USING DYNAMIC SYSTEM MODELS FOR WATER USE ACCOUNTABILITY AND PLANNING IN GEORGIA

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Abstract. Effective water use planning relies on the ability to first quantify the distribution of water within a system and then evaluate alternative strategies to identify the outcome that offers the greatest improvement of accountability and conservation. Since the outcome is typically dependent on complex systems that are difficult to predict, even the most sophisticated planners may conclude that the unknowns are insurmountable, and end up making decisions based on intuition. Dynamic system models provide a decision framework that can be used to evaluate strategies ranging from an intuitive to more rational, quantitative approach.

INTRODUCTION

Surface and groundwater use within Georgia is undergoing greater scrutiny from State and regional regulators and stakeholders. Large regional water users, both industrial and municipal, are consumers that will inevitably experience pressures from the state and regional authorities to provide accountability for water use, generate data to show system efficiency, and develop and institute water conservation efforts. Georgia industries are responding to increased regulation and accountability for water use within the state by adopting tools to better manage water use.

One tool for planning and evaluating water use accountability includes the development of expandable (dynamic) system models to assess water use (water balance) for various end users. The dynamic system model or DSM can be used as a tool to assess how water is used, where it is moving from/to, how much water is being consumed or lost, water quality impacts, and the associated costs. The results of the system model can be used to improve water use and reporting within the industry or agency and serve as a basis for supporting water conservation and recycling efforts.

System simulation models provide a framework for organizing the components, processes and interactions of water users and then explore different scenarios to gain a diagnostic understanding of the system. The process of developing a system model provides a common basis for sharing specialized knowledge, expertise, experience and priorities with local and corporate experts, decision makers and stakeholder groups.

BACKGROUND

Golder Associates Inc. (Golder) has developed DSMs for a variety of applications and industries including water resources, mining, manufacturing, and transportation. The practice grew out of development of performance assessment models for proposed nuclear waste repositories in the United States, Canada, Europe, and Asia. The performance assessment models included fully coupled component models of both the natural system (climate, host rock, groundwater, biosphere, etc.) and the engineered barriers (underground tunnels, waste packages, backfill, etc.). The models were used to project the waste isolation performance of the repository over tens of thousands of years. The methodology and technology used was easily adapted to other processes and analyses.

Golder has developed a number of software products including GoldSim, which is a platform for creating dynamic models that simulate the performance of complex systems in business, engineering, and science. The models are used to gain a diagnostic understanding of the system, ask "what if" questions about it, and evaluate alternative designs, policies, and plans. The relationship and interdependencies of the components of a system are often too complex and interrelated to have an intuitive understanding of the system's behavior. There are just too many moving parts to keep track of. The DSM is highly graphical and extensible, able to quantitatively represent the uncertainty inherent in all complex systems, and allows the user to create compelling models that are easy to communicate and explain to diverse audiences.

DSM PROCESS

A typical DSM consists of a series of integrated submodels that represent the various components of the facility, industry, or system. These components typically represent water storage and transport (ponds, reservoirs, diversions, pumping and conveyance), mass transport (dissolution, conveyance of materials), the climate conditions (precipitation, runoff, and evaporation), the operational conditions (processing, groundwater and surface water withdrawals, and recycle water), cost (operating, maintenance) and the compliance conditions. The DSM is scalable allowing for expansion from facility to industry-wide levels or from drainage to multi-basin levels.

The general methodology used by Golder (Figure 1) to develop and apply a dynamic system model consists of the following steps:

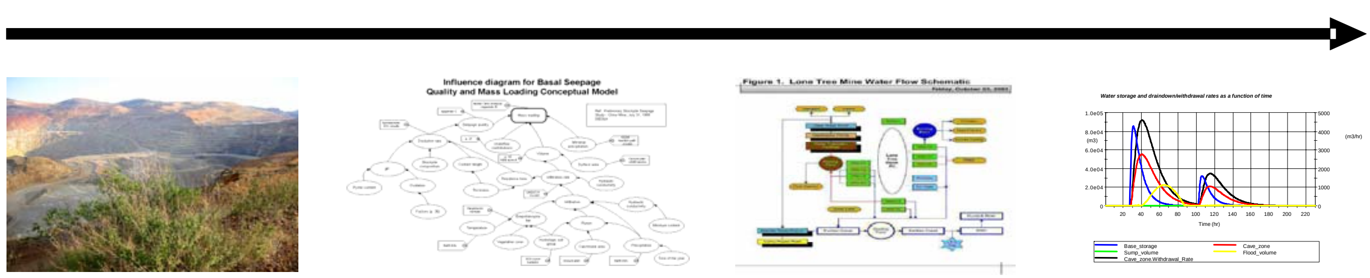
1. Assemble Team of Experts – An expert is needed who is knowledgeable about each of the components that will be included in the system model.
2. Identify Facilitator – the facilitator's job is to ensure the group understands the process for developing a system model and that the participants share information with each other.
3. Establish objective(s) – agree on what question or issue the model will be used to address.
4. Define scope – specify the time and spatial domain of the simulation, operational alternatives to be considered, and performance metrics that will be used for comparing alternatives.
5. Develop conceptual model of the system – use influence diagrams, causal effects diagrams, etc., to identify the components and processes included in the system and the interrelationships between them.
6. Develop abstractions – the results of detailed process models (e.g., a finite difference groundwater model) and/or analytical models are used to develop abstraction (simplified) models of the system components and processes; cost models for process operations are often included in the model.
7. Construct simulation model – abstracted models are combined into a system model using a simulation modeling platform.
8. Assemble data – input parameters for the abstraction models including parameter uncertainty.
9. Run projections – simulate alternatives; examine behavior; compare results.
10. Sensitivity analysis – identify parameters, and processes that have the greatest impact on system performance.
11. Revise/refine model – increase level-of-detail in abstraction models (if necessary) for most important processes/components; revise abstractions as results from studies become available.
12. Communicate results – assemble graphical and written material that illustrates the components and interrelationships in the system model and its projected behavior or performance under different conditions or scenarios.
13. Update as needed – e.g., investigate alternative conceptual models to address stakeholder concerns.

