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**ENVIRONMENTAL
RESTORATION
PROGRAM**

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**Second Annual Report of the
Environmental Restoration Monitoring
and Assessment Program at Oak Ridge
National Laboratory**

**R. B. Clapp
and
J. A. Watts, Editors**

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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Energy Systems Environmental Restoration Program
ORNL Environmental Restoration Program

**Second Annual Report of the Environmental Restoration Monitoring
and Assessment Program at Oak Ridge National Laboratory**

**R. B. Clapp
and
J. A. Watts, Editors**

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ACRONYMS

ARARs	applicable or relevant and appropriate regulations
BMAP	Biological Monitoring and Abatement Program
BNI	Bechtel National, Inc.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRRI	Clinch River RI
CYRTF	Coal Yard Runoff Treatment Facility
DCG	derived concentrating guide
DOE	Department of Energy
DQO	data quality objective
EPA	Environmental Protection Agency
ER	environmental restoration
ERA	ecological risk assessment
ERMA	Environmental Restoration Monitoring and Assessment
ESP	Environmental Surveillance and Protection Section
FFA	Federal Facility Agreement
FS	feasibility study
GIS	geographic information system
GW OU	groundwater operable unit
GWPP	Groundwater Protection Program
HFIR	High Flux Isotope Reactor
HHMS	Hydrostatic Head Monitoring Station
HSPF	Hydrologic Simulation Program—FORTRAN
IP	integration point
MB (MBR)	Melton Branch
MBK	Melton Branch kilometer
MCL	maximum contaminant levels
MEPAS	Measurement and Evaluation Program Assessment System
MLE	most likelihood exposure
MSL	mean sea level
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRWTF	Nonradiological Wastewater Treatment Facility
OECD	Office of Environmental Compliance and Documentation
OREIS	Oak Ridge Environmental Information System
ORRHAGS	Oak Ridge Reservation Hydrologic and Geologic Study
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PCB	polychlorinated biphenyl
QA/QC	quality assurance/quality control
QC	quality control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RI	remedial investigation
RI/FS	remedial investigation/feasibility study

ROD	record of decision
SDWA	Safe Drinking Water Act
SI	site investigation
STP	sewage treatment plant
SWMU	solid waste management unit
SWSA	solid waste storage area
T&E	threatened and endangered
TDEC	Tennessee Department of Environment and Conservation
TDS	total dissolved solids
TRC	total residual chlorine
TRE	total rare earths
TRU	Transuranic (or Transuranium) Processing Facility
USGS	United States Geological Survey
USRADS	Ultrasonic Ranging and Data System
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 environmental monitoring and field investigations conducted to support the Environmental Restoration (ER) Program at the Oak Ridge National Laboratory (ORNL). This report focuses on the watershed scale, striving to provide an ORNL site-wide perspective on types, distribution, and transport of contamination. The results presented are used to enhance the conceptual understanding of the key contaminants and 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.

This report summarizes 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 where public access is allowed. 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, the remedial investigation was integrated with a series of environmental monitoring and SI activities at ORNL that address pathway and processes important for contaminant movement.

In addition to the results from WAG 2/SI monitoring and field investigations, this report includes information from other site-specific remedial investigations and feasibility studies (RI/FS) for contaminated sites at ORNL and data from other ongoing monitoring programs conducted by other organizations [e.g., the National Pollutant Discharge Elimination System (NPDES) compliance monitoring conducted by the Environmental Surveillance and Protection Section]. This information is included to provide an integrated basis to support ER decision making. This report summarizes information gathered through early 1993. Annual data, such as annual discharges of contaminants, are reported for calendar year 1992.

The objectives of this annual report are to

- list 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 stream reaches between monitoring stations in WOC in order to gain more understanding of where radioactivity is accumulating or being mobilized in the system;
- describe recent advances in the fundamental understanding of 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 activities (Surface Water, Groundwater, Soil and Sediment, and Biota). Information generated from these major activities, with data from other organizations, are used to assess the "contaminants of concern" and levels of risk at each of the ORNL WAGs.

CONTAMINANTS OF CONCERN AND RISK ASSESSMENT

The ORNL site has been divided into source-control operable units (waste area groupings or WAGs with buried wastes and leak sites) and integrator operable units (surface water system, WAG 2 and the ground water regime, WAG 21) which integrate contaminant releases from source units. The classification is based on common sense recognizing that the source-control WAGs should be remediated prior to cleaning up the integrator WAGs. Further, data gathered in the integrator units support decision making and risk assessment to prioritize the WAGs for remedial actions.

Contaminants of concern are listed by WAG in the appendix to this report. Contaminants are classified as either "on-the-WAG," leading to possible hazardous exposures to workers or future WAG occupants, or "mobile," leading to possible off-site exposure. It is the mobile contaminants that are the initial concern at the site-wide scale because they can accumulate in the integrator WAGs, and they potentially could result in unacceptable off-site doses. To date, screening risk assessments completed on WAGs 1, 2, 5, 6, 13 and WOC Embayment suggest that the public is not in danger from contamination currently released from the WOC watershed. All locations at ORNL where contaminant risks on the WAG are unacceptably high have restricted access. In addition, results to date generally show that water leaving WAG 2 at White Oak Dam (WOD) is slightly higher than the EPA action level (i.e., 10^{-4}) but the public has no direct access to the stream.

For the purpose of calculating risk, the assumed pathway for exposure is ingestion of stream water discharged at WOD over a period of 30 years, although the public has no direct access to WOC at or below the dam. This potential off-site risk to human health caused by hydrologic discharges from the ORNL site is derived almost entirely from radionuclides and not from organic compounds or metals. In terms of risk the primary mobile contaminants are ^3H and ^{90}Sr and, to a much lesser extent, ^{137}Cs and ^{60}Co . Further downstream, the dilution of the Clinch River reduces the risk below the action level for the maximally exposed individual at Clinch River mile 9.5, the closest downstream public-access point where land-based activities can occur (e.g., growing irrigated crops). The maximally exposed individual is assumed to ingest Clinch River water, eat food produced with river water, and receive exposure from surface sediments.

SURFACE WATER

In addition to ongoing surface water flow monitoring, the Surface Water activity has a number of focused tasks. The Seep and Tributary Task group provided detailed snap-shot pictures of the spatial pattern of contamination in the WAG 2 area during dry-season and wet-season baseflow conditions. The results show the main sources of ^3H , ^{90}Sr , ^{137}Cs and ^{60}Co

flowing into the WOC surface water system. The information will be used to guide localized actions to reduce contaminant releases.

The Tributary Assessment Task was initiated to describe the dynamic behavior of contaminant transport between the WAGs and the main streams. A conceptual model for tributary contaminant transport is described that relates the concentration of contamination measured in stream water to the rate of stream flow during a storm. However, data collected on the main stem of WOC at a larger temporal scale show opposite behavior. It is postulated that contaminant releases to WOC may be related to higher contaminant fluxes in the shallow groundwater interval than previously thought. Resolution of this discrepancy will enhance our understanding of contaminant transport processes and may help us to understand the extent to which we have a near-surface soil contamination problem or a groundwater contamination problem. The discrepancy in the data does not negate the ORNL hydrologic conceptual model because that model does not specifically address how contaminant concentrations might vary during storms or over a period of several years. The issue will be addressed in the Watershed Data Integration activity planned for FY 1994.

At the watershed scale, mass balance of the main radionuclides for major stream reaches in the WOC watershed for 1992 indicated that lower WOC/WOL was a source for ^{137}Cs , ^{60}Co , and ^{90}Sr , and that ^3H probably passed through the reach without much increase. Cesium-137 showed a seasonal trend with WOL being a source during the winter months and a sink during the summer months. This trend will be investigated by examining storm sampling data currently being collected and by surface water, sediment, and contaminant transport modeling.

Performance monitoring will become critically important as remedial technologies are implemented and evaluated. Three approaches to performance monitoring based on surface water monitoring are presented. These methods address different scales within the watershed and when applied judiciously, they will provide ER with scientifically defensible evidence of the effectiveness of remediations.

GROUNDWATER

Due to the complex hydrogeology of the ORR, contaminant flux in groundwater is probably the most difficult environmental parameter to ascertain. This complexity leads to a multifaceted groundwater investigation program to meet ER needs.

Ongoing activities in the Groundwater Task include the WAG Perimeter Well Monitoring Task and the new Groundwater Level Monitoring Task. Data from the perimeter monitoring activity showed little change from that summarized the previous year, therefore there is no new analysis presented in this report. The data were used for geochemical assessment and statistical methods showed three geochemical water types. Ongoing statistical analyses of the data are being used to subdivide groundwater data for establishing background conditions, identification of lateral flow paths, and identification of vertical groundwater zones. The data contribute to our fundamental understanding of the flow system.

Two directed investigations were initiated in late FY 1993. The first is a special study using shallow drive points to observe the flow paths between buried wastes and nearby contaminated seeps on tributaries near WAGs 5, 6, and 7. A second directed investigation will examine an anomalous high chloride concentration observed in wells to the south of WAG 7.

High chloride concentrations are especially important because deep groundwater is known to be briny with abundant chloride. There are no known naturally occurring hydrological connections between the deep groundwater system and the surface, but these high chloride concentrations may be evidence of such a connection. If this is true then many assumptions about the hydrologic isolation of the deep aquiclude must be revised and the implications to ER (especially to WAG 10 Hydrofracture) are profound.

The HHMS Task examines the vertical movement between the intermediate groundwater zone and the deep, briny aquiclude. Work during the past year centered on defining flowpaths in the water gap between Bethel and Melton Valleys. The conceptual hydrologic model suggests there should be little or no hydrogeologic communication between these valleys. If this is not the case, then subsurface contamination may move from one valley to the other.

The Groundwater Modeling Task has set up a 3-D solution grid for Melton Branch Valley using HHMS data and other data sources to define the system boundaries for future modeling of water and contaminant transport. To date, the initial model simulations indicate that there may be underflow beneath the Copper Ridge, the topographic divide to the south of WOL. The state-of-the-art model is running on a parallel mainframe. A reliable, calibrated model is essential to the WAG 2/RI effort for the prediction of future releases under no-action and other exposure scenarios.

SOILS AND SEDIMENTS

Contaminated soils and sediments are a key concern for on-site risk. Gamma-emitting radionuclides sorbed to soil and sediment particles provide significant exposure hazards within WAG 2. Furthermore, the mobilization and transport of contaminated sediments in the WOC system is a potentially important pathway for the off-site discharge of contaminants. This pathway is being intensively investigated through field studies and modeling.

An extensive gamma-survey walkover on the WOC floodplain in WAG 2 has been used in health and safety planning and in the development of soil sampling programs. Results show that relatively high radiation levels occur closer to WOC, and that levels decrease rapidly with distance away from WOC, with the exception of the Intermediate Pond Site. Data will be used in computer modeling investigations to determine risks related to contaminant mobility during severe storms (25-, 50-, and 100-year return periods) that may mobilize these sediments and carry them off-site.

On March 23, 1993, a relatively small flood event (enough for over-bank flow) was intensively sampled, and the results comprise the first comprehensive storm sediment data base. The flood had an estimated return period of about 1 year, and total discharge of ^{137}Cs was estimated to be 0.044 Ci over 3.3 days. This discharge is about 3 to 10% of the annual ^{137}Cs discharges measured at WOD over the past 10 years. Results suggest that lake-bottom sediments and other material in the lower WOC reach can remain immobile during a 1-year flood event while suspended sediments are transported from WOC to WOD (and then to the Clinch River).

The intensive storm sampling provides important insights into the hydrologic behavior of the WOC system, however, the real benefit of these data will come with the calibration of the HSPF model for contaminated sediment movement. The calibrated model will be used

to predict the watershed response to conditions that cannot be directly observed, such as extreme precipitation events or planned remedial actions. Data collection, modeling and integration of the results into ER planning will ensure that no remedial design will inadvertently cause scour and erosion of contaminated sediments in WAG 2 that could, in turn, lead to unacceptable risk to the off-site public.

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 (BMAP) effort and augments these data to develop models of contaminant flow through the biota, to identify organisms at risk and potentially unacceptable human exposures, and to document changes and impacts on biotic communities.

In the past year, periphyton monitoring showed improving physiological condition of the algae with distance from ORNL discharges. PCBs and mercury in fish were below FDA action levels in all except for PCBs in one bass specimen. Bioaccumulation of chlordane continues to decline. Toxicants (primarily chlorine) associated with point-source discharge are probably the most significant cause of adverse effects to benthic macroinvertebrate communities in WOC, whereas at downstream locations factors such as siltation and nutrient enrichment may be more important than point-source discharge. Raccoons are currently being used as indicator organisms, and baseline data are being collected. Kingfishers and mink are being evaluated as additional indicator species.

Results generally show a highly impacted ecosystem that is stable and, in some cases, improving due mostly to discharge reductions. Monitoring within BMAP, ecological assessment, and long-term monitoring as part of the WAG 2 RI will continue to provide the biological information needed by ER program decision makers.

ADDITIONAL DATA NEEDS AND UPCOMING EFFORTS

Risk assessment and ultimately the direction of the entire environmental restoration endeavor rely on the ultimate land use at the ORNL site (or any other DOE facility land). Land use decisions determine risk exposure scenarios, remediation goals, and remedy selection. A process has been initiated through the ER Technical Programs group as a pilot program for a nationwide DOE study of land use development. The approach will be to get major stakeholders (public, regulatory agencies, DOE, and DOE contractors) into an interactive process that considers all major factors: technical limitations, cost, public safety concerns, and desire for economic growth.

Within the Surface Water Task, additional data needs relate to (1) increased accuracy of hydrologic measurements and (2) better assessment of groundwater and surface water interactions. Efforts for improved accuracy have begun with the assistance of the USGS in rating the weirs.

There is a need to couple the extensive surface water sampling with shallow groundwater elevation measurements and water quality sampling at some point in the future. No plans for

this kind of coordinated monitoring have been developed yet. Instead, in the coming year, data analysis in the Watershed Data Integration activity described later will address current uncertainties in the hydrologic conceptual models. The emphasis will be on the analysis of existing data so that subsequent field investigation can be as focused and effective as possible.

There are two complementary sampling programs to investigate seeps at the ORNL site. The Seeps and Tributary sampling provides the most comprehensive spatial investigation of contamination sources to surface water in the WOC drainage below WAG 1, and it will continue with two more sampling campaigns in FY 1994. In contrast, for the Seep Survey Task, the goal is to locate all seeps in the uncontaminated areas of the WOC basin and to get limited water quality data at each site. The survey covers a much wider area than the Seeps and Tributary Task does. The resulting data should yield fundamental information on the direction and magnitude of groundwater flowpaths, which will help guide localized remedial actions.

Several of the responsibilities now in the WAG 2/SI Groundwater Task will be transferred to the Groundwater WAG 21 manager. Intensive shallow groundwater investigations (using the shallow drive points) will be continued in order to identify and quantify the transport of contamination between buried waste and seeps in nearby tributaries. This information is vital to understanding the relative magnitude of primary (waste trenches) versus secondary (contaminated soil/rock) sources. Identifying the flow paths that conduct contamination to the surface water system will lead to near-term corrective actions designed to rapidly reduce off-site fluxes and potential exposures to contaminants.

In the Soil and Sediment Task, investigations of contaminant inventories and erosion rates will continue. More intensive sediment data are needed during extreme storms, and the sampling team is in place to collect the data. Nature must be cooperative. During the coming year the HSPF model will be calibrated and used to evaluate contaminant transport in several hydrologic scenarios. These simulations will provide ER management with insight into the risks related to extreme floods.

In the Biota Task, indicator species for assessment of terrestrial contamination effects must be identified and baseline data collected. These efforts are planned for FY 1994 and will be conducted along with continued monitoring and evaluation efforts conducted by the ORNL BMAP.

In addition to work on the four primary tasks, two new multidisciplinary tasks are currently being initiated and will continue in FY 1994. Both activities will integrate hydrologic, geologic, and biotic data. The first activity is aimed at improved ecological risk assessments by evaluating the movement of contaminants through the biota on an ORNL site-wide basis. The second activity, named the Watershed Data Integration, is aimed at better understanding the (largely) abiotic transport mechanisms via surface and subsurface hydrology. Both will use a compatible geographical information system (GIS); therefore, data will be transferable, and task staff are in regular communication both directly and through WAG 2/SI program management.

1. INTRODUCTION

Oak Ridge National Laboratory (ORNL), located on the U.S. Department of Energy's (DOE's) 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 49 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 Environment and Conservation (TDEC) 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).

The ORNL Environmental Restoration (ER) Program was established (1) 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 (2) to manage the efforts to achieve comprehensive remediation of releases and threatened releases of hazardous substances, hazardous wastes, pollutants, or contaminants at or from 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.

The ER Program supports numerous environmental monitoring and data collection activities. This report summarizes environmental data collected by the ORNL ER Program and by other groups at ORNL and presents assessments of those data. This report is prepared as part of the *Environmental Restoration Monitoring and Assessment* activity within the *WAG 2/Site Investigation (SI) Program*. This program and its objectives are described in detail later in this section. Briefly, the WAG 2/SI is a structured, multidisciplinary effort that is focused on collecting and assessing environmental information that will lead to an orderly, environmentally sound, and cost-effective remediation of contaminated sites at ORNL.

The Annual Environmental Restoration Monitoring and Assessment (ERMA) Report is generated to meet the following general goals:

- To provide an annual summary of environmental data collection within the WAG 2/SI Program and pertinent data collection by other groups and to show the importance of these data to the needs and goals of the ORNL ER Program.
- To assess the data in terms of risk to human health and to the environment because the prioritization of remedial actions and the selection of remedial technologies for site cleanup are primarily driven by risk reduction.
- To inform the public, the regulators, and DOE managers about current environmental conditions and associated risks at the ORNL facilities managed by the ORNL ER Program.

The ERMA report strives to provide an ORNL site-wide perspective on types, distribution, and transport of contamination. Reports for investigations at individual waste disposal areas provide the detailed information on local contamination levels. This report is a follow-on to the first ERMA report (ERMA 1992). This report summarizes information gathered through early 1993. Annual data, such as annual discharges of contaminants, are reported for calendar year 1993.

To aid the reader, each section contains a brief outline, as shown here.

Section Outline

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/SI Program.

Section 1.3 reviews the key aspects of the hydrology of the ORNL site that mobilize and transport contaminants within the watershed.

1.1 ORNL SITE

Because of the large number of contaminated sites and the hydrologic complexity at ORNL, the strategy developed in response to regulatory requirements is based on waste area groupings (WAGs), as shown in Fig. 1.1, rather than individual sites. The WAGs are generally defined by small watersheds that contain contiguous and similar remedial action sites. In some cases, hydrologic interaction has occurred 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, 14 of which 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 "contaminant source WAGs."

WAG 2 consists of White Oak Creek (WOC) below the 7500 bridge monitoring station, Melton Branch (MP), 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. Ten WAGs that drain to the WOC and WAG 2:

Fig 1.1. Map showing ORNL waste area groupings.

WAG 1	the main plant area,
WAG 3, 4, 5, and 6	former waste disposal facilities called Solid Waste Storage Areas (SWSAs),
WAG 7	the former "Pits and Trenches" liquid waste disposal area,
WAG 8	the High Flux Isotope Reactor (HFIR) and associated transfer lines and disposal facilities,
WAG 9	the Homogeneous Test Reactor, and
WAG 17	ORNL service areas.

WAG 10 is the deep Hydrofracture Waste Disposal facility, and although there are wellheads in WAG 2 and WAG 5, the disposed waste is associated predominately with deep geological units.

WAG 2 is downgradient from all the WAGs in the watershed; therefore, it receives and integrates the contaminants released from the other WAGs in the watershed. Consequently, WAG 2 is termed an "integrator WAG, and it serves as a conduit to contaminants from the ORNL WAGs to off-site areas.

The ORNL Groundwater Operable Unit (GW OU), also referred to as WAG 21, is shown in Fig. 1.2. It encompasses the groundwater beneath the ORNL site, and it is divided into two OUs (Bethel Valley OU and Melton Valley OU). The GW OU is identified as a separate entity because contaminants can migrate in the subsurface from one area to another. The GW OU is also an integrator WAG because it receives the contaminants from the source WAGs that move through the groundwater system.

1.2 SITE-WIDE, INTEGRATED APPROACH TO ENVIRONMENTAL MONITORING

Early in FY 1992, two large-scale ORNL ER projects [the WAG 2 Remedial Investigation (RI) and the SI Program] were merged to better achieve their complementary 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 WOC watershed, and a series of directed monitoring efforts and investigations that identify and quantify the pathways and processes important for contaminant movement from ORNL WAGs within the WOC watershed. 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; (4) biotic populations and contaminants in the biota; and (5) 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.

Fig. 1.2. Map showing WAG 21, which is divided into two groundwater operable units.

The WAG 2/SI Program is a key component of the ORNL Operable Unit (OU) strategy, wherein WAG 2 and the GW 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 ER Program's activities for the major source WAGs at ORNL, leading to the eventual remediation of WAG 2.

The designation of "contaminant-source" and "integrator" is critical to understanding the systematic approach to environmental cleanup at ORNL. The basic ORNL ER strategy for prioritization of remedial actions and allocation of resources is to address the cleanup of contaminated sites in an orderly fashion by first ensuring that all on-site risks to workers and other potentially exposed individuals are minimized. After that is assured, the source WAGs generating the largest proportion of off-site risk will generally be remediated first to reduce off-site flux of contamination, thereby reducing the potential hazards to the public. After contaminant source WAGs are controlled, then the integrator WAGs (WAG 2 and the GW OU) will be remediated, although it may be decades before final remediations to the integrator WAGs are started. In the meantime, early actions and interim corrective actions will be initiated to reduce off-site flux of contaminants using the same risk-based prioritization approach used for identifying WAG remediations.

This site-wide approach for controlling contamination movement and associated health risks led to a recent decision for WAG 6. In the second quarter of FY 1993, regulators and DOE representatives with input from the public opted for "deferred action" for WAG 6 rather than a previously proposed "interim" remedial action involving the placement of extensive, but temporary, hydrologic barriers to reduce contaminant release from the site. The decision for no action at the present time was based on the low relative risk caused by WAG 6 to an individual hypothetically located downstream of ORNL. Relative risk refers to the portion of the risk to an off-site individual that is attributable to contaminant releases from WAG 6. The decision-makers concluded that other WAGs, such as WAGs 1, 4, 5, and 7, constitute more of a potential health hazard; therefore, resources should be allocated to them rather than to WAG 6. This decision does not mean that contamination at WAG 6 is suddenly considered to be insignificant. After other source WAGs are remediated, then WAG 6 will again be considered for remedial action.

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 an 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 have 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 ongoing 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 cannot adequately be addressed at the WAG level (e.g., ecological assessment and sediment transport), and (c) 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 RI to contribute to an integrated assessment of the effects of releases from DOE facilities.
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

The WAG 2/SI Program is divided into four major technical tasks: Surface Water, Groundwater, Soil and Sediments, and Biota (Fig. 1.3). Each major task was divided into tasks

Fig. 1.3. Major tasks for the WAG 2/SI Program. Arrows indicate the flow of information discussed in this report.

with individual task leaders and staff. Over the past year, work on tasks begun in FY 1992 was continued, and some new investigations were initiated as our knowledge of the system grew and as technical staff became available.

The Surface Water Task consists of five components:

- **Surface Water Hydrology:** Focusing on precipitation and surface water discharge monitoring to support a variety of ER projects.
- **Hydrologic Pathways Investigation:** Identifying subsurface pathways for contaminant movement and secondary contamination sources.
- **Seeps and Tributaries Survey:** Identifying the spatial distribution of contaminant sources in seeps and tributaries, interacting with surface water chemistry and groundwater tasks, and supporting remediation of contaminant sources.
- **Tributary Assessment:** Investigating the dynamic behavior of contaminant discharge from tributaries draining waste areas, important because the dynamic response implies hydrologic flow path and release mechanism. This task is new for FY 1993.
- **Surface Water Chemistry:** Using data for water chemistry collected at the major monitoring stations to support risk assessment and construct mass balances for contaminants.

The purposes of the Hydrologic Pathways Investigation are to identify subsurface flow paths that can conduct contaminants from buried wastes to nearby streams and to evaluate the potential of contaminated soil/rock to serve as a secondary contamination source after wastes have been removed or isolated. There are no reportable activities since those described by Hicks et al. (1992). Field activities will recommence at the WAG 5 study site near the end of FY 1993.

The Soil and Sediment Task has three components:

- **Floodplain Soils and Aquatic Sediments:** Determining the inventories of contaminants in floodplain and aquatic sediments to (a) identify contaminant sources areas, (b) support and integrate sediment management programs to minimize the potential for contaminant release to the off-site area, and (c) evaluate interim corrective measures and potential future remedial actions.
- **Storm Sediment Monitoring:** Collecting samples of suspended sediment and associated particle-reactive contaminants during extreme storms in order to understand the movement of contaminants and to calibrate a computer model of water, sediment, and contaminant transport.
- **Sediment Transport Modeling:** Developing a calibrated computer model to predict the potential for the erosion and transport of sediment and particle-reactive contaminants following changes in the watershed (e.g., as a result of remedial actions) and during extreme storm events. This task was part of the Storm Sediment Monitoring Task during the previous fiscal year.

The Groundwater Task has three components:

- **Groundwater Monitoring and Data Assessment:** Collecting data for metals, radionuclides, and organic contaminants from a series of 168 wells located on the perimeters of the ORNL WAGs, collecting water levels for the whole site, and analyzing the results for temporal and spatial trends.
- **Directed Studies:** Focusing on specific uncertainties in the groundwater system, including the **Hydraulic Head Monitoring Stations (HHMSs) Task** (collecting data for watershed exit pathways and exploring hydrologic communication between intermediate and shallow groundwater by monitoring well clusters).
- **Groundwater Modeling:** Constructing a 3-dimensional model of groundwater flow to better support the selection and evaluation of remedial actions.

Note that the GW OU Program has only recently been established. Most of the WAG 2/SI groundwater tasks will transition to the ORNL site-wide groundwater effort (GW OU) 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 an 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) in-stream monitoring of invertebrates and fishes; (e) the radioecology of WOL; and (f) contaminants in terrestrial biota.

WAG 2/SI Program support includes several activities:

- human health and ecological risk assessment for WAG 2 and risk-based prioritization of contaminant sources at ORNL;
- data management and quality assurance/quality control (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 from these tasks for the year (until about April 1992) are summarized in this document.

