Computer Software Tool for Sustainable Water Allocation and Management - REALM

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Abstract: REALM (REsource ALlocation Model) is a generalised computer simulation package that models harvesting and bulk distribution of water resources within a water supply system. Like other water resource simulation models, REALM uses mass-balance accounting at nodes, while the movement of water within carriers is subject to capacity constraints. It uses a fast network linear programming algorithm to optimise the water allocation within the network during each simulation time step, in accordance with user-defined operating rules. Outputs from REALM simulations include various descriptors of system status and behaviour during each time step. REALM facilitates the graphical presentation of raw or post-processed outputs. A suite of utility programs is provided with REALM software package for the latter purpose. This paper will describe the main features of REALM and provide potential users with an appreciation of its capabilities. It will also describe two case studies covering major urban and rural water supply systems. These case studies will illustrate REALM's capabilities in the use of stochastically generated data in water supply planning and management, modelling of environmental flows, and assessing security of supply issues.

Keywords: *Water Supply; Planning and Management; Simulation Modelling; Sustainable Water Allocation*

1. INTRODUCTION

Simulation models are widely used by water authorities around the world for planning and management of water supply systems. These water supply systems consist of 'nodes' such as reservoirs, demand centres, diversion weirs, stream junctions and pipe junctions, and 'carriers' such as rivers and pipes. They supply irrigation and urban water demands, meet environmental flows, and provide releases for hydropower generation and other uses.

REALM (REsource ALlocation Model) is a generalised computer simulation software package that models the harvesting and bulk distribution of water resources within a water supply system. Attractive features of REALM include generality in modelling a wide range of water supply systems with diverse forms of operating rules, flexibility in terms of analysing "what if" scenarios, and high reliability of the package obtained through extensive testing and use in practical applications. It has been developed in close conjunction with its major users, and many enhancements were made in response to suggestions and feedback from these users. As a result, not only is it now able to meet the needs of a diverse set of users in the water industry, but it has also developed into a comprehensive tool for water supply planning and management. There are now REALM water resource planning models of all major water supply schemes in Victoria, Australia. The states of Western Australia and South Australia are also major users of REALM.

This paper will describe the main features of REALM and provide potential users with an appreciation of its capabilities. It will also describe two case studies covering major urban and rural water supply systems. These case studies will illustrate REALM's capabilities in the use of stochastically generated data in water supply planning and management, modelling of environmental flows, and assessing security of supply issues.

2. REALM SOFTWARE

Due to space limitations, only a brief overview of REALM software is presented. The reader is referred to REALM User's Manual, available from http://www.nre.vic.gov.au/vro/water, for more details. The software can also be downloaded free of charge from this site.

REALM enables developing a water supply system model using a comprehensive set of modeling elements. For example, reservoirs are configured through reservoir nodes, which can explicitly model maximum capacity and dead storage, evaporation and reservoir inflows. Two different types of demand nodes are available, one for urban demands and the other for rural or irrigation demands. These nodes differ in the way that restrictions are applied. A stream junction node is used to model river confluences, which can have streamflow input at the junction. Pipe junction nodes are available to configure pipe junctions. Stream terminator nodes configure the terminating points of the water supply system.

The above nodes are connected by either river or pipe carriers. These carriers can model minimum flows, maximum capacities, and transmission losses either as fixed quantities or as percentages of flow in the carrier. In addition, the preferred flow distribution in the water supply system can be modelled by user-defined penalties in the carriers. These penalties are generally small (in the order of 0 to 1,000). When there are two or more flow paths between two nodes, flow will first occur in the carrier with the lowest penalty up to its capacity, then the carrier with the next higher penalty will be used and so on until the required flow is received by the downstream node. Two carrier types, defined on the basis of maximum capacity, are available in REALM. The first type deals with fixed maximum monthly capacities. The second type, a variable capacity carrier, computes its capacity based on one or more system variables such as reservoir storage, demand or carrier flow.

A wide range of operating rules can be modelled either directly or indirectly by utilising the functional attributes of various node and carrier types that are used to configure the water supply system. Complex operating rules can be modelled through the powerful variable capacity carriers in REALM with appropriately high positive or negative penalties. The long-term optimisation over the planning period is done implicitly by proper selection of long-term operating rules such as reservoir target storage curves and demand restriction rules.

