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R. B. Clapp, Editor

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ACRONYMS

ATDD	Atmospheric Turbulence Diffusion Division
BMAP	Biological Monitoring and Abatement Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CYRTF	Coal Yard Runoff Treatment Facility
DCG	Derived Concentrating Guide
DOC	Dissolved Organic Carbon
DOE	Department of Energy
DQO	Data Quality Objective
EPA	Environmental Protection Agency
ERP	Environmental Restoration Program
ESD	Environmental Sciences Division
ESP	Environmental Surveillance and Protection Section
ETF	Engineering Test Facility
FFA	Federal Facilities Agreement
FS	Feasibility Study
gpm	Gallons Per Minute
GWPP	Groundwater Protection Program
HFIR	High Flux Isotope Reactor
HHMS	Hydrostatic Head Monitoring Station
HRE	Homogenous Reactor Experiment
ICM	Interim Corrective Measures
LLLW	Liquid Low Level Waste
LLW	Low Level Waste
MB (MBR)	Melton Branch
MBK	Melton Branch Kilometer
MCL	Maximum Contaminant Levels
MMES	Martin Marietta Energy Systems
MSL	Mean Sea Level
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRWTF	Non-Radiological Wastewater Treatment Facility
NWT	Northwest Tributary
OECD	Office of Environmental Compliance and Documentation
OEHP	Office of Environmental and Health Protection
ORRHAGS	Oak Ridge Reservation Hydrology and Geology Study
ORHSP	Oak Ridge Hydrology Support Program

ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PCB	Polychlorinated Biphenyl
RA	Remedial Action
RAP	Remedial Action Program
RCRA	Resource Conservation and Recovery Act
RfD	Reference Dose factor
RFI	RCRA Facility Investigation
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
SI	Site Investigation
STP	Sewage Treatment Plant
SVOCs	Semivolatile Organic Carbons
SWMU	Solid Waste Management Unit
SWSA	Solid Waste Storage Area
TCE	Trichloroethylene
TD	Technology Demonstration
TDEC	Tennessee Department of Environment and Conservation
TOX	Total Organic Halides
TRC	Total Residual Chlorine
TRE	Total Rare Earths
TRU	Transuranics or Transuranium Processing Facility
USGS	United States Geological Survey
VOC	Volatile Organic Compound
WAG	Waste Area Grouping
WCK	White Oak Creek Kilometer
WOC	White Oak Creek
WOCE	White Oak Creek Embayment
WOCHW	White Oak Creek Headwater
WOD	White Oak Dam
WOL	White Oak Lake

EXECUTIVE SUMMARY

This report summarizes the salient features of the annual efforts of the investigations and monitoring, conducted to support the Environmental Restoration (ER) Program at Oak Ridge National Laboratory (ORNL). The results presented can be used to develop a conceptual understanding of the key contaminants amd the sources, fluxes, and processes affecting their distribution and movement. This information forms a basis for prioritizing sites and for selecting, implementing, and evaluating remedial actions. Selected information from remedial investigations and feasibility studies (RI/FS) for contaminated sites at ORNL, and data from other ongoing monitoring programs at ORNL (e.g., the ORNL Environmental Compliance organization) are included to provide an integrated basis for supporting ER decision making. This summary primarily reflects the efforts of the Waste Area Grouping (WAG) 2 and Site Investigations (SI) program. WAG 2 is the lower portion of the White Oak Creek (WOC) system which drains the major contaminated sites at ORNL and discharges to the Clinch River. The remedial investigation for WAG 2 includes a long-term multimedia environmental monitoring effort that takes advantage of WAG 2's role as an integrator and conduit of contaminants from the ORNL site. During fiscal year 1992, this was integrated with a series of environmental monitoring and investigation efforts (i.e., SIs) at ORNL that address pathways and processes important for contaminant movement.

The objectives of this report are to

- identify the chemicals and radionuclides and the pathways that can potentially lead to unacceptable exposures to humans, and unacceptable ecological risk;
- summarize the results from environmental monitoring and data collection activities conducted during the past year by the WAG 2/SI program and by other monitoring programs;
- report radionuclide flux and mass balance calculations for reaches in WOC in order to improve the understanding of where in the system radioactivity is accumulating or being mobilized;
- describe recent advances in the fundamental understanding of the hydrologic processes whereby contaminants are mobilized and transported in surface and subsurface hydrologic systems;
- provide assessment of both the monitored data and our knowledge of the contaminant transport processes in order to gain a reasoned perspective on the diversity, as well as the extent and movement, of contaminants; and

- describe future data collection and monitoring activities.

The WAG 2/SI program has developed a comprehensive, integrated approach to providing information to support ER efforts at ORNL. The work has been divided into four major tasks (Surface Water, Groundwater, Soil and Sediment, and Biota), as well as support activities such as risk assessment and remedial alternatives assessment.

A review of completed risk analyses at ORNL indicates that the most significant risk to the on-site worker and to the inadvertent intruder is exposure to gamma radiation, primarily from ^{137}Cs in soils and sediments, although ^{60}Co and (for WAG 6) europium-series radionuclides also contribute radiation. Contaminants in fish (PCBs, ^{137}Cs, Hg, ^{90}Sr) are also of potential human health concern. Radionuclides (especially ^{137}Cs, ^{60}Co, and ^{90}Sr) constitute the majority of the risk from the ORNL WAGs. Metals (e.g., Hg, As, and Cr), and organic contaminants (PCBs and solvents) are of concern in certain locations. Prioritization of the ORNL WAGs based upon risk to the public, ranked WAG 1 as the highest followed by WAG 4; by WAGs 2, 6, and 7—which could not be evaluated separately due to the available water quality data; followed by WAG 5. Other WAGs were rated lower.

Surface Water. The conceptual model for watershed hydrology indicates that virtually all water that infiltrates the soil (except for evapotranspirational losses) eventually migrates to local streams through either the shallow subsurface stormflow zone or the thin layer at the top of the groundwater zone referred to as the water table interval. The estimated downward flux below the water table interval is estimated to be <1 cm/year. Thus, surface water is the ultimate receptor of contaminant fluxes and the primary pathway for contaminant transport off-site. The WAG 2/SI surface water group issued a comprehensive annual hydrologic data summary for ORNL. This was the third in a series produced by the ER Program. Mass balances for selected contaminants were computed for two of the main stream reaches in the WOC watershed using data for 1991. The middle reach of WOC accumulated both ^{137}Cs and ^{60}Co. This reach includes the sediments from the old Intermediate Holding Pond, known to be highly contaminated with gamma radiation. The ratio of accumulation to outflow was largest for ^{60}Co (i.e., >59). The lower reach of WOC including White Oak Lake was apparently a net source for both of these radionuclides. These numbers are provisional and may change as the current sampling system is evaluated on the basis of sediment sampling during storms. Mass balances for ^{3}H and ^{90}Sr indicated that these radionuclides were transported into the lower WOC reach and probably passed through lower WOC and White Oak Lake without interaction.

Analysis of 55 months of flux data for ^{3}H and ^{90}Sr showed that concentration tends to increase with increasing flow at three monitoring sites on WOC. This is significant because it suggests large sources of these contaminants that can be mobilized by hydrologic fluxes (i.e., water flowing through trenches or contaminated soils). Evaluation of the relationship of contaminant concentrations in surface water to water flow or discharge (Q) has been shown to be a useful measure of the effectiveness of remedial actions to reduce contaminant fluxes. For example, the examination of concentration-discharge relationships for one of the tributaries draining WAG 6 indicates that there has been a 50% reduction in tritium flux following the installation of interim caps at WAG 6 in 1988.

Surface water efforts also include a seep and tributary survey and monitoring program to identify sources of contaminants to WOC and to evaluate the need for interim corrective actions.

Groundwater. The results from the WAG perimeter well sampling provides the first site-wide data set for extensive contamination parameters derived from high-quality monitoring wells. Median concentrations of contaminants for 160 wells were compared to regulatory maximum concentration limits (MCL); 53% of the wells exceeded one or more of the MCLs (unfiltered), and 46% of the wells exceeded one or more of the MCLs (filtered). WAGs 4, 5, and 6 had the greatest percentage of wells with parameters exceeding drinking water standard MCLs. Local exceedances were observed at WAGs 1, 3, and 7. Overall about half of the wells exceeded one or more MCL. Nickel was the principal metal detected with subordinant amounts of chromium, mercury, selenium, and cadmium. Volatile organic compounds, including fuel hydrocarbons and solvent compounds, were detected in a small percentage of the wells. Radiological contaminants (especially tritium and strontium) were widespread and were the most significant problem at ORNL.

The complex hydrogeology of the ORNL site makes contaminant flux in groundwater the most difficult parameter to ascertain. Most of the special investigations in WAG 2/SI during FY 1992 addressed some important aspect of contaminant flux in groundwater. Because of the discrete nature of groundwater, flow paths through fractures, seeps, and surface water, and not through monitoring wells, provide the most representative and unambiguous information about contaminant discharge from waste sites. The widely spaced fractures in the bedrock are capable of moving relatively small amounts of contamination large distances in relatively short times. Because ORNL is underlain by fractured, porous rock, molecular diffusion will transport significant quantities of contaminant into the rock matrix when the fracture is transporting high concentrations of contaminants; however, after the primary source is removed, the porous rock acts as a secondary source, resupplying contaminants to water in the fracture.

In the ongoing WAG 2/SI investigation of secondary sources, for the first time direct evidence of a diffusion gradient (of ^{3}H) away from an apparent fracture flow path has been documented. If matrix diffusion is occurring, then this ^{3}H in the rock matrix will become a secondary source of contamination to the same fracture flow path after the primary source is removed or hydrologically isolated (e.g., by capping). Computer simulations based on the initial data indicate that a slight difference in the rate of water movement through the fracture could significantly affect the flushing of this secondary source after the primary source is isolated or removed. Both the amount of contamination stored in secondary sources and the fracture hydrologic characteristics are important to performance after remediation has been completed. If the secondary sources are below the water table, then they will continue to mobilize contaminants, following remediation of upgradient contaminant sources.

An investigation of groundwater-producing fractures resulted in a method to calculate the important fracture hydrologic properties from bore hole flowmeter measurements. The investigation was made possible by an electromagnetic bore hole flowmeter recently invented at the Engineering Laboratory of Tennessee Valley Authority. Fracture parameters are required for analysis of secondary sources and fracture-flow groundwater models. The investigation also produced direct evidence of the water table interval, a key layer identified in the conceptual model, that conducts contamination to surface-water seeps.

A fully three-dimensional model of groundwater flow has been implemented on state-of-the-art parallel processing computers at ORNL. The model is applied to the lower portion of WOC as it flows through Melton Valley. Such a model will allow evaluation of groundwater issues (e.g., contaminant transport and responses to surface capping) that can not be addressed adequately with conventional two-dimensional models.

Soils and sediments. Contaminated soils and sediments are a key concern for on-site risk. The transport of contaminated sediments during storms is a key pathway for the off-site transport of contaminants. Data from a gamma radiation walkover survey of the WAG 2 floodplain are being used to identify hot spots, identify contaminant input areas, design a floodplain soil sampling program, and support efforts to manage contaminated soil and sediment at ORNL. In addition, the WAG 2/SI program initiated an intensive sediment sampling project during the past winter that includes automatic sample collection of surface water at seven sites in WOC watershed. The data are being used to calibrate a hydrologic model (HSPF) that will be used to evaluate the impacts of alternative remedial actions and the impacts of extreme floods on the off-site transport of contaminated sediments.

Biota. The Ecological Assessment task of the WAG 2/SI provides a focal point for the integration, and evaluation of data for biota and ecologial risk in the WOC watershed. The Biota task also supports several components of the ORNL Biological Monitoring and Abatement Program (BMAP). These efforts are collecting baseline information for biotic communities, monitoring instream and effluent toxicity, identifying sources of stress to biotic populations, and developing models of contamiant flow through biota, in order to suggest remedial actions and to document the responses to those actions.

Instream toxicity testing that regularly included 7-day laboratory bioassays with water from each of 15 sites found instream toxicity in a reach in WAG 1 and found toxicity associated with coal yard runoff and the ORNL sewage treatment plant (both located in WAG 1). Biotic communities apprear to be under less stress with distance from ORNL facilities.

with coal yard runoff and the ORNL sewage treatment plant (both located in WAG 1). Biotic communities apprear to be under less stress with distance from ORNL facilities.

Mercury concentrations in fish collected from WOC in winter 1990-91 were elevated over those in fish at reference streams but were below the U.S. Food and Drug Administration (FDA) action level throughout the watershed. Although channel catfish in the Clinch River near WOC are likely to contain PCBs in excess of the FDA limit, bioaccumulation studies showed that PCBs and chlordane in indicator organisms collected in the WOC system appear to be decreasing steadily. Other biological analyses and population-level studies showed that conditions in the WOC system are steady or improving.

Efforts to characterize the radioecology of White Oak Lake are emphasizing pathways for radiological contaminants off site and to humans. A waterfowl census and sampling program is coordinated with reservation-wide efforts. The results of ongoing biological monitoring show an impacted ecosystem that is stable and, in some cases, improving because of reductions in discharges of toxicants.

1. INTRODUCTION

The Oak Ridge National Laboratory (ORNL), located on the Department of Energy's (DOE) Oak Ridge Reservation (ORR) in eastern Tennessee, is a multidisciplinary research facility managed by Martin Marietta Energy Systems, Inc. (Energy Systems), for DOE. The Oak Ridge site was established in 1943, and 48 years of operations have produced a diverse legacy of contaminated inactive facilities, research areas, and waste disposal areas that are potential candidates for remedial action. The ORR was added to the National Priorities List (NPL) in December of 1989. A Federal Facility Agreement (FFA) between DOE, the U.S. Environmental Protection Agency (EPA) region IV, and the Tennessee Department of Health and Environment (TDHE) coordinates remedial response actions. To bring the facilities into compliance with applicable federal, state, and local requirements for environmental restoration, a series of corrective activities have been identified and prioritized at ORNL (DOE 1992).

In particular, the ORNL Environmental Restoration (ER) program was established to coordinate DOE's response obligations to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA) and other relevant regulations and to manage the efforts to achieve comprehensive remediation of releases and threatened releases of hazardous substances, hazardous wastes, pollutants, or contaminants at or from the ORNL. The ER Program follows a structured path of site characterization, site maintenance and surveillance, interim corrective action, alternative assessment, technology development, engineering design, and eventual site closure or remediation.

This report summarizes monitoring data collected by the ORNL ER Program and by other groups at ORNL and presents assessments of those data. This report was prepared within the combined programs of the Waste Area Grouping (WAG) 2 Remedial Investigation (RI) and the ORNL Site Investigation (SI), collectively referred to as the WAG 2/SI program. Within this combined effort, there are numerous data collection efforts, and they vary in both purpose and scope. To aid the reader in finding information, each section of this report includes a brief outline of the contents.

Chapter outline for Section 1:

Section 1.1	describes the ORNL site.
Section 1.2	describes the site-wide approach for environmental monitoring developed to support the ORNL ER Program office, including the objectives and components of the WAG 2/Site Investigation program.

Section 1.3.1	provides information for location and contaminants for each WAG.
Section 1.3.2	discusses contaminants of concern in WAG 2 (including the White Oak Creek Embayment), WAG 1, WAG 5, and WAG 6, based upon human health risk assessment or risk based contaminant screening. Radionuclides (especially ^{137}Cs, ^{60}Co, and ^{90}Sr) constitute the majority of the risk from the ORNL WAGs. Metals (e.g., Hg, As, Cr), and organic contaminants (PCBs and solvents) are of concern in certain locations.
Section 1.3.3	presents information for ecological risk for the ORNL WAGs. Although contaminants in biota and in environmental media are at levels that could result in toxicity, severe effects are not observed.
Section 1.3.4	presents results of a health risk-based ranking of the ORNL WAGs. WAG 1 was found to be the greatest contributor to potential off-site risk.
Section 1.3.5	presents plans for updating the risk-based ranking of the ORNL WAGs.

1.1 ORNL SITE

Because of the large number and hydrologic complexity of the ORNL sites, the strategy developed in response to regulatory requirements is based on Waste Area Groupings (WAGs) rather than individual sites. The WAGs are generally defined by small watersheds that contain contiguous and similar remedial action sites. In some cases, there has been hydrologic interaction among the sites within a WAG, making individual sites hydrologically inseparable. The use of groupings allows perimeter monitoring of both groundwater and surface water and the development of a response that is protective of human health and environment. Twenty-one WAGs have been identified at ORNL (Fig. 1.1), of which 14 are definite candidates for further action. With the exception of WAGs 2 and 21, these WAGs are sources of contaminants to other areas and have been termed "source WAGs".

WAG 2 consists of White Oak Creek (WOC) below the 7500 Bridge monitoring station, Melton Branch (MB) and associated floodplains, White Oak Lake (WOL), and the White Oak Creek Embayment (WOCE) at the confluence of the Clinch River. WAG 2 is downgradient from the contaminant source WAGs; WAGs 3, 4, 5, and 6 include former waste disposal facilities called Solid Waste Storage Areas (SWSAs).

WAG 2 is downgradient from all the WAGs in the WOC watershed; therefore, it receives and integrates the contaminants released from the other WAGs in the watershed. Furthermore, WAG 2 is a conduit to contaminants from the ORNL WAGs to off-site areas. Likewise, WAG 21 is also an integrator WAG because it receives the contaminants from the

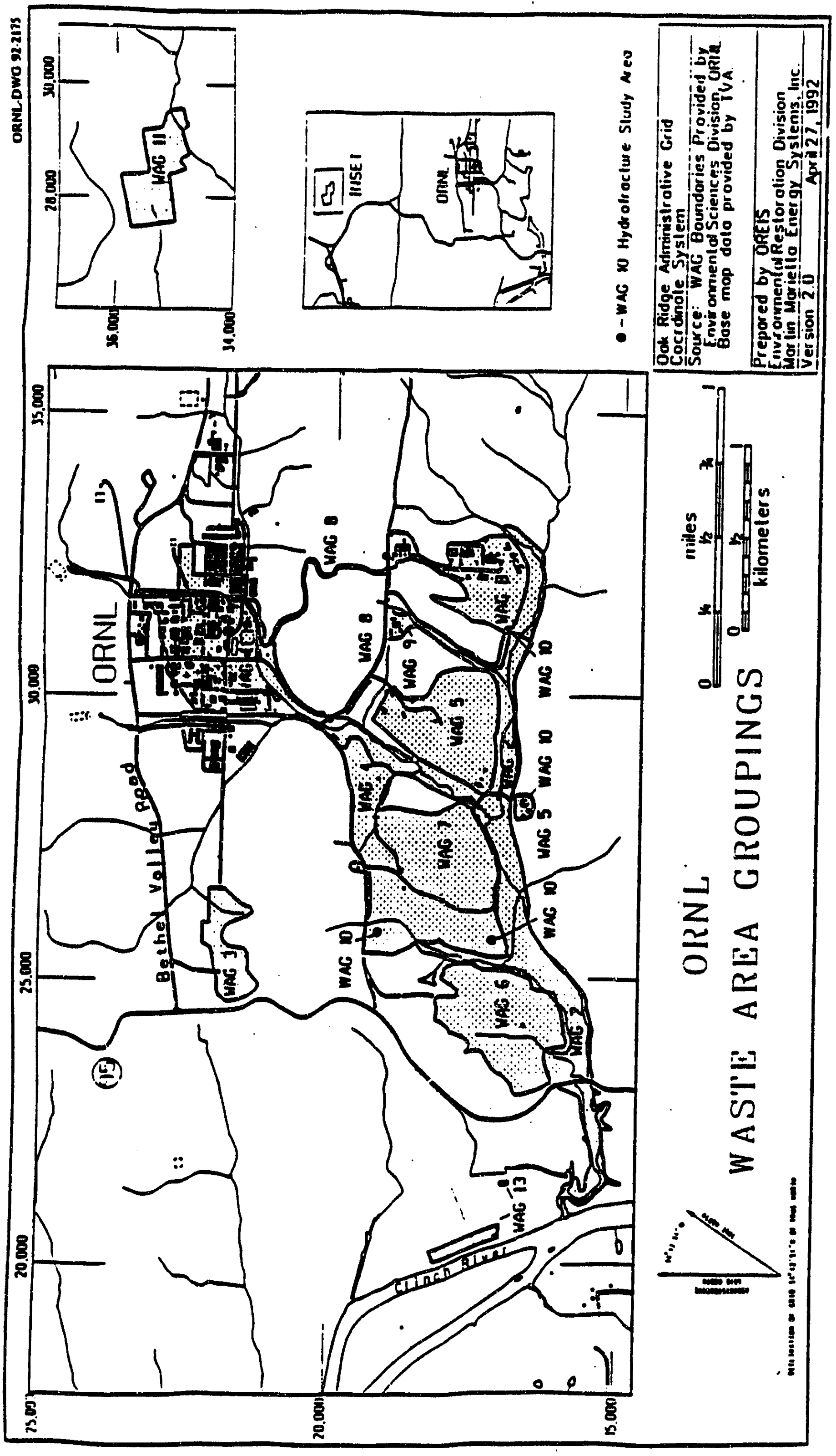

Fig. 1.1. Site-wide WAG map.

source WAGs that migrate to the groundwater system. WAG 21 encompasses the groundwater beneath the ORNL site, and it was designated as a separate WAG during FY 1992.

1.2 SITE-WIDE, INTEGRATED APPROACH TO ENVIRONMENTAL MONITORING

Early in FY 1992, two ORNL ER large scale projects [the WAG 2 Remedial Investigation (RI) and the Site Investigation (SI) Program] were merged to better achieve their complimentary objectives. The resulting WAG 2/SI Program consists of the remedial investigation/feasibility study (RI/FS) for WAG 2, a long-term monitoring effort for the White Oak Creek watershed, and a series of directed monitoring efforts and investigations directed at pathways and processes important for contaminant movement from ORNL WAGs in the White Oak Creek watershed.

WAG 2 consists of White Oak Creek (WOC) and its tributaries downstream of the ORNL main plant area, White Oak Lake (WOL), White Oak Creek embayment (WOCE) on the Clinch River, and the associated floodplain and subsurface environment (Fig. 1.1). The WOC system is the surface drainage for the major ORNL WAGs and has been exposed to a diverse array of contaminants from operations and waste disposal activities in the WOC watershed. WAG 2 acts as a conduit through which hydrologic fluxes carry contaminants from upgradient areas to the Clinch River. Water, sediment, soil, and biota in WAG 2 are contaminated and continue to receive contaminants from upgradient WAGs.

The Site Investigation activities are a series of monitoring efforts and directed investigations that support ER activities by providing information for: (1) watershed hydrology; (2) contaminants, pathways, and fluxes for groundwater at the ORNL site; (3) hydrologic pathways and fluxes that move contaminants through shallow depths and create secondary sources of contaminants; and (4) biotic populations and contaminants in the biota, in addition to other support and coordination activities. These efforts fill the gaps in existing monitoring programs and provide information at the watershed-level that is needed to effectively conduct RI/FS activities for the ORNL WAGs.

The WAG 2/SI Program is a key component of the ORNL Operable Unit (OU) strategy, wherein WAG 2 and the groundwater OU have been termed "integrator" units because they receive and integrate contaminant inputs from numerous source WAGs. WAG 2 is the surface water linkage and so the primary pathway for contaminant fluxes from the ORNL WAGs to the Clinch River (off-site). The subtasks of the WAG 2/SI Program take advantage of WAG 2's integrating role to guide, support, and evaluate the Environmental Restoration Program's activities for the major source WAGs at ORNL, leading to the eventual remediation of WAG 2.

1.2.1 Program Objectives

The long-term objective of the WAG 2/SI is the completion of the remedial investigation of WAG 2 at ORNL leading to a Feasibility Study (FS) and decisions concerning actions for this area. The continued input of contaminants to WAG 2 from upgradient areas and WAG 2's role as an integrator of contaminant fluxes has resulted in the formulation of a strategy that focuses on four key goals while upgradient WAGs are being remediated:

1. Implement long-term monitoring and tracking of contaminants leaving other WAGs, entering WAG 2, and being transported off-site.

2. Provide a conceptual framework to integrate and develop information at the watershed-level for pathways and processes that are key to contaminant movement, and so support remedial efforts at ORNL.

3. Continually assess the risk (both human health and ecological) associated with contaminants accumulating in and moving through WAG 2 to off-site areas.

4. Support the ER prioritization and evaluation of remedial actions for ORNL WAGs through long-term monitoring and risk assessment, .

The objectives of the multimedia environmental monitoring program are to provide a consolidated basis of support for the ORNL ER program office by:

1. Collecting data and using data from on-going programs (e.g., DOE order driven Environmental Surveillance monitoring) to develop a reach-by-reach mass balance for contaminants to determine contaminant releases from each ORNL WAG, and to provide a record of contaminant release from the watershed. Data are being collected for storm conditions because much of the contaminant flux occurs during storms;

2. Estimating risk to off-site areas from individual WAGs (based upon contaminant fluxes), and so supporting efforts to prioritize remedial activities;

3. Supporting remedial actions for source units by: (a) investigating the pathways and process that are important for contaminant fluxes, (b) providing watershed-level information for processes that can not adequately be addressed at the WAG-level (e.g., ecological assessment and sediment transport), and (c) by providing technical support;

4. Providing information from long-term monitoring of environmental media and biota) to evaluate the effectiveness of remedial actions at ORNL;

5. Providing a link with the Clinch River Remedial Investigation to contribute to an integrated assessment of the effects of releases from DOE facilities; and

6. Gathering information to support the eventual remediation of WAG 2.

Achieving these objectives will provide a site-wide, integrated analysis of contaminant movement in the WOC watershed and from WAGs outside the watershed to support ORNL ER activities.

Jointly these projects are building conceptual models of contaminant mobilization and transport to find historical trends that would enable researchers to understand and quantify the controls of contaminant movement in the WOC watershed. The combined programs must address specific tasks for WAG 2 and have a watershed-wide and site-wide perspective also. The SI component provides the special investigations that are needed to understand and quantify key processes identified as critical to the transport and fate of contaminants in the environment. Building submodels of critical processes will eventually lead to better site conceptual models. The SI component calls for communication among other ER groups to identify data sources and data needs, and among outside groups that may have data or information pertinent to ER Program objectives.

1.2.2 Program Strategy and Organization

During FY 1992 the WAG 2/SI Program was divided into four major technical tasks: Surface Water, Groundwater, Soil and Sediments, and Biota (Fig. 1.2). Each major task was divided into tasks with individual task leaders and staff. Over the past year, tasks were initiated in a phased manner as technical staff and supporting staff became available.

The **Surface Water task** consists of four components:

- **Surface Water Hydrology**: focusing on water budgets and surface water flux needed to quantify, track, and remediate contaminant sources.

- **Surface Water Chemistry**: using data for water chemistry to support risk assessment, construct mass balances for contaminants, development of discharge versus concentration relationships, and support investigations of mechanisms of contaminant transport.

- **Seeps and Tributaries**: identifying seeps and tributaries that are contributors to contaminant fluxes, interacting with surface water chemistry and groundwater tasks, and supporting remediation of contaminant sources.

- **Hydrologic Pathways**: investigating subsurface pathways of contaminant movement from buried wastes to streams, and evaluating the potential of the soil matrix downgradient of

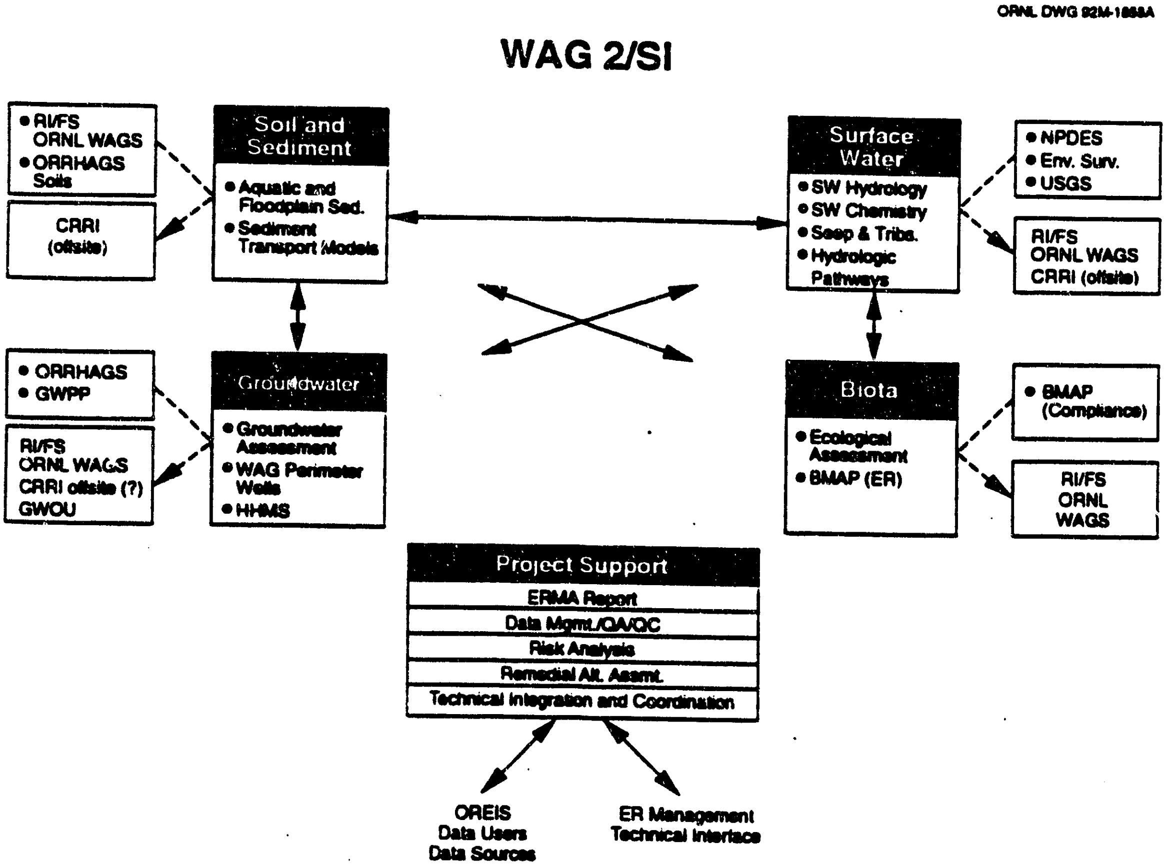

Fig. 1.2. Major tasks for the WAG 2/SI Program. Arrows indicate flow of information.

buried wastes to act as a secondary source of contaminants after the buried wastes have been removed or isolated.

The **Soil and Sediment task** has two components:

- **Floodplain Soils and Aquatic Sediments:** determining the distribution and inventories of contaminants in flood plain and aquatic sediments to: (a) identify contaminant sources areas, (b) to support and integrate sediment management programs to minimize the potential for contaminant release to the off-site area, and (c) to evaluate interim corrective measures and potential future remedial actions.

- **Sediment Transport Modeling:** developing a series of spatially nested areas (WAG, drainage system, watershed, off-site) to predict the potential for the erosion and transport of sediment following changes in the watershed (e.g., as a result of remedial actions) and during extreme storm events.

The **Groundwater task** has three components:

- **Groundwater Assessment:** (a) gathering data for well locations, geologic strata sampled, contaminants in groundwater, and groundwater fluxes to support the identification of contaminant sources and the selection, implementation, and evaluation of remedial actions and (b) constructing a 3-dimensional model of groundwater flow to better support the selection and evaluation of remedial actions.

- **WAG Perimeter Wells:** collecting data for metals, radionuclides, and organic contaminants from a series of 168 wells located on the perimeters of the ORNL WAGs.

- **Hydraulic Head Measuring Stations (HHMS):** collecting data for watershed exit pathways and communication between intermediate and shallow groundwater by monitoring well clusters and individual wells with multi-level sampling capability (to about 400 ft. depth).

  [Note: The GW Operable Unit program has only recently been established. Most of the WAG 2/SI groundwater tasks will transition to the ORNL site-wide groundwater effort (GW Operable Unit) in the coming years.]

The **Biota task** has two components:

- **Ecological Assessment:** (a) coordinating efforts of an ORNL-wide biological monitoring program with efforts in individual WAGs to develop and integrated long-term monitoring program to measure impacts and document changes in biotic communities; (b) developing models of contaminant flow through the biota to identify organisms at risk, and (c) obtaining needed data not being collected by other programs to support the selection, implementation , and evaluation of remedial actions.

- **ER supported components** of the ORNL Biological Monitoring and Abatement Program (BMAP): (a) ambient toxicity monitoring and effluent toxicity testing; (b) bioaccumulation studies; (c) biological indicators studies; (d) instream monitoring of invertebrates and fishes; (e) the radioecology of White Oak Lake; and (f) contaminants in terrestrial biota.

- **WAG 2/SI Program support** activities include human health and ecological risk assessment for WAG 2 and risk based prioritization of contaminant sources at X-10; data management and QA/QC functions for all WAG 2/SI efforts, technical integration and coordination for WAG 2/SI efforts with other sampling, monitoring, evaluation, and assessment efforts in the WOC watershed; and other activities including the preparation of the annual ERMA report.

The results of FY 1992 efforts for these tasks are summarized in this document. All tasks identified in Fig. 1.2 are described in subsequent sections of this report. During the year additional groups were identified to address particular problems or issues, for example:

- Preliminary Impermeable Cap Assessment (PICA)—a group of WAG 2/SI staff and engineers to evaluate hydrologic problems related to a membrane-only cap as a remedial alternative for WAG 6.

- Tributary Assessment—a surface-water group.

For each major task, outside groups were identified for the exchange of data and information. The outside groups include the following:

- National Pollution Discharge Elimination System (NPDES)—monitoring conducted by Environmental Surveillance and Protection (ESP) group with the ORNL Office of Environmental Compliance and Documentation (OECD).
- U.S. Geological Survey (USGS)—subcontracted for streamflow monitoring and hydrologic expertise.

- RI/FS subcontractors—Bechtel National, Inc. (BNI) for WAGs 1, 5, 10, and the RCRA facility investigation (RFI) at WAG 6.

- Biological Monitoring and Abatement Program (BMAP)—for the compliance component; the ER component is a task within WAG 2/SI.

- Oak Ridge Reservation Hydrologic and Geologic Study (ORRHAGS)—an ongoing integrated study of the hydrology, geology, and soils of the reservation in support of many groups, including the ER Program.

- Clinch River RI (CRRI)—the remedial investigation of surface water, down stream of WOC.

- Groundwater Protection Program (GWPP)—a groundwater activities coordination effort, now the manager for WAG 21.

WAG 2 is the appropriate starting point for the analysis of hydrologic and contaminant fluxes because WAG 2 is the integrator WAG, receiving contaminants from most of the other source WAGs. WAG 2/SI will expand its scope to the entire watershed and outlying WAGs by systematically choosing new sites for data collection and analysis on the basis of several factors: initial survey sampling results, priorities related to risk and risk reduction, and ER programmatic goals.

1.2.3 Reporting

Each component of the WAG 2/SI effort issues reports. This document seeks to summarize the objectives of various ER and other related activities, and to summarize the significant features of those efforts in order to provide an overview of conditions, activities, findings, and future work for readers interested in ER activities at ORNL.

FY 1992 has been a transition year in that many of the activities described in this report were recently initiated. During the second quarter, sampling began in WAG 2 (see Boston et al. 1992). For some tasks, analytical results from initial investigations have not been received; therefore, in many cases this report is mostly a plan for describing future work. The Sediment Transport Monitoring/Modeling Task was initiated in the spring, but because of dry conditions, limited data were collected. Consequently, the level of detail in the results among the activities is not uniform.

Specifically, the objectives of this annual report are to:

- identify the chemicals/radionuclides and the pathways that can potentially lead to unacceptable exposures to humans;

- summarize the results from environmental monitoring and data collection activities conducted during the past year by the WAG 2/SI program and by other monitoring programs;

- report radionuclide flux and mass balance calculations for reaches in WOC in order to gain more understanding of where in the system radioactivity is accumulating or being mobilized;
- describe recent advances in the fundamental understanding of the hydrologic processes whereby contaminants are mobilized and transported in surface and subsurface hydrologic system;
- provide assessment of both the monitored data and our knowledge of the contaminant transport processes in order to gain a reasoned perspective on the diversity, as well as the extent and movement of contaminants; and
- describe future data collection and monitoring activities.

1.3 CONTAMINATED SITES, KEY CONTAMINANTS, AND PATHWAYS OF CONTAMINANT MOVEMENT

1.3.1 Contaminated Sites

The RI process for WAG 2 was developed to provide long-term support for the RI/Fss for the other ORNL WAGs in the WOC watershed. Other Ris are currently being conducted for WAGs 1, 5, 6, 10, and 13. Although available information does not support full characterization of all WAGs, the waste inventory and known release data were used to identify key potential contaminants from each WAG (Table 1.1). The ORNL WAGs located in the WOC watershed are described below.

WAG 1

WAG 1 is the ORNL main plant area, which includes all the operating research and development facilities within the main security fence at ORNL (Fig.1.1). WAG 1 drains into WOC directly, through storm drains, and through two small tributaries, First Creek and Fifth Creek, which flow through WAG 1 approximately from north to south. Conceptual modeling studies have demonstrated the potential for rapid transport of contaminants along the massive array of subsurface pipeline trenches directly to WOC and its WAG 1 tributaries. Historic release data indicate that WAG 1 was a major source for radionuclide, heavy metal, and chemical waste releases to WOC. Analysis of the 1989 Environmental Monitoring Report for the Oak Ridge Reservation (Energy Systems 1990) suggests that WAG 1 is still the primary source of ^{60}Co, ^{137}Cs, and ^{90}Sr to the WOC/WOL system. An active RI for WAG 1 is currently being conducted and is expected to yield data on groundwater contamination and

Table 1.1. Contaminants known or suspected to have been released from each WAG

WAG	Contaminants[a]
1	^{60}Co, ^{90}Sr, ^{137}Cs, ^{15X}[b]Eu, ^{232}Th, ^{23X}U, ^{23X}Pu, ^{241}Am, ^{244}Cm, other radionuclides, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Zn, TRE, PCBs, chlordane
2	^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{137}Cs, ^{15X}Eu, ^{23X}U, ^{23X}Pu, ^{241}Am, ^{244}Cm, Ag, Cd, Cr, Cu, Hg, Pb, Se, TRE, PCBs, chlordane, VOCs, nitrates
3	^{3}H, ^{90}Sr, ^{137}Cs, TRE
4	^{3}H, Co, ^{3}H, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{137}Cs, ^{23X}Pu, other radionuclides, TRE
5	^{3}H, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{233}U, ^{23X}Pu, ^{241}Am, ^{244}Cm, other radionuclides, Cr, Hg, PCBs, Ni, Pb, Zn, PCBs
6	^{3}H, ^{14}C, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{15X}Eu, ^{23X}U, Cr, Cu, Hg, Mo, Ni, Pb, Zn, VOCs, nitrates
7	^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{137}Cs, ^{233}U, Cr, Ni, Zn, nitrates
8	^{60}Co, ^{90}Sr, ^{137}Cs, Cr, Cu, Zn
9	^{60}Co, ^{90}Sr, ^{137}Cs, Cr, Zn
10	^{90}Sr, ^{137}Cs, ^{244}Cm, TRU isotopes
11	^{238}U, Cd, Cu, Zn, Cr, organics
13	^{137}Cs
17	^{137}Cs, Cd, Cr, Cu, Zn, fuel-derived hydrocarbons, and solvents

[a] Based primarily on data in ORNL RCRA Facility Investigation (unpublished and environmental data packages for each WAG. Ruthenium-106 and TRE have short half-lives (e.g., ~1 year) and should have decayed to trivial levels by this time.

[b] X represents the radioactive isotope series.

release rates to WOC. Existing surface-water monitoring programs provide periodic data on continuing releases of selected radioisotopes from WAG 1.

WAG 2

WAG 2 consists of WOC and its tributaries downgradient of the ORNL main plant area, WOL, WOCE on the Clinch River, and the associated floodplain and wetland environment (Fig.1.1). Although no wastes were buried in WAG 2, contaminants have been introduced into the area from contaminated subsurface and surface-water flow from upgradient WAGs. WAG 2 is the major drainage system for ORNL and the surrounding facilities and receives contaminant inputs from the ORNL main plant area (WAG 1), SWSAs, (WAGs 3, 4, 5, and 6), liquid waste seepage pits and trenches (WAG 7), and the experimental reactor facilities (WAGs 8 and 9).

Contaminant releases from the WOC system (releases over the WOL Dam and remobilization of contaminated sediments from WOCE) have historically been a major source of contaminants to off-site areas (Kimmel et al. 1990). Resuspension and downstream transport of highly contaminated sediment from the WOCE necessitated a CERCLA time-critical corrective measure to construct a sediment retention structure at the mouth of WOCE, which was completed in the spring of 1992.

WAG 3

WAG 3 is located in Bethel Valley about 1 km (0.6 mile) west of the west entrance to the ORNL main plant area (Fig.1.1). WAG 3 drains into the Northwest Tributary (NWT) of WOC. The NWT enters WOC downstream from the main plant area and could contaminate the lower reach of WOC within WAG 1 and ultimately the lower reaches of WOC and WOL (WAG 2) as well as the Clinch River. Monitoring data (Energy Systems 1990) and historical studies (Steuber et al. 1981) suggest that WAG 3 contributes small quantities of ^{90}Sr and ^{137}Cs to the NWT. However, no data are available on heavy metal or organic contamination. Additional monitoring and characterization data will be required to determine whether WAG 3 is a source of contaminants other than ^{90}Sr and ^{137}Cs.

WAG 4

WAG 4 is located southwest of the ORNL main plant area (Fig. 1.1). WAG 4 drains to WOC directly and through an unnamed tributary on its southern boundary. Monitoring data (Energy Systems 1990) suggest that WAG 4 is a major source of ^{90}Sr to the WOC/WOL system and is the largest contributor of ^{3}H to the reach of WOC above MB. No data are available on continuing elemental or organic contamination from WAG 4. Additional data will be required to determine whether and to what extent WAG 4 is a continuing source of heavy metals and organics.

WAG 5

WAG 5 is approximately 2 km (1.2 miles) south of the main plant area in Melton Valley between WOC and MB, upgradient from their confluence (Fig.1.1). WAG 5 drains into WOC directly, into two unnamed tributaries to WOC, into MB, and into an unnamed tributary to MB.

Radioactively contaminated groundwater has been identified around WAG 5 (Wickliff et al. 1991). Monitoring data (Energy Systems 1990) suggest that WAGs 5 and 9 combined contribute about one third of the ^{90}Sr and more than half of the ^{3}H that enters WOC. It is not possible, with current monitoring data, to separate the contribution of WAG 5 from that of WAG 9. However, an active RI is under way for WAG 5, and contaminant source issues are being further addressed (ORNL 1988, DOE 1911).

WAG 6

WAG 6 drains to WOL directly through four unnamed surface drainages and indirectly from its eastern hillslope to the West Seep tributary to WOL in WAG 7 (Fig 1.1). WAG 6 covers 28 ha (68 acres) and is the only operating low-level waste (LLW) disposal site at ORNL. Tritium, ^{60}Co, ^{90}Sr, and ^{137}Cs were the principle radioactive contaminants found in samples of 35 groundwater wells. These same contaminants were found in surface water and in both surface and subsurface soil samples. Trace levels of transuranic (TRU) isotopes were also found in two wells and two surface samples. Interim corrective measures (ICMs) monthly base-line monitoring of WAG 6 tributaries is currently under way. Radionuclide, metals, and ^{3}H data from this monitoring effort will contribute to the WAG 6 contaminant identification and source data base.

WAG 7

WAG 7 is in Melton Valley about 1.6 km (1 mile) southwest of the main plant area (Fig 1.1). WAG 7 drains to the East and West Seep tributaries to WOL, to WOC directly, and to two unnamed tributaries to WOC. Characterization studies suggest that WAG 7 has been a source of ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, chromium, and zinc. No organic contamination traceable to WAG 7 has been found. Existing monitoring data are insufficient to characterize contaminant releases from WAG 7. A WAG 2 seep and tributary sampling effort is currently under way to identify potential contaminant sources from WAG 7.

WAG 8

WAG 8 is in Melton Valley south of the main plant area and north of MB. Most of the reactor facilities other than those in WAG 1 are in Melton Valley. WAG 8 drains directly into MB and into the West Seven tributary to MB (Fig 1.1). Recent monitoring data suggest that WAG 8 is the source of about half of the ^{60}Co entering the WOC/WOL system. The WAG contributes negligible amounts of other radionuclides. Additional data will be required to determine past and continuing contributions of heavy metals (especially chromium and zinc) and organics from WAG 8 to WOC. No data are presently available on organic contaminants.

WAG 9

WAG 9 is in Melton Valley about 1 km (0.6 mile) southeast of the main plant area just south of Melton Valley Drive (Fig 1.1). WAG 9 drains to the Homogeneous Reactor Experiment (HRE) tributary to MB. The primary isotopes contributing to radioactivity levels in WAG 9 are ^{90}Sr and ^{137}Cs (Stansfield and Francis 1986).

WAG 10

WAG 10 consists of the injection wells and grout sheets from four solid waste management units (SWMUs), two of which were experimental sites used in the development of the hydrofracturing process at ORNL. The other two sites were operating facilities (now inactive) used to dispose of ORNL's liquid LLW. All four SWMUs are located in Melton Valley; however, they are not adjacent to one another. WAG 10 is significantly different from the other WAGs in that its grout sheets are at depths of 90 to 300 m (300 to 1000 ft) below ground.

Samples collected from groundwater wells, installed to monitor releases from the grout sheets, have detected ^{90}Sr contamination. No other contaminants have been found, and there is no indication of WAG 10 contamination reaching shallow groundwater or surface water. There is currently no monitoring data to determine the input, if any, of WAG 10 contaminants to WOC; however, the WAG 10 RI will begin addressing this issue in FY 1993.

WAG 13

WAG 13, part of what is now called the 0800 Area, is west of State Highway 95 (White Wing Road) near the Clinch River (Fig 1.1). There are two SWMUs within WAG 13, both associated with research on transport of ^{137}Cs through the environment. Existing monitoring data do not provide enough resolution to determine if WAG 13 is a source of ^{137}Cs. An RI plan is currently being prepared for WAG 13, and execution of that plan should help to determine if the WAG is a source of ^{137}Cs to WOCE and to the Clinch River.

WAG 17

WAG 17 is about 1.6 km (1.0 mile) east of the main plant area, south of Bethel Valley Road (Fig 1.1). This area is the major craft and machine shop area for ORNL. WAG 17 drains into WOC just south of Bethel Valley Road. WAG 17 effluents, entering WOC approximately 5 km (3 miles) upstream from WOL, may ultimately reach WOL and the Clinch River. There are no reports of releases of radionuclides or hazardous materials from WAG 17; however, stream gravel surveys show that ^{137}Cs may have been released in the past. The surveys also suggest the presence of cadmium, chromium, copper, and zinc. In addition, semivolatile organics were found to be present as tar-like grains on the gravels.

1.3.2 Key Contaminants

Health and ecological risk screening analyses were conducted on contaminants in WAG 2 (Blaylock et al. 1992) to determine which contaminants of concern would require immediate consideration for remedial action and which contaminants could be assigned a low priority for further study. Screening-level risk analyses have been done for WAG 1, and a base-line risk assessment has been completed for WAG 6.

WAG 2 Health Risk. Screening indices were used to evaluate the potential human health risk from contaminants found in WAG 2 and are described in Blaylock et al. 1992. For screening purposes, WAG 2 was divided into four geographic reaches: reach 1, a portion of WOC; reach 2, MB; reach 3, WOL and the floodplain area to the weirs on WOC and MB; and reach 4, the WOCE, for which an independent screening analysis has been completed (Hoffman et al. 1990). The screening index for a carcinogen is an estimate of exposure (ingestion, inhalation, external) multiplied by an EPA-approved or suggested slope factor to indicate the potential lifetime risk of excess cancer. A risk of $\geq 10^{-4}$ excess cancers for a lifetime exposure to carcinogens is considered an action level by the EPA. Risks between 10^{-4} and 10^{-6} excess cancers per lifetime is a range where risk levels are of concern; negotiation on remedial action alternatives occurs and additional investigation is probably justified. A risk below 10^{-6} excess cancers per lifetime indicates that a carcinogen is of little concern and can be assigned a low priority for further investigation. Table 1.2 shows the results of a nonconservative screening of the detectable contaminants data base.

Screening indices for noncarcinogens are an estimate of the daily ingestion or inhalation of the contaminant divided by a "reference dose (RfD) factor". The reference dose is an EPA-approved daily noncarcinogenic contaminant exposure level below which adverse effects should not occur. For noncarcinogens, a screening index ≥ 1.0 is considered an action level, an index between 0.1 and 1.0 requires further investigation before taking action, and an index ≤ 0.1 indicates a low priority for further action. Table 1.3 shows the results of a nonconservative screening of the data base for noncarcinogens assigned to different screening categories.

Groundwater was screened as an independent pathway. Nonconservative screening of the detectable contaminants data base for groundwater indicated that none of the carcinogens or

Table 1.2. Carcinogens assigned to different screening categories by nonconservative screening of data base where at least one value for each contaminant was above detection limits

Contaminant type	Contaminant	Reach[a]	Exposure pathway
High priority—require immediate consideration for remedial action screening indices $\geq 10^{-4}$			
Inorganic	Arsenic[b]	2, 3	Water ingestion
Organic	PCB-1254 (Aroclor 1254)	1, 3	Fish ingestion
Radionuclide	^{60}Co	1, 2, 3	External exposure
	^{137}Cs	1, 3	External exposure
Require further investigation before taking action screening indices 10^{-4} to 10^{-6}			
Organic	Dichlorobromomethane	1	Water ingestion
	PCB-1254 (Aroclor 1254)	2	Fish ingestion
	PCB-1254 (Aroclor 1254)	1	Water ingestion
	PCB-1254 (Aroclor 1260)	1, 2, 3	Fish ingestion
	PCBs (total)	1, 2, 3	Water ingestion
Radionuclide	^{137}Cs	1, 2, 3	Fish ingestion
	^{137}Cs	2	External exposure
	^{137}Cs	1, 3	Water ingestion
	^{90}Sr	1, 2, 3	Water ingestion
	^{3}H	1, 2, 3	Water ingestion
	^{152}Eu	1, 2, 3	External exposure
	^{152}Eu	2	Water ingestion
	^{134}Cs	1, 2, 3	External exposure
	^{154}Eu	1, 2, 3	External exposure
	^{154}Eu	2	Water ingestion
	^{234}U	3	Water ingestion

[a] Arsenic is a possible artifact since the number of samples with detectable concentrations is small.

[b] Reach 1 White Oak Creek weir to 7500 bridge.
Reach 2 Melton Branch weir to just above HFIR tributary.
Reach 3 White Oak Dam to White Oak Creek and Melton Branch weirs.
Reach 4 White Oak Creek Embayment.

Table 1.3. Noncarcinogens assigned to different screening categories by nonconservative screening of data base where at least one value for each contaminant was above detection limits

Contaminant type	Contaminant	Reach[a]	Exposure pathway
High priority—require immediate consideration for remedial action screening indices ≥1.0			
Inorganic	Thallium[b]	1, 2, 3	Water ingestion
Require further investigation before taking action screening indices 0.1 to 1.0			
Inorganic	Arsenic	2	Water ingestion
	Mercury	1	Fish ingestion

[a] Reach 1 White Oak Creek weir to 7500 bridge.
Reach 2 Melton Branch weir to just above HFIR tributary.
Reach 3 White Oak Dam to White Oak Creek and Melton Branch weirs.

[b] A possible artifact because only one sample was analyzed in each reach.

noncarcinogens could be assigned a high priority. However, because of the lack of verification of the limited data base, additional data will be required for groundwater. Lead was not included in the screening analysis because an EPA-approved RfD was not available, but an EPA uptake/biokinetic model predicted that lead would be a problem in groundwater in reaches 1 and 3.

Results of the hypothetical intruder scenario indicated that the potential lifetime risk of excess cancers was $>10^{-4}$ from the ingestion of fish in reaches 1 and 3 and from external exposure in reaches 1, 2, and 3. PCBs and ^{137}Cs in reach 1 and PCBs in reach 3 were the greatest contributors to risk in the fish ingestion pathway. Cobalt-60 and ^{137}Cs in reaches 1 and 3 and ^{60}Co in reach 2 had screening indices of $>10^{-4}$ in the external exposure pathway.

As the result of a CERCLA removal action in response to uncontrolled contaminated sediments in WOCE, the information available for the extent of contamination in WOCE was more thorough than that available for the remainder of WAG 2 (Blaylock et al. 1992). A screening analysis was conducted using methods similar to those for the remainder of WAG 2. The screening analysis for carcinogens identified several substances as definitely high priority and requiring immediate consideration: arsenic in water ingestion, PCBs in fish ingestion, and ^{60}Co and ^{137}Cs in the sediment external exposure pathway. Arsenic in water was a possible artifact, because arsenic was detected in only 2 of 24 samples analyzed. Two organic, six inorganic, and six radiological contaminants had screening indices that would require further investigation before taking action. The screening for noncarcinogens did not identify any contaminant that could definitely be assigned high priority.

Screening of the WOCE nondetectable contaminants data base identified 16 organic carcinogens as definitely high priority. For these compounds it will be necessary to either improve the detection limits or to use source-term data to verify their presence.

WAG 1

The most frequently detected radionuclides in WAG 1 surface water were ^{90}Sr and ^{137}Cs. Radium-228 and ^{23X}U were also detected but less frequently and at lower concentrations. Only the volatile organic carbons (VOCs) pyridine and *p*-dioxane may be of concern, but they were not widely or routinely detected. Tritium was widely detected, but concentrations were generally below reference levels. The most frequently detected radiological contaminants in groundwater were ^{137}Cs, ^{3}H, ^{90}Sr, ^{60}Co, ^{99}Tc, ^{147}Pm, and ^{241}Am. Among the VOCs, trichloroethylene (TCE), chloroform, 1,2-dichloroethene, vinyl chloride, and toluene were the most frequently detected compounds. Silver, cadmium, chromium, and lead were detected in unfiltered samples at concentrations exceeding maximum contaminant levels (MCLs) in groundwater. Of the man-made radionuclides detected in sediment (^{137}Cs, ^{60}Co, ^{90}Sr), ^{137}Cs was detected most frequently.

The WAG 1 preliminary human health evaluation indicates that risk from radioactive contaminants was driven by external exposure (99% of total risk) to ^{137}Cs (ORNL 1992a). For chemical contaminants, the potential carcinogenic risk does not exceed the upper limit of EPA's target risk range (10^{-4}). Inhalation of particulates and ingestion of surface water were the primary pathways for conservative exposure assumption. Arsenic was the primary contributor for the inhalation pathway, and volatile organic *p*-dioxane was the major chemical contributor to the surface-water ingestion pathway. However, high analytical uncertainties are associated with arsenic results and the resulting risk assessments may be overestimated. The noncarcinogenic hazard index for the ingestion of surface water (pyridine) is greater than the adverse effect threshold of 1.

WAG 5

Strontium-90, ^{3}H, ^{137}Cs, and ^{60}Co account for the majority of groundwater and surface-water contamination in WAG 5. Risks from these nuclides were evaluated in the screening-level risk assessment. Using a nonconservative screening measure for an on-WAG resident, the highest risk (6×10^{-3}) was associated with the drinking water exposure route. On-WAG risk associated with external exposure was lower (8×10^{-5}). Conservative estimates of risk to the off-WAG Clinch River resident indicate risk factors of 1×10^{-8} (drinking water) and 4×10^{-9} (fish exposure route). Surface and subsurface soil contamination in WAG 5 is limited to specific areas, and these areas do not appear to represent significant secondary sources areas (ORNL 1991a).

WAG 6

Tritium was the most prevalent radionuclide in WAG 6 groundwater (ORNL 1991b). Off-WAG migration of ^{3}H in the groundwater system is probable because this radionuclide has been detected in close proximity to WAG 6 boundaries. Both ^{3}H and ^{90}Sr are the most prevalent radionuclides in surface water. In sediments, ^{60}Co, ^{90}Sr, ^{3}H, and ^{137}Cs were detected; however, ^{137}Cs was detected most frequently. Radiological soil contamination is limited to ^{90}Sr and ^{60}Co. VOCs and semivolatile organic carbons (SVOCs) were detected in surface water and groundwater in WAG 6. Except for one sampling location, organic compounds—primarily VOCs—were detected in every sediment sample collected at WAG 6. Although various organic compounds have been found in WAG 6 soils, some of the compounds are suspected to be sampling- or laboratory-induced contaminants. Lead and barium dominated groundwater metal concentrations, while barium and cadmium concentrations exceeded reference or MCL values in surface water. Sediment sampling results indicate no metals present in concentrations significantly above reference concentrations. Metal concentrations in soils appear to be localized, with arsenic, lead, mercury, and ^{60}Co detected in a few samples at concentration above background.

The primary media by which contaminants are transported off-WAG are groundwater and surface water. There is some transport via sediments, soils, and air; however, these appear to be relatively minor pathways. Sediments, although contaminated, are not transported off-WAG at significant rates because of the intermittent nature of streams and because of erosion control features.

Carcinogenic risk from radionuclides dominated all exposure scenarios. This risk is attributable to external exposure to ^{152}Eu, ^{154}Eu, ^{60}Co, and ^{137}Cs. Risk estimates for the off-WAG homesteader scenario is 6×10^{-5} with the dose 90% attributable to ^{60}Co and ^{137}Cs (ORNL 1991b).

1.3.3 Ecological Risk

WAG 2

A screening assessment of ecological effects in WAG 2 has been conducted concurrently with the human health assessment (Blaylock et al. 1992). This assessment considered three lines of evidence concerning the risks to nonhuman organisms posed by contaminants in WAG 2: biological surveys, toxicity tests of ambient media, and exposure/response analysis for measured contaminant concentrations. The biological survey data indicate that aquatic effects are not severe because a diverse and productive aquatic community is found in WAG 2. However, comparison of the aquatic biota with those of reference streams indicates that the composition of the benthic invertebrate community may be modified and fish reproduction may be disrupted. Biological survey data are not available for terrestrial biota.

Recent toxicity tests of water from WAG 2 do not indicate toxicity to *Ceriodaphnia dubia* or to larval fathead minnows in 7-day exposures. No toxicity tests have been performed on sediments or soils (Loar et al. 1992).

Comparison of media concentrations with toxicological benchmarks produced ambiguous results because of the large number of chemicals that were not detected but had limits of detection higher than potentially toxic concentrations. Mercury and PCBs were found at potentially toxic concentrations in both water and sediments in all reaches. Aluminum, cadmium, chromium, copper, and lead exceeded national ambient water quality criteria and state standards, and twelve other metals exceeded potentially toxic concentrations. Of the chemicals that had been detected in sediments and for which available concentrations could be estimated, barium, cobalt, mercury, silver, zinc, benzene, di-*n*-butyl phthalate, methylene chloride, and PCBs are potentially toxic to benthic organisms. Selenium and possibly cadmium were found in fish flesh at concentrations indicative of toxic effects. Mercury and PCBs occurred in fish flesh at concentrations that are potentially toxic to piscivorous wildlife based on dietary toxicity data, and many other chemicals occurred at concentrations that would exceed the reference dose for human health effects when wildlife consumption rates were used. No analyses could be performed for toxic effects on terrestrial organisms other than piscivorous wildlife.

This evidence suggests that ecotoxicological effects may be occurring in WAG 2, but they are not as severe as would be indicated by the exposure/response analysis using the reported chemical concentrations. This discrepancy is due in part to the conservatism of the screening criteria, but it is likely that the principal factor is the inappropriateness of many of the analyses as estimators of bioavailable concentrations. Therefore, future activities should focus on estimation of actual exposure levels. In addition, chemical and biological data are needed from terrestrial portions of WAG 2. Future assessments will focus on improving the relevance of exposure/response estimates to conditions in WAG 2 and will continue to attempt to reconcile the three lines of evidence concerning ecological effects.

