# AN INTEGRATED HYDROLOGIC AND GEOLOGIC STUDY TO SUPPORT MONITORING, COMPLIANCE, AND ENVIRONMENTAL RESTORATION ACTIVITIES ON THE U. S. DEPARTMENT OF ENERGY OAK RIDGE RESERVATION*

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## ABSTRACT

The U. S. Department of Energy's Oak Ridge Reservation contains three major Department of Energy research and production facilities – Oak Ridge National Laboratory, the Oak Ridge Y-12 Plant, and the Oak Ridge Gaseous Diffusion Plant. Site investigation, characterization, and remediation activities at all three facilities are localized and deal only with individual contamination occurrences related to specific sites within each facility. However, implementation of a Federal Facilities Agreement negotiated in response to the inclusion of the Oak Ridge Reservation on the U. S. Environmental Protection Agency's National Priorities List and implementation of Department of Energy Order 5400.1 require sophisticated understanding of the hydrologic systems throughout the entire Oak Ridge Reservation.

The Oak Ridge Reservation Hydrologic and Geologic Study program was initiated in October 1989 and has four components: (a) hydrologic studies, (b) geologic studies, (c) soil studies, and (d) data management. The major objectives of the program are to describe the basic features of the groundwater flow systems operative throughout the Oak Ridge Reservation, to define background and baseline hydrologic and geologic conditions throughout the Oak Ridge Reservation, and to provide state-of-the-art technical support to address regulatory concerns as they relate to contaminant migration in groundwater. The study is designed to serve as the foundation for reservation-wide geologic and hydrologic data that can be used for a variety of on-going and future studies conducted to meet the requirements of Department of Energy Order 5400.1 and the Federal Facilities Agreement. It also is designed to provide state-of-the-art technical support to address whatever regulatory concerns related to contaminant migration via groundwater that may arise during future environmental restoration activities.

## INTRODUCTION

Three major research and production facilities – Oak Ridge National Laboratory, the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 Site (formerly the Oak Ridge Gaseous Diffusion Plant) – are located on the U. S. Department of Energy's (DOE) Oak Ridge Reservation (ORR). Site investigation, characterization, and remedial actions are presently in progress at all three facilities to address groundwater contamination problems that have been identified at multiple sites within each facility. Typically, such investigations are localized and deal only with individual contamination occurrences related to specific sites within each facility. Prior to 1989 there was no integrated effort to determine the larger-scale hydrogeologic setting of the individual sites being investigated, or to determine the overall hydrogeologic characteristics of the ORR. During 1989, the entire ORR was placed on the U. S. Environmental Protection Agency's (EPA) National Priorities List. In response to this action, a Federal Facilities Agreement (FFA) was negotiated between DOE, EPA Region IV, and the Tennessee Department of Health and Environment. Implementation of the terms of the FFA and of DOE Order 5400.1 (1) requires a sophisticated understanding of the hydrologic systems of the ORR. It is therefore prudent to assemble and develop relevant data at this time so that regulatory

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demands can be addressed in the most effective and efficient manner. This is especially true for representative geologic and hydrologic data, which require long periods of time to gather for an area as hydrologically and geologically complex as the ORR.

The Oak Ridge Reservation Hydrologic and Geologic Study (ORRHAGS) project, initiated in 1989, has as its major objectives (a) elucidation and characterization of the basic features of the groundwater flow systems throughout the ORR; (b) definition of background and baseline hydrologic and geologic conditions throughout the ORR; and (c) to provide state-of-the-art technical support to address regulatory concerns related to contaminant migration in groundwater. The study is designed to provide reservation-wide geologic and hydrologic data that can be used for a variety of on-going and future site-specific studies conducted to meet the requirements of the FFA and DOE Order 5400.1.

This purpose of this paper is to summarize the ORRHAGS project and to provide an overview of its activities to date. For background purposes, a brief summary of ORR hydrogeology is provided in the next section of the paper, and subsequent sections provide a description of four components of the ORRHAGS project.

