# CONCEPTUAL GROUNDWATER MODEL DEVELOPMENT FOR NEW NUCLEAR POWER PLANTS

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## Abstract

Conceptual models of hydrological systems are a key tool for evaluating environmental impacts and in the safety analyses of nuclear power plants. Conceptual models developed before plant construction are a useful tool to re-evaluate and revise the hydrologic system during and after plant construction. For conceptualization, site modifications during construction and post-construction can be characterized by three stages: (1) pre-construction or ambient conditions; (2) construction and construction activities; and (3) post-construction when the flow system equilibrates to the new plant and associated structures. In the first stage, development of a pre-construction phase conceptual model is performed by consolidating available information into a model which demonstrates the current and fundamental understanding of the geologic framework and ground water flow system. Once the pre-construction stage conceptual model is defined, the subsequent impacts of construction activities in the second stage may be evaluated using information collected during construction. Construction activities may impact site hydrology temporarily or permanently and include dewatering, altered ground cover that impacts recharge and runoff, deep excavations and engineered fill within power block, and surface water diversion and impoundments. The third stage (post-construction) may include permanent surface and subsurface alterations (e.g., parking lots and deep foundations) that may have a lasting impact on surface and ground water flow conditions. As a result, these potential impacts and their related effects on the safety of the plant and environmental conditions are described and evaluated during the reactor licensing process.

## INTRODUCTION

A conceptual site model (CSM) of a hydrologic system is defined as an overall understanding of the characteristics and dynamics of the system based on an interpretation of the available data. Developing a CSM for a proposed nuclear power plant (NPP) site is an essential component of the licensing process as a sound CSM is key factor in the evaluation of the safety and environmental effects of the NPP. The primary role of CSM is to evaluate risks from hypothetical radionuclide releases from the NPP liquid wastes management system (LWMS) to the surface and subsurface environment.

The CSM serves as the basis for modeling groundwater flow systems and associated radionuclide transport. An erroneous CSM results in a flawed understanding of the fundamental processes that drive the hydrogeologic flow system. In many cases, a flawed understanding may be carried through to the analysis of key regulatory objectives which include characterization of chemical or radionuclide transport in the subsurface required for new NPP applications. Authors such as Carrera and Neuman (1986) and Samper and Neuman (1989) have noted that an inadequate model structure (conceptualization) is far more detrimental to its predictive ability than a suboptimal set of model parameters. From a hydrologic perspective, the CSM incorporates many forms of information and data including:

- Geologic maps and cross sections;
- Potentiometric head data;
- Geochemistry;
- Subsurface field tests;
- Laboratory testing of subsurface properties;
- Meteorological and hydrological records;
- Information and data from previous studies and field work;
- Surface water data including spring and seepage data; and
- Available well construction and lithologic logs, and well test data.

For new NPPs, the primary purpose of the CSM is to develop plans or mitigative measures to minimize the impacts to the public health and safety during the plant operation under the normal operating conditions and, abnormal conditions such as accidental releases. From a regulatory perspective for new NPPs, the conservative estimation of radionuclide transport and impacts to existing and future water users are guiding principles in the evaluation of the CSM. Initially, the CSM is developed from a set of one or more plausible configurations of available site data and characteristics that could define the hydrological flow system. Plausible alternative conceptualizations should clearly demonstrate why one particular conceptualization may be more conservative than another (NUREG 0800, Section 2.4.13), and evaluate the need for site-specific monitoring and sampling to establish a more refined understanding of site-specific processes.

The conceptualization process is an initial key step in the hierarchical analysis of fate and groundwater transport of radionuclides (Figure 1 provides an example of the hierarchical approach as proposed in Interim Staff Guidance (ISG) 014). This analysis is central to determining if a significant risk of radionuclide releases to groundwater exists by iteratively applying refinements to the overall radionuclide transport model until either that no significant risk is found to exist, or that changes must be made to plant operation or design in order to reduce this risk. Clearly, the hierarchical analysis can be reliable only if based on a sound CSM.

