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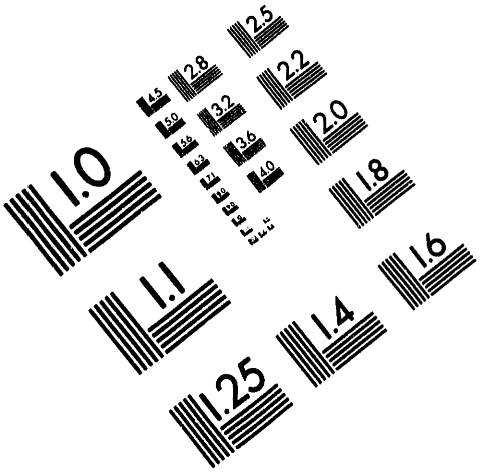

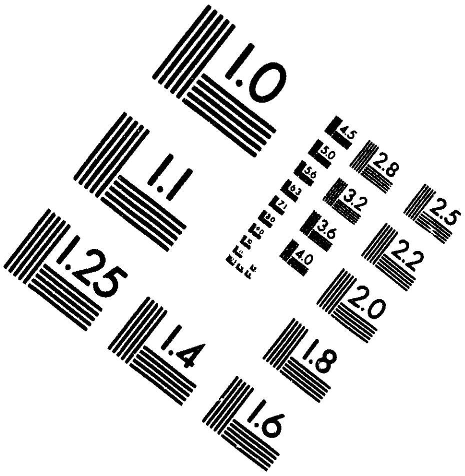

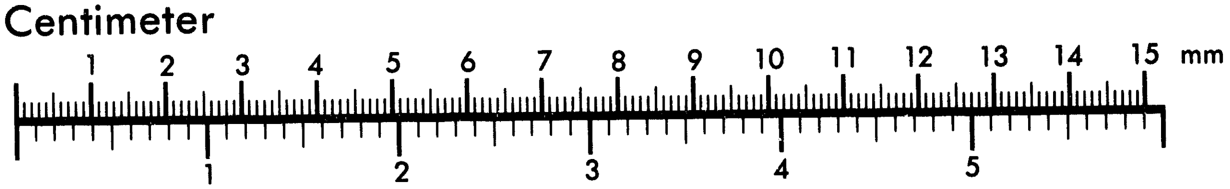

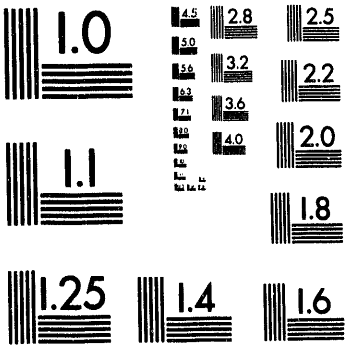

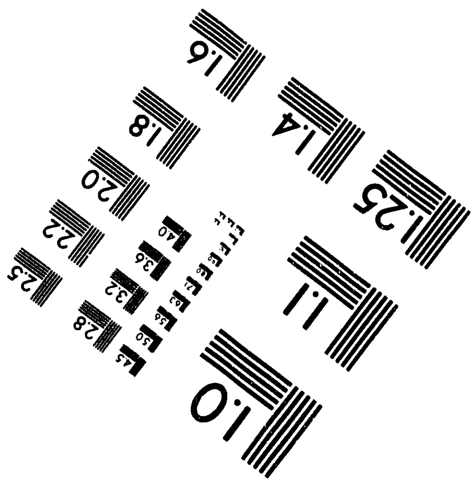

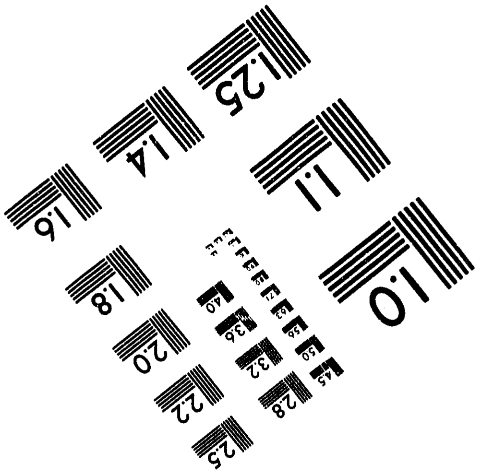

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ORNL/GWPO-005

ENVIRONMENTAL SCIENCES DIVISION GROUNDWATER PROGRAM OFFICE ANNUAL REPORT FOR FISCAL YEAR 1993

September 30, 1993

Prepared by the
Environmental Sciences Division
Oak Ridge National Laboratory
ESD Publication 4285

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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CONTENTS

FIGURES

ABBREVIATIONS

CERCLA	Comprehensive Environmental Restoration, Compensation and Liability Act
DOE	U.S. Department of Energy
DOE-OR	U.S. Department of Energy Oak Ridge Site Office
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
FY	Fiscal Year
GWPO	Groundwater Program Office
GWPP	Groundwater Protection Program
IAG	Interagency Agreement
IRM	Interim Remedial Measure
MMES	Martin Marietta Energy System
OREIS	Oak Ridge Environmental Information System
ORHSP	Oak Ridge Hydrology Support Program
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
ORRHAGS	Oak Ridge Reservation Hydrology and Geology Studies
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
RCRA	Resource Conservation and Recovery Act
RMO	Resource Management Organization
TDEC	Tennessee Division of Environment and Conservation
UST	Underground Storage Tank
WSRC	Westinghouse Savannah River Corporation

EXECUTIVE SUMMARY

This first edition of the Martin Marietta Energy Systems, Inc., (Energy Systems) Groundwater Program Annual Report summarizes the work carried out by the Energy Systems Groundwater Program Office (GWPO) for fiscal year (FY) 1993. The GWPO is responsible for coordination and oversight for all components of the groundwater programs at the three Oak Ridge facilities [Oak Ridge National Laboratory (ORNL), the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 Site], as well as the Paducah and Portsmouth Gaseous Diffusion Plants (PGDP and PORTS, respectively.)

This report describes the administrative framework of the GWPO including staffing, organization, and funding sources. In addition, summaries are provided of activities involving the Technical Support staff at the five facilities. Finally, the results of basic investigations designed to improve our understanding of the major processes governing groundwater flow and contaminant migration on the Oak Ridge Reservation (ORR) are reported. These investigations are conducted as part of the ORRHAGS program. The relevance of these studies to the overall remediation responsibilities of Energy Systems is discussed.

1. INTRODUCTION

1.1 PURPOSE

This first edition of the Martin Marietta Energy Systems, Inc., (Energy Systems) Groundwater Program Annual Report summarizes the work carried out by the Energy Systems GWPO for fiscal year (FY) 1993. This introductory section describes the GWPO's staffing, organization, and funding sources. The GWPO is responsible for coordination and oversight for all components of the groundwater program at the three Oak Ridge facilities [ORNL, the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 Site], and the PGDP and PORTS, respectively.

Several years ago, Energy Systems senior management recognized that the manner in which groundwater activities were conducted at the five facilities could result in unnecessary duplication of effort, inadequate technical input to decisions related to groundwater issues, and could create a perception within the regulatory agencies of a confusing and inconsistent approach to groundwater issues at the different facilities. Extensive interactions among management from Environmental Compliance, Environmental Restoration (ER), Environmental Sciences Division, Environmental Safety and Health, and the five facilities ultimately led to development of a new technical umbrella organization for groundwater. On April 25, 1991, the GWPO was authorized to be set up within ORNL thereby establishing a central coordinating office that would develop a consistent technical and administrative direction for the groundwater programs of all facilities and result in compliance with all relevant U.S. Environmental Protection Agency (EPA) regulations such as RCRA and Comprehensive Environmental Restoration, Compensation and Liability Act (CERCLA) as well as U. S. Department of Energy (DOE) regulations and orders. For example, DOE Order 5400.1, issued on November 9, 1988, called for each DOE facility to develop an environmental monitoring program for all media (e.g., air, surface water, and groundwater). With respect to groundwater, the requirements of this Order go beyond regulations promulgated by the states and the EPA.

In addition to an administrative coordination and oversight role, the GWPO has a technical mission that is fulfilled by the Oak Ridge Hydrology Support Program (ORHSP). The coupling of the technical functions of ORHSP with the program management functions of the GWPO is both a unique feature and a strength of the current groundwater program.One component of the technical mission of ORHSP is the responsibility for providing technical support to the five site Groundwater Programs to ensure consistency of approach and technical sufficiency. Hydrogeologists on the staff of ORHSP work directly with the site Groundwater Programs providing a broad range of technical assistance.

ORHSP also sponsors a spectrum of basic hydrogeologic investigations designed to develop a fundamental understanding of groundwater flow and contaminant migration on the ORR that can directly impact potential remediation strategies. These investigations are performed by a team of scientists associated with the ORRHAGS group. ORRHAGS was established because geologists and hydrogeologists working on the ORR have recognized for many years that the geology and hydrology of this region is complex and the ability of groundwater programs on the Reservation to successfully meet regulatory requirements depends on enhanced knowledge of how groundwater flow, geology, and contaminant migration interrelate. Several examples of benchmark investigations undertaken by ORRHAGS staff include completion of a revised geologic map of the ORR (R. D. Hatcher et al., 1992) and a conceptual groundwater flow model for the reservation (Solomon et al. 1992). In addition, an update to the conceptual model was issued recently (Moore et al. 1993).

In summary, the GWPO has developed a groundwater program that:

- complies with all applicable federal and state environmental laws, DOE orders, Executive Orders, and Energy Systems policies and procedures;
- is comprehensive and technically sound;
- ensures consistency of well installation, development, sampling, maintenance, plugging and abandonment, and data management and reporting throughout Energy Systems;
- ensures consistency in the technical approach that is used for all components of the groundwater program at all sites;
- provides a basis for trend analysis and predictive capability; and
- effectively communicates with DOE, EPA, the states, and the public.

1.2 ORGANIZATION

Figure 1 illustrates the organization of the Energy Systems GWPO. There are three key components of this organization: ORHSP, Site Groundwater Protection Programs (GWPP), and Energy Systems central organizations.

GWPO provides the overall administrative coordination for the Energy Systems groundwater program. ORHSP is responsible for the leadership and technical coordination of the program (e.g., Technical Support staff and generic studies conducted by ORRHAGS) that benefit each site. The Environmental Surveillance activities of ORHSP are limited to oversight and coordination of site environmental surveillance activities as defined in DOE Order 5400.1. Figure 2 presents a more detailed organization of ORHSP.

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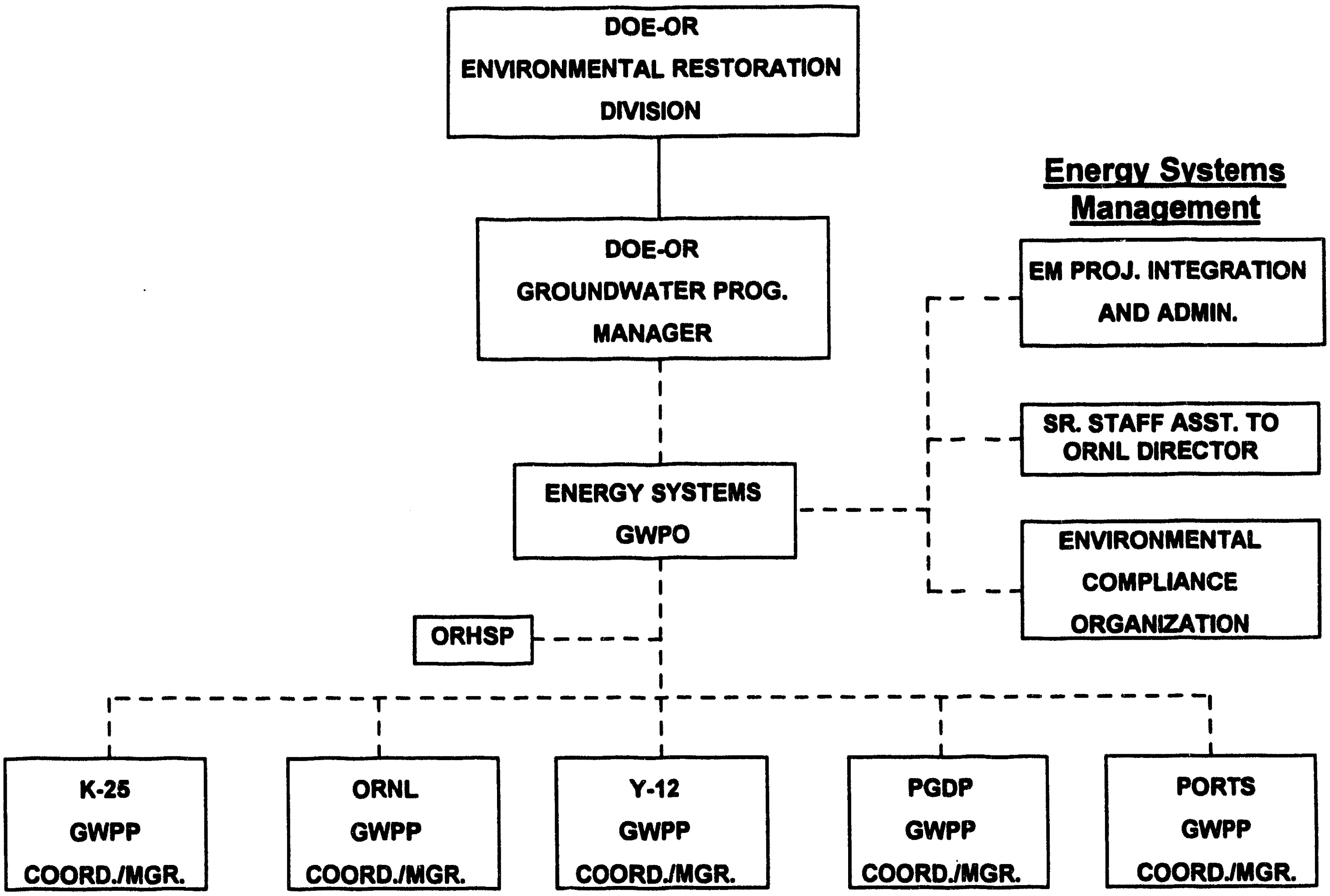

Figure 1. Organization chart illustrating the relationship between GWPO, DOE-OR, Energy Systems Management, and the GWPP coordinators managers.

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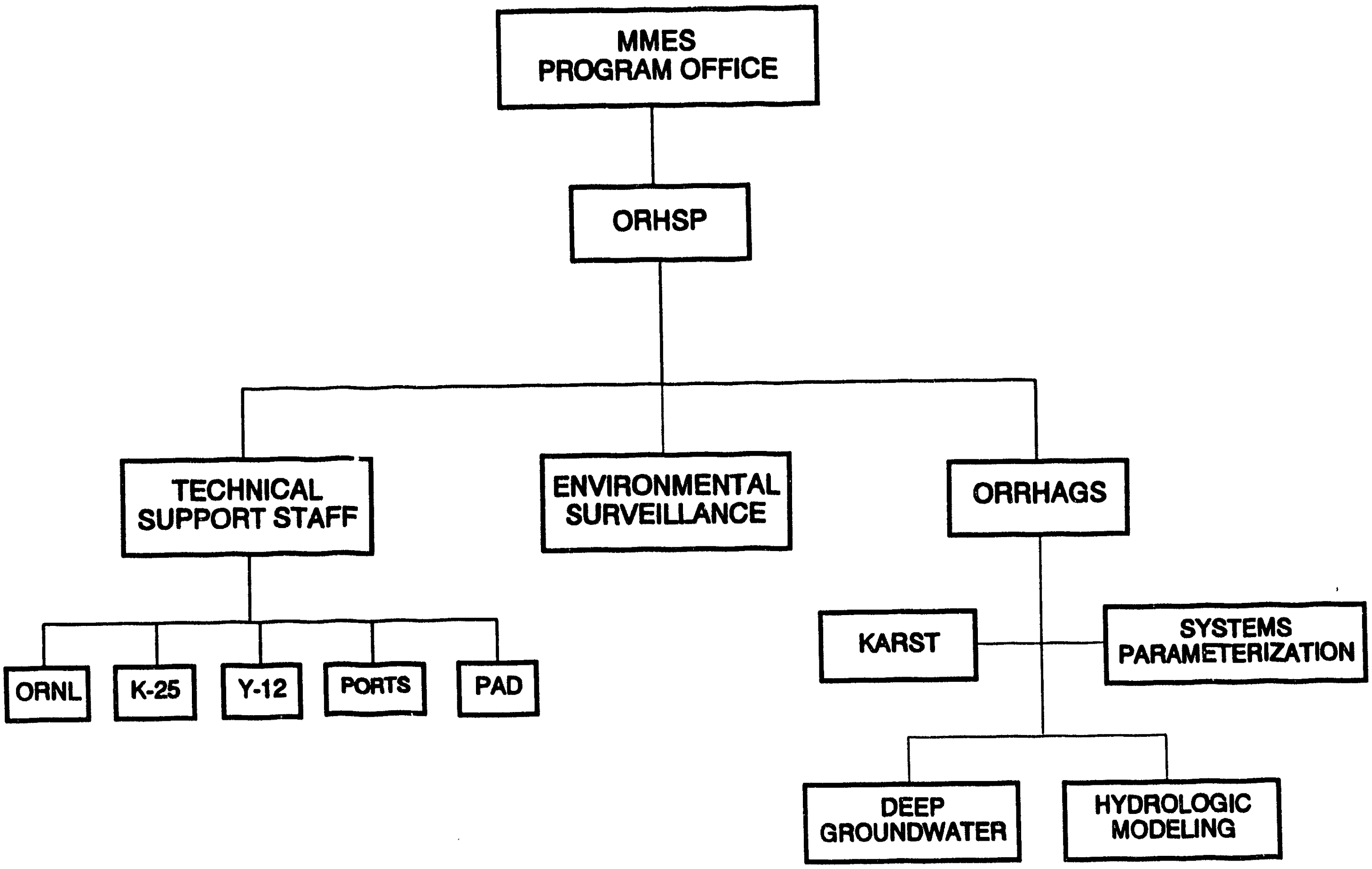

Figure 2. Organization chart illustrating the components of ORHSP.

1.2.1 Relationship of GWPO to Site GWPPs

Each site has a GWPP coordinator/manager[1] who is responsible for integrating all components of the groundwater program at that site. Because groundwater programs are spread among several organizations (primarily site Compliance and ER organizations), the GWPP coordinator/manager guides all of these individual programs to promote consistency and efficiency.

GWPO interfaces with each of the five Energy Systems facilities through the respective site GWPP coordinators/managers. The GWPP coordinator/manager is the single point of contact at each facility for all activities related to groundwater. The GWPP coordinator/manager has established a matrix organization for administrative purposes that includes those functions associated with groundwater (Compliance, ER, Waste Management, Engineering, quality assurance, field sampling, and laboratory analysis).

The site groundwater programs include certain monitoring activities that lie beyond the boundaries of DOE land. For example, studies being conducted along East Fork Poplar Creek and off-site monitoring associated with the environmental monitoring plans fall into this category. In addition, certain parts of the DOE land on the ORR are the direct responsibility of organizations other than Energy Systems. To ensure that all parts of the ORR have groundwater oversight, key groundwater personnel from each of the ORR sites subdivided all DOE land into areas of groundwater oversight responsibility for respective GWPP coordinators/managers. Insofar as possible, the boundaries between areas of responsibility are defined by natural surface-water and groundwater flow divides. The GWPP coordinator/manager oversees any activity related to monitoring well installation (location, depth, or purpose), well inspection, maintenance, plugging and abandonment, groundwater sampling, analyses, data interpretation, and reporting within his/her area of responsibility.

As a result of extensive investigations during the past 5 years, especially on the ORR (e.g., Solomon et al. 1992), it has become apparent that a close relationship exists between the shallow groundwater flow system (and associated contaminant migration) and surface water. Consequently, the GWPPs at each site establish the appropriate interfaces with the surface water program to ensure that surface water-groundwater interactions are addressed.

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[1] Recent reorganization of the groundwater programs at three Energy Systems sites will result in formation of a groundwater organization headed by a GWPP Manager with line responsibilities and authority for implementing all groundwater programs. The other two sites preferred to retain a more decentralized groundwater organization in which the different components are linked by a GWPP Coordinator. With respect to insuring integration of the site groundwater programs, the roles and responsibilities of both the GWPP Manager and Coordinator are identical.

1.2.2 Relationship of GWPO to ORHSP

ORHSP represents a key technical support component of the Energy Systems groundwater program. Jointly, GWPO and ORHSP provide the site GWPPs with an integrated approach to groundwater issues; GWPO provides administrative guidance and ORHSP is responsible for the direct technical leadership. Three components comprise ORHSP: Technical Support, Environmental Surveillance, and ORRHAGS. The organization chart for ORHSP is presented in Figure 2. For the Technical Support function, ORHSP has assigned a team of technically qualified hydrogeologists to work with the GWPP coordinators/managers. They assist the GWPP coordinators/managers in all technical questions related to groundwater and serve as a conduit for communicating technical guidance related to the site groundwater programs. The scope of their involvement includes but is not limited to:

- assisting in planning, review, and technical guidance for groundwater (and closely related surface water) projects;
- reviewing geologic, hydrologic, and geochemical data obtained by the site groundwater program, assisting in its evaluation and integrated analysis;
- reviewing procedures to ensure their consistency;
- participating in meetings with regulators and the site environmental advisory committee;
- assisting in audits of the technical components of the groundwater program;
- reviewing technical documents developed by the plant and their subcontractors;
- preparing selected documents; and
- providing an interface between ORRHAGS and the site groundwater programs.

The environmental surveillance component of ORHSP is intended to ensure consistency and technical sufficiency for surveillance activities mandated by DOE Order 5400.1. With respect to groundwater, environmental surveillance refers to perimeter and exit pathway monitoring that ensures contaminants associated with groundwater are not crossing facility boundaries and that the location and extent of potential contaminant migration pathways are well-defined. Environmental surveillance also includes privately owned domestic water supply wells located beyond the boundaries of DOE land. The strategy to be followed for environmental surveillance of groundwater for the Energy Systems facilities is described by Forstrom (1990b). Draft Environmental Surveillance Plans for groundwater have been prepared for each site.

As noted, ORRHAGS is a component of ORHSP that, as originally defined, is responsible for developing a fundamental understanding of the underlying principles that control groundwater flow and contaminant migration on the ORR. These studies included revision of the geologic map and development of a soils map for the ORR, evaluation of background hydrochemical properties of groundwater, development of appropriate computer models and data bases for ORR applications, and exploration of the interaction of the hydrologic and geologic regimes on contaminant migration. With the incorporation of ORRHAGS into ORHSP, the scope of the ORRHAGS activities is expected to expand in the future to include the Paducah and Portsmouth facilities.

Technical support personnel of ORHSP communicate to ORRHAGS the technical problems at each site and work with the GWPP coordinator/manager to understand and implement the results of ORRHAGS technical studies into site groundwater programs. The ORHSP staff resides in the Environmental Sciences Division at ORNL and also employs scientists from academic institutions. The management of the GWPO and ORHSP also resides within the Environmental Sciences Division.

1.3 FUNDING SOURCES

GWPO and ORHSP are funded from two sources. During FY 1993, approximately 50% of the required support came from the ER Division. The other component of funding for GWPO and ORHSP is provided by the Corporate Services function of MMES which funds other multi-site programs.

GWPO and ORHSP work directly with the ER Program, the site GWPP coordinators/managers, and ORNL's financial organization to develop scopes of work, budget requirements, performance schedules, and appropriate milestones and deliverables. GWPO and ORHSP also are responsible for budget tracking and preparation of financial reports to support financial audits and budget validation activities.

The site GWPPs are funded by each facility in a manner deemed appropriate by the site. Funding responsibilities may be shared by the major components of the site groundwater programs (i.e., ER and Compliance) or be covered by a single organization.

2. GWPO ACTIVITIES DURING FY 1993

One of the primary reasons that GWPO was established was to provide a single point of contact for and improve communications among the different components of the groundwater program within Energy Systems (e.g., among the sites and between site Compliance and ER programs) and between Energy Systems and the U.S. Department of Energy Oak Ridge Site Office (DOE-OR), the regulatory agencies, and the public.

2.1 COORDINATORS' MEETINGS

Every two to three months the GWPO sponsors a meeting for the benefit of the groundwater programs at the three facilities managed by MMES and the two managed by Martin Marietta Utility Surfaces for DOE. Attendance at these meetings includes the staff of the GWPO, the site Groundwater Coordinators, representatives of the MMES ER Program and Environmental Compliance organization, the DOE-OR Groundwater Program Manager, a representative of the DOE-OR Environmental Protection Division, and other interested individuals. The objectives of these meetings are to:

- provide a forum for each site Groundwater Coordinator/Manager to review progress on groundwater-related activities at his/her site and to take advantage of lessons learned to build consistency into the overall program;
- inform attendees about relevant meetings, workshops, and regulatory issues that may have an impact on the site groundwater programs;
- introduce information on new characterization and remediation technologies that might be beneficial to the sites;
- demonstrate applications of software that might assist the sites in data management and mapping requirements, and
- review the progress of basic investigations being conducted by scientists associated with ORRHAGS.

2.2 PROJECT MANAGEMENT PLAN

The GWPO recently completed a management plan for the Energy Systems Groundwater Program (Early, T. O. 1993). The purpose of this plan is to identify the primary objectives of the GWPO, present the organization chart, and define the roles, responsibilities, and authority of the key people in the program including the GWPO, ORHSP, and ORRHAGS staff and the site Groundwater Coordinators. This plan has been approved by the plant manager at each facility as well as the MMES Vice Presidents for Environmental Compliance and ER and Waste Management.

2.3 PGDP PUMP AND TREAT EVALUATION

In March, 1992 the GWPO was asked to participate in the evaluation of a pilot pump-and-treat project that had been proposed for the Northwest contaminant plume at the Paducah Gaseous Diffusion Plant (PGDP). The Northwest Plume is a region in which groundwater in the Regional Gravel Aquifer (RGA) is known to be contaminated with TCE and Tc-99. It was suspected that the source of contamination might involve a dense nonaqueous phase liquid which would significantly affect any decision on defining appropriate remediation methods. DOE had proposed to EPA that a pilot-scale pump-and-treat project could demonstrate the feasibility of this process to control and remediate the plume.

Several members of the GWPO participated on a team composed of DOE-OR and MMES personnel to evaluate the proposal. In an initial report (Bodenstein et al, 1992) the team attempted to clarify the goals of the project and evaluate the adequacy of existing data in reaching a decision on the value of the project. The team recommended that PGDP acquire additional data on the plume before the pump-and-treat option could be fully evaluated. During October, 1993 the additional data were collected and showed that a dense nonaqueous phase liquid is present in the RGA near the source of the contaminant plume. Consequently, the team recommended that the initial focus should be on source containment and that plume control or remediation should be of secondary importance (Bodenstein et al, 1994).

