GoldSim:
Engineering and Environmental Simulation Software
for the Mining Industry

White Paper

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Abstract

GoldSim is a powerful and flexible Windows-based computer program for carrying out probabilistic simulations of complex systems to support management and decision-making in engineering, science and business. The program is highly graphical, highly extensible, able to directly represent uncertainty, and allows you to create compelling presentations of your model. Although GoldSim can be used to solve a wide variety of complex problems, it is particularly well-suited to applications in the mining industry. In particular, it allows you to create realistic models of mine systems in order to carry out risk analyses, evaluate potential environmental impacts, support strategic planning, and make better resource management decisions. It has been used at mines around the world for mine water management studies, to support environmental compliance and permitting, and for evaluation of mine development, expansion, remediation and closure plans. This paper provides a brief overview of GoldSim, with special emphasis on mining applications.

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Introduction

The Challenge of Mine Evaluation Studies. One of the greatest challenges for mine evaluation studies (e.g., studies to support mine water management, environmental compliance and permitting, or evaluation of mine development, expansion, remediation and closure plans) is to quantitatively evaluate alternative approaches for carrying out the project and to identify and manage the associated risks. The outcomes of these projects are often inherently risky and uncertain, since they typically involve systems made up of many component parts that are interrelated, and in some cases poorly characterized. In most situations, the system is dynamic (i.e., it constantly evolves over time) and involves uncertain processes, parameters, and events.

The challenge when evaluating such systems is to find an approach that can incorporate all the knowledge available to planners and management into a quantitative framework that can be used to predict the outcome of alternative approaches. For many complex systems, this can only be addressed by developing a computer simulation model of the mine system.

The Solution. The GoldSim Technology Group has addressed this problem by developing a dynamic probabilistic simulation tool, GoldSim, that can be used to help mining companies effectively integrate risk management into their organizations and thereby improve the financial performance of their operations. As used here, simulation is defined as the process of creating a model (i.e., an abstract representation or facsimile) of an existing or proposed system in order to identify and understand those factors that control the system and/or to predict (forecast) the future behavior of the system. Almost any system that can be quantitatively described using equations and/or rules can be simulated. The objective in modeling such a system is to understand the different ways it could evolve, to project its performance (financial, environmental, etc.), and to determine what can be done to influence the outcome.

System simulation is a powerful and important tool because it provides a framework and methodology for integrating the different components and considerations that are typical in mining projects, and for explicitly representing the interrelationships and feedback mechanisms and uncertainties about the conditions and processes involved. Traditionally, the components (e.g., water balance, contaminant transport, mine operations) have been considered separately or as a linear or weakly coupled system. If important interrelationships or feedbacks are missing, it is difficult or impossible to gain a diagnostic understanding of the system or to identify the most important processes/issues to consider when evaluating alternatives.

