model to vary in accordance with modelling objectives. In E2, and thus in the RSMT, the model structure and algorithms are not fixed, they are defined by the user, who can choose from a suite of available options. Model selection requires the user to be familiar with the detail, applicability and data requirements of different component models, and the implications of joining component models. Therefore, E2 and the RSMT are intended to be tools for experienced catchment modellers.

The key functionalities that will be included in the RSMT are:

1. Water ownership.
2. Multiple supply storages and multiple supply paths.
3. An ability to write custom management rules.
4. Resource assessment.

Each of these functionalities can be described as a generic methodology. These functionalities are being investigated to ensure that the best available and most appropriate methodology for each is used in the RSMT.

The underlying software of the RSMT will be flexible so that users can develop additional functionality to meet their catchment and management-specific needs. The software will also be modular and extensible so that additional functionality can be added as plug-ins after the completion of the RSMT project.

River systems modelled in E2 are represented as catchments connected together by nodes and links. In the underlying software: inflows are associated with catchments; extraction and operational rules are associated with nodes; and storage, flow and water quality routing processes are associated with links. This differs slightly from existing models where sub-catchment inflows and storages are at nodes rather than links.

## 3 E2 and RSMT functionality

### 3.1 Association between E2 and RSMT

The E2 catchment modelling software 'provides a flexible approach to whole-of-catchment modelling, supporting creation of integrated models through selection and linking of component models of a complexity appropriate to the management or research questions being addressed, and the available data and knowledge' (Argent et al. 2007a). E2 includes component models for:

- Rainfall runoff.
  - Sacramento (Burnash et al. 1973).
  - SIMHYD (Chiew et al. 2002).
  - The Australian Water Balance Model (AWBM) (Boughton 1996).
  - Baseflow separation (Nathan and McMahon 1990).
  - Soil Moisture Accounting Runoff model (SMAR) (O'Connell et al. 1970; Kachroo 1992; Tuteja and Cunnane 1999).
  - Simple Urban Runoff Model (SURM).
- Constituent generation.
- Constituent filtering.
- Routing in rivers and storages.
  - Straight through (no delay, no attenuation and no lag).
  - Lagged flow (flow in a link is delayed by a user-specified time).
  - Laurenson (Laurenson and Mein 1997) non-linear, with and without lag (uses a semi-empirical storage-outflow relationship).
  - Muskingum (Miller and Cunge 1975), with and without losses (represents reach storage as the sum of a prism storage and a wedge storage).
- In-stream water quality.
- Constant demand and observed concentration nodes.

The E2 routing models will be integral to the RSMT, and the rainfall runoff models listed above will be accessible from within the RSMT.

E2 has only limited water management capabilities compared to the river-system models that are currently in use, and unregulated river systems cannot currently be modelled in E2 because orders/demands currently must be placed on a storage. E2's water management capabilities include:

- Storage operations: airspace and rule curve operations, gated storage flood release operations.
- River operations: flow targets.
- Supply: order accumulation, maximum flow constraints, physical extraction constraints.

Although the storage operations listed above have been developed, they are not yet fully integrated into E2. Their methodologies are described in Appendix C.

### 3.2 Time discretisation

E2 operates on a continuous basis and is able to simulate river-system behaviour for periods ranging up to hundreds of years. The E2 engine makes no assumption about the time step of the input, so hourly inputs are possible. In practice, E2 models to date mostly use daily data and time steps.

### **3.3 E2 storages**

Storages in the RSMT are represented on the interface as nodes. However, storages are implemented as links in E2 because water flows through them.

E2 storages currently operate by maintaining the water mass balance. The storage model assumes that the change in storage height across a time step is small compared to the storage fluxes.

Alternate storage models are discussed in Appendix A.

## 4 Water ownership

Ownership will be assigned to inflows, losses, water in storage and in transit so that all owners' shares will be known everywhere in the system. This allows flexibility on how these shares are managed. For example, constraints can be reconciled, and rules can be applied to individual owners. Water in storage, in transit and ordered should be able to be traded between owners.

The following sections discuss the different types of water users, and the ownership of inflows, water in storage and water in transit.

### 4.1 Water users

There are two types of water users: consumptive and non-consumptive users. Both consumptive and non-consumptive users will be modelled in the RSMT. Consumptive users abstract water from the river and might return some water (return flows) at another point along the river. Each consumptive user is constrained to only abstract water from its own share of flow. For example, if the entire flow in a river at a particular abstraction point belongs to one owner, another owner may not abstract any water.

Non-consumptive users can include the environment. The environment can require minimum flows and river flow targets. Non-consumptive use adds complexity to ownership because the water does not leave the river but needs to change ownership once past the relevant reference point. This water has a dual role of first meeting non-consumptive user requirements before it is possibly shared for consumptive use. Non-consumptive environmental flows can have an identity and their ownership can be managed.

### 4.2 Ownership of inflows, gains and losses

Inflows, gains and losses, both in storages and in transit, will have ownership assigned. Evaporation and rainfall on storages will be shared in proportion to share volume on the basis that the volume is in proportion to surface area. The shares in inflows are specified by the user for each owner in the system. Losses in transit are shared in proportion to each owner's share in the flow.

### 4.3 Ownership in storages

Water ownership in storages can be conceptualised as horizontal storage levels or as vertical storage slices. Town water supplies are typically conceptualised as being divided into horizontal slices (Section 5.2). In this case, access to the water is increasingly constrained as the storage level reduces between zones.

Irrigation reservoirs are conceptualised as being divided into vertical slices, which have individual owners. In this case, storage inflows are apportioned into these slices. This can lead to an individual vertical slice being full while others still have airspace, and hence the storage does not spill. This situation results in an internal spill: the excess water from one vertical slice spills into the other shares according to some user-specified distribution rules. When all shares in the storage are full the storage will spill.

The inflow can be apportioned differently from the storage volume. For example, the Glenlyon Dam, located along the border between NSW and Queensland, has storage shares of 57:43 (NSW:Qld) but the inflows are shared 50:50.

Individual ownership can apply to states, groups, individuals or the environment. Ceding is the change in water ownership in a water storage. These transfers can occur before an owner's share is full. The rules that govern ceding will be input by the model user. Storage shares, and internal spilling priorities and proportions will also be specified by the model user.

Implementing internal spilling can involve multiple passes, as unregulated flow is assigned and re-assigned to different owners, or spills from the storage.

Each owner's proportion of the dead storage volume is the same as their proportion of the full storage volume. Each owner's proportion of the storage outlet capacity can be the same as their proportion of the storage volume at a particular time step (i.e. it will reduce as the owner's volume in storage reduces) or it could be a user-specified input (e.g. the same proportion and user share as in the full storage volume). This is an approximation because the outlet capacity should be shared in proportion to the hydraulic head of each owner's share.

## **4.4 Ownership of water in transit**

Tracking ownership within a river as the water moves through the river system is more complex than tracking ownership in a storage.

There is an amount of water 'stored' in each river reach. Each owner's share of the in-reach storage is increased by their share of the inflows and gains, and decreased by their share of the losses and demands. Rainfall and evaporation for a given time step are shared in proportion to each owner's share of the in-stream storage during that time step.

If there is insufficient head to drive the orders downstream, the restriction is shared according to the demands. Uncontrolled losses in a reach are shared in proportion to the owners' shares in the river. Groundwater gains and losses are also shared in proportion to the owners' shares in the river.

Flow constraints and uncontrolled losses, where water flows out of an effluent with the regulators closed, are shared in proportion to each owner's share of the river flow.

## 5 Multiple supply modelling

In many of the regulated river systems in Australia there is more than one upstream reservoir that could be used to supply an order. These reservoirs can be in series, where one reservoir is directly upstream of another, or in parallel, where upstream storages are located on different branches in the river system, or a combination of these. In addition, the presence of anabranches provides options for flow routing. Moving orders through a network of river branches is reasonably complex and operators must ensure that the river system is run efficiently.

### 5.1 Storages in series

Storages in series are managed to minimise the unnecessary spilling of the lower storage. To achieve this, the lower storage is depleted to meet downstream demands before using the upper storage. Water resource reliability in the lower storage is maintained by ensuring a minimum amount of water is held in there, this minimum is defined by a rule curve (Appendix C).

Storages in series can be configured so that:

- The downstream storage is small compared to the upstream storage. The downstream storage is then a re-regulating storage.
- The re-regulating storage is off the main river.
- The downstream storage is large compared to the upstream storage. The downstream storage is then a supply storage.

Re-regulating storages can allow a river to be operated more efficiently because they can be used to catch rejected orders or unregulated flows and re-regulate them for downstream users. Re-regulating storages can also be used to buffer variations in river flow caused by variations in orders and the uncertainty in operating the river.

Re-regulating storages off the main river are typically filled prior to an irrigation season and emptied as quickly as possible to minimise evaporation losses. Both their inflows and outflows can be regulated. Inlet regulators, which are driven by head differences and have complex operating rules, are used to control the amount of water that enters an off-river storage. Harmony operating rules apportion orders between the re-regulating off-river storage and the larger upstream storage. Water supplied from the upstream storage bypasses the inlet of the off-river storage and can be supplemented by releases from the off-river storage. Water in excess of orders can be channelled into the off-river storage and released later.

