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ENVIRONMENTAL RESTORATION PROGRAM

Waste Area Grouping 2 Phase I Remedial Investigation: Sediment and Cesium-137 Transport Modeling Report

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Energy Systems Environmental Restoration Program

Waste Area Grouping 2 Phase I Remedial Investigation: Sediment and Cesium-137 Transport Modeling Report

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PREFACE

This *Waste Area Grouping 2 Phase I Remedial Investigation: Sediment and Cesium-137 Transport Modeling Report* (ORNL/ER-367) was prepared in accordance with requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This work was performed in the Environmental Restoration Program under Work Breakdown Structure 1.4.12.6.1.02.40.08.04 Phase I Soil and Sediment (Activity Data Sheet 3326). Publication of this document meets a project deliverable of June 28, 1996. This document is the last of five reports for Waste Area Grouping (WAG) 2 at Oak Ridge National Laboratory (ORNL) and presents results of the WAG 2 Sediment Modeling Task. It includes modeling results and data collected during storms at monitoring stations in WAG 2 in the White Oak Creek watershed. Two calibrated computer models that together simulate the release of sediment-bound Cs-137 from White Oak Creek and the movement of the material in the Clinch River/Watts Bar Lake system were used to estimate the effects of a 100-year flood. Risk analysis shows that the effects of the flood are predominately within the Environmental Protection Agency target risk range and that a brief period of slightly elevated risk is quickly reduced by natural dispersion of sediments in the Clinch River. This report examines the incremental risk related to the effect of a flood because risk levels due to Cs-137 in sediments in the Clinch River are already known to be elevated and the public is protected by regulation against unsafe use of dredged sediment from the river channel.

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

ACD	Analytical Chemistry Division
AWQC	ambient water quality criteria
CLP	Contract Laboratory Program (EPA)
CVAA	Cold Vapor Atomic Absorption
DOE	U.S. Department of Energy
EPA	U. S. Environmental Protection Agency
ERMA	Environmental Restoration Monitoring and Assessment
ER	Environmental Restoration (Program)
GFAA	Graphite Furnace Atomic Absorption
HFIR	High-Flux Isotope Reactor
HRT	Homogeneous Reactor Test
ICP	Inductively Coupled Plasma
MB	Melton Branch
NRWTF	Non-Radiological Wastewater Treatment Facility
OECD	Office of Environmental Compliance and Documentation
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
QA	quality assurance
QC	quality control
RI	remedial investigation
SOP	standard operating procedure
TDEC	Tennessee Department of Environment and Conservation
VOC	volatile organic compounds
WAG	Waste Area Grouping
WOC	White Oak Creek
WOCET	White Oak Creek Embayment
WOD	White Oak Dam
WOL	White Oak Lake

EXECUTIVE SUMMARY

This report is one of five topical reports that provide follow-up information to the Phase I Remedial Investigation (RI) Report for Waste Area Grouping (WAG) 2 at the Oak Ridge National Laboratory (ORNL). The five reports address areas of concern that may present immediate risk to public health at the Clinch River and ecological risk within WAG 2 at ORNL.

Since the start of operations at ORNL in the 1940's, contaminated sediments have accumulated in WAG 2 and have been discharged into the Clinch River. WAG 2 consists of the portion of White Oak Creek (WOC) below the main plant area of ORNL, the lower part of Melton Branch creek, White Oak Lake, and the WOC Embayment below the lake, and the associated floodplain. The levels of contamination in the soils and sediments in the WAG have led to concerns about direct exposures to on-site workers in the WAG and about erosion and transport of contamination off-site during extreme storms and flooding when erosive water flows are greatest. Off-site movement of contaminated sediment could potentially lead to deposition and accumulation of contamination downstream at unsafe levels. The Sediment Transport Modeling (STM) Task was implemented to address the off-site risks related to contaminated soils and sediments in WAG 2.

The first goal of the STM Task was to determine if the contaminated soils and sediments in WAG 2 could lead to an unacceptable risk to the off-site public due to contaminant transport during floods in the White Oak Creek watershed. Based on the direction given at the Data Quality Objectives meeting in June 1994, the task team focused on the effects of a 100-year flood. The second goal of the STM Task was to improve the conceptual understanding of how particle-reactive contaminants are mobilized and transported within the White Oak Creek (WOC)watershed. An accurate and reliable conceptual model of the contaminated sediments in WAG 2 is required in order to identify, select, and design the most appropriate remedial alternative. A sound conceptual model assists engineers and planners in predicting how the contaminated soils and surface water system may change in time and how they may change as other conditions in the watershed are changed.

The companion Clinch River Remedial Investigation (CRRI) Program recently reported two results that were important to this task (DOE 1996). First, ^{137}Cs is the only radionuclide that is currently discharged from ORNL and that is also found in the Clinch River at levels of potential concern for health and environmental risk. The cesium ion binds almost irreversibly to sediment particles that are subsequently discharged at White Oak Dam and then deposited in the river. As a consequence of this finding by the CRRI, this task focused exclusively on ^{137}Cs.

The second important result deals with potential levels of risk to human health due to current contamination in the Clinch River/Watts Bar Reservoir system. Calculated risks of excess cancer based on direct measurements of ^{137}Cs in fish, water, and sediments were compared to the EPA target risk range (10^{-6} to 10^{-4}). The CRRI report has shown that risk exceeds the target risk range for the fish ingestion scenario and the dredging scenario. The analysis of the fish ingestion scenario indicated that eating fish is potentially unsafe under very limited conditions, however, the dredging scenario resulted in risk > 10^{-4} for sediments sampled at 3 of the 4 reaches in the Clinch River. The risk is caused by direct exposure to the gamma emissions of the ^{137}Cs after the dredged material is spread on the soil surface.

Although the current contamination levels in the Clinch River exceed the target risk level, the public and regulators have an expectation that contamination released from the White Oak Creek watershed during an extreme flood should not significantly worsen the current condition of the sediments in the river system. Based on this, it seems reasonable that an extreme flood should not lead to additional or incremental risk of 10^{-4}. For this task, the *incremental risk* is defined as the predicted risk associated with the 100-yr flood minus the predicted risk with no extreme storm. Results described below indicate that the computed incremental risks to the off-site public do not warrant near-term remedial actions in WAG 2.

Approach Taken in This Study. To achieve the task goals, the STM task team implemented both storm sampling in the field and a computer modeling activity. Storm sampling was implemented at 8 stations within the WOC watershed, later the number of stations was reduced to 5. Each station was equipped with automatic sample collectors that were triggered by a rise in the stream stage. Field teams also sampled the streams manually to check the representativeness of the automatic sampling. Thousands of samples were collected and results from over 1300 analyses were reported. The main laboratory tests were sediment concentration in the water and ^{137}Cs concentration on the sediment solid particles. The task has generated an extensive screening level data set for calibrating a computer model and for refining the conceptual model of ^{137}Cs transport in the WOC watershed. Results from five storms that occurred over a 25-month period are reported in detail.

In the modeling activity, two computer models were used to estimate on-site and off-site processes. The Hydrologic System Program-Fortran (HSPF) model was an effective tool used to model ^{137}Cs mobilization and transport within the WOC watershed. It produced a baseline sequence of water, sediment, and ^{137}Cs discharges for "normal" conditions and a separate sequence that included a 100-year flood. Results from the watershed model were used as input to the off-site transport model that estimated the transport and deposition of ^{137}Cs in the Clinch River/Watts Bar Reservoir system. A modified version of the Hydrologic Engineering Center (HEC) -6 model, originally developed by the U.S. Army Corps of Engineers, was used to model ^{137}Cs transport from White Oak Dam through the river/lake system. In turn, results from the off-site model were used in the risk analysis.

Results of Storm Sampling and Analysis of Other Data. For each storm and each monitoring station, sediment and ^{137}Cs loads were estimated from the sampling results. For the intensively monitored storms, the estimated sediment loads discharged at White Oak Dam ranged from about 26,000 to 130,000 kg per event. Within the watershed, the sediment load tended to increase in the downstream direction as more eroded material entered the stream. Below the WOC weir, there was substantial deposition, presumably in White Oak Lake, although some material may have been deposited on the floodplain. Below White Oak Dam, both deposition and scour was observed among the five storms. The change in the estimated sediment load between the dam and the Sediment Retention Structure at the mouth of WOC varied from 10% deposition to 10% additional material (scouring).

For the five storms, the estimated ^{137}Cs loads ranged from 0.012 to 0.078 Ci. At the dam the ^{137}Cs loads tended to increase with increasing sediment loads, but within the watershed the pattern was not clear cut. The ^{137}Cs loads at 7500 Bridge station and WOC weir were comparatively low for one storm which followed a series of smaller storms, suggesting that the time between storms also affects ^{137}Cs loads. The data suggest that the time between storms allows the comparatively low levels of ^{137}Cs in the effluent from the Non Rad Waste Treatment Facility (NRWTF) (located upstream from the 7500 Bridge station) to sorb to creek sediments and to accumulate along the channel bed in WOC. Subsequent storms can mobilize and transport the sediment-bound ^{137}Cs. Cesium-137 is deposited in the floodplain/lake reach along with the sediments. Below White Oak Dam, the embayment is a conduit or a minor source of ^{137}Cs during storms. The largest gain in ^{137}Cs in the embayment for all intensively sampled storms was only 0.013 Ci.

The intensive storm sampling data describe the contaminant fluxes for brief periods. In contrast, the continuous monitoring conducted by ORNL Office of Environmental Compliance and Documentation indicates the long-term trends in ^{137}Cs transport. The compliance data show that ^{137}Cs releases at White Oak Dam have not exceeded 2 Ci/year since 1967. In recent years the ^{137}Cs releases have trended downward from 1.64 Ci in 1991 to 0.31 Ci in 1995.

Results of the Transport Modeling. The calibrated HSPF model was used to model water, sediment, and ^{137}Cs discharges within the watershed for the period 1990-1994. The degree of agreement between the simulated and observed annual flux of ^{137}Cs at White Oak Dam ranged from good to excellent.. The calibrated HSPF model was also used to estimate the ^{137}Cs flux related to a 100-year flood. In this task, the estimated 100-year peak water flow was about 2900 cfs or 20% greater than the largest previous estimate. The simulated ^{137}Cs release was about 3 Ci.

The simulated time series for flow, suspended sediments, and ^{137}Cs concentrations were used as input to the modified HEC-6-R model to simulate off-site transport. The HEC-6-R was developed and tested as part of the CRRI program. Based on modeling experience, during floods in White Oak Creek the concurrent water level in the Clinch River has a large effect on the erosion or deposition of ^{137}Cs in the embayment. This observation led to two different modeling scenarios. In one, the 100-year flood in WOC watershed coincides with the 100-year wide-scale regional flood; in the other, the 100-year flood in the WOC watershed is modeled as an localized event independent of flows in the Clinch River. For the first scenario, the water levels in the Clinch River are extremely high, causing backwater conditions to occur in the WOC Embayment along with deposition of sediment and ^{137}Cs in the embayment. In the second scenario, water levels in the Clinch are relatively low, and there is significant scour as the White Oak Creek flood waters discharge from the embayment. A baseline simulation with no extreme floods was also generated for comparison.

The two off-site scenarios produced two very different results. For the regional 100-year flood, backwater conditions in the embayment result in deposition in the embayment for a total release of about 2.5 Ci to the Clinch River. The extreme flows in the Clinch River/Watts Reservoir cause a general scouring in the Clinch River and transport of the material into Lower Watts Bar Reservoir and beyond. For the localized 100-year flood, the erosion in the embayment (with no sediment retention structure in the simulation) generates an additional 2 Ci of ^{137}Cs for a total release of about 5 Ci into the Clinch River. Most of the ^{137}Cs is deposited in the Clinch River with a small portion being deposited in Lower Watts Bar Reservoir.

Results of the Risk Analysis. For risk analysis, three exposure scenarios were considered (fish ingestion, shoreline exposure, and dredging).

- The fish ingestion pathway was evaluated qualitatively, with no significant incremental risk identified.
- Results of the shoreline exposure scenario produced incremental risk levels within the EPA target risk range, 10^{-6} to 10^{-4}.

The most complex risk results were related to the dredging scenario in which the dredged material is assumed to lead to exposure to gamma radiation from the ^{137}Cs. Results were very different for the 100-year flood in entire Clinch River/Watts Bar system (regional flood) as compared to the 100-year flood in WOC only (local flood).

- For the regional flood case, the incremental risk is always < 10^{-5} due to the backwater in the embayment during the flood that causes deposition of ^{137}Cs there and also to the enhanced transport and dispersion in the Clinch River caused by large water velocities of the 100-year flood event.

In contrast, for the local-flood scenario, transient accumulations of ^{137}Cs in sediment in the Clinch River cause incremental risk levels slightly >10^{-4}. This was the only incremental risk above the EPA target risk range observed in the simulations, however the elevated risk is short lived. The typical high flows of the next winter season scour ^{137}Cs from the upper portion of the Clinch River and disperse it downstream. Thereafter the incremental risk is generally < 10^{-5}. Given the fact that sediments in the Clinch are known to be contaminated and the fact that there are regulations are in place that limit dredging in the Clinch River, the transient and small exceedence of the 10^{-4} level determined from the simulation may not be significant. This exceedence of the 10^{-4} risk level does not warrant remedial actions.

- Consequently, the computer simulations presented here show that a 100-year flood in the White Oak Creek watershed will not mobilize and transport sufficient ^{137}Cs to cause a significant increment in risk to the public off-site.
- No near-term measures to remove or isolate soils and sediments in WAG 2 are required, based on the analysis of potential off-site risks.

Refinement in the Conceptual Model of ^{137}Cs Transport in the Watershed. Based on measurements at White Oak Dam, there has been a decline in the annual ^{137}Cs release from the WOC watershed, from 1.43 Ci in 1990 to 0.31Ci in 1995. In addition, ^{137}Cs releases from the watershed in 1990 and early 1991 were relatively episodic, driven by high flows related to storms. Since mid-1991, the watershed transport system has become less storm-driven. The cause for the change is uncertain. The HSPF model calibrated for 5 years of data tends to generate results that are more "storm-driven" than the current watershed transport system is, therefore, the model predictions are considered to be conservative.

The largest reductions in ^{137}Cs flux within the watershed occur in the lower WOC floodplain/White Oak Lake reach where deposition occurs. The filling rate is uncertain; the HSPF model calculated a rate of filling of about 0.1 cm/year. Although this rate is judged to be low, it suggests that filling the 3-m deep lake is not a problem, especially for the next 20-30 years. Reliable data is obtainable only be replicating the precision bathymetry every 5-10 years.

If the White Oak Lake fills to an equilibrium level where annual net deposition is zero and the release from White Oak Dam equals the flux measured upstream at the WOC weir, the release at White Oak Dam would increase by only about 15% causing no significant increase in the off-site incremental risk. It is conceivable that the ^{137}Cs transport in the WOC watershed may become more episodic in the future (more storm-driven) as the lake fills and storms start to erode the lake sediments. There are no predictions if or when this could happen, however, there is no evidence in the data trends or in the HSPF modeling that filling of the lake with sediments will lead to storm fluxes significantly greater than the 3 Ci predicted for the 100-year flood. Because the downstream system can accommodate up to at least 5 Ci with only a marginal exceedance of the incremental risk, it is concluded that filling of the lake with sediments does not pose large increases in risk off-site for near term (20-30 years), especially if vegetation stabilizes portions of the filled lake.

Primary Recommendations. The data analysis and the computer modeling showed that erosion is the predominant transport mechanism for introduction of ^{137}Cs in the WOC surface water system.

Because the vegetation cover on the Intermediate Holding Pond area and the floodplain in WAG 2 is effectively the only barrier to erosion and is the main controlling mechanism affecting off-site releases of ^{137}Cs during extreme storms, future remedial actions intended to isolate ^{137}Cs in WAG 2 should ensure that any new cover or containment technology for these areas is as effective or more effective than the current vegetation cover.

- The work presented in this report was conducted at the watershed scale. Any proposed action to address specific problem areas in WAG 2 (such as vegetation removal, stream channelization, or large-scale capping) should be evaluated in detail and designed to minimize the potentially detrimental effects of increased erosion.
- To maintain low levels of ^{137}Cs flux in the watershed, it is recommended that the current low level of ^{137}Cs discharge from the Non Rad Waste Treatment Facility (0.30 Ci in 1995) be maintained, if technically feasible.
- Secondary recommendations in the report deal with efforts to evaluate the effectiveness of ^{137}Cs transport barriers, i.e., White Oak Dam and the Sediment Retention Structure.

1. INTRODUCTION

This report is one of five reports issued in 1996 that provide follow-up information to the Phase I Remedial Investigation (RI) Report for Waste Area Grouping (WAG) 2 at Oak Ridge National Laboratory (ORNL). The five reports address areas of concern that may present immediate risk to public health at the Clinch River and ecological risk within WAG 2 at ORNL. A sixth report, on groundwater, in the series documenting WAG 2 RI Phase I results were part of project activities conducted in FY 1996. The five reports that complete activities conducted as part of Phase I of the Remedial Investigation (RI) for WAG 2 are as follows:

- Waste Area Grouping 2, Phase I Task Data Report: Seep Data Assessment
- Waste Area Grouping 2, Phase I Task Data Report: Tributaries Data Assessment
- Waste Area Grouping 2, Phase I Task Data Report: Ecological Risk Assessment
- Waste Area Grouping 2, Phase I Task Data Report: Human Health Risk Assessment
- Waste Area Grouping 2, Phase I Task Data Report: Sediment and ^{137}Cs Transport Modeling

In December 1990, the *Remedial Investigation Plan for Waste Area Grouping 2 at Oak Ridge National Laboratory* was issued (ORNL 1990). The WAG 2 RI Plan was structured with a short-term component to be conducted while upgradient WAGs are investigated and remediated, and a long-term component that will complete the RI process for WAG 2 following remediation of upgradient WAGs. RI activities for the short-term component were initiated with the approval of the Environmental Protection Agency, Region IV (EPA), and the Tennessee Department of Environment and Conservation (TDEC).

This report presents the results of an investigation of the risk associated with possible future releases of ^{137}Cs due to an extreme flood. The results are based on field measurements made during storms and computer model simulations.

1.1 WAG 2 RI BACKGROUND

WAG 2 consists of White Oak Creek (WOC) and its tributaries downstream of the ORNL Main Plant area, White Oak Lake, the White Oak Creek Embayment of the Clinch River and the associated flood plains, and the subsurface environment (Fig. 1.1). The WOC system drains the WOC watershed, an area of approximately 16.8 km^2 that includes ORNL and associated WAGs. The WOC system has been exposed to contaminants released from ORNL and associated operations since 1943 and continues to receive contaminants from adjacent WAGs.

The WAG 2 RI Plan developed in 1990 was not a prototypical RI plan. It was recognized that full implementation of an RI was inappropriate while contaminants continue to enter the system. A phased effort was adopted in response to the need to take initial steps to protect the public and the environment and to characterize and assess risks associated with WAG 2 and the limitations imposed by changing contaminant input. Three phases were initially identified: Phase I was the initial scoping activity to determine the need for early action; Phase II included interim activities during remediation of upgradient WAGs to evaluate potential changes in the contamination status of WAG 2 that would require revaluation of the need for early action; and Phase III would be completion of the

Comprehensive Environmental Response, Compensation, and Liability Act process following remediation of the upgradient WAGs. Field activities were initiated in FY 1992 consistent with the RI Plan (ORNL 1990) and a report summarizing Phase I results to date was published in 1995 (DOE 1995a).

On June 20 and 21, 1994, a Data Quality Objectives (DQO) Workshop was held with representatives of the Department of Energy (DOE), EPA, and TDEC. Decisions were made defining the nature and boundaries of the problems for the WAG 2 RI, decision criteria, and inputs to be used for characterizing the site for decision-making purpose. During the workshop, the regulators made recommendations that would alter the initial WAG 2 RI plan. Consequently, the Federal Facility Agreement (FFA) managers from the EPA, TDEC, and DOE directed that FY 1995 WAG 2 RI activities would concentrate on meeting FFA requirements.

The FFA managers also directed that the WAG 2 RI be changed to a two-phase field program by eliminating Phase II activities and transferring needed elements into the newly-formed ORNL Environmental Restoration Surface Water Program. A separate FY 1995 WAG 2 RI Work Plan was developed (DOE 1994) to replace previously identified planning and tasking documents. Emphasis was to be on analysis of existing data, data interpretation, and reporting of results. In keeping with that decision, this document is a report on the results of the Sediment Transport Modeling Task.

1.2 GOALS AND OBJECTIVES

1.2.1 Goals

As described in this section, the Sediment Modeling Task was developed to address two general goals and one specific objective.

Contaminated sediments have accumulated in the White Oak Creek watershed and have been discharged into the Clinch River since the start of operations at ORNL in the 1940's. The current inventory of sediment-bound contaminants in WAG 2 represents a possible source for off-site transport during extreme floods. One goal of the Sediment Transport Modeling Task was to determine if there is an unacceptable risk to the public off site due to the mobilization and transport of the sediment-bound contaminants in WAG 2 during an extreme flood. The second goal of the STM task was to improve the conceptual understanding of how particle-reactive contaminants are mobilized and transported within the White Oak Creek Watershed system.

1.2.2 Findings of the Clinch River Remedial Investigation

This task builds on the results of the Clinch River Remedial Investigation (CRRI) Program, a comprehensive investigation aimed at quantifying risks in the Clinch River/Watts Bar Reservoir system related to contaminants released from ORNL, the Y-12 Plant, and the K-25 Plant. The *Remedial Investigation/Feasibility Study of the Clinch River/Popular Creek Operable Unit, Vol. 1* (DOE 1996) reported two results that were important to defining the scope of the Sediment Transport Modeling task. First, ^{137}Cs is the principal radionuclide currently being discharged from ORNL that is still found in the Clinch River at levels that exceed risk criteria. Other rationuclides are either very soluble (e.g., ^{3}H and ^{90}Sr) in which case they become diluted and they pass through the river/reach system without accumulation, or they have decayed to inconsequential levels (e.g., Ru-106). In

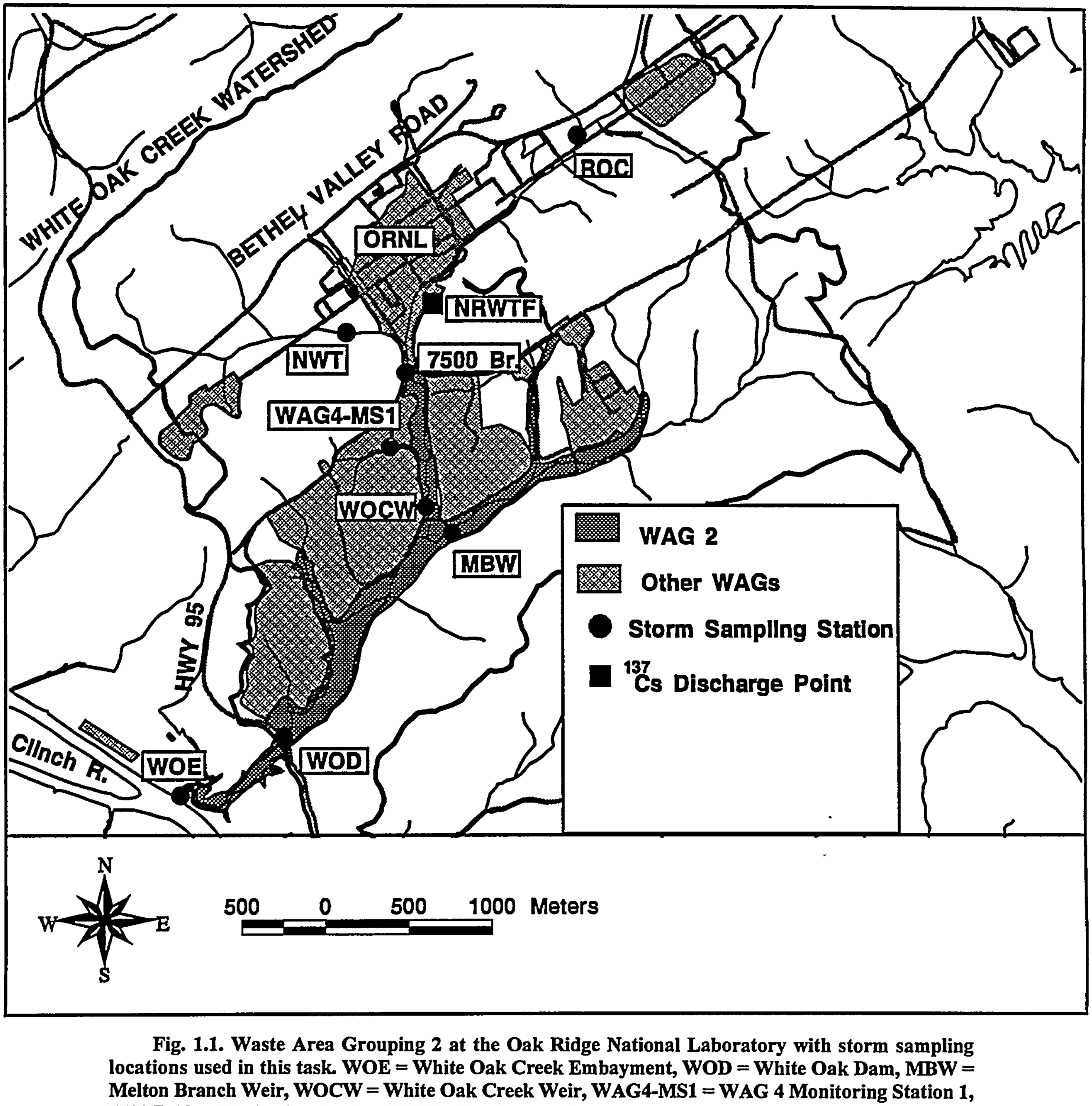

Fig. 1.1. Waste Area Grouping 2 at the Oak Ridge National Laboratory with storm sampling locations used in this task. WOE = White Oak Creek Embayment, WOD = White Oak Dam, MBW = Melton Branch Weir, WOCW = White Oak Creek Weir, WAG4-MS1 = WAG 4 Monitoring Station 1, 7500 Bridge Monitoring Station, NWT = Northwest Tributary, ROC = Rock outcrop station, NRWTF = Non Rad Waste Treatment Facility; its effluent adds ^{137}Cs to White Oak Creek.

contrast, ^{137}Cs binds almost irreversibly to clay and silt particles and to soil aggregates, all of which accumulate as sediment in the river system. This sorbed ^{137}Cs continues to be present in river sediments due to its relatively long-half life (30-years). As a consequence of this finding by the CRRI, this task is focussed exclusively on ^{137}Cs.

The second important result deals with levels of risk to human health due to contamination in the current sediments in the Clinch River/Watts Bar Reservoir system. The CRRI report has shown that all exposure scenarios excluding the dredging scenario result in excess risks of cancer $< 10^{-4}$ (the EPA target risk level), however, the dredging scenario in which river sediments are removed and used for agricultural purposes resulted in risk levels slightly $> 10^{-4}$ for sediments sampled at several locations in the Clinch River. Other contaminants found in the Clinch River contribute to this risk level, however, the contribution of ^{137}Cs by itself to the risk is $> 10^{-4}$.

1.2.3 Incremental Risk

When the DQO meeting of June 1994 resulted in a general charge to the WAG 2 RI to determine if ^{137}Cs could result in unacceptable off-site risks, the results of the CRRI study were not available and the quantitative measure for an unacceptable risk in light of the currently known levels of risk in the Clinch River was not defined. Although the actual ^{137}Cs levels in the Clinch River sediments exceed the target risk level, the public and regulators have a expectation that ^{137}Cs released from the White Oak Creek watershed during an extreme flood should not worsen the current condition of the sediments in the river system. It seems reasonable that an extreme flood should not lead to an additional or incremental risk of 10^{-4}. For this task, the *incremental risk* is defined as the predicted risk associated with the 100-year flood minus the predicted risk with no extreme storm.

The idea of an incremental risk is best served by a simple illustration. If, for example, there is a current risk level of $1.5x10^{-4}$ due to ^{137}Cs in the sediments in a segment of the river, additional deposition of flood-transported contaminated sediment should not cause the level of risk to exceed 2.5 10^{-4}. Zero impact due to a possible flood event is unreasonable due to the ^{137}Cs stored in WAG 2 sediments will be discharged. It is technically infeasible to isolate the ^{137}Cs in WAG 2 quickly (say 1–2 years) and undoubtedly very expensive to do so over several years. Therefore, some incremental change in risk must be accepted. The 10^{-4} increment is judged to be reasonable.

1.2.4 Task Objectives

At the DQO meeting the WAG 2 Program was also directed to focus on the effects of the 100-year flood only. As a consequence, the objective of the task is:

- Determine if there is an off-site incremental risk that exceeds the EPA target risk range ($> 10^{-4}$) due to the transport of ^{137}Cs from WOC to the Clinch River and Lower Watts Bar Reservoir system (Fig. 1.2) following a 100-year flood.

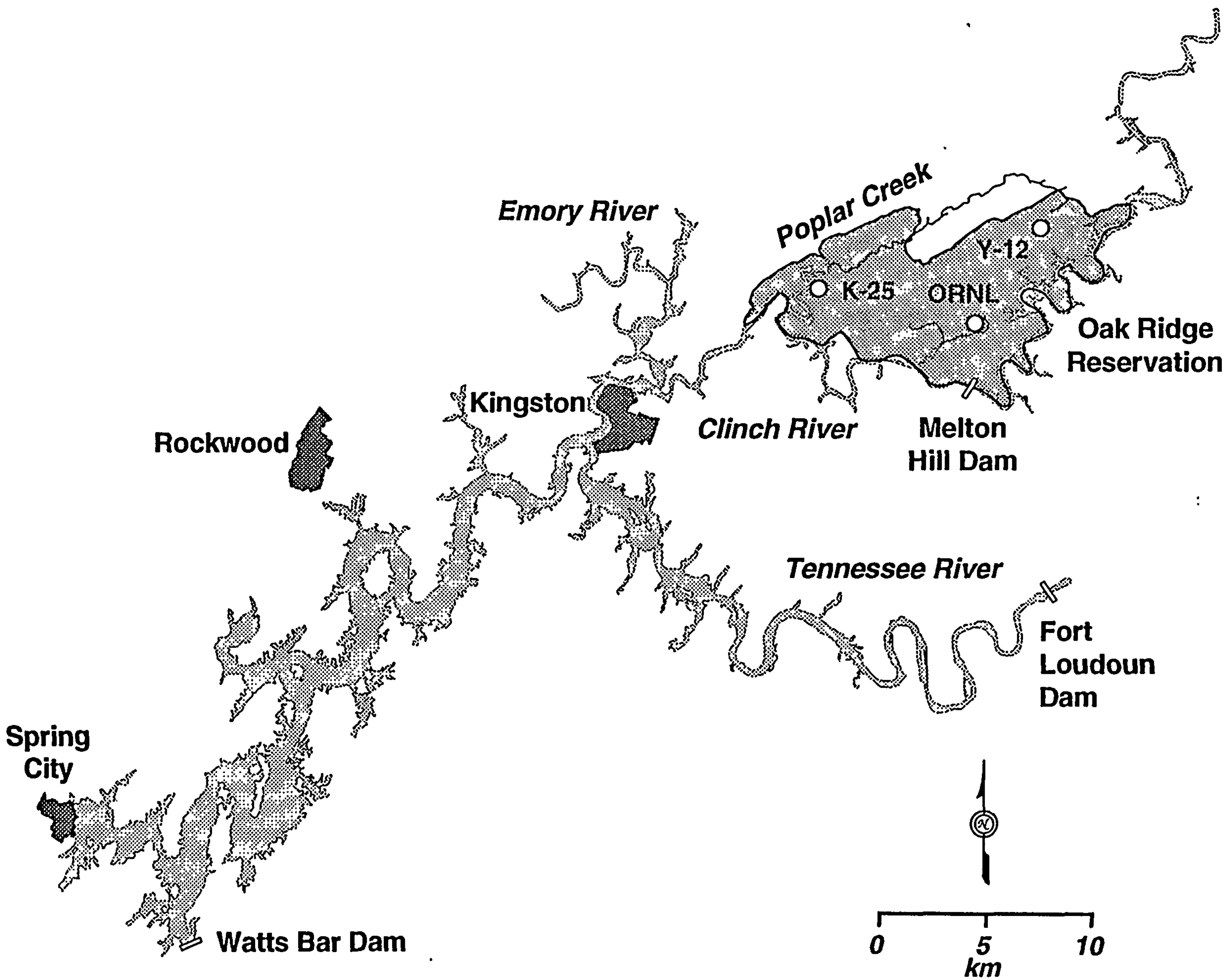

Fig. 1.2. The Clinch River and Watts Bar Reservoir system.

1.2.5 Sediment Retention Structure

In setting up the task objectives at the DQO meeting there was no specific requirement to evaluate the performance of the Sediment Retention Structure that was installed on White Oak Creek at its confluence with the Clinch River in 1992 (Fig. 1.1). The retention structure is a permeable, coffer-cell dam that keeps an elevated water level in the embayment even during the winter when water elevation in the Clinch River is reduced by a combination of low water in Watts Bar Reservoir for flood control and periodic low releases from Melton Hill Dam located upstream. The sediment retention structure provides several benefits:

- It keeps the otherwise uncontrolled Cs-137-contaminated sediments in the embayment from the erosive washing action of inflow and outflow caused by daily releases of water from Melton Hill Dam.
- It keeps those contaminated sediments in the embayment from becoming dry and exposed to erosive rainfall.
- It is a barrier for boaters who may otherwise wander up the embayment.
- It provides a blanket of water that reduces gamma radiation from the remaining ^{137}Cs contaminated sediments in the embayment.

Recently, there is interest in evaluating the effectiveness of this early action. Accurate measurement of the sediment retention efficiency of the structure requires the measurement of flow at the structure, however, the structure is not rated (no relationship between water level at the structure and flow); moreover, the permeable coffers in the dam make rating very difficult. Nevertheless, the Storm Sampling subtask collected some data at the Sediment Retention Structure, and its performance is discussed in Chaps. 3 and 7. Evaluation of the Sediment Retention Structure is not one of the explicit task objectives.

1.3 APPROACH

This investigation consisted of four major subtasks: storm sampling, watershed transport modeling, off-site transport modeling, and risk analysis. The relationship between the key components of the Sediment Transport Modeling task including the modeling activities is shown in Fig. 1.3. This chapter lists the objectives of each subtask, and a guide to where results are presented in this report.

As background, the next section of this report lists the results from other investigations in order to identify the ^{137}Cs inventories in WAG 2 and to identify the sources of ^{137}Cs that flow into the White Oak Creek drainage system. Following the background information, there are separate sections reporting results of each subtask.

1.3.1 Storm Sampling Subtask

A system of 8 sampling stations were instrumented in the White Oak Creek watershed at locations shown in Fig. 1.1. Automatic samplers were placed at these sites to determine the suspended

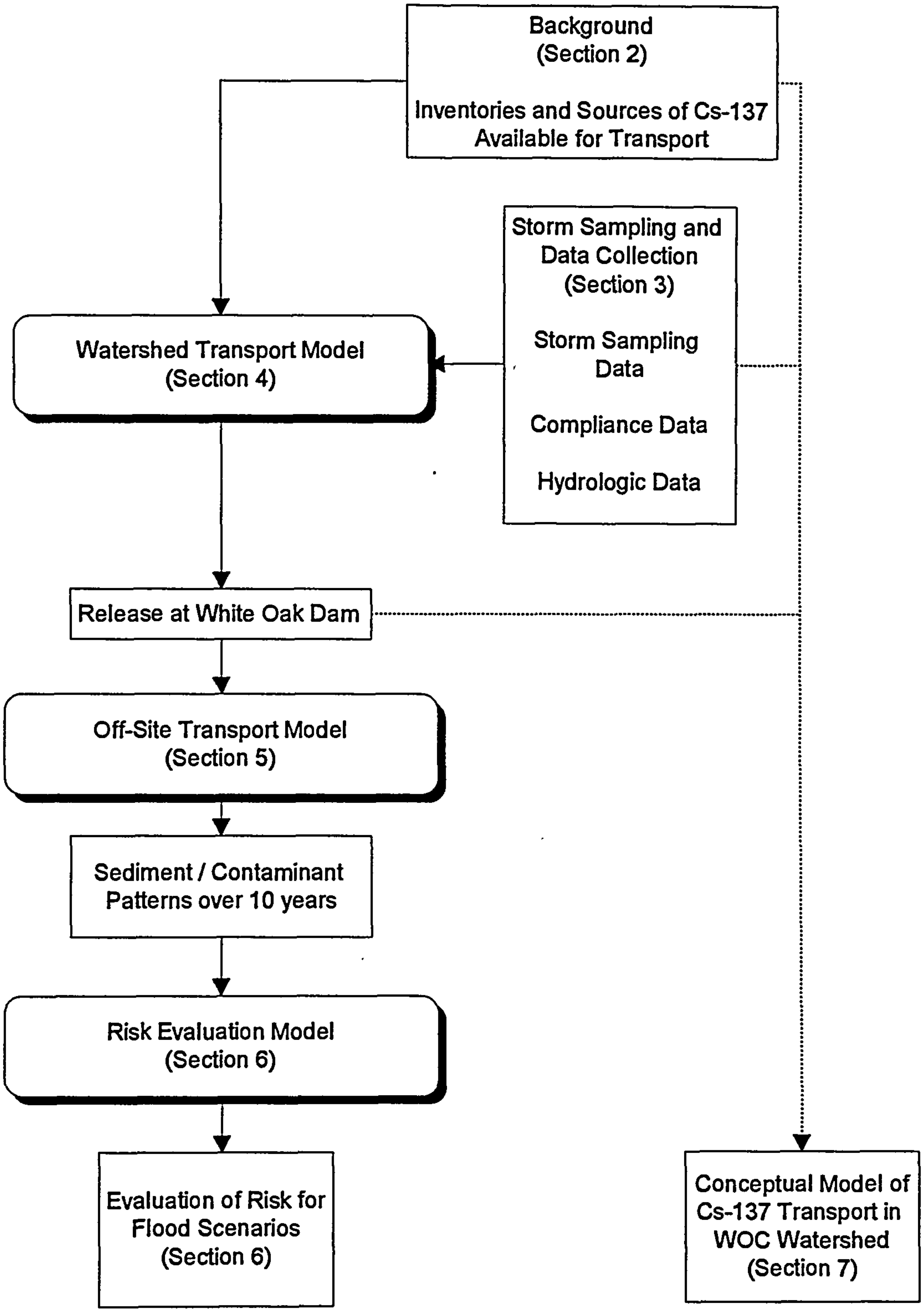

Fig. 1.3 Key components of the Sediment Transport Task.

sediment concentration (mg/L) and the sediment-bound ^{137}Cs concentrations (pCi/mg) along White Oak Creek and the main tributaries to WOC during storms. The data were used for two purposes:

- Provide input for the watershed model for the purposes of calibration and validation.
- Assist in the development of the conceptual model for transport of ^{137}Cs in the WOC watershed through the assessment of the storm sampling results, and the integration with data generated by other groups (e.g., the WAG 2 seep and tributary investigations, the compliance data collected by the Office of Environmental Compliance and Documentation, OECD).

The results of the data collection activities including the storm sampling subtask are reported in Chap. 3.

1.3.2 Watershed Modeling

After a formal selection process, the Hydrological Simulation Package—Fortran (HSPF) model was selected to simulate the water, sediment, and contaminant transport in the WOC watershed because it is comprehensive with respect to hydrology and contaminant mobilization and transport mechanisms (Fontaine 1991). Subsequently, the model was used for the following purposes:

- Determine the flood frequency for discharge at the White Oak Dam and estimate the 100-year flood. The HSPF model was used to generate a time-series of synthetic discharges based on rates measured at a nearby weather station. The flood frequency was computed from the synthetic hydrograph. (Results reported at the end of Chap. 3.)
- Simulate the discharge and ^{137}Cs mass flux within the WOC watershed and at the exit point (White Oak Dam) for the period 1990-94, using the storm data and the compliance data for calibration and validation.

Results from the HSPF model are reported in Chap. 4.

1.3.3 Off-site Transport

Sediment-bound contaminants released at White Oak Dam move through the White Oak Creek Embayment past the Sediment Retention Structure and are released into the Clinch River below Melton Hill Dam. The Clinch River flows into the Watts Bar Lake where slower water velocities allow sediments to settle and accumulate. Flow patterns are influenced by tributaries that feed the river and the lake.

As part of the CRRI, the Hydrologic Engineering Center (HEC) - 6 model was modified to include the transport of radionuclides, and the revised version (HEC-6-R) was used to recreate the current sediment and ^{137}Cs distribution in the river/reservoir system. The HEC-6-R model was used in this study to:

- determine the transport and accumulation of the sediment and ^{137}Cs in the White Oak Creek Embayment, Clinch River, and Watts Bar Reservoir system based on the estimated release for the 100-year flood, as generated by the HSPF model.

The same calibrated HEC-6-R model that was used in the CRRI was used in this subtask. The model does not include the effects of the Sediment Retention Structure. Results are presented in Chap. 5.

1.3.4 Risk Analysis

There are several scenarios that potentially lead to exposure to the ^{137}Cs-contaminated sediments that build-up in the river and the lake, including the following:

- Determine the resulting incremental change in risk to human health based on the distribution of ^{137}Cs contaminated sediments as generated by the off-site transport model.

Results are reported in Chap. 6.

1.4 SYNOPSIS OF RESULTS AND TASK BENEFITS

1.4.1 Risk Results

The main result of this task are the findings related to the incremental risk resulting from the 100-year flood. The incremental risk for the shoreline exposure scenario is within the EPA target risk range (10^{-4}– 10^{-6}). In general, for the dredging scenario the incremental risk in the Clinch River is < 10^{-4} (the limit to the EPA target risk range) and usually below 10^{-5}, however, the modeling indicated that a transient risk (> 10^{-4}) that may occur at the mouth of the WOC where comparatively large concentrations of ^{137}Cs may be deposited for several months following the 100-year storm until seasonal storms the following winter move the material downstream. The river bottom near the mouth of the WOC is routinely scoured thus even the temporary accumulation of ^{137}Cs was not expected. Because dredging of contaminated sediments is limited by regulation, the potential risk to human health is avoided.

1.4.2 Conceptual Model of ^{137}Cs in the Watershed

When the task was initially planned, the underlying conceptualization of ^{137}Cs transport was based primarily on familiarity with sediment-transport principles -- mainly that sediment transport increases dramatically with increased stream discharge. The mobilization and movement of particle-reactive contaminants in WOC watershed were expected to be storm-driven.

Data collected during the large storms plus the continuous monitoring data collected by OECD shows a system that was storm-driven in late 1990-early 1991. Since mid-1991, ^{137}Cs fluxes have been less storm-driven and more uniform through time, still with a seasonal variation and slight storm-driven signature.

The main active source of ^{137}Cs to the WOC system is the effluent from the Non Rad Waste Treatment Facility (NRWTF). Although the levels of ^{137}Cs in the effluent are low and within regulatory requirements, the releases are the single largest source to WOC under normal hydrologic conditions. Cesium-137 in the effluent from the NRWTF is released in a dissolved state. It is sorbed to channel sediments that later become mobilized during storms. Modeling results suggest that extreme storms cause soil erosion and an associated ^{137}Cs flux that exceeds the magnitude of the ^{137}Cs effluent from the NRWTF. The new conceptual model is derived from the data in Chaps. 2 and 3 and the modeling results in Chap. 4; it is described in Chap. 7 at the end of the report.

1.4.3 Calibrated Watershed Model

The task utilized the HSPF model, a comprehensive, process-oriented watershed model, as described later. The model is calibrated to flows in White Oak Creek and sediment and sediment-bound contaminants (specifically ^{137}Cs) and it is an asset for future Environmental Restoration planning and assessment.

The HEC-6-R model calibrated for the river/reservoir system for the CRRI and used in this study is also a valuable resource.

1.4.4 Other Benefits

One benefit was the development of a new laboratory method to separate suspended sediment into size-class subsamples for subsequent chemical or radiological samples. For contaminant transport analysis it is important to know the portion of contaminant fixed to the sands, silts, and clays because they behave differently in the river system. This new method provides for better separations of the sample and more accurate determination of the contaminant load per size class of sediment particles.

Another benefit was the development of a combination methodology using both expert-system concepts and parameter-optimization methods to evaluate parameters in complex computer models. The new combination methodology saves time for the modeler and ensures accuracy by using some of the common-sense knowledge about the model and/or the real system that is known to the modeler.

2. BACKGROUND

The possibility of unacceptable off-site risks due to ^{137}Cs releases during extreme storms is based on the fact that there are large quantities of ^{137}Cs-contaminated soils and sediments in WAG 2 that are not controlled or fixed in place. Before quantifying the releases of ^{137}Cs based on data analysis (Chap. 3) and on modeling (Chap. 4), this chapter of the report describes the extent of the ^{137}Cs inventories in WAG 2 and the sources of ^{137}Cs that are continuing to supply the radionuclide to the surface water system. The final results of the study indicate that vegetation on the contaminated soils control the erosion of ^{137}Cs, and that the large inventories of ^{137}Cs in their current condition do not supply unsafe amounts of ^{137}Cs to the Clinch River.

2.1 SITE DESCRIPTION

ORNL is located on the Oak Ridge Reservation, and the majority of ORNL's plant facilities, active and inactive waste management areas, and potential sources of contaminants lie within the White Oak watershed boundaries. WAG 2 includes WOC below 7500 Bridge and Melton Branch and the floodplains adjacent to these streams. WAG 2 receives the surface water drainage and the water-borne contaminants from the adjacent WAGs (Fig. 2.1).

2.2 SITE HISTORY

As reported by DOE (1996), the original mission of ORNL, or X-10, as it was known during the Manhattan Project, was the pilot-scale production of plutonium for use in nuclear weapons research at Los Alamos (Johnson and Schaffer 1992). Construction at the X-10 site began in January 1943, and plutonium was produced at the Graphite reactor which came on-line in October. By the end of 1944, the use of the graphite reactor shifted from plutonium production to research and the production of other radionuclides. Following the end of World War II, ORNL became a center for the development and testing of nuclear reactors, for the chemical and physical separation of radionuclides, and for the production of radionuclides used in research, medicine, and industry (DOE 1994a).

The most significant operations at ORNL that have released contaminants to off-site surface waters have been the management of liquid and solid wastes. The X-10 site was planned as a temporary pilot facility, and therefore waste production was anticipated to be small. A series of tanks were constructed to contain liquid wastes; however, as the mission of the site was expanded the capacity of the tanks was exceeded. To extend the capacity of the tanks, the particle-reactive contaminates and sludges were precipitated and the supernate was released to WOC, along with large quantities of diluting water. In the spring of 1943, the Intermediate Holding Pond was constructed to the south of the Haw Ridge water gap in order to provide a downstream settling basin for particle-bound contaminants (Fig. 2.2). Significant quantities of radionuclides accumulated in the pond, but in the fall of 1944, the earthen dam that formed the pond was breached by high water. Subsequently, WOC channel was moved and routed around the pond sediment areas. Also in 1943, White Oak Dam was constructed to provide a final settling pond for remaining solids before they were released off-site. From this point through the mid 1960's several steps were taken to dispose of wastes and to reduce the off-site releases. Pond 3513 was build to provide remove particle-bound radionuclides and to allow for decay of short-half-life radionuclides. Disposal pits and trenches in Melton Valley were constructed and used for liquid waste disposal. In 1966, liquid wastes were disposed using

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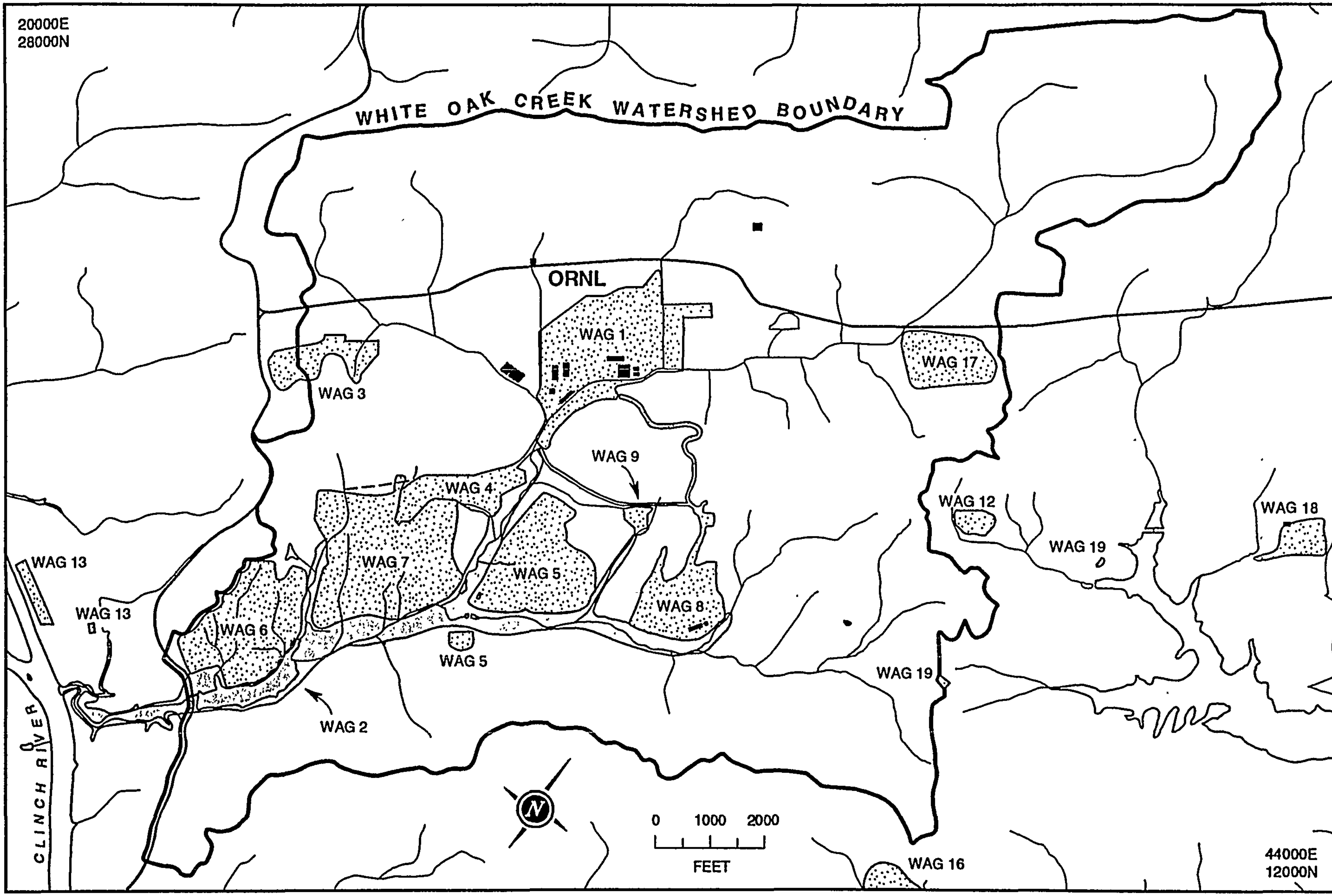


Fig. 2.1. Map showing Oak Ridge Reservation waste area groupings.

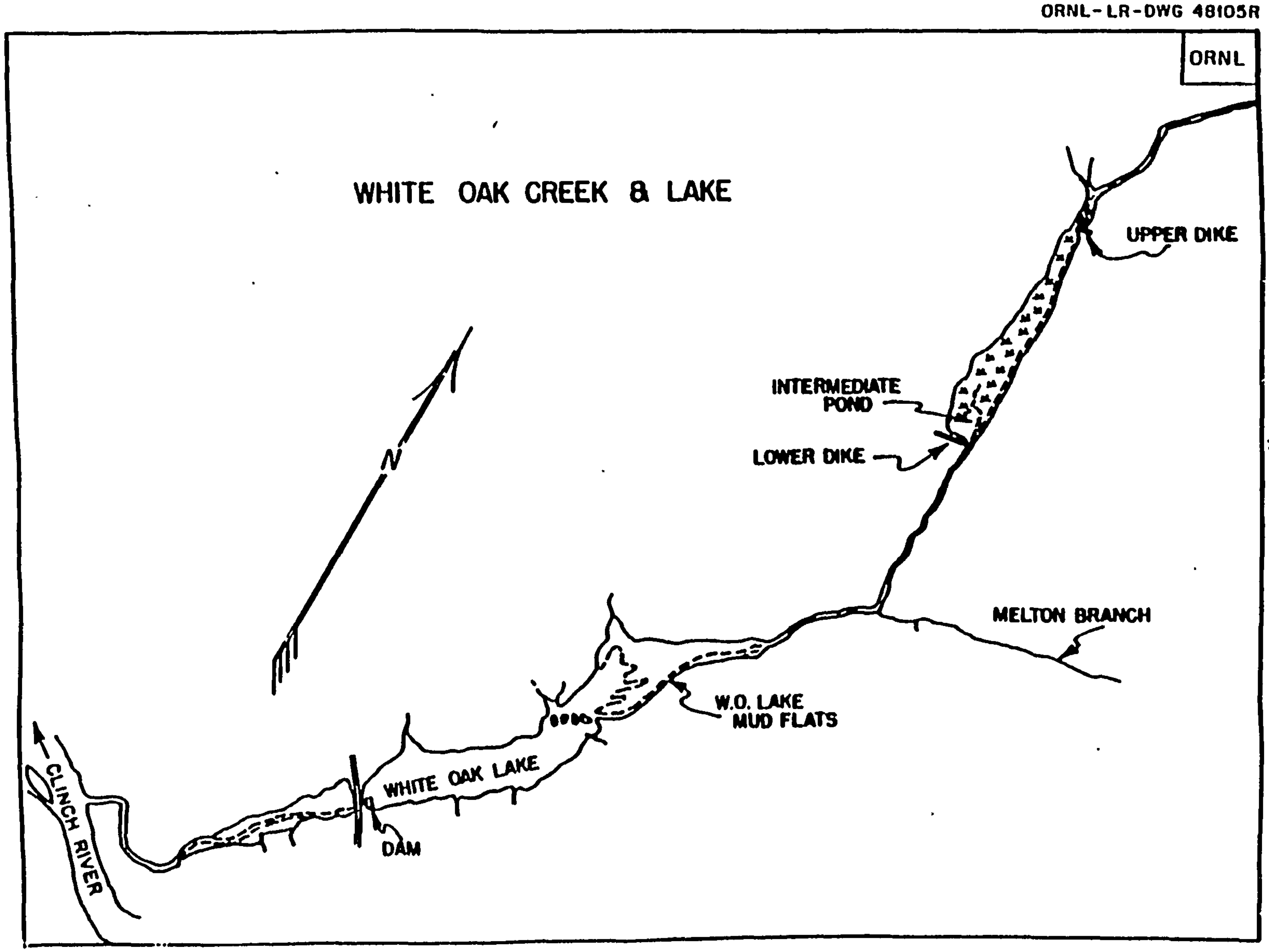


Fig. 2.2. Location of the Intermediate Pond in relation to White Oak Creek and White Oak Lake.

hydrofracture technology (Spalding and Boegley 1985). Solid wastes were disposed in the Solid Waste Storage Areas (SWSAs) and the largest areas (SWSAs 4, 5, and 6) are located in Melton Valley. They are incorporated into WAGs 4, 5, and 6, respectively, as shown in Fig. 2.2.

2.3 HISTORICAL RELEASES

Operations at ORNL have resulted in the release of radionuclides from White Oak Creek, shown in Table 2.1. As reported by DOE (1996), ^{137}Cs is the principal radionuclide discharge from ORNL that is still expected to be found in the Clinch River in significant levels, because ^{137}Cs binds tightly to clay and silt particles in the river sediments and because the half-life of ^{137}Cs is moderately long (30 years). Tritium and Sr-90 are more soluble, and historical releases are expected to have moved through the Clinch River system. All releases of Ru-106 and other fission products have been reduced by decay to inconsequential amounts. Since 1968, ^{137}Cs releases have been relatively minor, ≤ 2 Ci per year. Releases of ^{137}Cs for 1990-1995 have been recomputed for this investigation.

2.4 CURRENT CONDITIONS

2.4.1 Cesium-137 Inventories in WAG 2

Ford et al. (1996) reported estimates of ^{137}Cs inventories in WAG 2 based on analyses of soil cores. Their report subdivided the main reaches of White Oak Creek and Melton Branch into subreaches, as shown in Fig. 2.3.

ORNL plant reach. The WOC stream in the main plant area above 7500 Bridge monitoring station. Historically, the Process Waste Treatment Plant discharged significant quantities of ^{137}Cs to the reach. Since 1990, the PWTP effluent has been routed to the Non Rad Waste Treatment Facility (NRWTF) for additional treatment and contaminant removal. As shown later, although the NRWTF operates within guidelines and regulations it is the largest source of ^{137}Cs to the WOC system under normal hydrological conditions. Northwest Tributary and First Creek contribute minor amounts of ^{137}Cs to the plant reach.

Middle White Oak Creek (MWOC) reach. This reach extends from 7500 Bridge weir to the WOC Weir. The WAG 4 tributary drains to this stream reach. The stream section is subdivided into two subreaches.

Intermediate Holding Pond (IHP). Located between 7500 Bridge Weir and the site of an old earthen dam about 0.5 km downstream. Most of the radioactivity is due to ^{137}Cs but there are other radionuclides including plutonium, americium, and curium.

Lower Middle White Oak Creek (LMWOC). This floodplain area stretches from the IHP downstream to the WOC weir. The quantities of radionuclides are significantly lower than those for the IHP area, but radionuclides are associated with the sediments in the stilling pool behind the WOC weir. The weir pool sediments were removed in December 1995.

Table 2.1. Estimated discharges (in curies) of radionuclides from White Oak Creek to the Clinch River, 1949–1995

Year	^{137}Cs	^{106}Ru	^{90}Sr	TRE[b]	^{144}Ce	^{95}Zr	^{131}I	^{60}Co[c]	^{3}H	TRU[d]
1949	77	110	150	77	18	180	77			0.04
1950	19	23	38	30		15	19			0.04
1951	20	18	29	11		5	18			0.08
1952	10	15	72	26	23	19	20			0.03
1953	6	26	130	110	7	8	2			0.08
1954	22	11	140	160	24	14	4			0.07
1955	63	31	93	150	85	5	7	7		0.25
1956	170	29	100	140	59	12	4	46		0.28
1957	89	60	83	110	13	23	1	5		0.15
1958	55	42	150	240	30	6	8	9		0.08
1959	76	520	60	94	48	27	1	77		0.68
1960	31	1900	28	48	27	38	5	72		0.19
1961	15	2000	22	24	4	20	4	31		0.07
1962	6	1400	9	11	1	2	0.4	14		0.06
1963	4	430	8	9	2	0.3	0.4	14		0.17
1964	6	190	7	13	0.3	0.2	0.3	15	1900	0.08
1965	2	69	3	6	0.1	0.3	0.2	12	1200	0.50
1966	2	29	3	5	0.1	0.7	0.2	7	3100	0.16
1967	3	17	5	9	0.2	0.5	0.9	3	13300	1.03
1968	1	5	3	4	0.03	0.3	0.3	1	9700	0.04
1969	1	2	3	5	0.02	0.2	0.5	1	12200	0.20
1970	2	1	4	5	0.06	0.02	0.3	1	9500	0.40
1971	1	0.5	3	3	0.05	0.01	0.2	1	8900	0.05
1972	2	0.5	6	5	0.03	0.01	0.3	1	10600	0.07
1973	2	0.7	7		0.02	0.05	0.5	1	15000	0.08
1974	1	0.2	6		0.02	0.02	0.2	0.6	8600	0.02
1975	0.6	0.3	7				0.3	0.5	11000	0.02
1976	0.2	0.2	5				0.03	0.9	7400	0.01
1977	0.2	0.2	3				0.03	0.4	6200	0.03
1978	0.3	0.2	2				0.04	0.4	6300	0.03
1979	0.2	0.1	2.4				0.04	0.4	7700	0.03
1980	0.6	0	1.5				0.04	0.4	4600	0.04
1981	0.2	0.1	1.5				0.04	0.7	2900	0.04
1982	1.5	0.2	2.7				0.06	1.0	5400	0.03
1983	1.2	0.2	2.1				0.004	0.3	5600	0.05
1984	0.6	0.2	2.6				0.05	0.2	6400	0.03
1985	0.4	0.007	3.0					0.6	3700	0.008
1986	1.0	0	1.8					0.54	2600	0.024
1987	0.6	0	1.2					0.12	2500	0.006
1988	0.4	0	1.1					<0.07	1700	
1989	1.2	0	2.9					0.13	4100	
1990	1.4[f]	0	3.1					0.12	3100	
1991	1.6[f]		2.7					0.12	2100	
1992	0.68[f]		2.1					0.04	1900	
1993	0.52[f]		2.1					0.04	1700	
1994	0.54[f]		2.8					0.07	2200	
1995	0.31[f]									
Total	700.	6931.6	1214.6	1295	341.93	376.61	175.33	325.53	183100	5.248

[a]All digits carried through to avoid rounding errors. Only first two are significant.
[b]Total rare earth elements, exclusive of cerium.
[c]Blank cells indicate no data reported.
[d]Transuranic radionuclides.
[f]This report.