REALM attempts to satisfy the following water assignment criteria (in decreasing order of priority) when allocating water within the system during each simulation time step:

- Satisfy evaporation losses in reservoirs.
- Satisfy transmission losses in carriers.
- Satisfy all demands (which may be restricted), to maximise reliability.
- Minimise spill from the system, to maximise yield.
- Satisfy minimum flow requirements.
- Ensure that the end-of-season storage volumes meet the reservoir targets.

These water assignment criteria are achieved through so called 'system penalties' that are built into the REALM code, which are several orders of magnitude greater than the user-defined penalties.

At each simulation time step, REALM converts the modelling elements (such as reservoirs, demand centres, carriers etc.) of the supply system into a network of generic nodes and arcs. It then solves the network for flows using a fast network linear programming algorithm. Finally, it provides the results as attributes (e.g. storage volume, flow) for each element in the system.

A detailed description of the REALM structure including the built-in water assignment criteria, long term operating rules and theory of REALM can be found in Perera and James (2003).

3. CASE STUDY 1 - THE GOULBURN WATER SUPPLY SYSTEM (RURAL/IRRIGATION SYSTEM)

Key attributes of the REALM model of the Goulburn water supply system in Victoria and some of its typical applications in water resource planning and management are described below.

3.1. The Goulburn Simulation Model

REALM was used to build the Goulburn Simulation Model (GSM) which simulates the major water supply systems in the Goulburn, Broken, Campaspe and Loddon valleys. These systems supply about two million megalitres annually to both irrigation areas and urban centres in northern Victoria, Australia.

Twenty storages and 58 demand areas are represented in the GSM. The largest storage is Lake Eildon with a capacity of 3.4 million megalitres and an average inflow of 1.5 million megalitres per year, while the total inflow to the four valleys is about four million megalitres per year. The model runs on a monthly time-step and simulates the water supply operation of the four valleys over 110 years of hydrological data. A schematic representation of the GSM is shown in Figure 1 below.