Overview of the GoldSim Simulation Framework

GoldSim is a powerful and flexible platform for visualizing and numerically simulating nearly any kind of physical, financial or organizational system. In a sense, GoldSim is like a "visual spreadsheet" that allows you to visually create and manipulate data and equations. Unlike spreadsheets, however, GoldSim allows you to readily evaluate how systems evolve over time, and predict their future behavior. The GoldSim simulation environment is highly graphical and completely *object-oriented*.
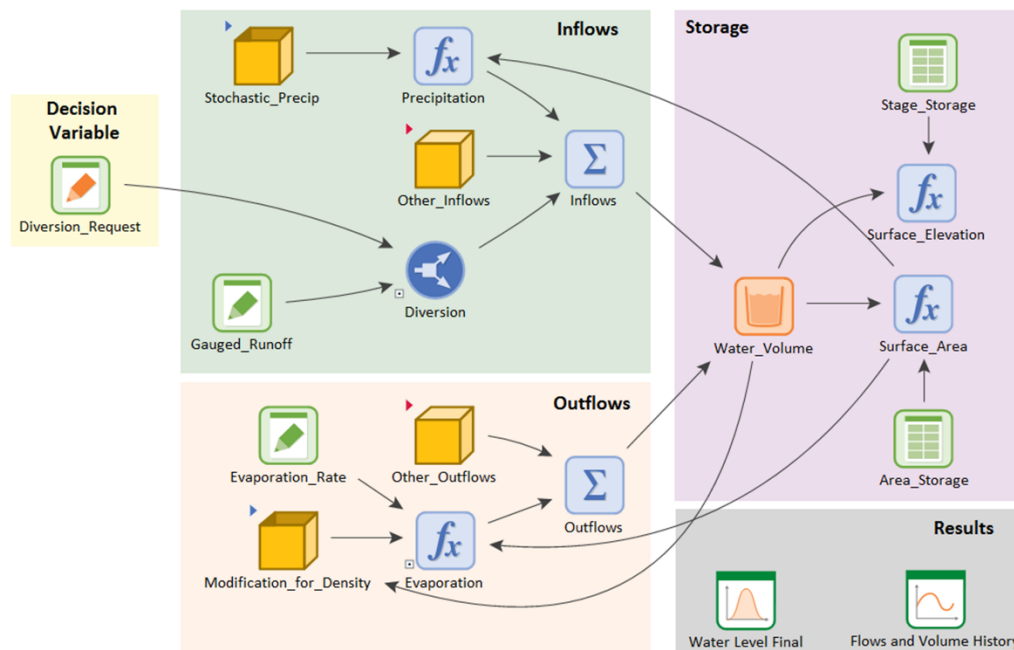
That is, you create, document, and present models by creating and manipulating graphical objects (referred to as *elements*) representing data and relationships between the data. Based on how the various objects in your model are related, GoldSim automatically indicates their influences and interdependencies by visually connecting them in an appropriate manner.

Because simulation can be such a powerful tool for understanding and managing complex systems, a number of simulation tools currently exist. The following combination of features, however, makes the GoldSim approach unique:

GoldSim allows models to be built and modified very rapidly. The time savings over programming an equivalent model "from scratch" is typically ten-fold or more. Moreover, GoldSim's built-in configuration management tools (such as the ability to record the changes made to a model over time) ensures that modifications are made in a traceable and organized manner. As a result, an iteration of a GoldSim model can be carried out within a timescale of hours or days, rather than the weeks required for many other modeling frameworks.

GoldSim is extremely flexible, allowing it to be applied to nearly any kind of system. GoldSim is a generic, probabilistic simulation framework. As such, it can be (and has been) applied to a wide variety of systems, ranging from mining to manufacturing to finance. As a result, the same tool can be used to simultaneously model not only the water management at a mine, but also nearly any other aspect of the mine operations, including waste management, material management and financial analysis.

GoldSim supports creation of hierarchical, modular models, and this facilitates the reuse and sharing of models across an organization. GoldSim models can be built in a hierarchical and modular manner, by creating and linking together subsystems (submodels). The submodels can include custom (legacy) codes that can be linked dynamically into GoldSim. These submodels, after being built for one application or project, are often readily transferable with only minor modifications to another application.
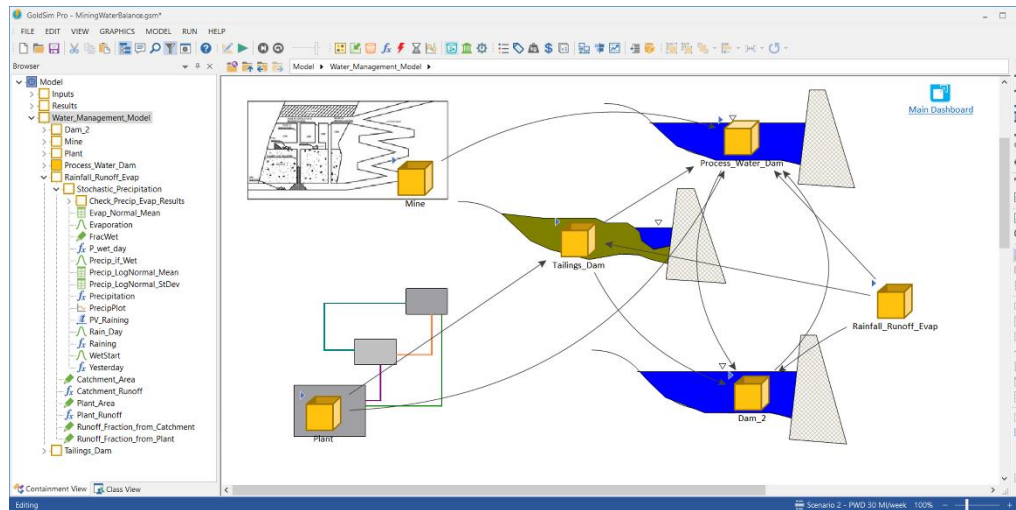
The GoldSim framework is designed to allow submodels to be saved (and perhaps posted to an internal website), and then re-used in other models for other projects within the organization. Sharing and re-using submodels in this manner can result in significant cost savings by eliminating the need to "reinvent the wheel". In effect, GoldSim acts as a framework to share knowledge and experience across the organization. Not only does this reduce redundant efforts, it promotes consistency in the assumptions and approach to environmental modeling within the organization.