For each major task, internal and external organizations were identified for the exchange of data and information. The internal and external organizations 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, seep surveying, and hydrologic expertise.
- RI/FS subcontractors—Bechtel National, Inc. (BNI), for WAGs 1, 5, and 10, and SAIC/CDM for WAGs 6 and 1.
- Biological Monitoring and Abatement Program (BMAP)—for the compliance component; the ER-supported 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 (CRRRI)—the remedial investigation of surface water system downstream of WOC.
- Groundwater Operable unit—ORNL site-wide ER groundwater investigations and remediation.
- Groundwater Protection Program (GWPP)—an ORNL site-wide groundwater activities coordination effort, including non-ER activities. GWPP Coordinator maintains documentation related to groundwater well status.

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 is expanding 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

Most component tasks of the WAG 2/SI effort issue focused reports complete with detailed analyses and supporting data. A report will be issued soon that contains detailed information and data from WAG 2 investigations through September 1992, as described in the planning document by Boston, ed. (1992).

The ERMA report 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. Specifically, the objectives of this annual report are to

- list 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 extent and movement of contaminants; and
- describe future data collection and monitoring activities.

1.2.4 Data Quality

Data and results summarized in Sects. 3 through 6 of this report were derived from several activities guided by different Quality Assurance (QA) plans. Data generated by the WAG 2/SI Program were collected in accordance with objectives described in the program QA plan (Atwood and Miller 1992). The recent Phase I RI report for WAG 2 has detailed results of QA determinations and data validation activities. Surface water and groundwater quality data summarized in Sects. 2 and 3 were collected and validated by the ORNL Office of Environmental Compliance and Documentation to conform to standards required for monitoring under NPDES and DOE Order 5400.1. These data collection activities have had extensive audits and reviews. In Sect. 3 surface water quality data for WAG 6 were collected as a preliminary investigation within the Interim Corrective Measures Monitoring Program. Data were collected for the purpose of creating statistical models of contaminant concentration ranges and for guiding future monitoring of WAG 6 releases. Those data were collected to meet data quality level II in accordance with WAG 2/SI documentation. In Sect. 6 data collected within the compliance portion of the BMAP program conform to QA standards identified in seven project level QA plans focused on the different activities within BMAP, and data collected for ER assessment purposes conform to WAG 2 specification (Atwood and Miller 1992).

1.3 THE HYDROLOGIC SYSTEM AT ORNL

Because surface water is the main driver for contaminant transport leading to off-site exposures and because groundwater provides the linkage between the buried waste and the surface water pathway, the reader must be at least somewhat familiar with the hydrologic system at ORNL in order to understand the monitoring summaries of this report. In ERMA (1992) the ORNL site conceptual hydrologic model was explained in detail; a brief synopsis is offered here.

The development of the conceptual hydrologic framework by the ORRHAGS team (Solomon et al. 1992) for the ORR has been the basis of ORNL site-specific and WAG-specific conceptual hydrologic models. The conceptual framework emphasizes the importance of several mechanisms affecting contaminant transport:

- In the shale formations where most of the waste is buried at ORNL, the subsurface hydrology is divided into the near-surface stormflow zone, the vadose zone, and the groundwater zone, as shown in Fig. 1.4. The groundwater zone is divided into the relatively thin upper water table interval, intermediate and deep intervals, and a briny aquiclude that is not shown in Fig. 1.4.

The depth of the water table zone generally conforms to the depth of weathering, and it mimics the surface topography.

Flow in the groundwater zone is affected by fracture zones that cause preferential flow in the strike direction (anisotropy).

These observations mean that a 3-dimensional model best can portray groundwater flow paths at ORNL.

- Lateral flow in the transient near-surface stormflow zone and, to a lesser degree, in the shallow water table interval account for most of the flow to tributaries and streams.

Stormflow is highly transient, and no method for directly monitoring flow or quality has been devised. Indirect methods based on hydrograph separation or comparisons of discharge and concentration (Q-C) measured at weirs are promising.

- Fractures provide discrete flow paths, and they conduct material between buried wastes and seeps where contaminated groundwater emerges at the surface.

Consequently, seeps and springs are considered to be better than shallow groundwater wells for monitoring groundwater quality because they represent the active flow system.

- In a medium that is both fractured and porous, matrix diffusion stores and buffers the contaminant transported from primary waste sources to seeps and springs.

The buffering effect safeguards the system from sharp increases in surface water concentrations. When a buried waste container breaks open and releases large quantities of leachate, most of it diffuses into the matrix.

Because of the complex hydrogeology of the ORR, contaminant movement in groundwater is the most difficult parameter to ascertain. This complexity necessitates a multifaceted groundwater investigation program to meet ER needs.

Dip Section

Strike Section

Fig. 1.4. Conceptual hydrologic model for subsurface flow in shale aquatard at the Oak Ridge Reservation.

2. CONTAMINANTS OF CONCERN AND RISK ASSESSMENT

2.1 INTRODUCTION

The purpose of this section is to summarize human health risk and ecological risk assessment activities associated with the ORNL WAGs. The methodologies used for conducting human health and ecological risk assessments on source and integrator OUs are described in this section. Results of the risk assessment activities are given for the individual WAG source units and for the WAG 2 integrator unit, and issues related to risk analysis are identified. Contaminant source and integrator operable units are described in Sect. 1.2

2.1.1 Section Outline

- Section 2.2 describes contaminants of concern that have been identified in screening level human-health risk assessments and through comparison to regulatory benchmarks.
- Section 2.3 summarizes results of human health risk assessments performed at ORNL.
- Section 2.4 describes the surface water and groundwater OUs and explains the approach used to assess risk at source control and integrator OUs.
- Section 2.5 identifies issues of concern for risk analysis related to environmental restoration activities.
- Section 2.6 reviews the recent progress in ecological risk assessments.
- Section 2.7 provides a section summary.

2.1.2 Assessment and Decision-Making

The technical objective for environmental restoration design activities is to select a course of action from a range of alternatives that meet imprecisely defined acceptable risk criteria. Making these decisions while operating with significant uncertainties is the main challenge of environmental cleanup activities. Considerable effort and resources are often expended to collect site characterization data for reducing these uncertainties and to provide the necessary information to determine whether or not action is needed and, if so, the type of action to implement. Within this context, the economic objective of data collection is to minimize the cost of meeting the technical objective. Data collection and acceptable risk problems then become decision problems (Fischhoff et al. 1981). The goal of risk assessment activities at ORNL is to assess risk in a manner conducive to consistent risk management practices and in a way that leads to decisions that attempt to resolve these problems and that confront the many issues facing environmental restoration. The ER Program at ORNL proposes to confront these issues by using risk and decision analysis to assess risk in a manner consistent with the conceptual model for ORNL, ensure early public involvement in the decision process, quantify background risks, and explore the issue of acceptable risk.

2.2 CONTAMINANTS OF CONCERN

The identification of contaminants of concern is the initial stage in ER risk assessment problem definition. Contaminants known or suspected to have been released from ORNL WAGs are identified in Table 2.1. These contaminants were determined primarily based on information in CERCLA RIs, RFIs, site characterization reports, or environmental data

Table 2.1. Contaminants known or suspected to have been released from each WAG

WAG	Contaminants ^a		
	Radionuclides ^b	Metals	Other
1	⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, ¹⁵⁴ Eu, ²³² Th, ²³⁸ U, ²³⁹ Pu, ²⁴¹ Am, ²⁴⁴ Cm, other radionuclides	Cd, Cr, Cu, Hg, Mo, Ni, Pb, Zn, TRE	PCBs, chlordane
8			
2	³ H, ⁶⁰ Co, ⁹⁰ Sr, ⁹⁹ Tc, ¹³⁷ Cs, ¹⁵⁴ Eu, ²³⁸ U, ²³⁹ 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, ⁶⁰ Co, ⁹⁰ Sr, ¹⁰⁶ Ru, ¹³⁷ Cs, ²³⁹ Pu, other radionuclides	TRE	
5	³ H, ⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, ²³⁸ U, ²³⁹ Pu, ²⁴¹ Am, ²⁴⁴ Cm, other radionuclides	Cr, Hg, Ni, Pb, Zn	PCBs
6	³ H, ¹⁴ C, ⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, ¹⁵⁴ Eu, ²³⁸ U	Cr, Cu, Hg, Mo, Ni, Pb, Zn	VOCs, nitrates
7	³ H, ⁶⁰ Co, ⁹⁰ Sr, ⁹⁹ Tc, ¹⁰⁶ Ru, ¹³⁷ Cs, ²³⁸ 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		
13	¹³⁷ Cs		
17	¹³⁷ Cs	Cd, Cr, Cu, Zn	fuel-derived hydrocarbons and solvents

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

^bX is the radioactive isotope series.

packages for each WAG. Although the available information does not support full characterization of releases from each WAG, these existing reports do provide information on waste inventories within the WAG, limited data on known releases, and results of various characterization studies. These results indicate that for integrator OUs and certain source OUs, the list of potentially site-related chemicals that require evaluation during RIs is lengthy. A common method for paring the contaminant list at particular WAGs is identifying contaminants of concern. *Risk Assessment Guidance for Superfund* (EPA 1989) presents a variety of procedures for identifying contaminants of concern.

The present section provides information on contaminants of concern that have been identified for ORNL WAGs based on procedures in *Risk Assessment Guidance for Superfund*. Screening-level risk assessments have been completed for WAGs 1, 2, 5, 6, 13, and the WOCE. Because risk assessments are site specific, each individual assessment should be consulted for an explanation of the exposure assumptions that were used to specify the contaminants of concern. However, the general methods used for identifying contaminants of concern are similar. In some instances, Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs), TDEC Water Quality Criteria, and DOE derived concentration guides (DCG) were used as reference points for assigning contaminants of concern. The applicability of these regulations is site and land-use specific. Finally, contaminants of concern are categorized as either "on-the-WAG" or "mobile," depending on the pathway leading to exposure.

2.2.1 Contaminants on the WAG

Screening-level risk assessments were the primary method used to determine the WAG contaminants of concern. The list of contaminants, based primarily on nonconservative screening assumptions, appears in Table A.1, Appendix A. They are summarized by individual WAG in Sect. 2.3.

2.2.2 Mobile Contaminants

In the conceptual model for ORNL, the groundwater and surface water regimes are shown to be closely linked. In the hilly terrain, virtually all the water infiltrates into the soil and eventually migrates to local streams through either the shallow subsurface stormflow zone or the thin layer at the top of the groundwater zone. In contrast, in some low-lying places, direct overland flow to streams occurs. The fact that nearly all water moves to local streams and that there is virtually no deep groundwater movement out of the watershed has important implications for identifying water-borne contaminants of concern and assessing off-site risks. In the screening-level risk assessments performed on the ORNL WAGs, risks related to surface water were evaluated. The list of surface water contaminants resulting from nonconservative screening is presented in Table A.1 in Appendix A.

Data for 1992 surface water monitoring stations on WOC and MB and WAG perimeter wells were compiled from Quarterly Environmental Surveillance Reports by Goldberg (1992, 1993a-c). Surface water data were compared to SDWA MCLs, TDEC drinking water regulations, and DOE DCGs to screen for contaminants of concern. Groundwater quality monitoring wells at ORNL are the main source of information for the groundwater regime. Groundwater and its related quality are not regulated like other environmental media. Consequently, there are no mandated groundwater quality criteria. In an effort to provide a basis for evaluation of analytical results and for identifying contaminants of concern at ORNL

WAGs, drinking water limits and other similar criteria were used to screen contaminants. It should be emphasized that while drinking water limits are used for identifying contaminants, it is unrealistic to assume that members of the public are going to drink groundwater from ORNL WAGs. The contaminants that exceeded these drinking water criteria at least once during 1992 are considered contaminants of concern and are listed in Table A.2, Appendix A. This table shows that ^{90}Sr and ^3H are the most common contaminants of concern identified at the source WAGs.

2.3 RISK ASSESSMENT

In this section, the results of human-health risk assessments conducted at integrator and source OUs are summarized and presented.

2.3.1 WAG 2

WAG 2 is the surface water integrator OU at ORNL, and it is a component of an integrated hydrologic system. Surface water is important because it transports contaminants in the dissolved state and on suspended particles from contaminated areas in the WOC watershed into WOL. Contaminants released in surface water over White Oak Dam (WOD) may be dissolved or absorbed onto particles and deposited as sediment in WOCE or transported into the Clinch River. Surface water is the primary pathway by which contaminants are released to the off-site environment from the ORR. Three assessments have been conducted which impact identification of contaminants of concern and analysis of risk in WAG 2. They include screening analyses for (1) the Clinch River downstream from the ORR (Hoffman et al. 1991), (2) the WOCE (Blaylock et al. 1993), and (3) the sediment and surface water of WAG 2 (Blaylock et al. 1992).

Preliminary screening of contaminants in the surface water downstream of the ORR (Hoffman et al. 1991) identified WOCE as a high-priority area requiring immediate consideration for remedial action. The contaminant of concern was ^{137}Cs , and the critical exposure pathway was external exposure to radionuclides in sediment. As a result of the screening, an extensive sampling and analysis program was initiated in WOCE to determine the extent and concentration of ^{137}Cs in sediment.

Concentrations of ^{137}Cs in the surface sediment near the mouth of WOC, which is located at Clinch River mile 20.8, were as high as 45,000 pCi/g dry weight. In addition to the potential for external exposure from sediment in WOCE of greater concern was the potential for relatively high concentrations of radionuclides to be transported from the embayment into the Clinch River. Data from a sediment sampling program along with extant data were used for a site-characterization and contaminant-screening analysis of WOCE (Blaylock et al. 1993). Because WOCE is surrounded by a personnel exclusion fence and the size of the area is relatively small, the number of exposure pathways considered was limited to four: (1) external exposure to shoreline sediments, (2) ingestion of sediments, (3) ingestion of fish, and (4) ingestion of water. In addition to the conservative and nonconservative screening scenarios, calculations were also made for an intruder fisherman scenario. The screening analysis identified arsenic from the ingestion of water, Aroclor-1254 [polychlorinated biphenyls (PCBs)] from the ingestion of fish, and ^{60}Co and ^{137}Cs from the external exposure to radionuclides in sediment as high-priority contaminants requiring immediate consideration for remedial action. In 1992, a coffer cell dam was constructed at the mouth of the embayment

in order to impede the off-site migration of sediment-bound contaminants. When the time-critical removal action was completed, WOCE became part of the WAG 2 integrator unit.

The WAG 2 contaminant screening of the WAG 2 integrator unit assessment considered four exposure pathways (Blaylock et al 1992): (1) external exposure from shoreline sediment and floodplain soils, (2) ingestion of sediment and floodplain soil, (3) ingestion of fish and (4) the ingestion of water, both surface water and groundwater. The approach used in the screening analysis is similar to the one used for the preliminary screening analysis of the Clinch River off-site environment and the WOCE. Because of the relatively high levels of ^{137}Cs that are known to exist in the sediments and floodplain of WOL, the area will likely require remedial action for the sediments. In addition, WAG 2 is surrounded by a personnel exclusion fence that is patrolled on a regular schedule, and it is highly unlikely that institutional control of this area will be lost. Therefore, calculations based on a homesteader scenario and inclusion of dredging and irrigation scenarios were not considered in this screening analysis. The data used in the screening analyses included a compilation of existing data from previous and current monitoring programs, surveys, and scientific studies. The data base contained measurements of contaminants in sediment, surface water, groundwater, and fish. Nonconservative screening of contaminants identified ^{60}Co and ^{137}Cs as high-priority contaminants for external exposure and PCB-1254 for fish ingestion. Other contaminants classified as being of concern and requiring further investigation for the four pathways include 11 carcinogens (^{137}Cs , ^{90}Sr , ^3H , ^{152}Eu , ^{154}Eu , ^{134}Cs , ^{234}U , dichlorobromomethane, arsenic, PCB-1254, and PCB-1260) and three noncarcinogens (thallium, mercury, and arsenic). Contaminants are identified by stream reach in WAG 2 in Appendix Table A.1. The contaminant screening assessment also identified data gaps for ^{241}Am , ^{244}Cm , ^{238}Pu , ^{239}Pu , thallium, and arsenic. As additional information becomes available on contaminants in surface water in WAG 2, additional screening analyses will be conducted.

2.3.2 Groundwater Integrator

The GW OU (WAG 21) at ORNL is divided into two parts, the Melton Valley OU and the Bethel Valley OU. As part of the WAG 2 screening analysis (Blaylock et al. 1992), groundwater was screened as an independent pathway. Nonconservative screening of the detectable contaminants data base for groundwater indicated that none of the carcinogens or noncarcinogens could be assigned a high priority. However, because of the lack of verification on the limited data base, additional risk analysis will be required for groundwater based on more recent and comprehensive sampling results.

2.3.3 Source WAGs

2.3.3.1 WAG 1

The risk assessment for the Phase I RI consisted of three elements: a preliminary human health evaluation, an environmental evaluation, and a hazard screening index calculation. The preliminary human health evaluation characterized the risk for a hypothetical WOC floodplain residential receptor to surface water and sediments under a no-action scenario for current conditions. The pathways assessed included external exposure to floodplain soils, ingestion of surface water, inhalation, ingestion, and dermal contact with floodplain soils. Risks from radioactive contaminants of concern for the nonconservative and conservative approaches both exceed the upper limit of the EPA's target risk range (i.e., 1×10^{-4}). These results

suggest a continued need for action to address migration of contaminated soils in the WOC floodplain and radioactive contaminants in surface water originating from WAG 1. The Hazard Screening Index, a relative measure of the potential hazard posed by the OUs, identified the Gunitite and Associated Tanks OU (GAAT OU) as highest priority for a remedial action activity at WAG 1.

Based on the results of the Hazard Screening Index, a RI for the GAAT OU is proceeding. A risk assessment for the GAAT OU is being conducted and is designed to support remedy selection at this source OU. In order to effectively make risk management decisions at the GAAT OU, the risk assessment will evaluate the risk from direct exposure to the GAAT OU to provide a quantification of risk for the no-action alternative in the FS and evaluate the current or future impact on environmental media (actual or potential). The risk work for the RI phase will serve as a baseline for the FS where the degree of risk reduction for the assessed alternatives will be quantified.

2.3.3.2 WAG 5

A screening level risk assessment was performed for WAG 5 as part of the RI Work Plan to evaluate the existing data for WAG 5 with regard to possible human health exposures. A conservative screen was conducted for hypothetical receptors at MB Monitoring Station (MS4) and on the Clinch River. At MS4, the total risk from all pathways was above the EPA's action level (1×10^{-4}). This assessment demonstrated a need for an RI of WAG 5, but the data were of insufficient quantity and resolution to pinpoint sources of the contamination. (The location of Monitoring Station MS4 is shown in Fig. 3.1.)

The RI for WAG 5 is in the field data collection phase. For risk assessment purposes, the WAG will be broken up into components that include the Old Hydrofracture Facility Pond, the Process Waste Sludge Basin, SWSA 5, the transuranic (TRU) waste area, and miscellaneous leak/spill sites. These areas are potential or actual sources of contaminants that may be released into groundwater/surface water regimes and they will be assessed dependent upon whether they are targets of removal, interim, or final actions. Data will also be collected to resolve groundwater issues common to WAG 5, WAG 10, and the GW OU (WAG 21).

2.3.3.3 WAG 6

The WAG risk calculated for the WAG 6 RFI report (Energy Systems 1991) indicated risks greater than unity for the hypothetical WAG adult homesteader receptor. Most of the on-site risk was associated with external exposure resulting from isotopes of europium from the reactor control plates in the high-activity auger hole area.

A deferred action alternative (continued monitoring prior to any interim or final action) was selected on the basis of the minimal amount of relative off-site risk caused by WAG 6 to an individual located downstream of ORNL. Relative risk refers to the portion of the risks to an off-site individual that is attributable to WAG 6 contaminant releases. Relative risk to off-site surface water was low compared with other ORNL WAGs. In this case, off-site risk are based on exposure by ingestion of water only, and the point of exposure is water that is discharged over WOD. Consequently, for the deferred action, the forthcoming WAG 6 environmental monitoring plan (DOE 1993) has as a primary objective the calculation of the relative contribution of risk at WOD that will be reported each year. The complexity of the topography and the geology of WAG 6 makes the estimation of total contaminant discharge

a technical challenge. Four flow path groups have been identified: (1) interior surface water that flows to gaged sites, (2) surface water that drains gullies along the ungaged perimeter, (3) shallow subsurface water that also drains to the ungaged perimeter, and (4) groundwater moving in the intermediate and deep interval. The risk model, which is used to calculate the cumulative risk, is closely linked to the site hydrologic conceptual model (based on Solomon et al. 1992); and the risk model incorporates numerous assumptions about the physical system. The model utilizes all monitoring data from tributaries, seeps, and wells. Computed from a variety of historical data, the preliminary results indicate that tritium provides the greatest risk, followed by ^{90}Sr and then by ^{137}Cs . Some risk is also attributed to organics observed in the perimeter wells and in water draining FB, one of the tributaries. These calculations indicate that WAG 6 contributes about 4% of the ^3H to discharge at WOD but only about 1.7% of the risk. (Tritium provides about 1.5% of the total risk with the remaining 0.2% provided by other radioisotopes and, to a lesser extent, by organics.) These preliminary calculations have proved useful in guiding the development of the monitoring plan allowing resources to be applied to the high-risk flow paths in addition to groundwater sampling required by RCRA. This preliminary cumulative risk estimate will be superseded with more reliable calculations after the 18-month baseline environmental monitoring at WAG 6 is completed. Furthermore, the risk model itself will be refined during the baseline effort as more data become available. If relative risk should increase because of perhaps, waste container failure, then the deferred action status of WAG 6 will be reevaluated and remedial action will be considered. Deferred action status will also be reevaluated if the relative risk becomes large because of cleanup efforts of other WAGs such that WAG 6 becomes a major contributor of the risk measured at the WOD.

2.3.3.4 WAG 13

A preliminary health risk assessment study was conducted for WAG 13, and the only contaminant of concern was determined to be ^{137}Cs . The exposure scenarios examined in the risk assessment included a worker who mows the area, a fisherman/boater on the Clinch River who comes within 150 ft of the cesium plots, and a future on-site homesteader who lives inside the area that is currently fenced. External exposure to ionizing radiation poses most of the risk to the exposed populations and was determined to be the dominant pathway of concern for all three scenarios. The risk to the worker and to the on-site homesteader was determined to be greater than EPA's action level of 1×10^{-4} . The risk to the fisherman/boater on the Clinch River was estimated to be in EPA's range of concern. The results suggested that if no action were taken, actual or potential release of ^{137}Cs from the WAG 13 cesium plots may present a current or potential threat to public health. A record of decision (ROD) has been signed and ^{137}Cs -contaminated soil will be removed from WAG 13 in fall 1993.

2.3.3.5 Past Prioritization

Shevenell et al. (1992) conducted a human health risk assessment for the ORNL WAGs based on data for contaminants in surface water. The assessment on four radionuclides (^3H , ^{60}Co , ^{90}Sr , and ^{137}Cs) used data for contaminants in surface water because it is the primary pathway of contaminant transport off-site. The assessment endpoints 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. Total risk at Clinch River mile 9.5 from all WAGs was within EPA's range of concern. This approach found that ^{137}Cs

and ^{90}Sr were the two largest contributors to risk. 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). These were followed by WAG 5, WAG 9, WAG 3, and, finally, WAG 8.

2.4 APPROACH

2.4.1 Source OUs

The risk assessment strategy for source OUs is designed to assist the ER Program by focusing actions on sites that are a high-risk priority for either on-site or off-site exposures and to provide adequate risk baselines for measuring the potential effectiveness of proposed remedial alternatives. The goal of the risk assessment strategy for source OUs is to clearly delineate off-site and on-site risks as well as exposure assessment differences between current land use and proposed future land uses. The strategy consists of two sets of exposure assumptions reflective of the current land use situation in and around the ORR. The Most Likelihood Exposure (MLE) assessment provides information concerning the relative on-site risk under current land use conditions, while the Integration Point (IP) assessment provides information concerning the relative contribution of the source control OU under investigation to off-site contaminant transport and migration. Therefore, the results of these assessments provide the risk manager with the risk information needed to demonstrate that a proposed action is necessary to stabilize the site, prevent further degradation, or achieve significant risk reduction quickly. In addition, the results of these assessments can be used to prioritize the source control units with respect to risk.

2.4.1.1 On-Site Risk

The MLE assessment is designed to be protective of current land use considerations within the ORR. The exposure pathways evaluated in the MLE assessment include ingestion and dermal contact with contaminated soil or sediment, inhalation of wind-generated particulates, and external exposure to radioactive contaminants. The ingestion, inhalation, or dermal contact with surface water or groundwater contaminants and the resulting risk/hazard associated with these exposures will not be evaluated as part of the MLE assessment. In the case of exposure to surface water, the risk/hazard associated with the various types/magnitudes of exposure will be evaluated as part of the IP assessment. Exposure to groundwater contaminants will be evaluated in the integrator GW OU risk assessments. The purpose of the MLE assessment is to identify, expedite, and support interim actions at source control units that are high risk with respect to on-site exposures.

2.4.1.2 Off-Site Risk

Most of any off-site public exposure to ORNL contaminants results from surface water, which is the major transport mechanism for contaminant fluxes to off-site receptors. Other potential transport mechanisms such as the food chain, the air pathway, and direct groundwater transport are not currently primary sources of off-site contaminant fluxes. Because the integrator OUs serve as a potential exposure point to off-site receptors, each integrator OU will undergo a complete baseline risk assessment following the evaluation of all source control OUs within its boundaries and before the issuance of a final ROD. In the meantime, the objective for source control activities is to identify and remediate or control

the primary contributors to off-site risk to levels that are as low as reasonably achievable. To achieve the objective, it is necessary to formulate an assessment that takes account of contamination transported out of each source area via all hydrologic flow paths, including surface water and groundwater. The IP assessment provides this measure, like a pulse or body temperature, to judge the overall contribution of each source to off-site risk. The percent contribution to risk at WOD (with flow-weighting) will be tracked for all the source OUs at which contaminant flux data can be calculated. In concept, each source area drains to a single collection point, and the concentrations of contaminants of concern at this point are multiplied by risk factors and flow volumes and compared to these same parameters at the WOD integration point to yield the contribution to off-site risk.

The IP assessment is performed at WOD using the 95% upper confidence limit on annual flow-weighted concentration data. Surface water pathways are assessed at the point with the assumption of residential use of the water. This would entail using standard risk assessment parameters, which are available in *Risk Assessment Guidance for Superfund*, for these pathways. Primary pathways to be assessed include ingestion of surface water, dermal contact while showering, and indoor inhalation of contaminants resulting from water use. The risk at this point is then compared with action levels of excess cancer risk and to the noncarcinogenic hazard index of 1. Action under CERCLA is generally warranted if either of these action levels is exceeded. The next step is to use contaminant fluxes and risk to identify the primary contributors to the risk at the integration point.

