Subject: Groundwater Modeling Guidance for Mining Activities

The use of groundwater models at mine operations is widely practiced for analyzing water resource impacts, mine operations, and mine closures. Groundwater-flow and fate and transport models have been utilized to evaluate numerous hydrogeologic conditions. Groundwater flow models are used to calculate the groundwater flow rate, quantity, and direction of movement of groundwater through aquifers and confining units in the subsurface. Fate and transport models estimate the association/disassociation of concentrations of chemicals in groundwater, and evaluate the rate of movement, concentrations, and pathways.

Purpose

The use and protection of water resources is an important environmental and economic issue. As mining has the potential to have significant quality and quantity impacts to the State of Nevada water resources, it is important and necessary that the Bureau of Land Management (BLM) adequately address water resource concerns through National Environmental Protection Act (NEPA) analysis as an integral part of Plans of Operation (POOs) approvals. Groundwater and fate and transport models are useful tools to aid in the NEPA evaluation of potential impacts from mining.

It is necessary that the BLM adequately address water resource concerns in the review of all proposed Mining POOs conducted under 43 CFR Subparts 3802 and 3809 - Surface Management Regulations. The goals of this policy are:

- To ensure the continued health of the land and water resources
- To ensure the use of good science in making informed decisions
- To collaborate with appropriate Federal, State, local and tribal agencies and other interested parties

Policy

This guidance is intended to focus specifically on groundwater modeling, conceptual design and evaluation processes. The Nevada BLM Groundwater Modeling Guidance for Mining Activities requires that groundwater resource investigations involving groundwater modeling, at a minimum, meet protocols outlined in this policy. This guidance will ensure that a consistent approach is followed for groundwater modeling studies and reports required to meet POO and NEPA standards.

It is also the policy of the Nevada BLM to collaborate with the appropriate State regulatory agencies, specifically, Nevada Department of Conservation and Natural resources (NDCNR), Division of Environmental Protection (NDEP) and Division of Water Resources (NDWR). In certain situations, BLM may evaluate potential impacts at a level of detail or breadth of analysis that exceeds State requirements. For example, the BLM might require a detailed groundwater model analysis associated with each mining alternative as proposed within the NEPA document. Such departures should be coordinated with the appropriate State agency.

Implementation

This instruction should be followed when developing groundwater investigative studies in support of NEPA documents and POO approvals. Attachment 1 "Nevada Bureau of Land Management Groundwater Modeling Guidance for Mining Activities" is intended as a flexible document to aid in

meeting requirements of this policy. Also included is a glossary of useful terms pertinent to groundwater hydrology and modeling and a table of relevant references on groundwater modeling.

Contact Person

Questions concerning this policy and the attached guidance document should be directed to Dr. Tom Olsen, BLM Nevada State Office, Division of Minerals Management at (775) 861-6451.

Attachment 1

Nevada Bureau of Land Management Groundwater Modeling Guidance For Mining Activities

The following guidelines are provided to facilitate the implementation of the Nevada Bureau of Land Management (BLM) Groundwater Modeling Guidance for Mining Activities conducted under 43 CFR subparts 3802 and 3908 Surface Management Regulations. The guidance document is intended as a flexible document specific to water resource protection, and all sections of this document may not apply to every mining operation. For example, there may be projects where the mining will not intercept the water table or saturated zone. In such an instance, groundwater modeling may not be necessary. If there is any indication of potential mine operation/water resource conflicts, the proposed activity should be evaluated by the BLM, in coordination with the State and the mining company.

1.0 Use

The use of groundwater flow models is widely accepted in the field of environmental hydrogeology. Models have been applied to evaluate numerous hydrogeologic conditions associated with mining projects. In addition, groundwater models have been applied to predict the fate and transport of contaminants for risk evaluation purposes. This guide is intended to assist BLM staff specialists, contractors and mining companies in the evaluation and development of work plans that propose to utilize groundwater models, and to aid BLM staff specialists in the assessment of models that have been developed for mine dewatering, water management, remedial design, developing performance monitoring, and risk assessment.