On-river re-regulating storages capture inflow, which can optionally be retained or released/spilt. Water that is released can be used to meet a downstream order, or can be the through-flow of an order from the upstream storage.

Supply storages are used as the primary source for water supply, while small upstream storages are used to meet local orders and maintain reserves. Typically, the smaller upstream storages have lower evaporative losses, and they provide flexibility in meeting orders throughout the system. Consequently, the downstream supply storage is emptied prior to the upstream storage. Some river valleys have complex rules to ensure that upstream reserves are released sufficiently early to allow for any delivery constraints, and to ensure there is a sufficient hydraulic head in the downstream storage to meet orders.

Sometimes the transfers between storages are driven by airspace rules in both storages to minimise the likelihood of either storage spilling.

## 5.2 Storages in parallel

Storages in parallel can be operated in five different ways.

### 1. Independently

Orders are directed to different storages based on the type of user. River systems that have independent orders from storages are usually access- or group-based. Access-based users might only have one upstream storage. Group-based users are typically state-based (e.g. Qld, NSW) and are restricted to pass orders up a particular branch.

### 2. Harmony operation

Storages are accessed to minimise the likelihood of a spill. This is a common approach to operating multiple storages. Harmony operation can be complex to model. If the harmony rules adjust flows to equalise relative volume or airspace, the storage that is proportionately fuller will release water until the proportions are the same, then both storages will release water. However, if the harmony operation includes relative differences in inflow, different target ratios will apply.

### 3. Order splitting

The split of orders to each reservoir is specified. This can be based on storage volume, airspace or the amount of an order. The split can be controlled by a look-up table using storage volume, airspace and the ordered amount. Values in an order-splitting look-up table could be derived from prior modelling and may be intended to achieve harmony operation of the storages.

### 4. Access zones

Storages with a lower priority zone provide water until the priority zones are equalised, then storages provide water in a defined ratio or based on harmony rules. This is used for town water supply schemes where storages are divided into zones that are defined as horizontal slices representing different security levels at different volumes. Lower priority zones must be depleted before higher priority zones can be accessed. This is typically achieved by order splitting, but is included separately as it is driven by different objectives.

The implementation of this method of operation in REALM (VU and DSE 2005b, p. 41) has storages divided into above- and below-target water-level zones. A drawdown priority value for each zone is input by the model user. Below-target storage zones with the lowest priority values are drawn down first; above-target storage zones with the highest drawdown priorities are recharged first.

### 5. Supply constraint/efficiency

Orders are passed up river branches based on harmony operations, delivery constraints and operational efficiency. This method apportions flow between alternative flow routes. Physical channel and outlet constraints can reduce the amount of an order sent along a flow route; unregulated flows can be accessed by increasing the flow sent along a particular route.

## 5.3 Travel path selection

There are two potential approaches to distributing water through river systems in the RSMT: a heuristic (rules-based) approach, and an optimisation approach. The heuristic approach is used in IQQM and MSM-Bigmod. It relies on relationships and look-up tables to dictate which storage supplies the water and the supply system that it flows through. The optimisation approach uses constraints and weightings for the different branches, with linear programming, to find an optimum split of orders between storages and along flow paths. This approach is used in REALM.

The heuristic approach is more transparent. It also uses less computing time because the optimisation approach uses recursive routines to find a solution. A heuristic approach is best-suited to river systems with few branches, as dominate in NSW and Queensland. An optimisation approach is most useful with river systems with many short branches, as occur in Victoria.

The optimisation approach in REALM uses a penalty value that the model user assigns to each link, called a carrier, to determine the optimum water supply path. When there are two or more alternative paths to supply water from one node to another, the route with the lowest penalty is used first. When the capacity constraints of these low-penalty routes are reached, the more 'costly' paths are used sequentially (VU & DSE 2005a:25) There are also storage drawdown priorities (VU & DSE 2005b, p. 41) and demand shortfall priorities (VU & DSE 2005b, p. 46) that will influence the choice of the optimum travel path.

To reduce processing times, REALM models often use monthly time steps, although these can be daily or shorter time periods. Decimal input values are converted to integers before the solver is invoked (VU & DSE 2005b, p. 27).

A compromise solution could be achieved by ensuring that there are sufficient numbers of supply and demand iterations to capture close to optimum path use behaviour. A sub-project is planned to investigate this aspect of the modelling of multiple supply paths more fully and ensure all aspects of multiple supply path modelling are covered.

## 6 Water-management rules engine

Some management rules are very specific and some are very complex. For example, opening a regulator for environmental flooding might depend on current water restrictions, which are dependant on the water level of an upstream dam, and perhaps the time of year. The number and variety of these rules makes it impossible to build interfaces for each rule. The RiverManager product will provide facilities for describing these rules using a water-management rules engine. In the existing models, IQQM uses a tree structure and control tables, REALM uses an equation parser and MSM-Bigmod has river-management rules hard-coded in the software.

The purpose of the expression engine is not to create model functionality that should be captured generically during software development, but to allow the option of entering a parameter value as an expression. In this way, model parameter values can be dynamically dependent on the values of other model parameters. An example of this would be the setting of minimum river flows based on the water levels in a number of storages.

Parameters that could have the option of being entered as an expression include order quantities, minimum flow requirements and unregulated flows. This list will be expanded after consultation with the eWater partner agencies.

Operations that will be available in the expression engine include:

- minimum, maximum, average, sum, absolute value, truncate, round;
- addition, subtraction, multiplication, division, exponentiation, logarithm, square root;
- sin, cos, tan;
- lookup tables;
- if, else, and, or, not, bracketing.

Order of precedence will be preserved, e.g.  $1+2*3 = 7$ .

## 7 Resource assessment

This section describes resource assessment and discusses the resource assessment regimes that will be available in the RSMT. A sub-project is planned to investigate the resource assessment requirements of the eWater partner agencies .

### 7.1 Resource assessment methodology

A resource assessment is used to quantify the water resources in a river system. For example, the results of a resource assessment are used when water allocations are announced. Such a resource assessment for a single owner is performed as follows:

1. Calculate the active (current – dead) storage of an owner.
2. Add the water used by this owner since the start of the water year, including orders in transit.
3. Estimate the future inflows, losses, high-security water and the carry-over reserve for the time until the end of the water accounting period for all owners as follows:
  - a. Add a conservative estimate of the future inflow to each storage. This will take into account recessions on current inflows and historical minimum inflows. No allowance will be made for rainfall on storages.
  - b. Add a conservative allowance for future downstream inflows that will be used to supplement regulated releases. This will be based on an estimated utilisation of historical minimums.
  - c. Subtract an estimate of the future storage loss. Evaporation loss will be based on surface area. Seepage loss is based on hydraulic head (or volume), so changes in dam levels may need to be projected into the future.
  - d. Subtract an estimate of the future delivery losses. Transmission and operation (e.g. minimum flow, dilution flow) losses can be estimated using look-up tables that list storage volume versus delivery loss, or can be estimated by forward projecting the model.
  - e. Subtract commitments for future high-security requirements, which may include environmental contingency allowances. This can be estimated from a look-up table or by forward projecting the model.
  - f. Subtract an estimate of the future carry-over reserve. The carry-over reserve is an estimate of the water that is required to deliver high-security requirements through the worst drought on record. It can be estimated using a look-up table that lists the time of the year versus the estimated allocation.
4. Each owner's share of the water volume calculated in Step 3 is based on their licensed allocation volume.
5. The total share of the resource calculated for each owner may be adjusted for sleeper licences, or the maximum allocation may be capped at 100% of their licensed allocation volume.

As the losses are a function of allocation level, an iterative solution is required to determine the final allocation level. The forward projections of the model required in Step 3 above could be done on a monthly time step to reduce model run times. If forecasting is not necessary, look-up tables can be used to estimate parameters.

Due to the morphology of some river systems, some users' physical locations could prevent them from having equal access to resources in the river system. This can occur when a group of users is located upstream of a storage or is on a river tributary. When the users' shares would be unequal, the allocations that are available to all the users in the system are constrained by the resource availability to the users with access to the limited resources.

The resource assessment described above will determine for each user:

- Total active volume in all storages.
- Volumes of water that are in transit.
- A running balance of all water use since a specified point in time.
- Estimates of total forecast inflows into all user's storages.
- Estimates of forecast rainfall into all user's storages.
- Estimates of forecast evaporation into all user's storages.
- Estimates of downstream tributary utilisation by all users.
- Estimates of transmission and operation losses for all users.

## 7.2 Resource assessment regimes

There are four resource assessment regimes:

- Annual licence.
- Annual accounting.
- Continuous accounting.
- Capacity sharing.

Each owner should be associated with only one resource assessment system. If an owner is not associated with a resource assessment system, the owner will not have any constraints on ordering, but will be constrained on releases and extractions when their share in the storage has been used. Owners who are associated with a resource assessment system may have their orders constrained, and may also be constrained on releases if their water cannot be released.

Ownership will need to be enabled in the model for resource assessment to be available. The minimum frequency of resource assessments will be one day.

### 1. Annual licence

An owner with an annual licence is restricted to an annual allocation volume. This allocation volume is not affected by the amount of water in storage unless the storage runs dry.

The resource assessment will calculate the remaining resource available as the difference between the allocated volume and the use to date.

