MANAGEMENT SIMULATION ENGINE: A FLEXIBLE, HIERARCHICAL CONTROL ARCHITECTURE OF THE REGIONAL SIMULATION MODEL (RSM)

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Abstract The Management Simulation Engine (MSE) component of the Regional Simulation Model (RSM) consists of a multilevel hierarchical control scheme incorporating a wide selection of control algorithms and decision making tools. The MSE is intended to allow a flexible, extensible expression of a wide variety anthropogenic water resource control schemes integrated with the hydrological state evaluations of the RSM.

INTRODUCTION

Considerable progress has been made in the functionality of integrated hydrological models which can provide evaluation of anthropogenic control and management policies of water resources. Nonetheless, there is still room for improvement in the coupling and expression of water control policies in conjunctive hydrological models [Belaineh et al. 1999]. The Regional Simulation Model (RSM) is an integrated hydrological model which includes comprehensive incorporation of management features with the hydrological model through the synergy of a Hydrologic Simulation Engine (HSE), and the Management Simulation Engine (MSE).

The MSE [SFWMD, 2004] component of the RSM consists of a multilayered control hierarchy which enables generalized control of hydraulic structures within the model. From a hydroinformatics perspective, the RSM architecture emphasizes the decoupling of hydrological state information from the management information processing applied to the states. Given a well defined interface between the two, this approach enables multiple information processing algorithms to execute in parallel, with higher levels of the hierarchical management able to synthesize the individual results which are best suited to the managerial objectives. For example, the MSE enables interoperation and compatibility of diverse management algorithms such as PID, Fuzzy control, Linear Programming; as well as the dynamic switching of control processors.

Regional Simulation Model In the RSM, the Hydrologic Simulation Engine (HSE) [Lal 1998, Lal et al. 2005] provides hydrological and hydraulic state information (Σ), while operational policies dictate managerial constraints and objectives (Λ). In the MSE this state and process information can be functionally transformed or filtered by Assessors (A). The MSE then produces water management control signals (χ, μ) which are applied to the hydraulic control structures in order to satisfy the desired constraints and objectives. Figure 1 illustrates this overall cyclic flow of state and management information in the RSM.

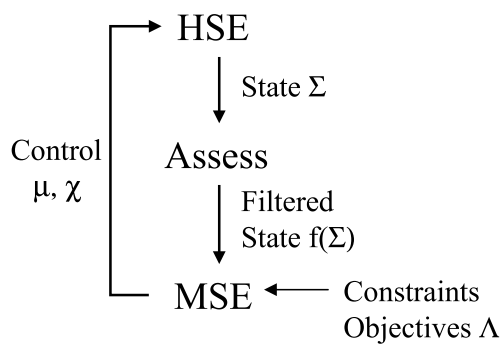

Figure 1: RSM state and management information flow

MANAGEMENT SIMULATION ENGINE

The MSE architecture is based on a multilayered hierarchy, with individual water control structures regulated by 'controllers' while the regional coordination and interoperation of controllers is imposed by 'supervisors'. Supervisors can change the functional behavior of controllers, completely switch control algorithms for a structure, or override the controller output based on integrated state information and/or rules. A schematic depiction of the HSE-MSE layered hierarchy is shown in figure 2.