The team recommended that there are technically feasible and more cost effective alternatives that may be preferable to the pump-and-treat option. However, the current plan calls for PGDP to install two pumping wells near the source of the plume and two more down-gradient wells near the distal end of the most contaminated part of the plume to contain the contamination. Treatment of pumped water will be accomplished by a combination of air stripping and ion exchange. In addition, PGDP will explore the practical application of other, innovative technologies such as the use of zero valence metals (e.g. iron) in a permeable, reactive wall as a replacement to the pump-and-treat process. A focused feasibility study for source control of the Northwest Plume has been prepared and it appears to favor a hydraulic containment option.

2.4 TECHNICAL EXCHANGES WITH THE REGULATORS

During FY 1993 the Groundwater Program staff interacted with personnel of the Tennessee Division of the Environment and Conservation (TDEC). These interactions were largely related to discussions associated with the development by MMES of a comprehensive groundwater program as specified in the Tennessee Oversight Agreement and with issues related to the adequacy of the surface water monitoring program on the ORR. In addition, the Technical Support staff periodically is involved in discussions with TDEC and similar state regulatory agencies in Kentucky and Ohio in their capacity as technical advisors to the groundwater programs at the five facilities. Likewise, there are similar interactions with the US EPA in Region IV (Tennessee and Kentucky).

In FY 1992 the GWPO initiated a technical information meeting with TDEC and EPA

(Region IV) technical staff in order to discuss our conceptual understanding of groundwater flow and contaminant migration on the ORR. The purpose of this meeting was to describe the technical basis for the conceptual model consider some of the implications of the most important processes to remediation of contaminated groundwater on the Reservation. It is our intent to make this technical information meeting an annual event where results of ongoing research are presented and the impact of these investigations on the conceptual model is discussed. We attempted to schedule a meeting in September, 1993, but conflicting schedules of participants prevented it from taking place. The technical information meeting is being rescheduled for early in FY 1994.

2.5 INTERACTION WITH WESTINGHOUSE SAVANNAH RIVER GROUNDWATER PROGRAM

For the past year the Energy Systems Groundwater Program has participated in quarterly technical information exchange meetings with Westinghouse Savannah River Corporation (WSRC). The ER Programs at WSRC and Energy Systems organize these meetings to cover a broad range of issues associated with ER activities. The agenda permanently includes a session on common groundwater issues for the two sites. These sessions are aimed at exchanging the lessons learned on different groundwater issues, so that each firm can benefit from the other's experiences. One example of the value obtained from this type of exchange occurred at the May 1993 meeting, in which WSRC described their technically and regulatorily acceptable approach to collecting groundwater samples. The WSRC approach minimized waste generation and improved representative sampling. As a result, the GWPO intends to implement a similar program for Energy Systems.

2.6 ADVISORY COMMITTEE

The Groundwater Program Management Plan specifies that an advisory committee shall be appointed to review the activities of the program on an annual basis. The committee evaluates the program and recommends future improvements. For FY 1993 the committee comprised the following people:

- Dr. Stanley N. Davis, Univ. of Arizona (emeritus)
- Dr. William B. White, Pennsylvania State University
- Mr. J. Stone, Deputy Manager of Y-12 Plant Waste Management Div.

The committee met in Oak Ridge in late July, 1993 with the GWPO staff and a large cross section of the MMES staff associated with groundwater programs at all five facilities. Based on their visit, the committee prepared a report that identified the strengths of the program and some concerns that require attention. A copy of their report appears in Appendix A.

The Committee considered the credibility of the GWPO staff vis-à-vis their colleagues on the groundwater monitoring and compliance staffs. All conversations with staff and managers indicated that GWPO scientists were held in esteem and their advice and opinions were valued.

The Committee concluded that the projects undertaken by various elements of the GWPO were technically and scientifically sound as well as essential for the economic fulfillment of compliance and remediation requirements. The various investigative techniques used by hydrogeologists at the ORR were judged to represent state-of-the-art procedures. Furthermore, in many projects some useful innovations have been developed.

The working relationship between hydrogeologists in the GWPO and parallel professionals in agencies and organizations outside of ORR was not fully explored due to time constraints. However, working relations with individuals in the DOE appeared to be very good.

The Committee ranked their concerns with the GWPO as follows:

- The Committee was very concerned about the level of staffing in the GWPO. In particular, a full-time technical professional is needed for each of the five sites managed by Energy Systems. GWPO's expertise in karst hydrology was found to be severely limited, and the recruiting of a karst hydrologist should be given high priority.

- The roles and responsibilities of various organizations need to be better defined. Some confusion remains at the sites and other organizations on what role ORHSP versus Oak Ridge Reservation Hydrology and Geology Studies (ORRHAGS) performs for the GWPO.

- The Committee recommended that GWPO take more account of surface water and seeps and springs, particularly in the karstic portions of ORR.

- The Oak Ridge Environmental Information System (OREIS) database appears to be consuming large amounts of effort in constructing the software system while comparatively little effort has been expended to enter real data into the database. The Committee recommended that resources be devoted to filling the database in addition to constructing its architecture. It would also be helpful if part-time and guest investigators who work with GWPO could access data directly from off-site locations.

- The Committee considers it important that the professionals assigned from the ORHSP to the sites for technical support should be at the sites 80-90 percent of the time. GWPO should evaluate the assignments at PORTS and PGDP to determine the need for full-time relocation to these sites due to travel time.

- The Committee felt that priorities should be established within the GWPO for future work.

- The management structure of GWPO and its relationship to other groundwater monitoring and compliance groups at ORR raises some questions concerning the implementation of its advice. No clear management structure exists that defines the authority of GWPO advice.

- The Committee suggested that an engineer be assigned as a part-time member of the GWPO. This engineer would help define the high-level research needed to solve the more utilitarian problems of groundwater monitoring and remediation. Second, the engineer should serve as a liaison between scientific personnel and the engineering-oriented individuals who are served by the GWPO. Numerous people interviewed expressed concern with some of the research priorities and occasionally questioned the underlying value of the research. The engineer assigned to the GWPO should have experience both in applied engineering as well as research.

- ORRHAGS has a large component of small university-type contracts involving part-time employees. Although the GWPO should never stifle scientific creativity by trying to micromanage individual research, the work as a whole probably needs some additional overall organization.

- The GWPO should take the lead to ensure understanding and application of lessons learned from the ORR and across the country to the various organizations involved in the groundwater program. The Committee considered it important that the GWPO should be consulted before significant contracts related to groundwater are negotiated.

- The Committee was concerned with the personnel activity assignments. Care should be taken to assure that all GWPO staff have a comparable mix of research and service activities.

- The Committee considers the need for vehicle and office space an important factor. The shortage of vehicles hinders efficiency and interactions with site programs. The shortage of office space hinders the recruitment and retention of professional staff.

2.7 CONTRACTS

The GWPO recognizes the necessity to provide certain types of services to the site Groundwater Programs that ensures consistency of approach and promotes efficiency of operation. Consequently, during FY 1993 the GWPO took steps to establish a number of contracts to facilitate these objectives. Specific examples include:

- A multi-site drilling contract for drilling coreholes, installation of monitoring wells, and plugging and abandonment of existing wells

- A geotechnical services contract to provide technical support at the drill site for logging core, etc.

- A contract to review all existing groundwater procedures and to develop a guidance document for groundwater data assessment

- An administrative support services contract to handle a variety of administrative duties that allows groundwater professionals in the program to spend more time addressing technical activities

- Contracts for technical support in hydrogeologic, data base, and modeling activities

Many of these subcontracts were initiated in FY 1993, but will carry forward into FY 1994 and beyond.

2.8 OTHER STAFF ACTIVITIES

In addition to normal day-to-day activities, staff of the GWPO participate in a variety of special activities that either broaden their experience or provide representation of the Groundwater Program, ORNL, and MMES beyond the five facilities. Part of the outreach function of the GWPO is to keep the MMES groundwater programs aware of these activities, provide technical summaries of meetings and workshops that might be of interest to the sites, and encourage participation of site groundwater staff in similar activities. Examples of these types of activities include:

- Participation in the Dense Nonaqueous Phase Liquid National Task Team for DOE-HQ

- Technical session chairs and participants at the National Technology Information Exchange Workshops

- Participation in the DOE-HQ (EM) initiative to develop a new strategy for doing

R&D research

- Attendance at a variety of short courses and workshops:
  - USGS Geochemistry
  - Geostatistics
  - Expedited Site Characterization Demonstration
  - Others
- Participation in national professional society meetings, both in organizing symposia and presenting work

2.? FY 1994 PLANS

During FY 1994 the GWPO will continue in its primary mission of providing technical guidance to the site Groundwater Programs in an effort to promote consistency of approach across all facilities. Several major initiatives of the GWPO for FY 1994 include continued participation in the ORR Land Use planning effort, extensive review of existing groundwater procedures, expansion of the scope of the GWPO to include centralized oversight of surface water activities, and further development of modeling capabilities.

The GWPO anticipates several key additions to its staff that will expand the experience base of our program and will address concerns raised by the Advisory Committee. Specifically, several additional Technical Support personnel and a karst hydrogeologist will be added to the staff.

3. ORHSP ACTIVITIES DURING FY 1993

This section summarizes the activities of the ORHSP staff during FY 1993. Section 3.1 focuses on the technical support function and highlights the major areas of activity during the year. Section 3.2 presents a synopsis of investigations conducted by the ORRHAGS staff in FY 1993.

3.1 TECHNICAL SUPPORT

The following subsections summarize the major activities of ORHSP Technical Support staff members during FY 1993 at the five DOE facilities operated by MMES.

3.1.1 Oak Ridge National Laboratory

T.F. Zondlo

The following describe significant ORHSP Technical Support contributions to the groundwater program at ORNL.

- Authored the 1992 Resource Conservation and Recovery Act (RCRA) Groundwater Quality Assessment Report (GWQAR) for the Solid Waste Storage Area 6 site at ORNL. This document is both a regulatory requirement and a MMES award-fee milestone. The GWQAR was submitted on time and was regarded as a significant improvement over previous editions. The work involved organizing and leading a field party to acquire a complete round of water levels from approximately 150 wells at the site (in support of RCRA requirements for an annual potentiometric map), compilation and interpretation of annual and historic groundwater sampling results, and authoring the report (including mapping and graphics).

- At the request of the ORNL Groundwater Coordinator, developed and prepared a formal response to the DOE Phase II Well Installation and Abandonment Study. This effort involved generation of a detailed report (following the questionnaire format) assessing current and projected programmatic and cost factors related to well installation, monitoring, and plugging and abandonment.

- Provided significant technical support to ORNL site planners and developers in siting the new Biological Sciences building complex to be situated west of Building 1505 at ORNL. The hydrogeologic input and recommendations reportedly altered the entire design under consideration to date, resulting in significant reduction in projected costs and potential environmental concerns.

- Served as the technical lead for the Seeps and Springs Inventory component of the ORNL Groundwater Operable Unit effort. Prepared and provided technical oversight of an Interagency Agreement (IAG) with U. S. Geological Survey to conduct this project (total costs: $130K). Provided direction and oversight of field effort, and subsequent evaluation and interpretation of results. This project is now being used as the model for other similar projects to be conducted at other ORR facilities in the coming year.

- Served as technical lead for the acquisition of a TVA electromagnetic borehole flowmeter and associated services through an IAG with TVA. Was directly responsible for preparing the Statement of Work, subsequent IAG, and required National Environmental Protection Act documentation. Developed a field program to evaluate various capabilities of the flowmeter and allow for training of ORNL staff. Subsequently directed the field effort, which involved performing flowmeter surveys on approximately ten existing wells in an uncontaminated aquifer. Responsible for interpretation and reporting of results. Total cost of this project was $30K.

- Served as the "hydrology" representative of the Natural Resources Group of the Resource Management Organization (RMO). As such, provided technical guidance and recommendations to the RMO relative to hydrologic aspects related to various proposed projects under review by the RMO.

- Provided technical assistance and oversight of ongoing ER projects as requested (WAG 5, WAG 10, WAG 6, WAG 2). Involvement included review of numerous Federal Facilities Agreement primary and secondary documents, participation in scoping workshops, presentations, and meetings.

- Provided technical oversight and direction to the Underground Storage Tank (UST) program at ORNL. Provided critical review of numerous primary documents required under UST regulations. Contributed to the effort to integrate the CERCLA and UST programs and the corrective actions proposed for a contaminated site at ORNL.

- Provided technical guidance to an empowered team comprised of personnel from DOE, MMES and regulatory agencies that was charged with deciding whether to proceed with capping WAG 6 or selecting a no action and monitoring alternative. Contributed key interpretations to the final decision.

3.1.2 Y-12 Site

C.T. Rightmire and G.K. Moore

ORHSP major activities for FY 1993 include:

- Provided major technical support to developing the approach for the Bear Creek Groundwater Operable Unit (OU) Remedial Investigation. Under what at the time was believed to be direction from and concurrence of both the U.S. EPA Region IV and TDEC, an approach was developed to address, as an interim measure, the presence of contaminated groundwater in the shallow *active* flow system in Bear Creek Valley. This flow system incorporated the water table interval related to known potential contaminant sources with the Bear Creek Valley, including the S-3 Ponds Site, the Oil Landfarm and the Bear Creek Burial Grounds, the conduit and shallow fracture flow interval within the Knox Aquifer comprising the Maynardville Limestone and the Knox Group formations within the Bear Creek watershed, and the surface water associated with the gaining/losing reaches of Bear Creek and its tributaries. The observational approach was followed to help focus the investigations data requirements on those alternatives believed, based on existing information, to be most viable.

During the review and comment process, the regulators indicated a change in their approach. The regulators requested that the entire groundwater system be examined but on an individual source unit or plume basis. This new approach is inconsistent with the groundwater operable unit strategy currently being followed and may ultimately be incompatible with the observational approach.

- In addition to the technical lead for Bear Creek OU 4, ORHSP provided conceptualization, planning, and review support for Remedial Investigation plans for Bear Creek OU1 and OU2, Chestnut Ridge OU1, OU2, OU4, and Upper East Fork Poplar Creek OU 3.

- During this process, approximately 4 meetings and 2 field tours were conducted to provide information to and interface with Tennessee Oversight Agreement staff.

- An IAG was initiated to provide support from the U.S. Geological Survey Waste Remediation Division for a spring and seep survey in Bear Creek Valley and adjacent ridges. The survey will assess potential discharge points for the karst flow system. Planning and execution of any future tracer tests in this area requires the information contained in this survey.

- Provide support to Environmental Sciences Division scientists conducting research and development activities at Y-12 including dense nonaqueous phase liquid studies, density flow modeling associated with the S-3 Site, pulse testing to assess well interconnection in the vicinity of the well pickets, storm event monitoring and sampling in well GW-734, and fracture and conduit studies attempting to resolve baselevel for the "active" shallow flow system.

- Provided guidance and facilitated establishment of an IAG with the USGS for surface water monitoring in East Fork Poplar Creek and at Bear Creek sites.

3.1.3 K-25 Site

P.A. Rubin and T. F. Zondlo

- GWPO personnel served as technical leads providing support and direction to the K-25 groundwater program. Contributions include support in development of the scope of FY 1994 groundwater activities to be performed as part of the compliance and ER programs.

- Provide technical support and direction to the K-25 Groundwater Coordinator and ER project managers (chiefly the newly formed Groundwater Operable Unit).

- An important contribution was made in incorporating the ORR hydrologic framwork into plans for site characterization.

- Played a central role in setting up an IAG with the USGS to provide continuous water level measurements in a selection of key monitoring wells that intersect solution features.

- Provided technical justification for incorporating karst characterization activities into the long range plans of the K-25 Groundwater Program.

3.1.4 Paducah Gaseous Diffusion Plant (PGDP)

C.T. Rightmire and G.K. Moore

A variety of support services in hydrogeology were provided to PGDP in FY 1993. the largest effort consisted of an analysis and interpretation of groundwater chemistry data; this task is only partially complete, but considerable progress has been made. PGDP requested the task after a few groundwater samples, collected and analyzed by a contractor, were found to have high metal concentrations, which state and federal regulators believed might be contamination. The statistical characteristics of the data have been calculated, and the locations of high and low values for all chemical constituents have been compared. There is no evidence of contaminant plumes for metals in and near the PGDP Main Plant, and most high values occur in background wells. The one exception is two wells in the Main Plant where water samples showed a relatively high concentration of chromium and where a contaminant source is possible.

Other preliminary conclusions from the analysis and interpretation of groundwater chemistry data at PGDP include (1) many constituent concentrations do not meet generally accepted standards for comparisons with older data and for the reproducibility of analyses on sequential samples from the same wells; (2) the results of anion and cation water balances and the results of comparisons of specific conductance with total dissolved solids do not meet generally accepted standards; (3) many metal contents are artifacts and apparently result from the acidification of groundwater samples that contain colloidal particles of clay, iron oxide, and manganese oxide; and (4) all groundwater in the upper continental deposits, the regional gravel aquifer, and the McNairy Sand is a single chemical type that represents near-surface materials in the recharge areas.

Other support included a detailed, comprehensive review of the PGDP Phase III report on hydrogeology, the identification of data gaps in the Phase III report and those in the Phase II report by CH2M Hill, and written descriptions of both the data gaps and the tasks required to fill these gaps. This information was included in the PGDP Groundwater Strategy Document. The data gaps include the need for a water budget to confirm the conceptual model of groundwater occurrence and flow, the need for a more accurate measurement of annual groundwater recharge, and the need for a better determination of the recharge locations and areas.

Six other reports and work plans were reviewed, and written comments were provided for consideration by the authors. Different interpretations of the results of pumping tests in two of these reports were compared, and a determination was made that there is not one simple, correct interpretation of the data. In response to another request, computer models of hydrogeologic conditions were used to determine optimal locations of both pumping wells and monitoring wells for control and containment of the Northwest contaminant plume.

One report review led to an opinion on the possibility of continued seepage of water with a high iron content from a closed landfill near the southwestern edge of the PGDP into nearby streams. ORHSP personnel believe that past remedial actions have been effective in minimizing water infiltration and waste leaching but that seepage will continue because of (1) the volume of contaminated groundwater stored in the permeable subsoils beneath the landfill, (2) the groundwater mound in the same area, and (3) the hydraulic gradient toward the streams. An interception trench was suggested as an appropriate solution to the problem.

ORHSP personnel participated on the technical committee that developed the PGDP Groundwater Strategy document.

3.1.5 Portsmouth Gaseous Diffusion Plant (PORTS)

C.T. Rightmire

GWPO provided input and guidance to PORTS for the development of its groundwater program. GWPO personnel participated in an off-site meeting to help establish program roles and responsibilities and priorities for the utilization of limited personnel resources. The priority issues that rose to the top were all based on regulatory requirements, documentation, and deliverables. Key technical activities include data validation, lab turnaround, technical tools (maps, logs, etc.) and improved communication with the regulators and management. Important management activities are budgetary and cost control, the establishment of a master schedule and the development of roles and responsibilities. While the field activities generally had low priorities, the data from those activities were of recognized importance.

A draft integrated master schedule for the groundwater program has been developed and is currently being resource loaded to assist in predicting staff and/or subcontractor requirements for the next several years. The budget and cost and schedule control have been addressed through the most recent round of cost account plan sheet iterations. Documentation, in the form of standard operating procedures and practices are being developed; required plans have been identified and scheduled for completion. Action on data validation requirements is being held up pending the development of an Energy Systems wide approach to the data validation process. The PORTS groundwater organization is actively involved in oversight of field activities related to groundwater activities at the facility.

In response to the Geoprobe detection of contamination in the groundwater south of Perimeter Road, an independent groundwater assessment of the X-749 area was performed. ORHSP provided a technical lead for PORTS during the execution of interim remedial measure (IRM) activities by Hazardous Waste Remedial Action Program under the direction of a PORTS Project Manager. While the Phase I - Additional Characterization - was quickly conceptualized, obtaining regulatory approval for the work plan and initiation of field activities caused significant delay.

The additional characterization proceeded much like the Argonne Expedited Site Characterization but without regulatory concurrence with the decision process. The Geoprobe was used to collect sediment samples continuously to total depth for lithologic description and to ascertain the presence of groundwater which was then sampled for screening for trichloroethylene using a field gas chromotograph. A potentiometric surface map was developed using water level measurements from a "snapshot" and this map and the Geoprobe data was used to place piezometers for additional control prior to selecting monitoring well locations.

A second water level snapshot indicated that the piezometers were located in the appropriate places for monitoring wells. With the exception of being constructed of polyvinyl chloride instead of stainless steel, these piezometers were constructed to monitoring well protocols. PORTS requested and received approval to use the piezometers as monitoring wells. The EPA requested only two additional wells to the piezometers, so this approach saved the time and costs associated with installing approximately 8 stainless steel monitoring wells. The decision making process, while not as streamlined as the Expedited Site Characterization process, utilized transmittal of maps and data and conference calls for making almost real-time decisions on well locations.

All drilling activities for the X-749 IRM at PORTS have been completed. One confirmatory well was installed and four wells were redeveloped and slug tested, two pumping tests were conducted, and a trench to determine lithologic characteristics was installed. A refined groundwater flow/contaminant transport model under development should assist PORTS in deciding whether an IRM in needed as opposed to continuing with the RCRA Facility Investigation/Corrective Measures Study process. Communication is being maintained among the Hazardous Waste Remedial Action Program; Environmental Consulting Engineers, Inc.; PORTS; and ORHSP to ensure all parties are aware of the status of project deliverables as work progresses.

During the winter and spring (February through May), technical support staff spent all or part of every other week at PORTS providing technical leadership and support to the X-749 IRM project and other groundwater activities at the facility. In mid-June PORTS requested that a technical support staff member fill the role of acting Groundwater Program Manager with the specific objective of providing senior technical direction, developing a master schedule and a strategic plan for the PORTS groundwater program, and finding and hiring a full time GWPP Manager. These activities have been initiated.

During the last year detailed reviews of the Quadrant III and Quadrant IV RCRA Facility

Investigation Reports were conducted. Following review of the Quadrant III document Geraghty and Miller asked the technical support staff to participate in the review of their in-house draft. Technical support staff's participation in the development of the Quadrant IV report made the review process a little smoother.

3.1.6 Other Staff Activities

Data Management

B. K. Thompson and D. D. Huff

During 1993, two reports documenting aspects of the data management activity were completed. A database management plan was written to document the development and maintenance of the ORRHAGS Groundwater Database. It contains information on database objectives, roles and responsibilities of personnel involved, and a discussion of the flow, updating, and storage of the data (Thompson, 1993, ORNL/TM-12048). A database dictionary was also produced. It describes the data contained in the ORRHAGS Groundwater Database and the structure, conventions, and use of the dataset (Thompson, 1993, ORNL/TM-11909).

In addition to activities associated with the development and maintenance of the database, a significant capability to produce maps of geologic and hydrologic information using a geographic information system (GIS) format was further refined and applied. For example, a complete ORR coverage map showing geologic formation strike and dip information was produced in conjunction with a status report on the geology of the ORR (Hatcher, et al., 1992, ORNL/TM-12074). Ongoing incorporation of soil-type units into a comprehensive map coverage of the ORR was also carried out. Finally, the development of a three-dimensional visualization capability for ORR geologic formations was initiated. This will be done in conjunction with the OREIS workstation that will be used by GWPO staff in the future. Work continued on updating and revising a comprehensive data base for use by ORRHAGS and ORHSP staff as well as the site programs.

3.1.7 FY 1994 Plans

Successful recruitment of the full contingent of technical support staff continues as a major issue for FY 1994. During FY 1993, one of the permanent staff positions was vacated and temporarily replaced through utilization of one of the ORRHAGS scientific staff members. A goal for FY 1994 is to complete the task of finding a full contingent of five full-time technical staff members, one for each of the Energy Systems sites, and to allow the ORRHAGS staff member to return to more basic research in support of the site programs. Increased technical support staff participation in the design and implementation of ORRHAGS projects will be emphasized in FY 1994. Finally, use of OREIS groundwater data will grow with greater workstation access to the database. Technical support staff are expected to play a leadership role at the site program level in taking full advantage of the growing capabilities..

3.2 OAK RIDGE RESERVATION HYDROLOGY AND GEOLOGICAL STUDY

The ORRHAGS is being conducted by a multidisciplinary team of environmental scientists. The primary objective of ORRHAGS is to develop an understanding of contaminant transport pathways, mechanisms, and rates so that technically credible waste management and ER decisions can be made. To fulfill this objective the following investigation themes have been established:

Matrix Diffusion/Water Table Interval
Model Development
Deep Groundwater Flow and Fracture Toughness Testing
Karst
Mapping

Significant progress was made during FY93 in each of these areas and highlights of this progress is documented in this report.

3.2.1 Matrix Diffusion/Water Table Interval

W.E. Sanford, D.K. Solomon, T. Brown, and W. Stadler, H. Ingracia

The burial of wastes on the ORR generally has been in the shales of the Conasauga Group, which is one of the units comprising the ORR aquitards. It is believed that much of the shallow subsurface flow of groundwater and transport of contaminants occur in discrete, fractured zones of relatively high permeability located within the water table interval. As a result of the weathering process, saprolite has formed in the upper portion of the water table interval. Saprolite can be described in broad terms as having a low permeability yet a relatively large porosity. As a consequence there is a great potential for diffusive exchange to occur between the groundwater in the fractured zones and the groundwater in the matrix (unfractured saprolite). Matrix diffusion can have a significant effect on contaminant transport and site remediation. Once wastes have been diffused into the matrix, removal of wastes will be limited thus slowing possible remediation. This project seeks to quantify the matrix diffusion process to support future modeling and provide a quantitative basis for remedial decision making.

Objectives. A groundwater tracer test designed to study the effects of matrix diffusion is underway in West Bear Creek Valley on the ORR. The site is the location of a tracer study started in 1988 (Lee et al., 1992) using the fluorescent dye Rhodamine-WT. The dye appears to have migrated down gradient along a very narrow path, suggesting flow along a fracture.

The main objective of the current study is to determine the importance of diffusive exchange between groundwater flowing in a fracture and groundwater in the matrix material by using a suite of dissolved noble gases as tracers. The advantages of using noble gases are: 1) the gases behave nearly identical except for differing diffusion coefficients; therefore, any differences in the transport of the various noble gases are due to the effects of diffusion; 2) the injection water can be saturated several orders of magnitude above background levels without significantly altering the physical properties of the fluid; and 3) the samples can be analyzed to C/C_0 of 10^{-5}. The gases used in this study will be helium and neon. Helium has a molecular diffusion coefficient which is 1.5 times larger than neon.

