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Abstract: Water resources management is increasingly dealing with competing demands for fixed or diminishing available supplies. In this, the allocation and accounting of water consumption between competing users, including environmental uses, plays a critical role. Various software tools have been developed to cover aspects of water resources planning and allocation, operation, and catchment management. In line with the requirements of water management agencies, attention is turning to the development of integrated tools with a broad range of capabilities that include water resource planning under different climatic and allocation policies, water supply under various operating rules and user behaviour, and catchment management and ecosystem condition assessment under different management regimes. This paper describes a preliminary software structure for water allocation, planning and management, starting from the basic concepts of availability, supply, demand and accounting, and outlining the class structure and interactions required to develop such as system. Classes are defined to provide a balance between elegance and utility, with much of the complexity that commonly arises from rule-based systems being contained within the availability and supply components. Development and testing of this structure is planned within an integrated tool designed to cover aspects such as water supply under short term forecasts, resource reliability under long term scenarios, and system response to a range of management behaviours.

Keywords: Water allocation; Software systems; Software design; Catchment management

1. INTRODUCTION

The technical and operational requirements for water resources management have increased markedly in recent decades, with improvements in asset assessment, codification of water rights, returning flows for environmental purposes, and the realisation that many of our water resources are either fully or over allocated. One area where the increasing intensity of water management has required technological development is that of water operations, to meet and track water allocations between competing users with a variety of demands, and to account for water demanded and delivered. Trading of water rights and allocations is another influencing factor in this arena, where system operators must also keep track not only of how much water has been consumed, but how much has also been traded. A complicating factor in some areas is inter-basin trading, where water sold and bought have to be delivered through different physical systems. A range of water management planning and operational tools are available but, as yet, there appears to be no single conceptual structure designed to facilitate software construction to meet the wide range of requirements. This paper describes requirements for a water resources software system (WRSS), and proposes a basic WRSS structure to support this.

2. PRIMARY PROBLEMS

The kinds of problems that occur in water systems management fall into three areas – resource investigation, system management and system operation - each of which has particular attributes.

Water *resources investigation* covers the areas of long term planning and assessment under a range of conditions. Issues of interest are yield and overall system behaviour, including assessment of risks and responses to long term changes in water availability and demand. Long term planning assessment can also be used to formulate policy and broad scale procedures to maintain or exploit available water resources.

System management aspects operate at shorter time frames than general resource investigations, and encompass weekly to seasonal to annual planning and behaviour. This includes annual water allocations and changes to these as seasons progress, planting and other management decisions by water users, and system behaviour in response to water trading. At the shorter end of the time scale are operations that include the tracking of antecedent conditions, the effects of farm dams, and short term forecasts to gauge inflows from unregulated systems and losses along waterways. These latter analyses are also important to the operation of system software for water resource operations.

Water *system operation* is possibly the most familiar requirement for water resources software, dealing with short term operation, responses to demands and orders for water, dam releases and operating rules, and analysis of water availability now and in the near future. System operation components can also be required to track water ordering and supply, and undertake water accounting. Additionally, operational components need the capability to allocate limited supply to meet competing demands, and also to assess supply from a range of possibly sources, each with particular costs and limitations related to supply availability.

3 THEORY AND SOFTWARE

Various WRSS have been developed to meet the above needs over many years. Early examples have included general WRSS created to undertake flow and storage analysis, to investigate flood peaks and travel times, to track system state, and to assess the effects of different management rules. Specific system problems, such as water allocation between competing users, and from alternative sources, have been attacked through application of optimisation techniques such as linear programming (e.g. Kuczera, 1989; e.g. Salman *et al*., 2001).

In recent times, research attention has also turned to more integrated problems and the application of new software engineering techniques. For example, Babel et al. (2005) developed a system analysis tool for optimally allocating across demands using a combination of reservoir operation, economic analysis and water allocation software components. The approach supported supply analysis for demands of different priority, and provided techniques for water assessment to meet different objective functions, being the maximisation of net economic return and the maximisation of satisfaction.

Object-oriented (OO) techniques, which have come to the fore in many areas of computational science, have also been applied to WRSS. McKinney and Cai (2002) used an approach based upon two basic object types – *spatial objects* and *thematic objects*, where spatial objects represented physical system components, while thematic objects represented methods and topics relevant to the spatial objects. Thematic objects were then further classified into:

- Network objects, linking spatial objects and other thematic objects;
- Control objects, providing controlling signals to other objects, such as via balances and physical boundaries, and
- Model objects, formed from aggregation of network and control objects.

This formulation was developed to support integration of water resource systems modelling with GIS, with class specification determined largely by the GIS requirements.

