# Integration of Regional and Site Scale Models for an Open-Pit Mine

John Rupp[1], Geoff Beale[2], Kevin Howerton[3], Max Allen[4]

[1]*Senior Hydrogeologist, Piteau Associates, 9090 Double Diamond Parkway, Unit 1, Reno, Nevada, USA, 89521, jrupp@piteau.com*

[2]*Principal, Piteau Associates, 9090 Double Diamond Parkway, Unit 1, Reno, Nevada, USA, 89521, gbeale@piteau.com*

[3]*Principal Hydrogeologist, Round Mountain Gold Corporation, 1 Smoky Valley Mine Road, Round Mountain, Nevada, USA, 89045, kevin.howerton@kinross.com*

[4]*Junior Hydrogeologist, Piteau Associates, 9090 Double Diamond Parkway, Unit 1, Reno, Nevada, USA, 89521, mallen@piteau.com*

## Abstract

Numerical groundwater modeling has progressively become the standard industry tool to evaluate and predict hydrogeologic responses to mine dewatering. Experience has shown that most mine sites require at least two numerical models, each at distinctly different scales, to answer key water management questions. This paper draws on over 30 years of dewatering data from an open pit mine in Nevada, USA to illustrate the importance of scale selection on model development. It uses the experience gained from a 3-D regional-scale model and a 2-D pit-scale model to highlight how both are needed to adequately assess the mine's water management system.

**Keywords:** Numerical, Model, Open-Pit, Mining, Dewatering

## Modeling Background

Numerical models are used to support all phases of mine water management evaluations from initial scoping to mine closure. Key mine site numerical modeling needs include: (i) defining potential impacts from mining activities on the regional groundwater system, (ii) demonstrating the environmental performance of a mine, during operations and/or closure, and (iii) developing and managing the mine dewatering or pit slope depressurisation programs.

A few basic issues need to be addressed before mine-specific numerical models are developed:

1. What questions does the model need to answer?
2. What decisions need to be made using the results?
3. At what scale do these questions need to be answered?
4. How do those scales relate to the physical hydrogeologic processes that will drive the answers?

Experience has shown it is usually more efficient and effective to use at least two independently scaled groundwater models than to develop one model to address all study needs. For example, mine environmental departments most often need regional-scale models to support permitting and closure. These studies usually require regular (1 to 5 year) updates with a high level of modeling effort over a period of months or even years. In contrast, the mine engineering or operations departments typically need models to answer sector-specific mine dewatering and/or pit slope design questions to support monthly or quarterly water management decisions. Trying to use one model to address both efforts would sacrifice operational flexibility and overwhelm longer-term regional evaluations with unnecessary detail.

The two most common model scales for mine water management studies are Regional-Scale Numerical Models (RSNMs) and Mine-Scale Numerical Models (MSNMs). The following two sections highlight the key differences and uses of these two types of groundwater models.

### *Regional-Scale Numerical Models*

First and foremost, a RSNM defines the hydrogeological interaction between the mine site and the surrounding regional groundwater system. RSNMs are used to define the potential for future impacts from (i) proposed mine dewatering programmes, and (ii) new facility development (such as tailing, water, and/or waste rock storage), as well as to better understand current or past effects from mining on the regional groundwater system. RSNMs are also used to evaluate mine water supply feasibility. Since RSNMs are based on hydrogeologically significant basin-scale boundaries, they can also be used to define internal boundary conditions for site-scale or facility-specific models.

A RSNM encompasses hydrogeologically significant boundary conditions such as basin divides, rivers, lakes, or groundwater discharge zones. Depending on the setting and mining operation scale, a RSNM may extend for tens of kilometres beyond the mine property boundaries, potentially across administrative boundaries or international borders.