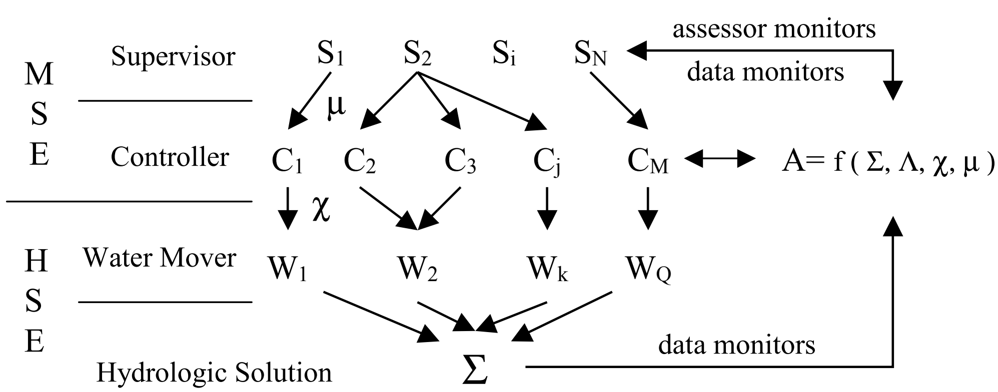

Figure 2: HSE MSE schematic

At the lowest layer is the hydrological state information (Σ) computed by the HSE. This information includes water stages, flow values, rainfall, ET, hydrologic boundary conditions, or any other state variable used as input or computed as output by the HSE. All such variables are made available to the MSE and Assessors through the implementation of a uniform data monitor interface. The data monitor interface extends naturally to the MSE input/output variables. Therefore, the input state information available to a controller or supervisor is not limited to water levels or flow values, but can include control information, decision variables, constraints or any other management variable from any other controller or supervisor in the model. This transparency of state and process information throughout the model is central to the efficient synthesis and processing of heterogeneous information required to simplify and naturally express complex water management policies.

The top level of the MSE is the supervisory layer. There is no limit on the number of supervisory algorithms, or constraint on the number of controllers that a supervisor may influence. Based on state and process information, which optionally may have been filtered or assessed, the function of a supervisor is to produce the supervisory control signal (μ) for a single, or collection of hydraulic structure controllers. The supervisors are therefore able to comprehensively coordinate the global behavior of multiple independent, or coupled hydraulic structures.

The intermediate layer consists of the hydraulic structure watermover controllers. A controller is responsible for local regulation of structure flow. It is possible to attach multiple controllers to a structure watermover, although only one controller at a time is activated. This activation is controlled by a supervisor. For example, a fuzzy controller optimized for wet condition operations may be selected by a supervisor during significant rain events, while a standard rulecurve could be enforced during normal operations. In this manner the MSE provides for dynamic switching of hydraulic structure control functions in response to state or process information.

Once the controllers have computed their respective control values (χ), these signals are applied as flow constraints to the structure watermovers in the HSE. Each watermover will compute a maximum flow capacity based on the hydrological state conditions and hydraulic transfer function of the structure. The resultant controlled flow will be some fraction of the currently available maximum flow capacity.

MSE Functionality This section lists some of the features available in the RSM MSE [SFWMD, 2004]. The currently available controller modules in the RSM include:

- One & two dimensional rulecurves
- Piecewise linear transfer function
- Proportional Integral Derivative (PID) feedback control
- Sigmoid activated PI feedback control
- Fuzzy control
- User defined (C, C++ module) finite state machine

In relation to the controllers, which are multi-input, single-output (MISO) processors, the supervisors are multi-input, multi-output (MIMO) processors. Supervisors have the ability to change individual response characteristics of controllers, or, in the case of multiple controllers attached to a watermover, to dynamically select and activate a specific controller for a watermover. Specifically, the supervisory functions are capable of:

- Synoptic assessment of state and process information
- Controlling multiple parameters of multiple controllers

- Dynamic switching of multiple controllers for a flow structure
- Flow regulation override for controller(s)

This is done through a uniform interface to the controllers ensuring interoperability between different supervisory processors and any controller.

There is no practical limit on the number of supervisors allowed in a model, or on the number of controllers that a supervisor may affect. It is common to have a hybrid selection of different supervisors, each one regulating a specific sub-regional collection of hydraulic structures. The ability to selectively tailor management control algorithms, as well as the flexibility to easily reconfigure them in a plug-and-play fashion lends considerable power to the implementation of diverse and complex operational management scenarios. The currently available supervisor modules in the MSE include:

- Fuzzy supervision
- User defined (C, C++ module) finite state machine
- Linear Programming
- Graph theory flow optimization
- Heuristic MSE Assessors

Specifically, the following management functionality is enabled by the MSE implementation:

Arbitrary Control The modeler can implement an arbitrary control or management algorithm through the use of a user created C or C++ module. The code is compiled into a shared library which is loaded at runtime, with I/O data passed between the control library and the model through a well defined interface. The control code is able to access arbitrary hydrological state information from the model, and is able to dictate hydraulic structure control to the model.