Uncertainty in processes, parameters and future events can be explicitly represented. Uncertainty in processes and parameters can be represented by specifying model inputs as probability distributions. This capability makes it relatively easy to generate stochastic records of precipitation, evaporation and other system drivers. The impact of uncertain events (e.g., earthquakes, floods, sabotage) can also be directly represented by specifying the occurrence rates and consequences of such "disruptive events". GoldSim uses Monte Carlo simulation to propagate uncertainty through the model.
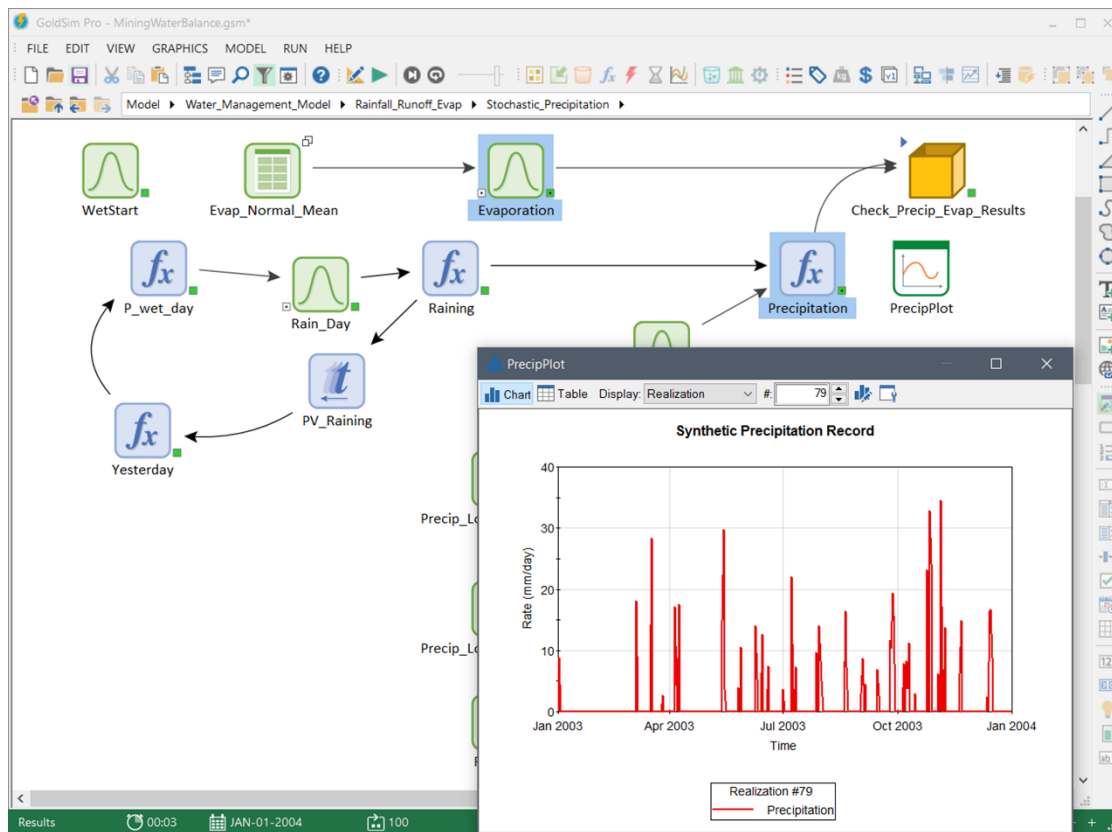
GoldSim is highly extensible. GoldSim provides a wide variety of built-in objects ("elements") from which you can construct your models, and, if desired, you can program your own custom objects, and link them seamlessly into the GoldSim framework. In particular, you can dynamically link your own custom external programs or spreadsheets directly into your GoldSim model. In addition, GoldSim was specifically designed to support the addition of customized modules (program extensions) to address specialized applications.