Basin fill groundwater systems are often represented as lumped hydrogeological units even though systems may be highly layered with variable hydraulic properties. Key regional-scale geology and structures may be incorporated from water-supply and geologic investigations, but the available information is typically not as detailed as the data-rich open pit area. Lumping of geologic and hydraulic parameters to fit typical RSNM grid scales often 'smears out' smaller-scale (slope-scale) geological or hydrogeological details in the pit area that may be important for operational considerations but does not adversely affect the regional-scale evaluation.

A key limitation for RSNMs are computational and data management requirements. Computational requirements are driven by the number of cells (or elements) and layers selected. Grid telescoping, including quadtree grid refinement, is almost always useful to optimize the higher-resolution data in the pit area and the lower-resolution data in outlying areas. However, RSNMs with hundreds of thousands to millions of cells are cumbersome compared to the smaller MSNMs. RSNMs usually require hundreds of man-hours to calibrate even with the assistance of numerical optimization and require substantial time and effort to manage the associated massive quantity of input and output data.

### *Mine-Scale Numerical Models*

A Mine-Scale Numerical Model (MSNM) normally includes part or all of the open pit and/or key project facilities. The purpose of the MSNM is to incorporate geological and hydrogeological details related to fine-scale facility-specific processes that cannot be captured adequately or efficiently with the RSNM.

A MSNM most often provides a groundwater head and gradient distribution in the immediate mine vicinity for operational or mine design analysis. These models also predict the potential range of groundwater inflow rates, based on sectorspecific geology and hydrogeological conditions. MSNMs can assist in planning and design of the general mine dewatering system, the pumped water discharge system, and sensitivity of alternative mine plans to dewatering requirements and sequencing. A MSNM can also be fundamental to understanding the uncertainty in the local hydrogeological system variables, including geology, rock mass hydraulic parameters, the characteristics of known structures, or the variability in local recharge conditions.

A MSNM normally requires local areas of increased data intensity, facilitating identification and characterisation of geological and hydrogeological features that are important to open-pit or facility performance. Geological units surrounding an open pit or facility that are 'lumped' for the RSNMs may need to be sub-divided in an MSNM based on lithology, alteration type or structural domain, and assigned distinct hydraulic properties. The MSNM grid spacing is fine compared to a RSNM, normally on the order of a few tens of meters or less. The MSNM simulates a substantially smaller area compare to a RSNM, because the study area is focused on pit-scale processes.