Dynamic Control This feature refers to the ability to dynamically alter or adjust the control behavior of hydraulic structures. For example, a closed loop feedback controller such as a PID may have it's target value, or, any adjustable parameter of the controller changed in response to a dynamic variable. Another feature is to provide for dynamic switching of management algorithms. For instance, a rule-based fuzzy algorithm optimized for flood-control operations can dynamically replace a rule-curve or setpoint controller of a hydraulic structure in response to any observable state variable.

Multi Supervision The management algorithms are capable of multi-input, multi-output operations. For example, a supervisor is capable of setting the structure flow characteristics for multiple structures simultaneously.

Optimization The model incorporates a linear programming optimization package able to solve constrained optimization problems which can allocate hydraulic structure flows, water storage control, or other resource management decisions.

RSM MSE EXAMPLE

In this section we demonstrate some basic MSE operational controls applied to a RSM model application which represents the Florida lower east coast. This model covers roughly the area from Lake Okeechobee in the northwest to southern Miami-Dade county in the southeast. Figure 3 illustrates the HSE mesh and canal network. Regarding the MSE implementation of this model, there are 192 hydraulic structure watermovers, with a controller assigned to each watermover. The MSE implements 12 supervisors to control coordination of selected controllers.

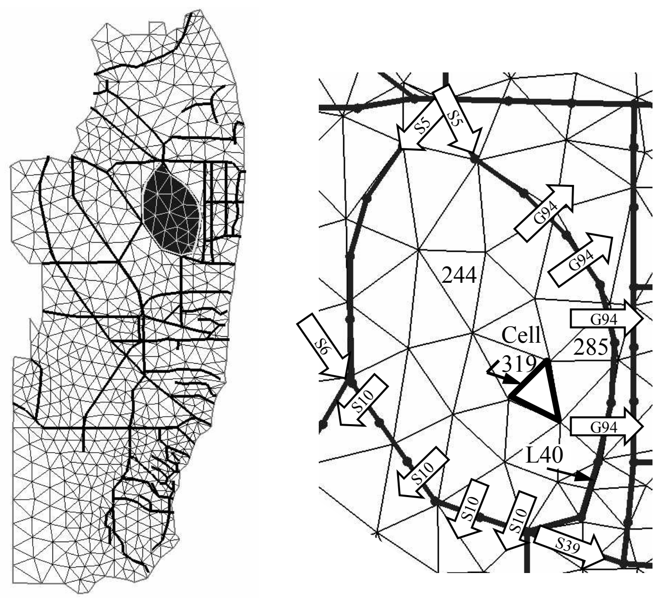

Figure 3: Example RSM application mesh and canal network, with WCA1 model conceptualization.

The highlighted area in figure 3 corresponds to the northernmost extent of the Everglades which is commonly referred to as Water Conservation Area 1 (WCA1). It is surrounded by a canal and levee system which effectively isolates it from the adjacent lands. Water levels inside WCA1 are controlled through a series of inlet and outlet hydraulic structures located on the perimeter canals of the basin. Figure 3 depicts a schematic representation of the WCA1 model representation with the major flow control structures indicated as arrows.

The primary outlet flow structures from WCA1 are the series of S10 structures along the lower left canal rim. These structures discharge into the adjacent Everglades referred to as Water Conservation Area 2 (WCA2). The hydraulic structure S39 controls the flow from the southern rim canal into a coastal outlet canal. Additionally, the series of G94 structures are capable of discharging from WCA1 into the adjacent drainage district (though these structures are usually controlled by the drainage district into which they discharge.) In the model, the controllers for the S10 and G94 structures are piecewise linear transfer functions while the S39 controller is a user defined (C++) finite state machine module. When the supervisor is not in effect, these controllers regulate the flow through the structures.

In this demonstration, a supervisor has been created from a user defined C++ module to coordinate the operation of the S10, S39 and G54 structures in an attempt to lower the canal and aquifer levels in WCA1 in response to stage and rainfall state information. The input stage information is an assessed spatial average of watertable levels in the three mesh cells 244, 285 and 319 (figure 3). The input rainfall is a spatio-temporal moving average assessed over the same three cells and a 24 hour period.