The flux data for each of the sources are used with WOD flux data to rank the relative importance of the different sources within the context of the WOD integration point. Given the generalized cancer risk equation for multiple substances:

$$\text{Risk}_T = \Sigma \text{Risk}_i ,$$

where

Risk_T = the total cancer risk, expressed as a unitless probability, and

Risk_i = the risk estimate for the i^{th} substance.

The equation for calculation of carcinogenic effects for the flux-based risk assessment at each of the sources is

$$\text{Risk}_{sf} (\%) = \{ \Sigma [\text{Risk}_i (\text{Flux}_{is} / \text{Flux}_{ip})] \} / \text{Risk}_T ,$$

where

Risk_{sf} = percentage of risk at the integration point which originates at the identified source,

Flux_{is} = flux of the i^{th} substance originating at the identified source, and

Flux_{ip} = flux of the i^{th} substance identified at the integration point.

Similarly, the standard equation for calculation of noncarcinogenic effects is

$$\text{Hazard Index}_i = \Sigma E_i / \text{RfD}_i ,$$

where

E_i = exposure level (or intake) for the i^{th} toxicant,

RfD_i = reference dose for the i^{th} toxicant, where

E and RfD are expressed in the same units and represent the same exposure period (i.e., chronic, subchronic, or shorter term).

The calculation for the flux-based risk assessment of noncarcinogenic effects is:

$$\text{Hazard}_{\text{sr}} (\%) = \Sigma [E_i \text{Flux}_{\text{is}} / RfD_i \text{Flux}_{\text{ip}}] / \text{Hazard index}_i,$$

where

$\text{Hazard}_{\text{sr}}$ = percentage of the hazard index at the integration point that originates at the identified source.

2.4.2 Integrator OUs

2.4.2.1 WAG 2

The purpose of the risk strategy for the surface water integrator (WAG 2) is to (1) identify environmental pathways, reaches, and contaminants that would require further investigation and (2) identify pathways, reaches, and contaminants that have a low priority for further investigation (Blaylock et al. 1992). The screening approach used conservatively biased calculations to identify contaminants, exposure pathways, and reaches that have a low priority for further investigation. It is unlikely that these conservative calculations will underestimate the potential maximum exposure to an individual in the critical subgroup of the population. The second approach used nonconservative calculations and assumptions to identify contaminants, pathways, and reaches that have a high priority for further investigation. These nonconservative risk estimates should not substantially overestimate maximum exposures to critical subgroups of the population. Results of this screening assessment do not constitute a baseline risk assessment and are not intended to address issues regarding compliance with regulatory limits. The purpose of the screening exercise is to help guide the development of a sampling plan that will focus on the collection of data for contaminants of concern and identify exposure pathways where adverse health effects may be indicated. A baseline risk assessment will follow the completion of data collection and analyses.

Conservative and nonconservative screening criteria are applied to the EPA action level (FR, March 8, 1990) to categorize contaminants as low priority, high priority, or requiring further investigation before being designated as either high or low priority. Low priority indicates that a contaminant is of little concern for further investigation; high priority requires either immediate consideration for remediation or further analysis; and contaminants identified as neither low nor high priority must be evaluated further before this determination can be made. Preliminary health risk screening will be conducted as data become available. These data may represent OUs, seeps, weirs, etc. Results of these preliminary screening analyses will help focus future data collection on contaminants of concern and will provide a method to estimate the contribution of specific data sets to the WAG 2 human health risk.

2.4.2.2 Groundwater OU

The assessment strategy for the GW OU will involve general risk characterization on a subcatchment basis and incorporate any large-scale predictive capabilities that are developed. The general objective is to prevent any further deterioration of groundwater quality at ORNL. Risk strategy development for the GW OU will involve coordination with the groundwater group at ORNL to interpret the perimeter well results by using risk screening methods to identify contaminants and areas of concern that affect the WAG 2 and off-site environments. General risk characterization will be performed on a subcatchment basis throughout the WOC watershed to support this objective. Particular areas of concern for potential remedial actions in the near future include the flowpath into First Creek associated

with Corehole 008 in WAG 1 and groundwater discharges from the southern edge of WAG 5 into MB.

2.5 RISK ANALYSIS ISSUES

2.5.1 Human Health Prioritization

Assessment strategies have differed for integrator and source OUs because these investigations have different objectives. However, there is a need to reconcile the approaches of integrator and source OUs investigations within a risk framework to meet larger program objectives such as prioritization. Risk assessment work in the near future will consist of a prioritization effort based on available data while the WAG 2 SI continues. The human health prioritization task will apply a consistent method for determining contaminants of concern and prioritizing sites. The prioritization effort will build on previous Measurement and Evaluation Program Assessment System (MEPAS) studies at the WAG level and will rank WAGs and individual sources within WAGs for on-site risks and will be on the basis of annual flux contributions off-site.

2.5.2 Characterization of Background Risks

The goal of producing a comprehensive data base for naturally occurring concentrations of soil constituents on the ORR is to support the need to differentiate contamination of naturally occurring constituents from anthropogenic sources. Quantitative analysis of the inorganic (metals) and radionuclide analytes found in undisturbed soil (no organic analytes were detected) have identified the potential risks to human health associated with exposure to these naturally occurring constituents. The Phase I background soil data (Energy Systems 1992), collected from the Dismal Gap and Nolichucky formations (Horizon A) on the ORR and from Anderson and Roane counties, were evaluated in terms of potential adverse effects to human health. This background risk evaluation provides a context for the discussion and comparison of risks associated with site-related contamination and for determining contaminants of concern for that site.

Three primary pathways of exposure were evaluated for inorganic analytes and radionuclides: (1) direct ingestion of soil, (2) dermal contact with soil, and (3) external exposure to radionuclides in the soil. Background risks for individual analytes and total pathway risk estimates (i.e., the sum of the background risks of all analytes within a pathway) were determined. The carcinogenic-risk and noncarcinogenic-hazard indices determined for individual analytes (found in Horizon A of the Dismal Gap Formation) were very similar for the three sampling areas (ORR and Anderson and Roane counties). The total pathway background risks independent of anthropogenic sources exceeded EPA's action level for external exposure and was in EPA's range of concern for the dermal contact and soil ingestion pathways. The external exposure pathway showed that ^{137}Cs , ^{40}K , ^{226}Ra , and ^{228}Th are the main contributors to risk for the external exposure pathway. The total hazard indices for both pathways (i.e., ingestion of inorganics plus dermal exposure to inorganics) in the Dismal Gap Formation exceeded the hazard index of one for ORR, Anderson County, and Roane County. Arsenic and manganese are the major contributors to the hazard index for the ingestion pathway, and the main contributors to the hazard index for the dermal exposure pathway are manganese and vanadium.

These background risk estimates should be considered only in comparison with site-related risk. The EPA action level of 1×10^{-4} refers to risks related to hazardous waste sites. The background risk results are not indicative of concerns or actions that would be identified with similar potential risks from a contaminated site, and care should be taken not to misinterpret these results to pertain to remediation decisions.

2.5.3 Future Land Use Development

The range of potential future land use alternatives at ORNL has a myriad of implications for ER at ORNL since the assumptions regarding OU land use drive risk assessment exposure scenarios, remediation goals, and remedy selection. The main goal of land use plan development is to get major stakeholders involved in an interactive process of determining future land use within the context of restoration issues like technical limitations, cost, and risk while also considering more traditional land use concerns such as development potential, growth trends, resource values, and access. This process has been initiated at the ORR level through ER Technical Programs as a pilot program for a nationwide DOE study. The process has been initiated at the ORNL level with the development of a WOC ROD that will identify a strategy for environmental cleanup at ORNL and establish site-wide objectives.

2.5.4 Decision Analysis

Decision analysis techniques have been applied in other areas analagous to environmental restoration activities and have been found helpful in optimizing the usefulness of collected data and also in recognizing and reducing the uncertainties propagated in the environmental decision process (Freeze et al. 1990). In this framework, the worth of collected data is based on a risk-cost-benefit objective function that measures the contribution of collected data towards reducing the uncertainty in the decision process (Freeze et al. 1992). Consistent application of this approach has potential to improve the technical basis of decisions and to collect data in a cost-effective manner. This can be achieved by evaluating the sampling and analysis plan during the data quality objectives (DQO) process and relating this information to the final decision. Implementation of decision analysis techniques consists of linking models that are often used independently in the environmental restoration process. Simulation models that incorporate groundwater and surface water flow and transport, uncertainty models that incorporate human health and ecological risk assessment, parameter and geological uncertainty, and an engineering reliability model are all subjected to a decision model that allows for a risk-cost-benefit comparison of different remedial designs.

2.6 ECOLOGICAL RISK

Ecological risk assessment (ERA) evaluates the probability that adverse effects on nonhuman biota are occurring or will occur because of stressors (e.g., chemicals) in the environment. The goals of ERA are to identify the magnitude, extent, and causes of the adverse impacts and to help identify the optimal remedial alternatives. Also, an ERA conducted after remediation may evaluate the effectiveness of the remedial option.

The ERA process parallels the human health risk assessment process. ERA is important in addition to human health risk assessment because protection of human health does not always ensure protection of nonhuman biota. For example, nonhuman organisms are exposed to different concentrations of chemicals (e.g., a heron eats an entire fish instead of the

relatively less contaminated muscle that people would eat). Also, exposure conditions often are very different (e.g., fish may live in contaminated water that people would come into contact with relatively infrequently). ERA evaluates risks to on-site and off-site biota under current conditions and considering a future scenario where loss of institutional controls allows reversion of the site to a natural state. Human health risk assessment places greater emphasis on off-site risks and considers different land use practices.

2.6.1 General Approach

An iterative hierarchical approach to the assessment of ecological risks is taken at the ORR (Suter et al. 1992). The lowest level is the individual waste site or source control OU, or WAG. These sites constitute the source of release of contaminants to the wider environment, or integrator OUs. Integrator OUs receive and integrate the releases from multiple waste sites and other sources of contamination or disturbance. The integrators for aqueous contaminants are watersheds. For ORNL, the integrator OU for aqueous contaminants is WAG 2. The integrator for terrestrial contaminants is the entire ORR.

2.6.2 Background

The ORNL site is largely forested, and the forested area is predominantly natural (there are areas of planted pine forest and other species). However, this area is segmented by roads, buildings, and waste sites. The forested area, along with WOC and its tributaries, provides habitat for abundant wildlife.

Wetlands and floodplains and threatened and endangered (T&E) species and their habitat are receptors of special concern in ERA. At the ORNL site, there are floodplains associated with WOC and its tributaries and a number of wetlands around the site (Cunningham and Pounds 1991). There are no federally listed T&E species present. However, there may be species that are listed by the state of Tennessee as T&E or "in need of management" (Kroodsma 1987; Parr 1992 cited in Etnier et al. 1992).

Assessing the risks of the waste sites to biota requires several different types of information, including media contaminant concentrations, field surveys, and toxicity test results. Existing programs collect some of this information, and therefore the ERA team collaborates with other program personnel. For example, the BMAP collects information that is useful for assessment of the creeks (see Sect. 6). However, the BMAP does not collect all of the information needed for an ERA. ERA has specific data needs that are not required for the BMAP (e.g., whole-body fish analyses to determine risks to fish-eating wildlife). Also, the aquatic component of BMAP has been the major focus in the past; so the ORR-wide assessment is needed to address terrestrial risks to biota.

2.6.3 ERA Activities at Source OUs

ERA activity at ORNL this year has centered around WAG 5. WAG 5 consists of 13 solid waste management units (SWMUs) covering an area of ~20 ha, >75% of which is included in SWSA 5. Most of the area is covered by grass, but deciduous forests fringe SWSA 5. WOC and MB border WAG 5, but these streams and most of their floodplains lie outside the defined boundaries of WAG 5; they are part of the integrator operable unit WAG 2 (Ashwood et al. 1992).

An ecological assessment plan for WAG 5 was prepared (Ashwood 1992), and a screening-level ERA was performed to serve as a preliminary hazard identification for the baseline ERA for WAG 5 and to identify data needs (Ashwood et al. 1992). This assessment identified the need for surveys of T&E, or state-listed species; wetland surveys; aquatic toxicity tests on water from the six seeps and two ephemeral tributaries; earthworm and seed germination toxicity tests on soil; and wildlife surveys (wild turkeys, burrowing animals).

The WAG 5 assessment plan (Ashwood 1992) was reviewed with representatives from EPA Region IV and TDEC in March 1993. It was decided that for a WAG-specific assessment, species should be selected for investigation that are ecologically important and that have a home range appropriate to the size of the WAG. Consequently, risks to wild turkeys will not be assessed. Furthermore, it was determined that full baseline ERAs will be prepared for each WAG. This means that not only do current conditions need to be evaluated (institutional controls intact), but future risks in the absence of institutional controls (DOE abandons the ORR and for example, mowed lawns undergo succession to forests) also must be evaluated. The WAG 5 ecological assessment plan is being rewritten to address these issues.

Regulators also are requiring that ecological risks be evaluated for the entire ORR, that is, that the Reservation be viewed as a single ecological unit. Environmental Sciences Division ecologists are preparing a plan for this assessment.

2.6.4 ERA Activities at the WAG 2 Integrator OU

A screening assessment of ecological risks at WAG 2 was completed in late 1992 (Blaylock et al. 1992). The purpose of the screening assessment was to identify hazards associated with wastes in WAG 2, prioritize them with respect to their potential risks, and identify data needs on the basis of that analysis. The screening 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.

Because there was no complete inventory of the chemicals that have been disposed of in the WOC watershed, it was not possible to identify a complete list of potential contaminants of concern. There also was no survey of watershed contaminants that was sufficiently sensitive and reliable for a complete screening to be performed.

The screening assessment was able to establish that no severe effects are occurring in the aquatic habitats of WAG 2, although there is some evidence of effects on fish reproduction and on benthic invertebrate community composition. Toxicity tests of surface water do not indicate toxicity to *Ceriodaphnia dubia* or to larval fathead minnows in 7-day exposures. No toxicity tests have been conducted for sediment or soil.

Comparison of media concentrations to 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. Some chemicals in all media occurred at concentrations that are potentially toxic.

There are still significant uncertainties concerning the ecological risks posed by contaminants in WAG 2. As a result of these uncertainties, a list of data needs was compiled.

These data needs included surveys of biotic communities, additional abiotic and biotic sampling, and toxicity testing. 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 (Blaylock et al. 1992).

An ongoing WAG 2 activity includes the work of the WOC Watershed Ecological Risk Assessment Task Force, which meets quarterly. Objectives of the group include improving communication with EPA Region IV and TDEC, identifying areas for future BMAP efforts, development of a conceptual site model for WAG 2, and development of a geographic information system- (GIS-) based integration of existing BMAP data to support the ERA activities.

2.6.5 Challenges of an Integrated, Iterative Approach for ERA

The ORR is a large, complex site. Each WAG may consist of several individual trenches, underground storage tanks, and other sources of contamination. These WAGs are located near aquatic and terrestrial habitats for diverse floras and faunas.

Because neither contaminants nor organisms respect WAG boundaries, ERAs must assess risks not only within the boundaries of the WAG, but also at a larger, more ecologically relevant scale. Full baseline ERAs must be done at each WAG. However, only organisms that live in close association with the WAG can be used as endpoint species for the ERA (e.g., soil invertebrates, small mammals). Depending on the nature of the site and its contamination, these organisms may be difficult to sample. The terrestrial integrator for all WAGs is the entire ORR. It is at this level that impacts to the larger organisms (e.g., deer, hawks) must be assessed. Because risks to these organisms are not currently assessed, the proposal for an ORR-wide ecological assessment is in preparation. It will be an important task to justify the selection of ecological assessment endpoints for this assessment and develop appropriate assessment methods to estimate risks to ORR-wide resources from site-specific actions.

ERA also faces a challenge in its attempt to assess risks at an appropriate level of ecological organization (independent of the size of the site). Ideally, assessments would address the most important ecological effects, which are those at the higher levels of ecological organization (e.g., ecosystem level). Although some biological survey data address population and ecosystem properties, toxicity tests and some field measurements are focused at the organism level. Methods must be developed to integrate and reconcile information concerning responses at different levels of ecological organization.

2.7 SUMMARY

To facilitate decision making, the ORNL site has been divided into source control OUs (WAGs with buried wastes and leak sites) and integrator operable units (surface water system, WAG 2 and the groundwater regime, WAG 21) which integrate contaminant releases from source units. The classification is based on common sense recognizing that the source control WAGs should be remediated prior to cleaning up the integrator WAGs. Further, data gathered in the integrator units support decision making and risk assessment to prioritize the WAGs for remedial actions.

Because of the magnitude and complexity of contamination problems at ORNL, remedial activities must be prioritized. Risk management decisions must be made as to the priority of on-site hazards versus off-site hazards, which WAGs to remediate first, and which OUs within WAGs to remediate first. For site characterization, decisions must be made as to what contaminants pose the largest hazards, therefore requiring early attention, and what contaminants pose little risk and ought not be investigated.

Contaminants of concern can be classified as either "on-the-WAG" leading to possible hazardous exposures to workers or future WAG occupants, or "mobile," leading to possible off-site exposure. Mobile contaminants are the initial concern at the site-wide scale because they can accumulate in the integrator WAGs and result in unacceptable off-site doses.

To date, screening risk assessments on human health and the environment have been completed on WAGs 1, 2, 5, 6, 13, and WOCE. In addition, risk levels associated with naturally occurring soils in the vicinity of ORNL have been evaluated. Human-health screening risk assessments generally use nonconservative screening criteria and exposure pathways that are limited in number and complexity. The risk assessment process identifies contaminants of concern and the most hazardous pathways of exposure.

Risk assessments conducted at ORNL suggest that the public is not in danger from contamination currently released from the WOC watershed. All locations at ORNL where contaminant risks on the WAG are unacceptably high have restricted access. In addition, results to date generally show that water leaving WAG 2 at WOD is slightly higher than the EPA action level (i.e., 10^{-4}).

For the purpose of calculating risk, the assumed pathway for exposure is ingestion of stream water discharged at WOD over a period of 30 years, although the public has no direct access to the WOC at or below the dam. This potential off-site risk to human health caused by hydrologic discharges from the ORNL site is derived almost entirely from radionuclides and not from organic compounds or metals. In terms of risk, the primary mobile contaminants are ^3H and ^{90}Sr and, to a much lesser extent, ^{137}Cs and ^{60}Co . Further downstream, the dilution of the Clinch River reduces the risk below the action level for the maximally exposed individual at Clinch River mile 9.5, the closest downstream public-access point where land-based activities can occur (e.g., growing irrigated crops). The maximally exposed individual is assumed to ingest Clinch River water, eat food produced with river water, and receive exposure from surface sediments.

Risk assessment provides the best way to evaluate hazards on- and off-site and to prioritize ER activities. The monitoring activities and SIs cited in the remainder of this report collect the contaminant concentration and flux data needed to calculate risks, although the data are also used for other purposes such as environmental compliance, remedial action design, and understanding the environmental system. Key issues to be addressed in the risk assessment domain relate to (1) the ultimate use of the land, which affects risk scenarios and cleanup criteria, (2) the appropriate scale of ecological risk assessments that must be done on both a WAG basis and site-wide basis, and (3) the further integration of risk assessment into decision-making. Risk assessment is a central component in WAG 2/SI activities, and results of these assessments are used to guide monitoring and sampling and to assist in the prioritization of major ER activities. With risk information, managers can focus and refine the site characterization process. After more rigorous baseline risk assessments, managers can identify alternative remedial actions.

3. SURFACE WATER

3.1 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. 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 has infiltrated into the soil, traveled through the subsurface, and emerged at springs or seeps (Solomon et al. 1992).

The hydrologic data collected in the Surface Water Task serves the ER Program in numerous ways. Precipitation and stream discharge measurements are essential for modeling and understanding contaminant transport through the WOC system and for the selection and design of ER remedial actions. Water quality measurements at seeps and tributaries provide the necessary spatial information needed to locate the main sources of contamination and the temporal data from which we can infer what flowpaths (shallow or deep) that conduct most of the contamination from their sources to the surface and ultimately to discharge at WOD. Data collected by others, especially Environmental Surveillance and Compliance, provides a more complete picture of the hydrologic system. The big picture based on continuous sampling at the main monitoring stations indicates discharge patterns among the WAGs, leading to the prioritizations based on risk, as described in Sect. 2.

Among other things, this section describes three different ways to conduct performance monitoring, that is, the monitoring needed to evaluate the effectiveness of a remedial action). In addition to cleanup activities at the WAGs, the ER Program must be ready to institute performance monitoring to ensure that costly remediations are effective. Despite the importance of performance monitoring, our early performance monitoring results may be misleading, causing us to declare a success or failure falsely without basic knowledge of the hydrologic system. This is one reason why there is special emphasis in this section on the conceptual models of hydrology as they pertain to origin of surface water and transported contamination.

The distinction between surface water and groundwater is blurred. In this section, groundwater flowpaths are used to explain surface water flows and contaminant fluxes. Generally, surface water investigations are concerned with the shallow subsurface stormflow zone and the shallow water table interval. Groundwater activities reported in Sect. 4 are concerned with these regions and deeper zones, which are important because of the potential for large storage of contaminants in deeper parts of the groundwater system. The distinction is further blurred because groundwater investigators are actively surveying seeps and springs in order to identify and sample groundwater flowpaths, using approaches and methods similar to those used in the spring and seep survey. The integration of information and collaboration among surface and subsurface hydrologists is described in the final section of the report.

3.1.1 Section Outline

- Section 3.2 presents conceptual models of contaminant transport in surface water in the WOC watershed.
- Section 3.3 summarizes the hydrological data collected in the WOC watershed.
- Section 3.4 presents spatial patterns and fluxes of radionuclides in seeps, tributaries, and main streams.
- Section 3.5 identifies hydrologic relationships that can be used to evaluate remedial actions. The relationship between groundwater levels and contaminant discharge is also discussed.

3.2 HYDROLOGIC CONCEPTUAL MODEL: CONTAMINANT DISCHARGE FROM TRIBUTARIES

The ORNL hydrologic site conceptual model described in detail in ERMA (ERMA 1992) is based mostly on the report of Solomon et al. (1992). In the conceptual model, nearly all precipitation falling on hillslopes underlain by the shale formations (where most of the waste is buried) infiltrates into the soil. Most of the infiltrated water moves laterally to nearby tributaries via the macropores and fractures in the stormflow zone (upper 1-2 m of soil). A small portion of the infiltrated water moves vertically to the water table, where it again tends to move laterally to the nearby tributary via fractures in the saprolite (weathered rock) and bedrock. This shallow groundwater zone is termed the water table interval. A very small portion moves downward to the intermediate and deep groundwater intervals. Contaminants leached from shallow burial trenches can be transported in all these flow paths.

In this section, we examine the hydrologic system at different scales (seeps, tributaries, and the main streams) in context of the conceptual model. Section 3.4.2.1 describes a portion of the overall conceptual model that links contaminant concentration levels with discharge flow paths for the tributaries that drain the waste areas. In particular, at the tributary scale, we see contaminant concentrations that tend to decrease with increasing flow, that is, partial dilution of contaminants entering tributaries during storms. In contrast, data reported in ERMA 1992 and described in Sect. 3.5 indicate that at the main weirs, particularly WOC MS3 and WOD, concentrations of contaminants (e.g., ^3H and ^{90}Sr) increase with discharge. In other words, the partial dilution observed in tributaries does not occur on the larger scale.

This lack of dilution is important to the ER Program because of implications to monitoring, to understanding where and how contaminants are mobilized, and to modeling the system responses to changes in the watershed, specifically remedial actions. If contaminant flux increases with increased flow, then monitoring must emphasize data collection at high flows, and remedial actions must be directed to contaminant pools that respond to high flows, such as groundwater contaminants that may have accumulated near groundwater discharge areas.

Presently, we cannot resolve the issue of scale, but we are defining the problem better and beginning to collect the basic data needed to resolve scale differences. This issue will be addressed by the Watershed Data Integration activity that will commence in FY 1994, as

described in the latter part of Sect. 7. During FY 1993, field work has focused primarily on the movement of contaminants from seeps and springs adjacent to the source WAGs and the contaminant discharge in tributaries to WOC and MB. The seep sampling provides a good spatial picture of contaminant sources to the watershed, but it does not provide much dynamic information, although there are some differences between dry-season and wet-season baseflow conditions. Samples were collected during a storm event from three tributaries during the year, but the results are not yet available.

After a review of the types of hydrologic data collected by the WAG 2/SI Program in the next section, the following sections describe monitoring results at the seep, tributary, and watershed scales.

3.3 SURFACE WATER HYDROLOGY

The annual hydrologic data summary report for WOC (Borders et al. 1993) was prepared to provide hydrologic data for ER activities that use monitoring data to quantify and assess the impact from releases of contaminants from ORNL WAGs. 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 monitoring stations in the WOC flow system.

3.3.1 Precipitation

Precipitation is gathered at nine sites in the WOC watershed and vicinity by WAG 2/SI staff. For calendar year 1992, total precipitation averaged 112.9 cm (44.44 in.) for raingages in the vicinity of the WOC watershed. Precipitation measured at the Oak Ridge township site maintained by the National Oceanographic and Atmospheric Administration (NOAA) was nearly identical, 111.4 cm (43.85 in), or 81% of normal precipitation. This below-normal precipitation follows a 3-year period of above-normal precipitation, which followed a previous 4-year drought.

The WAG 5 RI Project staff analyzed the historical precipitation record maintained at the NOAA meteorological station. The purpose was to determine the frequency of extreme rainfall rates. This information is important to the ER Program because extreme storms drive contaminants, especially particle-reactive contaminants in soils and sediments, through the watershed, leading to off-site discharges.

Extreme precipitation from the 38-year record for 1-, 2-, 3-, 6-, 9-, 12-, 24- and 48-h periods has been tabulated, and return periods have been estimated. As an example, precipitation depths are plotted vs return period for storm intervals of 24-h in Fig. 3.1 along with depths reported by Huff and Frederick (1984) which were based on a regional analysis. The Huff and Frederick data have been used extensively for engineering design and safety analysis. Comparison of the Huff and Frederick (1984) data to the newer results indicates that the 24-h precipitation rate with a 100-year return period is 1.09 in. greater, which is a significant difference. The implications to remedial action design and safety analyses must be considered in the coming year.

Fig. 3.1. Extreme rainfall frequency—24-hour duration. Solid squares are storm depths previously reported by Huff and Frederick (1984), based on regional analysis of rainfall records.

3.3.2 Discharge

Streamflow data are currently collected at 18 monitoring stations in the vicinity of the WOC watershed (Fig. 3.2). In the WOC watershed, there are at least 8 more streamflow monitoring stations outfitted with at least a hydraulic control device (i.e., weir or flume) in various states of repair. Several of these sites (HRT adjacent to WAG 5, T2A and MS1 on the tributary below WAG 4, and the small flumes in WAG 6) have recently been reactivated and instrumented for discharge measurement and water quality sampling primarily during storms. In addition, discharge monitoring stations on East Seven, West Seven, and Center Seven creeks were reactivated in FY 1993 by the USGS in order to gather data to support the new waste disposal operations in SWSA 7 that will occur as SWSA 6 (in WAG 6) is closed down.