### 2. Annual accounting

Under annual accounting, the water available to users is reconciled back to the start of the water year for each assessment during the year. At the end of a water year, any unused resource is returned to the group of users and shared out. This system encourages inefficient water use because, toward the end of the water year, allocations will be used for low value returns rather than returning the water to the user group. To discourage this practice users may be able to carry-over unused allocations for a defined period into the next water year.

Constraints on carry-overs include:

- Carry-over water is consumed before any other allocation.
- If the dam spills the carry-over volume is first to spill or all carry-over water is set to zero.
- Limits are set on the amount of water that may be carried over.
- Limits are set on the length of time that water can be carried over.
- Functions are imposed that discount carry-over water over time.
- Evaporative losses are applied to carry-over water first.

There are also systems that include an over-draw, which lets users borrow from the next year's expected allocation.

The resource assessment will calculate the volume of water available using the methodology in the previous section. If this is less than the target volume, water will be ceded from lower security users to fill higher security user shares. A carry-over reserve, discount function<sup>1</sup>, previous minimum allocation, maximum allocation or carry-over constraint may be imposed on the remaining volume. The water that is left will be allocated to users in proportion to their licence volume. The resource available to each user will be the difference between this volume and the volume used since the start of the water year.

### 3. Continuous accounting

Continuous accounting is similar to annual accounting with carry-over. It is more complex because of the numerous accounts that need to be maintained, including:

- high-security requirements and associated carry-over reserves,
- an account for each general security user, and
- transmission and operation loss allowances, which are usually specified as a function of the total general security volume, which is often a fixed ratio.

The procedure for continuous accounting is:

1. Inflows into storages:
  - first supplement high security requirements and associated carry-over reserves,
  - then bring transmission and operation deficits up to the required ratio of the total general security volume,
  - then supply general-security users and the transmission and operation loss account, ensuring the required ratio is maintained.
2. When water is released to meet downstream orders, it is taken from the transmission and operation loss share.
3. When water is extracted by a water user, the water is paid back by a transfer from the user's storage share to the transmission and operation loss share. Note that this can be quite complex in systems with multiple supply storages.
4. A user's share is defined by their proportion of the general-security capacity in each storage, and cannot exceed this amount. When inflows exceed the capacity of the share, the excess is shared to the remaining users in proportion to their shares. Resolving this internal spilling is an iterative operation and can result in the dam spilling.
5. Users may be constrained to an annual cap or average annual usage over a defined period.
6. Effective allocations are estimated by dividing the general-security volume by the total of the general-security licences. Note that these give an overall picture of allocation, but users are constrained to the amounts in their accounts. For example, if there were two users of equal shares, one empty and the other full, the effective allocation of each would be 50%, but the empty user would have an actual allocation of 0% while the other user would have 100%. Annual usage can be constrained by effective allocations.

The resource assessment will calculate the volume of water available using the methodology described above. If for any group of users this volume is less than their target volume, water will be ceded from lower security shares to fill higher security shares. Water will also be ceded to meet transmission and operation loss targets. However, releases will be shared across all users' accounts in proportion to their licence volumes and paid back from a user to all other users in proportion to the licence volumes. The water that is remaining in a user's account will be available to the user subject to constraints imposed on that volume, such as maximum volume in a year.

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<sup>1</sup> A discount function refers to water that is discounted from (taken off) the available water calculated after the resource assessment is done because a rule has come into play, for example based on the water level in a water storage.

#### **4. Capacity sharing**

Capacity sharing is similar to continuous accounting, except that transmission and operation loss allowances are contained within each individual's share. The estimate of this allowance is quite complex for each user because it depends on where the user is located in the system. Users closer to tributaries and to the supply storage will have a small loss allowance, while users at the end of the system will have much larger loss allowance. Shares are almost impossible to estimate for individual users because the delivery losses are a function of all of the downstream users and change with any changes in demand. This approach, however, may be workable for groups of users. Capacity sharing is typically applied for state user groups.

The resource assessment will calculate the remaining resource available as the remaining active volume in a user's account after the user's use has been subtracted.

## 8 Groundwater–surfacewater interactions

This chapter provides a summary of the models being created by the AHMI-GSWIT project. These models will link into the RSMT.

Rivers, floodplains and wetlands are affected by groundwater–surfacewater interactions. These interactions are dependent on the relative water surface elevations and the permeability of the intervening lithology. For example, river water is lost as leakage through the riverbed into the underlying groundwater when the river water level is above the water table. The river gains from groundwater leakage when the adjacent water table is higher than the river water level. Groundwater enters the river channel up through the riverbed sediments and horizontally through the river banks. The lithology affects the rate of water movement.

Surfacewater features can be classified as dominantly losing or dominantly gaining. This classification can be applied to rivers at the scale of river reaches. However, a large rainfall event typically involves both groundwater losses and gains in a single reach. There will initially be an increase in leakage to groundwater as river water levels rise rapidly, then as surfacewater levels fall, groundwater will seep into the river.

The spatial scale at which a groundwater–surfacewater interaction model is applied dictates its level of complexity, and hence what processes are, and are not accounted for. Large-scale models usually adopt a lumped approach that requires less parameterisation; smaller scale physically-based models can explicitly account for more processes. Rassam and Werner (2008) defined three levels of complexity, namely:

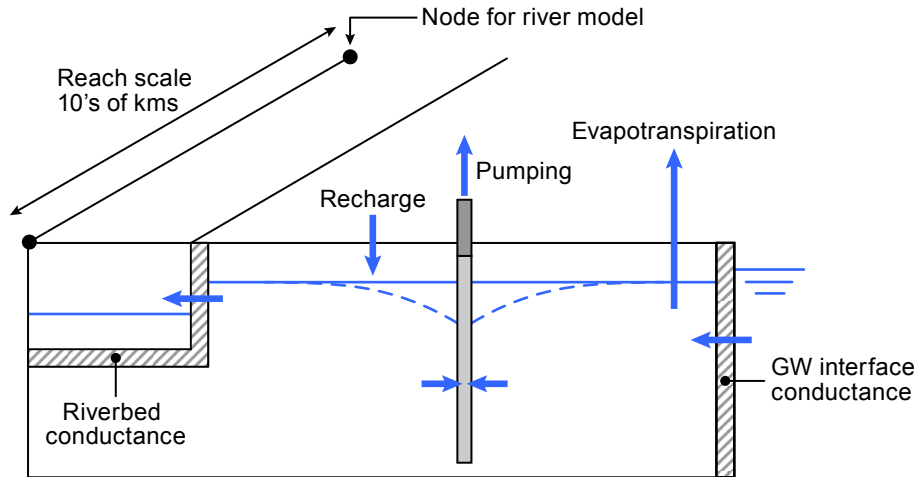
- Level 1. First-order lumped parametric models based on empirical relations derived from numerous field observations or concepts.
- Level 2. Second-order models that operate at finer temporal and spatial scales compared to first-order models and have more conceptual resolution and process complexity.
- Level 3. Process-based, distributed, deterministic models.

In the context of this project, the tools to evaluate groundwater–surfacewater interaction processes need to be compatible with the RSMT. In particular, the spatial scale of the groundwater–surfacewater interaction model needs to be compatible with the river model node spacing.

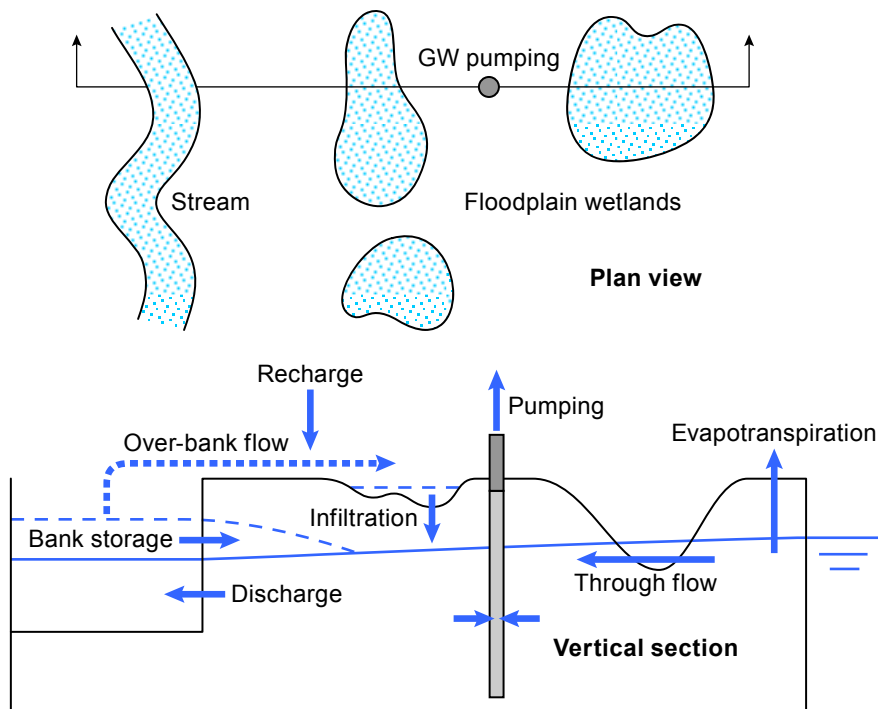
Given the complexity of the processes of groundwater–surfacewater interaction, the general scarcity of data required to validate and/or calibrate complex models, and the need to integrate groundwater process in the RSMT in an efficient manner, it was decided that simple modelling approaches would be adopted. The GSWIT project, which is aligned with the RSMT, is developing routines to incorporate groundwater–surfacewater interactions into the RSMT. Different modules are required for different landscapes and for different levels of complexity (as governed by the available data). Two types of modules are planned in the GSWIT project for incorporation into the RSMT:

1. A reach scale, Level 1 complexity, groundwater–surfacewater link model, which operates as a groundwater link to river models (Figure 8.1). The expected outcome of this model is accounting for groundwater–surfacewater interactions at the river-reach scale.
2. A sub-reach scale, Level 2 complexity, floodplain processes model, which dynamically models bank storage, evapotranspiration, and floodplain inundation (Figure 8.2). The expected outcome is modelling of groundwater–surfacewater interactions at higher resolution and the capacity to link to ecological response models.

