MSE NETWORK: AN INTEGRATED DATABASE & STREAM FLOW NETWORK REPRESENTATION IN THE REGIONAL SIMULATION MODEL (RSM)

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Abstract The Regional Simulation Model (RSM) maintains an abstraction of the stream flow and associated operational control parameters of hydraulic structures in a combined graph-theory/database representation. The database provides integrated state-variable and control parameter access for model processes. The graph representation provides a flexible, extensible network representation that can be applied to standard graph-theory network flow solutions.

INTRODUCTION

A crucial aspect of effectively storing and accessing state information for water resource management in hydrologic models is the maintenance of an efficient storage mechanism which associates hydrological state information with the proper managerial abstractions. In the Regional Simulation Model (RSM) hydrological state information is computed in the Hydrologic Simulation Engine (HSE), while the Management Simulation Engine (MSE) computes operational control signals applied to hydraulic control structures. In the MSE this data access is achieved by storing hydrological and managerial information relevant to a water control unit (WCU) in a data storage object defined in a MSE Network. The MSE Network is an abstraction of the stream flow network and control structures suited to the needs of water resource routing and decisions. It is based on a standard graph theory representation of a flow network comprised of arcs and nodes.

The MSE Network data objects serve as state and process information repositories for management processes. They maintain appropriately filtered state information, parameter storage relevant to WCU or hydraulic structure managerial constraints and variables, and serve as an integrated data source for any MSE algorithm. It also provides a mathematical representation of a constrained, interconnected flow network which facilitates efficient graph theory solutions of network connectivity and flow algorithms. This paper describes the MSE Network implementation in the RSM.

MSE NETWORK

A central feature of the MSE which enables decoupling of the hydrological state information maintained by the HSE and the operational process information of the MSE is the MSE network. The MSE network is an abstraction of the stream flow network and control structures suited to the needs of water resource routing and decisions. It is based on a standard graph theory representation of a flow network comprised of arcs and nodes [Ahuja, 1993]. The MSE network data objects serve as state and process information repositories for management processes. They maintain assessed and filtered state information, parameter storage relevant to WCU or hydraulic structure managerial constraints and variables, and serve as an integrated data source for any MSE algorithm seeking current state information. It also provides a mathematical representation of a constrained, interconnected flow network which facilitates the efficient graph theory solution of network connectivity and flow algorithms.

From the hydrological perspective, the HSE stream network is composed of an interconnected network of flow segments, with each segment maintaining parameters relevant to aquifer-stream interaction, flow resistance, spatial coordinates and other physical properties. The spatial representation of HSE segments are typically dictated by topographic and physical parameters. From the water resource management viewpoint of the MSE, the important features of the flow network are it's connectivity, flow capacities, flow regulation structures and policies, and assessed state information relevant to managed sections of the network. The MSE network maintains a mapping between these two representations.

The primary object in the MSE network is the Water control unit (WCU). A WCU maps a collection of HSE stream segments that are operationally managed as a discrete entity to a single WCU in the MSE network. WCU's are typically bounded by hydraulic control structures, which are represented as nodes in the MSE network. Each WCU includes associative references to all inlet and outlet hydraulic flow nodes. Some of the variables stored in a structure (node) object include:

1. flow capacity
2. maximum design flow capacity
3. reference to hydraulic watermover
4. reference to structure controller
5. operational policy water levels
6. supply
7. demand

while the WCU objects incorporate:

1. flow capacity
2. seasonal maintenance levels
3. inlet flow
4. outlet flow
5. water depth
6. water volume

Each WCU in the MSE network is referenced by a unique label, and has an associative data storage object which dynamically allocates storage for assessment results. This allows multiple, independent assessments of the WCU state. For example, one assessment of WCU inlet structure flows might come from a graph algorithm, while another could be stored from a LP model. The abstraction from hydrological objects to managerial objects condenses the network representation facilitating the organization and storage of relevant assessed state and process information.