The WOC surface water flow system has been divided into a network of reaches (Fig. 3.3) to identify stream sections as measurable and manageable components of the hydrologic system. Table 3.1 lists the reach and subreaches along with mean flows and mass balance data. Most reaches have a positive mass balance, in part because ungaged tributaries contribute runoff to the reach although groundwater inputs can be important, also. In addition, cumulative "dry" month losses that typically occur during the summer and early fall are presented for several major reaches. In terms of annual gains, these "dry" months are masked by high runoff in wet months. Mass balances for radionuclides and chemicals are possible for only a few reaches where there is continuous streamflow and water quality monitoring.

3.4 SURFACE WATER CHEMISTRY

In this section, results from sampling and monitoring at seeps, tributaries, and stations on the main streams are summarized. The purpose is to provide a spatial picture of where and under what flow conditions contamination is being released into the surface water system. The dynamic behavior of contaminant discharge can give insights as to whether the contamination is traveling via shallow or deep pathways, and this difference can affect remediation decisions significantly.

3.4.1 Seeps

The major pathways for water movement and associated contaminants in the subsurface are through the shallow water table and the stormflow zone (Solomon et al. 1992). Water that infiltrates the soil surface moves through these shallow pathways intercepting and leaching contaminants from primary sources (trenches) and/or secondary sources (downgradient soil matrix) and then emerges at seeps, where it discharges to the surface water system. Because of the close link between the groundwater and surface regimes, seeps mark the preferred groundwater and contaminant flow pathways. In addition, tributaries serve as spatial integrators of contaminant release from areas adjacent to WAG 2. Thus, water quality sampling of seeps and tributaries is useful in determining contaminant releases to WAG 2. Besides visible seeps, groundwater seepage directly into stream channels also occurs. By sampling along stream reaches (transects), significant increases in contaminant concentrations can identify these areas of contaminated groundwater discharge.

Fig. 3.2. Location of surface water monitoring stations in the vicinity of the White Oak Creek watershed.

Table 3.1. Stream reaches in the White Oak Creek Watershed

Subwatershed reach/subreach	Area (mi ²)	Inc. area (mi ²)	Contributing tributaries		CY 1992 mean flow (ft ³ /s)	Gain (+) or loss (-) (ft ³ /s)	Cumulative dry month losses (ft ³ /s)	Dry months (1992)
			Gaged	Ungaged				
Melton Branch (MB)								
MB Headwaters	0.499		1	0	0.46	0.46		
Upper MB	1.16	0.66	2	1	NA ^a	NA	<i>b</i>	
Lower MB MS4	1.51	0.35	1	1	2.65	2.19	<i>b</i>	
Bethel Valley WOC								
WOC Headwaters	0.804		0	2	0.83	0.83		
Upper WOC	1.29	0.49	0	2	0.76	-0.07	-0.18	1-6, 8, 9
Main Plant	2.09	0.80	1	4	4.48	4.33		
First Creek	0.319		0	0	0.70	0.70		
NW Tributary	0.667		1	2	0.74	0.74		
West End	3.26	0.18	1	0	8.39	2.47		
Middle WOC MS3	3.61	0.35	1	2	8.69	0.3	-0.5	5
Melton Valley WOC								
Lower WOC + WO Lake MS5	6.15	1.03	6	0	11.24	0.1	-0.31	3, 5-8, 10-12
WOC Embayment	6.5	0.35	0	1	NA	NA		
Subtotal			14	18				
Total	6.5			32				

^aNA = Not applicable or not available.^bLosses may occur in MB during dry months.

The primary objective of the WAG 2 RI Seep and Tributary Task is to identify seeps and tributaries that are significant sources of contaminants and quantify their input to the total contaminant flux in WAG 2. During FY 1992 two extensive screening sampling rounds were conducted. Samples were collected from ~30 seep locations and 100 tributary and stream locations once during a wet-season baseflow condition and once during a dry-season baseflow condition (Fig. 3.4). Table 3.2 lists the analyses for the samples collected. Greater focus is given to identifying sources of ^3H and ^{90}Sr along stream reaches because these two contaminants pose the greatest risk at WOD from water ingestion. The results from the FY 1992 efforts have been summarized in this report and are given in greater detail in the WAG 2 Phase 1 RI report to come.

Table 3.2. Analyses associated with different sampling locations

Locations	Main streams, tributaries, and seeps	Stream transects
Analyses	^3H , ^{90}Sr , gamma (water & filter), metals (dissolved), anions, alkalinity, and field parameters	^3H and ^{90}Sr

Figures 3.5 to 3.8 show the distribution of radionuclide concentrations at the seep, tributary, and main stream locations found during this initial screening. The highest concentrations of ^3H and ^{90}Sr are seen in seeps and tributaries in and around WAGs 4 and 5. Elevated levels of ^{60}Co in seeps and streams are primarily found in and around WAG 7, whereas, the distributions of ^{137}Cs is more scattered among the WAGs. In general, dissolved metal concentrations were below federal and state criteria [applicable or relevant and appropriate regulations (ARARs)] in most of the seeps sampled in and around WAG 2.

Contaminant fluxes (the product of the contaminant concentration and streamflow) were estimated for those locations where streamflow measurements can be made (Fig. 3.9). These fluxes are given in Table 3.3 as percent of the total flux at WOD. These data provide snapshot pictures of the contaminant source areas during the two different hydrological conditions (wet-season baseflow and dry-season baseflow). The ^3H and ^{90}Sr fluxes at WOD during the wet-season baseflow sampling were about nine and three times greater, respectively, than the fluxes during the dry-season baseflow sampling. Results from both sampling rounds indicate that WAG 5 is the source for over half of the ^3H flux in the watershed, with WAG 4 being the other major contributor primarily during the wet season (Table 3.3). WAGs 1 and 5 are the main sources of ^{90}Sr , with WAG 4 being a significant contributor during the wet season. Because of the errors associated with both analytical results and flow measurements (5% assumed), small inputs of contaminants may be overlooked; however, flux data used with the stream transect sampling identified key areas of contaminant inputs to the WOC watershed. Though not shown in Table 3.3, results from the sampling efforts indicate that WAG 1 is the primary source of ^{137}Cs and that WAG 7 is the primary source of ^{60}Co .

Fig. 3.4. Sampling locations for WAG 2 RI Seep and Tributary Task.

Fig. 3.5. Distribution of ^3H in the White Oak Creek watershed. Concentrations are averages of wet- and dry-season samples, except where only one sample was collected.

Fig. 3.6. Distribution of ^{90}Sr in the White Oak Creek watershed. Concentrations are averages of wet- and dry-season samples, except where only one sample was collected.

Fig. 3.7. Distribution of ^{137}Cs in the White Oak Creek watershed. Concentrations are averages of wet- and dry-season samples, except where only one sample was collected.

Fig. 3.8. Distribution of ^{60}Co in the White Oak Creek watershed. Concentrations are averages of wet- and dry-season samples, except where only one sample was collected.

Fig. 3.9. Stream flow monitoring and sampling locations for WAG 2 RI Seep and Tributary Task.

Table 3.3 Percent of contaminant fluxes at White Oak Dam (WOD)

Sampling Location	Wet Season Baseflow		Dry Season Baseflow	
	³ H Flux at WOD = 104 μ Ci/s		³ H Flux at WOD = 11.6 μ Ci/s	
	⁸⁷ Sr Flux at WOD = 86 nCi/s		⁸⁷ Sr Flux at WOD = 28 nCi/s	
	% ³ H	% ⁸⁷ Sr	% ³ H	% ⁸⁷ Sr
WOC MS3 (WCWEIR)	22 $\pm$ 2	48 $\pm$ 10	6 $\pm$ 4	48 $\pm$ 11
NWTRIB (GS4)	< 1	2 $\pm$ 1	< 1	< 1
FIRST CREEK (GS1)	no sample		< 1	7 $\pm$ 1
WOC 7500 BRIDGE	4 $\pm$ 3	32 $\pm$ 6	2 $\pm$ 8	37 $\pm$ 10
WAG4 MS1	15 $\pm$ 5	10 $\pm$ 1	1 $\pm$ 1	< 1
MB MS4 (MBWEIR)	75 $\pm$ 5	43 $\pm$ 6	70 $\pm$ 5	32 $\pm$ 5
SW5-4	< 1	25 $\pm$ 3	< 1	16 $\pm$ 3 ¹
MID DRAIN	10 $\pm$ 1	3 $\pm$ 1	3 $\pm$ 1	< 1
HRT-2	13 $\pm$ 1	9 $\pm$ 1	17 $\pm$ 1	10 $\pm$ 1
HRT-3	< 1	8 $\pm$ 1	< 1	9 $\pm$ 1
MB-15	< 1	< 2	< 1	< 2
EAST SEEP	< 1	< 1	< 1	< 1
WEST SEEP	< 1	3 $\pm$ 1	< 1	< 1
WAG6 MS2 DA ²	1 $\pm$ 1	< 1	2 $\pm$ 1	< 1
WAG6 MS3 FB	4 $\pm$ 1	< 1	1 $\pm$ 1	< 1

¹Value inferred from concentration changes along stream transect.

²Locations are shown in Fig. 3.2 for most sites, Fig. 3.10 for Melton Branch sites, and Fig. 3.11 for WAG 6 sites.

Results from the stream transect sampling indicated that there were not any significant ^3H or ^{90}Sr inputs into the WOC reach below WOC 7500 Bridge other than stream discharges from the WAG 4 tributary, MB, and a potential groundwater seep discharging elevated levels of ^3H in WOC near WC MS3 (WCWEIR). Transect sampling along MB identified four areas of significant contaminant groundwater input. These inputs are apparent from the increases in ^3H and ^{90}Sr concentrations that occur at the downstream locations (Figs. 3.10 and 3.11). One of these four areas is where a fairly discrete seep discharges groundwater having high ^3H levels to the MB tributary between HRT-2 and HRT-3 (Fig. 3.10). Another significant ^3H input appears to be a more diffuse area along the southern boundary of WAG 5 (Fig. 3.10). Sharp increases of ^{90}Sr in MB occur as a result of input from seep SW5-4 on the southern edge of WAG 5 (Fig. 3.11). This seep is a major source (estimated 16-25%) of ^{90}Sr to the watershed. Results from the first round of stream transect sampling along MB also revealed another significant ^{90}Sr input below MB MS4 (MB WEIR) and above the confluence with WOC (Fig. 3.11). This seep was later visually identified, and samples were collected from it during the second round of sampling.

Transect sampling along the WAG 4 Tributary indicated that contaminated groundwater discharges all along the reach, and that discrete inputs were not pronounced.

In summary, results from these two rounds of sampling have identified key seeps and areas that contribute significantly to the total contaminant flux in WAG 2 and that are major contributors to the risk at WOD. In addition, the results are already being used in directing focused investigations and potential removal actions at specific source areas in WAG 5 (Newsom et al. 1993).

During FY 1993 a round of samples was collected following a large rain event when subsurface stormflow was active to determine the variability of source areas during different hydrologic conditions. In addition, two more baseflow sampling rounds will be completed in FY 1993. These data will be combined with the other baseflow sampling results to clarify the distribution of contaminant fluxes and sources in WAG 2. As key seeps and areas of contaminant discharge are identified and prioritized, more extensive sampling will be conducted to identify contaminant pathways and sources.

The WAG 2 seep team will continue to interact and work with other ER efforts to gather data needed to prioritize seeps/source areas for focused corrective actions and for longer term monitoring to evaluate the effectiveness of remedial actions.

3.4.2 Tributaries

3.4.2.1 Conceptual model of tributary discharges

Figure 3.12 depicts the conceptual model of tributaries that drain into the main streams at ORNL. As shown, subsurface flow paths conduct water and leached contaminants from disposal sites to the receiving tributaries. Three regimes or stages of streamflow in tributaries can be defined:

- (1) Under baseflow conditions, streamflow is generated entirely from groundwater contributions from lateral flows draining the shallow water table interval plus minor groundwater input from the intermediate zone.

Fig. 3.10. Transect sampling ^3H results along Melton Branch.

Fig. 3.11. Transect sampling ^{90}Sr results along Melton Branch.

Discharge and Soluble Contaminant Fluxes Draining ORNL Disposal Sites

Hydrologic components:

Baseflow - Lateral flow at the water table interval plus minor groundwater from the intermediate interval

Subsurface Stormflow - Lateral flow in upper 2 meters of soil

Overland Flow - Surface runoff from contributing areas, typically uncontaminated

Fig. 3.12. Conceptual model for tributaries draining ORNL waste sites.

- (2) During moderate precipitation events, rainwater infiltrates into the surface soil layer and reaches the stream via shallow subsurface stormflow (lateral flow in the upper 2 m of the soil).
- (3) During extreme storm events, the intensity of precipitation is greater than the infiltration capacity of the surface soil, and rainwater collects on the surface and flows downslope to the stream in the form of overland flow.

The three flow regimes described above define the conditions that transport contaminants into tributaries and to their eventual discharge off-site. Figure 3.13a shows a simplified relationship between concentration, flux, and discharge for a tributary draining waste disposal sites at ORNL. Under baseflow conditions, all three parameters are relatively steady (constant). As precipitation begins, increased flow mobilizes contaminants in subsurface pathways, resulting in partial dilution. Therefore, as discharge increases, there is a subsequent decrease in concentration but an increase in contaminant flux. When discharge further increases due to overland flow, concentration decreases significantly because of complete dilution, and flux remains constant (because no further contaminants are being mobilized).

Figure 3.13b presents much of the same information but in a different mathematical form. In this figure, contaminant concentration (C) is plotted against discharge (Q) using the logarithmic transformations. The log transformation allows the partial dilution and complete dilution relationships to be plotted as straight lines. Under baseflow conditions, relatively high-concentration groundwater reaches the stream undiluted; thus, concentration tends to be constant. With the input of subsurface stormflow, additional contaminants are mobilized, and partial dilution occurs while contaminant flux continues to increase. When precipitation increases to the point that significant surface runoff begins, additional runoff completely dilutes the streamflow because surface runoff is typically uncontaminated. This hydrologic regime is identified by a slope of -1 on the C-Q plot.

Intensive sampling during storms plus occasional (monthly) baseflow sampling produces the data needed to generate the C-Q relationship for a tributary. Comparison of C-Q relationships before and after remediation provides a straightforward way of determining the effectiveness of a remedial action because C-Q relationships remove the climatic influence. (More rain generally yields more contaminant flux, and this fact may confound the evaluation of a cleanup activity.) These relationships, if developed before and after remediation activities (e.g., installation of impermeable caps), may provide a relatively quick indication of improvement as opposed to looking for changes in groundwater quality which may not show discernible improvement for decades.

3.4.2.2 Tributary assessment task

The Tributary Assessment Task was initiated in FY 1993 to determine contaminant transport characteristics and to develop C-Q flux relationships from tributaries draining the source WAGs into WAG 2. The assessment of contaminant flux on small tributaries will support the development of a site-wide perspective on the mobilization and transport of contaminants. These efforts, in coordination with the Seep and Tributary Monitoring Task, will lead to decisions on remediation of individual waste trenches and/or remediation of waste on a larger scale. In addition, by establishing baseline contaminant fluxes, the data will be available to evaluate the effectiveness of future remedial methods.

Fig. 3.13. Conceptual model relating discharge, contaminant flux, and contaminant concentration vs time in (A) and log transformed in (B). Numbers refer to the flow regime in the text.

To date, grab samples have been collected at 17 tributaries to prioritize sites (from a risk/dose perspective) for intensive sampling. Based on that prioritization, automatic stream flow sampling during storms has been initiated on three tributaries, primarily to determine C-Q relationships for selected radionuclides. Sediment from several tributaries also will be sampled for particle-reactive contaminants, metals, and anions. No analyses were available at the time of this writing.

3.4.2.3 WAG 6 C-Q relationships

During 1992, discharge measurements and water quality samples were collected from the tributaries draining WAG 6 (Fig. 3.14). Samples were analyzed for the main radionuclides: ^3H , ^{90}Sr , ^{137}Cs , and ^{60}Co . Figures 3.15 and 3.16 show the C-Q relationships for ^3H for tributaries FB and DA, respectively. Both tributaries show the initial hydrologic regime with the relatively constant C resulting from groundwater input. For tributary FB in Fig. 3.15, the next stage shows partial dilution (slope < 1), whereas for tributary DA there is total dilution (slope app. = 1), suggesting that during storms, runoff at DA is a mixture of contaminated groundwater and uncontaminated surface runoff. In fact, tributary DA receives the effluent from the south french drain outfall (pure groundwater) and runoff from nearby impermeable membrane caps (pure overland flow); thus the conceptual model fits exactly.

Table 3.4 shows the estimated mean contaminant concentration and contaminant flux for the tributaries in WAG 6 during CY 1992. These estimates were generated from C-Q relationships and continuous measurements of discharge, and these calculated fluxes are preliminary estimates used to guide the formulation of the monitoring proposed for WAG 6. There are numerous sources of uncertainty to these estimates, and more reliable measurements of contaminant flux will be obtained during the 18 months of intensive baseline monitoring planned to start in late CY 1993. C-Q relationships can be used as a monitoring tool and as a diagnostic indicator of remediation effectiveness.

Table 3.4. Estimates of annual tritium flux and average concentration for WAG 6 drainages, 1992

Drainage	Annual tritium flux (in Ci)			Annual total flow volume (L)	Average
	Base flow	Quick flow	Total		
FB	10.20	27.17	37.37	24.59×10^6	1.52×10^{-6}
DA	17.99	4.70	22.69	30.40×10^6	0.75×10^{-6}
DB	0.69	1.74	2.43	14.35×10^6	0.17×10^{-6}
Total	28.88	33.61	62.49	69.34×10^6	0.90×10^{-6}

Fig. 3.14. Surface water monitoring stations at WAG 6.

Fig. 3.15. Relationship between flux (Q) and concentration (C) for drainage FB at WAG 6 based on 1992 data.

Fig. 3.16. Relationship between flux (Q) and concentration (C) for drainage DA at WAG 6 based on 1992 data.

3.4.3 Main Streams

The data in this section are obtained from the quarterly environmental surveillance reports for 1992 (Goldberg et al. 1992 and 1993a, b, and c).

3.4.3.1 Nonradiological contaminant discharge

Concentrations of metals, anions, and other contaminant indicators measured at the Environmental Surveillance and Compliance surface water monitoring 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 in the headwaters of White Oak Creek (WOCHW). 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. With respect to organic contaminants, very low analytical values are suspect; therefore a value five times the analytical detection limit was used as a nominal rule by Environmental Surveillance and Compliance for assessing the presence of organics. Based on this criterion, no significant organic contamination was found at the three Environmental Surveillance and Compliance ambient surface water stations.

3.4.3.2 Radionuclide fluxes at main stations

For radiological monitoring within the WOC watershed, sampling locations are WOC MS3, MB MS4, 7500 Bridge, First Creek, Northwest Tributary, Fifth Creek, Middle MB (MB2), WOCHW (background monitoring), and WOD MS5. Figures 3.17-3.20 show the monthly fluxes during 1992 for ^3H , 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. Continuous flow proportional sampling for the stations at middle WOC reach and lower WOC/WOD reach allows mass balances to be computed. 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, that is, the radionuclide is either being mobilized within the reach or added to the reach by unmeasured inflow from tributaries or groundwater. A negative value, indicating a sink, means that the reach is accumulating radionuclides, either by deposition (particle-bound contaminants can be deposited) or by some uptake mechanism. Of course, the mass balance is a spatial average; therefore, a radionuclide can increase/accumulate in some areas while it is simultaneously mobilized from other areas within a given 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

Fig. 3.17. Tritium discharge at gaging stations in White Oak Creek Watershed, 1992.

Total Strontium

Fig. 3.18. Total strontium discharge at gaging stations in White Oak Creek Watershed, 1992.

Cesium-137

ORNL-DWG 93H-9129

Fig. 3.19. Cesium-137 discharge at gaging stations in White Oak Creek Watershed, 1992.

Cobalt-60

Fig. 3.20. Cobalt-60 discharge at gaging stations in White Oak Creek Watershed, 1992.

Source (or sink)
Flux out

can provide a simple indication of the reliability that a reach classified as a radionuclide source is truly a source or a reach classified as a sink is truly a sink. In other words, small values of the ratio may be suspect. Furthermore, negative values, indicating a contaminant sink, for soluble contaminants ^3H and total strontium are suspect because of the chemistry of these radionuclides.

During 1992, as in 1991, the monthly radionuclide fluxes generally show a seasonal trend. As shown for the soluble contaminants ^3H and total strontium (Figs. 3.17 and 3.18, respectively), the minimum monthly flux occurred in September, when conditions were the driest, and the maximum monthly fluxes occurred in January, February, March, and December, when runoff was greatest.

Although ^{137}Cs shows a somewhat similar pattern, the ^{137}Cs flux at middle WOC was highest in July and lowest in March and December. Conversely, the ^{137}Cs flux at WOD was highest in March and December and at a relatively low and steady rate during the entire summer (May through October). Figure 3.19 indicates that lower WOC and WOL act as a source of ^{137}Cs during the winter season, when flows are high, and as a sink during the drier summer season. Because WOC is the main source of ^{137}Cs for lower WOC/WOL, it is expected that ^{137}Cs levels at both monitoring stations 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 and more dependent on seasonal factors. Perhaps aquatic vegetation acts to slow the water velocity, causing sediment-bound ^{137}Cs to settle out in the lower WOC/WOL reach during the growing season.

Cobalt-60 shows a different pattern of discharge than the other radionuclides (Fig. 3.20). The maximum monthly ^{60}Co fluxes at WOD occurred 1-2 months after the peak monthly streamflows. The reason for the delayed response is related to the contaminant flow path. 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. The highest flux of ^{60}Co from WOD occurred in March, two months after January's high streamflows. In addition, increases in ^{60}Co flux were recorded in August and December after relatively high flow rates in July and November. This relationship between peak flows and subsequent ^{60}Co releases was also observed in 1991.

Table 3.5 lists the annual mass balances for radionuclides for the middle WOC reach and the lower WOC/WOL reach. Middle WOC reach is a source for ^3H and total strontium, and the main source for both radionuclides in this reach is known to be a small unnamed tributary draining WAG 4. (See the maps from the seep sampling in Figs. 3.5-3.6). The mass balances also indicate that the reach accumulated ^{137}Cs and was a source of ^{60}Co during the year. A small tributary on the west edge of WAG 5 discharges ^{60}Co to the reach. The source/flux ratio for the middle WOC reach is 0.9, 0.38, -0.63, and 1.0 for ^3H , total strontium, ^{137}Cs , and ^{60}Co , respectively. These values (absolute) are judged to be large, thus the pattern of sources and sinks among the radionuclides is probably correct.

For the lower WOC/WOL reach, the pattern is reversed for ^3H , which appears to be accumulating in the reach. This does not make sense because it is not plausible to accumulate ^3H , which is water soluble. The source/flux ratio is relatively small (-0.14), suggesting

Table 3.5. Annual fluxes and mass balances for radionuclides in WAG 2 for 1992

REACH	GAGE/ STATION	AVG. DISCHARGE (L/s)	AVERAGE CONCENTRATION (pCi/L)				DISCHARGE (Ci)				SOURCE (+) or SINK (-) (Ci)			
			³ H	Sr ¹	¹³⁷ Cs	⁶⁰ Co	³ H	Sr ¹	¹³⁷ Cs	⁶⁰ Co	³ H	Sr ¹	¹³⁷ Cs	⁶⁰ Co
	7500 Br. ²	238	5900	95	65	0	55	0.6	0.75	0				
	WOC	246	64000	130	60	0.22	500	0.97	0.46	0.0017				
Middle WOC											450	0.37	-0.29	0.0017
	MB-MS4	75	800000	370	0.66	0.19	1900	0.88	0.0016	0.0004				
	WOD	318	210000	210	68	4.7	2100	2.1	0.69	0.048				
Lower WOC + WOL											-300	0.25	0.23	0.046

3-29

¹Total strontium = ⁸⁸Sr + ⁹⁰Sr.

²7500 Bridge on WOC below Melton Valley Dr.

uncertainty of sink vs source. The problem lies with errors associated with discharge measurements or flow-paced sampling. These errors do not invalidate the flux measurements themselves.

Lower WOC/WOL is a source for total strontium, although the source/flux ratio is small (0.12). The reach was also a source for the discharge of ^{60}Co and ^{137}Cs at WOD during 1992.

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 somewhat surprising that this reach is a source of ^{137}Cs for the embayment. However, as stated earlier, it appears that lower WOC/WOL reach is a source of ^{137}Cs during the winter and a sink during the summer. This finding may be contrary to our accepted knowledge that WOL has been accumulating contaminated sediments over the years. Intensive storm sampling reported in Sect. 5 is intended to examine when and how ^{137}Cs is deposited or mobilized in WOL.

3.4.3.3 Derived concentration guidelines for contaminant discharges

The discharge data presented in Table 3.5 for the four main radionuclides transported in the WOC basin can be merged in Table 3.6. The radionuclides are presented as the percent of that radionuclide's DCG, and the percent DCGs are summed to represent the integrated contaminant signature for the monitoring location. A DCG is the concentration of a radionuclide in water that would result in a dose of 100 mrem if an individual consumed 2 L of water per day for 1 year. Calculating percent DCGs is a means of summing radionuclides together in a meaningful way. The results show that water discharged at WOD is less than the DCG criterion for action. The DCG at MB MS4 is >100% for 1992, but this level has not been observed in recent years.

Table 3.6. Cumulative derived concentration guide (DCG) levels at surface water monitoring stations, based upon data for 1992

Location	% Contribution to % DCG by radionuclide				%DCG
	Sr total ¹	^3H	^{137}Cs	^{60}Co	
MB-MS4	40	64			104 ²
WOD	18	11	2.3	<1	32
WOC-MS3	13	3.0	2.8		19
7500 Bridge	8.1	<1	4.1		12

¹Sr total = ^{89}Sr + ^{90}Sr .

²Summed %DCG for MB MS4 has been <80% for the last two years due to a reduced ^3H signature.