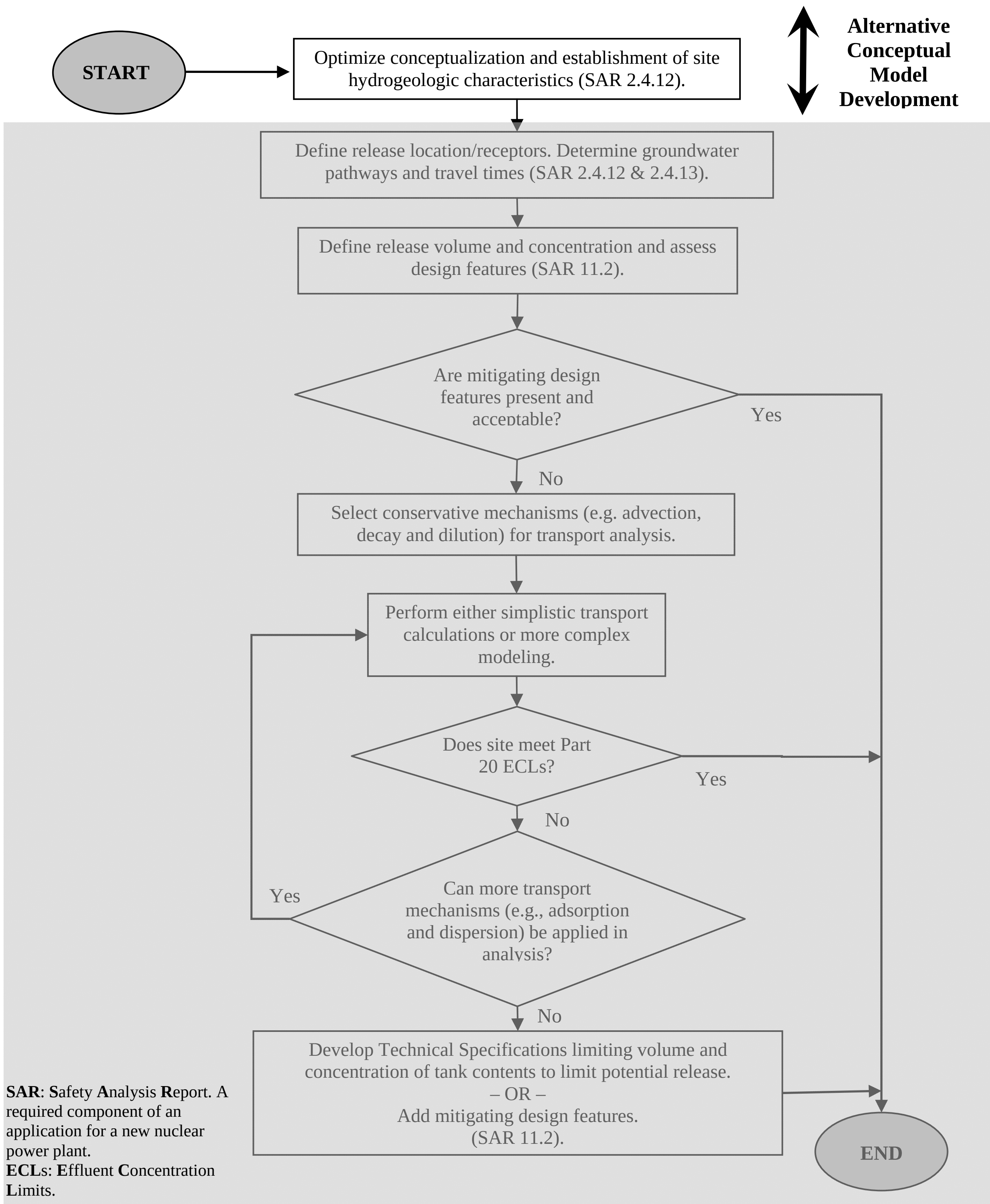


**Figure 1. Example of** the hierarchical approach for analyzing radiological consequences in groundwater based upon ISG-014.

The pre-construction stage conceptual model is based on the initial construction plans which are often modified during the actual plant construction. Therefore, the CSM can be expected to be dynamic and shaped by site alterations spanning a period of years due to construction activities and the modifications to post-construction structures and features. During construction, the hydrologic system adjusts to temporary features (e.g., sediment ponds) and newly installed plant structures and features. Post-construction conditions represent a stabilized environmental condition adapted to permanent changes to features including surface cover, topography and engineered backfill that may extend into the water table. To evaluate changes induced over several years from pre-construction through to plant operations, CSMs are ideally suited to be evolutionary to accommodate the transitory nature of the hydrogeologic flow system over the plant life.