Results. Work accomplished in the past year has included preliminary 1-D computer modeling, determination of rhodamine distribution in groundwater samples, the drilling of new holes for installation of multilevel sampling devices, the distribution of rhodamine in the subsurface determined from saprolite core analyses, the measurement of groundwater fluxes using point dilution tests, and laboratory work to improve sample collection and analytical capabilities for detection of He and Ne. A brief summary of these accomplishments follows.

Computer Modeling. A simple 1-D fracture flow model was used to determine if matrix diffusion can significantly influence the He-to-Ne ratio measured at points along a migration pathway. The model was run using average parameters for the ORR for fracture aperture and spacing (Solomon et al., 1992) with a mixture of the two gases injected for a period of 360 days, after which time the source was turned off. The model results are presented in Figure 3 which shows the ratio of the gases in the fracture at various distances from the source. If matrix diffusion did not influence the transport of the two gases, then the ratio should be equal to one for all times. As can be seen for the early times, the ratio is less than one, indicating that He is diffusing into the matrix at a faster rate than Ne. After the source of gas is turned off, the ratio becomes greater than one (the time depending on distance from the source) indicating that He is diffusing back out of the

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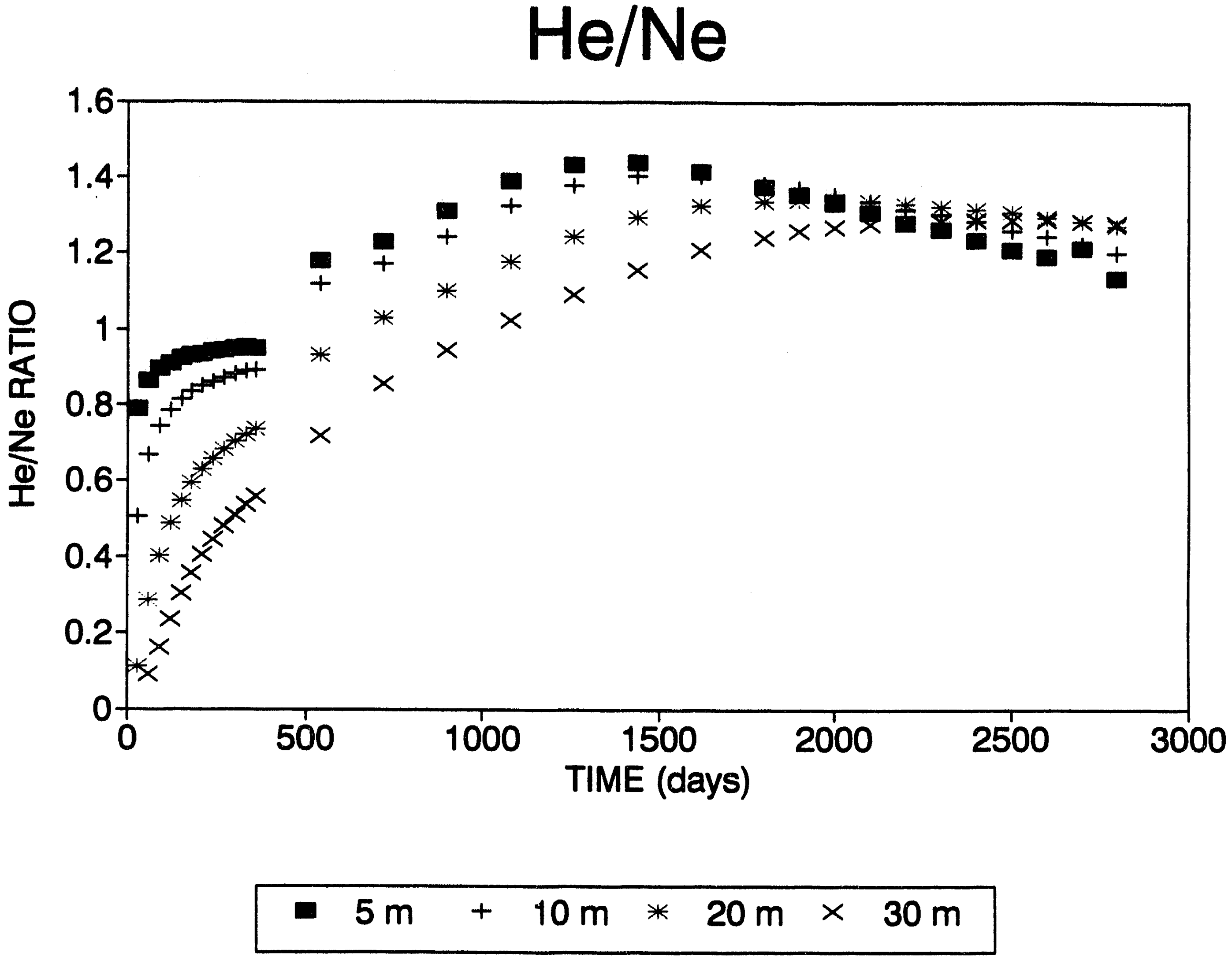

Figure 3. Ratio of He/Ne for the Fracture at Various Distances from the Source.

matrix more rapidly than Ne. The modeling results were used to determine that for the actual field experiment, the gases should be injected for at least 6 - 12 months.

Rhodamine Distribution in Groundwater. A 10 L slug of a 40% rhodamine solution was injected in Well 484 (Figure 4) during the original tracer experiment. In the summer of 1992, groundwater samples were collected from the existing wells at the tracer test site to determine the current distribution of rhodamine in the groundwater. The highest concentration was found in the source well (> 1800 ppb). The 10 ppb contour of rhodamine based on groundwater samples is shown in Figure 4. The basic shape of the plume is long and narrow as if flow was along a fractured interval. The location of the 10 ppb contour is not significantly different than the same contour 3 months after the injection of the dye suggesting that the majority of the rhodamine is still in the subsurface in the vicinity of the source well. This finding offers evidence that matrix diffusion is an important attenuation mechanism.

New Wells. The information from the rhodamine analyses of the groundwater coupled with the results of the simple 1-D modeling indicate that the West Bear Creek Tracer Test Site is well suited for an investigation into the effects of matrix diffusion. New multi level sampling wells which are designed to collect samples from the main permeable zone and from the surrounding matrix need to be installed. Surface locations of the new wells were based on the shape of the 10 ppb rhodamine contour (Figure 4). Groundwater samples, however, do not allow a determination of the vertical distribution of rhodamine, information which is needed for well installation. Toward this end, a core of the saprolite was collected during drilling and analyzed for rhodamine content.

In February, 1993 holes were drilled in which the multilevel sampling wells will be installed. A six-inch hollow stem auger was used with a continuous sampling split spoon in order to collect the core material. All holes, except for F and J, were drilled to the depth of auger refusal, which is taken as the top of competent bedrock. Holes E, K, and L, which are along the centerline of the rhodamine plume (Figure 4), each had an additional 15 feet of core collected from the bedrock below auger refusal. Holes F and J were drilled to depths which are saturated during the winter when the depth to the water table is at a minimum and unsaturated during the summer when the depth to the water table is at a maximum. Soil solution samplers will be installed in these two holes to collect samples for bromide analysis.

Vertical Distribution of Rhodamine. The saprolite core collected from each hole was divided into 4-inch segments. The pore water from each segment was extracted and analyzed for rhodamine. The vertical rhodamine distribution for Holes E, K, and L are shown in Figure 5. The rhodamine was found at a much greater concentration in Hole E with the concentration decreasing away from the source well, further indicating that most of the rhodamine is still near the source well. The rhodamine is concentrated in a zone about 5 to 8 feet in thickness that appears to be the main pathway for transport. The

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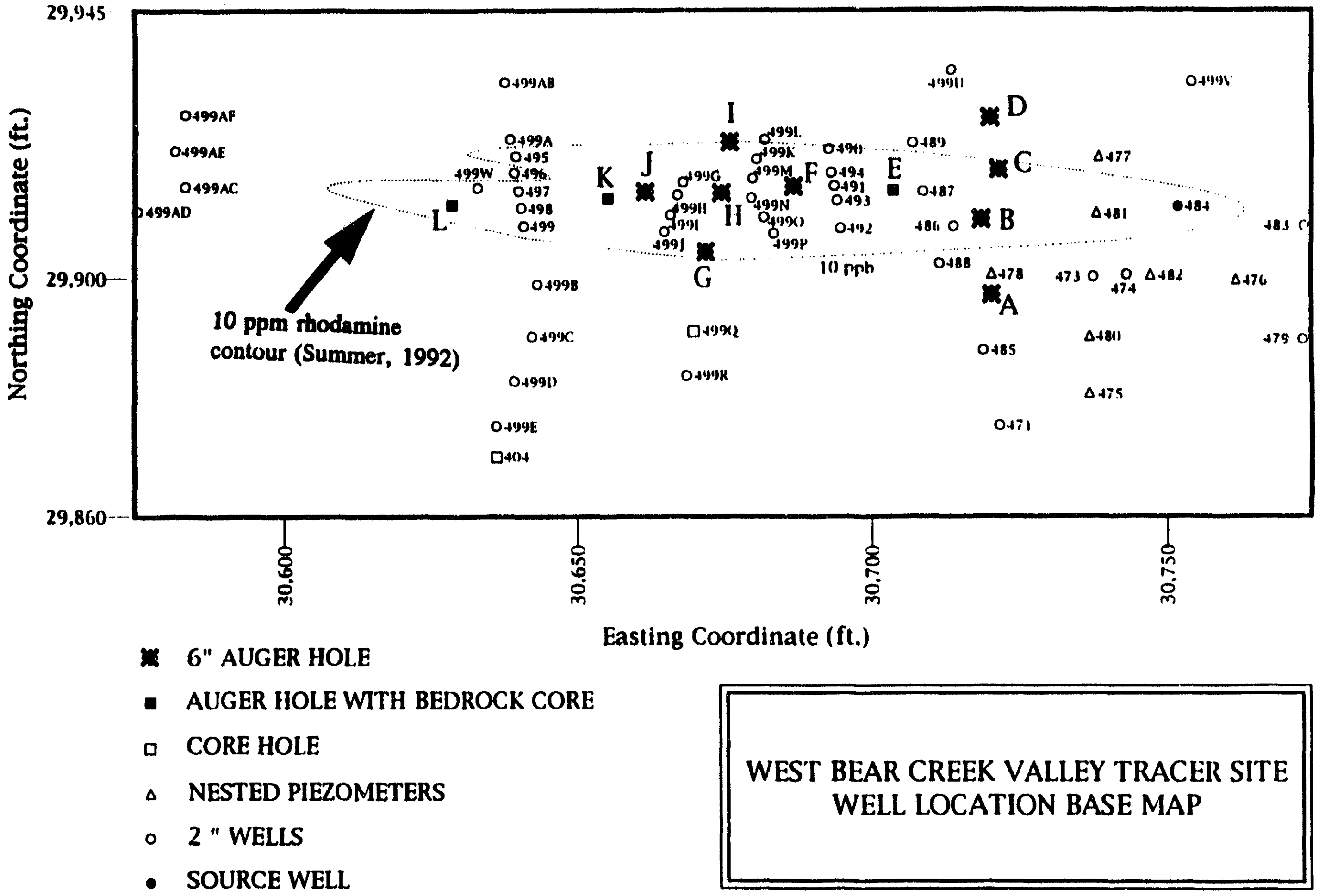

Figure 4. West Bear Creek Valley Tracer Site Well Location Base Map.

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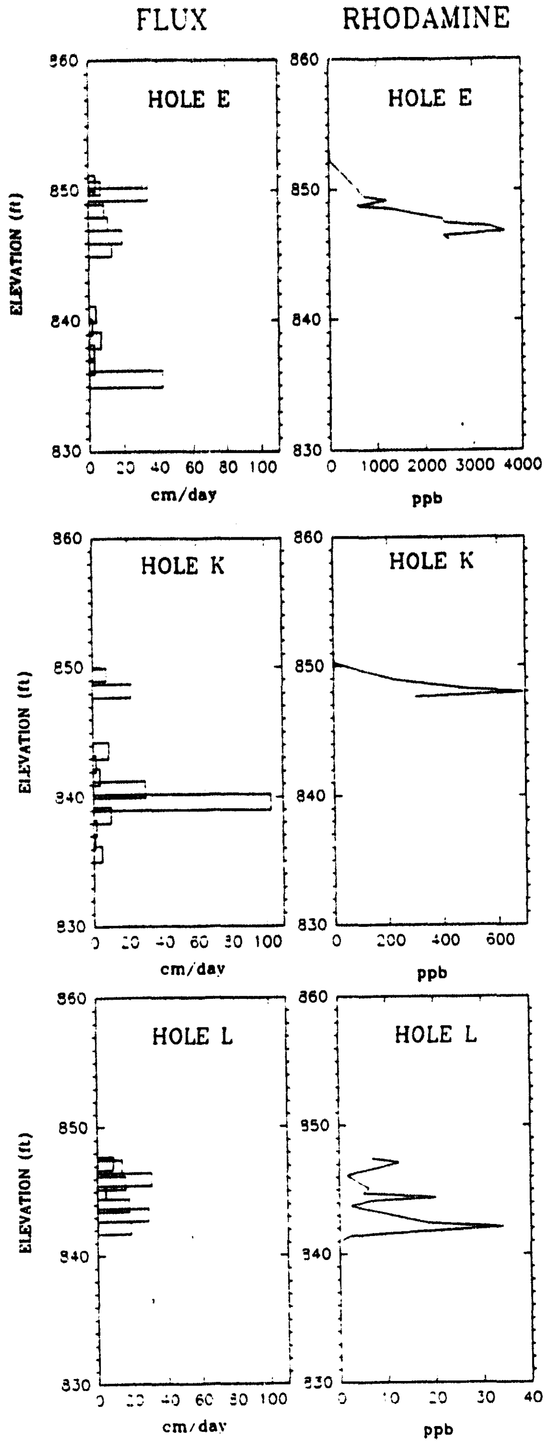

Figure 5. Vertical Rhodamine Distribution and Water Flux from Point Dilution Tests for Holes E, K, L.

profiles from Holes E and K suggest that there is rhodamine at greater depths; however, those depths correspond to the transition zone from saprolite to bedrock and core recovery from this zone is extremely poor because coring methods do not work well in the transition zone.

The general shape of the rhodamine profiles is similar to that expected if there was transport along the permeable zone accompanied by diffusion into the matrix above. This would explain the gradual decrease in concentration with decrease in depth. Unfortunately, the profiles do not extend deeper. The sharp decrease in concentration seen at the deeper core from Hole L may be attributed to the fact that at auger refusal and below, the rock is more competent and has less porosity, hence diffusion downward will be inhibited.

Point Dilution Tests. The results from the core analyses have identified the zone through which much of the rhodamine has migrated. Additional data was needed to determine if this zone is a relatively permeable zone and to identify other permeable zones in order to optimize the selection of depths from which to collect groundwater samplesduring the noble gas tracer test. Point dilution tests were performed in both the saprolite and bedrock segments of Holes E, K, and L. Point dilution tests are a method to determine the specific flux of groundwater through a well segment under natural gradients (Drost et al., 1968; Hicks et al., 1992). The tests use two inflatable packers to isolate a segment of the core hole.

Tubing runs through the upper packer to allow the circulation of water into and out of the interval. Also, a pressure transducer is attached to measure the pressure head in the packed interval. Initially, water is pumped out of the well, through a specific conductance (SC) meter and back to the interval until a steady reading of SC is reached. The water is then pumped out of the interval but is replaced by distilled water which has a low SC. When the SC reaches a value of at least one quarter of the original, the interval water is then recirculated. During this time, the SC of water is continuously measured and recorded. The rate at which the SC increases is related to the flux of groundwater through the interval. During the entire test, the hydraulic head measured in the interval is kept as close to the initial value as possible in order to maintain the ambient groundwater flow paths. The results of the point dilution measurements from Holes E, K, and L in terms of vertical distribution of water flux are shown in Figure 5.

The data show that there are permeable intervals associated with the zone of increased rhodamine concentration. There is also a relatively permeable zone identified approximately 10 feet below the rhodamine level in the bedrock portions of Holes E and K. No measurements were made in the bedrock portion of Hole L because it had become filled with mud and debris. It appears that the shallow groundwater flow beneath the tracer test site is controlled by discrete permeable zones separated vertically by relatively impermeable zones near the water table.

A similar pattern was identified in gamma activities measured by Olsen et al. (1986) in wells in the seepage area near Trench 7 in Melton Valley which has a similar geologic setting as the West Bear Creek Tracer Test Site. The gamma radioactivity profiles show 2-3 peaks in each well that are separated vertically by 3 to 10 feet in the vicinity of the water table that represent permeable zones through which groundwater traveled. The point dilution tests at the tracer site in West Bear Creek Valley were run in the summer when the water table is at its maximum depth; therefore, it is possible that there is an additional permeable zone located at a shallower depth that is active only during periods of high water table.

Laboratory Work. During the past year laboratory work was performed to improve the method for collecting groundwater samples for noble gas analysis and to improve the resolution of the analysis itself. The sampling procedure was tested and improved in the lab by collecting samples of water in which helium was bubbled for a period of time. It was determined that samples could be collected using evacuated glass bulbs with vacuum stopcocks. This method allows for easy sampling and injection into the analytical system.

The dissolved gases from the water samples are analyzed using a gas chromatograph with a thermal conductivity detector. After the water is degassed, the gas is injected into a line which travels through a 10 m long column of molecular sieve for separating He and Ne. Tests were repeated in which various column flow rates and temperatures were used to determine the parameters which provide the best separation of the two gases. It was found that a flow rate of 20 cc/min and a temperature of 5° C provide good separation with the best sensitivity, especially at low gas concentrations.

Taken together, the results demonstrate that flow occurs along permeable zones, probably containing connected fractures. The porous matrix bordering these permeable zones captures materials dissolved in flowing groundwater. Both modeling and dye trace results suggest that this capture significantly retards movement.

Future Work. Future work will include the final installation of all wells and the initiation of the gas injection in early FY 1994. The depths to the sample intervals will be based on the results of the rhodamine analyses and the point dilution tests. Additional work planned is to install devices to measure the head at various depths in the aquifer in order to relate the transport of the tracers to changes in the hydraulic gradient. The feasibility of per forming a colloid-sized tracer test on the site will be examined. This tracer test will provide information on the actual velocity of the groundwater through the fracture zones in the absence of matrix diffusion effects. Laboratory work using He and Ne as tracers through a core of saprolite will be performed. These small scale experiments will further define the size-scale where a suite of noble gases can be effective in determining the importance of diffusion and transverse dispersion of contaminant migration in groundwater.

3.2.2 Groundwater Model Development

L.E. Toran, O.M. West, and J.P. Gwo

Groundwater models are needed to assess waste transport and remediation schemes. Models can be used to support risk assessment and to better quantify our conceptual models of groundwater systems. However, due to the complex nature of groundwater flow and solute transport on the ORR, conventional models may not be appropriate and could produce highly misleading results.

Modeling work reported in this section has been and continues to be supported by funding from several sources. ORRHAGS frequently has been a source of support in the early stages of model development activities, whereas the ER Program provides funding to support application of the models to site-specific problems.

Objectives. A variety of codes and approaches have been used to examine groundwater flow and transport of contaminants in the complex hydrogeologic setting of the ORR. Models have been developed at both the regional and local scale, for both site-specific and generic problems. Two regional models are described below. One is a cross-sectional model adjacent to the S3 Ponds at Y-12, developed to understand the regional flow field and background geochemistry in a setting containing contaminanted water more dense than ambient groundwater. This regional modeling was followed by a density driven transport model of the waste plume. The second regional model is located in Melton Valley and is being used to simulate and study groundwater flow in waste areas using regional boundary conditions. Generic modeling of 2-dimensional fracture flow and transport was conducted to evaluate the assumptions and limitations of porous media models. Finally, a subcontract with the University of Waterloo was placed to take advantage of a 3-dimensional code developed by them that incorporates saturated/unsaturated flow and transport in fractured, porous media.

Results. To quantify and evaluate the regional setting of a dense plume of contaminants near the S3 Ponds at Y-12, groundwater samples collected at depths of 200 to 1000 ft from multiport monitoring systems were modeled with a groundwater flow model (MODFLOW) and a reaction path geochemical model (CHILLER). Evolution of groundwater from Ca-HCO_3-type in recharge areas to Na-HCO_3-type further along flow paths is typically attributed to exchange of Na for Ca on exchange sites of clays. Geochemical modeling indicates that the Na-HCO_3 waters observed here also can be produced by aluminosilicate alteration and precipitation of secondary minerals. Residence times of the Na-HCO_3 zone calculated from a particle tracking groundwater flow model indicate that this zone has stable hydrochemical properties as a result of having been flushed by thousands of pore volumes.

Flow modeling provides further evidence that the proposed aluminosilicate alteration process is at least in part responsible for the observed groundwater geochemistry because if Na-HCO_3 groundwater was produced by cation exchange, it should be flushed out by the Ca-Mg-HCO_3 recharge water when exchange sites are filled. Thus, the lower boundary of the Ca-Mg-HCO_3 groundwater may be an indicator of active circulation and important in determining depth of monitoring for contaminants. Evolution of Ca-Mg-SO_4-type water in the study area has been influenced by dedolomitization driven by gypsum dissolution.

A model of a density-dependent contaminant plume along the cross section described above explains contamination at depths of 800 ft and the over-pressuring associated with the zone of contamination. A waste source containing nitric acid with a density up to 1.07 g/cm^3 was disposed in the S3 Ponds. Multi-port monitoring systems showed that the waste source is located in the regional groundwater discharge area, where groundwater should have a strong upward flow component. However, density-driven flow might explain the downward flow of contamination against the upward gradient. This hypothesis was tested with a density-driven transport model, SWIFT/386. The dense plume reached the observed depths when a high hydraulic conductivity zone (300 ft/year in contrast to 3 ft/year for surrounding rock) was modeled in the contaminated area. A fracture zone could account for the higher hydraulic conductivity, but it is difficult to determine the effects of fractures on permeability by looking at core from the site. The model can be used to predict the rate of decline of the pressures and contaminant concentrations. This work was initiated by ORRHAGS, but now receives support from the Y-12 ER Program.

A 3-dimensional, 40,000 node groundwater flow model of Melton Valley was constructed to evaluate the role of groundwater in contaminant discharge (Figure 6) with particular emphasis on Waste Area Grouping (WAG) 6. Simulations were made on the ORNL supercomputer using PFEM, a parallel version of 3DFEMWATER. The model area includes WAGs 4, 6, and 7, and part of WAG 2. WAGS 5, 8, and 10 are currently being added to expand the area of study. The model is calibrated to about 150 measurements of groundwater levels at various depths and baseflow fluxes obtained from five surface water measuring stations. Model calibration has provided new information about the hydraulic conductivity and flow system boundaries not available from existing field data. A ratio of vertical to horizontal hydraulic conductivity of 0.2 produces a better match to data from the deep system. Topographic ridges in the model may act as groundwater divides, or water may underflow the ridge. A better match was achieved when underflow was used, but the model also indicated that the source of this water was not shallow contaminated areas.

The model also is being used for calculating groundwater fluxes to streams where gages are not available, thus improving estimates of off-site contaminant migration. An earlier version of the model predicted that if waste trenches in WAG 6 were capped, the decline in water levels would be less than 10 ft, and very little change in contaminant stream fluxes would occur. Thus, capping would not have reduced groundwater flow

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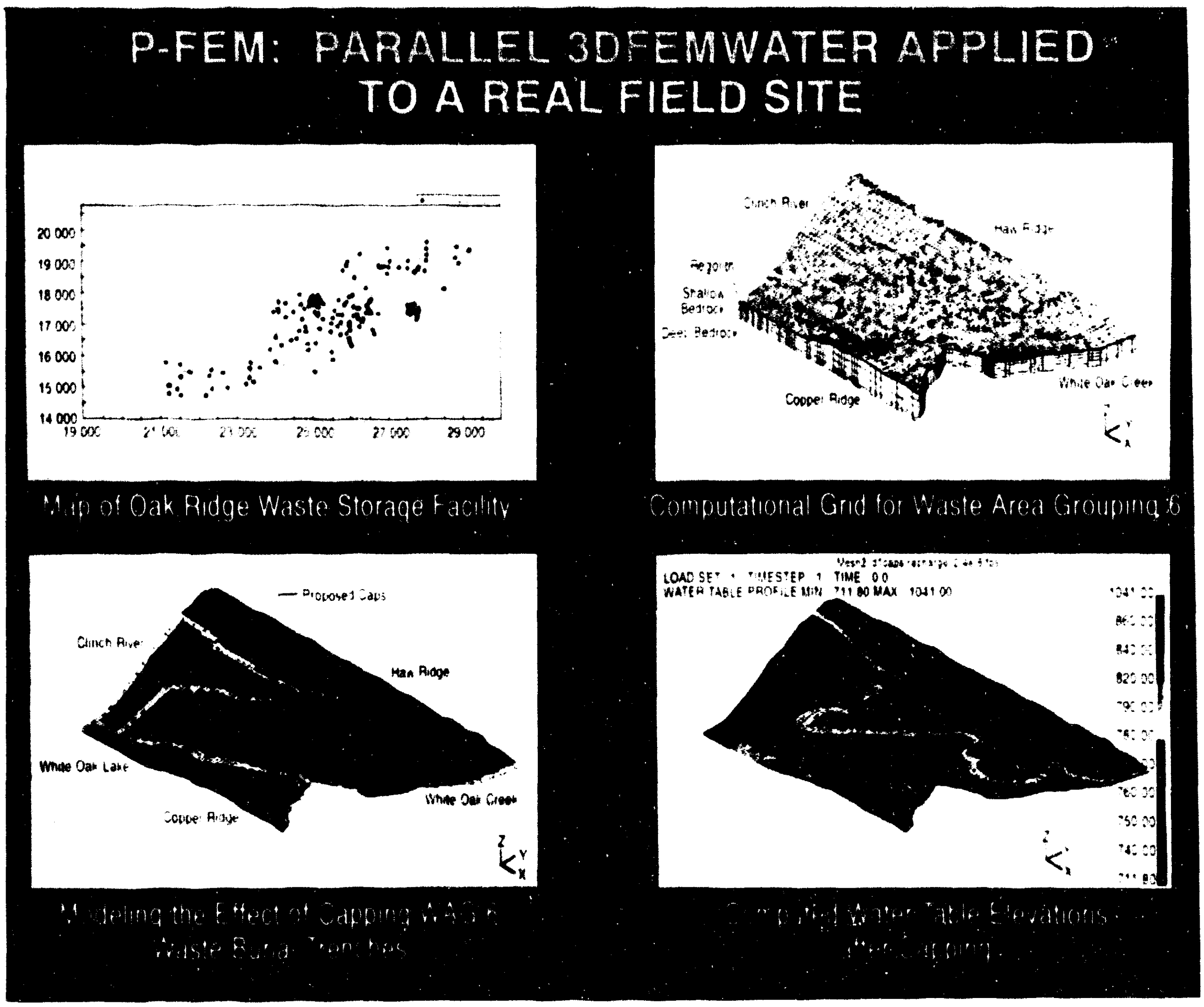

P-FEM: PARALLEL 3DFEMWATER APPLIED TO A REAL FIELD SITE

Map of Oak Ridge Waste Storage Facility

Computational Grid for Waste Area Grouping 6

Modeling the Effect of Capping WAG 6 Waste Burial Trenches

Computed Water Table Elevations After Capping

Figure 6. 3DFEMWATER Applied to a Real Field Site.

through waste trenches in some portions of the model area. The model described here estimates the steady state contribution of groundwater flow in the saturated zone; a separate effort will consider stormflow. Through a better definition of groundwater flow boundaries, the calibrated model will help identify contaminant pathways and construct smaller scale models of individual watersheds or waste areas. ORRHAGS funded this work in FY92 and the beginning of FY93, but now the ORNL ER Program supports it.