An ecological assessment activity has been created under the WAG 2 SI which integrates the ORNL BMAP with the ecological assessment component of WAG 2 and with the ecological assessment components of the source WAGs. The WAG 2 ecological assessment will address, on a watershed scale, the population- and community-level concerns that would be inappropriate to address on the smaller spatial scale of other individual WAGs. Available ecological assessment information for source WAGs is provided below.

WAG 1

Relying on BMAP studies and Phase I RI data for WAG 1, the environmental evaluation demonstrated a present or potential risk of detrimental effects to the environment in the absence of any remediation of WAG 1. Of the nonradiological contaminants, mercury and PCBs are likely to cause adverse effects to aquatic species and piscivorous animals. Regulatory standards for radionuclides for the protection of environmental receptors are lacking; however, both waterfowl and groundhogs collected from WAG 1 had high tissue concentrations of radionuclides (ORNL 1992a).

WAG 5

Results of the ORNL BMAP have shown the following: ^{90}SR and ^{137}Cs are accumulated in aquatic biota in WOC (Loar 1991a); fish contaminated with ^{137}Cs present a significant risk to human health (Blaylock et al. 1992); turtles collected from WOL downstream of WAG 5 contained elevated concentrations of ^{60}Co, ^{90}Sr, and ^{137}Cs; samples from waterfowl from around ORNL show that ^{137}Cs accumulates in breast tissue (Loar 1991a); and deer confiscated during managed hunts on the ORR showed elevated ^{90}Sr levels (Ashwood 1992).

Very few data are available on nonradioactive contamination in biota around ORNL. BMAP bioaccumulation studies have shown that PCBs and mercury occur in fish and clams in WOC, including reaches of WAG 5 (Loar 1991b). Terrestrial BMAP studies have measured PCB concentrations in two species of turtles in WOL and suggest that migratory waterfowl may accumulate mercury and other trace metals (e.g., lead, selenium, and silver) during stopovers on WOL (Loar 1991b).

WAG 6

As an operating solid waste disposal facility, the majority of WAG 6 has been cleared of natural habitat. Regular site mowing and ongoing construction have discouraged reestablishment of natural habitats and wildlife communities.

Strontium-90 would likely pose a significant threat to wildlife at WAG 6. It is readily absorbed and deposited in bone tissue, where it can result in bone tumors and leukemia. Species from lower trophic level, such as rabbits and shrews, may bioaccumulate ^{90}Sr in their bone tissues, suffer adverse effects, and subsequently cause adverse effects in red-tailed hawks and raccoons that prey upon them.

Calcium, copper, and ^{90}Sr could potentially affect fish populations. Cadmium and copper exceeded both chronic and acute ambient water quality criteria for protection of aquatic organisms.

Macroinvertebrate communities could potentially be affected by cadmium and copper. These two metals produce chronic effects at concentrations above 10 ppb. The maximum concentration of copper was 88 μg/L. Both values exceed those reported to produce chronic effects in macroinvertebrates. Bioconcentrations of ^{90}Sr by macroinvertebrates is expected to be low because of their short life cycle and frequent molting (ORNL 1991b).

1.3.4 Risk Assessment Rankings of the ORNL WAGs

Shevenell et al. (1992) conducted a human health risk assessment for the ORNL WAGs based upon data for contaminants in surface water. The exercise used data for contaminants in surface water because surface water is the primary pathway of contaminant transport off-site. The exercise used data for four radionuclides (^{60}Co, ^{137}Cs, ^{90}Sr, and ^{3}H) because these contaminants are among the most important for all ORNL WAGs (especially in terms of off-site release). The assessment end points were the maximally exposed individual on-site in WAG 2 and off-site at Clinch River mile 9.5. The exposure pathways considered were ingestion of vegetables, beef, fish, water, and milk as well as exposure to shoreline sediments and soils following irrigation. The ranking of the individual WAGs based on risk at Clinch River mile 9.5 show that WAG 1 ranks highest, followed by WAG 4, then WAGs 2, 6, and 7 (combined because they could not be separated by the data available). These were followed by WAG 5, then WAG 9, then WAG 3, and finally WAG 8 (Table 1.4). Total risk at Clinch River mile 9.5 from all WAGs was 8.5E-05 probability of excess cancers. This approach found that ^{137}Cs and ^{90}Sr were the two largest contributors to risk.

Table 1.4 Ranking of ORNL WAGs[a]

Rank No.	Original MEPAS[b] (WAG No.)	MEPAS with time weighting (WAG No.)	MEPAS without time weighting (WAG No.)	ORNL/ESD (WAG No.)
I	5	4	1	1
II	7	1	4	4
III	4	9	5	2[c]
IV	6	3	9	6[c]
V	1	6	3	7[c]
VI	2	5	2[c]	5
VII	9	2	6[c]	9
VIII	3	7	7[c]	8
IX		8	8	3

[a] Rankings are receptor independent. Future tank releases were not considered in the original MEPAS formulation, nor in the ORNL/ESD formulation, for WAGs 1 and 5. Hence, future risks associated with WAGs 1 and 5 may be higher than those calculated in this work.

[b] Multimedia Environmental Pollutant Assessment System.

[c] WAGs 2, 6, and 7 have the same calculated health risks associated with them.

The WAG rankings in Shevenell et al. (1992) were based on bioaccumulation factors and al. transfer coefficients recommended by the International Atomic Energy Agency and the National Council on Radiation Protection. This ranking is compared with a ranking of the ORNL WAGs using the Multimedia Environmental Pollutant Assessment System (MEPAS) approach (Table 1.4) that is used by DOE (Whelan et al. 1987). Shevenell et al. (1992) suggested that the bioaccumulation factors and transfer coefficients used by the MEPAS formulation might not be reliable for site-specific evaluations; further, the MEPAS approach used Hazard Potential Indices rather than risk to rank the WAGs.

1.3.5 Updating the Risk-Based Ranking of Contaminated Sites

As noted by Shevenell et al. (1992) exposure to contaminated floodplain sediments were not considered in the WAG ranking; if so, WAG 2 would have been ranked first. Data now becoming available from the WAG 2/SI project for sediment, vegetation, and waterborne contaminants; data from ORNL compliance monitoring; and data from the ORNL WAG RI/FS projects will allow us to better separate out the contributions of individual WAGs and operable units to on-site and off-site risk. Rankings or prioritizations of remedial action sites based on human health and ecological risk will be used to guide environmental restoration efforts in terms of prioritizing sites for actions, selecting actions based on risk reduction, developing performance criteria, and assessing performance of remedial actions. This activity is supported as part of the FY 1993 activities for the WAG 2/SI project and is linked to other ER and ORNL compliance activities.

2. SURFACE WATER

2.1 INTRODUCTION

Surface water is critically important because it transports contaminated groundwater that seeps to the land surface, it erodes and transports contaminated sediments, and it deposits those sediments downstream, potentially causing exposures to people and biota. Surface water at ORNL is classified by the state as supportive of fish and aquatic life (TDEC 1991); therefore, it is a resource to be maintained and remediated.

At the ORNL site, surface water must be viewed as a component in an integrated hydrologic system. The distinction between surface water and groundwater, as it appears in regulations and as reported herein, is largely artificial because most of the surface water in the geological setting at ORNL is actually groundwater that has emerged at the surface. Even during storms, the direct runoff is affected by subsurface flows. As the watershed becomes wetter, shallow subsurface flow moves down hillslopes and saturates the low-lying areas where direct precipitation, in turn, becomes direct runoff. Thus subsurface flow leads to direct runoff, which leads to erosion and transport. It follows that characterization of the hydrologic system of the WOC watershed is critical for understanding the processes that drive contaminant transport in the watershed.

The Surface Water Task within the WAG 2/SI supports the RIs at all ORNL WAGs (except WAG 10), the selection and engineering design of ICMs and remediations at all WAGs, and the long-term evaluation of remediation performance. In addition, Surface Water Task staff assist staff in OECD, especially in the ESP section, by sharing hydrologic data and expertise.

The first objective of the Surface Water Task is to collect and process climatic and hydrologic data and then to provide the data to other ER activities. Precipitation and other climatic data (mainly for the calculation of evapotranspiration) are used in computer modeling, especially in the Sediment Transport Sampling/Modeling subtask. The stream discharge measurements are used for calculation of contaminant fluxes and also in modeling. All hydrologic data are used in characterization and design.

The second objective is to gather surface-water quality data collected by others (e.g., the ESP group, RI subcontractors) and, when needed, collect water quality data in the field. Much of these data are presently collected by OECD, but as ER begins to focus on seeps and tributaries as monitoring points for groundwater quality, WAG 2/SI will be collecting more water quality samples.

The third objective is to interpret surface-water discharge and water quality data. Trends in space and time are used to identify the variability due to terrain and to storms and seasonal changes. In turn, the variability due to remedial actions can be assessed and predicted.

The last objective is to enhance our understanding of the hydrologic mechanisms that affect water quality. Understanding the role of shallow subsurface stormflow and shallow groundwater is important so that remediation efforts can be aimed at the correct source of contamination.

The core staff for the Surface Water Task includes members from ESD, the ESP Section of the Office of Environmental and Health Protection (OEHP), and the Department of Civil Engineering at the University of Tennessee (UT). Staff work closely with many groups: the WAG 2/SI Groundwater Task group and the Sediment Transport Monitoring/Modeling group; the U.S. Geological Survey; ER Engineering; the RI teams; and subcontractors, especially Environmental Consulting Engineers (ECE). In addition, the Surface Water group exchanges information with researchers in the Walker Branch Watershed project and the Subsurface Initiative studies at MB subsurface weir; hydrogeologists in the Oak Ridge Hydrology Support Program (ORHSP) that are assigned to other Oak Ridge Reservation (ORR) sites and those in the ORRHAGS investigation; and with staff of the Clinch River RI.

2.1.1 Section Outline

Section 2.2	presents the hydrological conceptual framework model for addressing question of contaminant flux and remedial responses. This model indicates that most subsurface flow is in the upper 1-3 m of soil, and that subsurface flows generally discharge to local streams. Recharge of the permanent groundwater table is slow and groundwater flux is small. Thus, surface water is the primary transport pathway for contaminants.
Section 2.3	summarizes surface water hydrological data for the White Oak Creek watershed.
Section 2.4.2	presents radionuclide fluxes at the major monitoring stations in the watershed to identify source reaches.
Section 2.4.3	compares data for average radionuclide concentrations with risk-based guidelines.
Section 2.4.4	presents data for discharge, contaminant concentration and contaminant flux, and shows how the relationships among these parameters can provide insight into sources and pathways of contaminant fluxes, and can be used to evaluate the success of remedial actions.

Section 2.5	presents information for preliminary efforts of the seep and tributary task, including historic data for seeps in and near WAG 2.
Section 2.6	presents information for the surface water investigations conducted in the source WAGs. Discharge vs contaminant concentration relationships for a tributary in WAG 6 provide information for pathways of contaminant flux and offer a potential useful approach for evaluating the success of remedial actions.

2.2 HYDROLOGIC CONCEPTUAL FRAMEWORK: IMPLICATIONS TO SURFACE-WATER TRANSPORT

During the past year Solomon et al. (1992) presented a conceptual model of the hydrology of the ORR based on the interpretation of numerous investigations and reports issued over the past two decades. Their ongoing work is part of ORRHAGS, which was established in 1989 as an integrated study of the hydrology, geology, and soils of the reservation in support of the activities in environmental monitoring, environmental restoration, waste management, and regulatory compliance on the ORR.

The conceptual model or hydrologic framework identifies the major pathways for water movement in the subsurface environment and the associated movement of contaminants, where present. In the conceptual model, the groundwater and surface water regimes are shown to be closely linked. Most water that infiltrates the soil surface moves through shallow pathways to seeps and springs where it emerges as surface water that has leached and moved materials along its flow path. The conceptual model is a significant breakthrough for the WAG 2/SI and other ER characterization activities because it provides a logical framework for interpreting measurements of surface- water quality and groundwater quality. Although significant uncertainties remain to be resolved, without the conceptual model the investigation of each new site on the ORR might reveal apparently random distributions of contaminants that could not be related to known sources in a straightforward manner. For example, chemical concentrations in wells often do not correlate with those observed in nearby streams. In the conceptual model, the discrete nature of fracture flow paths are shown to lead to contaminated springs and seeps while bypassing monitoring wells. WAG 2/SI activities, such as the investigation of groundwater-producing fractures, have provided information to ORRHAGS that has been incorporated into the conceptual model.

The conceptual model is reviewed in two places in this report. In this section, the basic flow paths are presented and the implications to surface water are discussed. In Sect. 3.2, the groundwater components of the conceptual model are described along with some of the implications for its use in remedial actions.

2.2.1 Areal and Vertical Hydrologic Units

As shown in Fig. 2.1, geological units of the ORR are assigned to two broad hydrologic groups: (1) the Knox aquifer—formed by the Knox Group and the Maynardville Limestone—in which flow is dominated by solution conduits and which stores and transmits relatively large volumes of water and (2) the ORR aquitards—made up of all other geologic units of the ORR—in which flow is controlled by fractures, which may store fairly large volumes of water, but transmit only limited amounts of water.

In the vertical, as shown in Fig. 2.2, the Knox aquifer and the ORR aquitards are divided into the following:

- The stormflow zone is a thin region at the surface where water moves laterally to seeps and springs at the bottom of hillslopes. Transient, precipitation-generated flow amounts to an estimated 90% or more of the water moving through the subsurface. This zone is a major pathway for transporting contaminants from the subsurface to the surface.

- The vadose zone is a mostly unsaturated zone above the water table.

- The groundwater zone, which is continuously saturated, is the region in which most of the remaining 10% of subsurface flow occurs.

- The aquiclude is a zone in which water movement, if it occurs, is probably on a geologic time scale.

Surface runoff, which leads to flooding and to soil and stream-bank erosion, is generated when subsurface stormflow converges in valley bottoms causing transient soil saturation and precipitation excess. Overland flow and flooding are more common in the aquitard areas than in the Knox aquifer areas. Stormflow zone in the ORR aquitards moves more water downslope and the valley bottoms are flatter and more subject to transient saturation than in the Knox aquifer. Figure 2.3 compares the quick hydrograph response and the wetter soils in Center Seven Creek (C7C) watershed, underlain by the aquitards, to the damped response and the drier soils in Walker Branch Watershed (WBW), underlain by the Knox formation. Conditions at C7C are probably typical of vegetated areas in the WOC watershed. Quantifying flows in the stormflow zone is important to predicting contaminant movement in this layer and to predicting floods, erosion, and sediment transport. Movement of particle-bound contaminants is a major pathway for contaminant movement, as shown in Sects. 2.4 and 4. The stormflow zone coincides with the root zone where flow occurs in root channels, worm holes, and fractures, collectively referred to as large pores. The average saturated hydraulic conductivity is 0.01 cm/s. The mean porosity has been computed as 50% (Davis et al. 1984), whereas the porosity of the large pores that conduct most of the water is only about 0.2% (Watson and Luxmoore 1986).

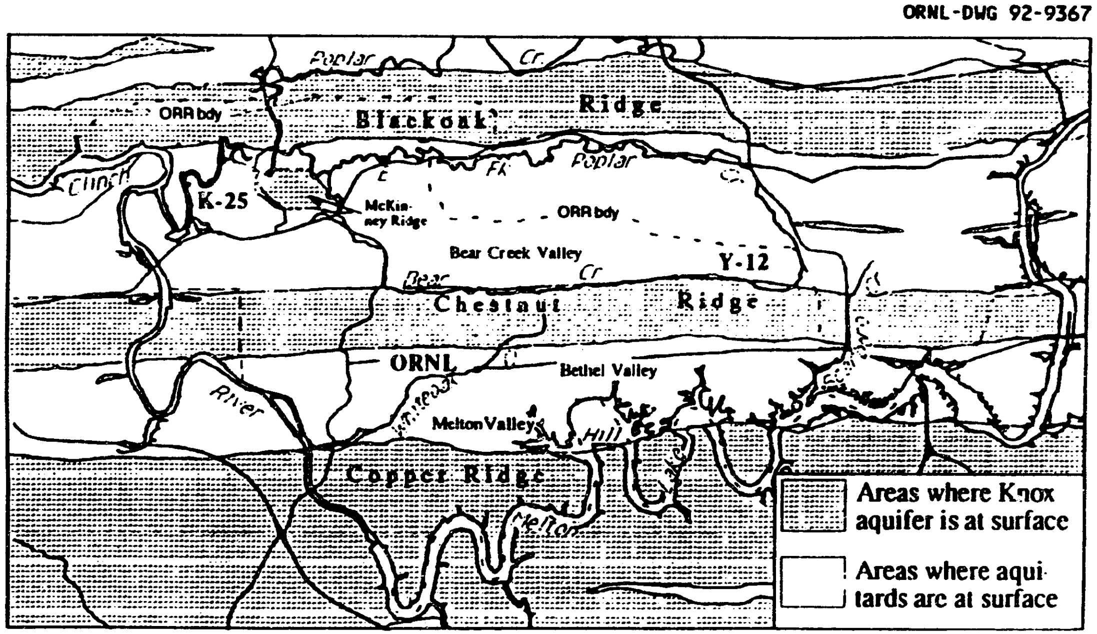

Fig. 2.1. Surface locations of the Knox aquifer and the Oak Ridge Reservation aquitards.

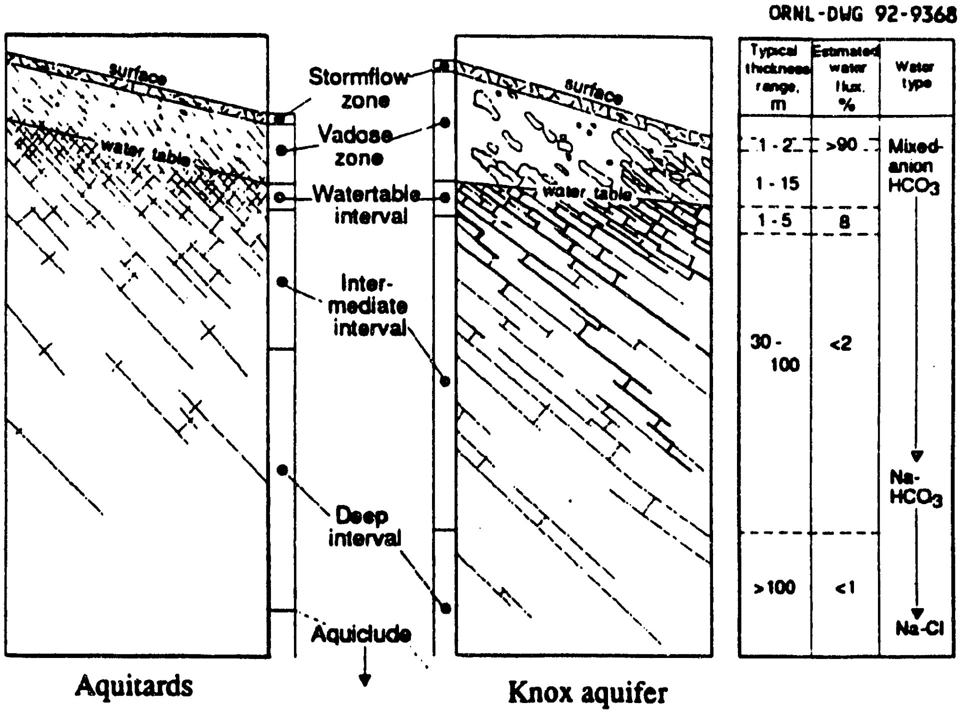

Fig. 2.2. Schematic vertical relationships of flow zones of the Oak Ridge Reservation with estimated thicknesses, water flux, and water types.

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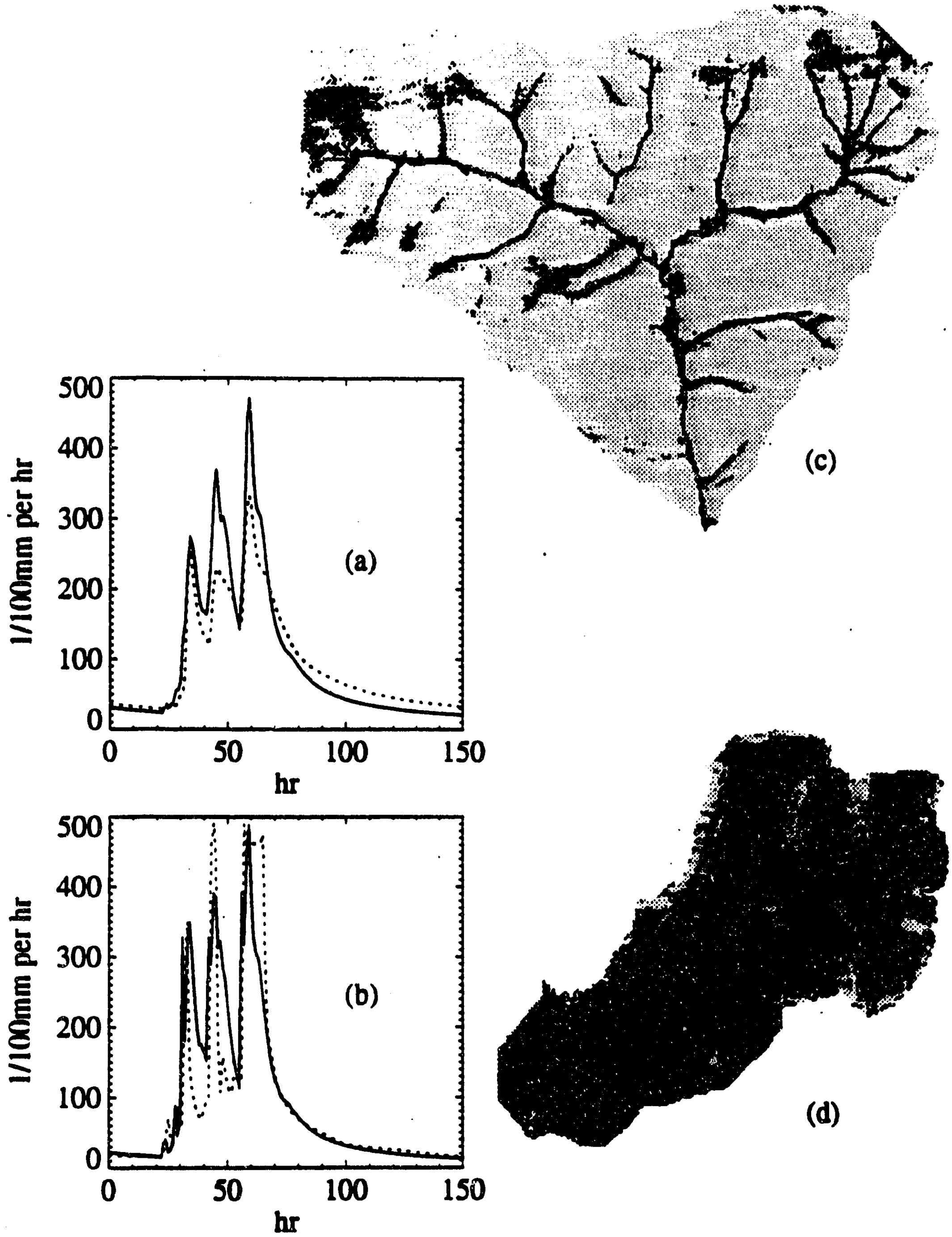

Fig. 2.3. Storm hydrographs starting 5/4/84 1:00 am, showing simulated (solid) and actual (dotted) discharge for Walker Branch Watershed (WGW) (a) and Center Seven Creek (C7C) (b). The soil water deficit is shown at saturation (black) and below saturation to 60 mm (dark gray) for WBW (c) and C7C (d). Simulations were computed using TOPMODEL as reported by Clapp et al. (1992).

Although the portion of subsurface water estimated to move though the groundwater zone is relatively small to that moving in the stormflow zone, the interconnection between the groundwater and surface-water regimes is of critical importance to environmental restoration. Because the ORR aquitard underlies most of the ORNL plant site, all of the burial grounds, and most of WAG 2, understanding the water movement in the aquitard is more important to planning, implementing, and evaluating environmental restoration at ORNL. Consequently, mechanisms of water flow in the Knox aquifer will not be discussed in detail because flow in the Knox aquifer does not significantly effect contaminant migration in WAG 2.

The stormflow zone may be a major pathway for contaminant transport from waste disposal areas on the ORR. Studies of contaminant release to streams during rain events in the MB watershed indicate that contaminant mass flow, defined as the contaminant mass per unit time, increases dramatically during events. For example, ^{3}H mass flow in MB changed from 7 to >40 Ci/d in <6 h during a January 1989 rain storm (Solomon et al. 1991).

In the ORR, groundwater in the aquitards, moves through fractures in the upper portion of the bedrock and the overlying weathered rock. This soil/bedrock interface tends to mimic the surface topography. This water is directed downgradient to nearby seeps and springs along the tributaries and the main streams. Because fracture pathways are discrete, in contrast to distributed flow typical of a conventional porous medium, groundwater monitoring wells are apt to be placed in hydrologically inactive areas and major contaminant pathways are usually not monitored. Therefore, Solomon et al. (1992) observe that the most representative and unambiguous information about contaminant movement and discharge from a waste site can be obtained from surface-water records on nearby drainage ways, where the nonhomogeneities of the subsurface materials within the basin are integrated. This fact has led to an emphasis within all WAG RI programs on water quality sampling in seeps, springs, and tributaries in order to infer groundwater quality rather than sampling in groundwater wells.

These recommendations are being implemented in phases starting in FY 1993. Water levels at a few sites will be monitored continuously as part of the initial WAG 21 Groundwater Operable Unit RI. The specific monitoring sites have not yet been identified. Within WAG 2/SI project, alternative methods of monitoring the relative contribution from stormflow and groundwater will be explored. Stormflow and groundwater often have unique chemical signatures that can be used for hydrograph separation. If unique signatures are found then monitoring of surface water chemistry may suffice, and no direct water level measurements will be needed.

Solomon et al. (1992) also conclude that there is a need to develop water budgets that quantify all flow processes on the ORR, including overland runoff, stormflow, and groundwater flow. This requires concurrent, continuous monitoring of natural streamflows and records of water levels in the stormflow and groundwater zones.

2.3 SURFACE-WATER HYDROLOGY

The annual hydrologic data summary report for WOC (Borders et al. 1992) was prepared to provide and describe sources of hydrologic data for ER activities that use monitoring data to quantify and assess the impact from releases of contaminants from ORNL WAGs. Also, it briefly summarizes specific components of the ER Program, lists hydrologic and contaminant flux data, and provides brief reviews of programs outside of the ER Program that provide hydrologic data that could benefit ER Program goals. The majority of the hydrologic data in the annual report are available from the Oak Ridge Environmental Information System (OREIS). Surface-water data available within the WOC flow system include discharge and runoff, surface-water quality, radiological and chemical contamination of sediments, and descriptions of the outfalls to the WOC flow system. Climatological information available for the Oak Ridge area include precipitation, temperature, relative humidity, wind speed, wind direction, and pan evaporation data. Anomalies in the data and problems with monitoring and accuracy are discussed.

The annual hydrologic data summary report is the third in the series of annual reports (see also Borders et al. 1989, and Borders et al. 1991). Although the need for hydrologic data will evolve in time, it is absolutely imperative that long-term hydrologic data collection be maintained and that key measurements be made without interruption. The initial plans for the newly established groundwater operable units at ORNL also call for long-term hydrologic data acquisition (see Sect. 3.9). Over the coming year hydrologic data needs of all ER groups at ORNL will be identified, and data collection activities will be coordinated.

2.3.1 Precipitation

Precipitation is probably the most important climatic factor in hydrologic studies, since it establishes quantity and variations in runoff and streamflow. It also replenishes groundwater. Maximum, mean, and minimum annual precipitation for stations near ORNL during the period 1954–1983 was 190.0, 132.6, and 89.7 cm (74.8, 52.2, and 35.3 in.), respectively (Webster and Bradley 1987).

Figure 2.4 shows the record (hyetograph) of daily precipitation at the Engineering Test Facility (ETF) rain gage in the WOC watershed. Figure 2.5 shows the locations of this and other meteorological stations for which data are available in the OREIS data base system. Borders et al. (1992) reported the maximum total rainfall recorded for durations of 1, 2, 3, 6, 12, 24, 48, and 72 h over the 2-year period 1990–1991. ORNL-specific maximum rainfall

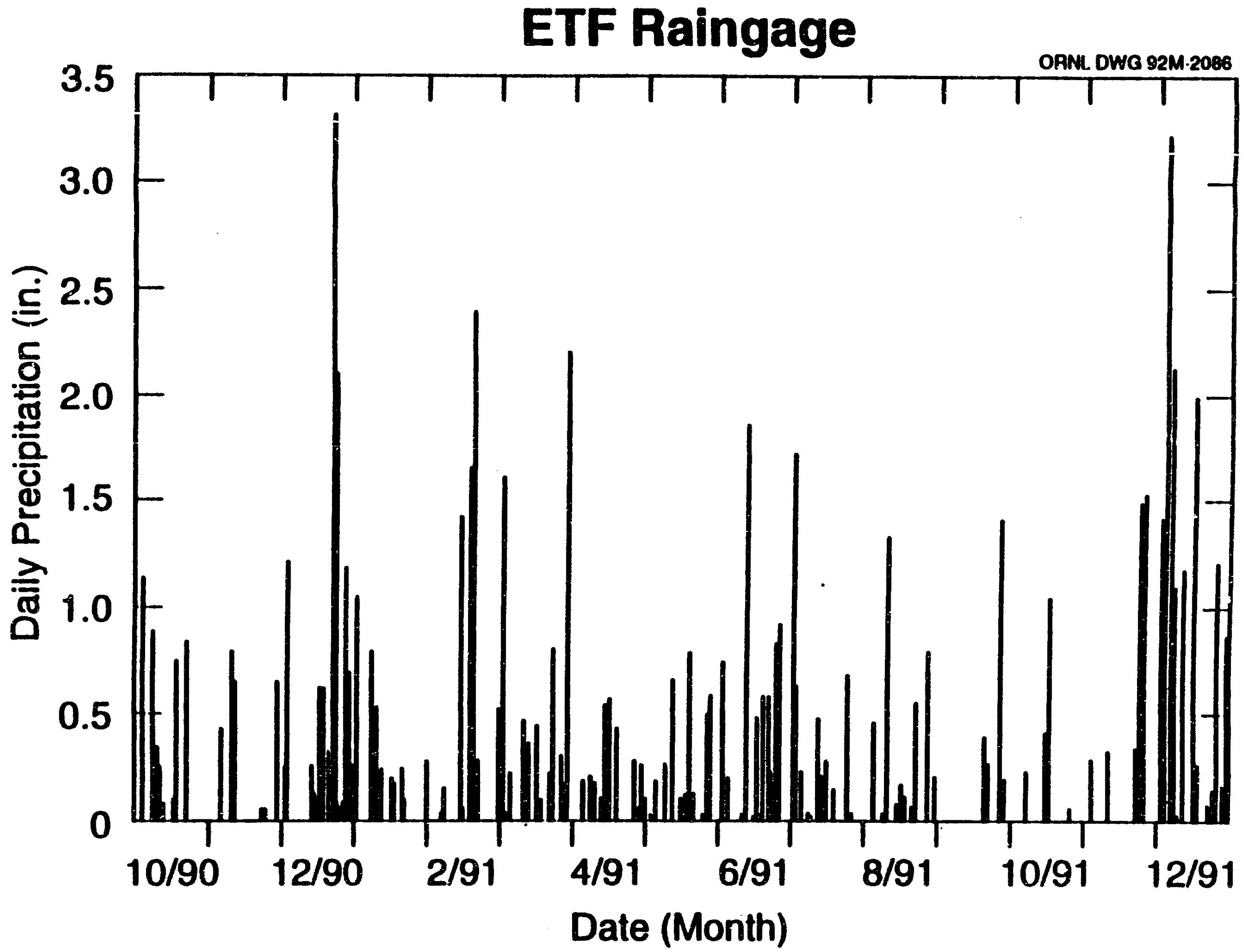

Fig. 2.4. Daily precipitation measured at the Engineering Test Facility rain gage in the White Oak Creek watershed during the period October 1990–December 1991.

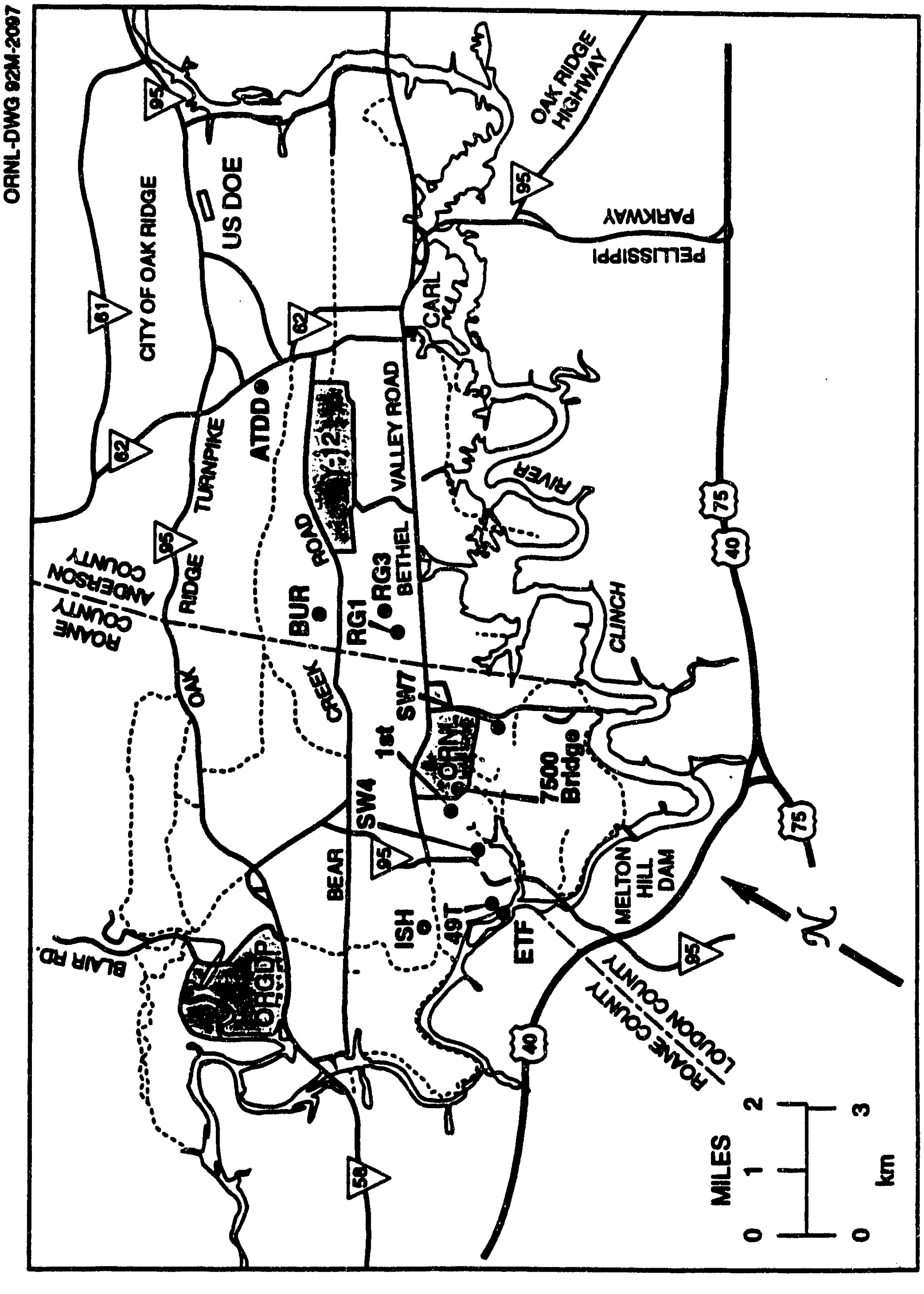

Fig. 2.5. Meteorological stations in the White Oak Creek watershed for which data are available through the Oak Ridge Environmental Information System data base system. (Station locations are marked with site identification labels).

data are requested by many engineering design groups, and the WAG 2/SI Surface Water group is developing a historical record.

The normal (mean) precipitation for the National Oceanic and Atmospheric Administration (NOAA)/Atmospheric Turbulence and Diffusion Division (ATDD) station, based on the 30-year mean (1961–1990) period of record, is 137.2 cm (54.02 in.). Calendar year 1991 is the third year of a period of recovery (above-normal precipitation) following the previous 4-year drought (~1985–1988). The drought is evident in the ratio of annual to normal precipitation:

1985	86%	
1986	72%	
1987	75%	
1988	91%	(extremely dry conditions until November)
1989	122%	
1990	111%	
1991	120%	

There is evidence that this climatic variability on a multiyear scale has had a measurable effect on contaminant mobility in the WOC watershed. As shown in Energy Systems (1992), the total derived concentration guide (DCG) risk factor for water discharged at the White Oak Dam (WOD) rose during the last part of the drought. (The DCG risk factor is discussed in a later section; it is related to the concentration levels of radionuclides.) The rise and leveling of the DCG has been related to annual discharge at WOD, but it is also correlated with changes in precipitation. (This relationship is not altogether unexpected because annual discharge, itself, is correlated with annual precipitation.)

Although this trend has not been fully explored, the example is important to ER because variability in hydrology due to year-to-year climate changes, seasonality, and individual storms potentially can confound the evaluation of remedial actions. The Surface Water Task staff is working to identify these trends in order to factor them into remedial action evaluations.

2.3.2 Discharge

2.3.2.1 Surface-water reaches

The WOC surface-water flow system has been conceptually divided into a network of reaches (Fig. 2.6) to identify stream sections as discernible, manageable components of the hydrologic system. Most of these reaches are delineated according to the location of monitoring stations where discharge measurements, coupled with concentrations, will provide mass fluxes of contaminants (e.g., ^{137}Cs, ^{3}H, etc.) at points of interest. However, some points, or nodes, where stream gaging is not presently available, were selected as logical divisions in

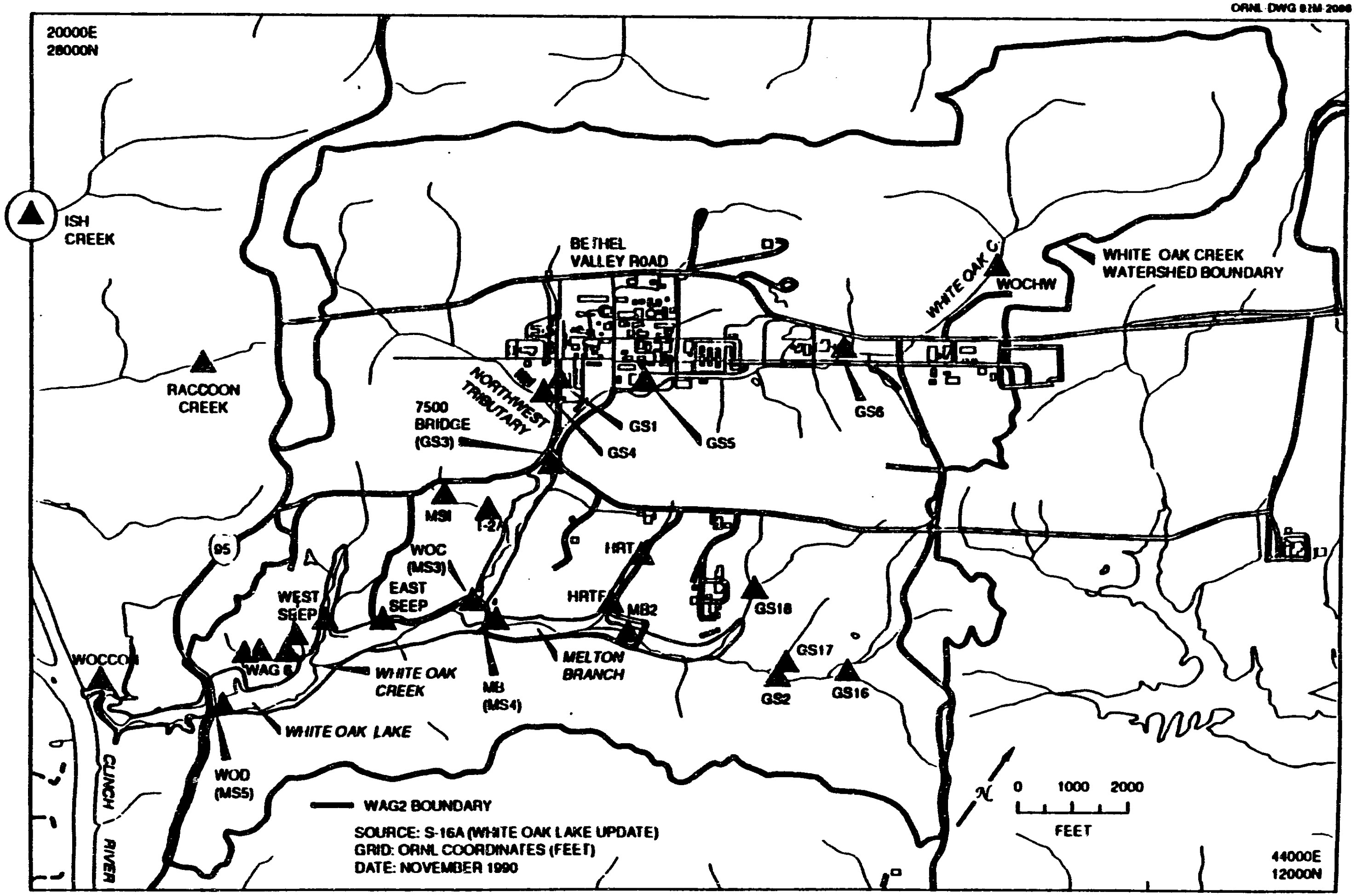

Fig. 2.6. **Locations of surface-water monitoring stations in the vicinity of the White Oak Creek watershed.**

the system (e.g., WOL is separated from lower WOC). Mass flux determinations at these locations are not currently possible.

Ultimately, these reaches were selected for the determination of contaminant mass balances for subareas within ORNL WAGs and the WOC watershed. The use of reaches enables the identification of areas of concern (sources and sinks of contaminants) for potential remediation. As seeps and tributaries are isolated and gaged, and representative incremental areas of reach outfalls are better characterized, discrete source and sink areas can be pinpointed and identified. This will facilitate the prioritization of these contaminated areas for remediation. It is likely that source areas would be remediated first, and areas that act as sinks for contaminants would not be remediated until all upslope sources had been stabilized. In addition, relationships between contaminant concentrations and stream discharge can be developed at reach discharge points to evaluate the effectiveness of future remediation, as illustrated in Sect. 2.6.2. In reaches where ungaged or unmonitored tributaries contribute significant quantities of material, the mass balance approach is uncertain. In the planned Tributary Assessment subtask (Sect. 2.5), tributary sources will be identified and sampled/monitored.

The reaches are also useful for identifying stream sections that gain or lose flow because of groundwater interactions. Table 2.1 shows incremental areas for each stream reach, the number of contributing tributaries, the average annual flow rate, and the subsequent annual gain (or loss) in each reach. In addition, cumulative dry month losses are presented for several major reaches. In terms of annual gains, these dry month losses are masked by high runoff in wet months. For example, according to Borders et al. (1992), upper WOC reach is a losing reach. This reach had a cumulative loss for seven months in 1991; however, it also had a cumulative annual gain due, primarily, to wet season runoff. Table 2.2 lists the gaging stations at each reach discharge point, their common station names, and the gage status of each.

2.3.2.2 Discharge at main stations in WOC watershed

Streamflow data are currently collected at 15 monitoring stations in the vicinity of the WOC watershed (Fig. 2.7). In the WOC watershed, there are at least 11 more streamflow monitoring stations outfitted with at least a hydraulic control device (i.e., flume or weir). These devices are in various states of repair, but each could be upgraded and instrumented to collect streamflow data. Some of these sites are currently being considered for upgrades to provide additional streamflow monitoring and/or intermittent storm sampling for water quality analyses in FY 1993 or later.

Data on surface-water discharge and quality are collected at numerous sites in the WOC flow system from numerous studies and by several organizations. The ESD Surface Water Hydrology group collects streamflow data for ER Program activities at nine monitoring

Table 2.1. Stream reaches in the White Oak Creek Watershed

Subwatershed reach/subreach	Area (mi²)	Inc. area (mi²)	Contributing tributaries		CY 1991 mean flow (ft³/s)	Gain (+) or loss (−) (ft³/s)	Cumulative dry month losses (ft³/s)	Dry months (1991)
			Gaged	Ungaged				
Melton Branch (MB)								
MB Headwaters	0.499	0.499	1	0	0.88	0.88		
Upper MB	1.16	1.16	2	1	NA[a]	NA	[b]	
Lower MB	1.51	1.51	1	1	3.7	2.82	[b]	
Bethel Valley WOC								
WOC Headwaters	0.804	0.804	0	2	1.7	1.7		
Upper WOC	1.29	1.29	0	2	1.99	0.29	−0.13	1, 4, 5, 7–10
Main Plant	2.09	2.09	1	4	6.61	4.62		
First Creek	0.319	0.319	0	0	1.03	1.03		
NW Tributary	0.667	0.667	1	2	1.19	1.19		
West End	3.26	3.26	1	0	11.9	3.07		
Middle WOC	3.61	3.61	1	2	12.4	0.5	−0.23	4–11
Melton Valley WOC								
Lower WOC	5.48	5.48	0	3	NA	NA		
WO Lake	6.15	6.15	6	0	16.5	0.4	−0.42	1, 7–11
WOC Embayment	6.5	6.5	0	1	NA	NA	—	—
Subtotal			14	18				
Total	6.5			32				

[a] NA = Not applicable or not available.

[b] Losses may occur in MB during dry months.

Table 2.2. Gaging stations at reach discharge points

Subwatershed	Name	ID	Gage status	Reach drained
Melton Valley				
	MB Headwaters	MBHW	Continuous record (USGS)	MB Headwaters
	Upper MB	MB-MS2	No record	Upper MB
	MB MS4	MB-MS4, X13	Continuous record (ESD)	Lower MB
Bethel Valley WOC				
	WOC Headwaters	WOCHW	Continuous record (ESD)	WOC Headwaters
	Upper WOC	UWOC	Continuous record (USGS)	Upper WOC
	Main Plant Flume	WOCMP	Continuous record (USGS)	Main Plant
	First Creek	1ST	Continuous record (USGS)	First Creek
	NW Tributary	NWT	Continuous record (USGS)	NW Tributary
	7500 Bridge	7500-B	Continuous record (USGS)	West End
Melton Valley WOC				
	WOC MS3	WOC-MS3, X14	Continuous record (ESD)	Middle WOC
	Lower WOC	(no gage)	Continuous record (ESD)	Lower WOC
	WOD	WOD, X15	Continuous record (ESD)	WO Lake
	Coffer Dam	WOCE-CD	No record; to be rated	WOCE

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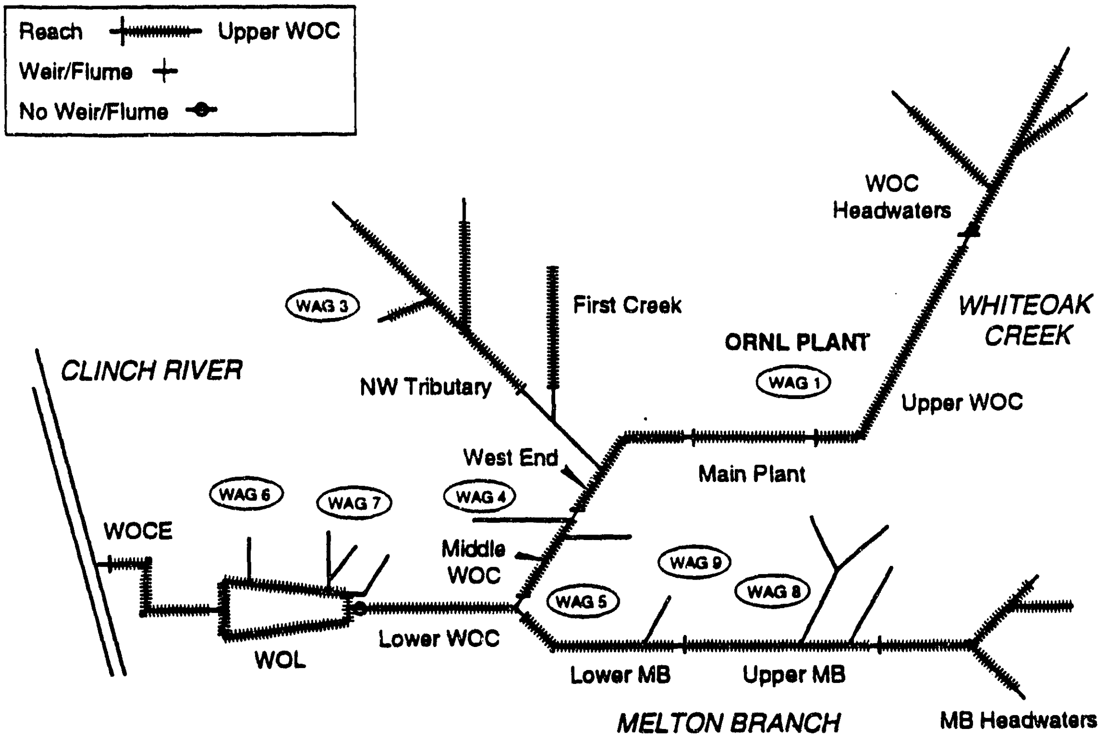

Fig. 2.7. Schematic diagram of reaches along White Oak Creek and Melton Branch.

stations. The USGS is also an integral component in the collection of streamflow data for ER Program activities. The USGS collects stream discharge data at six monitoring stations in the WOC watershed. As part of the monitoring and compliance program associated with the NPDES permit, ESP collects flow and water quality data at monitoring stations on WOC, MB, and WOD (Fig. 2.6). In addition, limited data are available from independent studies, ESD research projects, and RIs from other WAGs.

Accuracy of the stage–discharge relationships at all flumes and weirs is critically important. The ER Program has embarked on an activity to field-rate the high-flow flumes at WOC MS3 and MB MS4 (Fig. 2.6) using the expertise of the USGS. These flumes were initially rated using physical models and have not been field-rated. Known problems of submergence, especially at MB MS4, have been temporarily solved with flow-adjustment equations, but the field rating will help in the short run. ORNL ER staff are looking for a long-term solution at this site that will involve significant modification to the flume structure.

2.3.3 Recent Progress

In FY 1992 there have been immediate uses of the monitoring data in the Sediment Transport Sampling/Modeling Task, the Seep and Tributary Sampling Task, for groundwater modeling, and by RIs of other WAGs. In turn, the quality and coverage of hydrologic data collection has been enhanced in response to needs identified by the Sediment Transport Sampling/Monitoring Task staff.

During the past year there has been a vast increase in the emphasis on the Quality Assurance (QA) of hydrologic data leading to the generation of better data products. The Surface Water Monitoring Program QA Plan was completed, procedures were developed and implemented, and corrective actions resulting from an ORNL audit of the project in October 1991 were completed successfully. In addition, data quality has been enhanced by increased emphasis on instrument calibration, improved data processing software, quicker dissemination of data, and a sustained initiative to improve the surface-water monitoring network, including upgrades to monitoring stations, improved rating of weirs, and improved maintenance procedures.

2.3.4 Future Activities

Future hydrologic data summaries will continue to be produced as part of the WAG 2/SI Program. Staff, including subcontractors, will perform the data collection, compilation, and processing, as well as maintenance and oversight of surface-water monitoring upgrade activities and stream tributary water quality sampling. The data will be incorporated into annual Environmental Restoration Monitoring and Assessment (ERMA) reports that will provide a comprehensive picture of ER facilities at a watershed scale by identifying and interpreting spatial and temporal trends in contaminant movement within the WOC watershed.

A reconnaissance will be conducted at WOD (MS5) by the USGS in order to determine a feasible method for calibrating the high-flow measurement device at the surface-water monitoring station. The high-flow control must be calibrated to provide accurate discharge measurements and to meet regulatory guidelines for NPDES monitoring. A proposal will be developed and submitted to project personnel with calibration scheduled to begin in FY 1994. Likewise, the Sediment Retention Structure at the mouth of WOC will be rated in a project with UT Civil Engineering. The rating is not straightforward because the coffer cell dam is permeable.

2.4 SURFACE-WATER CHEMISTRY

One of the primary objectives of the WAG 2/SI is to integrate information from various existing programs for the purpose of estimating mass balances and fluxes of contaminants through the WOC watershed. Measurements of contaminant fluxes are useful in the identification of contaminant sources, the establishment of base-line levels for design, and eventual evaluation of remedial actions. Fluxes within the watershed can be compared to fluxes discharging to public access areas in order to assess the importance of different contaminant sources. Mass balance information describes the accumulation and discharge of contaminants within a particular reach where both inputs and outputs are known. To assess the long-term affects of climate and manipulations to the watershed, it is important to understand relationships between mass balances and hydrologic conditions. Under normal flow conditions reaches can act as contaminant sinks, accumulating contaminated sediments; but when runoff is increased by large storms, especially in combination with remedial measures like capping that enhance runoff, the same reach can be a contaminant source as those sediments are mobilized. It follows that the impact of extreme storms is largely dependent on the history of contaminant accumulations and losses from the affected reach. Hydrologic data and surface-water chemistry data are also important because they can reveal the mechanisms whereby contaminants are mobilized and transported. Differences in contaminant concentrations during storm runoff and baseflow can reveal the relative roles of overland runoff, subsurface stormflow, and groundwater.

2.4.1 Environmental Compliance and Surveillance Monitoring for 1991

The following information is summarized from the *Oak Ridge Reservation Environmental Report for 1991* (Energy Systems 1992). The surface-water monitoring and surveillance programs at ORNL include four functional categories of surface waters: reference surface waters that are unaffected by the facilities operations, off-reservation surface waters that sampled downstream from the DOE plants, facility effluents, and reservation surface waters that receive effluents. WOC and MB are classified as reservation surface waters that receive effluents where both nonradiological and radiological monitoring are required by NPDES permit and DOE Order 5400.5.

Concentrations of metals, anions, and other contaminant indicators measured at the NPDES ambient surface-water stations MB MS4, WOC MS3, and WOD were compared to averages of reference values calculated from data collected at upgradient stations at Melton Hill Dam and at White Oak Creek Headwater (WOCHW) stations. Constituent concentration averages that exceed the reference location averages by more than 35% are considered as elevated over the reference value, as reported in Energy Systems (1992). At MB MS4, WOC MS3, and WOD, excess sulfate, fluoride, and zinc were detected. In addition, at WOD, the final release point from the ORR, excess chromium, aluminum, iron, manganese, total organic carbon, oil and grease, phosphorus, and total dissolved solids (TDS) were detected. WOC results are comparable with those at WOD, but MS4 metals are more like those found in the reference waters.

A value five times the analytical detection limit was used as a nominal rule for assessing the presence of organic contaminants. As such, no significant organic contamination was found at the three NPDES ambient surface-water stations.

2.4.2 Radionuclide Fluxes at Main Stations

For radiological monitoring within WOC watershed, sampling locations are WOC MS3, MB MS4, First Creek, Northwest Tributary, and WOD. Continuous flow-proportional sampling for the stations at middle WOC reach and lower WOC/WOD reach allows mass balances to be computed. Figures 2.8–2.11 show the monthly fluxes during 1991 for ^{3}H, total strontium, ^{137}Cs, and ^{60}Co, respectively, for lower WOC/WOD. Total strontium is the sum of ^{89}Sr and ^{90}Sr; and the calculated fluxes at MB were corrected for submergence at the monitoring weir. Accumulation or loss of material is calculated by:

$$\text{source or sink} = \text{flux out} - \text{flux in},$$

where a positive value means that the reach is a source, i.e., material, either being mobilized within the reach or added to the reach by tributaries or groundwater inflow. A negative value means that the reach is a sink, accumulating material. Of course, the mass balance is a spatial average, and material can accumulate in one area and be mobilized to another area.

During 1991 the monthly radionuclide fluxes generally show a seasonal trend. As shown for the soluble contaminants ^{3}H and total strontium (Figs. 2.8 and 2.9, respectively), the minimum monthly flux occurred in September when conditions were driest, and the maximum monthly fluxes occurred in February and November when runoff was largest.

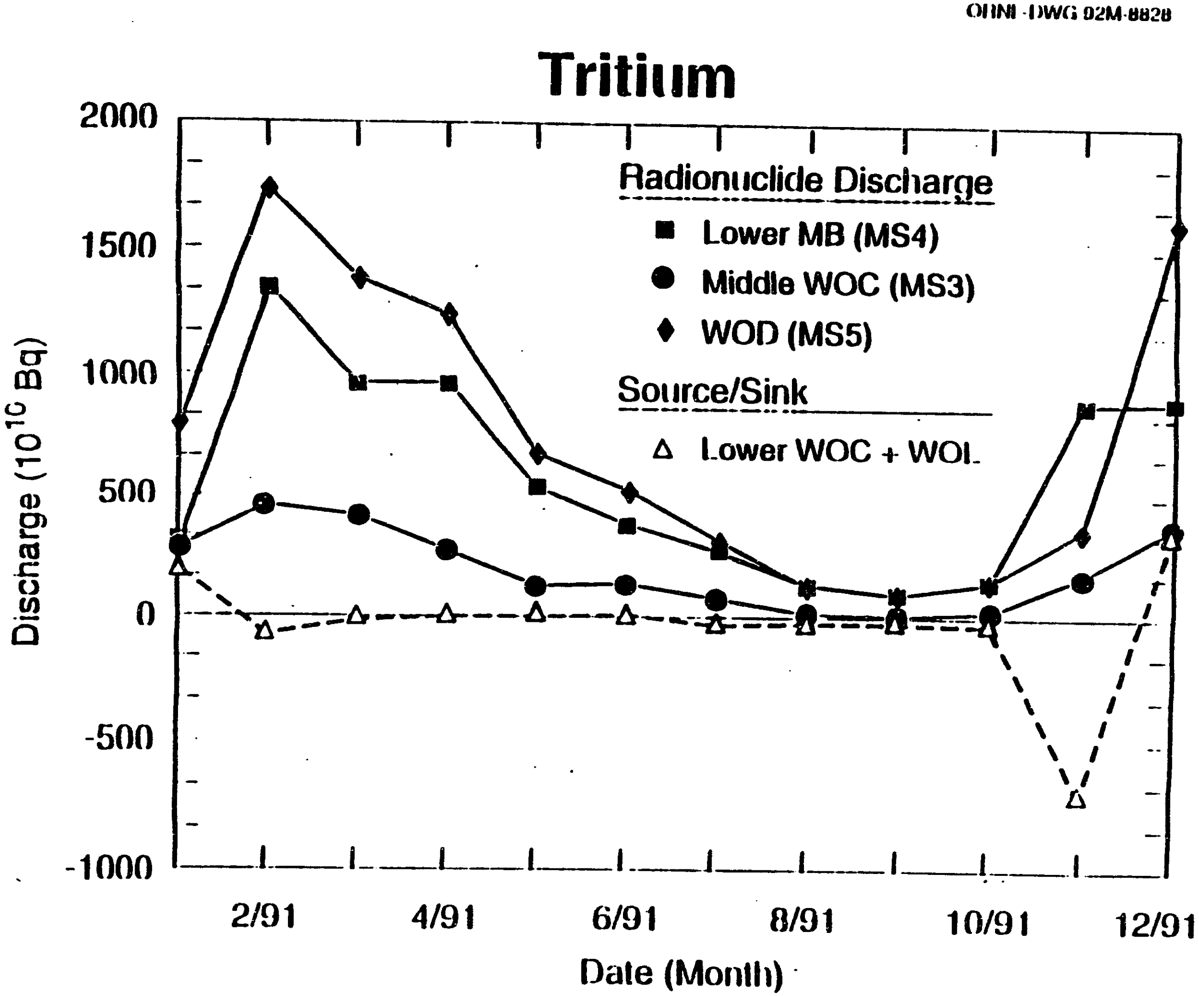

Fig. 2.8. Monthly discharges of tritium for lower White Oak Creek and White Oak Lake during 1991.