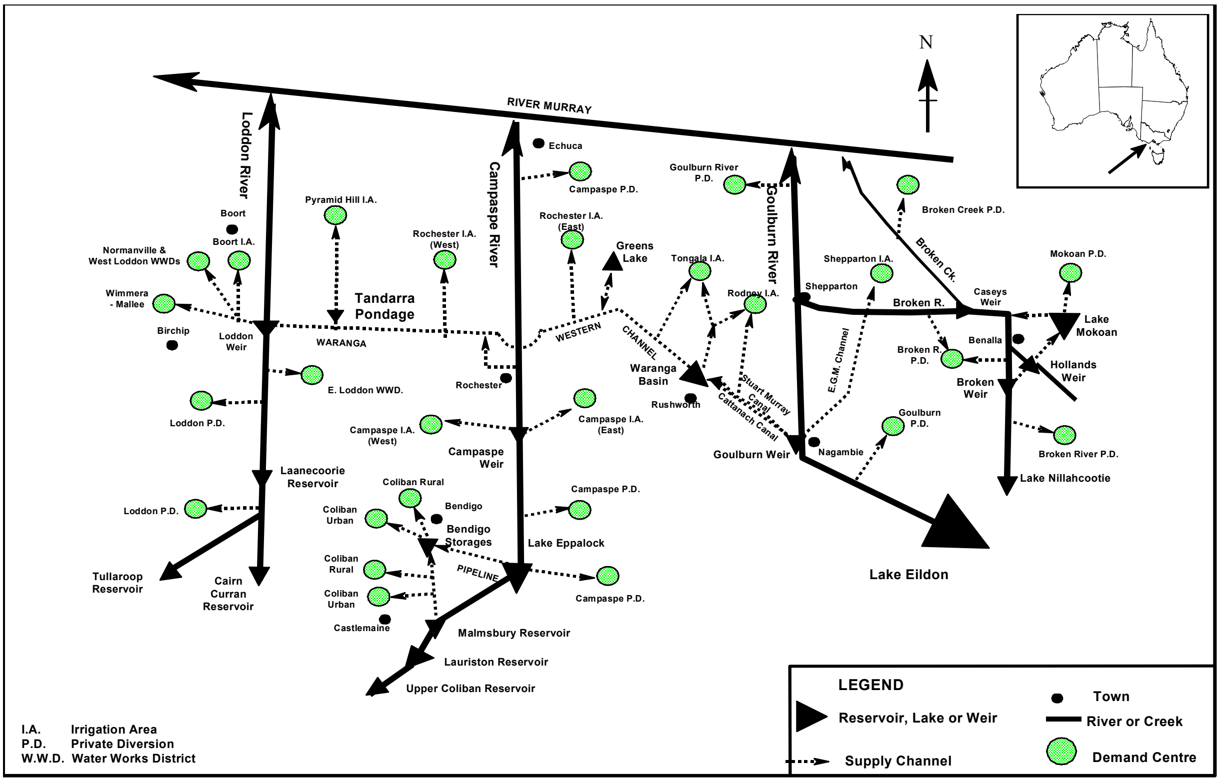

Figure 1. Schematic Representation of the Goulburn Simulation Model

The Goulburn System supplies irrigation water to farmers in the Goulburn valley as well as the lower Campaspe and lower Loddon valleys via the interconnecting Waranga Western channel (3000 ML/day capacity). This channel was constructed because the Goulburn River has a much more reliable flow than the Campaspe and Loddon rivers.

As most irrigation areas can be supplied from more than one source, complex operating rules have been developed to ensure all parts of the integrated system receive an equitable share of the total resource. For example, the Boort irrigation area can receive water from the Loddon, Campaspe or Goulburn storages but the source of supply at any time will depend on the run-of river flow below storages, the amount of resource in each storage, the availability of channel transfer capacity and the time of year.

REALM is well suited to modelling the integrated nature of this system. Being based on a network LP, it can utilise capacities and penalties built into each part of the many delivery routes to determine the appropriate sources of supply at any time. The user defined storage target curves also enable the model to simulate the timely transfer of water between Lake Eildon and Waranga Basin during the irrigation season.

When there is insufficient transfer capacity to satisfy all the irrigation requirements in any part of the distribution system, penalty functions in the demand nodes enable the network LP to find a flow solution that will equitably distribute shortfalls to the affected demands. Thus the GSM is able to accurately simulate the rationing rules applied in practice by the rural water authority.

3.2. Modelling Environmental Flow Scenarios

The GSM is currently being used to assess the ability of the Goulburn system to provide improved environmental flows in the Loddon and Goulburn rivers and to quantify impacts on security of supply to consumptive users. A panel of environmental experts has determined a suite of flow requirements needed to improve river health, ranging from seasonally based minimum flows to less frequent but higher volume freshes and flood flows. Sophisticated accounting mechanisms are being built into the GSM to keep track of previous flow events and to trigger environmental releases from storages at the appropriate times.

This is being achieved by setting up groups of variable capacity carriers to calculate environmental flow triggers. These carriers are not part of the flow network as their sole purpose is to calculate a trigger, that will activate an environmental flow carrier within the flow network, to release water from storage for the environment. These groups of "accounting carriers" are very powerful. They can perform complex computations applying numerous operations to any system variable such as flow, allocation or storage in the current or any previous timestep. The accounting carriers, while behaving in a similar way to the lines of a subroutine in a computer program, can be set up by modellers who have no computer programming knowledge as they are executed at run time in a similar way to the cell equations in a spreadsheet.

3.3. Defining Water Entitlements

The GSM has been a key tool in the conversion of previously poorly defined rights of water authorities to water in the Goulburn system, into clear and explicit bulk water entitlements. During this process it was used to define the security of supply of various types of water entitlement, determine water sharing rules during droughts and determine the impacts on water supplies of proposed environmental flow rules. It will continue to be used to help resolve water management issues such as potential impacts of water trading, and the competing needs of water users and the in-stream and wetland environments.

3.4. Detection of Growth in Diversions

The Goulburn, Broken, Campaspe and Loddon valleys are part of the much larger Murray-Darling Basin. As extractions from this basin have reached the sustainable yield, diversions from each valley are not allowed to increase above what they were at 1993/94 level of development. This limit or diversion cap is not a constant value but will go up in a dry year-provided there is water in the storages, and down in a wet one. The GSM is used to calculate the annual cap targets to check that usage in these valleys has not increased above the 1993/94 level.

This is achieved by updating the input data to the GSM (rain, evaporation, inflows and demands) each year and running a version of the model, which is calibrated at 1993/94 level of development, to determine the diversion cap target for that year. The actual diversions for that year are then compared with the cap target and, if diversions are seen to be increasing, water allocations will be reduced in following years to bring usage back to the agreed levels.

3.5. A Forecasting Tool

The GSM is also used to help water authorities estimate likely water sales over the next two years for budgeting purposes and to provide information to water users on the probability of water allocations increasing over the remainder of the current season. While the volume of water in storage is known and can be allocated, there is uncertainty in future water allocations because of uncertainty in the volume and timing of future inflows. The amount of water actually used will depend, not only on the amount allocated, but also on the amount and timing of rainfall in the irrigation areas.