To better understand the importance of fracture flow in sedimentary rocks, a hypothetical problem using sensitivity analysis was performed on Fractran, a 2-dimensional fracture flow and transport code developed by the University of Waterloo. Six parameters were varied in addition to the fracture network design, using a Latin hypercube sampling matrix over a range of values selected to be representative of the Reservation (Table 1). The effect of each parameter on time to 50% breakthrough of the total mass of contaminants was evaluated. Matrix characteristics were as important as fracture configuration (Figure 7). In particular porosity and matrix permeability had a strong influence on breakthrough time. Fracture aperture and fracture retardation were not significant variables. This information has been useful in pointing out the need to collect more data on the matrix properties of important rock units (eg. porosity) and selecting preliminary values for unknown parameters in fracture flow models. A 3-dimensional, saturated plus unsaturated zone version of the code will be tested next year.

Future groundwater modeling on the ORR should take advantage of the ORNL supercomputer for solving larger grids, comparing relative importance of complex physical and chemical processes, and using computationally intensive inverse methods. Coupled physical and chemical modeling will be a focus of ORRHAGS in FY94. The work on fracture flow modeling will make heavy use of the recently acquired 3-dimensional model developed by the University of Waterloo. This effort is needed to advance our understanding of on-site contaminant movement, and will continue as a modeling theme (as described above). Uncertainty analysis, geostatistics, and cost/benefit analysis are important statistical tools that will be included in future expansion of our program as staff are added. To meet these goals for groundwater modeling, funding for field data collection must be provided. For example, natural and artificial tracers are important for integrating data across scales appropriate for predicting contaminant movement. Hydraulic tests, more detailed vertical sampling, stormflow monitoring, and geophysics are other important tools for a coupled field and modeling program. By changing and updating our models with new field data, a living model can be created that provides the true benefit of groundwater computer models -- to provide more realistic predictions of flow and contaminant transport on the ORR.

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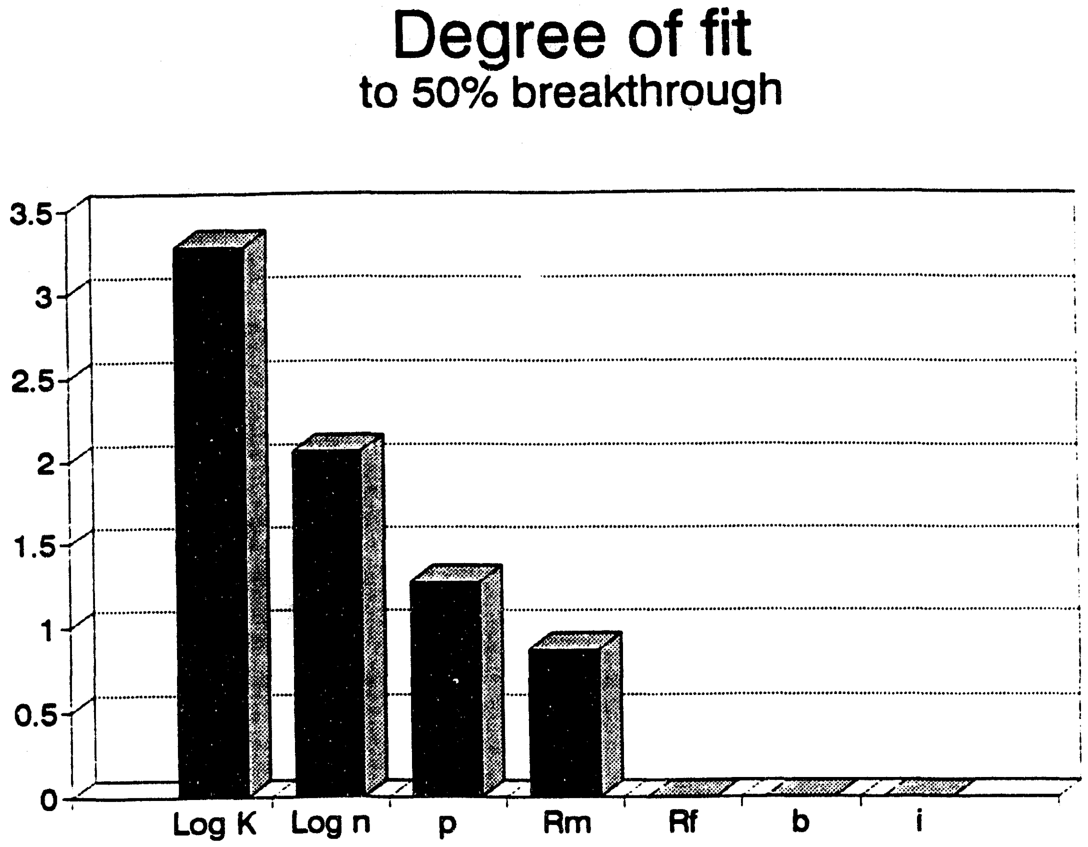

K	matrix permeability
n	matrix porosity
p	fracture density
Rm	matrix retardation
Rf	fracture retardation
b	fracture aperture
i	hydraulic gradient

Figure 7. Results of Sensitivity Analysis of Solute Transport in a Fractured Porous Media.

Table 1. Parameter ranges for fracture flow modeling

Matrix permeability (log)	3.15x10^{-5} to 3.15 m/y
Porosity (log)	0.001 to 0.1
Matrix retardation	1 to 10
Fracture retardation	1 to 10
Aperture	5 to 50 μm
Gradient	0.001 to 0.01
Fracture density (as a probability from 0-1)	0.15 to 0.97
fracture length	1 to 5 m
fracture spacing	1 to 7 m

3.2.3 Deep Groundwater Flow

Off site releases of contaminants from the ORR via groundwater represents a potential risk worthy of additional study. Because the horizontal extent of groundwater flow paths are closely linked to the vertical extent of active groundwater flow it is critical that an integrated study of deep groundwater and shallow stormflow occur. The current conceptual model holds that the majority of groundwater flow beneath the ORR is shallow, of short duration, and discharges into local (on site) streams; there also is evidence suggesting that localized groundwater flow occurs at intermediate depths. Other evidence (i.e. the occurrence of extremely high salinity water at intermediate depths) suggests that, on average, deep groundwater is relatively stagnant. The goal of this research theme is to resolve such apparently "contradictory" evidence in order to assess the potential for off site releases of contaminants through groundwater.

Studies to assess the vertical extent of active groundwater flow include a hydrogeochemical evaluation of the deep flow system, geological characterization of permeable groundwater intervals, and fracture toughness testing of bedrock core samples from the ORR. Objectives and an overview of FY93 results for each of these studies are included in this annual report.

3.2.3.1 Hydrogeochemical evaluation of the deep flow system

R. Nativ, A. Holleran, and A. Hunley

Objectives. While several previous studies have examined the deep groundwater system at specific locations (e.g. Dreier and Toran 1989; Stow and Haase 1986; Dreier et al. 1991) this study was the first attempt to directly monitor and evaluate groundwater flow and solute migration in the deep geohydrologic system underlying the entire ORR. It addresses the following questions: Is groundwater in the deep system stagnant? If it is flowing, at what rate? If contaminants are present, is migration controlled by diffusion only, or is advection important? Where are the potential outlet points? Answers to these questions will support decision making regarding the remediation needs for the deep groundwater system or, alternatively, will help clarify the risks involved in avoiding remediation of contaminated deep groundwater.

Results. If the deep groundwater systems is a zone of active circulation and potential hydraulic connection with the shallow system, then several indicators should be observed. These include: (1) hydraulic head/pressure distribution and variation, (2) evidence of high permeability, (3) temperature variations, (4) chemical and stable isotope composition, and (5) relatively young groundwater age.

These properties of the deep groundwater system have been studied during the past two years. Seasonal variations in water levels in the deep groundwater (suggesting recharge of this system) were documented, and potential areas where the deep groundwater could discharge into the shallow system were identified. Available chemical analyses, though of questionable quality, suggest that the brine water does not result from halite dissolution by actively flowing meteoric water. If correct, this finding would imply little exchange from the shallow to the deep system.

New data collection activities during the last two years include (1) logging 18 deep wells across the ORR for electrical conductivity to assess the presence of and depth to saline water, (2) packing the saline lower depth interval within 8 deep wells to monitor water pressure variations over a period of 1 month to assess the confinement level of the deep water, (3) purging and sampling water from packed intervals for chemical and isotopic analyses, and (4) sampling and analysis of brine from four deep oil and gas wells outside the ORR for chemical and isotopic composition for the purpose of regional comparison to the ORR brine. In addition, one deeply cased well was monitored weekly for six months to identify water level response to precipitation, and the location of the interface between the saline and fresh water has been monitored in 3 wells for several months to assess mechanisms controlling the depth of the brine.

Two separate investigations were initiated and will supplement the study of the deep system: (1) the characterization of the springs in the eastern section of the ORR will help determine potential discharge points of the deep groundwater system, and (2) the isotopic characterization of precipitation, runoff, soil water and the shallow groundwater system in the Walker Branch Experimental Watershed will provide the reference lines for comparing the isotopic composition of the deep waters.

Several problems associated with field activities within the deep wells have limited the extent of results achieved to date. Many deep wells had not been accessed for years and had blockages which had to be opened to obtain measurements. Because of their great depth the packing, monitoring, purging and sampling of the deep wells presented special concerns for this project. Care was taken to prevent damaging the sensitive pressure transducers during pumping and to avoid the need to remove packers between pressure monitoring and purging activities. The restrictions placed on shipping groundwater samples to outside laboratories has caused groundwaters samples taken a year ago to remain unanalyzed. Consequently, some of the most important goals of this study (eg. assessing the residence time of the brine and evaluating the possible evidence of recharge from the shallow groundwater system) have not been achieved to date.

The analysis of available data provide conflicting evidence regarding the degree of interaction between the shallow and deep groundwater systems. Tidal and barometric pressure variations indicate confinement within all stratigraphic units (Figure 8). While water levels in some areas indicate upward vertical hydraulic gradients, providing the potential for discharge of deep groundwater into shallow system, no obvious outlet points have been identified to date and this could indicate stagnation of the deep system. On the other hand, deep groundwater discharge may be occurring into adjacent, more permeable units, and dilution during discharge may be complicating the geochemical signature of the brine.

Other observations indicate deep groundwater response to recharge, in the form of seasonal fluctuations and rapid storm response (Figure 9). Because there is an upward hydraulic gradient in the location of the HHMS 2A well, the storm response shown in Figure 9 has to originate from a lateral rather than vertical source. Additionally, temporal variation in the depth to the saline interface (Figure 10) may indicate significant interaction between the shallow and deep groundwater systems.

Future Directions. During the next fiscal year, additional deep wells will be accessed to (1) monitor temporal variations in pressure, water level, conductivity, and temperature, and (2) sample the water for chemical and isotopic analyses. If feasible, point dilution testing may be done in two of the wells to provide velocity information. Geochemical data from historical sampling of shallow wells and springs will be statistically and spacially examined to identify saline groundwater signatures as a means of identifyng exit pathways where dilution during discharge is occurring. These activities will increase the spatial and temporal density of the data set and will provide input for a geochemical/isotopic model (NETPATH) that will support conclusions regarding subsurface residence time of the brine and its potential reactions with the host rocks.

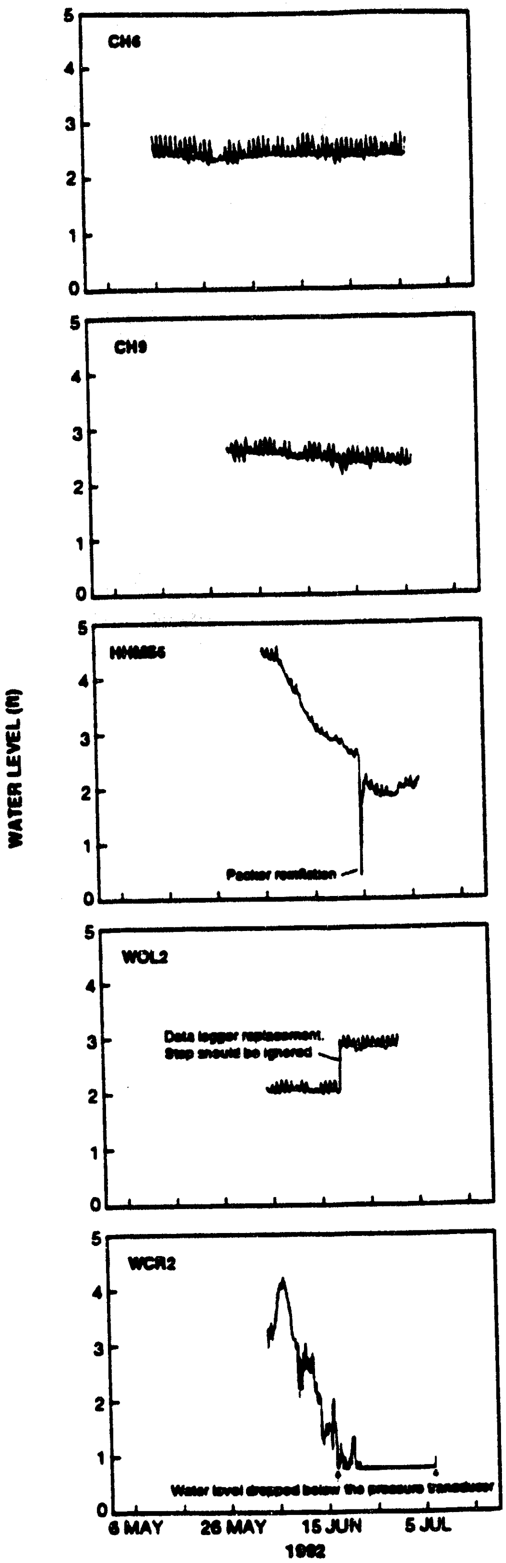

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Figure 8. Water-level variations in the packed intervals of five deep wells. Daily tidal variations, and longer-term barometric pressure variations suggest confinement of the deep groundwater.

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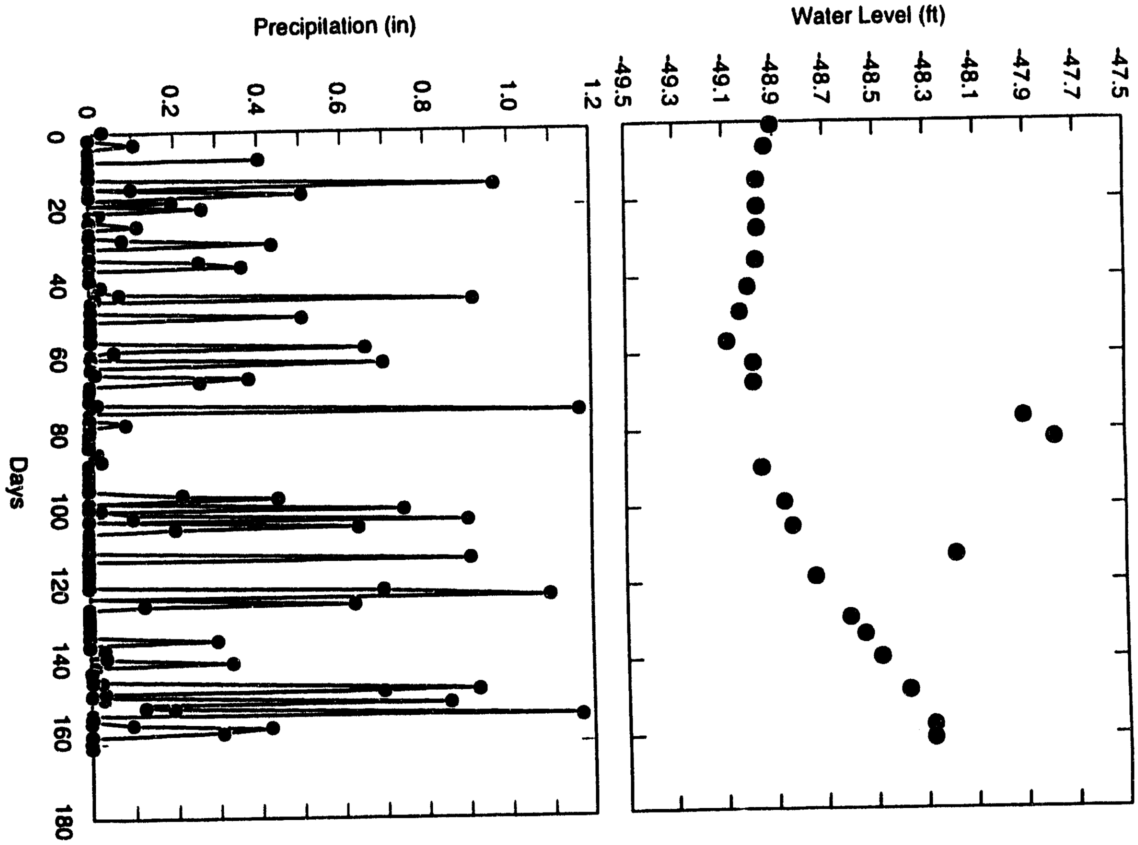

Figure 9. Weekly measurements of water levels in the HHMS2a well (a) and precipitation during the monitoring period. (b) One response to a large precipitation event was documented over the monitoring period, suggesting fast response of the deep groundwater to local recharge.

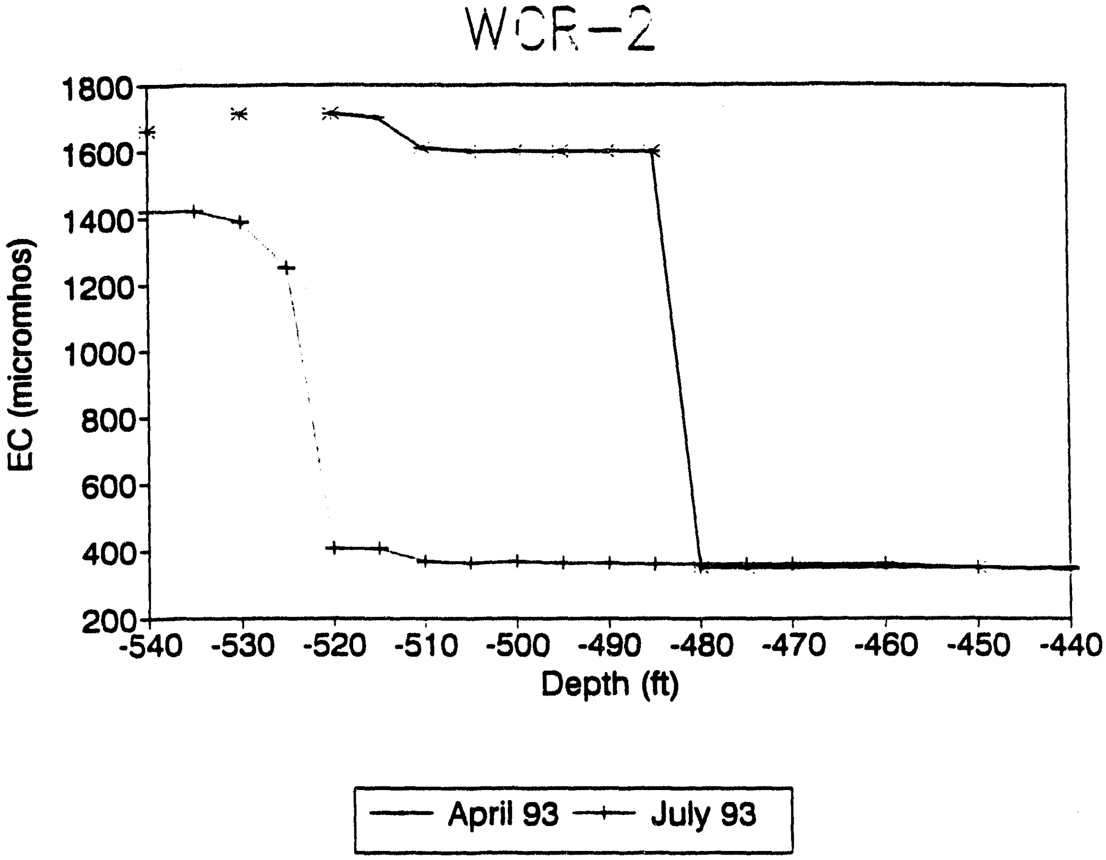

Figure 10. Monthly measurements of electrical conductivity in the WCR-2 corehole. The logs suggest the fluctuation in the location of the saline water by 45 ft. over 4 months.

3.2.3.2 Geologic characteristics of permeable groundwater intervals defined by electromagnetic borehole flowmeter surveys on the Oak Ridge Reservation

P.J. Lemiszki, P.S. Neuhoff, and R.B. Dreier

Objectives. The major objective of this study was to determine the geologic characteristics of the permeable groundwater intervals defined by a borehole flowmeter. If a particular geologic feature (structure, rock type, etc) consistently correlates with permeable groundwater intervals, then we would have a way to predict potential groundwater flow paths. In addition, various other aspects of the flowmeter surveys were examined that were not considered in previous studies, such as (1) how reproducible were the flowmeter results in wells with more than one survey; (2) how do the results compare with identification of permeable intervals using temperature and fluid resistivity logs; (3) can the permeable intervals be correlated between core and piezometer wells; (4) how does the permeable interval length defined by the flowmeter survey compare with the length of the actual transmissive feature.

Results. In order to determine the distribution of permeable groundwater intervals, an electromagnetic borehole flowmeter, developed by the Tennessee Valley Authority, was used to survey 60 piezometer wells and 12 coreholes on the ORR. Piezometer well depths ranged from 5 to 80 ft with screen lengths of approximately 10 ft at various depths, and open corehole surveys reached depths of 350 ft. Previously, the results were used to develop a model for groundwater flow paths by assuming that permeable intervals consist of a single fracture intersecting the borehole. Our purpose was to test this assumption by direct examination of core within permeable intervals.

Occasionally, pinpointing the exact feature responsible for flow within a permeable interval was hampered by a relatively large sampling interval (>1 ft) of the flowmeter surveys. Regardless, potential transmissive features were identified by the presence of iron staining, euhedral calcite and gypsum crystallization, partial infilling of fractures, and dissolution features.

Within carbonate units (Chickamauga Group and Maynardville Formation), permeable intervals are associated with a number of different features (1) open fractures normal and oblique to bedding that are parallel, oblique, and perpendicular to bedrock strike; (2) vugs that form within fracture mineral fillings; (3) solution cavities that are not fracture related; (4) open bed-parallel clay seams; and (5) open bed-parallel shear fractures (Table 2). For example, CH12 is a well that was cored in the Witten Formation of the Chickamauga Group. The flowmeter survey was conducted under ambient flow conditions and identified three permeable intervals (Figure 11). Core analysis of these intervals revealed that each one was related to one of the three main fracture sets that occur on the reservation.

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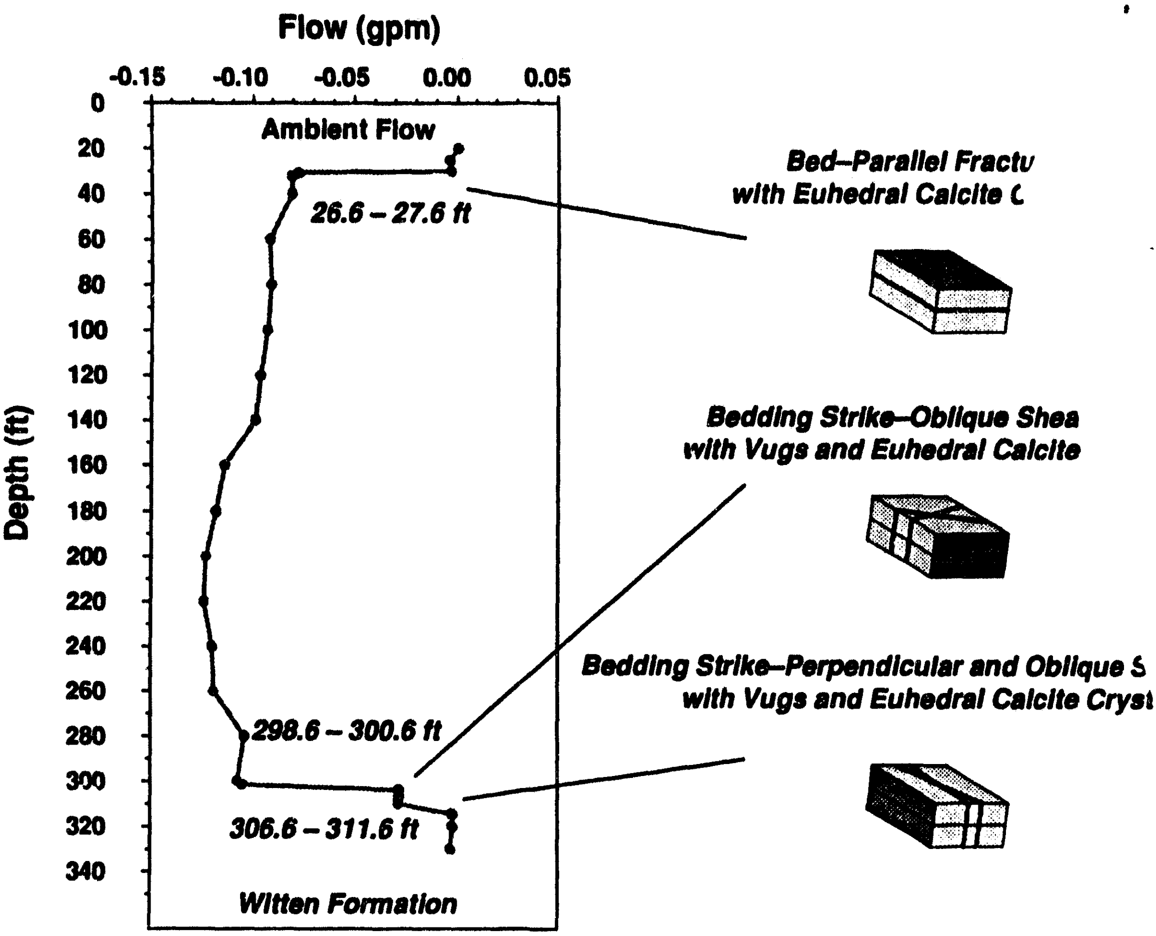

Figure 11. CH12 Flowmeter Survey and Results from Core Analysis.