GoldSim allows you to create compelling presentations of your model, and therefore facilitates effective interaction with stakeholders. A model that cannot be easily explained is a model that will not be used or believed. GoldSim was specifically designed to allow you to effectively document, explain and present your model. You can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences. The ability to create hierarchical, top-down models, coupled with GoldSim's powerful documentation features, allows you to design transparent, highly-graphical models that can be effectively explained to any audience at an appropriate level of detail. Moreover, GoldSim facilitates real-time model experimentation (e.g., the ability to answer stakeholder "What If?" questions during a meeting). Transparent, easy to understand models and real-time model experimentation promote effective interaction with regulators and other stakeholders, and help to build trust. This ultimately can help you avoid costly delays and requests for additional (and technically unnecessary) modeling studies or data collection.

GoldSim provides a specialized set of tools that allow you to create custom interfaces, or "dashboards" for your models to make them accessible to non-technical users. Models created using the GoldSim Authoring tools can be saved and subsequently viewed and run using the free GoldSim Player. The interfaces can be designed to include buttons, input fields, sliders and result displays, and the author can embed text, tool-tips and graphics to provide instructions on the use of the model. Such an interface allows a model to be easily used by someone without requiring them to be familiar with either the GoldSim modeling environment or the details of the specific model. In effect, this allows you to use GoldSim as a high-level programming language to create custom simulation applications for distribution to end users who may not necessarily be modelers.
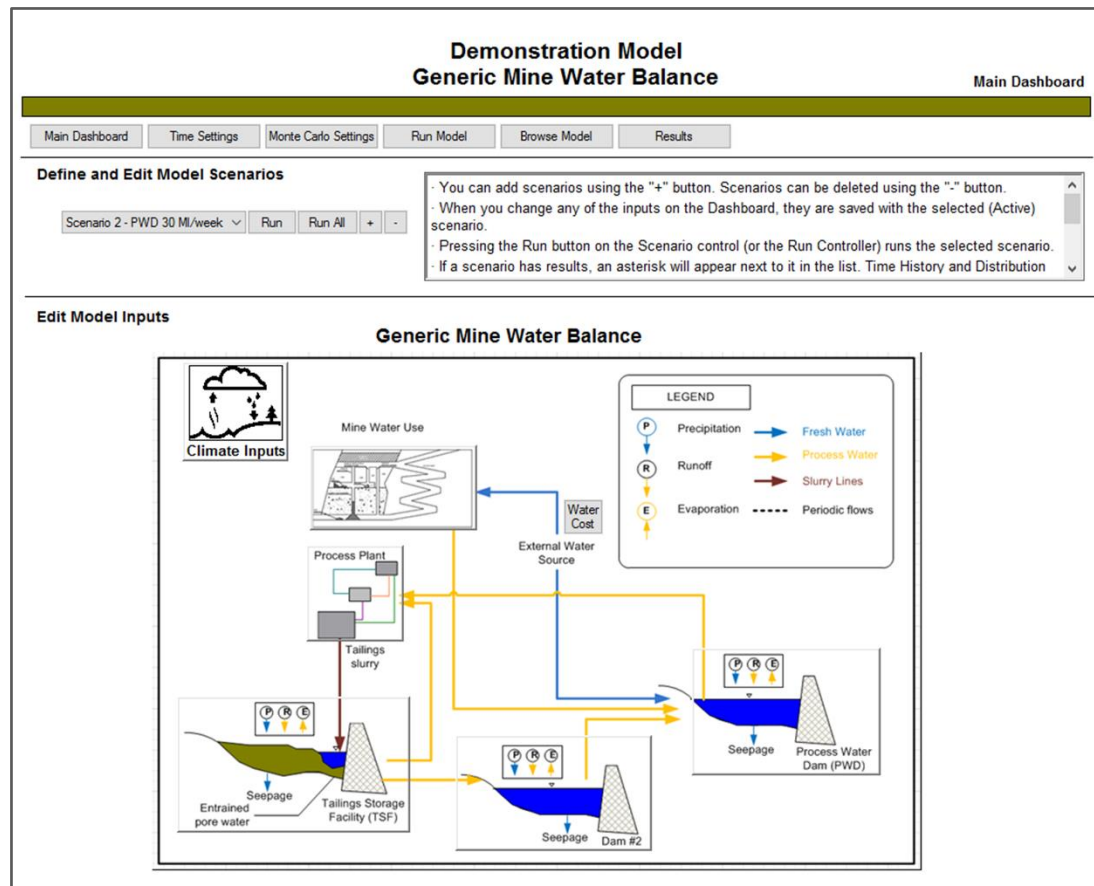
The GoldSim Methodology