The guidance document describes the following general concepts:

- Use of groundwater flow and transport models for saturated flow conditions
- Level of hydrogeological characterization needed to develop a model
- Different types of models
- Modeling procedures
- Appropriate degree of model documentation
- Model submittal procedures
- Need for verification sampling

It is not the purpose of this document to provide BLM staff specialists with a detailed examination of groundwater modeling procedures, or of particular groundwater models. A number of technical terms are used throughout this guide when describing numerous aspects of

groundwater modeling. A glossary of these and other widely used modeling terms and their definitions are contained in Appendix 1. A list of selected references, which provide more specifics on the concepts presented in this guidance, is presented in Appendix 2.

2.0 Groundwater models

Models are conceptual descriptions or approximations that describe physical systems using mathematical equations, they are not exact descriptions of physical systems or processes. The applicability or utilization of a model depends on how closely the mathematical equations approximate the physical system being modeled. To evaluate the applicability or utilization of a model, it is appropriate to have thorough understanding of the physical system and of the assumptions applied in the derivation of the mathematical equations. A specific discussion of the assumptions and derivations of the equations that are the basis of different groundwater models is beyond the scope of this guide.

Groundwater models describe groundwater flow and fate and transport processes using mathematical equations that are made on specific simplifying assumptions. These assumptions generally involve the direction of groundwater flow, geometry of the aquifer, heterogeneity or anisotropy of the sediments or bedrock within the aquifer, and contaminant transport mechanisms and chemical reactions.

Groundwater models are useful investigation tools that hydrologists, hydrogeologists, engineers, and water resource specialists can use for mine project assessment, such as:

- Evaluation of regional groundwater resources
- Designing a groundwater monitoring network
- Evaluating mine dewatering projects
- Evaluating water disposal proposals
- Tracking the possible migration pathway of groundwater contamination
- Assessing environmental risk
- Evaluating pit lake recovery
- Evaluating design of hydraulic containment and pump-and-treat systems

It is important to have a general understanding of both groundwater flow and fate and transport models to ensure that applications or evaluation of these models can be performed correctly.

2.1.1 Groundwater Flow Models

Groundwater flow models are used to evaluate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface. These calculations are referred to as simulations. The simulation of groundwater flow requires a thorough understanding of the hydrogeologic characteristics of the mine operation or area to be modeled. The hydrogeologic study should include a complete characterization of the following:

- Extent and thickness of aquifers, confining units, and structural controls

- Hydrologic boundaries that control the rate and direction of movement of groundwater

- Hydraulic properties of the aquifers and confining units
- A description of the horizontal and vertical distribution of hydraulic head throughout the modeled area for initial conditions, steady-state conditions and transient conditions when hydraulic head may vary with time
- Distribution and amount of groundwater recharge, pumping or injection of groundwater, leakage to or from surface water bodies

The outputs from the model simulations are the hydraulic head and groundwater flow rates that are at equilibrium with the hydrogeologic conditions defined for the modeled area. Figure 1 shows the modeled flow field for a test site at which pumping from a well creates changes in the groundwater flow field.

Through the process of model calibration and verification that is discussed in later sections of this guide, the values of the different hydrogeologic conditions are varied to reduce any disparity between the model simulations and field data, and to improve the accuracy of the model. The model can also be used to simulate possible future changes to hydraulic head or groundwater flow rates as a result of future changes in stresses on the aquifer system.