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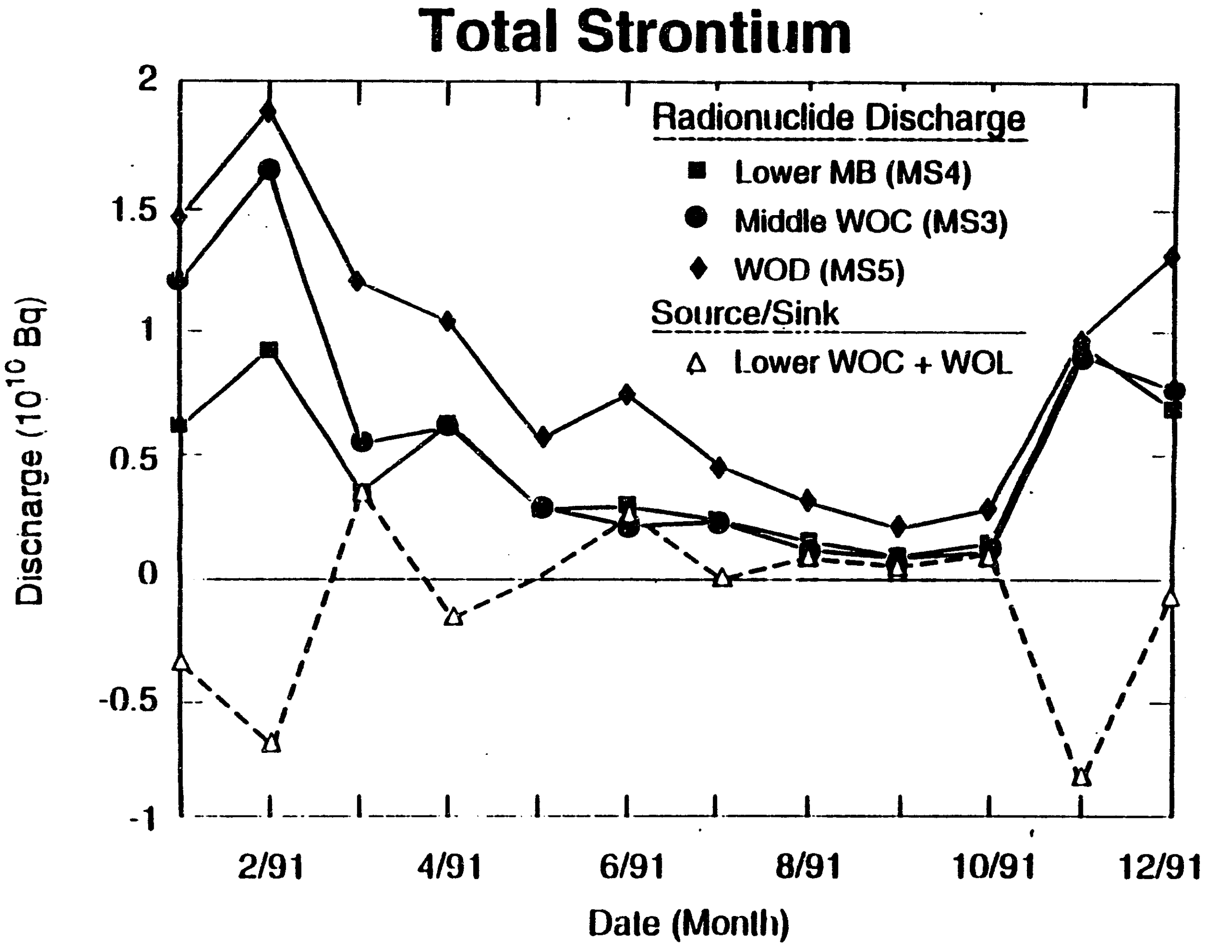

Fig. 2.9. Monthly discharges of total strontium for lower White Oak Creek and White Oak Lake during 1991.

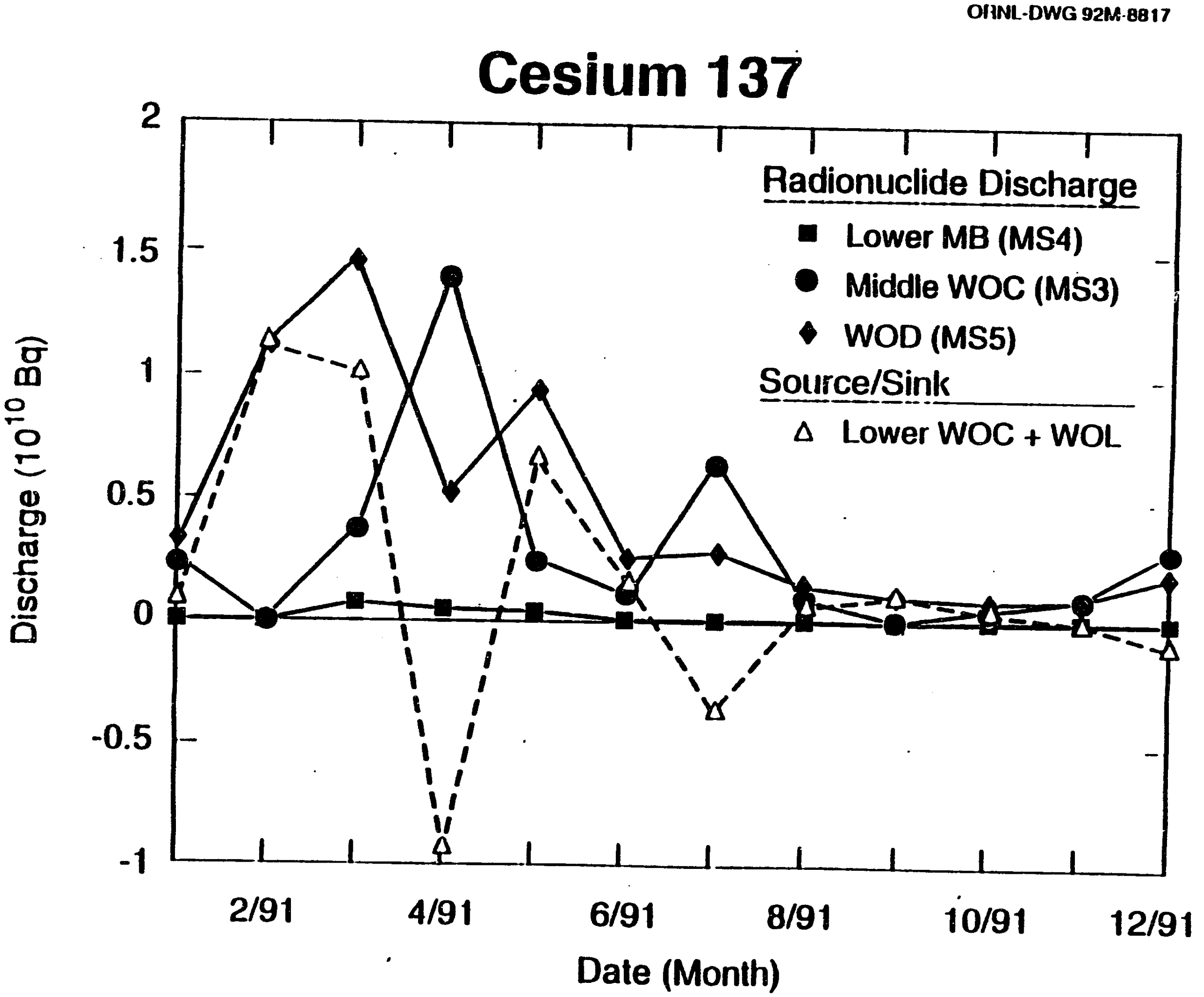

Fig. 2.10. Monthly discharges of ^{137}Cs for Lower White Oak Creek and White Oak Lake during 1991.

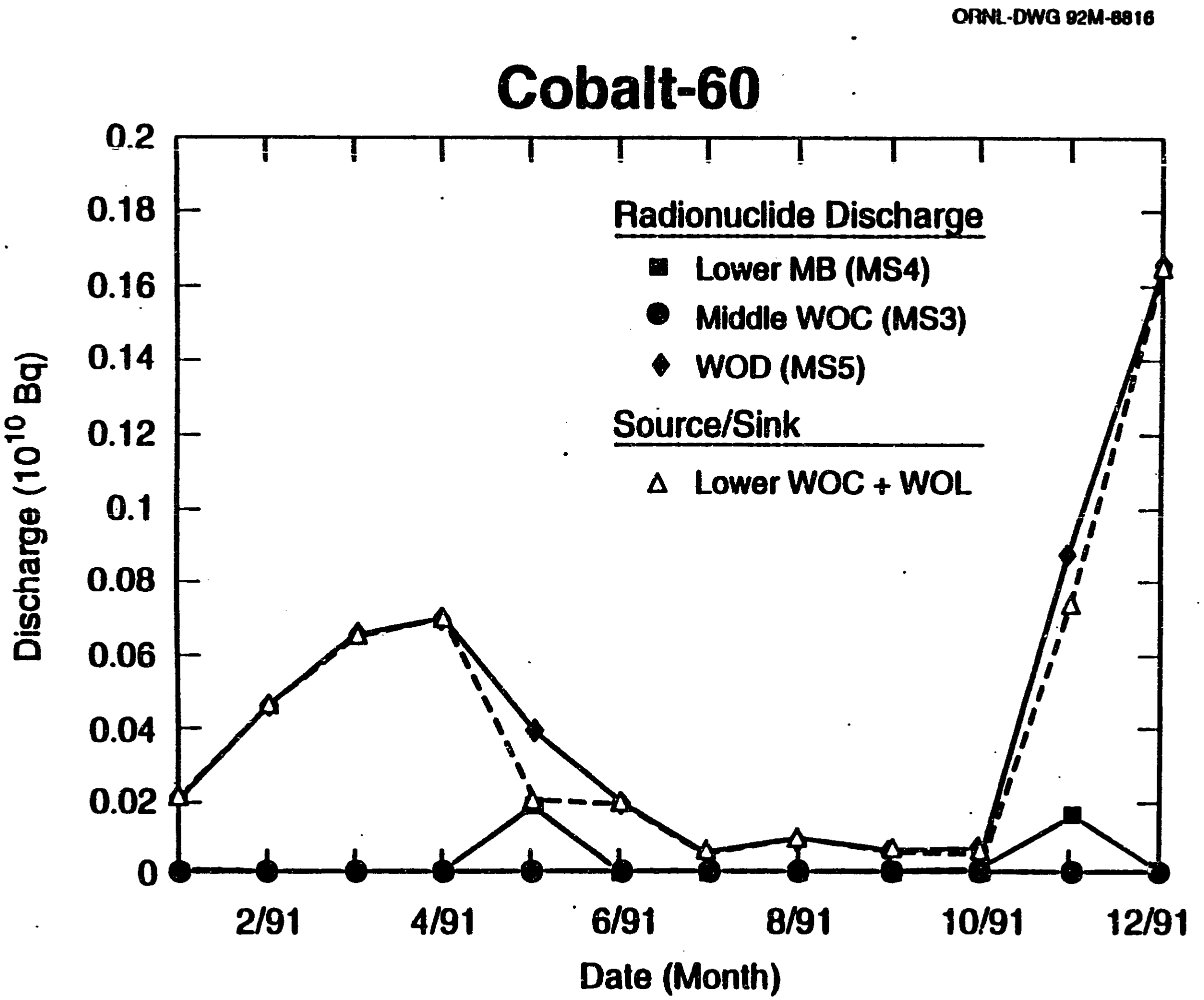

Fig. 2.11. Monthly discharges of ^{60}Co for Lower White Oak Creek and White Oak Lake during 1991.

Although ^{137}Cs shows a somewhat similar pattern, the ^{137}Cs flux during the first half of 1991 shows large month-to-month variation, probably because ^{137}Cs is particle-reactive, and its movement is associated with large peak flows that occur infrequently. Because WOC is the main source of ^{137}Cs for lower WOC/WOD, it is expected that ^{137}Cs levels at both monitoring sites would be correlated, which does not appear to be the case. It appears that ^{137}Cs discharge from WOD is somewhat independent of input from WOC.

Cobalt-60 (Fig. 2.11) shows a different pattern. The maximum ^{60}Co flux at WOD occurred 1–2 months after the peak monthly flows. The reason for the delayed response is probably related to the contaminant flowpath. The major source of ^{60}Co is a groundwater seep in WAG 7 that drains to a small ungaged tributary to WOC. The groundwater response from this and other seeps is delayed relative to surface-water discharge.

Table 2.3 lists the annual mass balances for the middle WOC reach and the lower WOC/WOL reach. The source/sink estimates are considered to be provisional because there are several sources of uncertainty, as discussed later. Because the source/sink factor is the difference between two uncertain values, the uncertainty can be magnified. The ratio:

$$\frac{\text{source (or sink)}}{\text{flux out}}$$

can provide a simple indication of the reliability of the mass balance. Small values of the ratio may be suspect. Furthermore, negative values, indicating a contaminant sink, for soluble contaminants ^{3}H and total strontium are suspect because there is no place to accumulate these radionuclides over the long term.

The mass balances in Table 2.3 indicate that middle WOC reach is a source for ^{3}H and total strontium. Main source in this reach is known to be the small unnamed tributary draining WAG 4. The mass balances also indicate that the reach accumulated ^{137}Cs and ^{60}Co during the year. To compute the source/flux ratio for ^{60}Co it was assumed that the input to the reach was < 0.001 Ci, therefore the ratio becomes < -59. For all the radionuclides, the source/flux ratio is 0.92, 0.41, −0.35, and < -59 for ^{3}H, total strontium, ^{137}Cs, and ^{60}Co, respectively. These values are judged to be large (absolute), thus the pattern of sources and sinks among the radionuclides is probably correct. The Middle WOC reach, which was already heavily contaminated with gamma radiation at the Intermediate Holding Pond site, retained all of the ^{60}Co that flowed into the reach during 1991.

For lower WOC/WOL reach, the pattern is reversed, and ^{3}H and total strontium appear to be accumulating in the reach. The source/flux ratios are small: −0.10 and −0.02 for ^{3}H and total strontium, respectively; therefore, these values have a large uncertainty. In contrast, the ratios for ^{137}Cs and ^{60}Co are larger: 0.34 and 0.93, respectively; thus the reach was probably a source for the discharge of these two radionuclides at WOD during 1991.

Table 2.3. Annual fluxes and mass balances for radionuclides in WAG 2

Reach	Gage station	Average discharge (L/s)	Average concentration (pCi/L)				Discharge (Ci)				Source (+) or Sink (-) (Ci)			
			^3H	Sr[a]	^{137}Cs	^{60}Co	^3H	Sr[a]	^{137}Cs	^{60}Co	^3H	Sr[a]	^{137}Cs	^{60}Co
	7500 Bridge	348	3,100	80	130	5.4	34	0.88	1.5	0.059				
	WOC-MS3	366	44,000	130	95	0.000	520	1.6	1.1	0.000				
Middle WOC											480	0.66	-0.39	<-0.059
	MB-MS4	107	530,000	400	14	4.0	1800	1.4	0.049	0.014				
	WOD	468	140,000	190	120	10	2100	2.9	1.7	0.15				
LWOC+WOL											-200	-0.057	0.58	0.14

[a] Total strontium = ^{89}Sr + ^{90}Sr.

Because of the cobalt seep in WAG 7 that drains to Lower WOC/WOL, it is not surprising that this reach is a source for ^{60}Co. In contrast, the fluxes from seeps and tributaries known to be contaminated with ^{137}Cs are judged to be small, therefore it is surprising that this reach is a source of ^{137}Cs for the embayment. This finding is contrary to our knowledge that WOL has been accumulating contaminated sediments over the years. Nevertheless, the finding that this reach is a source of ^{137}Cs during 1991 is tentatively accepted, and the following sources of uncertainty are acknowledged:

- The ^{137}Cs inputs to the reach have not been quantified. (The Seep and Tributary Monitoring Task and the Tributary Assessment Task will provide the needed data.)

- Discharge measurements may be biased because the high flow structures at WOC MS3, MB MS4 and WOD have never been field rated. (Actions for field rating these structures in FY 1993 are underway.)

- The present flow-proportional sampling system is not specifically designed for sampling suspended sediment. (Sediment Transport Sampling activity [Sect. 4] will provide an assessment as to the accuracy of the present system.)

This type of mass balance analysis will be enhanced and extended to other sites in FY 1993. Data from monitored tributaries will be included. In the Sediment Transport Sampling activity, sample analysis will include the measurement of soluble ^{3}H and ^{90}Sr. Because the highest flux rates are associated with the highest rates of water discharge, storm sampling may suffice for calculating annual balances.

New monitoring or storm sampling on tributaries (Sect. 2.5) will commence next year. Of particular interest are the West End reach, in order to determine the fluxes of ^{90}Sr within the Plant area, and the WOCE reach because of off-site transport. Rating the Sediment Retention Structure at the mouth of WOC is a first step towards a sediment balance for WOCE. The choice of tributaries for monitoring or intermittent storm sampling will be made systematically after all initial sampling is completed (Sect. 2.5).

2.4.3 Risk Related to Surface-Water Fluxes

Data from the NPDES weirs are routinely compared to the derived concentration guides (DCGs) provided in DOE Order 5400.5. A DCG for water is that concentration in water for a given radionuclide that would result in an annual dose of 100 rem from consuming 2 L of water per day by reference man. Reference man is a model that was defined by the International Council for Radiation Protection for the purpose of standardizing dose estimates. Percent DCGs can be summed across isotopes to determine the total estimated potential impact of the monitoring point upon human health. If the summed DCG value exceeds 100%, the DOE Order requires that an analysis of the best available technology (BAT) to reduce the radionuclide releases be conducted. The DOE Orders also require that effluents be maintained at levels as low as reasonably achievable (ALARA), regardless of the summed DCG value.

Table 2.4 shows the summed percent DCGs for these ambient water stations and the contributing radionuclides for 1991. The DCG for ^{90}Sr was used to evaluate the total radioactive strontium concentrations. Upper MB is not included because its radioactivity signature was very low. The data show that all sites contain some levels of radionuclide contamination, but all are below the 100% criterion for further analysis. Furthermore, water at all these sites is inaccessible to the public.

- Releases of ^{137}Cs result from process discharges, as well as from elevated flow at the ambient stations, because heavy rainfall can resuspend ^{137}Cs-contaminated creek sediments. Although there is a process-related contribution of total radioactive strontium from the Sewage Treatment Plant (STP) and the Nonradiological Wastewater Treatment Facility (NRWTF), the primary sources are more diffuse and are probably the result of past activities and subsurface input. A similar diffuse source for ^{60}Co, such as the cobalt seep at WAG 7, may explain the significant nonzero concentration at WOD.

- Average ^{3}H concentrations at MB MS4, WOC MS3 and WOD were lower in 1991 than in 1990, significantly so at MB MS4 and WOC MS3. Most of the tritium is believed to come from SWSA 5. However, there is a process-related contribution from NRWTF. Otherwise, average concentrations observed in 1991 were comparable to those reported in 1990.

2.4.4 Discharge, Flux, and Concentration

Discharge, flux, and concentration relationships are being investigated in order to understand the dynamics of how contaminants are transported through the WOC system. These analyses are impacted by the spatial and temporal scale of the data being evaluated. This information analysis addresses monthly data collected over five years.

2.4.4.1 Data

The information used in this analysis consists of monthly concentration data resulting from continuous flow-proportional samples collected weekly and composited monthly for analysis and from daily flow totals accumulated at the monitoring stations and summed to provide monthly flows. Discharge is computed as the product of concentration and flow for a given month. The data set for WOD, WOC, and lower MB includes 58 monthly data pairs of flow

Table 2.4. Cumulative derived concentration guide (DCG) levels at surface water monitoring stations[a]

		% contribution to % DCG by radionuclide			
Location	% DCG	Sr total	^{3}H	^{137}Cs	^{60}Co
MB1 (MB MS4)	67	40	27		
WOD	31	19	7	4	<1
First Creek	29	29			
WOC (WOC MS3)	19	13	2	3	
7500 Bridge	13	8	<1	5	

[a] Data reported only at stations exceeding 5% BAT.

available for these last two locations, but validation of the flow record has not been completed. Composite samples were analyzed for ^{3}H, total radioactive strontium, ^{60}Co, and ^{137}Cs.

2.4.4.2 Information analysis results

The information analysis completed to date has addressed the tritium and strontium data only. These data are used because the wide range of these data is more likely to reveal information about relationships among concentration, discharge, and flux.

2.4.4.3 Data presentations

All of the data presented in Figs. 2.12 and 2.13 have been normalized relative to the maximum values across all five monitoring locations. The intent of this approach is to show the information in the context of the whole watershed. Each figure consists of five scatter plots for the five monitoring locations showing the relationship between discharge and flux. The sixth plot is a presentation of box-plot summaries for the monthly computed flux for each of the monitoring locations.

Each scatter includes an isoconcentration line plotted from the minimum discharge to the maximum discharge for that location. This line was computed as the median radionuclide concentration times the discharge data for the location. If the concentration of a radionuclide were constant for the range of flows at the monitoring location, then all of the data on the discharge vs flux plots would fall on this line. The scatter of points around the isoconcentration line shows how concentration changes with discharge. Points below the isoconcentration line result from concentrations below the median and points above the line result from concentrations above the median. The relative slopes of the isoconcentration lines represent the relative magnitude of the median concentrations. The higher the slope, the higher the median concentration.

2.4.4.4 Results

Tritium. Figure 2.12 shows that the tritium contribution to WAG 2 from above upper WOC and upper MB monitoring locations is negligible. The major source of tritium to the system is located between the two MB monitoring locations (i.e., WAG 5). Although the discharge from this stream is less than 40% of discharge at WOD, MB contributes a major portion of the tritium to WOD, as shown by the DCG data in Table 2.4 The tritium concentrations at lower MB tend to be relatively large, as indicated by the slope of the isoconcentration line in Fig. 2.12. The reach above lower WOC also makes a contribution to the flux of tritium. The contribution to flux of tritium from MB is consequent to high

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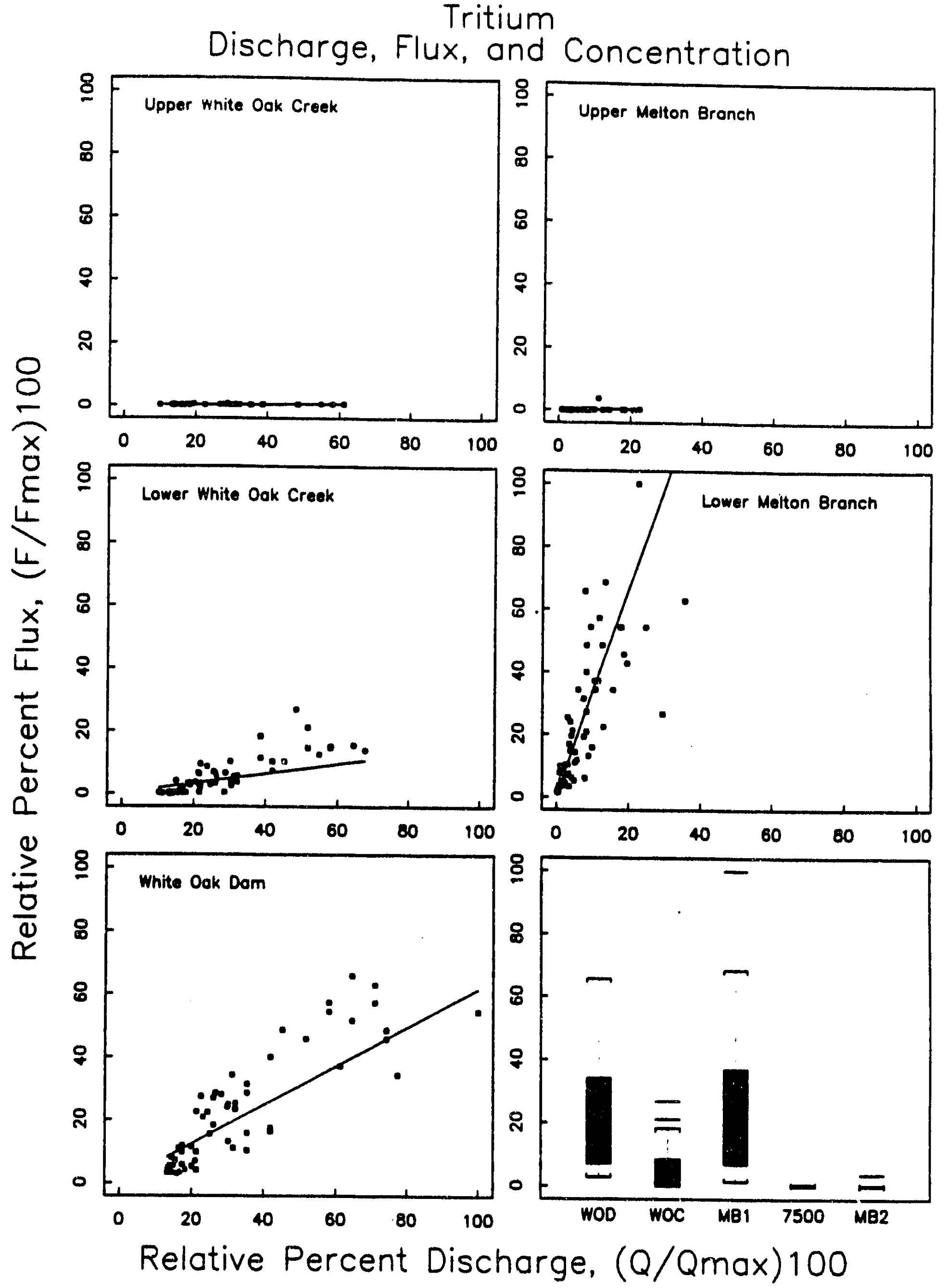

Fig. 2.12. Monthly mass flow of tritium at the National Pollution Discharge Elimination System (NPDES) sites in WAG 2. All data are scaled by maximum observations in the data set. The solid line is the product of the scaled median concentration and the scaled discharge. Observations below the solid line indicate radionuclide discharge at concentrations greater than the median, whereas observations above the line indicate discharge at concentrations greater than the median. Box plots show the distributions of flux at five monitoring stations.

concentration, as indicated by the relative slope of the isoconcentration line and the percent DCG data in Table 2.4. The discharge of this stream is less than 40% of the discharge at WOD. The reach above lower WOC also makes a contribution to the flux of tritium through lower concentration and higher discharge.

Examination of the scatter of points around the isoconcentration lines shows different phenomena in the two drainages. WOC and WOC data show that at lower flows the concentration of tritium is lower than the median concentration value. As flow increases above 40% of the maximum watershed discharge, the concentration of tritium also increases above the median value. In other words, tritium concentration increases with increasing discharge at the monthly scale. In contrast, the point scatter for lower MB does not indicate a change in concentration with discharge. (Concentration and discharge at MB are examined in detail in Sect. 2.4.6.).

The box plots corroborate that the primary source of tritium flux from the WOC watershed occurs from the reach represented by the lower MB monitoring location. Lower WOC makes a smaller contribution and inputs from upstream of WAG 2 are negligible. The magnitude of flux at MB appears to be equal to or slightly greater than that at WOD. Given that tritium is conservative, this result is very unlikely. The probable explanation for this anomaly is that discharge is overestimated at high flows at the lower MB monitoring location due to the known problem with submergence.

Total Radioactive Strontium. In contrast to the tritium results, the upper WOC monitoring location shows that there is a radioactive strontium input to WAG 2 from the main ORNL plant area (Fig. 2.13). This source of radioactive strontium is most likely associated with historic waste disposal and not present operations because flux is related to discharge. If the source were primarily-operations related, flux would be independent of discharge. Upper MB does not contribute to the strontium flux of the WOC watershed. The relative slopes of the isoconcentration lines indicate that the highest median concentration occurs at lower MB.

The scatter plots and isoconcentration lines for upper and lower WOC and WOD show that concentration increases with discharge at these monitoring locations. The lower MB location does not exhibit a change in concentration with a change in discharge. These concentration and discharge relationships for total radioactive strontium are generally the same as the relationships for tritium.

The increase in concentration with discharge is considered to be very significant because other investigations on smaller tributaries have shown a decrease in concentration (dilution) with increasing discharge (see Sect. 2.4.6). Sources of strontium and tritium above the 7500 Bridge gage need to be investigated.

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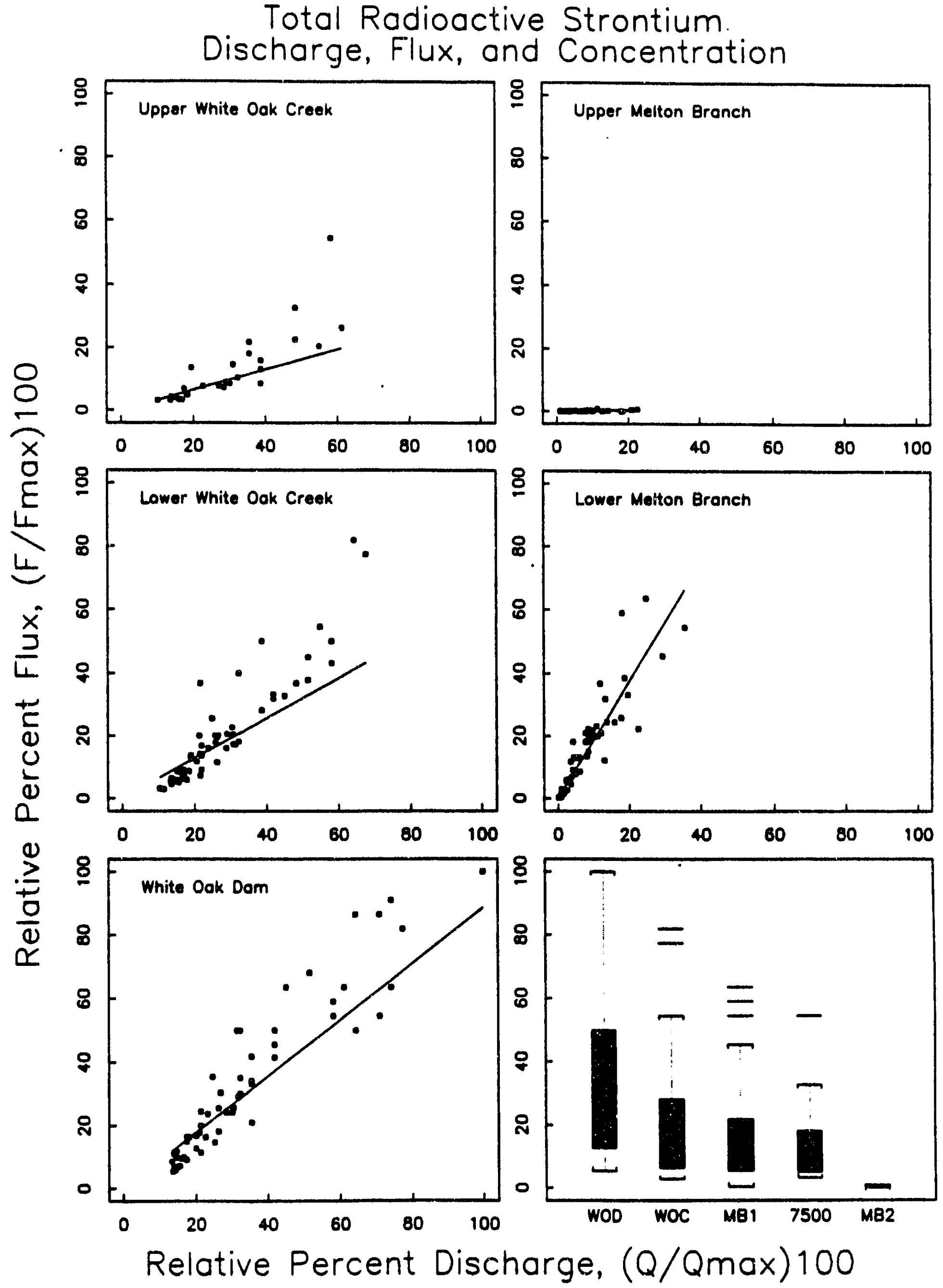

Fig. 2.13. Monthly mass flow of total strontium at the NPDES sites in WAG 2. All data are scaled by maximum observations in the data set. The solid line is the product of the scaled median concentration and the scaled discharge. Observations below the solid line indicate radionuclide discharge at concentrations greater than the median, whereas observations above the line indicate discharge at concentrations greater than the median. Box plots show the distributions of flux at five monitoring stations.

The box plots show that the major contributors to total radioactive strontium flux at WOD are lower MB and upper WOC. The lower WOC box plot represents the combined effect of the lower and upper reaches of WOC; the net impact of the lower reach is relatively minor.

2.4.5 Radionuclide Flux at Lower MB

Surface-water sampling may provide information as to the underlying transport mechanisms. For the analysis presented below it is helpful to consider a mathematical function for radionuclide concentrations. It has been found that concentration, C, for a dissolved radionuclide is often correlated with discharge, Q, (see Melroy et al. 1985, and Solomon et al. 1991). If the empirical relationship between C and Q can be established, then contamination discharge can be estimated from measurements of Q alone. Moreover, the relationship itself provides insight into the mechanism by which contaminants are released. A typical relationship has the functional form:

$$C = aQ^{-b} , \qquad (2.1)$$

where a and b are empirical parameters. Where $b = 1$, there is simple dilution; thus any increase in Q is offset by a decrease in C and the mass flux remains constant, such as when a steady source of contaminated groundwater is mixed with uncontaminated surface water. In cases where $b < 1$, it can be shown mathematically that the contaminant is diluted by storm runoff but that the amount of dilution is insufficient to decrease or maintain the mass flux, i.e., for increasing Q, the flux also increases. For $b = 0$, C is constant and flux varies linearly with Q. In cases were $b < 0$ the concentration increases with Q and flux increases rapidly with Q. (This appears to be the case for ^{3}H and ^{90}Sr for WOC and WOD.) The parameters of Eq. (2.1) can be easily evaluated by log-log or linear regression of the data.

Figure 2.14 shows the monthly average concentration of ^{3}H vs the monthly average discharge, the same data as shown in the lower MB scatter plot in Fig. 2.12 (without normalization). Also shown are data from discrete sampling collected during three storms in 1988 (Solomon et al. 1991). The log-log regression yields a b value of 0.5036, implying an increased flux at increased discharge rates. Solomon et al. (1991) used this relationship and a similar one for baseflow only. With the two C-Q relationships and an annual record of streamflow for 1988, they concluded that 16% of the ^{3}H was transported as quick flow (corresponding to stormflow) and the remainder was transported as baseflow (groundwater flow) during 1988. Furthermore, because groundwater was the source of most of the ^{3}H, remediation efforts aimed at controlling stormflow or the shallow buried material would probably be ineffective.

The C-Q relationship also has implications for the design of flumes or weirs for tributary monitoring stations. Where contaminant flux increases with discharge, as shown in this

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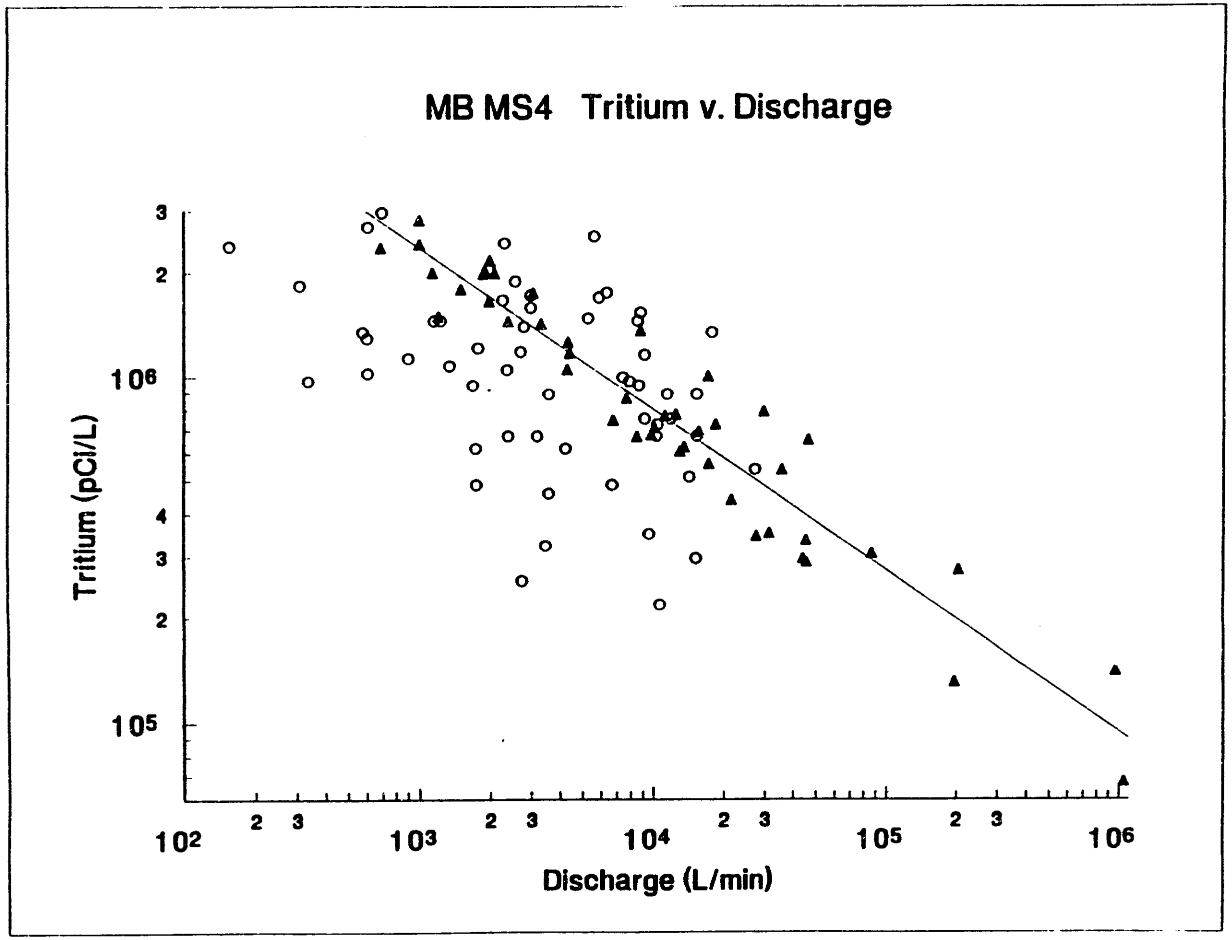

Fig. 2.14. Concentration versus discharge at Melton Branch MS4. Solid triangles are samples plotted versus the 10-minute average discharge (from Solomon et al. 1991). Samples were collected during 3 storms, and the solid line is the regression of the storm data. The open circles are the monthly flow-weighted mean concentrations plotted vs the monthly mean discharges.

example at MB MS4, accurate stream gaging and sampling at high flow rates is more important to the accuracy of the flux calculations; therefore, flumes/weirs should be carefully designed to measure high flows. Because the most frequent flow rates are very low for tributaries draining the ORR aquitards, there is a difficult trade-off in designing flumes/weirs for these sites. Using *C*–*Q* relationships and flow records, members of the Surface Water Task group, working with ESP staff and others, developed a systematic way to specify the flume/weir size for streamflow monitoring (Clapp et al. 1991).

The conclusions of Solomon et al. (1991) and this discussion lead to the following observations:

- The monthly averaging can obscure the relationship between concentration and flow, if it exists.
- Where relationships between *C* and *Q* can be identified, the relationship can be used to generate annual flux where *Q* alone is measured continuously.
- In some cases, relationships between *C* and *Q* can be interpreted in terms of contaminant transport mechanisms (e.g., stormflow and groundwater).
- Identification of the source (e.g., stormflow or groundwater) of contamination may aid in the selection of a particular remedial action.
- Relationships between *C* and *Q* may show increasing contaminant flux with increasing flow. For these cases, accuracy in measuring and sampling high flows is important to the computed contaminant flux. Flumes/weirs must be designed and maintained to measure the high, but infrequent, flows.

2.5 TRIBUTARIES AND SEEPS

Because seeps represent connections between subsurface and surface flow regimes, they may be useful for evaluating fluxes of contaminated groundwater from waste areas. Seeps can also provide insight into contaminant pathways to WAG 2 and so help to select and evaluate remedial alternatives. Consequently, a Tributaries and Seeps Monitoring subtask was initiated as part of the WAG 2/SI Surface Water Task. The objective of the subtask was to identify tributaries and seeps (discrete and diffuse areas of groundwater discharge) that are responsible for contaminant fluxes to the main channels of WAG 2. One spin-off will be a Tributaries Assessment subtask that focuses exclusively on selected tributaries known to contribute significant amounts of contaminants to WAG 2. This assessment subtask will be started in FY 1993.

A literature review of past seep and related studies was conducted and is summarized in Table 2.5. Most seeps identified in previous studies represent fairly discrete areas of groundwater discharge and have been located primarily by visual inspection. Little information exists about areas where contaminated groundwater is discharging directly into main stream reaches. Therefore, the first stage of the sampling and analysis plan is to locate seeps visually and to locate other areas of contaminated groundwater discharge by sampling along stream transects and measuring concentration differences.

Because contaminant transport pathways, processes that effect transport, and source areas may vary depending on different hydrologic conditions that exist during a year, the initial seep and tributary surveys will be conducted during three different conditions. Samples will be collected during two baseflow conditions—one in the wet season and one in the dry season. The third sampling will be conducted just following a rainstorm when lateral, shallow subsurface stormflow is believed to occur.

The first WAG 2 comprehensive sampling within the Seep and Tributary Monitoring subtask was completed in the spring of 1992 during wet-season base flow conditions. Table 2.6 lists the locations and analyses for the samples collected. The sampling locations are shown in Figs. 2.15 and 2.16. Analytical results will be available in late FY 1992. The second sampling effort is scheduled for August when dry conditions exist. Though many seeps (visible this spring) may be dry during the summer sampling, areas of contaminant groundwater discharged directly into the stream reaches may be more apparent.

Data collected from these initial surveys will be used to develop a Tributary and Seep Monitoring Program for WAG 2 so that key tributaries and seeps can be incorporated into a multimedia environmental monitoring of contaminant fluxes in the WOC watershed. For seeps that are found to be significant contributors to contaminant fluxes, efforts will be made to identify the sources and subsurface pathways of the contaminants and to evaluate the need for and effectiveness of ICMs. For these seeps it will be desirable to determine discharge. Where installation of a flume is not feasible, occasional direct flow measurements can be made concurrent with water quality sampling.

For tributaries, a Tributary Assessment subtask will be initiated in FY 1993 to determine contaminant transport characteristics and to develop discharge–contaminant flux relationships [similar to Eq. (2.1)] from tributaries draining upgradient WAGs into WAG 2. Sampling will include a few sites not covered in the original Tributary and Seep Monitoring survey. Sediment from several tributaries will be sampled for particle-reactive contaminants. Two to four tributaries, will be selected initially for intensive characterization. Automatic samples will be collected during baseflow conditions and during at least two discrete storm events. Samples will be analyzed for gamma, ^{90}Sr, ^{3}H, and metals, at a minimum.

Table 2.5. Summary of historic data for seeps in and near WAG 2

WAG	Seep ID	Date	^{90}Sr (Bq/L)	^{3}H (kBq/L)	^{137}Cs (Bq/L)	^{60}Co (Bq/L)	Others	Reference
7	RS-1	3/73	<5	NA	<2	<3		Duguid 1975
7	RS-2	3/73	<18	NA	<5	642		Duguid 1975
7	RS-3	3/73	0.3	NA	<15	1735	(95 Bq/L ^{106}Ru)	Duguid 1975
7	RS-4	3/73	1	NA	<5	192		Duguid 1975
7	RS-5	3/73	1	NA	<15	942	(155 Bq/L ^{106}Ru) (199 Bq/L ^{125}Sb)	Duguid 1975
7	RS-6	3/73	1	NA	<5	224		Duguid 1975
7	RS-7	3/73	<5	NA	<9	7990	(112 Bq/L ^{125}Sb)	Duguid 1975
7	RS-8	3/73	33	NA	63	<8		Duguid 1975
7	E. Seep	10/88	NA	2.7	NA	NA		Hicks
2	W. Seep	10/88	NA	1.3	NA	NA		Hicks
4	S-1	1/74	18	NA	<0.2	<0.4		Duguid 1975
4	S-2	8/73	7523	NA	90	2		Duguid 1975
4	S-3	3/73	232	NA	<3	3		Duguid 1975
4	Seep^{a}	4/80	901	NA	NA	NA		Huff et al 1982
4	BTT^{b}	1/89	1068	2.3	25	<2.5		Hicks
5	5NW-2	3/90	NA	0.35	<2.5	<2.5	(low gross alpha and beta)	Wickliff et al. 1991
5	5NW-1	3/90	NA	0.61	<2.5	<2.5	(low gross alpha and beta)	Wickliff et al. 1991
5	5NS-1	3/90	NA	0.61	<2.5	<2.5	(low gross alpha and beta)	Wickliff et al. 1990
5	S-1	11/73	0.3	NA	NA	NA		Duguid 1975
5	S-2	11/73	0.5	NA	NA	NA		Duguid 1975

Table 2.5 (continued)

WAG	Seep ID	Date	^{90}Sr (Bq/L)	^{3}H (kBq/L)	^{137}Cs (Bq/L)	^{60}Co (Bq/L)	Others	Reference
5	S-3	11/73	<1.3	NA	NA	NA		Duguid 1975
5	S-4[c]	3/74	517,080	2,002	NA	NA	(412 Bq/L ^{125}Sb)	Duguid 1975
5	S-5	3/74	5,838	984	NA	NA	(3 Bq/L ^{125}Sb)	Duguid 1975
5	S-6	3/74	133	817	NA	NA		Duguid 1975
5	S-7	3/74	88	2,836	NA	NA		Duguid 1975
5	S-8	3/74	<1.7	70	NA	NA		Duguid 1975
5	S-9	3/74	2,268	7,840	NA	NA	(3Bq/L ^{125}Sb) (13 Bq/L total alpha)	Duguid 1975
5	S-10[d]	3/74	599	3,836	NA	NA		Duguid 1975
5	S-11[d]	3/74	390	6,338	NA	NA		Duguid 1975
5	S-12[d]	3/74	22	734	NA	NA		Duguid 1975
5	S-13[d]	3/74	462	801	NA	NA		Duguid 1975
5	S-14	3/74	3	234	NA	NA		Duguid 1975
5	S-15	3/74	145	16,013	NA	NA	(10 Bq/L total alpha)	Duguid 1975
5	S-16	3/74	5	NA	NA	NA		Duguid 1975
5	T-2[e]	1980	7,700	NA	NA	NA		Spalding & Munro 1984
5	HRT[f]	7/88	54	13,705	18	<2.5		Hicks

[a] Seep and surrounding area appeared to contribute approximately 60% to ^{90}Sr flux from WAG 4.

[b] BTT contribruted 15 to 24% of ^{90}Sr flux in WAG 4 tributary in 1989.

[c] No longer exists because of corrective action (Duguid 1976).

[d] Below trench 117, which was treated (1979–1981) with caustic soda, etc. (Spalding 1984).

[e] T-2 may be same as Duguid's S-5. Strontium-90 is reported as a yearly average. In 1980, Melton Branch had a ^{90}Sr discharge of ~424 mCi and T-2 contributed 20% of the ^{90}Sr discharge.

[f] HRT Seep may be same as Duguid's S-15.

Table 2.6. Seep and tributary sampling locations and analyses

Streams and tributaries	Seeps and small tributaries		Transects
^{3}H, ^{90}Sr, gamma (water & filt.), Metals (ICP & K), IC, Alk, Field Parameters	^{3}H, ^{90}Sr, gamma (water & filt.), Gross α and β, Metals (ICP, K, GFAA, Hg), IC, Alk, Field Parameters		^{3}H, ^{90}Sr, Field Parameters
WOD	WCTRIB-1	5NW-1	WC-1 thru WC-19
WCWEIR	RS-1	5NW-2	
MBWEIR	RS-3	SW5-1	W4TRIB-1 thru W4TRIB4-12
WAG 6 MS1[a]	SW7-1	SW5-2	
WAG 6 MS2[a]	SW7-2	SW5-3	MB-1 thru MB-12
WAG 6 MS3A[a]	SW7-3	SW5-4	
WAG 6 MS3B[a]	SW7-4	SW5-5	HRT-1A
W. Seep[a]	SW7-5	SW5-6	HRT-1B
E. Seep[a]	SW7-6	SW5-7	HRT-1C
NWTRIB[a]	SW7-7	SW5-8	HRT-1D
WC7500	SW7-8	SW5-9	HRT-2
WCHead	WSTRIB-1	SW5-10	HRT-3
WAG 4 MS1[a]	SW2-1	SW5-11	HRT-4
WAG 4 T2A[a]	SW6-1		MBTRIB-1
MB-15 (MB2)[a]	WCTRIB-2		MBTRIB-2A
5NNT[a]	WCTRIB-3		MBTRIB-2B
5NNST[a]	WCTRIB-4		
	SW2-2		
	SW2-3		
	SW4-1		
	SW4-2		
	BTT		
	WAG5 Middle Drainage		

[a]include GFAA (As, Cd, Pb, Se) and Hg at these sites.

Note: Entries designated in bold type indicate gaging (flux estimations) possible.

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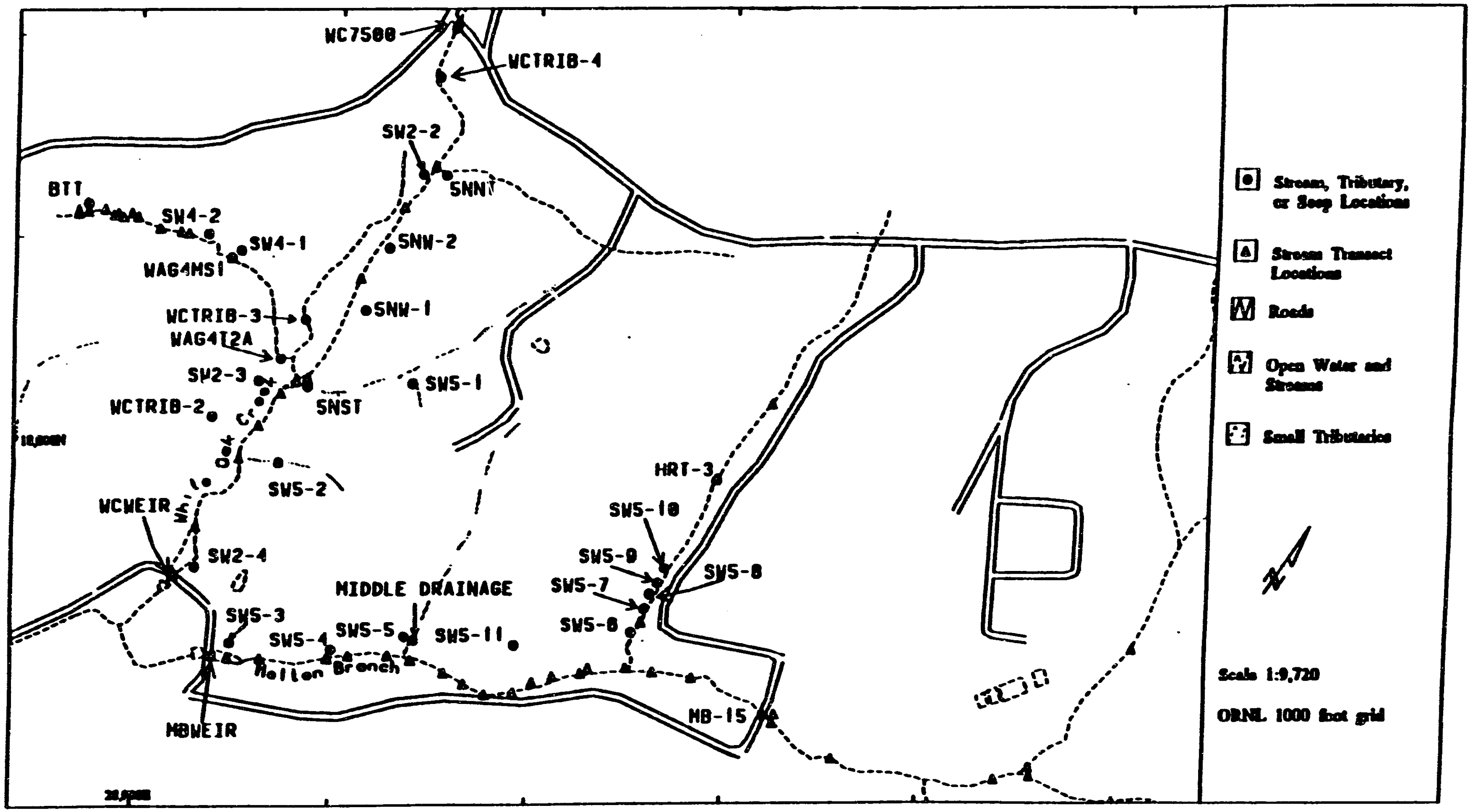

Fig. 2.15. Sampling locations for the WAG 2 Seep and Tributary survey (middle White Oak Creek/Melton Branch section).

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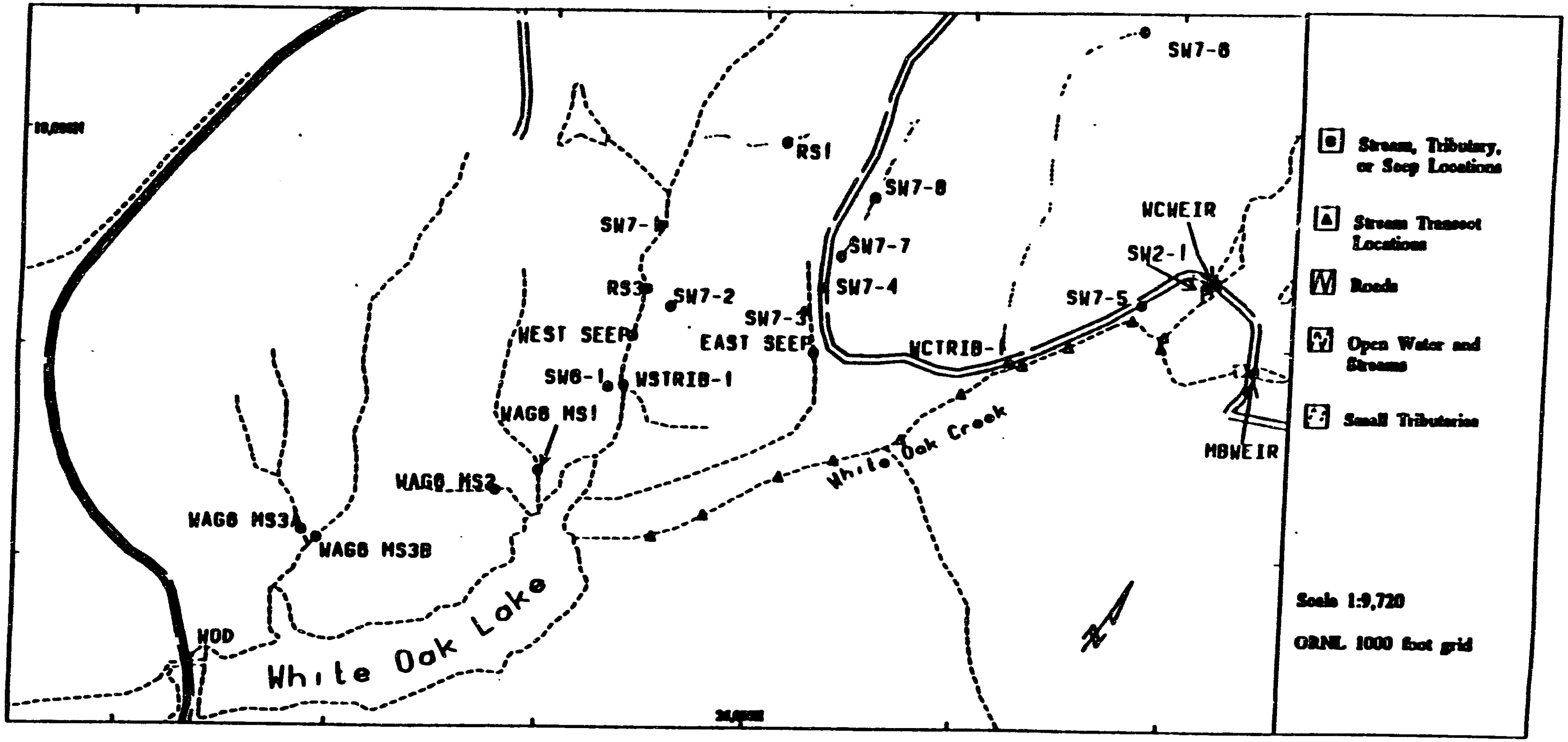

Fig. 2.16. Sampling locations for the WAG 2 Seep and Tributary survey (lower White Oak Creek section).

The Seep and Tributary Monitoring subtask and the Tributary Assessment subtask provide a systematic approach to collecting the data needed to assess discharge from upgradient WAGs to WAG 2. Information will be shared with groundwater specialists in order to provide an integrated analysis of contamination migration in groundwater and surface water.

2.6 SURFACE-WATER INVESTIGATIONS FOR SOURCE WAGs

Surface water investigations are conducted by RI/FS subcontractors with well-defined reporting schedules. WAG 2/SI staff communicate regularly with RI staffs to share information and results. The brief description of ongoing work in the source WAG RI/FS projects provides an overview of work that is relevant to WAG 2/SI.

2.6.1 WAG 1 Remedial Investigations

WAG 1 is an area of approximately 150 acres, comprising the majority of the original main plant area of ORNL (Fig. 1.1). Sources of identified or potential releases of hazardous substances to the environment include 30 inactive liquid low-level waste (LLLW) underground storage tanks, six surface impoundments, several waste burial grounds, spill locations, and an extensive network of underground waste transfer pipelines and storm drains.

Collection of groundwater, soil, sediment, and surface-water samples under Phase 1 of the RI was completed at the end of 1991. The purpose of the Phase 1 surface water investigation program was to identify the discharge areas associated with suspected major contaminant releases occurring within the interior of the WAG. Future supplemental sampling campaigns, if needed, will be designed to provide data needed to develop remedial action plans for specific operable units.

Surface-water quality samples were collected between October 1990 and March 1991 from 14 locations within First Creek, Fifth Creek, WOC, and the Northwest Tributary. Four of these locations (SW-5 through SW-8) coincide with flow gaging stations operated by the USGS. These locations were sampled so that flow data could be used to calculate contaminant flux at the time of sampling. Samples were also collected from three locations located upstream from WAG 1 to provide data on base-line surface-water quality. In general, samples were collected during low and high base flow conditions and during storm events. Sediment samples were also collected from the beds of the creeks during the low base sampling event. Samples were analyzed for VOCs, BNAEs, pesticides/PCBs, metals, radiologic parameters and isotopes, and other water quality parameters. Analyses for organophosphates, herbicides, and dioxins/furans were conducted on one sample.