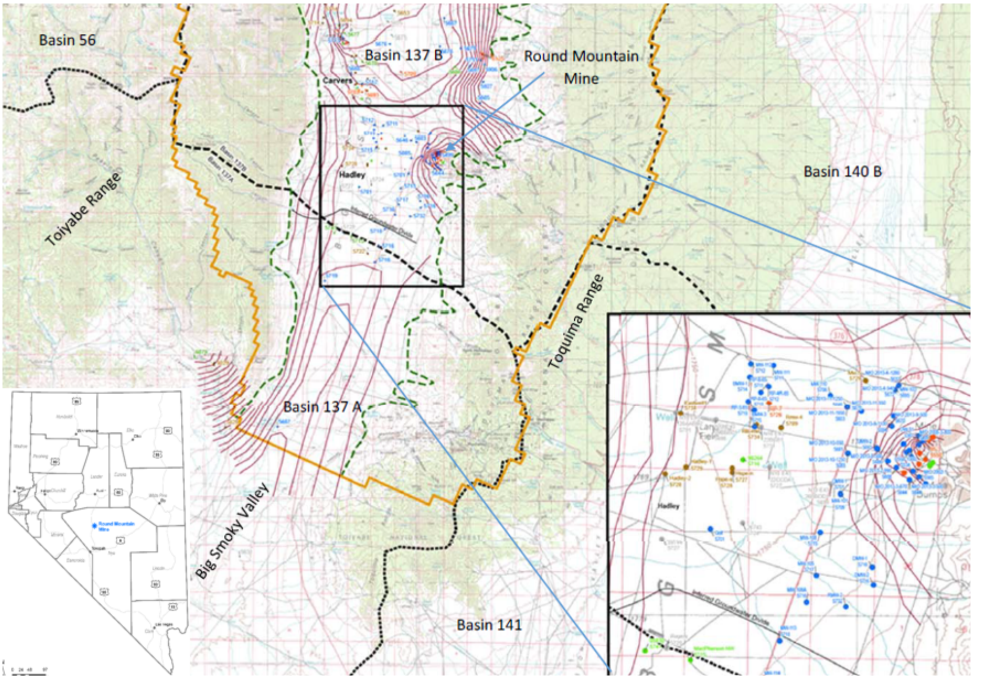


*Figure 1 Round Mountain Mine and Big Smoky Valley Location Map, Nevada, USA.*

## Case Study Example: Round Mountain Mine RSNM and MSNM

The following case study is focused on the open pit Round Mountain Mine, near Hadley, Nevada (Figure 1). The Round Mountain Mining District has been active since the 1800's. Modern mine dewatering commenced in the early 1990's followed by several mine expansions over the years. Numerical modeling commenced at Round Mountain in the late 1980's, providing 30-plus years of hydrogeologic data. Round Mountain Gold Corporation (RMGC) recently completed a feasibility study to evaluate the hydrogeologic effects from mining a six-year push back in the south-eastern part of the existing pit.

The Round Mountain Mine is located Nye County, Nevada, at the southern end Big Smoky Valley, within the Great Basin subprovince of the Basin-and-Range Physiographic Province. The principal hydrogeologic units in Big Smoky Valley are typical of the Nevada Basin-and-Range Physiographic Province:

- **Basin Fill:** This unit is comprised mostly of alluvium with playa and channel deposits. The most significant water-bearing strata in the area are in the coarser gravel and cobble-rich channel and alluvial deposits.
- **Bedrock:** This unit includes volcanic tuffs of Oligocene to Miocene age which were erupted from a group of several calderas in the southern Toquima Range, metasedimentary rocks of Cambrian to Ordovician age, and granitic plutons of Cretaceous age.

In addition to these principal units, the Stebbins Hill Formation, which is a mix of lacustrine clay and volcanic bedrock, forms a hydrogeologically significant aquitard at the western edge of the Round Mountain Pit.

## Round Mountain RSNM

The current iteration of the 3-D finite difference Round Mountain RSNM was originally developed in the early 2000's using MODFLOW-SURFACT (Hydrogeologic 2021). The key RSNM model goals are to (i) confirm analytically-estimated dewatering rates and potential drawdowns in the basin-fill and bedrock groundwater systems, (ii) to provide inputs for the water quantity impacts analysis, and to (iii) simulate the pit lake recovery rate and water balance in permanent closure.

Figure 2 shows the RSNM domain and boundaries. The model domain is large enough to reasonably simulate the 3-meter drawdown isopleths from pumping at Round Mountain without being constrained artificially by distal boundaries. The RSNM grid includes variable-mesh refinement, to reduce cell size in areas of key interest around the open pit. The model grid includes 198 rows, 147 columns and 11 layers, with a total of 320,166 cells. The smallest grid cells (91.4 m by 91.4 m) were specified near the Round Mountain Pit, where simulated pumping rates and drawdowns were the greatest. Progressively larger cells up to 732 m by 823 m were specified towards the model margins.

The RSNM domain shown in Figure 2 includes the entire area with potential for dewatering impacts from the Round Mountain Pit dewatering. The eastern and western boundaries are the surface topographic divides that form the hydrographic basin boundaries (Rush and Schroer 1970; Handman and Kilroy 1997). The northern boundary coincides with springs along the edge of the central-basin playa. The southern boundary is distant enough to avoid the constraint of model-simulated drawdowns from pumping. Groundwater flow out of this boundary is to the south.

The initial calibration process included three key periods: steady state calibration, transient calibration and transient verification. The RSNM currently requires 10 hours to run the entire calibration, predictive dewatering, and mine closure modeling sequence, generates roughly 200 MB of data per model run sequence, and requires 16 to 20 months to complete a bi-decadal level model update, including reporting.