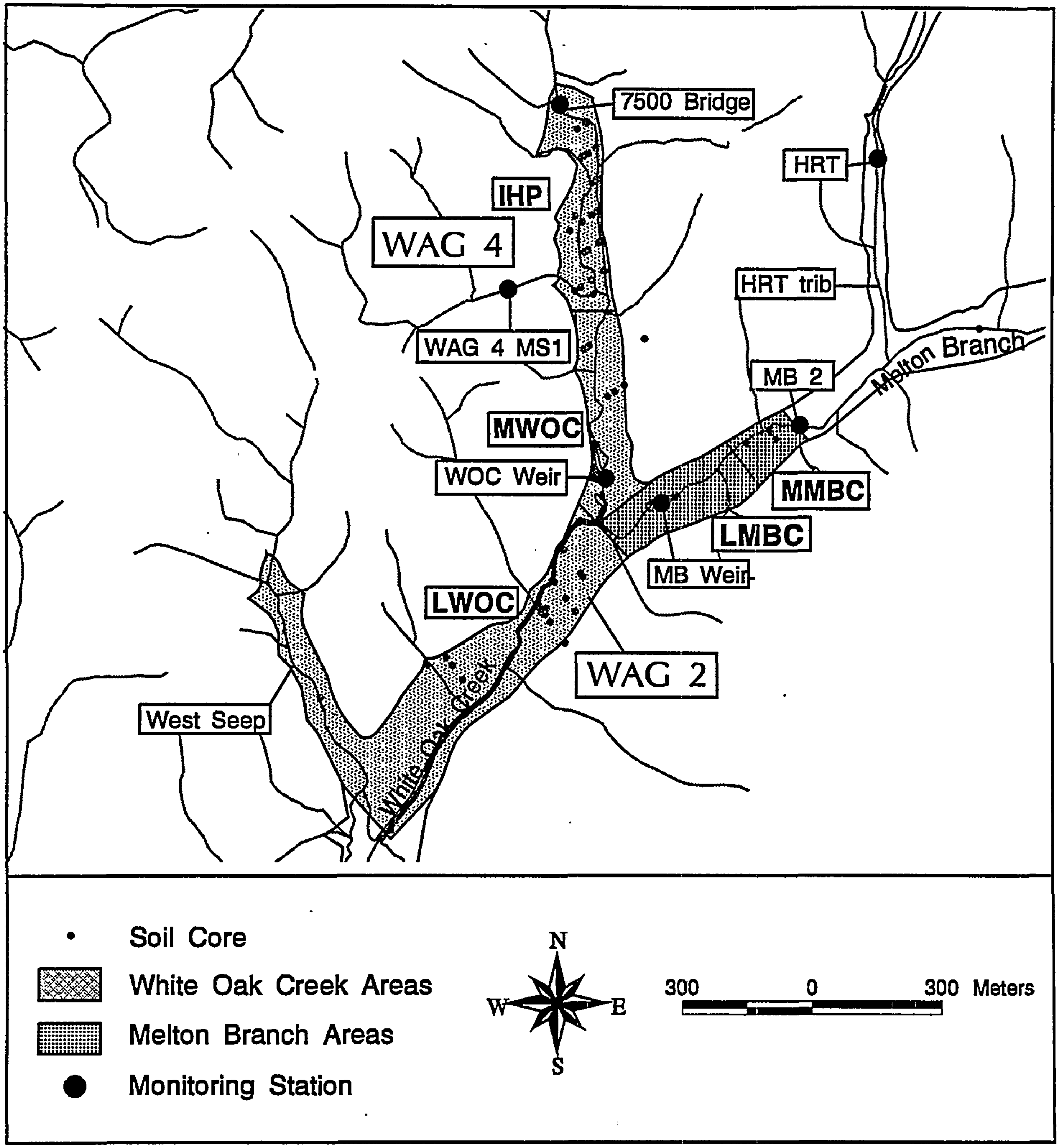


Fig. 2.3. WAG 2 divided into subreaches some of which have large ^{137}Cs inventories.

Melton Branch (MB) reach. This area extends from the headwaters of this tributary down to Melton Branch weir. Ford et al. (1996) subdivide the reach as follows:

Upper Melton Branch from the headwaters to a small monitoring station known as MB 2. Runoff from the High Flux Isotope Facility reactor and the settling ponds near the reactor led to soil contamination with ^{137}Cs and ^{60}Co in this subreach.

Middle Melton Branch (MMBC) the portion of Melton Branch near the confluence of the HRT tributary and Melton Branch. The HRT tributary drains WAG 9 and the western portion of WAG 5.

Lower Melton Branch (LMBC) extends from the HRT tributary to the MB weir. The main radionuclides entering Middle and Lower Melton Branch subreaches are H-3 and Sr-90. As shown later, levels of ^{137}Cs and Co-60 measured at MB weir are quite relatively low and insignificant to off-site transport.

Lower White Oak Creek / White Oak Lake Reach. This area extends from WOC and MB weirs down to White Oak Lake outlet at White Oak Dam.

The **White Oak Creek Floodplain** is the low-lying area from the weirs to upper end of White Oak Lake.

White Oak Lake is the shallow water body to the eastern side of State Route 95. It is formed by White Oak Dam, considered to be the last point of hydrologic control for ORNL and the main monitoring point for ORNL-site discharges of surface water. West Seep transmits surface water from both WAG 6 and WAG 7 to White Oak Lake.

White Oak Creek Embayment Reach. This area extends from WOD to the confluence with Clinch River. In 1992, a sediment retention structure was built on WOC in the embayment just above the confluence.

Over the years the radionuclide content of the soils in WAG 2 has been estimated from sampling data. Past estimates are shown in Table 2.2 with adjustment for radioactive decay and no adjustment for possible erosion or deposition.

For the IHP the estimate of the shallow ^{137}Cs inventory by Ford et al. (1996) is similar to the age-adjusted estimate in the previous table. Lower Middle White Oak Creek has a relatively small inventory of ^{137}Cs (about 1 Ci) although the samples did not include the sediment in the WOC weir pool that has since been removed.

Taken together the data in Tables 2.2 and 2.3 show that White Oak Lake sediments have the largest share of the ^{137}Cs (about 330-410 Ci). The ^{137}Cs estimates from the shallow cores are probably most relevant to the issue of ^{137}Cs mobility due to erosion. The next largest inventory is in the IHP (~55 Ci) followed by the lower WOC floodplain (~32 Ci) and the embayment (about 6-11 Ci). The estimates in Table 2.3 from Ford et al. (1996) seem to be reasonable and perhaps conservative (high). They did not include any adjustment for spatial variability, and the cores may have been gathered selectively from the hotter areas within the floodplain.

The data show the large amounts of ^{137}Cs in WAG 2 that are associated with contaminated soils and sediments. The ^{137}Cs in these inventories might be mobilized by erosion, although flux measurements in WOC reported in Chap. 3 indicate that there is not much ^{137}Cs erosion.

Table 2.2. Estimated ^{137}Cs Inventories in ORNL WAG 2

Site	Year of Estimate	Inventory (Ci)	Source	Estimate Adjusted to 1995 (Ci)
IHP	1974	105	Based on 53 cores on a 30 m grid (Dahlman and Van Voris 1976)	65
WOL + Part of Lower WOC Flood Plain	1962	704	17.8 ha of former WOL bed; 250 random locations cored to 2 ft depth. (Lomenick and Gardner 1965) Represents the Lake and a portion of the Lower WOC floodplain.	328
Same as above	1979	591	13.3-ha lake area (Oakes et al. 1982)	408
WOL	1986	405	Based on 6.9-ha lake area as determined by Sherwood and Loar (1987). Cores collected by Blaylock and Mohrbacher (Loar et al. 1988)	329
WOCE	1990-91	6-11	Embayment estimate (Blaylock et al., 1993)	6-11

Table 2.3. ^{137}Cs inventory estimates in WAG 2 based on average concentrations from soil and sediment cores and on reach area (Ford et al. 1996)

Area (# cores)	<20 cm (Ci)	20 cm to bottom of core	Total (Ci)
Intermediate Holding Pond (39)	53.6	71.7	125.3
Middle WOC (17)	0.9	0.187	1.087
Lower WOC floodplain (23)	32.1	38.6	70.7
Middle MB Creek (6)	0.0045	0.0005	0.005
Lower MB Creek (12)	0.805	0.829	1.634
Total (Ci):	107.4	131.3	198.7

*Due to the small number of observations for upper Melton Branch Creek inventory values were not calculated.

2.4.2 Cesium-137 Sources in WOC Watershed

The sources of ^{137}Cs to the WOC drainage system are listed below in the estimated order of magnitude, starting with the largest contributor:

1. Effluent from the Non-radiological Waste Treatment Facility (NRWTF),

2. Episodic erosion of ^{137}Cs contaminated soils from waste areas, the Intermediate Pond Holding area, and the floodplains to the creeks and tributaries,

3. Seepage of ^{137}Cs contaminated groundwater in WAG 4, and

4. possible diffuse contaminated groundwater inputs to the surface water system.

There is extensive data for the NRWTF effluent, some data for the WAG4 seeps, and no direct data for storm erosion or diffuse ^{137}Cs contaminated groundwater inputs.

2.4.3 Non Radiological Waste Treatment Facility

The NRWTF provides final treatment for the effluent from the Process Waste Treatment Plant, which removes radionuclides from low-level waste water from all radiological laboratories plus contaminated water pumped from building sumps. In addition, the NRWTF treats waste water from all ORNL laboratory and production areas except for the sanitary liquid waste which is processed in a separate facility. When the NRWTF came on-line in 1990, effluent monitoring at the facility consisted of automatic composite sampling at set time intervals (not flow-paced). In 1993 the current system of flow paced sampling was put in place. Monthly composite samples are retrieved by OECD staff and analyzed for gamma constituents, Sr-90, and H-3.

Annual ^{137}Cs discharges at the NRWTF are shown in Table 2.4 along with the discharges at White Oak Dam. Data in the table show that

- NRWTF is a very large source of ^{137}Cs to WOC system for all years;
- for 1990 and 1991 NRWTF releases are slightly less than 1/3 of the releases estimated for WOD; and
- for 1992-1995 NRWTF releases are roughly equal to or slightly greater than the releases at WOD.

While these data seem to suggest that -- for the period 1992-1995 -- the ^{137}Cs released at the NRWTF is transported directly to WOD and released there, the WOC system is not that simple, as will be shown in Chap. 3. Other data indicate that the ^{137}Cs from the NRWTF tends to sorb onto channel bed sediments in WOC channel during low flows then sediments and ^{137}Cs get resuspended during storms. Deposition in White Oak Lake also complicates the pattern of ^{137}Cs transport in the WOC watershed.

2.4.3.1 Seepage of groundwater in WAG 4

In comparison to the NRWTF effluent, the contribution of ^{137}Cs from groundwater or seepage is very much smaller and perhaps inconsequential to the annual releases at White Oak Dam. The ensuing analysis is included mainly for completeness.

Intensive sampling of seeps in WAG 2 and the other WAGs in Melton Valley resulted in the identification of only two seeps, both located in WAG 4, with significant ^{137}Cs contamination (Hicks 1996). There is no evidence of any input of ^{137}Cs contaminated groundwater directly to streams based on transect sampling along stream reaches.

Table 2.4 Annual ^{137}Cs Discharge from the Non Rad Waste Treatment Facility

Year	NRWTF (Ci)	WOD (Ci)
1990	0.43	1.43
1991	0.58	1.64
1992	0.74	0.68
1993	0.70	0.52
1994	0.67	0.54
1995	0.30	0.31

In WAG 4, Seeps BTT and SW4-2 had the highest ^{137}Cs concentration of all locations sampled in the watershed. These sites are located in the vicinity of the small tributary that drains WAG 4, as shown in Fig. 2.4. ^{137}Cs concentration was measured from grab samples 7 times between March 1993 and August 1994. Most of the ^{137}Cs in the samples was in the dissolved phase (i.e., in the filtrate that passed through a 0.45-µm filter), but some of the ^{137}Cs was associated with particulates.

Seep BTT. Average concentration (dissolved and particulate combined) for the 7 sampling events was 243 ± 140 pCi/L (mean ± 1 std. error) (Hicks 1996). Using concurrent flow measurements at BTT, the computed ^{137}Cs flux for the 7 samples averaged 116 ± 103 pCi/s (mean ± 1 std. error). This flux can be used to generate a rough estimate of the annual ^{137}Cs flux from BTT.

$$116\ pCi/s \times 86400\ s/day \times 365\ day/yr \times 10^{-9}\ mCi/pCi = 4\ mCi/yr$$

The flux of the mostly dissolved ^{137}Cs seepage probably increases during storms. Sampling uncertainty and variability in annual flows may result in an actual average annual flux from 2 to 4 times greater than the estimate shown above; therefore, an average annual flux of 8 to 16 mCi is considered to be a reasonable educated guess.

Seep SW4-2. Seep SW4-2 appears to be located at the end of an earth-covered waste trench. Samples at SW4-2 had an average of 220 pCi/L (based on the sum of dissolved and particulate concentrations as reported by Hicks, 1996). There were no concurrent flow measurements, so no fluxes can be calculated for the sampling episodes. Subsequent flow measurements at the seep showed that flows are short in duration and magnitude as compared to those at BTT (Energy Systems, 1995). For 3 months during the winter 1995, flow at site SCS2 (corresponding to SW4-2) was 1% of the flow measured at BTT (ER 1995). Consequently, the annual ^{137}Cs flux from seep SW4-2 is probably about 1% of that from BTT, and this quantity is insignificant compared to the annual ^{137}Cs fluxes in WOC.

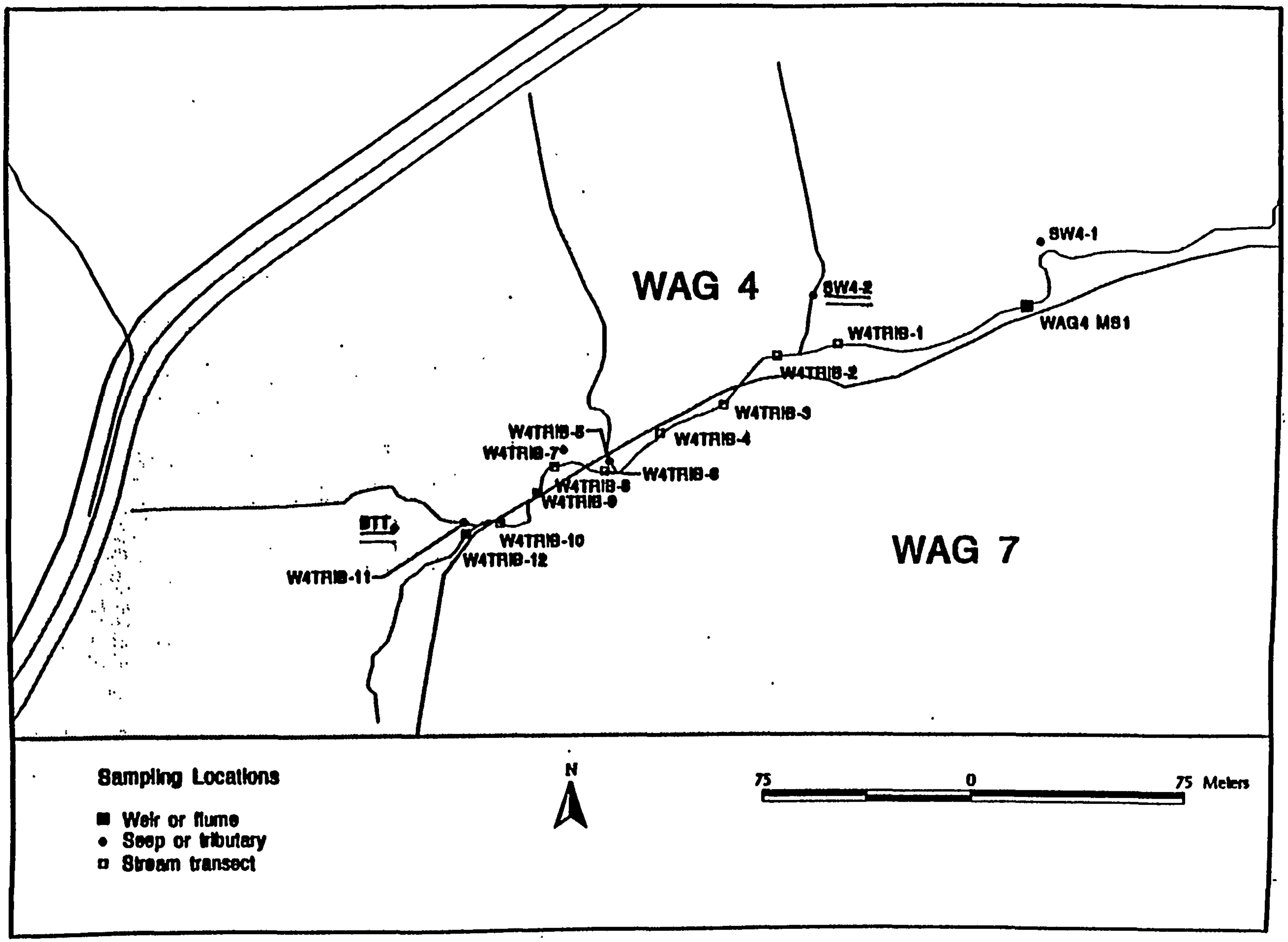


Fig. 2.4. Locations of seeps sampled along the WAG 4 tributary. Seeps BTT and SW4-2 have elevated levels of ^{137}Cs.

Monitoring station WAG 4 MS1 on the tributary that drains WAG 4 collects flows emanating from both BTT and SW4-2. During low flow, grab samples at WAG4 MS1 yielded ^{137}Cs levels below detection. Although dilution can be a factor in the non-detection, it seems reasonable that the ^{137}Cs discharged mostly in a "dissolved" state (< 0.45 µm) from the seeps adsorbs to sediments and/or other materials in the small channel above the monitoring station. The ^{137}Cs-contaminated sediments can be mobilized during high flows, and storm monitoring at WAG 4 MS-1 has indicated elevated levels of ^{137}Cs not seen in low flows (Borders et al. 1996).

In summary, the ^{137}Cs contaminated groundwater from the two seeps (BTT and SW4-2) are mobilized and transported to the main WOC during storms, therefore, these sources are indistinguishable from the washoff of contaminated soil during storms. There may be other, probably smaller groundwater sources of ^{137}Cs that also follow this pattern of seepage, sorption, and subsequent mobilization as streamflow increases during storms.

Besides WAG 4 tributary, HRT tributary east of WAG 5 was the only other tributary monitored in 1993 and 1994 that showed measurable ^{137}Cs levels during storms (Borders et al. 1996), although the levels at HRT were very low. HRT tributary drains WAG 9 and it empties into Melton Branch above MB weir. At MB weir storm samples usually showed ^{137}Cs below detection, suggesting that either ^{137}Cs from HRT tributary is removed by sorption along the water course and/or that dilution reduced the ^{137}Cs below detection limits.

2.4.3.2 Cesium-137 Contaminated Soil and Sediment Sources

Contaminated sediments in the tributary channels, such as WAG 4 tributary, are mobilized during storms. A much larger contribution of ^{137}Cs comes from contaminated soil that is mobilized and transported by erosion processes, i.e., sheet, gully and rill erosion. Sources of ^{137}Cs are presumed to be the areas known to contain large inventories of ^{137}Cs, as identified in the Table 2.3. The quantitative estimation of sediment loads and ^{137}Cs loads from these areas was part of the modeling task, and it is discussed in Chap. 4.

2.5 SUMMARY

WAG 2 has significant inventories of ^{137}Cs-contaminated sediments and soils in White Oak Lake, the IHP area, and WOC floodplain. The potential for mobilization, transport, and release from WOC watershed from the inventories by storm erosion is not directly measurable. These sources and potential sources of ^{137}Cs are simulated in the watershed transport model as described in Chap. 4. The known active sources of ^{137}Cs are the NRWTF which contributes a large fraction of the mobile ^{137}Cs, and two small seeps in WAG 4 which contribute a very minor faction of the mobile ^{137}Cs. The next chapter focuses on direct measurements of ^{137}Cs fluxes in the WOC surface water system.

3. STORM SAMPLING AND DATA COLLECTION

When this project was conceived the underlying assumption was that ^{137}Cs transport within the watershed is essentially storm-driven, with large increases in ^{137}Cs fluxes for increases in discharge in White Oak Creek. This was based on sediment transport theory in which the sediment transport capacity increases nonlinearly with streamflow. To test this idea and to gather the data needed to develop a model of sediment and ^{137}Cs transport in the WOC watershed, a storm sampling subtask was implemented.

This chapter describes the storm sampling effort, the resulting data, and the data analysis. The chapter also presents other data used in simulating the system as reported in Chap. 4 and in developing a conceptual model of the ^{137}Cs behavior in the WOC watershed. The sections present the following information:

- Sects. 3.1 through 3.4 describe where and how the data were collected. Over 1300 samples were analyzed to develop an extensive screening level data set for building a computer model.
- Sect. 3.5 briefly describes the climatic and hydrologic data that were gathered for the computer modeling.
- Sect. 3.6 is an analysis of the storm data which shows that ^{137}Cs movement does respond to increased peak flows but that the pattern among storms is complicated suggesting that the buildup of ^{137}Cs on channel sediments between storms is important, too.
- Sects. 3.7 and 3.8 show that ^{137}Cs is also transported at low flows at the upper end of WAG 2, and that ^{137}Cs transport is seasonal with a storm-driven component, although storms seem to be less effective in transporting ^{137}Cs in recent years. These observations are based on the compliance data collected at the main monitoring stations in the watershed.
- Sect. 3.9 provides an estimate of the 100-year peak flow for discharge at White Oak Dam. This peak flow is essential for the modeling reported in the next chapter.

Taken together the information in this chapter is the basis for a revised conceptual model of ^{137}Cs behavior in the WOC watershed, however, the conceptual model is not presented until the final chapter of the report because it builds from the results of the modeling presented in Chaps. 4 and 5.

The storm sampling system was developed in 1992. By March 1993 it was fully implemented, and sampling continued for 25 months through March 1995. Since then automatic sampling has been continued only at White Oak Dam as part of the ORNL Surface Water Project. The purpose is to collect only data from floods greater than any of those sampled to date.

The chances of sampling a truly large flood event in a two-year period are low. The probability of a 10-yr or greater flood during two years is 19%, and for a 25-yr and 50-yr flood the probabilities are 8% and 4%, respectively. Nevertheless, the task team collected data from several floods, defining a flood as bank-full flow or higher, in order to understand the behavior of ^{137}Cs transport in the watershed. The return periods for the sampled floods cannot be assessed because the flood frequency estimate generated in this task is considered to be tentative, requiring further refinement before it is applied.

3.1 SAMPLING LOCATIONS

The sampling system consisted of eight automatic sampling stations located throughout the watershed, as shown in Fig. 1.1 and listed in Table 3.1. Above the weir pools at stations on WOC and Melton Branch additional samplers were installed to determine the amount of deposition or scour in the weir pools. In March 1994, 3 of the stations on the smaller tributaries (NWT, ROC, WAG 4 MS1) were deemed to be nonessential, and they were eliminated to reduce costs.

Table 3.1. Storm sampling locations for sediment transport task

Task Site ID	Description	Alternative identifiers	Sub-sites	Sampling locations	Sampling period
WOE	White Oak Creek Embayment	WOCCON		~1.2 m upstream of sediment retention structure	NOV92 to MAR95
WOD	White Oak Dam	MS5, X15, USGS #3538000		~half distance between sharp crested weir and HY95 bridge	DEC91 to present
MBW	Melton Branch Weir	MS4, X13, MB1, USGS #3537500		~4.5 m downstream of weir pool	DEC91 to MAR95
	Upstream of MB Weir		Upstream	~7.6 m upstream of weir pool	DEC91 to MAR94
WOCW	White Oak Creek Weir	MS3, X14, USGS #3537000		~4.5 m downstream of weir pool	DEC91 to MAR95
	Upstream of WOC Weir		Upstream	~7.6 m upstream of weir pool	DEC91 to MAR94
WAG4-MS1	WAG4 Tributary	none		~3 m downstream of Parshall flume	FEB92 to MAR94
GS3	7500 Bridge	USGS #3536550		~8 m downstream of weir pool	FEB92 to MAR95
NWT	Northwest Tributary	GS4, USGS #3536440		~6 m downstream of weir pool	FEB92 to MAR94
ROC	Rock Outcrop	GS6, USGS #3536320		~8 m downstream of rock outcrop (control structure)	FEB92 to MAR94

3.2 SAMPLING AND ANALYSIS METHODS

This section presents the methods for collecting and analyzing the storm samples. Thousands of samples were collected by the automatic samplers, and over 1300 samples were selected for analysis in the laboratory.

3.2.1 Automatic Sampling

Automatic samples are collected in accordance with ER/WAG2-SOP-3205. Sampling stations were equipped with ISCO 2700 automatic samplers and Ominidata EasyLogger electronic data loggers connected with pressure transducers to detect stream stage. The loggers were programmed to trigger the automatic samplers when stream stage exceeded preset levels. Once turned on, the automatic samplers were programmed to sequentially collect samples at fixed intervals. Sample collection strategy varied among the sites and seasons. During the winter and spring, at WOD and the major weirs, two samplers were programmed so that the first sampler collected samples every 30 minutes followed by the second sampler that collected samples hourly. Often the filled sample bottles were collected, and a new round of hourly sampling was initiated with clean, empty bottles. During the summer and fall the protocol was changed. The first sampler was programmed to collect samples at 15-minute intervals, and the second sampler collected samples at 30-minute intervals. At sites on smaller tributaries, samples were generally collected at hour intervals.

At most sites, samples are collected through an intake tube at a point approximately 2/3 depth below the water surface during storm flow. Temporary intake lines were anchored with cables and held in the channel with weights that occasionally caught storm debris, sometimes causing the lines to break free losing sampling capability. Permanent ISCO intake lines were installed downstream from the weir pools at WOCW and MBW to prevent such losses. The permanent structure was an aluminum frame attached to the bridge's guardrails with the intake supported from a rocker arm which rotated to allow large debris to pass without damaging the structure. A permanent intake was also placed at the WOD site.

3.2.2 Manual Sampling

Stream sediments are not transported uniformly in the stream cross section. Sediments, especially the coarser sediments, tend to move in the lower parts of the cross section. Because automatic samplers have fixed intakes there was concern that these samples would be biased due to sediment stratification in the water column. To determine the representativeness of the automatic sampling, limited manual sampling was conducted in accordance with ER/WAG2-SOP-3103. Manual samples were collected using the equal-width-increment method by which the stream width is divided into sections and a special sample bottle is lowered carefully at a predetermined rate into the water at each section. As the bottle descends it fills steadily with water to get a vertically integrated sample. Together the vertically integrated samples at points equally spaced across the stream provided a complete sampling of sediment transported through the stream cross section. In the analysis there was no compensation for the possible differences in the velocity profile.

Manual sampling results are compared to those obtained by automatic sampler in Fig. 3.1. The good agreement ($R^2 = 0.97$) indicates that the fixed sampler intakes do not lead to biased suspended sediment concentrations for the WOC watershed system, probably because sampling sites are downstream of weirs or flumes where convergent flow has caused mixing within the water column. Demonstration of lack of sampling bias by the automatic sampler is an important test for quality assurance.

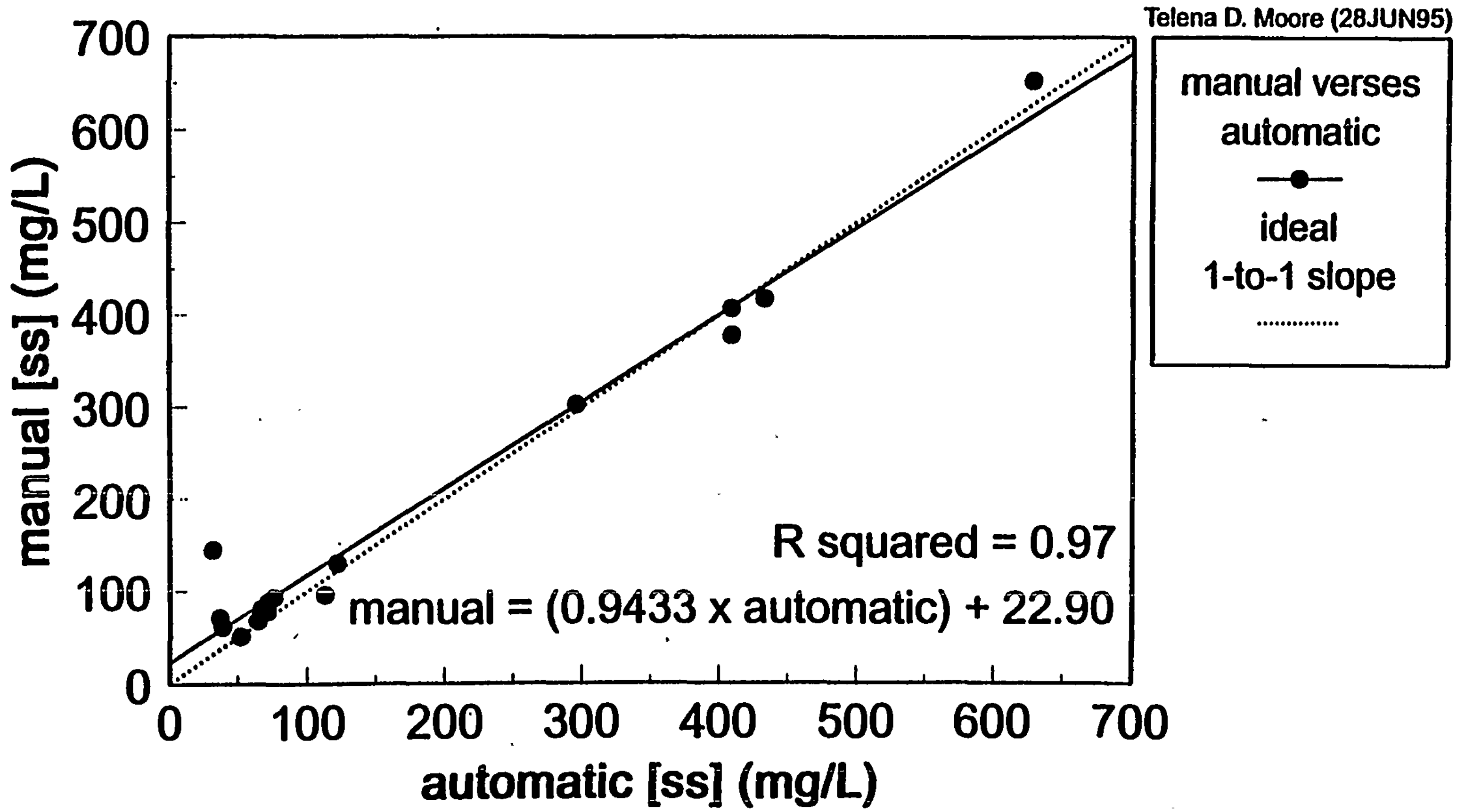


Fig 3.1. Suspended sediment concentration from automatic samplers and from manual sampling.

3.3 LABORATORY PROCEDURES

Samples collected during a storm were processed at an ESD laboratory. Samples were cooled to reduce the chance of algae growth and processed from one day to three weeks of the collection time. The field technician collected and processed the electronic log of the stream stage which also contained the times of sampling, as recorded by the logger. For the large storms it was not uncommon to collect 96 1-L bottles (4 tubs x 24 bottles/tub) therefore the task leader had to identify which samples to analyze. In general, most of the samples from the rising limb of the hydrograph, all hydrograph peaks, and a few samples from the recession limb spaced in roughly geometric progression were selected for analysis.

In the laboratory, samples were analyzed for suspended sediment concentration (ER/WAG2-SOP-4502); grain size distribution (ER/WAG2-SOP-4503 and ER/WAG2-SOP-4501); and gamma activity for ^{137}Cs and ^{60}Co using the germanium detector for fluid samples and sodium iodide detector for sediment/soil samples (ER/WAG2-SOP-4201 and ER/WAG2-SOP-4202). The record copies from these laboratory results and any additional information noted in the Research and Technical Notebooks are stored in the Environmental Restoration Document Management Center (DMC) in accordance with ER/WAG2-SOP-2401. The results from these samples were used to calculate sediment and contaminant storm loads and to develop the watershed sediment transport model.

3.3.1 Grain-size Analysis

Particle-reactive contaminants do not adhere to all sediment particles uniformly. Contaminants tend to sorb preferentially to clay and fine silt particles mainly because clay minerals have more reactive surfaces as compared to quartz and the other minerals that tend to constitute the sand and coarse silt fractions of the sediment load.

Knowledge of the grain-size fractions and the relationship between contaminant concentration and grain-size fractions is important to understanding sediment/contaminant transport. The watershed modeling required as input the fractions of clay ($\leq$ 4 µm), fine silt (4 to 16 µm), coarse silt (16 to 62 µm), and sand ($\geq$ 62 µm). The model also required average contaminant concentrations for each of these four particle size classes. Collection of these data was recognized as an important problem early in the study, and solutions were methodically sought.

Two separate problems were addressed. First, most grain-size distribution procedures were impractical because of the limited amount of suspended sediment available per sample in the WOC samples(storm sediment concentrations can vary from about 25 to 800+ mg/L). Therefore a method was sought that could efficiently separate small sediment samples into homogeneous size fractions for subsequent gamma analysis.

Second, most grain-size distribution test procedures required chemical additives to break down the natural soil structures that bind clay particles into larger soil aggregates (i.e., dispersants and organic removers). Research indicated that grain-size fractions vary significantly with chemically altered samples as compared to non-chemically altered results (Clevenger, 1995). Because results were used to develop a model for naturally occurring watershed processes, methods were modified to eliminate chemical treatments that would alter the natural, in-stream sizes of suspended sediments.

Due to its small sample size requirements, the bottom withdrawal test (Guy, 1969) was initially chosen for grain size analysis of the suspended sediments collected during storms. However, preliminary experiments revealed the subsamples separated by the Bottom withdrawal procedure were a mixture of smaller particle sizes (e.g., the fine silt sample contained both fine silt and clay fractions). Subsequently, a new test yielding homogeneous size fractions was developed by modifying the settling column test procedure of Loring and Rantala (1992). This modified column test provided homogeneous size fractions using a non-destructive process, as described in ER/WAG2-SOP-4503. Results from the modified column test results compared well with those from two other grain size distribution tests (Moore et al., 1994).

Both the original bottom withdrawal and the modified column test procedures required compositing of several sequential samples to gain sufficient sediment in the grain-size subsamples for gamma analysis. The bottom withdrawal procedure (ER/WAG2-SOP-4501) involves decanting and disposing the sample liquid after sediment settling has occurred. It was found that significant portion of the clay fraction was lost in the decanted portion, and that allowing the sample to sit overnight prior to decanting eliminates significant loss of the clay fraction. This was not determined until the storm of December 1993, and by then, work had begun on developing the column test SOP. Caution should be used when interpreting the BW results for December 1993 and earlier, because some of the clay fractions may be underestimated. After December 1993, the column test was used, and the size-fraction and contaminant-per-size-fraction data are considered accurate.

3.3.2 Assessment of Data Quality

The purpose for collecting and analyzing storm samples was to support the development of models of ^{137}Cs contaminated sediments transported within the WOC watershed and discharged from the watershed into the Clinch River. The DQO meeting with program staff and representatives from DOE and the regulators resulted in a specific objective: assessment of the effects of a 100-year storm to the off-site public. The issue is the chronic exposure to the ^{137}Cs that might accumulate at times and distances significantly removed from the measured data, which represent highly transient processes. The statistics of the contaminant concentrations observed in this task are not intended to be compared to regulatory standards; they are to be used to build models that introduce significant levels of uncertainty. For these reasons, the ^{137}Cs concentrations in the collected samples are considered to be *screen level data*. Furthermore, in this task contaminant mass flux is the important variable, and this variable is the product of the measured concentration times the flow, where the flow is field measured variable, itself considered to be screening level data.

When fully implemented for the storm of March 1993 (the first of 5 storms analyzed in detail) the steps to ensure data quality were the control of procedures, training and training documentation of the field and laboratory teams, chain of custody of samples, and development of laboratory data packages to support QA Levels III and IV (i.e., *definitive data*) for validation in keeping with the project DQO statement (Appendix A). In March 1994, in keeping with the intended use of the data and in keeping with DOE requests to limit extensive validation, the task DQO statement was revised to call for data to be considered screening level. Task files sent to the ER Document Management Center contain all task data packages including gamma sensor calibration data, results from rinsate analyses, and chain of custody documentation. None of the data from this task was included in the contract validation work for the WAG 2 RI program the occurred in FY 1995.

Gathering sequential samples during a flood-producing storm, which often occur during the night and other off-work hours, is difficult at best and sometimes impossible. Any concerns about data quality relative to the uses of the data were focused mainly on the representativeness and completeness of the samples rather than the analytical accuracy, which is judged to be sufficient for the intended purpose of model development. As already mentioned, manual sampling demonstrated that the single intake to the automatic samplers gave representative samples for the whole water column. Samples collected in this task were analyzed for particle-bound ^{137}Cs, which is interpreted as total ^{137}Cs because the samples were allowed to sit from 2 days to 3 weeks providing plenty of time for dissolved ^{137}Cs to sorb to sediments in the sample. Filtrates of selected samples had ^{137}Cslevels less than the detectable limits that averaged 4.5 pCi/L in all cases except one where there was a measurable level of 6.5 pCi/L. All field blanks were below detectable limits, as were rinsate samples. All filtrate, field blanks, and rinsate concentration concentrations are documented in the task files. Automatic sampling provided excellent coverage of the stream flows at and near the stream flow peak when contaminant fluxes tend to be greatest. Problems related to sampling at the very beginning of the storm and later at the end of the hydrograph recession are discussed later in this section. Beginning and ending concentration levels are estimated based on long-term averages and the results are not particularly sensitive to these estimates.

The data set generated to build the models described in the subsequent sections is judged to be good to excellent in terms of sufficiency and accuracy. Hard-copy files of the data in the Document Management Center provides backup information concerning quality control measures.

3.4 COMPLIANCE DATA

The intensive storm sampling by the Sediment Modeling Task team contrasts the continuous sampling of streamflow by the Environmental Surveillance and Protection Section within the ORNL OECD. This compliance group has collected flow-paced samples monthly at many of the same sites where automatic storm occurred. These data provide the long-term concentrations needed for estimation of chronic exposures. Compliance "months" typically run 4 to 5 weeks (28 or 35 days) and samples can be collected at all sites on the same day or within 24 hours. The main exception is White Oak Dam where flow-paced samples collected for gamma analysis only are retrieved weekly. While these records also include flow estimates the flow data are not suitable for flux calculations because they have not been corrected for short-term aberrations such as backflow conditions and recent updates to rating curves.

3.5 HYDROLOGIC DATA

Hydrologic data are essential for calculation of contaminant fluxes and for watershed modeling. For this investigation, hydrologic data were collected at monitoring stations in WOC watershed mostly by the ER Surface Water Monitoring Group within the WAG 2 RI and Site Investigation Program. Rainfall and stream gaging sites are described by Borders et al. (1989). Subsequently, the data are described in the annual hydrologic data summaries (e.g., Borders et al. 1995). Hydrologic data files used in the investigation are available in electronic form on removable mass storage disks transferred to the Environmental Restoration Document Management Center. A general listing of the types of data sets appear in Appendix B.

3.5.1 Precipitation

Hourly precipitation collected at seven sites in and near the WOC basin using recording weighing bucket gages was used in the watershed modeling. In the model, the watershed was divided into four subwatersheds and average precipitation was calculated for each subwatershed using the method of Theissen polygons. The details of the averaging method and the statistical weights used in the averaging are listed in Appendix B. In addition, hourly and daily rainfall records collected at the Oak Ridge town site for the 41-year period from 1953 through 1994 were used to simulate a long-term hydrograph for determining flood frequencies. The records were obtained through the National Climate Center of the National Oceanographic and Atmospheric Agency (NOAA), located in Asheville, North Carolina.

3.5.2 Runoff

Most of the streamflow discharge data was collected by the ER Surface Water Monitoring Group. The U.S. Geological Survey (USGS) measured stream discharge at three sites (Northwest Tributary, First Creek, and 7500 Bridge). OECD supplied the flows at the Non-Radiological Waste Treatment Facility. Stream stage data have been collected at the mouth of the WOC Embayment upstream from the Sediment Retention Structure.The retention structure has coffer cells filled with rock, and the entire structure is built to be permeable. Since about late 1994 the permeability has decreased presumably due to sediment accumulation in the rock-filled coffers. Establishing a time-varying rating curve would be difficult and has not been done. The stage data has assisted the analysis of the storm data in the WOC Embayment.

A interim revised rating curve for the high flow weir at White Oak Dam was issued in June 1995 (Clapp et al., 1995). The revised rating yields higher flows at a given stage compared to the earlier rating curve. The main consequence has been slightly higher flows at WOD using this method and better mass balance calculations for ^{3}H and ^{90}Sr in White Oak Lake (Clapp et al. 1995). The radionuclide mass balances for 1993-95 have been updated using flows calculated from this interim rating curve. All flows at WOD used in calibrating and documenting the watershed transport model in Chap. 4 are also based on the revised rating. The final revision of the rating curve will be issued in late FY1996, and historic flows and mass fluxes will be recalculated after that. The changes to the final revision of the rating curve are not expected to affect the results of this study significantly.

3.5.3 Evaporation

The watershed modeling used daily evaporation data from the long-term record of pan evaporation collected at the Agricultural campus at the University of Tennessee in Knoxville, as reported by NOAA.

3.5.4 Stream Temperature

Stream temperature is used in the calculation of sediment deposition in the watershed model. Data were obtained from the ORNL Biological Monitoring and Abatement Program.

3.6 ANALYSIS OF THE STORM SAMPLING DATA

A summary of data collection during storms is shown in Table 3.2. Five of the storms had data sets complete enough to assess the suspended sediment and the ^{137}Cs loads at White Oak Dam and points within the watershed.

Table 3.2. Summary of storm sampling data

Storm date	Precip freq.	Available data *	Sampling locations	Comments
1DEC91	5 - 10 yr	[SS], Γ, Φ, M	MBW, WOCW, WOD	First sampling event.
25FEB92	< 1 yr	[SS], Γ	ALL except WOE	Small data set.
18MAR92	< 1 yr	[SS], Γ	ALL except WOE	Small data set.
12APR92	≈ 2 yr	[SS], Γ	7500Br, WOCW, MBW	Samples from peak to falling limb. Small data set.
1JUL92	< 1 yr	[SS], Γ, Φ	7500Br, WOCW, MBW	Small peaks from 30JUN through 05JUL. Small data sets.
5SEP92	≈ 1 yr	Φ	WAG4-MS1	Check on Φ test.
2NOV92	< 1 yr	[SS], Γ	WOCW, MBW	2 small peaks 2NOV and 4NOV. Small data set.
22NOV92	< 1 yr	[SS], Γ	ALL	Small data set.
17DEC92	< 1 yr	[SS], Γ	WOCW, WOD	Caught peak at both sites.
24JAN93	< 1 yr	[SS]	ROC,NWT,WOCW,MBW, WOD	Very small data set.
21FEB93	< 1 yr	[SS]	WOCW, WOD	Only 3 analyses on WOCW, 8 at WOD.
23MAR93	2 - 5 yr	[SS], Γ, Φ, M	ALL	Some gaps but most complete data set to date.
4DEC93	≈ 10 yr	[SS], Γ, Φ, M	ALL	Limited data at 7500Br. Some time gaps.
10FEB94	2 - 5 yr	[SS], Γ, Φ, M	ALL	Missed peak at 7500Br.
23FEB94	1 - 2 yr	Φ	WOD	Sampled only 1 site due to low manpower
27MAR94	5 - 10 yr	[SS], Γ, Φ, M	ALL	Largest flow storm sampled to date.
8MAR95	< yr	[SS], Γ, Φ	7500Br,WOCW,MBW,WOD	

*where [SS]= suspended sediment concentration
Γ = gamma analysis (Cs-137 and Co-60)
Φ = grain size distribution - most include contaminant checks (note: used bottom withdrawal test prior to 1994, switched to column test starting in January 1994)
M = manual sample
ALL = ROC, NWT, WAG4-MS1, 7500 Bridge , WOCW, MBW, WOD, and WOE

The cumulative sediment discharge and ^{137}Cs discharge for each storm, referred to as sediment and ^{137}Cs loads, were calculated by integrating the data through time. Because there were no samples for the early and late parts of the hydrograph, the estimation procedure depends in part on the assumed concentrations of suspend sediment and ^{137}Cs before and after the storm. Because the stream discharge is relatively low at these points the computed loads are not sensitive to the estimates. Nevertheless, the results should be interpreted as "best estimates" rather than as precise values.

For the estimation of sediment and ^{137}Cs loads the time of integration started at midnight on the day of the storm, and it continued until there was no significant change in the cumulative sediment or contaminant fluxes. Time steps varied from 15 minutes (the smallest time step in the flow data) to several hours depending on the magnitude of the sediment and ^{137}Cs mass flux. Sediment concentrations (mg/L) and sediment-bound ^{137}Cs concentrations (pCi/g) were interpolated by drawing smooth curves through the measured values. To determine grain-size relationships, 2-3 of the sequential 1-L water samples were combined in the laboratory in order to have sufficient sample size for separation of the suspended sediment into grain-size fractions. These size-fractions were subsequently analyzed for ^{137}Cs concentration. For periods when these samples were merged, suspended sediment concentrations were estimated by specifying a smooth function such that the interval yielded the same average sediment content. Errors in the final computed contaminant load due to this qualitative adjustment are judged to be small, on the order of a few percent.

The average rainfall, the average runoff, the duration of the storm period, and peak flow at WOD are listed in Table 3.3. The duration of the storm is the period of time used to determine the average flow and to integrate the suspended sediment and ^{137}Cs data in order to generate the contaminant loads.

Table 3.3 Rainfall and discharge summary for intensively sampled storms

Storm	Average rainfall (mm)	Average runoff at White Oak Dam (L/s)	Duration of the storm period (hr)	Peak runoff at White Oak Dam (L/s)
23Mar93	53	2500	72	12000
04Dec93	116	3049	80	17000
10Feb94	16	5300	80	23100
27Mar94	130	6100	80	20300
08Mar95	42	2000	72	6100

The estimated sediment and ^{137}Cs loads for 5 storms and for the 4 main sites (7500 Bridge, WOC weir, MB weir, WOD and WOE) are shown in Table 3.4. Because ^{137}Cs concentrations were predominately undetectable at MB weir no ^{137}Cs loads were calculated for this station. Appendix C has detailed plots showing the discharge, measured data, estimated trends in the data, and the contaminant loads.

No data are available for 7500 Bridge site for storms of 4Dec93 and 10Feb94 because the sampling system failed. The sampler also failed at WOD during the peak of the hydrograph for the storm of 4Dec93. Concentration data collected at the embayment were used to estimate the suspended sediment and ^{137}Cs concentrations by transposing the data to account for the time of travel in the

Table 3.4 Summary of estimated contaminant loads for five storms

Storm	Site	Peak Flow [L/m (cfs)]	Time of Peak Flow	Volume (liters)	Storm Period[1] (hours)	Estimated Peak [SS][2] (mg/L)	Estimated Time of Peak [SS]	Suspended Sediment (kg)	^{137}Cs Load (Ci)
23MAR1993									
	WOE	NA[3]	NA	NA	72	NA	NA	39641	0.044
	WOD	7.46E5 (439)	23MAR 16:30	6.37e+08	72	183	24MAR 00:00	43870	0.044
	MBW	2.53E5 (149)	23MAR 15:00	1.43E8	72	1029	23MAR 13:45	39849	NA
	WOCW	8.07E5 (475)	23MAR 15:00	4.65E8	72	800	23MAR 14:00	84376	0.092
	7500Br	6.61E5 (389)	23MAR 14:15	3.84E8	72	700	23MAR 14:30	55230	0.034
4DEC1993									
	WOE	NA	NA	NA	80	NA	NA	55720	0.035
	WOD	1.01E6 (597)	04DEC 17:45	8.78E8	80	86 to 113	04DEC 17:30	51871 to 60035	0.028 to 0.033
				9.38E8	120			52708 to 60871	0.029 to 0.034
	MBW	3.08E5 (181)	04DEC 16:45	2.30E8	80	1158	04DEC 10:45	54388	NA
				2.36E8	120			54442	NA
	WOCW	8.02E5 (472)	04DEC 16:45	5.60E8	80	567	04DEC 10:30	66877	0.121
				5.99E8	120			67053	0.121
	7500Br	5.88E5 (346)	04DEC 16:00	4.30E8	80	NA	NA	NA	NA
10FEB1994									
	WOE	NA	NA	NA	80	NA	NA	143549	0.077
					120			149916	0.083
	WOD	1.39E6 (818)	11FEB 01:30	1.53E9	80	250	11FEB 00:00	129415	0.072
				1.72E9	120			138005	0.079
	MBW	3.50E5 (206)	10FEB 23:15	3.45E8	80	1110	10FEB 20:00	61634	NA
				4.01E8	120			70197	NA
	WOCW	7.42E5 (437)	11FEB 00:15	8.78E8	80	680	10FEB 21:00	128540	0.089
				1.03E9	120			141171	0.098
	7500Br	7.25E5 (427)	10FEB 23:45	7.70E8	80	440	10FEB 21:30	89454	0.037
27MAR1994									
	WOE	NA	NA	NA	80	NA	NA	137524	0.083
	WOD	1.22E6 (718)	27MAR 09:15	1.75E9	80	265	27MAR 10:00	130082	0.070
	MBW	3.18E5 (187)	27MAR 08:45	3.63E8	80	769	27MAR 07:30	63615	NA
	WOCW	9.17E5 (540)	27MAR 07:30	1.06E9	80	800	27MAR 07:00	122776	0.048
	7500Br	951E5 (560)	27MAR 07:00	8.36E8	80	NA	NA	NA	NA
8MAR1995									
	WOE	NA	NA	NA	72	NA	NA	26774	0.012
	WOD	3.65E5 (215)	08MAR 10:30	5.26E8	72	132	8MAR 10:30	25704	0.012
	MBW	1.44E5 (85)	08MAR 07:00	1.35E8	72	666	8MAR 04:00	21915	NA
	WOCW	3.01E5 (177)	08MAR 05:00	3.33E8	72	400	8MAR 04:30	26448	0.020
	7500Br	2.07E5 (122)	08MAR 04:30	2.75E8	72	473	8MAR 03:30	16434	0.006

[1]Storm period = length of time used to determine contaminant loads
[2][SS] = suspended sediment concentration
[3]NA = Not Available

embayment. Because of uncertainties in estimating the sediment and ^{137}Cs fluxes at White Oak Dam, range of values were estimated for the storm of 4Dec1993.

3.6.1 Sediment

At White Oak Dam the sediment load ranged from about 26,000 kg for the storm of 8Mar93 to about 130,000 kg for the storms of 10Feb94 and 27Mar94. Sediment load at WOD is related to the both the average flow stream flow and to the peak flow. Average streamflow and peak flow are interrelated and correlated, but the average streamflow seems to be a slightly better predictor of sediment loads. The summary data are plotted in Fig. 3.2. It can be seen that sediment movement in the watershed during the five storms can be divided into three groups:

Sediment load pattern among storms:

10Feb94 ≈ 27Mar94 > 23Mar 93 ≈ 4Dec93 > 8Mar94

In order to track the behavior of suspended sediments within the WOC watershed, sources and sinks of sediments were calculated for the 5 storms, as shown in Fig. 3.3.

The sediment loads in White Oak Creek change from the ORNL plant area to the embayment. For the three storms where sufficient data was retrieved from the 7500 Bridge station, sediment loads increased by 30-38% from 7500 Bridge to WOC weir. Thus the Middle White Oak Creek reach is considered to be a significant source of sediment. The sediment consists of the channel bed sediments deposited in previous storms and mobilized in the sample storms. As shown later the channel bed sorbs the dissolved ^{137}Cs released from the NWRT. The sediment also included erosion from the nearby WAGs. This net gain in sediments in the reach does not take into account the deposition which occurred in the weir pool above the WOC weir.

Sediments measured at WOC weir merge with those measured at MB weir. and they are transported to White Oak Dam. Comparison of inflow and outflow of sediments shows that the Lower White Oak Creek/ White Oak Lake reach is clearly a depositional area; 30 to 65% of the sediment load entering the reach was deposited. Melton Branch supplies a significant portion of the sediment to the lower reach. The Melton Branch portion of the sediment (32, 45, 33, 34, and 45% for the five storms in time sequence) that enters the lower reach is much larger than the relative area (24%) of the WOC watershed that is drained by the tributary.

The embayment seems to have a slight tendency to be a sediment source, but the gain in sediment from White Oak Dam to the sediment retention structure appears to be small. The gain ranged from 4, 5, and 10% for storms of 8Mar95, 27Mar94, and 10Feb94, however, there was 0% gain and a 10% loss of sediment for the storms of 4Dec93 and 23Mar94. So there is no clear trend.

3.6.2 Deposition in Weir Pools

Automatic samplers were installed at sites above the main weir pools for WOC and MB weirs in order to estimate the trapping efficiency of the weir pools. In both cases, the stream velocities at the upstream sites were controlled by the weirs, therefore there was undoubtedly some additional deposition upstream from these intermediary monitoring sites. The effective weir pools below these sites correspond to the areas where sediment capacity should be managed in order to keep proper design-control for the weirs. At the time of the investigation both weir pools had accumulated large

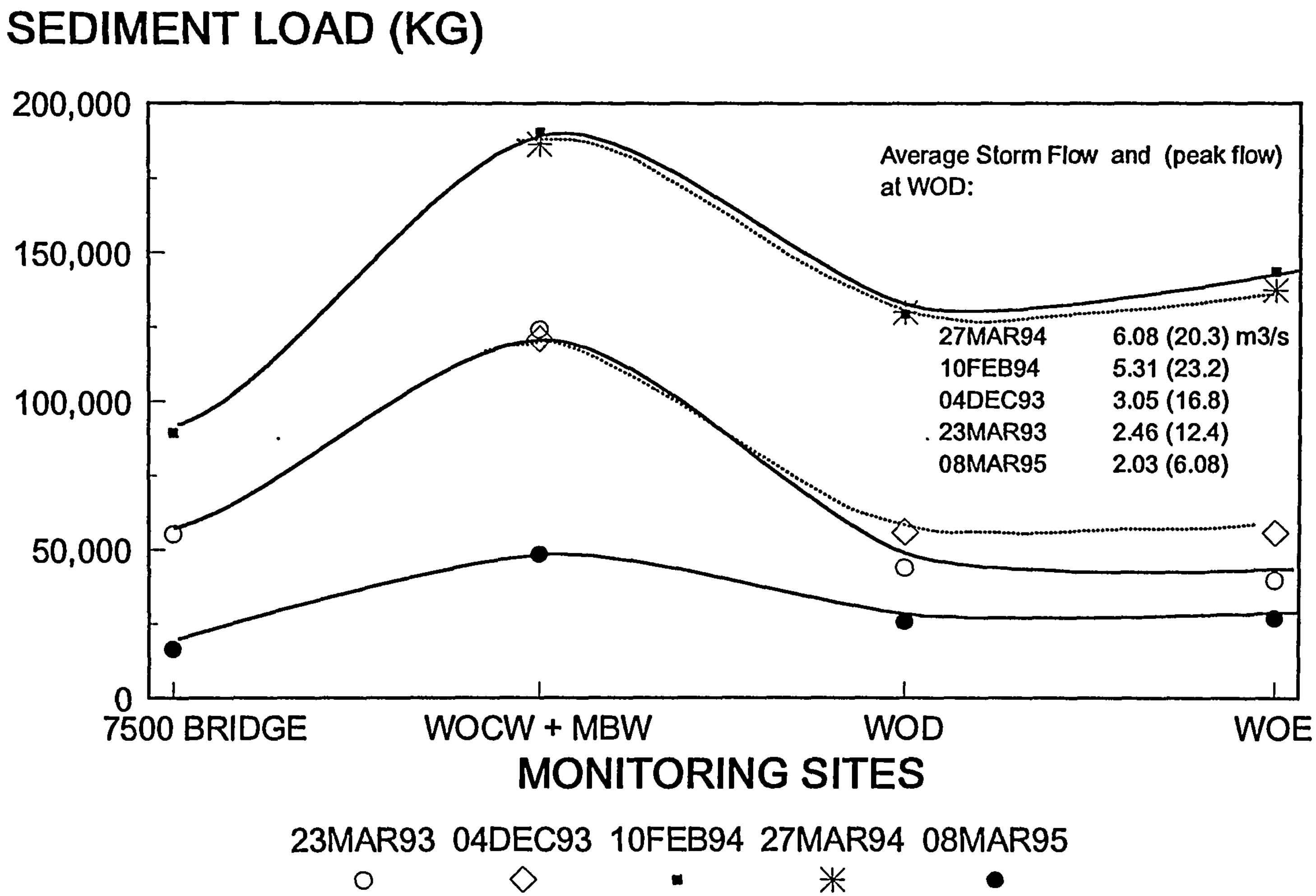


Fig. 3.2. Pattern of suspended sediment loads in White Oak Creek Watershed for five storms.

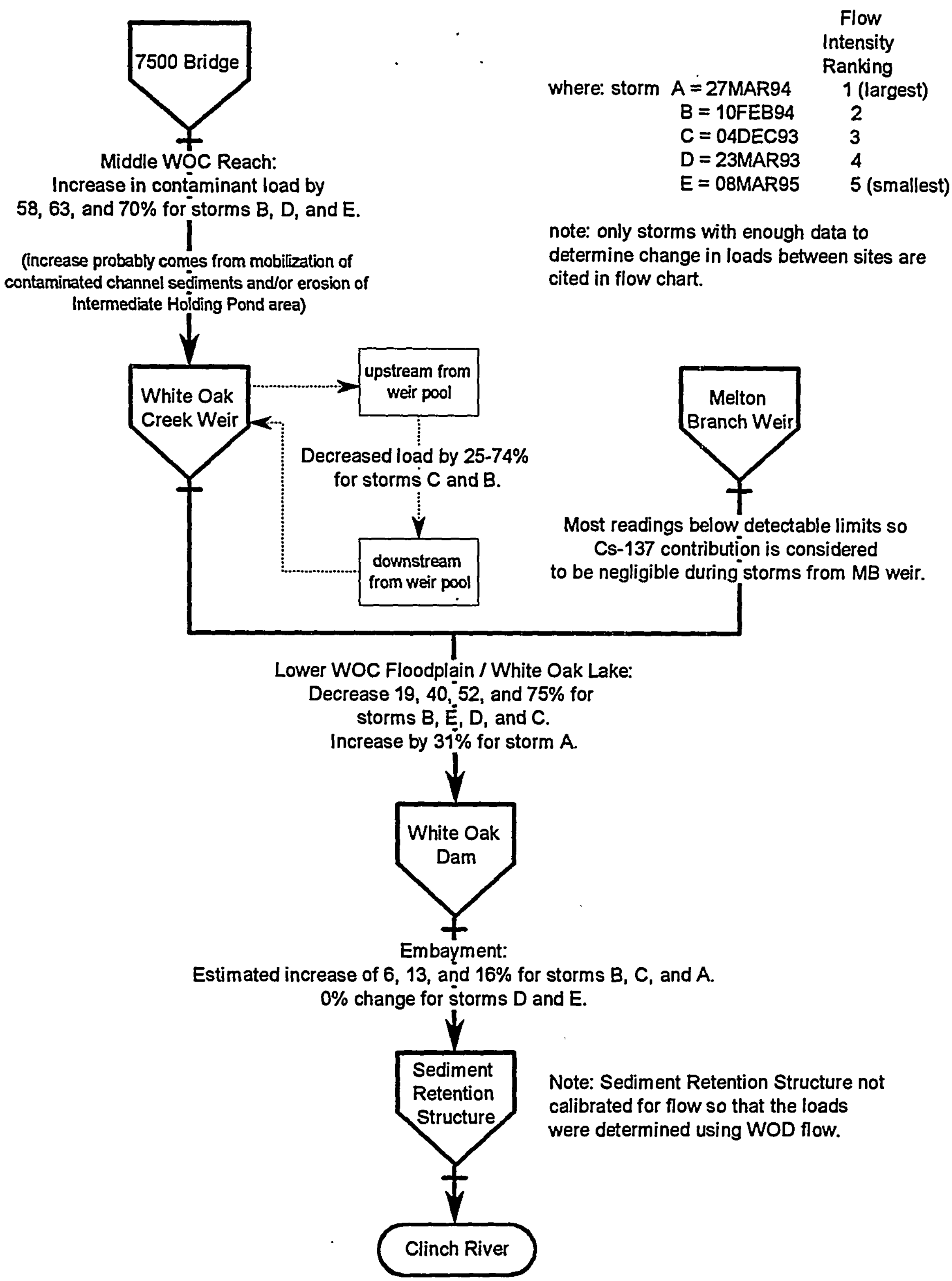


Fig 3.3. Pattern of mobilization and deposition of sediment in White Oak Creek watershed for five storms.

amounts of sediment; and vegetation, particularly cattails, had invaded the pools. The problem was especially acute at the MB weir station where the flow data at the weir had become suspect due to the clogged approach to the weir.