Within primarily non-carbonate units (Rome Formation and Conasauga Group), however, permeable intervals did not consist of individual fractures, but rather highly fractured zones (Table 2). The highly fractured zones are associated with changes in bedding dip and the development of shear fractures that are related to the development of faults and folds. For example, HHMS12 is a well that was cored in the Pumpkin Valley Shale and Rome Formation (Figure 12). The flowmeter survey conducted under ambient flow conditions did not detect any permeable intervals. The survey conducted at a pumping rate of 0.5 gpm, however, detected two permeable zones each of which was associated with a zone of deformation in the core. Analysis of the core away from the permeable intervals, however, revealed the presence of a number of deformation zones, which indicates that not all deformation zones develop into permeable intervals.

The foregoing results lead to the following interpretation, which remains to be tested. Faults and folds are common in the Conasauga Group and Rome Formation, because during regional thrusting they behaved as mechanically weak stratigraphic units. Prethrusting fracture development in these thin bedded units is expected to be less conducive to forming a connected flow system, because the fractures tend to be restricted to bedding and relatively short in all dimensions. The highly fractured zones associated with folding and faulting appear to provide laterally extensive permeable pathways that act to connect units with an initially high fracture density (Figure 13). Faults and folds in carbonate units, however, are less pervasive because the rock units are mechanically strong. Because of the strength of the carbonates, however, fractures tend to be larger in all dimensions. The development of long continuous fractures suggests that they are more likely to intersect and establish a connected flow pathway.

Future Directions. The results from this study indicate that borehole flowmeter surveys alone cannot be used to determine the geologic feature responsible for producing a permeable pathway. Furthermore, since the geologic feature cannot be identified, interpretations related to permeable pathway orientations and spacings cannot be constrained. The results from this study suggest that deformation zones throughout the area need to be more accurately characterized to determine the factors that control local fracture development (rock types involved in the deformation, amount of shortening in the zones, etc). In addition, more studies pertaining to controls on fracture development in thick carbonate sequences is needed.

3.2.3.3 Fracture toughness testing of bedrock core samples from the Oak Ridge Reservation

P.J. Lemiszki and J.D. Landes

Objectives. Rock mechanics testing of core samples is being conducted in order to determine the mechanical properties of each sedimentary rock type that underlies the ORR. Rock deformation moduli are fundamental physical properties required for characterizing the arrangement of rock mechanical units, for modelling

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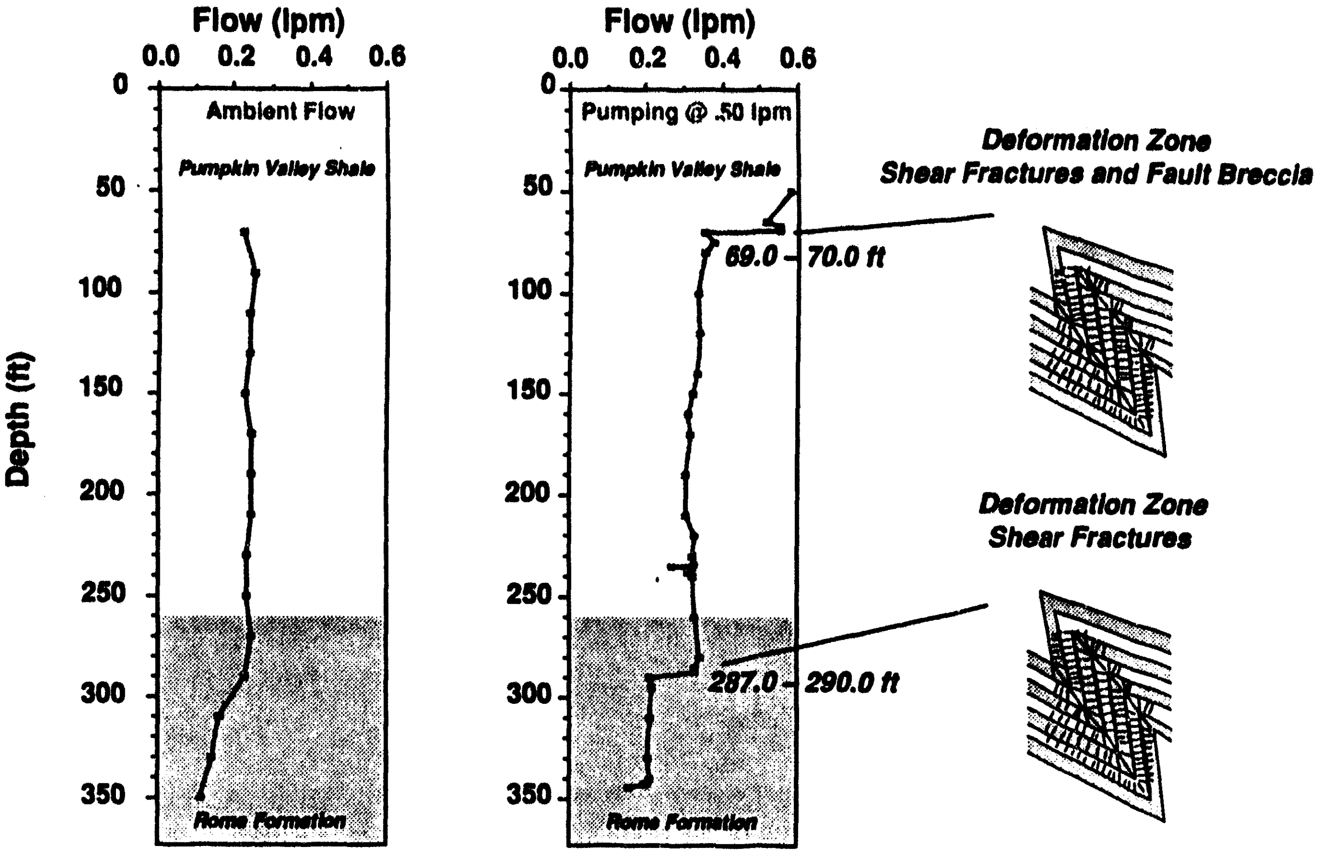

Figure 12. HHMS12 Flowmeter Surveys and Results from Core Analysis.

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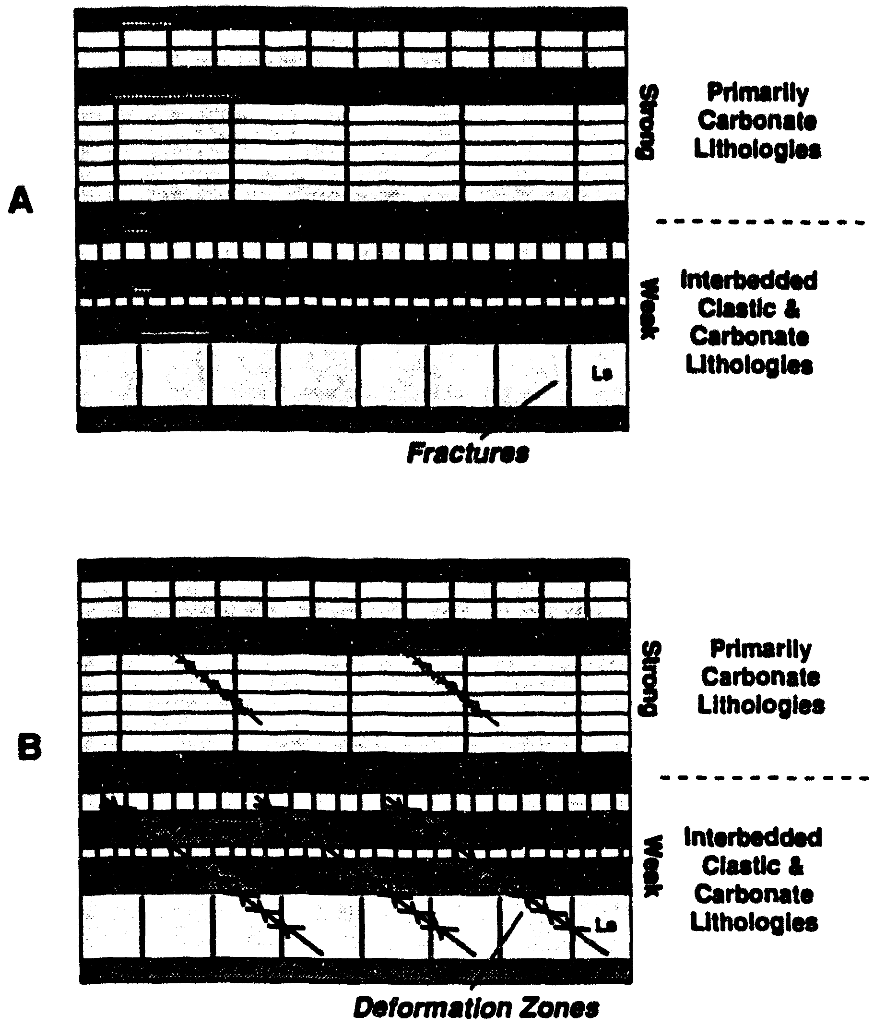

Figure 13. (A) Schematic Fracture Characteristics Prior to Regional Deformation. (B) Overprinting Fractures Related to Deformation Zone Developemnt During Regional Deformation.

Table 2. Permeable intervals detected by the electomagnetic borehole flowmeter and associated conductive features

Corehole	Defining Survey	Interval (ft) (Height) (m)	Rock Unit	Potentially Transmissive Feature(s) and (Bedding Dip)	Actual height (m)
CH 2	B	50.5-51.5 (0.3)	Rockdell	bed-parallel fracture with weathered striated surfaces and iron oxidation (35°)	0.05
	A	75.5-76.5 (0.3)	Rockdell	strike-parallel fracture with 1 cm of precipitated calcite and euhedral calcite crystals (32°)	0.12
CH 9	A	131.9-132.9 (0.3)	Witten	bed-parallel fracture with partial infilling (50°)	0.1
	B	218.9-220.9 (0.6)	Witten	bed-parallel fracture with platy calcite precipitation (40°)	0.07
	B	335.9-336.9 (0.3)	Benbolt	bed-parallel fracture with euhedral calcit precipitation (50°)	0.1
CH 12	A	26.6-27.6 (0.3)	Witten	bed-parallel fracture with iron oxidation and slickensides (30°)	0.07
	A	298.6-300.6 (0.6)	Witten	vuggy, oil stained strick-sub-parallel shear veins throughout with equant calcite (30°)	?
	A	306.6-311.6 (1.5)	Wittne	vuggy strick-sub-parallel shear vein (30°)	0.15
GW 404	B	122-123 (0.3)	Dismal Gap	numerous bed-parallel fractures and fault breccia (39°)	?
HHMS 12	B	69-70 (0.3)	Pumpkin Valley	bed-parallel fractures and fault breccia (70°)	?
	B	287-290 (0.9)	Rome	shear fractures throughout (40°)	?
WOL 2	B	52.5-53.5 (0.3)	Nolichucky	bed-parallel fractures with iron oxidation (5°)	?
	B	55.5-56.5 (0.3)	Nolichucky	breccia and shear fractures (10°)	?
	B	57.5-58.5 (0.3)	Nolichucky	gouge, breccia, bed-parallel fractures (15°)	?

fracture development in these units, and for modelling the response of the fractured units during regional uplift and erosion. The information is needed because many aspects of the groundwater flow system on the reservation are controlled by the fracture system. A number of mechanical models have been formulated to evaluate the variables that controlled local fracture development, but the results are poorly constrained, because the deformation moduli for rock units in the area are not known.

The major objective of this study is to sample each stratigraphic unit in the area and apply fracture mechanics testing procedures to determine the following rock deformation moduli: fracture toughness (a measure of the rocks strength), Young's Modulus, and possibly Poisson's Ratio. A number of rock fracture toughness test methods were considered before deciding on the Modified Ring Test (MRT) (Figure 14). Advantages of the MRT method are that it utilizes core sample geometries, requires little sample preparation, and does not require either precracking or crack length measurements. Disadvantages of the method are that it requires competent rock types that maintain their integrity during machining of the sample and core that is oriented nearly perpendicular to bedding.

Results. The project is in the final stages of sample preparation before actual testing begins. At the time of this writing, all nine samples selected for study have been successfully prepared for testing. A number of details had to be worked out before we were confident that the chosen method was suitable for the rock types encountered in this area. First, a finite element model of the sample and load configuration was needed in order to successfully employ the MRT method. Second, fixtures for the test machine were constructed to fit our sample configuration. Third, the samples had to be machined to specific dimensions, which required the development of special cutting tools and fixtures. Once preparations are completed, actual testing of the samples will only take a few days.

The first phase of the project was to construct a finite element model of the sample and load configuration to relate the magnitude of the stress intensity that develops at the crack tip with the range of expected crack lengths (Figure 15). The model was formulated on the Macintosh computer using a program called MacFracture, which was written by John Bryson from the Engineering Technology Division. The results from the finite element analysis were checked with a nuclear quality assurance finite element program called ABAQUS. The graph shown is our reproduction of results presented in the original paper on the MRT method. Although we could not match the published curve exactly, the results are similar and the shape of the two curves is the same. The minor differences are related to uncertainties in some of the model parameters chosen in the published paper.

Samples of dolostone, limestone, and sandstone from the JOY2 corehole have been selected because they are competent rock types and the core is cut nearly perpendicular to bedding. Samples are from the lower part of the Copper Ridge Dolomite, Maynardville Limestone, Nolichucky Shale, and Rome Formation. The original strike direction of the

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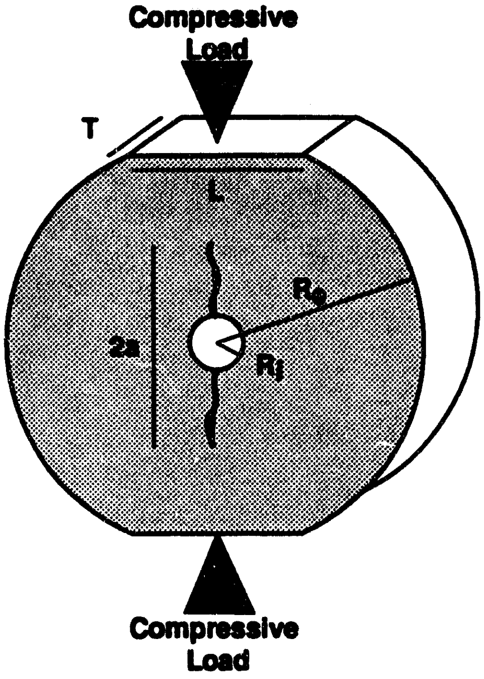

$R_e = 30$ mm

$R_i = 3.175$ mm

L = 10 mm

T = 30 mm

2a = Crack Length

Figure 14. Modified Ring Test Specimen Geometry.

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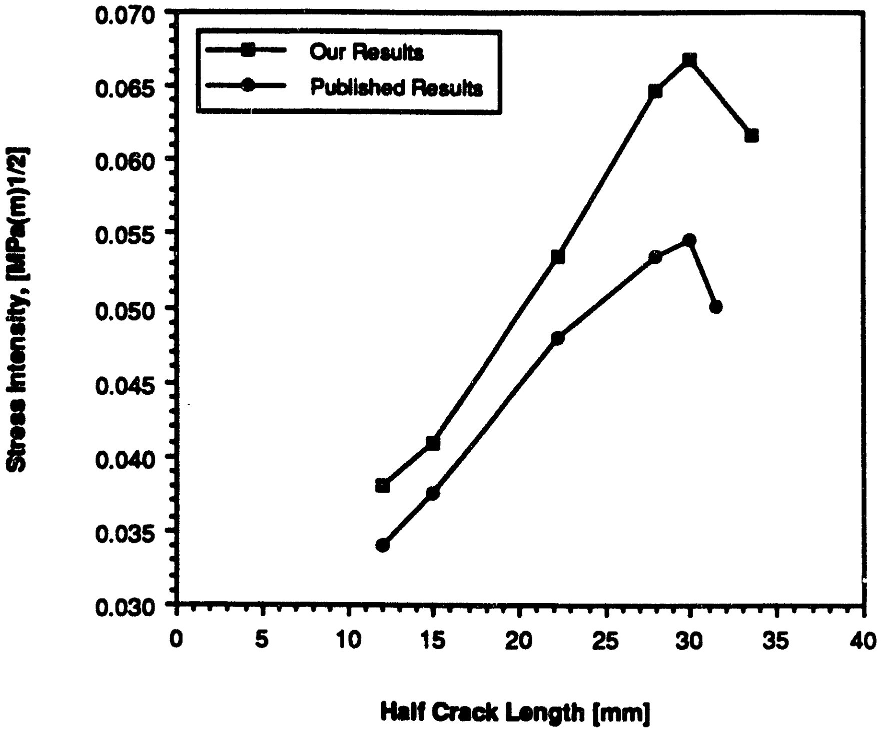

Figure 15. Comparison of Our Finite Element Model Results with Published Results.

core is not known, however, so the core cannot be used to investigate changes in rock fracture toughness as a function of fracture propagation direction. Enough material was collected to test 10 to 20 test samples from each rock unit. Sample preparation involves cutting the core into 30 mm thick disks, drilling a smooth center hole with a 6.35 mm diameter coring bit, and then grinding two diametrically opposed 10 mm long flat surfaces on the outer surface of the disk. During testing, the specimen is compressed across its diameter, using a constant displacement rate. The state of stress induced in the specimen causes a crack to initiate at the inner hole (a stress riser), and to propagate along the loading axis. During crack propagation, the magnitude of the stress intensity at the crack tip is estimated at the point of minimum load, which is a measure of the fracture toughness of the material.

Future Directions. If the test method provides valid fracture toughness and Young's modulus values, then future work should be aimed at testing the remaining rock types on the reservation. As our confidence with the MRT method improves, then future tests will compare the results between samples from drill core and surface outcrops. In addition, a confining pressure cell should be incorporated into the tests to more closely simulate the subsurface conditions that existed during fracturing. The confining pressure tests results can be used to compare mechanical property data interpreted from sonic logs so that the logging tool can be properly calibrated. As more data becomes available, the results will be combined with outcrop and core fracture analyses to divide the sedimentary sequence into specific packages of rock that have a distinct deformational style. This approach will be used to improve existing mechanical models of fracture development that examine the factors that control fracture length, frequency, and aperture. The data can be used to model the response of the bedrock fracture system to regional uplift, hydraulic fracturing during waste injections, and hydraulic testing. Eventually, results will support groundwater and contaminant transport model simulations for the ORR.

3.2.4 Karst

Much of the ORR is underlain by carbonate rocks. Groundwater flow in karst terrain can be extremely complex and can occur on a time scale that is significantly different than exists for the adjacent shale units. Physical evidence of the presence of subterranean karst networks on the ORR and surrounding area includes caves, sinkholes, sinking streams, springs, rapid subsurface flow indicated by tracer tests, grike and pinnacle topography, and boreholes that have encountered cavities.

An ORR-wide study of karst flow has not occurred. Much of ORRHAGS-sponsored activities in FY 1993 with regards to karst flow were centered around planning and the development of a conceptual model. In order to facilitate planning Dr. W. B. White (Pennsylvania State University) was invited to visit the ORR in December, 1993. In a written report Dr. White addressed the following questions:

(i) Do karst processes play a role in the groundwater hydrology of the ORR?
(ii) If so, how can the karstic aspects of the carbonate aquifers be characterized?
(iii) If localized karstic drainage paths are present in the carbonate aquifers, how can these features be monitored with respect to contaminant transport?

Dr. White's response (see appendix for entire report) outlines a variety of techniques that may help characterize karst flow on the ORR. This report is being used to develop a systematic ORR-wide approach to characterize groundwater flow in the carbonate units of the ORR. In addition to planning activities, a seep and spring study of a portion of the ORR began, and Copper Ridge Cave on the ORR was mapped. A brief description of these activities follows.

3.2.4.1 Seeps and springs study

S.B. Jones, R. Nativ, and D.K. Solomon

Objectives. Assessment of natural groundwater discharge on the ORR is considered an essential element of the hydrologic conceptual model recently proposed by Solomon et al. (1992). Characterizing the integrated subsurface flow regime in each hydrologic unit and evaluating source transport depends on several crucial factors: identifying discharge points, seasonal variations in discharge volumes, and the correlation between natural outlets and the contributing water-bearing units. To date, few surveys of natural surface discharge points (springs and seeps) on the reservation and surrounding areas have been made. Such surveys may be particularly important to identifying discharge points from karst features, where they exist.

Natural outlets of subsurface flow may be controlled by surface topography, formation lithology, karst features, and geologic structure (fractures, faults, folds). It has been postulated by Solomon et al. (1992) that there is an active shallow groundwater system (consisting of the stormflow, vadose, and watertable zones), a less active intermediate groundwater interval, and a deeper saline system that is considered to be sluggish and relatively immobile. By inventorying the existence, and monitoring the hydrologic and geochemical components of spring and seep discharges, further data about the character of groundwater flow will be gained. In addition, a major objective is to establish a protocol for developing seep and spring inventories on the ORR.

The study area chosen for this investigation encompasses a region to the east and south of the main Y-12 Plant area (Figure 16). The study described here encompasses an analysis of hydrologic, geochemical, and isotopic characteristics of spring and seep discharge waters. The identification of groundwater geochemical facies will make it possible to classify water types, help determine relative contribution of lithologic units to natural discharge, and establish residence times for groundwater in various components of the system. In addition, identifying discharge points for deep saline groundwater will aid in definition of deep groundwater flow paths (cf. Section 3.2.3).

Results. Two sweeps of the selected study area have been completed. One during the spring and summer months of 1992 and one during the winter of 1993. These sweeps consisted of an intensive field search for springs and seeps. During the 1992 sweep, 142 springs and seeps were located. The 1993 sweep yielded an additional 74 springs and seeps that resulted from wetter seasonal conditions (Figure 16).

Several parameters were recorded at each one of these springs: location, water temperature, specific conductance, dissolved oxygen, discharge, and lithology. Using these parameters, three classes of springs have been identified that appear to be controlled primarily by topography and lithology. Class I springs are characterized by very low specific conductance (< 100 micromhos/cm) and widely varying values for temperature and dissolved oxygen. Class III springs are characterized by relatively high specific conductance (>350 micromhos/cm) and little variation in temperature. Class II springs fall in between these two classes and have widely varying values for temperature and dissolved oxygen.

A subset of 30 springs was selected for chemical and isotopic sampling. This sampling was completed in mid-August and analytical results are pending. A monthly monitoring schedule of this subset of springs is now being implemented in order to obtain pH, temperature, specific conductance, dissolved oxygen, and discharge over a period of one year.

Future directions. A protocol for expanded spring and seep evaluation to extend the results of this study will be developed to increase efficiency and optimize data quality. During 1994, another sampling of the subset of 30 spings described above will be conducted. The objective is to examine chemical and isotopic variations between wet and dry seasonal spring discharges.

3.2.4.2 Mapping Copper Ridge Cave

P. A Rubin, B. Zerr, and G. Davies

A large air-filled cave passage in Copper Ridge has been mapped. It is hypothesized that this conduit, and other tributary cave passages, extend under much of the Copper Ridge segment supporting the Tower Shielding Facility and the former Health Physics Research Reactor.

The first 1,000 ± feet of Copper Ridge Cave descends steeply along fractures and aslant dip as a vadose canyon until reaching the lip of an 17 foot drop. Looking outward from the lip of the pit, it is possible to see the cross sectional dimensions of a major conduit to which the first 1000 ± feet is just a small feeder. From the lip of the pit the passage is approximately 40 feet high and 50+ feet wide. Water almost certainly infiltrates the groundwater basin tributary to this conduit along fractures and nearby sinkholes extending upwards to the summit of Melton Hill (Figure 17).

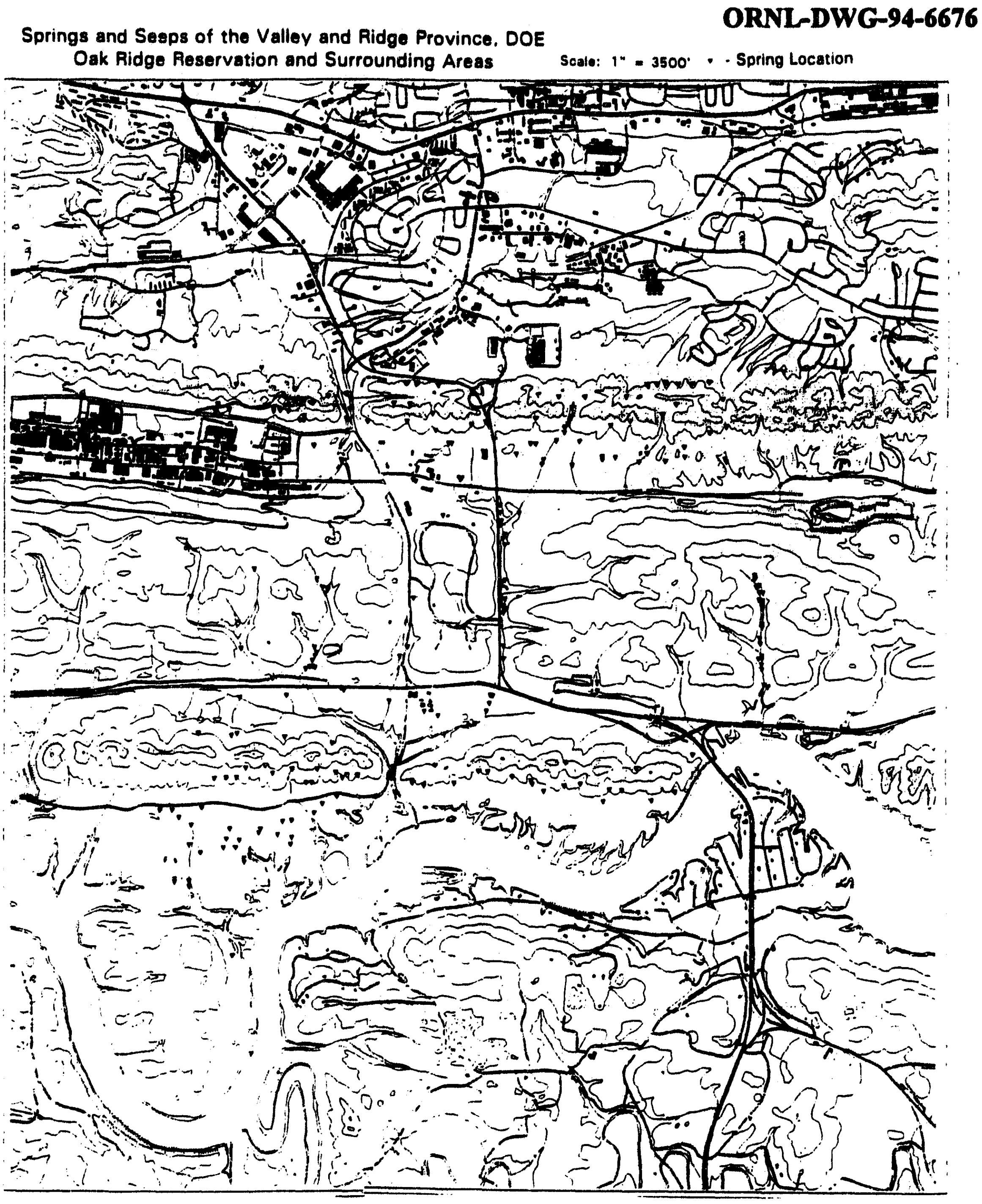

Figure 16. Locations of the 316 springs and seeps that have been identified in the area of this study.