The GoldSim software is most successful when applied using a structured methodology. This methodology is designed to support the full spectrum of planning and decision-support activities at a mine, from a strategic level to a more detailed operational level. The overall objective of the GoldSim methodology is to empower decision-makers to design and select the strategy that offers the highest likelihood of success. The key components are described below:

1) **Establish Clear Objectives:** The methodology starts by reviewing and clearly stating the objectives of the exercise, and an assessment of their feasibility. Defining the objectives is critical to keep the analysis focused, on time, under budget, and ultimately, successful.

2) **Decomposition**: It is important to understand that a GoldSim model will not provide useful results if it isn't based on an understanding of the system to be modeled. Therefore, building a conceptual model of your system is probably the most important part of any simulation effort. The greater your understanding of the critical factors that determine the behavior of your system, the more likely your simulation effort will provide useful results.

Building a good conceptual model of the system involves an analysis phase that results in decomposition of the system into a series of linked subsystems that define the key components of the system, the relationships between these components, and all relevant feedback mechanisms. Decomposition typically results in an influence diagram that is a conceptual picture of the system, its main components, and their interactions. An example of such a diagram is shown below:
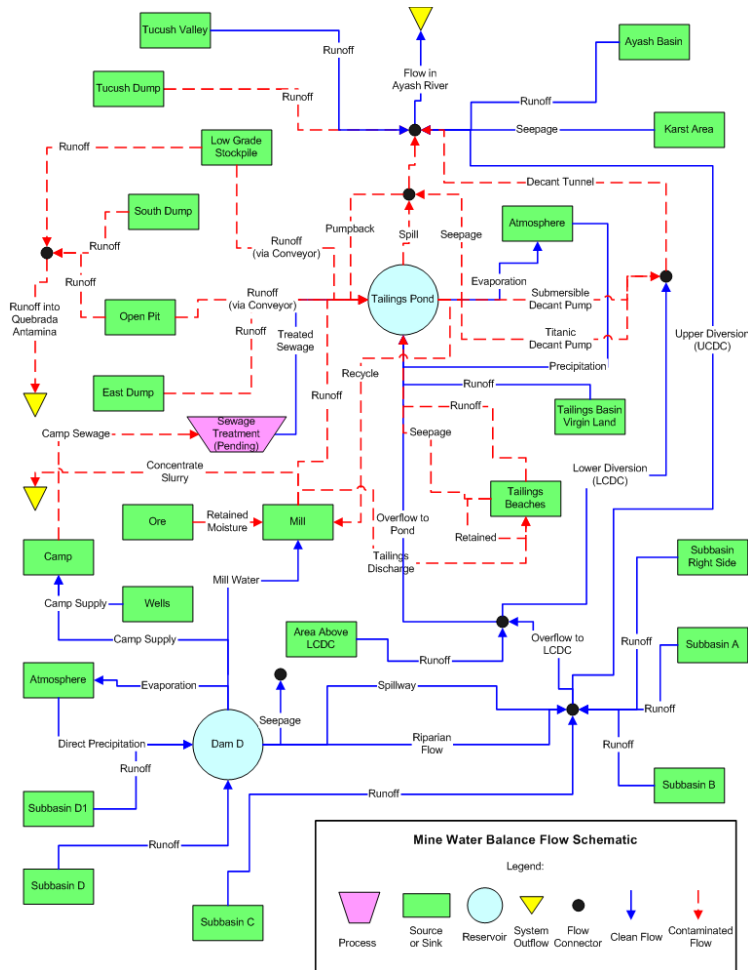
3) **Integration:** In order to address the full range of influences identified in the decomposition, the analysis must provide an integrated model of the system that couples each of the subsystems, rather than treating each part of the system independently. Developing such an integrated understanding of the system typically involves input and feedback from many people within the organization and thoughtful investigation of how the different elements of the system relate.