The development of the groundwater–surfacewater modules in the GSWIT will lag behind the development of the RSMT and so, in the interim, groundwater losses/gains can be represented as fixed-rate values determined during model calibration, with one groundwater loss/gain node per river reach.



**Figure 8.1. Conceptualisation of a gaining river system to be modelled in the groundwater–surfacewater link model.**



**Figure 8.2. Conceptualisation of the floodplain processes model.**

## 9 Interface components.

The interface between the model user and the underlying computer code will consist of a Graphical User Interface (GUI) and a reporting tool. These are discussed in the following sections.

### 9.1 GUI

Using the GUI, RSMT models will be constructed by selecting graphical icons representing system components, such as inflows, water storages and gauges, and defining the flow paths linking them through direct manipulation of the graphical elements. Attributes of the system components, such as inflows and owners' shares will be entered interactively or via text files.

There will be a schematic view of the river system that represents the logical sequence of nodes and links with a user-defined spatial representation.

### 9.2 Reporting

The Partner User Requirements developed for RiverManager identified a need to post-process inputs and results, including performing statistical analyses, for documenting model scenarios. This functionality will be developed for the RSMT.

The reporting function will record user-specified time series data from each model run. There will be a capacity to view time series of model outputs graphically, and basic statistics will be automatically generated. When two datasets are selected, the difference statistics can also be displayed. The available statistics will include:

- minimum,
- maximum,
- total,
- mean,
- median,
- standard deviation,
- skewness,
- coefficient of determination (square of the regression coefficient),
- linear regression coefficients (slope and y-intercept),
- regression coefficient.

There will be an option to aggregate from a daily time series to a weekly, monthly, seasonal or an annual time step. The aggregation options will be:

- sum,
- minimum,
- maximum,
- mean,
- a defined percentile.

The types of graphs that will be available include:

- continuous line (linear and semi-log) time series plots,
- histograms,
- cumulative plots,
- exceedence curves,
- difference graphs,
- ranked plots (for flow duration curves, reliability diagrams),
- residual mass,

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- scatter plots,
- difference plots.

There will be a capacity to zoom into sections of the graphs, and the graphs will be able to be saved to file or printed.

## Appendix A. Additional functionalities for RiverManager

This appendix describes RiverManager functionalities that are intended to be developed outside the scope of the RSMT. They include:

- Additional water storage models.
- Unregulated flow sharing.
- Irrigation demands.
- Custom management rules.
- Scenario management.
- Geographic view.
- Improved rainfall-runoff estimates.
- Routing disaggregation.
- Multi-stage routing.
- Hydropower nodes.
- Grouping of owners.
- Murray River resource assessment.

### Additional water storage models

There is scope for further work on water storages beyond what is currently implemented in E2. The sections below describe functionalities that might be developed for RiverManager. Some E2 storage functionalities are discussed in Appendix C.

#### Routing

The routing of water through an ungated storage can be modelled using the Modified Puls routing procedure, which assumes that storage is a function of outflow and storage level. Prior knowledge of the storage-discharge relationship for each ungated storage is required. Modified Puls routing is most suited to reservoirs if the effects of flood waves are damped by the storage. The model time step should be less than the travel time through the storage. Ideally, it should be about 20% of the time to rise of the inflow hydrograph.

The Modified Puls routing procedure is based on the continuity equation

$$\frac{I_{t-1} + I_t}{2} \Delta t - \frac{O_{t-1} + O_t}{2} \Delta t = S_t - S_{t-1} \quad (1)$$

from which outflows can be calculated as

$$O_t = \frac{2(S_{t-1} - S_t)}{\Delta t} - O_{t-1} + I_{t-1} + I_t \quad (2)$$

where  $I_{t-1}$  = inflows at the start of the time step,  $I_t$  = inflows at the end of the time step,  $O_{t-1}$  = outflows at the start of the time step,  $O_t$  = outflows at the end of the time step,  $S_{t-1}$  = water in storage at start of the time step,  $S_t$  = water in storage at the end of the time step.

#### Wetlands

Off-river wetlands can receive water:

- as a fixed component when a minimum environmental requirement needs to be supplied even during a zero allocation year, plus a variable additional component that is a function of general security allocations,

- as a fixed component when a minimum environmental requirement needs to be supplied even during a zero allocation year, plus a variable additional component intended to prolong an inundation event started by a natural flood, or
- in accordance with a specified daily time series of demands for each year.

## On-farm storages

On-farm water storages are replenished in accordance with their intake capacity, physical constraints and the requirement for no spilling.

The operational rules for on-farm storages depend on the water accounting scheme that applies. Both water use and water order debit schemes allow unregulated flows that are excess to orders to be diverted to an on-farm storage, and water to be ordered toward the end of the water year to replenish on-farm storages with any remaining allocation credit. For the latter, the additional order is the minimum of the predicted unfilled storage in the on-farm storages at the time the additional order will reach the offtake node associated with the on-farm storage; and the inlet capacities of the on-farm storages.

In addition, a water order debit scheme allows excess ordered water that is not required for irrigation to be diverted to an on-farm storage at any time of the year. The excess water is usually due to rainfall between the time the order was placed and when it arrived.

## Unregulated flow sharing

Unregulated flow sharing refers to the sharing of river flows that are in excess of orders placed downstream. The terminology used to describe this water varies between jurisdictions. For example, it is also known as supplementary access and sales water.

The eWater partner agencies will be consulted to ensure all areas of unregulated flow sharing have been considered prior to implementing the chosen methodology.

The amount of the unregulated flow that irrigators can access in a regulated system can be determined using the ratio of the unregulated access volume to either the licensed volume or the pump capacity of each water user. The decision of who may share in the unregulated flows can depend on the amount of the unregulated volume and the relative volumetric access individual water users (including downstream environmental constraints) have had to unregulated flows since the start of the water year.

Five schemes for modelling the sharing of unregulated flows in both regulated and unregulated river systems are recognised. These are the same as those used in IQQM:

- Flow thresholds for identifying when unregulated flows may be used may be different for the beginning and end of flow sharing events (Figure A.1).
- The flow threshold for identifying when unregulated flows may be used is an amount in excess of the regulated flow that may have a different start and stop threshold (Figure A.2).
- The unregulated flow volume is shared between the environment and consumptive users.
- Unregulated flows are allocated up to the annual cap, or the average annual cap on diversions over a period of time.
- The unregulated flow that may be used is assigned based on the threshold class that the river flow lies within (Figure A.3).

Unregulated flows are distributed by first dividing rivers into reaches, whose boundaries are located downstream of major tributaries, confluences and regulated effluents (discharge points). Long river reaches are sub-divided based on travel time. The availability of unregulated water extractions is declared independently for each of these reaches. In the RSMT, the unregulated flow to be shared in these reaches will be controlled by unregulated flow sharing nodes.

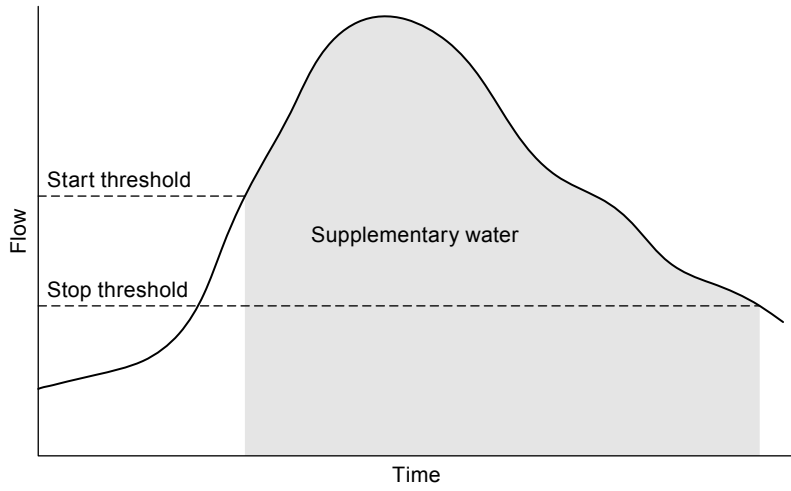


Figure A.1. Unregulated flow sharing using thresholds (after Podger 2006).