In addition to, and incorporating, these various theoretical advances, a range of WRSS have been developed over the years to provide some of the resource investigation, system management and system operation aspects mentioned previously. In Australia, IQQM and REALM are two examples that are used commonly, while Aquator is a recent development that provides a range of planning functions.

IQQM is an integrated water quantity and quality modelling system that generally runs on a daily time-step. It is designed to assess water resource planning and management policies for regulated and unregulated streams. It represents system behaviour through a node-link network approach, with a range of possible node and link behaviours to represent physical system components and operational requirements. One of the strengths of IQQM is the analysis of water demands and supply from an extensive and flexible range of sources, and resultant water sharing and system operation requirements.

In some ways similar to IQQM, REALM is a water resource system simulation tool using a node-based network representation of the physical system, including dams, channels, pipes and stream reaches. Fundamental to REALM operation are the variety of nodes and 'carrier types' that can be configured to represent system behaviour. Input streamflow data are used to seed the system, and network linear programming is used for optimisation analysis of water allocation to different demands.

Aquator uses a multi-pass daily system operation and allocation approach to 'optimise' water supply to competing demands. For a given day the multi-pass approach works by firstly adding incoming river flows, then allowing flow augmentation by operators to meet system constraints. Demand requirements and the extent of supply are then assessed, looking at the complete range of available sources. Reservoir fill and spill is then determined. This process is undertaken in high detail for a number of passes to ensure that the final water allocation and control behaviour meets the balance of system requirements and also represents realistic operation.

4. PRIMARY FUNCTIONS

These and other WRSS have been developed to provide solutions to particular water resources problems or needs, and cover a variety of space and time scales. The following list provides an overview of the features or functions that are required of WRSS, and which must be addressed in development of a conceptual software system for water allocation, planning and catchment management:

- System operation, covering the physical system constraints and capabilities;
- Hydraulic and hydrological characteristics, including evaporation, losses and gains in channels, and travel times;
- Times, places and behaviour of demands;
- Variations in demand in response to changing conditions, such as water availability, economics or climatic;
- Analysis of security of supply and risk assessment;
- Climatic inputs, and possible changes in these in future;
- Water allocation using a variety of methods;
- Changes to water allocation and possibly allocation methods, over time;
- System condition and state, used to inform water allocation;
- Seasonal forecasting to estimate future system condition;
- Operating rules for a range of system components under a range of different conditions;
- System analysis for optimally providing for demands from a range of supply points;
- Volume and cost accounting for water ordered, delivered, consumed, sold and owned by users, and
- Assessment of future available resources and allocation under a range of capping or limitation agreements.

The above provides a broad basis for formulation of a new and comprehensive software system for water management.

5. SOFTWARE SYSTEM COMPONENTS

In developing a conceptual software system for water resources analysis, the primary functions can be grouped and classified in a number of ways. We have chosen to identify four primary components, namely:

- Availability
- Supply
- Demand
- Accounting

In designing each of these components, there are a range of fundamental requirements to be met, as discussed below.

5.1 Availability

The availability component includes most aspects of the amount of water coming into, moving through, held within, and moving out of the system. This includes mass balance, losses, forecasts, inflows, and interaction with monitoring systems. The assessment of availability is based upon a combination of current and near future system analysis, requiring links with or inclusion of short term behaviour forecasting.

5.2 Supply

The supply component addresses aspects of water delivery to meet demands under various system constraints. There are two types of constraints on the supply of water; physical constraints on the delivery of water, and water management rules that constrain resource shares and access.

The *physical constraints* on flow can be broken into four groups; storages, pipes, rivers and effluents. Storages limitations are determined by valves or gates, or by airspace for non-gated storages. Piped supply can be limited by pipe dimensions, head, friction losses and possibly pumping capabilities. The constraints on rivers relate to the channel capacity, and are determined by hydraulic characteristics, while those on effluents and channels are similar to those of rivers. Water quality may also be a constraint when the quality of water is not sufficient for its intended use.

Management constraints are provided to maintain the structures and health of the river system. They also provide a means of sharing resources and physical limitations between users. In the case of storages, releases may be constrained by target levels in storages, or by safe release rates and levels through valves and gates. For pumps, the cost of pumping may be a constraint on when pumps are used. In rivers, bank height may limit maximum channel flow so that flooding does not occur. Flow velocity may also be a constraint to limit erosion. Effluents and channels may be limited by meeting higher priority mainstream users. *Management rules* limit supply based on shares in stored resources or shares in physical constraints such as valve and channel capacities. In such cases user orders can be limited and, therefore, demand may be unmet. In some systems the amount of hydro power that is generated is limited to the orders that are placed on the storage.