3.5 CONTAMINANT DISCHARGE IN THE MAIN STREAMS

This section provides an overview of recent analyses of the compliance monitoring data collected at the main stream stations. Two reasons for analyzing contaminant transport at these main stations in the WOC watershed are (1) to infer what physical processes are controlling contaminant transport and (2) to assess the utility of surface water monitoring at the main stream stations for performance monitoring. Performance monitoring is the environmental monitoring that demonstrates whether or not a remedial action has reduced contaminant transport to levels deemed to be acceptable. These data consist of weekly flow-paced samples that are composited and analyzed monthly from June 1987 through March 1992. The contaminant data used for this analysis are total radioactive strontium and ^3H because these contaminants exhibit the greatest range of values and consequently are most likely to elucidate the dynamics of contaminant transport.

3.5.1 C-Q for Main Streams

Figure 3.21 shows two examples of concentration and stream discharge data for total radioactive strontium at WOC MS3 and MB MS4 respectively. Two points are apparent from these plots: (1) Concentration generally increases with discharge at WOC, whereas concentration appears to be independent of discharge at MB MS4. (The C-Q relationships for WOC and MB do not conform to the tributary conceptual model.) (2) There is a range of concentration values for a given discharge level for each location. This suggests that watershed system parameters other than discharge are influencing contaminant concentration.

In the first step of the analysis, flux (F) was analyzed relative to stream discharge for the purpose of investigating predictive models (Tardiff and Wolf, 1993). Flow-paced contaminant concentration and stream discharge volume can be multiplied together to compute the contaminant flux for the time period represented by the contaminant and discharge data. Although there are statistical difficulties in modeling flux as a function of discharge because flux is computed from discharge, nevertheless, the insight gained through this analysis was that regression model was improved through classifying the data as winter or summer data and fitting a combined the regression model. One interpretation of these results is that the winter and summer categories are surrogates for wet and dry periods of the yearly climatic cycle. Seasonality is likely to impact the contaminant flux via the relative saturation of the subsurface; that is, periods of relatively high groundwater levels correspond to periods of high contaminant flux.

3.5.2 Groundwater Level As a Statistical Predictor

The seasonal variation in the local hydrologic cycle leads to annual variation in the relative saturation of the subsurface. This condition can be represented mathematically using water elevation measurements from groundwater wells.

In the second part of the analysis, water elevation records from several wells were investigated as predictors of contaminant flux at WOD, WOC MS3, and MB MS4. The best regression fits resulted from log transformed flux data and wells with a nominal depth of 10 ft. Wells can be classified as either being in discharge areas (near baseflow-fed streams) or recharge areas (on hillslopes or hilltops). Further analysis using water elevations from a shallow discharge well adjacent to upper MB and those from a shallow recharge well above MB showed that the recharge well water elevations were a better predictor of flux than the

Fig. 3.21. Total radioactive strontium vs discharge at White Oak Creek MS3 and Melton Branch MS4.

discharge well elevations. Figure 3.22 shows the strontium flux data, the regression line, and confidence bands for the regressions using water elevation data from well 1124 in Melton Valley. The regression lines are curved because the regression was computed from the log transformed data.

3.5.3. Performance Monitoring Using Statistical Models

The last step of the analysis was to develop statistical methods using regression models to evaluate reductions in contaminant flux after remedial actions are completed. A key issue is the reduction in contaminant flux necessary to document statistically that a reduction has actually occurred. The question can be restated slightly differently: For a given number of monthly samples, what is the minimum reduction in contaminant flux that can be detected with statistical validity after a change?

Figure 3.22 shows two confidence bands below each of the regression models. These confidence bands are based on a simultaneous testing procedure. The band for the $k = 10$ sample is farther from the regression line because the test is for any one of ten samples to exceed the confidence band. The percent reduction required for statistical significance increases with sample size in order to compensate for the increased likelihood of erroneously deciding that there is a significant reduction. This compensation is the purpose for using a simultaneous technique. The uppermost band corresponds to a 45.5% reduction in flux. If a single sample (monthly flux measurement combined with a groundwater well observation) plots below this line, then these data represent a significant reduction in flux. The lower confidence band corresponds to a 62% reduction in flux, and if one of ten samples plots below this line, then these data collectively represent a significant flux reduction.

Surface water monitoring at the main weirs is a viable performance monitoring strategy provided that the anticipated decrement in strontium signature consequent to remedial action exceeds a specified level for a given number of samples. If the anticipated flux reduction of the remedial action is less than the flux decrement corresponding to the computed confidence limit, then alternative performance monitoring approaches should be investigated. The regression results for tritium were similar although required reductions are greater for a given number of samples.

Additional information analysis will be conducted to investigate nonlinear regression techniques for improving the statistical model and reducing the change in signature required for a significant difference.

3.5.4 Implications to the Conceptual Model of Stream Discharges

The implications of these results to the conceptual model of how contaminants are transported through the main part of WOC are as described below.

The relationship between groundwater elevation and flux suggests that the mechanism for contaminant movement is a "piston" phenomenon. When the groundwater elevation is low and the subsurface is relatively unsaturated, the flux of contamination is low. As the groundwater elevation increases and the subsurface becomes more saturated, contaminant flux ranges from moderate to high. Conceptually, a saturated subsurface is required for high fluxes of contaminants. Given a saturated subsurface, high fluxes occur consequently to rainfall. The rainfall acts as a piston push upon the system to move contaminants into the surface water

Fig. 3.22. Total radioactive strontium flux as a function of groundwater elevation at White Oak Dam MS5, White Oak Creek MS3, and Melton Branch MS4.

system. If this conceptual model is correct, then the range of concentrations associated with a given discharge value, as noted in Fig. 3.21, is related to the relative saturation of the subsurface.

This model varies from the conceptual model for tributary discharges. For WOC, fluxes vary with groundwater elevation, suggesting that the shallow water table interval may be more active than assumed. There may be more contamination in the groundwater system or it may be more mobile than previously assumed. In either case, the C-Q relationship that is effective on the tributary scale with measurements made on the time scale of an hour (or less) differs from the C-Q relationship for the watershed weir stations, where data is collected on a monthly basis.

Resolution of this discrepancy between conceptualizations of how contaminants move at the tributary and watershed scales is important and should be investigated. Such an investigation will enhance our understanding of contaminant transport processes and help us understand the extent to which we have a near-surface soil contamination problem or a groundwater contamination problem. The discrepancy in the data collected at the tributary and watershed scales does not negate the ORNL hydrologic conceptual model because the site model does not specifically address how contaminant concentrations might vary during storms or over a period of several years. The issue will be addressed in the Watershed Data Integration activity planned for FY 1994, as described in the latter part of Sect. 7. That activity will emphasize the examination of existing data to guide future field investigations.

3.6 SUMMARY

The Surface Water Task includes a variety of data collection programs to determine the distribution, type, and discharge rates of contamination that moves through the WAG 2 drainage system. Results from the Seep and Tributary Task and the Tributary Assessment Task support the site-wide prioritization efforts by ER staff described in Sect. 2 and the GW OU investigations described in Sect. 4. Precipitation and stream discharge data support the Sediment Transport Modeling Task in Sect. 5 and engineering design of remedial actions. The data collection activities are aimed at the seep, tributary, and watershed scales.

According to the ORNL site conceptual hydrologic model, the seeps offer the best opportunity to monitor shallow groundwater because subsurface fracture flow mostly bypasses monitoring wells; therefore, seep sampling is extensive in the WAG 2/SI Program, providing a comprehensive picture of the places where contamination is moving to the surface. Sampling results show that most radioactivity is associated with ^3H and ^{90}Sr , which seep mainly from WAGs 4 and 5; ^{60}Co , which is seeping mainly from WAG 7; and ^{137}Cs , which is more widely distributed than the other radionuclides. There are few seeps having metal concentrations greater than state or federal criteria. Seep and tributary sampling has been used to prioritize the intensive storm sampling currently being conducted within the Tributary Assessment Task. Similar surface water quality sampling conducted at WAG 6 supports the formulation of an environmental monitoring program for that WAG, and the data conform to the hydrologic regimes of the tributary conceptual model described in Sect. 3.4.2. The distribution of contaminant fluxes at the mainstream weir stations in the WOC watershed reflect the spatial pattern of contamination measured at the seeps and tributary outlets.

The hydrologic data presented in this section are the basis for three methods for performance monitoring to evaluate future remedial actions; (1) water quality data at seeps provide the small scale changes caused by changes upgradient; (2) C-Q relationships characterize the release of contaminants for tributaries draining WAGs, and this approach is advantageous because it is climate independent; and (3) at the largest scale, a statistical method using the monthly data collected at the main weirs and water levels measured in an indicator well can be used to define significant reductions in contaminant flux.

One round of high-flow seep and tributary sampling has been completed, but the results are not yet available. Two more rounds of sampling during wet- and dry-season baseflow will help clarify the picture of spatial distribution of contaminated seeps. Tributary Assessment will continue to collect data at weir sites throughout the watershed to capture the dynamic nature of contaminant releases. These data will be merged and analyzed with the mainstream weir data collected under the Environmental Surveillance and Compliance program to get an integrated, large-scale, dynamic picture of releases. Sources of contamination that become mobilized during high-flow conditions must be identified so that remedial efforts can be focused on them.

4. GROUNDWATER

4.1 INTRODUCTION

Environmental media in WAG 2 function as integrators of contaminant fluxes passing through the lower WOC and MB hydrologic systems from adjacent WAGs to discharge into the Clinch River. Figure 1.1 shows the location of WAG 2 with respect to the principal contaminant-source WAGs and major surface water features at ORNL. Groundwater flow and contaminant transport in the WAG 2 floodplain areas is a significant pathway for contaminant fluxes to migrate from the source WAGs to the surface water system of MB and WOC.

WAG 2-related groundwater investigations are being performed to meet the following broad objectives:

- long-term observation of contaminant concentrations and fluxes moving through discrete flow zones from sources to discharge areas;
- documentation of temporal changes in these flow paths resulting from source area remedial activities;
- planning and implementation of source control measures in contaminant-source WAGs in cooperation with other ER groups;
- determination of any areas within WAG 2 where groundwater remediation will be required after stabilization of adjacent sources has occurred; and
- supporting confirmation and refinement of the conceptual model of groundwater hydrologic processes at ORNL (Solomon et al. 1992).

Fulfillment of these long-term objectives is reached through investigation and monitoring of groundwater to determine the hydrogeochemical setting, contaminant loading in groundwater, and groundwater flow and solute transport fluxes in WAG 2. The WAG 2 Groundwater Task is coordinated with site characterization activities for adjacent contaminant source WAGs and the proposed investigations to be performed as part of the ORNL GW OU Program.

4.1.1 Section Outline

This section includes descriptions of several investigations performed to better define conditions that control groundwater flow and solute movement in the groundwater system. Investigations discussed in this section include

- Section 4.2 describes ongoing WAG perimeter monitoring and a new groundwater level measurement task that will provide consistent, long-term information on changes in water table elevation.
- Section 4.3 summarizes several directed investigations to determine the flow patterns in the shallow water table zone: a drive point study to delineate flow paths between

buried waste areas and tributaries, a site-wide spring and seep survey, and an investigation of a high-chloride anomaly in the shallow groundwater.

Section 4.4 summarizes recent activities in the Hydrologic Head Monitoring Station Task.

Section 4.5 describes recent progress in the development of the Melton Valley 3-D groundwater model.

Section 4.6 provides a section summary.

4.2 MONITORING TASKS

4.2.1 Water Quality Monitoring at WAG Perimeters

The WAG Perimeter Water Quality Monitoring Task consists of collecting water quality samples semiannually from 160 high-quality monitoring wells. (Quarterly samples are collected at WAG 6 to meet RCRA regulations.) In ERMA (1992), the distribution of wells and the radiological and chemical analytes measured at the wells are described, and the sampling results are summarized in tables and graphs. The radionuclides and chemicals that exceed health-based criteria during 1992 are listed in Table A.2, Appendix A. Because there is no significant change in the spatial and temporal patterns of contamination observed in the WAG perimeter wells since the summary in ERMA (1992), no detailed results are reported here.

4.2.2 Hydrogeochemical Data Assessment

The Hydrogeochemical Data Assessment Task has focused on analysis and interpretation of the general chemistry of groundwater samples collected from the ORNL WAG perimeter monitoring network. The data assessment explores the relationships between groundwater chemistry, geologic host material, and well location within the flow system. The purpose for performing this task is to improve the conceptual understanding of groundwater occurrence and chemical zonation and to determine how groundwater chemistry can be used to interpret the position of individual wells in the flow system. This understanding of groundwater chemistry is important to statistical analysis of data at WAG perimeters and identification of background wells for different geologic materials at ORNL. This approach is useful at ORNL because groundwater flow characteristics are dominated by geologic materials and the presence of fractures and weathered zones.

The data assessment was accomplished using three techniques, beginning with principal components analysis, which identified dominant sources of variation in the data and reduced the dimensionality of the data from ten water quality measurements to two principal components based upon five dominant water quality measurements. Cluster analysis was used to identify associations among the monitoring wells based on the similarities in principal component scores. Tree-based modeling was used to develop a classification structure based on the cluster analysis results that could be used to assign additional monitoring results in the associations derived from the cluster analysis.

The results of these analyses show that host geologic material in which wells are constructed plays a major role in the general chemistry of groundwater. Three general water

types are identified on the basis of the principal components analysis and cluster analysis. These water types are best described as (1) a very low alkalinity water that occurs in a small percentage of wells constructed in shales, (2) an intermediate alkalinity water that occurs most commonly in wells constructed in shale-type formations, and (3) a higher alkalinity water that occurs predominantly in wells constructed in limestone-type formations.

The data analysis methods have been established and may be applied to other additional water analytical results as further monitoring activities are performed to better evaluate temporal changes in groundwater chemistry.

4.2.3 Groundwater Level Monitoring

Periodic monitoring of groundwater levels is a fundamental aspect of site monitoring that provides data used to determine general groundwater flow directions, velocities, and variations in the quantity of mobile groundwater. The WAG 2 groundwater level monitoring activity consists of monthly water level and specific conductance data measurements from 104 wells distributed throughout Melton Valley and in WAGs 3 and 17. Figure 4.1 shows the locations of wells included in this ongoing data collection activity. Water level measurements made by the WAG 2 Program are complemented by similar measurements made by Bechtel National, Inc., for 47 wells in the WAG 1 area and 269 wells in WAG 5. Locations of wells included in water level measurement activity in WAG 1 are also shown in Fig 4.1. The areal distribution of wells monitored provides general area coverage of the contaminant-source WAGs as well as resolving the water table configuration within WAG 2.

The data obtained in this task are used in several tasks reported elsewhere in this report, including interpreting groundwater geochemical conditions, interpreting the role of stormflow and groundwater contributions to discharge fluxes of contaminants in the surface streams, and calibrating groundwater flow models. This task is envisioned as one that will continue for a long duration (years) to provide continuity in ORNL's records for groundwater data.

4.3 DIRECTED INVESTIGATIONS

4.3.1 Installation of Shallow Drive Points

As an integrator of contaminant movement through the WOC flow system, WAG 2 characterization and monitoring activities include performing sampling and analysis of all media that carry contaminants from the source WAGs (WAGs 4-9) to discharge via the surface water system. During FY 1993 the groundwater component of WAG 2 is installing shallow groundwater sampling devices in three general areas to complement investigations in progress at WAGs 5 and 6. Two areas of shallow drive point installation lie adjacent to WAG 5 and support both the investigation of contaminated seep discharges (Wickliff et al. 1991, and Hicks et al. 1992) and source control investigations in WAG 5 (Newsome et. al. 1993). Four principal seeps to MB (identified alphabetically from "A" through "D" in Fig. 4.2) have been identified and are the subject of focused investigations to speed remediation of the seepage pathways and control discharge of contaminants from the source areas feeding the seeps. The WAG 2 Groundwater Task Group is installing the shallow drive points in two general areas to map the flowpaths of contaminants from the area of seep emergence back toward contaminant sources. This mapping is important as predesign information for the possible treatment of contaminated seepage.

Fig. 4.1. Location of wells included in routine water level measurement programs at ORNL.

Fig. 4.2. Areas in WAG 5 where shallow drive point installation will occur.

In the area between WAGs 6 and 7, six drive points are being installed to enable sampling WAG 7 contributions to contaminants entering the stream near the West Seep. The flow of contaminated groundwater into the stream in this area has been known for many years and the construction of these additional sampling points will help differentiate the flux of contaminants entering the stream from WAG 7 as opposed to those originating from WAG 6.

Completion of this task benefits the ORNL ER Program by providing basic mapping of groundwater contaminants at the individual seep scale in portions of WAG 2 where significant contaminant inputs are known to occur. The information will allow specific corrective measures to be applied to these areas in order to significantly reduce the contaminant flux to tributaries and to surface water discharge at WOD, thereby reducing potential exposures off-site. Programmatically, this task demonstrates the ability of WAG 2 investigations to complement SI activities conducted in contaminant-source WAGs.

4.3.2 Investigation of Shallow Groundwater Anomaly

Sampling and analysis of groundwater from shallow piezometers in the WOC floodplain in 1987 showed anomalously high chloride concentrations in piezometers south of WAG 7 (liquid waste disposal pits and trenches) and west of hydrofracture sites 3 and 4. This area of anomalously high chloride concentration in shallow groundwater is significant because chloride is elevated by about 40- to 200-fold over normal concentrations for shallow groundwater. The source of this chloride is presently unknown but may originate from natural or induced artesian leakage upward from the transition zone groundwater. The highest detected chloride concentrations occur in bedrock wells. The purpose of performing geophysical surveys in the area of this anomaly is to determine whether the chloride provides an electrically mappable signature and whether the depth from which the chloride originates can be measured with surface geophysical methods.

Investigation of anomalous groundwater chemical conditions is important for defining local groundwater conditions, which may reflect unusual flow patterns. The use of surface geophysical methods for performing such investigations is a rapid and cost-effective alternative to installation of additional wells.

4.3.3 Groundwater Operable Unit Spring and Seep Survey

A spring and seep survey of the ORNL GW OU area is being conducted by the USGS by way of an interagency agreement. The survey area includes 17 subbasins exclusive of the areas investigated in the WAG 2 spring and seep investigations. The purpose of the survey is to locate and classify groundwater discharge points within the GW OU boundary. In turn, this information will assist ORNL ER in understanding groundwater/surface water interactions; quantifying recharge/discharge relationships and groundwater circulation patterns; and developing a long-term groundwater monitoring program.

The survey is being conducted in two phases: a wet-season, high-baseflow survey, followed by a dry-season, low-baseflow survey. The wet-season survey, conducted in March to May 1993 was conducted in two steps: an initial reconnaissance effort to locate significant discharge points in each basin, followed by a subsequent discharge and water quality parameter measurement survey. The reconnaissance survey was performed during seasonally wet conditions in March and April on each subbasin to identify and stake the locations of spring and seeps and to identify candidate sites for obtaining discharge measurements. A total

of 782 springs, seeps, and discharge measurement points was identified. A Global Positioning System (GPS) was used to provide survey quality location information for a total of 469 of these sites. Locations of other sites were determined from detailed topographic base maps with distances from known locations or GPS survey points. Following the reconnaissance effort, flow quantity and water quality measurements (pH, temperature, and specific conductance) were obtained for each of the staked locations between April 29 and May 10, 1993. By May 10, ~27% of the previously identified springs and seeps had gone dry, resulting in collection of discharge volume and physicochemical parameter measurements on a total of 565 locations. Discharge measurements were made by volumetric methods, Pygmy flow meter, or direct estimation. The dry-season survey is anticipated to be performed during September and October. A single visit to each previously staked location is anticipated during the dry-season survey.

Spring and seep inventories are important for determining the locations where groundwater enters the surface water flow system. By establishing the locations of these discharge points and making fundamental measurements of physicochemical properties, it is possible to differentiate bedrock groundwater sources from stormflow discharges. The systematic inventory of springs will enable the ORNL GW OU to establish a minimal network of sampling locations that can be used to confirm the knowledge of contaminant discharge locations in the future.

4.4 HYDROLOGIC HEAD MONITORING STATIONS

The HHMSs are a network of wells (Fig. 4.3) constructed to obtain vertical head measurements and groundwater samples for chemical analyses through a range of depths as great as several hundred feet. Data from this network of wells are used for several purposes, including determination of the depth to which active fresh water circulation extends using both hydraulic head and chemical data from the wells; determination of flow boundary conditions; determination of potential underflow conditions at potential boundaries such as major ridges and surface water bodies.

Data collected to date suggest that essentially all the wells recharge to the shallow aquifer at the ORR discharges to the local surface water system through the mechanisms of shallow stormflow and groundwater discharge. This local flow system is known to transport contaminants laterally to streams that drain the area. This conceptualization of the local and deep hydrogeologic systems is shown in Fig. 4.4.

The investigations performed in the HHMS installation project at ORNL benefit the ER Program in several important ways. These investigations are critical to defining the vertical groundwater flow potential. Through construction and monitoring of these wells, it is possible to ascertain the general directions of groundwater movement in the major flow zones to depths of several hundred feet. Data from this type of well are necessary to determine the boundaries to different portions of the groundwater flow system in the ORNL area. Use of the multiport sampling devices allows very precise sampling of important flow zones, reduces the amount of groundwater purged prior to sampling, minimizes waste generation, and provides the highest integrity samples obtainable from these zones.

Fig. 43. Locations of Hydrostatic Head Measuring Station wells.

Fig. 4.4. Conceptual model of local and deep flow systems based on Hydrostatic Head Monitoring Station data.

4.4.1 Vertical Groundwater Zonation

Interpretation of existing data indicates that the local shallow groundwater flow system discharges to the local streams, primarily WOC, and ultimately to the Clinch River. The depth to the base of the local flow system is controlled by the distribution, density, and connectivity of fractures in bedrock. The base of the system occurs between 200 and 400 ft and is determined from a variety of data, including (1) decreases in hydraulic conductivity; (2) absence of direct or indirect evidence of fractures; (3) increase in TDS and a change toward NaCl-type water, and (4) little to no head response to precipitation events.

Flow directions in the local flow system are governed by the local ridge-valley-ridge topography with discharge to surface streams. Geologic features modify these local topographically driven flow paths, creating a heterogeneous and anisotropic flow system. Underlying the local flow system is a zone of sluggish to stagnant, briney groundwater that may be up to 270 million years old.

4.4.2 Multiport Well Data

During FY 1992 the first three multi-port HHMS wells (HHMS 12-14) were constructed at ORNL (Fig. 4.3) in order to define the flow paths at the water gap between Bethel Valley and Melton Valley. Previously, 11 well clusters (HHMS 1-11) comprising three individual wells were constructed to measure hydraulic head to depths of 400 ft below ground surface. A summary of results from the cluster wells is presented in Dreier and Toran (1989).

4.5 GROUNDWATER MODELING

A 3-D, numerical groundwater flow model of Melton Valley has been constructed to understand the role of groundwater in transport of contaminants from local waste disposal sites. The model includes 40,000 nodes arrayed in nine layers and is executed on the ORNL supercomputer using a parallel version of 3DFEMWATER.

These calculations include only saturated groundwater flow, not stormflow and other transient flow. However, modeling groundwater fluxes is needed to test hypotheses about the role of stormflow and to help construct transient stormflow models.

4.5.1 Model Boundaries and Physical Properties

The groundwater model covers an area of about 1158 acres within western Melton Valley. Boundaries of the simulated domain coincide with Haw Ridge to the north, Copper Ridge to the south, the Clinch River to the west, and the north-trending reach of WOC to the east (Fig. 4.5). Parts of WAG 2 (including WOL, WOC, and some of its tributaries), WAGs 4, 6, and 7 are included in the modeled area.

The base of the model was set at elevation 200 ft above mean sea level (MSL) because measured hydraulic conductivity data suggest sluggish to stagnant groundwater flow conditions at this depth. Since the lowest topographic point within the modeled region is at elevation ~740 ft, the minimum thickness of the model is about 540 ft. Steady-state conditions are assumed for all boundary conditions, including recharge and constant head and flux boundaries. Typical annual water level fluctuations in the area are less than 10 ft.

Fig. 4.5. Area included within the Melton Valley 3-dimensional groundwater model.

The groundwater model was constructed with three hydraulic conductivity zones corresponding roughly to the regolith (highest conductivity), shallow bedrock, and deep bedrock (lowest conductivity). This conceptualization of the groundwater flow system, shown in Fig. 4.4, follows that of Tucci (1992) and Solomon et al. (1992) with layering based on the observed trend of decreasing hydraulic conductivity with increasing depth. In this conceptualization the vadose zone and water table interval are included in the regolith, the shallow bedrock corresponds to the intermediate modeled layer, and deep bedrock corresponds to the bottom model layer. Flow in the stormflow zone is not simulated in this model since it is a transient flow phenomenon.

The base of the model and vertical sides underlying Haw Ridge, the Clinch River, and WOC on the eastern model boundary (Fig. 4.6) were specified as no-flow boundaries. This assumption implies that Haw Ridge is a groundwater divide and that groundwater within this modeled domain does not underflow the no-flow boundaries. The possibility of underflow leaving the model domain at specified depths is allowed in the model. This underflow is used as a model calibration parameter. The use of underflow beneath Copper Ridge in shallow and deep bedrock improves calibration but actually has little influence on contaminant pathways because the modeled flow path does not encounter waste areas. In fact, the use of a discharge boundary in shallow bedrock here can be considered the equivalent of moving the boundary with the flow having to go through the tedious process of regriding a 40,000-node problem domain. These boundary conditions are used to test the respective concepts at each boundary and suggest that additional data are required along the boundaries to better define boundary flows. Lakes and streams are incorporated in the model, and recharge over land portions of the model is applied as a uniform value in two regions north and south of WOL. Recharge in the area south of WOL is assumed to be lower than that north of the lake because of the local steep topography.

The groundwater model is calibrated using data obtained from piezometers within the modeled area, as well as data from fully recovered wells in the HHMS well network.

4.5.2 Model Results

Modeling activities to date have focused on calibration of the model by variation of hydraulic conductivity, recharge rates, and underflow fluxes beneath Copper Ridge to achieve a best fit to the water level data used as the calibration target. The best calibrated model run to date has a root mean square error of 11.89 ft.

Model runs with a vertical to horizontal anisotropy ratio of 0.2 indicate a better match to the deep system, and further testing of ratios and rotation of the anisotropy axis is under way. There is a good comparison between dry-season flow measured at tributary weirs, which should represent groundwater baseflow, and groundwater discharge calculated by the model.

The development and calibration of a site-wide groundwater flow model is critical to the ORNL ER Program. Many of the long-term issues associated with final closure of ER sites are related to subsurface transport of contaminants from these sources. Only through use of well calibrated models can estimates of the contaminant mobility and future risk to human health and the environment be developed.

Fig. 4.6. Cross-sectional layers used in Melton Valley groundwater model.