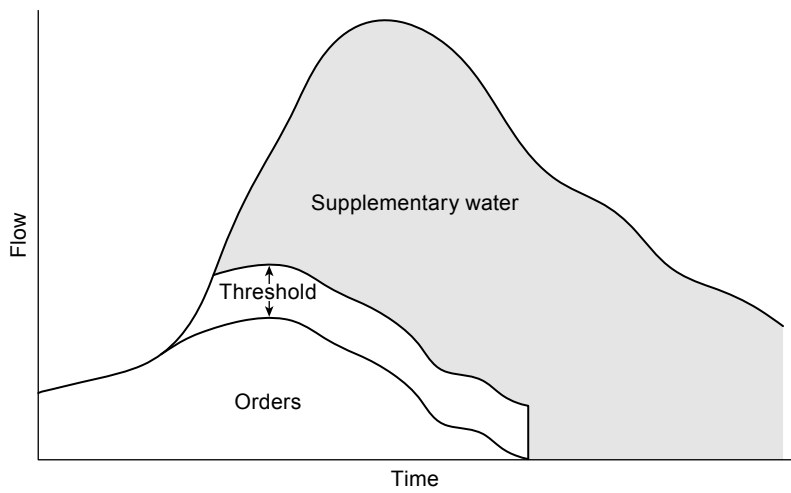


Figure A.2. Unregulated flow sharing above orders (after Podger 2006).

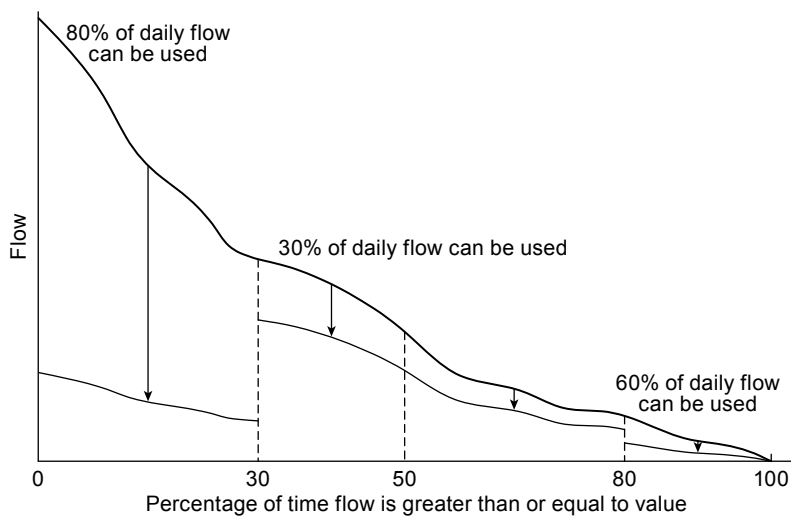


Figure A.3. Threshold classes (after Podger 2006).

To determine if the flow is in excess of downstream requirements, the unregulated flow volume received by each reach is compared with the unregulated flow volume received by reaches downstream. The unregulated flow in a reach is declared available for use if the reach has had less or equal access to unregulated flows compared to the reaches downstream. Once the excess is declared in a reach, the unregulated flow volume is shared between the water users in proportion to their licensed volumes. These computations are carried out daily at the unregulated flow sharing nodes. A declaration of unregulated flows is active until flows are no longer in excess of the downstream water orders.

At the beginning of each day's simulation, the model determines whether there is excess flow that should be made available. Starting from the bottom of the river system, the model searches up until it finds an environmental requirement, a storage, or the bottom of the next unregulated flow reach. The unregulated flow volume available to irrigators is the excess volume after environmental requirements have been satisfied and storages have been filled, noting that the filling of off-river storages may be constrained by their inlet capacities.

To facilitate the sharing of unregulated flows, the RSMT user will have entered:

- for each unregulated flow sharing node, the volume above which the flow is considered to be in excess to the downstream requirements, and
- a look-up table specifying a relationship between flow in excess of downstream orders and the number of days travel time down the river that the downstream requirements could potentially share the unregulated flow.

The calculation carried out at each unregulated flow sharing node is:

1. The look-up table is used with the computed unregulated flow to decide which reaches can potentially share the excess flow.
2. Any environmental requirements that can potentially use the unregulated flow are identified from the look-up table. If an environmental requirement is below a re-regulating storage, then the volume required to fill the re-regulating storage is considered as part of the environmental requirement. The volume of water required to satisfy the environmental requirements is then deducted from the unregulated flow.
3. Any on or off-river storages in the reaches that can potentially use the unregulated flow are identified from the look-up table. The volume required to fill on-river storages is deducted from the unregulated volume. Subject to inlet capacity, the volume of water required to fill off-river storages is also deducted from the unregulated flow. This leaves the volume of water that can be declared as excess to downstream requirements.
4. For each unregulated flow reach, a check is carried out to determine if any of the downstream unregulated flow reaches that could potentially access this event, have had fewer opportunities to draw from unregulated flow events as compared to the current unregulated flow reach. The level of access is determined using a ratio of the volume of unregulated flow water made available to an irrigator to either the licensed volume or pump capacity of that irrigator. This decision is made by the river modeller.
5. If any of the reaches that can potentially use the unregulated flow (as identified from the look-up table) have had unequal access to unregulated flow events since the start of the water year, the unregulated flow access between reaches is equalised, subject to the limitations of available pump capacity, remaining unregulated volume, and regulated effluent capacities.
6. Any remaining unregulated volume is shared equally among all the irrigation license holders, subject to the limitations of available pump capacity and regulated effluent capacities, in proportion to their licensed volumes or pump capacities in accordance with Equation 3 or 4, depending on the method chosen to equalise access:

$$V_{lic} = S \frac{L_i}{L_t} \quad (3)$$

$$V_{sf} = S \frac{P_i}{P_t} \quad (4)$$

where  $V_{sf}$  = unregulated flow volume available to the water user,  $V_{lic}$  = unregulated flow volume for the water user based on licensed volume,  $S$  = total unregulated flow volume available for use after environmental and storage requirements are satisfied and irrigator access has been equalised,  $L_i$  = licensed volume of the user,  $L_t$  = total licensed volume of all users who will share the current unregulated flow,  $P_i$  = pump capacity of the user, and  $P_t$  = total pump capacity of all users who will share the current unregulated flow.

If  $V_{lic}$  is smaller than  $P_i$  over the time step then  $V_{sf} = V_{lic}$ ; otherwise  $V_{sf} = P_i$  and  $V_{lic} - P_i$  is shared between other irrigators with remaining pump capacity.

The irrigators in the current unregulated flow reach may divert unregulated flows up to their share limit, allowing for travel time. At the next (downstream) unregulated flow reach computations are carried out considering the water actually diverted upstream and inflows from the unregulated tributaries in this reach.

The unregulated flow procedure could be implemented for groups of users, with sharing between users in a group based on their proportion of the group. Hierarchical rules similar to those described for sharing internal spills in storages (Section 4.3) can be used to share between groups. There should also be some functionality for water borrowed from other groups to be paid back in reservoirs.

## Ownership of unregulated flows

Ownership will be assigned to unregulated flows when they spill, inflow or pass a non-consumptive node. Unregulated flow is not always shared, and the sharing of unregulated flows is sometimes coupled with payback.

When unregulated flows are not shared, the water that is not used will flow on to the next sharing reach or out of the end of the system. If the unregulated flows are shared, they will be apportioned to the owners in proportion to their requirements. When payback is required, the availability of payback water in a specified storage will also be considered. The payback will be constrained by the amount of stored water available for the payback and the available airspace in the receiving owner's share. Various discount functions that allow for delivery loss can be applied to the payback.

Flexibility could be built into the management of unregulated flows so that users can define how unused water is traded to others in the system.

## Irrigation demands

Enhanced demand modelling functionality for irrigation, urban and hydroelectricity demands will be required for RiverManager.

Currently, it is assumed that demands used in the model are generated using an outside source and there is either a monthly pattern of use or a demand file available for input to the model. Some existing crop models (IQQM Crop Model 2 and Pride) will be made available in RiverManager. A new crop model that includes irrigator decisions and uncertainty, called NGenIrr, is being developed by eWater staff at Melbourne University for incorporation into RiverManager.

## Custom management rules

There are on-going discussions between the eWater partner agencies around the need for, and desirability of, custom management rules beyond the scope of the water management expression engine. The specifications for any custom management rules that cannot be implemented using the expression engine will be left until it is implemented, and until an existing sub-project that is considering additional customisation functionality requirements is completed.

## Scenario management

The Partner User Requirements identified that a record-keeping tool is required to track and store model versions, data, outputs and associated parameters. This tool needs to be able to recall and reproduce scenarios.

## Geographic view

A spatially-referenced geographic view, which will be useful for ensuring that features are properly located, will be developed for RiverManager. This will be available in parallel with the schematic representations, which are less cluttered at locations with multiple nodes.

## Improved rainfall-runoff estimates

WaterCAST, which is a software tool currently being developed by the eWater CRC using the E2 catchment model as an engine (eWater CRC 2007), will provide improved rainfall-runoff estimates for modelling flow in upstream catchment areas. RiverManager will include access to this tool.

## Routing disaggregation

Flow routing in the IQQM simulation models uses 6-hourly time steps with the model outputs reported as daily values. To replicate this in the RSMT will require the construction of 6-hourly time step models, with the outputs aggregated to daily time steps in the reporting functions. Model time step and river reach lengths are interdependent, as described in Podger (2004, p. 38).