HSE Network Example As an example, figure 1 depicts an HSE stream network consisting of 63 nodes and 62 segments. Some of the nodes correspond to locations of hydraulic control structures, though the association is not apparent from examination of the HSE network. Each stream segment has a unique identifier which allows the modeler or MSE processor to monitor state information of the segment. However, as pointed out earlier, it may be appropriate to make water management decisions based on some assessed or filtered version of aggregated stream segment states.

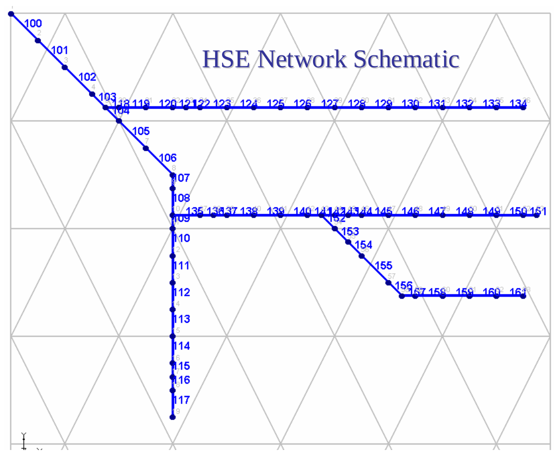

Figure 1: Example HSE stream network segments and nodes.

MSE Network Example Consider now an abstraction of the HSE network into 10 WCU's, regulated by 11 hydraulic structures. An example of such a MSE network is presented in figure 2. In the MSE network each line segment represents a WCU, while each node represents a hydraulic structure which regulates a WCU. The modeler or MSE processor is able to directly monitor information stored in any of these object data containers, information which has already been assessed and automatically stored in the appropriate WCU data object at each timestep.

As with other RSM model inputs, the WCU mapping from the HSE stream network is performed with an input XML entry. The excerpt below shows basic elements in the construction of an MSE network. The `mse_node` supplies parameter and data values for hydraulic structures. The `mse_unit` establishes a collection of HSE stream segments as a single entity, and defines the nodes which connect to this water control unit.

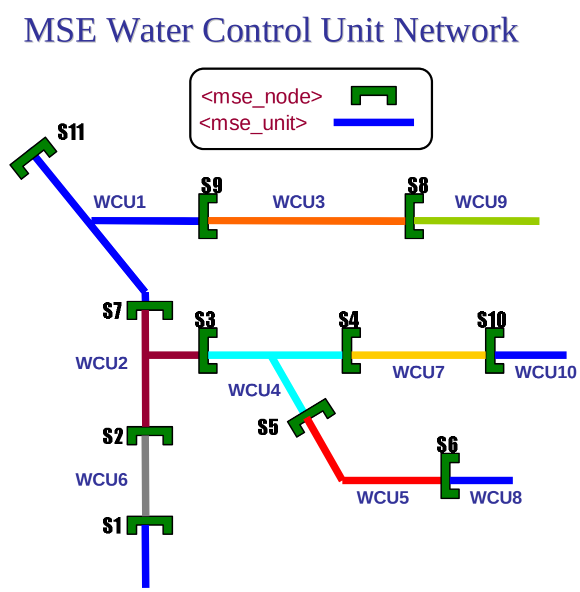

Figure 2: Example MSE network abstraction of HSE network into WCU's and structures.

```
<mse_network name="Test Network">
  <mse_nodes>
    <mse_node name="S11" purpose="WaterSupply" designCap="3000.">
      <open   name="S11 Open">   <rc id="2"></rc> </open>
      <close  name="S11 Close">  <const value="5.5"> </const> </close>
    </mse_node>
    <!-- more mse_node entries.... -->
  </mse_nodes>
  <mse_units>
    <mse_unit name="WCU1">
      <hse_arcs> 100 101 102 103 </hse_arcs>
      <maintLevel name="maint"> <const value="5.5"> </const> </maintLevel>
      <inlet  name="S11 inlet">  "S11" </inlet>
      <outlet name="S7 outlet" > "S7"  </outlet>
      <outlet name="S9 outlet" > "S9"  </outlet>
    </mse_unit>
    <!-- more mse_unit entries.... -->
  </mse_units>
</mse_network>
```

RSM-MSE Network Integration Figure 3 illustrates the overall integration of the MSE Network with the RSM information flow and processing. The HSE provides hydrological and hydraulic state information (Σ), which can be functionally transformed or filtered by Assessors (A). The raw or processed state information is then stored in the appropriate data object of the MSE Network. For example, the total water volume above a maintenance level can be stored in a WCU data object. The MSE also uses the MSE Network data objects to store operational control information such as maintenance levels, flows, and other constraints and objectives. Based on the state and control information accessible from the MSE Network data objects. 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.