Sampling at the upstream stations at WOC weir and MB weir was limited, because the samplers were inaccessible due to high water during the storms. The filled bottles were not changed out until the stream stage had receded; consequently, for some storms the recession portion of the hydrograph was not sampled but the effect on the results is not considered to be significant. For the sampled intervals in the 5 storms, deposition ranged from about 10,000 to 17,000 kg for the WOC weir pool, and from about 10,000 to 53,000 kg at MB weir pool. As a fraction of the suspended sediment measured at the upstream stations (for the period of sampling), deposition in the weir pools ranged from 20 to 51% for the WOC weir pool and 22 to 67% at MB weir pool. Assuming a bulk density for the deposited sediments of 1.5 g/cm^3 and a nominal area of 890 m^2 (9600 ft^2) for the weir pool, the deposition of 20,000 kg results in 1.5 cm in lost depth of the pool.

In December 1995, the accumulated sediments in the weir pools were dredged and transported to a bermed area to the south of MB weir. This action was intended to assure the accuracy of the flow measurements and the automatic flow-paced sampling at these sites, but it will also increase the trapping efficiency of the weir pools. The sediment loads to the Lower WOC floodplain and WOC Lake are expected to decrease at least for the short term.

3.6.3 Cesium-137 loads

The discharge of ^{137}Cs at WOD during the sampled storms ranged from 0.012 to 0.072 Ci. As shown in Fig. 3.4, at WOD the pattern of ^{137}Cs loads among the 5 storms was similar to that for suspended sediment loads:

^{137}Cs load pattern among storms:

10Feb94 ≈ 27Mar94 > 23Mar 93 ≈ 4Dec93 > 8Mar94,

however, the pattern pertains only to loads at WOD and not to other sites within the watershed. Moreover, the two large storms discharged about 1.8 times the ^{137}Cs discharged by the two middle-sized storms, although they discharged 2.6 times the sediment of the middle-sized storms.

The pattern of ^{137}Cs loads within the watershed is more complex, as shown in Fig. 3.4. Starting at the upstream site, there is a small amount of ^{137}Cs transported from the ORNL Plant reach. Middle WOC reach which is a source of sediments appears to be a source of ^{137}Cs, too. The ^{137}Cs source in the reach probably has three components; (1) mobilization of freshly deposited channel sediments that have sorbed ^{137}Cs from NRWTF, (2) erosion of contaminated soils from the IHP area, and (3) runoff from the WAG 4 tributary.

In contrast, ^{137}Cs behavior is more complex in the Lower WOC floodplain/White Oak Lake reach. Four of the storms show a loss (deposition) in the reach whereas the fifth storm (which is the largest one) there was a gain of ^{137}Cs indicating net erosion or mobilization of the contaminant. The mobilization and deposition for all five storms is diagramed in Fig. 3.5.

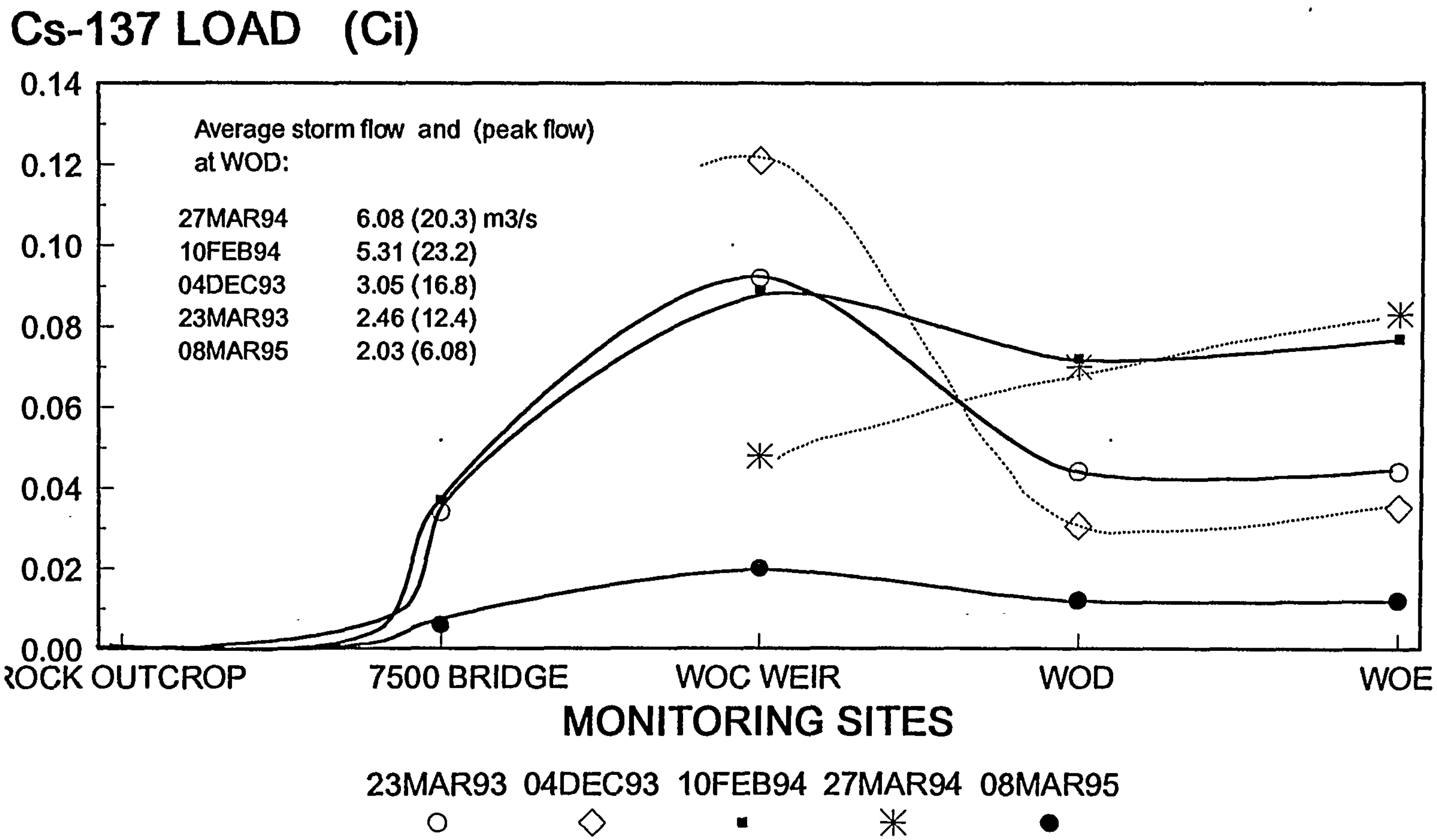


Fig. 3.4. Pattern of ^{137}Cs loads in White Oak Creek Watershed for five storms.

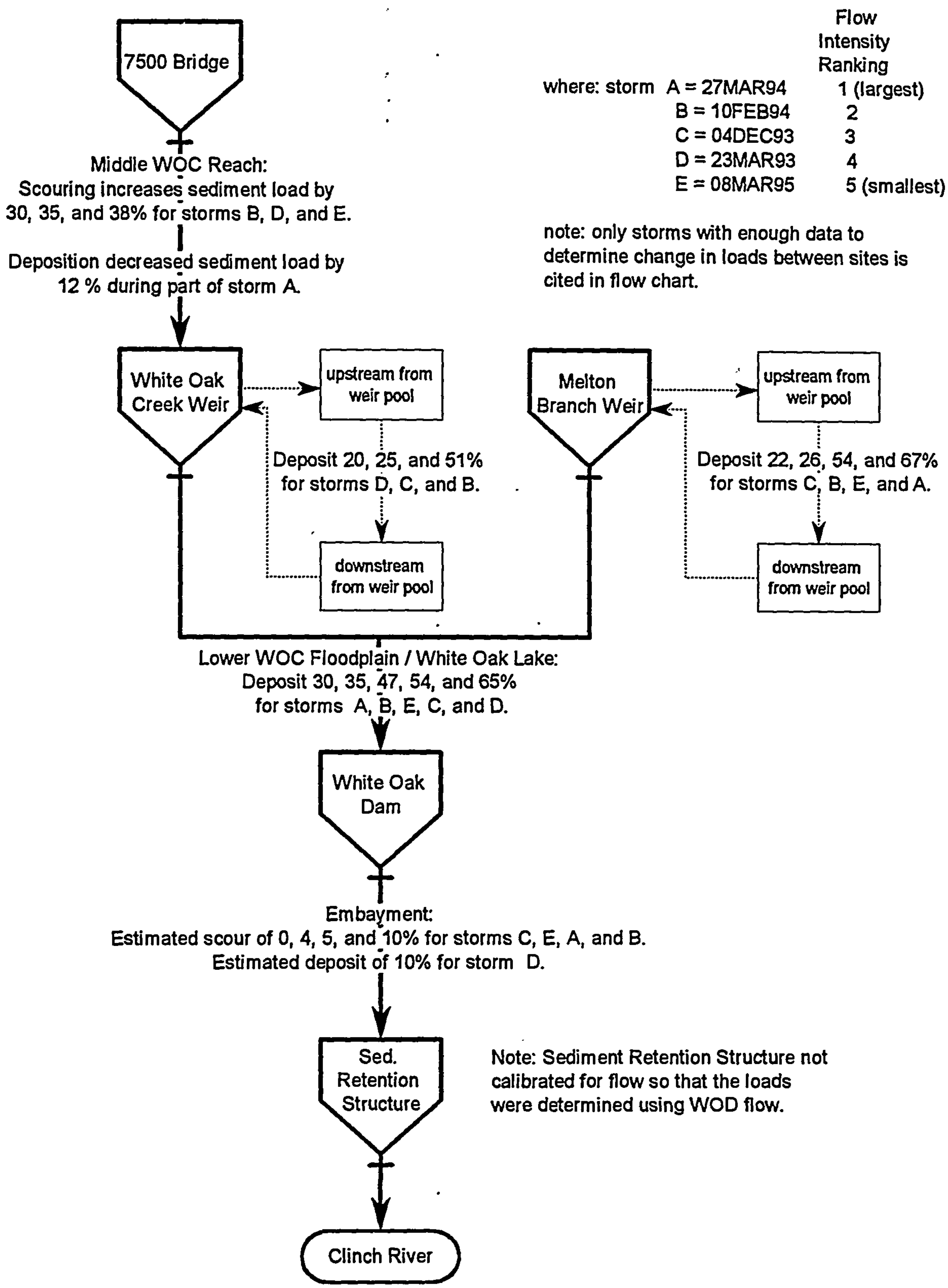


Fig 3.5. Pattern of mobilization and deposition of ^{137}Cs in White Oak Creek watershed for five storms.

The stream discharge, particularly the total flow or the average flow, is correlated with sediment transport through the watershed, and sediment transport appears to play some role in ^{137}Cs loads, but the relationship is not straightforward. Loading of the ^{137}Cs on the channel sediments also appears to be one of the important factors.

3.6.4 Changes in Sediment Grain Size

The grain size distribution is expected to affect the transport of particle-reactive contaminants. Selected storm samples were processed in order to determine the grain-size distribution and the ^{137}Cs concentration per size fraction. As shown in Fig. 3.6, the streamflow in the minor tributaries (WOC at Rock outcrop, Northwest Tributary, and WAG 4 Tributary) transport a large fraction of coarse silt and sand as compared to the main stem of White Oak Creek and Melton Branch. Along the main stem of WOC from 7500 Bridge to White Oak Dam, the clay fraction increases. Presumably, the sand fraction is settling out of the water column at the weir pools. The change in fine-grained sediments is largest between WOC weir and White Oak Dam due to settling of particles in White Oak Lake. The similar mean values for the relative clay content and silt content also suggest that on-average the embayment does not affect the grain-size distribution in the discharge water released at White Oak Dam. The slight increase in grain-size variability (as shown by the error bars) for clay and fine silt at WOC Embayment relative to that at WOD suggests that erosion and deposition are occurring in the embayment.

Fig. 3.7 shows the fraction of the ^{137}Cs concentration that is associated with each grain-size fraction. Due to low or undetectable ^{137}Cs concentrations at the Rock Outcrop site, Northwest Tributary, and Melton Branch it was not possible to divide the ^{137}Cs load among the size class fractions at those sites. As water flows from 7500 Bridge to the White Oak Dam, the clay fraction tends to transport a larger portion of the ^{137}Cs. Between White Oak Dam and the discharge point for the embayment, the mean percent transported by clay and by silt remains unchanged, suggesting that the embayment is a passive conduit for the water released at WOD.

The average grain-sized distributions and the relative amount of ^{137}Cs per grain-size fraction are used as input to the watershed transport model presented in Chap. 4.

3.7 ^{137}Cs MOVEMENT DURING LOW FLOW CONDITIONS

The storm samples provide a information of ^{137}Cs flux during high flow conditions when sediments are most mobile and are most likely to be released from the watershed. Grab samples collected during low flow conditions show how the channel system accumulates ^{137}Cs for subsequent transport during storms. Cesium-137 concentration and concurrent flow measurements were collected at 7500 Bridge and WOC weir and combined to yield ^{137}Cs flux values, as shown in Table 3.5.

The data show consistent ^{137}Cs deposition between 7500 Bridge and WOC weir during low flows. Above 7500 Bridge the main source of ^{137}Cs is the effluent from the NRWTF, and the ^{137}Cs in the effluent is mostly in a dissolved state. It appears that about 40% of the ^{137}Cs that enters Middle WOC reach is adsorbed to the channel-bottom sediments or otherwise captured in the reach. The average rate of deposition is 0.54 ± 0.15 mCi/day (mean $\pm$ std error). The channel sediments are mobilized/scoured during flood events, thus the channel sediments provide short-term storage for ^{137}Cs in the surface water system.

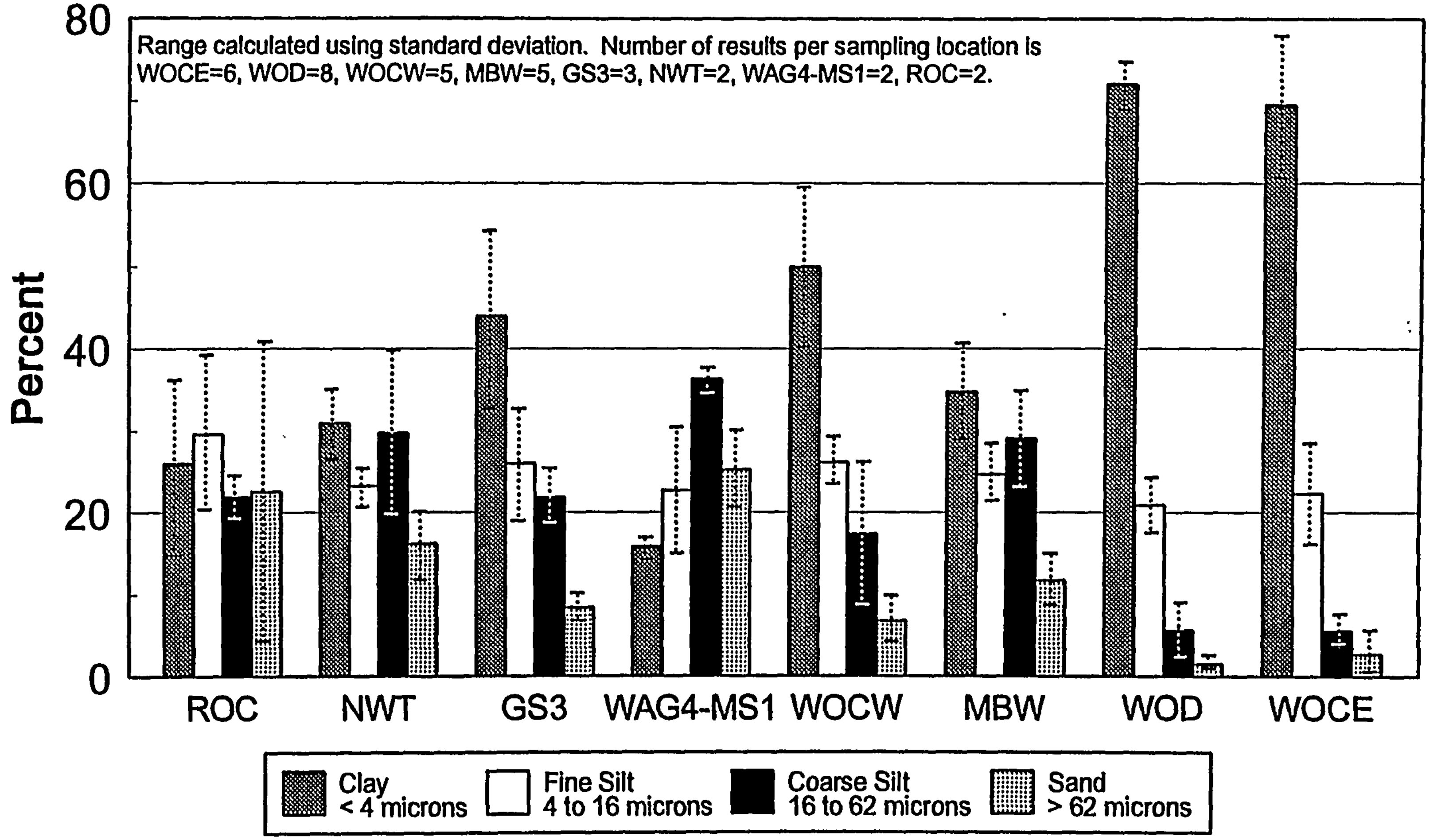


Fig. 3.6. Grain-size distributions at the storm sampling sites in White Oak Creek watershed for storms sampled in 1994 and 1995. The column test method was used to separate the suspended sediment in the sample into size fractions.

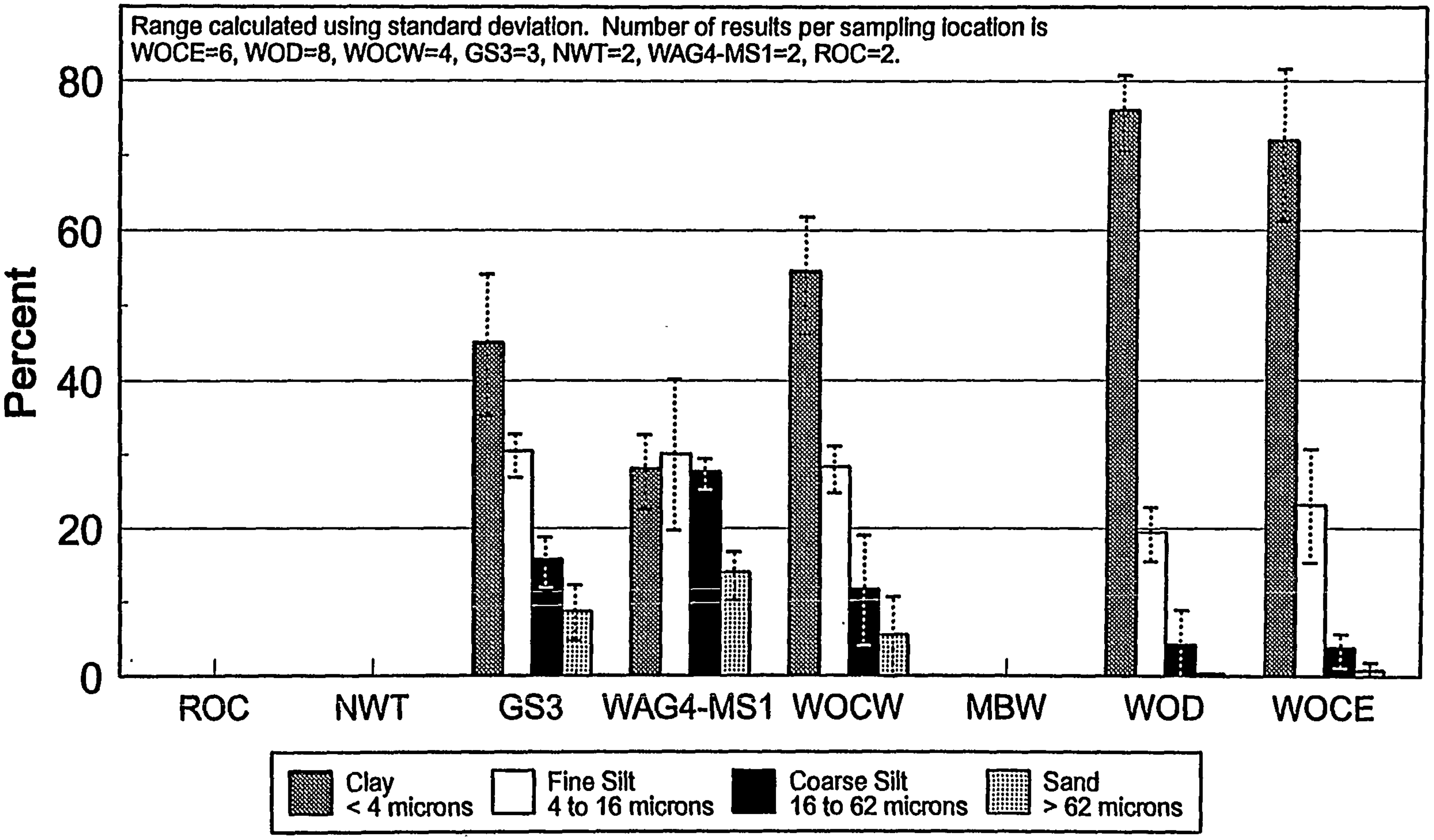


Fig 3.7. Relative amount of ^{137}Cs per grain-size fraction for storms sampled in 1994 and 1995.

Table 3.5 ^{137}Cs flux measurements during low flow

Date	7500 bridge (mCi/day)	WOC weir (mCi/day)	Deposition (mCi/day)	Fraction deposited
4/2/92	2.09	1.65	0.43	0.21
9/17/92	0.73	0.53	0.19	0.27
3/11/93	1.02	0.80	0.22	0.22
5/24/93	2.13	0.81	1.32	0.62
7/21/93	1.52	1.23	0.29	0.19
9/30/93	1.52	0.43	1.09	0.72
9/30/93	1.25	0.71	0.54	0.43
12/1/93	0.88	0.62	0.26	0.30
Average	1.39	0.85	0.54	0.39
Std Error	0.19	0.14	0.15	

3.8 COMPLIANCE DATA

The ^{137}Cs mass flux at the monitoring stations was calculated from the flow-weighted concentrations from the monitoring network maintained by OECD. The weekly flux at White Oak Dam for the period 1990-1995 is shown in Fig. 3.8. The plot shows that ^{137}Cs releases are seasonal with larger fluxes in winter and spring months. The plot also shows that ^{137}Cs releases are partially storm-driven, i.e., within the winter/spring releases there is variability because the system is partly "storm-driven". The large ^{137}Cs release in December 1990 was caused by the storm of Dec. 23, 1990, when the peak hourly flow at White Oak Dam was 1140 cfs, larger than any of the storms that were sampled as part of this task.

Fig. 3.9 shows the cumulative plots of the ^{137}Cs fluxes for NRWTF, 7500 Bridge, WOC weir, MB weir, and WOD. ^{137}Cs fluxes at First Creek are excluded because they are small. Over the 6-year period the cumulative ^{137}Cs flux from First Creek was 0.038 Ci, too small for inclusion in the figure.

Fig. 3.9 shows the large trends in ^{137}Cs transport within the WOC watershed. Effluent from NRWTF provides most of the ^{137}Cs observed at 7500 Bridge. There is a significant gain in ^{137}Cs between 7500 Bridge and WOC weir, reflecting the erosion of contaminated soils mostly in the IHP area and the smaller contributions of seeps in WAG 4. WOC contributes most of the ^{137}Cs to Lower White Oak Creek/White Oak Lake; the contribution from Melton Branch is nearly insignificant. Comparing the combined plots for WOC weir and MB weir to that of White Oak Dam shows that the floodplain/lake is clearly a depositional area, as was observed for 4 of the 5 storms sampled.

Another predominant feature shown by the cumulative ^{137}Cs flux plots is the change from a storm dominated system in late 1990 and early 1991 to a smoother, more steady regime in 1992-1995. The abrupt increases in the plots starting with the storm of December 1990 show the effects of storms; effects not seen in the later data.

The change in the variability of the system from 1990 to 1995 is important. The change may reflect a system that has drained itself from the contaminated sediments that built up in the channel sediments before the NRWTF was on-line and the Process Waste Treatment Plant discharged large quantities of ^{137}Cs. The improved management of sediments at construction sites and at contamination sites may also be a factor.

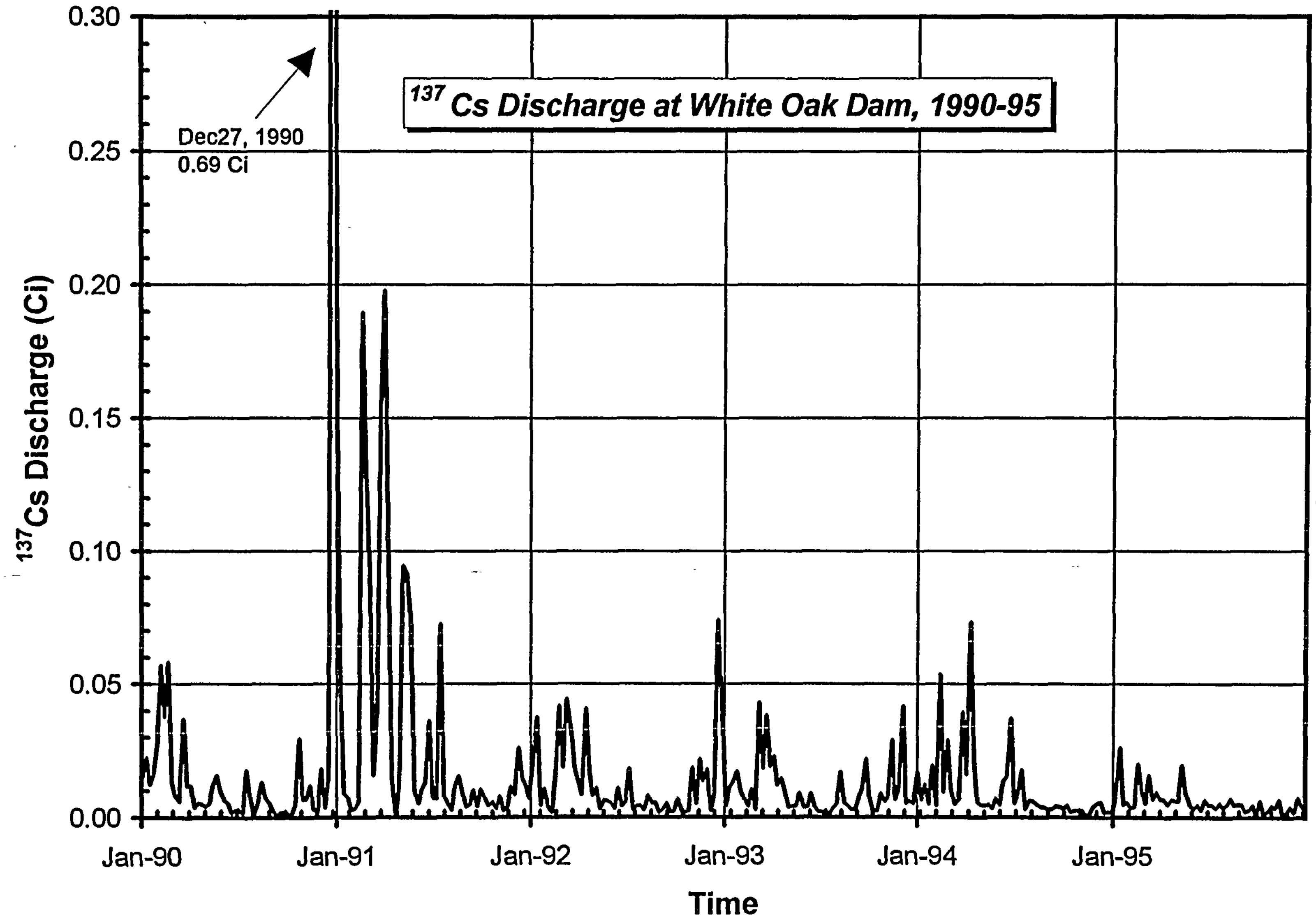


Fig. 3.8 Monthly ^{137}Cs flux at White Oak Dam, 1990–1995.

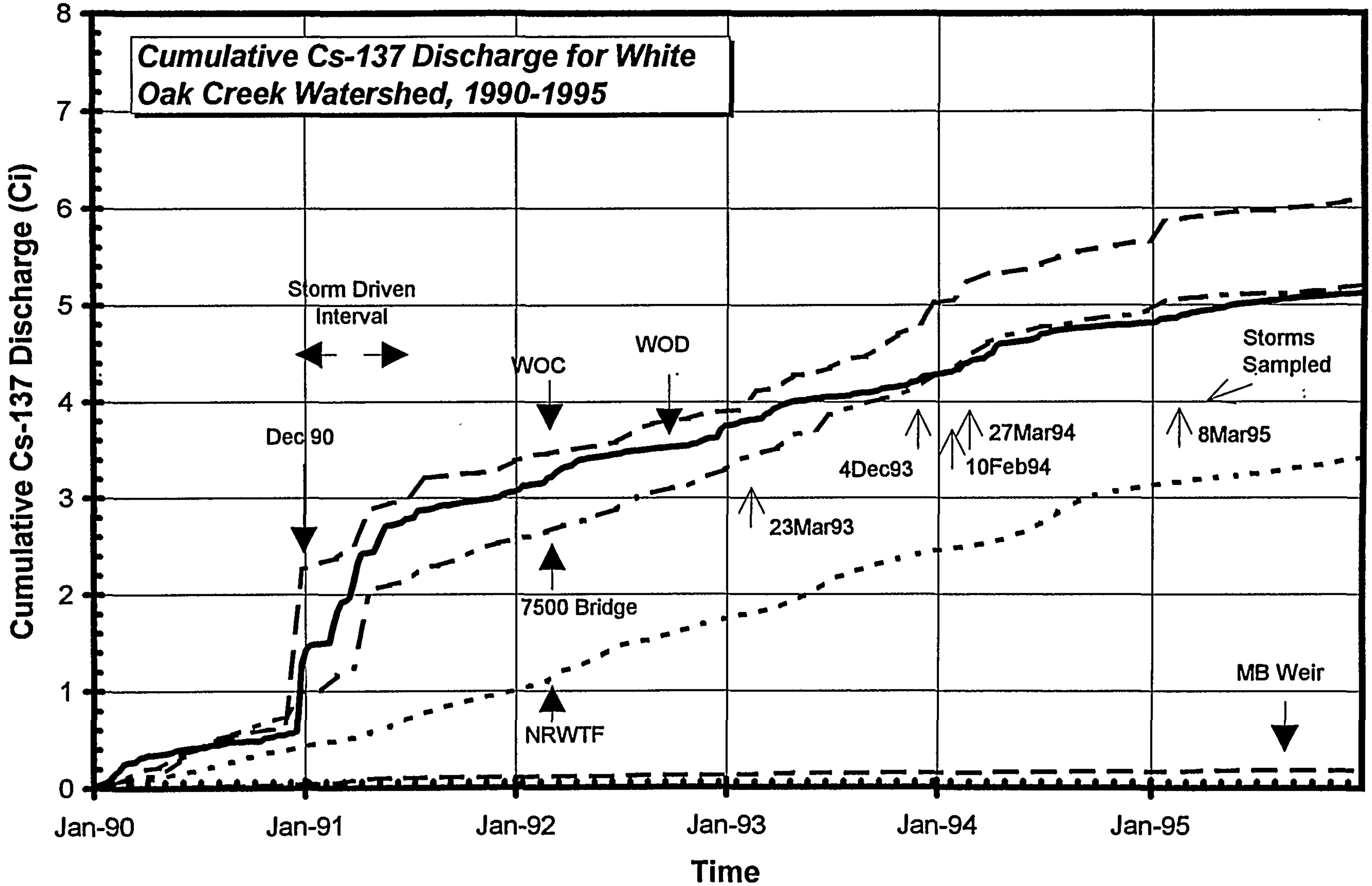


Fig. 3.9 Cumulative ^{137}Cs flux in the White Oak Creek Watershed, 1990–1995. (The five arrows with dates indicate when the intensive storm sampling campaigns occurred).

For the Sediment Transport Task, the cumulative fluxes are critically important. The general trends in the cumulative ^{137}Cs flux plots (Fig. 3.6) become the targets for the watershed transport modeling described in Chap. 4.

3.8.1 Comparison of Compliance Fluxes and Storm Loads

Data-collection and data-processing methods for the monthly ^{137}Cs fluxes and for the estimated storm loads are very different. To determine if these two data sets are compatible, the storm loads and the corresponding monthly fluxes are plotted in Fig. 3.7. Excluding one outlier where the storm load is greater than the monthly flux, the data behave reasonably well, i.e., the storm loads are less than or equal to the monthly flux. Furthermore, the data (minus the outlier) are correlated (R^2=0.73) and the relationship is best for 7500 Bridge and WOC weir data. The correlation is not as good for the data at White Oak Dam. Taken together, the monthly and storm data sets suggest that although the system seems to respond smoothly, moving ^{137}Cs through the system without abrupt changes, there is also a smaller-scale storm response. Of course, these observations apply to the "normal" hydrologic conditions that existed over the past 3 years. The effects of a big and infrequent storm/flood can only be evaluated by simulation.

3.9 FLOOD FREQUENCY ESTIMATION

To meet the task objective of simulating the effects of the 100-year flood it was necessary to quantify the 100-year peak flow. Previous estimates are:

- 1574 cfs developed using the HEC-1 model results coupled with an adjustment for the storage capacity of White Oak Lake (Tschantz 1987),
- 1,870 cfs estimated from U.S. Geological Survey (USGS) equations for Tennessee hydrological area I, and
- 2,400 cfs based on regional curves generated by the Tennessee Valley Authority.

The calibrated HSPF watershed model (described in Chap. 4) provided an opportunity to calculate a potentially better estimate, and Professor B. A. Tschantz of the Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, assisted in this task. To generate that estimate, the 41-year precipitation record collected at the township of Oak Ridge was used as input, and the calibrated model was used to calculate a synthetic hydrograph. Analysis of the model results showed that the estimates of peak flows for short (3-hr), intense storms were unreasonably large. These storm conditions occurred almost exclusively in the summer time, so the problem was avoided by considering only the non-summer portions of the synthetic hydrograph. The resulting flood frequency curve generated from the censored synthetic flow data is considered to be tentative. The computed 100-year peak flow is 81.4 m^3/s (2,875 cfs). This peak flow is 20% greater than the largest of the previous estimates, and 83% greater than the flood estimate generated by HEC-1 modeling. Consequently, the computed 100-year peak flow used in this study is considered to be large (conservative).

The tendency to over predict runoff for extreme summer storms is not considered to be a problem for this investigation because there are no 3-hr, intense storms in the 5- year data set used to develop the model and to simulate the transport of sediment and sediment-bound ^{137}Cs. It is recommended that in the future the WOC watershed model be recalibrated using the rainfall data since 1994 and that the model be reconfigured to explicitly model the Chestnut Ridge portion of the watershed which has high infiltrability/low runoff during the summer. These changes may lead to a more robust model. It is also infiltrability/low runoff during the summer. These changes may lead to a more robust model. It is also recommended that the 41-year synthetic hydrograph and the flood frequency be recomputed.

From the 41-year synthetic hydrograph, it was observed that the storm of November 22, 1973, resulted in computed peak flow approximately equal to the 100-year storm. Consequently, the precipitation pattern for November 22, 1973 was used (with some scaling) to yield a the 100-year storm for the modeling reported in Chap. 4.

3.10 SUMMARY

The intensive storm sampling in the WOC watershed yielded an extensive set of screening-level data needed to identify the behavior of sediment and sediment-bound ^{137}Cs. For 5 storms, the sediment and ^{137}Cs loads were estimated by integrating the data over the duration of the storm hydrograph.

During storms the suspended sediment load increased along WOC as the water enters White Oak Lake where deposition occurred in all 5 storms. The amount of suspended sediment mobilized during the storm depends on the peak flow or on the total storm flow (which are interdependent quantities). The grain-size data show that the small tributaries yield a mix of clay, silt, and sand particles, but the main stem of WOC a relatively larger fraction of the sediment is comprised of clay and fine silt as the water travels from the plant area to the discharge at WOD. The largest increase in the clay fraction occurs in the Lower WOC/White Oak Lake reach probably due to particle settling in the lake itself.

As for ^{137}Cs, the patterns of the contaminant loads tend to correspond to patterns of the suspended sediment loads, but not entirely. The storm of 27March94 did not mobilize much ^{137}Cs from middle WOC reach as expected based on the pattern of the other storms, and a partial explanation may be that there was not much time for build-up of ^{137}Cs in the channel sediments since the last large storm. Low-flow measurements of ^{137}Cs flux show the build-up of ^{137}Cs in middle WOC reach between storms. Five storms is an insufficient number to develop statistical models relating contaminant loads to independent factors.

The estimations of suspended sediment and ^{137}Cs loads provide only a broad indication of the behavior of the WOC Embayment with the Sediment Retention Structure that was constructed in 1992. The estimated loads suggest that the Embayment can be a slight source or sink for suspended sediments (changes in load varied from -10% to +10% among storms) and a passive conduit or a slight source of ^{137}Cs (changes in load varied from 0 to 16%). The possible mobilization of ^{137}Cs in the embayment is probably best considered to be the addition of a few 1/100ths of a Ci ^{137}Cs rather than as a percentage of the incoming load. It can be said that the data show there is no wholesale erosion of ^{137}Cs-contaminated sediments during floods with the Sediment Retention Structure in place.

The compliance data collected at the main monitoring stations in WOC watershed show that the NRWTF is the largest single source with the watershed and that there are other sources in the Plant area and along middle WOC reach that must be related to the erosion of the ^{137}Cs inventory associated with contaminated soils and sediments. Cesium-137 movement is seasonal and also storm-driven, but the large fluxes in the past 5 years occurred during the very large flows associated with the storm of Dec. 23, 1990 and in the winter months after the storm. The channel system may have been flushing the ^{137}Cs accumulated before the NTWTF came on-line. Since then ^{137}Cs in the WOC system appears to be less storm-driven.

Finally, the estimated 100-year peak flow of 81,400 L/s (2,880 cfs) is large relative to past estimates, and therefore it is judged to conservative.

4. WATERSHED TRANSPORT SIMULATION

The data presented in the previous chapter shows that dissolved and particle-bound ^{137}Cs move through the watershed in a complex pattern of deposition and resuspension. A computer model is needed to synthesize this information and to predict the ^{137}Cs release during extreme floods.

In this chapter, the data presented in the previous sections are used to develop a computer model of the Cs-137 transport processes. The model simulates watershed rainfall-runoff, sediment erosion/deposition, and ^{137}Cs transport through the watershed and release to the off-site environment at White Oak Dam during normal flow and during the 100-year flood. In this chapter, after a description of the HSPF model and the required input, the model calibration and validation are presented. The simulation results are presented for a baseline scenario and for 100-year flood. In Chap. 5 and 6, the Cs-137 released from the watershed during the 100-year flood will be used as input for the off-site transport modeling and risk assessment (Fig. 4.1).

Supporting information for the watershed modeling subtask appears in Appendix IV, including details of the HSPF model parameters and the calibration system used to determine parameter values. The calibration system, called OPTICAL, is unique and it was developed specifically for this project.

4.1 DESCRIPTION OF HSPF

Hydrologic Simulation Program - FORTRAN (HSPF) is a comprehensive computer model developed by EPA to simulate hydrology and water quality in watershed and river channel systems. HSPF can continuously simulate rainfall-runoff, sediment interaction (erosion, deposition, and transport), and movement of various contaminants with water and sediment through adsorption and desorption.

4.2 HSPF MODELING PROCESSES AND INPUT DATA REQUIREMENTS

Numerous parameters are required for HSPF modeling. Required data for contaminated surface water transport has been divided into categories based on key physical processes. The processes and the model parameters are listed in Appendix IV.

4.3 HSPF MODEL SETUP

Table 4.1 (summary of related HSPF modules) categorized the relevant modules of HSPF for White Oak Creek watershed simulation, their governing equations, and the data requirements.

4.3.1 Physical Representation

The White Oak Creek basin area is about 16 km^2 (6.15 mi^2) with 80% forest, 10% riparian, and 10% developed area such as buildings, roads, and parking lots. Slope of the primary channels is in a range from 1/1000 to 4/1000.

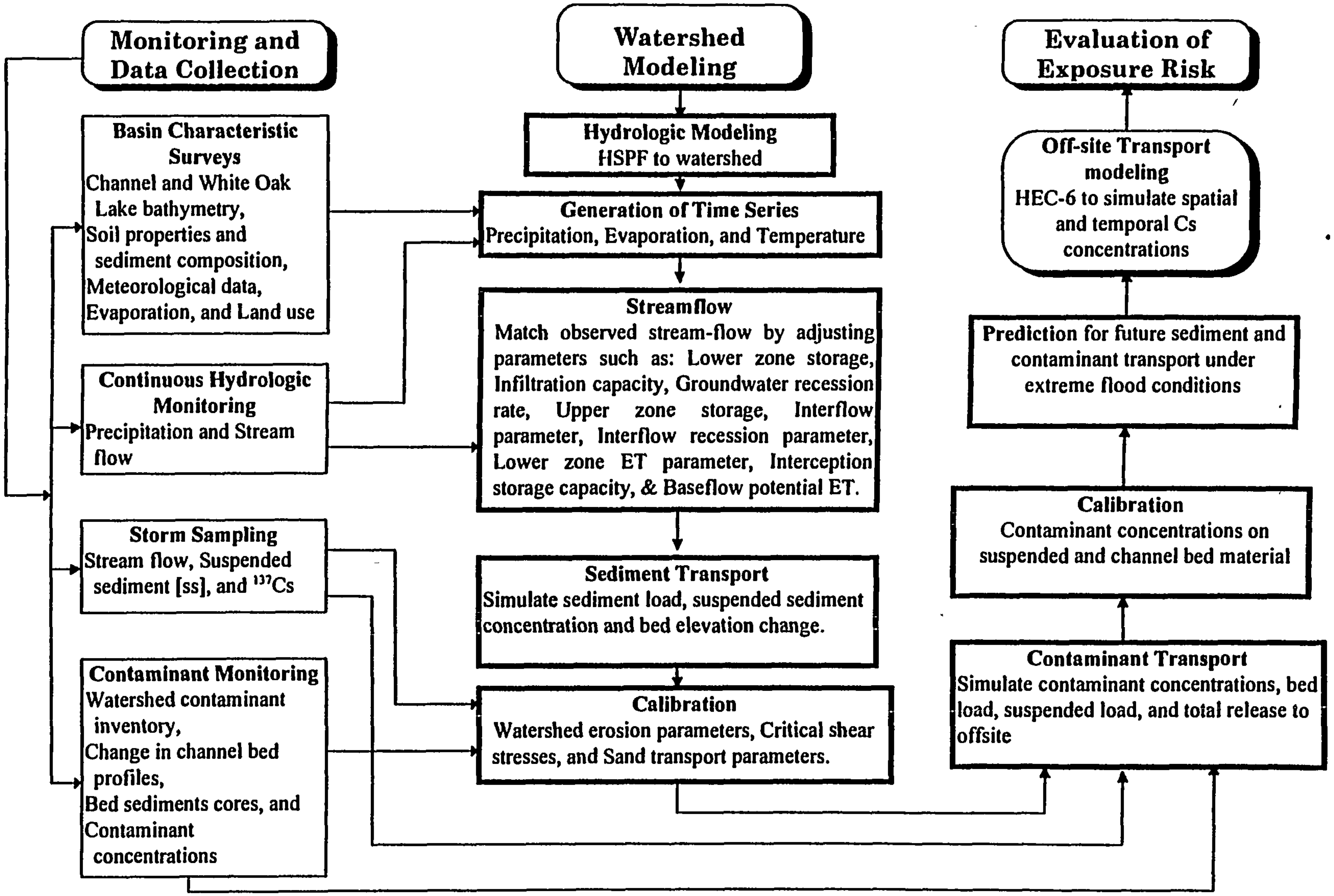


Fig. 4.1. Flow chart of contaminated sediment transport modeling and exposure risk assessment.

TABLE 4.1. Modeling processes, governing equations input parameters required in HSPF submodules

Process	Governing equations	Data requirements	Comments
Over land removal of sediment	Kinetic energy from rainfall on soil detached particles; power function for washoff of detached sediment; power function for detachment and transport of soil particles from the soil matrix (scour). Separates pervious land segment from the impervious land segment.	Precipitation and evaporation time series, drainage area, slope, land use, soil, vegetation, observed stream flow records.	
Hill slope contaminant transport	Constituents can be associated with sediment yield, overland flow, interflow, and active groundwater outflow	Potency factors, storage of available contaminant on the surface.	
Stream flow routing	Kinematic wave equation for routing.	Channel cross-sections, length, energy slope, median diameter of bed sediment, and roughness for each reach.	Flow-storage relationship is predetermined using backwater profile programs (e.g., HEC-2) for each reach.
Sediment transport in channel	Noncohesive material (sand): (1)Toffaleti equation that channel is divided into three zones vertically plus a bed zone and the sediment concentration at each zone is integrated to calculate the total sediment load (2)Colby equation between discharge of sands and mean velocity, bed sand size, depth of flow and water temperature, or (3) user-specified power function method. Cohesive material (silt and clay): Krone equation for deposition and Partheniades equation for scour;	Sediment sizes, fall velocity bulk density, critical stresses for scour and deposition, relationship between reach water surface area, depth, width and water volume, water temperature, stream reach slope	Colby equation was developed for small rivers (flow depth less than 2 ft). Toffaleti equation was developed for large rivers (flow depth greater than 10 ft).
Channel contaminant transport	Advection of dissolved material; advection of adsorbed suspended material; deposition and scour of adsorbed material; adsorption/desorption between dissolved and sediment-associated phase (sand, silt or clay).	Initial bed thickness, initial composition of sand, silt and clay in the bed material, source concentration, first order decay rate for adsorbed to suspended sediment and bed sediment, temperature	No diffusion process considered in the model
Decay processes	Decay of suspended and bed material. Decay of dissolved material: hydrolysis, oxidation, photolysis, volatilization, biodegradation, and generalized first-order decay.	First order decay rate, temperature correction coefficient for first order decay, decay rate for constituent adsorbed to suspended sediment, decay rate for constituent adsorbed to bed sediment, water temperature, initial concentration of constituent.	User specified daughter chemical or radionuclide. Up to three generalized quality constituents is allowed.

In the HSPF modeling approach, a land segment is a subdivision of the watershed, and reaches or reservoirs link the land segments together (Bicknell et al. 1993). As shown in Fig. 4.2, White Oak Creek basin is represented by four pervious land segments (PLS1 to PLS4) that are connected through seven channel reaches (reaches 2 to 8). Melton Branch Creek subwatershed is modeled in PLS3 with outlet of subwatershed directly discharged to Melton Branch Weir. The exclusion of channel reaches for Melton Branck Creek simplifies the model without sacrifice of the modeling accuracy in simulating ^{137}Cs release to off-site because of low level of ^{137}Cs inventory in PLS3 (Tables 4.2 and 4.3). The drainage area, channel reach length, location of the end of reach, and stream-flow gage station corresponding to each PLS are listed in Table 4.2 (PLS/reach/gage station).

Rainfall inputs are specified for each PLS. Rainfall data were collected from six rain gauges within or near the boundary of White Oak Creek basin were averaged using the method of Thessen polygons, as described in Appendix IV.

4.3.2 Pervious Land Sediment Erosion

The HSPF model simulates two separate erosion processes for hillslopes: washoff and scour. Washoff refers to the sediment detached by rainfall splash and transported with overland flow. Scour (or gully) erosion occurs when significant overland runoff is flushed over the surface soil and water channels develop. The water flow momentum causes both soil detachment and movement, which is similar to channel bed erosion (Bicknell et al. 1993). The coefficients of gully erosion equation (based on the method of Negev, 1967) were derived from observed flow and suspended sediment measured at 7500 bridge near outlet of PLS1 during 1992-95 (Fig. 4.3). Because there is limited data regarding soil/sediment erosion for the watershed, the same washoff and gully erosion equations are used for all subwatersheds (PLS1 to 4).

4.3.3 ^{137}Cs Load (Sources)

There are three point and nonpoint sources contributing ^{137}Cs in White Oak Creek basin:

(1) Flow discharge from the Non-Rad Waste Water Treatment Facility (NRWT) provides point source of ^{137}Cs influx into the system. NRWT is located within PLS1 and the point source was modeled as direct effluent into Reach 2 from the outlet of PLS1. Figure 4.4 shows flow and ^{137}Cs content in effluent from NRWT observed during a six-year period of 1990-95. Flow effluent from NRWT is between 0.5 to 1.0 cfs which is part of point flow discharge at Oak Ridge Reservation (ORR) estimated to be 3.8 cfs. The annual loading of ^{137}Cs/yr in NRWT effluent is between 0.3 to 0.7 Ci and is mainly in dissolved form.

(2) The operation of and waste disposal activities at ORNL over a period of 50 years have resulted in accumulation of ^{137}Cs that is bound to sediments distributed in the White Oak Creek basin. The contaminated sediments are primarily located along the floodplains and in White Oak Lake near the basin outlet (Clapp et al. 1994 and Oakes et al. 1982). The ^{137}Cs loading from non-point sources in the White Oak Creek basin is typically storm induced due to the surface soil erosion. Fig. 4.5 (figure of 3D map for contaminant from C. Ford) shows the heterogeneous spatial distribution of ^{137}Cs which is characterized in PLS1 to 4. As shown in the cesium inventory Fig. 4.5 and Table 4.3, the ^{137}Cs stored in PLS3 soil is negligible.

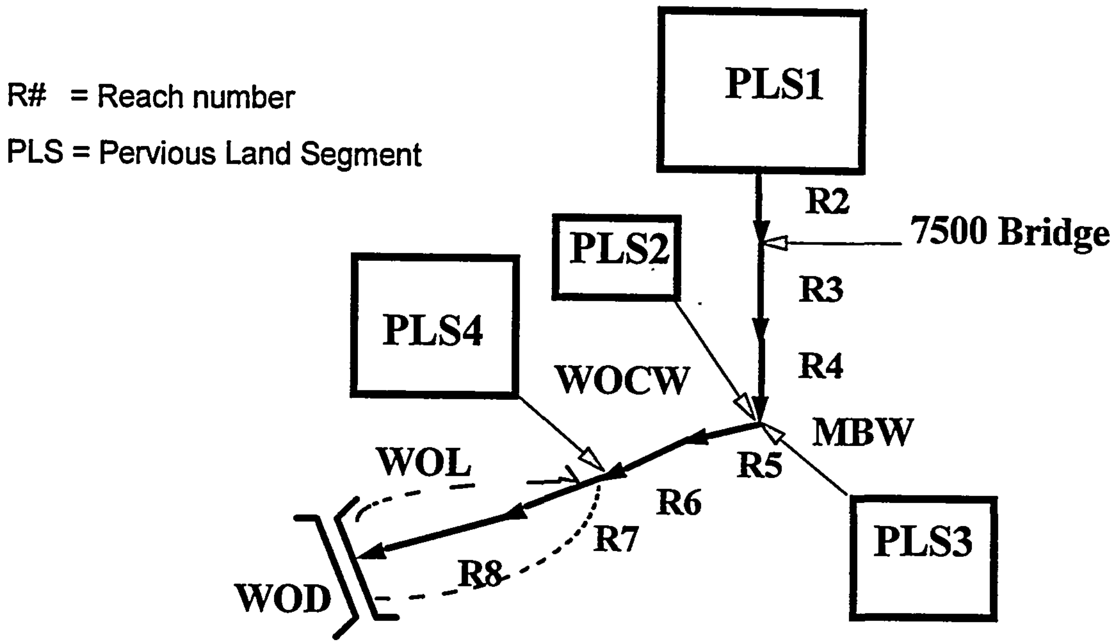


Fig. 4.2 Model elements representing White Oak Creek watershed.

Table 4.2 Pervious Land Segments and Channel/Lake Reaches for White Oak Creek Watershed

PLS	Reach/ Reservoirs	River Mile WOC	Location	Drainage Area (acre)	Stream Flow Gage Station
1	2	2.21-2.18	7500 Bridge	2099	7500 bridge
2	3	2.18-1.90	Inter. Pond	204.8	White Oak Creek Weir
	4	1.90-1.63	WOC Weir		
3			MBW	960	Melton Branch Weir
4	5	1.63-1.40		672	White Oak Creek Dam
	6	1.40-1.48			
	7	1.18-0.83	WOC Lake		
	8	0.83-0.60	WOC Dam		

Table 4.3 ^{137}Cs inventory estimated based average measurements for soil and sediment cores in the WAG2 floodplain (adapted from Ford et al. 1996)

Land segment	Number of core samples	Surface to < 20 cm inventory (Ci)	20 cm to bottom inventory (Ci)	Total inventory (Ci)
PLS1	*	*	*	*
PLS2	56	54.5	71.8	126.3
PLS3	13	0.9	0.2	1.1
PLS4	23	32.1	38.6	70.7

* Not in WAG 2; no cores retrieved.

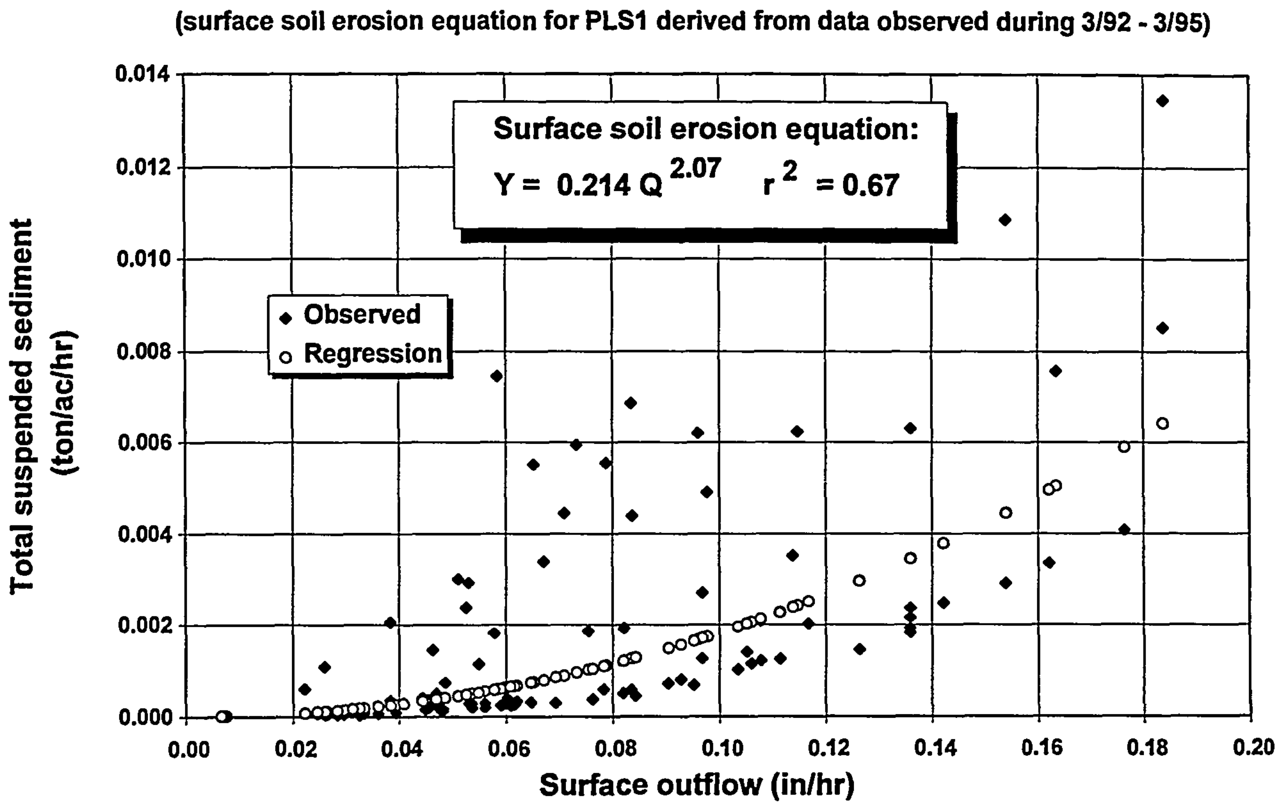


Fig. 4.3 Relationship between flow and suspended sediment at 7500 Bridge.

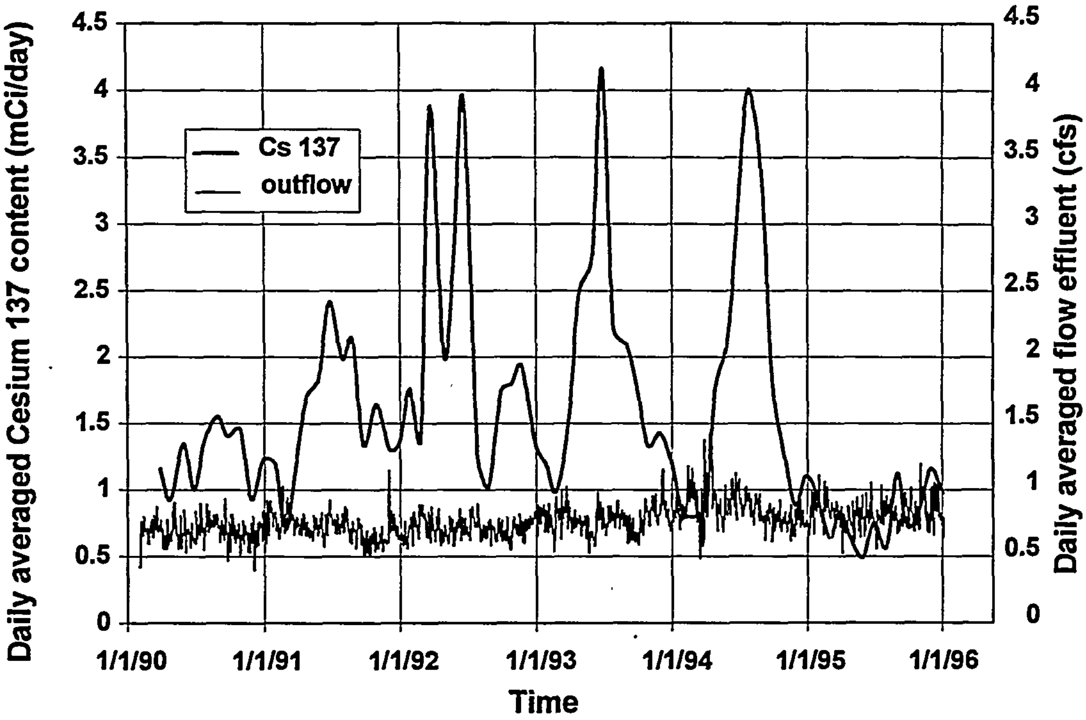


Fig. 4.4 Cesium-137 discharge from the Non-Radiological Waste Treatment Facility.