The integration phase provides a critical opportunity to foster communication, and get buy-in and support from a broad range of constituents within the organization (e.g., operational managers, technical experts, senior management). As a result, prior to even running the simulation model, most people find that the exchange of information and ideas that occurs while formulating the conceptual model in and of itself provides valuable insights and better understanding of the system.

4) **Top-down/relevance driven:** Models of large, complicated systems can be difficult to calibrate, explain, and maintain. As a result, the analysis should begin at a high (simplified) level and detail should only be added only when the preliminary results indicate that the additional detail is necessary and relevant. This top-down philosophy helps to control the time and expense of gathering and incorporating data, process information, etc. Investments are made only in areas where additional information will help to reduce uncertainty or improve the confidence in critical system components.

5) **Explicit representation of uncertainty and stochastic processes:** All water resource systems have key components that are stochastic (e.g., precipitation, evaporation, demand). In addition, complex systems have many uncertainties: How much will it cost to develop a new facility? How will prices for raw materials change? How will competitors respond to market conditions? What new technologies will emerge in the next five years? How will the general economy influence sales? How would the system handle the 100-year storm? What happens if a pump fails?

Since most water resource modeling addresses systems with significant uncertainty and stochastic behavior, it is critical that the analysis explicitly accounts for the full range of possibilities (rather than relying on conservative or "best-guess"estimates). This includes uncertainties in costs and durations of activities, uncertainties in the consequences and effects of carrying out various activities, and uncertainties regarding the occurrence of outside events (e.g., accidents, lawsuits, extreme weather events) or new developments (e.g., a change in interest rates, changes in political office, changes in economic conditions).

Incorporating uncertainty regarding the *consequences* of carrying out various activities and/or the occurrence of unplanned or unlikely incidents or developments can alert the strategic planner to flaws in the strategy and provide guidance for improving the strategy. It may never be possible to completely avoid such incidents or developments (e.g., a drop in commodity prices). However, if these possibilities are explicitly considered in the planning stage of the project, then

additional activities can be carried out beforehand and/or contingency plans can be prepared that will either reduce the likelihood of the incidents or lessen the impact should they occur.

6) **Dynamic Simulation:** Sound strategic planning must allow for changes in the plan depending on future conditions. It should be expected that managers will make future decisions based on information available at the time. For example, when simulating a supply chain, a good model must simulate the manner in which production managers would respond to changing demands.

In short, the simulation model should specify the planned responses to the uncertain aspects of the strategy, and how these in turn will affect the manner in which the system behaves from that point forward. Thus, good strategies incorporate the contingency plans necessary to respond to new developments or incidents in the system. Dynamic (time dependent) simulation provides the mechanism to then predict the full range of possible futures, analyze the results, and communicate findings to stakeholders and decision-makers.

7) **Communication:** The process should be conducted in a clear and transparent manner that provides the means to communicate the structure of the model and the results to the stakeholders. This communication element is critical for several reasons:
   - Communication during the model development phase is necessary to ensure that the conceptual model accurately represents reality.
   - Stakeholders find it much easier to trust an analysis that they can understand.
   - Decision makers need to be able to quickly understand a model and the associated results in order to make informed decisions.