## A REGULATORY PERSPECTIVE OF CONCEPTUAL SITE MODELS

According to the Title 10 of Code of Federal Regulations (CFR), Part 52 (10 CFR Part 52), an application for a new nuclear power plant must include a safety analysis report (SAR). The SAR must evaluate the hydrogeologic characteristics of the site to determine the effects of an accidental release of radionuclide liquid effluent on ground and surface waters, and to determine the effects of the NPP on existing known and likely future uses of ground and surface water. Therefore, the SAR submitted with the application contains an initial draft of the CSM subject to revision and amplification during the review process. The areas of regulatory review within the SAR include alternative conceptual site models, contaminant pathways, and site characteristics that affect radionuclide transport.

The application must meet the relevant requirements of Nuclear Regulatory Commission (NRC) regulations, including:

- 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," and 10 CFR Part 20, "Standards for Protection against Radiation." The specific regulatory requirement for the consequence analysis is Section 20.1302 of 10 CFR Part 20 that specifies the regulatory requirement for the combined license (COL) applicant to comply with dose limits for individual members of the public. These are the primary NRC regulations to ensure that licensees maintain adequate control over radioactive effluent discharges.
- 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," contains General Design Criterion (GDC) 60, "Control of Releases of Radioactive Materials to the Environment," and GDC 61, "Fuel Storage and Handling and Radioactivity Control." These criteria apply to the design of tanks containing radioactive material and associated components outside the reactor containment. Meeting these criteria helps assure that accidental releases during normal operations or anticipated operational occurrences will not result in radionuclide concentrations in potable water exceeding the concentration limits specified in 10 CFR 20, Appendix B.
- 10 CFR Part 100, "Reactor Site Criteria," as it relates to identifying and evaluating hydrological features of the site.

From a regulatory perspective, an applicant for a new NPP shall satisfactorily describe the processes affecting release, migration and fate of radionuclides in groundwater. The source term from a postulated accidental release is reviewed under NRC's "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition" (NUREG-0800). Specific guidance on the assumed release is in section 11.2, "Liquid Waste Management System," in particular following the guidance provided in Branch Technical Position (BTP) 11-6, "Postulated Radioactive Releases Due to Liquid-containing Tank Failures."

In keeping with the NRC's mission of ensuring the health and safety of the public, the CSM must incorporate NRC regulations and guidance into the characterization of a radionuclide release scenario based on a release that is postulated, following BTP 11-6, to be from the rupture of a tank and associated components that releases 80 percent of the volume capacity of that tank and components. The fate of the radionuclides is analyzed in terms of their potential effect on receptors such as humans or wildlife. The receptor for the release is assumed to be in the unrestricted area closest to the site (i.e., the area where access is neither limited nor controlled by the licensee).

In addition to Nuclear Energy Institute (NEI) industry publications, several NRC guidance documents including regulatory guides (RGs), technical reports (NUREG or NUREG/CR publications, interim staff guides (ISGs), and standard review plans (SRPs) have been developed to guide the applicant and staff in preparation and review of new NPP applications in areas related to groundwater. These include:

- NEI 07-07, 2007. "Industry Ground Water Protection Initiative – Final Guidance Document". Identifies an industry Ground Water Protection Initiative and associated actions to improve utilities' management and response to instances where the inadvertent release of radioactive substances may result in low but detectible levels of plant-related materials in subsurface soils and water.
- NEI 08-08, 2008. "Generic FSAR Template Guidance for Life-Cycle Minimization of Contamination". A Combined License (COL) applicant's program that is consistent with this NEI guidance document is an acceptable alternative method to RG 4.21 (NRC, 2008).
- ISG-013, (Draft). "Interim Staff Guidance on NUREG-0800, Standard Review Plan Section 11.2 and Branch Technical Position 11-6, Assessing the Consequences of an Accidental Release of Radioactive Materials from Liquid Waste Tanks for Combined License Applications Submitted under 10 CFR Part 52".
- ISG-014, (Draft). "Interim Staff Guidance on Standard Review Plan Sections 2.4.12 and 2.4.13, Assessing Groundwater Flow and Transport of Accidental Radionuclide Releases".
- NUREG/CR 6805, 2003. "A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites". Describes a strategy that embodies a systematic and comprehensive approach to hydrogeologic conceptualization, model development and predictive uncertainty analysis.
- NUREG/CR-6884, 2006. "Model Abstraction Techniques for Soil-Water Flow and Transport". The report objective is to identify, test, and confirm the practicality of various model abstraction techniques for establishing the appropriate combination of site specific models and supporting data collection programs to simulate water flow and contaminant transport through soils (i.e., the unsaturated zone).