The user defined supervisor receives the assessed stage and rainfall information as input state variables, and assigns structure control outputs to the S10, G94 and S39 structures based on two modes of operation. In the default mode the control outputs are set for each structure based only on the assessed stage values decomposed into four ranges of average stage s: ($s < 3.66$), ($3.66 <= s < 3.96$), ($3.96 <= s < 4.27$), ($s >= 4.27$) m. The supervisor also computes a threshold comparison on accumulated values of the assessed rainfall. A sliding accumulator stores assessed rainfall over a three day moving window. If the sum of the accumulated rainfall exceeds a threshold (3.05 mm) and the assessed stage is greater than 3.66 m, then an alternate set of control values are applied to the structures intended to increase the outflow from WCA1.

Figure 4 plots the default (unsupervised) control signals and resultant flows for selected structures. With the supervisors enabled, the corresponding control signals and flows are shown in figure 5.

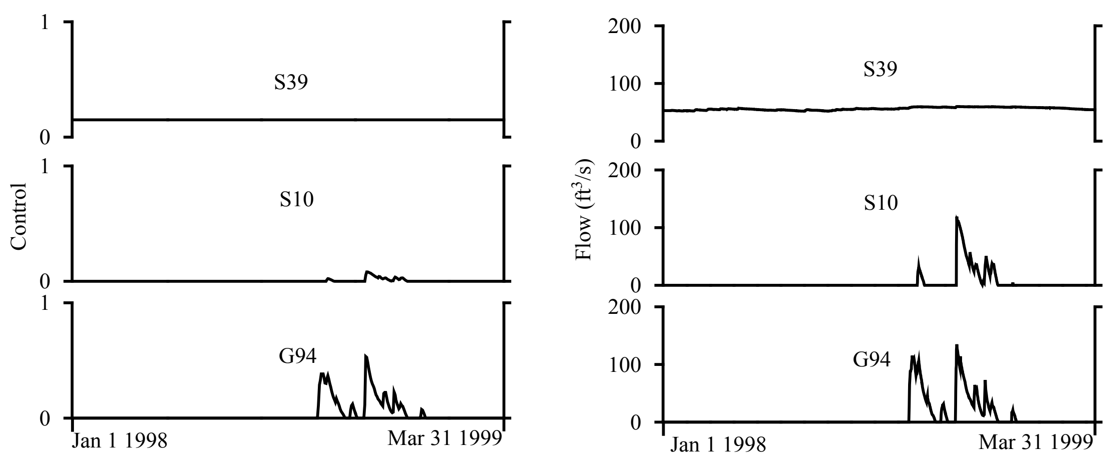

Figure 4: WCA1 outlet structure control signals (left) and flows (right) without supervision.

A comparison of the modeled canal stage in the L40 canal segment with and without supervision is depicted in figure 6. The lower portion of figure 6 plots the model input observed rainfall applied to cell 319, which was used as one of the inputs to the assessed rainfall. The supervisory control has lowered the L40 canal stage by approximately 45 cm. The effect of the supervisory control is clearly evident in the lower water levels achieved with the coordinated outlet flows.