If disaggregation of daily inflows is required to modify the input data to match the selected time step duration, mean daily flow volumes from the current day, previous day and next day can be used to estimate the shape of the hydrograph. A disaggregation procedure is described in Podger (2004, p. 33–36). Disaggregation in REALM is discussed in VU and DSE (2005a).

## Multi-stage routing

Multi-stage routing will be developed for RiverManager. Multi-stage routing recognises that flow through a river reach for over-bank flows will be different from in-bank flows. For multi-stage routing a river reach is conceptualised as consisting of up to three layers: a basal in-bank reach and up to two overlying, progressively wider over-bank reaches. Each layer is assigned its own routing parameters. River water fills the lowest layer/s first and the river reach outflow is the sum of the outflow from all the layers. For further explanation see Podger (2004, p. 39–40).

## Hydropower nodes

Hydropower nodes will be developed for RiverManager. Hydropower, which is a non-consumptive user, can be generated from storage releases for other users, in which case a change in ownership is not required. Alternatively, hydropower could be generated from an ordered release from a hydropower node. In this case, the release would be owned by the hydropower organisation. When the water is returned to the river its ownership will need to be reassigned to other owners in the system.

## **Grouping of owners**

The grouping of owners could be included in RiverManager. Such groupings could be based on State. A user might belong to a number of groups. The modelling and tracking of groups will not be required, but groups could be used to aggregate information about a number of water users.

## **Murray River resource assessment**

Resource assessment rules for the Murray River are the most complex. To satisfy Murray River resource assessment requirements, the following inflow conditions will be considered:

- serially correlated minimums,
- minimum historical inflows,
- recession of current inflows until flows reduce to zero,
- 75% exceedence conditions, and
- two-year assessments against the worst historical two-year drought, with minimum inflows in the second year.

## Appendix B. River management modelling concepts

This chapter presents concepts associated with river management modelling. Generic methodologies for applying these concepts in a river-system model and for modelling supply and demand are described.

### Inflows

Inflows to a river-system model can be rainfall-generated inputs, pumped/ piped inflows/returns or irrigation returns. They can include rain falling directly on a river or a storage, hill-slope runoff, inflow from ungauged tributaries and treated water returns from towns. Rainfall-generated runoff/inflow values are determined during model calibration. These inflows may be generated as a direct output from another model or may be a time series input derived from another source.

### Losses

Losses from a river system can be regulated or uncontrolled. Regulated losses are associated with the delivery of water to users and are taken into consideration during river operations to ensure the correct volumes are delivered to users. These losses depend on the supply path. Uncontrolled losses include seepage under a dam wall, water that is lost as evaporation from the river water surface and transpiration from riparian vegetation, and seepage to groundwater. Evaporation and transpiration losses can be combined into a single loss value per river reach. The value is proportionate to the surface area of the river (length of thalweg x river width), which varies with river stage, and potential evapotranspiration rate. Losses to groundwater are a function of the groundwater head, riverbed lithology, wetted perimeter and river stage along the thalweg. Loss values are determined during model calibration.

### Generic methodology: river-system modelling

The basic steps in the simulation of a regulated river system are:

1. Assess the resource available to water users at the start of the water year and at nominated intervals thereafter.
2. For each day, check the amount of flow in the river and water available in storages, and then determine if the river flow is in excess of orders placed on the previous day. If this is the case, compute each user's share of the unregulated flow.
3. Calculate the daily water order, allowing for the water travel time to its destination. Water requirements are estimated for various consumers including irrigators, towns, stock and domestic supply, minimum flow and wetland requirements at nominated locations. Water orders to the storages may increase or decrease depending on tributary inflow, losses in transmission, outflows to effluent systems, associated returns and flow constraints. Water orders are directed to a nominated supply source as specified in the input or calculated by harmony rules for operation of reservoirs in parallel (Section 5.2).
4. Route flows starting from the node furthest upstream, working toward the end of the system, adjusting the water balance at each node as water is either extracted or added.

For unregulated systems, only Step 4 is carried out, and if river flow exceeds the licence conditions for water users in that system, those users are allowed to pump water from the river according to their licence constraints.

The simulation of a regulated river system also requires that information on the state of the system at a downstream location is available for changing the state of the system at an upstream location. For example, if flows at the end of a system are estimated to be less than the target flows, releases from an upstream storage might need to be increased to meet the target.

Providing for this feedback requires a two-pass calculation procedure for each day of a simulation. The first-pass calculation starts at the most downstream node in the system, calculating requirements at each demand node and passing orders upstream. In each river reach the orders are increased to allow for the estimated water losses and decreased to allow for the estimated water inflows. The timing of inflows from a reservoir is lagged to allow for travel time down the river. The amount of an inflow is estimated using a standard flow recession curve for the river reach. The orders are thus propagated upstream until they reach a storage reservoir. If there is a confluence of two regulated tributaries, the orders are split between them according to management rules.

The amount of water required to be released from the storage to meet the orders is now calculated. If the storage or supply channel cannot meet the orders, and there is another storage or supply path upstream, the orders are passed upstream to the next storage. This continues until the orders are fully met or it is not possible to fully meet the orders. Users are subsequently notified that only a proportion of their order will be supplied.

The second-pass calculation starts from the most upstream node in the system. Releases are made from the headwater storage, flows are routed down the system and extractions are made to fill orders. The flows are reduced for losses and increased for inflows. The flows are also checked to see if they are in excess of downstream requirements. The allocation of this water is unregulated flow sharing, which is described in Appendix A.

In unregulated systems no water orders can be placed by water users, so the two-pass calculation is not required. The water users' rights to pump water from the river depend on their licence conditions and the river flow.

## **Generic methodology: supply and demand**

The water management functionality for supply and demand modelling is conceptualised into nine phases of operation: generation of catchment inputs, resource assessment, demand adjustment, system forecasting, unregulated flow sharing, demand constraints, ordering, flow distribution, and output and checks. These are described in the following sections.

### **Generation of catchment inputs**

Inflow from catchment runoff for RiverManager will be provided by WaterCAST, in conjunction with flow sequences developed from recorded data. WaterCAST operates within the E2 catchment model.

Other catchment inputs, such as direct rainfall and evaporation, will be based on observed data.

### **Resource assessment**

A resource assessment in a regulated river system defines users' shares of the regulated supply, and subsequently sets constraints on water ordering and use. This assessment is optional; it can be activated in a model or not used. When activated it does not need to be implemented at each time step. A frequency of weekly or monthly or even annually might be sufficient, depending on the particular river operation constraints. The resource assessment might require the model to be run into the future to estimate the distribution of water within storages, tributary utilisation, and transmission and operation losses. Resource assessment is discussed in more detail in Chapter 7.

Unregulated systems do not have resource assessment constraints.

## Demand adjustment

Planting decisions are typically made twice a year for summer and winter crops, but triple cropping is also practiced. The timing for these decisions is affected by climate, crop type, soil moisture and frost considerations. Planting decisions are based on the available water resources, a farmer's risk behaviour, and crop water requirements. These planting decisions will affect future demands from water storages.

Economic considerations can also affect planting decisions and future water demand. These include water trading, the type and area of crop grown, and whether to retire a crop to dryland. Decision dates would be required for this analysis.

For a regulated river system, planted areas and patterns of water use are adjusted, and crop models are used to generate water demands. Water demands can be calculated elsewhere and input as time series.

There is no demand adjustment in an unregulated river system. Water requirements are not met if there is not enough water in the river.

## System forecasting

This phase is implemented to allow for the difference in water travel time between release and use. In many of the regulated river systems in Australia the travel time between storages and users is up to weeks. This creates a unique set of issues for water users whereby they need to project their requirements ahead of when they need the water. There are several ways that this can be approached:

- Pattern demand – achieved by looking forward the appropriate number of days in the demand pattern.
- Hydropower demand – demand is driven by storage volume/head targets; the future volume/head can be estimated using projected releases.
- Irrigation demand – achieved by projecting crop demands on the soil moisture and on farm water storages, assuming no rainfall (or a conservative allowance), a specified number of days into the future.
- Environmental demand – achieved via a combination of pattern forecasts, projected soil moisture and wetland volumes.

In addition to projecting user demands, it is necessary to estimate inflows along the flow route during the time a demand is in transit to its user. Typically this is calculated by assuming an average or minimum recession hydrograph, which is of the form

$$Q(t) = aQ^{-kt} \quad (5)$$

where  $Q(t)$  = inflow rate that is forecast for  $t$  days ahead,  $t$  = number of days ahead,  $Q$  = present flow rate, and  $a$  and  $k$  are recession constants.

Alternatively, forecast flows could be estimated by stochastic or rainfall runoff models.

Where there are multiple reservoirs and constraints on transfers between them, the model may need to forecast up to several years into the future to work out if transfers need to start or stop on the present day. There are examples of this in both IQQM and MSM-Bigmod river models.

## Unregulated flow sharing

Unregulated flow sharing precedes demand constraints and ordering because the allocation of unregulated flows influences orders by both consumptive and non-consumptive users. Flows that are excess to orders can be caused by the spilling of storages, or inflows from unregulated tributaries, or a reduction in demand due to higher than expected rainfall, termed rain rejection. The management of these unregulated flows is required when river flows are in excess of downstream requirements, which typically occurs over a period of days.