In unregulated systems there are various rules that are imposed on access to events. The rules relate to sharing of event volumes between downstream users that would have access to the event. In many rivers a major downstream user will be the environment. Access may also be limited by volume or pumping rates at different flow levels.

5.3 Demand

The demand component manages demand from a range of sources, operating over a range of timescales. The two primary components of demand assessment are the volume and timing of demand, with these varying in response to a range of internal and external factors. External factors include climate and the characteristics of the growing season, while internal factors can include previously unmet demand, the storage or source from which demand is to be met, and economic and water trading considerations.

5.4 Accounting

Water accounting can be applied to both regulated and unregulated water, where *regulated water* is that water released from storages, and *unregulated water* comes from storage spills or unregulated tributaries downstream of storages. The rules for accounting for both regulated and unregulated water can become quite complex. In regulated systems water is accounted for in storage, in transit and when it is extracted. A major complication is that the water volume released from storages is not the same as the volume delivered downstream due to losses, gains and delays in transit. In Australian regulated rivers there are four accounting schemes:

- No accounting
- Annual accounting
- Continuous accounting
- Capacity sharing

No accounting is used where orders are placed on storages, and releases are made until the storage is emptied. Typically this is in systems with a single major user, such as a town water supply. *Annual accounting* is based on a water year, whereby at the start of the year allowances are made for future year needs, delivery and storage losses, minimum inflows through the year, and high security supply requirements. The remaining share is announced as an allocation to users, and may increase during the year as resources increase. *Continuous accounting* occurs where individual or group shares of the storage are defined after future year needs, delivery and storage losses are considered. Under this scheme each user has a defined volume in the storage that increases with inflow and decreases with releases for that user. Note that in this scheme the storage and delivery losses are socialised. *Capacity sharing* provides every user a defined (but possibly different) share of the storage and inflow. Each user has to manage an account in the storage or storages, and losses in the storage and during delivery are also accounted against users.

Continuous accounting and capacity sharing also have complex accounting rules for transferring water between shares, and these must be supported by the Accounting component. Factors include the use of internal storage spills when some accounts become full, and accounting for volumes when they are either released or extracted in different systems.

In *unregulated systems* caps (limits) may be imposed on the total amount of water that is extracted. These caps may vary over time and may also be a function of water derived from other supplies. Unregulated water may also be accounted differently depending upon the flow range from which it is taken, with e.g. water extracted from higher flows being accorded a discount rate. The water may also be accounted differently dependent upon its use, with, for example, water put in on-farm storages being accounted for at a higher rate.

6 SYSTEM INTERACTIONS

The use of Availability, Supply, Demand and Accounting components provides a useful approach to delineating the primary functions required for a software system for water resources management, although there are, naturally, many ways that these functions could be grouped. It is the *interactions* between these components that determines how these components need to function, both internally and externally. Figure 1 displays the envisaged actions within, and interactions between, components that are relevant within a calculation step.