2.1.2 Fate and Transport Models

Fate and transport models simulate the movement and chemical change of contaminants as they move with groundwater through the subsurface. Fate and transport models require the development of a calibrated groundwater flow model that has based on field data. The model simulates the following:

- Movement of contaminants by advection and diffusion
- Removal or release of contaminants by sorption or desorption
- Spread and dilution of contaminants by dispersion
- Chemical changes of the contaminants by chemical reactions that may be controlled by biological processes or physical reactions

Besides a thorough hydrogelogical investigation, the simulation of fate and transport processes requires a complete characterization of the following:

- Horizontal and vertical distribution of average and linear groundwater velocity determined by a calibrated groundwater flow model or through determination of direction and rate of groundwater flow from field data
- Boundary conditions for the solute
- Initial distribution of solute
- Location, history and mass loading rate of chemical sources or sinks.
- Effective porosity
- Soil bulk density
- Fraction of organic carbon

- Water partitioning coefficient
- Density of fluid
- Longitudinal and transverse dispersivity
- Diffusion coefficient
- Chemical decay rate

The outputs from the model simulation are the contaminant concentrations that are in equilibrium with the groundwater flow system, and the geochemical conditions defined for the model area. Figure 2 shows the simulation migration of a contaminant at a test site.

As with groundwater flow models, fate and transport models must be calibrated and verified by adjusting values of the different hydrogeological or geochemical conditions to reduce any disparity between the model simulations and field data. This process may result in a re-evaluation of the model used for simulating groundwater flow if the adjusted values of geochemical data do not result in an acceptable model simulation. Predictive simulations may be made with a fate and transport model to predict the expected concentrations of contaminants in groundwater as a result of a remedial action.

2.2 Types of Models

The equations that describe the groundwater flow and fate and transport process may be solved using different types of models. Certain models may be exact solutions to equations that describe very simple flow or transport conditions and others may be approximations of equations that describe very complex conditions. Each model may also simulate one or more of the processes that govern groundwater flow or contaminant migration rather than all of the flow and transport processes. An example is the particle tracking model MODPATH, which simulates advective transport of contaminants, but does not account for other fate and transport processes. In selecting a model for use at a site or area, it is necessary to determine whether the model equations account for the specific processes occurring at the site or area. Every model, whether it is a simple analytical model or a complex numerical model, can have applicability in hydrogeological and remedial investigation.

2.2.1 Analytical Models

Analytical models are an exact solution of a specific groundwater flow or transport equations. The equation is a simplification of a more complex three-dimensional groundwater flow or solute transport problem. Analytical models are typically steady-state and one-dimensional, although selected groundwater flow models are two dimensional, and some contaminant transport models assume one-dimensional groundwater flow conditions. An example of output from a one-dimensional fate and transport analytical model (Domenico and Robbins, 1985) is shown in figure 3.

Because of the simplifications associated with analytical models, it is not possible to account for field conditions that change with time or space. This includes variations in groundwater flow

rate or direction, variations in hydraulic or chemical reaction properties, changing hydraulic stresses, or complex hydrogeologic and chemical boundary conditions.

Analytical models are best used for:

- Designing data collection plans prior to beginning field activities
- Initial site or area assessments where a high degree of accuracy is not needed
- An independent check of numerical model simulation results
- Sites or areas where field conditions support the simplifying assumptions associated with an analytical model

2.2.2 Numerical Models

Numerical models are able to solve the more rigorous equations that describe groundwater flow and solute transport. These equations usually describe multi-dimensional groundwater flow and solute transport, but there are one dimensional numerical models. Numerical models use approximations to solve the differential equations describing groundwater flow or solute transport. The approximations require that the model domain and time be discretized. In the discretization process, the model domain is represented by a series of grid cells or elements, and time of the simulation is represented by time steps or increments. A simple example of discretization is presented in Figure 4. The curve represents the continuous variation of a parameter across the model space or time increment. The bars represent a discrete step-wise approximation of the curve.

The accuracy of numerical models depends on the model input data, the size of the space and time discretization, and the numerical method used to solve the model equations. Numerical models have the capability to represent a complex multi-layered hydrogeologic system. This is done by dividing the framework into discrete cells or elements. An example of representing a multi-layered aquifer system in a numerical model is shown in Figure 5.

Besides complex three-dimensional groundwater flow and solute transport problems, numerical models can be used to simulate very simple flow and transport conditions, that can be as easily simulated using an analytical model. Additionally, numerical models are generally used to simulate problems that cannot be accurately described using analytical models.