To provide these estimates, the 110 years of input data are reformatted into 109 replicates, each of two years duration. The GSM is then run in multi-replicate mode to perform 109, two year simulations with each simulation starting at the current storage levels. As the climatic sequence in each replicate is different, 109 different results are produced and the probability distribution of water allocations and usage over the next two years is calculated. The water users are then informed of the probabilities of allocations increasing over the season and the authorities know the probabilities of reaching key sales volumes, hence revenue targets.

4. CASE STUDY 2 - THE MELBOURNE WATER SUPPLY SYSTEM (URBAN SYSTEM)

The Melbourne Water REALM model is outlined below, with special reference to the application of stochastically generated data. The results presented in this section are preliminary, as Melbourne Water is currently in transition to the use of stochastically generated data for water resources planning and management.

4.1. Melbourne Water Supply System

Melbourne Water provides wholesale water and sewerage services to three retail water companies – City West Water Ltd, South East Water Ltd, and Yarra Valley Water Ltd. Melbourne Water also provides supplies to Gippsland Water, Southern Rural Water and Western Water. Bulk Water Supply Agreements define Melbourne Water's delivery requirements at various customer interface points. Each retail water company has licence obligations to provide retail water and sewerage services within defined areas. The system provides water supply to a population of about 3.5 million people.

Melbourne's water supply system is shown schematically in Figure 2. It currently utilises 10 major reservoirs including harvesting reservoirs and seasonal balancing storages. They have a total storage capacity of 1,773,000 ML of which 60% is in Thomson Reservoir. Water from the harvesting reservoirs is transferred via pipelines and aqueducts primarily by gravity flows to seasonal balancing storages closer to Melbourne, for supply to the three retail companies. Limited pumping also occurs from Yarra River into the Sugarloaf Reservoir pumped storage. The part of the system described above is known as the headworks system.

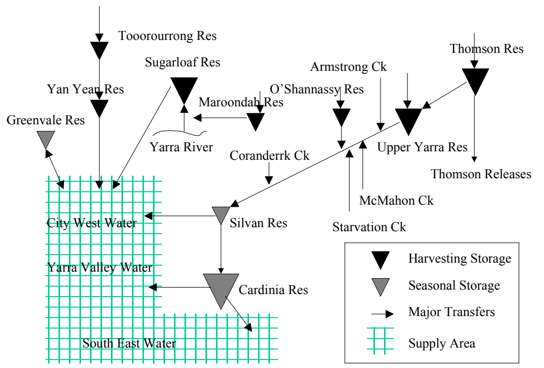

Figure 2. Melbourne Water Supply System

4.2. Melbourne Water REALM Model

Melbourne Water's REALM simulation model represents the harvesting and transfer system in greater detail, and denotes the supplies to retail companies through 17 demand centres. Among the key aspects modelled are all harvesting sites, major reservoirs and transfers, influence of climate on monthly demands, demand restriction rules, environmental flows, harvesting by pumping from Yarra River into the off-stream Sugarloaf Reservoir, operation of hydro power stations downstream of Thomson and Cardinia Reservoirs and treatment plant outputs. The key application areas of Melbourne Water REALM model include the assessment of bulk water entitlements, environmental flow volumes and security of supply; drought planning; augmentation planning; and the evaluation of alternative operating strategies.

Currently, the REALM simulations are carried out using historic streamflow and climatic data, and future demand forecasts. The historic data are recyled within REALM to create a number of potential data replicates. However, Melbourne Water is committed to incorporating generated data into the planning process in recognising the need to fully understand climate variability, and hence overall hydrologic risk.

4.3. Stochastic Data Generation and Its Use in Melbourne Water REALM Model

In the past, varying degrees of success were achieved with stochastic data generation techniques employed at Melbourne Water. Melbourne Water's current stochastic data generation model developed by Melbourne University (Wang, 2002) generates multiple data sequences that represent the statistical characteristics of historic data. Particular consideration is given to the interpretation of catchment regrowth impacts embedded in historic data following bushfires, and to the incorporation of the impact of potential future bushfires on future water resources availability. The Kuczera bushfire model (Kuczera, 1985) is used to describe the impact of bushfires on flows.

A key component in the application of generated data has been the development of an appropriate framework for processing generated data for use in REALM. Figure 3 displays the data processing requirements from the data generation phase up to the use of generated data in the REALM model.