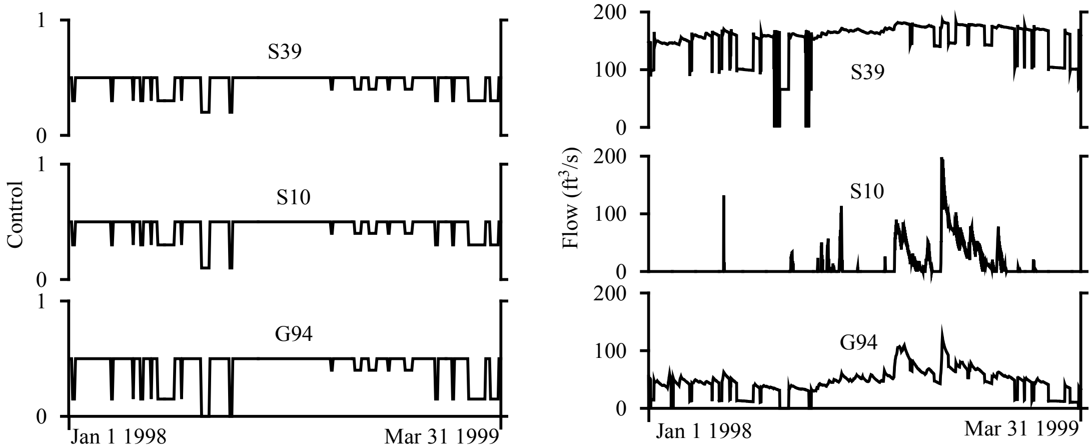

Figure 5: WCA1 outlet structure control signals (left) and flows (right) with supervision.

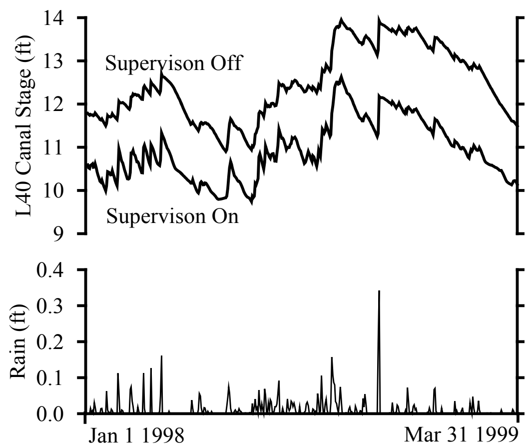

Figure 6: L40 canal stage comparison with and without supervision.

This simplistic demonstration is by no means comprehensive in terms of utilizing the wide spectrum of tools and capabilities enabled with the multilayer control hierarchy of the MSE. It does however illustrate a coordinated structure control scenario which is naturally expressed by the use of supervisors and controller layers.

CONCLUSION

The MSE has been designed based on principles of interoperability of control algorithms, decoupling of hydrologic state and managerial process information, and a multilevel control hierarchy. The combination of these features results in a powerful, extensible methodology to express a wide variety of anthropogenic water resource control policies. The multilayered control scheme allows for the specification of local water control policies at individual water control structures, with the ability to coordinate, activate, or override the control function of multiple water control structures in a natural way. Some of these management features available in the MSE include:

Multilayer control hierarchy:
Local control algorithms for individual hydraulic structures, supervisory control of multiple controllers for synoptic and coordinated structure operations.

Control process interoperability:
Decoupled state and process information with a uniformly designed interface allows compatibility between various control algorithms.

Decoupled hydrologic state and management information:
Enables isolation of hydraulic control algorithms from hydraulic and hydrological state algorithms.

Dynamic switching of control processors:
Multilayered control hierarchy with management process interoperability allows dynamic switching of control algorithms based on hydrological state or management process variables.

Integrated state and information variable monitoring:
Input and output variables for both hydrologic state, and managerial process variables are accessed with a uniform interface known as monitors, allowing MSE objects to access any needed state information.

Suite of assessors:
Provides specialized quantification of hydrological state variables, freeing managerial algorithms from data preprocessing.

Generalized data filtering:
Common statistical and mathematical functions are implemented as a series of piped filters, enabling simple, yet powerful and flexible modulation of state variables.

References

[Belaineh et al. 1999] Belaineh, G., Peralta, R. C., Hughes, T. C., (1999). Simulation/Optimization Modeling for Water Resources Management, ASCE Journal Water Resources Planning Management, 125(3), 154-61

[Lal 1998] Lal, W. A. M., (1998). Weighted implicit finite-volume model for overland flow, ASCE Journal of Hydraulic Eng., 124(9), 941-950

[Lal et al. 2005] Lal, W. A. M., Van Zee, Randy and Belnap, Mark, Case Study: Model to Simulate Regional Flow in South Florida, ASCE Journal of Hydraulic Engineering, in press, manuscript HY/2003/023398, April 2005

[SFWMD, 2004] Regional Simulation Model (RSM) User's Manual, Management Simulation Engine (MSE) Supervisors, South Florida Water Management District, Model Development Division (4540), 3301 Gun Club Road, West Palm Beach, FL March 2004