## HYDROGEOLOGIC SETTING OF THE DOE OAK RIDGE RESERVATION

The ORR is located in the Valley and Ridge province of the Appalachian orogenic belt, characterized from Alabama through Pennsylvania by a series of regional thrust faults. Motion along the faults during the Alleghenian orogeny formed a series of northeast-striking, imbricate thrust sheets that repeat numerous times a stratigraphic succession consisting of sandstones, shales, and limestones. Within the sediments of each of the imbricate thrust sheets there is a significant amount of smaller-scale folding and faulting that results in a complex structural fabric.The strike of strata at the sites ranges from N 45° to N 55° E and dip ranges from 10° to 55° SE.

Because of the thrust fault geometry of the ORR, the stratigraphic units crop out in northeast-to-southwest-trending linear belts. Major stratigraphic units on the ORR are of Lower Paleozoic age, and include the Chickamauga Group, the Knox Group, the Conasauga Group and the Rome Formation. The Chickamauga Group, total thickness 500 to 700 m, is lithologically variable and consists of alternating sequences of medium- to thinly-bedded limestones and thinly-bedded calcareous shales and siltstones. The Knox Group, total thickness of 800 to 900 m, consists primarily of massive to thickly bedded siliceous to nonsiliceous dolostone with subordinate amounts of nodular-to-bedded chert and thinly-bedded limestone. The Conasauga Group, 500 to 600 m thick, like the Chickamauga Group, is lithologically variable and is comprised of an alternating sequence of limestones and calcareous and noncalcareous shales with subordinate siltstones. The Rome *Formation*, 100 to 250 m thick, consists of massive sandstones, thinly bedded siltstones and laminated shales and mudstones. For a more complete discussion of various aspects of Oak Ridge Reservation geology see Refs. 2, 3, 4 , 5, 6.

Groundwater movement throughout the ORR is complex and spatially variable. Groundwater occurs in fractured bedrock and in the overlying weathered unconsolidated material that in places retains relict fractures and other structural features . Generally, there is no sharp distinction in hydraulic characteristics between between bedrock and overburden. In bedrock, groundwater movement is in restricted to fractures, which are present in sets oriented perpendicular to, parallel to, and at high-angles to bedding. Discrete, individual fractures occur throughout all strata and are locally concentrated in 1- to 20-cm-thick zones; pervasively fractured, 0.2- to 1.5-m-thick intervals also occur sporadically. Because of fracture control, permeability of bedrock varies areally and with depth, and is anisotropic. Aquifer tests to determine hydraulic properties in the more clastic units are typified by very low yields (generally less than five gallons per minute) and ellipsoidal water-level cones of depression, elongated parallel to geologic strike. These observations have been interpreted by investigators to reflect the low permeability and strong anisotropy of the formations where bedding planes provide preferred groundwater flow paths along strike.

Groundwater movement within the Knox Group and the immediately underlying carbonate strata of the Conasauga Group occurs in more or less solutionally enlarged fractures. Commonly, the water-bearing capacity of these rocks has been greatly enhanced by karst development along features such as fractures, joints, and bedding planes. This karstified system forms the major source of groundwater discharge to streams throughout the ORR. Local karst conditions are present in some strata of the Chickamauga Group. Additional details of ORR hydrogeology are contained in references (7, 8, 9)

## ORRHAGS COMPONENTS

ORRHAGS activities are aimed at providing basic information on hydrological and geological processes of the ORR. The scope and time-frame of such activities are established by their application to compliance-driven environmental monitoring and restoration activities. As such, most activities are anticipated to have durations ranging from 1 to 3 years. The major emphasis of ORRHAGS activities is process delineation rather than site characterization. The objective of ORRHAGS in this regard is to identify and describe the mechanisms by which major hydrologic processes operate to control contaminant

migration. Additionally, key parameters associated with these processes will be identified and ranges of values for such parameters will be determined. Most site characterization activities on the ORR are supported by specific environmental monitoring or remediation programs, and information obtained by these programs will be used to support ORRHAGS activities. Characterization activities will be undertaken by ORRHAGS only in those situations where the appropriate data are unavailable or will not be obtained by other characterization programs.