2.2.3 Inverse Models

Groundwater flow and groundwater fate and transport models try to predict behavior of groundwater and groundwater contaminants. However, model predictions are not exact, one of the reasons is the heterogeneity of the subsurface soils and rock which are usually not well known throughout the entire model domain. Use of inverse models improve evaluation of prediction reliability because the results yield not only parameter estimates and head and flows simulated for the stresses of interest, but also confidence intervals for estimated parameters and the heads and flows, which are used to explain the reliability of the model results.

The main benefit of inverse modeling is the capability to automatically calculate parameter values that produce the best fit between observed and simulated hydraulic heads and flows. Secondly, other benefits are, 1) improved model calibration, 2) identifying data needs, 3) better estimates and predictions help support model studies. Additionally, the uncertainty and correlation of estimated parameters can be improved through automated calibration.

3.0 Groundwater Model Development Procedure

3.1 Hydrogeologic Characterization

Good characterization of the hydrogeological conditions at a site or area is necessary in order to understand the importance of flow and solute-transport processes. It is important that a thorough site characterization be completed. This level of characterization requires more site-specific field work than just an initial assessment, including more monitoring wells, water samples, water levels, and an increase in the number of laboratory and field parameters. Without appropriate site characterization it is not possible to select a model or develop good calibrated model, the following hydrogeological information must be available in a characterization process:

- Topographic data, to include surface water elevations
- Regional data, to include subsurface geology
- Surface water bodies and measured stream discharge data
- Geologic cross sections from soil borings and well logs
- Measured hydraulic head
- Well construction diagrams and soil boring logs
- Estimated hydraulic conductivity, from aquifer tests
- Location and estimation of flow rate of groundwater sources or sinks
- Identification of chemicals of concern in contaminant plume*
- Vertical and horizontal extent of contaminant plume*
- Mass loading or removal rate for contaminant sources or sinks*
- Direction and rate of contaminant migration*
- Identification of downgradient receptors
- Organic carbon content of sediments*
- Geochemical field parameters (e.g. dissolved oxygen, Eh, pH, etc.)*

*required only by fate and transport models

These data must be presented in map, table, or graph format in a report documenting model development.

3.2 Model Conceptualization

Model conceptualization is the process where data describing field conditions are gathered in a systematic way to describe groundwater flow and contaminant transport processes at a site or area. The model conceptualization helps in determining the model approach and which model software to use.

Questions that should be asked during conceptual model development include, but not limited to:

- Are there adequate data describing the hydrogeology?
- In how many directions is groundwater moving?
- Can the groundwater flow or contaminant transport be defined as one, two or three dimensional?
- Is the aquifer system made up of more than one aquifer, and is vertical flow between aquifers significant?
- Is there recharge to the aquifer by precipitation or leakage from a river, drain, or infiltration system?
- Is groundwater leaving the aquifer by seepage to surface water bodies, flow to a drain, or extraction well?
- Does it seem that the aquifer's hydrogeological characteristics remain? uniform or do or does the geologic data indicate considerable variation?
- Have boundary conditions been defined around the modeling domain, and what is the basis?
- Do groundwater flow or contaminant source conditions remain the same, or do they change with time?
- Are there receptors located down-gradient of the contaminant plume?
- Are there geochemical reactions taking place in onsite groundwater and are the processes understood?

Other questions related to site-specific conditions may be asked. This conceptualization step must be completed and described in the model documentation report.

3.3 Model Software

After hydrogeological characterization of the site or area has been completed, and the conceptual model developed, computer model software is selected. The selected model must be capable of simulating conditions encountered at the site or area. The following guidelines should be utilized in evaluating the appropriate model:

Analytical models should be used where:

- Field data indicates that groundwater flow or transport processes are relatively simple
- An initial assessment of hydrogeological conditions or screening of remedial alternatives is needed

Numerical models should be used where:

- Field data indicate that groundwater flow or transport processes are quite complex
- Groundwater flow directions, hydrogeological or geochemical conditions, and hydraulic or chemical sources and sinks vary with space and time

One dimensional groundwater flow or transport model should be used where:

- Initial assessments where the degree of aquifer anisotropy and heterogeneity is not known
- Sites where a potential receptor is immediately downgradient of the contaminant source

Three-dimensional flow and transport models should be used where:

- Hydrogeologic conditions are well know
- Multiple aquifers are present
- Vertical movement of groundwater or contaminants is vital

The reasoning for selection of appropriate model software should be discussed in the model documentation and report. The selection of the appropriate model software program for a project is the responsibility of the modeler. Any groundwater flow or fate and transport model software may be used provided that the model code has been tested, verified, and documented. However, it is recommended that the model developer contact the BLM at the beginning of the investigation to discuss the model software.

3.4 Model Calibration

Model calibration consists of changing values of the model input parameters to better match field conditions within acceptable criteria. This requires that field conditions at the site or area be adequately characterized. The lack of adequate characterization results in a model that is calibrated to a set of conditions that are not representative of actual field conditions. Calibration processes typically involve calibrating to steady-state and transient conditions. In steady-state simulations, there are no observed changes in hydraulic head or contaminant concentration with time for field conditions being modeled. Transient simulations involve the change in hydraulic head or contaminant concentrations with time. These simulations are needed to reduce the range of variability in the model input data where there are numerous choices of model input data values that can result in similar steady-state simulations.

At a minimum, model calibration should include comparisons between model-simulated conditions and field conditions for the following data:

- Groundwater flow direction
- Hydraulic head
- Hydraulic gradient
- Water mass balance,
- Contaminant migration rates *
- Contaminant concentrations *
- Degradation rates *
- Migration direction *

*required only for fate and transport models

These comparisons should be presented in maps, tables, or graphs. Simple graphical comparison between measured and computed heads is shown in Figure 6. In this example, the closer the heads fall on the straight line, the better is the goodness-of-fit. Typically, the difference between simulated and actual field measurements should be less than 10 percent of the variability in the field data across the model domain. An example of a plot showing residuals for monitoring wells is shown in Figure 7. The appropriate reasoning for establishing acceptable quantitative calibration target residuals and residual statistics for analyzing model error depends on several factors: the degree of natural heterogeneity, complexity of boundary conditions, location, number and accuracy of water level measurements, and the model purpose. The acceptable residual should be a small fraction of the difference between highest and lowest heads across the site or area and be based on:

- Magnitude of the change in heads over the model domain
- Ratio of the Root Mean Square (RMS) error to the total head loss should be small
- Head differential for the residual mean and standard deviation, and for the ratio of the standard deviation to total head change

After calibration, the coefficient of variation as well as the difference between calibrated targets and simulated heads and fluxes should be presented in the model documentation report.

The modeler must not adjust model input data on a scale that is smaller than the distribution of field data. Such a process is referred to as "over calibration," resulting in a model that looks calibrated, but has been based on a dataset that is not supported by field data.

3.5 History Matching

A calibrated model utilizes specific values of hydrogeological parameters, sources and sinks and boundary conditions to match field conditions for specific calibration time periods. The choice of the parameter values and boundary conditions used in the calibrated model is not unique, and other combinations of parameter values and boundary conditions may provide similar model results. History matching uses the calibrated model to reproduce a set of historic conditions. The process has been referred to as model verification. The most common history matching process consists of reproducing an observed change in hydraulic head or solute concentration over a different time period (see Figure 8). The best processes for model verification are ones which use the calibrated model to simulate the aquifer under stressed conditions. The process of model verification may result in the need for further calibration adjustment of the model. After a model has successfully reproduced measured changes in field conditions for both the calibration and history matching time periods, it is ready for predictive simulations.