- NUREG/CR-6948, 2007. "Integrated Ground-Water Monitoring Strategy for NRC-Licensed Facilities and Sites". Presents a logical framework for assessing what, how, where and when to monitor underground water in order to ensure that a licensed nuclear site or facility is behaving within the expected limits as described by the performance assessment.
- RG 4.21, 2008. "Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning". Describes a method acceptable to the U.S. Nuclear Regulatory Commission for use in the implementation of 10 CFR Part 20.1406, "Minimization of Contamination".

As RG 4.21 (NRC, 2008) states, the conceptual site model based on site characterization and facility design and construction can be a significant tool in (1) understanding the site, (2) planning and implementing a contaminant monitoring program, and (3) planning and implementing mitigative actions. RG 4.21 describes a method acceptable to the U.S. Nuclear Regulatory Commission (NRC) for use in the implementation of 10 CFR 20.1406, "Minimization of Contamination", and states that applicants should evaluate the system design with respect to the hydrogeology of a site before construction to (1) gather information to develop a conceptual site model, (2) assess the effect of construction on the hydrogeologic characteristics of the site, and (3) identify potential migration and ground-water transport pathways for potential environmental contaminating events. Because the original design features during the planning stage can be changed during the construction and operation stages with an anticipation to alter groundwater flow pathways and locations of associated receptor points, the conceptualization process may be re-evaluated during and after the plant construction (Figure 2). The following discussion summarizes a potential framework for conceptual model development in the context of large power plant construction projects.

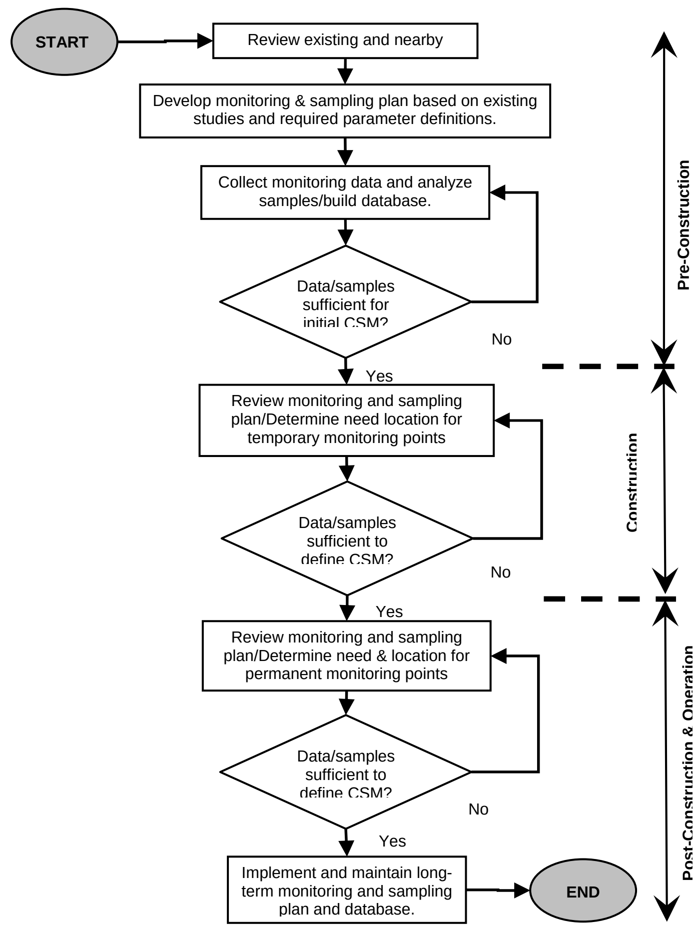


**Figure 2.** Pre-construction through post-construction conceptualization process.

## EVOLUTIONARY CONCEPTUALIZATION

For conceptualization, site modifications during construction and post-construction can be characterized by three stages: (1) pre-construction or ambient conditions; (2) construction and construction activities; and (3) post-construction when the flow system equilibrates to the NPP and associated structures.