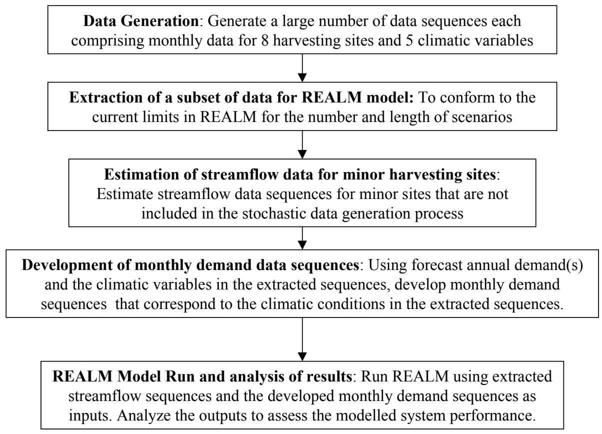

Figure 3. Processing of generated data for use with REALM headworks system simulation model (Kularathna et al, 2002)

These data processing requirements prompted Melbourne Water to develop a series of in-house utility programs to extract, analyse and manipulate the generated data in a form suitable for use with the REALM model.

As an initial case study, two REALM model runs were carried out to assess the behaviour of the current water supply system under historic and generated data. Both model runs used stationary demand conditions corresponding to a future demand of 540 GL/year. To limit the size of the generated data set used in REALM, only 100 streamflow data replicates (each of which is 100 year long) were processed.

From the model results, system performance was assessed by estimating the monthly reliability (percentage of months without restrictions in a streamflow sequence) for each streamflow sequence. For each model run, this resulted in a range of estimates for monthly reliability. This enabled a probabilistic representation of reliability, as shown in Figure 4. However the representation of historic data in Figure 4 is biased due to the recycling of historic data to create multiple replicates. Nevertheless, Figure 4 demonstrates the potential outcomes due to the wide range of streamflow conditions represented in stochastically generated data.

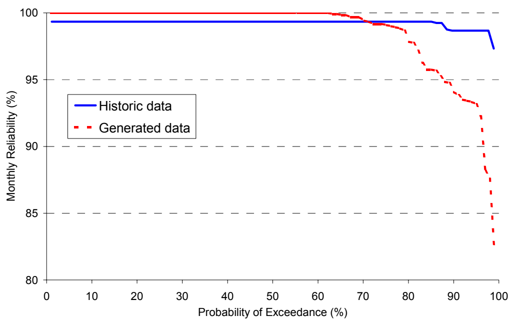

Figure 4. Monthly system reliability, modelled with historic and generated data

In another study, stochastic data were used in a REALM model run with growing long-term demand forecasts. Unlike the stationary demand run which required no modifications to the REALM model, this run required significant modifications. These modifications were required to specify the long-term restriction rule in relation to average annual demand (AAD). Such a rule can be readily modelled with REALM's built-in functionality in a model run using recycled historic data. However REALM does not use AAD data in a run using multiple replicates of generated data. This led to modifications that were aimed at bypassing REALM’s built-in restriction functionality, and modelling the restrictions indirectly, using the powerful variable capacity carriers.

5. CONCLUSIONS

A brief description of the generalised water supply simulation package, REALM, is presented in this paper. Attractive features of REALM include generality in modelling a wide range of water supply systems with diverse forms of operating rules, flexibility in terms of analysing “what if” scenarios, and high reliability of the package obtained through extensive testing and use in practical applications.

The REALM model of the Goulburn and Campaspe Systems has been used to quantify the security of supply and the impact of improved environmental flows when defining Bulk Water Entitlements. The complex operating rules used to run this highly interconnected water supply system were easily modelled by REALM, with innovative use of variable capacity carriers and the appropriate selection of penalties used by the network linear program. The model is currently being used to determine the potential impacts of increased environmental flows in the Loddon and Goulburn rivers. It will continue to be an essential tool for water allocation planning and to assess compliance with the Cap on diversions.

Stochastically generated data have been successfully modelled through Melbourne Water's REALM model. It is expected that the transition to stochastic data would assist Melbourne Water in further assessing climate variability, and hence overall hydrologic risk and security of supply. Adaptation of REALM model to use generated data has been straightforward in carrying out model runs with stationary demands. However, the model had to be modified to simulate generated data with growing demand forecasts. The modifications included bypassing of REALM's built-in restriction modelling functionality. REALM's powerful variable capacity carriers provided the means for achieving this modelling objective.

6. REFERNCES

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