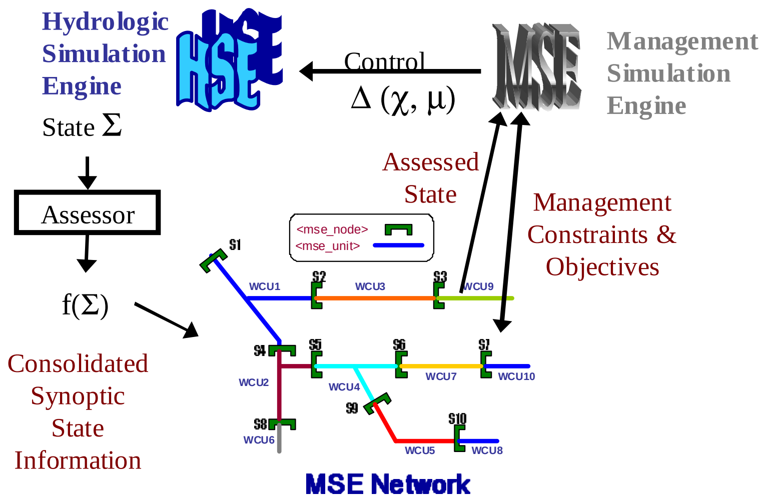

Figure 3: Integration of MSE Network with RSM information processing.

GRAPH FLOW OPERATIONAL CONTROL

From the perspective of mathematical graph theory, there is a well developed body of work regarding the assessment of flows in interconnected networks [Ford, 1962, Ahuja, 1993]. Graph representations of flow networks for water distribution and stream flow networks are common, and useful [Diba, 1995, Ostfeld, 2005]. The MSE maintains a graph theory based representation of the managed canal network. In order to effect operational control of hydraulic structures in a coordinated fashion, the MSE implements a multilayer control hierarchy with controllers and supervisors. Supervisors are capable of controlling the flows at multiple hydraulic structures. The MSE Graph supervisor implements the maxflow, feasible flow, and mincost feasible flow algorithms. These algorithms are essentially minimal numerical procedures which solve constrained optimization problems on the network flow by taking advantage of the network properties, rather than solving a set of simultaneous equations explicitly. The constraints consist of the canal arc capacity, the hydraulic structure capacity, demand and supply flows at the structures, and flow cost weights assigned to the canal arcs.

Each graph supervisor solves the network flow based on it's own network representation. As a result, a graph supervisor can solve the flow for the entire network, or for any subset of the network for which a graph has been defined.

CONCLUSION

One of the challenges facing hydrologic modelers tasked with simulation of complex, heavily managed watersheds, is the integration of hydrologic state information with the operational control algorithms of the managed water control structures. In many cases present at South Florida Water Management District control structures, state information used as input to these algorithms is a synthesis of spatially and temporally averaged water levels, along with state-dependent decision variables. If the modeler has to pre-process this state information for each simulation scenario, a degree of inflexibility and overhead is introduced to the simulation cycle.

The Regional Simulation Model addresses this issue with the incorporation of an integrated state-variable database which also serves as an abstraction of the operationally controlled structures and canal flow network. The abstraction is based on a standard graph-theory representation which facilitates the use of graph-theory network flow optimization algorithms. The abstraction also serves to maintain a mapping between the hydrological representation required by the numerical model, and the operational control model referred to by operators and the control algorithms. The inclusion of data object storage and transparent access throughout the model ensures the maintenance of an efficient storage mechanism which can associate processed hydrological state information with the proper managerial abstractions.

References

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