The four components of the ORRHAGS program are: (1) hydrologic studies, (2) geologic studies, (3) soil studies, and (4) data management. Because of basic relevance to ongoing and planned monitoring, compliance, and remediation activities, the major focus of ORRHAGS is the hydrologic studies. The other components of the program are designed to support activities within the hydrologic studies component.

## Hydrologic Studies

Key objectives of this task are to (a) develop a reliable, effective conceptual model for the the fracture-flow dominated hydrologic system on the ORR, (b) evaluate the statistical distribution of values for key hydrogeological flow properties and processes and chemical parameters,and (c) evaluate numerical techniques that can be applied to groundwater and associated contaminant movement of the ORR.

Identification of a practical conceptual model of hydrologic system properties and processes on the ORR will allow the overall importance to contaminant transport to be assessed. The conceptual model will provide the basis for additional studies that may be required to more accurately define the role of specific hydrogeologic regimes in ORR groundwater and contaminant movement patterns. One example of the type and scope of studies to be undertaken in this activity is the analysis of conduit flow systems in karstified regions of the ORR. The potential for rapid flow over considerable distance in the ORR has been documented in previous studies (3). Such flow occurs through fractures and solution cavities which are likely rapid-exit pathways for contaminant transport from the waste areas located in karst areas. It has been shown elsewhere that application of standard groundwater monitoring approaches in solution-dominated terranes is generally of limited use and that large-scale reconnaissance of springs and associated stream systems provides a more defensible method for acquiring basic information (10). The key principle for characterizing groundwater flow in these systems is to adopt a framework that encompasses major features that extend well beyond individual drainage basins. Analysis of such systems, beyond the scope of the site-specific studies, is within the scope of the ORRHAGS program.

Another major ORRHAGS activity is a complete review of all applicable ORR hydrogeological and environmental data and an assessment of the data adequacy; this can be used to identify the need for additional studies and the ability to respond to regulatory requirements. This data assessment activity is technical in nature and requires rather extensive effort, since it is a basis for planning and implementation of the ORR analysis and characterization activities in an orderly fashion. There must be continual information interchange between this activity and characterization activities sponsored by compliance monitoring and environmental restoration activities at the three facilities on the ORR. During the the initial phase of ORRHAGS, systematic analysis of relevant hydrologic and geologic data on the ORR will identify major data gaps, for which a plan will be formulated to address them. Additionally, hydrologic data, such as groundwater flow parameters and chemical data will be statistically analyzed to determine characteristic or baseline values for each of these parameters in different portions of the flow system.

Numerical modeling of fracture-flow dominated hydrogeologic systems like that at the ORR is technically demanding and at the edge of state-of-the-art modeling knowledge (11). Several computer codes are available, each with its own set of simplifying assumptions and range of applicability. The ORRHAGS program is undertaking an evaluation these codes to determine which is most appropriate for conditions on the ORR. During initial phases of this activity, test areas will be identified that cover the range of hydrologic conditions observed on the ORR. Hydrologic data obtained from these areas will be modelled using available computer codes, and the performance of the codes will be evaluated to determine which is best suited to a given set of site conditions.

## Geologic Studies

Major objectives of the geologic studies activity are (a) production of a state-of-the-art geological map for the ORR and (b) analysis of formation and distribution of structural features throughout the ORR that control the development of secondary permeability necessary for groundwater flow. Results from these activities support the hydrologic studies component by helping to define the link between groundwater behavior and site geology.

A modern geologic map of the ORR is a mandatory ingredient for the ORRHAGS program. This map will contain final stratigraphic nomenclature for geological formations throughout the ORR and will illustrate the distribution of geologic formations (not simply groups of stratigraphically related formations that may have very different characteristics). Because the present map of the ORR (2), completed in 1963, does not contain the needed detailed information to quantify geological influence on

ORR hydrologic systems, preparation of an updated geological map is considered a high priority and is currently approaching completion.