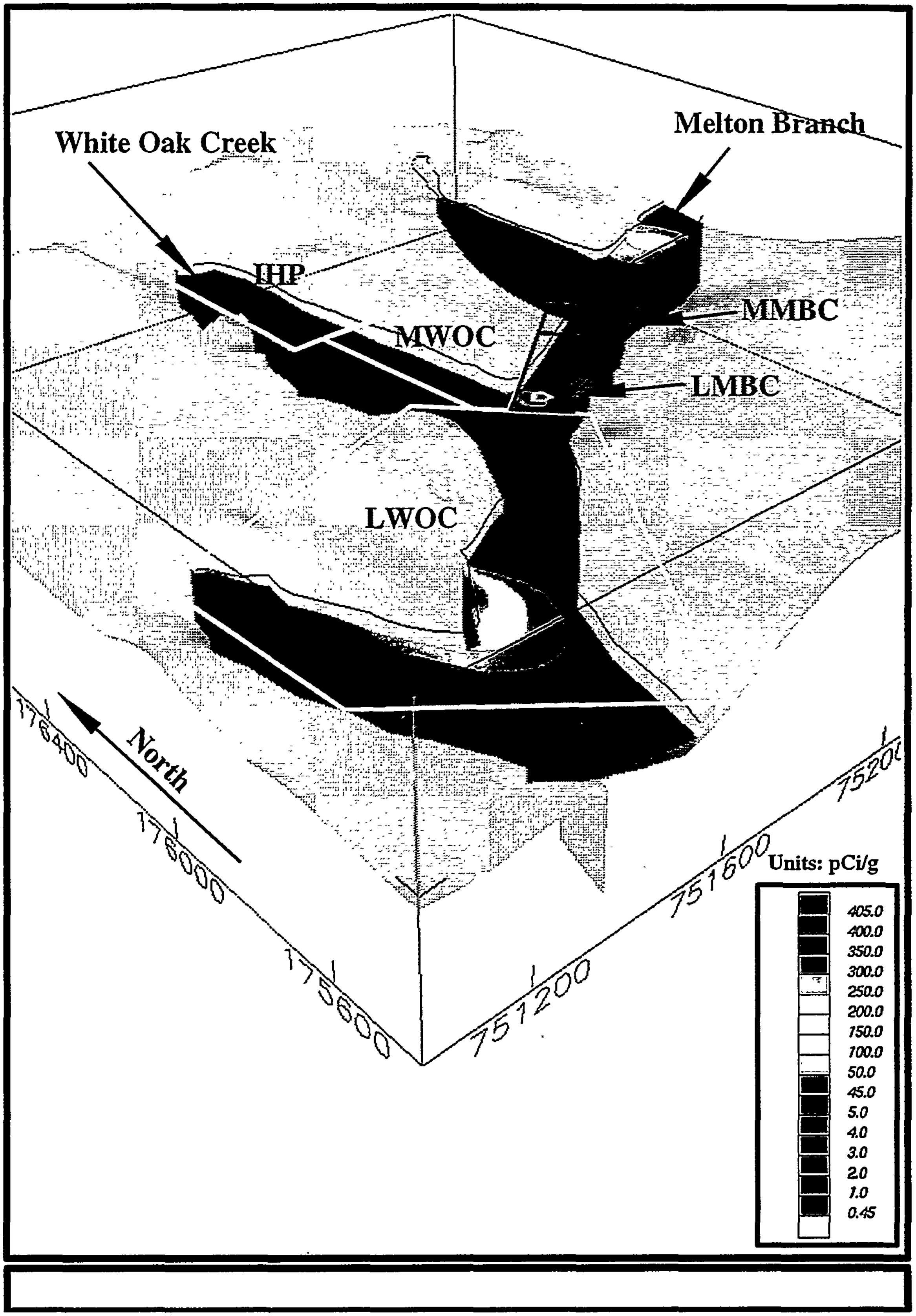


Fig. 4.5. Cesium-137 distribution in WAG 2.

(3) Channel bed and White Oak Lake can serve as source or sink depending on the channel flow, sediment and ^{137}Cs concentrations. During storms, White Oak Lake is generally a non-point source (Lomenick and Gardner 1965, Struxness et al. 1967, and Oakes et al. 1982).

Transport of sediment associated ^{137}Cs by detached sediment washoff and by scouring of the soil matrix is assumed to be directly proportional to the amount of sediment removal. The constants of the proportionality are defined as washoff potency factor (POTFW) and scour potency factor (POTFS). In general POTFW is larger than POTFS because washoff sediments are finer and thus have higher adsorption capacity. However, with 80% forest coverage and over 5% of paved area in White Oak Creek basin we assumed that ^{137}Cs from washoff is negligible. POTFS was estimated based on the ^{137}Cs inventory in each subwatershed and average concentrations (Table 4.4).

Table 4.4 Washoff potency factor estimated for each subwatershed

Land segment	POTFS (mCi/ton)
PLS1	0.6
PLS2	1.2
PLS3	0.
PLS4	1.0

4.3.4 Channel Bed Sediment Deposition/Erosion

For cohesive sediment (silt and clay), simplified Krone's (1962) equation is used to calculate the deposition rate and modified Partheniades' (1965) equation for scouring rate (resuspension). Either Colby's method (1964), Toffaleti's method (1969), or user's supplied power function can be used to calculate sand transport capacity. Both Collby and Toffaleti methods were tried without satisfactory results. The power function was thus used in the simulation.

4.3.5 Adsorption/Desorption

Basic equations for exchange between the dissolved and adsorbed states in HSPF are six transfer equations for six types of sediments: suspended sand, silt, and clay, and bed sand, silt and clay and one equation for conservation of mass (Onishi and Wise 1979). Key input variables are distribution coefficient (K_d) and temperature corrected transfer rate (K_t). The adsorption rate for White Oak Creek was 100 /day based on results reported by (Cerling et al. 1990). The distribution coefficients for White Oak Creek are based on previous studies in the order of 10^3-10^5 L/kg (Robbins et al. 1979, Onishi 1980). To model irreversible adsorption of ^{137}Cs by suspended and bed sediments (Cerling et al. 1990, Sobocinski et al. 1990), the transfer equations in HSPF need to be modified. An alternative is to increase K_d to approximate irreversible adsorption. The latter approach was used in White Oak Creek watershed modeling (the values of K_d used in the model for suspended and bed sand, silt, and clay ranges from 400 to $3x10^5$ L/kg).

Table 4.5 summarizes the major categories of input data and sources for HSPF modeling of White Oak Creek watershed. Hourly on-site precipitation data were collected from rain gages installed in the watershed. Hourly flow data at the main monitoring weirs was supplied by the ER Surface Water Hydrology Group.

Table 4.5 Summary of input data for HSPF modeling

Date sets	Description
precipitation	41-year hourly from Oak Ridge NOAA; 6-year hourly on site (9 rain gages)
evaporation	1-year daily pan evaporation from Knoxville NOAA station
water temperature	1-year hourly from WOC
nonpoint sources	hillslope erosion, contaminant inventory
point sources	6-year waste water treatment plant effluent
stream flow	5-year hourly on site (4 gages)
storm samples	5 storms between 1993-95 for suspended sediment and Cs on site (5 stations)

Long term stream flow records were needed for flood frequency analysis to provide a better estimate of extreme flood magnitude (e.g., 100-year flood). 41 years of hourly precipitation data from Oak Ridge NOAA station were used to simulate the long term stream flow data at the White Oak dam under the assumption that the Oak Ridge township precipitation data is statistically representative to the White Oak Creek watershed.

The grain sizes and composition for suspended sand, silt, and clay are based on measured data from storm samples in 1994-1995. The bed sediments size and composition for sand, silt, and clay are based on the core samples measured in previous studies (Struxness et al. 1967, Blaylock et al 1972, and Oakes et al. 1982).

4.4 MODEL SCENARIOS

Two scenarios were analyzed in White Oak Creek watershed modeling, as shown in Fig. 4.6. First, the White Oak Creek basin Baseline scenario (WOCB) was simulated for a five-year period of 1990-94 the using onsite real data such as precipitation and evaporation time series to understand system characteristics of White Oak Creek basin in terms of watershed hydrology, surface soil erosion, sediment transport, contaminant fate, and channel bed interactions. Scenario WOCB was also designed to further investigate the conceptual model of sediment and ^{137}Cs transport developed from the storm data (Chap. 3) and the compliance data.

To advance the conceptual understanding of the system, the following questions need to be addressed. (1) Is White Oak Creek basin a storm driven system with respect to ^{137}Cs as reported in past (2) How do the point and nonpoint sources of ^{137}Cs interact through adsorption and sediment erosion/deposition in the channel system which consists White Oak Creek, Melton Branch Creek, and White Oak Lake. The source/sink in the channel system need to be identified. Impact of storm events on source/sink should also be investigated. The period of 1990-94 is unique combination of wet, dry and normal years. Within the five year period, significant storms occurred at the beginning and the end of 1990 ; 1991 is a normal year with several small storms in the winter and early spring; 1992 is a dry year; precipitation and flow increases in 1993, and 1994 is a typical wet year (Table 4.6).

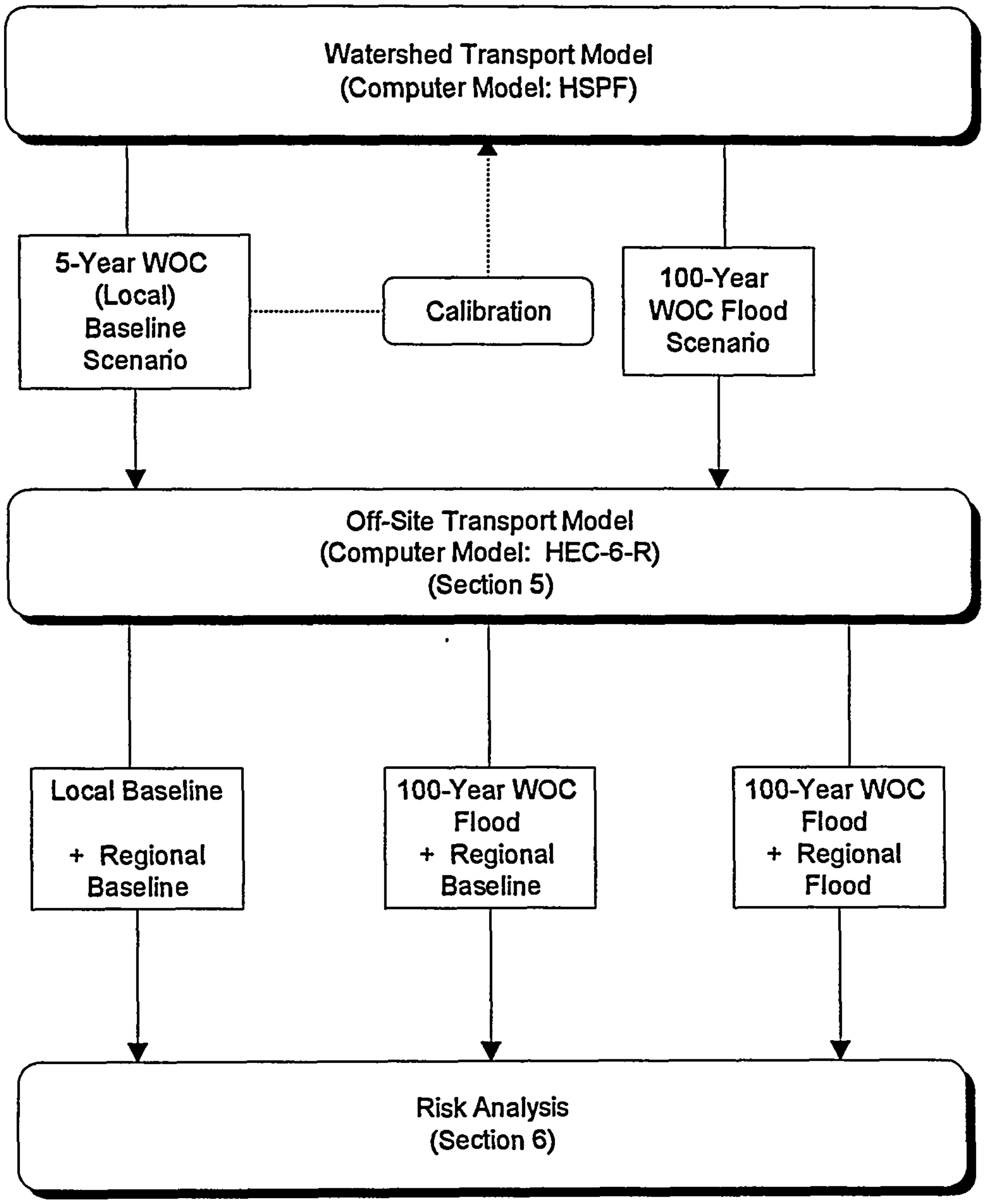


Fig. 4.6 Modeling scenarios for the White Oak Creek watershed simulations and the off-site transport simulations.

Table 4.6 Annual precipitation for each subwatershed calculated using Thiessen method based on data collected at onsite raingages

Annual precipitation for each subwatershed (in)					
	Year				
sub watershed	1990	1991	1992	1993	1994
pls1	63.83	56.15	44.17	46.08	63.52
pls2	63.32	55.11	44.26	47.2	64.05
pls3	62.29	57.24	43.73	45.39	61.11
pls4	62.73	56.18	44.4	46.51	64.39

The second scenario is referred to as the White Oak Creek basin Flood scenario (WOCF). It was simulated to quantify the effects of a potential 100-year flood event and the sediment transport and ^{137}Cs movement under the extreme flood condition. Three steps were needed for simulation under this scenario: 1) estimation of peak flow of extreme (100-year) flood, 2) selection and modification of storm event which resulted in 100 year flood, 3) simulation of flow, sediment and ^{137}Cs released to offsite under the extreme flood conditions.

In the development of the 41-year synthetic hydrograph based on the precipitation at Oak Ridge and the calibrated model, it was observed that the storm of November 22, 1973 resulted in a peak flow classified as a 100-year peak flow. Subsequently, the 100-year storm flood hydrograph at WOD was simulated by replacing the March 22, 1993 storm with adjusted November 27, 1973 storm rainfall data at NOAA Oak Ridge station. Because of the low soil moisture antecedent condition, the NOAA hourly rainfall intensities were increased by a factor of 1.3. The resultant peak flow simulated is 81.4 m^3/s as shown in Fig. 4.7 (2,875 cfs) which is compatible with the 100-year flood magnitude 2724 cfs estimated by flood frequency analysis.

4.5 HYDROLOGICAL CALIBRATION AND VALIDATION

The purpose of hydrologic model calibration is to adjust model parameters in a systematic fashion so that computed and observed values (e.g., flow discharge) agree as closely as possible. A new calibration method was developed by combining nonlinear optimization and an expert system. The system is called OPTICAL, and details of the system are described in Appendix IV.

Figs. 4.8 depict simulated flows discharge at White Oak Dam along with the observed values during the five years period. Similar data are shown in Appendix IV for the individual PLS's, indicating that the model depicts the hydrologic behavior of the watershed at this scale, too. Validation results for flow discharge are presented in the same figures for the last two years from 1993-94. The overall average difference in annual water balance between the simulated and observed values is 2.08%. Over a five-year period, the simulated flow discharge closely matches with the observed values at the White Oak Dam. A goodness-of-fit test with zero intercept on the linear regression relates the simulated and observed flows over a period of five years with coefficient of determination of 0.955 (Fig. 4.9 of least square regression). The time interval of simulation is 30-minute. Daily peak flow is determined to be the maximum hourly averaged flow in each day during the five-year simulation period. A goodness-of-fit test of power regression relates the simulated daily peak flow and observed daily peak flow with coefficient of determination of 0.8946 (Fig. 4.10).

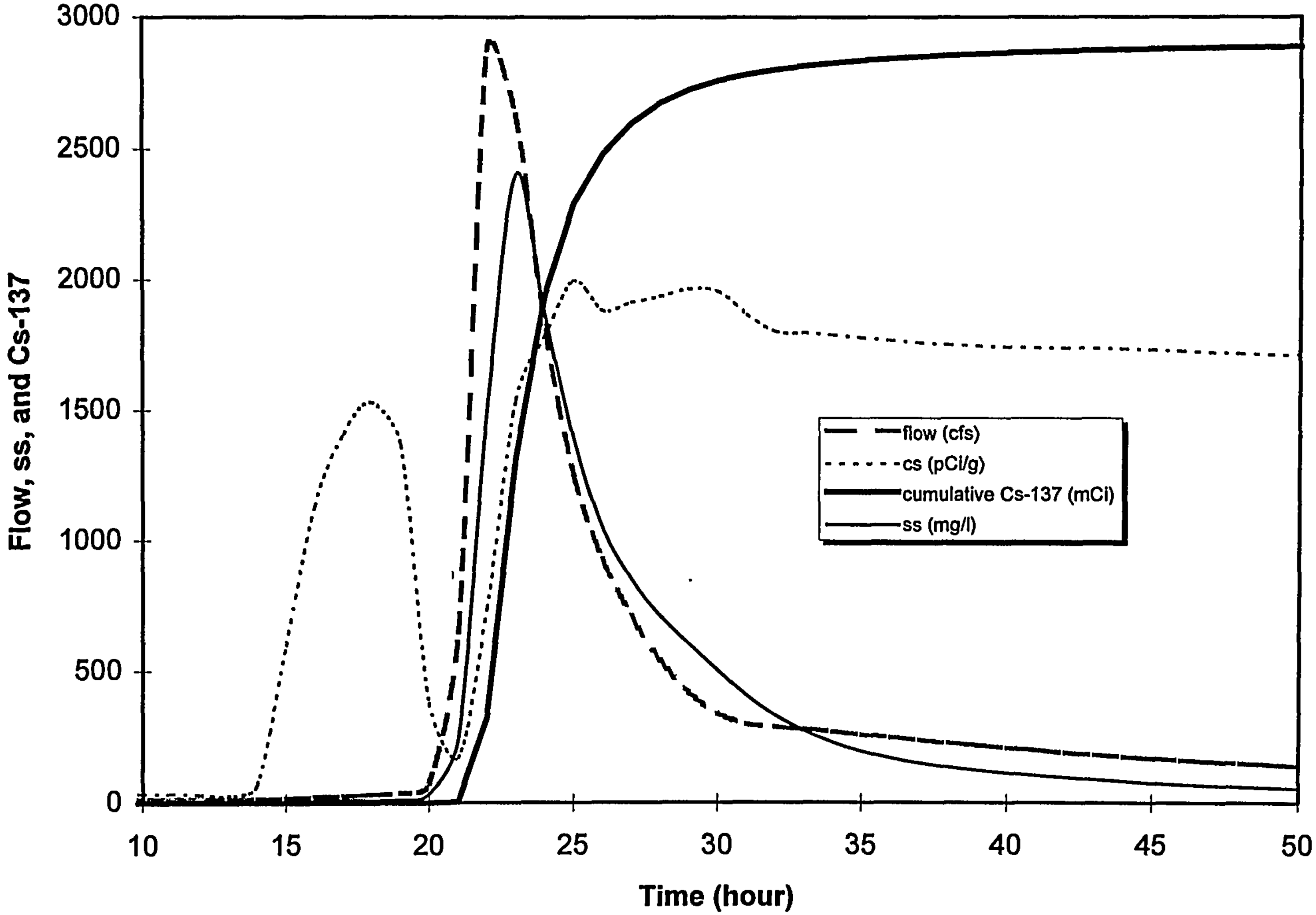


Fig. 4.7. Simulated flow hydrograph, suspended sediments and Cs-137 concentrations, and cumulative Cs-137 release at White Oak Dam for a 100-year flood.

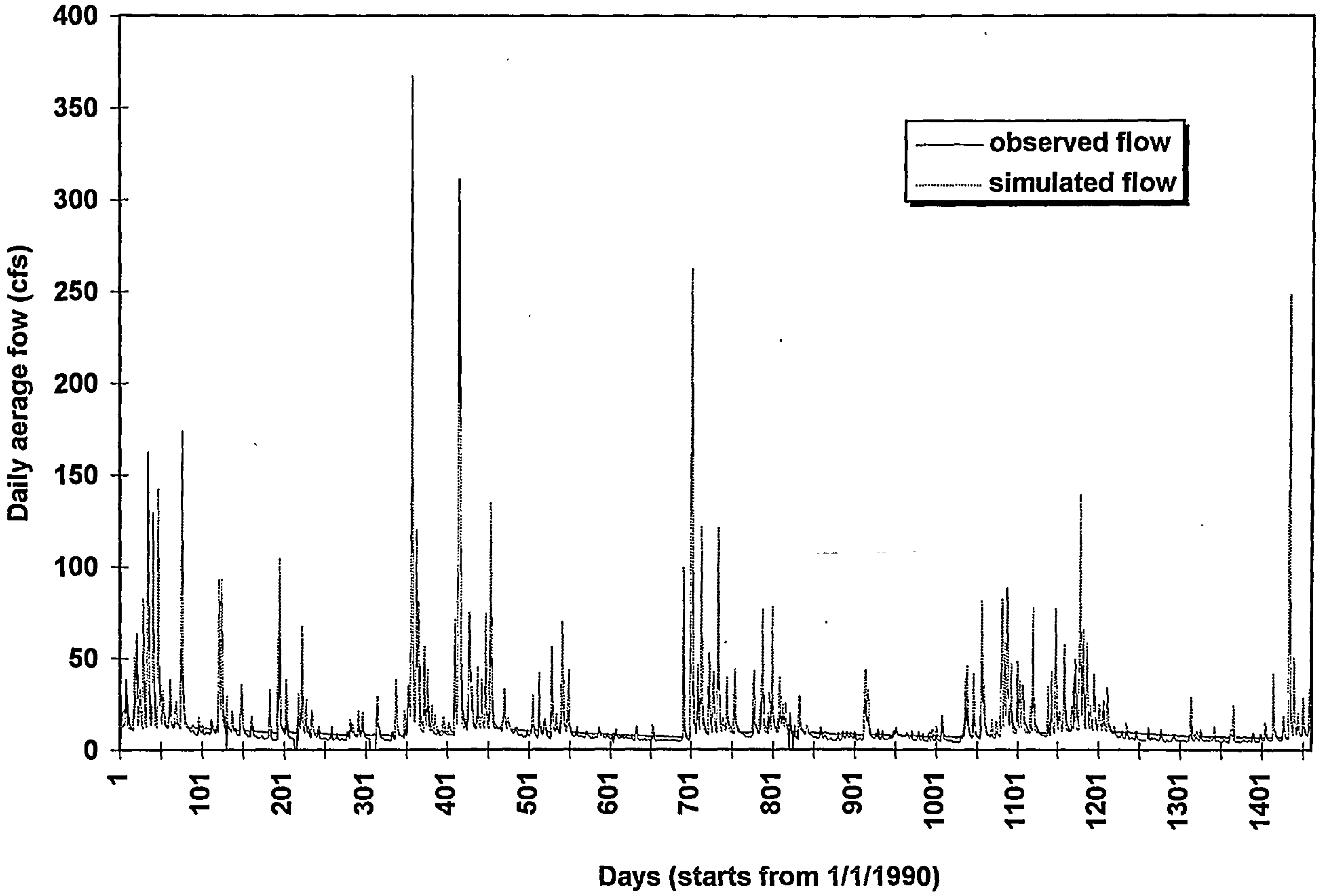


Fig. 4.8. Comparison between observed and simulated flow at White Oak Dam.

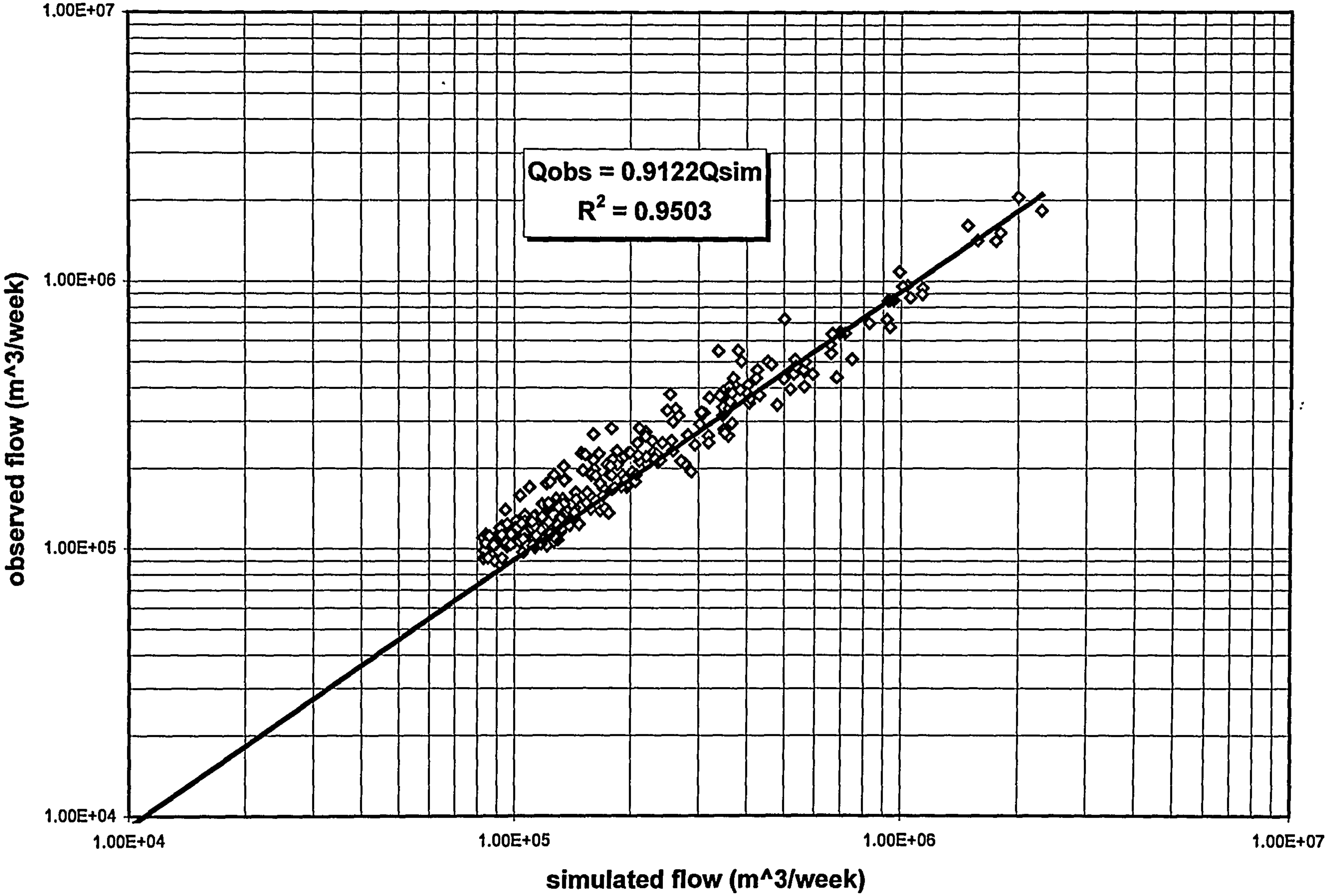


Fig. 4.9. Goodness of fit test for observed and weekly flow at White Oak Dam.

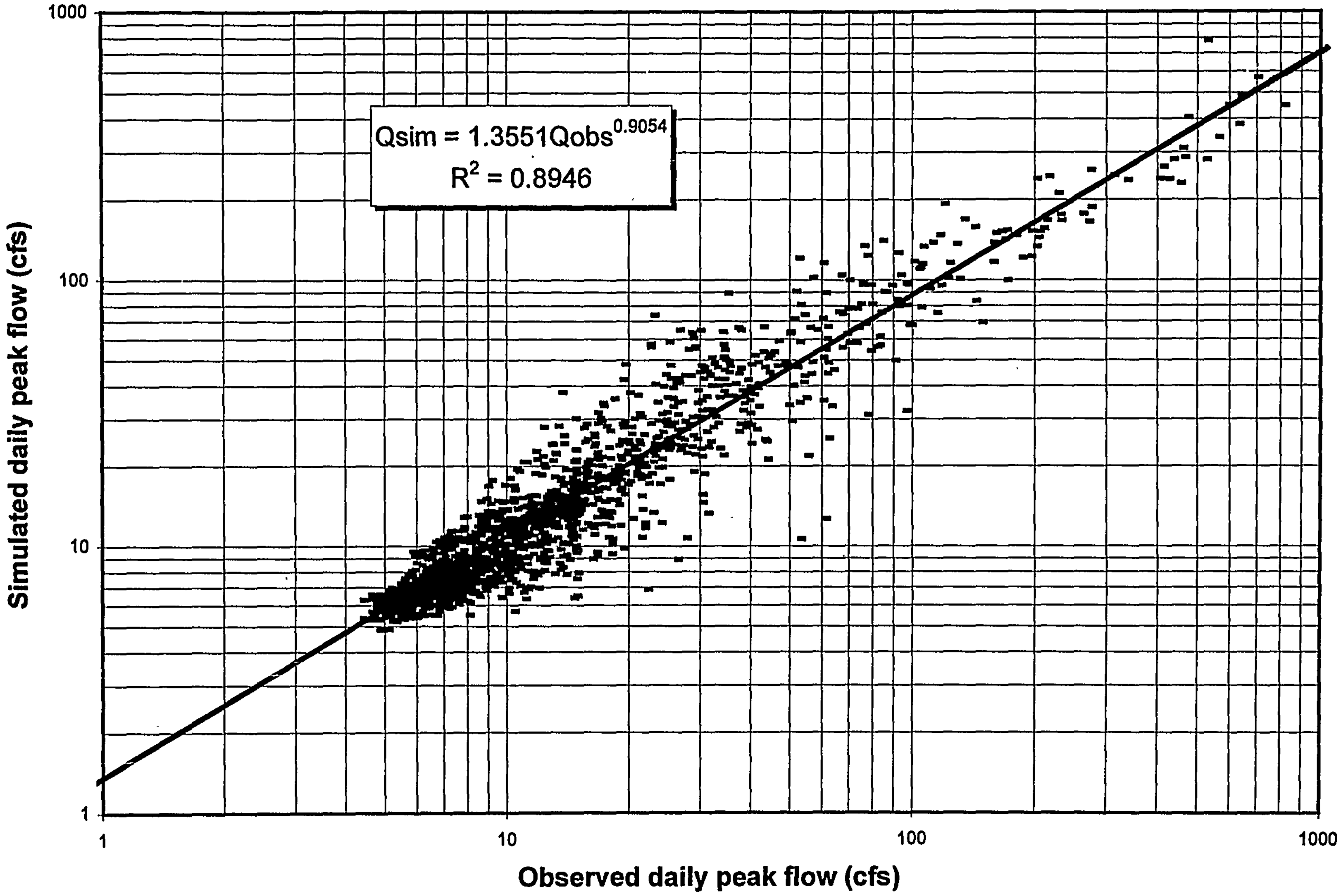


Fig. 4.10. Simulated and observed and daily peak flow at White Oak Dam.

4.6 CALIBRATION AND VALIDATION OF SEDIMENT AND CONTAMINANT FATE

4.6.1 Data Sets for Calibration and Validation

Only limited snapshot data are available for calibration and validation for sediment and ^{137}Cs simulations. The data were categorized into three groups:

1. Storm sampled data include sediment and ^{137}Cs concentrations, sediment loads, scour, deposition, and stream flow. Sediment and ^{137}Cs concentrations measured from five storms (cross reference to Telena's Table of summary of storms in previous section) sampled during 1993-95. Because of limit in number of samples collected during storms, the sediment and ^{137}Cs loads estimated for each storm based on storm sample data has large uncertainty and less accurate. Although the total suspended sediment and ^{137}Cs loads for each storm were still important and used in the calibration process, the emphasis was placed on comparison of the suspended sediment and ^{137}Cs concentrations;

2. Total ^{137}Cs load was measured from composited daily water samples at 7500 bridge, White Oak Creek Weir, and White Oak Dam during 1990-96. This data set is used for comparison of cumulative ^{137}Cs simulated at various locations. This data set was used for calibrating model for monthly and annual release of ^{137}Cs from White Oak Creek basin to offsite. The observed weekly ^{137}Cs releases at White Oak Dam were used to estimate the total ^{137}Cs load per storm at WOD independently from the storm samples; and Channel cross-sectional profiles were measured during a 25-month in 1992-94 at 8 channel cross sections along White Oak creek. This data set is used for validating model for spatial sediment deposition/erosion pattern in the channel.

The data sets include five storms, 5 years of composited ^{137}Cs flux, and 8 channel cross sections surveyed 6 times during a period from November 1992 to December 1994. Each data set was further partitioned into two parts, one for calibration and the other for validation purposes.

4.6.2 Calibration Strategy

The initial model parameters were estimated based on previous studies and/or best estimates from the data analysis. The parameters values were then adjusted by comparing the results with the observed data during calibration process. In principle, OPTCALI can be expended to calibrate sediment and ^{137}Cs transport. Because of the limit in data availability and relatively fewer calibration parameters involved, OPTCALI was not used for sediment and ^{137}Cs calibration. In stead, a iterative procedure was developed based on our simulation objective and data availability for calibrating contaminated sediment transport model as follows:

Watershed sediment erosion. Model is calibrated for sediment erosion over land segment. The controlling parameters are the coefficients in washoff and gully erosion equations. The coefficients were determined based on simulated overland flow and observed sediment concentrations in storm samples. The coefficients are adjusted during calibration to control the total sediment contributions from pervious surface in each land segment.

Instream sediment transport. RCHRES module in HSPF continuously simulates concentrations of sand, silt and clay. Results of sand transport by either Toffleti or Colby method were not satisfactory. The third method was used to model the sand transport as a power function of stream flow velocity. The coefficient (KSAND) and exponent (EXPSND) of the power function are considered as calibration parameters. For simulation of cohesive sediments (silt and clay), the major calibration parameters are the critical shear stress for deposition (TAUCD), critical shear stress for erosion (TAUCS), and erodibility coefficient (M) for each channel reach. Because in each channel reach, the bed grain sizes and composition of cohesive and non-cohesive sediments are not well defined, the grain sizes and sediment composition were also adjusted if necessary. However, such adjustment is secondary comparing to the critical shear stresses. The simulated sediment concentration, total sediment load during storm events are compared with storm sampled data for calibration and validation.

Instream erosion/deposition pattern. The simulated changes in channel depth were compared with the measured channel cross-sectional profiles to see the changes in sediment deposition and resuspension at particular reach. The rationale for checking the deposition/erosion pattern is to take into consideration of heterogeneous distribution of contaminated sediments in channel bed. In another word, only pocket areas (weir pools and near intermediate pond) have higher contaminated sediments in the channel. Similar calibration parameters such as critical shear stresses for silt and clay; channel bed grain sizes; and sediment composition are adjusted in this process.

Watershed ^{137}Cs influx. The potency factors (POTFW and POTFS) were first determined based on ^{137}Cs inventory data collected, then were adjusted during calibration for nonpoint source of sediment associated ^{137}Cs influx. The potency factors for nonpoint sources of ^{137}Cs were treated as calibration parameters because the concentrations of ^{137}Cs in watershed surface soil could not be determined precisely and insufficient data on sediment loads from each land segments.

^{137}Cs movement. The objective is to compare simulated and observed values for a) ^{137}Cs concentrations at upper, middle, and lower WOC channel during the storms, b) annual ^{137}Cs load at WOD, and c) cumulative ^{137}Cs for ^{137}Cs. The field and laboratory data of partition coefficients (K_d) and transfer rate from previous studies were used in the model. However, the values of partition coefficients were increased to model irreversible adsorption of ^{137}Cs by bed and suspended sediments. The K_d values for ^{137}Cs with suspended sand, silt, and clay and bed sand, silt, and clay were further adjusted as calibration parameters. The initial ^{137}Cs concentrations on suspended and channel bed sediments were adjusted during calibration The rationuclide decay rate and transfer rate are not changed for calibration purposes. Because ^{137}Cs transport depends on flow and interaction with suspended and bed sediments, other calibration parameters discussed in steps 1-4 will also affect ^{137}Cs simulation.

Flow is the driving force for sediment transport and ^{137}Cs comes from both point source in NRWT effluent in dissolved form and from nonpoint source adsorbed in the watershed surface soil. Sediment calibration, therefore, follows the hydrologic calibration but precedes the calibration for contaminant fate simulation. Details of the calibration approach is listed in Appendix IV. Results are summarized below.

4.7 BASELINE CASE SIMULATION RESULTS

The calibration and validation results for a five year period are WOCB Scenario are presented in this section to help understand the system characteristics for hydrology, sediment and ^{137}Cs transport.

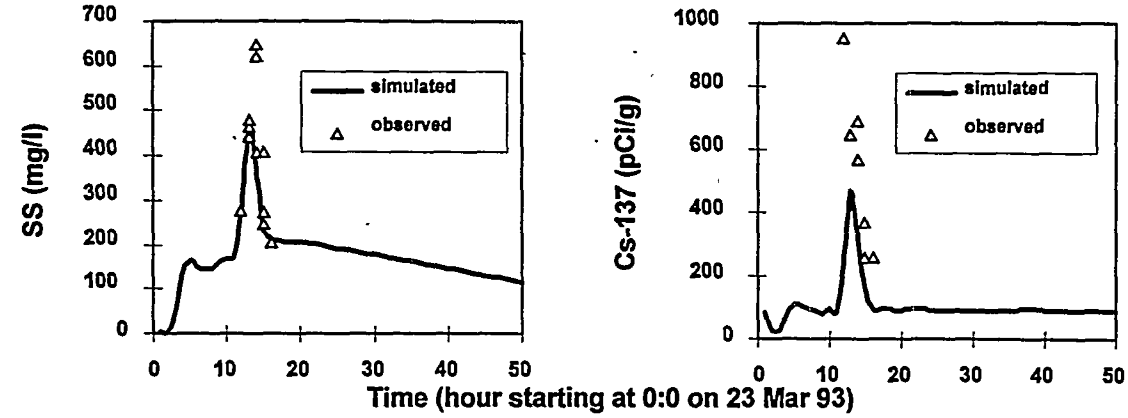
4.7.1 Suspended Sediment and ^{137}Cs Concentrations During Storms

Fig. 4.11 plots simulated and observed suspended sediments and ^{137}Cs concentrations at upper White Oak Creek (7500 bridge, immediate below the lab complex), middle White Oak Creek (White Oak Creek Weir), and basin outlet (White Oak Dam) during March 23, 1993 storm. As shown in the figure, model under simulates the peak suspended sediment concentration by 30% and under simulates peak ^{137}Cs concentration by 100% at upper WOC during the storm (Fig. 11c). The trend of both suspended sediment and ^{137}Cs concentrations at upper WOC closely match with the observed values. The simulated peak time for suspended sediment and ^{137}Cs concentrations also matches the observed peak time. At middle WOC, the simulated sediment concentration and ^{137}Cs concentration closely match the observed values. The observed suspended sediment concentration at WOD seems to be more attenuated and delayed in time.

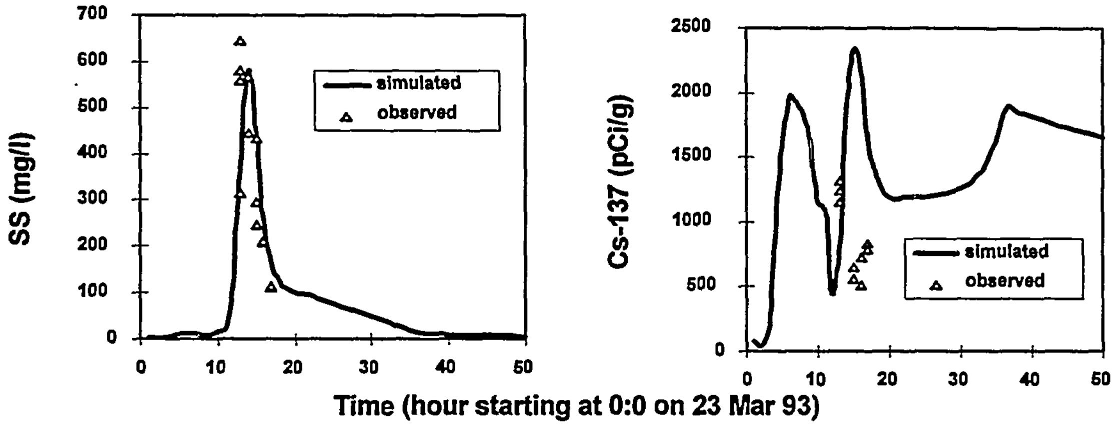
Overall, the observed ^{137}Cs concentrations at all three locations during the storm are in a range comparable with simulated results. Because of limit in storm samples, the observed ^{137}Cs only provides snapshots within a short time period of 10 hours. There is insufficient measured data to show trend of ^{137}Cs concentration profile during the storms.

The simulated results confirm the results of storm data analysis and the conceptual model that both sediment and ^{137}Cs concentrations increase in upper WOC to peak at WOCW and then decrease in lower WOC The simulated peak sediment concentration increases by 20% from upper WOC to WOCW then decreases by 100% at WOD. The spatial variation in sediment concentrations along the White Oak Creek implies that channel bed sediment erosion occurred in upper WOC channel and deposition occurred in White Oak Lake.

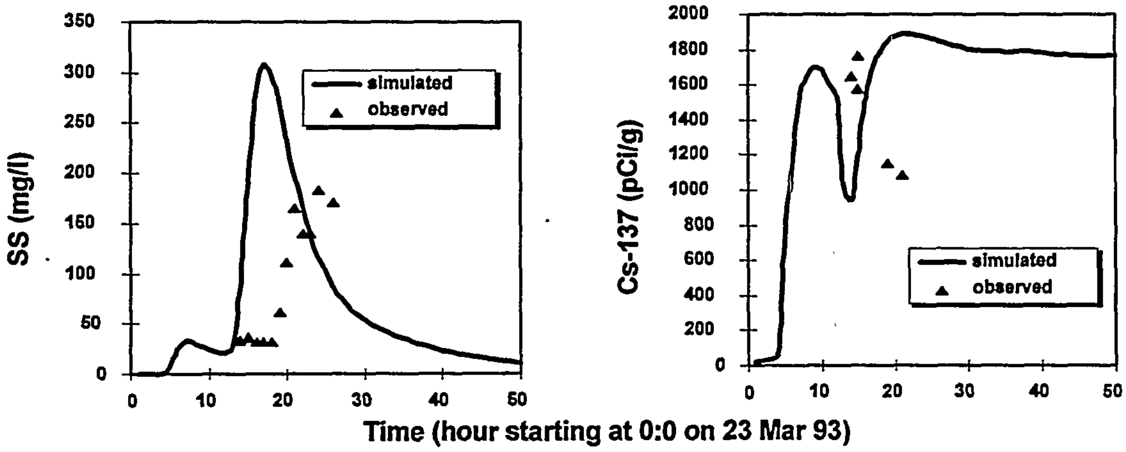
^{137}Cs concentrations plotted in Figs. 4.11-4.12 focus on suspended sediment associated ^{137}Cs. Fig. 4.12 presents hourly dissolved ^{137}Cs flux simulated at the upper, middle and lower basin (7500 bridge, WOCW, and WOD respectively) during a period from January 1, 1993 to March 23, 1993. The stair shape of dissolved ^{137}Cs at upper WOC (7500 bridge) resulted from monthly data used for point source of ^{137}Cs at NRWT. During a non-storm period, the dissolved ^{137}Cs flux reduces from upper WOC to White Oak Dam due to the sediment adsorption of ^{137}Cs. Typically, 72% of dissolved ^{137}Cs is absorbed to channel bed sediments between 7500 bridge and White Oak Creek Weir (WOCW). From WOCW to WOD additional 16% dissolved ^{137}Cs is absorbed to channel bed load. The remaining 12% dissolved ^{137}Cs is released to the Clinch River system at WOD. During storms, because of high ^{137}Cs concentrations (as shown in Fig. 4.11), limited desorption occurred in WOC resulting in increase of dissolved ^{137}Cs flux as shown in Fig. 4.12. Fig. 4.13 focuses on dissolved ^{137}Cs flux change in White Oak Creek simulated during March 23, 1993 storm. At the beginning of the storm, the high Kd values used in the model ensure that only ^{137}Cs adsorption occurred in WOC. Desorption of. ^{137}Cs in WOC starts at hour 4. The peaks of dissolved ^{137}Cs concentrations at WOCW and WOD indicate the maximum desorption of ^{137}Cs. The percentage of maximum increase in ^{137}Cs flux due to desorption of suspended- sediment associated ^{137}Cs flux at 7500 bridge, WOCW and WOD is 0.2.%, 0.9%, and 1.0% respectively. The dissolved ^{137}Cs will be reduced if further increase Kd values to enforce irreversible adsorption of ^{137}Cs. As shown in Fig. 4.13, the time to peak of dissolved ^{137}Cs is shifted about three hours at locations from 7500 bridge to WOD, which resembles to the three-hour time of concentration in WOC basin. Time of concentration is defined as the time taken for water from the most remote point of a basin to reach the outlet (Pilgrim and Cordery 1992). In another word, after



(a) at 7500 Bridge Station



(b) at White Oak Creek Weir



(c) at White Oak Dam

Fig. 4.11 Comparison between simulated and observed suspended sediments and Cs-137 during March 23, 1993 storm in White Oak Creek basin.

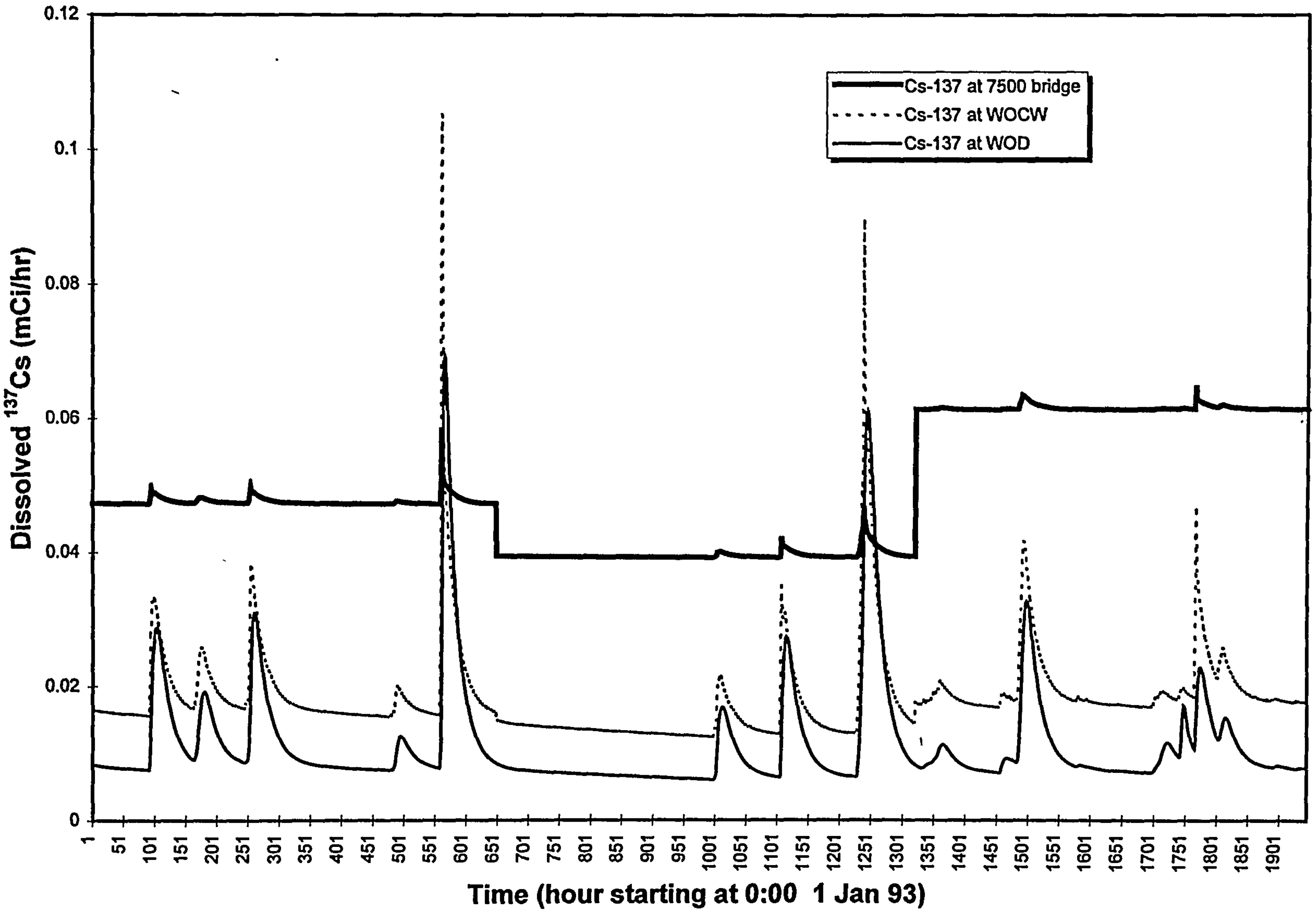


Fig. 4.12 Simulated dissolved Cs-137 at upper, middle, and basin outlet during January 1, 1993 to January 23, 1993.

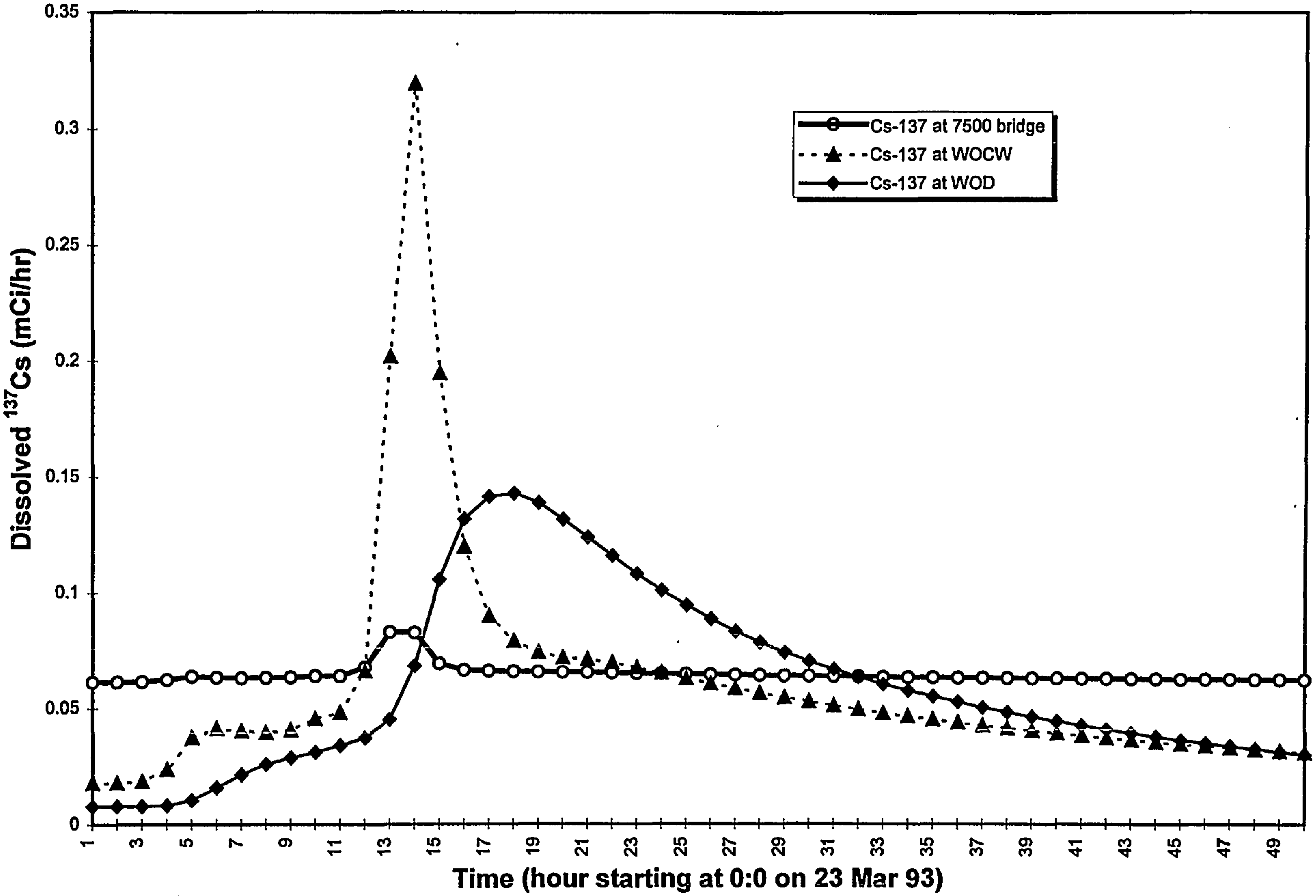


Fig 4.13 Increase in dissolved Cs-137 flux at upper, middle, and basin outlet during March 23, 1993 storm due to adsorption/desorption.

3 hours from the commencement of rainfall excess whole WOC basin are contributing simultaneously to flow at White Oak Dam.

Based on the following results from the watershed modeling:

- during storm period, the impact of desorption process of ^{137}Cs is negligible (less than 1%);
- significant increase in peak ^{137}Cs concentration from upper WOC to WOCW;
- increase in suspended sediment concentration at WOCW (30%); and
- significant decrease in sediment concentration from WOCW to WOD and less significant decrease in ^{137}Cs concentration.

The following conclusions can be drawn

- the bed sediment erosion occurred at upper WOC but not dramatically;
- sediment deposition occurred at WOL; and
- significant ^{137}Cs input from upper WOC channel bed erosion during the storm.

These conclusions conform to the field storm sampling data and to the conceptual model.

4.7.2 Total Annual Release of ^{137}Cs in WOCB Scenario

Simulated and observed annual ^{137}Cs releases at WOD under WOCB (baseline) scenario are plotted in Fig. 4.14. Within the five-year simulation period, the annual ^{137}Cs release is over simulated for wet years in 1990 and 1994, and is under simulated for dry years in 1991 and 1992. Simulated ^{137}Cs release in 1993 is reasonably close to the observed value. Overall, the simulated annual releases of ^{137}Cs to off-site locations match data within a factor of 2 for 1990-94.

Fig. 4.15 presents the cumulative ^{137}Cs simulation results during 5-year time period. Over the 5 year period, the total simulated ^{137}Cs release differs from the observed value by 2%, which validates the annual balance. The calibrated HSPF model of White Oak Creek watershed transport processes is basically a simulator of a storm driven system. As indicated in the plot there is a significant ^{137}Cs input due to erosion during December 1990 storms (large difference between ^{137}Cs release at WOD and the point sources at NRWT).

The observed data shows that the system of White Oak Creek watershed has been changed from a storm driven system with respect to the ^{137}Cs transport toward much less storm driven system within last five years. For instance, there was 0.65 Ci ^{137}Cs released within one storm in December, 1990, which was equivalent to half of the annual release measured for that year. In 1994 spring storms, the high flow (Fig. 4.7) resulted in significant increases in ^{137}Cs released to offsite but the amount of the released ^{137}Cs was only 10% of the ^{137}Cs release December 1990, although the 1994 storms were of comparable magnitude to the December 1990 storms events. The simulation model underestimated the ^{137}Cs transported during December 1990 storms and over estimated 1994 spring storms. In general, it predicts the ^{137}Cs concentration and flux within a factor of 1.5. The model has good overall performance, and for the purposes of estimating the effects of storm-driven ^{137}Cs releases, the model is considered to be conservative due to its storm driven characteristics.

Various reasons may have contributed to the shift of WOC basin system from a storm driven toward a more gradual response one with respect to ^{137}Cs transport. 1) There were possible activities causing watershed soil disturbance during the early season (1990-91) which resulted in more contaminated soil exposure and thus abnormal Cs release to offsite watershed erosion procedure

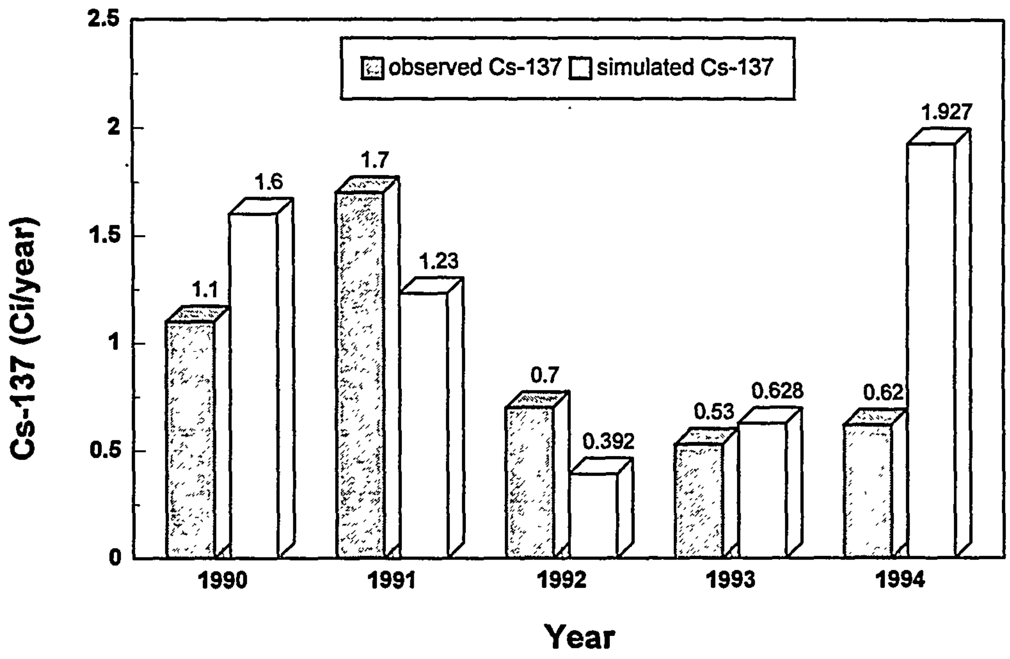


Fig. 4.14. Annual releases of Cs-137 at White Oak Dam.

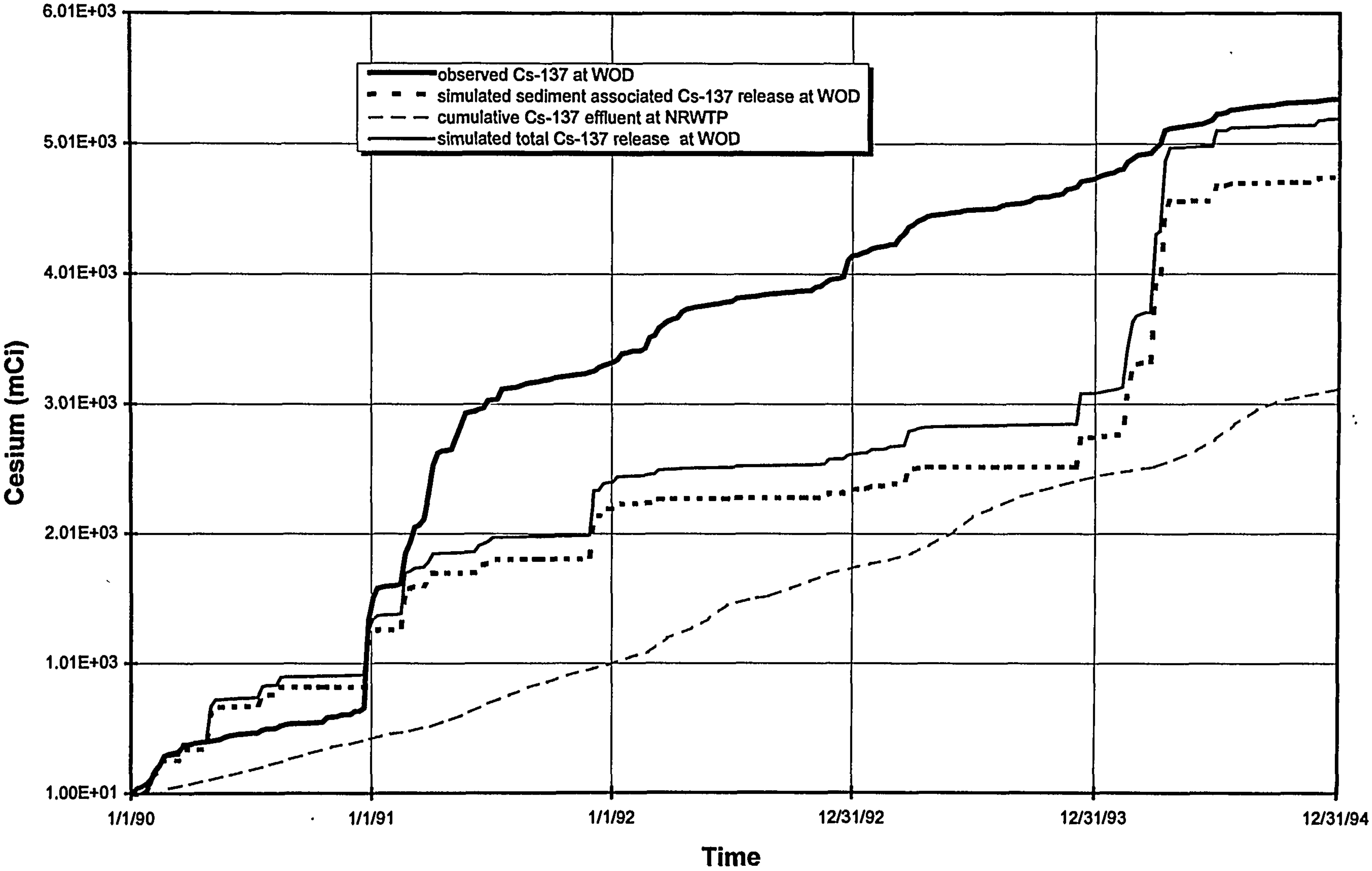


Fig. 4.15. Observed and simulated cumulative Cs-137 release at White Oak Dam.