4.6 SUMMARY

WAG 2 groundwater investigations include monitoring activities that document the characteristics of the groundwater flow and solute transport system, determine the flow pathways for contaminants originating from adjacent WAGs, and support development of groundwater modeling capabilities for flow and transport assessment. In combination, these investigations provide an extensive monitoring and assessment capability for WAG 2 and adjacent Melton Valley areas. Continuation and refinement of the monitoring and investigation activities is a key component of the ORNL ER strategy of enabling integration of area data to prioritize treatment of contaminant releases.

Continuation of sampling and analysis of WAG perimeter water quality wells in combination with area-wide water level monitoring provides record data to identify trends in contaminant concentration and migration. These records are also required for area-wide interpretation of contaminant release mechanism studies, which utilize stream discharge and contaminant flux records in combination with groundwater-level fluctuation records. The hydrogeochemical data assessment utilizes data collected from the WAG perimeter wells to investigate the dynamic nature of the groundwater flow and geochemical environment and to enable verification of the conceptual model of groundwater occurrence and flow. Investigations associated with the HHMSs provide data that enable interpretation of groundwater flow and geochemistry to depths of several hundred feet below the ground surface. These data complement near-surface data in defining the depth of active groundwater circulation within Melton Valley.

The GW OU Unit seep and spring survey locates and obtains initial measurements of spring flow volumes and water characteristics that complement the Seep and Tributary Task described in Sect. 3 by obtaining measurements from the entire area of the ORNL GW OU. The data from this survey are essential for locating key groundwater discharges which are appropriate for inclusion in long-term monitoring activities. Seep and spring location and discharge data are also useful for groundwater flow model calibration. The Melton Valley Area Groundwater Modeling Task makes use of data obtained in several of the tasks described and is intended to provide a synthesis of monitoring data and concepts in a coherent numerical simulation of the Melton Valley groundwater flow system.

5. SOIL AND SEDIMENT

5.1 INTRODUCTION

Contaminated soil can be a significant pathway of exposure for humans and for the environment (see Sect. 2). The movement of soils and sediments transports particle-bound contaminants, and deposition of eroded sediments can cause accumulation of contaminants. Deposition of sediment can also interfere with the functioning of weirs and change the hydrodynamic characteristics of the surface water system. Characteristics of soils and sediments in the ORNL WAGs influence remedial actions (e.g., treatability, construction, removal). 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.

Field work within the Soil and Sediment Task is focused on two activities: (1) inventorying contaminated sediments in the watershed and (2) measuring the flux of sediment and associated contamination in the WOC basin during extreme storms. Several investigations of contaminant inventories were initiated during FY 1993, but little of the analytical data were available by June 1993. As for collecting data during extreme storms, the weather has been largely uncooperative during the past 18 months even though the task team has been poised for intensive sampling. However, in March 1993, a high-flow event did occur, and the team collected an extensive data set that is summarized in Sect. 5.5.

5.1.1 Section Outline

- Section 5.2 describes the conceptual model for transport of contaminated sediments in WOC watershed.
- Section 5.3 describes efforts to identify and quantify sediment sources to the WOC system.
- Section 5.4 describes the different activities designed to inventory the contaminants within WAG 2, including the walkover studies.
- Section 5.5 summarizes the data collected during the storm at the end of March.
- Section 5.6 describes efforts to determine the sources of contaminated soil and sediments in WAG 2 and to develop models to predict the transport of contaminated sediment through the WOC Watershed.
- Section 5.7 provides a summary of Sect. 5.

5.2 CONCEPTUAL MODEL FOR CONTAMINATED SEDIMENT TRANSPORT

A diagram of the conceptual model for contaminated sediment transport in the WOC basin is shown in Fig. 5.1. The Soil and Sediment Task has data collection activities related to most of the components of the conceptual model. Other components of the conceptual model are investigated by other portions of the WAG 2/SI Program in order to generate a comprehensive picture of contaminant movement in the hydrologic system.

Fig. 5.1. Conceptual model for contaminated sediment movement in the White Oak Creek Watershed.

5.2.1 Sediment Sources

Hillslope erosion is important to overall sediment budgets. Sediment entering the WOC system will be mixed with particle-reactive contaminants as it moves downstream. The increased volume of material could lead to unacceptable exposures and to greater amounts to be remediated. Consequently, the erosion of surface soil and stream channels in uncontaminated regions impacts remediation efforts. The task team will be investigating natural rates of erosion throughout the watershed, starting in the summer of 1993.

5.2.2 Primary Contaminant Sources

Contamination in the WOC/WOL system is a result of subsurface releases from active and inactive sites in 11 WAGs located within the WOC watershed. Seepage of dissolved contaminants is addressed by the Surface Water and the Groundwater Task Teams. Particle-reactive contaminants bind to sediments and move through the WOC drainage system. The primary contaminant in the main streams and WOL is ^{137}Cs , which sorbs (nearly) irreversibly to soils and sediments. Other contaminants of concern associated with soils and sediments are ^{60}Co , ^{234}U , PCBs, arsenic and thallium found in the WOC floodplain system and WOL, as well as ^{152}Eu found in the WOCE sediments.

5.2.3 Deposition and Secondary Sources

Deposition of suspended sediments begins once the stream flow velocity falls below the settling velocity of a particle. All deposited materials become potential secondary sources of contamination. Resuspension can occur when severe storms lead to higher discharge velocities. The major sources of mobile contaminated sediment during flood events are these contaminated sediment deposits in the stream channels and floodplains, as indicated in Fig. 5.1. One goal of the Soil and Sediment Task is to inventory the contaminants of all secondary sources in the watershed and to measure or estimate their relative susceptibility to resuspension. A key assumption is that both the particle size and the cohesiveness of the sediments control the resuspension of secondary sources during floods.

5.2.4 Transport Processes

Increasing stream flow (discharge) generates increasing shear stresses on the channel bottom and stream banks and on the floodplain soils during floods. When the critical shear stress for the channel or soil material is exceeded, scour or erosion is initiated; and suspended sediments are entrained in the stream flow.

Moderate floods (1- to 10-year events) may carry particles up to fine sand through the weir pools and WOL but will deposit coarse sands and gravels, transported as bedload, in the larger weir pools and in WOL. Severe and extreme floods (20- to 100-year events) may develop enough energy to scour out significant amounts of the sediment deposits at weir pools and in the WOL bed. Therefore, the basic assumption is that the smaller floods tend to set up sources of sediment to be scoured and carried off-site into the Clinch River during larger floods.

5.2.5 Key Issues of the Sediment Transport Conceptual Model to Be Resolved

To understand the movement of contaminated sediments in the WOC system and to advance the conceptual model, the following issues must be resolved:

1. At what discharge do massive scour and resuspension of sediment rates occur in WOC and WOL?

This will be resolved through data collection (assuming some severe storms do occur) and computer simulation.

2. What are the critical shear stresses for the channel system, lake deposits, and floodplain materials?

The USGS has agreed to assist the WAG 2/SI Program by developing methods for measuring the critical shear stress in situ, a key parameter for sediment-transport modeling.

3. What is the relationship between contaminant concentration and particle size?

The conventional assumption is that higher concentrations of particle reactive contaminants (e.g., picocuries per milligram dry weight) are found on finer as compared to coarser particles because of the higher surface area/unit volume and surface chemistry properties of the fine grains. What the relationships are between particle size and contaminant concentrations in various parts of the system is not yet clear. Field surveys and storm sampling are planned to help resolve this issue.

5.3 SEDIMENT SOURCES

5.3.1 Soil Erosion

Movement of uncontaminated soil and sediment is important to the characterization of the WOC basin. All sediment moving through the system ultimately mixes with particle-reactive contaminants, thereby increasing the volume of sediments that may have to be remediated. WAG 2/SI will initiate preliminary erosion studies in the source WAGs in the summer of 1993. Background Soils Characterization Project (Energy Systems 1993) has investigated fallout ^{137}Cs data on stable landforms representing different geologic formations present at ORNL. A plan to sample unstable hillslope sites where erosion and deposition occur will be developed during the summer of 1993. Naturally occurring rates of erosion are being investigated by tracking the movement of surface soils using ^{137}Cs deposited via fallout and strongly sorbed by clay minerals in the upper horizon.

5.3.2 Stream Bank and Channel Erosion

Techniques for documentation of stream bank and channel erosion are primarily based on assessment of changes in channel form measured over time. A study of bank and channel has been initiated. Eight sites in the WOC watershed were surveyed in detail, and at each site four erosion pins (25 cm long) were driven into the eroding bank at different heights above the water level (base flow). Data will be collected three times a year or after major storms.

5.4 CONTAMINATED SEDIMENT INVENTORY

5.4.1 WAG 2 Floodplain Radiation Walkover

A radiation walkover survey was conducted in the spring of 1992 in order to map the gamma-emitting sources. The results have been used to (1) estimate the extent of sediment contamination, (2) locate and define hot spots, and (3) guide soil sampling efforts. The first set of sediment cores has been collected and is being analyzed. If 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 cocontaminants.

For efficiency, the survey team used the Ultrasonic Ranging and Data System (USRADS) developed at ORNL. The USRADS provides automatic data collection by instantly relaying the sensor measurement and the surveyor's location to a portable computer. Two sensors were used: one held close to the ground and the other held 1 m above the ground to simulate dose rate. For the WAG 2 survey, the sensors were calibrated to measure the gamma emission of ^{137}Cs , but wherever lower-energy gamma emitters (e.g., ^{90}Sr) were present, the sensor tended to overestimate the exposure. Consequently, the dose rate information shown in Fig. 5.2 should be viewed as an upper bound on the true dose rate. Recent investigations suggest that the dose rate may be overestimated by up to a factor of 9 for some parts of WAG 2. Nevertheless, the map in Fig. 5.2 shows reasonable spatial trends. The higher radiation levels occur closer to WOC, and the levels decrease very rapidly with distance away from WOC, with the exception of the Intermediate Pond Site.

In 1993 the WAG 2 walkover data set was merged with the USRADS walkover data previously collected for WAG 5 as part of a separate investigation. This combination of surveys is of interest because WAG 5 is one of the sources of WAG 2 contamination. Because different radiation detection instruments were employed in the WAG 2 and WAG 5 surveys, the two data sets do not agree exactly in areas of overlap although some adjustments can help to resolve this problem. The entire WAG 2 radiation data set has been loaded into the GIS ARC/INFO and is available for comparison with other data sets as they are collected. Because of the dense sampling pattern (with a typical density of 1 radiation reading/6.25 ft²), the WAG 2 radiation walkover data set contains a wealth of information that may be used to estimate gamma exposure levels for risk assessment scenarios; guide interim corrective measures, investigate correlations with soil type, and biotic data; locate contaminated seeps near burial grounds; estimate contaminant mobilization during flooding when used with stormflow models, and form the basis of geostatistical studies. In the past year, these data have been used by several WAG 2 researchers to guide their planning and sampling efforts.

Sediment cores collected in 1993 from the walkover areas are being analyzed, and additional soil cores will be collected in the coming year. Data from the cores will be used to (1) determine the distribution of radionuclides with depth, (2) calculate the theoretical gamma radiation field at the surface to compare with the measured values, and (3) test whether or not cocontaminant concentrations such as metals and organics correlate well with radionuclide concentrations. Additionally, we plan to merge the WAG 2, WAG 5, and WAG 1 walkover data. To ensure that the data are accessible to users, a considerable programming effort will be required because the final data set will contain over >1,000,000.

Fig. 5.2. Walkover radiation data for WAG 2.

5.4.2 Weir-Pool Sediments

Sediments at seven weir pools and at the old WOC bed in Intermediate Pond Site were sampled in May 1993. Results are not yet available.

5.4.3 WOL Sediments

A bathymetric study will be conducted in WOL. Eleven cross-sections were chosen for measurement of water depth using a level rod or a depth finder. Sedimentation rate will be estimated by comparing these data with results of earlier bathymetric studies.

Four sediment cores were collected along WOL. The vertical distribution of ^{137}Cs was similar to that found in earlier studies. In general, higher concentration and deeper contamination were found closer to the dam. The concentration of ^{137}Cs in the top 10 cm was below 1000 pCi/g.

5.5 STORM SAMPLING

5.5.1 All Storms

Intensive sampling has been conducted during eight storms since the beginning of the Soil and Sediment Task. Sampling results for three of the storms were reported in ERMA 1992. Only one of the remaining storms produced true flood conditions with over-bank flow. The only complete data set for an out-of-bank flood, collected during March 1993, is summarized below.

5.5.2 Storm of March 23, 1993

Figure 5.3 shows the contaminant discharge, starting at 0:00 hours on March 23, 1993, at WOD during the storm. Similar graphs are available for upstream stations, and they will be presented in detail in the WAG 2 RI report. The daily average precipitation measured at four rain gage stations in the catchment was 2.01 in. on March 23, 1993. Although the intensity and duration suggested the precipitation had a return period of slightly more than 1 year, saturated conditions due to previous storms on March 22 (0.11 in.) caused above bank-full runoff conditions at several locations along WOC. Intensive sampling was performed manually and with automatic samplers at eight sites in the watershed over a period of about 12.5 h, from 1:00 p.m. until 1:30 hours the next day.

The estimated cumulative discharge over WOD for the 3.3 days graphed in Fig. 5.3 was 0.044 Ci of ^{137}Cs . The discharge during the half-day of intensive sampling was calculated to be 0.028 Ci or 62% of the entire estimated discharge. To calculate the cumulative ^{137}Cs discharge the initial and final concentrations of ^{137}Cs (picocuries per liter) had to be assumed based on previous measurements. For this analysis average conditions derived from measurements taken at WOD by Solomon et al. 1991 were used.

The cumulative discharge can be compared to annual loadings (Table 5.1) measured at WOD by the flow-paced sampling system used for NPDES monitoring. The ^{137}Cs loading from this 3-day storm represents from 3 to 10% of the annual ^{137}Cs discharge measured over the past 10 years, which seems reasonable for what is judged to be a relatively minor flood.

Fig. 5.3. Preliminary analysis of discharge and ^{137}Cs release at White Oak Dam for storm of March 23, 1993.

Table 5.1. Annual discharge of ^{137}Cs at White Oak Dam

Year	^{137}Cs (Ci)
1982 ^a	1.5
1983	1.2
1984	0.6
1985	0.4
1986	1.0
1987	0.6
1988	0.4
1989	1.2
1990	1.1
1991 ^b	1.7
1992 ^c	0.7

^aBlaylock et al. 1993.

^bERMA 1992.

^cSect. 3, this report.

The contaminant loading can also be compared to the NPDES weekly flow-paced sampling at WOD. A weekly sample was recovered in the middle of the storm hydrograph (March 24); therefore, it is appropriate to consider the discharge for the 2-week (13-day) period March 18 through 31. During this interval the cumulative ^{137}Cs discharge based on flow-paced sampling was 0.047 Ci, which agrees almost exactly with the result of the intensive storm sampling. Assuming negligible sediment and ^{137}Cs discharge during the days not covered by the intensive sampling (13 days – 3.3 days = 9.7 days) and considering the uncertainty of the initial and final contaminant concentrations used in the analysis shown in Fig 5.3, the agreement is considered to be excellent. A single storm is not sufficient to assess the accuracy of either the intensive storm sampling approach or the NPDES flow-paced monitoring system, but the similarity in results is encouraging.

The dynamics of the contaminant movement within the watershed during the storm is informative. Peak suspended sediment concentrations occurred slightly before the peak flow at monitoring stations WOC MS3 and MB MS4 upstream of WOL, but the (first) peak of the suspended sediment concentration occurred 4.5 h after the peak flow at WOD. It appears that the suspended sediment moved through the lake from the inflow points to the dam as a pulse, that is, piston flow. Furthermore, this delay suggests that lake bottom sediments were not mobilized by the high flow of this storm. Grain-size analysis of the sediment samples at the monitoring stations (shown in Fig. 5.4) collected near peak flow show that the proportion of sand and fine sand was reduced by deposition during transit through the lake, as expected from the sediment transport conceptual model.

The ^{137}Cs per mass of suspended sediment (picocuries per gram), referred to as the contaminant/mass ratio, declined steadily during the initial part of the storm, continued to decrease during the falling limb of the hydrograph, but toward the end of the hydrograph, started to increase. Possible alternative explanations of this pattern are as follows: (1) Coarser

Fig. 5.4. Particle-size distributions at the main gaging stations near peak flow for each site (March 23, 1993).

silts and sands were transported through the system during the first part of the storm, and coarse materials (are assumed to) have lower contaminant sorption. (Though this hypothesis seems to contradict the observation that the coarse material settles out, some portion will be carried through the lake and discharged.) The coarse material will tend to reduce the contaminant/mass ratio. After water velocities decrease, the coarse material settles out, the clays and fine silts with the larger radioactive burden remain in the water column, and the contaminant/mass ratio increases. (2) Alternatively, the uppermost layer of sediments along the channel bottoms and stream banks may be the most contaminated because they are continually exposed to the contaminated water generated upgradient. This top layer is mobilized first by the scouring action of the stream, followed by the erosion of less contaminated materials beneath the upper layer. This difference between the contamination on the uppermost layer and deeper layers of soil/sediment causes the contamination/mass ratio to be reduced. At the latter part of the hydrograph, this contamination/mass ratio increases as shallow groundwater in the source WAGs drain and the subsurface contamination sources drain. These explanations, and others, will be explored more fully in the near future by analyzing the data more intensely and by simulating the storm results.

As mentioned above, the results are at least slightly sensitive to the assumed values of suspended sediment concentration and contamination/sediment mass at the leading edge of the hydrograph and during the hydrograph recession. Past sampling of smaller storm events (February 25 and March 18, 1992) suggest that the contamination/mass could start as high as 8000 pCi/g rather than the 2500 pCi/g assumed here. The cumulative loading is not very sensitive to this because initial and final flow rates are relatively small. Nevertheless, the data show the importance of early and late samples in understanding storm dynamics.

5.6 SEDIMENT TRANSPORT MODELING

Data from a single storm represent a snapshot of a very dynamic system. Variables that can affect contaminant movement collected during an individual event include the amount, peak intensity, and timing of rainfall; the peak and timing of surface water discharge; season; elapsed time since last flood and magnitude of last flood; and disturbances in the watershed (e.g., construction activities or remedial actions). Furthermore, our measurements of contaminant movement are affected by the location and timing of samples as well as analytical uncertainty. Assessing the impact of these variables can only be accomplished by computer simulation.

The HSPF (Hydrologic Simulation Program—FORTRAN) model distributed by the EPA has been selected and is being calibrated for this purpose. HSPF is a comprehensive model for hydrology, sediment transport, and water quality simulation. The model is currently partially calibrated based on hydrologic data and preliminary data for sediment and ^{137}Cs processes observed during floods. Additional calibration will continue as the data base is established for storm sampling; cores from WOL, weirs, and the floodplain; erosion surveys; and estimates for critical shear stresses.

Once the model is calibrated, it will be used to answer these questions:

1. What is the uncertainty of existing estimates of contaminated sediment transport?

2. What is the expected discharge of contaminated sediments during floods of varying return periods?
3. What is the expected discharge of contaminated sediments for a given disturbance in the watershed (e.g., a particular construction activity at a specific site)?
4. How effective will a proposed remedial action be in reducing contaminant flux?
5. What will be the effectiveness of WOL to act as a sediment trap if the lake continues to fill with sediment?

5.7 SUMMARY

The data collection activities in the Soil and Sediment Task are fully implemented, and some results of the particle-reactive contaminant inventories in WAG 2 will be available at the end of FY 1993. Data collection activities are designed to address the major components in the sediment transport conceptual model. Results from the walkover survey have already proved beneficial in health and safety planning and in the formulation of soil sampling programs.

The comprehensive data set collected during the March 1993 storm provides insights into sediment movement within the watershed. The deposition of sand and fine sand particles through the WOL reach conforms to the conceptual model, but the delay in the peak of the suspended sediment concentration (relative to the flow peak) at WOD was unexpected, suggesting that the lake bottom sediments and other material in the lower WOC reach can remain immobile.

Sediment sampling during severe storms is very important to the ER Program because it is required for HSPF model calibration and validation. In turn, the calibrated model will be used to predict the watershed response to conditions that cannot be directly observed. Furthermore, these data provide insight into how contaminants are actually being transported. This insight will be beneficial for the design of remedial projects for the integrator WAG. Data collection, modeling, and integration of the results into ER planning ensure that no remedial design will inadvertently cause scour and erosion of contamination in WAG 2 that could, in turn, lead to increased risks or harmful exposures to the public.

6. BIOTA

6.1 INTRODUCTION

The Biota Task of the WAG 2/SI includes three major components: (1) the BMAP (2) the ecological assessment of contaminant-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 baseline ERAs for those WAGs by obtaining WAG-specific data that are not available through BMAP or other sources. WAG 2 as the receptor for contaminants from the upgradient source WAGs integrates 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 1993, BMAP continued with all tasks as defined in 1986 (Loar et al. 1991), and an ecological assessment was initiated on WAG 5. The assessment work in WAG 2 consisted of baseline monitoring closely associated with BMAP. The results of the WAG 2 assessment tasks are reported in the BMAP subsections. Most of the BMAP results reported in this section are summarized in the report by Ashwood, ed. (1993).

6.1.1 Section Outline

Section 6.2 describes several subtasks of the ORNL BMAP.

Section 6.3 describes efforts to identify ecological indicator species for future monitoring and to assess ecological impacts for WAG 5, the only contaminant-source WAG with an active field investigation.

Section 6.4 briefly describes short- and long-term pollution abatement efforts to resolve water quality problems, including toxicity of some receiving streams.

Section 6.5 describes the initial effort to develop a GIS model relating contaminant-source data and biological monitoring data.

Section 6.6 provides a summary of Sect. 6.

6.2 BIOLOGICAL MONITORING AND ABATEMENT PROGRAM

BMAP takes advantage of WOC's function as an integrator of contaminant fluxes to identify point and nonpoint sources of toxicity and related impacts on aquatic communities. The BMAP currently consists of six major tasks that address both radiological and nonradiological contaminants in the aquatic and terrestrial environs at ORNL (Loar, ed. 1991). These tasks are (1) toxicity monitoring, (2) bioaccumulation monitoring of nonradiological contaminants in aquatic biota, (3) biological indicator studies, (4) in-stream ecological monitoring, (5) assessment of contaminants in the terrestrial environment, and

(6) radioecology of WOC and WOL. Tasks 3, 5, and 6 are fully funded by WAG 2/SI; Tasks 1 and 4 are jointly funded by WAG 2/SI and Environmental Compliance; and Task 2 is fully funded by Environmental Compliance.

6.2.1 Toxicity Testing

The goals of the BMAP toxicity monitoring task are to (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 the 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 (Loar, ed. 1991).

To date, studies under this activity have identified localized sources of toxicity within First and Fifth creeks and the section of WOC adjacent to WAG 1. Fish, invertebrate, and periphyton community studies suggest that contaminant-related impacts decrease with distance from WAG 1, which suggests that the sources within WAG 1 are more important than nonpoint sources associated with the downstream WAGs.

6.2.1.1 Ambient toxicity monitoring

From December 1991 through December 1992, ambient (in-stream) toxicity was evaluated in ten tests on water from NPDES site MB MS4 on lower MB at Melton Branch kilometer (MBK) 0.16 and in eight tests on water from NPDES site WOC MS3 on lower WOC at White Oak Creek kilometer (WCK) 2.65 (Fig. 6.1). Evaluations of toxicity were based on 7-day static-renewal tests that measured survival and growth of fathead minnow (*Pimephales promelas*) larvae and/or survival and reproduction of a small crustacean (*Ceriodaphnia dubia*) as toxicity endpoints. *Ceriodaphnia* survival and reproduction were high at both sites. Fathead minnow growth was equivalent to controls at both sites; however, minnow survival at MBK 0.16 was low on several occasions. Pretreatment of the water samples from MBK 0.16 with ultraviolet radiation improved minnow survival in five of seven tests.

Previous tests indicated that effluent from outfall 312 (downstream from WCK 5.1 near the 6000 area) was toxic to *Ceriodaphnia* even after dechlorination. This residual toxicity was eliminated by treating the water with EDTA to remove metals. Analyses of the water indicated that the effluent was enriched in copper and zinc compared to water from WOC immediately upstream from the outfall. These results and a review of the toxicological literature suggest that the toxicity of outfall 312 is due to copper.

Ambient toxicity tests have been routinely conducted on water from 15 sites (including MBK 0.16 and WCK 2.65) on five streams in the WOC watershed since March 1986 (Fig. 6.1). Of the 91 tests conducted with *Ceriodaphnia* during 1992, none yielded evidence of acute toxicity. Survival of fathead minnows was not substantially different among any of the 15 sites, and the tests did not provide evidence of acute toxicity at any site.

Previous toxicity tests demonstrated that total residual chlorine (TRC) is a major toxicant in some receiving streams at ORNL. Snails of the genus *Elimia* are extremely sensitive to TRC and will avoid stream reaches where TRC concentrations exceed 20 $\mu\text{g/L}$. A snail survey of WOC revealed that snails were present near WCK 5.1 but were absent below this point.

AMBIENT TOXICITY SAMPLING SITES

Fig. 6.1. Sampling sites for ambient toxicity tests of water from streams at ORNL.

When outfall 313, which discharges near the point where snails are no longer found, was tested for TRC, the concentrations were high enough to make conditions immediately downstream acutely toxic to fish and invertebrates. In situ, 7-day toxicity tests using *Elimia* suggest that lower First Creek and WOC at WCK 4.0 just below the confluence with Fifth Creek are toxic. These results are contrary to results from fathead minnow and *Ceriodaphnia* toxicity tests, which may reflect the loss of TRC during the sampling activities.

6.2.1.2 Effluent toxicity testing

Toxicity testing was conducted on wastewater effluents in 1992 with the same tests that were used to assess toxicity in the receiving streams. Effluent toxicity evaluations were conducted on the Coal Yard Runoff Treatment Facility (CYRTF), the Sewage Treatment Plant (STP), and the Nonradiological Wastewater Treatment Facility (NRWTF). Results indicated that effluent from the NRWTF was rarely toxic, effluent from the STP was also usually nontoxic to fathead minnow larvae but was sometimes moderately toxic to *Ceriodaphnia*, and effluent from the CYRTF was distinctly more toxic than effluents from the STP and NRWTF.

6.2.1.3 Periphyton studies

Inputs of toxic chemicals to streams can be monitored by measuring productivity and biomass of periphyton (attached algae and associated organisms). Changes in these parameters can be related to contaminant fluxes. Thus, aquatic toxicity testing and monitoring of the periphyton provide a sensitive method for evaluating the effects of discharges and the effectiveness of remedial actions at the very base of the food chain. Community studies of benthic invertebrates and fish provide a measure of the health of the aquatic biota at the next higher trophic levels (above the periphyton). Integration of the results of these community studies with the toxicity and periphyton studies provides a method for assessing the overall health of the biotic communities within WOC and MB.