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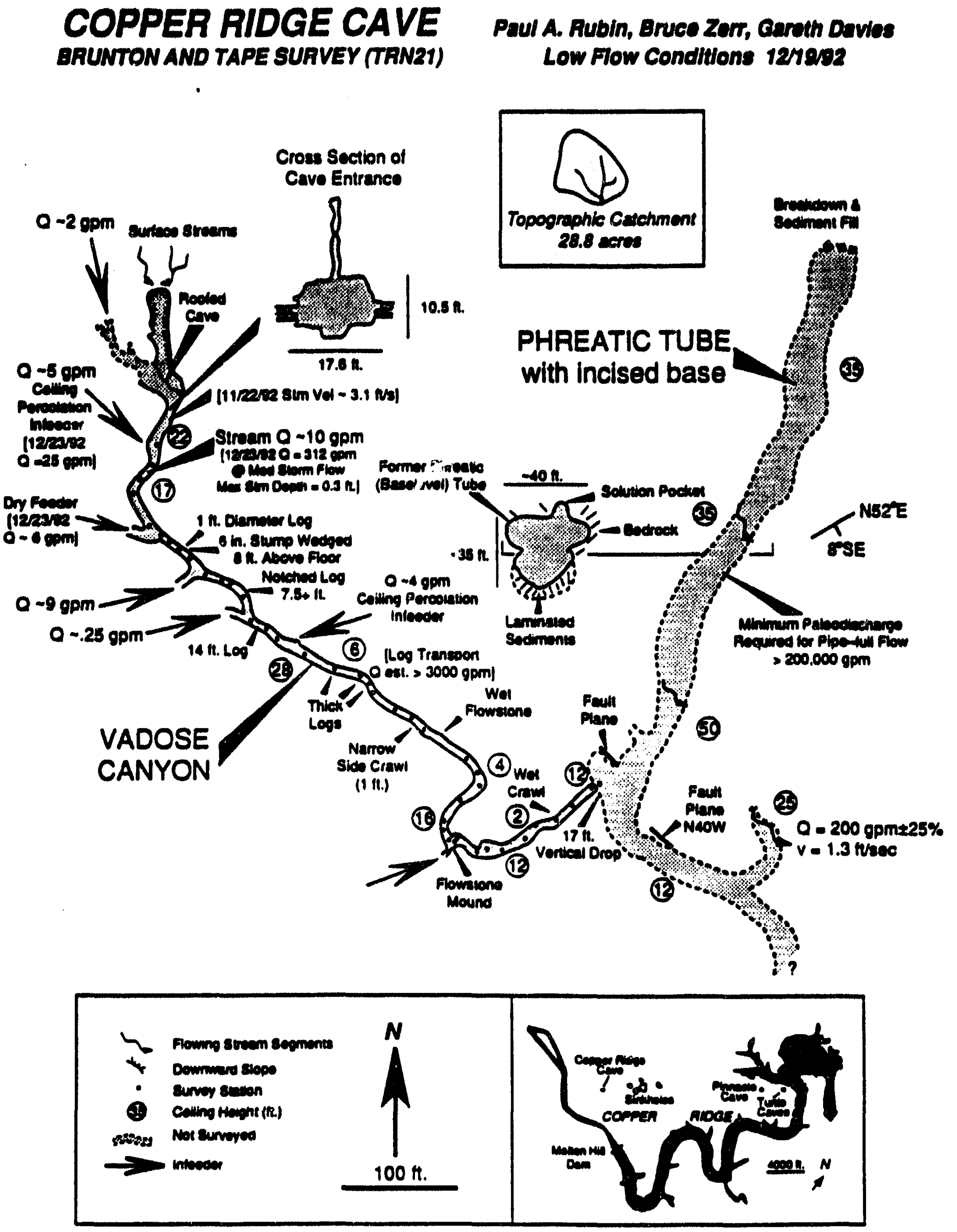

Figure 17. Low Flow Conditions, Copper Ridge Cave.

Further to the northeast and along strike, survey work at Cherokee Caverns document an upper level phreatic (tubular) conduit at an elevation of 973 ft. msl, with a similar phreatic conduit (where flow occurred prior to entrenchment) to the southwest at Eblen Cave with a ceiling elevation of approximately 820 ft. msl. These two relict caves are directly on-strike, separated by 14.8 miles. The hydraulic gradient between them is 0.0002, which is reasonable for long phreatic conduits. It is possible that these two caves were once the same cave, prior to erosional dissection by the Clinch River and other streams. Copper Ridge Cave lies directly between these caves, also along strike,and may once have been part of the same system, presuming strike aligned flow which is typical in steeply dipping karst settings (Ford and Ewers, 1978; Worthington, 1991, Rubin and Lemiszki, 1992; Ogden, 1992).

Since the formation of this cave is believed to be similar hydrologically and geomorphically to others beneath the ORR, (e.g., beneath Bear Creek Valley), information from it possibly can be used to infer the characteristics of other presently active karst systems (Rubin, Lietzke, and Schmidt, 1992). Understanding the relationship between conduit development and bedrock geology is important on the ORR because the presence of well-developed karst indicates the potential for rapid transport of contaminated groundwater from disposal sites. Copper Ridge Cave represents the first long and physically enterable ORR cave where these relationships can be examined.

Until recently, information on the active portions of Reservation karst systems has been limited to a small number of tracer tests; evidence of conduit flow systems inferred from numerous boreholes having encountered cavities; hydraulic head data from one well intersecting a large, mud-filled cavity; water chemistry data; surficial karst features; off-Reservation cave;, and aquifer tests largely conducted in slow-flow (< 0.001 m/sec) portions of the carbonate aquifers. Factors controlling groundwater flow in ORR karst flow systems may be observed firsthand in Copper Ridge Cave.

3.2.5 Mapping: Soil Survey and Characterization of the Oak Ridge Reservation

S. Y. Lee and D. A. Leitzke

Soils on the ORR have been used as host media for contaminant containment for more than forty years and land-based waste disposal practices likely will be continued in the future for economic reasons . However, future development on the ORR is rapidly becoming a limited resource .

Soil survey and soil physical, chemical and mineralogical characterization is a key component of land use and site development planning. Therefore, a detailed survey and characterization of the physical, chemical, and morphological properties of the ORR soils have been and are being conducted for the benefit of ER, land use planning, and soil conservation activities. Soil conservation planning and assessment is required by DOE Order 4300.1C. However, prior to this reservation wide soil characterization program a useable database on soils was not available. At the present time, approximately 70% of the 15,000 ha of ORR lands have been surveyed and the digitized results are in the Geographic Information System (GIS). Information in the GIS database includes a 1:12,000 scale soil map, descriptions of representative soils, and soil interpretations.

Objectives. The major objectives of this task are to (1) map soils in relation to bedrock formation, (2) conduct physical and chemical characterization of representative soils, and (3) determine soil erosion (sediment production) rates on the ORR. The results of this task will be used by ER projects, related Remedial Investigation/Feasibility Study activities, and will help evaluate containment and remediation implementation. In addition, the RMO for the ORR also needs such information for soil conservation and site development planning purposes.

Results. Soil survey information has already been utilized many different ways. The Background Soil Characterization Project (BSCP) selected soil sampling sites based on the detailed soil survey results where coverage was available. In return, a wealth of data was made available that is related to geologic formations through the analyses of residual soils (DOE, 1993). Residual soils from the Dismal Gap, Nolichucky, Copper Ridge, Chepultepec, and both Bethel Valley and K-25 sections of the Chickamauga Group were sampled. In addition, two off-site areas in the same strike belt as the Bear Creek Dismal Gap Formation and Chestnut Ridge Copper Ridge Formation were sampled in the northeast corner of Anderson County and the southwest corner of Roane County. Background concentrations of organic compounds, metals, and radionuclides were determined from these samples by many different state-of-the-art analytical methodologies.

The BSCP database will be used by the ER Program related to Remedial Investigation/Feasibility Study development, environmental impact statements for future disposal sites, land use planning, and reservation-wide geohydrological investigation. The soil survey and interpretative information are in the Environmental Sciences Division's Geographic Information System. The BSCP results are also stored in electronic form in the OREIS.

The Plant and Soil Science Department of The University of Tennessee has been working on the soil characterization task for the ORR. Soil characterization includes physical, chemical, and mineralogical studies of representative soil mapping units. Preliminary results are presented in ORNL/TM-10803 (Lee et al., 1988). In FY 1993, soil pH, texture, and bulk density were measured for about 120 soil samples collected from the BSCP sampling sites (soil profile locations are in a BSCP report to be published). The results are summarized in Table 3. The average pH of the soils ranged from 4.51 to 5.75 and varied among formations and soil horizons. There were no differences in soil pH between on-site and off-site soils. The particle size distribution showed that silt content decreases with depth and clay content generally increases with depth. The C horizon samples represent residual soils weathered from bedrock with minimal influence of pedogenesis. The bulk density of A horizons was lower than subsurface soil because of the presence of organic matter and soil structure. The bulk density of subsurface horizons (B and C) is more representative of the value for residuum of the sites.

Soil mapping, on a limited basis, has been underway in the region immediately east of the K-25 plant, in the area of McKinney Ridge. The Rome Formation on the west and south sides of McKinney Ridge is extremely brecciated. A shale unit occurs on the northwest side of the Knox Dolostones. The Maynardville Formation seems to be missing between this shale unit and the cherty Copper Ridge Formation. The Copper Ridge Formation on McKinney Ridge is also very highly brecciated. Most chert fragments are pea sized to gravel sized. There are very few chert fragments of cobble and boulder size on the surface, and where larger fragments have been observed, they all have sickensides. Indeed, there are only a few places on McKinney Ridge where there are rock piles of chert rock. Most of the chert has been so fragmented that it did not cause problems with agricultural tillage. Dolines are very scarce on McKenney Ridge, but other geomorphic features are abundant including topographic benches and colluvium covered northerly and easterly side slopes. Much of the flatter areas along the crest of McKinney Ridge are mantled with ancient alluvium of mostly local origin. This ancient alluvium occurs at an elevation of about 1100 feet, nearly the same elevation as the alluvium on the west end of East Fork Ridge.

The ORR has three major tributaries (White Oak Creek, Bear Creek, and East Fork Poplar Creek) for sediment and surface water discharge to the Clinch River. Sediments from these three watersheds have been contaminated by various constituents generated at all three DOE facilities. The contaminants coming from point sources have been mixed with non-contaminated sediments eroded from ORR soils. The result is that the eroded soils are hosting the contaminants as well as diluting them during the transport process off-site. Therefore, soil erosion rate determination and estimation of sediment input to the Clinch River through major tributaries in the ORR are important parameters for assessing off-site contaminant transfer.

Two years ago, soil erosion and deposition rates within doline areas were studied using fallout radiocesium redistribution as a model for watershed landscape. Three dolines were used, each under a different land use system: cropland, grassland and forest sites. The redistribution of ^{137}Cs was greatest in the cropland, followed by the grassland and then the forest. Soil erosion rates followed the same trend, with rates of 4.2 t ha^{-1} yr^{-1} for cropland, 6.5 t ha^{-1} yr^{-1} for grassland, and 2.2 t ha^{-1} yr^{-1} for forest sites. These soil erosion rates were compared with those estimated using the Revised Universal Soil Loss Equation (RUSLE). The RUSLE rates also showed the trend of decreasing erosion rates from cropland to grassland to forest.

Table 3. Average soil pH, particle size distribution, and bulk density of the soil developed from different geologic formations

Site	Formation	Horizon	pH	Sand	Silt	Clay	Bulk Density
ORR[a]	Dismal Gap	A	5.03	27	56	17	1.05
ORR	Dismal Gap	B	5.13	26	36	38	1.13
ORR	Dismal Gap	C	5.14	37	26	37	1.12
ORR	Nolichucky	A	4.76	20	57	23	1.15
ORR	Nolichucky	B	4.84	16	37	47	1.25
ORR	Nolichucky	C	4.94	28	25	47	1.26
ORR	Copper Ridge	A	5.03	25	51	24	1.10
ORR	Copper Ridge	B	4.58	15	34	51	1.27
ORR	Copper Ridge	C	4.55	18	20	62	ND[e]
ORR	Chepultepec	A	4.91	35	48	17	1.21
ORR	Chepultepec	B	4.55	18	29	53	1.31
ORR	Chepultepec	C	4.88	21	20	59	ND
ORR	Chickamauga B[b]	A	5.08	20	50	30	1.06
ORR	Chickamauga B	B	4.94	7	37	56	1.21
ORR	Chickamauga	C	5.75	6	32	62	ND
AND[c]	Dismal Gap	A	4.72	44	38	18	ND
AND	Dismal Gap	B	4.94	24	37	39	ND
AND	Dismal Gap	C	5.03	37	31	32	ND
AND	Copper Ridge	A	5.13	23	61	16	ND
AND	Copper Ridge	B	4.93	15	49	36	ND
AND	Copper Ridge	C	5.00	16	37	47	ND
RON[d]	Dismal Gap	A	4.70	22	53	25	ND
RON	Dismal Gap	B	4.79	14	52	34	ND
RON	Dismal Gap	C	4.68	24	39	37	ND
RON	Copper Ridge	A	4.80	31	57	12	ND
RON	Copper Ridge	B	4.51	18	52	30	ND
RON	Copper Ridge	C	4.66	19	33	48	ND

ORR[a] = Oak Ridge Reservation, Chickamauga B[b] = Bethel Valley Chickamauga, AND[c] = Anderson County, RON[d] = Roane County, ND[e] = not determined

The erosion rate for the cropland was the same as the rate calculated using ^{137}Cs redistribution, but this does not verify the ^{137}Cs equation for calculating soil erosion rates, since the cropland doline was concluded to be a partially open system with potential loss of ^{137}Cs and clay materials. The RUSLE computed grassland erosion rate of 0.6 t ha^{-1} yr^{-1} and the forest rate of 0.2 t ha^{-1} yr^{-1} were lower than the rate using ^{137}Cs, probably because at low erosion rates RUSLE tends to underestimate soil loss.

Paleosols were discovered in the depositional areas of the dolines, and were used to calculate the volume of sediment that had been deposited in each closed system. Radiocarbon dates from charcoal and soil samples taken from the Ab horizon provided a time frame to estimate the average rate of deposition that must have occurred to arrive at the volume of sediment accumulated above the Ab. The deposition rate for cropland was 3.6 t ha^{-1} yr^{-1} (over 480 yrs.) and 2.2 t ha^{-1} yr^{-1} (over 980 yrs.) for grassland. The forest showed a substantially higher deposition rate of 28 t ha^{-1} yr^{-1}. This high rate was assumed to have occurred when the forest was first cleared. However, the sediment deposition rate for the last 50 years was very low because of reforestation as shown by fallout cesium redistribution.

Future direction. Within the coming year, the soil survey of the Tower Shielding Reactor area and K-25 area will be completed. A reservation-wide digitized soil map with soil descriptions and an interpretive summary is planned. Soil characterization will continue to obtain basic information to support other geological and hydrological activities.

However, major efforts will be directed to soil erosion studies because of the urgent need of such investigation by the ER Program. The erosion study is a key to answering the following questions (1) what is the impact of soil erosion on contaminated sediment transport to off-site areas?, (2) what is the potential impact of land use and site development on sediment production?, (3) what is the potential impact of soil erosion on the containment or remediation strategy of contaminated sediments in stream tributaries? and (4) what is the life-time of soil caps on the existing waste burial grounds and engineered tumulus-type disposal areas?

3.2.6 Miscellaneous and Exploratory Activities

In addition to studies that fall under one or more of the FY 1993 research themes, a variety of exploratory studies and technique development activities occurred. Several of these activities were in response to specific problems identified by site groundwater coordinators. Other activities were undertaken in response to newly identified characterization needs or to new data or understanding with regards to groundwater flow and contaminant transport on the ORR.

3.2.6.1. Evaluation of mass exchange between clastics and carbonates

D. K. Solomon, P. G. Cook, R. Shropshire, and R. B. Dreier

The ORR is underlain by both clastic and carbonate rocks. The migration of contaminants through clastic rocks (where most wastes are located) occurs on a time scale of tens to hundreds of years, while travel times in the carbonates may be much shorter due to karst flow paths. A key question for assessing the risk associated with karst flow paths pertains to the interface between the clastic and carbonate flow systems. One hypothesis holds that diffuse flow through the clastics feeds conduit flow paths. Under this hypothesis the risk associated with karst flow paths is relatively low because contaminants must first migrate through the clastics. A second hypothesis holds that conduit flow paths are directly connected to actual or potential waste sources near land surface. Under this hypothesis rapid migration could occur following a near surface contaminant release.

Objectives. As naturally-occurring uranium and thorium decay, the noble gas helium-4 is produced. Because most of the rocks of the ORR are more than 400 MY old, significant amounts of helium-4 have been generated. Much of this helium is trapped within mineral lattices; however, because of its high diffusion coefficient, significant amounts of helium-4 escape the mineral lattice and dissolve in groundwater. As groundwater moves through U- and Th-rich rocks, dissolved He concentrations rise. Previous studies on the ORR suggest that dissolved He concentrations in clastic units are very high (up to 10,000 times greater than rain water values) due to long groundwater travel times and high natural U and Th contents. Thus, it was hypothesized that dissolved He might be an excellent tracer of deep, clastic-derived groundwater, which in turn would indicate potential for transfer of contaminants from shales to karst systems.

Results. Groundwater samples were collected from two monitoring wells equipped with Westbay sampling ports that allow samples to be collected at multiple depths. Well GW726 has eight sampling ports that range from 130 to 580 ft below land surface. GW726 samples water from the Middle and Lower Nolichucky Shale. Because of low yield, the deepest port of GW726 was not sampled. Well GW722 has eleven sampling ports that range from 87 to 620 ft below land surface. GW722 samples water from the Maynardville Limestone with the deepest port located in Upper Nolichicky Shale; however, because of low yield the deepest port was not sampled.

Because He is extremely volatile a special sampling device was used to prevent gas loss during sample collection. The modification is described in Section 3.3.6.2. of this report. Samples were collected in 125 ml flasks that were previously evacuated. Approximately 100 ml of water was collected leaving about 25 ml of head space in each flask. In the laboratory this headspace was expanded into the vacuum-gas-chromatographic system developed for the noble gas tracer test. Dissolved Ar was also analyzed on each sample as a check on leakage during sample collection and storage. The results of the He analyses are shown in Figure 18.

ORNL-DWG-94-6678

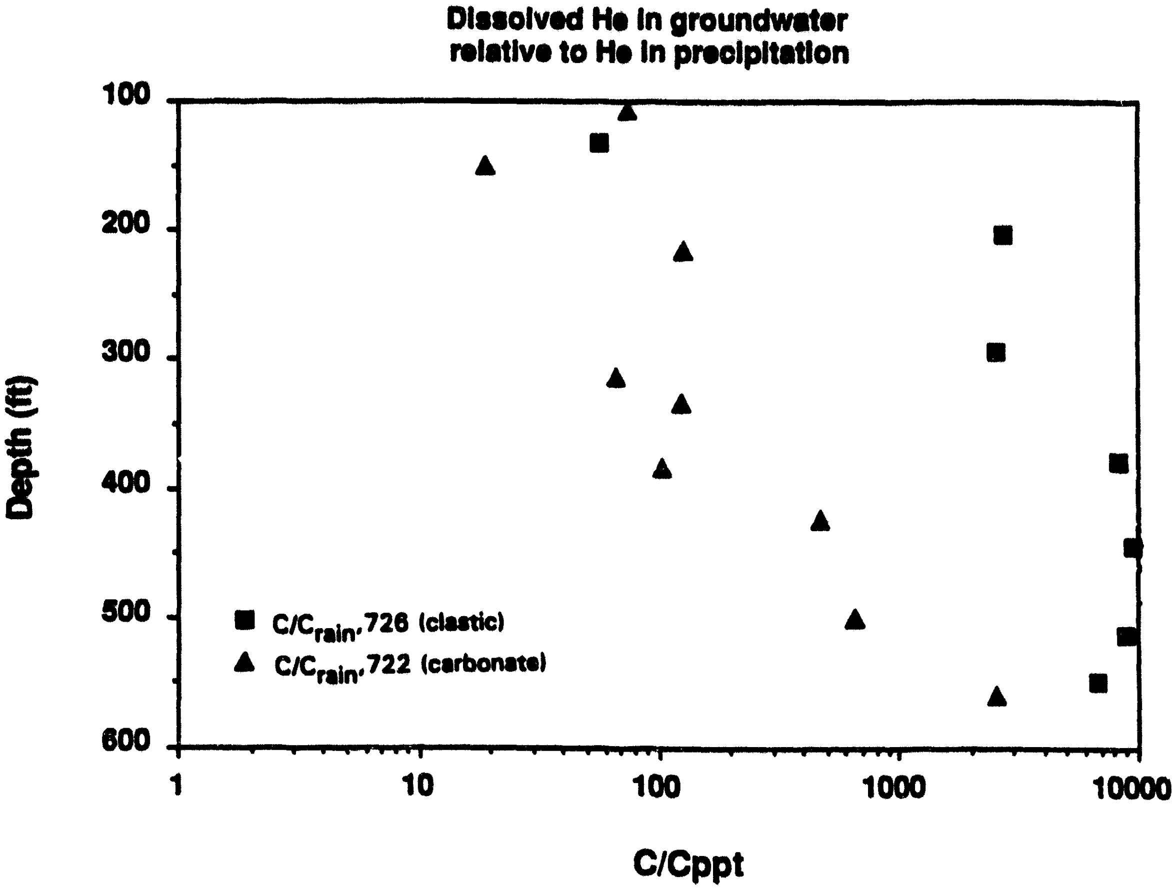

Figure 18. Dissolve He in Groundwater Relative to He in Precipitation.

Helium concentrations in GW726 increase from about 60 times atmospheric values at 130 ft to nearly 10,000 times atmospheric values at 580 ft. Helium concentrations in GW722 range from about 20 times atmospheric values at 150 ft to about 2500 times atmospheric at 560 ft. At depths of between 200 and 400 ft He concentrations in GW722 are approximately 100 times less than in GW726. One hypothesis is that approximately one part old-clastic-derived water is mixing with 100 parts young-carbonate-derived water. However, this hypothesis must be validated by testing water samples from GW722 and other wells finished in the carbonates for indications of young water.

Future Directions. In clastic formations the He content of water samples is a strong function of age. Preliminary data show stair-step-like increases in He with depth that likely delineates hydrologic zones. Because of on-site analytical capabilities it is possible to develop an ORR-wide data base of He concentrations and it may be possible to convert these values into groundwater travel times. In carbonate formations relatively large amounts of He may indicate mixing of small quantities of old-clastic-derived water with young-carbonate-derived water. Several new techniques are available (e.g. $^3H/^3He$ and CFCs) to date young groundwater. By comparing groundwater ages in the carbonates with He it may be possible to place further constraints on the water flux discharging across the clastic-carbonate interface.

3.2.6.2. Westbay gas sampling

P.G. Cook and D.K. Solomon

The Westbay System is a multilevel groundwater monitoring device, employing a single, closed access tube with valved ports. The ports are used to provide access to several different levels of a drillhole in a single well casing. The ports are sampled by lowering a sample probe into position, and electronically opening the valve. Groundwater enters through the probe, into previously evacuated sample bottles (Figure 19a). A bottom filling sample bottle has been designed for sampling volatile organics (Figure 19b).

The difficulty with sampling for dissolved gases with such a system, is that as the groundwater enters the evacuated sample bottle, it will degas. The result will be that most of the dissolved gases will be in the head space, which is not sampled. Also, current analytical methods for trace gases require sampling in crimped copper tubes (noble gases) and glass ampules (chlorofluorocarbons) which is not possible with the existing system.

The objective of the project is to measure chlorofluorocarbon and helium concentrations in deep wells on the ORR. Helium may provide a

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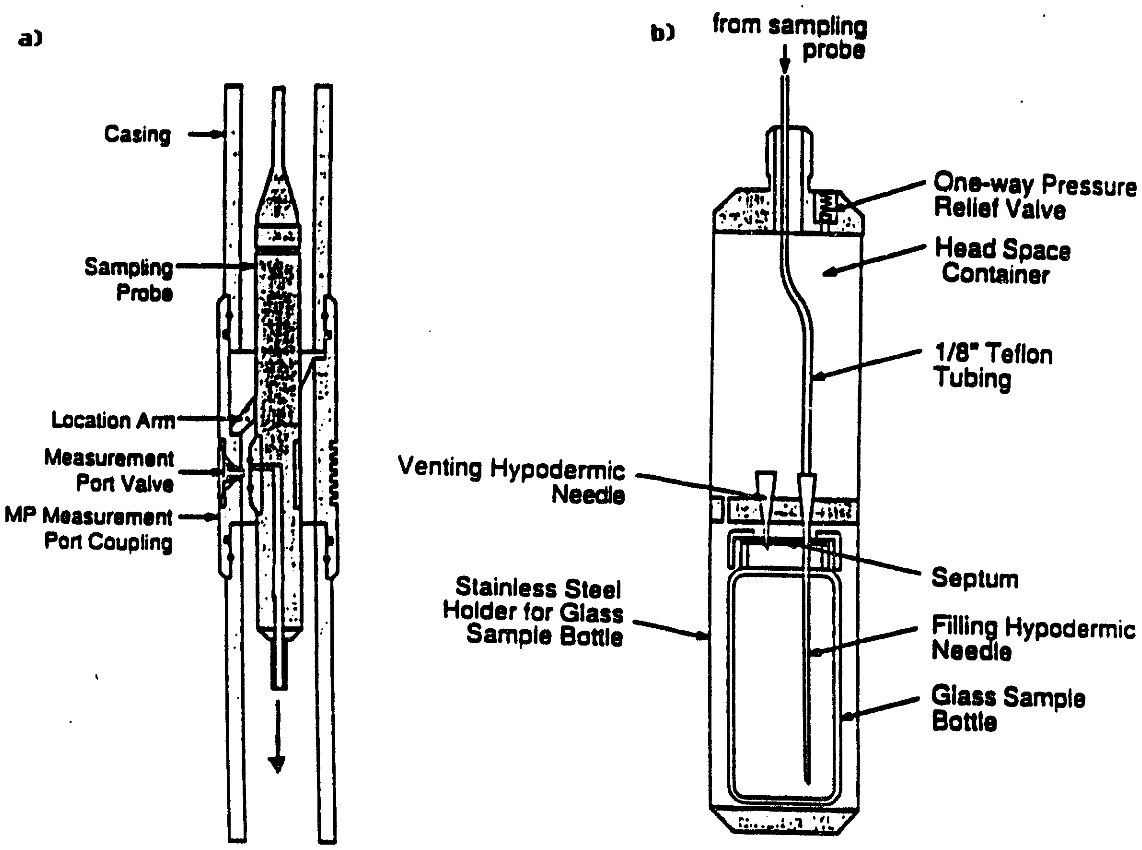

Figure 19. (a and b) Westbay system.

qualitative estimate of groundwater age. Chlorofluorocarbons, present in the atmosphere since the 1940s, are indicators of the presence of "modern" water.