A detailed summary and analysis of structural features that occur throughout the ORR is required. Structural features on various scales are directly related to the hydrology of the ORR. Joints, bedding planes, and small-scale ($\leq$ 3m) fractures define groundwater movement; an understanding of the distribution and occurrence of such features is essential. Larger scale (> 10m) structures, such as folds and faults, can be locally important conduits for or barriers to groundwater flow. A knowledge of the paragenesis and distribution of these features is essential to evaluation of the their relationship to groundwater flow throughout the ORR.

## Soil Studies

The objectives of the soil studies component are (a) production a state-of-the-art soils map for the ORR and (b) compilation of background soils physical and chemical properties and chemical data for the various soil types occurring throughout the ORR. Unlike the other components of the ORRHAGS program, activities within the soil studies are largely characterizational in nature. Like the information obtained in the geologic studies, however, information from the soil studies is aimed at supporting activities conducted in the hydrology component of the program.

Similar to completion of a detailed geologic map, production of a modern soils map of the ORR is an important ingredient of the ORRHAGS program. The map will serve to define a complete soils nomenclature for the ORR and provide a definitive description of the soils types throughout the ORR. Because soils properties and chemistry influence groundwater behavior within the upper portion of the aquifers on the ORR, preparation of the map has a high priority and is currently in progress.

## Data Management

There are many data bases that contain usable geologic and hydrologic data for the ORR at ORNL, Y-12, K-25, and elsewhere. Comprehensive availability of existing data on hydrogeological characterization of the ORR and the ability to expeditiously store, retrieve, and analyze all relevant data is essential to the success of a study of this nature. At this time there is incomplete knowledge of the nature and extent of geologic and hydrologic data available for the ORR.The major objectives of the data management component are (a) to make available a consolidated hydrogeological data base that contains all hydrological and geological data available for the ORR, and (b) to develop data management procedures for data from studies by other components of ORRHAGS and from the many site characterization studies conducted for compliance purposes throughout the ORR. The data base produced by this component of the ORRHAGS program will be a major resource to researchers working within ORRHAGS and to related projects throughout the ORR.

It is expedient to select a data management system that interfaces with others and that is easily accessed by investigators. The nature and extent of the relevant data are being assessed and an appropriate management system will be identified. Protocols to allow the transfer of data to ORRHAGS investigators in appropriate formats will be established. An additional concern of this activity is the development of protocols to manage data generated by ORRHAGS projects. In addition to compilation of the data base, interfaces with ArcInfo, a Geographic Information System (GIS), are being developed to allow rapid and flexible display of hydrogeological data.

This is a high priority activity and its completion precedes most of the other activities. It is not the objective of ORRHAGS to assume a centralized data management function for any of the ORR facilities or for the Environmental Restoration Program (ERP). To the greatest extent possible, however, ORRHAGS must use existing data bases and must coordinate data retrieval and management activities with the ERP.

## SUMMARY

The Oak Ridge Reservation Hydrologic and Geologic Study (ORRHAGS) project, established in October 1989, has the major objectives of (a) elucidation and characterization of basic features of the groundwater flow systems operative throughout the ORR; (b) definition of background and baseline hydrologic and geologic conditions throughout the ORR; and (c) provision of state-of-the-art technical support to address regulatory concerns related to contaminant migration in groundwater. It is designed to provide a state-of-the-art technical foundation designed to address regulatory concerns related to contaminant migration via groundwater.

Hydrologic studies, the major focus of ORRHAGS, will identify and evaluate the key hydrologic flow properties and processes and chemical parameters, define the character of hydrologic flow systems of the ORR, and evaluate numerical technics that can be used to model groundwater and associated contaminant movement on the ORR.

ORRHAGS will soon produce a state-of-the-art geological map for the ORR, including final stratigraphic nomenclature for geologic units throughout the ORR and a detailed summary of structural features throughout the reservation.

The soil studies component will provide a state-of-the-art soils map for the ORR, and will summarize background

chemical data for the various soil types occurring throughout the ORR.

The data management component is consolidating the extensive ORR data bases to make readily available all hydrogeologic data and is developing management techniques for data produced by studies conducted for other tasks within ORRHAGS. The data base produced by this task will be a major resource to researchers working within the other tasks of ORRHAGS and to other projects throughout the ORR.

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