3.6 Sensitivity

The sensitivity analysis is a process of varying model parameters over a reasonable range (range of uncertainty in values of model parameters) and observing the relative change in model response (see Figure 9). Generally, the observed changes in hydraulic head, flow rate or

contaminant transport are noted. At a minimum, the following parameters should be considered in the sensitivity analysis: hydraulic conductivity, recharge, dispersivity*, and porosity. Other inputs such as boundary conductance and heads that are likely to effect computed heads, groundwater flow rates and mass flux of contaminants may be varied as appropriate. The reason for the sensitivity analysis is to demonstrate the sensitivity of the model simulations to uncertainty in values of model input data. Sensitivity of one model parameter relative to other parameters is also shown. Sensitivity analyses are also utilized to determine the direction of future data collection activities. Data for which the model is relatively sensitive to would require future characterization, as opposed to data for which the model is insensitive to.

*required only by fate and transport models.

3.7 Predictive Simulations

A model may be used to predict some future groundwater or contaminant transport conditions. The model may also be used to assess remediation alternatives, such as hydraulic containment, pump-and-treat systems, and to assist in risk analysis. To be able to perform these works, the model, must be reasonably accurate, as demonstrated during the calibration process. Even a well calibrated model is based on oversimplifications and uncertainties. For this reason, model predictions should be provided as a range of possible outcomes that reflect the uncertainty in model parameter values. The range of uncertainty should be similar to that applied to the sensitivity analysis. Figure 10 shows the range in computed heads at the calibration targets for a particular point in time resulting from varying a model parameter over a range of uncertainty. Figure 11 shows hydraulic heads predicted for a future time period in response to changing stresses on the aquifer system. Likewise, the range in predicted heads should be presented so that good decisions may be made regarding the groundwater resource. Figure 12 shows a well head protection area for public water-supply. These simulations show a range of hydraulic conductivity values over time and distance. Figure 13 shows a simulated contaminant concentration down-gradient of a source area.

Model predictive simulations may be used to estimate the hydraulic response of an aquifer, the migration pathway of a contaminant, and the concentration of a contaminant at a point of compliance at some future point in time. As an example, the design of mine dewatering system may be based on predictive model simulations. A model may be used to predict the pumping rate needed to dewater a mine, as well as, water quantity during the dewatering process.

Predictive simulations are based on the conceptual model developed for the mine operation or site, the values of the hydrogeology or geochemical parameters used in the model, and the equations solved by the model software. Models are calibrated by adjusting values of the model parameters until the model response closely reproduces field conditions within some acceptable criteria to try to minimize model error. Given the uncertainty in model input parameters and the corresponding uncertainty in predictive simulations, model input values should be selected which result in a conservative simulation. Site-specific data may be used to support a more reasonable conservative scenario and also limit the range of uncertainty in predictive models. Figure 14 shows an example of the growth of model error over time for predictive a simulation.

4.0 Performance monitoring

Groundwater models are used to predict the future conditions of groundwater, and concentrations of contaminants in groundwater. The accuracy of a model prediction relies on successful calibration and verification of the model for determining groundwater flow directions, groundwater quantity, groundwater quality, transport of contaminants and chemical reactions. As a result, performance monitoring is required to compare future field conditions with the model predictions. Monitoring data will provide the necessary information to both compare and update model predictions, so that the model can be improved and become more accurate with time.

As previously mentioned, groundwater model simulations are an approximation of the actual system behavior and monitoring of field conditions are necessary to assess error in model predictions. As a result, performance monitoring is required as a means of physically measuring the actual behavior of the hydrogeologic system and demonstrating compliance with environmental and mining statutes. Groundwater model simulations are estimates and may not be substituted in place measurement of field data. Examples of the applications of groundwater and contaminant transport modeling requiring performance monitoring would include, but not be limited to the following:

- Groundwater and surface-water interface mixing zones that can potentially impact human receptors and sensitive ecological habitat
- Mine dewatering, that could potentially impact water rights and groundwater systems
- Water discharge and disposal that could potentially impact human receptors, ecological habitat and localized aquifer systems
- Hydraulic containment systems that have certain physically measured geochemical and hydraulic head criteria that measure the success of a remediation

The degree of performance monitoring required at a mine operation or site depends on the conditions or actions that have been simulated and the associated level of risk to groundwater systems, ecological habitat, and the environment. As an example, mine dewatering would require extensive groundwater monitoring for hydraulic head levels, groundwater quantities, chemistry, and surface-water systems, through a monitoring well system and monitoring program. Another example would be hydraulic containment of a contaminant plume by a pump-and-treat system that would require extensive monitoring of hydraulic heads and groundwater quality, through a monitoring well system and a water sampling program.