Establishing clear objectives for the DSM is a critical first step. The objectives will determine the scope of the model and help to focus the subsequent model development and application.

The conceptual model describes the operation of the system components and the interactions between them. Influence diagrams, causal effect diagrams and flow charts are often used to illustrate the basic structure of the system model. The behavior and interactions of the components are represented by analytical and empirical relationships derived from model abstractions and analysis of site data.

During conceptual model development, the system is decomposed or broken down into a series of linked subsystems that define the key components of the system, the processes involved, the relationships between components and processes, and relevant feedback mechanisms. These subsystems or submodels (e.g., climate models, surface/groundwater flow models, seepage models, mass loading models, etc.) are used to represent the various components of the system.

Resulting data from the submodels are combined into a series of high level (simplified) representations of component processes and behavior. These representations



System. **Influence Diagrams.** **Structural Diagrams.** **Equations/ Simulations.**

Figure 1 - The DSM Process.

or abstractions are then used as inputs to the mathematical representation of the system. The submodels and coupled subsystems are calibrated using available data or estimated using standard industry practices.

The mathematical model is developed using a dynamic, probabilistic simulation platform. There are a variety of software programs available (GoldSim, EXTEND, Stella). While simple, probabilistic models can be developed using spreadsheet programs with Monte Carlo add-on programs, they are not well suited for dynamic systems in which the performance can vary significantly as a function of time-dependent conditions or processes. Whatever platform is used, it is critical that the DSM be made as transparent as possible so that it can be understood at least at a basic level by non-technical reviewers who may be part of the stakeholder group interested in the basis of the model and the associated projections. To facilitate this, decision analysis tools used during the development of the model, e.g., influence diagrams and process flow sheets, causal-effect diagrams, etc., are often integrated or dynamically linked to the DSM for easy reference.

The uncertainty in the input parameters and processes are explicitly represented in a DSM and are propagated through the simulations using the Monte Carlo Method. The two benefits of the Monte Carlo Method is an appreciation of the range of possible outcomes of the projected behavior of the system and a means for evaluating what parts of the system have the greatest impact on its performance. The latter is achieved by performing sensitivity analyses with the DSM. The sensitivity analyses provide new insights into how to improve the performance of the system or where additional information may reduce the uncertainty in the overall system performance.

The sensitivity analyses may also result in the conclusion that the level-of-detail in one or more of the submodel or component models should be increased. Therefore, the DSM development is an iterative process. Conceptual model refinement, abstraction modification, mathematical simulation, and sensitivity analyses are performed until the system behavior has been represented at the appropriate level consistent with the objective of the study.

DSM APPLICATION TO INDUSTRY

Golder has applied DSMs to many complex problems, spanning a diverse range of applications and industries from management of combustion byproducts at coal-fired power plants to managing the operational processes of precious metal mines. In Georgia, industries such as those involved in mining, power, and manufacturing can utilize DSM applications to support their water accountability and conservation efforts to the regulatory community.

The mining industry, for example, can use DSMs to answer regulatory concerns regarding water use and conservation of a particular operation or the industry as a whole. Individual mining operations can be deconstructed or broken down into operational subcomponents such as separation, slurrying, degritting, drying, filtration, process water impoundment, groundwater and surface water extraction, and discharges. These subcomponents can be evaluated individually for water use and accountability and then combined with uncertainty analyses to assess the overall water consumption of an operation and the uncertainty associated with the water use estimates. The DSM can then be used to perform a series of “what if” scenarios to provide the best combination of conservation, accountability, and financial outcomes. These individual operational assessments can be scaled up, if required, to assess multi-facility or industry-wide operations.

SUMMARY

DSMs are utilized within the industry to assess, simplify, test, and predict the interaction of complex system components. These components can be part of a facility or industry process or parts of a watershed-basin system. The system models can be used for decision making in a wide variety of areas including ecological and natural resource management, pollution prevention, and environmental restoration.

The methodology and simulation software provide a platform for collecting and sharing knowledge about the critical system components and their interconnections and interactions. Planners can use the integrated system model to project the future behavior of the system under different scenarios and compare alternative strategies for influencing its behavior. In this way, the DSM approach provides a method by which alternative strategies can be evaluated without having to experiment on a real system, which may be prohibitively costly, time-consuming, or impractical to perform.

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