During the site planning stage, the baseline CSM may be formulated as a starting point for model calibration and verification that is used to simulate conditions during the construction and operation stages. As new information and data become available or deviations occur in the original plant construction plans, the initial CSM could be refined and updated.

Integral to conceptualization is a monitoring and sampling plan that gathers information and data to shape the understanding of the hydrogeologic flow system for each of the three stages. Rapid changes during construction (e.g., excavations, buildings, surface impoundments) may create lasting impacts to the flow system while the flow system may partially recover from temporary construction features (e.g., construction drainage systems and sedimentation impoundments) as some land cover is restored and dewatering rates are decreased or discontinued. Therefore, the construction stage is inferred to contain the greatest relative impacts of the three stages (Figure 3).

Post-construction plant features may result in an altered hydrogeologic flow system that eventually adapts to the permanent plant features. Gaps in characterization of the conceptual model evolution can be filled by adapting the monitoring and sampling plans during each site development stage to collect the necessary hydrologic data required for determining receptor point pathways. These pathways that are postulated to occur during the proposed plant operations can be, and usually are, impacted by modifications to plant structures and associated surface features.

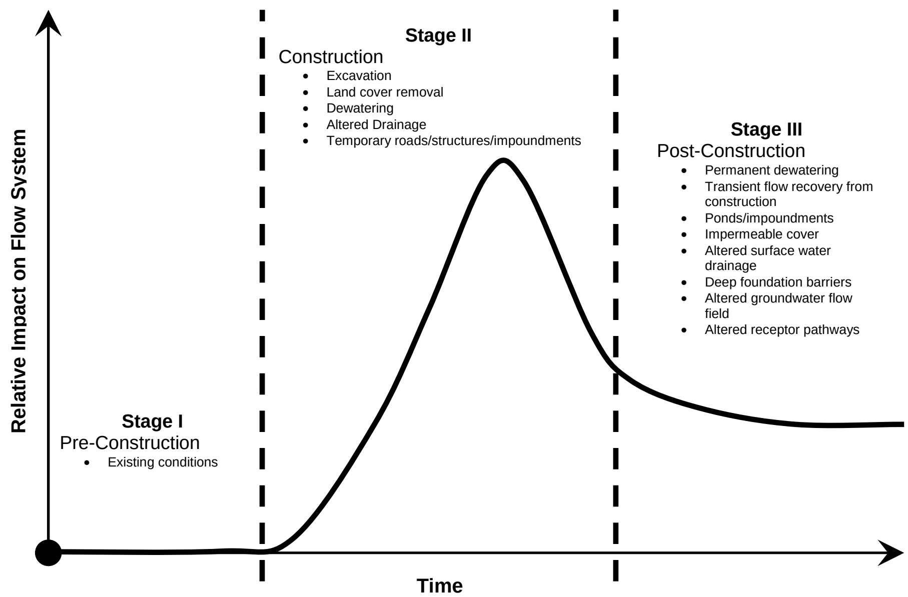


**Figure 3.** Relative impacts through time of evolving conceptual phases.

In the absence of site specific data, pre-construction conditions may be characterized by evaluating previous regional or nearby studies to determine the types of data and information that should be included in a hydrogeologic field investigation and associated monitoring plan. Intended as a supplement to site specific data, the interpolation and integration of previous studies are intended to a guide development of an on-site investigation and monitoring plan.

The characterization of pre-construction conditions establishes the base-line for estimating effects of postulated releases to receptor points, and allows evaluating the impacts to the initial hydrogeologic system during the construction and post-construction stages. Many monitoring points and sampling locations will be lost during construction and subsequent plant operations. Therefore, a well designed sampling and monitoring plan executed during the pre-construction stage to thoroughly characterize existing site conditions may include a strategy for filling the data gaps that will be created by the lost sampling points.