An additional screening survey of First Creek was completed during September and October 1991 as part of an investigation to assess the nature and extent of radiologic contamination encountered in groundwater during the installation of corehole CH008. Because it was hypothesized that this contaminated groundwater might migrate along bedrock fractures toward First Creek, samples were collected from the creek at intervals of approximately 50 ft between Bethel Valley and White Oak Avenue, as shown on the attached map (Fig. 1.1). Samples were also collected from four outfalls discharging into First Creek. The samples were analyzed for gross alpha, gross beta, gamma spectroscopy, and ^{3}H.

A Site Characterization Summary Report, which presents all sampling results as well as a description of the nature/extent and fate/transport of contamination, will be submitted to EPA and the Tennessee Department of Environment and Conservation (TDEC) by October 1, 1992. The results of this WAG 1 RI are important to WAG 2/SI investigations because they provide further information on contaminant sources to WAG 2 and they affect the overall budget of contaminants in the WOC basin.

2.6.2 WAG 6 Remedial Investigations

The WAG 6 tributary monitoring activity, initiated in FY 1992, serves as an example of the approach that will be taken in the WAG 2/SI Tributary Assessment subtask to be started in FY 1993, and it illustrates how storm sampling can be used to evaluate the effectiveness of remedial actions. The approach consists of storm sampling using automatic sample collectors combined with periodic grab sampling during baseflow. In the current WAG 6 program, only radionuclides and metals are being analyzed, and the results to date are considered to be provisional.

By way of background, the surface-water sampling is part of an environmental monitoring program for WAG 6 designed to evaluate the effectiveness of an ICM installed in FY 1989 (Ashwood and Spalding 1991; Clapp and Marshall 1991). The ICM consisted of the installation of 10.4 acres of plastic caps over trenches known to contain hazardous wastes as designated by RCRA to enhance hydrologic isolation. In FY 1992, the monitoring effort was expanded to include surface water sampling. The goal is to determine the radionuclide discharge both annually and on a storm-event basis in order to compare results with historical data and with future data to be collected during and after the WAG 2 remedial action. Historical storm runoff data include ^{3}H concentrations and discharge measurements collected in the FY 1987 by ESD staff, as well as similar data collected as part of the WAG 6 RFI (Energy Systems 1991a) in FY 1990 (Fig. 2.17).

Figure 2.18 shows the *C-Q* relationship for ^{3}H based on the data collected by Environmental Sciences Division (ESD) staff at WAG 6 MS3 in 1987. The relationship is represented by the straight line when the data are log-transformed. Also shown are the data for subwatershed WAG 6 MS3B, which is the main source of ^{3}H to WAG 6 MS3 collected during the RFI investigation (Energy Systems 1991a). The newer data tend to conform to the original regression despite the alterations to the subwatershed in the intervening years.

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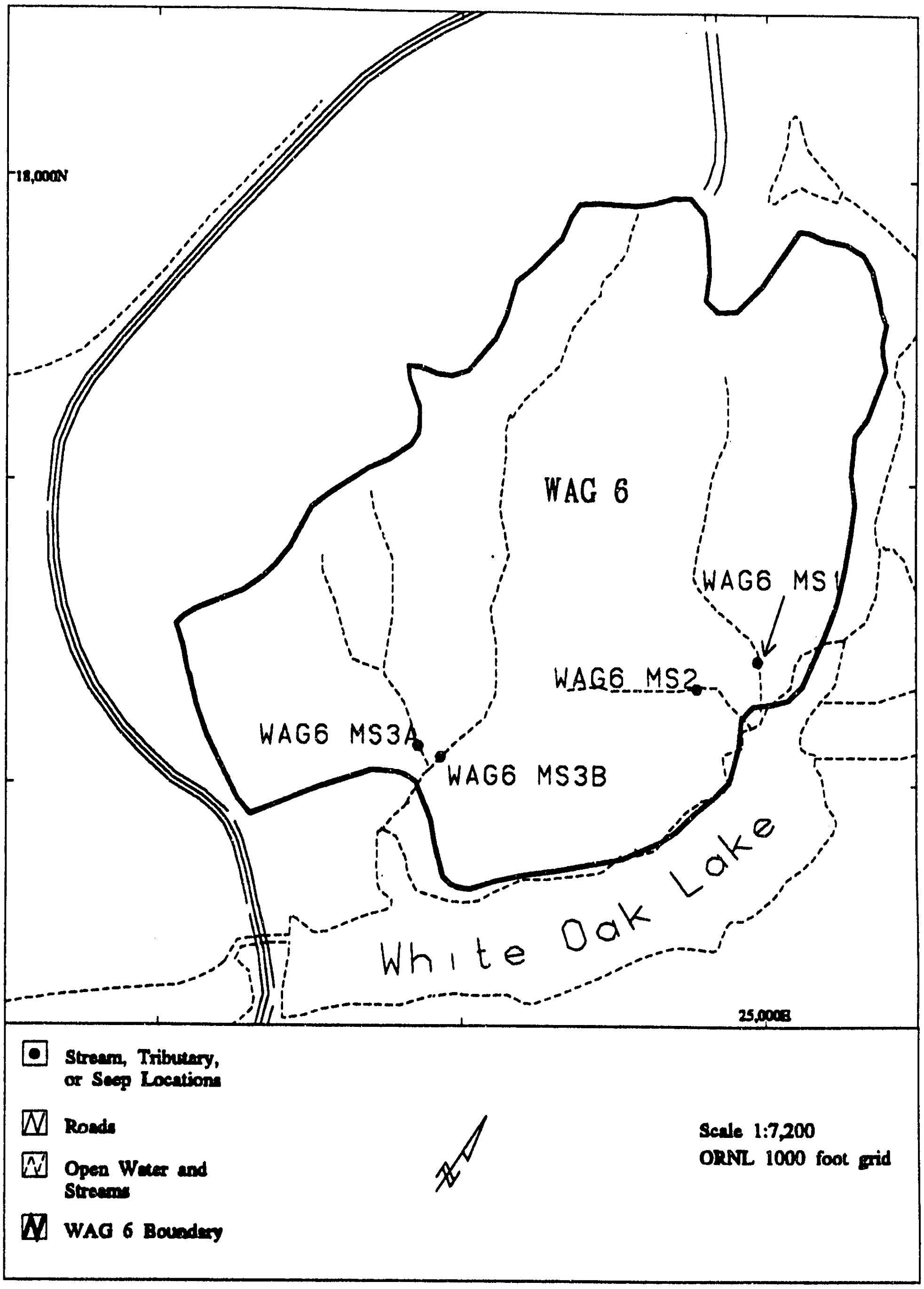

Fig. 2.17. Monitoring stations in WAG 6. Discharges from stations A and B flow to WAG6-MS3. During the past 8 years the stations not been used continuously and the locations of some have moved.

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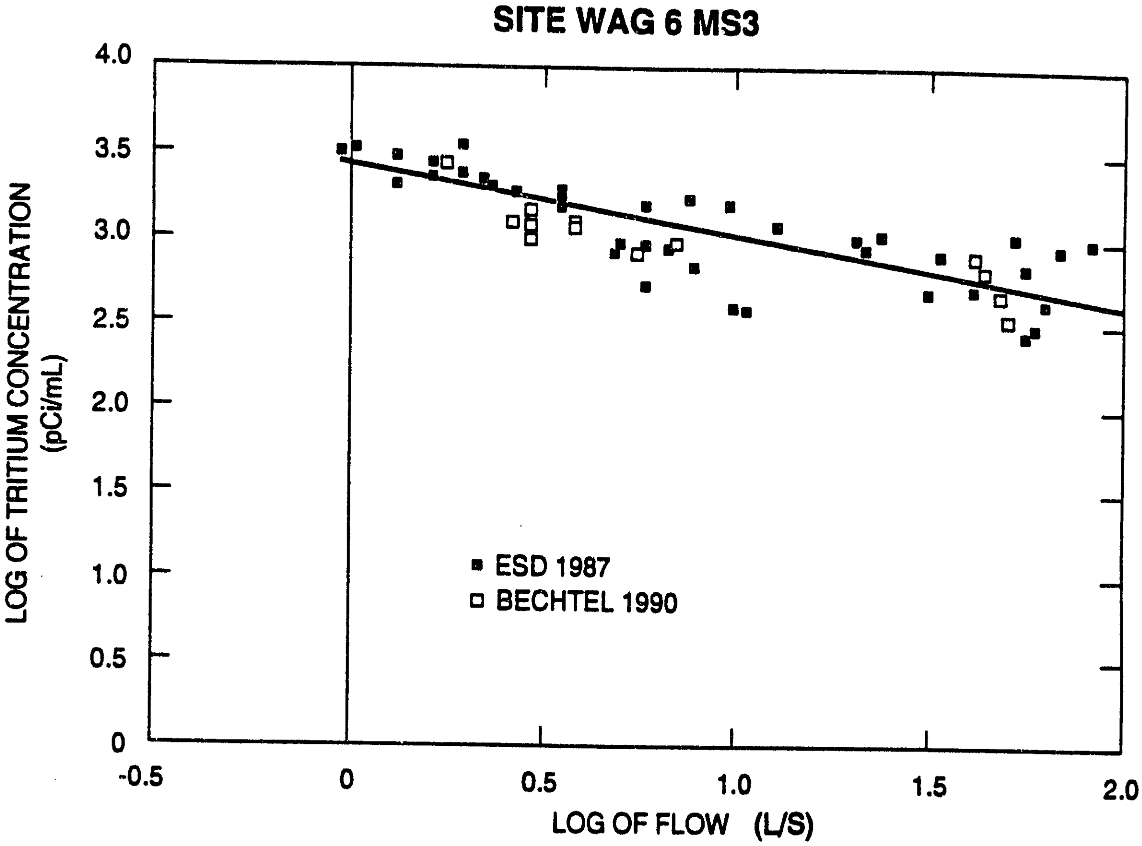

Fig. 2.18. Log-log transformed ^{3}H concentration vs discharge for WAG 6 MS3.

Several underground greater-confinement disposal units and two tumulus pads were built in the subwatershed, but only a small portion of the ICM caps were placed in the WAG 6 MSB (Ashwood and Spalding 1991).

A similar comparison of ^{3}H concentrations at the WAG 6 MS2 drainage station shows a more complex relationship. This drainage collects the groundwater, known to be contaminated with ^{3}H, discharged from the southern leg of the french drain. The 1987 data when plotted using the log-log transformation (Fig. 2.19) can be divided into two flow regimes. Broken line segments A and B meet at a flow of about 6 L/s. For the line segment A the slope [or the *b* exponent in Eq. (2.1)] has a slope less than 1, implying increasing mobilization of ^{3}H with increasing flow, i.e., ^{3}H flux increases with Q. For line segment B, the slope (or *b* exponent) is about 1, implying complete dilution. These two line segments suggest that in 1987, before the ICM caps were built, ^{3}H flux at MS2 appears to be controlled by subsurface pathways that tend to mobilize contaminants under wet conditions, up to a certain point. After that point there is dilution from (essentially) uncontaminated surface runoff, probably associated with the roads surfaces and/or saturated soil. In 1990, after the caps were put in place, the behavior is different. The relationship is moved down to line C, and dilution, perhaps from runoff from the cap, dominates the change in ^{3}H concentration. Mass flux through all flow values is about constant. The downward displacement of relationship from line segment B to line segment C corresponds to a reduction in concentration by a factor of 2. The outliers in Fig. 2.19 show that there is uncertainty that may be resolved with more sampling. Nevertheless, the change in line segments from B to C is judged to be a significant change in contaminant loading attributable to the ICM caps. It remains to be seen if the new data collected in FY 1992 follow the trends shown in Figs. 2.18 and 2.19.

Currently, storm samples from WAG 6 are being analyzed for ^{3}H, ^{90}Sr, dissolved and particulate gamma-emitting constituents, and metals for all four drainages. Evaluation of the C-Q relationships is in progress. The ^{3}H concentrations are summarized in Table 2.7. The average ^{3}H levels are larger than 150,000 pCi/L, the CY 1991 average for WOL (ORR 1992), suggesting that runoff from WAG 6 tends to elevate the ^{3}H level in the lake. The actual contribution of ^{3}H to WOL requires the use of both concentration and discharge data.

2.6.2.1 Evaluation of the effectiveness of remedial actions

A comprehensive compliance-monitoring and closure-evaluation program should have both flow-proportional sampling and the intensive sampling of several storms (combined with periodic baseflow sampling). Flow-proportional sampling will quantify the total mass outflow of contaminants over a year. However, the storm-sampling approach performed at WAG 6 and recommended here is a valid way to assess changes due to remediation, especially over short periods (1–3 years). The storm sampling is useful because the analysis is largely independent of the climate and individual storms. For example, a comparison of 12 monthly

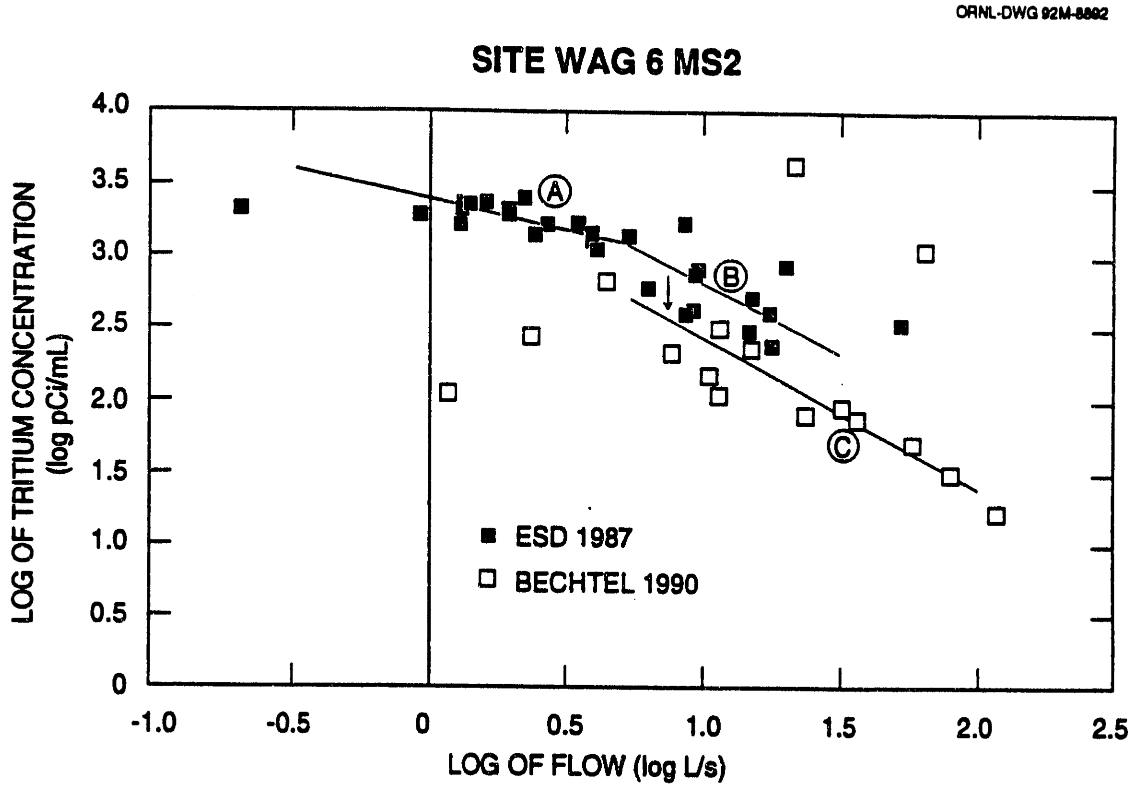

Fig. 2.19. Log-log transformed ^{3}H concentration vs discharge for WAG 6 MS2.

Table 2.7. Provisional surface water ^{3}H concentrations during FY 1992

Gage station:		FA	FB	DA	DB
Watershed area, ft^2		393,000	365,000	390,000	439,000
Storm data					
No. storms		3	2	4	5
No. samples		32	10	26	33
mean ^{3}H	(pCi/L)	95,000	2,402,000	303,000	148,000
min ^{3}H	(pCi/L)	31,400	1,120,000	61,000	51,800
max ^{3}H	(pCi/L)	177,000	4,857,000	1,400,000	278,000
std dev	(pCi/L)	39,200	1,184,000	307,000	65,800
Baseflow					
No. samples		1	1	1	1
mean ^{3}H	(pCi/L)	155,000	4,110,000	2,000,000	400,000

flow-proportional samples collected before and after a remedial action may be indistinguishable statistically because of changes in precipitation from year to year. Comparing *C–Q* relationships before and after remediation tends to remove the climatic influence.

For the storm-sampling approach, the data quality objectives (DQOs) should be adjusted. If both flow-proportional sampling and storm sampling are performed, then analytical costs for two rigorously documented programs would be unjustifiable. Storm sampling requires many more samples and analyses, thus it is potentially more expensive. Because the purpose of storm sampling is to build a mathematical model and not to compare a number to a regulatory limit, the DQOs for storm sampling should be relaxed. Only key contaminants or indicator parameters should be measured. If needed, rigorously documented samples could be collected occasionally to validate the model. Other useful parameters to measure would be cations or anions that can be used to separate surface flow, stormflow and groundwater input. In all cases, preclosure monitoring is needed to evaluate changes due to closure.

In summary, the WAG 6 ICM Environmental Monitoring Task provides more than useful data on contamination inputs to the WAG 2 investigation:

- The WAG 6 ICM Environmental Monitoring activity serves as a prototype for post-remedial action monitoring.

- The storm-sampling approach may provide insight into the mechanism of contaminant release based on the *b* exponent in Eq. (2.1) (it may show dilution by contaminant-free water).

- The approach illustrates how a remedial action can be evaluated on the basis of a change in the functional relationship describing the transport of contaminants rather than on a change in the average concentrations by themselves. Direct observations may be quite noisy; fitting a function to them smooths the randomness.

- For the storm-sampling, the DQOs should be relaxed because the purpose is to create a model of discharge behavior and not to provide a single concentration to compare to a regulatory limit.

2.7 SUMMARY

Surface water is both an agent that mobilizes and transports contamination and a valued resource that must be maintained and remediated. The Surface Water Task serves the goals of ORNL ER Program by (1) providing accurate hydrologic data for the long-term, (2) gathering water quality data collected by others and collecting data in the field where specific information is needed, (3) interpreting hydrologic and water quality data in order to discern spatial and temporal trends, and (4) enhancing our knowledge of the mechanisms of mobilization and transport of contaminants at the ORNL site. The Surface Water group interacts with many other ER groups in support of ER goals and with others at ORNL who collect data or who research water-related phenomena.

The development of the conceptual model by the ORRHAGS team (Solomon et al. 1992) for the hydrology of the ORR is a significant achievement. There are several important conclusions: (1) Virtually all water that infiltrates the soil (except for evapotranspiration losses) eventually migrates to local streams through either the shallow subsurface stormflow zone or the thin layer at the top of the groundwater zone referred to as the water table interval. The estimated downward flux below the water table interval is < 1 cm/year. (2) Because of the discrete nature of groundwater, flow paths through fractures, seeps, and surface water, and not through monitoring wells, provide the most representative and unambiguous information about contaminant discharge from waste sites. (3) The widely spaced fractures in the bedrock are capable of moving relatively small amounts of contamination large distances in relatively short times. (4) Because ORNL is underlain by fractured, porous rock, molecular diffusion will transport significant quantities of contaminants into the rock matrix when the fracture is transporting high concentrations of contaminants; but after the primary source is removed, the porous rock acts as a secondary source, re-supplying contaminants to water flowing in the fracture.

The intensive seep survey in the vicinity of WAG 2 is a direct response to the observation in the conceptual model about the importance of surface-water monitoring. The seep survey will identify the major contamination sources that will be characterized in greater detail for engineering design of Early Action remediations. Also based on these sampling results, the Tributary Assessment subtask will characterize the tributaries that are major sources of contamination. Discharge combined with intensive storm sampling will determine the transport of contaminants from upgradient WAGs to WAG 2. The resulting data may also result in Early Actions.

During FY 1992, the Surface Water Task group maintained seven rain gages, nine stream-gaging stations, and one micrometerological station. ER supports data collection at six sites by the USGS. Borders et al. (1992) issued a comprehensive hydrologic data summary for the period October 1990 through December 1991. The surface-water chemistry data were gathered from OECD, and a Seep and Tributary Sampling survey was initiated.

Activities to field-rate the high-flow flumes and the Sediment Retention Structure have been or will be initiated. Known problems with existing flumes that affect the accuracy of discharge measurements are being addressed with cooperation of OECD.

The hydrologic/water quality data collected in FY 1991 were interpreted in several ways. The mass balances for two reaches in the WOC show whether the reaches are sources (mobilize materials or receive materials from tributaries and groundwater) or sinks (accumulate materials). As shown for the 1991 data:

Reaches	^{3}H	total Sr[a]	^{137}Cs	^{60}Co
Middle WOC	source	source	sink	sink
Lower WOC/WOL	sink/UC[b]	sink/UC[b]	source	source

[a] $^{89}Sr + ^{90}Sr$.
[b] UC = uncertain.

Results for particle-reactive radionuclides are questionable because the sampling for suspended solids is complex and easily biased. The Sediment Transport Sampling/Modeling Task (Sect. 4) will acquire the data to evaluate the current monitoring system and possibly to revise these numbers. Revision may be required because of possible changes in the stage-discharge rating curves after field calibration.

In most cases, the major sources of contamination to these reaches is known, but the ^{90}Sr coming out of the plant area and entering the middle WOC reach needs to be investigated with the assistance of the WAG 1 RI team. The observation that monthly mean concentration tends to increase with monthly mean discharge is significant because it is contrary to experience elsewhere. This relationship was observed at the 7500 Bridge, WOC MS3, and WOD stations for ^{90}Sr and at WOC MS3 and WOD for ^{3}H. As for risk, based on annual average concentrations for key radionuclides, the largest DCG risk factor at all the NPDES sites was 67%. (For reference, a value of 100% is required before any action is required.)

Review of historical data showed trends that are important to ER. Annual changes in the DCG at WOD reflect changes in annual discharge at that site and also changes in the annual precipitation record. This observation demonstrates that contaminant mobilization at the annual scale reflects climate changes. The implication to ER is that evaluation of the effectiveness of ER remedial actions may be influenced by climate changes as well as by seasonality or individual storms. Documentation of this and similar trends is a necessary first step towards factoring their effects into an evaluation of cleanup effectiveness.

A review of ^{3}H discharge data at MB MS4 and a preliminary analysis of past data at WAG 6 tributary stations lead to several conclusions. This approach to data collection and analysis can be used to evaluate changes due to remedial actions, as shown for a subwatershed where an ICM membrane cap was installed in early 1989. The data suggest that ^{3}H output is decreased by half following the partial capping of the subwatershed. It is recommended that this approach be incorporated into pre- and postconstruction monitoring at remediation sites for evaluation of remediation effectiveness. Detailed storm sampling can provide concentration–discharge relationships that can reveal contaminant sources (surface water, stormflow zone, and groundwater inputs). Finally, the collection of monthly average data may not provide the resolution needed to see changes unambiguously. Interpretation of averaged data or low-frequency sample collection may be confounded by the effects of climate variations, seasonality, and individual storms. This problem may be especially pronounced when an evaluation of a remedial technology is needed just 1 to 3 years after installation.

The Surface Water Task group continues to provide accurate data to many ER functions and to provide interpretation and analysis that will help guide the selection and monitoring of ER remedial actions designed to minimize exposure to workers, to the public, and to the local and regional biota.

3. GROUNDWATER

3.1 INTRODUCTION

Groundwater contamination in the vicinity of ORNL facilities, has long been established. However, most of the previous studies of groundwater flow and geochemistry on which this knowledge was based were narrowly focused studies of single sites. The ER Program maintains a site-wide perspective on groundwater monitoring and assessment because (1) groundwater flow paths are not confined to the boundaries of the source WAGs, (2) site-wide assessment is needed to set priorities for groundwater remedial actions, and (3) information about groundwater transport mechanisms should be applied across the entire ORNL site.

The general goals for the WAG 2/SI Groundwater Task are (1) to provide site-wide assessment of groundwater quality based on data gathered at the WAG perimeter monitoring wells and (2) to estimate contaminant flux information for groundwater at WAG 2 and across the ORNL site. Because groundwater contaminant fluxes can only be estimated by computer model, WAG 2/SI supports modeling studies and special investigations that generate needed information for groundwater models.

3.1.1 Section Outline

Section 3.2	reviews the hydrologic frame work for the ORNL site with discussion of operational groundwater flow zones, porous media and fracture flow, and piezometric contours and discharge pathways.
Section 3.3	presents preliminary efforts to identify chemically distinct groundwater types and to relate these types to common geological and physical conditions as well as contaminant source areas.
Section 3.3.1	describes the approach used in reviewing groundwater geochemistry results and presents preliminary interpretations of WAG perimeter well geochemistry.
Section 3.3.2	presents a summary of existing data for contaminant distributions in the WAG perimeter wells. WAGs 4, 5 and 6 had the greatest percentage of wells with parameters exceeding drinking water standard MCLs. Local exceedances were observed at WAGs 1, 3, and 7. Overall about half of the wells exceeded one or more MCL. Nickel was the principal metal detected with subordinant amounts of chromium, mercury, selenium, and cadmium. VOCs including fuel hydrocarbons and solvent compounds were detected in a small percentage of the wells. Radiological contaminants (especially tritium and strontium) were widespread, and were the most significant problem at ORNL.

Section 3.4	reports on groundwater investigations in the source-WAGs.
Section 3.5	presents information from investigations of the pathways of the shallow subsurface pathways of contaminant fluxes, and the process of diffusion of contaminants into porous soil and rock matrices that can create secondary sources of contaminants following the remediation of the primary contaminant source.
Section 3.6	The movement of water though fractures in the bedrock is the primary pathway for deep groundwater flow at ORNL. This section reports on an investigation of the size, frequency, and hydraulic characteristics of hydrologically active features at ORNL.
Section 3.7	describes the Hydraulic Head Measuring Station (HHMS) project that is evaluating the transition between deep and intermediate groundwater and investigating possible pathways for off-site movement of groundwater.
Section 3.8	describes preliminary efforts to construct three-dimensional models of groundwater flow for the Melton Valley at ORNL.
Section 3.9	presents the rationale and objectives for the ORNL groundwater operable units (GWOU) project. This project will provide an integrated assessment of area-wide groundwater issues that can not effectively be addressed by the source-WAG efforts to support remedial efforts at ORNL.
Section 3.10	provides a summary of Sect. 3.

3.2 HYDROLOGIC FRAMEWORK: IMPLICATIONS FOR GROUNDWATER QUALITY

The hydrologic frame work or conceptual model (Solomon et al. 1992) serves as a starting point for understanding and studying the processes that control the migration of contaminants derived from leaks, spills, and leachates from buried wastes. The main ideas of the conceptual model were introduced in Sect. 2.2, where the emphasis was on the generation of surface water. This section emphasizes groundwater movement and groundwater quality.

3.2.1 Characteristics of the Groundwater Zone

As mentioned in Sect. 2.2, the most important characteristic of the stormflow zone (the permeable upper 1-2 m of soil), is its capacity to conduct water downslope during and shortly after a storm. In the conceptual model it is estimated that >90% (~55 cm/year) of the water that moves out of the stormflow zone (excluding evapotranspirtation) is routed to springs and seeps at the toe of the slope. Beneath the stormflow zone is the vadose zone, which receives <10% of the flux. The vadose zone exists throughout the study area except where the water table intersects the ground surface, such as along perennial streams and springs.

At the bottom boundary of the vadose zone, the water table serves as the upper boundary to the groundwater zone, which is subdivided into intervals. The uppermost subdivision is the water table interval estimated to be 1–3 m thick with interconnected fractures that direct water laterally to adjacent streams. Of the 10% (~6 cm/year) flux arriving at the water table interval, most is routed laterally and less than about 2% or 1 cm/year moves to the next interval.

The existence of a distinct water table interval is inferred from annual well hydrographs, which show that the seasonal change in groundwater elevation is confined to a small range and that water levels never drop much below the soil/bedrock interface even during prolonged droughts. Some hydrologic data do not support the concept of the water table zone. In the vadose zone and the upper part of the groundwater zone (i.e., the water table interval and the upper part of the intermediate interval) there appears to be little or no change in hydraulic conductivity with depth (to depths of approximately 50 m) within the unconsolidated material, and conductivity ranges from 0.006 to 0.3 m/d. This wide range in conductivity over most depth intervals indicates that some wells monitor zones of variable conductivities within the regolith such as fractured zones rather than more clay-rich zones.

With the conceptual model the base of the water table interval corresponds to the zone of transition of the soil (regolith) to the bedrock. Beneath the water table zone is the intermediate interval of the groundwater zone where groundwater movement occurs primarily in the permeable fractures that are poorly connected in three dimensions. Fracture sets and bedding planes control the flow directions. The system is shown in Fig. 3.1. Ketelle and Lee (1992) have used contaminant plume data, stratigraphic data, and structural geologic data to confirm the concept of stratabound flow of groundwater and contaminants in WAG 1 at ORNL.

With increasing depth the chemical characteristics of groundwater change from a mixed-cation–HCO_3 water type to a $NaHCO_3$ type at depths ranging from 30 to 50 m (Table 3.1 and Fig. 3.2). Although the geochemical mechanism responsible for this change is not entirely quantified, it probably is related to water residence time. The transition from Ca HCO_3 to $NaHCO_3$ serves as a useful marker and is used to distinguish the intermediate groundwater from the deep interval, a transition that is not marked by a distinct change in rock properties.

Below the intermediate interval, small quantities of water are transmitted through discrete fractures in the deep interval. The fractures are fewer in number and shorter in length than in the other intervals. Wells finished in the deep interval typically yield <0.1 L/min and thus have no potential for water supply.

The groundwater zone terminates at the aquiclude where the water is saline. The depth to the aquiclude is about 180–240 m in Melton and Bethel valleys.

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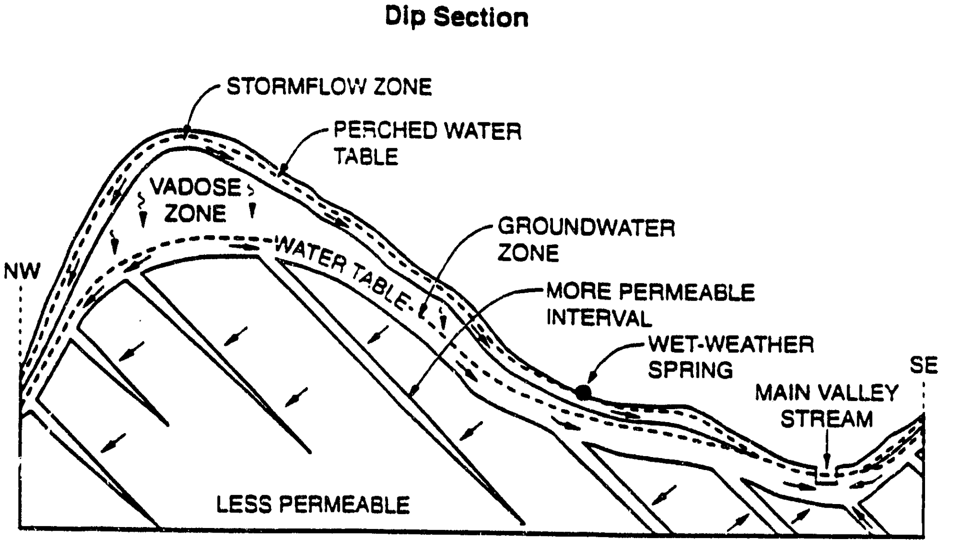
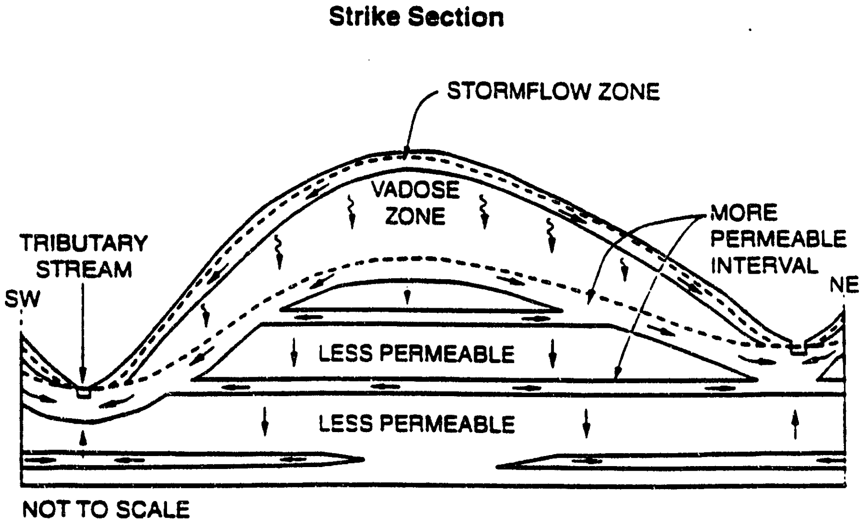


Dip Section

Fig. 3.1. Schematic diagram of the groundwater flow paths, perpendicular to strike (above) and parallel to strike (below).



Strike Section

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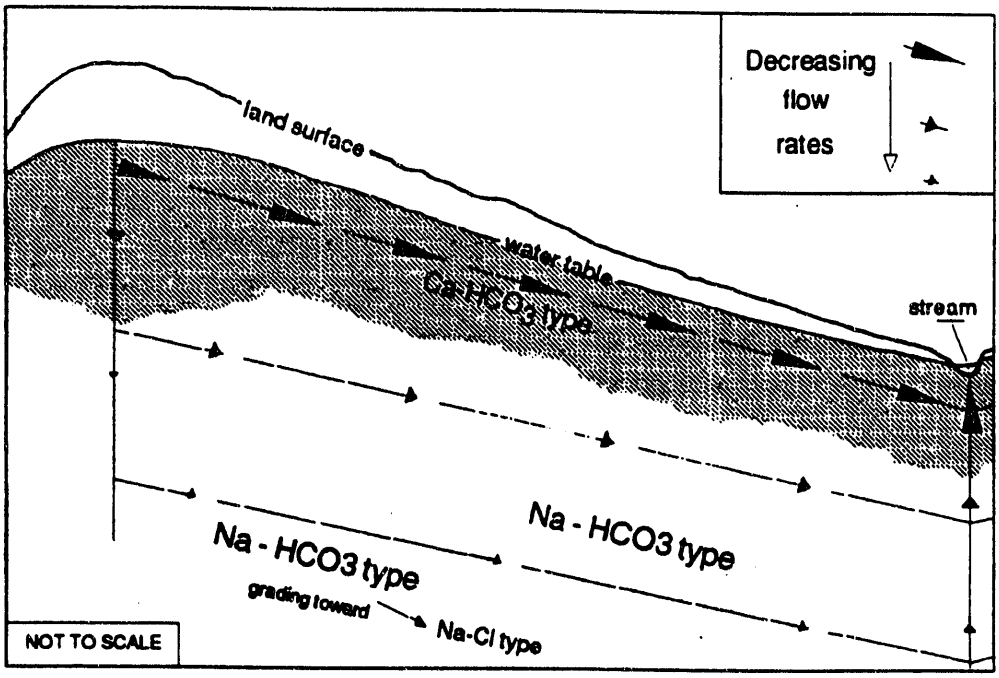

Fig. 3.2. Schematic cross section showing very generalized flow paths, related geochemical evolution, and relative flow rates.

Table 3.1. Approximate relationship among depth, flow interval, and water type for the ORR aquitards

Depth below permanent water table to bottom of flow interval (m)	Interval or zone	Water type
1 to 3	Water table	$Ca{-}HCO_3$
20 to 50	Intermediate	$Na{-}HCO_3$
150 to 400	Deep	$Na{-}HCO_3$ to $Na{-}Cl$

3.2.2 Importance of Fractures and Secondary Sources

In the conceptual model, fractures in the intermediate and deep zone are important because they can conduct small amounts of contaminants great distances over short time periods. Tritium observed in wells at depths of 60 to 100 m suggests that the radionuclide may have moved at velocities of about 150 m/year (Solomon et al. 1992, Toran et al. 1991). However, the mass of contaminants transported is small to insignificant compared with contaminant transport in other pathways. Flow in fractures also causes the accumulation of secondary sources of contamination, as described here.

Subsurface systems at the ORR consist of discrete fractures within a matrix of porous rock. When a contaminant is first introduced into fractured porous media, very large concentration gradients can occur between fractures and the surrounding porous matrix. Because of molecular diffusion, dissolved species can migrate into the porous matrix, even when no net transfer of fluid between fractures and matrix occurs. When the volume of matrix water is large relative to the volume of fracture water, this process, known as matrix diffusion, can result in substantial dilution and attenuation of migrating contaminants. However, once primary contaminant sources (i.e., waste trenches) diminish in strength, contaminants can diffuse out of the porous matrix into fracture pathways, resulting in secondary contaminant sources.

The process of matrix diffusion has far-reaching implications for environmental restoration on the ORR. The short-term effectiveness of remedial actions aimed at reducing the discharge of contaminants from subsurface to surface water systems depends critically on the mass of contaminants presently stored within the porous matrix (i.e., the strength of secondary sources relative to primary sources). If the contaminant mass within the matrix is small, source-level remediation such as source removal, grouting, compaction, and in situ vitrification would reduce contaminant discharge shortly after remediation. If the contaminant mass in the matrix is large, only remediations that eliminate both primary sources (e.g., trench leachate) and secondary sources (i.e., diffusion out of the matrix) will effectively reduce contaminant discharge. However, if the secondary source is located below the water table, even techniques for large-scale hydrologic isolation such as local capping and French drains may be unsuccessful because groundwater will continue to move through the secondary source area.

3.2.3 Hydrogeologic System

The shallow, subsurface geology of the ORNL area consists mostly of unconsolidated residuum and bedrock material of the Cambrian age Conasauga Group and the middle Ordovician age Chickamauga Group. These geological groups comprise the ORR aquitards in the vicinity of ORNL. In addition to the aquitards, alluvial deposits occur along the Clinch River and larger tributaries such as WOC. Mapped geologic formations in the ORNL area are shown on Fig. 3.3. WAGs 1, 3, and 17 are located in Bethel Valley and are underlain by predominantly argillaceous limestones (locally soluble limestones occur causing observed karstic conditions) and calcareous mudstones of the Chickamauga Group.

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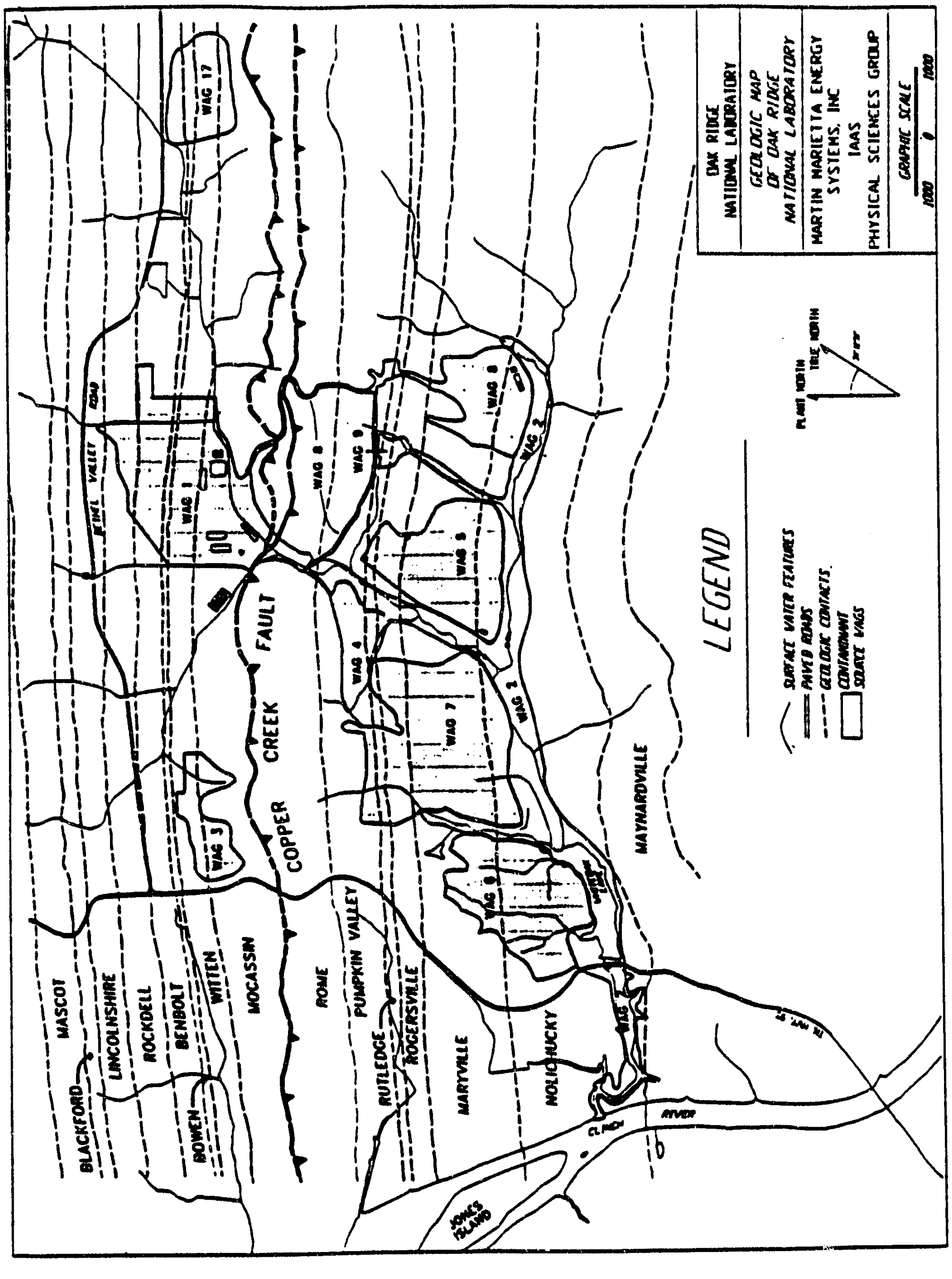

Fig. 3.3. Geologic map of the ORNL area.

Mappable formations in the Bethel Valley Chickamauga section include the Blackford, Lincolnshire (Eidson and Fleanor Members), Rockdell, Benbolt, Bowen, Witten and Moccasin Formations. WAGs 2, 4, 5, 6, 7, 8, and 9 are located in Melton Valley and are underlain by the shales, calcareous siltstones, and silty limestones of the Conasauga Group. Mappable formations of the Conasauga Group in Melton Valley include the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, and Nolichucky Shale.

The piezometric surface configuration and local gradients are used to estimate groundwater flow directions and to qualitatively estimate flow rate. This information forms the basis for interpreting solute distributions away from source areas and predicting the potential discharge zones for contaminants migrating through the shallow groundwater zone.

The piezometric surface within the Melton Valley area is shown in Fig. 3.4. Locations of perennial streams were used in the construction of Fig. 3.4 to control the contoured surface near streams. Streams are assumed to occur at the intersection of the water table and the ground surface. Piezometric contours are shown only in areas where well data are available from which to construct such contours. The piezometric surface largely corresponds to the soil/bedrock interface surface, as shown in Fig. 3.5. Hydraulic gradients within the WOC watershed range between 0.03 and 0.06 toward WOL and WOC. The hydraulic gradient along Melton Branch toward WOL is approximately 0.01.

3.3 HYDROGEOCHEMISTRY AND WATER QUALITY AT WAG PERIMETERS

This section of the report describes the initial results of a systematic approach to the screening and analysis of groundwater geochemical data with specific application to the WAG perimeter well data sets in Melton and Bethel valleys. The overall objectives of the investigation are to (1) identify chemically distinct groundwater types; (2) relate these distinct waters to common geologic conditions, physical conditions, or associations with contaminant sources; (3) relate the observed geochemical conditions and contaminant distributions to the proposed conceptual model of groundwater flow and define background and contaminant plume water characteristics; and (4) to provide an integrated site-wide description of groundwater contamination as revealed in the data collected at 160 WAG perimeter wells.

An array of water quality monitoring wells were installed along the perimeter of each WAG in an early phase of ER investigations and have been monitored for general hydrogeochemical and contaminant parameters. Locations of the WAG perimeter wells and a general description of the well installation program are reported by Greene (1991). WAG perimeter wells are components of a site-wide contaminant monitoring system which, when combined with the results of surface water, stream sediment, and biological monitoring, will help set priorities and focus characterization studies for the interior of specific WAGs.

WAG perimeter groundwater monitoring wells were constructed at locations and depths determined to be likely discharge pathways from the source areas based on preliminary data obtained from site geologic conditions and water level data from temporary piezometers. Well locations are shown in relation to the WAG boundaries on Fig. 3.6.

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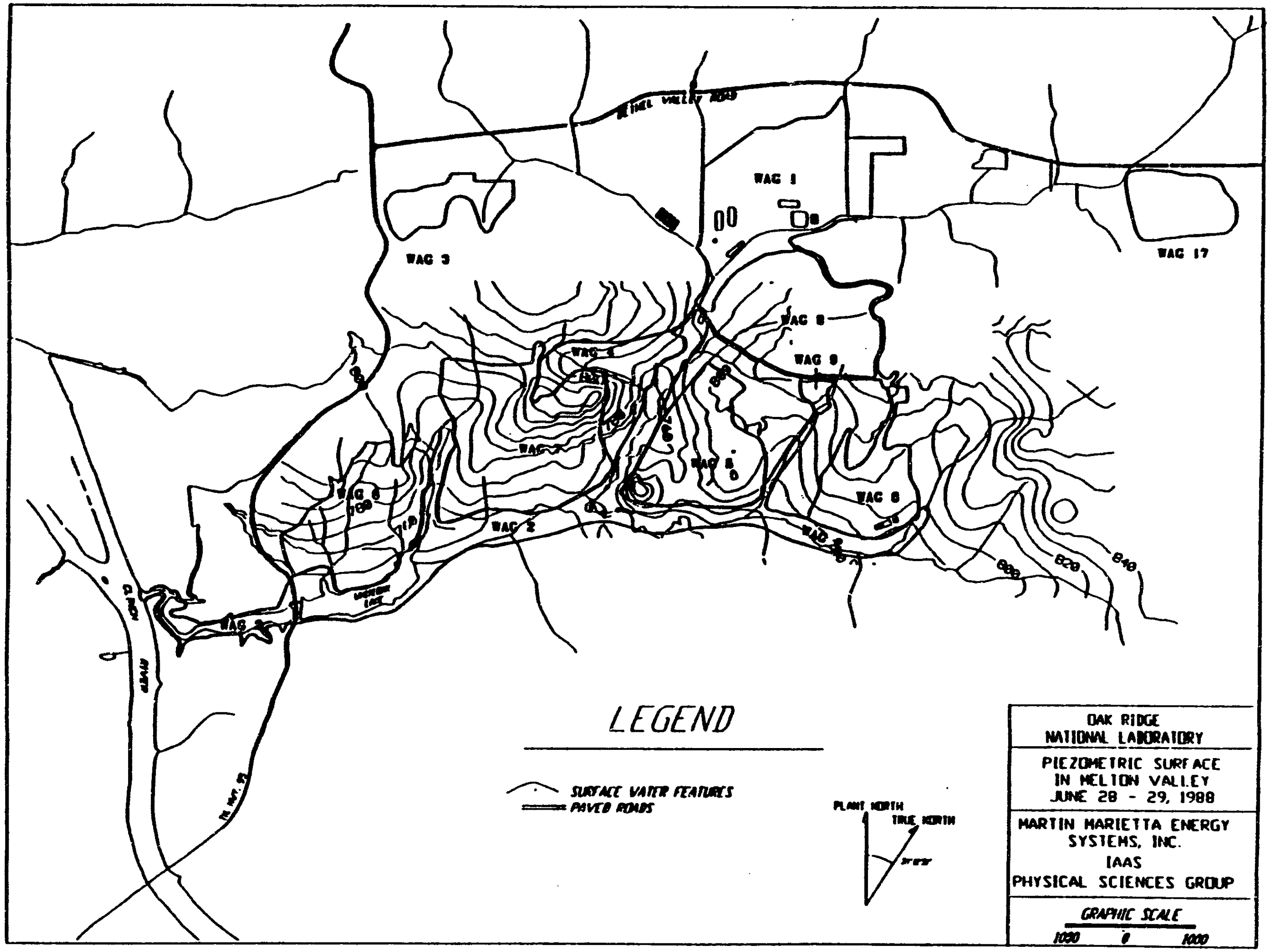

Fig. 3.4. Piezometric surface in Melton Valley, June 28–29, 1988.

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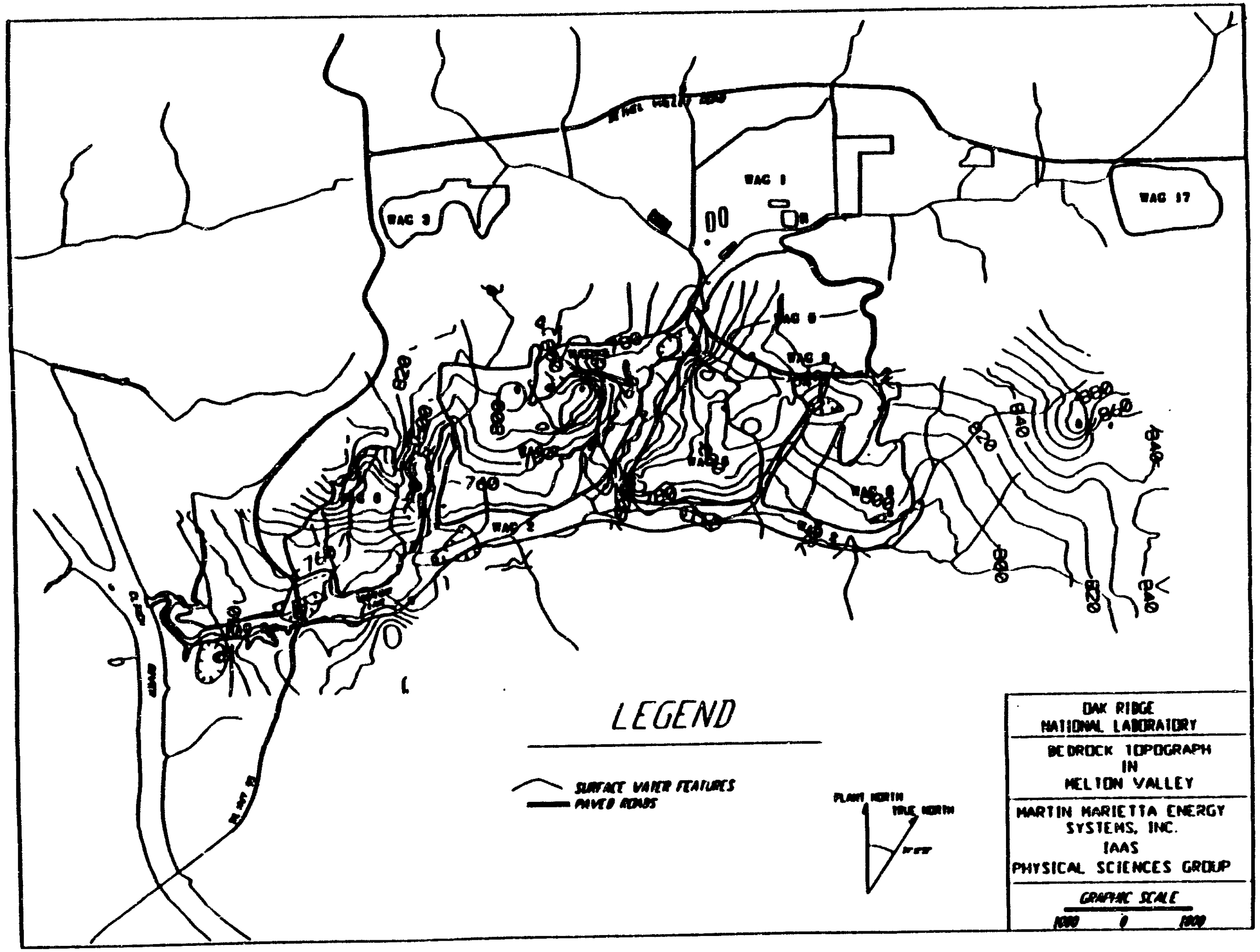

Fig. 3.5. Bedrock surface topography in Melton Valley.

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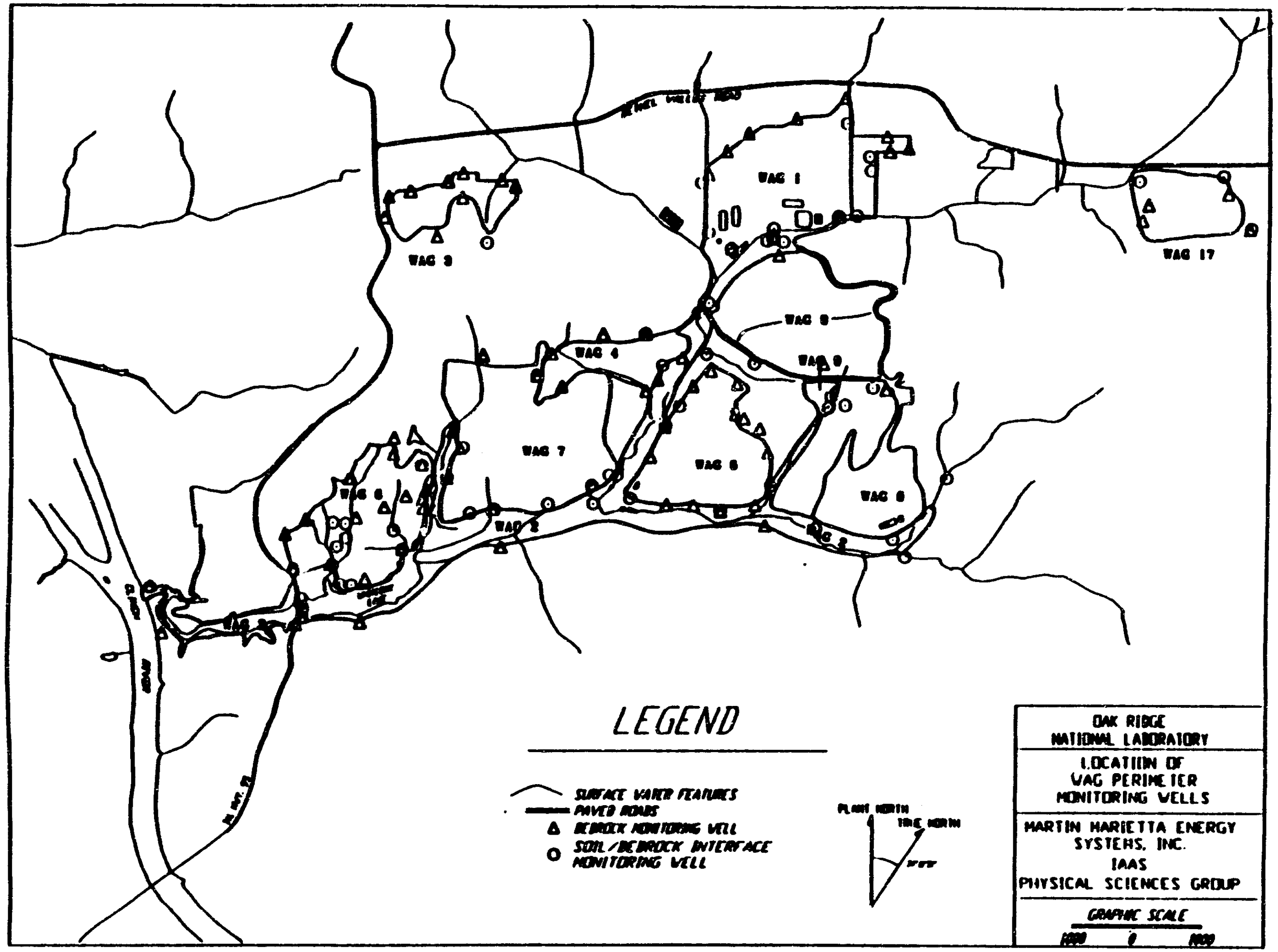

Fig. 3.6. Locations of WAG perimeter water quality monitoring wells at ORNL.

Table 3.2. Groundwater sampling and analysis at ORNL WAGs[a]

WAG	Wells	Well number	Parameters[b,c]
1	27	806–830, 946, 947 Note: 817 dry	Standard
2	20	1150–1156, 1185–1195, 1244–1245	Standard
3	15	985–988, 990–998, 1247–1248	Standard
4	15	948–962	Standard
5	22	963–984	Standard
6	16	745, 831–833, 835–839, 846, 855–860	Gross alpha, gross beta, total organic carbon, total organic halides, and tritium
6	8	840–844, 847, 1242–1243	Alkalinity, gamma spectrometry, gross alpha, tritium, total radioactive strontium, and volatile organics
7	16	1071–1086	Standard
8	9	1087–1095	Standard
9	2	1096, 1097	Standard
12	12	1139–1149, 1246	Standard
17	8	1196–1203	Standard

[a] Frequency may vary depending on availability of funding and other resources.

[b] Standard analytical parameters at most WAGs

Alkalinity
Anions
Gamma spectrometry
Gross alpha
Gross beta
ICP metals
ICP/MS metals
Semivolatile organics
Total dissolved solids
Total organic carbon
Total organic halides
Total phenolics
Total radioactive strontium
Total suspended solids
Tritium
Volatile organic compounds

[c] Field parameters measured at all WAGs

Conductivity
Dissolved oxygen
pH
Oxygen reduction potential
Temperature
Turbidity

Groundwater samples have been collected semiannually from each well in the WAG perimeter monitoring well network and submitted for analysis of parameter types listed in Table 3.2. Sampling was initiated at different times for each WAG, therefore, the number of completed sampling rounds varies among the WAGs. At the time data were obtained, data sets were available from perimeter wells for six sample rounds at WAG 1; four sample rounds at WAG 6; two sample rounds at WAGs 4, 5, and 7; and one sample round at WAGs 2, 3, 4, 8, and 9. Data included in this discussion of the distribution of contaminants were screened from the ORNL compliance data base.

3.3.1 Groundwater Geochemistry

Water chemical analysis results for major dissolved constituents are used to interpret the geochemical environment from which the sample was obtained. As groundwater flows through different subsurface zones, the dissolved chemical constituents can change as a result of soluble ions in soil and bedrock either dissolving or precipitating in response to changes in pH, redox potential, and dissolved gas content. The chemical mobility of some groundwater contaminants is controlled by the local geochemical environment either because of solubility controls or because of adsorption of solutes on soil or bedrock material surfaces.

3.3.1.1 Division of the data by location and depth

For purposes of investigation the data are stratified in two ways. First, results from wells located in Bethel Valley are compared to those in Melton Valley because the two areas are (or are assumed to be) hydrologically independent and because they are underlain by different rock types.

Second, the wells are divided into soil/bedrock interface wells and bedrock-only wells. The first group is screened at or above the soil/bedrock interface, defined as the depth at which drilling with a truck-mounted auger was terminated, because of refusal of hard rock. This group of wells presumably monitors the water table strata of the conceptual model. The bedrock wells are screened entirely below this interface, and they monitor the intermediate groundwater interval. It is expected that enhanced levels of $NaHCO_3$ or NaCl will be evident because the wells are not deep enough, although a thorough examination of this issue will be explored later.

3.3.1.2 Data screening methods

Prior to interpretation of the hydrogeochemistry of groundwaters sampled in the network of monitoring wells at WAG perimeter monitor well network, the analytical results for each sample are screened to verify the completeness and internal consistency of the data. Screening methods include determination of charge balance for each analysis; data substitution for occasional missing values of potassium and nitrate; substitution of calculated specific conductance values for missing data; computation of the saturation index (SI) values for major minerals, including calcite, dolomite, quartz, amorphous silica, kaolinite, and gibbsite; and determination of median concentrations for major dissolved constituents. The SI was calculated assuming dilute solutions (i.e., concentration equals activity).