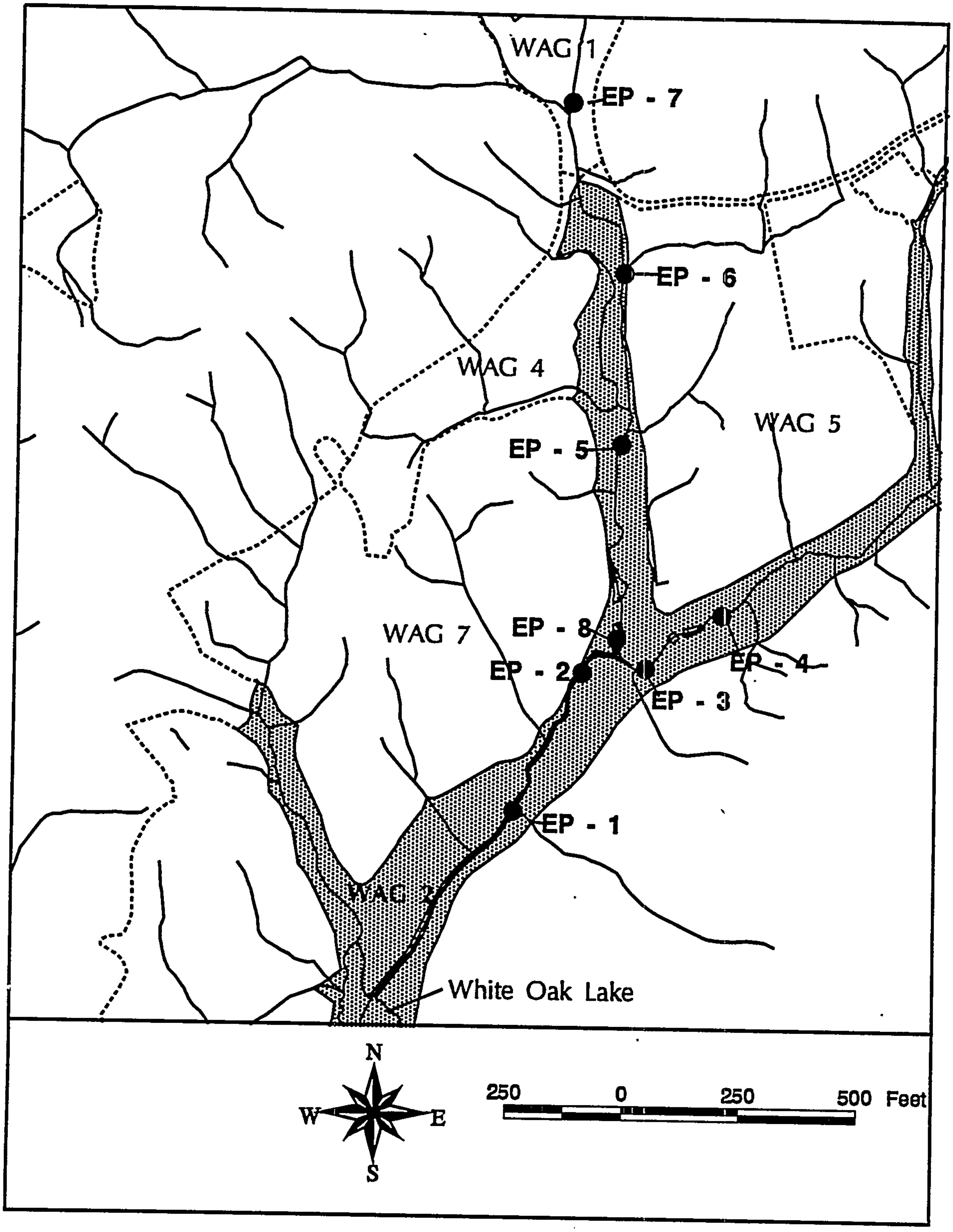


Fig. 4.16. Erosion survey sites in WAG 2.

established during the period. 2) The erosion prevention practices in recent years help reduce watershed soil erosion, therefore reduced the ^{137}Cs flux in 1994 storms.

4.7.3 Comparison of Channel Bed Erosion/Deposition Patterns

Over a period of 25 months in 1992-94 detailed cross sections of White Oak Creek and Melton Branch were surveyed several times for the purpose of documenting channel erosion and deposition (Fig. 4.16). Comparisons between measurements made a point along a stream to modeling results generated for a stream reach are not expected to be very good because of the different scales of the information. Nevertheless the comparison can be revealing.

Based on these survey data, average channel bed elevation was calculated by integral for cross-sectional area divided by the channel width. The incremental change in channel bed elevation for each cross-section between two surveys was calculated. Table 4.7 summarized the results of comparison between the simulated and surveyed channel bed elevation changes at upper, middle, and lower WOC.

The simulated incremental changes in channel bed depth do not match the survey data precisely. However, the general pattern of change, which indicate erosion or deposition in the channel, is reasonably good. For instance, at upper WOC the simulation results indicate erosion occurred consistently through the 25-month period, which is confirmed by the data measured from November 1992 to July 1994 except December 94. At the middle WOC, simulated total change in bed elevation closely match the surveyed data.

The following observations are made from the comparison of simulation results with the survey data. As mentioned above, it is difficult to compare the incremental change in bed erosion/deposition because of the uncertainty in the survey data and the infrequent timing of the surveys. It is more meaningful to analyze the pattern of erosion/deposition to draw general conclusions regarding erosion and/or deposition in channels.

- In general, the survey data confirms simulation findings that erosion occurs at upper WOC and less erosion at middle and deposition at WOL. The surveyed cross-section at lower WOC is near the inlet of White Oak Lake. Simulation results over 5-year period do show deposition at that location. However, the incremental simulation results corresponding to the survey time period show some erosion instead.

- The surveyed results confirmed that the model does simulate sufficient sediment deposition and resuspension. Before the validation, the simulated channel bed was considered to be too stable.

- Assuming the surveyed cross-sections are true without error, the model seems to over-simulate the erosion at upper WOC and under-simulate sediment deposition at lower WOC.

Table 4.7 Simulated and surveyed average channel bed elevation changes at upper, middle, and lower White Oak Creek (WOC) basin during a 25 months period (meters)

CHANGE IN AVERAGE CHANNEL BED ELEVATION (METER)						
	UPPER WOC		MIDDLE WOC		LOWER WOC	
Date	Observed EP7	Simulated R2	Observed EP8	Simulated R4	Observed EP1	Simulated R6
11/19/92	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/28/93	-2.03e-02	-6.20e-02	1.55e-02	-5.91e-03	2.36e-02	4.39e-03
2/1/94	-9.47e-03	-4.33e-02	8.56e-03	-7.68e-03	1.00e-01	-8.53e-04
2/15/94	-8.40e-03	-2.19e-02	-1.67e-02	-1.08e-02	-2.78e-02	-5.49e-03
7/25/94	-5.36e-02	-3.05e-02	1.43e-02	-3.99e-02	2.74e-02	-1.64e-02
12/15/94	1.82e-02	-1.62e-02	-8.44e-02	-1.34e-03	-8.89e-03	2.07e-03
Total	-7.37e-02	-1.74e-01	-6.29e-02	-6.56e-02	1.15e-01	-1.63e-02

4.7.4 Sedimentation in White Oak Lake

At the end of 5-year simulation, the White Oak Lake has only 0.0158 meter (0.052 ft) net sediment deposition. As indicated from the validation of model for bed elevation that the model may under-simulate the White Oak Lake sediment deposition. The simulated average lake deposition rate is 0.0033 m (0.01 ft). Based on the channel cross-sectional survey data at EP1 site (near the inlet of the White Oak Lake 1.3 river mile), the annual deposition rate is ~ 0.017 m (0.055 ft). More survey data in the lake are needed for better estimate and for model calibration for lake deposition/erosion.

4.8 EXTREME FLOOD SIMULATION RESULTS

Under the White Oak Creek basin Flood scenario (WOCF), an adjusted November 27, 1973 hourly rainfall intensity data at NOAA Oak Ridge station was super imposed to replacing March 23, 1993, storm to simulate the potential 100-year flood. The simulated peak flow for the potential 100-year flood is 81.4 m^3/s as shown in Fig. 4.7 (2,875 cfs). The calibrated model was run for the same time period of 1990-94 to simulate flow, sediment and ^{137}Cs released to offsite under the WOCF scenario.

4.8.1 Suspended Sediment and ^{137}Cs Concentrations During 100-year Flood

The simulated suspended sediments and ^{137}Cs concentrations are presented in Fig. 4.17 at 7500 bridge, WOCW, and WOD during the potential 100-year flood. In March 23, 1993 storm, the suspended sediment and ^{137}Cs concentrations increase in channel in upper WOC, reach their peaks in the middle WOC and decrease in White Oak Lake near the dam. During the 100-year flood, both suspended sediment and ^{137}Cs concentrations continuously increase as storm water moves to downstream and peak at White Oak Dam (Fig. 4.18). The results confirm the conceptual model that the contaminated sediments deposited in previous smaller storms in the lower WOC and White Oak Lake are eroded and transported to offsite at White Oak Dam.

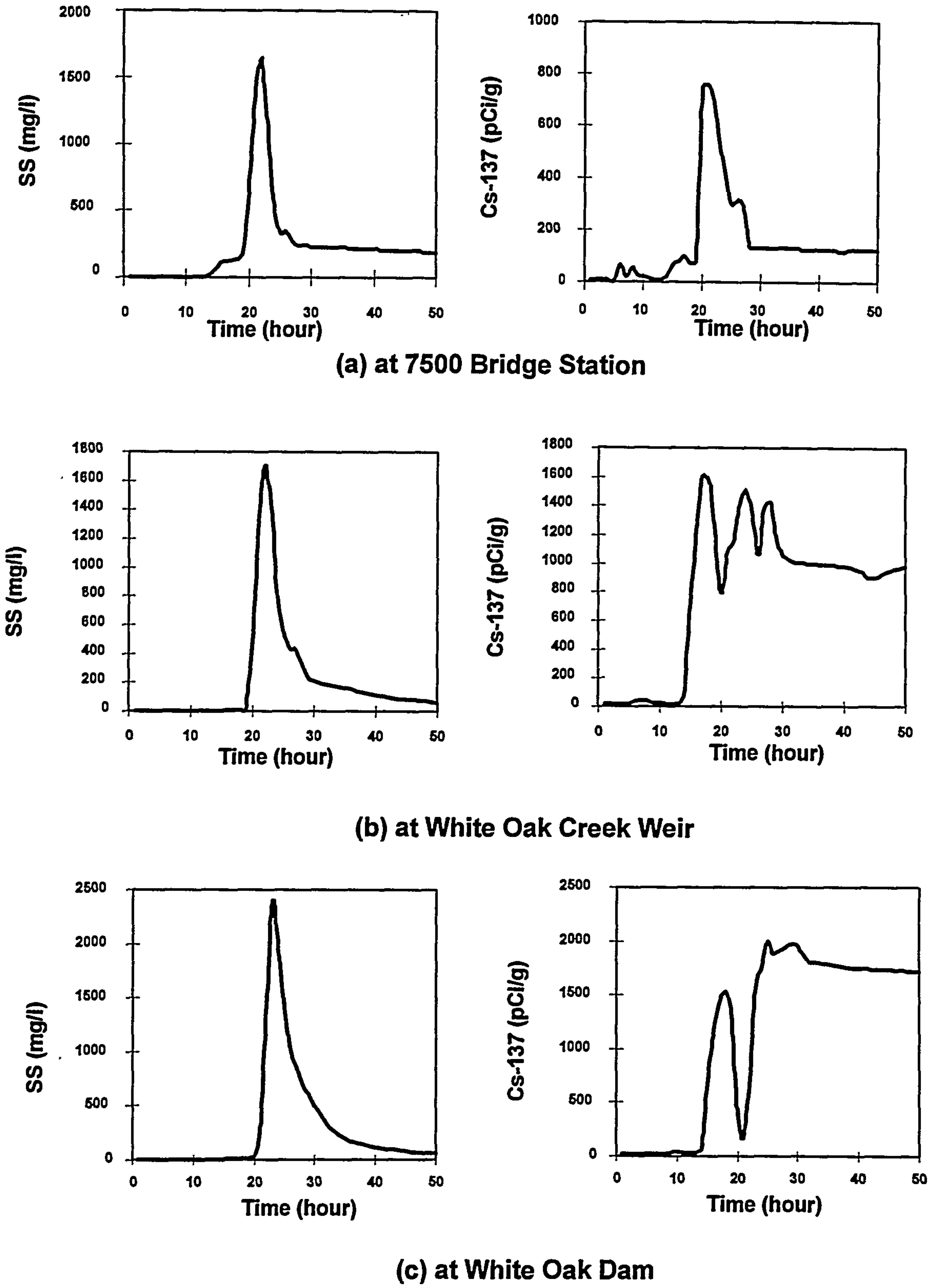


Fig. 4.17 Simulated suspended sediments and Cs-137 concentrations in White Oak Creek basin for the 100-yr flood.

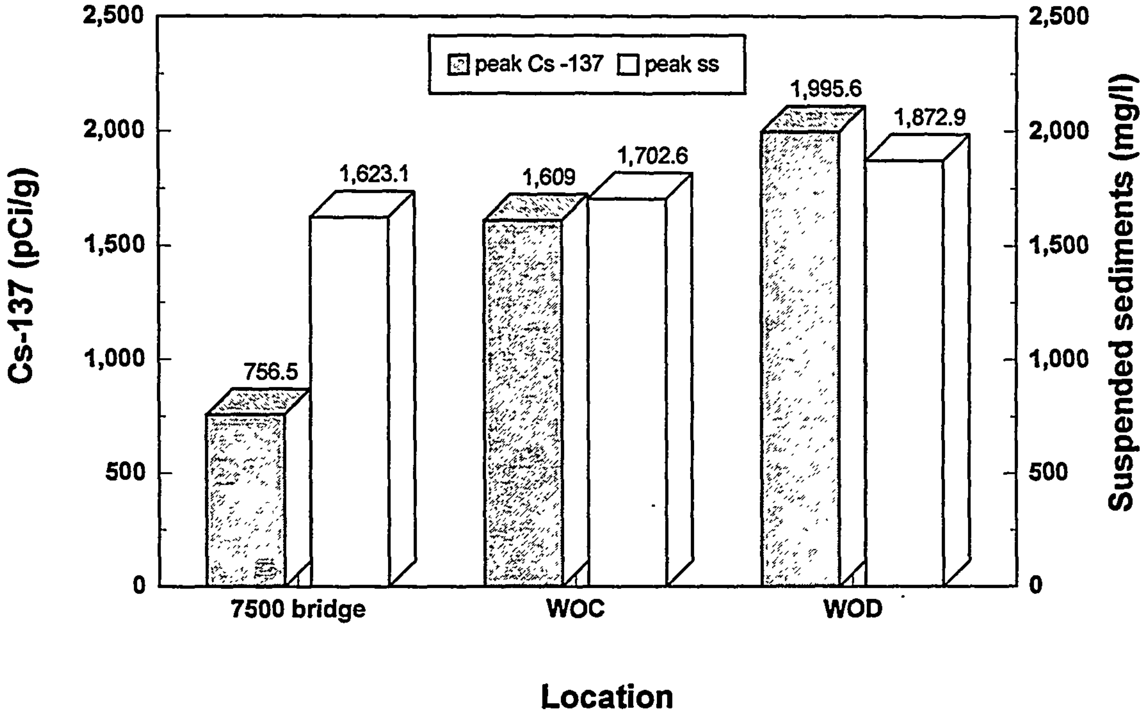


Fig. 4.18. Simulated peak suspended-sediment and Cs-137 concentrations in White Oak Creek watershed for the 100-yr flood.

The simulated suspended sediment concentration, ^{137}Cs concentration, and cumulative ^{137}Cs release at White Oak Dam are plotted along with the 100-year flood hydrograph during the storm (Fig. 4.7). Similar pattern of ^{137}Cs concentration was observed during other storms (Fig. 4.11). The change of ^{137}Cs concentration during a storm depends on rate of changes in flow and suspended sediment concentration, and sources of sediments. ^{137}Cs concentration increases at the beginning of the 100-year storm because the stream flow starts to increase with significant rate of change in flow which mobilizes the sediment-bound ^{137}Cs mainly in channel and lake bed loads. In this stage both suspended sediment concentration and stream flow remain relatively low magnitude. As flow increase, the rate flow increase is greater than the increase of sediment concentration (hours 17-20 in Fig. 4.7). Newly eroded non-contaminated sediments from Melton Branch Creek watershed enter the lake and mix with previous deposited contaminated sediments. Therefore, the ^{137}Cs concentrations decreases dramatically at the earlier rising limb of flood hydrograph. Because the relative low flow and sediment concentration, the cumulative ^{137}Cs release at White Oak Dam is negligible at hour 21. ^{137}Cs increase again as flood reaches to peak and at the beginning of descending limb when significant sediment erosion occurs at channel/lake beds and hillslope contributed sediment concentration reach to its peak. Significant ^{137}Cs is released to the off-site during a short time period as shown in ^{137}Cs cumulative curve. It was also observed that the peak sediment concentration occurs after the flood peak and is followed by the ^{137}Cs concentration peak.

4.8.2 Passing Sediment and Contaminant Load During 100-year Flood

Tables 4.8–4.9 summarize the total sediment, ^{137}Cs load with suspended sediment, and change in channel depth within 50 hours during the potential 100-year flood event. 2.887 Ci of ^{137}Cs is released to offsite due to the storm, which is 90% of the simulated annual ^{137}Cs release at WOD (3.191 Ci). The point source of ^{137}Cs from NRWT during the storm is negligible. During the 100-year flood, there are 1.984 Ci of ^{137}Cs eroded from watershed surface soils, in which 64% comes from lower White Oak Creek subwatershed including the White Oak Lake floodplain (PLS3). 0.903 Ci of ^{137}Cs comes from White Oak Creek bed load (32.3%).

Table 4.8 Simulated total sediment eroded from land segments and associated nonpoint sources of ^{137}Cs load during a potential 100-year flood

Land segment	Total sediment (ton)	^{137}Cs load in suspended sediment (mCi)
PLS1	995.9	597.5
PLS2	109.1	130.9
PLS3	111.5	0.
PLS4	493.1	1,255.4
sum	1709.6	1983.8

There is significant sediment deposited in the upper WOC channel (1.17 ft increase in channel bed elevation) because of high sediment load from PLS1. Erosion occurs in middle WOC, lower WOC and White Oak Lake. The difference between total sediment passing WOD and sediment load from PLS1-4 is net erosion of 481.6 ton of sediment from channel bed load.

Table 4.9 Simulated bed depth change, total passing suspended sediment, and ^{137}Cs load with suspended sediment in White Oak Creek reaches during a potential 100-year flood

Channel reach	Bed depth change (ft)	Total sediment (ton)	^{137}Cs load in suspended sediment (mCi)
R2 (7500 bridge)	1.170		591.6
R3	-0.115	889.6	
R4 (WOCW)	-0.05	1041.0	1136.1
R8	-0.01	—	
WOD		2197.2	2887.2

Comparison of ^{137}Cs movement between average flow and extreme flood conditions indicates that the White Oak Lake (WOL) and stream bed segments downstream of 7500 bridge are sinks for average flow condition and sources under extreme floods.

4.9 CONCLUSIONS AND RECOMMENDATIONS

The comprehensive modeling approach can provide a valuable tool for decision makers to quantitatively analyze (1) sediment erosion, deposition, and transport; (2) exposure risk related to radionuclides in contaminated sediment; and (3) various management strategies.

OPTCALI dramatically reduces the time required for calibration process and improves the modeling results significantly. The same principle that combines expert system with optimization can be expanded for water quality (sediment transport and contaminant fate) model calibrations.

WOC basin system was shifted from a storm driven toward a more gradual response one with respect to ^{137}Cs transport during 1990-94. The model is more conservative due to its storm driven characteristics and has good overall performance.

Simulated sediment loads and contaminant releases at various locations during storms match with the observed values within a factor of 1.5 for five storms that occurred in 1993-94.

During a normal flow year, the major source of 137Cs is from the Non Rad waste water treatment plant (NRWT). The simulation results confirm the conceptual model that the sediment freshly eroded from watershed is relatively clean and available to be sorbed with ^{137}Cs effluent from the NRWT.

The peak suspended and ^{137}Cs concentrations occurred at WOCW during small storms. The contaminated sediment deposited on the creek segment near WOCW during non-storm periods. The contaminated sediments freshly deposited in the WOC was mobilized during the storm periods and moved to downstream of WOD with part of the contaminated sediment settled at WOL.

The simulated average lake deposition rate is 0.0033 m/yr (0.01 ft/yr). Based on the channel cross-sectional survey data near the inlet of the White Oak Lake, the annual deposition rate is ~ 0.017

m/yr (0.055 ft/yr). More survey data in the lake are needed for better estimate and for model calibration for lake deposition/erosion.

During extreme flood period (100-year flood) the watershed and channel bed become the major sources of the ^{137}Cs. The total annual release of ^{137}Cs to offsite with 100-year flood event is 3.2 Ci v.s. 0.4 Ci for a normal year without 100-year flood. The peak concentration of ^{137}Cs is about 1960 pCi/g and maximum flux of ^{137}Cs is 0.99 Ci/hour during the extreme flood event.

Cooperation between the agencies is needed during the high contaminant releases or extreme flood event. For instance, one of the possible precautions to reduce exposure risk is for ONRL to inform TVA to increase flow release at the Melton Hill Dam to dilute the contaminant when high contaminant releases to offsite occurs.

5. OFF-SITE TRANSPORT MODELING

Contaminants released at White Oak Dam are transported through White Oak Creek Embayment where they are discharged into the Clinch River. In this chapter, the ^{137}Cs releases at WOD, as estimated by the watershed transport model, are used as input to the off-site transport model in order to determine the movement and deposition of ^{137}Cs in the Clinch River as it flows into the Watts Bar Reservoir. Two scenarios were generated by the watershed transport model, the 100-year flood scenario and the baseline scenario for the period, and these scenarios serve as input to the off-site transport model.

Water leaving White Oak Creek watershed mixes with the much larger flows in the Clinch River. Conditions in the Clinch River strongly influence the transport and deposition of contaminants generated in the smaller basin, therefore, two alternative scenarios for Clinch River flows (identified as "normal" and "flood" flows) are combined with the WOC watershed 100-year flood in order to define a range of off-site ^{137}Cs distributions. In turn, the output from this step of the analysis serves as input to the risk evaluation model of the next section.

The off-site transport model used here is the same computer model and parameter set as used in the CRRI study to recreate the ^{137}Cs distributions observed in the river-bottom sediments based on the historical ^{137}Cs releases from WOC. The off-site transport model does not include the effects of the Sediment Retention Structure constructed in 1992 to reduce the erosion of ^{137}Cs-contaminated sediments in the embayment.

5.1 OFF-SITE TRANSPORT MODEL DESCRIPTION

The off-site transport model is a modified version of HEC-6, a one-dimensional numerical model, originally designed by the U.S. Army Corps of Engineers to analyze long-term scour and deposition by simulating the interactions of the hydrodynamics of water flow, movable bed-sediments, and sediments entering the system (USACE, 1993). HEC-6-R, the modified version of the model, simulates the fate of particle-reactive radionuclides.

The model simulates transport of sediment and sediment-bound contaminants by simulating many of the same processes as does the HSPF model described in Chap. 4; however, there are several significant differences between HSPF and HEC-6. HSPF incorporates streamflow generation based on the Stanford Watershed Model (Linsley et al. 1982) and it simulates the processes of hillslope erosion and the transport of contaminated soil. HEC-6-R does not incorporate a hydrologic model. It requires as input the hydrographs for the river system being modeled. HEC-6-R does not simulate hillslope erosion, but it does track changes in the amount and type of channel sediments in detail. The thicknesses of active and inactive sediment layers and the distribution of contaminants sorbed to the sediments are modeled explicitly in HEC-6-R

5.1.1 Processes

The HEC-6-R model simulates three main components of the river-sediment system: the flow and energy distributions in the channel that lead to erosion and sediment movement; the dynamics of the sediments; and the relationships between the sediments and the particle-reactive contaminant(s). These components of the system are discussed briefly in this section.

In the HEC-6-R model, the river system is characterized by a series of cross sections of the channel that are specified by coordinate points and by the distance between cross-sections. In the model, the water discharge hydrograph is a required model input. It is interpreted a time series of steady flow discharges, and sediment transport is calculated for each step in the time series. The hydraulic parameters needed to calculate sediment transport capacity are velocity, depth, width and slope, which are derived from water surface profile calculations at each cross-section for each successive discharge in the time series. Water surface profiles are calculated using the standard step method to solve the one-dimensional energy and continuity equation (USACE, 1993; USACE, 1959). The energy loss in the equation is based on the friction loss, which is dependent on the Manning's roughness coefficient, the upstream and downstream cross-sectional areas of the river, and the distance between the cross sections.

Sediment transport in HEC-6-R is based on the concept of the alluvial reach (Einstein, 1950, from USACE, 1993), i.e., the bed sediment is composed of the same sediment material as that moving in the stream. There is no difference made between bed movement and suspended sediment movement when applying the continuity equation for sediment (the Exner equation).

Transport of non-cohesive sediment (sand particles > 0.0625 mm) is calculated from two variables: sediment transport capacity and sediment availability. Sediment transport capacity is determined from the empirical equations of Vanoni (1975). Sediment availability for all size-fractions of sediment particles is dependent on the upstream supply and the potential scour rate. Primary controls on scour rates are the thickness of the active sediment layer, the gradation of the bed material, and the surface area of the armored sediment. The thickness of the active layer is defined as the water depth below which no sediment transport for a particular grain size takes place. This equilibrium depth is calculated for a given grain size from a combination of the Einstein, Manning and Strickler equations (USACE, 1993). Armoring occurs when coarser particles on the bed surface protect finer particles underneath from being eroded, and the potential scour volume is reduced in relation to the armored surface area.

Sediment transport of clays and silts (particles < 0.0625 mm) depends on bed shear stress using the equations of Krone (1962) for deposition and the equations of Partheniades (1965) and Ariathurai (1977) for erosion. To account for a combination of non-instantaneous entrainment and flow turbulance, the scour rate is modified by an entrainment coefficient, dependent on reach length and flow depth.

Particle-reactive contaminants are transported by and interact with the sediments. Changes in the contaminant load depend on the upstream supply, sorption, desorption and radioactive decay of contaminants as shown in Fig. 5.1. Suspended and bed sediments equilibrate with the dissolved contaminant according to distribution coefficient (K_d) values that are specific for the contaminant, sediment particle size, and particle type. The K_d is based on the partitioning of contaminant between the sorbed and the dissolved phase, and transfer rates are calculated from the K_d (Hetrich, 1992). Solution of the continuity equation for contaminants yields a near-perfect mass balance during the simulations. An elaborate set of book-keeping algorithms was developed that keeps track, over time, of contaminant concentrations and layer thicknesses in the sediments.

5.2 THE CLINCH RIVER/WATTS BAR RESERVOIR SYSTEM

Discharge in the off-site system is largely regulated by dams, as shown in Fig. 1.2. Melton Hill Dam (Clinch River mile 23) controls the discharge in the Clinch River that flows past the White Oak

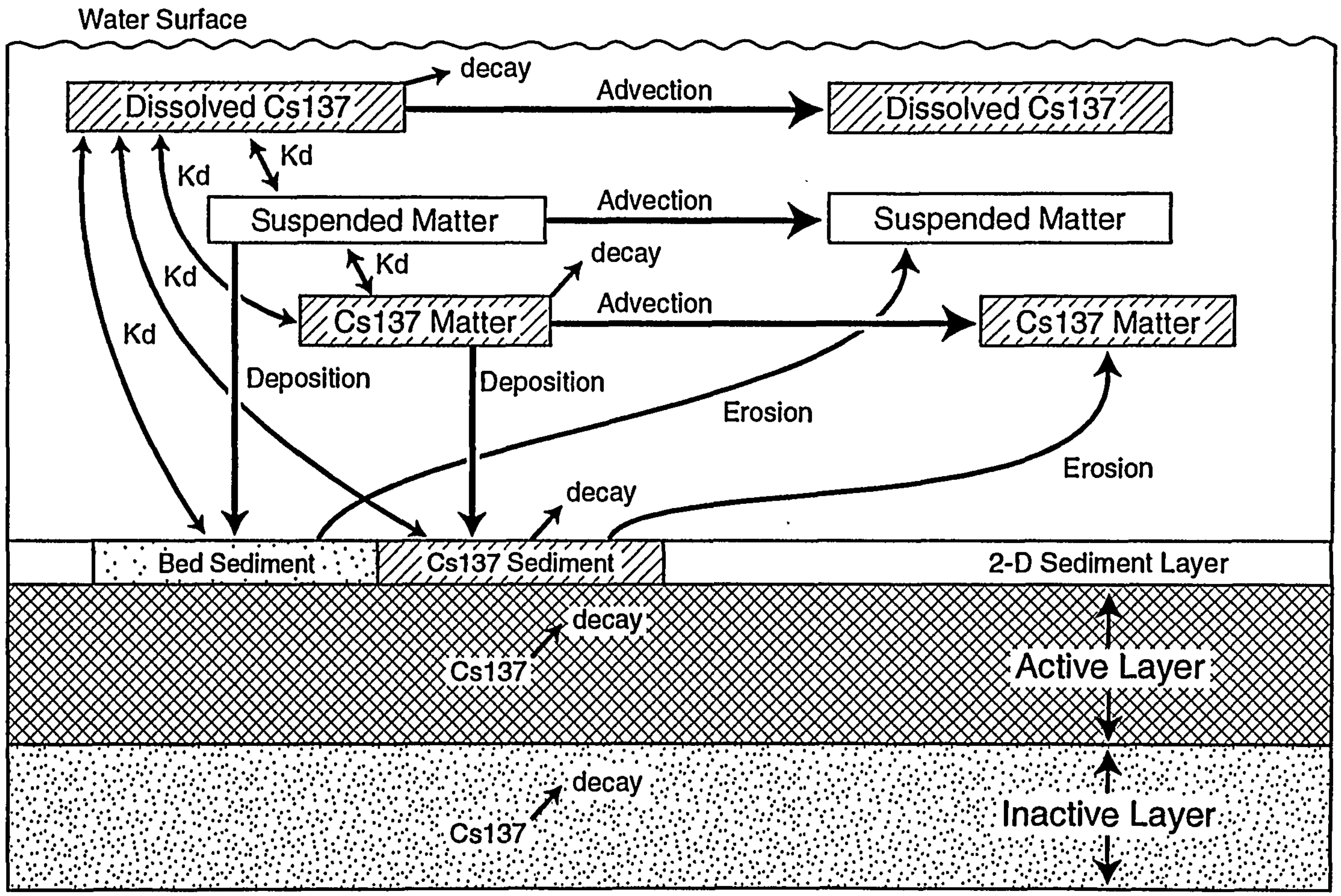


Fig. 5.1 HEC-6-R models process affecting ^{137}Cs accumulation in river sediments.

Creek discharge point (Clinch River mile 20.8) where the ^{137}Cs-contaminated sediments enter the system. From there the Clinch River flows to the confluence with the Tennessee River. Flow in the Tennessee River is controlled upstream by the Fort Loudoun Dam. Downstream the Watts Bar Dam (Tennessee River Mile 529.9) controls the water level in Watts Bar Reservoir. High-pool conditions maintained in the summertime elevate the water surface in the Clinch River, and the water levels in the river are affected all the way up to the tail waters of Melton Hill Dam. During the winter and spring, low-pool conditions are maintained in the reservoir for flood control. During this period the elevated water level of the reservoir extends approximately to Clinch River mile 12.

5.3 MODEL PARAMETERS

Model parameters were collected from measured data generally available or specifically measured for this project, and from the literature. The *bathymetry* of the system was based on cross sections measured by TVA. *Daily water discharge* and *downstream stage heights* are routinely measured at dams by TVA. For the Emory River and Popular Creek, *sediment inflows* are specified from published information. With regard to transport of sand, HEC-6-R includes empirical relationships and the no calibration is needed. The transport of clay and silt is dependent on critical shear for deposition and erosion and on an erosion rate parameter. Critical shear for erosion was measured for five sediment types from the Clinch and Lower Watts Bar sediments (Harris et. al., 1994), and based on these measurements, critical shear for deposition of 32.6 dyne/cm^2 and critical shear for erosion of 42.6 dyne/cm^2 were used in the model. For calculation of the ^{137}Cs transport the K_d was set to 3000 kg^{-1} for clays and silts and 30 kg^{-1} for sand. The adsorption rate for suspended sediments was 1 day^{-1} and the desorption rate was 0.0001 day^{-1}.

5.4 CALIBRATION AND VALIDATION RESULTS

Model calculations were calibrated against one data set and validated against an independent data set. Data for sediments were derived from periodic measurements made by the TVA of sediment accumulation at 41 cross-sections in the study area (McCain, 1957, 1992). Simulated sediment accumulation from 1951 to 1956, from 1956 to 1961 and from 1961 to 1991 compared well with measured amounts. Model goodness of fit tests, based on linear regression analysis showed coefficients of determination (R^2) of 0.54, 0.77 and 0.77 respectively, for the three time periods.

Cesium-137 distributions were computed and compared to available data for validation. The simulated ^{137}Cs activity in Clinch River in 1977 was 57 curies which compares well with the 42.5 curies estimated from sediment core data (Oakes et al. 1982). For the reservoir part of the system the model predicted only half of the expected ^{137}Cs activity, which was based on extrapolated core data (Olsen et al. 1992).

The HEC-6-R simulation results were compared with predictions made by two other models TODAM (Onishi et al, 1994) and CHARIMA (Holly et al, 1990) implemented by TVA and Batelle, respectively. These two models predicted low ^{137}Cs retention efficiency by the reservoir, similar to the result of HEC-6-R and giving cause to question the data extrapolation. The spatial pattern of the ^{137}Cs distribution in the reservoir computed by the HEC-6-R was good. Linear regression analysis showed a coefficient of determination (R^2) of 0.78.

As for ^{137}Cs in the WOC embayment, the three models (HEC-6-R, TODAM and CHARIMA) computed significant accumulation of ^{137}Cs over the period 1944-1990. Blaylock (1993) estimated the inventory in the embayment of 6-11 Ci whereas the models overestimated this amount by about a factor of 3.

As mentioned earlier, the model does not include the effects of the Sediment Retention Structure constructed in 1992. In this task we applied the model to current conditions that include the Sediment Retention Structure so the results have to interpreted cautiously.

5. 5 OFF-SITE SCENARIOS

The objective of the simulations reported below was to simulate the change in the distribution of ^{137}Cs contaminated sediments in the Clinch River and Lower Watts Bar Reservoir resulting from a 100-year flood in the WOC watershed. The modeling results were then used as input for the risk analysis reported in Chap. 6.

5.5.1 100-Year Flood Scenario

The White Oak Creek watershed transport model (as described in Chap. 4) was used to generate the sediment and ^{137}Cs fluxes caused by the 100-year flood (flood scenario) and the same fluxes without the flood (baseline scenario). The period of simulation is 1990-1994. In the flood scenario, the extreme storm that causes the flood occurs on March 23, 1994, where it replaces a much smaller storm in the baseline scenario. The 100-year flood releases 2.9 Ci of ^{137}Cs at White Oak Dam, and this release serves as input to the HEC-6-R model, which models the fate of the ^{137}Cs through the White Oak Creek Embayment, the Clinch River, and the Lower Watts Bar Reservoir.

Because conditions in the Clinch River strongly influence the transport and deposition of sediments in the WOC Embayment two alternative off-site flow scenarios are combined with the WOC scenarios to model the off-site system. At the time of the 100-year flood in the WOC watershed, off-site flows are considered to be either "normal" or "flood stage." For the first case, the flood in the WOC watershed is considered to be a *local flood*. For the second case, the flood in the WOC watershed is considered to be part of a *regional flood*. These assumed scenarios lead to three simulations:

System baseline:	WOC baseline + Off-site baseline
Local flood:	WOC 100 yr flood + Off-site baseline
Regional flood:	WOC 100-year flood + Off-site regional flood

as shown in the flow chart in the preceding section.

The simulations spanned a 10-year period following the 100-year flood, i.e., through March 1993 through March 2003. The simulations required an initial distribution of sediments and ^{137}Cs along the channel bottom of the river system (initial conditions), and also hydrographs, sediment loadings, and ^{137}Cs loadings for the simulation period (forcing function). For the initial conditions all model simulations started by simulating the period from 1944-1993 using the historic record of ^{137}Cs releases (from Table 2.1) in order to generate a "realistic" spatial pattern of sediments and ^{137}Cs prior to the 100-year flood. For the simulations, a ten-year sequence of measured flows in the Clinch River and Tennessee River (i.e., from 1981 to 1991) and measured ^{137}Cs releases were used to simulate future flow conditions to the year 2003.

The regional flood was based on flow records of May 1984 at Fort Loudon Dam when the peak flow was close to the 100-year flood. The results were scaled for flows in the Clinch River at Melton Hill Dam, and flows in the Emory River and Poplar Creek. The model generated a flood peak at Watts Bar Dam that was close to the estimated maximum flow of 476,000 cfs that occurred in 1867.

5.6 MODELING RESULTS

The movement of sediment and sediment-bound ^{137}Cs in the Clinch River/Watts Bar Reservoir system was simulated through year 2003, ten years after the 100-year flood that "occurred" in March 1993. Table 5.1 shows the ^{137}Cs in the sediments of the WOC Embayment, Clinch River, and lower Watts Bar Reservoir for the system baseline and the two flood scenarios.

For the system baseline scenario, the gradual decline in ^{137}Cs in the Clinch River and lower Watts Bar over the 10-year period is due mostly to radioactive decay. The values for year 10 do not follow the trend. Just prior to year 10 of the simulation, there is a large system-wide flood that causes backwater and a slight amount of ^{137}Cs deposition in the embayment plus flushing of some ^{137}Cs from the Clinch River and the reservoir. Fig. 5.2 shows the change in ^{137}Cs in the Clinch River over time, and the flushing around year 9 is evident.

For the flood scenarios the most important variable is the difference in the ^{137}Cs activity between the scenario and the baseline, as shown in parenthesis in Table 5.1. It is important to keep track of the amount of ^{137}Cs entering the Clinch River/Watts Bar Reservoir system. From Chap. 4, it is known that the 100-year flood discharges 2.9 Ci of ^{137}Cs into the embayment. As shown in Table 5.1, following the local flood the ^{137}Cs activity in the embayment is reduced by 1.98 Ci (~ 2 Ci), indicating that the 100-year flood is eroded about 2 Ci from the embayment sediments and that a total of 4.9 Ci (2 + 2.9) is released into the Clinch River. The erosion would be lower if the Sediment Retention Structure were incorporated in the simulation. Nevertheless, some erosion probably can occur and the loss of 2 Ci is perhaps high but not unreasonable; certainly it is conservative.

For the local flood, the Clinch River and lower Watts Bar Reservoir together gain 4.3 Ci (3.87 + 0. 43) indicating that 0.6 Ci (4.9 - 4.3) has been discharged across Watts Bar Dam. Thereafter, the ^{137}Cs activity in the river and the reservoir tends to decline due to radioactive decay but there is some transport downstream, too.

For the regional flood, the ^{137}Cs in the embayment does not erode, instead the embayment accumulates 0.53 Ci of ^{137}Cs due to high water levels in the Clinch River and backwater in the embayment. The backwater and the reduced water velocity in the embayment causes the deposition. The total ^{137}Cs released to the Clinch is decreased to 2.37 Ci (2.9 - 0.53). Furthermore, a large quantity has been transported down river and across Watts Bar Dam. The amount discharged at the dam is 1.87 Ci (2.37 - 0.27 - 0.23). It follows that the regional flood scours the river/lake system, thus only 0.59 Ci (0.27 + 0.23) ^{137}Cs accumulates in the Clinch River and Lower Watts Bar Reservoir. This accumulation for the regional flood is far less than the local flood (0.59 Ci as compared to 4.3 Ci)

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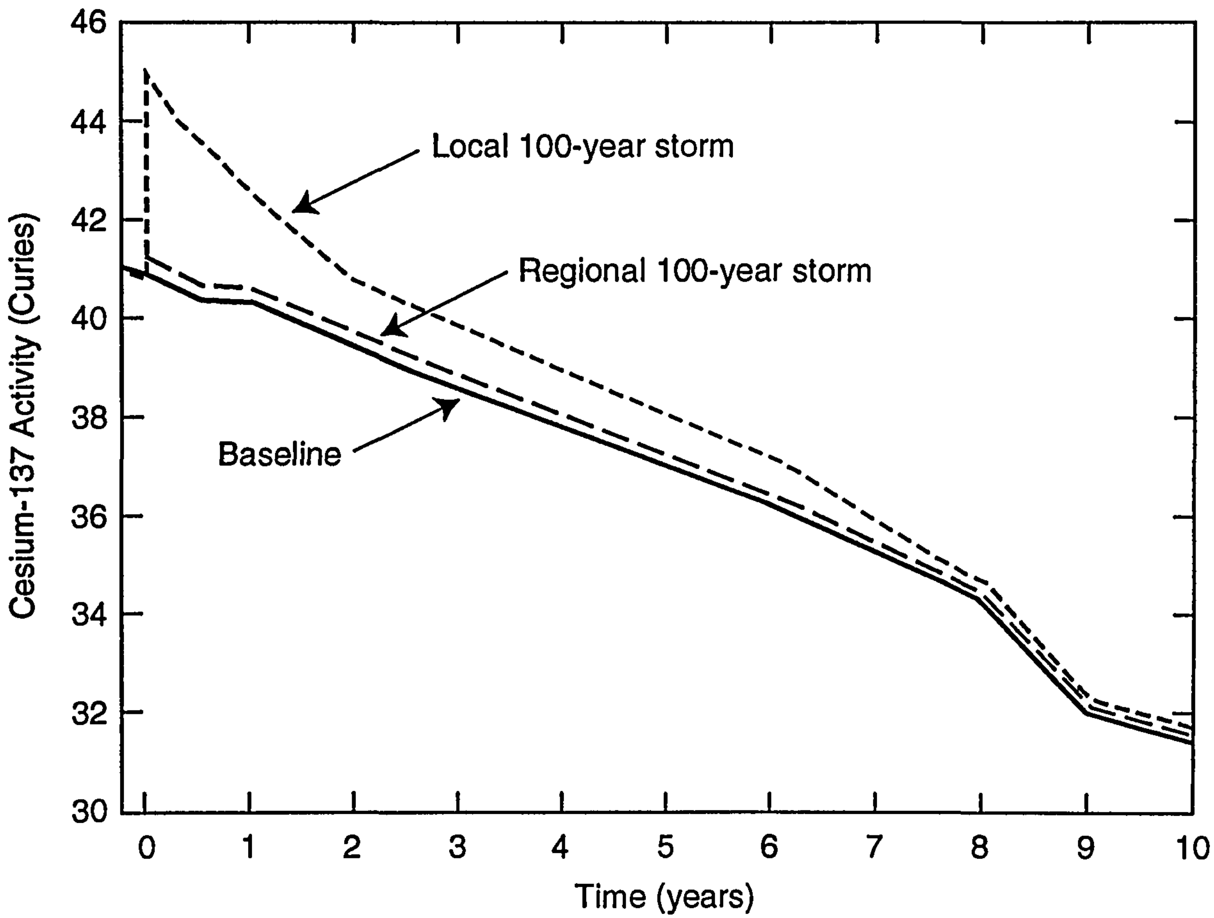

Fig. 5.2. Cesium-137 inventory in the sediments of the Clinch River for 10-year simulations.

Table 5.1 Cesium-137 stored in the river-reservoir system based on HEC-6-R simulations (Units: Ci)

Time since 1/1/44 (days)	Initial Conditions 18192	2 wks 18208	1 month 18224	½ yr 18377	1 yr 18559	2 yrs 18924	5 yrs 20384	10 yrs 21845
System Baseline								
WOCE	9.36	9.36	9.35	9.25	9.07	9.33	9.26	9.80
Clinch	40.75	40.83	40.78	40.37	40.32	39.40	36.24	31.41
LWB	95.60	95.51	95.41	94.49	93.69	91.84	84.38	78.35
Local Flood								
WOCE	Same	7.38 (-1.98)[1]	7.38 (-1.97)	7.31 (-1.94)	7.48 (-1.59)	7.79 (-1.54)	7.83 (-1.43)	8.52 (-1.28)
Clinch		44.70 (3.87)	44.57 (3.79)	43.59 (3.22)	42.44 (2.12)	40.75 (1.35)	37.20 (0.96)	31.72 (0.31)
LWB		95.94 (0.43)	95.86 (0.46)	95.23 (0.74)	94.92 (1.23)	93.17 (1.33)	85.66 (1.28)	79.75 (1.40)
Regional Flood								
WOCE	Same	9.89 (0.53)	9.87 (0.52)	9.76 (0.51)	9.48 (0.41)	9.67 (0.34)	9.56 (0.30)	10.09 (0.29)
Clinch		41.10 (0.27)	41.06 (0.28)	40.66 (0.29)	40.64 (0.32)	39.69 (0.29)	36.46 (0.22)	31.57 (0.16)
LWB		95.83 (0.32)	95.73 (0.32)	94.81 (0.32)	94.02 (0.33)	92.21 (0.37)	84.72 (0.34)	78.69 (0.34)

[1]Values in parenthesis are differences between results from the flood scenario and the system baseline scenario.

5.7 CONCLUSIONS

The results show the general nature of particle reactive contaminant deposition simulated by HEC-6-R in the Clinch River/Watts Bar Reservoir system. Without inclusion of the Sediment Retention Structure, the model shows a relatively large loss of ^{137}Cs from the embayment for the local flood, and a slight deposition of ^{137}Cs in the embayment during the system-wide flood. While backwater effects are expected to occur with the Sediment Retention Structure in place, the amount of erosion is problematic. The data collected in the storm sampling subtask suggest that some erosion in the embayment occurs but the largest estimate was about 0.013 Ci for the March 27, 1993 storm. Erosion of 2 Ci or 17-33% of the estimated ^{137}Cs inventory in the embayment is judged to be an overestimation.

The simulation results show that the sediment-bound ^{137}Cs will deposit in the Clinch River under average flow conditions (i.e., for the local 100-year flood). For the regional 100-year flood there is flushing though out the whole system and only a fraction of the ^{137}Cs released at White Oak Dam deposits in the river/lake system.

Much of the ^{137}Cs that deposits in the Clinch River under average flow conditions in the Clinch River will be remobilized by large flows. The detailed spatial analysis of the next section shows that the ^{137}Cs deposited in the Clinch just below the confluence with WOC moves downstream to deeper waters in the Clinch River with the typical high flows of winter. Larger flows move the ^{137}Cs out of the Clinch River and much of that remobilized material tends to move directly through Watts Bar Lake. Experience with the model suggests that of the scoured contaminated sediment from the Clinch River only 20% will be deposited downstream in the Lower Watts Bar and the remaining contaminated sediment leaves the system over Watts Bar Dam.

The simulated distribution of ^{137}Cs in the river-reservoir system generated by the HEC-6-R model allows the risk to human health to be analyzed for a 100-year flood in the WOC watershed. The risk is assessed in the following chapter.

6. HUMAN HEALTH RISK ASSESSMENT

The release of ^{137}Cs sediments from the White Oak Creek watershed during extreme flood events has been identified as a possible means for contaminants in WAG 2 to pose an off-site human health risk. Therefore, a human health risk assessment is conducted for future release scenarios. The methods and exposure assumptions employed parallel the pertinent aspects of the risk assessment for the Clinch River RI/FS (DOE 1996) that was based on measured contaminant concentrations in sediment cores. In particular, the risk in both this study and the Clinch River RI/FS is evaluated for an individual who regularly uses the resources of the Clinch River coupled with the assumptions that the current institutional controls are removed (dredging restrictions and fishing advisories) and that no remediation is performed. The risk from current exposure concentrations is documented in DOE (1996). This risk assessment focuses only on the additional incremental risk that would result from a major flood event releasing a quantity of ^{137}Cs to the Clinch River.

The Clinch River RI/FS calculated the risks for three exposure scenarios: shoreline exposure, a dredging scenario, and a fish ingestion scenario. The conclusions of DOE (1996) for ^{137}Cs in the Clinch River showed risks in the target risk range (for carcinogenic risk: 1E-4 to 1E-6) for the shoreline exposure scenario for those areas that could be impacted by releases from the White Oak Creek watershed. Risks exceeding the target risk range (>1E-4) for ^{137}Cs were observed for the dredging scenario (from external exposure) and are tabulated in Table 6.1. A single location yielded a fish ingestion risk for largemouth bass that exceeded the target risk range based on measured ^{137}Cs concentrations in fish. The rest of the fish ingestion results (four reaches, three species) were within or below the target risk range.

The risks presented in this assessment build on those results reported by DOE (1996) by considering possible future distributions of ^{137}Cs and associated levels of risk for the river/lake sediments. The risks are calculated from the simulated sediments distributions resulting from the 100-year flood, as described in Chaps. 4 and 5. As mentioned in the introduction to this report, the assessment addresses the incremental change in risk to human health due to floods. To calculate the incremental risk, the incremental change in ^{137}Cs concentration first is determined by subtracting concentrations for the 100-year flood from the baseline scenario at selected locations and times. The incremental change in concentration is used directly to generate the incremental risk caused solely by the ^{137}Cs releases due to floods. It is important to note that the actual risks due to exposures to Clinch River sediments would be the sum of the baseline and incremental flood risks if a flood event similar to what is modeled were to occur.

Table 6.1 Risk to adults from agricultural-dredging scenario[1]

Approximate Clinch River Mile	River reach from DOE (1996)	Nominal ^{137}Cs concentration pCi/g	Risk due to ^{137}Cs	Total risk
10.5	4.01	23	3.8E-4	1.3E-2
7.5	4.02	0.4	6.7E-6	7.6E-5
2.5	4.03	18	3.0E-4	1.3E-3
				7.8E-3

[1]DOE, 1996, Vol E. Table E.5, p. E-81.

6.1 EXPOSURE SCENARIOS

The primary areas of interest include the lower Watts Bar reservoir and the Clinch River from the outfall of White Oak Creek to its confluence with the Tennessee River. The Clinch River RI risk assessment calculates the risk from exposure to sediment from three different exposure situations. The first scenario, near-shore sediment exposure, has a high likelihood (receptors are currently exposed),

6.1.1 Shoreline Scenario

The shoreline scenario considers recreational activities such as walking, searching for artifacts, and wading in the fall and winter when the water level of the reservoir is at its lowest. For the modeled releases of ^{137}Cs to the Clinch River and Watts Bar, the near-shore sediment exposure scenario calculates the risk from five pathways: external exposure, inadvertent ingestion of sediment, inhalation of resuspended sediment, dermal contact with sediment, and dermal absorption of sediment. The risk results for ^{137}Cs are driven by the external exposure pathway. The exposure durations are intended to be representative of recreational use of the exposed shoreline during the months (up to five) of the year when heavier watershed runoff is expected. The management of the water levels serves multiple purposes including navigation, flood control, recreational activities, consistent hydroelectric production, insect control, and erosion control. Figure 6.1 represents the annual operating plan for Watts Bar by TVA. The period from September to April is when shoreline exposures to contaminated sediments is most likely to occur.

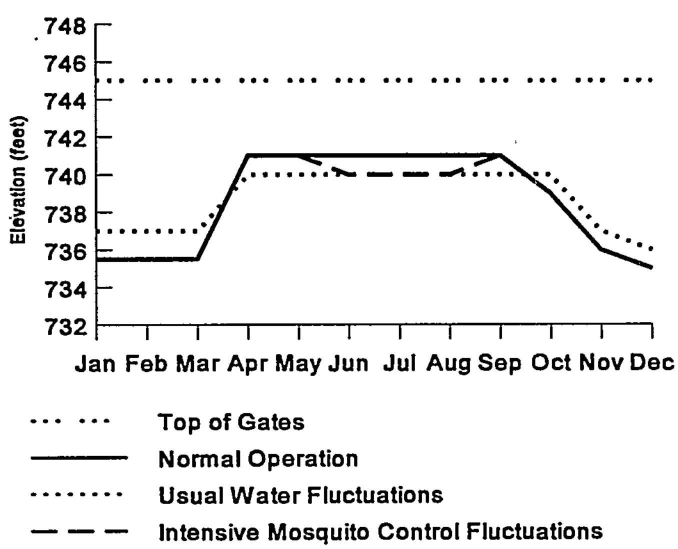

Fig. 6.1. Watts Bar annual operating guide.

The dose-rate factors used for determining exposures to a contaminated ground surface assume that the source is infinite in extent. Exposures for the near-shore scenario would occur along shorelines of a finite width and it is therefore appropriate to consider dose-reduction factors for different types of shorelines. NRC (1977) has recommended a dose-reduction factor of 0.2 for river shoreline and 0.3 for lake shore. Since a reservoir such as Watts Bar has the properties of a river and a shoreline, a dose-reduction factor of 0.25 was used.

6.1.2 Fishing Scenario

The fishing scenario conducted for the Clinch River RI/FS calculated the risk to a single pathway, the ingestion of fish, but considered the different uptakes of ^{137}Cs by different gamefish. The exposure parameters are intended to be representative of local exposure conditions on the Clinch and Tennessee Rivers. The species considered in the Clinch River RI risk assessment are bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), striped bass (*Morone saxatilis*), hybrid bass (*Morone chrysops/saxatilis*), and channel catfish (*Ictalurus punctatus*). The fishing scenario is not quantitatively considered here because there is inadequate information in the literature to determine the relationship between ^{137}Cs contamination in sediments and their uptake to fish. The fishing scenario is qualitatively considered to be not significant for the results that are presented for this report because the current measured ^{137}Cs concentrations in fish in the Clinch River do not currently pose a significant risk in the Clinch River and the small incremental inventory of ^{137}Cs added to the system as a result of a flood is not expected to add significantly to fish uptake.

6.1.3 Dredging Scenario

A dredging scenario is considered to address the possibility that current restrictions could be removed and that dredging may occur in the future. The assumptions for this assessment are similar to those used in the Clinch River RI/FS (DOE 1996). The scenario assumes that deep water sediment is removed from the reservoir and used as agricultural soils for growing crops and raising livestock. The sediment is also assumed to be thick enough that plowing would not significantly dilute the sediment concentrations by mixing with underlying soil. The dredged sediment exposure scenario calculates the risk from eight pathways: external exposure, inadvertent ingestion of sediment, inhalation of resuspended sediment, dermal contact with sediment, dermal absorption of sediment, and the ingestion of produce, meat, and milk as part of the agricultural scenario. The exposure parameters used for this scenario are typical of the parameters recommended for a baseline risk assessment in Risk Assessment Guidance for Superfund (1989b).

6.2 DERIVATION OF EXPOSURE CONCENTRATIONS

Risk results based on modeled future concentrations of ^{137}Cs were generated for 17 different locations in the Clinch River and 13 locations in Lower Watts Bar. Three different scenarios were used: a baseline case with no flood, a localized flood in the White Oak Creek watershed, and a regional flood that increased flows in the White Oak Creek watershed and in the larger Clinch/Lower Watts Bar watershed. In the output for the off-site transport model, the results were generated at points along the river. The results consisted of sediment thickness and ^{137}Cs concentrations of deposited sediment layers. This detailed distribution of ^{137}Cs allowed the dose to be more accurately determined for the shoreline exposure scenario. The concentration term for the dredging scenario was assumed to be uniformly mixed and was based on the average concentration in the top 30cm of the modeled core. Modeled concentrations were available for a ten year period following the flood event. The modeled concentrations are considered to be representative of both the near-shore sediments and the sediments in the deep water. The increase from the risk calculated for the baseline case with no flood and the risks calculated for the two flood scenarios represents the increased off-site carcinogenic risk from ^{137}Cs contaminated WAG 2 floodplain soil and sediments alone.

The dredging scenario assumed that uniform mixing of the deposited sediments result in a homogeneous concentration of ^{137}Cs in the agricultural soil. Therefore, dose conversion factors for an infinite, uniformly contaminated source was used to determine the dose. For the near-shore scenario the actual depth distribution of ^{137}Cs was considered for the determination of the external exposure dose based on the shielding properties of the shoreline sediment. The contact pathways and the fish ingestion pathway utilized the concentrations in the upper layer of the sediment.

6.3 RISK CHARACTERIZATION

The sediment concentrations are developed based on the release of ^{137}Cs associated with a 100-yr flood in the WOC watershed. Three scenarios are calculated: a baseline (no major flood) case, a localized flood in the White Oak Creek watershed, and a regional flood. The floods cause a 3-Ci discharge at White Oak Dam, but off-site conditions lead to substantially different releases from WOC Embayment. For the localized flood, the effect of the Sediment Retention Structure is not considered; therefore, erosion in the embayment mobilizes 2 Ci, and the total release is estimated to be 5 Ci. In contrast, backwater conditions for the regional flood causes deposition in the embayment and a release of only 2.5 Ci. The two flood scenarios yield ^{137}Cs releases that vary by a factor of 2 due largely to off-site conditions during the WOC flood.

A significant portion of the exposure calculated in the following scenarios is a result of historical contamination of the Clinch River by WAG 2 sediment releases. Therefore, the incremental risk from WAG 2 sediments originating after a flood event is calculated for the two flood scenarios by using the difference between the flood event concentrations and the baseline scenario.

6.3.1 Shoreline Scenario

None of the modeled locations indicate risk above the EPA's target risk range of 1E-4 to 1E-6 for the shoreline scenario for the 5-Ci flood or the 2.5-Ci flood.

6.3.2 Dredging Scenario

The risk results for the dredging scenario using both historical and flood generated concentrations were generated for each modeled location The incremental risks for the local and regional flood events are based on the difference in the concentrations between the flood events and the baseline scenario. The risk results are the thirty-year risk from residential/ agricultural exposures if the dredged sediments were removed at the time the concentration was modeled.

Figure 6.2 shows the locations in the Clinch River that were modeled for each of the flood scenarios. Figure 6.3 shows the incremental 30-year risks for six specified locations that show the model behavior over the ten-year period for the local watershed flood for both the local flood (5-Ci release) and the regional flood (2.5-Ci release).

For the local flood, Clinch River Mile 20.7, which is at the confluence of White Oak Creek and the Clinch River, shows the risks approaching 1E-3 in the period immediately following the flooding. The risk values for six months are the highest calculated incremental risk for any of the areas and flood events examined for this report. The calculated risk reaches the maximum value immediately after the 100-yr flood that "occurred" in March, and the risk stays elevated through the summer until seasonal winter floods sweep the contaminated sediments downstream. The risk results for the 5-Ci release for river reach between CRM 20.7 and CRM 11.8 tends to go below the 1E-6 level at some point, indicating that the sediments in that region get scoured sometime during the 10 years. For CRM 4.2 to CRM 0, the water elevation is maintained year-round by Watts Bar Dam. Because the water is deeper sediments tend to persist (i.e., they are not scoured) nevertheless the risk levels are all below the target level. CRM0.0 is the last measured location before the Clinch River flows into the Tennessee River.

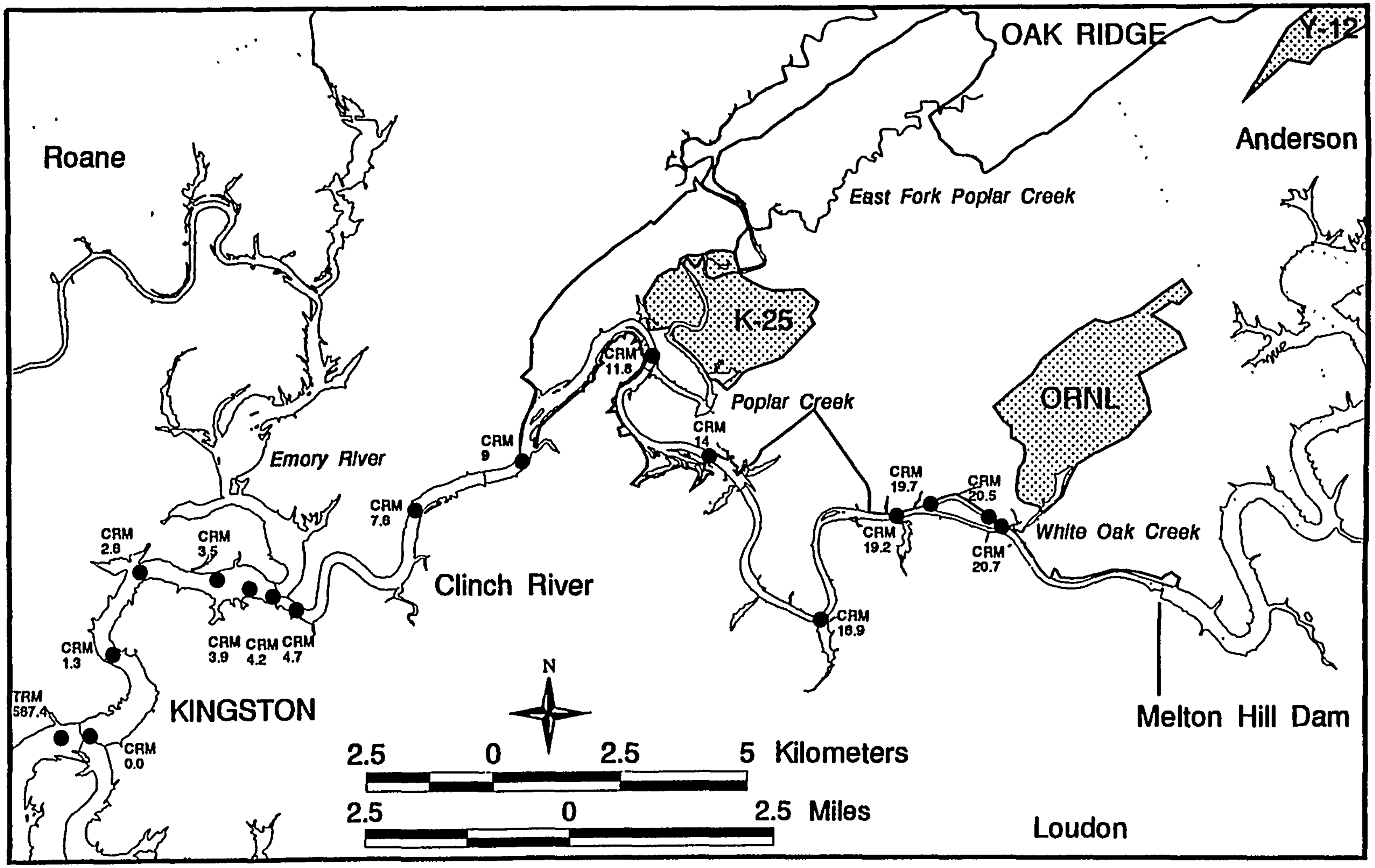

Fig. 6.2. Clinch River System. Points indicate locations where ^{137}Cs contaminated soils are simulated. The map also shows the Tennessee counties.