The potential loss of monitoring points during construction is particularly problematic given the relatively large areal extent and impact of construction activities. During construction, large (often several acre), areas of the site will be modified to accommodate plant structures, systems and components. Many pre-construction monitoring points in these areas will likely be sealed or abandoned. Where practicable, the gap of spatial and temporal monitoring points during construction should be filled with temporary monitoring (e.g., direct-push sampling) points. These temporary sampling methods are often less costly than permanent methods and are also a useful tool to reduce duration of pre-construction field investigations by focusing efforts on site areas needing further investigation.

An example of the magnitude of hydrogeologic system changes before and after construction through comparison of simulated (or predicted) post-construction conditions to observed pre-construction conditions for the Mid-Atlantic coastal plain environment is provided in Figure 4.

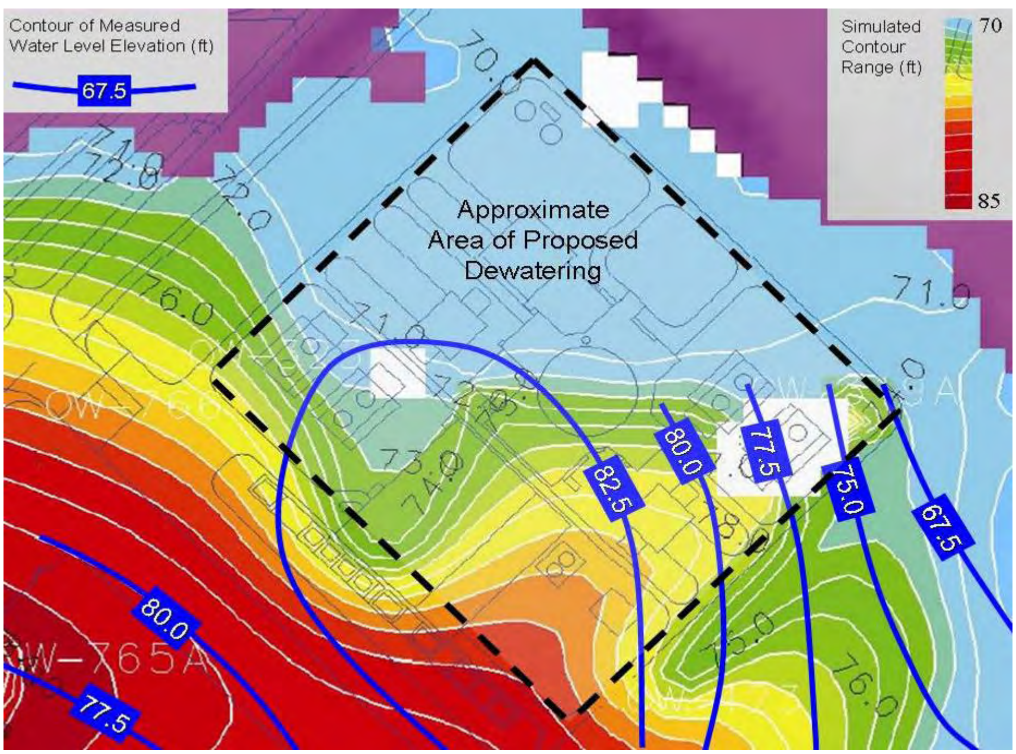


**Figure 4.** Observed water table elevations (white lines) and predicted post-construction groundwater contours (blue lines). Purple areas are no-flow model cells; white areas indicate simulated unsaturated areas.

As results indicate, significant changes may be expected in groundwater flow directions, gradients and flow velocities as a result of site modifications.

Towards the end of construction, a flow system may not have had sufficient time to reach equilibrium with newly constructed plant foundations and features. Adequate spatial and temporal coverage of the hydrogeologic regime during construction will help to determine how variations in the groundwater flow system may impact existing users, and assist in the determination of initial conditions leading into the plant operations (i.e., post-construction). For example, if the flow system is not equilibrated with plant structures due to a lag period in reaching an equilibrium with the flow system, anticipated times and rates of permanent dewatering systems would be expected to vary over the period of hydrogeologic (e.g., groundwater levels) system adjustment to plant structures and associated features. In addition, seasonal variations in hydrologic conditions superimposed over the adjustments of the hydrologic system to the plant and associated structures may be included in the consideration of the CSM development.