Application of the data quality screens indicates that the data obtained from the perimeter water quality monitoring wells are internally consistent in describing the general geochemistry of the shallow groundwater. Where data were complete, the charge balance calculations were within the expected and acceptable range (±10%). Calculated values of conductance compared favorably, at low conductivities, with those measured at the time of sample collection. Calculated values were higher than measured values as ionic content increased. Calculated values of the saturation index for various common minerals were relatively invariant over time within a well and, for calcite and quartz, close to thermodynamic equilibrium. Replacing missing alkalinity values with values calculated to achieve charge balance did not distinctly alter the trend in saturation indices of calcite and dolomite for individual wells.

3.3.1.3 Preliminary results of WAG perimeter geochemical interpretation

The geochemical characteristics of groundwater are determined by the source of water (local precipitation infiltration vs deep bedrock groundwater discharges), chemical composition of earth materials through which the water has flowed, and length of time the water has been in the subsurface environment. General geochemistry of the WAG perimeter groundwater quality data set has been investigated through determination of the state of saturation of water samples with respect to predominant minerals present in the local bedrock and through display of groundwater geochemistry on Piper diagrams to enable classification of the groundwater at ORNL according to chemical type.

Saturation Index. Regardless of valley, the saturation state of the majority of the water samples are consistent with near-equilibrium saturation with respect to calcite, dolomite, and quartz. The waters appear to be supersaturated with respect to both gibbsite (SI = 3.0) and kaolinite (SI = 4.0); however, the degree of supersaturation is probably less important than the consistency of the data. This apparent supersaturation is indicative of detection of aluminum and silicon in groundwater samples.

Piper diagrams. Piper diagrams were prepared separately for wells in Bethel (Fig. 3.7) and Melton valleys (Fig. 3.8). The median major element concentrations (expressed as milliequivalents/L) are dominated by groundwaters characteristic of carbonate terrains. Analyses clustered in the lower left apex of each ternary plot and the left apex of the quaternary plot are predominantly calcium bicarbonate groundwaters. Both plots show that for some samples cations are dominated by sodium and anions are dominated by chloride and/or sulfate. The majority of the sodium- and chloride/sulfate-dominated waters are from bedrock wells and that sulfate is the dominant anion (>50%) in 14 (11 bedrock and 3 soil/bedrock interface) Melton Valley wells. Whether sodium chloride and sulfate are derived from natural sources or from waste constituents is presently not known. Additional data analysis is planned to examine the relationship between unusual geochemical groundwaters and potential sources of the solutes. Recognition that different geochemical environments exist in the shallow aquifer is important in the preparation of a systematic groundwater assessment. One example of how such information is important is in consideration of how to identify natural sources of dissolved constituents such as sulfate and chloride, which could also be derived from disposed materials. Another example is the use of general geochemical

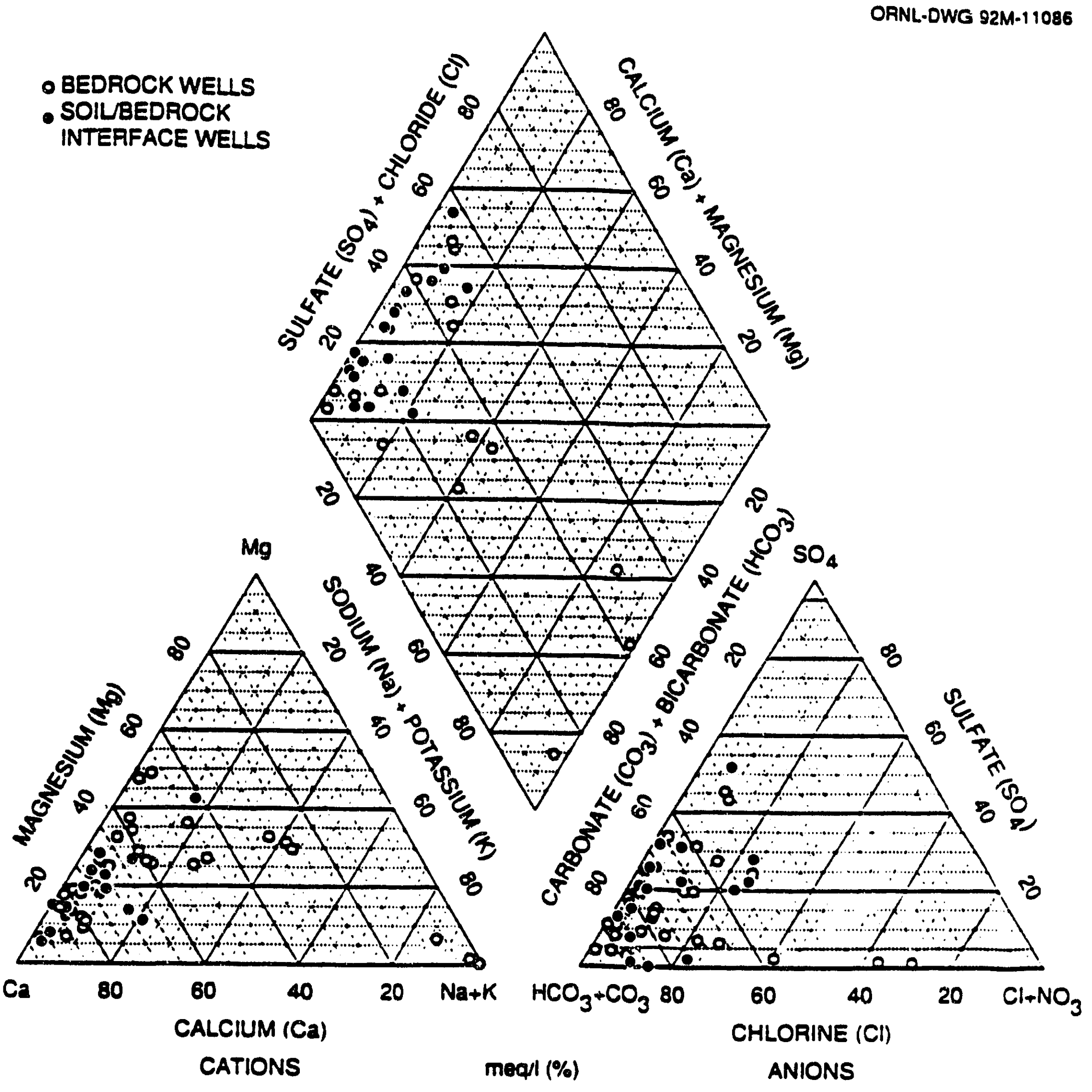

Fig. 3.7. Piper diagram of groundwater chemistry in WAG perimeter monitoring wells in Bethel Valley.

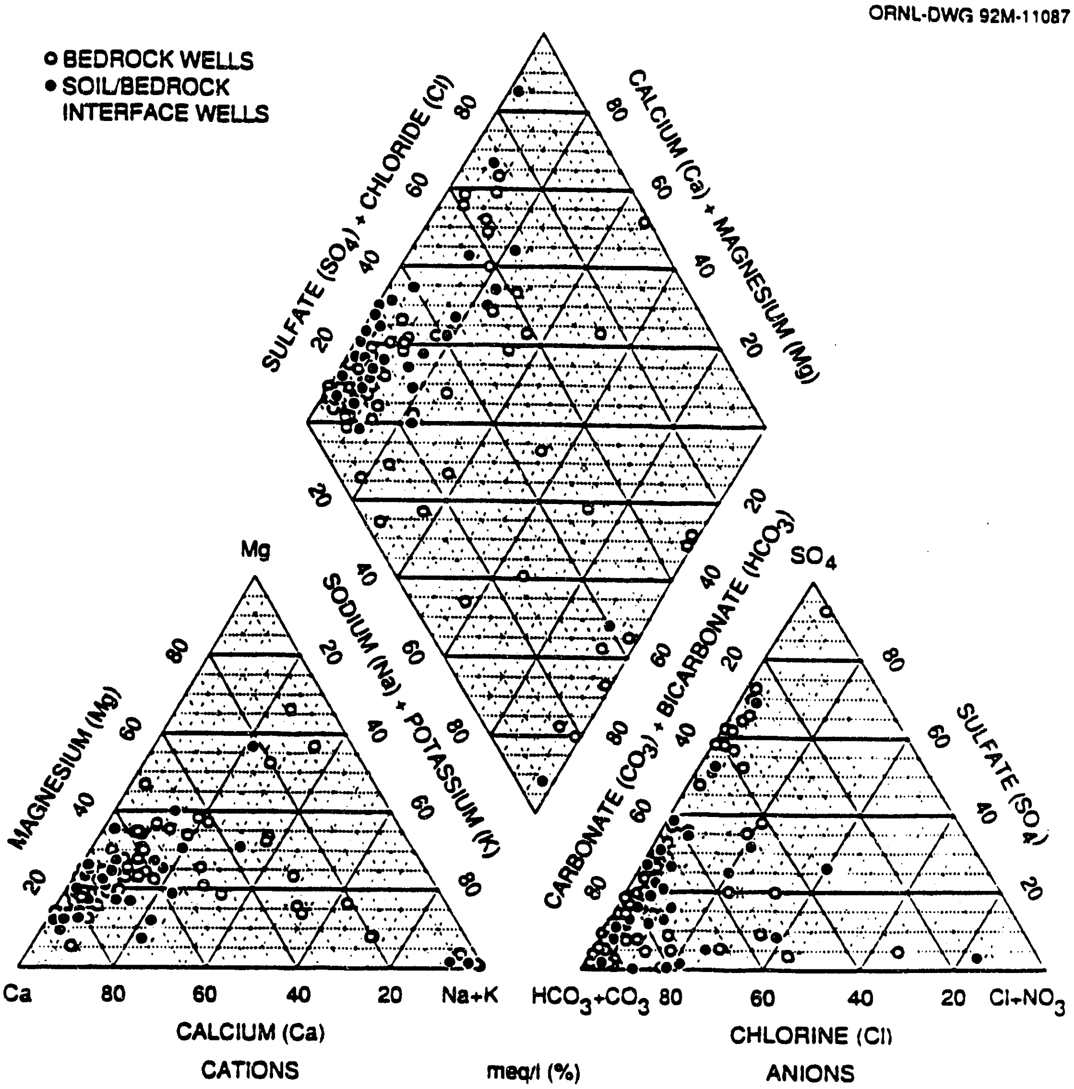

Fig. 3.8. Piper diagram of groundwater chemistry in WAG perimeter monitoring wells in Melton Valley.

principles to infer the source of sampled water according to the relative residence time in the subsurface as reflected by the concentration and proportions of major dissolved constituents.

Geochemical pattern recognition

PCA and cluster analysis are used to identify patterns of groundwater chemistry that are useful to identify similar or unique water types. The two techniques are similar and are complementary to one another.

Principal Component Analysis. Two types of PCA were applied to the WAG perimeter data. One method used a covariance matrix while the other used a correlation matrix.

The covariance method identified the same patterns of geochemistry that were apparent in the Piper plots. For Melton Valley the principal components were dominated by calcium bicarbonate with sodium, chloride, and sulfate. Separate evaluations of bedrock and soil/bedrock wells showed a tendency for chloride to dominate in soil/bedrock interface wells and for sulfate to dominate in bedrock wells.

A similar pattern was observed in covariance results from Bethel Valley. Groundwaters are calcium bicarbonate with additions of sodium, chloride, and sulfate. In a reversal of the situation in Melton Valley, there is a slight tendency for chloride to dominate in bedrock wells and sulfate in soil/bedrock interface wells.

PCA with correlation matrix input identifies some of the same patterns observed in the covariance analysis but also identifies more subdued patterns. PCA with correlations reveals waters dominated by calcium, magnesium, bicarbonate, and carbonate minerals (calcite or dolomite) with sodium, chloride, and sulfate additions. Magnesium, iron, manganese, and silicon appear in some of the first components and suggest the influence of the siliciclastic minerals in both bedrock formations and soils.

In Melton Valley bedrock wells, the first three components (using a combination of Sis and concentrations) suggest (1) clean carbonate bedrock, (2) clean siliciclastic bedrock (iron and manganese dominated), and (3) sulfate-containing carbonate bedrock. Whether that interpretation is valid or not, the correlation results support the observation that chloride is more likely found in soil/bedrock interface wells than in bedrock wells.

In Bethel Valley wells, the results of PCA with correlation matrix input are similar to previous results, with calcium and magnesium bicarbonate waters predominating and suggestions of a siliciclastic component. The results tend to reinforce the suggestion that bedrock wells are more likely to contain distinctive chloride concentrations, whereas sulfate is more characteristic of soil/bedrock interface wells.

Cluster analysis. Based on the results of the PCA, cluster analysis was performed using the combination of mineral Sis and element concentrations. The three largest clusters were identified and used to distinguish points in a three-dimensional plot of dolomite saturation vs kaolinite saturation vs sodium or chloride or sulfate. The plot of dolomite saturation vs

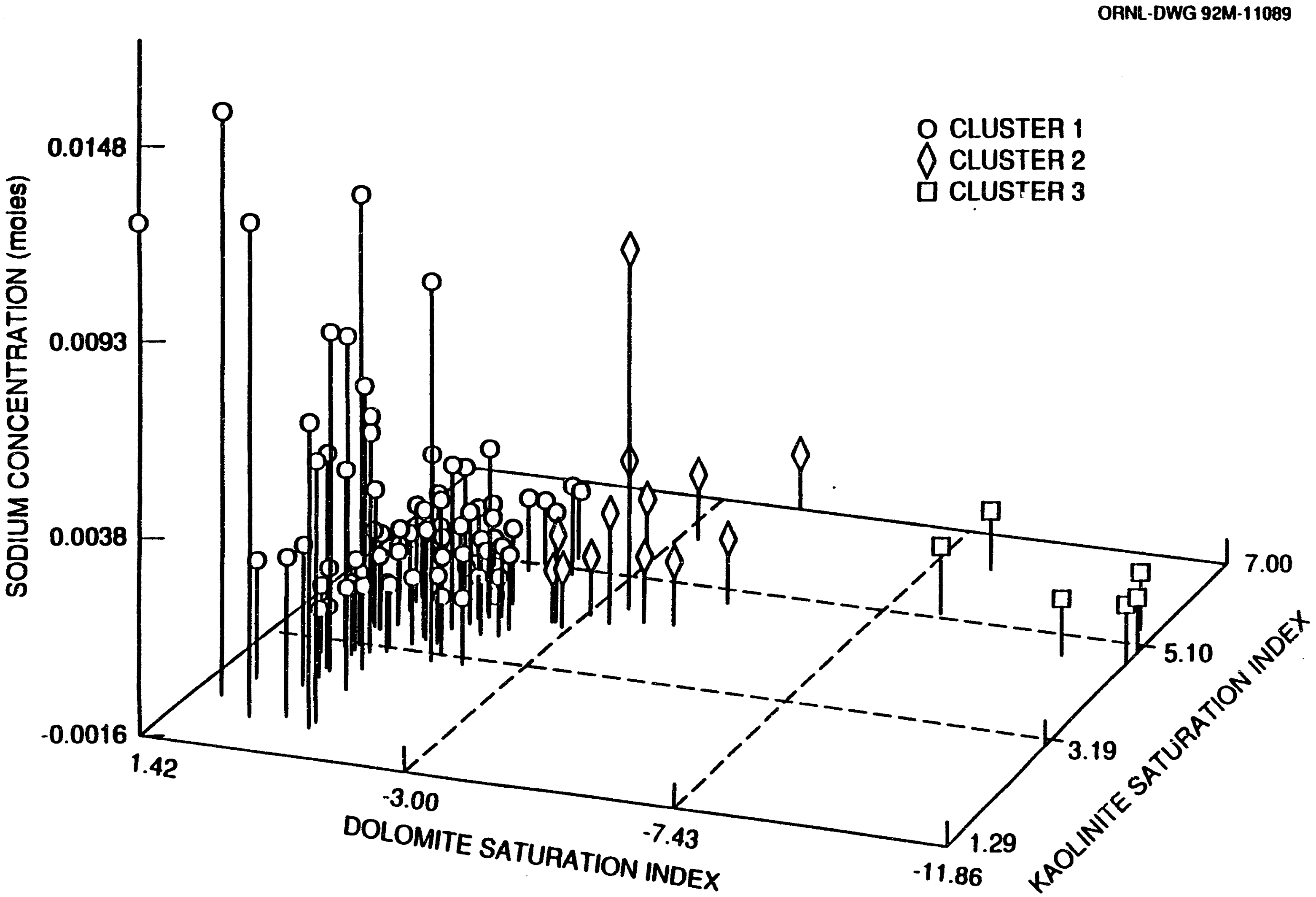

Fig. 3.9. Geochemical clusters identified in Melton Valley WAG perimeter groundwater monitoring wells showing sodium distribution.

kaolinite saturation vs sodium concentration Melton Valley data is shown in Fig. 3.9 as an example of the cluster analysis results.

In Melton Valley the clusters are distinguished by their dolomite saturation, with cluster 1 wells near saturation, cluster 2 wells undersaturated and centered around SI = -3.0, and cluster 3 wells the most undersaturated with respect to dolomite. Wells in clusters 2 and 3 also tend to be more saturated with respect to kaolinite. Two to three further subdivisions are possible using sodium, chloride, or sulfate concentration as the discriminator.

The largest group of wells has low sodium concentration (<4 mmoles/L) and includes wells from all three dolomite/kaolinite clusters (Fig. 3.8). A smaller, intermediate group in cluster 1 has sodium concentrations between 4 and 10 mmoles/L. The third and smallest group has the highest sodium concentrations (>10 mmoles/L) and encompasses the remaining wells in cluster 1 and one well in cluster 2.

Geochemical clustering for regolith vs bedrock zones. Figure 3.10 illustrates the results of plotting the same data used to generate the cluster plots with the symbols now designating the sampled interval, either soil/bedrock interface or bedrock-only, for the sodium example in Melton Valley wells. The data distribution in the figure shows that soil/bedrock interface does not represent a systematic interface for groundwater geochemistry. The soil interface wells rarely plot above a SI_k of 3.0 and most bedrock wells plot above a SI_d of -1.0. The heterogeneous nature of the bedrock types in the two valleys and the variability in depth of weathering may account for the overlap observed in geochemistry of bedrock and soil/bedrock interface interval samples.

3.3.1.4 Summary

For both Bethel and Melton valleys, groundwaters have been divided into three different types on the basis of geochemistry. Most wells in the WAG perimeter array produce waters of the calcium bicarbonate type. A relatively small proportion of wells produce waters in which calcium/magnesium sulfate or sodium chloride are present in significant concentrations. Groundwaters from soil/bedrock interface wells and bedrock wells in both valleys do not show consistent differences, although water from soil/bedrock interface wells tends to have higher sulfate levels and lower chloride levels than that from bedrock wells. The geochemical analysis is continuing. Detailed examinations of changes in geochemistry with depth and location will be examined in detail. Correlation among geochemistry, water types, and contamination will be explored. These analyses lead to greater understanding of the controls on geochemistry and solute transport.

3.3.2 Contaminant Distribution in WAG Perimeter Wells

Contaminant data have been processed through two steps in preparing a graphical presentation of results. The first step in data screening was determination of median concentrations for all detected contaminants listed in the primary and secondary drinking water regulations for wells having multiple sample rounds. The median contaminant concentration data set was then screened to determine all wells having median values

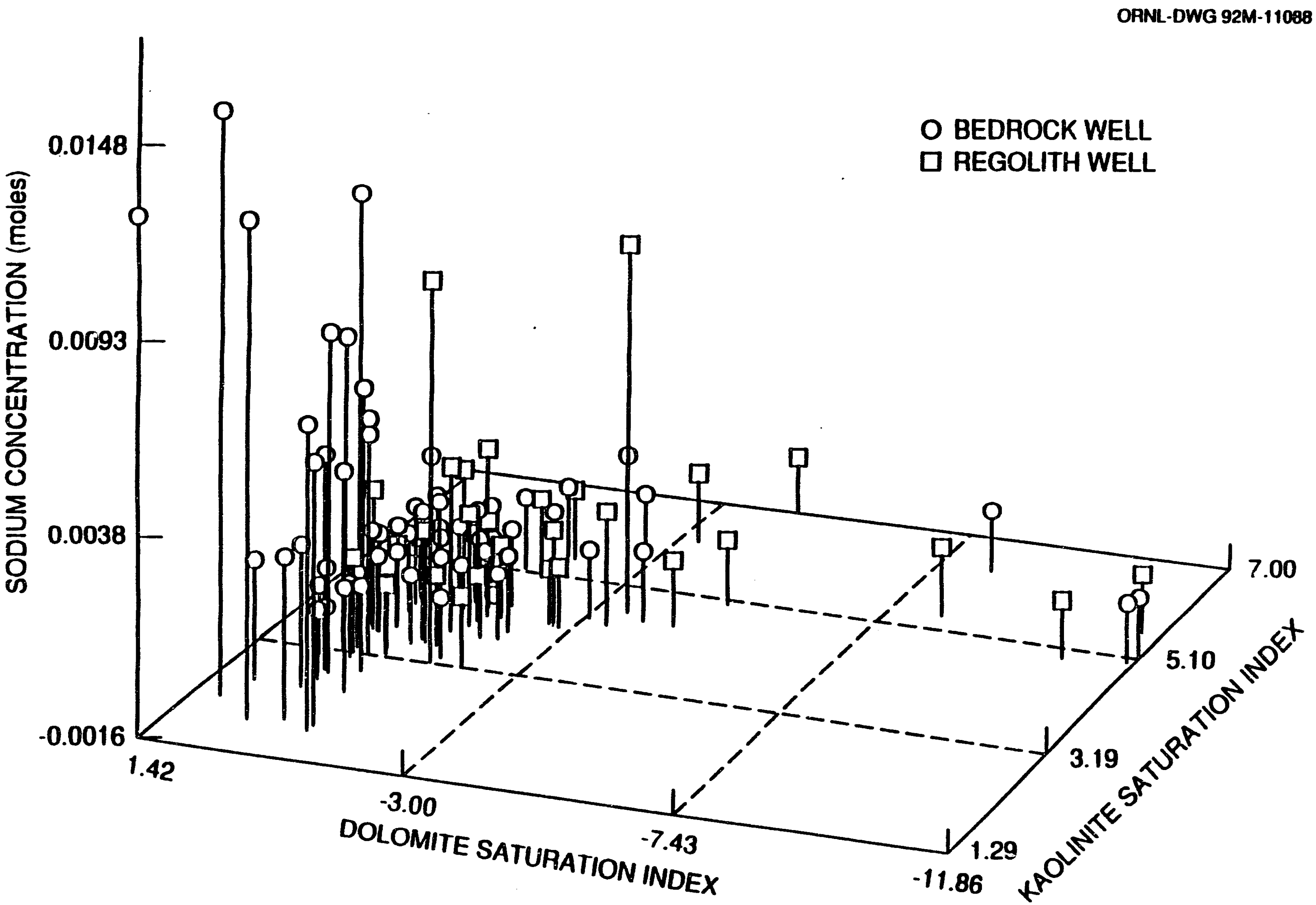

Fig. 3.10. Geochemical clusters identified as either soil/bedrock interface- (regolith) or bedrock-type wells.

exceeding the drinking water standards. The drinking water standard MCLs are used as reference values to point out areas where contaminant concentrations may be of concern during regulatory review.

Table 3.3 lists contaminants detected in unfiltered samples for which the median detected concentration exceeded the drinking water standard and the number of wells at each WAG where exceedance occurred. Table 3.4 includes a similar tabulation for contaminants detected in filtered samples. Organic compound analyses are performed only on unfiltered samples, therefore none are reported in Table 3.4. These tables show that some perimeter monitoring wells at all contaminant source WAGs have some wells in which contaminant concentrations exceed the standard MCLs for drinking water. The highest percentage of wells with MCL exceedances and the largest numbers of parameters exceeded occur at WAGs 4, 5, and 6. The data for unfiltered and filtered samples are generally consistent. However, a few inconsistencies are apparent, such as the detection of lead at exceedance concentrations only in filtered sample results at WAG 5 and more filtered than unfiltered samples exceeding the gross alpha MCL at WAG 4. Typically lower concentrations are observed after sample filtration because of particulate removal and sorption effects.

The areal distribution of major detected contaminants at WAGs in Bethel and Melton valleys are shown in figures described below. Concentration symbols used in these figures are multicomponent rose diagrams proportionally scaled to the parameters shown. The radius of each symbol is proportional to the sum of analytes represented in the rose, and the radii of individual sectors in the symbol represent the proportional contribution of each component. For radiological parameters and VOCs the symbols are scaled to the log of the sum of detected analytes in each class because of the extreme range in reported concentrations.

The areal distribution of detected metals exceeding drinking water MCLs is shown in Fig. 3.11. Symbol sizes are proportional to the median of the sum of detected metal concentrations. Nickel is the principal metal detected, with subordinate amounts of chromium, mercury, selenium, and cadmium. These metals are detected in the vicinity of solid waste disposal areas in Melton Valley with the exception of a low concentration of mercury, which is detected at WAG 3. The majority of wells where metal concentrations exceed the MCL are screened in the bedrock portion of the groundwater zone.

The areal distribution of detected VOCs is shown on Fig. 3.12. Concentration symbols are sized proportional to the median of the sum of detected VOCs, and individual components of the VOC population are shown as sectors in the rose diagrams for each well. The VOCs are primarily detected around solid waste disposal areas in Melton Valley with the notable exception of well 1201 at WAG 17 (the 7000 or service area) where the garage and paint shop are potential sources. The majority of wells having exceedance levels of VOCs, and those with the highest concentrations, are screened in the bedrock portion of the groundwater zone.

The areal distribution of detected gross beta and tritium activity exceeding the drinking water MCLs is shown in Fig. 3.13. The symbols are sized proportional to the log of the sum

Table 3.3. Summary of detected contaminant analytes whose median values exceed drinking water standard MCLs (unfiltered samples)

Analyte type	Analyte	WAG 1	WAG 2	WAG 3	WAG 4	WAG 5	WAG 6	WAG 7	WAG 8	WAG 9	WAG 11	WAG 17
Anions	Fluoride							1[a]				
	Nitrate		1					2				
Metals	Cd										1	
	Cr		1								1	
	Hg			1							1	
	Ni		1		3			2				
	Se				1							
Organics	1,1-Dichloroethene				2							1
	1,2-Dichloroethane						1					
	Benzene					1						1
	Carbon tetrachloride						1					
	Trichloroethylene	1		1	2	2	2			1	2	2
	Vinyl chloride	1			2	3						1
Radionuclides	G-Alpha	1		1	1	2		1			1	
	G-Beta	3	1	4	3	5		5	1	2	1	
	Tritium		4	1	6	12	6	4	1			
	^{60}Co							1				
	Total Sr	5	2	4	2	7			2	2		
	^{234}U	1										
General	pH	1	5	2	5	5	5	2	4			
	TDS		1			6		6				
Total wells sampled		26	20	15	15	22	16	16	9	2	11	8
Total wells exceeding MCLs		8	11	7	10	16	11	9	6	2	3	2

[a] Number of wells for which median analyte concentrations exceed the MCL.

Table 3.4. Summary of detected contaminant analytes whose median values exceed drinking water standard MCLs (filtered samples)

Analyte type	Analyte	WAG 1	WAG 2	WAG 3	WAG 4	WAG 5	WAG 6	WAG 7	WAG 8	WAG 9	WAG 11	WAG 17
Metals	Ni		1[a]		3			2				
	Pb					1						
Radionuclides	G-Alpha	1	1		1	3	1	1				1
	G-Beta	3	1	4	4	4	1	4	1	2		
	Tritium	1	4	1	6	12	10	4	1		1	
	^{60}Co						2	1				
	^{99}Tc							1				
	Total Sr	5	1	4	2	5			3	2	1	
	^{234}U	1										
General	TDS	6		5	5	7		6	2			
Total wells sampled		26	20	15	15	22	16	15	9	2	11	8
Total wells exceeding MCLs		10	5	6	9	16	10	8	5	2	2	1

[a] Number of wells for which median analyte concentrations exceed the MCL.

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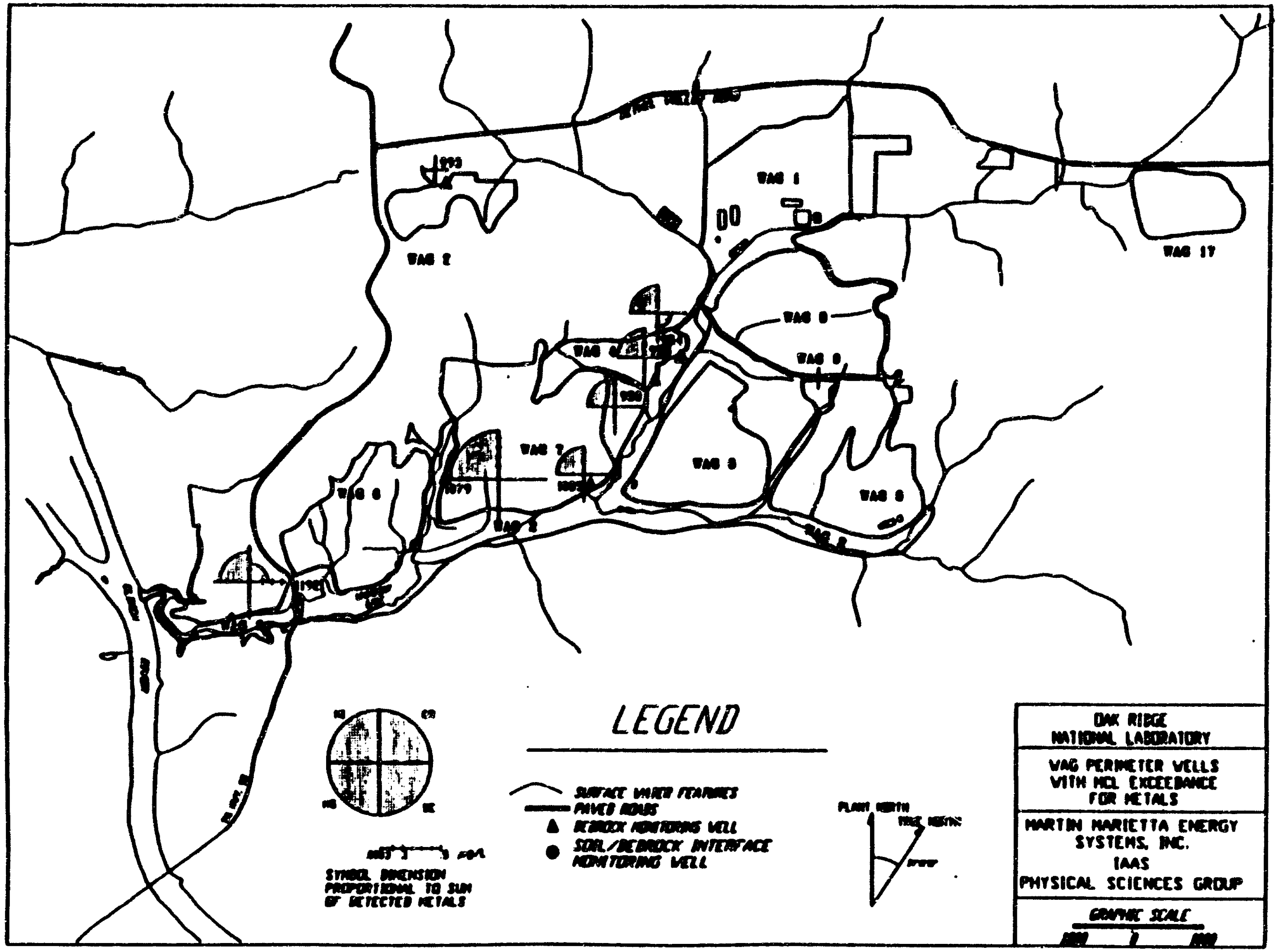

Fig. 3.11. Locations of wells where median concentrations of dissolved metals exceed the primary drinking water standard.

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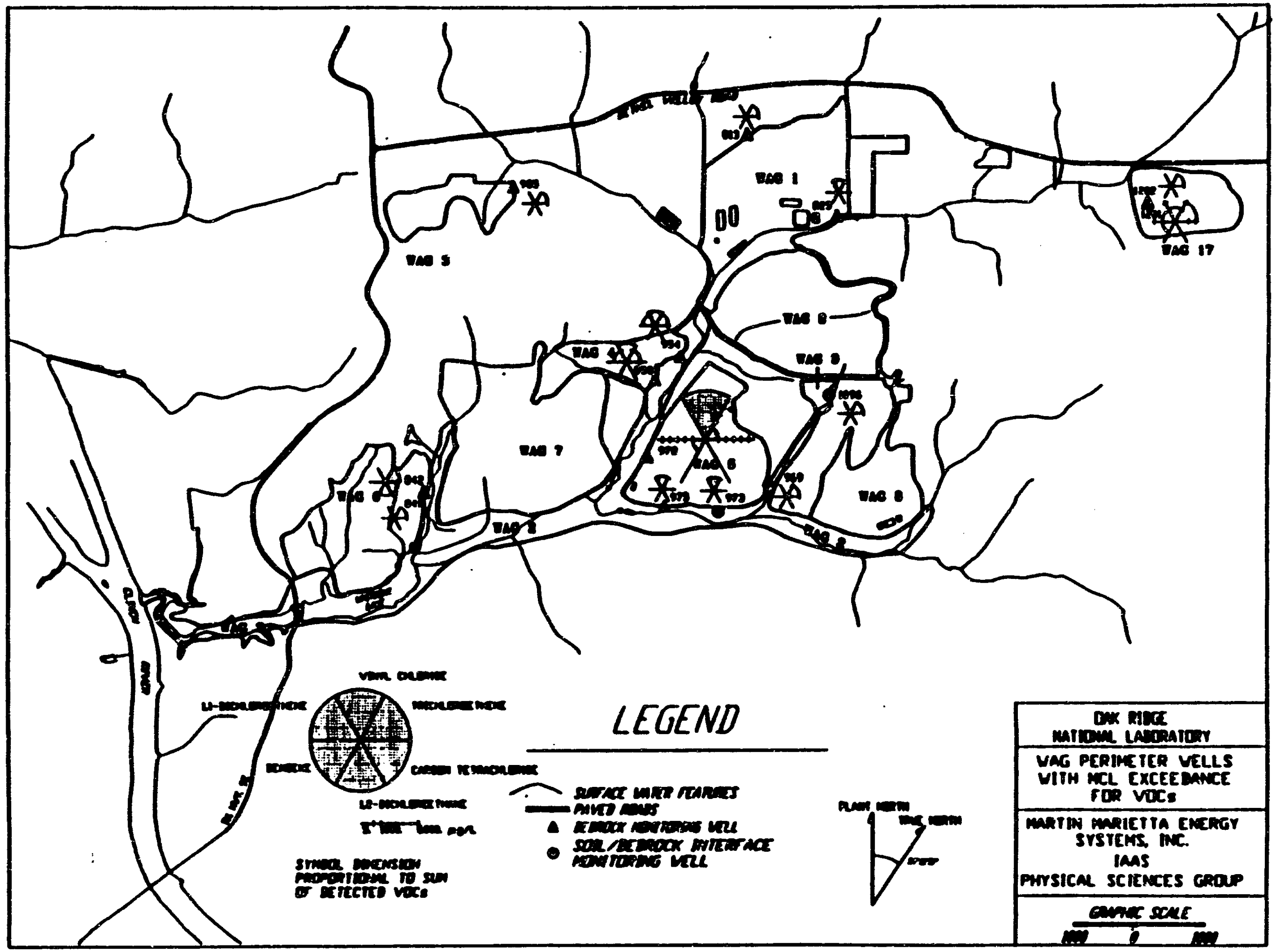

Fig. 3.12. Locations of wells where volatile organic carbons (VOCs) are detected.

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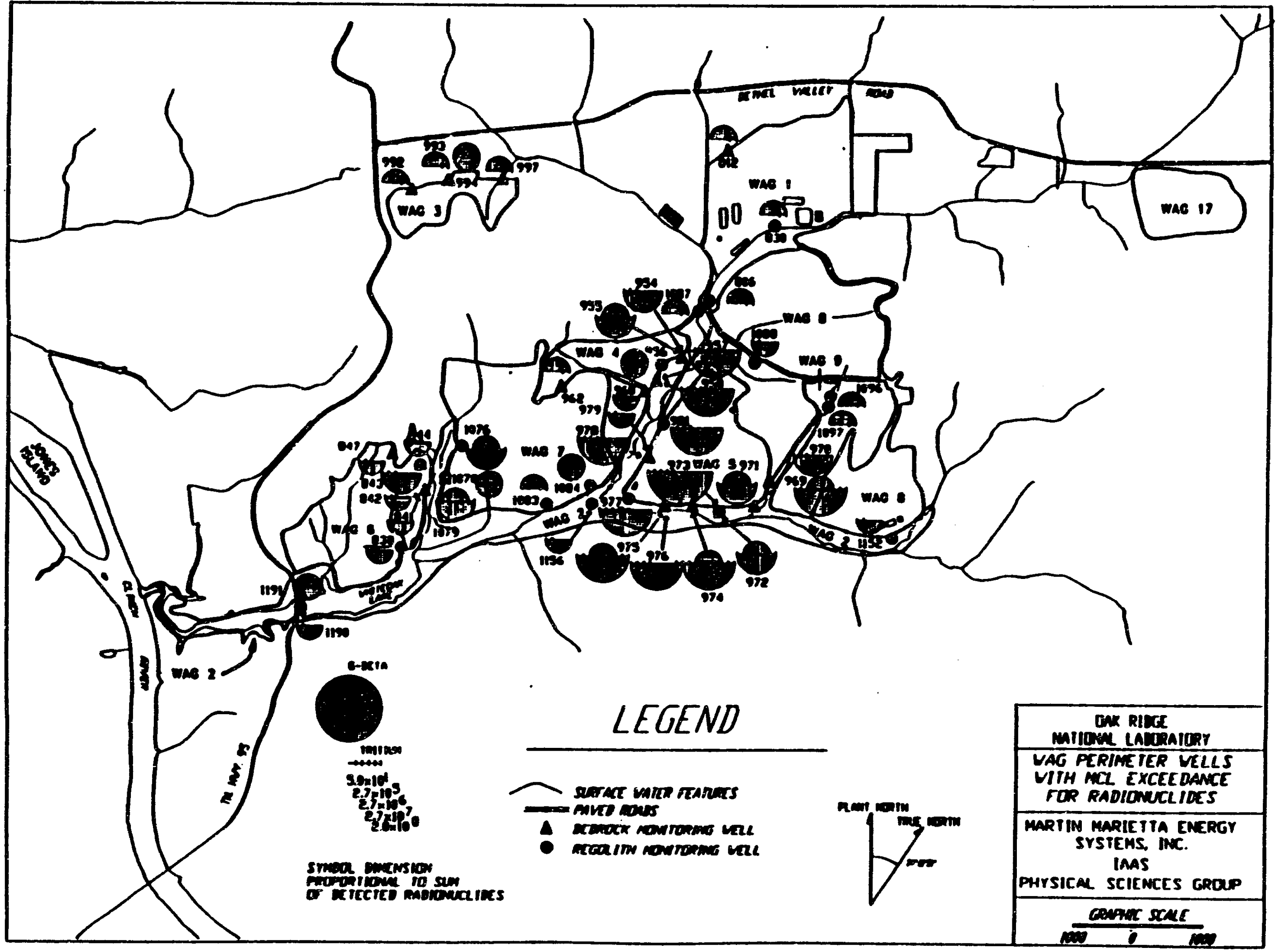

Fig. 3.13. Locations of wells where median concentrations of radiological contaminants exceed the primary drinking water standard.

of median gross beta and tritium, and rose diagram sectors are filled in proportion to the relative proportion of each analyte.

The data distribution shown in Fig. 3.13 indicates that gross beta activity usually exceeds the drinking water MCL in only one well in well pairs. The percentage of wells in which concentrations exceed the drinking water standards are nearly the same for bedrock wells and soil/bedrock interface wells. Gross beta activity in excess of the drinking water standards occurs most often around solid waste disposal sites with the exception of wells 812 and 830 in WAG 1 and wells 806 and 1087 located at the WOC water gap in Haw Ridge.

Tritium concentrations in excess of the drinking water MCLs are found only in wells around solid waste disposal areas. The percentage of wells in which concentrations exceed the drinking water standards are nearly the same for bedrock wells and soil/bedrock interface wells. The highest tritium concentrations in the WAG perimeter monitoring data occur at WAG 5.

The median gross alpha activity, which exceeds the drinking water standard at six wells in the ORNL area, is shown in Fig. 3.14, and the median gross alpha also exceeds the MCL at one well at WAG 11. The MCL exceedances for gross alpha occur primarily in bedrock zone wells downgradient of waste disposal areas. Exceptions to this are well 982, a soil/bedrock interface well downgradient of the TRU storage area in SWSA 5 North, and well 812 located on the western edge of WAG 1.

3.3.3 Summary of WAG Perimeter Well Analyses

The preceding overview of detected contaminants whose median values exceed drinking water MCL's shows clearly that radiological groundwater contamination is the most significant problem at the ORNL WAG perimeters. Additionally, the greatest problems with MCL exceedance are observed at the downgradient perimeters of WAGs 4, 5, and 6, with local problems observed at WAGs 1, 3, and 7. VOCs including both fuel hydrocarbons and solvent compounds, are detected in a small percentage of wells. The detection of contaminants in excess of the MCLs is not restricted to either the soil/bedrock interface zone or the bedrock zone. In some instances contaminants are migrating along flow paths in bedrock that extend to depths approaching 100 ft below ground surface. Detection of contamination at these depths in the bedrock portion of the aquifer is indicative that in some areas contaminants are moving through long and deep flow paths that will require very precise methods to delineate.

3.4 SOURCE WAG GROUNDWATER INVESTIGATIONS

This section consists of brief summaries of current activities at WAGs 1, 5, and 10, where RI programs are either underway or scheduled to begin. No data are included in the summaries because there are established schedules for reporting data from the RIs. WAG 6 is a special case because it is the only RCRA facility at ORNL. An RFI for WAG 6 was concluded in FY 1991 (Energy Systems 1991a). A brief description of some of the ongoing monitoring programs at WAG 6 are included.

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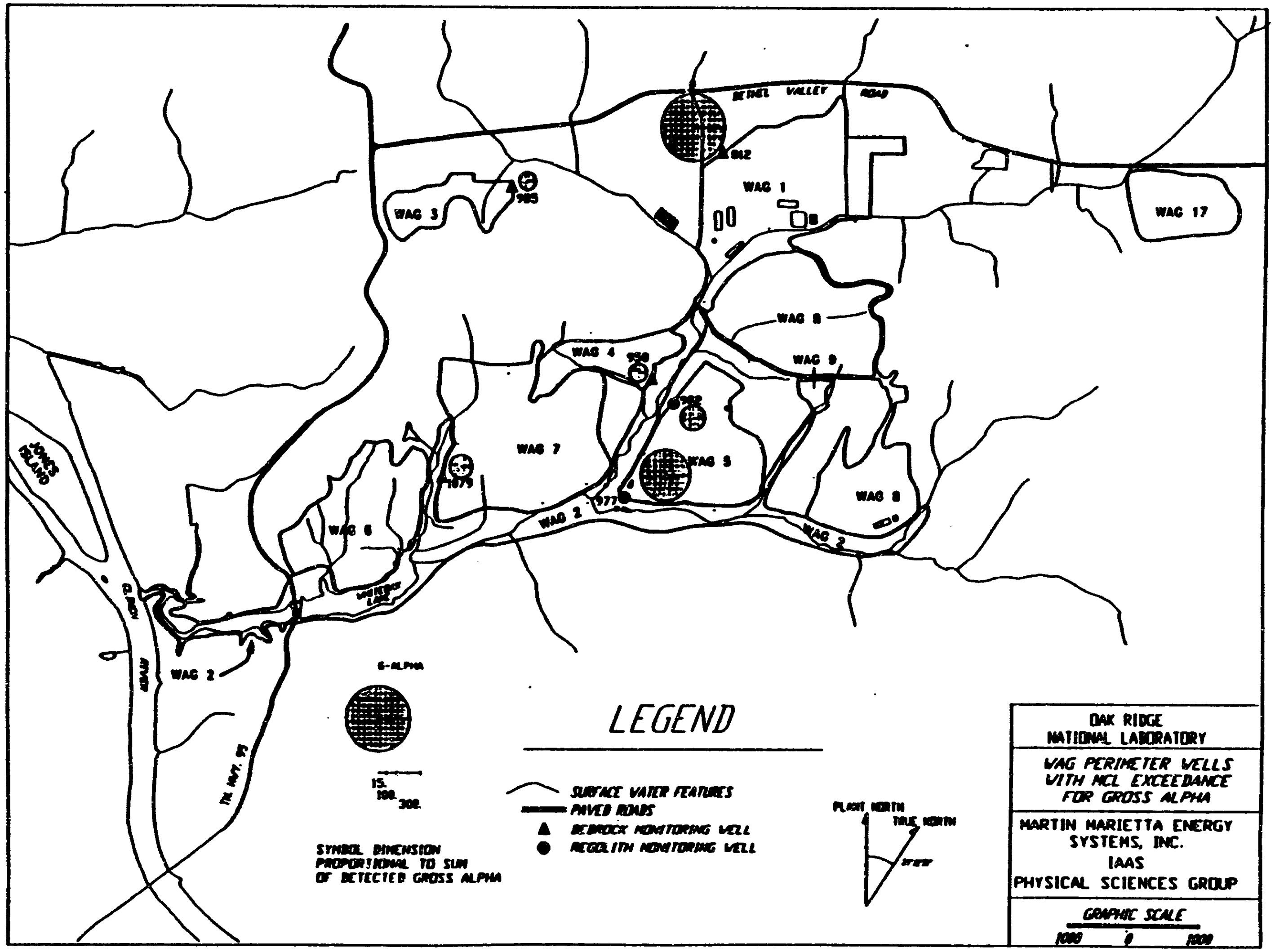

Fig. 3.14. Locations of wells where median alpha activities exceed the primary drinking water standard.

3.4.1 WAG 1

Collection of groundwater, soil, sediment, and surface-water samples under Phase 1 of the WAG 1 RI was completed at the end of 1991. The purpose of the Phase 1 groundwater program was to establish general patterns of groundwater flow and contamination. Future supplemental sampling campaigns will be designed to provide data needed to develop remedial action plans for specific operable units.

Groundwater samples were collected between the fall of 1990 and the spring of 1991 from 103 wells and piezometers; most wells were sampled during both low baseflow and high baseflow conditions, while a subset was also sampled during a storm event, during the high baseflow condition. These wells and piezometers are screened in either shallow overburden soils, shallow bedrock, or across the overburden/bedrock contact zone. Five wells located in areas that are not believed to be influenced by waste management practices were also sampled, to establish baseline groundwater quality conditions. Groundwater samples and potentiometric data were also collected from eight deep bedrock core holes and one multiport monitoring well, completed in bedrock during the summer and fall of 1991, as part of an effort to characterize groundwater quality in the deeper aquifer. The overall distribution of groundwater sampling locations is shown on the attached maps. Groundwater samples were analyzed for VOCs, BNAEs, pesticides/PCBs, metals, radiologic properties and isotopes, major cations and anions, and other parameters.

Groundwater levels were monitored during the Phase 1 investigation (Fig. 3.15). Water levels were determined monthly at 147 wells and piezometers. In addition, continuous water level monitoring was performed at 20 locations. These data were used to determine groundwater flow patterns and the degree to which groundwater recharge and surface-water flow are related to rainfall events.

A Site Characterization Summary Report, which presents all sampling results, as well as a description of the nature/extent and fate/transport of contamination, will be submitted to EPA and TDEC by October 1, 1992.

Additional monitoring is anticipated in 1993 and beyond. Groundwater samples will be obtained in 1993 from existing wells associated with significant areas of contamination in order to assess trends in the degree of contamination. A plan for additional groundwater monitoring wells and ICMs will be developed in 1993; the monitoring elements of this plan are expected to be implemented in 1994, while the ICMs will be implemented as soon as practicable.

3.4.2 WAG 5

WAG 5 is an area of 50 acres in Melton Valley, comprising the majority of the original SWSA 5 for ORNL. Sources of identified or potential releases of hazardous substances to the environment include seven inactive LLLW underground storage tanks, one inactive waste oil storage tank, two surface impoundments, extensive waste burial grounds, spill locations, an inactive landfill and site surface facilities for the new and old hydrofracture sites.

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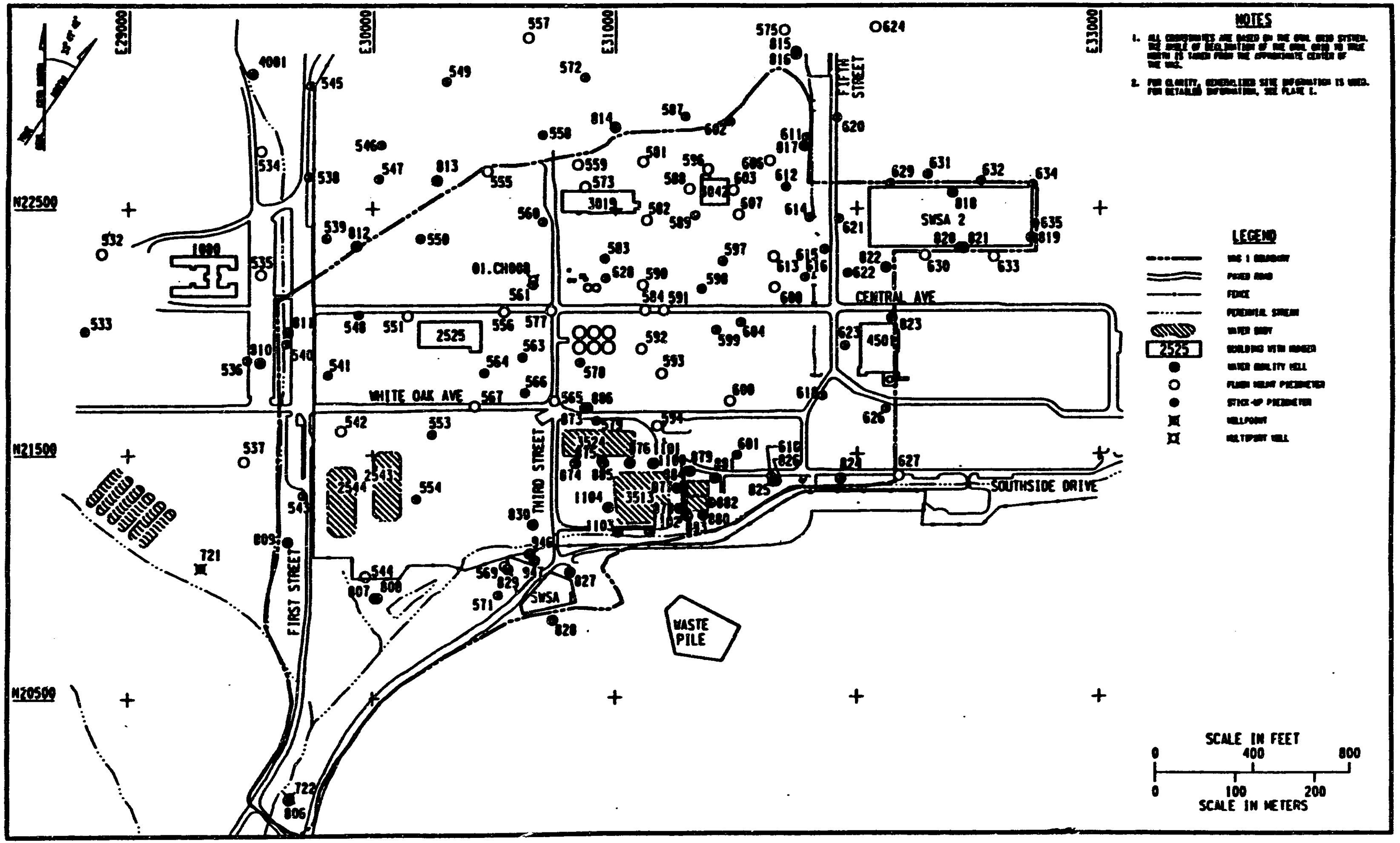

WAG1 01F297.DGN SRF, WEL, 6/15/92

Fig. 3.15. Location of wells in WAG 1.

Collection of groundwater, soil, sediment, and surface-water samples under a remedial investigation is currently under way. The purpose of the groundwater program is to develop sufficient data to establish general patterns of groundwater flow and contamination and to support risk assessment and the development of remedial alternatives. Data will also be collected to resolve groundwater issues common to WAG 5, WAG 10, and the groundwater operable unit (WAG 21).

Groundwater samples and potentiometric data will be collected among 230 existing wells within and adjacent to WAG 5. This well population includes 22 RCRA compliance wells and 4 CERCLA compliance wells; the balance are piezometers and wells from previous investigations, which date back to 1958. Well depths range from 5 to 200 ft. Locations of existing wells/piezometers are shown on Fig. 3.16.

Well construction planned for WAG 5 includes modifications to 10 existing wells by retrofitting and completion activities and the installation of 4 new shallow wells and 14 stormflow piezometers. Seven wells will be retrofitted to depths ranging from 100 to 200 ft. Three wells will be completed to 500 ft for installation of a multizone monitoring system between depths of 200 and 500 ft. Shallow wells and stormflow piezometers will be a maximum of 50 ft and 5 ft deep, respectively. Locations for new and modified well/piezometer construction are shown on the attached maps.

Most sampling will be performed during low base and high base groundwater table conditions. Samples will be analyzed for VOCs, BNAEs, pesticides/PCBs, metals, radiological constituents and isotopes, major cations and anions, and other parameters.

Groundwater levels will be measured monthly at 175 well/piezometer sites. Continuous water level data will also be collected at about 16 locations, and shallow stormflow levels will be monitored at 14 locations. These data will be used to assess groundwater flow patterns and the degree to which groundwater recharge and surface water are related to rainfall.

Data will be submitted periodically in the form of technical bulletins and technical memoranda. A RI report, which presents all investigation data, is scheduled for submittal in June 1994. Non-intrusive field work is near completion, and intrusive work is scheduled to began on September 1, 1992.

3.4.3 WAG 6

During FY 1992, RCRA compliance monitoring continued, and the groundwater data are included in the analysis of WAG perimeter wells in Sect. 3.3. An annual groundwater quality assessment report was issued (ORNL 1992b), and it was concluded that the monitoring showed that types of contaminants and concentration levels were mostly unchanged from results reported earlier (Energy Systems 1991a). Furthermore, contaminants in West Seep, the tributary that lies on the eastern edge of the WAG, probably are migrating from WAG 7 on the other side of the tributary and probably are not attributable to WAG 6.

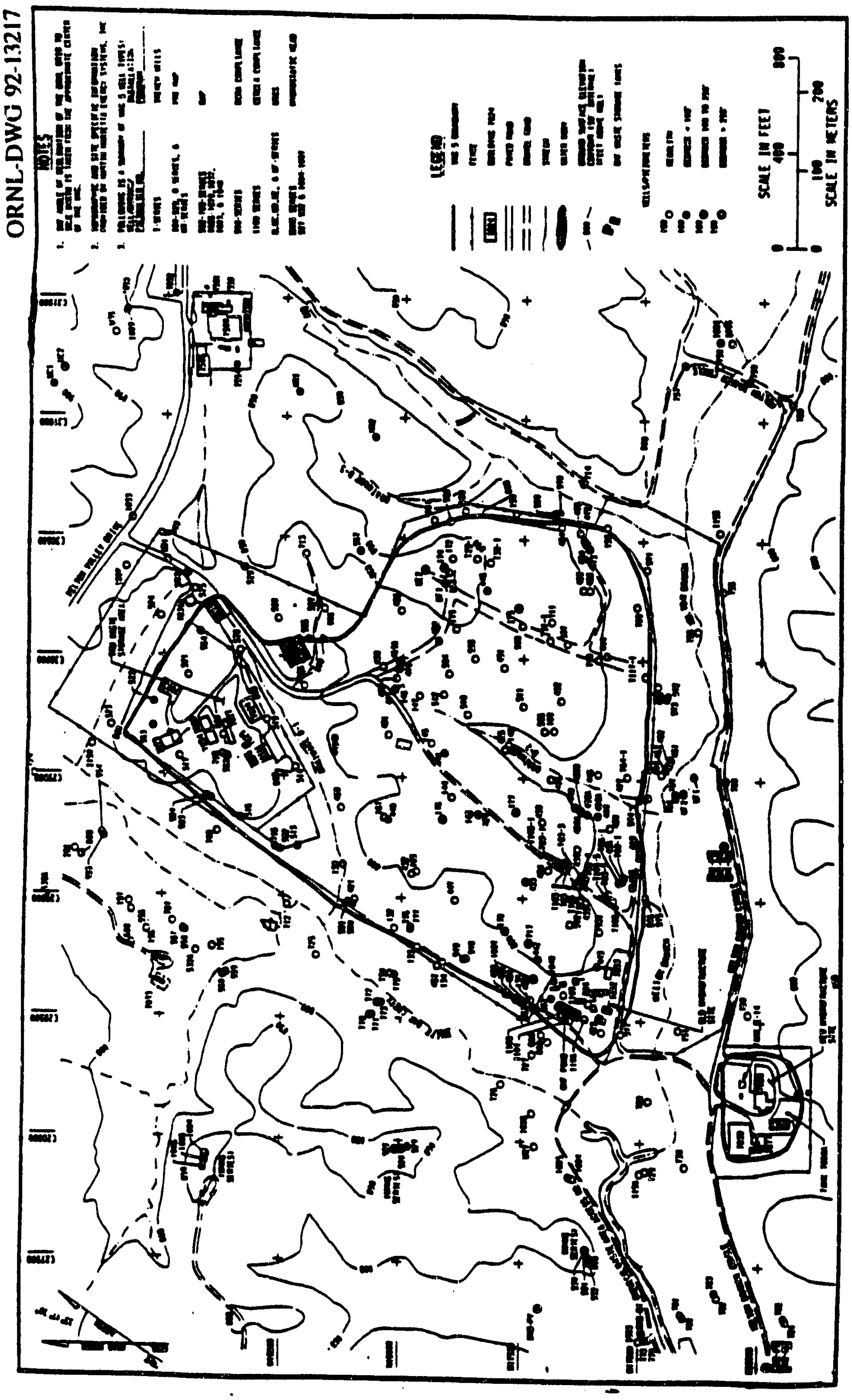

Fig. 3.16. Groundwater monitoring wells and piezometers at WAG 5.

In the WAG 6 ICM Environmental Monitoring Program, the hydrologic effects of the interim impermeable membrane caps were monitored. Data collection consisted of twice-monthly water level measurements in shallow groundwater wells and drive point wells for monitoring water levels in capped trenches. (Ashwood and Spalding 1991, Clapp and Marshall 1991). Fig. 3.17 shows the water level in a waste trench that receded after capping but continues to respond slightly to storms, probably due to inflow of stormflow. Fig. 3.17*b* shows the water level in a trench at Cap 5, where the wastes are continuously wet. For this trench the water level in an adjacent groundwater well tends to rise and fall slightly in advance of the trench water level, suggesting that local water table groundwater is driving water into the well and then draining water out. Some water levels in trenches adjacent to WOL respond to changes in lake levels.

The results of this monitoring effort are important to ER because they provide a basis for the design of more extensive caps for the interim closure of WAG 6. The results are also useful in the development of a monitoring strategy. Data collection during pre- and post-construction must include some performance measures, such as water levels in trenches, in order to evaluate the effectiveness of the cap to hydrologically isolate the wastes. This information is vital in order to determine if selected technologies perform as designed.