Results. A salient modification to the Westbay system was carried out to allow sampling of dissolved gases with minimal degassing. The system operates using two existing Westbay sample bottles (Figure 20). A coil of 3/16" stainless steel (SS) tubing is fitted into the upper sample bottle. It is attached to the sample probe at the top, and to the second sample bottle below, both via 1/8" tubing (stainless steel tubing was used to replace existing teflon tubing for these connections). The lower sample bottle is fitted with a similar coil, attached to the first coil via 1/8" SS tubing, but left open at the lower end. 1/8" teflon tubing is connected to the valve at the lower end of the second sample bottle, and is left open at the top.

Prior to sampling, the valve at the bottom of the second sample bottle is (manually) closed, and the system is evacuated. The system is then lowered down the casing to the sampling port, and the valve in the sample probe is (remotely) opened. Water from the formation passes through the sample probe, and begins to fill the coils. Once the coils have been filled, the lower sample bottle is filled. The valve is (remotely) closed and the system is removed from the well casing.

Because a vacuum is created in the bottles before filling. Water which initially enters the bottles will degas. However, with the arrangement shown in Figure 20, this water is used only to flush the coils, and remains in the second sample bottle. The water which fills the coils was the last water to enter the probe from the aquifer. Hence the tendency for degassing is lower.

Once the system is removed from the well, the valve at the top of the upper sample bottle is (manually) closed, and the sample probe is detached. Ultra high purity nitrogen is attached to the valve at the bottom of the second sample bottle, and used to push the water out of the coils, through the valve at the top of the upper sample bottle. The coils have a total volume of approximately 120 mls. Tubing can be attached directly to the top of the upper bottle, and this water forced directly into the chosen sampling bottles, without contact with the atmosphere.

Samples have been collected with this system from wells GW726 and GW722. The He analyses (reported in Section 3.2.6.1) compare favorably with previous measurements. Because He is extremely volatile, the sampling devices appear to be effective at preventing gas loss. However, organic analyses of samples from well GW722, revealed very high levels of contamination (CCl_4, CFC-113, and other unidentified compounds). Concentrations were not determined, as they were too high for the analytical system being used.

ORNL-DWG-94-6680

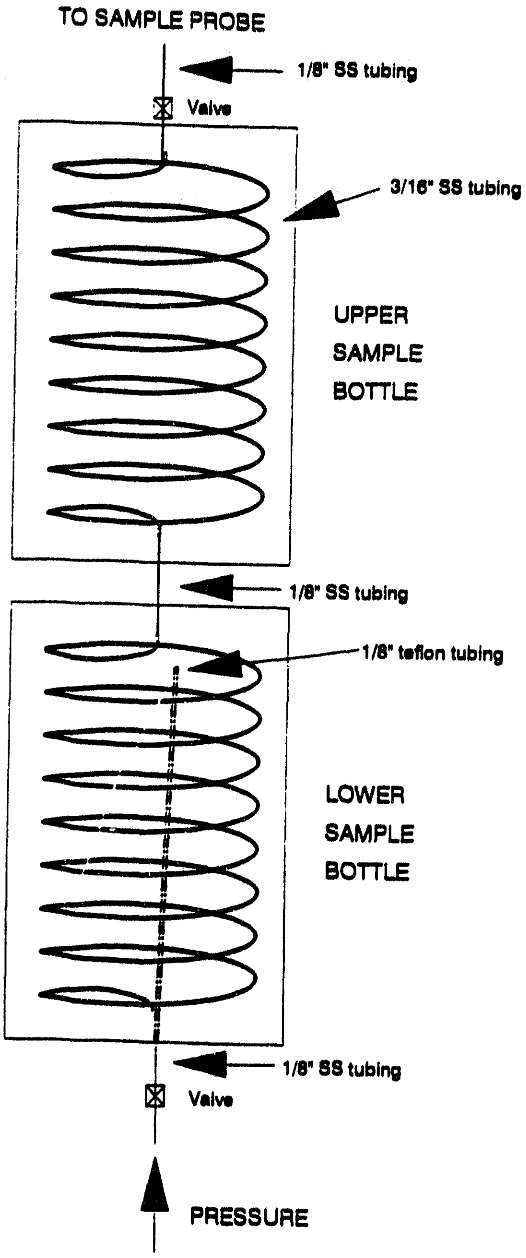

Figure 20. Westbay System Sample Bottle.

Three possible sources of the contamination have been considered:

1) the groundwater itself. This was considered unlikely, as even the very lowest sampling port (at approximately 600 feet depth) had very high levels of contamination. Water at this depth was thought to have been very old.

2) the sampling probe. This is currently being evaluated. Water of known CFC concentration was pumped into the sampling probe, and then into glass sampling bottles. Analyses are currently being carried out.

3) the Westbay well casing. Possible contamination of the casing itself, including possible leaching of CFCs from PVC is the "worst case" possibility. If proven, then Westbay wells may not be able to be sampled for CFCs. If no contamination of the probe is indicated, then testing for well casing contamination should be carried out by sampling Westbay wells in areas known to have no possibility of groundwater contamination.

3.2.6.3 Aerial surveying by model airplane

J.E. Nyquist and C.D. Farmer

Current airborne geophysical surveys employ sensors mounted on either fixed wing aircraft or in a "bird" suspended on a cable below a helicopter. Recent advances in electronics have reduced component size and power demands to the point where it is reasonable to consider placing geophysical sensors on a radio-controlled model aircraft. This approach has a number of advantages for site characterization at hazardous waste sites.

The principal advantage of using a model airplane for aerial surveying of waste sites is an enormous reduction in cost in comparison to conventional techniques. Rental of either a fixed wing airplane or helicopter is very expensive (up to $1000/day plus $900/hr of flight time). In contrast, a high-quality model aircraft can be purchased for less than $1000 and does not require the services of a licensed pilot, flight engineer, or mechanic. Additionally, two of the major advantages of aerial over surface geophysics are retained: sites can be covered quickly and there is no danger of exposing the operator to radiation or hazardous chemicals.

The disadvantages of scaling down to a model airplane are reduced range and reduced payload. Given the relatively small size of most waste sites, the reduced range of a model airplane is not a significant factor. Reduced payload is of concern, even in the age of microelectronics. However, because of the small size of hazardous waste sites, one can repeatedly overfly the area with a different sensor mounted on the aircraft for each flight.

During FY 1993 we tested a radio-controlled airplane designed by Jim Walker of Brigham

Young University for low-elevation aerial photography. Aerial photographs taken over waste areas on the ORR have proven effective in locating trench boundaries in some regions. Small depressions caused by the gradual settling of trench fill material collect water and result in growth of greener grass during the summer than in surrounding areas (Figure 21).

During FY 1994 funding has been obtained from DOE-HQ (EM-50) that will permit us to design the necessary electronics to mount dual, 3-component, flux-gate magnetometers and a global positioning system on a model airplane. These modifications will permit us to test the capability of a model airplane as a platform for obtaining low-elevation, geographically-referenced, magnetic data.

3.3 REPORTS, PUBLICATIONS, TECHNICAL PRESENTATIONS, AND OTHER STAFF ACTIVITIES

The following is a list of professional publications and/or presentations by ORRHAGS technical staff during FY 1993:

Dreier, R.B. and Toran, L.E., 1993. Geologic controls on flow patterns at the Oak Ridge Reservation. Technology Information Exchange Workshop. Fourth National Meeting, May 11-13, 1993, Knoxville, TN.

Hatcher, R. D., Jr. et al. 1992. Status Report on the Geology of the Oak Ridge Reservation. ORNL/TM-12074.

Kim, K. H., K. M. Turnage, S. Y. Lee, J. E. Foss, I. L. Larsen, R. J. Lewis, and M. E, Timpson. 1992. Soil erosion and deposition rates calculated within sinkholes using fallout radiocesium redistribution. Abstract. 1992 Soil Science Society and Clay Mineral Society Meeting.

Lee, S. Y., D. A. Lietzke, R.H. Ketelle, and J. T. Ammons. 1988. Soil and Surficial Geology Guidebook to the Oak Ridge Reservation, Oak Ridge, Tennessee. ORNL/TM-10803.

Lemiszki, P.J., Neuhoff, P.S., and Dreier, R.B., 1993, Core analysis combined with electromagnetic borehole flowmeter surveys is an effective way to document transmissive geologic structures Fourth National Technology Information Exchange Workshop Proceeding, p. 41.

Nativ, R., and Hunley, A., 1993 The deep Hydrogeologic Flow System Underlying the Oak Ridge Reservation, ORNL/GWPO-003, 39 p.

ORNL-PHOTO-5620-93

Figure 21. Aerial Photgraph of Waste Areas on the ORR.

Nativ, R., and Hunley, A., 1993 The deep Hydrogeologic Flow System Underlying the Oak Ridge Reservation, The Israeli Geological Society Annual Meeting, Arad.

Neuhoff, P.S., Lemiszki, P.J., and Dreier, R.B., 1993, Geologic characteristics of permeable groundwater intervals defined by electromagnetic borehole flowmeter surveys on the Oak Ridge Reservation Geological Society of America Abstracts with Programs, v. 25, p. 59.

Saunders, J.A. and Toran, L.E. Evidence for dedolomitization and mixing in Paleozoic carbonates near Oak Ridge, Tennessee. Accepted in Ground Water.

Toran, L.E., D'Azevedo, and Reyes, O.M., 1992. Modification of FEMWATER for parallel computing. American Geophysical Union Spring Meeting, Montreal, Canada, May 12-16.

Toran, L.E. and Saunders, J.A., 1992. Geochemical and groundwater flow modeling of multiport-instrumented coreholes (GW-131 through GW-135). YTS-875.

Toran, L.E. and Saunders, J.A. Evolution of Na-HCO3-type groundwater near Oak Ridge, Tennessee Flow path and lithologic controls. Submitted to Water Resources Research.

Toran, L.E. and Saunders, J.A., 1993. Geochemical and groundwater flow modeling of multiport-instrumented coreholes (GW-131 through GW-135). Y/TS-875.

Toran, L.E., Sjoreen, A.L., Dreier, R.O., submitted. Modeling of a density-dependent contaminant plume located in a regional discharge area on the Oak Ridge Reservation. Geological Society of American 1993 Annual Meeting.

Toran, L., Solomon, D.K., McMaster, W.M., and Morrisey, C.M., 1991. Matrix diffusion as a mechanism to explain recent tritium and old 14-C in groundwater from fractured sedimentary rocks. American Geophysical Union Spring Meeting, Baltimore May 28-31.

Toran, L., West, O.R., Gwo, J.P., 1993. Supercomputer model of an ORNL waste area. Technology Information Exchange Workshop. Fourth National Meeting, May 11-13, 1993, Knoxville, TN.

Turnage, K. M., S. Y. Lee, R. J. Lewis, and J. E. Foss. 1992, Abstract. 1992 Soil Science Society and Clay Mineral Society Meeting.

3.4 SUMMARY OF ORRHAGS FY 1994 PLANS

A fundamental objective for ORRHAGS is to provide a stable base for the investigation of key principles governing movement of groundwater and contaminants at Energy Systems sites. Activities within the major investigation themes identified earlier in this report (Section 3.2) will continue. Studies associated with the Matrix Diffusion theme will focus on tracer injection experiments at the west Bear Creek Valley field site. It is expected that the Deep Groundwater studies theme will resolve many of the concerns associated with the saline part of the groundwater system in FY 1994. There will be continued emphasis within the Model Development theme to incorporate the Paragon super computer at ORNL more fully into modeling activities. In addition, modeling investigations using the newly obtained Waterloo code will expand. An issue that probably will grow in importance during FY 1994 concerns the Karst theme where investigations will include development of geophysical methods for identifying solution conduits as well as further mapping of karst features. In addition, studies related to the transfer of groundwater between clastic rock units and carbonate rock units that exhibit solution conduit features will take place. Some additional soil mapping will take place in FY 1994 as part of the Mapping theme.

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Appendix A

GROUNDWATER PROG RAM ADVISORY COMMITTEE REPORT

Appendix B

REPORT ON KARST PLANNING FOR THE ORR

by William B. White

MARTIN MARIETTA

Internal Correspondence

MARTIN MARIETTA ENERGY SYSTEMS, INC.

AUG 30 1993

August 24, 1993

T. O. Early

Martin Marietta Energy Systems, Inc., Ground Water Program Advisory Committee

On behalf of the Martin Marietta Energy Systems, Inc., Ground Water Program Advisory Committee, I am pleased to submit the final report for the review of the ground water program.

The report has been divided into proficiencies and concerns. The list of concerns have been placed in a priority ranking, based upon the judgment of the committee.

We would like to express our appreciation to all the members of the ground water team for their time and effort during the review.

If you have questions, please contact any member of the Advisory Committee.

J. E. Stone

J. E. Stone, 9983-71, MS 8180, 4-6911 - RC

cc:
S. N. Davis-University of Arizona
J. E. Heiskell
D. D. Huff
T. H. Row
W. B. White-Pennsylvania State University

FINAL REPORT OF THE

MARTIN MARIETTA ENERGY SYSTEMS, INC.

GROUND WATER ADVISORY COMMITTEE

August 24, 1993

PROFICIENCIES:

1. The Committee considered the credibility of Ground Water Program Office (GWPO) staff in the eyes of their colleagues on the ground water monitoring and compliance staffs of the sites. All of our conversations with staff and managers indicated that the GWPO scientists were held in respect and their advice and opinions were valued.
2. The Committee concluded that the projects undertaken by the various elements of the GWPO are sound from both technical and scientific viewpoints as well as being essential for the efficient and economic fulfillment of compliance and remediation requirements.
3. The committee considered various investigative techniques used by hydrogeologists at the Oak Ridge Reservation (ORR). Those used were judged to represent state-of-the-art procedures. Furthermore, in many projects some very useful innovations have been developed.
4. The working relationship between hydrogeologists in the GWPO and parallel professionals in agencies and organizations outside of ORR was considered to be important by the Committee. Unfortunately, time restrictions did not allow an in-depth pursuit of this topic. Indications of problems in this area were absent. In fact, working relations with individuals in the Department of Energy appear to be very good.

CONCERNS:

1. The Committee is very concerned about the level of staffing in the GWPO. The intent is to provide an advisory person for each of five sites, but at present these positions are distributed among 2.5 full-time equivalents. Under these circumstances, the site managers are unlikely to feel that they are getting the services that they are paying for. Further, the individual GWPO personnel are stretched too thin. The Committee understands that the GWPO has an active recruiting program but wishes to underscore the importance of bringing the staff to its full contingent of five so that GWPO's obligations to the sites can be met.

   Due to the recent resignation of a staff member with an interest in karst hydrology, GWPO's expertise in karst hydrology is severely limited. Considering that much of the ORR is underlain by carbonate rocks, expertise in karst hydrology is greatly needed. The recruiting of a karst hydrologist should be given a high priority.

   The committee suggests that an overall evaluation be made to determine if the staffing levels in the GWPO and support organization are adequate to support the initiatives and address concerns of the ground water program.

2. The roles and responsibilities of the various organizations need to be better defined. There seems to be some confusion at the sites and other organizations on what role Oak Ridge Hydrology Support Program (ORHSP) verses Oak Ridge Reservation Hydrology and Geology Studies (ORRHAGS) performs for the GWPO. The Committee feels that more definition of roles and responsibilities would facilitate better communication and technical guidance to the sites and others.

3. A characteristic feature of karst hydrologic systems is the intimate interaction between ground water and surface water. Surface streams can be gaining streams in one reach and loosing

streams in another or can disappear altogether. Ground water in karst often moves through open conduits with velocities and contaminant transporting capabilities more similar to surface water than to ground water in porous media.

The Committee recommends that GWPO take more account of surface water, particularly in the karstic portions of ORR.

4. The Committee heard many comments about the sufficiency, management, and accessibility of ground water data. It was the opinion of a number of individuals that the Oak Ridge Environmental Information System (OREIS) data base is consuming large amounts of effort in constructing the software system while at the same time very little effort has been invested in entering real data into the data base. As a result different groups keep their own data systems with considerable difficulty in retrieving data and in transferring data from one location to another.

   The scientific use of ground water data and its effective use in monitoring long-term trends in the ground water system require that data be easily accessed and manipulated. It would also be helpful if the part-time and guest investigators who work with GWPO could access data directly from off-site locations. The Committee recommends that some resources be devoted to the filling of the data base in addition to constructing its architecture.

5. The Committee considers it important that the professionals assigned from the ORHSP to the sites for technical support should be at the sites 80-90 percent of their time. These professionals provide much needed technical guidance and support to the site programs. In light of this, the Committee feels that the GWPO should evaluate the assignments at the Portsmouth and Paducah Plants to determine the need for full-time relocation to these sites due to travel time.

6. The Committee deems it of great importance that priorities be established within the GWPO for future work. A determination must be made concerning what type of projects are necessary to support the environmental restoration programs. This determination must include what technical information will need to be available to make sound technical decisions during restoration activities.

7. The management structure of GWPO and its relationship to other ground water monitoring and compliance groups at ORR raises some questions concerning the implementation of its advice. In principle, GWPO offers advice to the site ground water staff. It is not clear, at least to the Committee, how such advice is integrated into site monitoring and compliance activities. If GWPO and site staff reach the same conclusions concerning a problem there will be no difficulty; however, if GWPO advice should run counter to site staff opinion, is there any mechanism to ensure the GWPO advice is at lease considered.

   The interaction between GWPO and the site staff appears to be excellent but the Committee was concerned that this happy situation may only arise because of good interpersonal relations between present staff members. It is not clear that there is a management structure that defines the authority of GWPO advice, an important consideration if the new and less compatible persons should occupy certain staff positions.

8. The Committee suggests strongly that an engineer be assigned as a part-time member of the GWPO. The purpose of such an individual would be twofold. First, the engineer would help define the high-level research needed to help solve the more utilitarian problems of ground water monitoring and remediation. Second, and perhaps even more important, the engineer should serve as an additional liaison between scientific personnel and the engineering-oriented individuals who are served by the GWPO. Although the direct utilitarian applications of present ground water research seemed important and almost self-evident to the Committee,

numerous remarks by individuals interviewed reflected skepticism of the wisdom of some research priorities and sometimes even of the fundamental values of the research. The type of engineer associated with the GWPO is very critical. Several members of the GWPO have had either direct training in, or close association with, engineering for many years. Perhaps such as individual could be identified from the GWPO and given the tasks mentioned above.

Based on the present overload on the GWPO personnel, however, an additional outside individual would probably serve better. The Committee definitely does not want a "cookbook" engineer any more than a "cookbook" hydrologist to be assigned to the GWPO. The engineer assigned should have experience both in applied engineering as well as research. Ideally, he or she should also have had experience with water-supply problems.

9. The Committee determined that work by ORRHAGS has a large component of small university-type contracts involving part-time employees. While this type of work is commonly cost effective and can tap a number of needed experts, the problem which may develop is creating too many channels of investigation without the time and funds to complete the work which has been started. Although the GWPO should never stifle scientific creativity by trying to micromanage individual research, the work as a whole probably needs some additional overall organization. Specifically, the nature of the subcontracts should fit into a very general work plan which has well-defined objectives and milestones.

10. The Committee considers the use of "Lessons Learned" throughout the ground water program as a very important factor in continuous improvements. The GWPO should take the lead in facilitating lessons learned to ensure understanding and application of lessons learned from the ORR and across the country to the various organizations involved in the ground water program. Specifically, the Committee suggest that each organization take advantage of the Soil Management Plan developed at the Y-12 Plant to determine the applicability of this

document during field work for soil deposition.

11. The Committee considered it important that the GWPO should be consulted before significant contracts related to ground water are negotiated. This consultation should begin with the Request For Proposal (RFP) stage and end with the completion report. The purpose of the consultation would be to ensure the scientific validity of the work and to ensure that it has the proper relationship with known hydrogeologic features of the ORR. Also, the GWPO would provide a check on terminology used in the reports to make sure that it is compatible with established terminology at the ORR. The Committee, however, does not believe that the GWPO as presently organized should assume a direct oversight position with respect to all major ground water contracts. This would be too time-consuming for the limited number of individuals available for this type of work. Nevertheless, the numerous small contracts which have been put into place by the GWPO should, of course, be monitored and supervised carefully by the GWPO.

12. The Committee was concerned with the assignment of activities of personnel. If the GWPO is to be staffed with high-quality scientists, there must be some appropriate mix of research and service work. The ORRHAGS group seems to have most of the research mission while the staff assigned to sites have a more service-oriented mission. Care should be taken to assure that all GWPO staff have a comparable mix of research and service activities.

13. The Committee considers the need for vehicle and office space an important factor. The shortage of vehicles hinders field work and slows the acquisition of needed technical data. The shortage of office space results in a twofold problem. First, the recruitment of high-level technical professionals is/will be hindered by the office space problem. Secondly, the retention of professionals will become a problem due to the office space situation. The Committee believes that the office and vehicle issue needs to be evaluated and corrective actions taken to alleviate the situation.

Carbonate Terrain Hydrogeology
at the
Oak Ridge Reservation

William B. White
Professor of Geochemistry
The Pennsylvania State University

December 31, 1992

1.0 INTRODUCTION

1.1 Objectives of This Report

The Oak Ridge Reservation is underlain in part by carbonate rocks. Aquifers within these rocks have at least the potential for developing the localized flow path characteristics of karstic aquifers.

This report addresses these questions:

(i) Do karst processes play a role in the groundwater hydrology of the Oak Ridge Reservation?

(ii) If so, how can the karstic aspects of the carbonate aquifers be characterized?

(iii) If localized karstic drainage paths are present in the carbonate aquifers, how can these features be monitored with respect to contaminant transport?

1.2 Basis of This Report and Its Recommendations

The opinions expressed in this report are based on a one-day overview field trip through the Oak Ridge Reservation (December 16, 1992), two days of conversations with ORNL and Y-12 environmental personnel (December 17, 18, 1992), review of reports and memoranda concerning the hydrogeology of the reservation, and an extensive background knowledge of karst, karst processes, and Appalachian karst in particular.

1.3 Concerning Karst: A Caveat

The term "karst" is applied to terrains or to aquifers where removal of rock by chemical dissolution is a significant part of the weathering process. At one end of the scale are terrains with no surface expression of karst and only minor solutional enlargement of fractures in the subsurface. At the other end of the scale are dramatic landscapes with huge closed depressions, in which all drainage is underground, and where all groundwater movement is through systems of integrated conduits. Most karst terrains in the Appalachians lie somewhere between these two extremes.

The important point is this: There is a tendency, particularly with regard to regulatory or monitoring issues, to classify particular terrains as "karst" or "not karst". Such classification is incorrect. The proper question is whether or not karstic processes impact a specified land use. The threshold for impact on issues such as groundwater monitoring and contaminant transport is much lower than the threshold for soil transport and ground stability. One must pose the proper question before the answer "karst" or "not karst" makes any sense.

2.0 THE HYDROGEOLOGIC FRAMEWORK

2.1 Carbonate Aquifers on the Oak Ridge Reservation

The Oak Ridge Reservation lies in the Valley and Ridge physiographic province. Rocks are folded and faulted parallel to regional strike giving a pronounced anisotropy to regional groundwater flow patterns. At the Oak Ridge Reservation overthrust faulting causes the various rock units to crop out in parallel bands with repeated units. Structure, mainly faulting, is an important hydrogeologic control in that it controls the placement of carbonate units with respect to less permeable clastic units.

The clastic rocks are mainly shales and siltstones with low primary permeability and a low fracture permeability. Characterization and modeling of contaminant transport in these rocks seems adequate although the interface between the clastic rock units and the carbonate rock units may require additional attention.

The carbonate units of greatest interest are the Maynardville Limestone, the Copper Ridge Dolomite (Lower Knox), the Chepultepec, Longview, Kingsport, and Mascot Dolomites (Upper Knox), and the Stones River Group of limestones. The latter mainly crop out northwest of the areas of greatest concern. It has been general experience in the northern Appalachians that karstic aquifer development is greatest in limestone units and that dolomites behave as solutionally-modified fracture aquifers. Such may not be the case in the southern Appalachians where there seems to be extensive karst development in dolomitic rocks.

2.2 Surface and Subsurface Karst Features

The diagnostic surface features of karst are closed depressions and sinking streams. Closed depressions occur mainly on the ridges with few examples on the valley floors. Many of these have depths greater than one contour interval (20 feet) and thus appear on the 1:24000 scale topographic map of the reservations. However, there are many more closed depressions than are mapped. Some are less than one contour interval deep; others may have been overlooked during map preparation because of the forest cover.

Closed depressions act as small catchment areas, channeling storm runoff to the drain at the base of the depression. The drains act to rapidly transmit the runoff into the underlying aquifer system. The opinion was expressed that the closed depressions on the carbonate ridges were surface phenomena caused by local dissolution of the bedrock. This is not likely to be correct. Most closed depression have drains which usually take the form of solutionally widened fractures or chimneys. Beneath the soil mantle, some sinkholes are bowl-shaped depressions in the bedrock; others are filled with rubble from the collapse of underlying cavities. The drain for a bedrock basin (solution sinkhole) depression is a small object. Not finding the drain with a test drilling is not proof that drain does not exist.

Small tributary streams rising on the ridges sometimes go underground in well defined swallow holes. The small stream that drains into Copper Ridge Cave is the best example seen by the writer. More significant from a quantitative point of view may be loosing streams where the water is lost over a reach of stream bed with no obvious swallow hole. The larger streams on the valley floors may also be loosing streams of this sort.