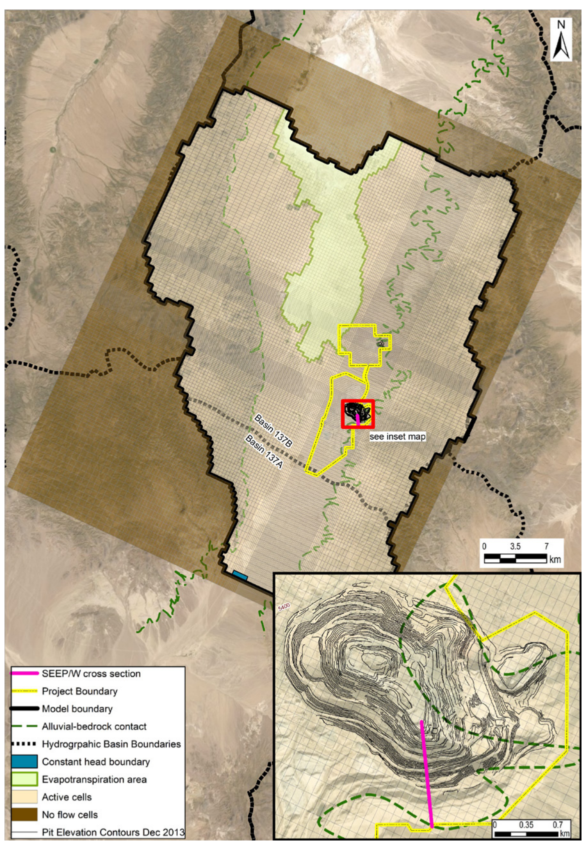


***Figure 2*** *RSNM boundary conditions, grid, 2-D cross section location, and conceptual model.*

Key model output from the RSNM include pit filling hydrographs and predicted drawdown isopleths. The stabilized pit lake levels are primarily a balance between groundwater inflow and pit lake evaporation. Groundwater-driven inflows are primarily derived from the alluvial groundwater system. Although results show that peak dewatering rates approach 631 L/s and infilling from the alluvium to the pit lake could exceed 189 L/s, the potential impacts to the surrounding groundwater system are manageable.

Two independent validations were completed on the RMGC RSNM (Piteau 2021). The model validations confirm the RMGC RSNM performs well for the regional-scale impacts analysis. However, as noted above, (i) it requires too much time and effort to update the model for operational studies and (ii) the grid spacing is 91.4 $m^2$ in the pit area, which is too large to meet the needs of the finer pit-scale evaluations.

## Round Mountain MSNM

A MSNM was needed to support: (i) the year-by-year dewatering plan for a mine expansion, and (ii) geotechnical stability analysis. Pore pressure was seen to significantly decrease the effective stress of the slope materials, so the input to the geotechnical analysis required a high degree of discretization and accuracy.

The 2-D finite element MSNM was constructed using SEEP/W (Geostudio 2021) (Figure 3). The model cross section corresponds to the key geotechnical design section in the west wall of the Round Mountain Pit (inset on Figure 2). The finite element mesh was defined to correspond with stratigraphic and structural features known to control the pit-scale pore pressure distribution. Mesh refinement ranged from 5 m around the pit slope and structures to 15 m at the more distant model boundary (Figure 3). Because of its simple geometry and limited complexity, the 2-D MSNM can be updated, calibrated, and run in approximately 7 to 10 days. Subsequent predictive scenarios can be run on a calibrated model within 1 to 2 days.