3.4.4 WAG 10

WAG 10 comprises the underground components of the ORNL hydrofracture sites. The hydrofracture process was a waste disposal technique that resulted in disposal of approximately 3.2 million gall of low-level radioactive wastes containing an aggregate of approximately 1.4 million Ci of radioactivity into a low-permeability shale formation. The waste materials were mixed with grout and additives and injected under pressures of 2000 lb/in.^{2} or more. The injected slurry spread along fractures and bedding planes for hundreds of feet from the injection points, forming thin grout sheets.

Four different sites in Melton Valley were used in the development and full-scale application of hydrofracture operations. These are designated as Hydrofracture Experiment Site 1, Hydrofracture Experiment Site 2, Old Hydrofracture Facility, and New Hydrofracture Facility. This method of waste disposal was used intermittently between 1959 and 1984.

In February of 1992 DOE developed an ER strategy for WAG 10. Integral to the strategy was the proposed division of WAG 10 into three operable units (OUs): OU1—Grout Sheets, OU2—Groundwater, and OU3—Wells and Bore hole. In the near term, the strategy focuses available resources on achieving an Interim Record of Decision (IROD) for plugging and abandonment of existing wells and bore hole. In the intermediate term, the strategy calls for additional investigations to evaluate the nature and extent of groundwater contamination; this information will support design of a long-term monitoring network for WAG 10 and, if required, remedial design for groundwater remediation.

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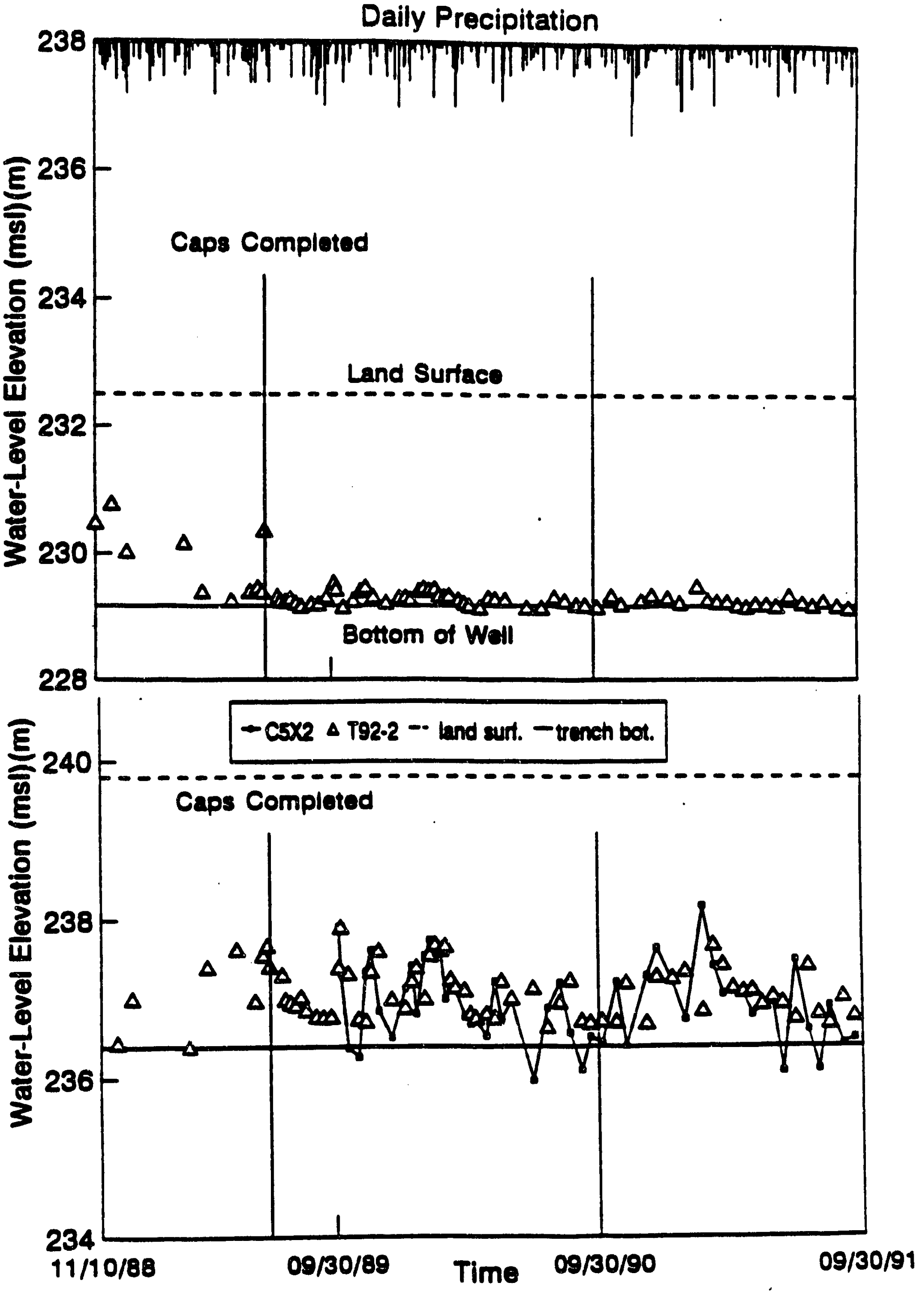

Fig. 3.17. Water levels in trenches at WAG 6: (a) hydrograph for cap area 6 well T101, (b) hydrograph for cap area 5 well T92-2 and nearby groundwater well C5X2.

In May 1992, a WAG 10 Sampling and Analysis Plan for OU3: Wells and Bore hole was submitted to EPA and TDEC. The data collection activities specified in this plan are meant to provide data to support determination of which of the approximately 100 wells should be plugged and abandoned and which may potentially be modified for use during subsequent investigations.

Beginning in June 1992, a worker environmental, safety, and health (ES&H) survey will be conducted for the area around each wellhead. This survey will identify potential hazards to workers and will include a survey of the area around each well for surface radiological contamination. Following this survey, each wellhead will be inspected (without opening the well). Using the information collected during this survey, a detailed plan will be prepared for tapping each well (without removing the cap) and for measuring well headspace gas pressures. (Note that WAG 10 wells may be under pressure and caps cannot be removed until pressure measurements have been made.)

Upon completion of the detailed plan, work will begin on this activity and continue into FY 1993. Additional activities to be conducted during FY 1993 include well headspace gas sampling, well water sampling, and bore hole geophysical logging. Also, a seismic reflection survey will be conducted to confirm the presence of a fault in the vicinity of WAG 10 that may impact contaminant transport. WAG 10 OU3 field activities are expected to be complete by September 1993, and results will be documented in technical memoranda and an OU3 SI Report to be completed in April 1994.

3.5 HYDROLOGIC PATHWAYS AND SECONDARY SOURCES

The previous parts of this discussion have focused on monitoring at the site-wide scale or the individual WAG scale. There is also a series of special studies incorporated into the SI Program that focuses on the processes that control the transport and discharge of contaminants in the subsurface regime. These studies generate information that is needed to model fluxes of contaminants in groundwater, a key objective of the WAG 2/SI Groundwater Task. This section describes the first of four of those studies.

An important component of risk assessment is the source term, defined as the release rate of contaminants as a function of time and space. A preliminary investigation of processes that affect source term identification was initiated in 1991 (Wickliff et al. 1991). The source terms associated with burial areas on the ORR are difficult to quantify because the disposal records are deficient and the hydrogeochemical system is complex. It may be possible to define the source term of a large area such as a subwatershed within a WAG using water quality data from streams, storm flow, and groundwater. This approach requires an understanding of major processes that control subsurface contaminant transport. Sect. 3.2.2 discusses how a secondary source is generated and some of the implications to ER.

3.5.1 Methods and Results

SWSA 5 is known to be a significant source of tritium (^3H) to the WOC watershed (Fig. 3.18). Because ^3H mobility is not attenuated significantly by geochemical processes, the sustained ^3H discharge many years after disposal began suggests that matrix diffusion is an important process in SWSA 5. An area on the southeastern edge of SWSA 5, where a known contaminant plume exists, was selected for investigation to gain understanding of processes (particularly matrix diffusion) that may be affecting contaminant transport from primary waste sources to streams. Soil core and groundwater samples were collected along vertical profiles to a depth of about 3 m. Subsurface collection tubes were also installed in the area to collect stormflow samples in the vadose zone during and following rain storms.

Tritium activities in the groundwater and soil core samples increase with depth with the highest activities found at the greatest depth below the water table (Fig. 3.19). The vertical distribution of ^3H is very smooth, unlike what might be expected in a fractured and heterogeneous environment. There was also little difference between ^3H activities in groundwater samples and activities in pore water extracted from soil cores. Both the distribution and the agreement between groundwater and pore water activities suggest that diffusion, rather than advection through hydraulically active fractures, dominates contaminant transport mechanisms over the interval (0–3 m) sampled in this study.

The ^3H activity in stormflow is much less than that observed in groundwater, indicating that storm flow is not as significant as groundwater in transporting ^3H from the burial ground to the stream in this area of SWSA 5. However, ^{90}Sr activities suggest that subsurface storm flow is more important for ^{90}Sr. Peak ^{90}Sr values do not coincide with peak ^3H values, which may indicate that ^{90}Sr and ^3H come from physically distinct primary sources.

The observed ^3H and ^{90}Sr values from SWSA 5 have been used to formulate a working hypothesis of contaminant transport, the role of matrix diffusion, and the existence of primary and secondary sources. The vertical profile of ^3H may be a result of upward diffusion from a hydraulically dominant fracture (or fractured zone) coupled with a small amount of lateral advective transport within the matrix. A hydraulically dominant fracture of high ^3H activity existing beneath the interval sampled would suggest that there is still a source upgradient supplying ^3H to the subsurface system and that the contaminant release from SWSA 5 to the stream will continue to increase until that source is depleted. This hypothesis is tentative, and additional data are required to make definitive statements.

A simple mathematical model was used to examine the general effects of matrix diffusion on contaminant transport in SWSA 5. The model accounts for one-dimensional transport along parallel fractures coupled with one-dimensional diffusion into and out of the surrounding matrix. The geometry of the modeled system is shown in Fig. 3.20, in which it is assumed that a system of parallel fractures intersects primary contaminant sources and conducts water and contaminants to discharge points in streams. The effects of matrix diffusion on contaminant transport are largely controlled by the flux of water in fractures relative to the mass of water stored in the porous matrix. Expected parameter values that bracket the range of fracture water flux relative to water mass in the matrix for SWSA 5 were

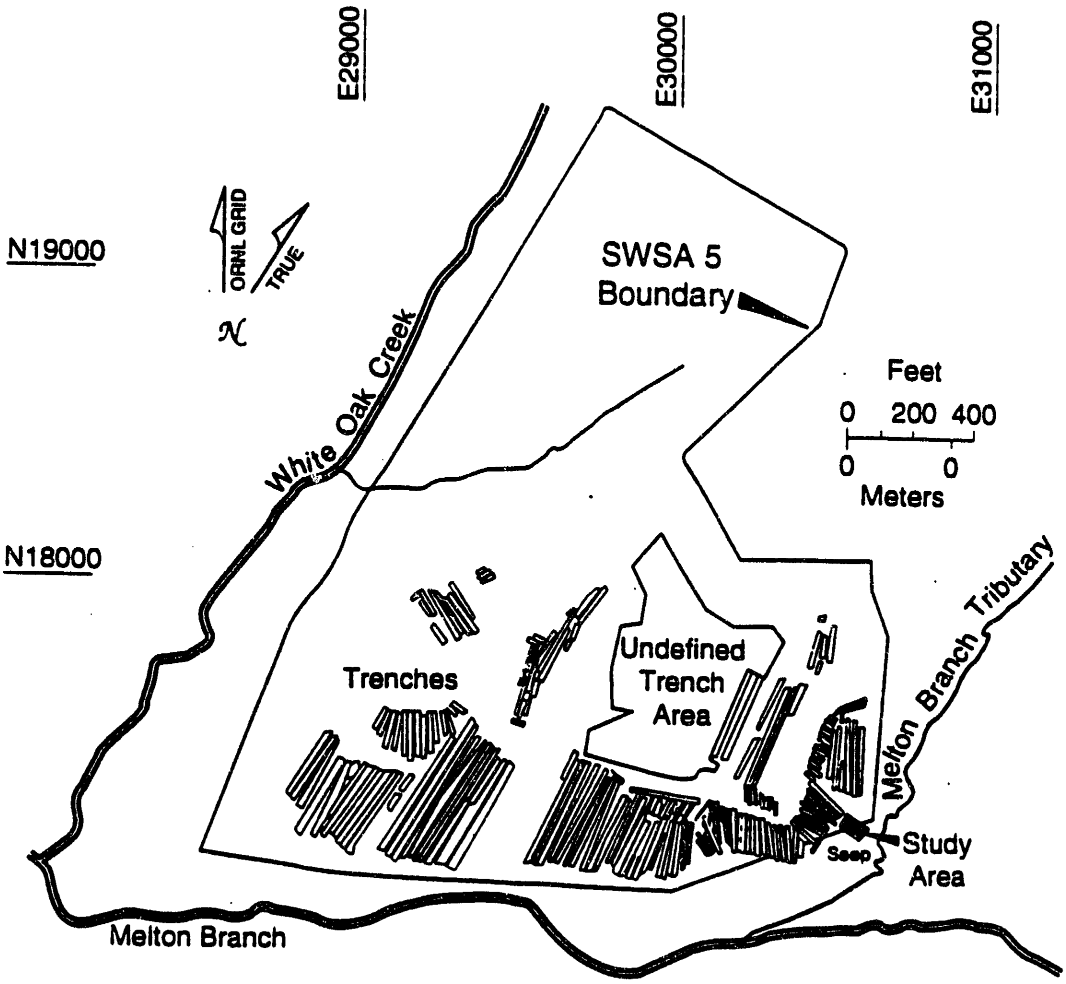

Fig. 3.18. Map of SWSA 5 showing investigation site.

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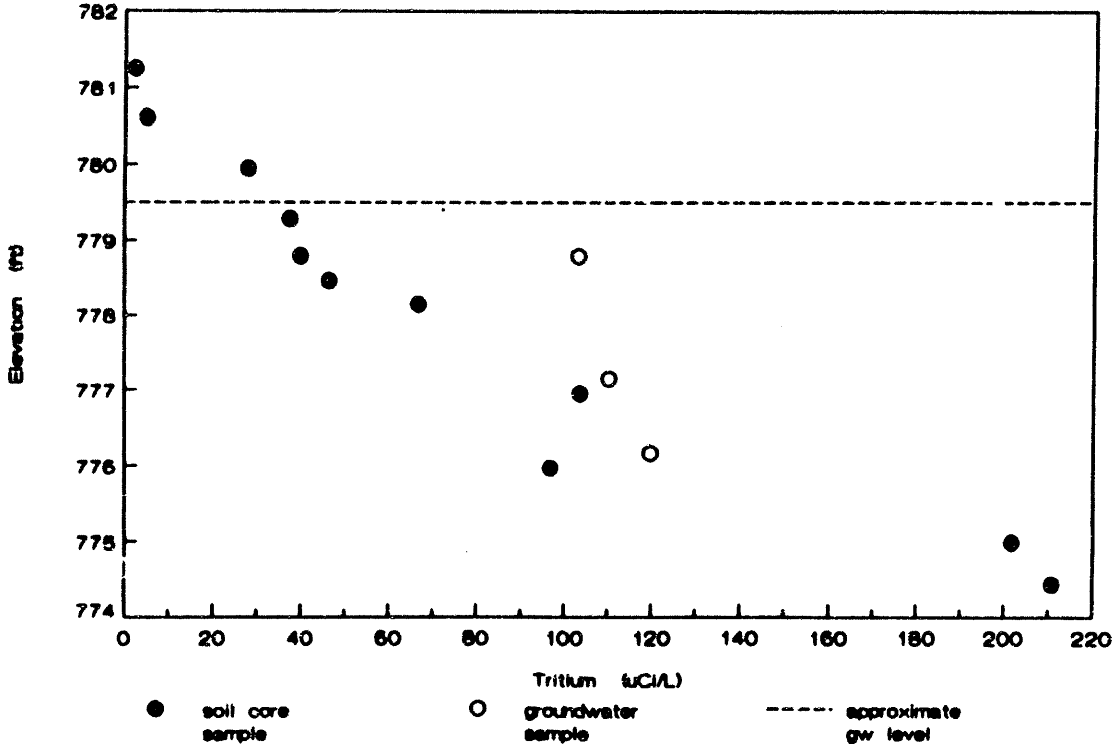

Fig. 3.19. Vertical distribution of ^{3}H at the southeast edge of SWSA 5.

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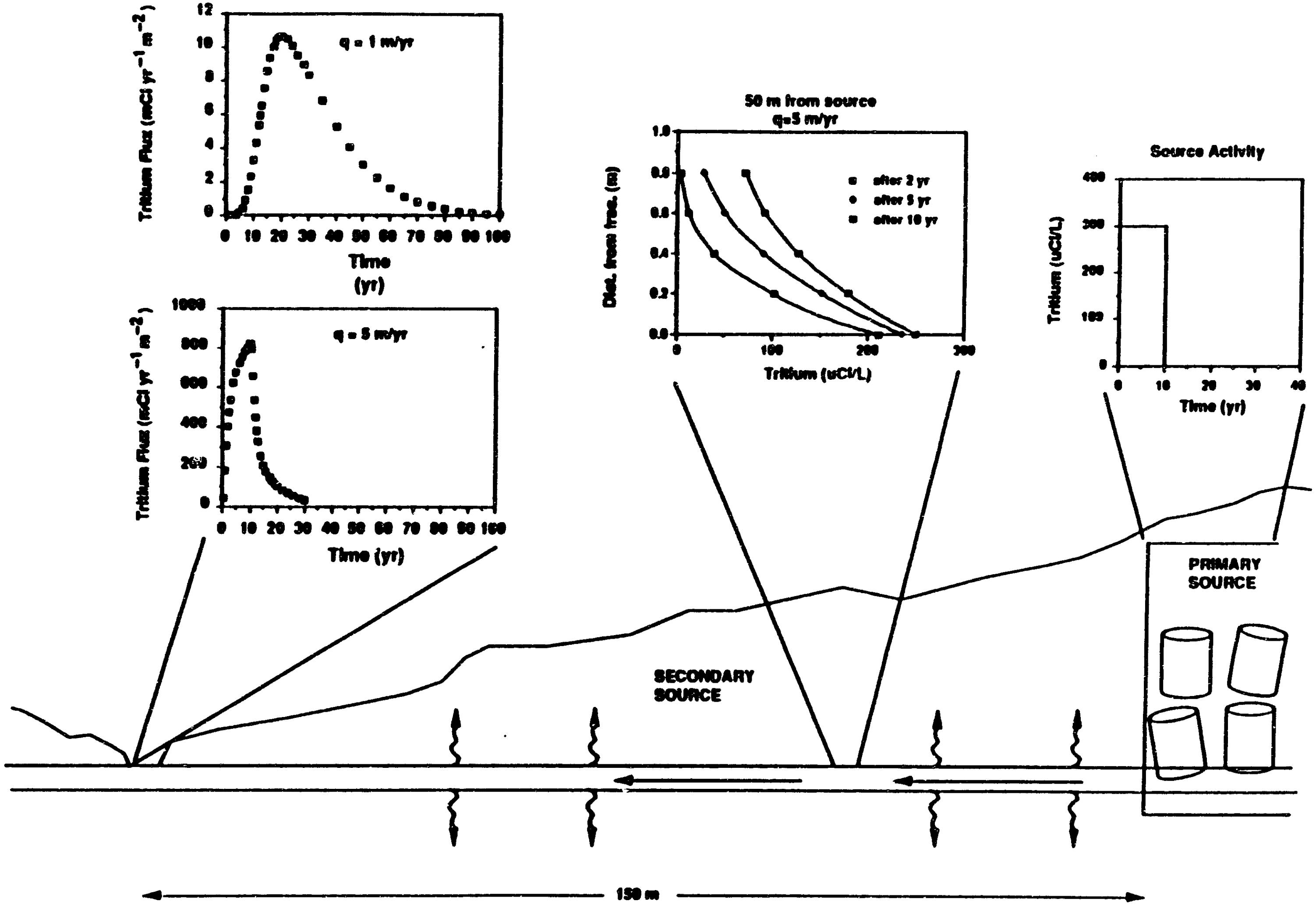

Fig. 3.20. Contaminant transport modeling results.

used in the simulations. Simulations of the ^{3}H profile resulting solely from molecular diffusion bear a striking resemblance to the observed ^{3}H profiles in the study area, suggesting that diffusive processes are important at SWSA 5.

3.5.2 Summary and Conclusions

Although preliminary analysis of the ^{3}H data from SWSA 5 suggests that primary sources are still active (and thus the ^{3}H discharge to streams may continue to rise for some time), existing data do not allow a prediction of the response of the systems resulting from proposed remedial actions. For example, transport simulations (for nonsorbing contaminants) indicate that if the specific discharge is 5 m/year, the remediation of primary sources would result in improved water quality within several months and secondary sources could be removed by natural flushing within about 10 years. (The specific discharge is the mean water velocity in the fracture.) However, if the specific discharge is 1 m/year, improvements in water quality could lag remedial actions by more than 10 years and secondary sources by natural flushing could take more than 70 years. Both the amount of contamination stored in secondary sources and the fracture hydrologic characteristics are important to performance after remediation has been completed.

This year additional sampling at greater depths (to determine the vertical extent of ^{3}H migration) along with point dilution and bore hole flow measurements will be completed. The point dilution and bore hole flow tests will determine the zones of greater flow and help define the specific discharge more precisely, which should enhance our ability to predict the system's response to proposed remedial actions. These results will be reported at the end of FY 1992.

3.6 GROUNDWATER-PRODUCING FRACTURES

In the Groundwater-Producing Fractures Investigation (Moore and Young 1992), the permable zones in piezometers, monitoring wells, and core holes were systematically identified and quantified for the first time on the ORR. The investigation was possible due to an innovative bore hole flowmeter developed at the Engineering Laboratory of the Tennessee Valley Authority (TVA). The objectives of this project were (1) to show the innovative ways in which the flowmeter can be used to generate useful information (2) to gather the evidence to confirm/refute the existence of a water table interval at the top of the groundwater zone, and (3) to generate the parameters describing hydrologically active fractures needed for groundwater modeling.

3.6.1 Electromagnetic Bore Hole Flowmeter

As described by Young et al. (1991), the purpose of the electromagnetic flowmeter is to measure the vertical flow rate of water at an elevation in a core hole or a screened portion of a monitoring well, as illustrated in Fig. 3.21. The bore hole flowmeter produces an absolute measurement of the flow rate up or down a well at a selected depth position; the relative change in flow rate between two depth positions indicates whether or not a pervious

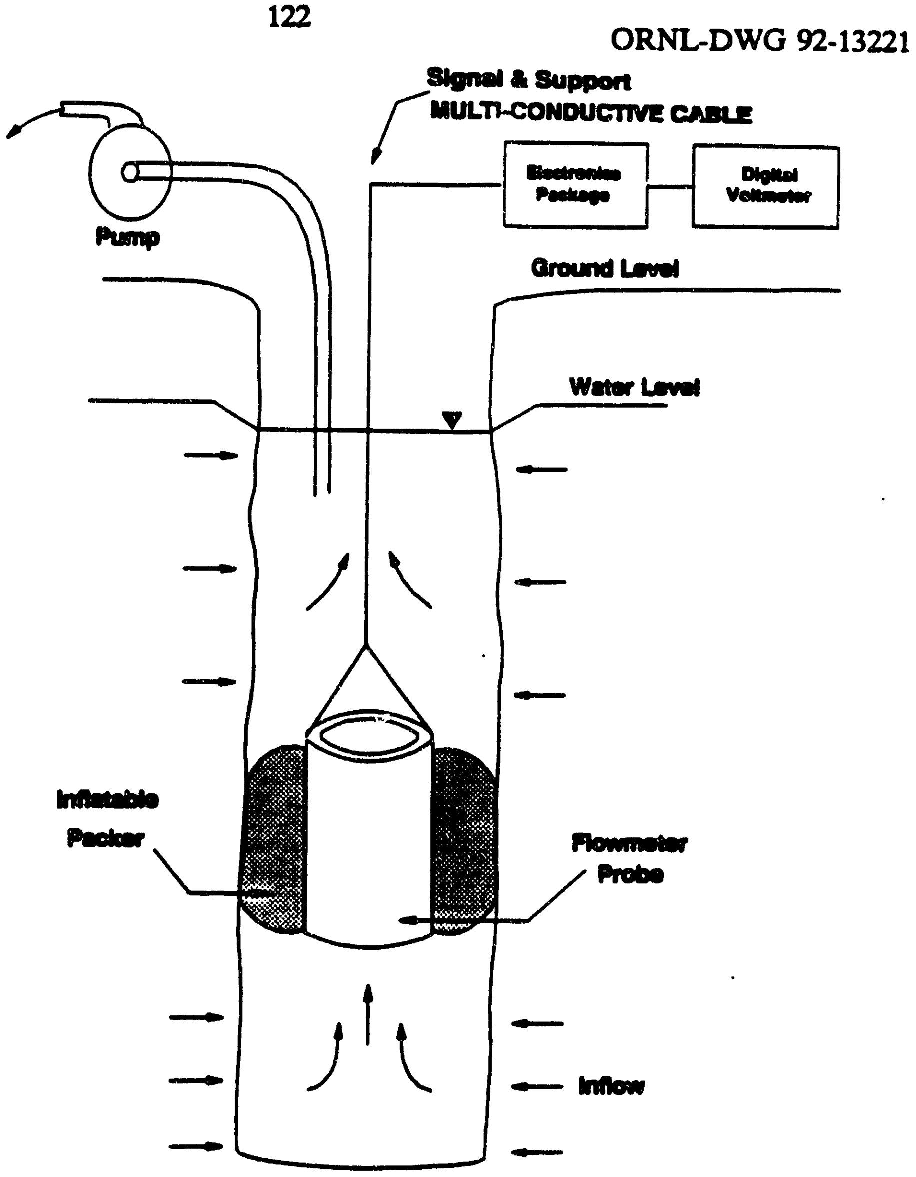

Fig. 3.21. Schematic of electromagnetic flowmeter system, Young et. al. (1991).

fracture occurs in the interval. If a well has no natural flow, flows are induced by pumping or injecting water. The instrument can measure a water velocity as small as 3.0 cm/min, and sequential measurements of flow rate within impermeable sections of a well generally differ by <0.02 L/min. The advantages of the TVA flowmeter relative to other commercially available flowmeters are that it has no moving parts, it is easy to decontaminate, it does not require frequent recalibration (a once-a-year check is sufficient), and it is useful in low-permeability bedrock because of its wide range and high sensitivity.

3.6.2 Uses of the Flowmeter

The bore hole flowmeter data on the ORR have been used to select monitoring depths in newly constructed wells, to check the accuracy of screen depths in well-construction archives, to evaluate the potential for cross contamination (a flow of pollutants in a well from one level to another), and to characterize permeable fractures in the rock (Moore and Young 1992). Fig. 3.22 shows the flowmeter data from three wells, and wherever the data trace is level there is not a loss of flow from the well, thereby indicating that the formation is impervious. Wherever the data trace is sloped there is inflow/outflow, indicating a flow zone, termed a pervious section.

Piezometer well 703 near ORNL, for example, is screened at depths of 18–24 m, but the flowmeter survey shows that the only pervious section occurs at depths of 22.9–23.6 m (Fig. 3.22, top); about 90% of the screen is ineffective. Also, for example, the archival data for piezometer well 575 (ORNL Main Plant) indicate a well screen at depths of 3.0–4.6 m; the bore hole flowmeter survey shows that the screen occurs at depths of 1.8–3.4 m and that the only pervious section occurs at depths of 1.8–2.4 m (Fig. 3.22, middle). The other flowmeter surveys show that well construction depths are correct or have errors of <0.6 m.

The results of the flowmeter surveys show that there are not natural flows of water in the piezometer wells where screen lengths are 1–10 m long. In these wells, cross contamination is not a concern if the bore hole annulus is sealed from the surface to the water table. However, natural flows were detected in all long, open core holes that were surveyed. In core hole 2 at the ORNL Main Plant, for example, there is downward flow from a pervious section above a depth of 6 m to a pervious section at 6–9 m as well as upward flow from an interval below 37 m to a pervious section at 23.1–23.5 m; the flowmeter data also suggest a permeable fracture that may be a sink for both upward and downward flows in the interval 12–15 m. Results of this type show a potential for cross contamination.

3.6.3 Permeable Intervals and Evidence for a Water Table Interval

Analysis of the bore hole surveys for about 70 wells on the ORR (Moore and Young 1992) found that hydrologically active sections of the bore hole existed at two scales. Slug tests at numerous wells and other data suggest that permeable intervals are separated by large (>3 m), impermeable or low-permeability intervals. Within the permeable intervals there is also variation in permeablility; therefore, these intervals are subdivided into pervious and impervious sections, as illustrated in Fig. 3.23. The terms permeable interval and pervious section apply to the large and small scales, respectively.

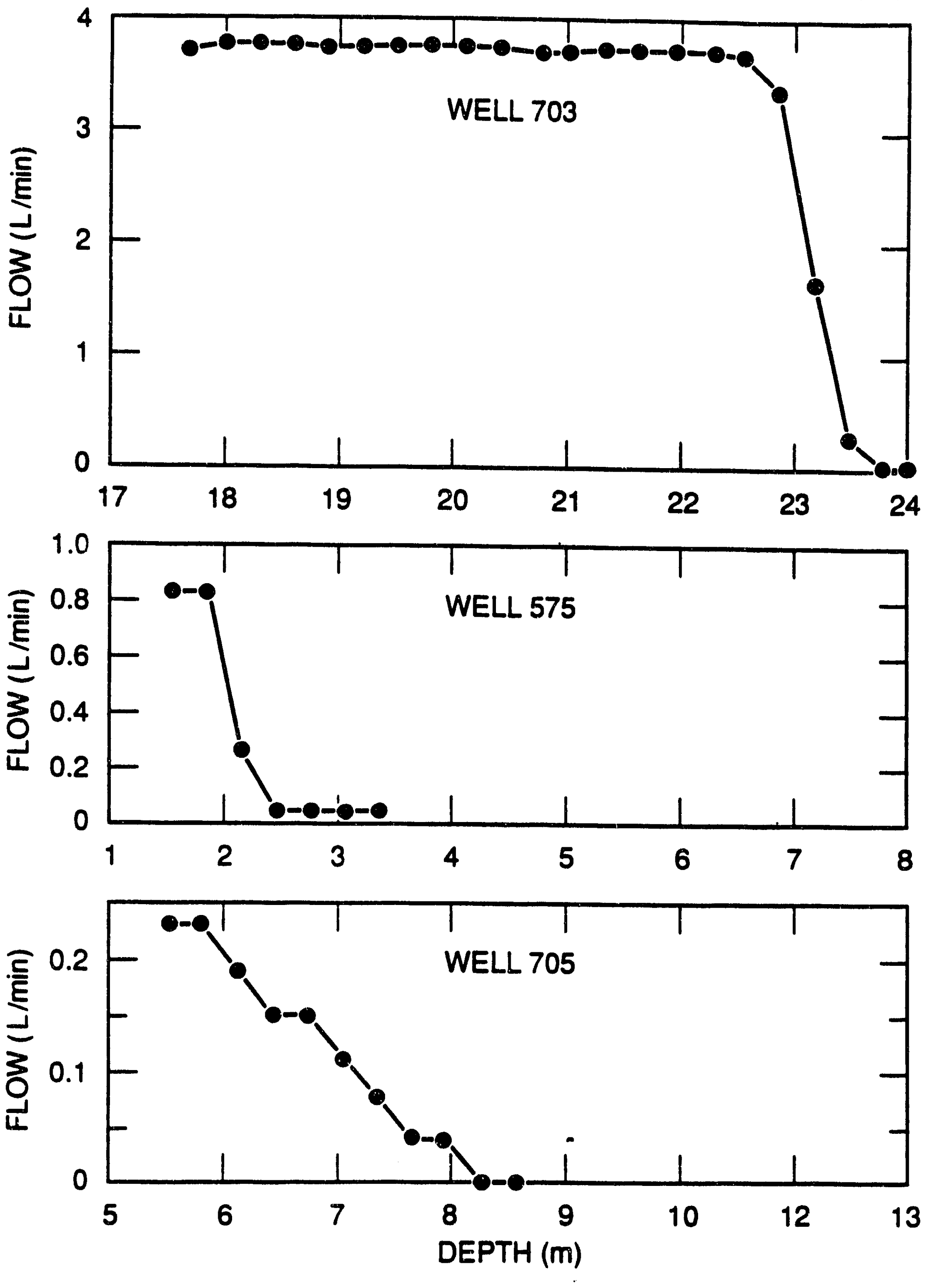

Fig. 3.22. Typical borehole flowmeter surveys on piezometer wells.

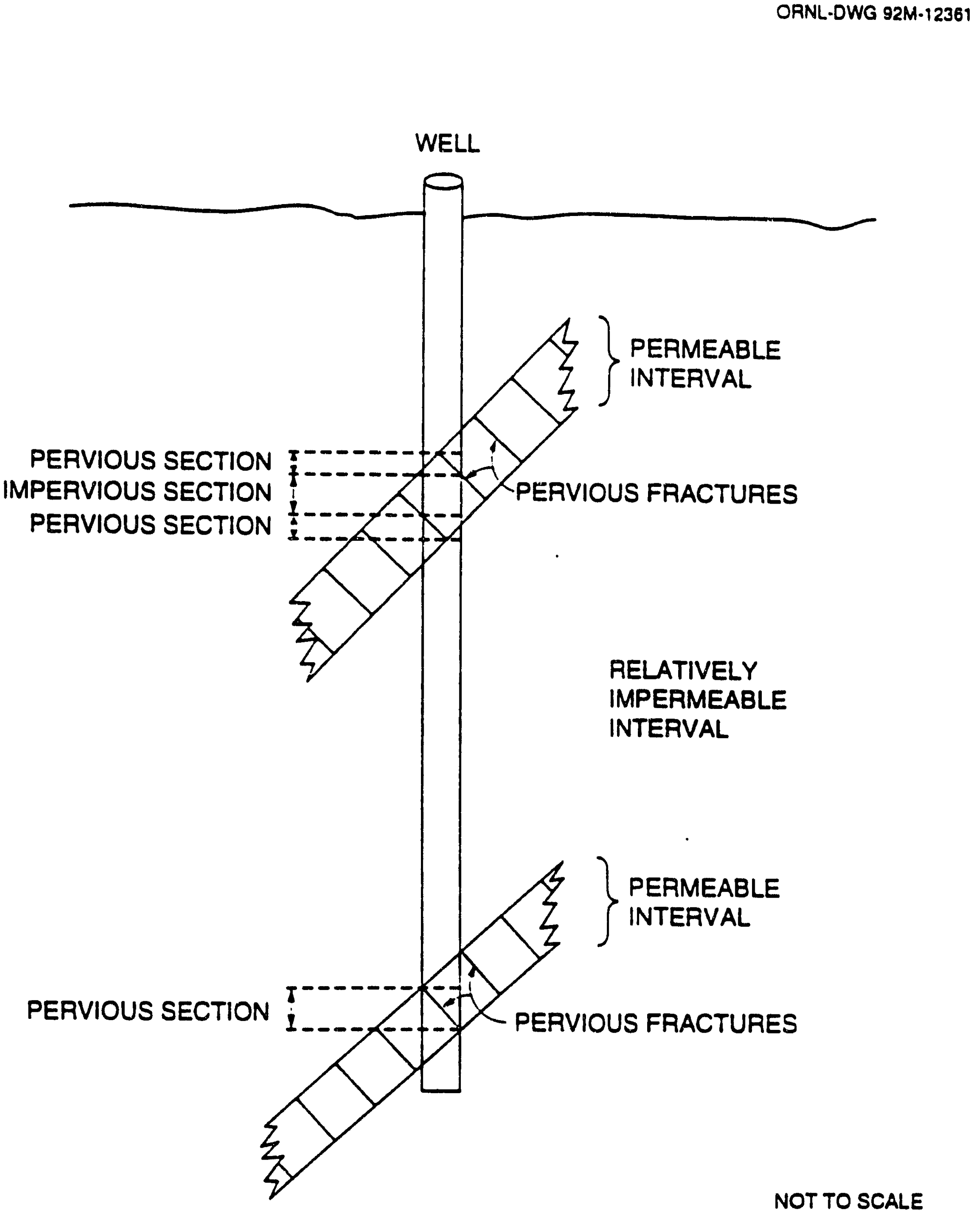

Fig. 3.23. Diagram showing the geometry for the calculation of fracture dip and spacing.

The borehole surveys show a nearly constant first derivative of flow rate within a pervious section and abrupt changes to a nearly constant flow rate at the top and bottom of the pervious section. From these characteristics it is assumed that each pervious section consists of a single fracture with a uniform hydrualic conductivity. These high-angles fractures are throught to span the thickness of a permeable bed, as shown in Fig. 3.23.

Table 3.5 shows the thickness (vertical extent) of individual pervious fractures for two depth classes as measured from the water table. For both depth classes the thicknesses are log normally distributed. For depths >6.1 m the thickness is signficantly less than for those 0-3 m deep. This difference in fracture thickness is direct evidence of a unique water table interval:

3.6.4 Inferred Fracture Dimensions

Moore and Young (1992) devised a system to use pumping test data with information on the distribution of pervious sections with a bore hole to compute hydrologic parameters of individual fractures. Their system shows that the geometric means for the hydraulic conductivity, inter-fracture orthagonal spacing within a permeable interval, and fracture aperture are 0.12 m/d, 0.44 m, and 9.5 10^{-5} m, respectively. The specific yield for the fractures is likely to be in the range from 9.2 10^{-5} to 7.5 10^{-4}.

The derived hydraulic parameters for fractures, based on the assumption of a single intersecting fracture per pervious section, are critically important to quantifying and modeling the groundwater regime on the ORR. Once these models are operative, the effects of the individual parameters can be investigated by simulation, but more field work is needed. Flowmeter data should be compared to direct observations, bore hole cameras, or inspection of core to find out how accurate the single frature assumption is. The mathematical theory relating bore hole measurements to fracture parameters needs further refinement and testing. Finally, bore hole flowmeter surveys should become part of the routine geophysical logging performed during well construction. ER should work with TVA to have an electromagnetic flowmeter specially designed and built for ER purposes.

3.7 HYDROLOGIC HEAD MEASURING STATIONS

The Hydraulic Head Measuring Stations (HHMS) are well clusters and single wells that provide data required for evaluating the transition between intermediate and deep groundwater systems and the nature of these systems (Fig. 3.24). Specifically, this project provides a means for defining the boundary of the uppermost aquifer, identifying potential pathways for off-site contamination for intermediate and deep groundwater flow, and evaluating the capacity for contaminant transport in intermediate and deep groundwater flow systems. As part of FY 1992 HHMS activities, three wells have been constructed along the southern perimeter of Haw Ridge. The wells are located roughly along geologic strike; two of the wells straddle WOC and the third is sited west of WOC (Fig. 3.25). The wells will be instrumented with multi-port measuring systems so that a vertical distribution of water samples and pressure measurements can be obtained. Initial examination of core and bore hole

Table 3.5. Height of permeable intervals within boreholes

Depth below water table (ft)	Number of fractures	Geometric mean	Fracture height (ft) Mean minus one standard deviation	Fracture height (ft) Mean plus one standard deviation
0–10	56	2.8	1.4	5.6
>20	38	1.6	1.0	2.5

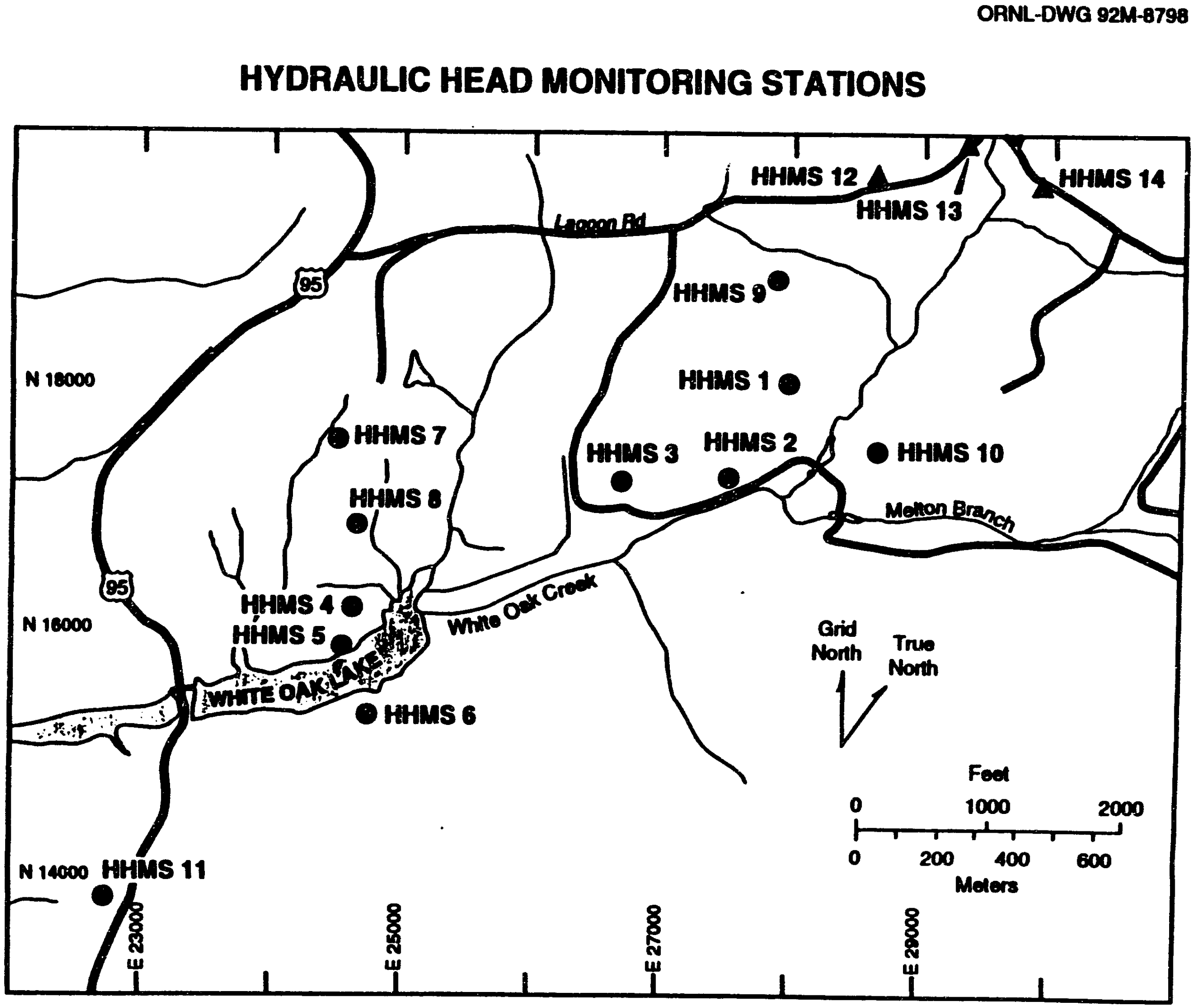

Fig. 3.24. Locations of Hydrostatic Head Monitoring Station wells.

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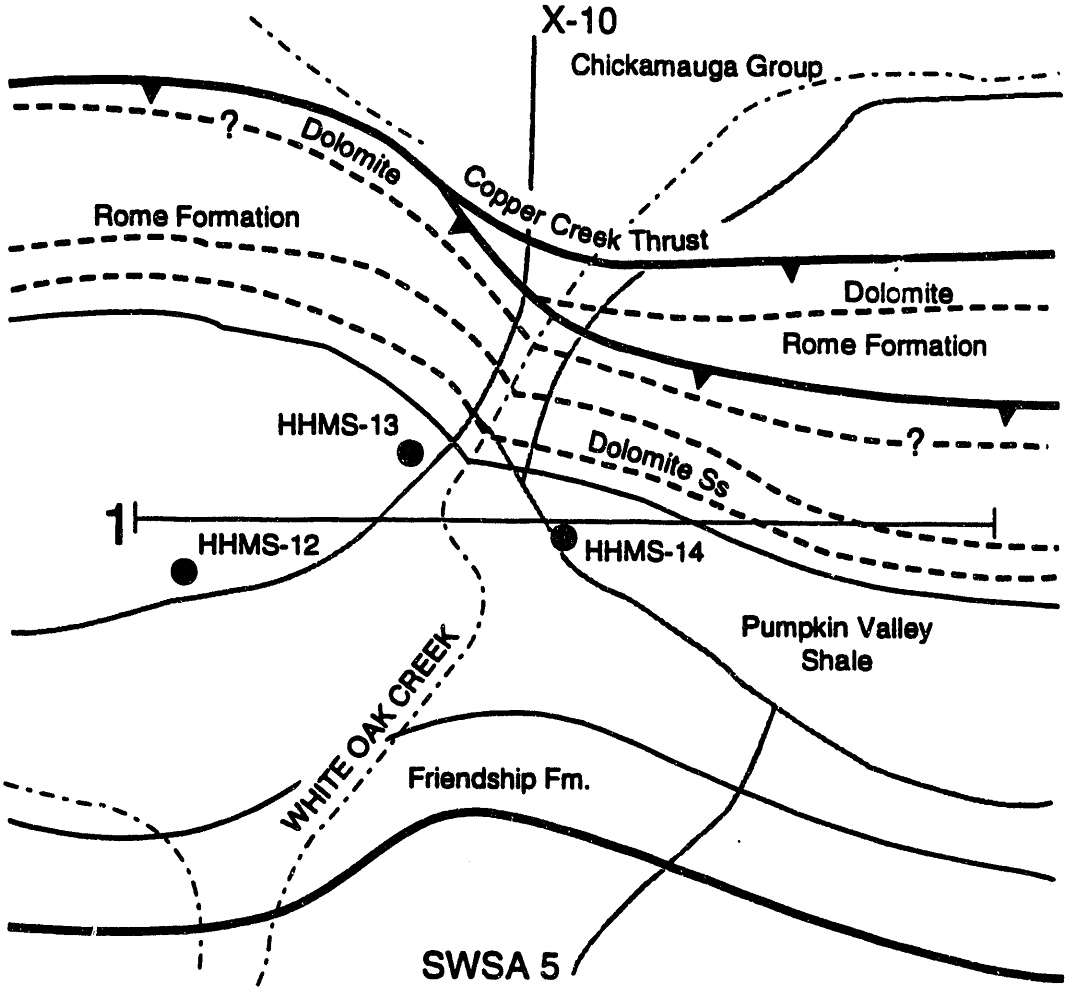

Fig. 3.25. Locations of Hydrostatic Head Monitoring Station wells to be drilled near the WOC water gap.

geophysical logs show that all three bore hole are collared in the Pumpkin Valley Shale and intersect the Rome Formation at varying depths, reflecting local relief in the Pumpkin Valley Shale–Rome Formation contact, which may be affected by the underlying Copper Creek Thrust Fault (Fig. 3.26). All three wells are flowing artisan, and the elevated heads are attributed to recharge from neighboring Haw Ridge. Estimated flow rates vary between the wells from approximately 0.1 to 2.5 gal/min. The largest flow rates are observed in two wells that intersect a dolomite-rich section of the Rome Formation (HHMS-13 and HHMS-14). In addition, HHMS-13 is apparently finished within or immediately above the Copper Creek Thrust Fault. This well will be deepened so that the well is finished in Chickamauga Group rocks within the footwall of the thrust fault. Water chemistry and hydraulic head measurements obtained from the finished wells will allow us to evaluate hydrogeologic relationships between proposed stratified flows systems and a thrust-faulted geologic system of carbonate and clastic lithologies.

The HHMS investigations will look for any evidence of active flow that may connect potentially contaminated groundwater from the intermediate interval to deeper levels. The working hypothesis that there is no significant flow in the deep zone is based on estimates of recharge, which are small (less than 1 cm/year, Solomon et al. 1992), relatively low frequency of fractures at depth and slow recovery of water levels in deep wells following development or sampling. Direct observation including geochemical investigations, are needed to provide further evidence for the extent of hydrologic isolation in the deep system.

3.8 GROUNDWATER MODELING

There has been no multidimensional large-scale groundwater modeling effort in Melton Valley since the early 1980s, and new information has become available that requires assessment by models. We are unable to assess flow paths or make predictions about effects of present and future remediation actions because of limitations in past modeling efforts (no true three-dimensional models and no fracture flow models in waste areas).

Specifically, we plan to address the following questions of relevance to predicting groundwater transport and waste management:

1. Does anisotropy cause preferential flow along strike in the intermediate and deep intervals? Strike orientation is parallel to Bethel and Melton valleys, and past studies have shown that fracture orientations cause shallow groundwater to move preferentially along strike. The effects of anisotropy at depth has not been explored. The interaction between strike-oriented flow paths and the tilted bedding is uncertain and these effects cannot be investigated with standard two-dimensional models. Because more detailed permeability measurements and stream discharge data are now available, we can better construct a three-dimensional model. In turn, modeling investigations will yield a clearer picture of the flow paths for contaminants that can be expected.

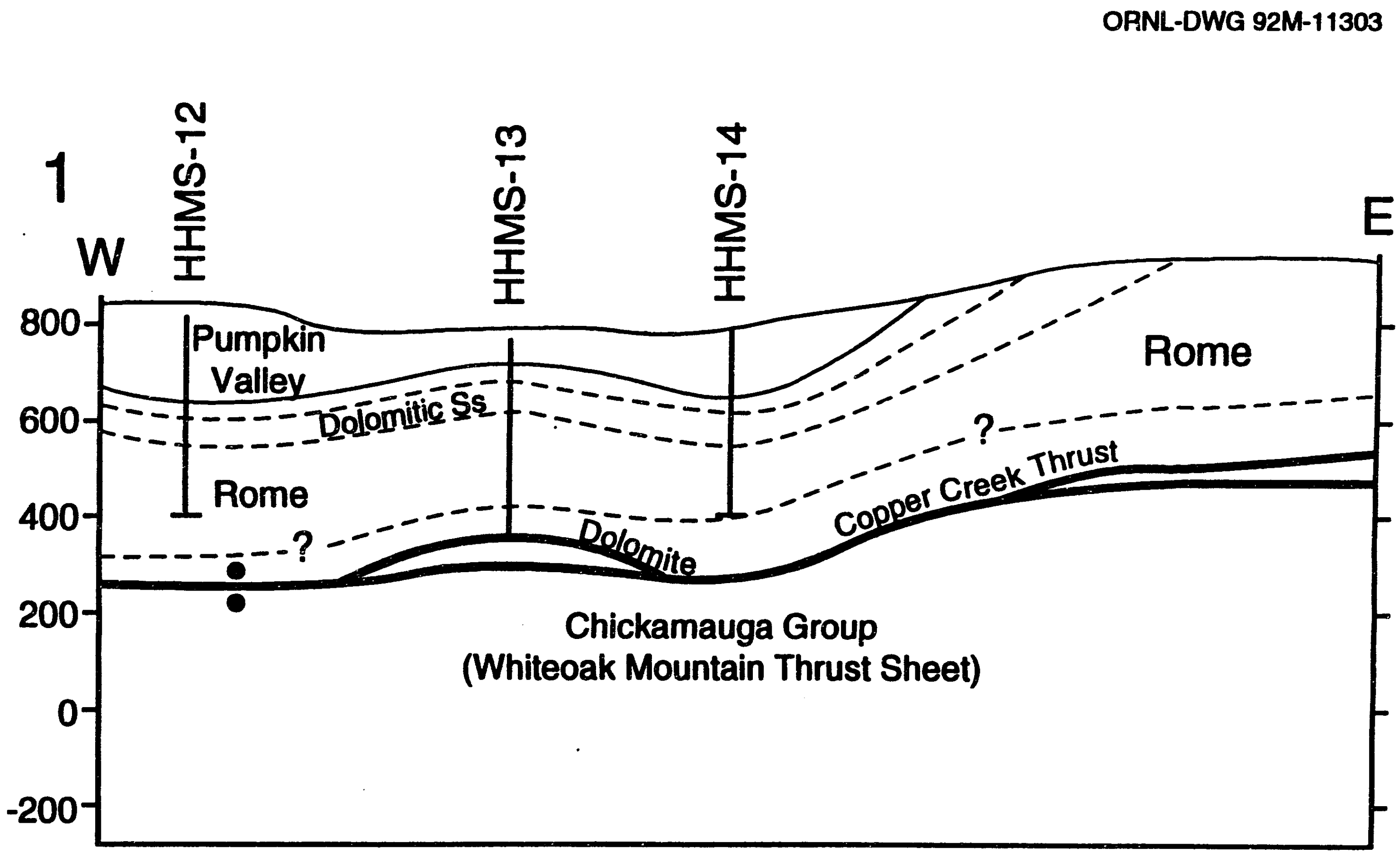

Fig. 3.26. Strike-parallel cross-section through Hydrostatic Head Monitoring Station wells near White Oak Creek watergap.

2. How does capping affect groundwater flow in three dimensions? Since many of the past models have been limited to waste areas and two-dimensional flow, we have not yet obtained full benefit of modeling in assessing cap effectiveness. Our model will incorporate spatial variation in recharge to simulate the effects of caps.

3. What is the component of groundwater flow to off-site surface-water and groundwater discharge? A calibrated groundwater flow model can help quantify the three important discharge components: discharge to the north-south tributaries to WOC and MB; discharge directly to MB, WOC; and WOL; and possible discharge outside the WOC basin caused by underflow beneath WOL. Although the latter flowpath is considered to be insignificant based on our current understanding of the hydrogeology on the ORR, it must be explored.

We propose to use new codes and new data to construct a three-dimensional groundwater model of the lower part of WOC basin that is located in Melton Valley. The area includes WAGs 4, 6, 7, and much of WAG 2. In addition, a large part of the area known to be affected by the hydrofracture disposal (WAG 10) is also included in this modeling investigation. The model application will consider the shallow (water table) groundwater interval (identified in this study as about 40 ft below the surface), the intermediate interval [to an elevation of 400 ft mean sea level (msl)], and the deep interval (to an elevation of 200 ft msl). For reference, the water level in WOL is about 750 ft msl. Although this work doesn't explicitly address fracture flow, the data from this study will be needed to assess possible effects of fractures on anisotropy, and to construct realistic boundary conditions for fracture flow models proposed for future work. An initial report describing the calibrated model for steady-state movement of water will be produced early in FY 1993, and the schedule for extending the modeling investigation to include solute transport has not been finalized.

This investigation is feasible because for the first time we have available groundwater models developed on supercomputers, which allows larger problems (including greater size, additional processes, and more dimensions) to be addressed at workable speeds. The computational aspects are being funded by the DOE High Performance Computing Initiative. The WAG 2/SI and WAG 21 RI (described in Sect. 3.9) are supporting the model application, because the results will be critical to our understanding of the groundwater interactions among the WAGs and to the assessment of groundwater remedial alternatives. Because we have begun to overcome the computational limitations that made more complex models difficult to construct, this effort represents a significant step forward in groundwater modeling on the ORR.

3.9 GROUNDWATER OPERABLE UNITS

Recently, Energy Systems and DOE's Oak Ridge Office, in consultation with EPA (Region 4) and TDEC, began to reexamine how groundwater investigations are conducted on the ORR. It was recognized that groundwater flow paths and therefore restoration activities are not constrained by WAG boundaries. By integrating WAG groundwater activities over a larger geographic area, it is possible to focus both technical and financial resources to address restoration activities in a more comprehensive manner. Consequently, groundwater (GW) OUs have been identified for each of the three ORR facilities.

An IROD will be prepared for each source WAG, and restoration activities conducted. Following restoration of the source WAGs, a final Record of Decision (ROD) will be prepared for each GW OU. A separate, combined source and groundwater ROD will be prepared for the remote WAG 11, White Wing Scrap Yard site.

3.9.1 Descriptions of GW OUs.

Two GW OUs have been defined at ORNL: the Melton Valley GW OU and the Bethel valley GW OU. Collectively, the two GW OUs are considered WAG 21. The GW OUs are viewed as three-dimensional entities, which are intended to encompass source OUs (i.e., WAGs). The limits of the GW OUs are based upon stratigraphy, geologic structure, and expected boundary conditions (recharge/discharge boundaries). The tentative extent of the GW OUs is shown on Figs. 3.27 and 3.28 in plan and cross-sectional view, respectively. The Bethel Valley GW OU encompasses WAGs 1, 2, 3, 9, and 17, and extends from the middle member of the Rome formation (Fm) along the axis of Haw Ridge on the south to the Fleanor Shale member (formerly designated Unit B) of the Chickamauga Group on the north, and from the Clinch river on the west to Bearden Creek on the east. The Melton Valley GW OU encompasses WAGs 2, 4, 5, 6, 7, 8, 9, 10, 12, 13, and 19 and extends from the axis of Haw Ridge (middle Rome Fm) on the north to the Maynardville limestone outcrop along the base of Copper Ridge to the south, and from the headwaters of Melton Branch to the Clinch River. Both GW OUs extend to depth following the south-southeast dip of the bounding strata identified to the saline water interface. Consequently, the extent of the GW OUs at depth differs from that at the surface and extends further to the south. The saline interface was selected as a lower boundary to align with the "Class C" designation outlined in the Draft Tennessee Groundwater Classification.

3.9.2 Definition of Objectives

The overall objectives of the GW OUs are to: (1) establish an overall long-term monitoring program to provide necessary information to design effective GW OU remedial measures and to monitor the performance of individual source OU WAGs; (2) identify and perform ICMs as required; (3) serve as an integrator for source OU/WAG investigations to determine the overall nature and extent of groundwater contamination (present and projected) and provide for ongoing assessment of groundwater contaminant transport and associated risks to human health and the environment. Additionally, characterization activities associated with the GW OUs will focus on refinement of a conceptual hydrologic model, an evaluation and recommendation for appropriate exit pathway monitoring, determination of reference water quality for groundwater and seeps/springs, and development of an appropriate three-dimensional groundwater flow and transport model (to be used for ongoing regulatory and public communication interfaces, hypothesis testing, remedial design analysis, and performance monitoring).