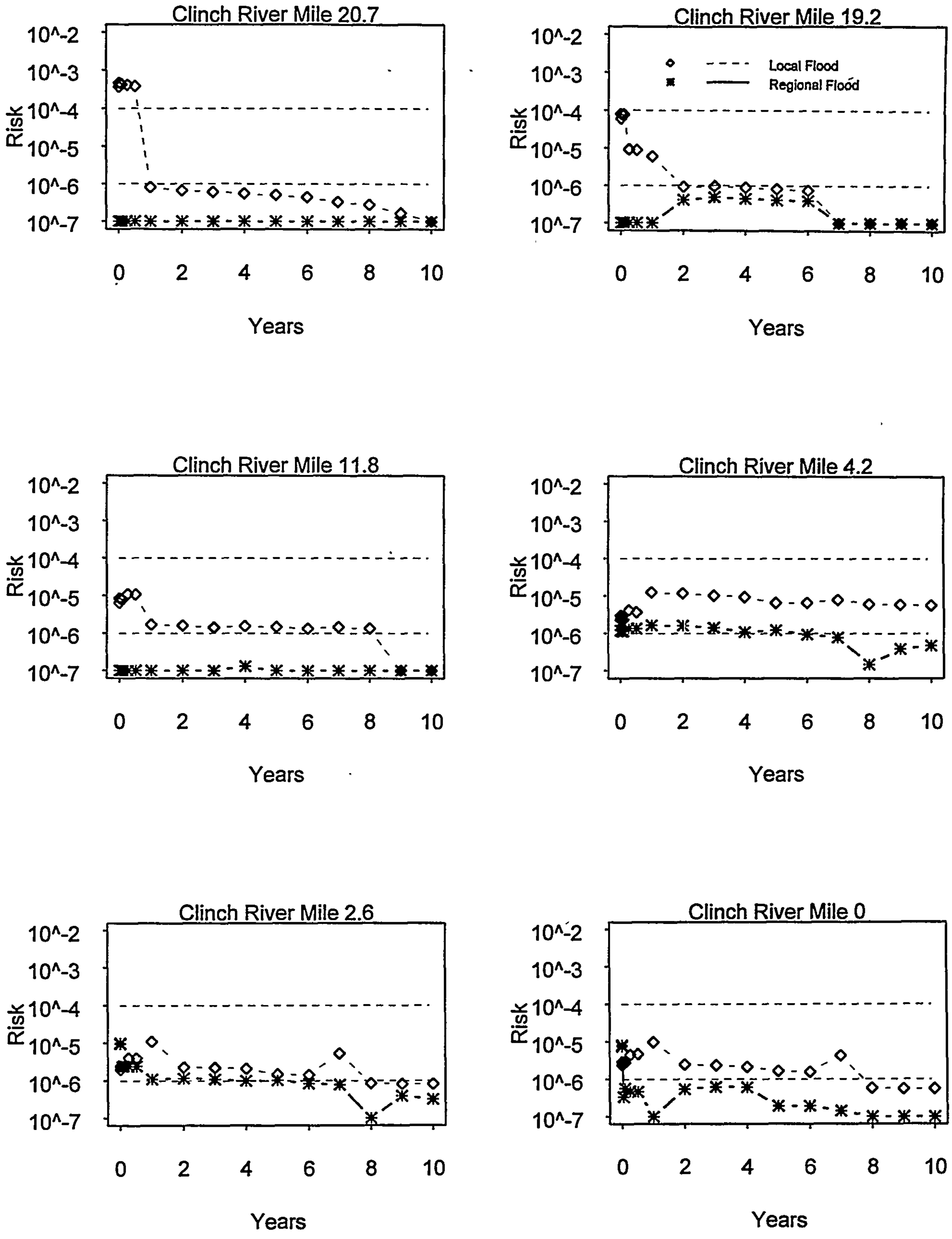

Fig. 6.3. Incremental cancer risk from dredging scenario for locations along the Clinch River for the local flood (diamonds) and the regional flood (asterisks).

Figure 6.3 also shows the incremental risk results for the regional flood in the Clinch River. Only 2.5 Ci of this load leaves the embayment during the flood due to backwater conditions. The low ^{137}Cs loading and the extreme flood conditions that transport and disperse the ^{137}Cs-contaminated sediment in the downstream direction combine to yield risk levels that are generally either below the risk range or in the lower end of the risk range at all locations.

Figure 6.4 maps the modeling locations for the Tennessee River. All of the risk plots for the Tennessee River are very similar and none of the results exceed the target risk range for either the local flood or the regional flood. Figure 6.5 shows examples for the local flood scenario and for the regional flood at locations.

6.4 SUMMARY

Quantitative human health risk estimates were generated for the shoreline exposure scenario and the agricultural dredging scenarios. Most of the results indicated that the off-site consequences of a flood event releasing contaminants to the Clinch River/ Watts Bar system would not exceed the EPA's target risk range for carcinogens. There was a very transient risk related to the agricultural dredging scenario. If a late spring flood results in deposition of sediment-bound ^{137}Cs at the confluence of WOC and the Clinch then the 1E-4 level may be exceeded for a brief time. The hazard disappears with the first large flows in river, usually associated with winter floods. Thereafter, risk levels tend to be midway in the target risk range (10-5) or lower. All of the results for the shoreline exposure scenario and the agricultural dredging scenario based on a 5 Ci flood event were either within or below the target risk range. The fish ingestion pathway is qualitatively assumed not to exceed the EPA's target risk range because this pathway does not currently exceed the target risk range based on fish concentrations in the Clinch River or in the White Oak Creek Embayment.

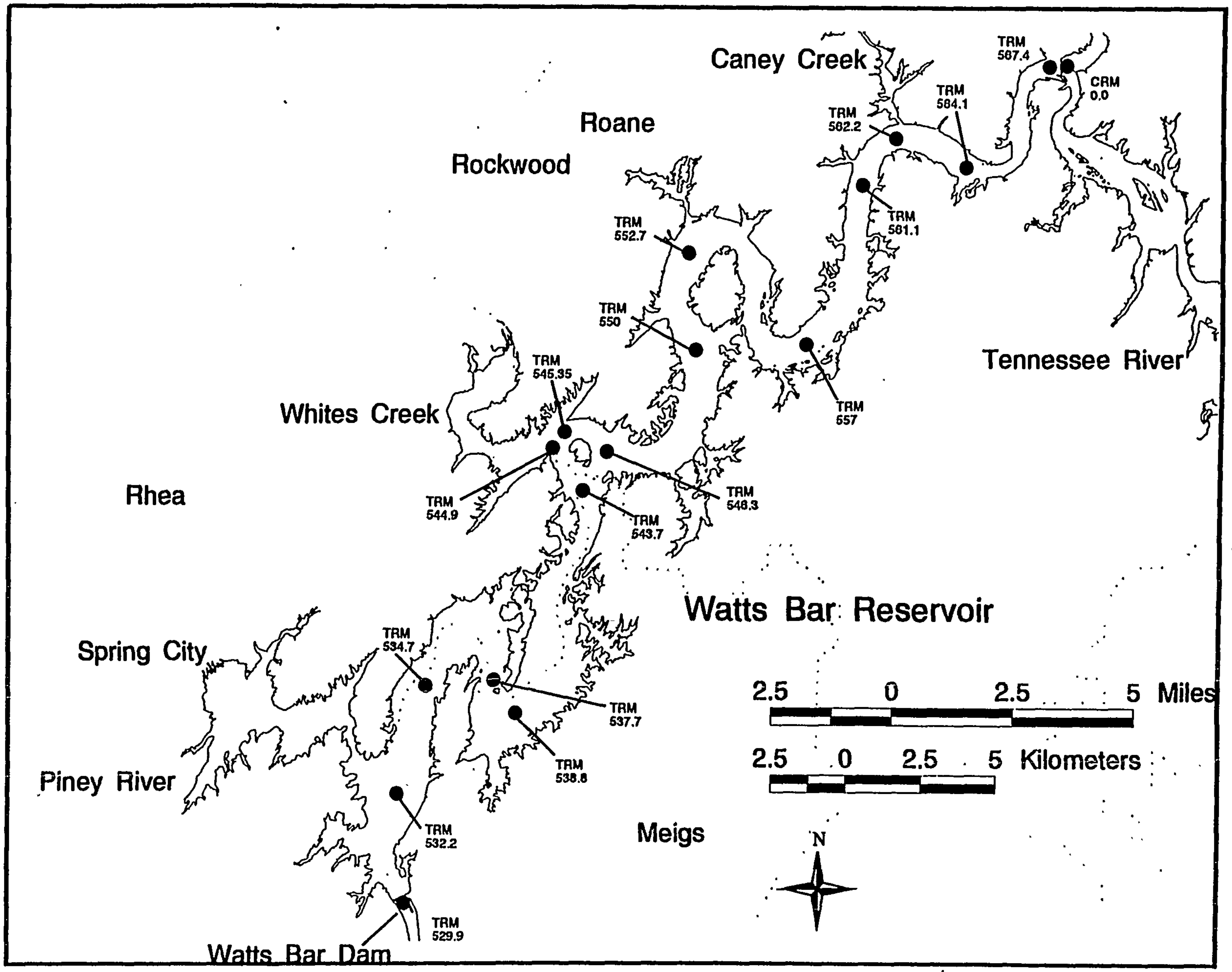

Fig. 6.4. Lower Watts Bar Reservoir. Points indicate locations where ^{137}Cs contaminated soils are simulated. The map also shows the Tennessee counties.

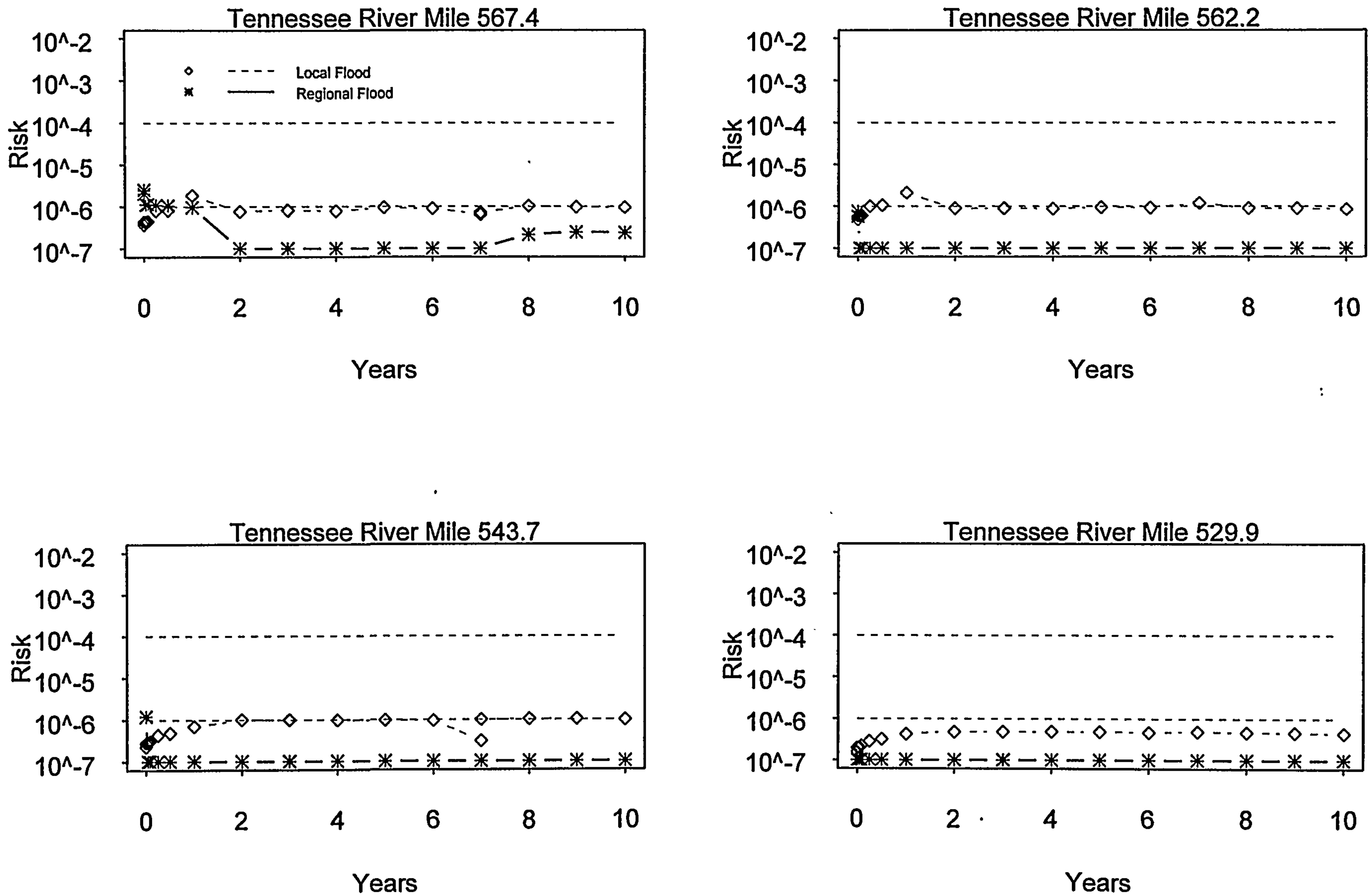

Fig. 6.5. Incremental cancer risk from dredging scenario at selected points in Lower Watts Bar Reservoir for the local flood (diamonds) and the regional flood (asterisks).

7. SUMMARY AND CONCLUSIONS

The levels of contamination in the soils and sediments in the WAG 2 have led to concerns about erosion and transport of contamination off-site during extreme storms and flooding when erosive water flows are greatest. Off-site movement of contaminated sediment could potentially lead to accumulation of contamination in the Clinch River at unsafe levels. When the Sediment Transport Modeling (STM) Task was implemented to address the off-site risks related to contaminated soils and sediments in WAG 2 the prevailing conceptual model suggested that large storms would erode and transport large quantities of ^{137}Cs. Intensive storm sampling, the long-term record of ^{137}Cs releases, and extensive hydrologic modeling, in fact, show a different picture. The analysis based on these sources of information shows a fairly steady release of low levels of ^{137}Cs at White Oak Dam with a seasonal variability and a slight storm-driven component in that release. The natural vegetation cover on the contaminated soils provides very effective control of the erosion.

7.1 MAIN CONCLUSION

This study builds on the results of the Clinch River Remedial Investigation, and the result relevant to this study is that exposure scenarios *excluding the dredging scenario* result in excess risks of cancer $< 10^{-4}$ (the EPA target risk level), however, the dredging scenario in which river sediments are removed and used for agricultural purposes resulted in risk levels $> 10^{-4}$ for sediments sampled at several locations in the Clinch River. Other contaminants found in the Clinch River contribute to this risk level; however, the contribution of ^{137}Cs by itself to the risk is $> 10^{-4}$. For this reason, this study focused on the incremental risk associated with the addition of any ^{137}Cs contaminated sediment to the Clinch River system.

The main finding of this study is based on results from two calibrated computer models that together simulate the release of sediment-bound ^{137}Cs from the WOC watershed and the movement of the ^{137}Cs in the Clinch River/Watts Bar Reservoir system. The system was used to model the effects of a 100-year flood in the WOC watershed.

Risk analysis of the simulation results shows qualitatively that there are no adverse impacts for the fish ingestion scenario. Risk results also show that for the shoreline exposure scenario the incremental risk of excess cancer is within the EPA's target risk range of 10^{-6} to 10^{-4}. The results for the dredging scenario in which sediments are removed and used for growing crops generally show the same levels of risk or lower. A very transient, elevated level of risk was identified in the simulation. If a late spring flood results in deposition of sediment-bound ^{137}Cs in the Clinch at the confluence with WOC, then the 10^{-4} level may be exceeded for a brief time. The hazard is reduced with the next large flows in the river, usually associated with winter floods. Thereafter, risk levels tend to be midway in the target risk range (10^{-5}) or lower. Given the fact that sediments in the Clinch are known to be contaminated and the fact that there are regulations in place to control dredging in the Clinch River, the transient and small exceedance in the risk analysis may not be significant. This exceedance of the 10^{-4} risk level does not warrant special remedial actions.

7.2 SUMMARY OF TASK ACTIVITIES

The STM task conducted an extensive storm sampling program and a series of computer modeling activities to complete the task objectives. The main activities within the storm sampling program were:

- Collection of stream samples during storms at 8 sampling sites equipped with automatic water samplers. In 1993, the number of sites was reduced to the 5 sites deemed to be essential.
- The field team collected thousands of samples, and over 1300 of them were selected for analysis which included measurements of suspended sediment concentration and ^{137}Cs concentrations on the solid particles. Twenty eight samples were separated into grain-size fractions which were analyzed for ^{137}Cs. The separation technique is referred to as a column test, which was modified and improved as part of this project. Results constitute an extensive screening level data base suitable for developing computer models and advancing the conceptual model of ^{137}Cs behavior in the WOC watershed.
- For five intensively monitored storms, the field data were integrated through time to yield estimates of suspended sediment load and ^{137}Cs loads for the individual monitoring sites.
- Manual sampling teams collected representative samples integrated across a representative stream cross-section. The amount of suspended sediment in the integrated samples matched that in the concurrent automatic samples, indicating that the automatic samplers with fixed intakes did not yield bias estimates.

The main activities in computer modeling were:

- The HSPF model, a comprehensive, process-based model of watershed hydrology and water quality, was calibrated to depict water, sediment, and ^{137}Cs movement in the WOC watershed for the period 1990-1994. The calibration used the storm sampling data and the compliance monthly ^{137}Cs data.
- A new method of model calibration was developed. Referred to as the OPTICAL system, which combines a nonlinear optimization scheme with an expert system. It may have broad applications in environmental simulation.
- The HEC-6-R model, a state-of-the-art sediment transport model, was used to simulate the off-site transport of ^{137}Cs. The model was developed and used in the Clinch River RI for the purpose of recreating the historical pattern of sediment movement and ^{137}Cs deposition in the Clinch River/Watts Bar Reservoir system. The model includes detailed modifications to account for a particle-reactive, radioactive contaminant. The model does not include the effects of the Sediment Retention Structure, installed in 1992 to reduce the erosion of the existing ^{137}Cs sediments in the WOC Embayment.
- Analysis of risks associated with the 100-year flood in WOC used methods identical to those used in the Clinch River RI. The analysis quantified the incremental risk to the off-site public related to the transport and deposition of ^{137}Cs at points along the Clinch River and lower Watts Bar Reservoir.

7.3 FINDINGS

The main finding of the STM task relates to the objective of quantifying the effects and the risks of the 100-year flood on ^{137}Cs transport in the WOC watershed and Clinch River/Watts Bar Reservoir system. The conceptual model of ^{137}Cs behavior within the WOC watershed was refined and it is described in Sec. 7.4. Results are:

- Modeling results indicate that during a 100-yr flood event about 3 Ci of ^{137}Cs are released at White Oak Dam, an amount judged to be small relative to the ^{137}Cs inventory in WAG 2 which is estimated to be ~330-400 Ci in White Oak Lake sediments, ~54 Ci in the shallow soils of the Intermediate Holding Pond area, and ~32 Ci in the shallow soils of the lower WOC floodplain, with smaller quantities at distributed in the WAGs.
- Water levels in the Clinch River affect the amount of ^{137}Cs leaving the embayment. For the regional 100-year flood, high water levels in the Clinch cause backwater in the embayment and partial deposition of the WOC ^{137}Cs load, thus the estimated off-site release is about 2.5 Ci (3 Ci released at the dam minus 0.5 Ci deposited). For the local 100-year flood when water levels in the Clinch River are "normal", the off-site model predicted erosion of about 2 additional Ci in the embayment for a total off-site release of 5 Ci. The model does not account for the effects of the Sediment Retention Structure, therefore the 2 Ci is considered to be an overestimate.

7.4 CONCEPTUAL MODEL OF ^{137}Cs TRANSPORT

Based on the extensive storm sampling effort plus the seep and tributary sampling efforts in the WAG 2 RI Project, the conceptual model describing mobilization and transport of ^{137}Cs through the WOC system has been significantly altered. Originally, the system was considered to be primarily storm driven. Analysis of compliance data, intensive storm sampling results, and computer simulation leads to a different picture. Specifically,

- The largest active source of ^{137}Cs directly to the WOC surface water system is the Non Rad Waste Treatment Facility. During the 6-year period (1990-1995) it has discharged an amount of ^{137}Cs equivalent to about 2/3 of that released at White Oak Dam. Although a portion of the ^{137}Cs from the NRWTF is probably deposited in White Oak Lake, the large quantity indicates that soil erosion has not been the dominant source for the past five years.
- The continuous monitoring at the main surface water stations by OECD for the period 1990-1995 shows that ^{137}Cs transport is seasonal with the highest values in the wet months, and it is also storm-driven. The a storm-driven component was largest in December 1990 through early 1991, thereafter storms appear to be less effective in mobilizing ^{137}Cs. The cause of the change to a less storm-driven system is uncertain. In 1990-1991, the system may have purged the channel sediments contaminated from effluent from the Process Waste Treatment Plant before its effluent was routed to the NRWTF for final treatment. The NRWTF came on-line in 1990.
- Maintaining high treatment efficiency and low ^{137}Cs discharges from the NRWTF may lead to low fluxes of ^{137}Cs in the watershed. The annual ^{137}Cs discharge from the NRWTF was only 0.030 Ci in 1995 (the lowest level in 6 years).
- In the ORNL plant area, First Creek and Northwest Tributary are minor contributors of ^{137}Cs. Other sources have not been specifically identified.

- The NRWTF discharges dissolved ^{137}Cs (i.e., ^{137}Cs in filtrate that passes through a 0.45 μm filter). Dissolved ^{137}Cs tends to sorb to fresh sediments deposited on the channel bed from recent storms. In the middle WOC reach, about 40% of the dissolved ^{137}Cs sorbs to channel sediments during low-flow conditions.

- Channel sediments provide a dynamic storage for ^{137}Cs. In 1993, a year with few storms, there was net deposition to the channel sediments in the middle WOC reach. In 1994, a year with above average precipitation there was net erosion of ^{137}Cs from the channel sediments. The size of the flood discharge and the time between storms (when ^{137}Cs sorbs to the channel sediments) affect the flux of ^{137}Cs sorbed to channel sediments.

- During storms the main sources of ^{137}Cs are the contaminated channel sediments and erosion of contaminated soil presumably from the IHP area and the WOC floodplain (areas with large ^{137}Cs inventories). For the period from 1992-1995 the erosion contribution to ^{137}Cs flux was relatively small.

- *The vegetative cover on the IHP and the floodplain provides an effective barrier to erosion during storms, and it essentially controls the off-site release of ^{137}Cs from the WOC watershed.*

- Two seeps in WAG 4 are the only identified groundwater sources of ^{137}Cs in Melton Valley and they are minor sources. The ^{137}Cs discharged from these seeps probably sorbs to sediment and other materials in the WAG 4 tributary, and it is transported to WOC during storms as washoff. There probably are, however, other unidentified groundwater sources of ^{137}Cs in the watershed.

- The lower WOC Floodplain/White Oak Lake reach is a net depositional area. For the 3-year period (1993-1995), ^{137}Cs deposition in the lake has averaged about 15% of the flux measured upstream at WOC weir. Within the reach, the erosion of ^{137}Cs-contaminated soils from the floodplain is exceeded by the deposition in White Oak Lake. The rate of soil erosion cannot be ascertained directly.

- The bathymetry of White Oak Lake is mostly flat and featureless without erosional features, indicating that deposition is the dominant process. Four of the 5 storms sampled in this task resulted in deposition in the floodplain/lake reach.

- The average grain-size distribution of sediments transported during storms changes from the ORNL plant area to White Oak Dam. At each successive weir in the downstream direction, there are more clays and silts and less coarse silts and sands. The change is most significant from WOC weir to White Oak Dam due to deposition of coarse material in White Oak Lake..

- The change in grain-size distribution may result, in part, from the breakdown of soil aggregates as they are transported downstream.

- The estimated sediment loads during the sampled storms suggest that the embayment can be a slight source of sediments (erosion) or a slight sink (deposition), but the ^{137}Cs loads suggest that the embayment is a simple conduit or a slight source of ^{137}Cs. A portion of the sediment in the embayment may originate in the Clinch River, entering the embayment during backwater events.

- The average grain-size distribution from White Oak Dam to the Sediment Retention Structure is virtually unchanged, suggesting that the embayment is a simple conduit for suspended sediment (evidence that it is neither a source or sink for sediment).

The behavior of the ^{137}Cs transport system in the WOC watershed over the next 30 years is important to environmental engineers and planners. Of particular interest is wether or not the system will remain relatively unresponsive to storms and wether or not White Oak Lake will fill with sediments and start to be an erosion source. The largest reductions in ^{137}Cs flux within the watershed occur in the lower WOC floodplain/White Oak Lake reach where deposition occurs. The sediment filling in the lake is uncertain; the HSPF model calculated a rate of filling of about 0.1 cm/year. Although this rate is judged to be low, it suggests that filling the 3-m deep lake is not a problem, especially for the next 20-30 years. Reliable data is obtainable only be replicating the precision bathymetry every 5-10 years.

If the White Oak Lake fills to an equilibrium level where annual net deposition is zero and the release from White Oak Dam equals the flux measured upstream at the WOC weir, the release at White Oak Dam would increase by only about 15% causing no significant increase in the off-site incremental risk. It is conceivable that the ^{137}Cs transport in the WOC watershed may become more episodic in the future (more storm-driven) as the lake fills and storms start to erode the lake sediments. There are no predictions if or when this could happen, however, there is no evidence in the data trends or in the HSPF modeling that filling of the lake with sediments will lead to storm fluxes significantly greater than the 3 Ci predicted for the 100-year flood. Because the downstream system can accommodate up to at least 5 Ci with only a marginal exceedance of the incremental risk, it is concluded that filling of the lake with sediments does not pose large increases in risk off-site for near term (20-30 years), especially if vegetation stabilizes portions of the filled lake.

7.5 WATERSHED MANAGEMENT

The modeling results for the 100-year flood can be considered to be an extrapolation of the measured ^{137}Cs transport in the WOC watershed in its current state. The model explicitly accounts for the nonlinear effects of extreme precipitation and streamflow on the mobilization of contaminated soils. Nevertheless, one might imagine two ways in which the state of the watershed could be altered dramatically and adversely, thereby negating or partially negating the results of this analysis:

- an extreme flood alters the vegetation system causing loss by large-scale erosion, or
- the watershed is mismanaged and the protective cover of the vegetation is eliminated.

The first situation is considered to be unlikely based on the 28-year historical record without observing these drastic changes and without measuring annual ^{137}Cs discharges in excess of 2 Ci.

Large-scale alteration can be avoided only by employing a system of environmental management and internal and external oversight. Projects that alter the basic watershed hydrology must be analyzed in detail on a case-by-case basis as they are proposed. Clearing of the floodplain vegetation, extensive stream channelization, and large-scale capping are radical measures that could alter the underlying relationships inherent to the current modeling and that could lead to unacceptable increases in ^{137}Cs releases. Likewise, many small alterations can have cumulative effects. Paving over ever larger portions of the watershed year by year is the most obvious example.

7.6 RECOMMENDATIONS

- Although the Non Rad Waste Treatment Facility is the largest continuous source of ^{137}Cs to the WOC surface water system, *during storms* erosion is the predominant transport mechanism for introduction of ^{137}Cs to surface water. Because the vegetation cover on the Intermediate Holding Pond area and the floodplain in WAG 2 is effectively the only barrier to erosion and is the main controlling mechanism affecting off-site releases of ^{137}Cs during extreme storms, future remedial actions intended to isolate ^{137}Cs in WAG 2 should ensure that any new cover or containment technology for these areas is as effective or more effective than the current vegetation cover.

- The work presented in this report was conducted at the watershed scale. Any proposed action to address specific problem areas in WAG 2 (such as vegetation removal, stream channelization, or large-scale capping) should be evaluated in detail and designed to minimize the potentially detrimental effects of increased erosion. The HSPF watershed transport model is an effective tool that can be adjusted to evaluate many proposed actions at an appropriate scale.

- To maintain low levels of ^{137}Cs flux in the watershed, it is recommended that the current low level of ^{137}Cs discharge from the Non Rad Waste Treatment Facility (0.30 Ci in 1995) be maintained, if technically feasible.

- The current automatic storm sampling at White Oak Dam conducted by the ORNL ER Surface Water Program should be discontinued. The sampling is intended to gather data on ^{137}Cs releases from the watershed in an extreme flood. Because all storms that have been monitored to date yielded relatively minor ^{137}Cs loads, the minimum flood that would give significantly new information would be larger than any flood sampled to date, i.e., a peak flow of about 1000 cfs or greater. Storms producing floods of this magnitude are so infrequent and the data to be gathered is of marginal value, therefore the cost of maintaining the sampling facility is unjustified.

- There is a need for a reliable flood-frequency relationship for WOC at White Oak Dam in order to build appropriate safety factors in engineering designs for remedial actions in WAG 2 or areas that drain to WAG 2. The new flood frequency will depend on simulation, which may be done by recalibrating and reconfiguring the current HSPF watershed transport model specifically for this purpose.

- The effectiveness of White Oak Lake and the WOC Embayment should be evaluated in order to understand how they affect sediment and ^{137}Cs transport. The evaluation would lead to improved management of the facilities and the selection of remedial alternatives. Evaluation of these facilities cannot be justified based on protection of the off-site public because risk levels based on model simulations are low.

- Monitoring the effectiveness of the WOC Embayment and the Sediment Retention Structure should be accomplished by coring the sediments at about 5-year intervals. A baseline study is needed, although the investigation of Blaylock et al. (1993) may suffice.

- Monitoring the effectiveness of White Oak Lake and White Oak Dam should be done by repeating the precision baseline survey of the bathymetry of White Oak Lake in December 1994 (ECE 1995) along with sediment coring and analysis.

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Appendix A:

TASK DATA QUALITY OBJECTIVES AND DATA TABLES

DQO ATTACHMENT

Revisions to Sediment Transport: Storm Sampling for WAG 2

Originally approved 3/24/94 by S. E. Herbes

Date: March 7, 1995

Revisions: Sampling at 5 rather than 8 sites; only ^{137}Cs and no other analytes; no manual sampling required; screening level in place of levels 3 and 4.

All revisions were identified in FY 1995 WAG 2 RI Work Plan -- a DOE approved document.

Justification for reduction in sites: concentration of efforts on main sources of sediment to White Oak Lake and known sources of ^{137}Cs.

Justification for ^{137}Cs only: no evidence of off-site risk due to other contaminants discharged from WOC.

Justification for screening level: data are used for modeling only; the important information is contained in the trends and average levels of contamination; individual measurements will not be compared to regulatory levels -- therefore in the unlikely event of outliers caused by sampling or lab errors, these errors will not effect important ER decisions which will be based on model results. Revision affects the documentation of analytical results much more than the accuracy of the results because analytical methods will not change. Revision conforms to the reduction in definitive analytical work to save costs as requested by DOE.

Justification for elimination of the manual sampling results: the excellent agreement between the automatic and the manual sampling results in the past, i.e., the manual sampling is considered to be unneeded.

Data Quality Objectives Summary Form

Date 3-23

Form Number SW-C

A-5

1. Component Sediment Transport: Storm Sampling for WAG 2

2. Objectives To: 1) Collect real storms that produce bankfull or above bankfull conditions in the White Oak Creek Watershed, 2) Evaluate the sediment loss and contaminant release from White Oak Creek Watershed, and 3) Compare data and computer model outputs with the conceptional or current understanding of the White Oak Creek Watershed.

3. Media (circle one)	Soil/Sediment	Ground Water	Surface Water	Air	Biota	Other ______

4. Data Uses (Circle all that apply)	Site Characterization	Baseline Risk Assessment	Screening Risk Assessment	Evaluation of Alternatives	Engineering Design	Monitoring Remedial Action	Permitting	Other ______

5. Key Assumptions : Maximum contaminant load off-site will be present during extreme storm events. Note: Extreme storm event is proportional to bankfull or above bankfull conditions.

6. Sampling Site Information

Area: WOC, MB, and WOD weirs along with USGS site # 3536320, NorthWest Trib, 7500 Bridge, WAG4-MS1, and WOCE

Comments: (Depth of Water, Soil Type) : site dependent

Historic Info Available: RI plan

7. Data Types (Circle Appropriate Data Type)

*see comments (#15)

A. Analytical Data

*VOA	*PCB/Pesticides	TOC	Gamma
Semivolatiles	*Organics	BTX	Strontium 90
TCLP	Total Metals	BNAs	Tritium
Cyanide	Dissolved Metals	______	gross alpha
*ICP Metals	______	______	gross beta

B. Physical Data

Permeability	Hydraulic Head	Dissolved Oxygen
Porosity	Penetration Test	Temperature
Grain Size	Hardness	______
Bulk Density	Total Suspended Solids	______
*pH	Conducuvity	______

Rational for analytical and physical data type selection ______

8. Sampling Methods (Circle Methods to be used)

Environmental	Random	Grid	Grab	Non-Intrusive	Phased	Non-Destructive
Source/Waste	Biased	Stratified	Composite	Intrusive	Storm Dependent	

9. Analytical Quality Objectives

What are the contaminants of concern? : ^{137}Cs and a screening of other contaminants to include As, Be, Sb, PCB-1254, PCB-1260, ^{60}Co, ^{90}Sr

Identify the level of concern for the contaminants listed above : Use SOW#118 detection limits for noted contaminants (note this meets our screening level requirement for level of concern.

Identify required detection limits : Dependent upon sample size, equipment, counting times

Identify any critical samples to be collected : Suspended sediments from extreme storm events

10. Analytical Levels (Indicate Level(s), Equipment and Methods)

Level 1 - Field Screening Equipment ______

Level 2 - Field Analysis Equipment ______

Level 3 - CLP/RAS Methods ______

Level 4 - CLP/RAS Methods 10% to 25%

Level NS- Non Standard ______

Briefly explain rationale for selection of Analytical Level: We are using 10% to 25% on level 4 for future potential use in risk assessment and comparability

W-003

Data Quality Objectives Summary Form

Date 3-23-9

A-6

11. Data Quality Indicators

Specify PARCC parameters

Precision (by method) : as stated in SOW#118

Accuracy (by method) : as stated in SOW#118

Representativeness : see Sampling and Analysis Plan attachment

Completeness

Comparability : using standard methods and SOP's

12. Sampling Procedures

List SOPs used for this activity: SOP#3103-Manual Suspended Sediment Sampling, SOP#3108-ISCO Sampling, SOP#4010-Lab Procedure for Suspended Sediment Concentrations, SOP#4012-Size Distribution Using Bottom Withdrawal, SOP#4008-Lab Gamma Count SOP#4503 Settling Column Test Procedure; SOP#3001 Bottle Washing (R.B.C 2/23/94)

13. Quality Control Samples (Confirm or Set Standard)

A. Field/Processing Lab

Collocated 5% or @(see #15) Replicate 5% or N/A

Field Blank 5% or 1 per team Trip Blank 1 per storm

Field Rinsate 1 per storm (rinse between sites with DI water, count in marinelli)

B. Laboratory

Laboratory QC information can be found: in SOP#'s 4008, 4010, 4012

14. Constraints The time of sampling event (day/night), amount of help, or severity of storm.

15. Comments: ISCO (automatic) sampling for all storms. ISCO will start sampling at site specific designated water depths and at net time intervals. Manual sampling will occur only during extreme storms/floods. Manual samples will help Q.A. ISCO samplers and provide additional samples for laboratory testing. Maximum samples will be taken during the entire stage of the runoff hydrograph.

*Full lab analysis will be performed only on selected extreme storm events (ie. more than a 5 year frequency event).

@ ISCO replicate not really necessary due to the way several ISCO samples plot (can tell if description from SS and gamma curve plots). A replicate on manual sampling will be performed on a transit that will not be a composite on last run. A second sample from one sub-section on this transit will be taken and used as the replicate for each storm sampling event.

16. Approval

Stephen E. Nieber 3/24/94 — Project Manager, Date

M.C. Bryant 3-23-94 — Quality Assurance Coordinator, Date

Terry L. [illegible] 3-24-94 — Analytical Services Coordinator, Date

Brent Ziegler 3-22-94 — Field Sampling Coordinator, Date

Roger B. Clapp 2/23/94 — Task Leader, Date

17. Revisions (Description & Rationale)

Refer to Attachment 3/7/95 M.C. Bryant

18. Revision Approvals

[illegible] 3/8/95 — Project Manager, Date

M.C. Bryant 3/8/95 — Quality Assurance Coordinator, Date

J. Daniel Marsh 3/8/95 — Analytical Services Coordinator, Date

~~Terry L. [illegible] 3-24-94~~ TLH 3-24-94

D.K. Rosa 03/14/95 — Field Sampling Coordinator, Date

R.B. Clapp 3/8/95 — Task Leader, Date

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	25FEB92	not avail.	not avail.	30.1	2797.0	13.4	
WOD	25FEB92	"	"	29.8	2522.0	120.0	
WOCW	25FEB92	"	"	42.9	2472.0	11.8	
WOCW	25FEB92	"	"	29.1	2732.0	14.4	
WOCW	25FEB92	"	"	30.9	2399.0	14.7	
MBW	25FEB92	"	"	79.5	14.0	20.0	
MBW	25FEB92	"	"	64.5	77.0	26.5	
7500bridge	25FEB92	"	"	42.5	1814.0	109.7	
7500bridge	25FEB92	"	"	42.0	1848.0	89.4	
ROC	25FEB92	"	"	33.5	BDL	—	
NWT	25FEB92	"	"	79.9	BDL	—	
Wag4MS1	25FEB92	"	"	49.5	284.2	45.1	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	18MAR92	14001-00-01	11:00	14.8	2800.0	200.0	
WOD	18MAR92	14002-00-01	11:00	19.6	3500.0	200.0	
WOD	18MAR92	14001-01-01	11:00	18.5	3200.0	200.0	
WOD	18MAR92	14002-01-01	11:00	20.5	3200.0	200.0	
WOCW	18MAR92	14010-00-01	11:00	23.7	6500.0	200.0	
WOCW	18MAR92	14011-00-01	11:30	13.5	7800.0	300.0	
WOCW	18MAR92	14012-00-01	11:30	13.1	7600.0	300.0	
WOCW	18MAR92	14011-01-01	11:30	8.7	5000.0	300.0	
WOCW	18MAR92	14010-01-01	11:00	10.2	6500.0	300.0	
WOCW	18MAR92	14012-01-01	11:30	12.0	6200.0	300.0	
MBW	18MAR92	14008-00-01	11:45	29.4	BDL		
MBW	18MAR92	14009-00-01	11:45	40.0	BDL		
MBW	18MAR92	14007-00-01	11:45	15.6	BDL		
MBW	18MAR92	14008-01-01	11:45	18.6	BDL		
MBW	18MAR92	14007-01-01	11:45	18.1	BDL		
MBW	18MAR92	14009-01-01	11:45	19.5	40.0	40.0	
7500bridge	18MAR92	14005-00-01	13:30	10.8	5200.0	300.0	
7500bridge	18MAR92	14006-00-01	13:30	11.5	6600.0	300.0	
7500bridge	18MAR92	14005-01-01	13:30	9.4	8300.0	400.0	
7500bridge	18MAR92	14006-01-01	13:30	8.6	6200.0	400.0	
ROC	18MAR92	14003-00-01	10:00	38.2	BDL		
ROC	18MAR92	14003-01-01	10:00	13.2	BDL		
NWT	18MAR92	14004-00-01	10:30	10.7	BDL		
NWT	18MAR92	14004-01-01	10:30	13.9	BDL		
Wag4-MS1	18MAR92	14000-00-01	11:45	22.2	300.0	100.0	
Wag4-MS1	18MAR92	14000-01-01	11:45	4.3	BDL		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCW	12APR92	14021-01	13:45	2187.0	1593.0	11.0	
WOCW	12APR92	14021-02	14:00	1452.0	1216.0	11.6	
WOCW	12APR92	14022-01	14:00	1275.0	1302.0	15.8	
WOCW	12APR92	14018-01	14:00	974.0	950.9	12.5	
WOCW	12APR92	14021-03	14:15	619.0	968.0	15.7	
WOCW	12APR92	14021-04	14:30	378.0	—		
WOCW	12APR92	14022-02	14:30	373.0	—		
WOCW	12APR92	14018-02	14:30	349.0	—		
WOCW	12APR92	14021-06	15:00	244.0	554.9	19.3	
WOCW	12APR92	14022-03	15:00	241.0	—		
WOCW	12APR92	14018-03	15:00	237.0	—		
MBW	12APR92	14025-01	13:30	2160.0	14.7	1.6	
MBW	12APR92	14020-01	13:30	2201.0	14.7	1.3	
MBW	12APR92	14020-02	13:45	1423.0	20.6	1.8	
MBW	12APR92	14019-01	13:45	1344.0	20.6	2.1	
MBW	12APR92	14025-02	14:00	1253.0	27.6	2.3	
MBW	12APR92	14020-03	14:00	1029.0	232.9	2.5	
MBW	12APR92	14020-04	14:15	696.0	19.7	2.7	
MBW	12APR92	14019-02	14:15	717.0	21.2	3.2	
MBW	12APR92	14025-03	14:30	464.0	22.2	3.8	
MBW	12APR92	14020-06	14:45	311.0	19.8	4.5	
MBW	12APR92	14019-03	14:45	313.0	23.5	5.0	
7500bridge	12APR92	14016-01	13:45	747.0	686.5	12.7	
7500bridge	12APR92	14016-02	14:45	371.0	305.2	47.0	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCW	30JUN92	14028-01	Not avail.	287.0	—		
WOCW	01JUL92	14028-04	"	412.0	—		
WOCW	02JUL92	14041-04	"	434.0	—		
WOCW	02JUL92	14042-02	"	384.0	—		
WOCW	02JUL92	14028-08	"	44.0	—		
WOCW	03JUL92	14028-10	"	113.0	—		
WOCW	05JUL92	14028-13	"	158.0	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
Wag4-MS1	05SEP92	14051-01	15:30	Consolidated for G.S.D. test			
Wag4-MS1	05SEP92	14051-02	15:45	Composite I.D. # = 14051BW01			
Wag4-MS1	05SEP92	14051-03	16:00	Consolidated for G.S.D. test			
Wag4-MS1	05SEP92	14051-04	16:15	Composite I.D. # = 14051BW02			

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	22NOV92	14032-01	13:45	26.0	1993.7	7.4	
WOD	22NOV92	14032-02	14:15	37.0	1230.4	6.9	
WOD	22NOV92	14032-04	15:15	28.0	1988.8	6.4	
WOD	22NOV92	14032-06	16:15	46.0	1720.5	5.9	
WOD	22NOV92	14032-08	17:15	77.0	—		
WOD	22NOV92	14032-14	20:15	92.0	1106.0	5.0	
WOD	23NOV92	14032-24	01:15	67.0	1066.4	5.9	
WOCW	22NOV92	14059-01	12:30	443.0	2789.0	0.6	
WOCW	22NOV92	14059-02	12:45	1272.0	2441.2	0.5	
WOCW	22NOV92	14060-08	12:45	853.0	2383.0	0.6	
WOCW	22NOV92	14059-03	13:00	1193.0	2198.0	0.5	
WOCW	22NOV92	14059-04	13:15	1060.0	1934.7	0.5	
WOCW	22NOV92	14060-09	13:15	667.0	2039.2	0.6	
WOCW	22NOV92	14059-05	13:30	664.0	1597.3	0.7	
WOCW	22NOV92	14059-06	13:45	396.0	1503.3	0.8	
WOCW	22NOV92	14060-10	13:45	331.0	1530.7	1.1	
WOCW	22NOV92	14060-12	14:45	129.0	1042.5	3.8	
WOCW	22NOV92	14059-10	14:45	131.0	1052.2	3.7	
MBW	22NOV92	14061-24	12:45	490.0	BDL		
MBW	22NOV92	14062-01	12:45	690.0	23.4	12.2	
MBW	22NOV92	14046-01	12:45	479.0	BDL		
MBW	22NOV92	14046-02	13:00	26.5	1616.0	10.7	
MBW	22NOV92	14046-03	13:15	42.3	1074.0	9.5	
MBW	22NOV92	14062-02	13:15	41.1	1269.0	6.2	
7500bridge	22NOV92	14050-01	12:35	1152.0	2065.2	0.5	
7500bridge	22NOV92	14057-01	12:35	1103.0	2024.6	0.5	
7500bridge	22NOV92	14050-02	12:50	725.0	1309.4	0.7	
7500bridge	22NOV92	14050-03	13:05	551.0	1054.7	1.1	
7500bridge	22NOV92	14057-02	13:05	588.0	1128.3	1.0	
7500bridge	22NOV92	14050-05	13:35	220.0	749.5	2.5	
7500bridge	27NOV92	14057-03	13:35	217.0	765.4	2.8	
WOCE	22NOV92	14054-01	15:35	28.0	951.0	7.5	
WOCE	22NOV92	14054-03	16:05	15.0	BDL		
WOCE	22NOV92	14055-02	16:05	16.0	1236.7	15.9	
WOCE	22NOV92	14055-05	16:35	14.0	BDL		
WOCE	22NOV92	14054-05	16:35	16.0	1535.6	11.3	
WOCE	22NOV92	14054-07	17:05	17.0	1669.9	9.9	
WOCE	22NOV92	14055-08	17:05	13.0	1713.5	12.8	
ROC	22NOV92	14052-01	12:30	791.0	—		
ROC	22NOV92	14052-02	12:45	256.0	—		
Wag4-MS1	22NOV92	14056-01	12:15	1026.0	295.5	2.2	
Wag4-MS1	22NOV92	14056-02	12:30	613.0	193.3	5.2	
NWT	22NOV92	14053-01	12:30	591.0	BDL		
NWT	22NOV92	10453-02	12:45	1204.0	BDL		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCW	02NOV92	14043-02	12:00	295.0	4361.0	0.7	
WOCW	02NOV92	14044-03	12:00	368.0	3632.6	0.6	
WOCW	02NOV92	14045-07	12:00	505.0	3652.3	0.5	
WOCW	02NOV92	14045-08	12:15	387.0	—		
WOCW	02NOV92	14043-03	12:15	243.0	—		
WOCW	02NOV92	14043-04	12:30	176.0	—		
WOCW	02NOV92	14044-04	12:30	184.0	—		
WOCW	02NOV92	14045-09	12:30	219.0	2690.4	1.0	
MBW	02NOV92	14048-02	12:00	1118.0	26.5	10.6	
MBW	02NOV92	14047-02	12:15	564.0	—		
MBW	02NOV92	14048-03	12:30	778.0	—		
MBW	02NOV92	14047-03	12:45	409.0	—		
MBW	02NOV92	14048-15	08:30	219.0	—		
MBW	02NOV92	14047-08	08:45	135.0	—		
MBW	02NOV92	14047-11	10:15	78.0	—		
MBW	02NOV92	14048-19	10:30	107.0	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	17DEC92	14064-01	04:15	26.5	2082.8	6.5	
WOD	17DEC92	14064-02	04:30	25.8	1792.6	8.1	
WOD	17DEC92	14064-03	04:45	25.1	1784.2	8.5	
WOD	17DEC92	14064-04	05:00	22.6	1831.6	7.8	
WOD	17DEC92	14064-05	05:15	23.7	2069.7	7.4	
WOD	17DEC92	14064-06	05:30	39.2	1422.9	6.7	
WOD	17DEC92	14064-07	05:45	34.4	1645.7	7.8	
WOD	17DEC92	14064-08	06:00	38.0	1449.3	7.3	
WOD	17DEC92	14064-09	06:15	47.3	1438.6	6.1	
WOD	17DEC92	14064-10	06:30	49.7	1164.9	6.9	
WOD	17DEC92	14064-11	06:45	48.5	1344.9	6.7	
WOD	17DEC92	14064-13	07:15	50.6	1321.9	6.5	
WOD	17DEC92	14064-15	07:45	56.2	1156.4	6.3	
WOD	17DEC92	14064-18	08:30	66.5	1011.1	6.0	
WOD	17DEC92	14064-21	09:15	59.7	834.0	8.0	
WOD	17DEC92	14064-24	10:00	58.8	791.2	9.1	
WOCW	17DEC92	14070-01	02:15	200.8	2017.7	1.3	
WOCW	17DEC92	14070-02	02:30	255.1	2043.8	1.3	
WOCW	17DEC92	14070-03	02:45	275.0	1926.7	1.2	
WOCW	17DEC92	14070-04	03:30	265.6	1848.3	1.2	
WOCW	17DEC92	14070-05	03:15	528.0	888.4	1.3	
WOCW	17DEC92	14070-09	04:15	107.7	1340.8	3.6	
WOCW	17DEC92	14070-13	05:15	68.8	840.7	6.9	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	24JAN93	14077-01	11:45	34.2	—		
WOD	24JAN93	14077-04	12:30	21.2	—		
WOD	24JAN93	14077-06	13:00	24.4	—		
WOD	24JAN93	14077-08	13:30	34.7	—		
WOD	24JAN93	14077-10	14:00	36.4	—		
WOD	24JAN93	14077-12	14:30	69.2	—		
WOD	24JAN93	14077-14	15:00	73.9	—		
WOD	24JAN93	14077-16	15:30	75.9	—		
WOD	24JAN93	14077-19	16:15	72.8	—		
WOD	24JAN93	14077-23	17:15	69.6	—		
WOCW	24JAN93	14079-01	09:15	274.4	—		
WOCW	24JAN93	14079-02	09:30	266.3	—		
WOCW	24JAN93	14079-03	09:45	271	—		
WOCW	24JAN93	14079-04	10:00	234.8	—		
WOCW	24JAN93	14079-05	10:15	200.9	—		
MBW	24JAN93	14082-01	10:00	4452.7	—		
MBW	24JAN93	14084-02	10:15	413.7	—		
MBW	24JAN93	14082-02	10:30	2195.0	—		
MBW	24JAN93	14084-03	10:45	308.5	—		
MBW	24JAN93	14082-03	11:00	1092.3	—		
MBW	24JAN93	14082-04	11:30	720.1	—		
MBW	24JAN93	14084-05	11:45	183.2	—		
MBW	24JAN93	14082-05	12:00	499.8	—		
ROC	24JAN93	14088-01	08:30	218.4	—		
ROC	24JAN93	14088-02	08:45	201.2	—		
ROC	24JAN93	14088-03	09:00	161.1	—		
NWT	24JAN93	14089-01	09:15	210.4	—		
NWT	24JAN93	14089-02	09:30	181.7	—		
NWT	24JAN93	14089-03	09:45	186.5	—		
NWT	24JAN93	14089-04	10:00	133.0	—		
NWT	24JAN93	14089-05	10:15	98.7	—		
NWT	24JAN93	14089-07	10:45	113.3	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	21FEB93	14090-01	14:15	24.5	—		
WOD	21FEB93	14090-02	14:30	24.6	—		
WOD	21FEB93	14090-03	14:45	26.9	—		
WOD	21FEB93	14090-04	15:00	31.4	—		
WOD	21FEB93	14090-05	15:15	41.3	—		
WOD	21FEB93	14090-12	17:00	85.5	—		
WOD	21FEB93	14090-16	18:00	84.9	—		
WOD	21FEB93	14090-20	19:00	76.1	—		
WOD	21FEB93	14090-24	20:00	92.8	—		
WOCW	21FEB93	14093-01	13:15	734.3	—		
WOCW	21FEB93	14093-02	13:30	1213.4	—		
WOCW	21FEB93	14093-03	13:45	557	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	23MAR93	14099-02	14:00	34.0	1647.0	6.2	
WOD	23MAR93	14099-03	14:30	33.0	—		
WOD	23MAR93	14099-04	15:00	35.0	1577.0	6.0	
WOD	23MAR93	14099-05	15:30	37.0	1763.0	5.2	
WOD	23MAR93	14099-06	16:00				
WOD	23MAR93	14099-07	16:30	Consolidated for G.S.D. Test			
WOD	23MAR93	14099-08	17:00	Composite Sample I.D. # = 14099BW01			
WOD	23MAR93	14099-09	17:30				
WOD	23MAR93	14099-10	18:00				
WOD	23MAR93	14099-12	19:00	62.0	1151.0	5.9	
WOD	23MAR93	14099-14	20:00	111.0	—		
WOD	23MAR93	14099-16	20:30	165.0	1087.3	2.5	
WOD	23MAR93	14099-17	21:30				
WOD	23MAR93	14099-18	22:00	Consolidated for G.S.D. Test			
WOD	23MAR93	14099-19	22:30	Composite Sample I.D. # = 14099BW02			
WOD	23MAR93	14099-20	23:00				
WOD	23MAR93	14099-21	23:30				
WOD	24MAR93	14099-22	00:00	183.0	—		
WOD	24MAR93	14099-24	01:00	170.0	—		
WOCW	23MAR93	14103-01	13:00	314.0	1314.4	1.5	
WOCW	23MAR93	14103-02	13:15	646.0	—		
WOCW	23MAR93	14106-01	13:15	774.0	—		
WOCW	23MAR93	14123-01	13:30	410.0	1096.4	1.2	
WOCW	23MAR93	14103-03	13:30	580.0	1156.0	1.0	
WOCW	23MAR93	14103-04	13:45	560.0	1238.6	1.0	
WOCW	23MAR93	14106-02	13:45	675.0	1129.6	0.9	
WOCW	23MAR93	14123-02	14:00	410.0	—		
WOCW	23MAR93	14103-05	14:00	Consolidated for G.S.D. Test			
WOCW	23MAR93	14103-06	14:15	Composite Sample I.D. # = 14103BW01			
WOCW	23MAR93	14103-07	14:30				
WOCW	23MAR93	14106-03	14:15	Consolidated for G.S.D. Test			
WOCW	23MAR93	14106-04	14:30	Composite Sample I.D. # = 14106BW01			
WOCW	23MAR93	14106-05	14:45				
WOCW	23MAR93	14123-03	14:30	Consolidated for G.S.D. Test			
WOCW	23MAR93	14123-04	15:00	Composite Sample I.D. # = 14123BW01			
WOCW	23MAR93	14103-08	14:45	Consolidated for G.S.D. Test			
WOCW	23MAR93	14103-09	15:00	Composite Sample I.D. # = 14103BW02			
WOCW	23MAR93	14103-10	15:15				
WOCW	23MAR93	14123-05	15:30	293.0	562.1	2.7	
WOCW	23MAR93	14103-11	15:30	296.0	—		
WOCW	23MAR93	14106-06	15:45	308.0	—		
WOCW	23MAR93	14103-12	15:45	248.0	650.1	3	
WOCW	23MAR93	14123-06	16:00	208.0	511.1	4.4	
WOCW	23MAR93	14103-14	16:15	212.0	726.7	2.9	
WOCW	23MAR93	14103-18	17:15	111.0	829.7	5.2	
WOCW	23MAR93	14106-09	17:15	144.0	—		
WOCW	23MAR93	14123-09	17:30	781.3	113.0	4.8	
WOCW	23MAR93	14106-13	19:15	65.0	895.1	5.5	
MBW	23MAR93	14083-01	13:00	404.0	—		
MBW	23MAR93	14083-02	13:15	704.0	—		
MBW	23MAR93	14083-03	13:30	875.0	—		
MBW	23MAR93	14083-04	13:45	1029.0	17.4	12.5	
MBW	23MAR93	14083-05	14:00	Consolidated for G.S.D. Test			
MBW	23MAR93	14083-06	14:15	Composite Sample I.D. # = 14083BW01			