Flows that are excess to orders moving through the system might trigger the ordering of piggy back flows, which supplement smaller events to enhance environmental outcomes.

Irrigators may extract water during these unregulated flow periods without utilising their volumetric water allocation for the year. This can be used to meet existing demands or to fill on-farm storages, which might reduce future orders. Unregulated flows can occur in different stretches of a river at different times. Alternatively, during very wet periods, unregulated flows can occur over the entire river system. Unregulated flow sharing is discussed in more detail in Appendix A.

## **Demand constraints**

The demand constraint phase extracts licence and allocation information that was entered by the model user, and imposes constraints on the amount of regulated water that can be ordered by a water user.

## **Ordering**

The ordering phase accumulates consumptive and non-consumptive orders from the bottom of the system to the top of the system. The non-consumptive orders might require extra water to be added to existing orders.

The accumulation of orders also takes into consideration losses that include:

- Losses at distributary nodes.
- Losses within river reaches (e.g. evaporation).
- Volumes held in storage within river reaches.

In river systems where there is more than one upstream supply reservoir, accumulated orders will have different travel times. This will affect the loss estimate. Consider, for example, a location that has two upstream supply storages in series two days apart. Orders placed to the downstream storage will arrive at the location two days earlier than orders placed to the upstream storage. Therefore, the orders accumulated for the upstream storage will have different losses when they reach the location, affecting the calculation of the total flow on the day.

The model also needs to allow for gains as it accumulates orders. Any tributary inflows that occur during the period that the release takes to reach its destination need to be estimated. Inflow forecasts also need to allow for the different travel times when there is more than one upstream supply reservoir.

As the orders pass up through the system they can be affected by physical constraints, such as outlet capacity and river flow constraints, which will be represented in the RSMT by constraint nodes. Typically, these restrict the maximum flow rate. Orders that were previously released and are in transit will need to be added to the flow when checking if the physical constraint will have an impact on the new demands. Constraints on orders are shared proportionately to each user. If the calculated flow is greater than the physical constraint will allow, the model will need to start again from the bottom of the system with reduced orders. A re-assessment is then required because the reduced orders will reduce loss estimates. This then propagates up to the next constraint and the process is repeated.

Orders passed up multiple paths and supplied by multiple reservoirs are discussed in Chapter 5.

## **Flow distribution**

In the flow distribution phase, water is moved through the system. In a regulated river system, water is released from storages or spills during flood events, and regulators, such as weir gates, are controlled to move water through the system. In an unregulated river system, river flow is driven by gravity. In both systems, abstractors take water subject to access rules.

## **Output and checks**

The output and checking phase includes:

- Mass balance checks on the system to ensure mass has been preserved. This includes checks on flow and user shares. The mass balance information will be saved as an output.
- Updating the model database and reporting outputs, such as flow, storage volumes and abstractions. These will be presented as graphs and statistics.
- Running other software that post-process outputs from the model.

## Appendix C. E2 water storage functionalities

The following are descriptions of water storage functionalities that have been implemented in E2.

### Water storage basics

The volume of water in a storage at the end of a time step is calculated as follows from the mass balance equation

$$S_t = S_{t-1} + (I_t + R_t) - (O_t + E_t + L_t) \quad (6)$$

where  $S_t$  = water in storage at the end of the time step,  $S_{t-1}$  = water in storage at start of the time step,  $I_t$  = inflows during the time step,  $R_t$  = rainfall over the area of the storage during the time step,  $O_t$  = outflows during the time step,  $E_t$  = evaporation over the area of the storage during the time step,  $L_t$  = seepage/leakage losses during the time step.

The outflows from on-river and off-river storages are limited by their outlet capacities. A relationship between storage volume and outlet discharge capacity will be entered by the model user for each storage outlet. Similarly, the inflows into off-river storages are constrained by their inlet capacities, and a relationship between river flow and inlet capacity will be entered by the model user.

If required, storage inflows are back-calculated from Equation 6 using reservoir volume changes determined from storage level records, as follows:

$$I_t = S_t - S_{t-1} + (O_t + E_t + L_t) - R_t \quad (7)$$

This requires the relationship between storage level, area and volume to have been entered by the user. The relationship between storage level and seepage rate will also be required. Negative inflows calculated using this mass balance approach can be removed by smoothing.

### Rule curves

Rule curves are time-varying volumes or target water levels for a storage. An on-river storage could have one (upper) rule curve for maintaining sufficient airspace for flood mitigation and another (lower) rule curve for maintaining storage water levels during the irrigation season where an upstream storage allows for this.

For the upper rule curve, once the storage level exceeds the target level, releases commence subject to the outlet capacity of the storage. For the lower rule curve, when the storage level falls below the target level, an order is placed to the next upstream storage to fill the storage to the target level.

For off-river storages, only the lower rule curve applies. When an off-river storage falls to the lower target level, it places an order to the next upstream storage, subject to inlet capacity constraints.

### Flooding

Gated storages can be operated to minimise downstream flooding. The gates are opened and releases commence with the aim of having the dam at its maximum level at the end of the flood. On the rising limb of the hydrograph, releases from the storage are less than the inflows into the storage to reduce the peak of the flood. The timing of the gate operation depends on

the estimated recession of the inflow hydrograph, water orders already placed and the current airspace.

There are four methods of operating gated storages during flood events:

1. No release, which occurs when the expected inflows are less than the available storage capacity (full storage volume), plus the surcharge (maximum storage) volume.
2. Normal gate operation, which occurs when gate operation can attenuate the flood. The outflow rate is less than the inflow rate.
3. Free overflow, which occurs when inflow exceeds the outflow rate through the maximum gate opening. The gates are fully open and the storage is spilling.
4. Evacuation of surcharge volume, which occurs while the inflow is receding. The inflow rate is less than the outflow rate and the surcharge volume in the storage is being released.

When a flood release is required, the release flow is compared with the target release flow from the storage to meet water orders. The water released from the storage is the greater of the release required to meet water orders and the release required for flood mitigation.

## **Flood detention storage**

During a flood, water from overbank flow can enter natural depressions or lakes located on an adjoining floodplain. Most of the water returns to the river as the flood recedes, but some remains in these storages and is lost through evaporation and seepage. Depending on the antecedent conditions, these detention storages can significantly affect the propagation of a flood wave.

Inflow into a detention storage is modelled using a relationship between river flow and the flow rate at which water will enter the floodplain detention storage. The return of water from a detention storage is modelled using a relationship between the river flow and the elevation of water in the detention storage.

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## Glossary and abbreviations

Source: Podger and Beecham (2004).

**AHMI.** Australian Hydrological Modelling Initiative.

**Allocation.** The percentage of their entitlement volume that is available for diversion by general security irrigators in the current water year in regulated rivers that use an 'annual accounting' system. This is supplied from guaranteed resources (i.e. from 'headwater storage' or minimum flows from unregulated tributaries downstream of the storage), also adjusted for 'carryover' and 'overdraw'. Does not include any 'supplementary water' that may become available. Allocations are announced publicly by the department at various times during the year. This term is being superseded by the term 'available water determination' in accordance with the Water Management Act 2000, but this new term is not yet in common use.

**Annual accounting.** The accounting and sharing out of water resources within a regulated river system (dam and useable tributaries) on an annual cycle (usually July to June in NSW). The department manages the water and makes regular announcements on the percentage of users' entitlement that is available for use.

**Annual Exceedance Probability (AEP).** Probability that an event of specified magnitude will be equalled or exceeded in any 12 month period, on average. In the context of natural resource management, examples of events include storms, floods, earthquakes, algal blooms and droughts. Expressed as 1 in y AEP event (sometimes without the AEP); for example 1 in 100 year flood. With storms, the duration is also important; hence terms such as the 1 in 20 AEP 24 hour storm are used. Duration is important with droughts as well, and here the AEP concept becomes complicated because droughts can persist for more than one year.

**AWBM.** Australian Water Balance Model.

**Baseflow.** The component of streamflow that originates from groundwater, and supports streamflows during long periods of no rainfall.

**Cap development conditions.** This is a scenario that represents water resource development infrastructure and management practices that existed in the 1993/94 water year (as defined in the MDBMC Cap). This term is relevant to hydrologic modelling for water management purposes, Water Sharing Plans and Cap accountability.

**Carryover.** A portion of allocated water in regulated river systems that can be carried over from one water year to the next by water users.

**Carryover reserve.** Water in storage in a regulated river system in a given year that is kept in reserve to meet high security requirements in the subsequent year (sometimes referred to simply as a 'reserve' to avoid confusion with 'carryover').

**Catchment.** The area of land drained by a water course that could range from a small runnel to a creek or a river. In hydrologic terms every point in the landscape is the outlet of a catchment of some description. As the term has a wide range of applicability it gets used very broadly (and loosely). The equivalent term in the US is 'watershed'.

**Cease to pump.** The water level at a gauging station, at which irrigators must stop pumping.

**Commence to pump.** The water level at a gauging station, at which irrigators can start pumping.

**Continuous accounting.** The sub-division of water resources in a dam (within a regulated river system) into user shares. The shares are updated on a frequent basis: e.g. currently monthly in the Gwydir and Namoi systems. Users manage their usage from their own account.

**CRC.** Cooperative Research Centre.

**Critical drought.** The duration in time that resulted in the either the lowest dam levels, aquifer levels or pressures, or longest duration of restricted water access.