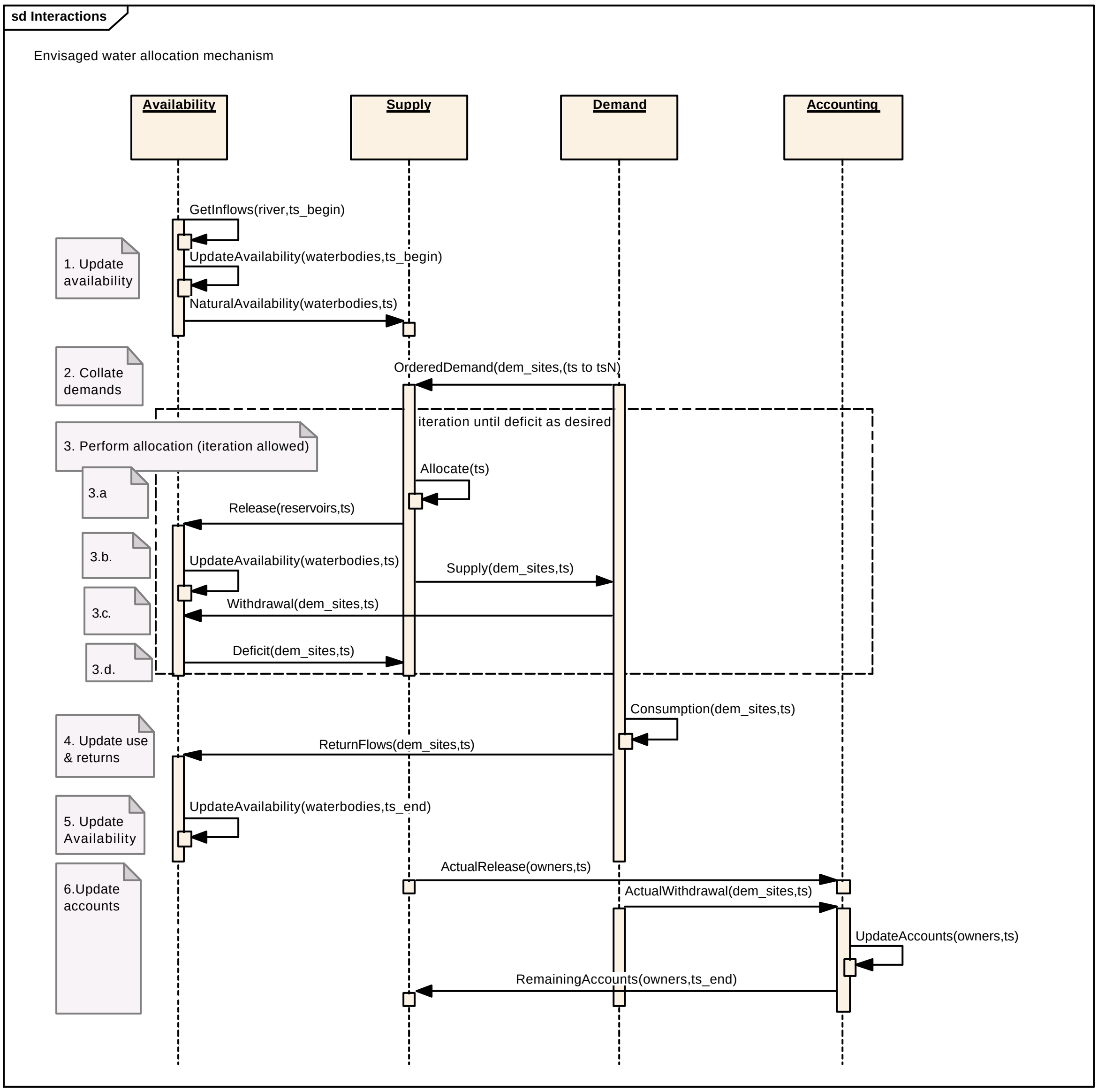

Figure 1. Interaction between the four components during the water allocation process

The sequence of operation shown in Figure 1 proceeds as follows:

1 The Availability component updates its 'natural' conditions for the forthcoming time step, by updating the volumes (and constituents) in the various water bodies based on the expected inflows for the forthcoming time step. The Supply component is informed of the *NaturalAvailability* for the forthcoming time step.

2 The Demand component collects or computes all water demands for the time span which influences the reservoir releases of the current time step.

3 The Supply component determines the allocation pattern, while the Demand and Availability component check the feasibility of the actual volume changes based on actual demand behaviour.

3a The Supply component takes the *OrderedDemands* and *ResourceAvailability* to identify through iteration an allocation pattern which meets other constraints as defined by the physical infrastructure, the operation and management rules and the *RemainingAccounts*.

3b The Supply component computes the required releases and the supply to the various demand sites. Based on the reservoir releases, the *ResourceAvailability* along the river network is updated by the Availability component.

3c As farmers and other water users may change their demands (e.g. due to expected rainfall), the actual *Withdrawal* from the water system might differ from the *OrderedDemand*. The Demand component will account for such change.

3d Based on the latest *ActualWithdrawal* and *ResourceAvailability*, the Availability component might detect an error or Deficit in the water balance. In such case, the Supply component is informed, triggering a new iteration to determine a suitable allocation pattern.

4 Once the Supply component has computed an allocation without any errors, the Demand component can compute the *Consumption* and *ReturnFlow*, taking the latest *ActualWithdrawal* into account.

5 Based on the return flows, the Availability component can determine the water availability status at the end of the time step.

6 Finally, the Accounting component can update the Accounts based on all changes. The Supply component is informed of the *RemainingAccounts* for all water owners.

The preceding focusses primarily on the *system operation* requirements of a WRSS, such as occurring under e.g. an annual accounting approach, with all components operating at a highly detailed level. For resource investigation and system management requirements, the four-component conceptual structure of Figure 1 provides the basic structure. However, the functions of, and interactions between, components would be altered to account for the longer timeframes, changed (e.g. lumped) behaviours, and different analyses required.

7 CONCLUSIONS

The conceptual structure described here provides a simple component-based approach for a WRSS, as well as the fundamental needs of a catchment management software system. Extension of this structure to meet the needs of catchment management would entail addition of, or integration with, relevant components, such as those dealing with water quality constituents, source and sink dynamics, speciation and transformation, load assessment and response to management interventions. Further development of this basic structure is being investigated as part of the 7-year research and development effort of the Australian eWater Cooperative Research Centre.

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