The MSNM Boundary conditions are shown in Figure 3. The MSNM boundary conditions correspond to internal boundaries derived from (i) the RSNM and (ii) the open pit. The lateral model boundary opposite the pit slope was assigned transient heads based on the RSNM simulation. The open pit was represented with a 'seepage' numerical

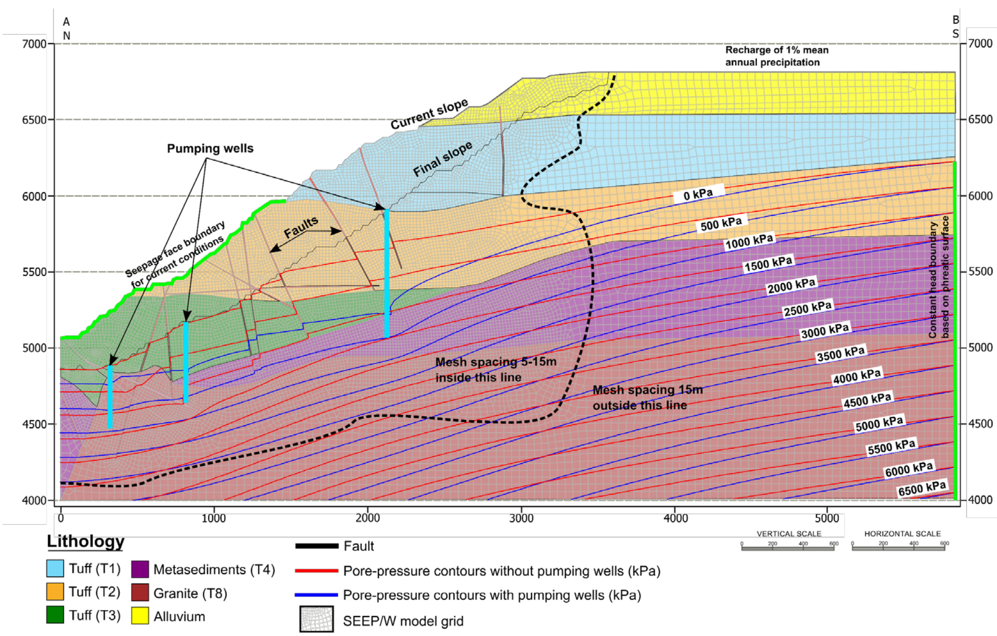


***Figure 3*** *MSNM 2D cross section with boundary conditions, model grid spacing, and pore pressure results with and without pumping wells.*

boundary condition. This boundary allows a seepage face to develop in areas where positive pore pressures occur at the pit wall.

The MSNM simulations predicted the pore pressure distribution with and without active depressurisation by dewatering wells and horizontal drain holes (HDHs). The model results support the current pit slope design and demonstrate that the dewatering program can address key issues identified in the slope design process, including the pore pressures associated with individual structures. These results provided key input to the geotechnical pit slope stability analysis that would not otherwise be obtainable from the RSNM.

## Conclusions

The results of the study have demonstrated the following:

- Experience has shown it is usually more efficient and effective to construct at least two groundwater models for a given site at different scales.
- RSNMs are used to define the potential for future impacts from (i) proposed mine dewatering programmes, and (ii) new facility development, as well as to better understand current or past effects from mining on the regional groundwater system.
- A key limitation for RSNMs are computational and data management study requirements that can take months or even years to complete.
- A MSNM provides a finer-scale groundwater head and gradient distribution in the immediate mine vicinity for operational or mine design analyses.
- Two independent validations confirm the RSNM performs well for the regional-scale impacts analysis. However, the RSNM requires substantial effort on the order of 16 to 20 months to complete and does not provide finer-scale resolution required for operational dewatering analyses.
- The MSNM model results support the current pit slope design and demonstrate that the dewatering program can address key issues identified in the slope design process, including the pore pressures associated with individual structures. These results were obtained quickly and efficiently because the MSNM is substantially smaller and required less effort.
- Although RSNMs and MSNMs are usually developed independently, added value can be achieved between them by (i) assigning consistent boundaries / hydraulic properties and (ii) adopting similar assumptions to represent key conceptual hydrogeologic processes and (iii) incorporating a "feedback loop" of learnings gained through iterative repeated studies.

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