Periphyton communities are monitored at 9 locations within WOC and MB. Periphyton biomass and photosynthetic rates at all 15 sites were higher in 1992 than in previous years. The pattern of improving physiological condition of the periphyton with distance from ORNL discharges was again apparent in 1992. There was some indication of an adverse influence located between WCK 3.4 and WCK 2.9 that occasionally resulted in very poor physiological condition of the periphyton at WCK 2.9. Previous data for the site at MBK 0.6 had demonstrated no adverse influence of HFIR restart activities. In 1992, periphyton at this site exhibited lower than usual physiological condition, compared with other sites, but no evidence of reduced biomass or photosynthesis.

Experiments aimed at developing improved methods for monitoring periphyton have produced two important results. Analyses of periphyton pigments can be used to quantitatively identify community-based no-observed-effects-concentrations for contaminants relevant to ORNL. Also, analysis of sterols is a less biased method of estimating periphyton biomass than the currently accepted method of measuring chlorophyll *a*.

6.2.2 Bioaccumulation Studies

The bioaccumulation monitoring is conducted in order to meet NPDES requirements, and it is not funded by ORNL ER. This task consists of measuring PCBs and metals

(particularly mercury) in fish from sites in WOC, WOL, MB, and Northwest Tributary. In addition, caged clams are placed for 4 weeks at selected sites in the WOC watershed and then analyzed for PCBs and pesticides.

Mercury concentrations in sunfish from most WOC sites were elevated over concentrations found in fish from uncontaminated reference sites. The mercury concentrations were well below the action level established by the Food and Drug Administration (FDA) although mercury concentrations in WOL bass have increased since 1988. The year-to-year increase may not indicate an increase of mercury inputs to the system.

Concentrations of PCBs in WOC sunfish appear to have stabilized in recent years at levels that are well below FDA action levels. The continued presence of PCBs in sunfish throughout WOC and the accumulation of PCBs by caged clams suggest that WOC continues to receive PCB inputs from a source upstream of WCK 3.5 (7500 Bridge on Melton Valley Drive). One of eight largemouth bass collected from WOL contained PCBs in excess of the FDA action level.

Mean chlordane concentrations found in caged clams have decreased steadily since 1988, suggesting that elevated concentrations of chlordane in WOC clams was a result of an episodic input and not a chronic release.

6.2.3 Biological Indicator Studies

This task assesses the health of redbreast sunfish in a reach of WOC upstream of WOL but downstream of all ORNL discharges. This task complements the long-term ecological monitoring of WOC by measuring various physiological parameters to evaluate fish health and by conducting age-growth and fecundity studies to determine growth rates and reproductive success of a target fish species (redbreast sunfish) in WOC. Fish are sampled once a year (in the summer) in a reach of WOC between WAG 1 and WOL and from three reference streams. In addition, embryos of the Japanese Medaka are reared in water from WOC to determine the effect of contaminants in the water on embryo development.

Based on an integrated evaluation of all parameters for the period 1989-1991, sunfish from WOC differed from sunfish from three reference sites. However, the 1990 and 1991 WOC responses compared to corresponding reference groups indicate an improvement in the health of the redbreast sunfish population over this period.

Reproductive potential of redbreast sunfish was reduced in 1991 in WOC and in two of three reference streams. In 1992, reproductive potential improved in all streams, but the improvement in WOC lagged behind that in the reference streams. The apparently similar effects in at least two reference streams suggest that the depression in reproductive potential in 1991 may have been due to natural causes rather than chemical toxicity.

Smaller length and age classes are underrepresented in the WOC redbreast sunfish population. At the same time, water from WOC downstream of WCK 5.1 was acutely toxic to Medaka embryos. While redbreast sunfish and other species inhabiting WOC may react differently to WOC water than do Japanese Medaka, the Medaka embryo data suggest that recruitment by younger age classes may be impaired.

6.2.4 Instream Ecological Monitoring

In-stream monitoring of fish and benthic invertebrate communities is conducted at 15 sites that correspond with the 15 ambient toxicity monitoring sites (Fig. 6.1).

6.2.4.1 Benthic macroinvertebrates

Benthic invertebrate communities were sampled quarterly. Because of a backlog of samples, however, only data for spring (April) are available from 1988–1991. Three primary parameters were measured: density, overall richness (number of species), and richness of three pollution intolerant groups (called EPT richness).

In First and Fifth creeks, the benthic invertebrate communities at downstream locations have lower total and EPT richness than do the benthic invertebrate communities at upstream sites on these streams. In lower Fifth Creek, there has been an improvement in the richness parameters since 1987, probably due to reductions in TRC discharges to the stream.

Density in the upstream site on Northwest Tributary has increased over the 5-year period, as have both richness parameters. A similar set of changes have occurred at the downstream site, although density has not increased. Total richness at the two sites is similar; however, EPT richness is somewhat higher at the upper site.

Benthic invertebrate communities at the two downstream sites in MB showed a marked change in total and EPT richness between 1987 and 1988, probably in response to the shutdown of the HFIR in November 1986. Since that time, values of both parameters have been similar to those of the upstream site.

In WOC, benthic invertebrate communities follow the same pattern as exhibited by toxicity tests and periphyton monitoring. Lowest values of density, total richness, and EPT richness occur at WCK 3.9 in the reach adjacent to the ORNL main plant area. Highest values of both richness parameters occur at the upstream reference site. Since 1989, there has been a marked increase in EPT richness at WCK 5.1, which may indicate recovery from an episodic input of chlordane to WOC just upstream of the site. The recovery period coincides with the steady decrease in chlordane concentrations observed in caged clams since 1988.

6.2.4.2 Fishes

Fish communities were sampled twice in 1992 at 15 sites in WOC and tributaries. Data analysis includes species richness and distribution, population size, length-frequency evaluation, and annual production.

Fourteen species of fish were collected during 1992. Patterns observed in species richness during 1992 were very similar to those in 1985–1991. The stoneroller continues to expand its range within the system. Species richness in lower Fifth Creek continues to increase, probably in response to the reduction of TRC discharges to this stream. Fathead minnow distribution has declined from a range that included seven to eight sites prior to 1989 to only two sites in 1992.

Total fish densities and biomass increased from spring 1991 to spring 1992 in WOC with the exception of WCK 2.3. The fish community in Fifth Creek increased in density and biomass from 1991 to 1992.

A fish kill occurred in WOC in late April 1992. More than 300 fish were killed as a result of a cooling tower blowdown spill upstream of WCK 3.9. Most of the dead fish were stonerollers. Dead fish continued to be collected from the stream reach below the spill until early November 1992, although the number of dead fish collected declined dramatically after the first week of the spill. A second, much smaller fish kill occurred as a result of elevated temperatures in MB near the HFIR discharge. Two fish, seven crayfish, and a salamander were killed.

6.2.5 Contaminants in Terrestrial Biota

Contamination may be transferred from the aquatic system to terrestrial food chains through consumption of contaminated aquatic biota by terrestrial predators or through direct ingestion of contaminated water and sediment by terrestrial animals and vegetation. One goal of the terrestrial component of the BMAP is to identify species that will serve as long-term monitors of aquatic-derived contamination in the terrestrial environment.

Raccoons (*Procyon lotor*) consume a wide variety of prey and vegetation, some of which is from aquatic systems. Studies throughout North America have demonstrated the potential for raccoons to serve as indicator species for a wide range of contaminants, including heavy metals, PCBs and organochlorine pesticides, and radionuclides. During 1991, limited sampling of raccoons from the lower WOC watershed suggested that these animals could be used to monitor the bioavailability of ^{137}Cs to biota in the terrestrial ecosystem (Chapter 7 in Loar, ed. 1991). Based on this evidence, a long-term monitoring program was initiated using raccoons as ecological indicators of biologically available contamination—especially mercury and ^{137}Cs —in the terrestrial ecosystem.

Beginning in 1991, raccoons from the WOC watershed and from an uncontaminated reference site were monitored for trace metals and gamma emitting radionuclides by obtaining samples of hair. In 1992, these hair samples indicated that WOC raccoons were more contaminated with ^{60}Co , ^{137}Cs , and mercury than were reference site raccoons. Other trace metals were observed at concentrations typical of reference site raccoons. FY 1993 represents the second full year of monitoring raccoons in the WOC watershed. Monitoring was expanded in FY 1993 to include analysis for PCBs and pesticides.

This monitoring activity is part of a long-term, Reservation-wide program to monitor the effects of remedial actions on the terrestrial ecosystem. Coupled with the Ecological Assessment Task, this activity provides data on spatial and temporal changes in levels of contaminants that are biologically relevant to terrestrial biota. Specifically, this task includes the monitoring of contaminant levels in hair and adipose tissue of raccoons from WAG 2 and from an uncontaminated reference site. A similar task in the K-25 Site BMAP measures contaminant levels in raccoons from lower East Fork Poplar Creek and Poplar Creek. Consideration is being given to adding a raccoon monitoring component to the next revision of the BMAP at the Y-12 Plant.

6.2.6 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. The task consists of a census of Canada geese and measurements of radionuclides in various compartments of the WOL ecosystem, including waterfowl.

The weekly census of waterfowl populations continued in 1992 at 58 locations, including sites at WOL and other radioactive waste ponds and contaminated areas near ORNL, the Oak Ridge Y-12 Plant, the K-25 Site, and several areas off the ORR. Leg bands were placed on 500 adult Canada geese during June 1992. The number of geese observed during 1992 was similar to previous years although there were some seasonal variations. The propane cannon installed late in 1991 continues to be effective in reducing the number of geese using WOL. Data from the weekly census has been used to estimate the size of the Canada goose population.

Two geese attempting to nest on the 3524 pond contained measurable ^{137}Cs concentrations in breast, liver, and bone. Of 15 geese sampled in June 1992, four contained measurable ^{137}Cs . Cesium-137 was also measured in six largemouth bass and in samples of floating vegetation from WOL.

6.3 ECOLOGICAL ASSESSMENT

This task was initiated in 1991 and has three goals: (1) support ecological risk assessments at the source, integrator, and Reservation scales; (2) monitor transfer of contaminants from the aquatic systems to the terrestrial system; and (3) predict and monitor the effects of remedial actions. This is the only task within the ORNL ER Program where (a) effects of remedial actions on biota are being modeled and monitored on a watershed scale and (b) aquatic and terrestrial components are being integrated.

During FY 1993, there were three components of this task: (1) assessment of two potential indicator species (mink and kingfishers); (2) completion of the ecological assessment of WAG 5, a source-control OU in the WOC watershed; and (3) development of a model to integrate data on contamination in soil, surface water, and groundwater with contamination measured in aquatic and terrestrial biota. The model development is discussed later in Sect. 6.5.

6.3.1 Indicator Species

The choice of an indicator species to monitor movement of contaminants in the food chain is based on assumptions about the pathways for exposure. There are three separate pathways for contaminant flux into biota: (1) groundwater and surface water transport to aquatic biota and consumption of contaminated aquatic prey by terrestrial predators, (2) direct exposure and ingestion of contaminated soil/sediment and water by terrestrial animals, and (3) uptake of contaminants from soil and groundwater by terrestrial vegetation and transfer up the food chain. The importance of these pathways is generally in the order given. Aquatic transport is the primary pathway. Ingestion of contaminated soil/sediment undoubtedly occurs, but soil-bound contamination may not be biologically available. Although tritium and ^{90}Sr are

readily accumulated in vegetation, the principal contaminants of concern in WAG 2 (^{137}Cs , mercury, and PCBs) have low bioaccumulation potential in vegetation.

Kingfishers are voracious predators of aquatic organisms, consuming >50% of their body weight daily in fish and crayfish. Kingfishers feeding on contaminated aquatic biota may, therefore, accumulate large concentrations of contaminants. Little is known about the effects of such contamination on kingfishers, although other fish-eating birds suffer reproductive failure and even death when consuming large quantities of fish contaminated with PCBs and mercury. During FY 1993, a literature review and preliminary kingfisher census were conducted (Landrum et al. 1993). A device for surveying kingfisher burrows and collecting samples has been developed, and samples will be collected to determine whether contamination from WAG 2 is adversely affecting kingfishers and whether kingfishers can be used as ecological indicators of contaminant flow from aquatic to terrestrial systems. In addition, three kingfishers killed by unknown causes have been recovered and will be analyzed for radionuclides, heavy metals, and PCBs.

Mink are also voracious predators of fish and crayfish. Mink are also highly sensitive to mercury and PCB contamination, suffering reproductive failure and death at concentrations typical of some ORR fish. In FY 1993, trapping of mink to collect samples was begun. Samples will be analyzed for heavy metals, radionuclides, and PCBs. Several mink will be fitted with radio transmitter implants to facilitate tracking.

Both of these monitoring programs are expected to become part of the Reservation-wide monitoring program. Coupled with existing programs using raccoons, waterfowl, and great blue herons, the mink and kingfisher work will provide a means of evaluating the effects of remedial actions on the terrestrial ecosystem.

6.3.2 WAG 5

During 1992 and 1993, work continued on the ecological assessment of WAG 5 as part of site remedial investigation activities. Toxicity testing was conducted on several seeps around WAG 5. Initial results showed evidence of chronic toxicity to *Ceriodaphnia* at two of the locations. Threatened and endangered species surveys and a wetlands survey were conducted. No threatened or endangered species were identified in WAG 5; the locations of wetlands were delineated. A screening-level ERA was completed. Results of these activities were documented in a preliminary report (Ashwood et al. 1992).

In March 1993, a meeting was held with representatives of EPA Region IV and the TDEC. As a result of this meeting, the ecological assessment plan was revised (Ashwood and Suter 1993). The principal changes in this revision were elimination of wild turkey sampling and addition of earthworm sampling. Results of the earthworm sampling will not be available until FY 1994.

6.3.3 Future Activities

We will evaluate results of the FY 1993 kingfisher sampling program to determine if kingfishers in WAG 2 are being adversely affected by contaminants and to assess whether kingfishers represent a viable indicator species for long-term ecological monitoring. If kingfishers from WAG 2 contain higher levels of contamination than those from

uncontaminated areas, then kingfishers will become part of the long-term monitoring program and samples will be collected during the summer of FY 1994.

The mink sampling program will be continued with trapping during the winter breeding season and analysis of samples to determine mink body burdens of mercury and PCBs. These body burdens will be compared to literature-derived values to ascertain whether mink are likely to be adversely affected by contaminants in WAG 2. This subtask will be closely coordinated with a mink feeding project being conducted by the Clinch River Remedial Investigation Program to determine if fish from various sources on and off the ORR are contaminated enough to cause mortality or reproductive impairment in mink.

Results from the ecological indicator-species monitoring and other assessment activities will be reported in the eighth annual BMAP report next year. Those results will be summarized in the next ERMA annual report.

6.4 ABATEMENT PROGRAM

Abatement efforts at ORNL within BMAP are not part of the ORNL ER-supported work. These efforts are directed toward providing both short- and long-term management and technical solutions to water quality problems, including toxicity of some receiving streams. Abatement projects include chlorine reduction, substitution for ethylene glycol in cooling systems, tank diking, elimination of Category III outfalls, PCB and mercury monitoring, wastewater piping repair, construction of the NRWTF enhanced environmental surveillance of construction projects, and implementation of Best Management Practices plans by staff of the ORNL Office of Environmental Compliance and Documentation.

6.5 GIS MODELING

Work has begun on a model of WAG 2 based on GIS software. GIS is a useful analytical tool for compiling spatial data and presenting results and thematic maps. GIS is being used to support a model that integrates data from other WAG2 tasks (i.e., seeps and surface water, soil, radiological walkover) with biota monitoring data to support ERAs and to design the long-term monitoring program required to evaluate the effects of remedial actions. In FY 1993, this work has primarily involved incorporation of data from various WAG 2 tasks into a GIS data base and evaluation of the potential for one type of landscape model to integrate this contamination data with biological community data.

6.6 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 monitoring conducted for ORNL ER, BMAP performs compliance monitoring according to the requirements of the ORNL NPDES permit.

For the first time, ambient toxicity tests indicate no evidence of acute or chronic toxicity in any of the 15 test sites. When tests showed evidence of toxicity in outfall 312, even after

dechlorination, analyses of the water were conducted, the toxicological literature was reviewed, and the toxicity was attributed to the presence of copper. Based on 7-day laboratory tests with *Ceriodaphnia* and fathead minnow larvae, no evidence of acute toxicity was found in the receiving streams near ORNL.

Periphyton monitoring, which provides a short-term indication of toxic releases, showed results similar to those in previous years. The general pattern of improving physiological condition of the algal periphyton with distance from ORNL discharges was again apparent. Analysis of periphyton pigments can be used to quantitatively identify community-based no-observed-effects-concentrations for contaminants relevant to ORNL. Analysis of sterols is a less biased method of estimating periphyton biomass than the currently accepted method of measuring chlorophyll *a*.

Bioaccumulation monitoring revealed that one of eight largemouth bass collected from WOL contained PCBs in excess of the FDA limit (2 ppm). However, PCB concentrations in sunfish from WOC watershed sites appear to have stabilized at levels well below FDA action levels. On the basis of bioaccumulation measured in caged Asiatic clams, the chlordane contamination near WCK 5.1 appears to be steadily decreasing with time. Mercury concentrations in fish collected from most WOC sites were elevated over those fish from reference sites but were below the FDA action level throughout the watershed.

Integrated analysis of physiological parameters measured in redbreast sunfish from WOC suggests that fish health may have improved from 1989 to 1992, but this improvement was less than the improvement observed in fish from three reference streams. Population-level studies showed that growth of redbreast sunfish in WOC was generally higher than in reference streams in 1992. However, samples from WOC downstream of WCK 5.1 were highly toxic to Medaka embryos, suggesting that recruitment of younger age classes may be impaired.

Benthic macroinvertebrate communities in WOC reflect 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 discharges. The lowest values of density, total richness, and EPT richness occur at WCK 3.9 in the reach adjacent to the ORNL main plant areas.

Fish species richness showed little change during 1992. Increases in abundance at some sites are probably associated with remedial actions, such as the reduction of chlorinated discharges since late 1989 and the replacement of several direct wastewater discharges to WOC with the NRWTF. A fish kill occurred in WOC as a result of a cooling tower blowdown spill in April 1992. Another much smaller kill occurred in May 1992 in MB near the HFIR discharge.

Raccoons are being used as biotoxicity integrators because they are high on the food chain and 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. Hair samples collected in 1992 indicated that WOC raccoons were more contaminated with ⁶⁰Co, ¹³⁷Cs, and mercury than were raccoons from reference sites. In FY 1993, monitoring was expanded to include analysis for PCBs and pesticides. The feasibility of using both kingfishers

and mink as additional ecological indicator species is being investigated by literature reviews, habitat studies, and preliminary sampling and analysis.

Kingfishers and mink are being monitored to determine if these voracious predators of aquatic biota are adversely affected by contamination in the aquatic system and to assess their effectiveness as ecological indicators of the transfer of contamination from the aquatic system to the terrestrial system. This monitoring effort will eventually become part of the Reservation-wide monitoring program.

Most work on the WAG 5 ecological assessment has been completed. There is evidence of chronic toxicity in two seeps in WAG 5. The ecological assessment plan was revised as a result of input from Tennessee and EPA regulators.

Biological monitoring has been performed extensively and continuously since 1986 and provides detailed information about ecosystem health within the WOC watershed. Results generally show a highly impacted, relatively stable ecosystem that is, in some cases, improving, mostly because of reductions in point-source discharges. Monitoring within BMAP, ecological assessment at the contaminant-source WAGs, and assessment and long-term monitoring in WAG 2 will continue to provide the biological information needed by ER Program decision makers for assessing remedial action alternatives.

7. SUMMARY

The WAG 2/SI Program has a comprehensive, integrated approach for gathering the relevant environmental data in support of the ER Program's ORNL Site Office. During FY 1993, the work has been divided into four major tasks (Surface Water, Groundwater, Soil and Sediment, and Biota) designed to collect the 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 summarizes the data collected for the past year and describes the importance of those data relative to the needs and goals of the ORNL ER Program.

During FY 1993, the ORNL ER strategy led to the decision for deferred action in WAG 6 in place of an expensive, interim remedial action. This decision reflects the approach of identifying and ranking the sources of contamination on a watershed-wide basis. As reported in Sect. 2, WAG 6 provides <2% of the risk as measured at the WOD. In contrast, WAGs 1, 2, 4, 5, and 7 each contribute a significantly larger fraction of the risk at WOD. A monitoring program at WAG 6 will be implemented to ensure that future releases do not increase to levels that indicate a need for immediate action or an increase in the prioritized ranking of WAG 6 such that interim or final actions are implemented at WAG 6 prior to other ORNL WAGs.

7.1 SUMMARY OF FINDINGS

7.1.1 Risk Assessment

Screening risk assessments have been completed at WAGs 1, 2, 5, 6, 13, and in the WOCE. Screening-level risk assessments have been used to determine the contaminants of concern on the WAG. Exposure to these contaminants is not a problem because of administrative controls and because barriers at these sites restrict public access. Mobile contaminants are transported primarily by water; therefore, off-site risk is determined mostly from water quality measurements made at WOD and outflow point of WOCE. Contaminants of concern for potential exposures off-site are ^{90}Sr and ^{137}Cs , followed by ^3H and ^{60}Co ; nonradiological mobile contaminants of greatest concern are PCBs, arsenic, and thallium.

With respect to risk to human health, water draining ORNL at WOD does exceed the 10^{-4} criterion for excess lifetime risk of cancer; however, there is no public access to this water. Because of dilution in the Clinch River, the risk goes below the 10^{-4} level at Clinch River Mile 9.5, the closest public access point. This analysis used conservative assumptions by including multiple exposure pathways (Shevenell et al. 1992). Risk levels in the range 10^{-6} to 10^{-4} are classified as "needs further investigation," and the investigations are being conducted by the WAG 2 RI Program for the ORNL ER Program in concert with the Clinch River RI Program.

Groundwater and its related quality are not regulated like other environmental media. Consequently, there are no mandated groundwater quality criteria, but drinking water limits

and other similar criteria were used to screen contaminants. It was found that ^{90}Sr and ^3H are the most common contaminants of concern identified at the source WAGs. It is emphasized that it is unrealistic to assume that members of the public are going to drink groundwater from ORNL WAGs.

Risk assessment strategy for source WAGs is designed (1) to assist the ER Program by focusing actions on sites that are a high-risk priority for either on-site or off-site exposures and (2) to provide adequate risk baselines for measuring the potential effectiveness of proposed remedial alternatives. To ensure comparability in risk assessments for the ORNL OUs, the strategy utilizes two sets of exposure assumptions. The MLE assessment provides information concerning the relative on-site risk, whereas the IP assessment provides information concerning the relative contribution of the source control WAG under investigation to off-site contaminant transport and migration. These methodologies will be applied to source control WAGs uniformly to develop comparative rankings for ER decision makers.

With respect to ecological assessment, wetlands and floodplains and T&E species and their habitat are receptors of special concern. At the ORNL site, there are floodplains associated with WOC and its tributaries and a number of wetlands around the site. There are no federally listed T&E species present; however, there may be species that are listed by the state of Tennessee as T&E or "in need of management."

Ecological risk assessment activity at ORNL this year has centered around WAG 5. An ecological assessment plan was developed. In discussions with regulators, it was determined that in WAG-specific assessments, species selected for investigation must have home ranges appropriate to the size of the WAG; therefore, risks to wild turkeys will not be addressed as first planned. Furthermore, it was determined that full baseline ERAs will be prepared for each WAG.

A screening risk assessment at WAG 2 was able to establish that no severe effects are occurring in the aquatic habitats of WAG 2, although there is some evidence of effects on fish reproduction and on benthic invertebrate community composition.

Regulators are requiring that ecological risk be evaluated for the entire ORR, that is, that the Reservation be evaluated as a single ecological unit. A plan is being prepared for this assessment.

7.1.2 Surface Water

The Surface Water Task Group issued the annual comprehensive hydrologic data summary for CY 1992 (Borders et al. 1993). This report is the fourth in a series produced by the ER Program which supports the long-term collection of hydrologic data for determination of contaminant fluxes and risk assessments and for engineering design of remedial actions.

To improve the hydrologic data, the USGS is assisting ER by developing field-rated stage-discharge relationships for the main weirs; however, development of a stage-discharge relationship for the WOCE Sediment Retention Structure was postponed until FY 1994 because of a lack of funds.

Accurate stage-discharge relationships are needed to reduce the uncertainty in water and contaminant mass balances for the main reaches on WOC and MB, leading to better assessment of contaminant dynamics and more accurate risk assessments.

The Seep and Tributary Task Group provided detailed snapshot pictures of the spatial pattern of contamination in WAG 2 area during dry-season and wet-season baseflow conditions. The results show the main sources of ^3H , ^{90}Sr , ^{137}Cs , and ^{60}Co flowing into the WOC surface water system. The information will be used to guide localized actions to reduce contaminant releases.

The Tributary Assessment Task was initiated to describe the dynamic behavior of contaminant transport between the WAGs and the main streams. The conceptual model for tributary contaminant transport has been described in detail, and data from drainages in WAG 6 tend to confirm the model. However, contaminant flux at the large flumes on WOC tends to behave differently, and the difference should be resolved. If there are contaminant sources activated only during high flows, as suggested by the data from the large flumes, then remedial measures should be developed to address the sources. Some evidence exists that the increased contaminant flux may come from the water table interval, which, if true, is important because it is generally thought that the stormflow zone and not the water table interval is the main flow path for contaminant transport. The discrepancy between data measured at different scales does not negate the ORNL site hydrologic conceptual model.

At the watershed scale, mass balance of the main radionuclides for major stream reaches in the WOC watershed for 1992 indicated that lower WOC/WOL was a source for ^{137}Cs , ^{60}Co , and ^{90}Sr and that ^3H probably passed through the reach without much increase. Cesium-137 showed a seasonal trend, with WOL being a source during the winter months and a sink during the summer months.

Performance monitoring will become critically important as remedial technologies are implemented and evaluated. Three approaches to performance monitoring were presented. (1) Changes in contaminant levels in seep water can provide small-scale, direct indications of water quality improvement. (2) The relationship between contaminant concentration and stream flow (C-Q) in tributary runoff may prove beneficial wherever stable C-Q relationships are established. The method has the advantage that it is climate independent, and it is appropriate where intensive storm sampling every few years to determine water quality changes is appropriate. (3) Performance monitoring based on statistical models and measurements at the main surface water monitoring stations is advantageous in that it addresses the largest scales within the watershed and it builds on readily available historical data. These methods address different scales within the watershed, and when applied judiciously, they will provide ER with scientifically defensible evidence of the effectiveness of remediations.