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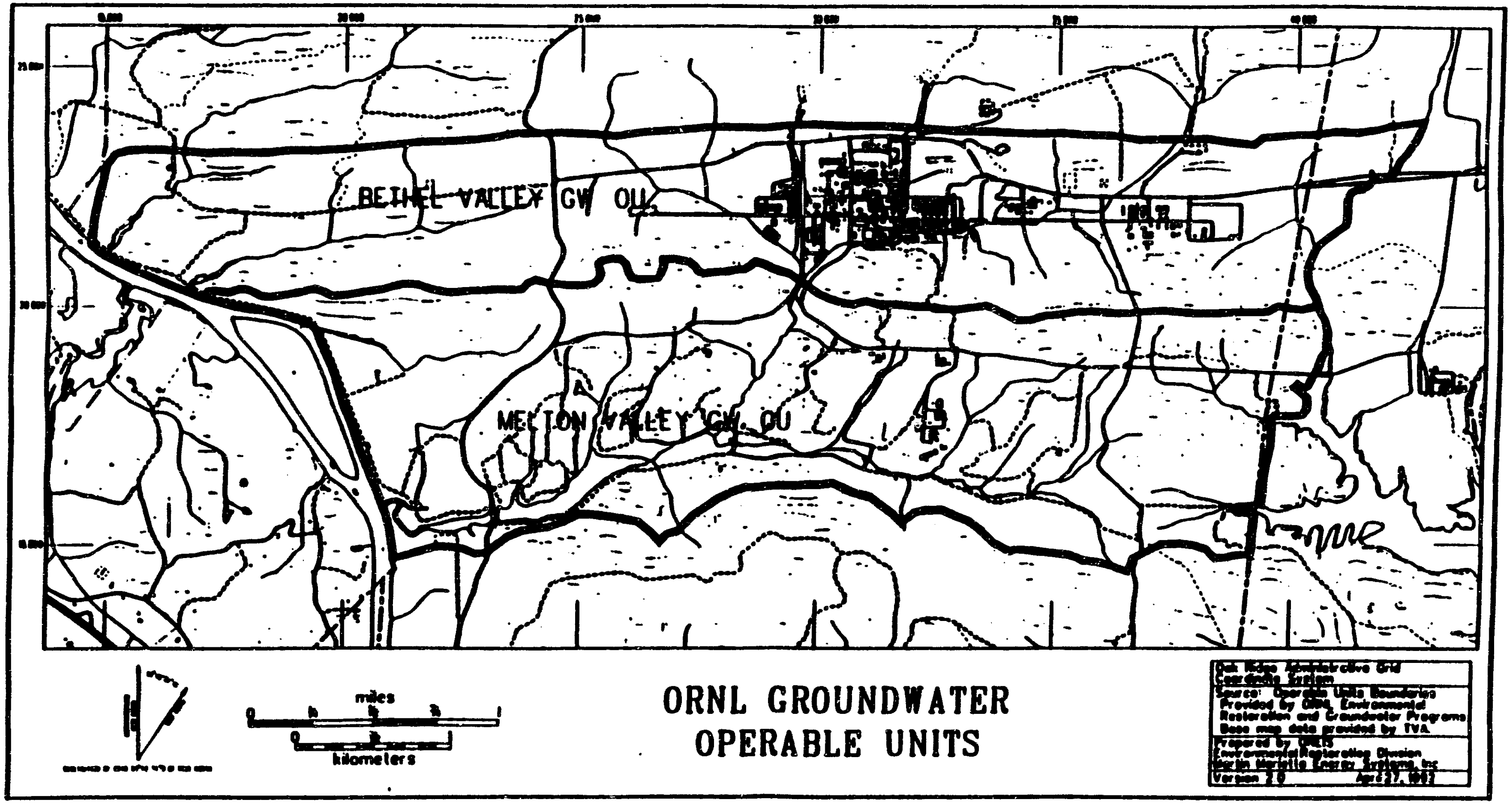

Fig. 3.27. Proposed ORNL groundwater operable units.

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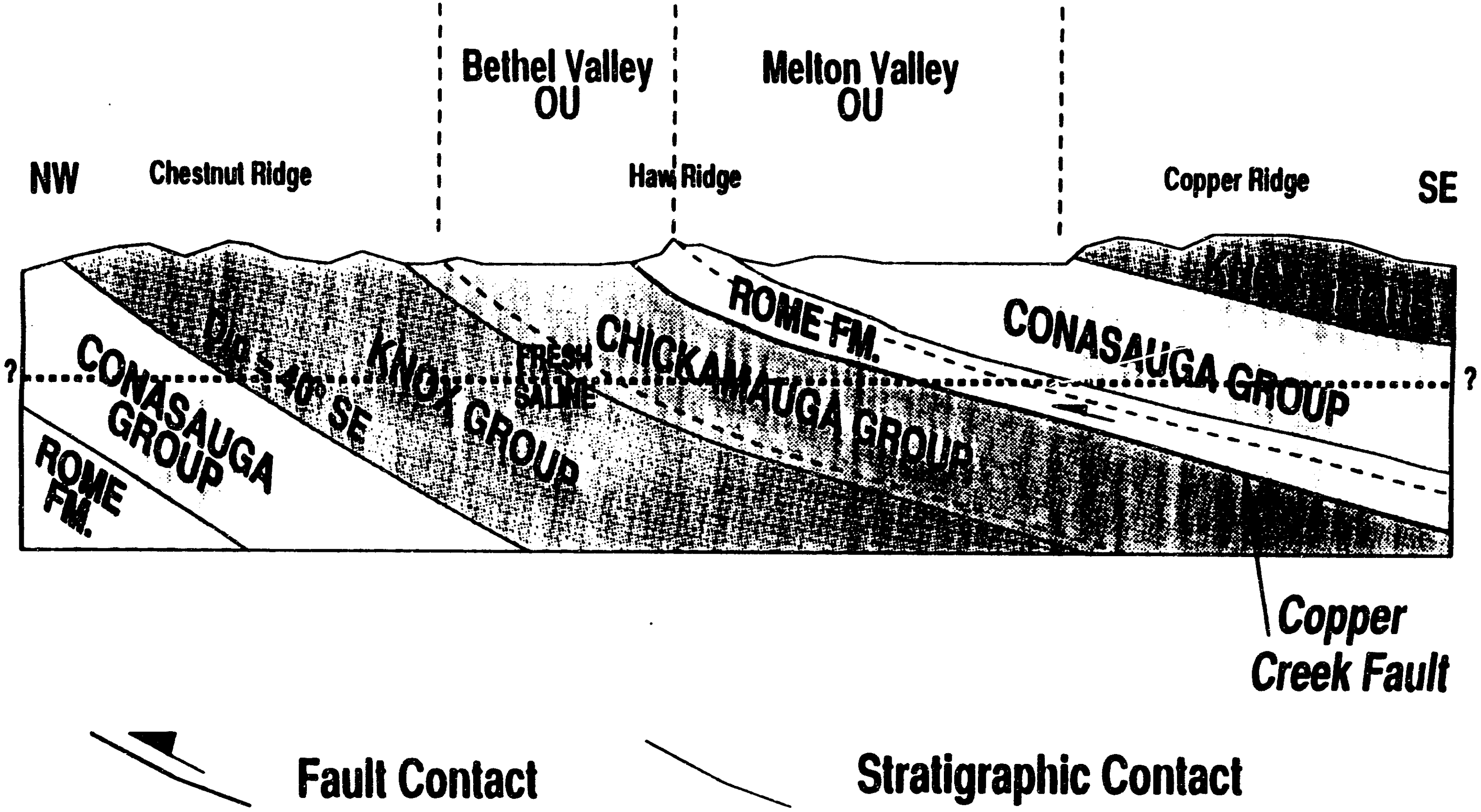

Fig. 3.28. Geologic cross section of groundwater operable units.

3.9.3 Key Technical Issues

Key technical issues include definition of the vertical and horizontal GW OU boundary conditions (evaluating Bearden Creek as a boundary condition, definition and delineation of the saline water interface); an assessment of the nature and extent of contamination in Bethel Valley exclusive of the WOC watershed and secondary sources of contamination within WOC watershed; the role of the Copper Creek Thrust fault as either a barrier or conduit for flow (i.e., is there underflow beneath Haw Ridge connecting Bethel and Melton valleys); and the role of the WOC water gap in groundwater flow and discharge.

3.9.4 Approach

Because of the extended time frame involved in ultimately remediating all source OU WAGs within the GW OUs, it is impractical to pursue remediation of groundwater prior to remediation of the source OUs. Rather, it is necessary to monitor the impacts and performance of source OU remedial actions collectively prior to remediating the GW OU(s) as a whole. Consequently, the GW OU strategy involves long-term monitoring and continual data integration interpretation in the interim. However, considering the large areal and vertical extent included in the GW OUs and the current schedules for RIs and Remedial Actions at source OU WAGs, it will be necessary, in the short term, to acquire characterization data in the non-WAG areas as well as in WAGs not currently identified for investigation or remediation. Additional data are also required to support and integrate source OU WAG RI/FSs. In order to accomplish this, the strategy for the GW OUs involves completion of a multiyear initial RI. In that effort, needed data can be obtained to support development of an appropriate three-dimensional flow and transport model to be used for hypothesis testing and remedial design performance assessment. Specifically, many uncertainties currently exist regarding the hydrologic framework of the GW OUs (including but not limited to definition of boundary conditions for the two GW OUs and understanding the interactions between the two OUs).

During FY 1993, ORNL GW OU tasks primarily focus on planning work for subsequent years. As part of this effort, it is expected that in FY 1993 an RI Work Plan will be developed outlining the approach for the GW OU. Initial characterization efforts of the RI to be performed in FY 1993 include the following:

- An extensive seep and spring survey will be conducted to identify active groundwater discharge points within the two ORNL GW OUs (Bethel Valley and Melton Valley) that make up WAG 21. The survey will build on the results of the WAG 2 Seep and Tributary survey (Sect. 2.5) and extend the coverage to Bethel Valley and portions of Melton Valley outside WAG 2. Initially, all seeps and springs will be located in the field using Global Positioning System (GPS) technology. Field parameters (pH, specific conductance, and temperature) as well as discharge (flow) rate will be measured and recorded for each location. Data will be entered into the appropriate data base, and a digital map of the seep and spring locations will be developed and maintained. The seep and spring survey will be conducted as soon as possible in FY 1993 to identify seeps and springs under baseflow conditions prior to the wet season. Subsequent field reconnaissance will also be conducted during the winter months to confirm previously identified seeps (flow and water quality), and identify new locations. It is expected that a seep and spring location map will be completed by the end of June 1993.

- Recognizing an essential need for basic hydrologic data (groundwater well water levels and quality, seep discharge rates and water quality, surface-water discharge data), a Long-Term Hydrologic Monitoring Plan (LTHMP) will be developed as an element of the RI Work Plan in FY 1993 to enable basic hydrologic data collection to commence in June 1993. Activities will include in this plan will include periodic surface-water discharge measurements and water quality monitoring at existing weirs and flumes not currently monitored as well as at new weirs or flumes where required. Surface-water data collection will be coordinated with the WAG 2/SI Surface Water Monitoring, specifically the Tributary Sampling task (Sect. 2.5), and with the Environmental Surveillance and Protection Division. Groundwater data collection will consist mainly of periodically and/or continuously monitoring water levels and basic water quality parameters (pH, specific conductance, temperature) at a large yet select population of wells. As an initial effort in development of the LTHMP, it is anticipated that two rounds of measurements of water levels and field parameters will be made on approximately 900–1000 existing wells. The plan will present the data acquired during the two initial data collection efforts and provide a geostatistical evaluation of the data to develop the appropriate DQOs with respect to temporal and spatial data density for subsequent monitoring. It is expected that a LTHMP will be completed and submitted to DOE by March 1, 1993.

- Work as specified in the LTHMP to be developed in FY 1993 will be initiated in June 1993. It is anticipated that Annual Hydrologic Monitoring Reports will be generated for each year. This activity must be merged with current ER surface-water monitoring and annual reporting. The first LTHMP contribution to such reports will be submitted in 1994.

The GW OU RI Work Plan will include a detailed summary and interpretation of existing data, an identification of data gaps (integrating existing data and planned activities for source OU investigations), a description of the DQOs for the data, and a complete schedule for project completion with links to surface OU RI/FSs clearly identified. A detailed Field Sampling and Analysis Plan (FSP) will be developed concurrently that will describe locations, sampling methodologies, rationale, and analytical protocols for obtaining the desired DQO data, specific project procedures (SOPs) as required, a Health and Safety Plan, a QA/QC Plan, and a Waste Management Plan. It is anticipated that the GW OU RI Work Plan will be delivered to DOE by September 30, 1993.

3.9.5 Recent Progress

To date, the GW OUs are not funded; however, an ORNL GW OU Life Cycle Costing Workshop was held in May of 1992 in order to develop an integrated technical scope, schedule, and budget baseline for all activities needed to complete environmental restoration of the GW OUs over the life of the program. Other activities to date center on developing the scope and identifying necessary funding for FY 1993 ORNL GW OU (WAG 21) activities.

3.10 SUMMARY

The WAG perimeter well sampling provides the first watershed-scale data set that includes an extensive list of radiologic and chemical parameters collected at high-quality monitoring wells. To provide a site-wide perspective on the data, median concentrations were compared to MCLs from primary and secondary drinking water standards to screen the data. Of the 160 wells sampled, 53% of the wells exceeded one or more of the MCLs (unfiltered samples) and 46% exceeded one or more of the MCLs (filtered samples). The list of the most common to least common types of contaminants were radionuclides (46 wells that exceed MCLs), volatile organics (14), metals (7), and anions (3). The most common radionuclide contaminant was tritium, followed by gross beta then total strontium. The most common metal in exceedance of MCLs was nickle, and the most common organic was tetrachloroethene. The metals in exceedance of MCLs were found mostly in the bedrock wells whereas the other contaminants were distributed almost evenly between the soil/bedrock interface wells and the bedrock wells. Further analysis will examine the data by WAG, depth, geochemical water type, cocontamination, and quality of nearby seep water.

Other WAG 2/SI groundwater investigations are primarily intended to enhance our understanding of groundwater flow mechanisms and to further our modeling capability.

An ongoing investigation of the ^{3}H/^{90}Sr seep in the southeast corner of WAG 5 was designed to determine the dynamics of the primary and secondary contaminant sources. The results of this investigation may have profound implications for the choice of remediation technique at all ORNL WAGs. The field observations coupled with a simple fracture/matrix model may show that many remediation techniques will not produce the expected effectiveness, as judged by changes in contaminant discharge at monitoring stations. If strong evidence for a significant secondary source emerges then there should be serious consideration among ER staff and regulators regarding the consequences to remedial action alternatives.

In the Groundwater-Producing Fractures investigation, 70 wells were surveyed for permeable zones within the bore hole using an electromagnetic bore hole flowmeter recently invented at TVA. The survey data provided the first direct evidence of a unique water table interval at the top of the groundwater zone.

The survey data were also used to calculate hydrologic parameters for fractures based on the assumption that each pervious section corresponds to a single, usually high angle, fracture. Quantifying these parameters is critically important for future fracture-flow groundwater models. Theoretical, laboratory and field investigations to enhance and verify methods of determining fracture hydrologic properties are strongly recommended. Bore hole surveys should be part of routine geophysical surveys for all new wells. ER will work with TVA to obtain a custom-built flowmeter.

During FY 1992, the HHMS project oversaw the installation of three new wells at the WOC watergap in Haw Ridge. This project addresses the issue of whether or not there is groundwater flow between the Bethel Valley OU and the Melton Valley OU.

The Groundwater Modeling project supported by WAG 2/SI is developing a full three-dimensional model of flow in the lower part of Melton Valley. Computer models are the only way to estimate contaminant fluxes in groundwater. The computer program is being implemented on the new ORNL parallel processing computers, allowing a significant increase in spatial resolution and overall complexity compared to standard computer models. When parameterized and tested, this new model will be a significant help for ER assessment capabilities and a significant advancement for groundwater modeling worldwide.

The ORNL groundwater OUs (Bethel Valley and Melton Valley) constitute the new WAG 21. Like WAG 2, it is an integrator WAG receiving contaminants from the source WAGs. In the coming year an RI Work Plan will be developed. Much of the proposed work will build on WAG 2/SI activities such as hydrologic data collection and the Seep and Tributary Sampling Task. WAG 2/SI staff and the WAG 21 manager will develop an integrated approach to collecting, processing, and interpreting data of mutual importance.

The first priority for FY 1993 work is the completion of the analysis and interpretation of the WAG perimeter water quality data set. The results will be used to review the list of analytes and sampling schedule to ensure that resources are allocated rationally. The results will also provide a more complete understanding of the extent of groundwater contamination. Work will be conducted with the input and cooperation of the WAG 21 manager.

The second priority is to assess the role of groundwater inputs to WAG 2. Existing data from many groups and activities must be integrated. The Groundwater Modeling task also will provide valuable information.

Tasks designed to understand the movement of water and contaminants in the subsurface will be continued into FY 1993: the Hydrologic Pathways and Secondary Sources Task, the Groundwater-Producing Fractures Investigation, and the HHMS project. Seep and tributary sampling results will be integrated with groundwater analysis.

4. SOIL AND SEDIMENT

4.1 INTRODUCTION

Information on soils and sediments at the ORNL site is important for the ER program. Contaminated soil can be a significant pathway of exposure for human health and environmental risk (see Sect. 1). The movement of soils and sediments can transport particle-bound contaminants, and the deposition of eroded sediments can interfere with the functioning of weirs and change the hydrodynamic characteristics of the surface-water system. Characteristics of soils and sediments on the ORNL WAGs influence remedial actions (treatability, construction, removal, etc.). Soils and sediments eroded from uncontaminated areas become contaminated as they enter contaminated areas (e.g., WAG 1 and WAG 2), thus sediment from both contaminated and uncontaminated areas are of concern.

Data for soils and sediments at the ORNL site are available from numerous scientific investigations, monitoring, and characterization studies dating back to the early days of activity at the Oak Ridge Site. More recently, efforts under way as part of the ER Program have reviewed existing data and collected additional data for soil characteristics and contaminant concentrations and distributions. The coverage of recent data collection activities and part of the RI/FS process for WAGs 1, 5, 6, 2, and the Clinch River, as well as the ORRHAGS Background Soils Survey, are shown in Fig. 4.1.

The issues associated with contaminated sediments concern many groups at ORNL and span broad spatial (within WAG to watershed release) and temporal scales (current vs future releases). An ORNL Sediment Task Force was formed to (1) share information on contaminated sediment and activities in the watershed that might change sources or transport of contaminated sediment; (2) link sediment transport modeling efforts; and (3) develop and implement a contaminated sediment management strategy. The groups currently participating in the sediment task force are listed in Table 4.1.

4.1.1 Section Outline

Section 4.2	describes on going efforts of the WAG 2 floodplain and aquatic sediments efforts.
Section 4.2.1	presents preliminary results of the USRADS ionizing radiation walkover of the WAG 2 floodplain. Data for surface radiation are being used to identify hot spots, identify contaminant input areas, design a floodplain soil sampling program, and support efforts to manage contaminated soil and sediment at ORNL.
Section 4.3	describes the ORRHAGS soil survey and characterization program that is mapping soils, characterizing background level of selected metals, organic compounds, and radionuclides to support ER efforts. Information for soil erosion rates from uncontaminated areas is obtained from data for fallout

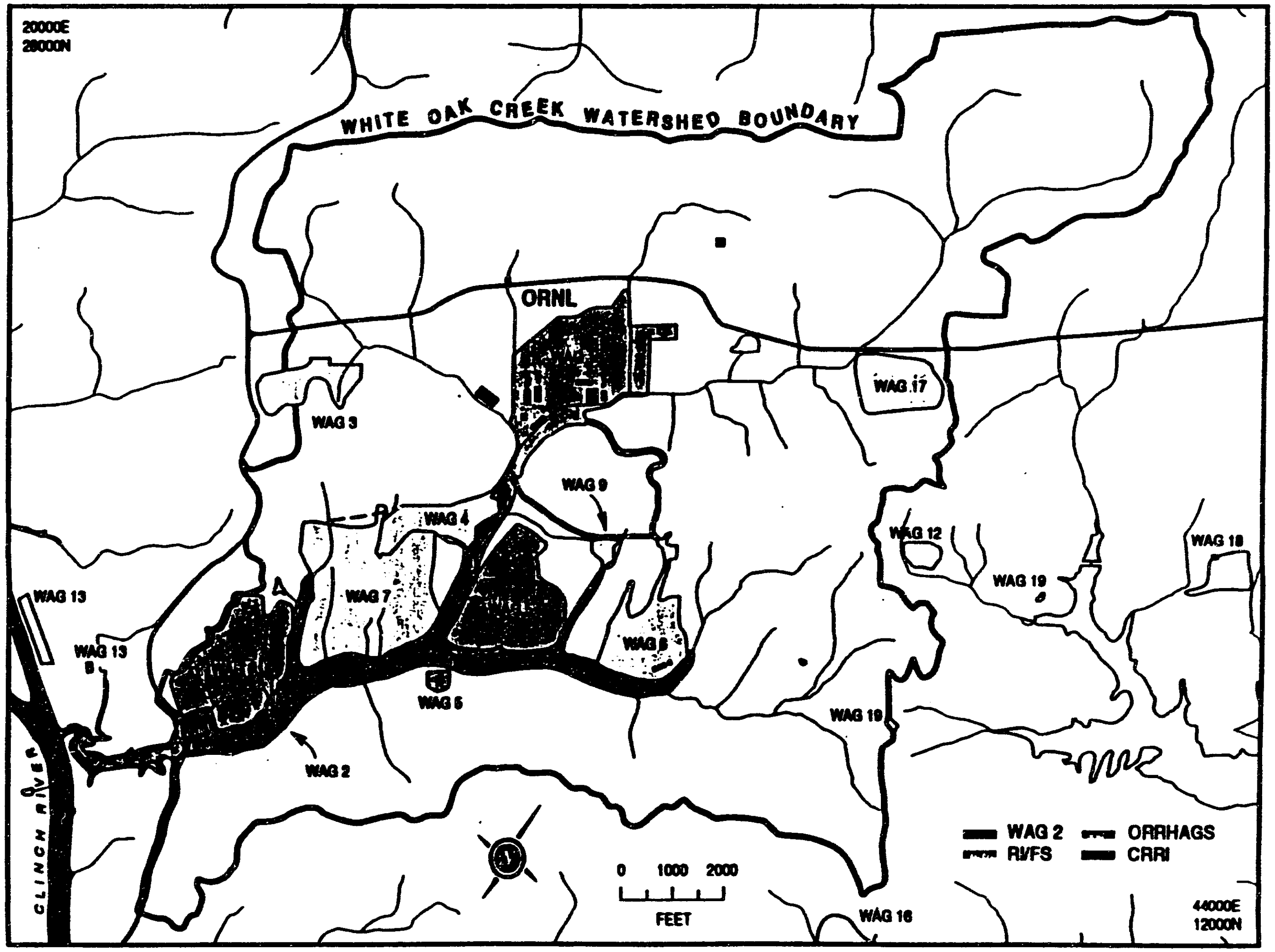

Fig. 4.1. Data coverage for sampling of contaminated sediments.

Table 4.1. Sediment Task Force

Member	Contribution
CRRI	Inventories and risk accumulation and transport (ORNL, TVA, PNL)
WAG 2/SI	Floodplain and aquatic sediment team Sediment transport modeling team (HSPF)
ECE	Support for WAG 2 efforts (HEC 1, HEC 2) Support for FS and RD (PICA evaluation)
Bechtel	RI/FS soil/sediment data for WAGs 1, 5, and 6 Sediment transport models for WAGs 1 and 5 (HSPF)
ORRHAGS	Background soil data and erosion rates
ORNL ES&H	Some soil and sediment data and suspended sediment (NPDES stormwater)
ES-Engineering	Land use (construction activities), planning engineering design and GIS support
Dr. B. A. Tschantz (UT/ECE)	Dam safety

^{137}Cs in soils. This section also discussed other efforts to evaluate erosion from contaminated areas and the filling of White Oak Lake.

Section 4.4 describes efforts to determine the sources of contaminated soil and sediments to WAG 2 and to develop models to predict the sources and magnitude of contaminated sediment transport out of the White Oak Creek Watershed.

Section 4.5 provides a summary of Sect. 4.

4.2 FLOODPLAIN AND AQUATIC SEDIMENTS

Contaminated sediment is one of the main focuses of the WAG 2/SI project's efforts during FY 1992 and FY 1993 because aquatic and floodplain sediments are the largest pool of contaminants in WAG 2, external exposure to radionuclides in sediments is the primary human health risk, and the transport of sediments is the most significant pathway for contaminant transport off-site. Efforts now underway in WAG 2 are focusing on several objectives. The first objective is to gather information on the locations and inventories of contaminated sediments. These data are needed to support sediment transport modeling efforts, to determine the need for ICMs or preventive measures, to avoid the transport of contaminated sediments during large storms, and to guide remedial actions and other activities in the watershed so that contaminated sediments are not inadvertently mobilized and released. For example, the Surface Water Task staff recently completed an evaluation of the potential implications for the safety of WOD and potential sediment scour that would result from placing impermeable caps over buried wastes in WAG 6. Although placing impermeable caps over WAG 6, and in fact over buried wastes in WAGs 3, 4, 5, and 7, would significantly increase the peak water discharge from capped area during storm events, the increased discharge would not affect dam safety. However, those efforts also indicated that measures would be required to prevent the remobilization of streambed and stream bank sediments in areas downstream of capped areas during large storm events. Inventories for ^{137}Cs in sediments is already available for some areas of WAG 2 based on data from previous efforts (Fig 4.2). The radiological walkover for WAG 2 (described below) was an important early step in obtaining data for other areas of WAG 2, improving the resolution in areas for which some data exist, and guiding additional sampling.

The second objective of current investigations is to identify the active sources of contaminant input into the main branches of the WOC drainage system. This effort relies on sampling bottom sediment at the major weirs or branch points in the lower drainage system and quantifying contaminant flux associated with suspended sediments moving during storms (see Sect. 3 of Boston et al. 1992). This effort also relies upon the sampling of tributaries to the main branches of suspended sediments. A tributary sampling program will begin with a screening survey in FY 1992 (see Boston et al. 1992). Bottom sediment are being collected from tributaries, and suspended sediment samples will be collected during a large storm event. Tributaries found to be potentially significant sources of contaminants willbe monitored on a regular basis, and contaminant source areas feeding contaminated tributaries will be evaluated as candidates for early actions.

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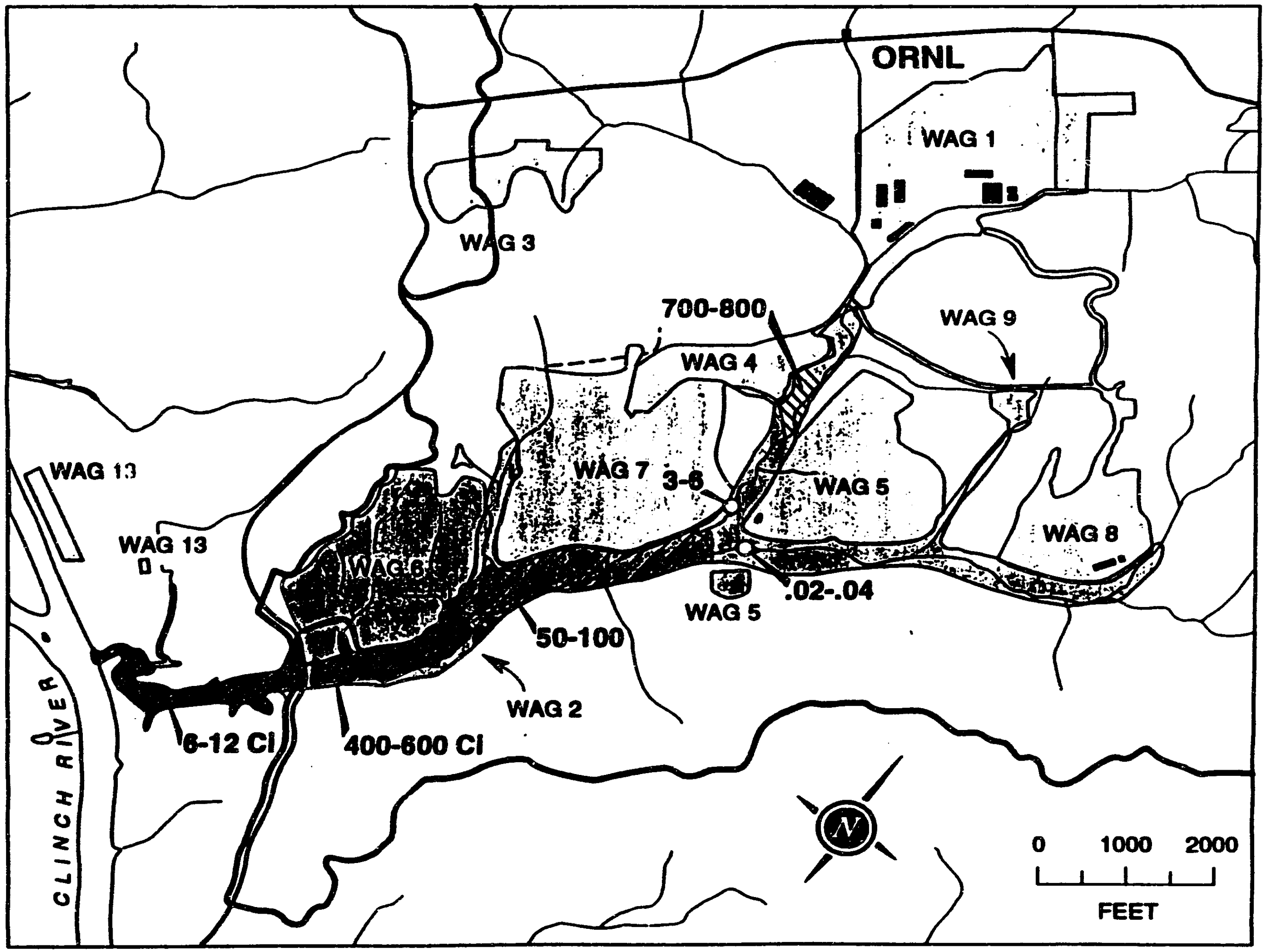

Fig. 4.2. Inventories of ^{137}Cs (curies) in WAG 2.

The third objective of the aquatic and floodplain sediment sampling program is to gather data to support corrective measures or remedial actions for contaminated sediments. Sediment sampling will focus on confirming or refuting existing information on the nature of the contaminants present and the extent of contamination as it relates to remedial actions. Sampling efforts, therefore, are focused on contaminant fluxes (current and potential) and data needed to evaluate, select, and implement remedial actions.

4.2.1 WAG 2 Floodplain Radiation Walkover

The preliminary risk assessment (Blaylock et al. 1992) indicated that direct exposure to gamma radiation to onsite workers is the primary threat to human health in WAG 2. Soils and sediments contaminated with ^{137}Cs is the main sources of gamma radiation in the WOC floodplain.

A radiation walkover survey was conducted in the spring of 1992 in order to map the gamma-emitting sources. The results of that survey will be used to (1) estimate the extent of sediment contamination, (2) locate and define hot spots, and (3) guide soil sampling efforts. If (as expected) the radionuclide levels are well correlated with metal and organic contamination levels, then the radiation data can be used to guide soil sampling for these co-contaminants.

4.2.1.1 Methods

For efficiency, the survey team used the Ultrasonic Ranging and Data System (USRADS) developed at ORNL. The USRADS provides automatic data collection. The measurements and the surveyor's location are instantly relayed for storage in a portable computer. Dose rate was measured with two NaI crystal instruments, one which was swung in an arc about 6 in. above the ground and a second positioned at a height of 1 m. USRADS recorded both instrument readings and the surveyor's location once each second. For the floodplain area within WAG 2, the entire data set contains measurements at over 500,000 points.

4.2.1.2 Current status

The data are currently being analyzed by WAG 2/SI staff. A preliminary plot of the data in Fig. 4.3 was prepared by averaging the data collected in contiguous 10-× 10-ft squares. The figure shows that the large areas of high gamma radiation are associated with the sediments and soils adjacent to WOC between the 7500 Bridge and WOL, as expected. Radiation levels tend to decrease away from the areas adjacent to the creek as one moves toward the hillslopes where sediments cannot accumulate. The largest area of high gamma radiation is the Intermediate Holding Pond Site just downstream from the 7500 Bridge. During the 1940s an earthen dam across WOC was used to retain the contamination released from the ORNL plant. In 1944 that dam was breached during a storm and material was transported downstream. At the Intermediate Holding Pond Site the gamma radiation ranges

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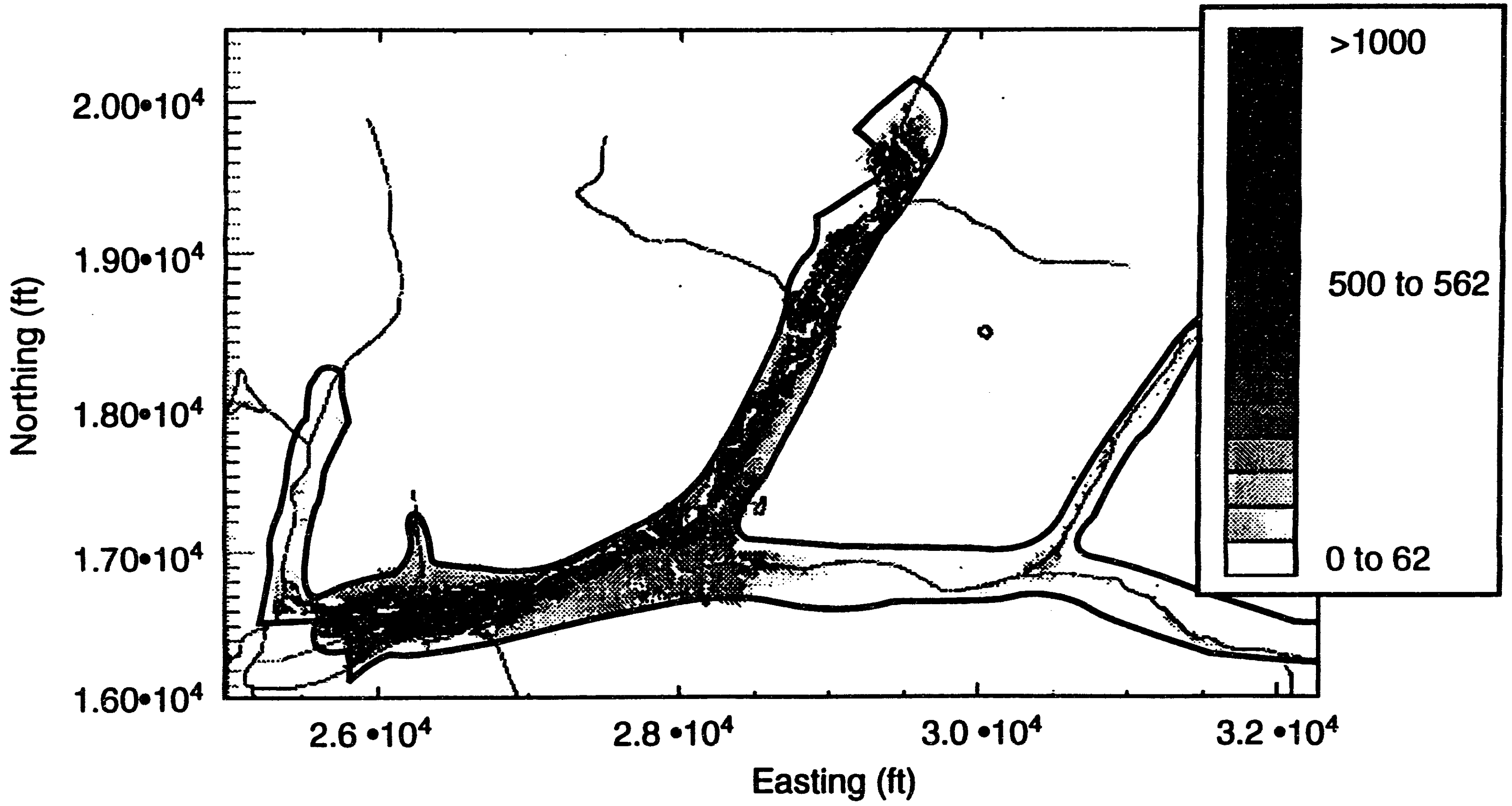


Fig. 4.3. Preliminary results of the radiation walkover survey for WAG 2 (units: μ R/hour).

to about 15 mR/h. Levels along MB are much lower, which conforms to the observation that gamma-emitting radionuclides are not in as great abundance as in the main branch of the WOC system.

4.2.1.3 Future work

Analysis of the data is in progress. We will be using the walkover data to select sample locations for the stream and floodplain sediment sampling programs. A number of sediment cores will be collected to determine how the radionuclides are distributed with depth.

The entire radiation data set will be implemented on a geological information system (GIS) and will be available for comparison with other data sets as they are collected. Whereas the site-wide maps of radiation levels, such as that shown in Fig. 4.3, are helpful in understanding the extent of contamination over the entire WAG, the main advantage of the data set lies in the detailed coverage. Because of the dense sampling pattern, this survey has yielded a wealth of data that may be used to (1) estimate gamma exposure levels for risk assessment scenarios and guide ICMs at specific locations; (2) investigate correlations between radiation levels and other variables such as soil type and biotic parameters; and (3) locate contaminated seeps near burial grounds and estimate contaminant mobilization during flooding when used in storm runoff modeling studies.

4.3 SOIL MAPPING AND HILLSLOPE EROSION

The ORRHAGS Soil Survey and Characterization is a critical first step in the development of RI. The major objectives are (1) to map soils in relation to geologic formations on ORR; (2) to evaluate landform stability, potential and past erosion, and drainage problems; and (3) to develop interpretative materials for hazardous waste disposal and other land-use planning. A five-digit number system was devised to code all important soil map information for computer sorting, mapping, and manipulation of the soil survey. The code represents geologic formation, geomorphology, soil type, slope classes, past erosion classes, and altered lands.

For intensive and detailed site planning, soil mapping with more detail is required, and eventually a site-specific data base is needed to plan for actual site development or intensive land use. Physical, chemical, and morphological soil properties are determined for the major layers of each soil in the survey area. Some of the collected data and their relation to RI are presented. Moisture characteristic and hydraulic conductivity functions are fundamental hydraulic properties required to model transport of radionuclides. Mineralogy, cation exchange capacity, and radionuclide sorption ratio characterize the rate of mobility of various radionuclides under certain hydrological conditions. Liquid limit and plasticity limit (Atterberg limits) and grain size distribution are important engineering characteristics (roadway and building construction) of the earth materials.

The Background Soil Characterization Project (BSCP) will provide background concentration levels of selected metals, organic compounds, and radionuclides in soils from uncontaminated on-site areas of the ORR and in off-site soils in the western part of Roane County and the eastern part of Anderson County. The BSCP will establish a data base, recommend how to use the data for contaminated site assessment, and provide estimates of the potential human health and environmental risks associated with background level concentrations of potential hazardous constituents.

WOL has been used as a sediment trap for sediments from the WOC drainage basin. Soil erosion has been and will continue be a major source of sediments to the lake. Therefore, the functional life of WOL as a sediment accumulation basin will largely depend on the erosion rate in the watershed. The erosion rate will depend on physical and chemical soil properties, landscape position and slope, precipitation, land use, and vegetative cover. Most present day sediment comes from point sources such as road ditches, knick points, bank erosion, and downward cutting of sediment-filled upper drainage ways.

Soil erosion rate can be determined by measuring the fallout ^{137}Cs losses. BSCP is collecting fallout ^{137}Cs data on stable landforms from different geologic formations present at the ORR. Preliminary data show approximately 9 pCi/cm^2 on stable landforms to a depth of 30 cm. These baseline data will give useful information necessary for the calculation of erosion rates on unstable hillslopes. Integrated ^{137}Cs losses will be converted to total soil losses or sediment input to WOL during the past 40 years and will be used to predict total sediment input during the next 100 years.

Soil erosion rate from landforms can also be determined by using calibrated water erosion prediction models. The Universal Soil Loss Equation (USLE) is an empirical formula that takes into account the rainfall, soil erodibility, slope length and steepness, vegetative cover, and erosion-control practices from which the average annual soil loss is calculated.

Another important source of sediments to the WOC and WOL is streambank soil erosion. The bank erosion rate will be influenced by physical characteristics of the stream and banks and by hydrological factors (precipitation, runoff, and water velocity). Some of the important stream physical characteristics are obstruction and flow deflectors, sediment traps, cutting, scouring, deposition, channel-bottom characteristics, channel capacity, and aquatic vegetation. Factors that affect bank soil erosion are slope, vegetative cover, and rock content. A stream-reach inventory and channel stability evaluation will be conducted on different cross sections of WOC. Bank soil erosion will be evaluated by using erosion pins. This technique uses a pin pushed into the soil bank as a benchmark, with the top of the pin being regarded as a fixed point to which changes in ground surface level are measured. Erosion pin studies should be repeated every year so the collected data represents average hydrological conditions. Stream inventory and erosion pin studies will be conducted in the same cross-sectional area of WOC.

4.4 SEDIMENT TRANSPORT

Contaminants associated with sediments are mobilized and transported with sediments during high discharge events. Data from Oakes, et al, (1982) (Fig 4.4) shows discharge,

ORNL DWG 91M-13702R2

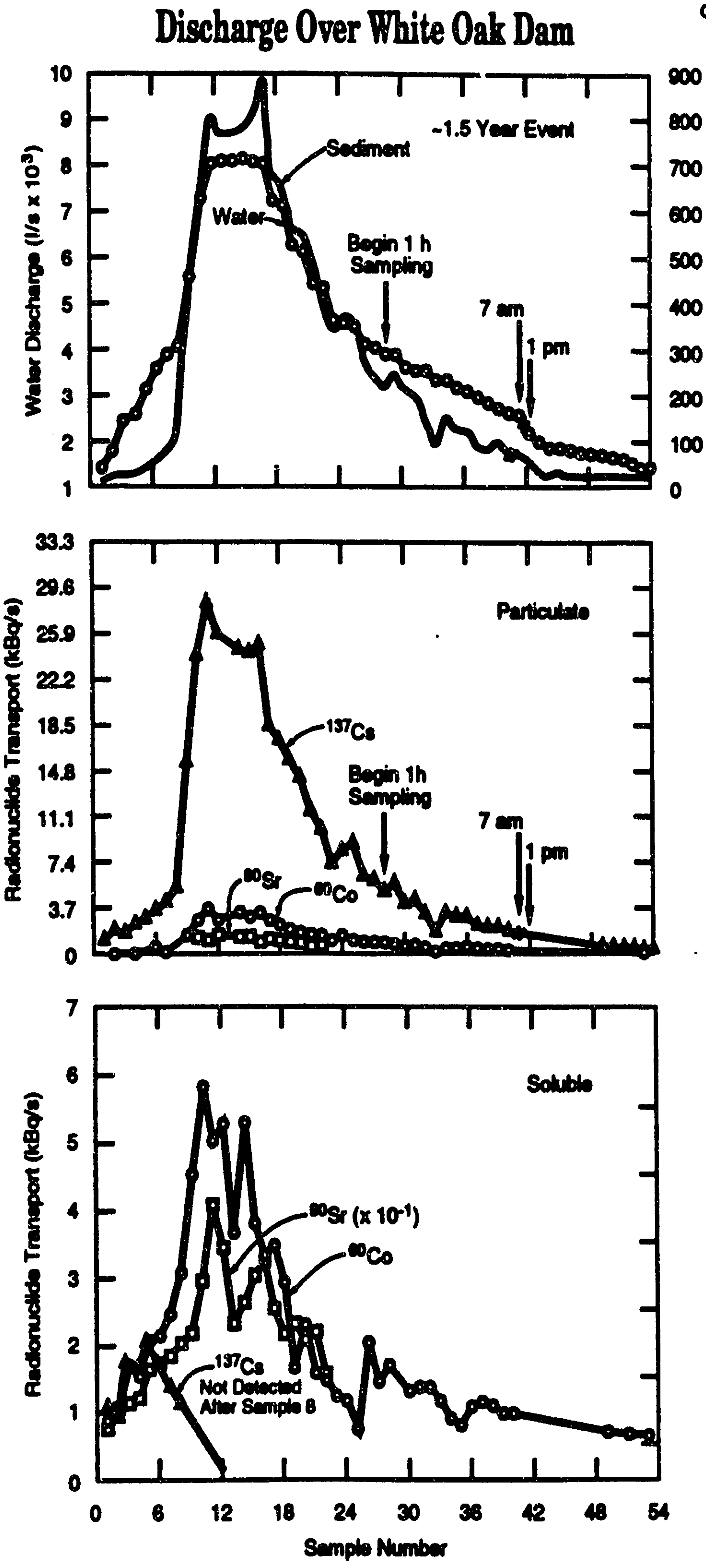


Fig. 4.4. Surface water, sediment, and radionuclide discharge at White Oak Dam during a storm, 1979.

sediment transport, and ^{137}Cs flux over WOD during a moderate-sized storm (about 1.5-year return frequency) in 1979. Data in Solomon et al. (1991) show that contaminant fluxes through WAG 2 increase greatly during storms. The current discharge monitoring system was not designed to quantify contaminant flux during the major events, although storm transport accounts for most of the sediment and sediment-associated contaminant transport. Our current understanding of watershed-level processes does not allow us to predict contaminant transport under extreme hydrologic and/or future land-use conditions.

Information for sources of contaminated sediments (e.g., easily erodible contaminated stream-bank sediments); information for sediment accumulation areas (e.g., WOL), and prediction of how the behavior of these areas will change with time, as a result of major storm events or as a result of remedial actions (e.g., capping large areas of the ORNL WAGs, are needed to effectively manage contaminated sediments.

WOL was created as a sediment/contaminant retention basin and has accumulated a large pool of contaminated sediment. Data for historic releases of contaminants from the WOC system (Fig 4.5) show that the largest releases of ^{137}Cs occurred during the late 1950s when storms washed sediment out of WOL after the WOD had been opened and the lake had been drawn down. WOD was closed again in 1960 and the releases of ^{137}Cs for WOL have decreased since the peak releases of the late 1950s. Data for annual releases of ^{137}Cs from WOD and data for major storms (Fig 4.5) show that although there have been large storms, large quantities of contaminants have not been released. These data indicate that WOD is an effective barrier. Estimates of the rate of filling of WOL, based on sediment depths measured by Cox et al. 1991 indicate that WOL will continue to serve as an effective contaminant retention basin for the next 20 to 30 years.

In the short term, a sediment management program is needed to control the input on sediment to WOL such that its effective life will not be shortened, sources of contaminated sediment must be located and controlled or remediated, and a strategy for the remediation of WOL must be identified and evaluated. All of these tasks are now under way.

4.4.1 WAG 2 Sediment Transport Efforts

The information required to address the issues associated with the movement of particle-reactive contaminants is being developed by the Sediment Transport Modeling/Sampling Task, which has the following objectives: (1) measure the movement of sediment and particle-reactive contaminants in WOC and through WOCE under existing conditions, (2) develop methods to predict the transport of contaminated sediment during floods, and (3) develop methods to predict the impact of various remedial action activities on the transport of contaminated sediment. These efforts are being coordinated with the environmental compliance monitoring at ORNL and with the off-site ER program (Clinch River RI).

In FY 1992, a sampling program (Boston et al. 1992, Fontaine 1991) was designed and initiated to begin monitoring contaminated sediment movement in WOC during floods and to produce the data required for developing predictive methods. The locations of the seven monitoring stations currently in use are shown in Fig. 4.6. The movement of contaminated

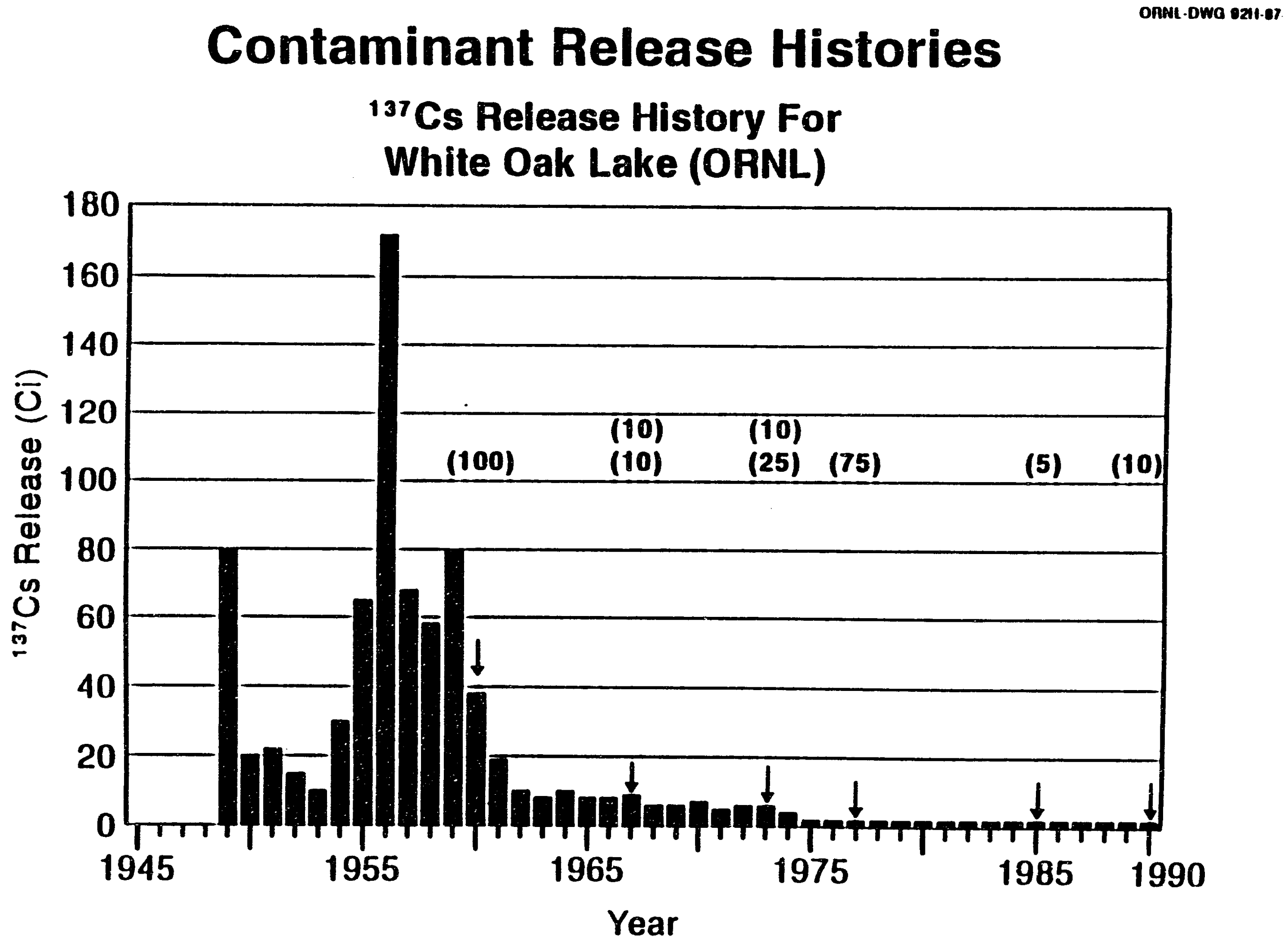
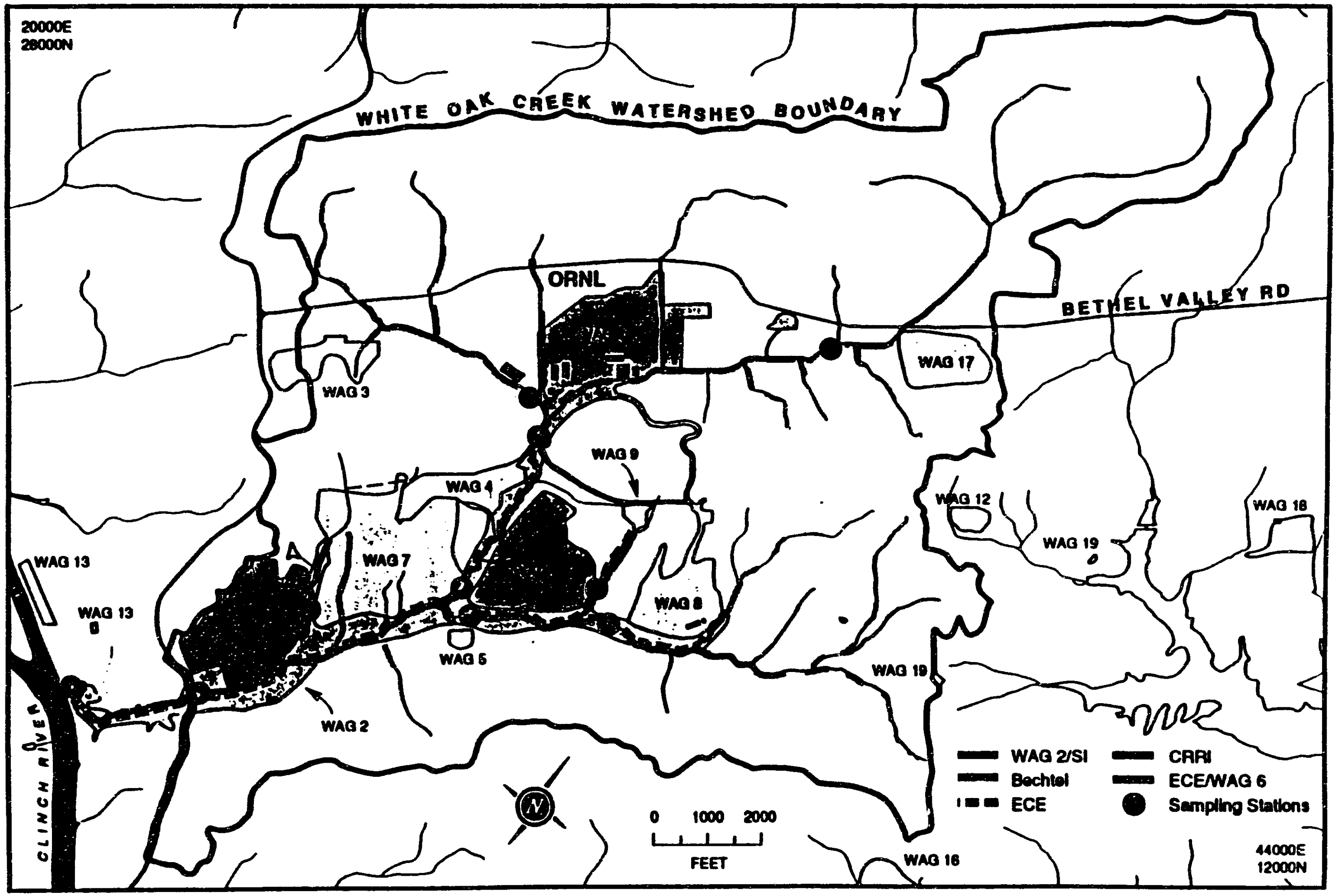


Fig. 4.5. History of ^{137}Cs releases from White Oak Lake.



Sediment Transport Modeling Efforts

Fig. 4.6. Sediment transport investigations include sampling at 7 sites and modeling different areas of the watershed.

sediment was measured at many of these sites during four storms in FY 1992. Summaries of available information for rainfall, discharge (Q), suspended sediment concentration [SS], particle size distribution, and activity of ^{137}Cs (as pCi/mg of oven-dried sediment) are shown.

4.4.2 Sediment Sampling Results

Data for [SS] and [^{137}Cs] from a typical winter storm (December 1 and 2 1991; 5.35 in. of rain in 40 h) at the middle WOC weir (MS3), the lower MB weir (MS4) and WOD (MS5) are shown in Table 4.2 and Fig. 4.7. The hydrograph from that storm is shown in Fig. 4.8. Preliminary particle size distribution analyses indicate that the suspended sediment is finer at WOD (4% sand, 7% coarse silt, 76% fine silt, and 12% clay) compared to the WOC MS3 (10% sand, 59% coarse silt, 27% fine silt, and 4% clay). These data tend to confirm that WOD is most effective at restricting the movement of coarse particles and least effective for fine particles, i.e., silts and clays. This storm was important for expanding the sampling program to additional sites and for the modification of field and lab procedures. Although the data do not include the entire storm, a log-log regression of Q versus [SS] at WOC weir was used to develop a predictive equation for [SS]:

$$[SS] = 0.074\ Q^{1.34} \quad (R^2 = 0.961), \tag{4.1}$$

with [SS] in mg/L and Q in ft^3/s.

Data at seven monitoring stations collected during two other small winter storms (February 25, 1992; 0.68 in. of rain over 12 h, and March 18, 1992; 0.6 in. of rain over 17 h.) are also presented in Table 4.2. These results were used to begin to establish the spatial distribution of ^{137}Cs at the seven monitoring sites and to provide an indication of [SS] and ^{137}Cs at normal stream flow rates during the wet winter season. For the March 18 event, both suspended solids and the filtered solutions were analyzed for gamma activity. Preliminary results indicate that the K_d concentration on solids vs concentration in solution for ^{137}Cs was approximately 250,000 L/mg. Thus, suspended sediments account for much of the transport of ^{137}Cs.

Data for [SS] and ^{137}Cs collected during a typical summer thunderstorm on April 12, 1992, (1.3 in. of rain in 0.5 h.) at station 6550 (the 7500 Bridge) and at MS3 and MS4 are shown in Table 4.2. A typical hydrograph of Q, [SS] and ^{137}Cs is shown in Fig. 4.9. The extreme intensity of precipitation caused a brief but large increase in streamflow at station 6550, WOC (MS3), and MB (MS4), which activated the automatic sampling equipment at these locations. The peak [SS] occurred before the peak discharge at each station. Comparison of the [SS] predicted by Eq. (4.1) developed from the December 1, 1991, storm with the observed [SS] at WOC weir indicates that the observed [SS] on April 12 was over 50 times greater than the [SS] predicted by the December 1 event. This comparison indicates that a complex relationship exists between Q and [SS].

The spatial distribution of rainfall was very uneven, with 1.3 in./30 min near the first Creek, 0.7 in./60 min at WAG 4, and 0.13 in./2 h at the ETF gage in WAG 6. The problem of high spatial variability in rainfall during summer storms will be resolved by installing about

Table 4.2. Peak sediment concentrations for storms sampled in FY 1992

Storm date	Analyte		Site: ID:	Upper WOC 6320	NWT 6440	7500 Bridge 6550	WAG 4-MS1	WOC-MS3 7000	MB-MS 4 7500	WOD
12/1-2/91	SS[a]	(mg/L)						300	N/A[d]	20
	^{137}Cs[b]	(pCi/mg)						1.3	0.07	2.0
2/25/92	SS	(mg/L)		33		42	50	35	70	30
	^{137}Cs	(pCi/mg)		0	0	2	0.3	3	0	3
3/18/92	SS	(mg/L)		25	12	10	22	20	30	18
	^{137}Cs	(pCi/mg)		0	0	7.5	0.3	7.5	0	3
	^{137}Cs[c]	(pCi/L)		0	0	30	0	36	0	8
4/12/92	SS	(mg/L)				747		2187	2201	
	^{137}Cs	(pCi/mg)				0.7		1.6	0	

[a] SS = suspended sediment

[b] Particulate ^{137}Cs concentration.

[c] Dissolved ^{137}Cs concentration

[d] No peak ss concentrations available

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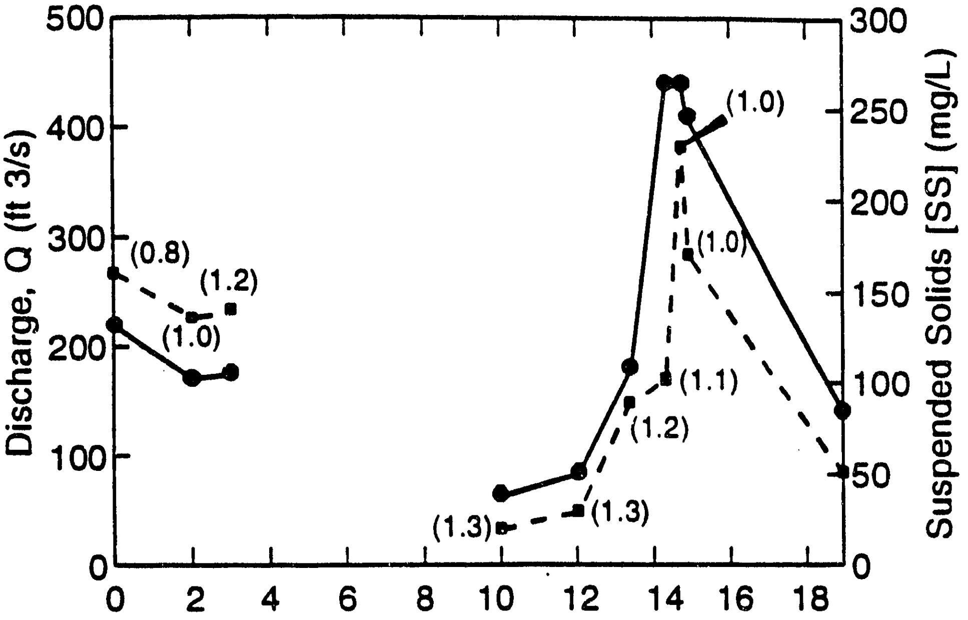
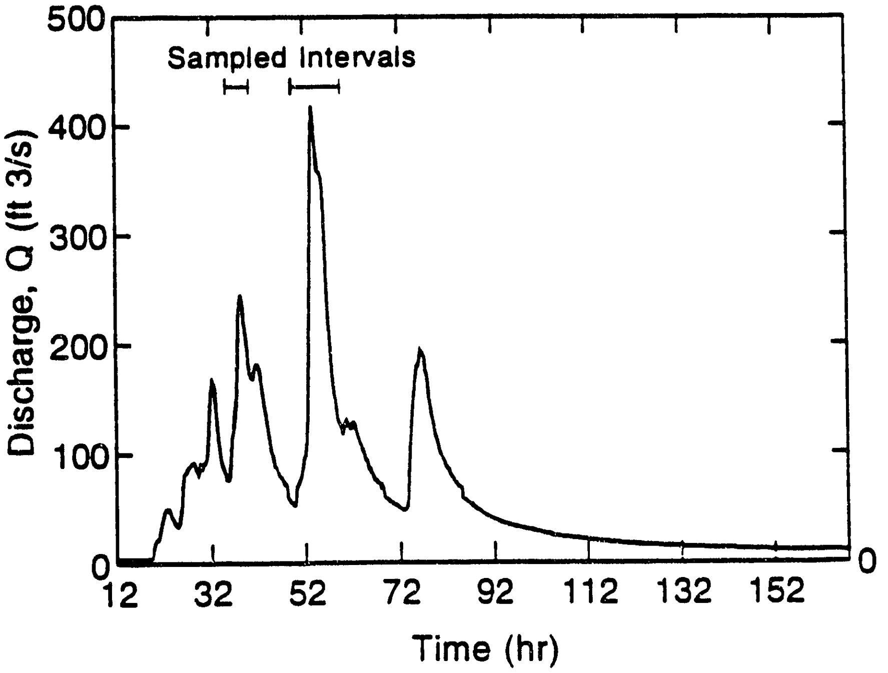


Fig. 4.7. (above) Results of sediment sampling during the storm of December 1-2, 1991. Specific activity of the sediment samples appear in the parentheses (pCi/mg).