The carbonate bedrock surface is often extensively sculptured with deep (a few feet to tens of feet) solution along fractures forming slots or troughs known as "cutters". The residual bedrock stands out in relief as pinnacles which may sometimes extend through the surface soil. The cutter and pinnacle bedrock topography is masked by thick layers of residual soils and can be observed casually only where the soils are thin such as on Copper Ridge. The zone of sculptured bedrock and overlying soils is known as the epikarst. The epikarst plays an important role in infiltration hydrology in that it acts as a reservoir and also may guide infiltration water laterally for considerable distances before an open fracture allows the water to move into the subsurface.

2.3 Relic Drainage Features

Caves are abandoned fragments of the ancient conduit drainage systems that fortuitously happen to be large enough for human exploration and to have a connection with the land surface that can be used as an entrance for the human explorers. Neither is a necessary or essential condition. As a result, cave populations give a sampling of conduit development in a particular region or rock unit but are seldom sufficient to reconstruct paleodrainage patterns. Their value in the evaluation of active hydrologic system of an aquifer is threefold:

(i) They provide an "existence theorem" for the presence of conduit drainage. Most karstic drainage systems evolve downward as base levels are lowered by surface erosion and the presence of abandoned conduits high above present day base levels is an indicator that active conduit drainage may exist at or below present day base levels.

(ii) Caves can form low resistance pathways for movement of water in the vadose zone. Instead of slow infiltration of surface water, there can be rapid movement along solutionally-widened fractures, along preexisting cave passages, and on down through other fractures to base level.

(iii) Comparisons of cave development between rock units can be used as a rough indicator of the susceptibility of these rocks to solutional modification and development of localized drainage. For example, the published surveys of Tennessee Caves list 42 caves in Anderson, Knox, and Roane Counties. Of these, 7 are in the Maynardville Limestone, 10 in the Copper Ridge Dolomite, and 7 in the Knox Group, undifferentiated.

The karst surface on the ridges of the Oak Ridge Reservation is old, early Pleistocene or possibly Pliocene in age. There has been a gradual lowering of the carbonate rock surface by solution over a very long period of time.

2.4 Springs and Groundwater Subbasins

It is characteristic of karst aquifers that the distinction between surface water and groundwater is blurred. Surface waters move by turbulent channel flow at high velocity. Response to storm events is flashy with a rapid rise in water levels followed by a recession to base flow conditions with a time constant of hours to days. Groundwater in porous media moves through pore spaces and small fractures by strictly laminar flow at extremely low velocities. The response time is much longer than the mean spacing between storms so that individual storms have little effect on water levels or flow velocities although water tables may rise and fall with seasonal wet and dry periods.

Karst aquifers have a distribution of water-transmitting openings ranging from unmodified fractures and bedding plane partings to pipe-like conduits of human size. Some of these are directly open to surface water recharge through sinking streams and sinkhole drains. Other openings receive infiltration water through the epikarst. The hydraulic resistance of the larger conduits is very low so that these act as internal drains within the aquifer and local hydraulic gradients point toward the conduits rather than toward surface outlets. Because of the low hydraulic resistance, the drains often show the same flashy response to storm events as surface streams, although usually with somewhat longer response times. These infeeders and internal drain systems carry water toward one or a related group of outlet points at karst springs. The spring orifices are, in effect, the interface between groundwater and surface water.

Because of the integrated drain system feeding a given spring, the spring becomes an effective gauge point for a groundwater basin in the subsurface. Karst groundwater basins generally have well-defined boundaries which do not, however, necessarily coincide with the boundaries of overlying surface water basins. Base flow discharge, storm flow response, and chemical and temperature variations of spring water make good probes of the segment of the aquifer represented by the groundwater basin.

The springs observed on the Oak Ridge Reservation are very characteristic of dolomite springs. Where the bedrock can be observed, a modest flow emerges from a small solution tube. It seems likely that these springs, located where the hill slopes meet the valley floors, drain small catchments on the carbonate ridges and are not regional in character.

3.0 GROUNDWATER FLOW SYSTEMS

3.1 Lateral Drains Parallel to Geologic Structure

Most important from the point of view of groundwater management and contaminant monitoring is the possibility of larger, more regional, groundwater systems within the carbonate rocks beneath the valley floors: the outcrop band of Maynardville Limestone along the Bear Creek Valley, the outcrop band of Upper Knox Group rocks beneath the Bethel Valley, and the carbonate rocks that underlie the K-25 Plant. If localized conduit drainage systems develop in these rocks, they are likely to be predominately strike oriented and will tend to be confined to beds favorable for dissolution within the carbonate rocks. These hypothesized conduits are here termed "lateral drains" with the implication that they have much the same hydraulic properties as storm drains and are parallel to the valley axes.

There is abundant evidence for solution cavity development in all of the carbonate rocks mostly derived from intersections of cavities by boreholes. The unknown aspect of the hydrology is the degree to which the cavities form integrated drainage paths. Evidence for integrated lateral drains is more circumstantial but includes the observation of gravels and cobbles in the fill material within the solution cavities and the collection of a chunk of secondary travertine from a well on the K-25 site. Transport of gravel or cobble sized material as bedload requires flow velocities, at least during flood flow, in the range of feet/second. Finding such material in a cavity implies that the cavity is a part of an integrated drainage system. Banded travertine forms in air-filled caves which suggests an open conduit which has been flooded by Watts Bar Lake.

The best evidence for a lateral drain comes from borehole GW-734 near the eastern boundary of the Y-12 site. Recording of a complete storm pulse by means of a pressure transducer is clear evidence for an active drain and means that the large void encountered must have inlet and outlet channels. It cannot be an isolated pocket. The pressure pulse records both a sharp rising limb and an exponential recession limb with a time constant on the order of a few days, only slightly larger than the recession constants for flood pulses in surface streams.

3.2 Surface Streams, Subsurface Diversions, and Water Balance

The surface streams on the Oak Ridge Reservation, like many other surface streams in the Appalachians, often cut across geologic structure. The Clinch River itself cuts across structure northeast of the reservation, then loops around, and cuts across the same structures again to the southwest. The Clinch River is the base level master stream to which all surface streams drain but because of the way that it bounds the reservation on three sides, the interaction between surface water and groundwater is likely to be complex.

Perennial surface streams show that much of the discharge of water from the reservation is by surface routes where it can be easily gauged and monitored. However, the presence of surface steams does not preclude the possibility of localized conduit drainage in the subsurface. Reports of loosing and gaining surface streams suggest there is both loss to the subsurface and return of groundwater to the surface although quantitative data seem to be lacking.

The balance between surface and subsurface flow is most important at the water gaps. Surface streams cut across the clastic rocks which act as groundwater dams. If the water gap were the only outlet, the ground water body would be ponded behind the barrier of clastic rocks, the water table would be brought to the surface, and the excess ground water would return to the surface channel and exit through the gap. But in the setting of the Oak Ridge Reservation, ground water moving in the lateral drain system in the carbonate rocks beneath the valleys has an alternative route. Rather than return to the surface channel, it could continue through a lateral drain system in the subsurface, cross the surface divide, and eventually discharge to the Clinch River where the carbonate rock outcrop line crosses the river channel.

The most interesting questions arise in the Bear Creek Valley. The valley itself, and the band of Maynardville Limestone that underlies the south side of it, intersects the Clinch River both east and west. Along the valley are no less that four surface water divides: The eastern 3 miles drain eastward along Union Valley to the Clinch. There is a short segment near Route 62 that drains south along Scarboro Creek. A short distance to the west, near the eastern end of the Y-12 Plant, a short segment drains north into the East Fork of Poplar Creek. Then from the western end of the Y-12 Plant, surface drainage is westward along Bear Creek as far as Route 95 where Bear Creek turns northward through a gap in Pine Ridge, crosses the clastics and leaves Bear Creek Valley. Westward, along the valley, across the fourth divide, Grassy Creek flows westward to the Clinch River. What, in the midst of this surface water complexity, is the pattern of groundwater flow, and what is the role of the (hypothetical) lateral drains? Did well 734 fortuitously intersect an east-flowing lateral drain? Does this drain, if it exists, flow eastward all the way to the Clinch or does it discharge into East Fork Poplar or Scarboro Creek? At the western end of the valley, does the groundwater discharge into Bear Creek before it goes through the gap or does it follow a lateral drain along strike beneath the divide directly to the Clinch River? Overall, what are the relationships between the water table and the surface drainage in Bear Creek Valley? Where are the underground divides?

3.3 Is There a Deep Karst Drainage System or Inter-Aquifer Transfer?

Concerns have been raised about a deep groundwater flow system which might receive recharge (and possibly contaminants) from the reservation and carry them long distances to discharge - perhaps - in the Tennessee River or even more distant points. Based on the geologic setting and the Pleistocene geomorphic history of the region, a deep flow system seems highly unlikely. Deep flow across the structure would have to cross the shale and siltstone aquicludes and also cross the thrust faults which in the Appalachians are likely to be hydrologic barriers rather than zones of high permeability.

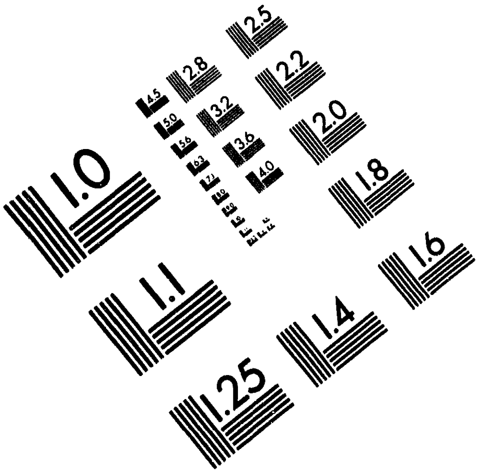
3.4 The Physical Characterization of Lateral Drains and Exit Portals

The hypothesis of lateral drains along strike in the carbonate rocks beneath the valley floors immediately raises some questions:

(i) Do lateral drains exist?

(ii) If they do exist, where do they discharge?

(iii) What is the physical character of the drains? Are they constructed like some of the relic cave passages - a few pipe-like openings with diameters measured in feet or tens of feet - or are they an assemblage of solutionally widened fractures and bedding plane partings?



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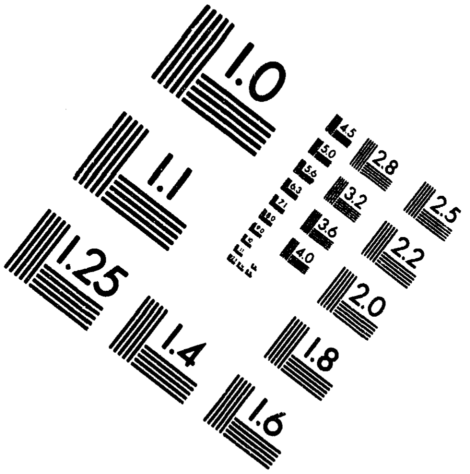

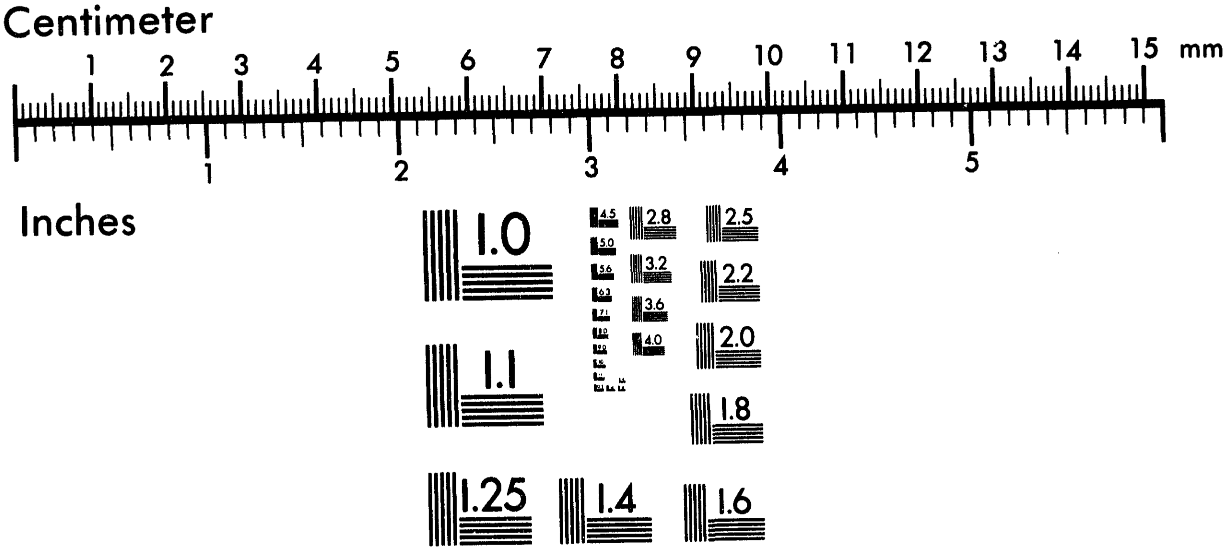

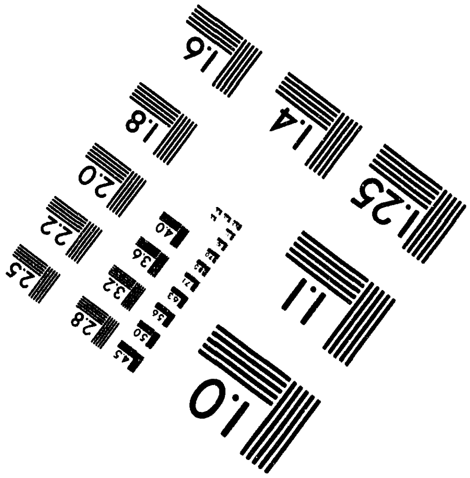

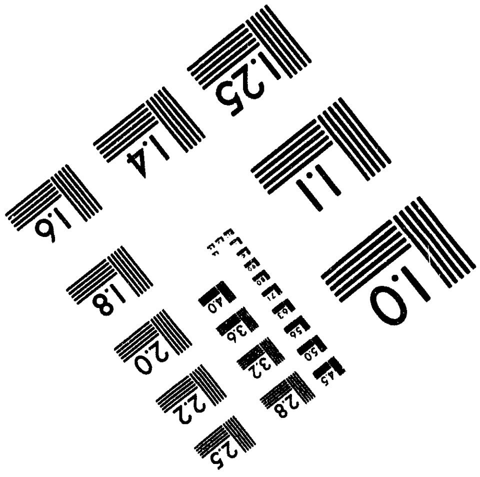

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A test for the existence of the drains is to demonstrate that the water in cavities penetrated by boreholes is moving at velocities greater than expected from normal groundwater. The pressure transducer test conducted in GW-734 is one such result. In additional to pressure transducers, conductivity probes could be inserted in wells that penetrate water-filled cavities. A characteristic of conduit water is that it is frequently undersaturated with respect to calcite and dolomite and also that the chemistry fluctuates with storm throughput because the transit time through the conduit system is actually less that the time required for the water to react to equilibrium with the wall rock. Conductivity is a bulk measurement of total dissolved solids so dilution of the ground water during storm throughput would be revealed by a dip in the conductivity curve. Observation of fluctuations in conductivity would be an indication that the cavity investigated was linked to the drain system.

Water table maps sometimes reveal the presence of conduit drain systems because the low hydraulic resistance of the conduits make them groundwater troughs. It would be interesting to know the relationship between the water table and the surface drainage channels. The reservation seems to contain a high density of boreholes although they tend to be concentrated in small areas. The possibility should be checked of using depth to water table measurements to construct a water table map.

The hypothetical lateral drains would have substantial catchment areas and therefore large discharges. Their outlets should be springs substantially larger than the local springs draining small catchments on the ridges. If such high discharge springs existed along the present-day surface drainage channels, they should have been noticed. Unfortunately, the expected location for the spring outlets of the lateral drain system are near base level where the bands of carbonate rock are cut by the master base-leveling stream, the Clinch River. These springs, if they exist, would be drowned beneath Melton Hill and Watts Bar Lakes.

The question, then, is how to locate the springs beneath the lakes. Both thermal probes and tracer tests could be considered.

Thermal probes would work best when there is maximum temperature contrast between the discharging spring waters and the water in the lakes. This can be further optimized by selecting a winter period when the lake water temperature is low. The springs would then be discharging warm water (relative to the lake water) which should rise as a thermal plume to the lake surface. Infrared imaging techniques operating in the far IR band could be used to search for the warm plume where it rises to the lake surface. At the eastern end of the system, interferences from the Bull Run Steam Plant are to be expected. Other interfering thermal sources would have to be considered.

An alternative approach would be to scan the lake bottom in the vicinity of suspected resurgences with a thermal probe, in this case something as simple as a thermister device, to look for ground water discharge into the lake.

Tracer tests with dyes or optical brightners would be difficult to carry out. If the conduit system that forms the lateral drain developed at grade or below grade with the natural channel of the Clinch River, the lower reaches of these conduits must now be flooded for a considerable distance by water backed up from the Lakes. Large dilution factors would require large dye charges with uncertain results.

A helium tracer test might be a more realistic possibility. He gas could be injected at locations such as well GW-734 and the entire system saturated with He. A helium detector could then be used to map the plume where the He-saturated spring water rose in the lake. Because the system would be He-saturated, there would be no problem of trying to catch the tracer pulse as it came through the system which is one of the difficulties with dye tracers.

If the presence of karstic lateral drains carrying ground water along the strike band of carbonate rocks to submerged springs in the Clinch River can be established, attention must then be given to the third question raised at the beginning of this section. The only known windows into the conduit system are through boreholes. If it were possible, through sensors placed in the boreholes, to determine the conduit cross-sectional area and some estimate of flow velocity, the resulting estimate of discharge would reveal whether or not the conduit flow is transporting a significant quantity of ground water off site.

3.5 Geophysical Investigation of Lateral Drains

There have been numerous attempts to map karstic cavities from the land surface by geophysical methods. The results have been a mixed bag. The problems has been the ambiguous nature of the target and the fact that cavity detection at significant depths is at the sensitivity threshold of present day geophysical measurements. Below the geophysical instrumentation on the land surface is the irregular soil/bedrock contact with its cutter and pinnacle topography. Below that at unknown depths in the bedrock are one or more conduits, perhaps at different depths, and which may be of various sizes and shapes and may be air-filled, water-filled, or mud-filled.

Techniques which show the greatest promise for locating the lateral drains are microgravity surveys and natural potential surveys. The latter, developed mainly by geophysicist Arthur Lang for use in karst systems, has the great virtue of using for measurement the natural potentials created by moving water. The technique therefore reveals the presence of moving water, not merely a static water table surface. Lang's techniques would be worth some consideration since they are non-invasive and might reveal the active drains rather then simply cavities in the subsurface.

Microgravity surveys, using the best of modern instrumentation, have a good track record for revealing anomalies to depths of some tens of feet depending on cavity size and filling. If other tests revealed which boreholes seem to have penetrated active conduits, gravity mapping outward from the borehole could reveal the extent and orientation of the conduits.

3.6 Shallow Groundwater Basins and Their Interaction with Lateral Drains

It would be useful to map out and characterize the shallow groundwater basins that drain to the various springs. Because the springs are accessible, a somewhat more direct approach is possible. The physical response of the springs to storm events can be examined. For those springs that drain areas of special environmental interest, the springs can be gauged to provide discharge hydrographs. From analysis of the storm hydrographs, some indication can be obtained of the physical character of the feeder system draining to the spring. From base flow measurements and some determination of specific runoff for the Oak Ridge Reservation, known with some accuracy from the gauged watershed program, an estimate of the spring catchment area can be made.

Calculations of the saturation index of calcite and dolomite from analyses of the spring water chemistry and the chemical response of springs to storms give further clues to the character of the aquifer system. Rapid throughput should reveal itself in undersaturated waters, short response time storm hydrographs, and a variability in the spring water chemistry.

To completely delineate groundwater basins for the springs and to determine interconnections between the basins, tracer experiments would be needed. This would be a large, complex, expensive, and time consuming activity. Because of the possible slow flow rates in some parts of the aquifer, long flushing times might be needed to clear the system of dye before another test could begin. Proper injection points much be chosen. If the injection points are wells, it must be demonstrated beforehand that the well does indeed penetrate the main flow system. Quantitative tracer tests that measure dye breakthrough curves are more reliable that point-to-point tracing with charcoal detectors but require continuous samplers.

4.0 CONTAMINANT MONITORING ISSUES

4.1 Contribution of Surface Streams

Where surface stream are flowing over carbonates there is the possibility of interchange between surface water and groundwater and discussion indicated that Bear Creek in particular has gaining and loosing reaches. Water lost to the subsurface is potentially water lost to the monitoring program if this water crosses reservation boundaries by unknown pathways.

A water balance study of the relevant reaches of surface streams, during low flow conditions when the groundwater interchange component is most important, might reveal places where the surface water is lost to the subsurface and more importantly, it might reveal deficits at the water gaps that would be evidence for strike-oriented flow in the subsurface. Surface water monitoring programs would have to be evaluated when the results of this study were in hand.

4.2 Effective Monitoring at the Exit Portals

The importance of the lateral drains is that, if present, they may carry ground water from the Oak Ridge Reservation beyond the site boundaries and ultimately to the Clinch River. It is the necessary that these waters be monitored for contaminants that might be derived from storage areas, and from accidental spills, pipeline breaks, and related incidents. The approach to groundwater monitoring is through the use of picket wells drilled in a transect across the projected flow path near the property boundary. If the flow is indeed localized in conduits, it must be demonstrated that the monitor wells do, in fact, adequately sample the conduit waters. The danger is that water quality in an improperly placed monitor well would remain satisfactory while a slug of contaminant drifted past in the unsampled master drain.

One possible way of connectivity between the monitor wells and the lateral drain system would be to follow the background chemistry of water sampled in a selection of the picket wells across the hydrograph for a storm event. If the same chemical fluctuations are observed in the monitoring wells as in the well penetrating the lateral drain, an efficient and effective hydrological connection must exist.

5.0 MODELING

5.1 Network Models for Karstic Drainage

Often the ultimate objective of a hydrogeological investigation is to reduce the system to a model so that new data can be input into a uniform framework and the model could allow prediction of system behavior for various scenarios.

It can be stated unequivocally that there is, at the present time, no satisfactory groundwater flow model for karst aquifers. Porous media models do not work. The rater of flow along conduit systems is so large, under low hydrostatic heads, that the conduits act as short circuits. Something might be accomplished with pipe network models but there has been little experience along these lines.

It would be safer to treat the carbonate aquifers under the Oak Ridge Reservations in terms of conceptual models only, with development of quantitative numerical models as a future objective.

5.2 Mixing Models for Inter-Aquifer and Surface-Aquifer Contaminant Transfer

To investigate the interchange of water between the stormwater flow zone, the clastic rock aquifer, and the carbonate aquifers segments, geochemical mixing models may prove of some help.

6.0 PRIORITIES AND RECOMMENDATIONS

6.1 Recommended Actions

(1) It is recommended that existing data from boreholes, geologic mapping, and other observations be combined with new field observations on closed depressions, caves, sinking streams, and springs to form the basis of a hydrogeologic map of the Reservation that could be superimposed on the existing geologic map. There is already in existence a very large body of hydrologic, hydrogeologic and geologic information. Much of this is fragmentary, has been collected by different people, at different times, and for different objectives. A hydrogeologic map would allow all information to be viewed in context with the underlying geology.

(2) It is recommended that a search for lateral drain systems in the carbonate rocks be undertaken. The suggestion is to begin at the east boundary of the Y-12 area because of the existing data base. The cavity intercepted by well GW-734 is a logical starting point because there is the very real possibility that a high flow conduit has already been "captured". Measurements should include down-hole cameras or sonar to determine the geometry of the cavity, measurements of water chemistry to allow calculations of the state of saturation of the water with respect to calcite and dolomite, and conductivity measurements during the passage of a storm pulse. It is important to gain information on the cross-section and flow velocity within the conduit. These together give the total discharge which, compared with surface stream flow volumes and other data, would allow an estimate of the fraction of the total water loss from the reservation is through the conduit system. This in turn provides an answer to the question of whether or not the conduit system makes a significant contribution to the hydrology.

(3) It is recommended to undertake a water balance study of the main surface streams on the reservation, beginning with Bear Creek, to determine gaining and loosing stretches and in particular to determine whether there is water loss to the subsurface before the streams exit the reservation.

(4) If item (2) is successful, it is recommended that similar activities be undertaken at other possible conduit drain exit pathways, identified by the locations where the band of carbonate rocks crosses the site boundaries.

(5) The outlets for the lateral drain systems must be located. Most likely they lie beneath the Melton Hill and Watts Bar reservoirs. An activity of thermal probing and/or He-tracer testing would be a possible starting points.

(6) It is recommended that a geophysics program be initiated to trace conduits along strike in areas where borehole data is insufficient. Microgravity surveys and natural potential surveys seem to offer the most promise. Natural potential surveys have the virtue of targeting on moving water, which is what the conduit drains are all about.

(7) If localized flow in conduits - lateral drains - turns out to be important, the exit pathway monitoring program must be examined in light of

these results. It must be demonstrated that designated monitor wells actually sample that drain system. Sampling programs must be adjusted, taking into account the measured flow velocities, so that slugs of contaminant could not pass the monitor system between samples.

(8) The interrelationship between the low permeability, fracture flow system in the clastic rocks and the groundwater system in the carbonate rocks should be investigated. Geochemical mixing models may be a way of approaching this problem.

6.2 Priorities

The recommendations are listed in rough order of priority because the action items must build on what has gone before. If it should turn out that localized conduit flow systems do not contribute to the carbonate aquifer hydrology on the Oak Ridge Reservation, then attention would need to turn to fracture flow models at a fairly early stage. There is also a question of cost and personnel. The hydrogeologic map is a long term, relatively low cost enterprise that would be a valuable reference document regardless of how the other investigations turn out. It was therefore listed first. Other items follow in order of priority but could be reordered based on cost, relationship to existing programs,

6.3 External Advisory Committee

The hydrology and hydrogeology of the Oak Ridge Reservation is sufficiently complex and of sufficient importance to monitoring and other environmental assessments, that there would be value in appointing an external advisory committee who would meet with appropriate Martin Marietta environmental staff from time to time. The committee should be composed of experts on karst hydrology, on low permeability media hydrology, and on geochemical and flow modeling. Such committees accomplish the following:

(i) The committee can act as sounding board for staff to test ideas, hypotheses, and conclusions. The staff can draw on the expertise of the committee.

(ii) The committee can act as an independent peer review on staff-generated results and reports.

(iii) The committee meetings become a focal point around which staff can organize their ideas and most recent results and which can enhance staff members communication with each other.

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