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
MBW	23MAR93	14104-03	14:15	32.7	—		
MBW	23MAR93	14083-07	14:30	961.0	—		
MBW	23MAR93	14104-04	14:45	831.0	—		
MBW	23MAR93	14083-08	14:45	833.0	BDL		
MBW	23MAR93	14083-09	15:00	Consolidated for G.S.D. Test			
MBW	23MAR93	14083-10	15:15	Composite Sample I.D. # = 14083BW02			
MBW	23MAR93	14104-05	15:15	711.0	—		
MBW	23MAR93	14083-11	15:30	490.0	BDL		
MBW	23MAR93	14104-06	15:45	436.0	BDL		
MBW	23MAR93	14083-12	15:45	397.0	—		
MBW	23MAR93	14083-14	16:15	287.0	BDL		
MBW	23MAR93	14104-08	16:45	270.0	BDL		
MBW	23MAR93	14083-17	17:00	213.0	—		
MBW	23MAR93	14083-20	17:45	163.0	BDL		
MBW	23MAR93	14104-11	18:15	149.0	1013.8	2.8	
MBW	23MAR93	14083-23	18:30	125.0	BDL		
7500bridge	23MAR93	14102-02	12:45	276.0	950.2	1.9	
7500bridge	23MAR93	14102-03	13:00	445.0	—		
7500bridge	23MAR93	14102-04	13:15	463.0	585.1	2.2	
7500bridge	23MAR93	14101-01	13:15	552.0	647.0	1.8	
7500bridge	23MAR93	14102-05	13:30	443.0	645.6	2.0	
7500bridge	23MAR93	14102-06	13:45	479.0	—		
7500bridge	23MAR93	14101-02	13:45	465.0	—		
7500bridge	23MAR93	14102-07	14:00	622.0	—		
7500bridge	23MAR93	14102-08	14:15	647.0	569.0	1.5	
7500bridge	23MAR93	14101-03	14:20	692.0	522.2	1	
7500bridge	23MAR93	14102-09	14:30	Consolidated for G.S.D. Test			
7500bridge	23MAR93	14102-10	14:45	Composite Sample I.D. # = 14102BW01			
7500bridge	23MAR93	14102-11	15:00				
7500bridge	23MAR93	14101-04	14:50	416.0	366.8	2.8	
7500bridge	23MAR93	14102-12	15:15	273.0	256.3	5.4	
7500bridge	23MAR93	14102-13	15:30	246.0	—		
7500bridge	23MAR93	14102-15	16:00	206.0	256.2	7.1	
WOCE	23MAR93	14066-01	13:35	188.0	1530.6	1.6	
WOCE	23MAR93	14066-02	13:50	28.0	—		
WOCE	23MAR93	14066-03	14:05	20.0	1267.7	12.7	
WOCE	23MAR93	14066-05	14:35	15.0	—		
WOCE	23MAR93	14066-07	15:05	22.0	1789.9	6.9	
WOCE	23MAR93	14065-02	15:15	36.0	903.3	9.9	
WOCE	23MAR93	14065-03	15:45	37.0	—		
WOCE	23MAR93	14066-10	15:50	33.0	1485.8	6.8	
WOCE	23MAR93	14066-12	16:20	39.0	1177.8	6.4	
WOCE	23MAR93	14066-13	16:30				
WOCE	23MAR93	14066-14	16:50	Consolidated for G.S.D. Test			
WOCE	23MAR93	14066-15	17:05	Composite Sample I.D. # = 14066BW01			
WOCE	23MAR93	14066-16	17:20				
WOCE	23MAR93	14065-05	16:45	39.0	1384.4	6.6	
WOCE	23MAR93	14066-17	17:35	58.0	1165.2	4.6	
WOCE	23MAR93	14066-19	18:05	84.0	—		
WOCE	23MAR93	14066-20	18:20	88.0	—		
WOCE	23MAR93	14066-21	18:35	102.0	—		
WOCE	23MAR93	14066-22	18:50	94.0	1026.4	3.5	
WOCE	23MAR93	14066-24	19:20	137.0	1019.8	2.9	
WOCE	23MAR93	14065-06	19:20	138.0	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCE	23MAR93	14065-07	21:20	138.0	689.1	4.5	
WOCE	23MAR93	14065-08	23:20	109.0	—		
WOCE	24MAR94	14065-09	01:20	88.0	725.0	5.5	
ROC	23MAR93	14091-01	15:15	415.0	BDL		
ROC	23MAR93	14091-02	15:30	296.0	—		
Wag4-MS1	23MAR93	14085-10	12:00	30.0	—		
Wag4-MS1	23MAR93	14085-11	12:15	45.0	BDL		
Wag4-MS1	23MAR93	14085-12	12:30	306.0	—		
Wag4-MS1	23MAR93	14085-13	12:45	850.0	—		
Wag4-MS1	23MAR93	14085-14	13:00	438.0	—		
Wag4-MS1	23MAR93	14085-15	13:15	314.0	—		
Wag4-MS1	23MAR93	14085-16	13:30	314.0	224.1	4.9	
Wag4-MS1	23MAR93	14085-17	13:45	Consolidated for G.S.D. Test			
Wag4-MS1	23MAR93	14085-18	14:00	Composite Sample I.D. # = 14085BW01			
Wag4-MS1	23MAR93	14085-19	14:15	Consolidated for G.S.D. Test			
Wag4-MS1	23MAR93	14085-20	14:30	Composite Sample I.D. # = 14085BW02			
Wag4-MS1	23MAR93	14085-21	14:45	173.0	250.3	8.2	
NWT	23MAR93	14100-10	12:30	433.0	—		
NWT	23MAR93	14100-11	12:45	724.0	—		
NWT	23MAR93	14100-12	13:00	651.0	—		
NWT	23MAR93	14100-13	13:15	622.0	BDL		
NWT	23MAR93	14100-14	13:30				
NWT	23MAR93	14100-15	13:45	Consolidated for G.S.D. Test			
NWT	23MAR93	14100-16	14:00	Composite Sample I.D. # = 14100BW01			
NWT	23MAR93	14100-17	14:15				
NWT	23MAR93	14100-18	14:30	448.0	BDL		
NWT	23MAR93	14100-19	14:45	344.0	—		
NWT	23MAR93	14100-20	15:00				
NWT	23MAR93	14100-21	15:15	Consolidated for G.S.D. Test			
NWT	23MAR93	14100-22	15:30	Composite Sample I.D. # = 14066BW02			
NWT	23MAR93	14100-23	15:45				
NWT	23MAR93	14100-24	16:00	134.0	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	04DEC93	14112-01	09:45	33.9	1450.0	9.9	
WOD	04DEC93	14112-02	10:00	25.6	1530.0	11.2	
WOD	04DEC93	14078-01	10:15	40.3	1176.0	9.7	
WOD	04DEC93	14078-01	"	"	1364.0	11.3	Gamma count repeat
WOD	04DEC93	14112-04	10:30	27.8	—		
WOD	04DEC93	14078-02	10:45	36.4	—		
WOD	04DEC93	14112-06	11:00	34.6	1271.0	11.6	
WOD	04DEC93	14112-08	11:30	42.9	—		
WOD	04DEC93	14078-04	11:45	66.1	735.0	10.4	
WOD	04DEC93	14112-10	12:00	46.9	1123.0	9.6	
WOD	04DEC93	14112-12	12:30	48.5	—		
WOD	04DEC93	14078-06	12:45	61.1	—		
WOD	04DEC93	14112-14	13:00	51.8	974.0	9.2	
WOD	04DEC93	14078-08	13:45	89.0	830.0	8.2	
WOD	04DEC93	14112-18	14:00	91.3	1095.0	6.3	
WOD	04DEC93	14112-19	14:15				
WOD	04DEC93	14112-20	14:30	Consolidated for G.S.D. test			
WOD	04DEC93	14112-21	14:45	Composite I.D. # = 14112BW01			
WOD	04DEC93	14112-22	15:00				
WOD	04DEC93	14112-23	15:15				
WOD	04DEC93	14078-09	14:15				
WOD	04DEC93	14078-10	14:45	Consolidated for G.S.D. test			
WOD	04DEC93	14078-11	15:15	Composite I.D. # = 14078BW01			
WOD	04DEC93	14078-12	15:45				
WOD	04DEC93	14112-24	15:30	99.6	—		
WOD	04DEC93	14078-13	16:15	95.5	675.0	9.2	
WOD	04DEC93	14078-14	16:45	81.0	566.0	11	
WOD	04DEC93	14078-22	20:45	84.1	358.0	14	
WOD	04DEC93	14078-23	21:15	75.8	362.0	13.6	
WOD	04DEC93	14078-24	21:45	71.9	374.0	15.7	
WOD	08DEC93	14136-08	00:30	7.0	1170.0	13	
WOD	08DEC93	14136-09	12:30	14.2	—		
WOD	09DEC93	14136-10	00:30	9.4	—		
WOD	09DEC93	14136-11	12:30	11.9	1329.0	13.1	
WOCW	04DEC93	14119-02	08:00	344.4	—		
WOCW	04DEC93	14119-04	08:30	322.4	1585.0	5.3	
WOCW	04DEC93	14119-06	09:00	215.1	—		
WOCW	04DEC93	14119-08	09:30	309.7	—		
WOCW	04DEC93	14119-10	10:00	406.8	2723.0	0.7	
WOCW	04DEC93	14118-01	10:30	567.2	2506.0	0.6	
WOCW	04DEC93	14119-12	10:30	754.1	1647.0	5.2	
WOCW	04DEC93	14119-14	11:00	570.4	—		
WOCW	04DEC93	14118-02	11:00	Consolidated for G.S.D. test			
WOCW	04DEC93	14118-03	11:30	Composite I.D. # = 14118BW01			
WOCW	04DEC93	14119-15	11:15	Consolidated for G.S.D. test			
WOCW	04DEC93	14119-16	11:30	Composite I.D. # = 14119BW01			
WOCW	04DEC93	14119-17	11:45	352.9	—		
WOCW	04DEC93	14118-04	12:00	216.3	—		
WOCW	04DEC93	14118-05	12:30	187.8	1880.0	1.6	
WOCW	04DEC93	14119-20	12:30	351.0	—		
WOCW	04DEC93	14119-22	13:00	266.9	—		
WOCW	04DEC93	14118-06	13:00	137.6	—		
WOCW	04DEC93	14118-07	13:30	111.0	1082.0	5.9	
WOCW	04DEC93	14118-08	14:30	104.4	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCW	04DEC93	14118-11	15:30	100.2	—		
WOCW	04DEC93	14118-13	16:30	281.1	1342.0	2.4	
WOCW	04DEC93	14118-14	17:00	195.7	—		
WOCW	04DEC93	14118-16	18:00	105.8	—		
WOCW	04DEC93	14118-17	18:30				
WOCW	04DEC93	14118-18	19:00	Consolidated for G.S.D. test			
WOCW	04DEC93	14118-19	19:30	Composite I.D. # = 14118BW01			
WOCW	04DEC93	14118-20	20:00				
WOCW	04DEC93	14118-21	20:30	64.2	—		
WOCW	04DEC93	14118-22	21:00	64.8	—		
WOCW	04DEC93	14118-23	21:30	75.7	—		
WOCW	04DEC93	14118-24	22:00	65.8	914.0	7.8	
WOCW	04DEC93	14123-01	23:30	38.1	—		
WOCW	05DEC93	14123-02	00:30	31.8	—		
WOCW	05DEC93	14123-03	01:30	28.9	—		
WOCW	05DEC93	14123-07	05:30	16.4	—		
WOCW	05DEC93	14123-12	10:30	11.1	BDL		
WOCW	05DEC93	14123-16	14:30	4.5	—		
WOCW	05DEC93	14123-20	18:30	9.0	—		
WOCW	05DEC93	14123-24	22:30	5.8	BDL		
WOCW	06DEC93	14135-01	12:30	2.4	—		
WOCW	07DEC93	14135-04	00:30	4.0	—		
WOCW	07DEC93	14135-06	08:30	4.5	—		
WOCW	07DEC93	14135-07	12:30	1.2	—		
WOCW	07DEC93	14135-08	15:15	1.7	BDL		
WOCW	07DEC93	14135-11	23:15	5.2	—		
WOCW	08DEC93	14135-12	11:15	3.1	BDL		
MBW	04DEC93	14105-01	08:00	959.0	BDL		
MBW	04DEC93	14105-02	08:15	667.0	—		
MBW	04DEC93	14105-04	08:45	493.0	—		
MBW	04DEC93	14105-08	09:45	376.0	—		
MBW	04DEC93	14105-09	10:00	304.0	—		
MBW	04DEC93	14105-11	10:30	787.0	—		
MBW	04DEC93	14105-12	10:45	1035.0	—		
MBW	04DEC93	14105-13	11:00	Consolidated for G.S.D. test			
MBW	04DEC93	14105-14	11:15	Composite I.D. # = 14105BW01			
MBW	04DEC93	14105-15	11:30	810.0	—		
MBW	04DEC93	14105-16	11:45	844.0	—		
MBW	04DEC93	14105-18	12:15	1005.0	—		
MBW	04DEC93	14105-21	13:00	622.0	—		
MBW	04DEC93	14105-24	13:45	563.0	—		
MBW	05DEC93	14127-01	00:30	53.8	—		
MBW	05DEC93	14127-02	01:30	49.9	—		
MBW	05DEC93	14127-03	02:30	50.1	—		
MBW	05DEC93	14127-09	08:30	28.6	—		
MBW	05DEC93	14127-15	14:30	21.1	—		
MBW	05DEC93	14127-21	20:30	19.3	—		
MBW	05DEC93	14127-24	23:30	21.2	BDL		
MBW	08DEC93	14117-09	01:00	7.9	—		
MBW	08DEC93	14117-10	13:00	9.0	—		
MBW	09DEC93	14117-11	01:00	8.1	—		
MBW	09DEC93	14117-12	13:00	6.2	BDL		
WOCE	04DEC93	14110-01	13:30	37.4	1099.0	11.3	
WOCE	04DEC93	14110-02	14:00	32.8	1062.0	12	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCE	04DEC93	14110-04	15:00	64.4	—		
WOCE	04DEC93	14110-06	16:00	86.9	1018.0	7.8	
WOCE	04DEC93	14110-08	17:00	105.0	830.0	8.2	
WOCE	04DEC93	14110-09	17:30	101.5	—		
WOCE	04DEC93	14110-10	18:00				
WOCE	04DEC93	14110-11	18:30	Consolidated for G.S.D. test			
WOCE	04DEC93	14110-12	19:00	Composite I.D. # = 14110BW01			
WOCE	04DEC93	14110-13	19:30				
WOCE	04DEC93	14110-14	20:00	82.6	739.0	9.6	
WOCE	04DEC93	14110-16	21:00	84.3	—		
WOCE	04DEC93	14110-18	22:00	86.4	513.0	10.7	
WOCE	04DEC93	14110-18	"	"	560.0	10.7	Gamma count repeat
WOCE	04DEC93	14110-20	23:00	81.9	—		
WOCE	05DEC93	14110-22	00:00	75.4	413.0	12	
WOCE	05DEC93	14110-23	00:30	72.5	—		
WOCE	05DEC93	14110-24	01:00	68.9	347.0	16	
WOCE	06DEC93	14111-11	12:00	36.0	612.0	15.4	
WOCE	06DEC93	14111-12	16:00	38.4	593.0	16	
WOCE	06DEC93	14111-13	20:00	34.7	—		
WOCE	07DEC93	14111-14	00:00	29.2	—		
WOCE	07DEC93	14111-15	04:00	35.6	—		
WOCE	07DEC93	14111-16	08:00	30.4	533.0	21.5	
WOCE	07DEC93	14111-17	12:00	109.0	305.0	12.6	
WOCE	08DEC93	14111-19	12:00	22.0	—		
WOCE	09DEC93	14111-20	00:00	20.1	1088.0	16.7	
WOCE	09DEC93	14111-21	12:00	28.8	1019.0	12.7	
ROC	04DEC93	14125-03	07:30	90.0	BDL		
ROC	04DEC93	14125-04	07:45	121.0	—		
ROC	04DEC93	14125-05	08:15	117.5	—		
ROC	04DEC93	14125-06	08:30	87.3	—		
ROC	04DEC93	14125-08	09:45	242.9	—		
ROC	04DEC93	14125-09	10:00	261.6	—		
ROC	04DEC93	14125-10	10:15	271.2	—		
ROC	04DEC93	14125-11	10:30	271.5	—		
ROC	04DEC93	14125-15	11:30	356.0	—		
ROC	04DEC93	14125-18	12:30	151.8	—		
ROC	04DEC93	14125-21	13:00	1964.4	—		
ROC	04DEC93	14125-22	13:15	179.4	—		
ROC	04DEC93	14125-23	13:30	306.2	—		
ROC	04DEC93	14125-24	13:45	306.4	BDL		
ROC	04DEC93	14131-01	19:15	59.0	BDL		
ROC	04DEC93	14131-02	19:45	51.1	—		
ROC	04DEC93	14131-03	20:00	48.1	—		
ROC	04DEC93	14131-05	20:30	47.8	—		
ROC	04DEC93	14131-08	23:15	36.4	—		
ROC	05DEC93	14131-14	02:00	23.7	—		
ROC	05DEC93	14131-20	05:00	20.0	—		
ROC	05DEC93	14131-24	07:00	16.5	BDL		
Wag4-MS1	04DEC93	14134-01	00:45	103.6	—		
Wag4-MS1	04DEC93	14134-07	06:45	16.6	—		
Wag4-MS1	04DEC93	14126-01	10:35	624.2	BDL		
Wag4-MS1	04DEC93	14126-02	10:40	297.6	—		
Wag4-MS1	04DEC93	14126-04	10:50	223.8	—		
Wag4-MS1	04DEC93	14126-05	10:55	Consolidated for G.S.D. test			

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
Wag4-MS1	04DEC93	14126-06	11:00	Composite I.D. # = 14126BW01			
Wag4-MS1	04DEC93	14126-07	11:05				
Wag4-MS1	04DEC93	14126-08	11:10	121.9	—		
Wag4-MS1	04DEC93	14126-10	11:20	106.4	BDL		
Wag4-MS1	04DEC93	14126-11	11:25	96.4	—		
Wag4-MS1	04DEC93	14126-12	11:30	98.2	BDL		
Wag4-MS1	04DEC93	14126-13	11:35	135.6	—		
Wag4-MS1	04DEC93	14126-14	11:40	113.7	—		
Wag4-MS1	04DEC93	14126-16	11:50	77.3	—		
Wag4-MS1	04DEC93	14126-19	12:05	55.7	—		
Wag4-MS1	04DEC93	14126-22	12:20	47.5	—		
Wag4-MS1	04DEC93	14126-24	12:30	44.4	BDL		
Wag4-MS1	04DEC93	14134-14	13:45	14.1	—		
Wag4-MS1	04DEC93	14134-24	23:45	11.1	BDL		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	09FEB94	14148-01	12:00	72.7	1628	9.5	
WOD	09FEB94	14148-01	"	"	1651	9.2	
WOD	09FEB94	14148-02	12:30	25.4	1624	8.9	
WOD	09FEB94	14149-01	12:45	24.9	—		
WOD	09FEB94	14148-03	13:00	23.1	1597	9.9	
WOD	09FEB94	14148-04	13:30	22.7	—		
WOD	09FEB94	14149-02	13:45	20.9	1611	10.7	
WOD	09FEB94	14149-02	"	"	1694	10.5	
WOD	09FEB94	14148-05	14:00	30.1	1446	8.5	
WOD	09FEB94	14148-06	14:30				
WOD	09FEB94	14148-07	15:00	Consolidated for G.S.D. Test			
WOD	09FEB94	14148-08	15:30	Composite I.D. # = 14148CT01			
WOD	09FEB94	14148-09	16:00				
WOD	09FEB94	14149-03	14:45	Consolidated for G.S.D. Test			
WOD	09FEB94	14149-04	15:45	Composite I.D. # = 14149CT01			
WOD	09FEB94	14149-05	16:45				
WOD	09FEB94	14148-10	16:30	94.7	613	8.3	
WOD	09FEB94	14148-11	17:00	97.0	—		
WOD	09FEB94	14148-12	17:30	92.2	587	8.0	
WOD	09FEB94	14148-13	18:00	88.7	—		
WOD	09FEB94	14149-07	18:45	86.9	568		
WOD	09FEB94	14148-15	19:00	87.5	—		
WOD	09FEB94	14148-17	20:00	74.6	581	9.0	
WOD	09FEB94	14149-09	20:45	74.0	583	9.1	
WOD	09FEB94	14148-19	21:00	73.7	—		
WOD	09FEB94	14148-20	21:30	73.7	547	9.6	
WOD	09FEB94	14149-10	21:45	66.8	—		
WOD	09FEB94	14148-21	22:00	71.2	—		
WOD	09FEB94	14148-22	22:30	70.1	—		
WOD	09FEB94	14149-11	22:45	63.7	658	9.0	
WOD	09FEB94	14148-23	23:00	65.2	574	10.6	
WOD	09FEB94	14148-24	23:30	61.3	—		
WOD	09FEB94	14149-12	23:45	58.2	—		
WOD	10FEB94	14149-14	00:45	37.9	762	12.1	
WOD	10FEB94	14149-16	03:45	36.6	—		
WOD	10FEB94	14149-17	04:45	31.9	1004	11.5	
WOD	10FEB94	14149-19	06:45	27.6	—		
WOD	10FEB94	14149-21	08:45	24.7	1210	11.8	
WOD	10FEB94	14149-23	10:45	28.2	—		
WOD	09FEB94	14149-24	11:45	28.2	959	13.0	
WOCW	09FEB94	14138-01	10:28	449.3	—		
WOCW	09FEB94	14138-02	10:58	263.6	467	6.1	
WOCW	09FEB94	14138-03	11:28	191.7	356	8.0	
WOCW	09FEB94	14138-04	11:58	543.2	914	1.2	
WOCW	10FEB94	14151-01	18:15	156.8	—		
WOCW	10FEB94	14164-01	18:45	151.5	531	7.5	
WOCW	10FEB94	14151-02	18:45	185.4	736	4.9	
WOCW	10FEB94	14164-02	19:15	208.1	490	7.0	
WOCW	10FEB94	14151-03	19:15	395.2	—		
WOCW	10FEB94	14139-01	19:45	386.1	—		
WOCW	10FEB94	14164-03	19:45	370.9	712	2.8	
WOCW	10FEB94	14151-04	19:45	507.8	765	1.3	
WOCW	10FEB94	14164-04	20:15	570.4	767	1.2	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCW	10FEB94	14151-05	20:15	704.2	—		
WOCW	10FEB94	14164-05	20:45	Consolidated for G.S.D. Test			
WOCW	10FEB94	14164-06	21:15	Composite I.D. # = 14164CT01			
WOCW	10FEB94	14164-07	21:45				
WOCW	10FEB94	14139-02	20:45	428.5	—		
WOCW	10FEB94	14151-06	20:45	984.2	1327	0.6	
WOCW	10FEB94	14151-07	21:15	891.2	—		
WOCW	10FEB94	14151-08	21:45	460.0	837	1.7	
WOCW	10FEB94	14139-03	21:45	396.9	552	3.7	
WOCW	10FEB94	14151-09	22:15	Consolidated for G.S.D. Test			
WOCW	10FEB94	14151-10	22:45	Composite I.D. # = 14151CT01			
WOCW	10FEB94	14164-08	22:15	409.6	727	2.1	
WOCW	10FEB94	14164-09	22:45	408.2	—		
WOCW	10FEB94	14139-04	22:45	328.5	—		
WOCW	10FEB94	14151-11	23:15	626.5	1332	0.8	
WOCW	10FEB94	14164-10	23:15	375.3	712	2.6	
WOCW	10FEB94	14139-05	23:45	686.0	311.4	3.2	
WOCW	10FEB94	14151-12	23:45	663.3	2092	0.6	
WOCW	10FEB94	14164-11	23:45	358.7	674	3.5	
WOCW	11FEB94	14151-13	00:15	522.9	1286	0.9	
WOCW	11FEB94	14164-12	00:15	343.1	748	2.6	
WOCW	11FEB94	14139-06	00:45	267.2	—		
WOCW	11FEB94	14151-14	00:45	425.6	—		
WOCW	11FEB94	14164-13	00:45	291.0	—		
WOCW	11FEB94	14151-15	01:15	297.1	—		
WOCW	11FEB94	14139-07	01:45	179.9	—		
WOCW	11FEB94	14151-16	01:45	248.7	701	3.9	
WOCW	11FEB94	14164-15	01:45	202.7	512	7.0	
WOCW	11FEB94	14151-17	02:15	221.1	—		
WOCW	11FEB94	14139-08	02:45	128.8	455	8.9	
WOCW	11FEB94	14164-17	02:45	156.1	—		
WOCW	11FEB94	14151-19	03:15	196.0	929	3.5	
WOCW	11FEB94	14151-19	"	"	808		
WOCW	11FEB94	14139-09	03:45	100.2	—		
WOCW	11FEB94	14164-19	03:45	115.4	498	9.1	
WOCW	11FEB94	14164-19	"	"	502		
WOCW	11FEB94	14151-21	04:15	165.7	—		
WOCW	11FEB94	14139-10	04:45	70.3	—		
WOCW	11FEB94	14164-21	04:45	106.7	—		
WOCW	11FEB94	14151-23	05:15	465.3	1345	0.9	
WOCW	11FEB94	14139-11	05:45	68.8	492	11.7	
WOCW	11FEB94	14151-24	05:45	129.9	—		
WOCW	11FEB94	14164-24	06:15	82.5	578	9.5	
WOCW	11FEB94	14139-13	07:45	67.2	—		
WOCW	11FEB94	14139-15	09:45	51.6	BDL		
WOCW	11FEB94	14156-01	23:00	25.4	BDL		
WOCW	12FEB94	14156-04	02:00	20.5	BDL		
WOCW	12FEB94	14156-06	04:00	19.4	BDL		
WOCW	12FEB94	14156-09	07:00	16.6	—		
WOCW	12FEB94	14156-12	10:00	12.5	BDL		
WOCW	12FEB94	14156-15	13:00	10.5	BDL		
WOCW	12FEB94	14156-18	16:00	12.0	BDL		
WOCW	12FEB94	14156-21	19:00	11.0	BDL		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCW	12FEB94	14156-24	22:00	10.8	BDL		
MBW	09FEB94	14140-01	11:45	534.0	—		
MBW	09FEB94	14140-02	12:00	393.0	—		
MBW	09FEB94	14140-03	12:15	904.0	BDL		
MBW	09FEB94	14140-04	12:30	702.0	—		
MBW	09FEB94	14140-05	12:45	288.0	—		
MBW	09FEB94	14140-06	13:00	236.0	—		
MBW	09FEB94	14140-07	13:15	181.0	—		
MBW	10FEB94	14175-01	18:15	430.2	—		
MBW	10FEB94	14175-02	18:45	501.4	BDL		
MBW	10FEB94	14175-03	19:00	1103.9	—		
MBW	10FEB94	14175-04	19:15	Consolidated for G.S.D. Test			
MBW	10FEB94	14175-05	19:30	Composite I.D. # = 14175CT01			
MBW	10FEB94	14155-01	19:15	402.6	BDL		
MBW	10FEB94	14155-02	19:45	669.8	—		
MBW	10FEB94	14155-03	20:15	Consolidated for G.S.D. Test			
MBW	10FEB94	14155-04	20:45	Composite I.D. # = 14155CT01			
MBW	10FEB94	14155-05	21:15				
MBW	10FEB94	14175-08	20:15	1220.7	—		
MBW	10FEB94	14175-09	20:30	1021.5	57	8.4	
MBW	10FEB94	14175-10	20:45	755.1			
MBW	10FEB94	14175-11	21:00	853.4	—		
MBW	10FEB94	14175-12	21:15	575.3	—		
MBW	10FEB94	14175-14	21:45	534.4	—		
MBW	10FEB94	14155-06	21:45	374	BDL		
MBW	10FEB94	14175-15	22:00	465.5	—		
MBW	10FEB94	14175-16	22:15	465.6	—		
MBW	10FEB94	14155-07	22:15	375.7	—		
MBW	10FEB94	14175-18	22:45	300.4	—		
MBW	10FEB94	14155-08	22:45	307.9	—		
MBW	10FEB94	14175-20	23:15	305.6	—		
MBW	10FEB94	14155-09	23:15	257.4	—		
MBW	10FEB94	14175-21	23:30	273.6	—		
MBW	10FEB94	14155-10	23:45	245.2	—		
MBW	11FEB94	14175-23	00:00	247.9	—		
MBW	11FEB94	14175-24	00:15	207.2	—		
MBW	11FEB94	14155-11	00:15	229.3	BDL		
MBW	11FEB94	14155-12	00:45	177.7	—		
MBW	11FEB94	14155-14	01:45	103.2	—		
MBW	11FEB94	14155-16	02:45	125.2	—		
MBW	11FEB94	14155-19	04:15	135.6	BDL		
MBW	11FEB94	14155-22	05:45	135.5	—		
MBW	11FEB94	14155-23	06:15	126.8	—		
MBW	11FEB94	14166-01	12:00	665.7	—		
MBW	11FEB94	14166-02	12:30	120.2	BDL		
MBW	11FEB94	14166-03	13:00	89.9			
MBW	11FEB94	14166-04	13:30	87.9	BDL		
MBW	11FEB94	14166-05	14:00	83.0	—		
MBW	11FEB94	14166-06	14:30	76.4	—		
MBW	11FEB94	14166-08	15:30	63.2	—		
MBW	11FEB94	14166-11	17:00	72.9	BDL		
MBW	11FEB94	14166-14	18:30	50.4	—		
MBW	11FEB94	14166-17	20:00	43.4	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
MBW	11FEB94	14166-20	21:30	39.1	—		
MBW	11FEB94	14166-23	23:00	32.2	—		
MBW	11FEB94	14165-01	23:00	32.8	—		
MBW	11FEB94	14166-24	23:30	28.9	—		
MBW	12FEB94	14165-03	01:00	32.8	—		
MBW	12FEB94	14165-06	04:00	27.8	—		
MBW	12FEB94	14165-09	07:00	24.4	—		
MBW	12FEB94	14165-13	11:00	20.3	—		
MBW	12FEB94	14165-17	15:00	23.7	—		
MBW	12FEB94	14165-21	19:00	21.2	1606	10.6	
MBW	12FEB94	14165-24	22:00	19.9	—		
7500Bridge	11FEB94	14162-01	01:15	204.1	255	7.9	
7500Bridge	11FEB94	14162-02	01:30	182.4	236	10.7	
7500Bridge	11FEB94	14163-01	01:45	Consolidated for G.S.D. Test			
7500Bridge	11FEB94	14163-02	02:45	Composite I.D. # = 14163CT01			
7500Bridge	11FEB94	14163-03	03:45				
7500Bridge	11FEB94	14162-03	01:45	167.3	—		
7500Bridge	11FEB94	14162-04	02:00	151.2	241	10.7	
7500Bridge	11FEB94	14162-05	02:15	140.4	—		
7500Bridge	11FEB94	14162-06	02:30	124.6	169	18.5	
7500Bridge	11FEB94	14162-07	02:45	119.3	—		
7500Bridge	11FEB94	14162-09	03:15	102.1	181	18.5	
7500Bridge	11FEB94	14165-11	03:45	96.2	—		
7500Bridge	11FEB94	14165-13	04:15	87.5	BDL		
7500Bridge	11FEB94	14163-04	04:45	115.1	259	11.3	
7500Bridge	11FEB94	14165-15	04:45	77.1	—		
7500Bridge	11FEB94	14165-17	05:15	69.9	BDL		
7500Bridge	11FEB94	14165-20	06:00	61.7	—		
7500Bridge	11FEB94	14165-24	07:00	66.7	BDL		
7500Bridge	11FEB94	14172-01	09:30	54.0	—		
7500Bridge	11FEB94	14172-02	10:00	43.7	BDL		
7500Bridge	11FEB94	14172-04	11:00	43.4	—		
7500Bridge	11FEB94	14172-06	12:00	41.0	BDL		
7500Bridge	11FEB94	14172-07	12:30	46.5	—		
7500Bridge	11FEB94	14172-08	13:00	47.9	BDL		
7500Bridge	11FEB94	14172-09	13:30	42.7	BDL		
7500Bridge	11FEB94	14172-10	14:00	36.9	BDL		
7500Bridge	11FEB94	14172-12	15:00	31.6	BDL		
7500Bridge	11FEB94	14172-14	16:00	30.2	BDL		
7500Bridge	11FEB94	14172-15	16:30	29.9	BDL		
WOCE	09FEB94	14146-01	12:00	19.5	BDL		
WOCE	09FEB94	14146-02	12:30	17.3	BDL		
WOCE	09FEB94	14147-01	13:00	14.3	1280	16.5	
WOCE	09FEB94	14146-03	13:00	17.3	BDL		
WOCE	09FEB94	14146-04	13:30	17.6	BDL		
WOCE	09FEB94	14147-02	14:00	16.3	BDL		
WOCE	09FEB94	14146-05	14:00	22.2	BDL		
WOCE	09FEB94	14146-06	14:30	22.7	BDL		
WOCE	09FEB94	14147-03	15:00	21.2	1082	13.9	
WOCE	09FEB94	14147-03	"	"	1095	14.9	
WOCE	09FEB94	14146-07	15:00	25.5	—		
WOCE	09FEB94	14146-08	15:30	26.5	BDL		
WOCE	09FEB94	14147-04	16:00	22.9	1049	14.5	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCE	09FEB94	14146-09	16:00	26.2	—		
WOCE	09FEB94	14146-10	16:30	29.5	BDL		
WOCE	09FEB94	14147-05	17:00	21.1	—		
WOCE	09FEB94	14146-11	17:00	29.1	—		
WOCE	09FEB94	14146-12	17:30	30.4	—		
WOCE	09FEB94	14147-06	18:00	30.0	868	12.3	
WOCE	09FEB94	14146-13	18:00	31.2	BDL		
WOCE	09FEB94	14146-14	18:30	32.1	—		
WOCE	09FEB94	14147-07	19:00	33.5	—		
WOCE	09FEB94	14146-16	19:30	39.5	549	14.1	
WOCE	09FEB94	14147-08	20:00	47.6	773	11.8	
WOCE	09FEB94	14147-09	21:00				
WOCE	09FEB94	14147-10	22:00	Consolidated for G.S.D. Test			
WOCE	09FEB94	14147-11	23:00	Composite I.D. # = 14147CT01			
WOCE	10FEB94	14147-12	00:00				
WOCE	10FEB94	14147-13	01:00	70.1	—		
WOCE	10FEB94	14147-14	02:00	79.4	—		
WOCE	10FEB94	14147-15	03:00	72.6	—		
WOCE	10FEB94	14147-16	04:00	72.9	—		
WOCE	10FEB94	14147-17	05:00	69.5	BDL		
WOCE	10FEB94	14147-18	06:00	70.0	—		
WOCE	10FEB94	14147-19	07:00	64.9	468	15.6	
WOCE	10FEB94	14147-20	08:00	59.0	653	10.0	
WOCE	10FEB94	14147-21	09:00	56.7	687	11.5	
WOCE	10FEB94	14147-22	10:00	54.4	526	13.0	
WOCE	10FEB94	14147-23	11:00	50.9	—		
WOCE	10FEB94	14147-24	12:00	46.9	614	14.7	
WOCE	10FEB94	14158-01	16:45	30.7	BDL		
WOCE	10FEB94	14158-02	17:15	32.2	—		
WOCE	10FEB94	14159-01	17:15	38.5	617	16.1	
WOCE	10FEB94	14158-04	18:15	32.9	BDL		
WOCE	10FEB94	14159-02	18:15	37.5	—		
WOCE	10FEB94	14158-06	19:15	45.6	—		
WOCE	10FEB94	14159-03	19:15	37.2	829	10.9	
WOCE	10FEB94	14158-08	20:15	20.7	BDL		
WOCE	10FEB94	14159-04	20:15	36.5	—		
WOCE	10FEB94	14158-10	21:15	35.6	—		
WOCE	10FEB94	14159-05	21:15	40.5	549	15.7	
WOCE	10FEB94	14159-05	"	"	407	19.9	
WOCE	10FEB94	14158-12	22:15	40.8	BDL		
WOCE	10FEB94	14159-06	22:15	42.8	505	15.9	
WOCE	10FEB94	14158-14	23:15	48.0	—		
WOCE	10FEB94	14158-15	23:45	63.3	778	10.6	
WOCE	10FEB94	14158-15	"	"	652	11.5	
WOCE	11FEB94	14158-16	00:15	101.5	—		
WOCE	11FEB94	14159-08	00:15	102.8	483	12.6	
WOCE	11FEB94	14159-09	01:15	Consolidated for G.S.D. Test			
WOCE	11FEB94	14159-10	02:15	Composite I.D. # = 14159CT01			
WOCE	11FEB94	14159-11	03:15				
WOCE	11FEB94	14158-17	00:45	147.3	629	8.9	
WOCE	11FEB94	14158-17	"	"	633	8.4	
WOCE	11FEB94	14158-18	01:15	190.9	549	9.6	
WOCE	11FEB94	14158-18	"	"	564	7.9	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCE	11FEB94	14158-19	01:45	Consolidated for G.S.D. Test			
WOCE	11FEB94	14158-20	02:15	Composite I.D. # = 14158CT01			
WOCE	11FEB94	14158-21	02:45				
WOCE	11FEB94	14158-22	03:15	195.4	482	9.7	
WOCE	11FEB94	14158-22	"	"	551	7.5	
WOCE	11FEB94	14158-23	03:45	181.2	480	9.8	
WOCE	11FEB94	14158-23	"	"	534	7.3	
WOCE	11FEB94	14158-24	04:15	172.4	466	9.3	
WOCE	11FEB94	14158-24	"	"	464	8.7	
WOCE	11FEB94	14159-12	04:15	168.6	445	9.8	
WOCE	11FEB94	14159-13	05:15	163.3	422	10.1	
WOCE	11FEB94	14159-14	06:15	130.8	427	9.7	
WOCE	11FEB94	14159-15	07:15	118.9	420	10.3	
WOCE	11FEB94	14159-16	08:15	105.2	460	9.8	
WOCE	11FEB94	14159-17	09:15	96.5	437	10.3	
WOCE	11FEB94	14159-18	10:15	68.9	—		
WOCE	11FEB94	14159-19	11:15	71.5	—		
WOCE	11FEB94	14159-20	12:15	60.3	416	15.5	
WOCE	11FEB94	14169-01	13:15	56.3	—		
WOCE	11FEB94	14169-02	13:30	61.2	449	14.0	
WOCE	11FEB94	14169-03	13:45	57.6	485	13.5	
WOCE	11FEB94	14169-05	14:15	61.9	—		
WOCE	11FEB94	14169-07	14:45	58.0	485	14.0	
WOCE	11FEB94	14169-09	15:15	60.3	—		
WOCE	11FEB94	14169-11	15:45	58.9	—		
WOCE	11FEB94	14169-13	16:15	51.4	516	14.2	
WOCE	11FEB94	14169-15	16:45	49.9	—		
WOCE	11FEB94	14169-18	17:30	48.0	554	13.3	
WOCE	11FEB94	14169-20	18:00	48.4	—		
WOCE	11FEB94	14169-22	18:30	47.6	—		
WOCE	11FEB94	14169-24	19:00	47.0	431	17.7	
WOCE	11FEB94	14168-02	19:30	46.0	—		
WOCE	11FEB94	14168-04	20:30	44.0	—		
WOCE	11FEB94	14168-07	22:00	41.0	—		
WOCE	11FEB94	14168-10	23:30	37.8	549	15.6	
WOCE	12FEB94	14168-13	01:00	35.4	—		
WOCE	12FEB94	14168-17	03:00	35.1	738	12.2	
WOCE	12FEB94	14168-21	05:00	34.1	—		
WOCE	12FEB94	14168-24	06:30	30.7	655	16.1	
ROC	10FEB94	14160-01	18:30	95.7	—		
ROC	10FEB94	14160-02	19:00	124.9	—		
ROC	10FEB94	14160-03	19:30	208.1	—		
ROC	10FEB94	14160-04	20:00	274.2	—		
ROC	10FEB94	14160-05	20:30	341.3	—		
ROC	10FEB94	14160-06	21:00	376.0	—		
ROC	10FEB94	14160-07	21:30	Consolidated for G.S.D. Test			
ROC	10FEB94	14160-08	22:00	Composite I.D. # = 14160CT01			
ROC	10FEB94	14160-09	22:30				
ROC	10FEB94	14160-10	23:00	325.1	BDL		
ROC	10FEB94	14160-11	23:30	272.6	—		
ROC	11FEB94	14160-12	00:00	280.9	BDL		
ROC	11FEB94	14160-13	00:30	269.1	—		
ROC	11FEB94	14160-14	01:00	269.8	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
ROC	11FEB94	14160-15	01:30	201.5	—		
ROC	11FEB94	14160-16	02:00	185.4	—		
ROC	11FEB94	14160-19	03:30	153.3	—		
ROC	11FEB94	14160-21	04:30	110.2	—		
ROC	11FEB94	14160-23	05:30	97.2	—		
ROC	11FEB94	14160-24	06:00	98.9	—		
Wag4-MS1	10FEB94	14157-01	18:05	54.2	—		
Wag4-MS1	10FEB94	14157-02	18:30	60.1	BDL		
Wag4-MS1	10FEB94	14157-03	19:05	142.7	—		
Wag4-MS1	10FEB94	14157-04	19:35	246.7	—		
Wag4-MS1	10FEB94	14157-05	20:05	292.4	—		
Wag4-MS1	10FEB94	14157-06	20:35	Consolidated for G.S.D. Test			
Wag4-MS1	10FEB94	14157-07	21:05	Composite I.D. # = 14157CT01			
Wag4-MS1	10FEB94	14157-08	21:35				
Wag4-MS1	10FEB94	14157-09	22:05	720.1	—		
Wag4-MS1	10FEB94	14157-10	22:35	506.2	122	9.5	
Wag4-MS1	10FEB94	14157-11	23:05	578.4	—		
Wag4-MS1	11FEB94	14157-13	00:05	479.0	—		
Wag4-MS1	11FEB94	14157-14	00:35	631.6	—		
Wag4-MS1	11FEB94	14157-16	01:35	348.1	—		
Wag4-MS1	11FEB94	14157-18	02:35	82.6	—		
Wag4-MS1	11FEB94	14157-20	03:35	198.8	—		
Wag4-MS1	11FEB94	14157-22	04:35	47.0	—		
Wag4-MS1	11FEB94	14157-24	05:35	29.0	930	13.8	
Wag4-MS1	11FEB94	14167-01	14:05	13.4	—		
Wag4-MS1	11FEB94	14167-03	15:05	12.3	—		
Wag4-MS1	11FEB94	14167-06	16:35	10.4	BDL		
Wag4-MS1	11FEB94	14167-09	18:05	11.5	—		
Wag4-MS1	11FEB94	14167-12	19:35	11.1	—		
Wag4-MS1	11FEB94	14167-16	21:35	9.1	—		
Wag4-MS1	11FEB94	14167-20	23:35	10.5	BDL		
Wag4-MS1	12FEB94	14167-24	02:05	28.2	BDL		
NWT	10FEB94	14150-01	10:15	502.1	—		
NWT	10FEB94	14150-02	10:45	396.5	—		
NWT	10FEB94	14150-03	11:15	268.3	BDL		
NWT	10FEB94	14150-04	11:45	187.3	—		
NWT	10FEB94	14150-05	12:15	117.9	—		
NWT	10FEB94	14150-06	12:30	85.7	—		
NWT	10FEB94	14161-01	18:00	77.9	—		
NWT	10FEB94	14161-02	18:30	137.8	BDL		
NWT	10FEB94	14161-03	19:00	269.4	—		
NWT	10FEB94	14161-04	19:30	637.1	—		
NWT	10FEB94	14161-05	20:00	Consolidated for G.S.D. Test			
NWT	10FEB94	14161-06	20:30	Composite I.D. # = 14161CT01			
NWT	10FEB94	14161-07	21:00				
NWT	10FEB94	14161-08	21:30	854.3	BDL		
NWT	10FEB94	14161-09	22:00	666.4	—		
NWT	10FEB94	14161-10	22:30	610.9	—		
NWT	10FEB94	14161-11	23:00	566.6	—		
NWT	10FEB94	14161-12	23:30	610.4	—		
NWT	11FEB94	14161-13	00:00	601.6	BDL		
NWT	11FEB94	14161-14	00:30	472.0	—		
NWT	11FEB94	14161-15	01:00	352.4	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
NWT	11FEB94	14161-17	02:00	253.9	—		
NWT	11FEB94	14161-19	03:00	182.5	—		
NWT	11FEB94	14161-22	04:30	124.1	—		
NWT	11FEB94	14161-24	05:30	102.1	—		
NWT	11FEB94	14171-01	09:00	97.8	—		
NWT	11FEB94	14171-02	09:30	75.2	—		
NWT	11FEB94	14171-04	10:30	65.2	—		
NWT	11FEB94	14171-07	12:00	47.5	—		
NWT	11FEB94	14171-08	12:30	46.9	—		
NWT	11FEB94	14171-09	13:00	44.1	BDL		
NWT	11FEB94	14171-10	13:30	42.0	—		
NWT	11FEB94	14171-13	15:00	37.3	—		
NWT	11FEB94	14171-16	16:30	25.0	—		
NWT	11FEB94	14171-20	18:30	23.5	—		
NWT	11FEB94	14171-24	20:30	19.7	BDL		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	23FEB94	14178-01	12:00	Consolidated for G.S.D. test Composite Sample I.D. = 14178CT01			
WOD	23FEB94	14178-02	12:30				
WOD	23FEB94	14178-03	13:00				
WOD	23FEB94	14178-04	13:30				
WOD	23FEB94	14178-05	14:00				
WOD	23FEB94	14178-06	14:30				
WOCE	23FEB94	14177-01	10:00	Consolidated for G.S.D. test Composite Sample I.D. = 14177CT01			
WOCE	23FEB94	14177-02	10:30				
WOCE	23FEB94	14177-03	11:00				
WOCE	23FEB94	14177-04	11:30				
WOCE	23FEB94	14177-05	12:00				
WOCE	23FEB94	14177-06	12:30				

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	27MAR94	14200-01	08:45	143.7	606.5	7.3	
WOD	27MAR94	14200-02	09:45	Consolidated for G.S.D. test			
WOD	27MAR94	14200-03	10:45	Composite I.D. # = 14200CT01			
WOD	27MAR94	14200-04	16:30	62.3	518.3	14.3	
WOD	27MAR94	14200-05	17:30	63.8	496.5	12.9	
WOD	27MAR94	14198-08	21:15	54.6	391.6	14.9	
WOD	27MAR94	14198-09	21:45	56.3	509.9	10.8	
WOD	28MAR94	14198-16	01:15	48.2	BDL		
WOD	28MAR94	14198-17	01:45	47.4	—		
WOD	28MAR94	14198-18	02:15	46.8	333.2	19.0	
WOD	28MAR94	14198-19	02:45	43.5	—		
WOD	28MAR94	14198-21	03:45	40.4	BDL		
WOD	28MAR94	14198-23	04:45	37.9	381.8	19.9	
WOD	28MAR94	14198-24	05:15	36.6	387.2	22.8	
WOD	28MAR94	14200-06	06:00	31.6	BDL		
WOD	28MAR94	14200-07	06:30	31.6	BDL		
WOD	28MAR94	14200-10	08:00	30.3	—		
WOD	28MAR94	14200-13	09:30	30.0	BDL		
WOD	28MAR94	14200-16	11:00	29.1	—		
WOD	28MAR94	14200-17	11:30	27.5	BDL		
WOD	28MAR94	14200-18	12:00	27.5	—		
WOD	28MAR94	14200-19	12:30	25.3	BDL		
WOD	28MAR94	14200-20	13:00	27.1	—		
WOD	28MAR94	14200-21	13:30	26.8	BDL		
WOCW	27MAR94	14185-02	03:45	286.9	152	9.2	
WOCW	27MAR94	14185-03	04:15	189.3	821	2.8	
WOCW	27MAR94	14185-05	05:15	118.8	—		
WOCW	27MAR94	14185-07	06:15	5492.0	—		High [SS]
WOCW	27MAR94	14185-08	06:45	722.3	157	4.7	
WOCW	27MAR94	14185-09	07:15	Consolidated for G.S.D. test			
WOCW	27MAR94	14185-10	07:45	Composite I.D. # = 14185CT01			
WOCW	27MAR94	14185-11	08:15	321.8	256	6.6	
WOCW	27MAR94	14185-12	08:45	243.1	142	10.4	
WOCW	27MAR94	14185-14	09:45	140.8	—		
WOCW	27MAR94	14185-16	10:45	93.9	395	9.7	
WOCW	27MAR94	14185-19	12:15	72.8	427	10.7	
WOCW	27MAR94	14185-21	13:15	87.8	473	8.9	
WOCW	27MAR94	14186-01	13:15	678.2	—		
WOCW	27MAR94	14186-02	14:15	336.5	284	7.4	
WOCW	27MAR94	14185-24	14:45	88.5	334	12.0	
WOCW	27MAR94	14186-03	15:15	147.8	277	12.3	
WOCW	27MAR94	14186-04	16:15	138.5	—		
WOCW	27MAR94	14194-01	16:30	115.7	—		
WOCW	27MAR94	14194-02	17:00	87.6	359	10.9	
WOCW	27MAR94	14194-03	17:30	69.8	—		
WOCW	27MAR94	14186-05	17:30	17.0	BDL		
WOCW	27MAR94	14194-04	18:00	59.8	1428	5.0	
WOCW	27MAR94	14194-05	18:30	80.0	—		
WOCW	27MAR94	14186-06	18:30	19.7	BDL		
WOCW	27MAR94	14194-06	19:00	73.2	352	14.3	
WOCW	27MAR94	14186-07	19:30	15.8	BDL		
WOCW	27MAR94	14194-08	20:00	66.3	346	14.5	
WOCW	27MAR94	14194-09	20:30	66.7	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCW	27MAR94	14186-08	20:30	16.7	—		
WOCW	27MAR94	14194-10	21:00	60.1	387	14.1	
WOCW	27MAR94	14186-09	21:30	16.0	—		
WOCW	27MAR94	14194-12	22:00	57.1	—		
WOCW	27MAR94	14186-10	22:30	15.7	BDL		
WOCW	27MAR94	14194-14	23:00	47.2	BDL		
WOCW	27MAR94	14186-11	23:30	18.7	—		
WOCW	28MAR94	14194-17	00:30	41.8	—		
WOCW	28MAR94	14194-19	01:30	35.3	BDL		
WOCW	28MAR94	14186-13	01:30	17.5	—		
WOCW	28MAR94	14194-21	02:30	36.9	—		
WOCW	28MAR94	14194-23	03:30	35.7	BDL		
WOCW	28MAR94	14186-15	03:30	16.7	—		
WOCW	28MAR94	14194-24	04:00	35.9	BDL		
WOCW	28MAR94	14186-16	04:30	14.9	BDL		
WOCW	28MAR94	14186-18	06:30	15.6	—		
WOCW	28MAR94	14186-21	09:30	15.3	—		
WOCW	28MAR94	14186-24	12:30	15.2	BDL		
WOCW	28MAR94	14210-01	14:00	30.6	BDL		
WOCW	28MAR94	14210-02	14:30	29.1	BDL		
WOCW	28MAR94	14210-05	16:00	26.4	—		
WOCW	28MAR94	14210-08	17:30	24.2	—		
WOCW	28MAR94	14210-10	18:30	41.2	BDL		
WOCW	28MAR94	14210-12	19:30	21.0	—		
WOCW	28MAR94	14210-13	20:00	20.1	—		
WOCW	28MAR94	14210-17	22:00	19.5	BDL		
WOCW	28MAR94	14210-20	23:30	18.1	—		
WOCW	29MAR94	14210-23	01:00	17.5	BDL		
WOCW	29MAR94	14210-24	01:30	18.0	BDL		
MBW	27MAR94	14189-01	03:30	567.7	—		
MBW	27MAR94	14189-02	04:30	428.6	—		
MBW	27MAR94	14189-03	05:30	287.5	—		
MBW	27MAR94	14189-04	06:30	429.1	BDL		
MBW	27MAR94	14188-01	06:45	733.3	—		
MBW	27MAR94	14187-01	07:00	2431.6	—		
MBW	27MAR94	14188-02	07:15	674.4	—		
MBW	27MAR94	14187-02	07:30	Use for G.S.D Test: Sample ID#14187CT01			
MBW	27MAR94	14189-05	07:30	768.2	—		
MBW	27MAR94	14188-03	07:45	517.6	—		
MBW	27MAR94	14187-03	08:00	915.1	—		
MBW	27MAR94	14188-04	08:15	298.5	—		
MBW	27MAR94	14187-04	08:30	1268.3	—		
MBW	27MAR94	14189-06	08:30	270.4	—		
MBW	27MAR94	14188-05	08:45	217.7	—		
MBW	27MAR94	14187-05	09:00	992.5	—		
MBW	27MAR94	14189-07	09:30	228.0	—		
MBW	27MAR94	14187-07	10:00	710.2	—		
MBW	27MAR94	14189-08	10:30	178.3	—		
MBW	27MAR94	14187-09	11:00	346.7	—		
MBW	27MAR94	14189-09	11:30	132.1	—		
MBW	27MAR94	14189-10	12:30	122.0	—		
MBW	27MAR94	14189-11	13:30	146.3	—		
MBW	27MAR94	14189-12	14:30	132.8	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
MBW	27MAR94	14189-13	15:30	257.3	—		
MBW	27MAR94	14189-14	16:30	146.8	—		
MBW	27MAR94	14195-01	17:15	Consolidated for G.S.D. test			
MBW	27MAR94	14195-02	17:45	Composite I.D. # = 14195CT01			
MBW	27MAR94	14195-03	18:15	107.1	—		
MBW	27MAR94	14195-04	18:45	121.0	—		
MBW	27MAR94	14195-05	19:15	97.4	—		
MBW	27MAR94	14195-06	19:45	128.6	—		
MBW	27MAR94	14195-07	20:15	103.2	—		
MBW	27MAR94	14195-08	20:45	96.4	—		
MBW	28MAR94	14204-01	11:15	31.1	—		
MBW	28MAR94	14204-02	11:45	35.4	—		
MBW	28MAR94	14204-04	12:45	23.9	—		
MBW	28MAR94	14204-06	13:45	32.8	—		
MBW	28MAR94	14204-10	15:45	29.2	—		
MBW	28MAR94	14204-14	17:45	25.8	—		
MBW	28MAR94	14204-17	19:15	24.7	—		
MBW	28MAR94	14204-20	20:45	24.7	—		
MBW	28MAR94	14204-23	22:15	21.7	—		
MBW	28MAR94	14204-24	22:45	28.8	BDL		
7500bridge	27MAR94	14183-01	20:15	Consolidated for G.S.D. test			
7500bridge	27MAR94	14183-02	20:45	Composite I.D. # = 14183CT01			
7500bridge	27MAR94	14183-03	21:15	170.6	298	10.8	
7500bridge	27MAR94	14183-04	21:45	118.0	227	18.1	
7500bridge	27MAR94	14183-06	22:45	63.2	—		
7500bridge	27MAR94	14183-08	23:45	47.7	BDL		
7500bridge	28MAR94	14183-11	01:15	37.9	—		
7500bridge	28MAR94	14183-13	02:15	36.5	BDL		
7500bridge	28MAR94	14183-14	02:45	33.7	—		
7500bridge	28MAR94	14183-16	06:30	32.5	—		
7500bridge	28MAR94	14183-17	07:45	31.0	—		
7500bridge	28MAR94	14183-18	08:15	22.3	BDL		
7500bridge	28MAR94	14183-21	11:30	20.2	—		
7500bridge	28MAR94	14183-24	13:00	17.2	BDL		
WOCE	27MAR94	14192-02	05:15	39.3	570	14.8	
WOCE	27MAR94	14192-03	05:45	43.3	—		
WOCE	27MAR94	14192-05	06:15	38.4	1052	9.6	
WOCE	27MAR94	14192-06	06:45	40.9	—		
WOCE	27MAR94	14192-07	07:15	41.9	1123	7.3	
WOCE	27MAR94	14192-08	07:45	44.9	—		
WOCE	27MAR94	14192-09	08:15	64.6	1026	5.9	
WOCE	27MAR94	14192-10	08:45	90.1	—		
WOCE	27MAR94	14192-11	09:15	117.4	821	4.7	
WOCE	27MAR94	14192-12	09:45	150.7	—		
WOCE	27MAR94	14192-13	10:15	182.7	705	4.1	
WOCE	27MAR94	14192-14	10:45	199.7	649	4.0	
WOCE	27MAR94	14192-15	11:15	214.4	560	3.9	
WOCE	27MAR94	14192-16	11:45	Consolidated for G.S.D. test			
WOCE	27MAR94	14192-17	12:15	Composite I.D. # = 14192CT01			
WOCE	27MAR94	14192-18	12:45	196.6	430	4.2	
WOCE	27MAR94	14192-19	13:15	192.0	—		
WOCE	27MAR94	14192-20	13:45	174.3	351	6.5	
WOCE	27MAR94	14192-21	14:15	164.5	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOCE	27MAR94	14192-22	14:45	145.2	378	6.7	
WOCE	27MAR94	14192-23	15:15	130.1	—		
WOCE	27MAR94	14192-24	15:45	121.5	433	7.5	
WOCE	27MAR94	14209-01	19:00	70.3	516	9.9	
WOCE	27MAR94	14209-02	19:30	74.6	484	9.6	
WOCE	27MAR94	14209-03	20:00	77.1	503	9.6	
WOCE	27MAR94	14209-04	20:30	79.0	585	7.1	
WOCE	27MAR94	14209-04	"	"	639	7.1	Gamma count repeat
WOCE	27MAR94	14209-05	21:00	79.0	—		
WOCE	27MAR94	14209-06	21:30	72.5	433	13.3	
WOCE	27MAR94	14209-07	22:00	68.9	578	8.3	
WOCE	27MAR94	14209-08	22:30	67.3	435	11.0	
WOCE	27MAR94	14209-09	23:00	61.0	—		
WOCE	27MAR94	14209-10	23:30	58.8	644	8.4	
WOCE	28MAR94	14209-11	00:00	60.8	—		
WOCE	28MAR94	14209-12	00:30	57.9	—		
WOCE	28MAR94	14209-13	01:00	64.9	430	11.5	
WOCE	28MAR94	14209-15	02:00	53.4	—		
WOCE	28MAR94	14209-18	03:30	49.7	477	8.9	
WOCE	28MAR94	14209-21	05:00	44.1	—		
WOCE	28MAR94	14207-01	06:00	44.1	583	11.0	
WOCE	28MAR94	14209-24	06:30	41.3	613	12.7	
WOCE	28MAR94	14207-02	07:00	40.5	—		
WOCE	28MAR94	14207-03	08:00	38.3	—		
WOCE	28MAR94	14207-04	09:00	36.6	711	10.9	
WOCE	28MAR94	14207-05	10:00	38.2	—		
WOCE	28MAR94	14207-06	11:00	43.1	659	10.9	
WOCE	28MAR94	14207-07	12:00	47.1	571	11.9	
WOCE	28MAR94	14207-08	13:00	46.5	666	9.8	
WOCE	28MAR94	14207-09	14:00	39.2	728	10.2	
WOCE	28MAR94	14201-01	14:30	31.5	BDL		
WOCE	28MAR94	14201-02	15:00	31.2	670	15.1	
WOCE	28MAR94	14201-03	15:30	27.8	779	15.5	
WOCE	28MAR94	14201-03	"	"	611	18.9	Gamma count repeat
WOCE	28MAR94	14201-04	16:00	29.8	642	11.7	
WOCE	28MAR94	14201-05	16:30	30.0	738	14.6	
WOCE	28MAR94	14201-06	17:00	29.8	BDL		
WOCE	28MAR94	14201-07	17:30	45.1	603	11.8	
WOCE	28MAR94	14201-08	18:00	32.3	459	21.8	
WOCE	28MAR94	14201-11	19:30	29.3	—		
WOCE	28MAR94	14201-14	21:00	27.9	841	12.9	
WOCE	28MAR94	14201-18	23:00	31.0	—		
WOCE	29MAR94	14201-22	01:00	29.2	944	11.4	
WOCE	29MAR94	14201-23	01:30	33.5	—		may have overfilled
WOCE	29MAR94	14201-24	02:00	60.3	471	12.1	may have overfilled
WOCE	29MAR94	14207-10	02:00	43.5	806	8.7	
WOCE	29MAR94	14207-11	03:00	41.1	800	9.8	
WOCE	29MAR94	14207-12	04:00	36.2	614	12.5	
WOCE	29MAR94	14207-12	"	"	795	10.6	Gamma count repeat
WOCE	29MAR94	14207-13	05:00	31.8	1297	7.0	
WOCE	29MAR94	14207-13	"	"	888	10.2	Gamma count repeat
ROC	27MAR94	14179-01	02:30	301.8	—		
ROC	27MAR94	14079-02	03:00	230.4	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
ROC	27MAR94	14079-03	04:00	117.3	—		
ROC	27MAR94	14079-06	05:00	95.1	—		
ROC	27MAR94	14079-07	05:30	84.0	—		
ROC	27MAR94	14079-08	06:00	90.1	—		
ROC	27MAR94	14079-09	06:30	Consolidated for G.S.D. test			
ROC	27MAR94	14079-10	07:00	Composite I.D. # = 14079CT01			
ROC	27MAR94	14079-11	07:30	468.9	—		
ROC	27MAR94	14079-12	08:00	760.0	—		
ROC	27MAR94	14079-13	08:30	175.4	—		
ROC	27MAR94	14079-15	09:30	99.6	—		
ROC	27MAR94	14079-18	11:00	68.3	—		
ROC	27MAR94	14079-21	12:30	66.5	—		
ROC	27MAR94	14079-23	13:30	59.1	—		
ROC	27MAR94	14079-24	14:00	162.0	—		
ROC	27MAR94	14197-01	16:45	71.2	—		
ROC	27MAR94	14197-02	17:15	57.7	—		
ROC	27MAR94	14197-03	17:45	55.4	—		
ROC	27MAR94	14197-04	18:15	52.8	—		
ROC	27MAR94	14197-05	18:45	58.6	—		
ROC	27MAR94	14197-06	19:15	53.9	BDL		
ROC	27MAR94	14197-07	19:45	60.8	—		
ROC	27MAR94	14197-08	20:15	345.9	—		
ROC	27MAR94	14197-09	20:45	58.0	—		
ROC	27MAR94	14197-10	21:15	53.0	—		
ROC	27MAR94	14197-11	21:45	47.4	—		
ROC	27MAR94	14197-13	22:45	43.1	—		
ROC	28MAR94	14197-16	00:15	38.0	—		
ROC	28MAR94	14197-20	02:15	36.8	—		
ROC	28MAR94	14197-22	03:15	38.3	—		
ROC	28MAR94	14197-24	04:15	34.2	—		
ROC	28MAR94	14203-01	11:45	22.4	—		
ROC	28MAR94	14203-02	12:45	22.7	—		
ROC	28MAR94	14203-05	16:45	17.9	—		
ROC	28MAR94	14203-09	20:45	15.7	—		
ROC	29MAR94	14203-13	00:45	12.9	—		
ROC	29MAR94	14203-17	04:45	11.9	—		
ROC	29MAR94	14203-21	08:45	10.1	—		
ROC	29MAR94	14203-24	11:45	11.3	BDL		
Wag4-MS1	27MAR94	14180-01	02:35	290.0	—		
Wag4-MS1	27MAR94	14180-02	03:05	199.9	—		
Wag4-MS1	27MAR94	14180-03	03:35	170.9	—		
Wag4-MS1	27MAR94	14180-04	04:05	60.7	—		
Wag4-MS1	27MAR94	14180-06	05:05	40.8	—		
Wag4-MS1	27MAR94	14180-08	06:05	764.9	—		
Wag4-MS1	27MAR94	14180-09	06:35	13281.0	—		Bottle not full/gravel
Wag4-MS1	27MAR94	14180-10	07:05	428.8	—		Bottle not full/gravel
Wag4-MS1	27MAR94	14180-11	07:35	526.5	105	8.6	contained gravel
Wag4-MS1	27MAR94	14180-12	08:05	144.9	—		
Wag4-MS1	27MAR94	14180-14	09:05	62.0	—		
Wag4-MS1	27MAR94	14180-17	10:35	37.8	—		
Wag4-MS1	27MAR94	14180-18	11:05	40.7	—		
Wag4-MS1	27MAR94	14180-19	11:35	54.2	—		
Wag4-MS1	27MAR94	14180-20	12:05	44.0	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
Wag4-MS1	27MAR94	14180-21	12:35	53.6	—		
Wag4-MS1	27MAR94	14180-23	13:35	29.0	—		
Wag4-MS1	27MAR94	14180-24	14:05	130.1	—		
Wag4-MS1	27MAR94	14199-02	17:45	48.1	—		
Wag4-MS1	27MAR94	14199-03	18:15	49.3	—		
Wag4-MS1	27MAR94	14199-04	18:45	56.9	475	12.5	
Wag4-MS1	27MAR94	14199-05	19:15	41.4	—		
Wag4-MS1	27MAR94	14199-06	19:45	36.6	—		
Wag4-MS1	27MAR94	14199-07	20:15	32.0	—		
Wag4-MS1	27MAR94	14199-08	20:45	29.8	—		
Wag4-MS1	27MAR94	14199-11	22:15	23.4	—		
Wag4-MS1	28MAR94	14199-15	00:15	15.7	—		
Wag4-MS1	28MAR94	14199-19	02:15	19.6	—		
Wag4-MS1	28MAR94	14199-20	02:45	14.7	—		
Wag4-MS1	28MAR94	14199-22	03:45	17.0	—		
Wag4-MS1	28MAR94	14199-24	04:45	15.0	—		
Wag4-MS1	28MAR94	14202-01	04:45	22.3	—		
Wag4-MS1	28MAR94	14202-02	04:45	23.1	—		
Wag4-MS1	28MAR94	14202-04	05:15	12.5	—		
Wag4-MS1	28MAR94	14202-06	06:15	13.7	—		
Wag4-MS1	28MAR94	14202-07	07:15	17.2	—		
Wag4-MS1	28MAR94	14202-08	07:45	14.5	—		
Wag4-MS1	28MAR94	14202-10	09:15	18.8	—		
Wag4-MS1	28MAR94	14202-13	10:45	21.5	—		
Wag4-MS1	28MAR94	14202-17	12:45	14.8	—		
Wag4-MS1	28MAR94	14202-21	14:45	14.7	BDL		
Wag4-MS1	29MAR94	14208-01	03:15	10.4	—		
Wag4-MS1	29MAR94	14208-02	03:45	10.5	—		
Wag4-MS1	29MAR94	14208-06	05:45	7.4	—		
Wag4-MS1	29MAR94	14208-10	07:45	6.1	—		
Wag4-MS1	29MAR94	14208-14	09:45	6.3	—		
Wag4-MS1	29MAR94	14208-17	11:15	8.3	—		
NWT	27MAR94	14181-01	06:45	1554.2	—		
NWT	27MAR94	14181-02	07:15	Use for G.S.D Test: Sample ID#14187CT01			
NWT	27MAR94	14181-03	07:45	5507.6	—		
NWT	27MAR94	14182-01	18:30	114.7	—		
NWT	27MAR94	14182-02	19:00	113.7	—		
NWT	27MAR94	14182-03	19:30	106.2	—		
NWT	27MAR94	14182-04	20:00	94.4	—		
NWT	27MAR94	14182-05	20:30	81.6	—		
NWT	27MAR94	14182-06	21:00	60.5	—		
NWT	27MAR94	14182-07	21:30	60.3	—		
NWT	27MAR94	14182-09	22:30	66.7	—		
NWT	28MAR94	14182-12	00:00	52.2	—		
NWT	28MAR94	14182-15	01:30	38.2	—		
NWT	28MAR94	14182-18	03:00	26.3	—		
NWT	28MAR94	14182-19	03:30	28.1	—		
NWT	28MAR94	14182-20	04:00	27.8	—		
NWT	28MAR94	14182-22	05:00	30.4	—		
NWT	28MAR94	14182-24	06:00	27.3	—		