Fig. 4.8. (below) Hydrograph and intervals of sediment sampling for the storm of December 1-2, 1991.



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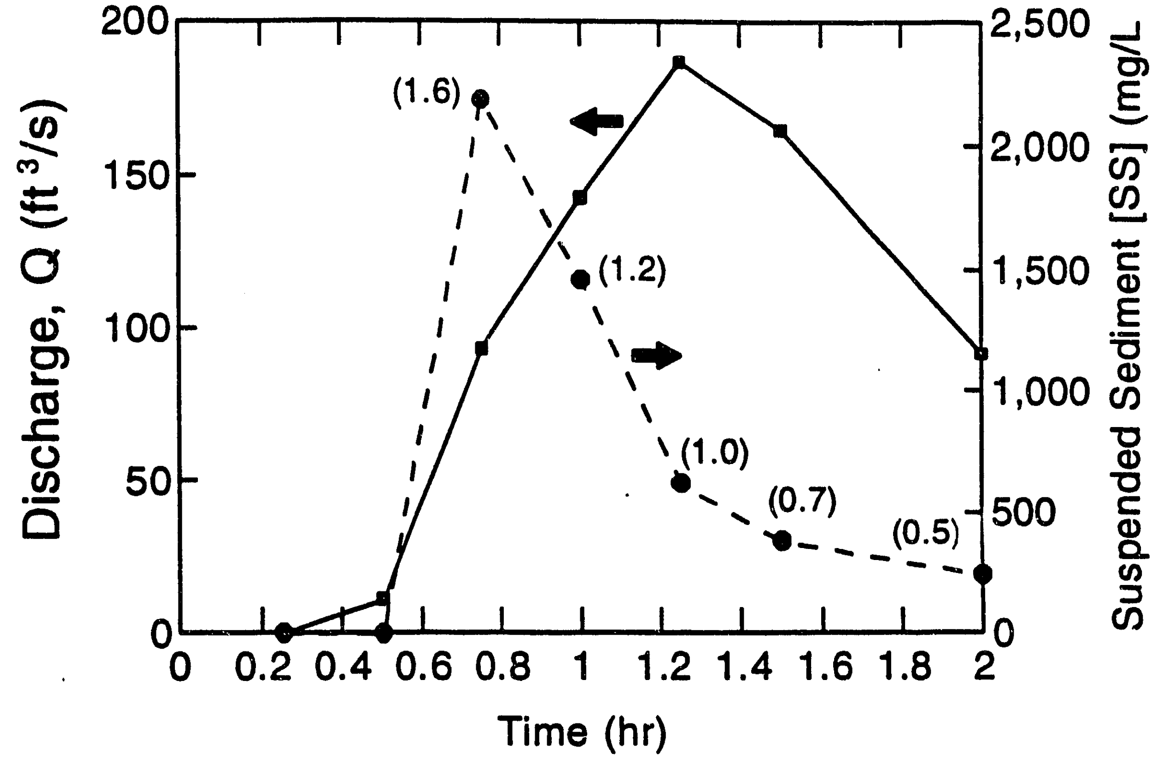

Fig. 4.9. Results of sediment sampling during the storm of April 12, 1992. Specific activity of the sediment samples appear in parentheses (pCi/mg).

12 wedge gages throughout the watershed and at the recording gage at the headwater region of WOC along Chestnut Ridge. In addition, a communications system to warn the sampling personnel of potential intense rainfall during evenings and weekends will also be implemented, so that severe summer storms can be adequately sampled manually as well as automatically.

The following conclusions are based on the data from these four storms:

1. The sources and fate of contaminated sediments for different-sized storm events and different seasonal conditions must be identified.

2. The concentration of ^{137}Cs on suspended solids varied from 0.5 to 7.5 pCi/g dry wt at WOC weir. Factors governing the concentrations (and so the fluxes) of key contaminants throughout the watershed are needed.

3. The relationships among discharge, suspended sediment concentrations, and contaminant concentrations are not simple. Data from additional storms in conjunction with the modeling efforts will be needed to predict contaminant transport under current and future conditions.

4.4.3 Sediment Transport Modeling

The field sampling of contaminated sediment during storms is accompanied by the development of a computer model to predict the transport during floods in the future and the impact of changes in land use. The HSPF (Hydrological Simulation Program-Fortran) (EPA 1984) computer model was selected for simulating the flood hydrology, sediment dynamics, and contaminant–sediment interaction in WOC. The model was calibrated (adapted for specific conditions in WOC) for hydrology and the erosion of suspended sediment from subcatchments upstream of the WOC weir. Excellent results were obtained for simulating floods during the 1990 and 1991 streamflow record.

4.4.4 Future Work

The following work is planned for FY 1993: (1) continue sampling winter and summer storms for suspended sediment concentration, particle size and mineralogy, and gamma activity (mainly for ^{137}Cs and ^{60}Co); (2) initiate analyses for ^{90}Sr metals, and organic contaminants for selected samples; (3) survey the sediments in WOL and WOCE to estimate contaminant inventories; (4) using the computer model, simulate the transport of contaminated sediment during moderate to extreme floods, with a variety of land-use conditions; and (5) continue calibrating the model and estimating the uncertainty in the model results.

The sediment surveys of erosion and deposition areas in WOL and WOCE will serve as baseline data to estimate rates of scouring and filling and possibly to estimate contaminated sediment transport during historic extreme floods for use in WAG 2 and CRRI projects. Field surveys, sampling programs, and computer model simulations will make it possible to identify the critical sources, transport mechanisms, and deposition zones of contaminated sediment.

4.5 SUMMARY

Soils and sediments are major pools for contaminants in the ORNL WAGs. Exposure to sediment contaminants are important for potential human health and ecological risk. Erosion, or resuspension, and transport of contaminated sediments, are potentially important pathways for contaminant transport to the Clinch River.

There are numerous sources of contaminated soils and sediments in WOC watershed. Uncontaminated soil and sediment becomes contaminated upon entering WAGs 1 and 2. Thus, a watershed sediment management program is being implemented to coordinate efforts to (1) characterize areas of contaminated soils and sediments to allow the evaluation of future remedial actions; (2) consider interim corrective actions; and, (3) ensure that changes in the watershed due to development or remedial actions do not result in increased releases of contaminated sediment under future conditions. Better coordination and communication among organizations involved in monitoring, restorations, constructions, planning, etc., is the best approach for a logical and integrated means of addressing issues related to contaminated soils and sediment.

Preliminary estimates indicate that WOL will continue to serve as an effective sediment trap for the next 20 to 30 years. Hydrologic models are being established to predict the behavior of contaminated stream-bank and bottom sediments under future conditions. Questions being addressed include the role of the new WOC Sediment Retention Structure in mitigating the release of contaminated sediment from WOL and the remainder of the watershed; predictions of potential contaminant losses during large hydrologic events under future conditions as WOL becomes shallower and impermeable caps are placed over buried wastes in the ORNL WAGs. To address these questions, an integrated modeling effort has been established as part of the sediment task force. The distribution of modeling efforts as part of the sediment task force are shown in Fig 4.6. As part of this effort, groups concerned with the transport of contaminated sediment are working to link sediment transport models so that, for example, contaminated sediments released from WAG 1 can be followed into WAG 2 and eventually into the Clinch River. Once in the Clinch River, sediment can be followed downstream and deposited where the potential contribution to human health risk can be estimated. These efforts will help to evaluate potential problems, prioritize future action, and take effective measures to protect human health and the environment.

5. BIOTA

5.1 INTRODUCTION

The Biota Task of the WAG 2/SI includes three major components: (1) the ORNL Biological Monitoring and Abatement Program (BMAP), (2) the ecological assessment of source WAGs, and (3) the ecological assessment and long-term monitoring of WAG 2. BMAP provides long-term monitoring of contaminant levels in biota and ecological effects in WOC and its tributaries. Ecological assessment of individual source WAGs is primarily aimed at supporting the baseline ecological risk assessments for those WAGS by obtaining WAG-specific data that is not available through BMAP or other sources. WAG 2 as the receptor for contaminants from the upgradient source WAGs integrates the inputs from those WAGs. The WAG 2 ecological assessment consists of a preliminary characterization component and a long-term monitoring component. The long-term monitoring component of the WAG 2 ecological assessment consists primarily of the development of a conceptual ecological model that integrates the aquatic and terrestrial systems and provides a basis for prediction and evaluation of the impacts of remedial action alternatives.

During 1991 BMAP continued with all tasks as defined in 1986 (Loar et al. 1991) and an ecological assessment was begun on WAG 5. The assessment work in WAG 2 consisted of baseline monitoring closely associated with BMAP. This section is divided into subsections on BMAP and on WAG 5. The results of the WAG 2 assessment tasks are reported in the BMAP subsections.

5.1.1 Section Outline

Section 5.2	describes the components of the ORNL Biological Monitoring and Abatement Program that collects baseline information for biotic communities and instream and effluent toxicity to identify sources of stress to biotic populations, to suggest remedial actions, and to document the responses to those actions.
Section 5.3	describes the toxicity testing task. This task regularly conducts 7-day laboratory bioassays with water from each of 15 sites. Toxicity to standard laboratory test organisms has been associated with areas within WAG 1. An effluent toxicity testing program has found toxicity associated with effluent from a coal yard and the ORNL sewage treatment plant (both located in WAG 1). A periphyton (attached algae and heterotrophs) monitoring effort has also found adverse effects associated with discharges in WAG 1.
Section 5.4	summarizes the results of bioaccumulation studies using freshwater clams placed at strategic locations at ORNL, as well as sampling of fishes.

Section 5.5	presents information from efforts to evaluate ecological effects based on a series of physiological indicators measured in fish populations at ORNL.
Section 5.6	describes the instream ecological monitoring task that characterizes the spatial and temporal changes in macroinvertebrate assemblages and fish populations.
Section 5.7	presents efforts to characterize the radioecology of White Oak Lake, with emphasis on pathways for radiological contaminants off-site and to humans. A waterfowl census and sampling program is coordinated with reservation-wide efforts.
Section 5.8	describes efforts to characterize the key contaminants in terrestrial biota and the sources of those contaminants.
Section 5.9	describes efforts to assess ecological impacts for the source-WAGs in the White Oak Creek watershed.
Section 5.10	provides a summary of Sect. 5.

5.2 BIOLOGICAL MONITORING AND ABATEMENT PROGRAM

As a condition of the NPDES permit issued to ORNL on April 1, 1986, a BMAP was developed for WOC; selected tributaries of WOC, including Fifth Creek, First Creek, MB, and Northwest Tributary; and the Clinch River. BMAP currently consists of six major tasks that address both radiological and nonradiological contaminants in the aquatic and terrestrial environs at ORNL (Loar 1991). These tasks are (1) toxicity monitoring, (2) bioaccumulation monitoring of nonradiological contaminants in aquatic biota, (3) biological indicator studies, (4) instream ecological monitoring, (5) assessment of contaminants in the terrestrial environment, and (6) radioecology of WOC and WOL.

5.3 TOXICITY TESTING

The toxicity monitoring task of BMAP has three goals (Loar 1991): (1) identify sources of toxicity in the WOC watershed; (2) monitor toxicity of water in WOC and its tributaries and, in the process, assess the usefulness of the toxicity test systems in detecting ambient toxicity; and (3) monitor periphyton/microbial communities and use manipulative field experiments to test relationships between ambient toxicity and processes regulating energy flow in streams within the WOC watershed.

5.3.1 Ambient Toxicity Monitoring

Since implementation of BMAP in March 1986, water from each of 15 sites on five streams (Fig. 5.1) has been evaluated for toxicity on 39 occasions. Several of these sites have been evaluated more frequently. Results of these tests and their attendant chemical analyses have generated a core data set that is used to provide an understanding of ambient toxicity patterns in streams at ORNL. The 15 sites used for these ambient studies were initially selected to encompass both point- and area-source contributions to toxicity in the receiving streams. Four of the 15 sites (upstream sites on First Creek, Fifth Creek, WOC, and MB; Fig. 5.1) have no contaminants in toxic concentrations and are used as reference sites. Two of the remaining 11 sites [WOC kilometer (WCK) 2.65 and MB kilometer (MBK) 0.16, which are represented as sites 7 and 6, respectively, on Fig. 5.1] are also listed as sites that must be tested under the Toxicity Control and Monitoring Program section of the ORNL NPDES permit. The evaluations of toxicity were based on 7-day static renewal tests that utilized the survival and growth of fathead minnow (*Pimephales promelas*) larvae and/or the survival and reproduction of a small crustacean (*Ceriodaphnia dubia/affinis*) as toxicity end points.

Of the 80 toxicity tests conducted with *Ceriodaphnia* during 1991, only three tests (all at WCK 3.8, which is site 11 on Fig. 5.1) yielded evidence of toxicity (Loar 1992). Total residual chlorine (TRC) values for these three tests were below threshold values previously shown to be toxic to *Ceriodaphnia*. Other factors that increase the persistence of chlorine or other toxicants may be responsible for the observed toxicity. Survival of fathead minnows was always greater than zero in the 80 tests conducted during 1991, and only five tests yielded mean survival <40% (Loar 1992). Of those five tests, three were at reference sites, and in all but one of the five tests, mean survival was associated with a large coefficient of variance (>70%). Thus, the fathead minnow tests did not provide evidence for acute toxicity at any of the sites.

Because previous toxicity tests demonstrated that TRC is a major toxicant in some receiving streams at ORNL, data from 5 years of ambient toxicity testing and associated water quality monitoring were subjected to various statistical tests to identify the factors that contributed to toxicity in the mid-reaches of WOC and Fifth Creek within the main plant area. Several conclusions can be reached on the results of these analyses: (1) TRC in Fifth Creek and WOC declined substantially after May 18, 1989; (2) following the decline in TRC, *Ceriodaphnia* survival and mean reproduction and fathead minnow survival all increased; (3) maximum TRC was a very influential factor with respect to *Ceriodaphnia* survival; and (4) because TRC and other measured parameters explained only a relatively small percentage of the variance in Ceriodaphnia survival, water quality factors that were not measured (especially nitrogenous and organic compounds) could have contributed to toxicity (Loar 1992).

5.3.2 Effluent Toxicity Testing

As required by ORNL's NPDES permit, toxicity testing was also conducted on wastewater effluents and receiving streams in 1991. Effluent toxicity evaluations were conducted on the Coal Yard Runoff Treatment Facility (CYRTF), the Sewage Treatment Plant (STP), and the

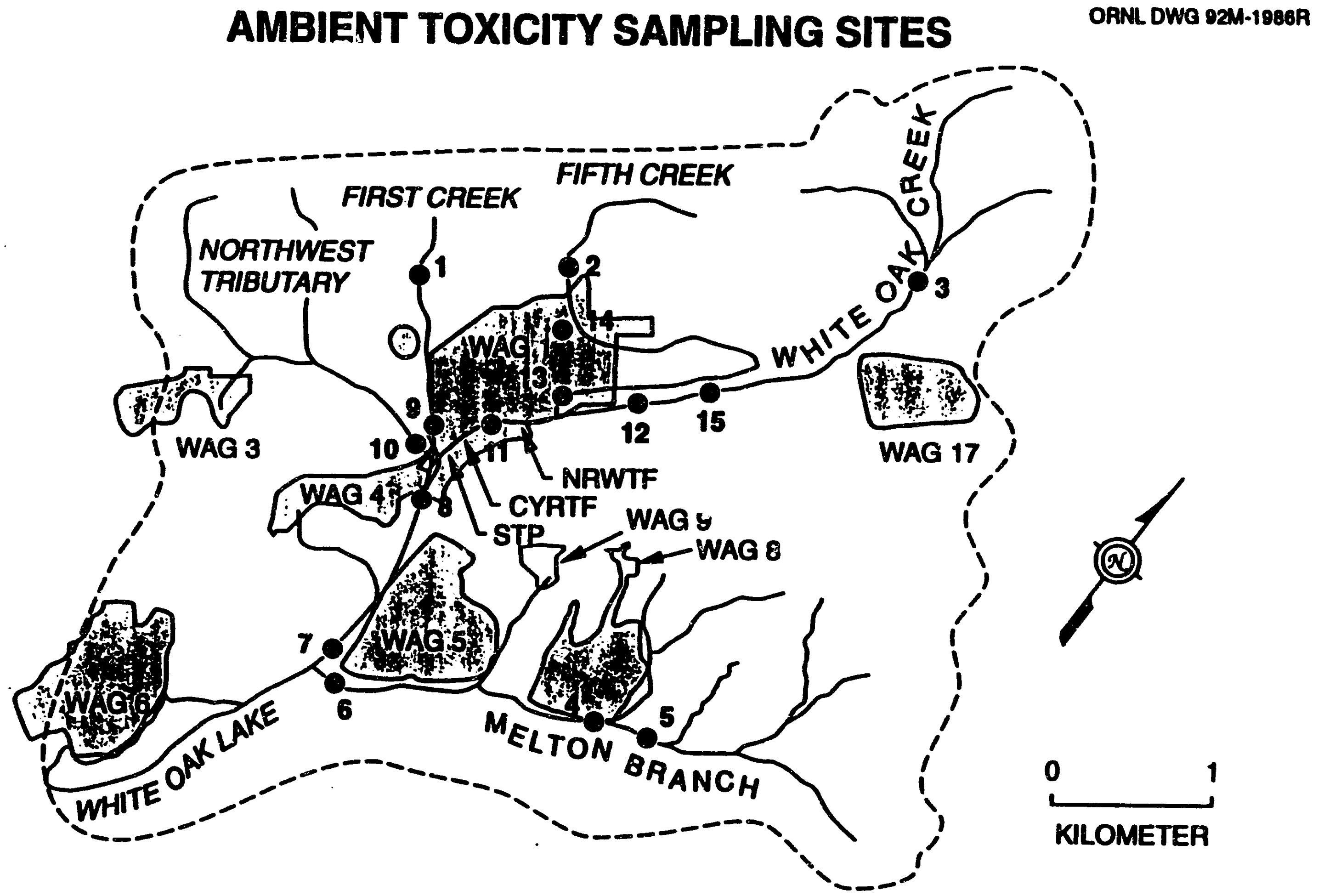

Fig. 5.1. Sampling sites for ambient toxicity tests of water from streams at ORNL.

Nonradiological Wastewater Treatment Facility (NRWTF) (Fig. 5.1). Results indicated that (1) CYRTF effluent was toxic to made *Ceriodaphnia* and occasionally toxic to fathead minnows, (2) STP effluent was sometimes moderately toxic to *Ceriodaphnia* and nontoxic to fathead minnows, and (3) NRWTF effluent was consistently nontoxic to fathead minnows and only rarely toxic to *Ceriodaphnia*.

5.3.3 Periphyton Studies

Periphyton communities in lotic (running water) ecosystems are complex assemblages of autotrophs (algae) and heterotrophs (fungi, bacteria, protozoa) that are attached to substrates and often embedded in a polysaccharide matrix. Monitoring of these communities is an important part of the ORNL BMAP (Loar 1991) because they represent a high-quality food resource for many of the lotic invertebrates and herbivorous fishes and are an entry point for contaminants into the food chain. Periphyton communities possess several properties that make them particularly useful in detecting short-term environmental changes: they are ubiquitous, easy to sample, and have short generation times. Consequently, infrequent pulses of toxicants may be easier to detect in periphyton than in longer lived organisms. Rocks with associated periphyton are collected monthly from 6 of the 15 sites used for ambient toxicity testing (1, 2, 3, 5, 8, and 11; Fig. 5.1) and from three additional sites (WCK 2.3, WCK 2.9, and MEK 0.6). During 1991, a site on WOC (WCK 5.1) was added to the monitoring program to be representative of conditions in WOC after the stream has been visibly influenced by ORNL operations in the 7000 area (Loar 1992).

Results of the 1991 monitoring of periphyton suggest that (1) overall biomass and photosynthesis of algal periphyton were similar to those measured in previous years; (2) the pattern of improving the physiological condition of the algal periphyton with distance from ORNL discharges was again apparent, as in previous years, although there was some evidence of adverse influence between WCK 3.4 (site 8 in Fig. 5.1) and WCK 2.9 downstream; (3) stone rollers (*Campostoma anomalum*) were observed grazing on algae at WCK 2.9 for the first time, possibly indicating an improvement in stream condition at this site; and (4) periphyton communities in MB continue to show no substantial impact of the restart of High Flux Isotope Reactor (HFIR) operations (Loar 1992).

5.4 BIOACCUMULATION STUDIES

The bioaccumulation monitoring task of the ORNL BMAP (Loar 1991) has five subtasks with the following objectives: (1) determine what materials present in the WOC system accumulate to unacceptable levels in aquatic biota, (2) identify specific sources of any observed contamination, (3) calibrate water quality monitoring data against contaminant levels in biota, (4) determine the source and scope of polychlorinated biphenyl (PCB) contamination of channel catfish in WOCE and the Clinch River, and (5) assist development of the capability to forecast future levels of biotic contamination under various remedial action alternatives. Sunfish were collected at three sites on WOC (WCK 3.5, WCK 2.9, and WCK 2.3) and single sites on WOL, (WOL) WOCE, Northwest Tributary, and MB. Most sites on WOC, MB, and Northwest Tributary correspond closely to benthic invertebrate and fish sampling sites. Asiatic clams (*Corbicula fluminea*) were placed at various locations in WOC and tributaries, WOL, and WOCE to monitor for PCBs and organic contaminants.

Results from the monitoring of PCBs in channel catfish in 1991 supported previous conclusions, i.e., some channel catfish caught by anglers in the Clinch River near WOC are likely to contain PCBs in excess of the FDA limit of 2 µg/g (Loar 1992). A significant fraction, although not necessarily most, of the PCB content of those catfish originates in the WOC discharge and/or WOCE The concentrations of PCBs found in catfish from the Clinch River and WOCE in 1991 support the Precautionary Fish Consumption Advisory currently in effect for this reach of Watts Bar Reservoir.

Concentrations of PCBs in bluegill and redbreast sunfish collected in 1990–1991 at sites in WOC watershed did not exhibit the decreasing downstream gradient between WCK 3.5 and WOL reported previously, and mean PCB concentrations did not differ significantly among sites in WOC and MB (Loar 1992). PCB concentrations in sunfish from some sites in WOC and WOL appear to have decreased over the period from December 1987 to July 1991 (Loar 1992). PCB concentrations in large-mouth bass from WOL decreased from 1990 levels (Loar 1992). However, year-to-year fluctuations in PCB concentrations in bass do not necessarily indicate variations in PCB inputs to the system.

The chlordane contamination in upper WOC appears to be steadily decreasing with time (Loar 1992). The mean chlordane concentration in clams placed in the WCK 5.4 tributary in 1991 was only 5% of the concentrations found at that site in 1989 (Loar 1992). These results confirm previous conclusions that the high chlordane concentrations in clams placed in WOC were the result of an episodic rather than a chronic release.

Mercury concentrations in fish collected from WOC in winter 1990–1991 were elevated over those in fish from reference streams but were below the Federal Drug Administration (FDA) action level throughout the drainage (Loar 1992). The highest mercury concentrations were found in sunfish from WCK 2.9 (between SWSAs 4 and 5). Mercury levels in large-mouth bass from WOL have increased significantly over the past 3 years, but this increase does not indicate that mercury inputs to WOL have increased; mercury concentrations in WOL sunfish, for example, have not increased during the same time period (Loar 1992). All other metals were present in fish from WOC watershed at concentrations similar to those found in fish from the reference stream (Loar 1992).

5.5 BIOLOGICAL INDICATOR STUDIES

In addition to the routine fish community surveys that are conducted twice yearly at 15 sites in WOC watershed, the health of a target fish population is assessed annually. In 1990 the health of the redbreast sunfish population in lower WOC was assessed and compared with that of the same species from three uncontaminated reference streams (Hinds Creek, Brushy Fork, and Paint Rock Creek). The assessment was based on a suite of biochemical and physiological parameters that included indicators of (1) detoxification enzyme induction, (2) organ dysfunction, (3) histopathological condition, (4) fish condition, and

(5) nutritional status. Adult redbreast sunfish in WOC exhibit characteristics of a population under some level of physiological stress. On the basis of the integrated site analysis, some evidence exists to indicate that conditions in WOC may have improved from 1989 to 1990, a finding that is consistent with the results of ambient toxicity tests.

To complement the assessment of the health of individuals, extensive population-level studies were conducted to determine the reproductive competence, age distribution, and growth of the redbreast sunfish population in WOC. Data obtained in 1990 on the reproductive competence of female redbreast sunfish indicated that the reproductive potential of this species in WOC equalled or exceeded that of sunfish in the reference streams. Female sunfish in WOC reach reproductive maturity more than a month earlier than sunfish from the reference streams, but the seasonal cessation of spawning in WOC may be within the normal range of the species in other East Tennessee streams. Analysis of age- and size-frequency distributions of redbreast sunfish populations at several sampling sites in WOC suggests that suitable spawning habitat at many sites may be limited and/or over-winter mortality is highly size-specific, since small individuals (<6 cm) were absent at most sites in both spring and fall 1991. Finally, results of the age–growth analyses showed that growth of redbreast sunfish in WOC was generally higher than that of sunfish in the reference streams in both 1990 and 1991.

5.6 INSTREAM ECOLOGICAL MONITORING

The objectives of the instream ecological monitoring task are to (1) characterize spatial and temporal patterns in the distribution and abundance of the benthic macroinvertebrate and fish populations in WOC watershed; (2) identify contaminant sources that adversely affect stream biota, including differentiation between point and area sources wherever possible; and (3) monitor these populations and evaluate the future effects on community structure and function from operation of new wastewater treatment facilities, from improvements in waste management operations, and from implementation of remedial actions directed at area source control (Loar 1991).

5.6.1 Benthic Macroinvertebrates

During the first year of BMAP, the benthic macroinvertebrate communities of the lower reaches of the streams in the WOC watershed exhibited characteristics indicative of degraded water quality. These impacted downstream reaches were typically characterized by low taxonomic diversity and richness and the absence or relatively low abundance of major taxonomic groups that are generally intolerant of pollution. Studies of the benthic macroinvertebrates continued after the first year with the specific objectives of (1) further characterizing the communities in WOC watershed and documenting the impacts on these communities from past and current ORNL operations, (2) continuing efforts to identify causal factors responsible for observed adverse impacts, and (3) documenting the responses of these communities to remedial actions.

Benthic macroinvertebrates were sampled approximately from May 1987 through October 1987 and in January and April 1988 from the 15 sites in Fig. 5.1. Although some of these sites differ slightly from the 15 toxicity test locations, they generally represent the same stream reaches. Sampling of the 15 sites is continuing on a quarterly basis, but later samples have not been processed prior to this report date because of unavoidable delays in processing of the samples.

The structure and composition of the benthic macroinvertebrate communities in the streams of the WOC watershed continue to exhibit evidence of varying degrees of water quality degradation. Lower Fifth Creek and mid-WOC were the most highly impacted stream reaches studied, although there was evidence that some very minor recovery may have occurred at these sites as well as at WCK 3.4 (Loar 1992). MB appears to have exhibited some recovery as a result of the HFIR shutdown. (Samples that would indicate status of the benthic communities after restart have not yet been processed.) Toxicants (primarily chlorine) associated with point-source discharges are probably the most significant cause of the adverse effects observed on the benthic community in the main plant area (Loar 1992). High densities (relative to reference sites) at downstream sites suggest that other factors, such as siltation and nutrient enrichment, may be more important than point-source discharges, although very low toxicant concentration may continue to impact the invertebrate communities at some of these downstream sites.

5.6.2 Fishes

Fish population and community studies can be used to assess the ecological effects of changes in water quality and habitat. These studies offer several advantages over other indicators of environmental quality and are especially relevant to assessment of the biotic integrity of WOC. For example, fish communities include several trophic levels, and species that make up the sport fishery in WOC are at or near the end of the food chains. Consequently, they potentially integrate the direct effects of water quality and habitat on primary producers (periphyton) and consumers (benthic invertebrates) that are utilized for food. Because of these trophic interrelationships, the well-being of fish has often been used as an index of water quality. The objectives of the instream fish monitoring task (Loar 1991) are to (1) characterize spatial and temporal patterns in the distribution and abundance of fishes in the WOC watershed and (2) document any effects on fish community structure and function resulting from implementation of remedial actions.

Qualitative sampling of fish populations at 15 sites in WOC and its tributaries (Fig. 5.1) continued in 1991. Resulting data were used to determine species composition; estimate population size; and determine age structure, growth rates, and length-frequency values.

Data on species richness in the WOC watershed showed little change during 1991. The total number of species found in the watershed in 1991 was 14 and appears to be relatively stable (Loar 1992). Fish were collected for only the third time in lower Fifth Creek (Loar 1992). The improvements in the fish community in this reach of stream may reflect a general reduction in chlorinated discharges since late 1989. The stoneroller expanded its distribution in WOC watershed in 1991 to include First Creek, lower Fifth Creek, and lower

Northwest Tributary (Loar 1992). In addition, the density at WCK 3.9 in the main plant area and at WCK 2.9 near SWSA 4 increased by a factor of 15 between spring and fall 1991 (Loar 1992). Relatively high total densities (>1.5 fish/m^2) have only been observed at WCK 3.9 since fall 1990; prior to that time densities were very low, generally below 0.1 fish/m2 and often near 0.01 fish/m2 (Loar 1992). The improvement in the fish community at this site is probably associated with completion of the NRWTF in March 1990, which eliminated several wastewater discharges to WOC.

Two fish kills, each involving only a single fish, occurred in 1991: one in January on First Creek and the second in November on MB.

5.6.3 Interpretation of Biotic Changes

A proper evaluation of changes in stream communities that may occur following remedial action requires the identification of those natural conditions that could affect the communities independently of their recovery due to remedial actions. Large-scale natural variation in stream communities was examined with a large data set consisting of physical and biological properties of 107 sites in seven river systems in the Tennessee Valley. On the basis of principal components analysis, strong correlations were found between many physical parameters and fish and insect community structure attributes. These correlations support the initial hypothesis that parameters such as watershed area and stream gradient could be used as simple predictors of biotic community structure in unimpacted streams.

5.7 CONTAMINANTS IN TERRESTRIAL BIOTA

Contamination may enter terrestrial food chains through consumption of contaminated aquatic biota by terrestrial predators or through direct ingestion of contaminated soil and vegetation. Raccoons have been selected for long-term monitoring of spatial and temporal patterns of contamination within the WOC watershed because they feed heavily on aquatic prey that is at or near the top of the aquatic food chain and they are also exposed to potentially contaminated floodplain soils.

During 1991 the focus of the raccoon monitoring task was on verifying that raccoons could be used in a long-term monitoring program. Key parameters of this verification included adequate population size for statistical tests, ease of live capture, and ability to accumulate primary contaminants of interest (e.g., PCBs, mercury, ^{90}Sr, and ^{137}Cs).

A review of the literature indicated that raccoons can accumulate PCBs, various chlorinated pesticides, mercury, and other heavy metals to levels that are reflective of contamination levels in their environment. Hair samples from raccoons live-trapped in the WOC environs and from road-killed raccoons from around the ORR were analyzed for gamma-emitting radionuclides. Bone samples from road-killed raccoons were analyzed for ^{90}Sr. Results of these radionuclide analyses suggest that raccoons accumulate ^{60}Co, ^{90}Sr, and ^{137}Cs in sufficient concentrations above background that these animals can be used to monitor radioactive contamination in their food and ingested soil. In 1992 baseline data on concentrations of all key contaminants in raccoons from WOC and reference sites will be collected to support the long-term monitoring effort.

Because raccoons forage primarily on prey from the aquatic system, they do not serve as a monitor species for contamination entering the terrestrial system through purely terrestrial sources (e.g., contaminated soil and vegetation). Therefore, a second objective of the terrestrial monitoring task is to identify a species that can monitor terrestrial sources.

Because coyotes feed almost exclusively on terrestrial prey and carrion, scent stations were used to evaluate the distribution and abundance of coyotes on the ORR. However, the ORR coyote population is too small and the coyotes range over too large an area for these predators to be used as monitors of contamination on a site the size of an individual WAG. Further investigations will be made to identify a terrestrial organism for long-term monitoring.

5.7.1 Radioecology of WOL

Radioecological studies of WOL are being conducted to establish an inventory of radionuclides in the biotic and abiotic components of WOL and floodplain and to evaluate the significance of human exposure to contaminants in WOL. A seven-compartment model of WOL was developed to ascertain the impact of various scenarios on radionuclide inventories in WOL. The model predicts that cessation of all external ^{137}Cs inputs to WOL would reduce dissolved ^{137}Cs concentrations by 92%, but remobilization of sediment-bound ^{137}Cs would maintain dissolved ^{137}Cs concentrations at the reduced level for several years.

The weekly census of waterfowl populations continued in 1991 and included WOL and other radioactive waste ponds and contaminated areas near ORNL, sites near the Oak Ridge Y-12 Plant and K-25 Site, and several sites off the ORR. The census was designed to evaluate the potential transport of radionuclides from these areas into the human food chain via ingestion of waterfowl. Because of the increasing size of the population and the potential for contaminant bioaccumulation, the Canada goose census was emphasized. To deter approximately 200 Canada geese from using WOL during winter, a propane cannon was purchased and installed near the lake in December 1990. Between December 1990 and February 1991, the cannon substantially reduced the use of WOL by Canada geese and other waterfowl.

Only 3 of 12 Canada geese sampled in 1991 had detectable concentrations of ^{137}Cs. A gadwall, two coots, and two wood ducks also contained measurable ^{137}Cs concentrations (Table 5.1). The highest concentration of ^{137}Cs occurred in a kingfisher taken from WOL (Table 5.1).

5.8 ECOLOGICAL ASSESSMENT OF SOURCE WAGs

The first source WAG for which an ecological risk assessment is being conducted is WAG 5. WAG 5 primarily consists of SWSA 5 and the surface facilities for the Old and New

Table 5.1. Concentration of radionuclides (pCi/g fresh wt) in the tissues of waterfowl and waterbirds (other than Canada geese) collected in 1991

Location	Species	Tissue	^{137}Cs	^{60}CO
K-25 Site (K-901-A holding pond)	Coot	Muscle	ND	ND
		Liver	0.08 ± 0.07	ND
		Bone	ND	ND
	Coot	Muscle	ND	ND
		Liver	0.19 ± 0.06	ND
		Bone	ND	ND
	Gadwall	Muscle	30.1 ± 4.6	ND
		Liver	3.1 ± 1.1	ND
		Bone	ND	ND
Clinch River	Wood duck	Muscle	0.4 ± 0.1	ND
		Liver	0.5 ± 0.1	ND
		Bone	ND	ND
		Muscle	2.6 ± 0.1	ND
		Liver	1.5 ± 0.2	ND
		Bone	1.4 ± 0.4	ND
White Oak Lake	Coot	Muscle	6.8 ± 0.1	0.1 ± 0.03
		Liver	ND	ND
		Bone	ND	ND
	Kingfisher	Muscle	568.0 ± 2.7	1.3 ± 0.03
		Liver	404.0 ± 2.9	3.0 ± 0.05
		Bone	532.0 ± 11.0	ND

Hydrofracture Facilities. WAG 5 is drained by ephemeral streams and tributaries to WOC and MB.

A screening-level ecological risk assessment identified data gaps related to the toxicity of surface streams and seeps within WAG 5 and to the presence or absence of threatened and endangered species within WAG 5. An ecological assessment plan (Ashwood 1992) was developed to address these data gaps. The plan also includes measurement of contaminant levels in wild turkeys that feed in WAG 5 as a possible vector in the human health risk assessment.

After two rounds of ambient toxicity testing, three seeps have shown evidence of toxicity. Two of these seeps are located along WOC west of SWSA 5. The third seep is east of SWSA 5 along a small tributary.

Three female turkeys that were part of a flock suspected of feeding in WAG 5 were trapped and analyzed for radiological contamination. None of the turkeys contained gamma emitting radionuclides above background levels. One turkey contained beta contamination in its leg bones that was 50% greater than background. This turkey was sacrificed for further analysis. The remaining turkeys were transported to a Tennessee Wildlife Resources Agency game management site and released.

5.9 SUMMARY

The Biota Task of the WAG 2/SI includes three major components: (1) BMAP, (2) the ecological assessment of source WAGs, and (3) the ecological assessment and long-term monitoring of WAG 2. In addition to investigations and assessments conducted for ER, BMAP performs compliance monitoring according to the requirements of the ORNL NPDES permit.

Generally, biological tests showed that the aquatic ecosystems that receive effluents from ORNL facilities, including old waste disposal facilities, are remaining steady or improving in 1991 compared with earlier years. Of the 80 toxicity tests with small crustaceans during 1991, only three tests (all located at a site on WOC within the main plant area) yielded evidence of toxicity, and residual chlorine, a problem in the past, did not appear to be the cause of the toxicity. The flathead minnow toxicity tests did not provide evidence for acute toxicity at any of the sampling sites.

Periphyton monitoring, which provides a short-term indication of toxic releases, showed results similar to those in the previous years. The general pattern of improving physiological condition of the algal periphyton with distance from ORNL discharges was again apparent.

Accumulation studies showed that PCBs in channel catfish in the Clinch River near WOC are likely to contain PCBs in excess of the FDA limit. However, PCB concentrations in sunfish from some sites in the WOC watershed appear to have decreased over the period from December 1987 to July 1991. On the basis of bioaccumulation measured in Asiatic clams, the chlordane contamination in upper WOC appears to be steadily decreasing with time. Mercury concentrations in fish collected from WOC in winter 1990–91 were elevated over those in fish at reference streams but were below the FDA action level throughout the watershed.

Results of an integrated analysis of physiological factors suggest that conditions in WOC may have improved from 1989 to 1990, a finding that is consistent with the results of the ambient toxicity tests summarized in Sect. 5.3.1. Population-level studies showed that growth of redbreast sunfish in WOC was generally higher than in reference streams in both 1990 and 1991.

Benthic macroinvertebrate communities in the WOC exhibit the effects of varying degrees of water quality degradation. There are areas of high impact and two areas showing signs of recovery. Toxicants (primarily chlorine) associated with point-source discharges are probably the most significant cause of adverse effects in the main plant area, whereas downstream factors such as siltation and nutrient enrichment may be more important than point-source discharge.

Studies of fish populations in WOC watershed showed that species richness showed little change during 1991. Increases in populations at a few sites probably reflect cleanup measures such as the reduction of chlorinated discharges since late 1989 and the replacement of several direct wastewater discharges with the NWTF.

Radioecology studies of WOL are being conducted to gain an ecosystem perspective on the transfer of radionuclides between the biotic and abiotic components of the lake. Modeling results show that if all external ^{137}Cs inputs to WOL were stopped, the dissolved ^{137}Cs would decrease by 92%, but that remobilization of sediment-bound ^{137}Cs would maintain dissolved ^{137}Cs at the reduced level for several years.

The use of raccoons as biotoxicity integrators was evaluated. They are high on the food chain so they can accumulate PCBs, chlorinated pesticides, heavy metals, and radionuclides from a variety of organisms at lower trophic levels. Currently, baseline data on concentrations of contaminants in raccoons are being collected to support long-term monitoring efforts. Raccoons are mainly fish-eaters so they do not serve as indicators of contamination in the terrestrial system. A suitable species for terrestrial bioaccumulation studies and long-term monitoring is presently being sought.

Biological monitoring that has been performed extensively and continuously since 1986 provides detailed information about ecological status within the WOC watershed. Results generally show a highly impacted ecosystem that is stable and, in some cases, improving, due mostly to discharge reductions. Monitoring within BMAP and ecological assessment and long-term monitoring in WAG 2 will continue to provide the biological information needed by ER Program decision makers.

6. SUMMARY

The WAG 2/SI program has developed a comprehensive, integrated approach for supporting the Environmental Restoration Program's ORNL Site Office. During FY 1992 the WAG 2/SI program incorporated the WAG 2 RI and the ER Site Investigation projects. The work has been divided into four major tasks (Surface Water, Groundwater, Soil and Sediment, and Biota) designed to collect information needed to develop a site-wide perspective of the types, distribution, and fluxes of contaminants, to support screening-level risk assessments, and to support preliminary components of the WAG 2 RI. This document represents the annual Environmental Restoration Monitoring and Assessment Report for the ORNL site.

6.1 SUMMARY OF FINDINGS

6.1.1 Risk Assessment

Risk assessment plays a key role in identifying the contaminants (e.g.„ radionuclides) and pathways (e.g., sediment and ingestion of biota) of greatest potential risk to inadvertent intruders or to off-site areas. Data from risk assessments are also important for determining the need for remedial efforts, prioritizing remedial efforts, determining appropriate cleanup levels, and selecting among remedial alternatives. Thus collecting data to support screening level risk assessments and incorporating risk into planning are important for the WAG 2/SI efforts and managing Environmental Restoration for the ORNL site.

A review of completed risk assessment or screening activities at ORNL indicates that the most significant risk to the on-site worker and to the inadvertent intruder is exposure to gamma radiation, primarily from ^{137}Cs in soils and sediments, although ^{60}Co and (for WAG 6) ^{15X}Eu also contribute radiation. Contaminants in fish (PCBs, ^{137}Cs, Hg, ^{90}Sr) are also of potential human health concern. Radionuclides (especially ^{137}Cs, ^{60}Co, and ^{90}Sr) constitute the majority of the risk from the ORNL WAGs. Metals (e.g., Hg, As, Cr), and organic contaminants (PCBs and solvents) are of concern in certain locations. Prioritization of the ORNL waste areas groupings (WAGs) based upon risk to the public, ranked WAG 1 as the highest followed by WAG 4; followed by WAGs 2, 6, and 7—which could not be evaluated separately due to the available water quality data; followed by WAG 5.

6.1.2 Surface Water

The conceptual model for watershed hydrology indicates that virtually all water that infiltrates the soil [except for evapotranspirational (ET) losses] eventually migrates to local streams through either the shallow subsurface stormflow zone or the thin layer at the top of the groundwater zone referred to as the water table interval. The estimated downward flux below the water table interval is <1cm/year. Thus, surface water is the ultimate receptor of contaminant fluxes and the primary pathway for contaminant transport off-site.

The WAG 2/SI Surface Water group issued a comprehensive hydrologic data summary for ORNL (Borders et al. 1992) covering the period October 1990 through December 1991. This report is the third in a series produced by the ER Program which supports the long-term collection of hydrologic data. Activities to field-rate the high-flow flumes and the Sediment Retention Structure will improve discharge measurements needed to support water and contaminant mass balances in the watershed.

For 1991, mass balances for selected radionuclides were computed for major stream reaches in the WOC watershed. The lower WOC/White Oak Lake reach was a source for both ^{137}Cs and ^{60}Co. Mass balances for ^{3}H and ^{90}Sr indicated that these radionuclides were transported into the lower WOC reach and probably passed through lower WOC/WOL without interaction.

Analysis of 55 months of flux data for ^{3}H and ^{90}Sr showed that concentration tends to increase with increasing flow at WOD and at the lower WOC weir. This is significant because it is not the pattern seen on several smaller tributaries and because it implies that areas of buried waste and or contaminated soil act as sources of contaminants during high discharge periods. Thus, discharge and contaminant concentrations must be accurately measured during large flows to allow accurate calculations of contaminant flux.

Evaluation of the effectiveness of remedial actions to reduce contaminant fluxes has become a critical issue with the upcoming interim closure of WAG 6. Because contaminant movement is hydrologically driven, data for contaminant release should be evaluated relative to discharge. Evaluation of the relationship of contaminant concentrations in surface water to water flow or discharge (i.e., flux) has been shown to be a useful measure of the effectiveness of remedial actions to reduce contaminant fluxes. For example, the examination of concentration discharge relationships for WAG 6 indicates that there has been a 50% reduction in tritium flux following the installation of interim caps at WAG 6 in 1988. Evaluation of the early success hydrologic isolation of buried wastes for source control could be aided by evaluation of contaminant concentration–discharge relationships developed before and after interim actions.

Surface water efforts also include a seep and tributary survey and monitoring program to identify sources of contaminants to WOC and to evaluate the need for interim corrective actions.

6.1.3 Groundwater

In the complex hydrogeology of the ORR, contaminant flux in groundwater is the most difficult parameter to ascertain. Several directed investigations conducted as part of the WAG 2/SI project during FY 1992 addressed some important aspect of contaminant flux in groundwater. The development of the Conceptual Model by the ORRHAGS team (Solomon et al. 1992) for the hydrology of the ORR generated generic models that are important to ER activities. The observations are listed below.

(1) Virtually all water that infiltrates the soil (except for ET losses) eventually migrates to local streams through either the shallow subsurface stormflow zone or the thin layer at the top of the groundwater zone referred to as the water table interval. The estimated downward flux below the water table interval is <1cm/year. (2) Because of the discrete nature of groundwater, flow paths through fractures, seeps, and surface water, and not through monitoring wells, provide the most representative and unambiguous information about contaminant discharge from waste sites. (3) The widely spaced fractures in the bedrock are capable of moving relatively small amounts of contamination large distances in relatively short times. (4) Because ORNL is underlain by fractured, porous rock, molecular diffusion will transport significant quantities of contaminant into the rock matrix when the fracture is transporting high concentrations of contaminants; but after the primary source is removed, the porous rock acts as a secondary source, resupplying contaminants to water in the fracture.

This conceptual model was important in guiding efforts of the WAG 2/SI program and in turn these efforts provided information to verify and/or modify our conceptual understanding of subsurface processes.

The results from the WAG perimeter well sampling provides the first site-wide data set for extensive contamination parameters derived from high-quality monitoring wells. Median concentrations of contaminants for 160 wells were compared to MCLs; 53% of the wells exceeded one or more of the MCLs (unfiltered) and 46% of the wells exceeded one or more of the MCLs (filtered). Based on results from the unfiltered samples, radioactivity is the most frequently encountered type of contaminant (29%) found in these wells, followed by volatile organics (9%), metals (4%) and anions (2%). Maps showing the distributions and levels of contamination reveal interesting patterns and outliers. WAGs 4, 5 and 6 had the greatest percentage of wells with parameters exceeding drinking water standard MCLs. Local exceedances were observed at WAGs 1, 3, and 7. Overall about half of the wells exceeded one or more MCL. Nickel was the principal metal detected with subordinate amounts of chromium, mercury, selenium, and cadmium. VOCs including fuel hydrocarbons and solvent compounds were detected in a small percentage of the wells. Radiological contaminants (especially tritium and strontium) were widespread, and were the most significant problem at ORNL. Analysis of data for samples collected during 1992 will help to improve the picture of groundwater contamination at ORNL and help to guide future efforts.

In the ongoing WAG 2/SI investigation of secondary sources, for the first time on the ORR direct evidence of a diffusion gradient (of ^{3}H) away from an apparent fracture flow path has been documented. If matrix diffusion is occurring, then this ^{3}H in the rock matrix will become a secondary source of contamination to the same fracture flow path after the primary source is removed or hydrologically isolated (e.g., by capping). Computer simulations based on the initial data and estimated rates of water movement through the fracture are developing predictions of the rate at which water quality will improve following the removal/isolation of the buried wastes. Initial estimates area that the remediation of primary sources would result in improved water quality within several months and secondary sources removed by natural flushing within several to tens of years . Efforts planned for FY 1993 will gather data to refine the estimates of the rate of improvement in water quality following remediation of the primary source of contaminants. These data will be important for section of remedial alternatives, developing performance criteria, and in assessing performance of remedial actions.

The Groundwater-Producing Fractures investigation produced three breakthroughs: (1) For the first time on the ORR the permeable zones (fracture zones) that intersect core holes and the open intervals of piezometers and monitoring wells have been systematically identified and charted. It was found that hydrologically active zones occur at two scales: permeable intervals are spaced >3 m apart, but permeable zones can be subdivided into pervious and impervious sections. (2) A method was devised to calculate the important fracture hydrologic properties from bore hole flowmeter measurements. Fracture parameters are required for analysis of secondary sources and fracture-flow groundwater models. This method has to be validated. (3) The investigation also produced direct evidence of the water table interval, a key layer identified in the Conceptual Model that conducts contamination to surface-water seeps. The investigation was made possible by an electromagnetic bore hole flowmeter recently invented at the TVA Engineering Laboratory.

A fully three-dimensional model of groundwater flow has been implemented on state-of-the-art parallel processing computers at ORNL. The model is applied to the lower portion of WOC as it flows through Melton Valley. This model holds the promise for providing important information for groundwater processes not available from standard two dimensional representations of the subsurface such as anisotropy and the effects of capping on groundwater movement.

A statistical analysis of the geochemistry of groundwater at ORNL has begun. It has shown that for both Bethel Valley and Melton Valley the groundwater can be divided into three distinct geochemical types. This type of investigation will provide important reference data and may prove helpful in tracking water types through the subsurface system.

6.1.4 Soils and Sediments

Contaminated soils and sediments are a key concern for on-site risk and the transport of contaminated sediments during storms is a potentially important pathway for the off-site movement of contaminants. A gamma radiation walkover survey of the WAG 2 floodplain was conducted during FY 92. These surface radiation data are being used to identify hot spots, identify contaminant input areas, design a floodplain soil sampling program, and support efforts to manage contaminated soil and sediment at ORNL. The WAG 2/SI initiated an intensive sediment sampling project during the past winter that includes automatic sample collection at seven sites in WOC watershed. Data from four storms indicate that the flux of suspended sediments and particle-reactive contaminants is highly variable and there is no apparent pattern among storms yet. The data are being used to calibrate a hydrologic model (HSPF) that will be used to evaluate the impacts of alternative remedial actions and the impacts of extreme floods.

6.1.5 Biota

The Ecological Assessment task of the WAG 2/SI provides a focal point for the integration, coordination, and evaluation of data for biota and ecological risk in the WOC watershed. This effort uses data from the site-wide Biological Monitoring and Abatement Program monitoring efforts and augments these data to develop models of contaminant flow through the biota, to identify organisms at risk and potential human exposure, and to document changes and impacts on biotic communities. The BMAP collects baseline information for biotic communities and conducts instream, effluent, and ambient toxicity tests to: (1) identify sources of stress to biotic populations, (2) suggest remedial actions, and (3) document the responses to those actions. Ambient and effluent toxicity testing is regularly conducted using 7-day laboratory bioassays with water from each of 15 sites. Toxicity to standard laboratory test organisms has been associated with areas within WAG 1. Effluent toxicity testing has found toxicity associated with effluent from a coal yard and the ORNL sewage treatment plant (both located in WAG 1). A periphyton (attached algae and heterotrophs) monitoring effort has also found adverse effects associated with discharges in WAG 1. Efforts to characterize the radioecology of White Oak Lake are emphasizing pathways for radiological contaminants off-site and to humans. A waterfowl census and sampling program is coordinated with reservation-wide efforts. The results of ongoing biological monitoring show an impacted ecosystem that is stable and, in some cases, improving due to reductions in discharges of toxicants.

6.2 ADDITIONAL DATA NEEDS AND UPCOMING EFFORTS

Within the Surface Water Task, additional data needs generally relate to: (1) increased accuracy of hydrologic measurements, (2) better assessment of groundwater–surface-water interactions, and (3) contaminant mass balances for additional reaches. In support of the Sediment Transport Modeling Task, a more complete coverage of rainfall measurements across the watershed is needed to accurately characterize storms for hydrologic modeling.

Water quality in seeps and springs provide the most accurate information on subsurface contaminant discharges from WAGs. A comprehensive and integrated system for identifying and sampling seeps is needed for the site-wide coverage in WAG 2/SI and for the GW OUs. At individual seeps data need to be collected to evaluate the need for remedial actions and to support on-going remedial actions.

Data needs extend to water quality monitoring or intensive storm sampling (to determine *Q–C* relationships) combined with flow measurements to determine fluxes. Contaminant fluxes are most efficiently monitored at the tributary level. A tributary monitoring effort will begin during FY 1993.

The Seep Task, is providing the information needed to assess the water quality of subsurface discharges from WAGs. Building on that sampling work, the Tributary Assessment Task will combine continuous flow monitoring and water quality sampling during storms to determine *Q–C* relationships and estimate contaminant fluxes. The first step will be the systematic selection of 2–3 sites with existing flumes/weirs. In FY 1994 installation of new flumes/weirs will extend this effort to sites that are currently ungaged. The data will support calculation of contaminant mass balances.

Additional data needed in support of the Groundwater Task pertain to: (1) the assessment of groundwater conditions site-wide and (2) understanding groundwater systems and calculation of contamination fluxes in groundwater.

Additional needed data in support of site-wide assessment of groundwater quality will be identified and coordinated by the WAG 2/SI manager and the WAG 21 manager who must prepare a plan for future efforts by the GW OU project.

In support of groundwater modeling to determine groundwater fluxes, information and special data are needed. Information on the extent and behavior of secondary sources must be acquired. Fracture hydrologic characteristics to evaluate secondary sources and to establish parameters groundwater models are also needed. Although data collected on fracture characteristics in FY 1992 indicated a breakthrough, more information is needed to validate and extend this work. Methods to monitor contaminant flux in the shallow subsurface stormflow zone are also needed.

In the Soil and Sediment Task, background data on soils are needed to establish reference levels for contaminants. Data on soil erosion and stream-bank erosion are needed, including parameters for soil erosion models. Data for floodplain and aquatic sediments, data for streambank erosion, data for the transport of contaminated sediments during storms will continue to be collected during FY 1993. These data will support efforts to identify source areas for contaminated sediments, efforts to predict the movement of contaminated sediments under future conditions, and efforts to effectively manage contaminated sediments at ORNL.

In the Biota task, indicator species for assessment of terrestrial contamination effects must be identified and baseline data must be collected. These efforts are planned for FY 1993 and will be conducted along with continued monitoring and evaluation efforts conducted by the ORNL BMAP.

6.3 ORGANIZATIONAL APPROACH

As mentioned in Sect. 1, FY 1992 has been a transitional year for the WAG 2/SI program. Two programs were merged, and the main work shifted from planning to data collection in the field and data interpretation. The WAG 2/SI teams corresponding to the tasks in Fig. 1.2 are in place and actively working to achieve programmatic objectives.

In FY 1993, two forums will be established for the purpose of exchanging information within various ER teams. These teams are needed in order to ensure that the proper information is being generated to meet ER Program objectives and that the data collected in RIs and other ER activities are collected uniformly and shared among groups. The Core Technical Integration group will represent the management levels in Remedial Investigations and in ER functions. The Technical Coordination groups will consist of a series of groups organized by technical specialty. Both groups will meet monthly. The linkages of these groups to other ER functional groups are identified in Fig. 6.1.

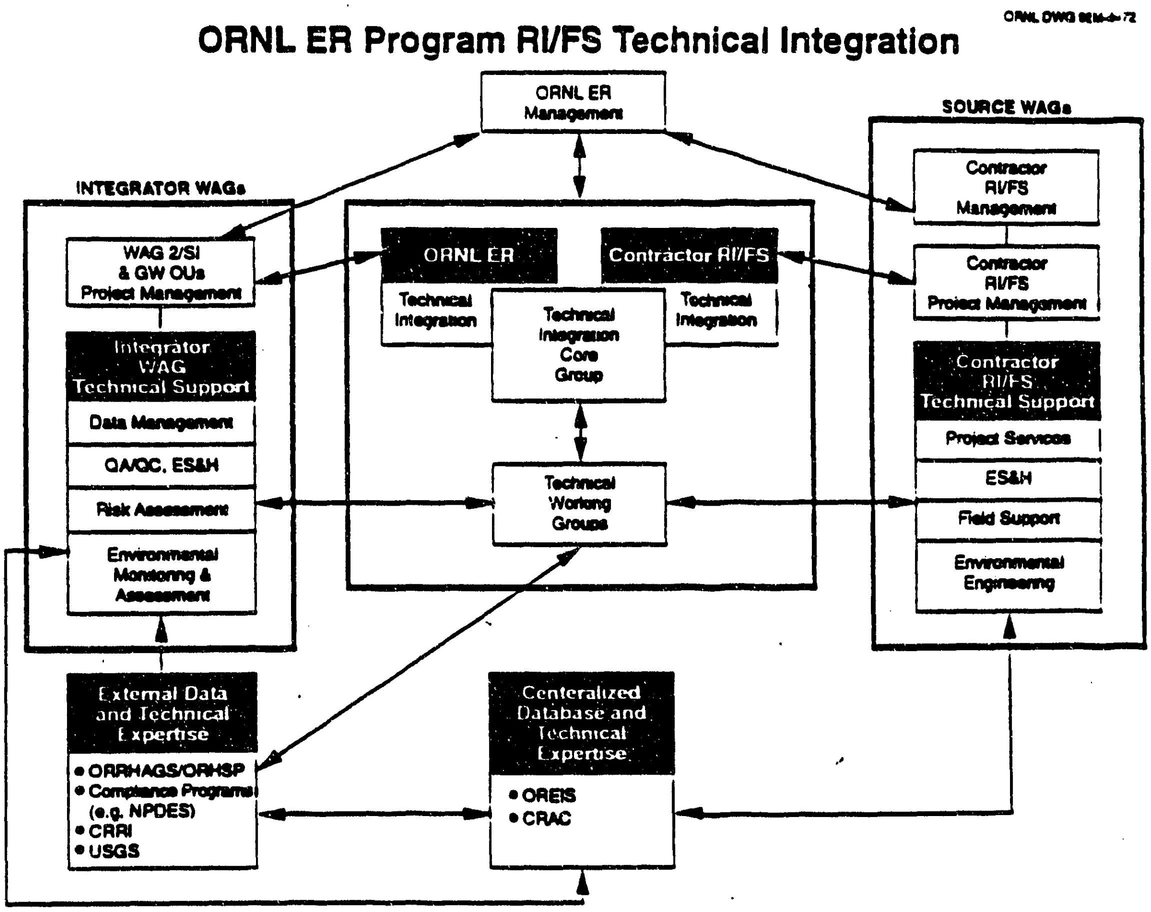

Fig. 6.1. ORNL ER Program RI/FS Technical Integration.

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