Example GoldSim Mining Applications

Evaluation of a Water Management Scheme for a Proposed Gold Mine Project. GoldSim was used to assist a mining company in its evaluation of the feasibility of opening a gold mine. Gold would be extracted using the conventional cyanidation and carbon stripping process. Process water and natural run-off would be re-circulated from the tailings facility to the mill. Make-up water would be obtained from a reservoir located approximately 2 km from the proposed plant site. The primary purpose of the GoldSim model was to develop a water management scheme that provided for flexible and continuous mill operation, and minimized potential impacts on the project.

A GoldSim model with multiple uncertain parameters was developed to support decision-making and system design. The model was used to estimate inflows to the tailings facility under various hydrological and operating conditions, to determine the storage capacity of the fresh water storage pond and to estimate the risk of water shortage during the mine start-up period. Run-off water available for the start-up period was estimated based on the probability distribution of historical monthly precipitation.

Integrated Mine Water Management Planning and Implementation. GoldSim was used to addressed the current and future water management issues

at a mine in Tasmania through the development of predictive models that allowed an assessment of different water management scenarios, taking into account surface water and groundwater inflows to two existing pits. A site wide water balance model was constructed to represent the existing surface water movement that related to the site. This model, built using GoldSim, considered rainfall, evaporation, evapotranspiration, infiltration and the movement of surface water around the site. By combining surface water model components with results from the MODFLOW groundwater model, the GoldSim model was extended to include the results of groundwater modeling, and therefore provided a useful predictive tool by which to compare options for surface and groundwater management. A reliability model of the potential range of inflows to the mine was also developed in GoldSim, to aid in understanding the amount of pumping that would be required to ensure a dry mine floor after heavy rain and/or a higher than usual groundwater inflow.

Site-Wide Water Management Plan for Diamond Mine in Canada. In support of an Environmental Impact Assessment (EIA) submission, GoldSim was used to simulate the site-wide water quality conditions and mass loadings to the system both during and following the proposed project. The GoldSim model integrated the results of independent groundwater flow and geochemical models, and simulated concurrently the movement of 39 solutes through the subsurface mine and surface facilities. Solute sources considered included four different waste rock and tailings types, explosives use in the mine; sewage treatment plant discharge and the application of recycled process water for dust suppression. Separate solubility constraints were identified for different regions of the flow system (e.g. underground mine; treatment facility; surface water bodies) and temperature dependent rate constants were used to calculate mass inputs from surface waste rock sources.

Water Management at a Phosphate Mine in Florida. GoldSim was used to simulate water management at the mine and also account for nutrient levels in the water and soils. The main objectives of the model were to estimate the probability that the mine would need to discharge water from the mine and/or the nutrient levels would exceed regulation limits. The model takes into account the operations decision making at the various facilities and handling of materials and water. Results indicated that the model accurately predicted discharge probabilities and levels by simulating the water management decisions throughout the mine. Secondary objectives were to predict pond water levels during varying hydrologic scenarios. This was then used to improve management decisions (what level to hold ponds at in preparation for rainy season and major storms).

Reclamation and Closure of Uranium Mine. The objective of the study was to evaluate alternative strategies for the reclamation and closure of an underground uranium mine in Germany. The closure concept was to stop pumping water from the mine and allow the regional groundwater in the area to slowly return to the pre-mining level. However, the oxidized minerals in the mine workings were expected to generate acidic water with dissolved metals (including uranium and radium) and other contaminants for hundreds of years that could impact local wells and surface waters once the water level approached steady-state conditions. It was clear that the mine water would have to be managed at some point in the future.

There were several concepts for collecting and treating the mine water until the quality improved and it could be allowed to freely discharge to the environment.

The performance metrics for comparing the strategies were closure cost, the contaminant concentrations downstream from the water treatment plant outfall, and the time it took for the mine water quality to improve to groundwater standards.
A system model and the alternative closure activities were developed using the GoldSim software.