5.0 Documentation of Models

A groundwater model developed for a mine operation or site, either an analytical or numerical model, should be described in sufficient detail so that the model reviewer can determine the appropriateness of the model for the mine operation or site or problem that is simulated. The submittal of a model documentation report and model dataset is required. A suggested format for this report is contained in the following sections. Groundwater modeling documentation

must detail the process by which the model was selected, developed, calibrated, verified and utilized. The model documentation report must include the following information:

- Description of the purpose and scope of the model application
- Hydrogeologic data used to characterize the project
- Documentation of the source of all data in the model whether acquired from published sources or measured or calculated from field or laboratory tests
- Model conceptualization
- Model applicability and limitations
- Model approach
- Documentation of all calculations
- Summary of all calibration, history matching and sensitivity analysis results all model predictive simulation results as a range of probable results given the range of uncertainty in values of model parameters.

The format of the report should include the following sections:

- Title page
- Table of contents
- List of figures
- List of tables
- Introduction
- Objectives
- Hydrogeologic characterization
- Model conceptualization
- Model software selection
- Model calibration
- History matching
- Sensitivity analysis.
- Predictive simulations or use of the model for evaluation of alternatives
- Recommendation and conclusions
- References
- Tables
- Figures
- Appendices

5.1.1 Tables

The following is a list of tables that should appear within the body of the model documentation:

Well and boring data including:

- name of the wells or borings
- top of casing elevation
- well coordinate number
- well screen interval

- hydraulic head data
- elevation of bottom of model
- hydraulic conductivity or transmissivity
- groundwater quality chemical analyses
- aquifer test data
- model calibration and verification results showing comparison of measured calibration targets and residuals
- results of sensitivity analysis showing the range of adjustment of model parameters and resulting change in hydraulic heads or groundwater flow rates

Other data, not listed above, may lend itself to presentation in tabular format. The aquifer for which the data apply should be clearly identified in each table.

5.1.2 Figures

The following is a list of the types of figures (maps or cross sections) which should be included in the model documentation report:

- Site map showing soil boring or well locations and site topography
- Regional location map with topography
- Geologic cross sections
- Map showing the measured hydraulic-head distribution
- Maps of top and /or bottom elevations of aquifers and confining units
- Maps showing structural control
- Map of areal recharge
- Model grid with location of different boundary conditions used in the model.
- Simulated hydraulic-head maps
- Contaminant distribution map(s) and/or cross sections showing vertical distribution of contaminants (for fate and transport modeling)
- Map showing simulated contaminant plume distribution (for fate and transport modeling)

Other types of information, not listed above, may be presented in graphic format. Figures that are used to show derived or interpreted surfaces such as layer bottom elevations and hydraulic-head maps should have the data used for the interpolation also posted upon the figure. As an example, measured hydraulic-head maps should identify the observation points and the measured hydraulic-head elevation. Likewise, the simulated hydraulic-head maps should locate the calibration target points and the residual between the measured and modeled data.

All figures should provide the following information:

- North arrow (for maps)
- Date of figure preparation
- Title bar
- Scale bar
- Legend

All maps or cross sections should be drawn to scale with an accurate scale clearly displayed on each figure. When appropriate, all figures should be the same scale. Figures that apply to specific aquifers should be clearly labeled.

5.1.3 Additional Data

Additional data may be required to be presented in the model documentation report. Examples of additional data are as follows:

- Additional studies work plans providing for the collection of additional data where model simulations indicate data deficiencies
- Groundwater monitoring plans/recommendations to collect data needed to verify model predictions.

Other data may be required, depending on the conditions of the project or site. These additional subjects should be addressed within the body of the report. This may include additional figures and tables, or report sections.