**Current development conditions.** This is a scenario that represents water resource development infrastructure and management practices at the current point in time; this scenario requires regular updating. This term is in common use but can be misleading

without a specific reference date. This term is relevant to hydrologic modelling for water management purposes and Water Sharing Plans.

**Dam Safety Emergency Plan.** A continually updated set of instructions and maps that deal with possible emergency situations or unusual occurrences at a major dam.

**Deep drainage.** Water in the soil that percolates down below the root zone of plants ( i.e. a component of infiltration water), and therefore cannot be transpired by plants. See also 'infiltration' and 'recharge'.

**Developed area.** The maximum area that a farmer has the infrastructure to irrigate.

**Discount function.** Refers to water that is discounted from (taken off) the available water calculated after the resource assessment is done because a rule has come into play, for example based on the water level in a water storage.

**DSE.** Victorian Department of Sustainability and Environment. <http://www.dse.vic.gov.au>

**Effluent.** The term 'effluent' is used in a number of different ways:

- Effluent is commonly thought of as being the wastewater discharged from sewage treatment plants or industries into receiving waters, but it could be any discharge (e.g. from a dam to a river downstream).
- The term 'effluent' is used to denote a stream which conveys water away from the main river (i.e. a distributary stream or anabranch).
- An effluent stream or waterway is one which loses water to groundwater (also known as a 'losing stream').

**End-of-system flow.** Streamflow at the end of a given river system; e.g. Murrumbidgee River at Balranald.

**En-route storage.** A water storage (weir or lake) located either instream or off-stream in the middle or lower part of a river system (e.g. Hay Weir on the Murrumbidgee).

**Environmental flow/allocation.** The provision of water within wetlands, rivers and groundwater systems to maintain aquatic ecosystems and their benefits where the ecosystem is subject to competing water uses, e.g. irrigation.

**FEBIGS.** Floodplain Ecosystem Benefits of Interactions between Groundwater and Surfacewater.

**Floodplain harvesting.** Includes water:

- Pumped from the floodplain to an on farm storage during large floods using secondary lift pumps.
- Entering an on farm storage from the floodplain because flood levels are high enough to allow it to flow in by gravity.

**Flow duration curve.** A graphical representation of a ranking of all the flows in a given period, from the lowest to the highest, where the rank is the percentage of time the flow value is equalled or exceeded. These curves may be derived for flows in any time interval, such as daily flows, monthly flows or annual flows.

**Flow routing.** The change in magnitude, speed and shape (height and duration) of a flow hydrograph as it moves downstream, due to channel and floodplain storage and frictional effects.

**Full Supply Level (FSL).** The maximum normal operating level of a reservoir behind a dam. The water level can go above this, such as during floods when the spillway is operating (referred to as flood surcharge), but if the water level rises above the crest of the dam then the dam will be overtopped, and it may fail. For example, Burrinjuck Dam was overtopped on one occasion, but did not fail.

**GL (gigalitre).** One thousand million litres (also equal to 1 million cubic metres).

**GSWIT.** Groundwater–SurfaceWater Interaction Tool.

**GUI.** Graphical User Interface.

**Headwater storage.** A water storage reservoir created by a dam in the upper (usually higher rainfall) part of a river valley (e.g. Burrendong Dam).

**Hydrologic cycle.** The circulation of water from the oceans through the atmosphere to the land and ultimately back to the ocean.

**Hydrograph.** The trace which describes the change in stream flow (or water level) over time at a given location in a river system.

- Infiltration.** The process by which water soaks into the soil from rainfall, snowmelt or irrigation. See also 'deep drainage' and 'recharge'.
- Influent stream.** An influent stream is one which gains water from groundwater (also known as a 'gaining stream').
- IQQM.** Integrated Quantity and Quality Modelling.
- LAM.** Lumped Alluvial Model.
- Lateral throughflow.** Relatively rapid subsurface flow through cracks, pipes, macropores in the soil – also referred to as lateral subsurface flow and interflow.
- MDBC.** Murray-Darling Basin Commission. <http://www.mdbc.gov.au>
- MSM.** Murray Simulation Model.
- Natural development conditions.** This term denotes a scenario that comprises conditions in a river system without any water resources development (dams, water supply infrastructure, irrigation development). Catchment land use changes that have occurred over the years, such as land clearing, are ignored in this definition. This term is relevant to hydrologic modelling for water management purposes and Water Sharing Plans.
- NSW.** New South Wales.
- NWC.** National Water Commission. <http://www.nwc.gov.au>
- On farm storage.** A large private water storage on an irrigation property, such as a cotton farm. Some are formed by modifying billabongs but usually they are constructed at any convenient location on the property.
- Off-river storage.** A water storage (weir or lake) in the middle or lower part of a river system which is off the main stream (e.g. Lake Brewster in the Lachlan).
- Operation loss.** The volume of water released from a dam to meet irrigator water orders that is subsequently not diverted by the irrigators. This occurs when irrigators reject their ordered water because local rainfall has met their water needs since a water order was placed. This 'loss' also includes an allowance for operator uncertainty in predicting how the river system as a whole will behave during the time the release water takes to travel from the dam to the users.
- Overbank flow.** Water which flows out of a river channel onto floodplains or into billabongs and wetlands during high flows. Some of this water will not return to the river when water levels subside as it goes into storage (see transmission loss).
- Overdraw.** A portion of next water year's reserved water in a regulated system that can be used in the present water year.
- Overland flow.** Surface runoff, which is caused either because the underlying soil is saturated and cannot accommodate any more water or because the intensity of rainfall is greater than the soil's capacity to infiltrate it.
- Permanent transfer.** Transfer of a water entitlement (licence to take water) from one licensed user to another.
- Planted area.** The area that an irrigation farmer plants in a season
- Precipitation.** Rain, snow, hail, sleet, dew.
- Probable Maximum Flood (PMF).** The flood resulting from PMP, and where applicable snow melt, coupled with the worst flood-producing catchment conditions that can be realistically expected in the prevailing meteorological conditions.
- Probable Maximum Precipitation (PMP).** The theoretical greatest depth of precipitation for a given duration that is physically possible over a particular catchment area, based on generalised methods.
- Qld.** Queensland.
- Quickflow.** The component of streamflow that has travelled through the catchment as interflow or across the surface as overland flow.
- Rain rejection.** This occurs when irrigators in a regulated river system reject their ordered water because local rainfall has met their water needs since a water order was placed.
- Rainfall-runoff harvesting.** Water from a rainfall event that is harvested on irrigation farms via a water recirculation system. (see also 'floodplain harvesting')
- REALM.** REsource ALlocation Model (Perera et al. 2005).
- Recharge.** The process by which surface water soaks downwards to replenish an unconfined (e.g. water table) aquifer.

- Regulated river.** The section of river that is downstream of a major storage from which supply of water to irrigators or other users can be regulated or controlled. In NSW these storages and rivers are operated by State Water and the regulated rivers are designated by legislation.
- Regulated flow.** Water that is released from storage to meet downstream requirements.
- Resource assessment.** The process of calculating an 'allocation' based on the current and predicted water resource availability and water requirements of all water users.
- Riparian zone.** The zone adjacent to streams and rivers; usually there is some exchange of water and nutrients between this zone and the stream.
- River diversion.** Water diverted (by pump or gravity) from a river
- RSMT.** River System Management Tool.
- Seepage.** The movement of water downwards through soils or permeable rock. This water can originate from a very wide range of sources, including all water bodies and most land surfaces. Seepage water may percolate far enough to reach groundwater.
- SMAR.** Soil Moisture Accounting Runoff.
- Storage behaviour.** The time varying change in a water storage status, influenced by rainfall, inflows, outflows and evaporation.
- Sub-catchment.** Area of land within a catchment; used in specific contexts to distinguish components of a larger catchment. See also 'catchment'.
- Supplementary water.** Water in a regulated river that is generally uncontrolled and in excess of any flow replenishment or environmental needs and ordered water. Previously this was called 'off allocation' water.
- SURM.** Simple Urban Runoff Model.
- Temporary transfer.** Transfer of a volume of water, during a water year, from one licensed user to another.
- TIME.** The Invisible Modelling Environment.
- Translucency.** An operational practice that involves releasing a portion of dam inflow to meet downstream targeted needs (e.g. environmental flows).
- Transmission loss.** The flow volume that is 'lost' from a river or stream as water travels downstream. It includes seepage to groundwater, overbank flow that goes into floodplain depressions, wetlands and billabongs and never returns to the river, and evaporation from the water surface. It also includes the effects of uncertainty in river flow gauging measurements and unaccounted water usage.
- Transparency.** An operational practice that passes dam inflows straight through the storage.
- Unregulated rivers.** All rivers that are not regulated, including rivers where the flow is controlled by dams or weirs constructed by urban water suppliers or private users.
- VU.** Victoria University. <http://www.vu.edu.au>
- Water orders.** Water ordered by an irrigator in a regulated river system to be supplied by State Water. Normally the water must be ordered 7 days in advance.
- Water trade.** Describes the practice of water transfers (both permanent and temporary)
- Water year.** A continuous twelve-month period starting from a specified month for water accounting purposes. The water year is 1 July to 30 June, except in the Border Rivers where it is 1 October to 30 September.