The model tracked the flooding, discharge, treatment and sludge generation rates and considered physical limitations in the system (e.g., plant and storage capacities). A cost model for tracking operating and maintenance expenses was integrated into the model. The system model was used to evaluate twelve strategies. Each strategy was a different combination of water collection, water treatment, and sludge disposal options. The reliability, capital and operating costs varied between options. The results from the system analysis saved millions of dollars of cost by supporting selection of a technically defensible and cost effective option.

Evaluation of Alternative Closure Plans for a Smelter. The objective of the study was to compare the performance metrics of alternative closure actions for a smelter site and determine the environmental and financial impacts for each of the alternatives. The baseline closure plan was simulated using GoldSim to establish the expected performance measures for the strategy. These included the completion times for the various closure activities (e.g., soil remediation activities) and the associated costs. Uncertainty about the closure activities (e.g., start times) and the system conditions (e.g., TDS concentrations in the groundwater plume, depth and aerial extent of soil contamination) were explicitly represented in the model.

The model included a climate model that simulated rainfall and evaporation based on 10 years of historical data for the site and reproduced the variability in climate during this period (cool wetter years and hot, dryer years). The model tracked all capital and operating costs associated with the closure activities, including maintenance and replacement costs.

The simulation of the baseline closure plan indicated the interceptor wells would exceed the capacity of the passive water treatment system (dilution and evaporation) and require a brine concentrator to be operated for one to two months during a 10 to 20 year period. An alternative plan was developed that involved diluting additional water and constructing a pipeline to transport the water during the summer months to a nearby ranch for agricultural use. The volume of water diverted from the evaporation ponds was sufficient to eliminate the need for the brine concentrator, saving an estimated $20 million over the projected duration of the closure activities.

Evaluation of Proposed Tailings Disposal Facility. GoldSim was used to assist in the evaluation of the feasibility of expanding an In-Pit Tailings Management Facility (TMF), as well as to assess final site closure alternatives for the management of both tailings and waste rock at a uranium mine site. To provide an assessment of the impact of the potential expansion and final closure on groundwater conditions in the area, GoldSim was used in conjunction with a detailed 3-D numerical groundwater flow model of the facility to complete the

detailed solute transport calculations. Groundwater flow directions and rates in each of the principal hydrostratigraphic units were established with the 3-D numerical model while GoldSim solved the solute transport equation. The source terms were defined by the results of external geochemical models. Radionuclides, arsenic and nickel were considered in the assessment. From the early phases of the project through detailed technical studies, GoldSim was used extensively to assess the performance of the facility (relative to regulatory water quality criteria) and direct alternative engineering designs for tailings and waste rock management at closure.

Summary

GoldSim is a powerful and flexible Windows-based computer program for carrying out probabilistic simulations of complex systems to support management and decision-making in engineering, science and business. The program is highly graphical, highly extensible, able to directly represent uncertainty, and allows you to create compelling presentations of your model.

GoldSim is particularly well-suited to applications in the mining industry. In particular, it allows you to create realistic models of mine systems in order to carry out risk analyses, evaluate potential environmental impacts, support strategic planning, and make better resource management decisions.

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About the GoldSim Technology Group

The GoldSim Technology Group is a privately held software company dedicated to delivering software and services to help people understand complex systems and make better decisions. The combination of our diverse technical and business backgrounds, our extensive experience in modeling complex systems, and our ability to continuously enhance our state-of-the-art simulation tools allow us to efficiently solve difficult problems that cannot be readily addressed by others.

Our flagship GoldSim software package is based on technology developed over a period of 17 years. GoldSim has been used by and/or for a diverse set of customers and clients, including government agencies in over 10 countries, and commercial organizations worldwide, including engineering firms such as AECOM, Hatch, Golder Associates, CDM, CH2M Hill, Jacobs and Bechtel; mining companies such as Anglo American, Newmont Mining Corporation, and Rio Tinto, and manufacturing firms such as Caterpillar.

The GoldSim Technology Group focuses on building great simulation software and supporting the technical aspects of building effective GoldSim models. To provide other dimensions of complete solutions, we maintain close relationships with partners around the world, including consulting firms with specific expertise in the mining industry.

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