For post-construction, the groundwater flow field will eventually transition to accommodate the permanent plant structures and systems and alterations of the aquifer system (e.g., adjustments to the hydrogeologic flow system due to ground settling). Characterization of the post-construction conditions may help to define receptor pathways, and capture temporal changes to the flow system due to the plant geometry and associated structures. Parameters determined from pre-construction and construction phases are used in the receptor pathway estimations. The post-construction stabilization of hydrogeologic conditions can be evaluated through data trends or model simulation as compared to the pre-construction base-line. Where temporal and spatial changes indicate that impacts (e.g., changing groundwater levels) due to the plant structures are apparent, additional monitoring points may be established. Monitoring points offering no additional information or that are unchanging over time could be eliminated or abandoned.

The conceptual site model is capable of addressing both the horizontal and vertical variability of the on-site hydrogeology and the potential effect of the layout of structures, foundations, footings, and engineered backfills. A plan for implementing and updating the conceptual site model may comprise one component of the proposed facility operating procedures. Specifically, following facility construction, any impacts of site construction activities on final site hydrogeologic characteristics could be identified. If there are observable (physical or operational) changes at the site during the operating life of the facility, the conceptual site model may be re-evaluated and adjusted with appropriate adjustments/changes made to the on-site and off-site monitoring program as outlined in NUREG/CR 6805 and EPRI Report 1016099.

The final stage of the post-construction monitoring plan is be optimization of the monitoring and sampling network to detect and evaluate radiological contamination of the groundwater during the operation and post-operation of the nuclear power plants. Periodic reviews of the post-construction hydrogeology would serve to assess the uncertainty in the collected and estimated data and parameters, focus data collection efforts, and help to enhance monitoring and remediation plans for radiological contamination.

NEI 07-07 and NEI 08-08 provide are helpful in conceptual model development and the development and maintenance of site contamination monitoring plans. Currently under review, ISG-014 provides a context for developing a site conceptual model as a basis for groundwater modeling of hydrologic systems at new nuclear power plant sites. In addition to the publications specific to conceptualization for new plant sites, there is a broad bandwidth of applicable industry literature describing the conceptualization process for site conditions (e.g., ASTM D 5979 – 96, 2002 and ASTM E 1689 – 95, various U.S. EPA (http://www.epa.gov) documents and studies) from which site conceptualization for new NPP has been based.

## SUMMARY

The conceptual modeling process is important for forming the basis of a correct and fundamental understanding of site conditions, providing a sound basis for simulations to evaluate impacts to existing and future water users, and for evaluating and analyzing the consequences of a hypothetical radionuclide release within the NRC's regulatory framework. As indicated by the U.S. EPA (Bear et al., 1992), the selection of an appropriate conceptual model and the degree of simplification depends on factors including the objectives of the problem, and the applicable regulatory framework. Within the context of regulatory oversight, site conceptualization falls within the process of reviewing applications for new NPPs.

From NRC's regulatory perspective, the primary objective of a CSM is to understand the hydrologic system sufficiently to allow prediction of plausible pathways and travel times, which in turn serve as a basis for analyzing radionuclide transport in the subsurface (NUREG 800). The secondary objective of the understanding gained from a CSM includes but is not limited to the following: (1) predicting a maximum groundwater level for use in designing structures, foundations, and dewatering systems; (2) predicting the effects of water uses on the plant and unrestricted area (public) users; and (3) setting up, implementing and maintaining a groundwater monitoring program.

The CSM evolves with the site during the stages of pre-construction, construction and plant operations as new monitoring points and data become available. During the site planning stage, the baseline CSM is formulated as a starting point for model calibration and verification that is used to predict conditions during the construction and operation stages. As new information and data become available or deviations occur in the original plant construction plans, the initial CSM may be refined and updated and the simulations could be revisited for verification. Finally, to help facilitate eventual decommissioning; the CSM may assist in developing mitigation measures to minimize contamination of the facility and the environment.

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- Appendix A, "General Design Criteria for Nuclear Power Plants"
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