7.1.3 Groundwater

Ongoing activities in the Groundwater Task include the WAG Perimeter Well Monitoring Task and the new Groundwater Level Monitoring Task. Data from the perimeter monitoring activity showed little change from that summarized the previous year; therefore, there is no new analysis presented in this report. The data were used for geochemical assessment, and statistical methods showed three geochemical water types. These and other statistical observations will be used to subdivide groundwater data for establishing background

conditions, identifying lateral flow paths, and identifying vertical groundwater zones. The data contribute to our fundamental understanding of the flow system.

Because of the complex hydrogeology of the ORR, contaminant flux in groundwater is probably the most difficult environmental parameter to ascertain. This complexity leads to a multifaceted groundwater investigation program needed to meet ER needs.

Two directed investigations were initiated in late FY 1993. The first is a special study using shallow drive points to observe the flow paths between buried wastes and nearby contaminated seeps on tributaries near WAGs 5, 6, and 7. A second directed investigation will examine an anomalous high chloride concentration observed in wells to the south of WAG 7. High chloride concentrations are especially important because deep groundwater is known to be briny with abundant chloride. There are no known naturally occurring hydrological connections between the deep groundwater system and the surface, but these high chloride concentrations may be evidence of such a connection. If this is true, then many assumptions about the hydrologic isolation of the deep aquiclude must be revised, and the implications to ER (especially to WAG 10 Hydrofracture) are profound.

The HHMS Task examines the vertical movement between the intermediate groundwater zone and the deep, briny aquiclude. Work during the past year centered on defining flow paths in the water gap between Bethel and Melton Valleys. The conceptual hydrologic model suggests that there should be little or no hydrogeologic communication between these valleys. If this is not the case, then subsurface contamination may move from one valley to the other.

The Groundwater Modeling Task has set up a 3-D solution grid for MB valley using HHMS data and other data sources to define the system boundaries for future modeling of water and contaminant transport. To date, the initial model simulations indicate that there may be underflow beneath the Copper Ridge, the topographic divide to the south of WOL. The state-of-the-art model is running on a massively parallel mainframe. A reliable, calibrated model is essential to the WAG 2/RI effort for the prediction of future releases under no-action and other exposure scenarios.

7.1.4 Soil and Sediment

Contaminated soils and sediments are a key concern for on-site risk. Gamma-emitting radionuclides sorbed to soil and sediment particles provide significant exposure hazards within WAG 2. Furthermore, the mobilization and transport of contaminated sediments in the WOC system is a potentially important pathway for the off-site discharge of contaminants. This pathway is being intensively investigated through field studies and modeling.

An extensive gamma survey walkover on WOC floodplain in WAG 2 has been used in health and safety planning and in the development of soil sampling programs. Results show that relatively high radiation levels occur closer to WOC, and that levels decrease rapidly with distance away from WOC, with the exception of the Intermediate Pond Site. Data will be used in computer modeling investigations to determine risks related to contaminant mobility during severe storms (25-, 50-, and 100-year return periods) that may mobilize these sediments and carry them off-site.

On March 23, 1993, a relatively small flood event (enough for over-bank flow) was intensively sampled, and the results comprise the first comprehensive storm sediment data

base. The flood had an estimated return period of about 1 year, and total discharge of ^{137}Cs was estimated to be 0.044 Ci over 3.3 days. This discharge is about 3 to 10% of the annual ^{137}Cs discharges measured at WOD over the past 10 years. Results suggest that lake-bottom sediments and other material in the lower WOC reach can remain immobile during a 1-year flood event while suspended sediments are transported from WOC to WOD (and then to the Clinch River).

The intensive storm sampling provides important insights into the hydrologic behavior of the WOC system, however, the real benefit of these data will come with the calibration of the HSPF model for contaminated sediment movement. The calibrated model will be used to predict the watershed response to conditions that cannot be directly observed, such as extreme precipitation events or planned remedial actions. Data collection, modeling, and integration of the results into ER planning will ensure that no remedial design will inadvertently cause scour and erosion of contaminated sediments in WAG 2 that could, in turn, lead to unacceptable risk to the off-site public.

7.1.5 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 BMAP effort and augments these data to develop models of contaminant flow through the biota, to identify organisms at risk and potentially unacceptable human exposures, and to document changes and impacts on biotic communities.

Briefly, during CY 1992, periphyton monitoring showed improving physiological condition of the algae with distance from ORNL discharges. PCBs and mercury in fish were below FDA action levels in all except for PCBs in one bass specimen. Bioaccumulation of chlordane continues to decline. Toxicants (primarily chlorine) associated with point-source discharge are probably the most significant cause of adverse effects to benthic macroinvertebrate communities in WOC, whereas at downstream locations factors such as siltation and nutrient enrichment may be more important than point-source discharge. Raccoons are currently being used as indicator organisms, and baseline data are being collected. Kingfishers and mink are being evaluated as additional indicator species.

Results generally show a highly impacted ecosystem that is stable and, in some cases, improving mostly because of discharge reductions. Monitoring within BMAP, ecological assessment, and long-term monitoring as part of the WAG 2 RI will continue to provide the biological information needed by ER Program decision makers.

7.2 ADDITIONAL DATA NEEDS AND UPCOMING EFFORTS

Risk assessment and ultimately the direction of the entire environmental restoration endeavor rely on the ultimate land use of the land at the ORNL site (or any other DOE facility land). Land use decisions determine risk exposure scenarios, remediation goals, and remedy selection. A process has been initiated through the ER Technical Programs Group as a pilot program for a nationwide DOE study of land use development. The approach will be to get major stakeholders (public, DOE, and DOE contractors) into an interactive process

that considers all major factors: technical limitations, cost, public safety concerns, and desire for economic growth.

ERA staff will initiate work on a Reservation-wide ecological assessment. The effort will be linked to the development of a GIS-based model, as described later in Sect. 7.2.1.

Within the Surface Water Task, additional data needs relate to (1) increased accuracy of hydrologic measurements and (2) better assessment of groundwater-surface water interactions. Efforts for improved accuracy have begun with the assistance of the USGS in rating the weirs. There is a need to explore and, where possible, quantify groundwater-surface water interactions. Data collection in the Tributary Assessment Task will help.

There is a need to couple the extensive surface water sampling with shallow groundwater elevation measurements and water quality sampling at some point in the future. No plans for this kind of coordinated monitoring have been developed yet. Instead, in the coming year, data analysis in the Watershed Data Integration activity described later will address current uncertainties in the hydrologic conceptual models. The emphasis will be on the analysis of existing data so that subsequent field investigation can be as focused and effective as possible.

There are two complementary sampling programs to investigate seeps at the ORNL site. The Seeps and Tributary sampling provides the most comprehensive spatial look at contamination sources to surface water in the WOC drainage below WAG 1, and it will continue with two more sampling campaigns in FY 1994. In contrast, for the Seep Survey Task the goal is to locate all seeps in the WOC basin and to get limited water quality data at each site. The survey covers a much wider area than the Seeps and Tributary Task does. The resulting data should yield fundamental information on the direction and magnitude of groundwater flow paths. In turn, this information will help guide localized remedial actions.

In the Groundwater Task, many of the responsibilities will be transferred to the Groundwater WAG 21 manager. Intensive shallow groundwater investigations (using the shallow drive points) will be continued in order to identify and quantify the transport of contamination between buried waste and seeps in nearby tributaries. This information is vital to understanding the relative magnitude of primary (waste trenches) vs secondary (contaminated soil/rock) sources. Identifying the flow paths that conduct contamination to the surface water system will lead to near-term corrective actions designed to rapidly reduce off-site fluxes and potential exposures to contaminants.

In the Soil and Sediment Task, investigations of contaminant inventories and erosion rate will continue. More intensive sediment data are needed during extreme storms, and the sampling team is in place to collect the data. Nature must be cooperative. During the coming year the HSPF model will be calibrated and used to evaluate contaminant transport in several hydrologic scenarios. These simulations will provide ER management with insight into the risks related to extreme floods.

In the Biota Task, indicator species for assessment of terrestrial contamination effects must be identified and baseline data collected. These efforts are planned for FY 1994 and will be conducted along with continued monitoring and evaluation efforts conducted by the ORNL BMAP. A site-wide conceptual biological model will be developed.

7.2.1 Technical Integration

As identified by the peer review committee for the WAG 2/SI Program in April 1993, a WAG 2 multimedia conceptual model is needed to integrate hydrologic, geologic, and biotic data. In response, two activities have recently begun. While seemingly redundant, these activities have different goals. The first one is aimed at improved ERAs, whereas the second is aimed at better understanding of the (largely) abiotic transport mechanisms via surface and subsurface hydrology. Both will use a compatible GIS system; therefore, data will be transferable, and task staff are in regular communication both directly and through WAG 2/SI Program management.

7.2.1.1 GIS-based biota conceptual model

The White Oak Creek Watershed Ecological Risk Assessment Task Force has identified a goal of generating an integrated data base incorporating BMAP data, contaminant seep/spring data, gamma radiation walkover data, and habitat parameters into a multimedia model. The purpose is improved ERAs. This approach is appropriate for the Reservation-wide ecological assessment required by regulators, and it will provide a useful tool for prioritizing characterization activities and for communication with regulators and the public.

7.2.1.2 Watershed Data Integration

The integration of data for the WOC watershed has been initiated this year and will continue into the next fiscal year. The objectives of this data integration are to provide an empirical basis for confirming or modifying our conceptual models for contaminant transport in the system, to identify sources of contaminants with the highest off-site impacts, to support the development of risk-based priorities for remedial activities, and to identify discontinuities in the coverage of our remedial investigation data that diminish our ability to make empirically based decisions. This activity will address the differences in contaminant fluxes observed at the tributary and watershed scales. This effort is being organized spatially, using a GIS, and will include data from surface water, seep, sediment, and groundwater monitoring, and radiation walkover surveys. Some biological monitoring information will be incorporated, too. Topography will be used to subdivide the watershed into subbasins, and stratigraphy will be used to associate groundwater monitoring information with the local terrain features. This approach builds on extensive statistical analyses performed for groundwater assessment and surface water chemistry tasks in the WAG 2/SI. It is anticipated that the results will help to guide subsequent field investigations so that issues of groundwater-surface water interactions can be addressed efficiently.

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Appendix A

**TABLES OF CONTAMINANTS LISTED BY WAG
AND BY SAMPLING SITE**

Table A.1. Summary of nonconservative screening risk assessment results for on-WAG and/or boundary receptors

Location	Contaminant Assignment by Media			
	High priority ^a	Media	Requires further investigation ^b	Media
WAG 1	137Cs (c)	Soil (EE) ^c	²⁴¹ Am (c)	Soil (I) ^d
			²²⁸ Ra (c)	Surface Water
			⁹⁰ Sr (c)	Surface Water
			Arsenic (c)	Soil (I)
			Pyridine	Surface Water
WAG 2				
(Middle WOC) ^e	⁶⁰ Co (c)	Soil (EE)	¹³⁷ Cs (c)	Fish Surface Water
			⁹⁰ Sr (c)	Surface Water
	¹³⁷ Cs (c)	Soil (EE)	⁹⁰ Sr (c)	Surface Water
			³ H (c)	Surface Water
	PCB-1254 (c)	Fish	³ H (c)	Surface Water
			¹⁵² Eu (c)	Soil (EE)
	Thallium	Surface Water	¹³⁴ Cs (c)	Soil (EE)
			¹⁵⁴ Eu (c)	Soil (EE)
			Dichlorobrom o-methane (c)	Surface Water
			PCB-1254 (c)	Surface Water
			PCB-1260 (c)	Fish
			PCB Total (c)	Surface Water
		Mercury	Fish	
(Upper & Lower MB) ^e	⁶⁰ Co (c)	Soil (EE)	¹³⁷ Cs (c)	Fish Soil (EE)
			⁹⁰ Sr (c)	Surface Water
	Arsenic (c)	Surface Water		Surface Water

Table A.1 (continued)

Location	Contaminant Assignment by Media			
	High priority ^a	Media	Requires further investigation ^b	Media
(Upper & Lower MB, cont.)	Thallium	Surface Water	³ H (c)	Surface Water
			¹⁵² Eu (c)	Soil (EE) Surface Water
			¹³⁴ Cs (c)	Soil (EE)
			¹⁵⁴ Eu (c)	Soil (EE) Surface Water
			PCB-1254 (c)	Fish
			PCB-1260 (c)	Fish
			PCB Total (c)	Surface Water
			Arsenic	Surface Water
(Lower WOC & WOL) ^c	⁶⁰ Co (c)	Soil (EE)	¹³⁷ Cs (c)	Fish Surface Water
	¹³⁷ Cs (c)	Soil (EE)	⁹⁰ Sr (c)	Surface Water
	PCB-1254 (c)	Fish	³ H (c)	Surface Water
	Arsenic (c)	Surface Water	¹⁵² Eu (c)	Soil (EE)
	Thallium	Surface Water	¹³⁴ Cs (c)	Soil (EE)
			¹⁵⁴ Eu (c)	Soil (EE)
			²³⁴ U (c)	Surface Water
			PCB-1260 (c)	Fish
			PCB Total (c)	Surface Water

Table A.1 (continued)

Location	Contaminant Assignment by Media			
	High priority ^a	Media	Requires further investigation ^b	Media
(WOCE) ^c	¹³⁷ Cs (c)	Soil (EE)	¹³⁷ Cs (c)	Fish Soil (I) Surface Water
	⁶⁰ Co (c)	Soil (EE)	³ H (c)	Surface Water
	PCB-1254 (c)	Fish	⁹⁰ Sr (c)	Surface Water Soil (I)
	Arsenic (c)	Surface Water	¹⁵² Eu (c)	Soil (EE)
			Arsenic	Surface Water
WAG 5 ^d	N/A	N/A	¹³⁷ Cs (c)	Soil (EE) VMM ^e
			⁹⁰ Sr (c)	Surface Water VMM
			³ H (c)	Surface Water VMM
WAG 6 ^d	¹⁵² Eu (c)	Soil (EE) Soil (I) VMM	N/A	N/A
	¹⁵⁴ Eu (c)	Soil (EE) Soil (I) VMM		
	⁶⁰ Co (c)	Soil (EE) Soil (I) VMM		
	¹³⁷ Cs + D (c)	Soil (EE) Soil (I)		
	¹⁵⁵ Eu (c)	Soil (EE) Soil (I)		
	²³² Th (c)	Soil (EE) Soil (I) VMM		

Table A.1 (continued)

Location	Contaminant Assignment by Media			
	High priority ^a	Media	Requires further investigation ^b	Media
WAG 6 ^c (cont.)	⁹⁰ Sr + D (c)	Soil (I) Surface Water VMM		
	²³³ U (c)	Soil (I)		
	²³⁸ U (c)	Soil (I)		
	^{234m} Pa (c)	Soil (EE)		
	³ H (c)	Surface Water		
	²³⁴ Th (c)	Soil (EE)		
	²³⁴ Pa (c)	Soil (EE)		
	²⁴¹ Am (c)	Soil (EE) Soil (I)		
	²⁴⁴ Cm (c)	Soil (I)		
	Vinyl Chloride (c)	Ground Water		
WAG 13	¹³⁷ Cs (c)	Soil (EE)		

Information is summarized from Blaylock (1992 a,b) and Goldberg (1992; 1993a, b, and c).

^aNonconservative carcinogen screening indices $> 10^{-4}$ and noncarcinogen screening indices > 1 . (c) denotes a carcinogen.

^bNonconservative carcinogen screening indices from 10^{-6} to 10^{-4} and noncarcinogen screening indices from 0.1 to 1. (c) denotes a carcinogen.

^c(EE) refers to external exposure to soil.

^d(I) refers to ingestion and/or inhalation of soil.

^eWOC, MB, WOL, and WOCE refer to White Oak Creek, Melton Branch, White Oak Lake, and White Oak Creek Embayment respectively.

^fA nonconservative screening was not performed. Contaminants with conservative carcinogen screening indices $> 10^{-4}$ and noncarcinogen screening indices > 1 are classified as requiring further investigation before taking action. Contaminants with conservative carcinogen screening indices from 10^{-6} to 10^{-4} and noncarcinogen screening indices from 0.1 to 1 are classified as requiring further investigation before either taking action or designating low priority. These contaminants cannot be classified as high priority.

^gVMM refers to the ingestion of vegetation and/or milk and/or meat.

^hThe category Requires Further Investigation is meant, in this case, for the screening assessments. Since a baseline has already been conducted, this category has been designated Not Applicable (N/A).

Table A.2 Contaminants exceeding drinking water criteria a minimum of once in 1992 at major surface water monitoring stations and WAG perimeter wells

Location ^a (station or well #)	Contaminant ^b	Reference Criteria Exceeded		
		Value	Units ^c	Source ^d
Major Surface water monitoring stations				
7500 Road Bridge	¹³⁷ Cs	3,000	pCi/L	DCG
	⁸⁹⁻⁹⁰ Sr	8	pCi/L	SDWA
Melton Branch (X-13)	⁸⁹⁻⁹⁰ Sr	8	pCi/L	SDWA
	³ H	20,000	pCi/L	SDWA
White Oak Creek (X-14)	¹³⁷ Cs	3,000	pCi/L	DCG
	⁸⁹⁻⁹⁰ Sr	8	pCi/L	SDWA
	³ H	20,000	pCi/L	SDWA
White Oak Dam (X-15)	¹³⁷ Cs	3,000	pCi/L	DCG
	Gross alpha	15	pCi/L	SDWA
	Gross beta	50	pCi/L	SDWA
	⁸⁹⁻⁹⁰ Sr	8	pCi/L	SDWA
	³ H	20,000	pCi/L	SDWA
WAG Perimeter Wells				
WAG 1				
(812)	Gross alpha (f)	15	pCi/L	SDWA
(812)	Gross alpha (u)	15	pCi/L	SDWA
(806, 812, 830)	Gross beta (f)	50	pCi/L	SDWA
(806, 812, 830)	Gross beta (u)	50	pCi/L	SDWA
(806, 809, 812, 813, 829, 830, 946)	⁸⁹⁻⁹⁰ Sr (f)	8	pCi/L	SDWA
(806, 812, 829, 830, 946)	⁸⁹⁻⁹⁰ Sr (u)	8	pCi/L	SDWA
(830)	³ H (f)	20,000	pCi/L	SDWA
(830)	³ H (u)	20,000	pCi/L	SDWA
(813, 827)	Benzene (u)	5	µg/L	TDEC

Table A.2 (continued)

Location ^a (station or well #)	Contaminant ^b	Reference Criteria Exceeded		
		Value	Units ^c	Source ^d
WAG 2				
(1244)	⁶⁰ Co (f)	5,000	pCi/L	DCG
(1244)	⁶⁰ Co (u)	5,000	pCi/L	DCG
(1244)	Gross alpha (f)	15	pCi/L	SDWA
(1244)	Gross alpha (u)	15	pCi/L	SDWA
(1191, 1244)	Gross beta (f)	50	pCi/L	SDWA
(1191, 1244)	Gross beta (u)	50	pCi/L	SDWA
(1191)	⁸⁹⁻⁹⁰ Sr (f)	8	pCi/L	SDWA
(1151, 1191)	⁸⁹⁻⁹⁰ Sr (u)	8	pCi/L	SDWA
(1152, 1156, 1190, 1191, 1244)	³ H (f)	20,000	pCi/L	SDWA
(1152, 1156, 1190, 1191, 1244)	³ H (u)	20,000	pCi/L	SDWA
(1195)	Arsenic (u)	50	μg/L	TDEC
(1151)	Cadmium (f)	10	μg/L	TDEC
(1190)	1,1-Dichloroethylene (u)	7	μg/L	TDEC
(1190)	Benzene (u)	5	μg/L	TDEC
(1190)	Trichloroethylene (u)	5	μg/L	TDEC
WAG 3				
(985, 995)	Gross alpha (f)	15	pCi/L	SDWA
(985, 995)	Gross alpha (u)	15	pCi/L	SDWA
(992, 993, 994, 997)	Gross beta (f)	50	pCi/L	SDWA
(992, 993, 994, 997)	⁸⁹⁻⁹⁰ Sr (f)	8	pCi/L	SDWA
(992, 993, 994, 997, 1248)	⁸⁹⁻⁹⁰ Sr (u)	8	pCi/L	SDWA
(994)	³ H (f)	20,000	pCi/L	SDWA
(994)	³ H (u)	20,000	pCi/L	SDWA
(1248)	Fluoride (u)	4	mg/L	SDWA
(985)	Trichloroethylene (u)			
WAG 4				
(955, 956, 959)	Gross alpha (f)	15	pCi/L	SDWA

Table A.2 (continued)

Location ^a (station or well #)	Contaminant ^b	Reference Criteria Exceeded		
		Value	Units ^c	Source ^d
WAG 4 (cont.)				
(954, 955, 956, 959)	Gross alpha (u)	15	pCi/L	SDWA
(948, 955, 956)	Gross beta (f)	50	pCi/L	SDWA
(956)	Gross beta (u)	50	pCi/L	SDWA
(955, 956)	⁸⁹⁻⁹⁰ Sr (f)	8	pCi/L	SDWA
(955, 956)	⁸⁹⁻⁹⁰ Sr (u)	8	pCi/L	SDWA
(954, 955, 956, 957, 960)	³ H (f)	20,000	pCi/L	SDWA
(954, 955, 956, 957, 960)	³ H (u)	20,000	pCi/L	SDWA
(954)	Fluoride (u)	4	mg/L	SDWA
(959)	Nitrate (u)	10	mg/L	SDWA
(948, 954, 958)	1,1-Dichloroethylene (u)	7	µg/L	TDEC
(954 ^y , 958 ^y)	1,2-Dichloroethylene (u)	5	µg/L	TDEC
(954, 958)	Trichloroethylene (u)	5	µg/L	TDEC
(954 ^y , 958 ^y)	Vinyl Chloride (u)	2	µg/L	TDEC
WAG 5				
(982)	Gross alpha (f)	15	pCi/L	SDWA
(982)	Gross alpha (u)	15	pCi/L	SDWA
(969, 971, 973, 975)	Gross beta (f)	50	pCi/L	SDWA
(969, 971, 973, 975)	Gross beta (u)	50	pCi/L	SDWA
(967, 969, 971, 973, 974, 975)	⁸⁹⁻⁹⁰ Sr (f)	8	pCi/L	SDWA
(969, 971, 973, 974, 975)	⁸⁹⁻⁹⁰ Sr (u)	8	pCi/L	SDWA
(968, 968, 970, 971, 973, 974, 975, 976, 977, 978, 979, 981)	³ H (u)	20,000	pCi/L	SDWA
(964)	Arsenic (f)	50	µg/L	TDEC
(978)	Benzene (u)	5	µg/L	TDEC
(969, 973, 978 ^y)	1,2-Dichloroethylene (u)	5	µg/L	TDEC
(969, 975, 978)	Trichloroethylene (u)	5	µg/L	TDEC

Table A.2 (continued)

Location ^a (station or well #)	Contaminant ^b	Reference Criteria Exceeded		
		Value	Units ^c	Source ^d
(973, 975, 978 ^y , 981 ⁱ)	Vinyl Chloride (u)	2	µg/L	TDEC
WAG 6				
(1243, 1244)	⁶⁰ Co (f)	5,000	pCi/L	DCG
(841, 842, 843, 844, 847, 1242, 1243)	³ H (f)	20,000	pCi/L	SDWA
(842)	Carbon Tetrachloride (u)	5	µg/L	TDEC
(842)	1,2-Dichloroethylene (u)	5	µg/L	TDEC
(842)	Trichloroethylene (u)	5	µg/L	TDEC
(842)	Vinyl Chloride (u)	2	µg/L	TDEC
WAG 7				
(1078)	⁶⁰ Co (f)	5,000	pCi/L	DCG
(1078)	⁶⁰ Co (u)	5,000	pCi/L	DCG
(1079)	Gross alpha (f)	15	pCi/L	SDWA
(1075, 1079)	Gross alpha (u)	15	pCi/L	SDWA
(1072, 1075, 1076, 1078, 1079, 1083, 1084)	Gross beta (f)	50	pCi/L	SDWA
(1075, 1076, 1078, 1079, 1083, 1084)	Gross beta (u)	50	pCi/L	SDWA
(1079)	⁸⁹⁻⁹⁰ Sr (f)	8	pCi/L	SDWA
(1076, 1078, 1079, 1084)	³ H (f)	20,000	pCi/L	SDWA
(1076, 1078, 1079, 1084)	³ H (u)	20,000	pCi/L	SDWA
(1078)	⁹⁹ Tc (f)	4,000	pCi/L	DCG
(1078)	Selenium (f)	10	µg/L	TDEC
(1075)	Fluoride (u)	4	mg/L	SDWA
(1078, 1079)	Nitrate (u)	10	mg/L	SDWA
WAGs 8 and 9				
(1090)	Gross alpha (f)	15	pCi/L	SDWA
(1087, 1090, 1096, 1097)	Gross beta (f)	50	pCi/L	SDWA
(1087, 1090, 1096, 1097)	Gross beta (u)	50	pCi/L	SDWA

Table A.2 (continued)

Location ^a (station or well #)	Contaminant ^b	Reference Criteria Exceeded		
		Value	Units ^c	Source ^d
WAGs 8 and 9 (cont.)				
(1088, 1096, 1097)	⁸⁹⁻⁹⁰ Sr (f)	8	pCi/L	SDWA
(1088, 1096, 1097)	⁸⁹⁻⁹⁰ Sr (u)	8	pCi/L	SDWA
WAG 17				
(1197)	Gross alpha (f)	15	pCi/L	SDWA
(1197, 1200)	Gross alpha (u)	15	pCi/L	SDWA
(1201)	Benzene (u)	5	µg/L	TDEC
(1201)	1,1-Dichloroethylene (u)	7	µg/L	TDEC
(1201, 1203 B)	Trichloroethylene (u)	5	µg/L	TDEC
(1201)	Vinyl Chloride (u)	2	µg/L	TDEC

Information is summarized from the 1992 quarterly environmental surveillance reports (Goldberg 1992a-d).

^aWells with qualified results are coded as:

B Found in the laboratory blank

J Value is estimated

Y Exceeded the calibration range and was diluted and reanalyzed

^bSodium, which exceeded the Safe Drinking Water Act (SDWA) standard at several wells, is not included. Vinyl chloride had a minimum detection level (MDL) greater than the SDWA standard and is included in this list only if the result was greater than the MDL.

Perimeter well contaminants are listed as filtered (f) and unfiltered (u).

^cAll radionuclide units were converted to pCi/L. Gross beta, regulated as 4 mrem/year, was converted to Bq/L in the Quarterly Reports.

^dSources are coded as:

DCG—Derived concentration guide for ingestion of water. From DOE Order 5400.5.

SDWA—40 CFR Part 141—National Primary Drinking Water Regulations, Subparts B and G, as amended.

TDEC—Rules of Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Chapter 1200-4-3, General Water Quality Criteria, as amended.

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