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
WOD	08MAR95	14218-01	04:30	37.0	1026.0	15.7	
WOD	08MAR95	14218-01	"	"	970.0	16.9	Gamma count repeat
WOD	08MAR95	14218-02	05:00	30.2	738.0	21.9	
WOD	08MAR95	14218-05	06:30	29.6	1119.0	12.6	
WOD	08MAR95	14219-03	07:30	39.9	—		
WOD	08MAR95	14218-08	08:00	64.0	454.0	19.5	
WOD	08MAR95	14219-04	08:30	72.7	—		
WOD	08MAR95	14218-09	09:00	111.1	—		
WOD	08MAR95	14219-05	09:30	115.8	—		
WOD	08MAR95	14218-12	10:00	128.3	402.0	9.3	
WOD	08MAR95	14219-06	10:30	114.3	318.0	13.1	
WOD	08MAR95	14218-13	10:30	124.1	—		
WOD	08MAR95	14218-14	11:00	Consolidated for G.S.D. Test			
WOD	08MAR95	14218-15	11:30	Composite I.D.# = 14218CT01			
WOD	08MAR95	14218-16	12:00				
WOD	08MAR95	14219-07	11:30	100.8	—		
WOD	08MAR95	14218-17	12:30	97.5	—		
WOD	08MAR95	14219-08	12:30	89.4	260.0	15.4	
WOD	08MAR95	14218-19	13:30	84.9	—		
WOD	08MAR95	14218-22	15:00	67.1	278.0	19.6	
WOD	08MAR95	14218-24	16:00	62.5	373.0	14.1	
WOCW	08MAR95	14214-01	06:30	345.5	—		
WOCW	08MAR95	14214-02	07:00	220.9	—		
WOCW	08MAR95	14214-03	07:30	155.0	—		
WOCW	08MAR95	14215-01	07:45	152.6	549.0	9.9	
WOCW	08MAR95	14216-01	08:00	Consolidated for G.S.D. Test			
WOCW	08MAR95	14216-02	09:00	Composite I.D.# = 14216CT01			
WOCW	08MAR95	14216-03	10:00				
WOCW	08MAR95	14215-02	08:15	111.3	477.0	12.9	
WOCW	08MAR95	14215-04	09:15	109.1	447.0	13.6	
WOCW	08MAR95	14215-06	10:15	71.2	BDL		
WOCW	08MAR95	14215-10	12:15	52.3	BDL		
WOCW	08MAR95	14215-16	15:15	41.9	BDL		
MBW	08MAR95	14212-01	04:00	666.2	—		
MBW	08MAR95	14212-02	04:30	637.1			
MBW	08MAR95	14212-03	05:00	Used with GSD Test. Sample ID = 14212CT01			
MBW	08MAR95	14212-04	05:30	389.8	BDL		
MBW	08MAR95	14212-06	06:30	357.2	—		
MBW	08MAR95	14211-01	06:45	780.7	BDL		
MBW	08MAR95	14211-02	07:15	697.2	—		
MBW	08MAR95	14212-08	07:30	277.3	—		
MBW	08MAR95	14211-03	07:45	649.9	—		
MBW	08MAR95	14212-11	09:00	182.0	—		
MBW	08MAR95	14211-06	09:15	297.2	—		
MBW	08MAR95	14212-16	11:30	124.8	—		
MBW	08MAR95	14211-11	11:45	189.6	—		
MBW	08MAR95	14212-22	14:30	78.8	—		
MBW	08MAR95	14211-18	15:15	187.5	—		
MBW	08MAR95	14211-24	18:15	153.4	—		
MBW	08MAR95	14213-13	18:15	61.8	BDL		
7500bridge	08MAR95	14217-01	03:30	473.1	444.0	8.0	
7500bridge	08MAR95	14217-02	04:00	400.0	377.0	7.7	
7500bridge	08MAR95	14217-03	04:30	Used with GSD Test. Sample ID = 14217CT01			
7500bridge	08MAR95	14217-04	05:00	186.4	267.0	10.3	

SITE	Date	Sample ID	Time	[SS] mg/l	[Gamma] pCi/g	Unc.	Comments
7500bridge	08MAR95	14217-05	05:30	135.0	219.0	14.6	
7500bridge	08MAR95	14217-07	06:30	95.5	190.0	22.1	
7500bridge	08MAR95	14217-09	07:30	80.6	BDL		
7500bridge	08MAR95	14217-12	09:00	66.3	—		
7500bridge	08MAR95	14222-03	10:00	80.1	—		
7500bridge	08MAR95	14217-14	10:30	57.3	—		
7500bridge	08MAR95	14217-17	14:30	42.1	—		
7500bridge	08MAR95	14222-17	17:00	24.9	—		
WOCE	08MAR95	14220-01	05:00	43.4	BDL		
WOCE	08MAR95	14220-02	05:30	40.9	BDL		
WOCE	08MAR95	14220-05	07:00	37.0	615.0	21.4	
WOCE	08MAR95	14220-08	08:30	42.6	606.0	19.7	
WOCE	08MAR95	14220-10	09:30	48.1	—		
WOCE	08MAR95	14221-05	10:30	46.4	521.0	19.1	
WOCE	08MAR95	14220-12	10:30	Consolidated for G.S.D. Test			
WOCE	08MAR95	14220-13	11:00	Composite I.D.# = 14220CT01			
WOCE	08MAR95	14220-14	11:30				
WOCE	08MAR95	14221-07	12:30	76.0	454.0	12.4	
WOCE	08MAR95	14221-08	13:30	81.1	—		
WOCE	08MAR95	14221-09	14:30	81.8	276.0	18.3	
WOCE	08MAR95	14221-10	15:30	82.4	—		
WOCE	08MAR95	14221-11	16:30	77.8	BDL		

GRAIN SIZE DISTRIBUTION AND CORRESPONDING FLOW RESULTS FROM STORM SAMPLING TASK

Storm ID Date	Sample ID #	Location	Day	Collection Time (Range)	Flow (cfs)	%Sand >63 um	%Coarse Silt 16-63 um	%Fine Silt 4-16 um	% Clay <4um	Suspended Sediment (mg/l)	Comments
01DEC91	BW#1	WOCW	01	16:00	168.99	16.00	52.00	31.00	1.00	85.70	
	BW#2	WOCW	01	16:10	168.99	8.00	50.00	37.00	5.00	66.70	
	BW#3	MBW	01	16:42	98.58	19.00	44.00	30.00	7.00	126.00	
	BW#6	WOCW	02	04:55	80.99	7.00	67.00	21.00	5.00	272.00	
	BW#7	WOD	02	15:25	290.88	4.00	7.00	76.00	12.00	15.00	
01JUL92	BW#1	7500 Brdg	01	20:13-20:38	~ 155	84.00	11.50	3.50	1.00	734.00	Flow under investigation
	BW#2	WOC	01	20:42	142.00	32.00	53.00	9.00	6.00	650.00	Unreliable Results
	BW#3	MBW d/s	01	20:30-21:00	37.00	10.00	70.00	13.00	7.00	1381.00	"
	BW#4	MBW	01	20:30-21:00	40.50	21.50	54.50	13.00	11.00	1432.00	"
05SEP92	14051-A	Wag4/ms1	05	15:30	unknown	7.00	66.00	22.00	5.00	417.00	
	14051-B	Wag4/ms1	05	16.00	unknown	1.00	57.00	34.00	8.00	221.00	
23MAR93	14066-25	WOCE	23	16:35-17:20	Stage Only	2.50	28.50	51.50	18.50	40.00	Tot sed = .2149g (low)
	14099-26	WOD	23	21:30-23:30	202.54	0.50	23.50	56.50	19.50	140.00	
	5251-25	WOD	23	16:30-17:10	421.24	1.50	9.50	60.50	28.50	139.70	
	14083-25	MBW	23	14:00-14:15	116.29	35.50	39.00	19.50	6.00	966.00	
	14083-26	MBW	23	15:00-15:15	147.87	16.00	45.00	27.00	12.00	628.00	
	5200-25	MBW	23	15:13-15:18	711.00	17.50	28.60	34.10	19.80	652.80	1st Vol off by 77ml
	14103-26	WOCW	23	14:45-15:15	421.28	14.80	52.70	23.70	8.80	433.00	
	5130-25	WOCW	23	15:00-15:07	474.96	3.30	46.30	33.20	17.20	433.00	
	14106-25	WOCW	23	14:15-15:15	431.38	26.00	49.70	15.50	8.80	675.00	
	14102-25	WOCW	23	14:30-15:00	464.26	5.10	55.20	28.50	11.20	409.00	
	14123-25	7500a	23	14:30-15:00	340.96	12.00	52.20	25.90	9.90	445.00	
	5050-25	7500	23	14:41-14:51	316.96	9.40	32.60	40.20	17.80	406.70	Tot sed=.4128 (17%low)
	14085-25	Wag4/ms1	23	13:45-14:00	235.10	51.00	38.00	7.20	3.80	1514.00	
	14085-26	Wag4/ms1	23	14:15-14:30	174.62	48.50	26.00	17.50	8.00	1797.00	Tot sed=3.52 (high?)
	5080-81-82-25	Wag4/ms1	23	14:25-14:33	163.65	13.50	47.40	30.10	9.00	332.40	Tot sed=.3877(22% low)
	14100-25	NWT	23	13:45-14:00	85.39	43.50	37.70	15.00	3.80	344.00	
	14100-26	NWT	23	15.00-15:45	50.20	9.20	52.90	25.30	12.60	195.00	
04DEC93	14126-25	WAG4-MS1	04	10:55-11:05	0.94	42.50	38.30	11.70	7.50	773.28	flow under investigation
	14118-25	WOCW	04	18:30-20:00	216.93	17.90	40.50	35.90	5.70	49.47	
	14118-26	WOCW	04	11:00-11:30	229.95	13.40	19.20	50.20	17.20	351.71	
	14119-25	WOCW	04	11:15-11:30	238.21	32.30	40.50	20.20	7.00	470.71	
	14122-25	MBW	04	10:45-11:15	98.23	23.50	50.50	16.00	10.10	1157.15	
	14078-25	WOD	04	14:15-14:45	82.66	3.30	31.60	48.90	16.20	81.75	
	14112-25	WOD	04	14:15-15:15	83.67	2.80	28.20	55.40	13.60	80.38	
	14110-25	WOCE	04	17:45-19:30	Stage Only	3.90	24.90	52.20	19.00	78.44	
	14105-25	MBW	04	10:34-11:14	92.18	34.50	52.10	8.20	5.10	800.00	
10FEB94	14164CT01	WOCW	10	20:45-21:45	85.70	7.07	32.31	27.48	33.14	555.93	
	14159CT01	WOCE	11	1:15-3:15	Stage Only	1.26	8.65	30.47	59.62	205.62	
	14158CT01	WOCE	11	1:45-2:45	Stage Only	1.70	7.64	34.57	56.10	227.39	
	14149CT01	WOD	9	14:45-16:45	107.64	1.53	2.55	21.40	74.52	91.03	
	14163CT01	7500 Brdg	11	1:45-3:45	283.77	8.96	25.64	33.89	31.51	153.36	
	14151CT01	WOCW	10	22:15-22:45	79.96	25.39	39.40	14.21	21.01	1378.28	
	14161CT01	NWT	10	20:00-21:00	71.18	13.38	36.83	21.78	28.00	918.84	
	14155CT01	MBW	10	20:15-21:15	137.06	14.77	39.00	22.22	24.01	689.56	
	14148CT01	WOD	9	14:30-16:00	109.01	1.36	2.08	27.17	69.39	74.88	
	5257-58CT01	WOD	11	10:48-10:57	75.37	2.72	7.94	21.91	67.42	55.24	
	14160CT01	ROC	10	21:30-22:30	164.93	35.40	23.71	22.97	17.92	572.60	
	144147CT01	WOCE	9	21:00-24:00	Stage Only	2.84	4.62	20.11	72.44	51.77	
	14175CT01	MBW	10	19:45-20:45	110.12	31.01	39.36	14.71	14.92	1748.32	
	14157CT01	WAG4-MS1	10	20:35-22:30	152.63	28.50	37.40	17.27	16.83	1167.80	
23FEB94	14178CT01	WOD	23	12:00-14:30	365.00	1.22	6.64	20.12	72.02	102.17	
	14177CT01	WOCE	23	10:00-12:30	Stage Only	1.02	4.70	17.70	76.58	73.06	
27MAR94	5260-61CT01	WOD	27	18:15-18:30	513.00	0.60	4.78	21.23	73.38	83.64	
	5203-04CT01	MBW	27	17:03-17:15	114.89	14.79	28.27	20.79	36.15	132.63	
	5137-38CT01	WOCW	27	16:33-16:53	350.31	4.04	14.72	27.82	53.42	101.81	
	14179CT01	ROC	27	6:30-7:00	235.92	9.54	20.17	36.13	34.16	515.06	
	14180CT01	WAG4-MS1	27	6:05	96.43	21.85	35.17	28.13	14.85	764.94	
	14181CT01	NWT	27	7:15	122.27	18.97	22.47	24.71	33.84	1276.49	
	14195CT01	MBW	27	17:15-17:45	102.60	12.50	26.20	24.22	37.07	122.16	
	14186CT01	WOCW	27	16:15	395.08	5.14	14.79	26.58.	53.48	138.53	
	14189CT01	MBW	27	7:30	180.73	8.30	24.54	28.89	38.26	768.16	
	14185CT01	WOCW	27	7:15-7:45	524.32	5.52	16.66	26.36	51.46	637.96	
	14187CT01	MBW	27	7:30	180.73	14.36	34.09	24.22	27.34	1476.40	
	14190CT01	WOD	27	5:00-6:00	177.80	2.92	5.32	21.42	70.34	27.20	
	14192CT01	WOCE	27	11:45-12:15	204.71	0.27	2.96	19.33	77.44	215.88	
	14183CT01	7500 Brdg	27	20:15-20:45	228.34	9.57	19.70	20.96	49.77	99.45	
	14200CT01	WOD	27	9:45-10:45	643.10	0.61	2.76	19.81	76.81	251.80	
08MAR95	14216CT01	WOCW	08	08:00-10.00	126.90	11.67	8.31	22.22	57.80	87.27	
	14218CT01	WOD	08	11:00-12:00	209.10	0.89	12.65	14.19	72.26	123.26	
	14220CT01	WOCE	08	10:30-11:30	Stage Only	7.31	8.57	21.93	62.18	56.53	
	14212CT01	MBW	08	05:00	74.86	8.22	27.04	26.87	37.86	473.28	
	14217CT01	7500 Brdg	08	04:30	122.39	6.43	19.30	23.31	50.96	278.79	

The Bottom Withdrawal Test (ER/WAG2-SOP-4501) was used on all samples collected from 1991 through 1993.
The Column Test (ER/WAG2-SOP-4503) was used on all samples collected in 1994 and 1995.

Cs-137 GRAIN-SIZE-FRACTION COLUMN TEST RESULTS (page 1 of 2)

14175CT01 AND 14187CT01 TAKEN UPSTREAM FROM MB WEIR POOL

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
MBW	-CL	0.4693	14.9	23	11	9.0
(7500A)	-FS	0.4627	14.7	47	22	18.1
14175CT01	-CS	1.2383	39.4	25	31	25.8
10FEB94	-SA	0.9754	31.0	58	57	47.1
	sum=	3.1457	100.0		120	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
MBW	-CL	0.4441	27.3	49	22	31.3
(7500A)	-FS	0.3934	24.2	42	17	23.8
14187CT01	-CS	0.5538	34.1	28	16	22.3
27MAR94	-SA	0.2333	14.4	67	16	22.5
	sum=	1.6246	100.0		69	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
MBW	-CL	0.4845	24.0	BDL	0	0.0
(7500B)	-FS	0.4485	22.2	BDL	0	0.0
14155CT01	-CS	0.7871	39.0	BDL	0	0.0
10FEB94	-SA	0.2980	14.8	BDL	0	0.0
	sum=	2.0181	100.0			0.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
MBW	-CL	0.0633	36.2	BDL	0	0.0
(7500B)	-FS	0.0364	20.8	BDL	0	0.0
5203-04CT01	-CS	0.0495	28.3	BDL	0	0.0
27MAR94	-SA	0.0259	14.8	BDL	0	0.0
	sum=	0.1751	100.0			0.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
MBW	-CL	0.0993	37.1	BDL	0	0.0
(7500B)	-FS	0.0649	24.2	BDL	0	0.0
14195CT01	-CS	0.0702	26.2	BDL	0	0.0
27MAR94	-SA	0.0335	12.5	BDL	0	0.0
	sum=	0.2679	100.0			0.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
MBW	-CL	0.3105	38.3	BDL	0	0.0
(7500C)	-FS	0.2345	28.9	BDL	0	0.0
14189CT01	-CS	0.1992	24.5	BDL	0	0.0
27MAR94	-SA	0.0674	8.3	BDL	0	0.0
	sum=	0.8116	100.0			0.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
MBW	-CL	0.1340	37.9	24	3	28.1
(7500B)	-FS	0.0951	26.9	22	2	18.3
14212CT01	-CS	0.0957	27.0	20	2	16.7
08MAR95	-SA	0.0291	8.2	145	4	36.9
	sum=	0.3539	100.0		11	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
7500 Bridge	-CL	0.1594	31.5	281	45	34.3
14163CT01	-FS	0.1714	33.9	255	44	33.4
10FEB94	-CS	0.1297	25.6	197	26	19.5
	-SA	0.0453	9.0	368	17	12.8
	sum=	0.5058	100.0		131	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
7500 Bridge	-CL	0.0874	49.3	173	15	52.0
14183CT01	-FS	0.0368	20.7	220	8	27.8
27MAR94	-CS	0.0364	20.5	114	4	14.3
	-SA	0.0168	9.5	102	2	5.9
	sum=	0.1774	100.0		29	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
7500 Bridge	-CL	0.1244	51.0	406	51	49.2
14217CT01	-FS	0.0569	23.3	545	31	30.2
08MAR95	-CS	0.0471	19.3	289	14	13.2
	-SA	0.0157	6.4	486	8	7.4
	sum=	0.2441	100.0		103	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
NWT	-CL	0.6950	28.0	BDL	0	0.0
14161CT01	-FS	0.5405	21.8	BDL	0	0.0
10FEB94	-CS	0.9142	36.8	BDL	0	0.0
	-SA	0.3322	13.4	BDL	0	0.0
	sum=	2.4819	100.0			0.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
NWT	-CL	0.3989	33.8	BDL	0	0.0
14181CT01	-FS	0.2913	24.7	BDL	0	0.0
27MAR94	-CS	0.2649	22.5	BDL	0	0.0
	-SA	0.2236	19.0	BDL	0	0.0
	sum=	1.1787	100.0			0.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WAG4-MS1	-CL	0.5317	16.8	326	173	31.8
14157CT01	-FS	0.5455	17.3	229	125	22.9
10FEB94	-CS	1.1812	37.4	135	159	29.3
	-SA	0.9003	28.5	97	87	16.0
	sum=	3.1587	100.0		545	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WAG4-MS1	-CL	0.1099	14.9	212	23	24.4
14180CT01	-FS	0.2081	28.1	171	36	37.3
27MAR94	-CS	0.2602	35.2	96	25	26.2
	-SA	0.1617	21.8	71	11	12.0
	sum=	0.7399	100.0		95	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
ROC	-CL	0.2560	17.9	BDL	0	0.0
14160CT01	-FS	0.3282	23.0	BDL	0	0.0
10FEB94	-CS	0.3387	23.7	BDL	0	0.0
	-SA	0.5058	35.4	BDL	0	0.0
	sum=	1.4287	100.0			0.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
ROC	-CL	0.2761	34.2		0	0.0
14179CT01	-FS	0.2920	36.1	not	0	0.0
27MAR94	-CS	0.1630	20.2	checked	0	0.0
	-SA	0.0771	9.5		0	0.0
	sum=	0.8082	100.0			0.0

Cs-137 GRAIN-SIZE-FRACTION COLUMN TEST RESULTS (page 1 of 2)

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCE	-CL	0.1632	72.4	1046	171	79.3
14147CT01	-FS	0.0453	20.1	904	41	19.0
10FEB94	-CS	0.0104	4.6	340	4	1.6
	-SA	0.0064	2.8	BDL	0	0.0
	sum=	0.2253	100 0		215	100 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCE	-CL	0.3210	56.1	772	248	62.7
14158CT01	-FS	0.1978	34.6	633	125	31.7
10FEB94	-CS	0.0437	7.6	426	19	4.7
	-SA	0.0097	1.7	340	3	0 8
	sum=	0.5722	100.0		395	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCE	-CL	0.1632	72.4	1618	264	61.0
14159CT01	-FS	0 0453	20.1	3184	144	33.3
10FEB94	-CS	0.0104	4.6	2061	21	5 0
	-SA	0 0064	2.8	509	3	0 8
	sum=	0.2253	100 0		433	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCE	-CL	0.3604	76 6	567	204	77.7
14177CT01	-FS	0.0833	17.7	599	50	19.0
23FEB94	-CS	0.0221	4.7	403	9	3.4
	-SA	0.0048	1.0	BDL	0	0 0
	sum=	0.4706	100.0		263	100 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCE	-CL	0.3449	77.4	490	169	85.0
14192CT01	-FS	0.0861	19.3	316	27	13.7
27MAR94	-CS	0.0132	3.0	209	3	1.4
	-SA	0.0012	0 3	BDL	0	0 0
	sum=	0.4454	100 0		199	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCE	-CL	0.0689	62.2	1112	77	67.1
14220CT01	-FS	0.0243	21.9	1066	26	22.7
08MAR95	-CS	0 0095	8 6	816	8	6.8
	-SA	0 0081	7.3	478	4	3.4
	sum=	0.1108	100.0		114	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.1163	67.4	669	78	73.3
5257-58CT01	-FS	0.0378	21.9	544	21	19.4
10FEB94	-CS	0.0137	7.9	495	7	6.4
	-SA	0.0047	2.7	218	1	1.0
	sum=	0.1725	100 0		106	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.2237	69.4	1007	225	79.2
14148CT01	-FS	0.0876	27.2	652	57	20.1
10FEB94	-CS	0.0067	2.1	161	1	0.4
	-SA	0.0044	1.4	246	1	0.4
	sum=	0 3224	100.0		285	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.2190	74.5	667	146	78.7
14149CT01	-FS	0.0629	21.4	568	36	19 3
10FEB94	-CS	0 0075	2 6	499	4	2.0
	-SA	0.0045	1.5	BDL	0	0.0
	sum=	0.2939	100.0		186	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.4656	72.0	698	325	72.9
14178CT01	-FS	0.1301	20.1	766	100	22.4
23FEB94	-CS	0.0429	6.6	451	19	4.3
	-SA	0.0078	1.2	204	2	0.4
	sum=	0.6465	100.0		446	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.2316	73.4	526	122	76.6
5260-61CT01	-FS	0.0670	21.2	464	31	19.6
27MAR94	-CS	0.0151	4.8	378	6	3.6
	-SA	0.0019	0.6	BDL	0	0 0
	sum=	0.3156	100.0		159	100 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.0555	70.3	709	39	74.7
14190CT01	-FS	0.0169	21.4	787	13	25.3
27MAR94	-CS	0.0042	5.3	BDL	0	0.0
	-SA	0.0023	2.9	BDL	0	0 0
	sum=	0.0789	100.0		53	100 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.3501	76.8	460	161	84.2
14200CT01	-FS	0.0903	19.8	305	28	14.4
27MAR94	-CS	0.0126	2.8	214	3	1.4
	-SA	0.0028	0 6	BDL	0	0.0
	sum=	0.4558	100.0		191	100 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOD	-CL	0.2827	72.3	464	131	69.2
14218CT01	-FS	0.0555	14.2	510	28	14.9
08MAR95	-CS	0.0495	12.7	588	29	15.4
	-SA	0 0035	0.9	281	1	0.5
	sum=	0.3912	100.0		190	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCW	-CL	0.6150	21.0	2435	1498	28.5
(7000A)	-FS	0.4159	14.2	2207	918	17.4
14151CT01	-CS	1.1535	39.4	1506	1737	33.0
10FEB94	-SA	0.7433	25.4	1491	1108	21.1
	sum=	2.9277	100.0		5261	100.0

14151CT01 TAKEN UPSTREAM FROM WOC WEIR POOL

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCW	-CL	0.5452	33.1	1006	548	44.6
(7000B)	-FS	0.4521	27.5	810	366	29.8
14184CT01	-CS	0.5315	32.3	511	272	22.1
10FEB94	-SA	0.1163	7.1	366	43	3.5
	sum=	1.6451	100.0		1229	100.0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCW	-CL	0.1350	53.4	323	44	53.6
(7000B)	-FS	0.0703	27.8	372	26	32.2
5137-38CT01	-CS	0.0372	14.7	235	9	10.7
27MAR94	-SA	0.0102	4.0	286	3	3.6
	sum=	0.2527	100.0		81	100 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCW	-CL	0.0499	53.5	BDL	0	0 0
(7000C)	-FS	0.0249	26 6	BDL	0	0.0
14186CT01	-CS	0.0138	14.8	BDL	0	0 0
27MAR94	-SA	0 0048	5.1	BDL	0	0 0
	sum=	0 0933	100 0			0 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCW	-CL	0.6465	51.5	568	380	64.1
(7000C)	-FS	0.3312	26.4	470	156	26.3
14185CT01	-CS	0.2093	16.7	230	48	8.1
27MAR94	-SA	0.0694	5.5	128	9	1.5
	sum=	1.2564	100.0		593	100 0

name, ID#, and date	class type	weight (g)	% of total weight	Cs-137 (pCi/g)	Cs-137 (pCi)	% of total Cs-137
WOCW	-CL	0.1189	57.8	623	74	55 9
(7000C)	-FS	0.0457	22.2	723	33	24 9
14216CT01	-CS	0.0171	8.3	453	8	5 8
08MAR95	-SA	0.0240	11.7	736	18	13.3
	sum=	0.2057	100.0		133	100.0

MEAN, STANDARD DEVIATION, AND RANGE OF COLUMN TEST GRAIN-SIZE-FRACTION AND Cs-137 PERCENTAGE RESULTS

WOE	mean grain size %	STD (n-1)	min %	max %
CL	69.5	8.5	61.0	78.1
FS	22.3	6.2	16.1	28.5
CS	5.5	2.1	3.4	7.6
SA	2.7	2.5	0.2	5.2
sum	100.0			

WOE	mean % Cs-137	STD (n-1)	min % Cs-137	max % Cs-137
CL	72.1	9.8	62.3	82.0
FS	23.2	7.8	15.5	31.0
CS	3.8	2.1	1.7	5.9
SA	0.8	1.3	-0.5	2.1
sum	100.0			

WOD	mean grain size %	STD (n-1)	min %	max %
CL	72.0	3.0	69.0	75.0
FS	20.9	3.5	17.4	24.4
CS	5.6	3.5	2.1	9.1
SA	1.5	0.9	0.6	2.4
sum	100.0			

WOD	mean % Cs-137	STD (n-1)	min % Cs-137	max % Cs-137
CL	76.1	4.6	71.5	80.8
FS	19.4	3.6	15.8	23.0
CS	4.2	5.0	-0.8	9.2
SA	0.3	0.3	-0.1	0.6
sum	100.0			

WOCW downstream	mean grain size %	STD (n-1)	min %	max %
CL	49.9	9.6	40.2	59.5
FS	26.1	2.3	23.8	28.3
CS	17.4	8.9	8.4	26.3
SA	6.7	3.0	3.7	9.7
sum	100.0			

WOCW downstream	mean* % Cs-137	STD (n-1)	min % Cs-137	max % Cs-137
CL	54.6	8.0	46.6	62.6
FS	28.3	3.3	25.0	31.6
CS	11.7	7.2	4.5	18.9
SA	5.5	5.3	0.1	10.8
sum	100.0			

* does not include 14186CT01 due to insufficient gamma data.

MBW downstream	mean grain size %	STD (n-1)	min %	max %
CL	34.7	6.0	28.7	40.7
FS	24.6	3.3	21.3	27.9
CS	29.0	5.7	23.3	34.8
SA	11.7	3.3	8.4	15.0
sum	100.0			

Downstream MBW gamma not calculated due to insufficient results.

GS3	mean grain size %	STD (n-1)	min %	max %
CL	43.9	10.8	33.1	54.7
FS	26.0	7.0	19.0	32.9
CS	21.8	3.4	18.5	25.2
SA	8.3	1.6	6.7	9.9
sum	100.0			

GS3	mean % Cs-137	STD (n-1)	min % Cs-137	max % Cs-137
CL	45.1	9.5	35.6	54.7
FS	30.5	2.8	27.7	33.3
CS	15.7	3.4	12.3	19.1
SA	8.7	3.6	5.1	12.3
sum	100.0			

NWT	mean grain size %	STD (n-1)	min %	max %
CL	30.9	4.1	26.8	35.1
FS	23.2	2.1	21.2	25.3
CS	29.7	10.2	19.5	39.8
SA	16.2	3.9	12.2	20.1
sum	100.0			

WAG4-MS1	mean grain size %	STD (n-1)	min %	max %
CL	15.8	1.4	14.4	17.2
FS	22.7	7.7	15.0	30.4
CS	36.3	1.6	34.7	37.9
SA	25.2	4.7	20.5	29.9
sum	100.0			

WAG4-MS1	mean % Cs-137	STD (n-1)	min % Cs-137	max % Cs-137
CL	28.1	5.2	22.9	33.3
FS	30.1	10.2	19.9	40.3
CS	27.7	2.2	25.6	29.9
SA	14.0	2.8	11.2	16.8
sum	100.0			

ROC	mean grain size %	STD (n-1)	min %	max %
CL	26.0	11.5	14.6	37.5
FS	29.6	9.3	20.2	38.9
CS	21.9	2.5	19.4	24.4
SA	22.5	18.3	4.2	40.8
sum	100.0			

Appendix B:

TIME SERIES FILES

Table B.1. Summary of Time Series Data Used for Input and Calibration of HSPF Model

DATA TYPE	ACTUAL DATES	COMMENTS
EVAPORATION	01JAN90 - 31DEC91	Pan Evaporation daily totals in 100th inch measurements. HSPF - TEHM format file developed by Tom Fontaine. Values from Knoxville NOAA station.
EVAPORATION	01AUG48 - 30JUN94	Estimated Pan Evaporation daily totals in 100th inch measurements. Developed by Bechtel using the HELP model (see Readme file on disk for more details).
WATER TEMPERATURE	23DEC92 - 04JAN94	Hourly WOC Celsius data from BMAP (6-3454).
PRECIP	01JAN90 - 31DEC93	1ST Creek raingage hourly totals saved in HSPF TEHM format (values in 100th of inch measurements). Data from Surface Water Monitoring Group (4-5991).
PRECIP	01JAN90 - 31DEC91	Flat File hourly precipitation totals for the 1ST, RG1, RG3, BUR, ISH, SW4, SW7, 49T, and ETF raingages.
PRECIP	01JAN53 - 31MAR94	Hourly totals from Oak Ridge NOAA saved in HSPF TEHM format developed by Bechtel. Values in 100th inch measurements
7500 BRIDGE (USGS 6550) FLOW	01OCT87 - 01JUN94	Observed hourly flow (cfs). Data obtained from USGS through Linda Allison (6-8449).
WOCW (USGS 7000) FLOW	01OCT89 - 31MAR94	Observed hourly flow (cfs). Note: missing flow data from 16JAN90 - 30JAN90 and 31OCT90 - 02NOV90. Data from Surface Water Monitoring Group (4-5991).
MBW (USGS 7500) FLOW	01OCT89 - 31MAR94	Observed hourly flow (cfs). Data from Surface Water Monitoring Group (4-5991).
WOD (USGS 8000) FLOW	01OCT89 - 31MAR94	Observed hourly flow (cfs). Data from Surface Water Monitoring Group (4-5991).

Table B.1 (continued)

7500 Bridge (USGS 6550) STORM SAMPLING RESULTS	23MAR93+*, 10FEB94+, 27MAR94+, and 08MAR95+	Average flow and laboratory results of Suspended Sediment (mg/L) and Cs-137 (pCi/g) downstream from 7500 bridge weir for the storms listed. Storms sampled and processed by Sediment Transport Task (6-1408).
WOCW (USGS 7000) STORM SAMPLING RESULTS	23MAR93+, 04DEC93+, 10FEB94+, 27MAR94+, and 08MAR95+	Average flow and laboratory results of Suspended Sediment (mg/L) and Cs-137 (pCi/g) downstream and/or upstream from WOCW for the storms listed. Storms sampled and processed by Sediment Transport Task (6-1408).
MBW (USGS 7500) STORM SAMPLING RESULTS	23MAR93+, 04DEC93+, 10FEB94+, 27MAR94+, and 08MAR95+	Average flow and laboratory results of Suspended Sediment (mg/L) and Cs-137 (pCi/g) downstream and/or upstream from WOCW for the storms listed. Storms sampled and processed by Sediment Transport Task (6-1408).
WOD (USGS 8000) STORM SAMPLING RESULTS	23MAR93+, 04DEC93+, 10FEB94+, 27MAR94+, and 08MAR95+	Average flow and laboratory results of Suspended Sediment (mg/L) and Cs-137 (pCi/g) downstream from White Oak Dam for the storms listed. Storms sampled and processed by Sediment Transport Task (6-1408).
WOCE STORM SAMPLING RESULTS	23MAR93+, 04DEC93+, 10FEB94+, 27MAR94+, and 08MAR95+	Laboratory results of Suspended Sediment (mg/L) and Cs-137 (pCi/g) downstream and/or upstream from WOCW for the storms listed. Storms sampled and processed by Sediment Transport Task (6-1408).

REV.0 (12JUN95).

* = The "+" means the results from these storms can be from a few hours up to a few days following the storm date. Full printout of storm results in Appendix A.

Table B.2. Contents of ANNIE WDM Data File Used for HSPF

DSN	TSTYPE	DATES	COMMENTS
40	EVAP	01JAN90 - 31DEC94	Daily Pan Evaporation data (100th of inch) from Knoxville NOAA site.
41	TEMP	01JAN89 - 31DEC94	Water Temperature from BMAP monitoring.
45	PRCP	01JAN90 - 31DEC93	Hourly Precip totals in 100th of inch measurements from the First Creek raingage (1ST).
51	PRCP	01JAN90 - 31DEC94	Weighted average precipitation data for PLS1 input.
52	PRCP	01JAN90 - 31DEC94	Weighted average precipitation data for PLS2 input.
53	PRCP	01JAN90 - 31DEC94	Weighted average precipitation data for PLS3 input.
54	PRCP	01JAN90 - 31DEC94	Weighted average precipitation data for PLS4 input.
110	FLOW	01JAN90 - 01DEC94	Observed hourly flow (cfs) from 7500 Bridge Weir.
120	FLOW	01OCT89 - 31DEC94	Observed hourly flow (cfs) from White Oak Creek Weir. Note: missing flow data from 16JAN90 - 30JAN90 and 31OCT90 - 02NOV90.
130	FLOW	01OCT89 - 31DEC94	Observed hourly flow (cfs) from Melton Branch Weir.
140	FLOW	01OCT89 - 31DEC94	Observed hourly flow (cfs) from White Oak Dam.
150	FLOW	01JAN90 - 31DEC94	Constant flow of 3.8 cfs used as HSPF input to account for the cooling tower effluent into White Oak Creek.

Where:

DSN = Data Set Number within WDM file

TSTYPE = ANNIE notation for type of file (EVAP = evaporation, TEMP = temperature, and PRCP = precipitation)

REV.1(20DEC94)

Appendix C:

ANALYSIS OF STORMS

Storm 1. 23MAR93

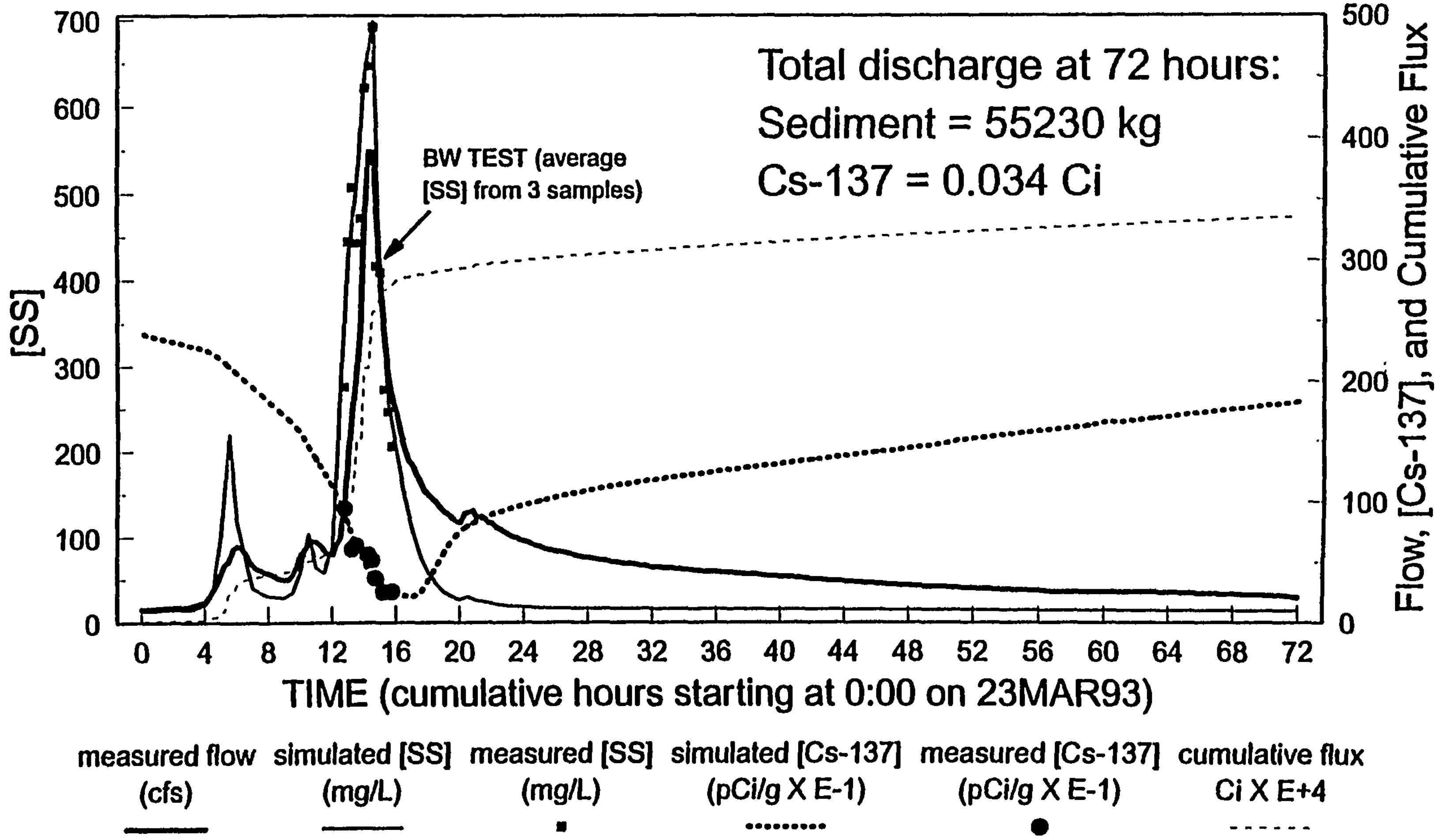

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 23MAR93 storm sampled at 7500 Bridge site (GS3).

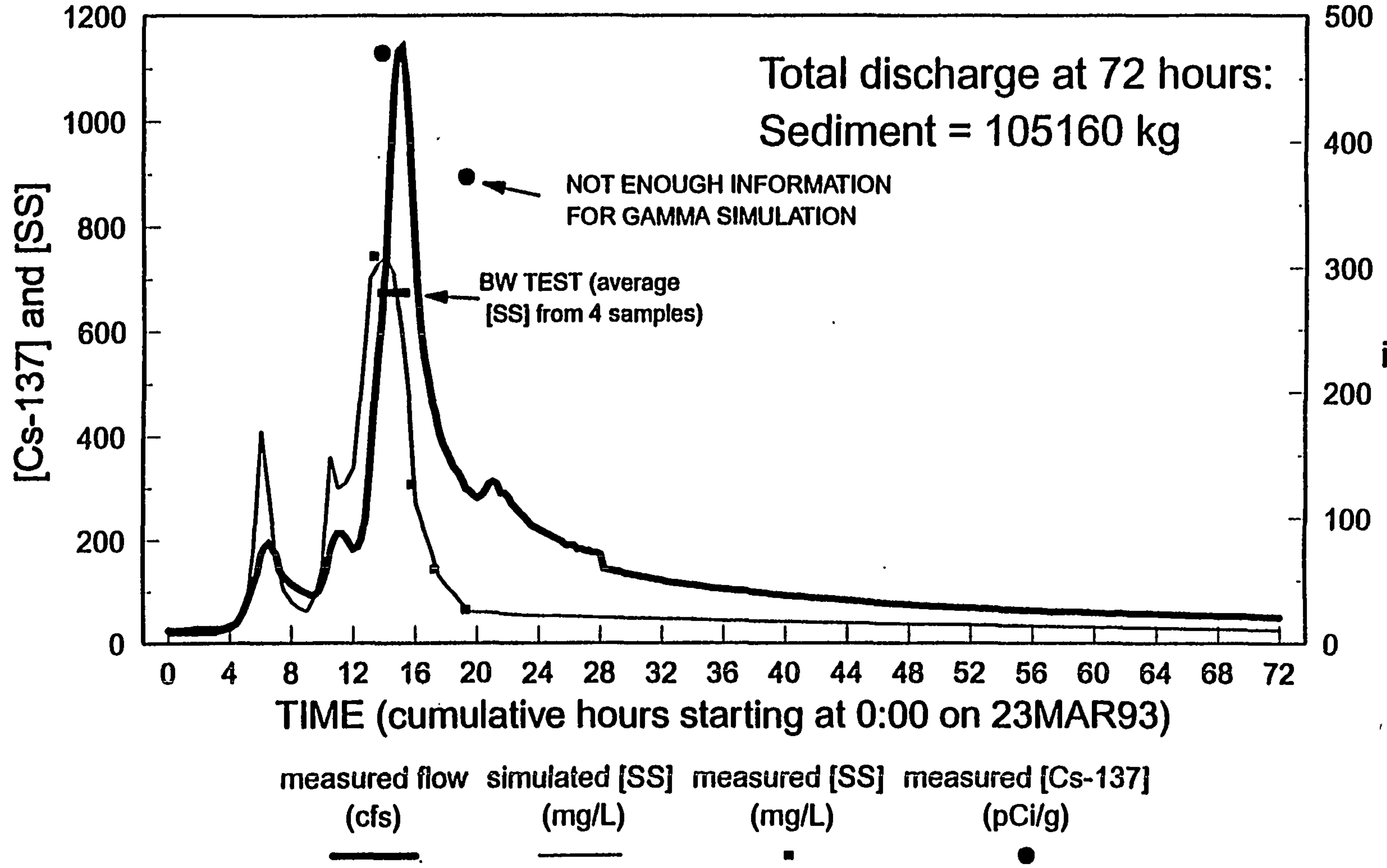

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 23MAR93 storm sampled upstream from the White Oak Creek weir pool (MS3).

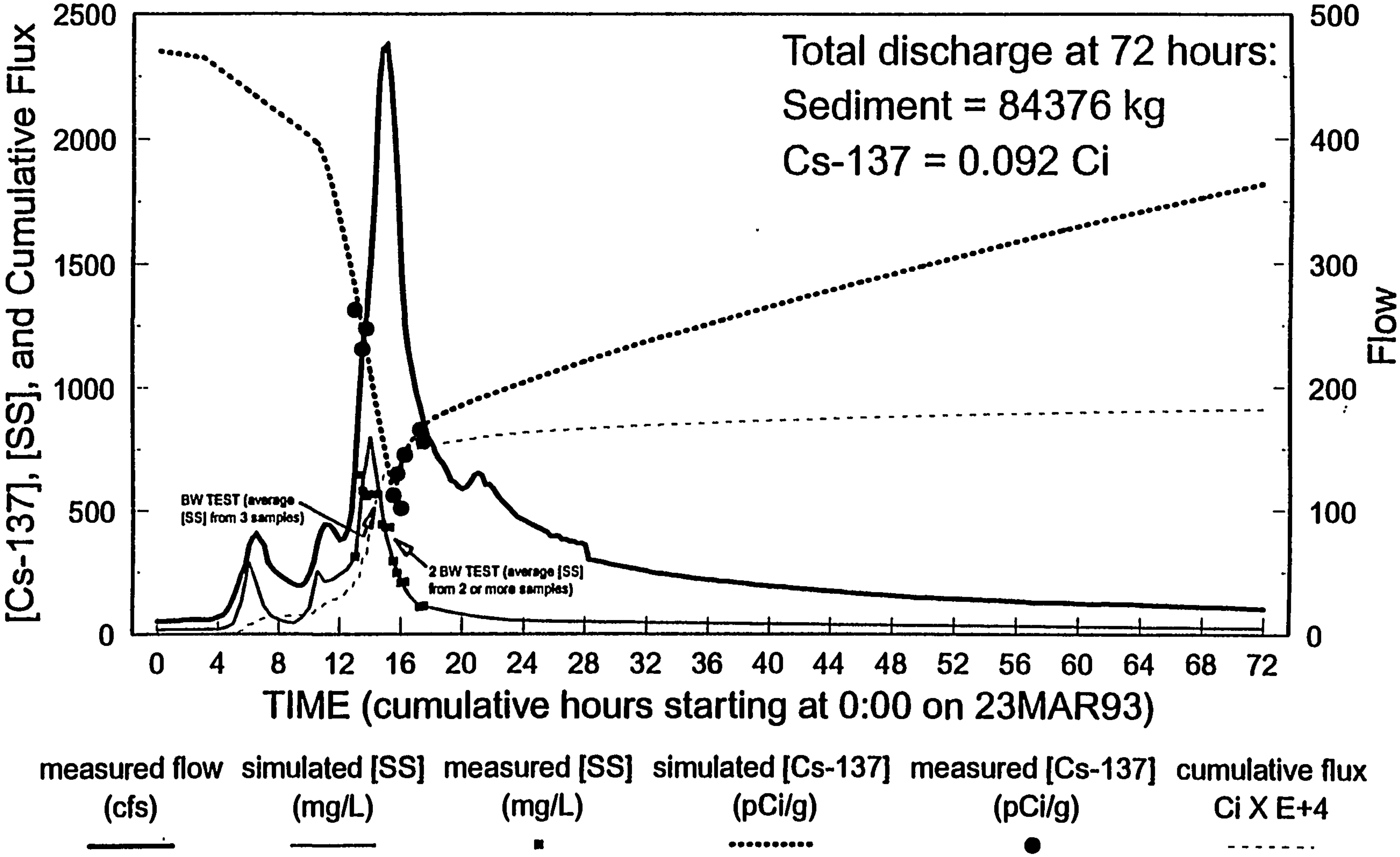

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 23MAR93 storm sampled downstream from the White Oak Creek weir pool (MS3).

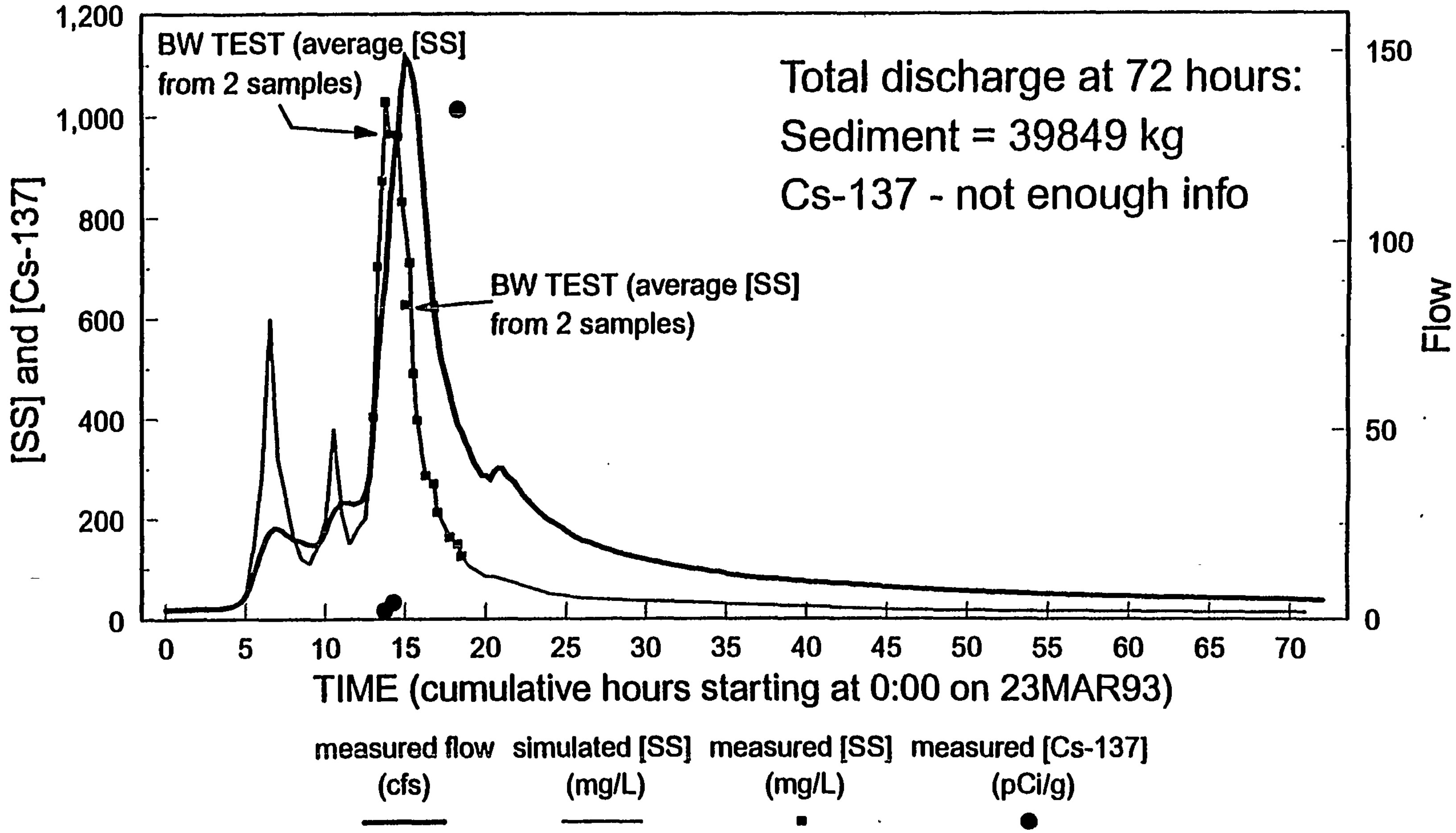

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 23MAR93 storm sampled downstream from the Melton Branch weir pool (MS4).

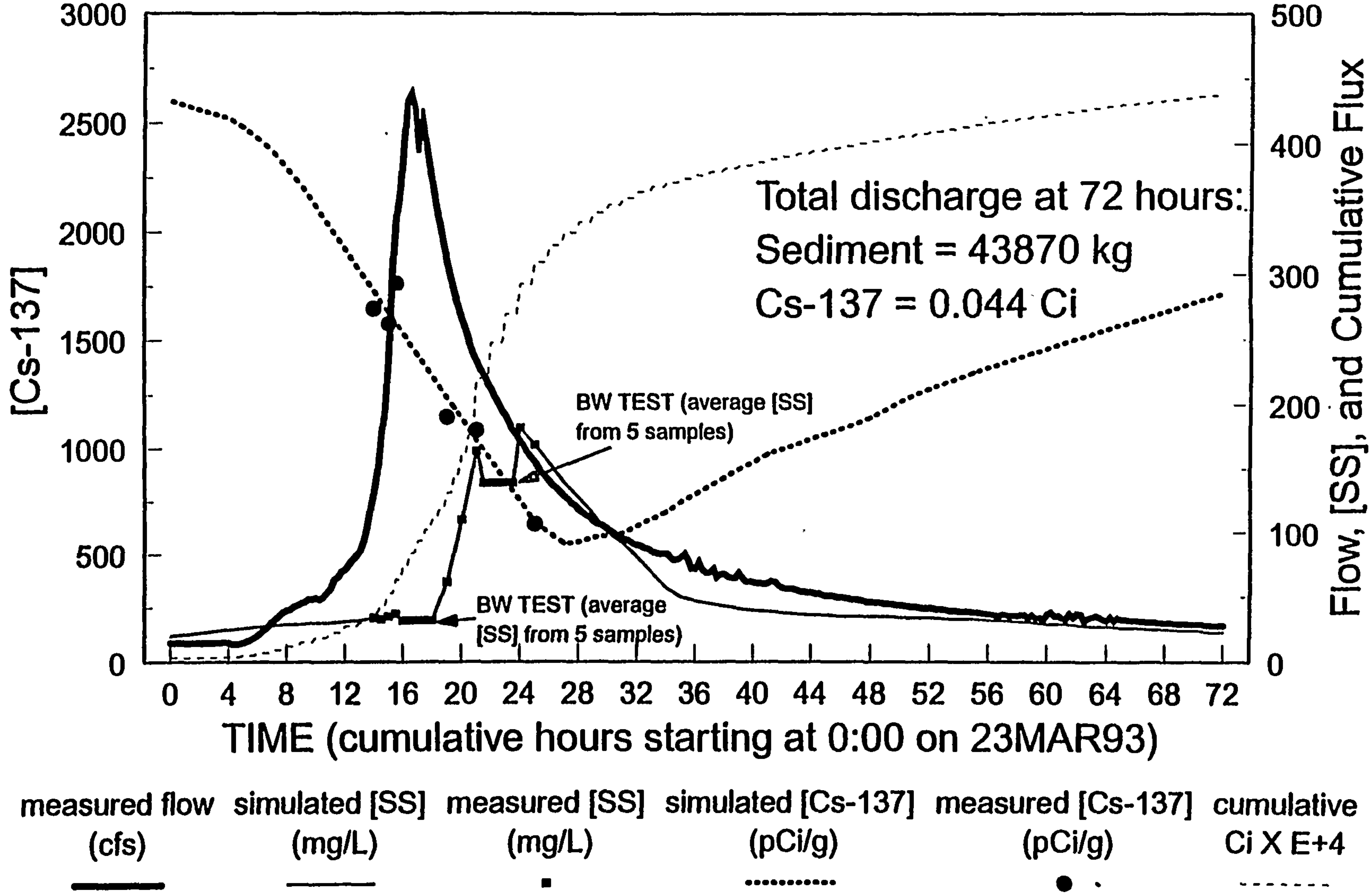

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 23MAR93 storm sampled at White Oak Dam (MS5).

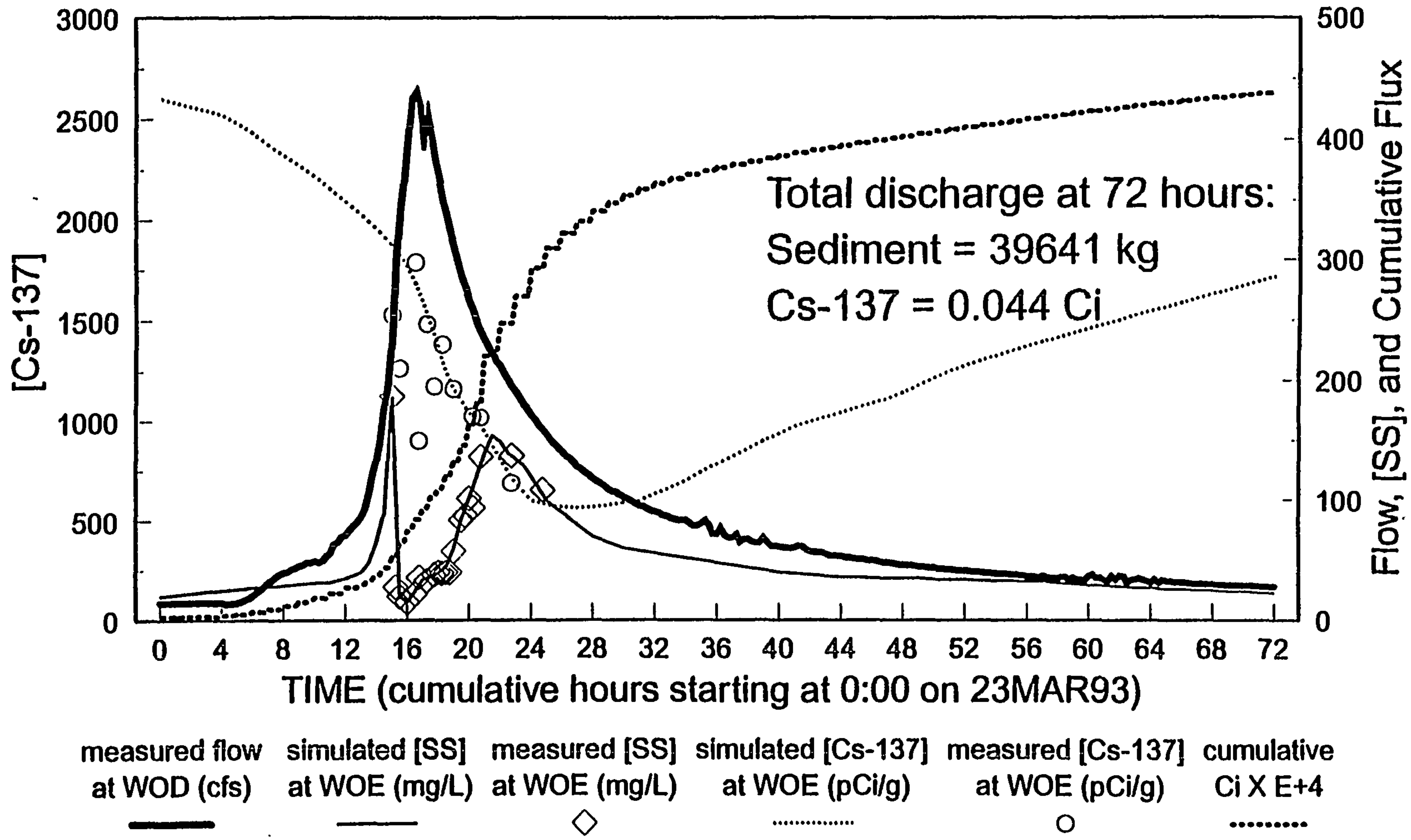

Figure $: Plot used to estimate WOE passing loads for the 23MAR93 storm by using measured flow from WOD (WOE data moved 1.5 hours to provide best comparative fit with WOD data).

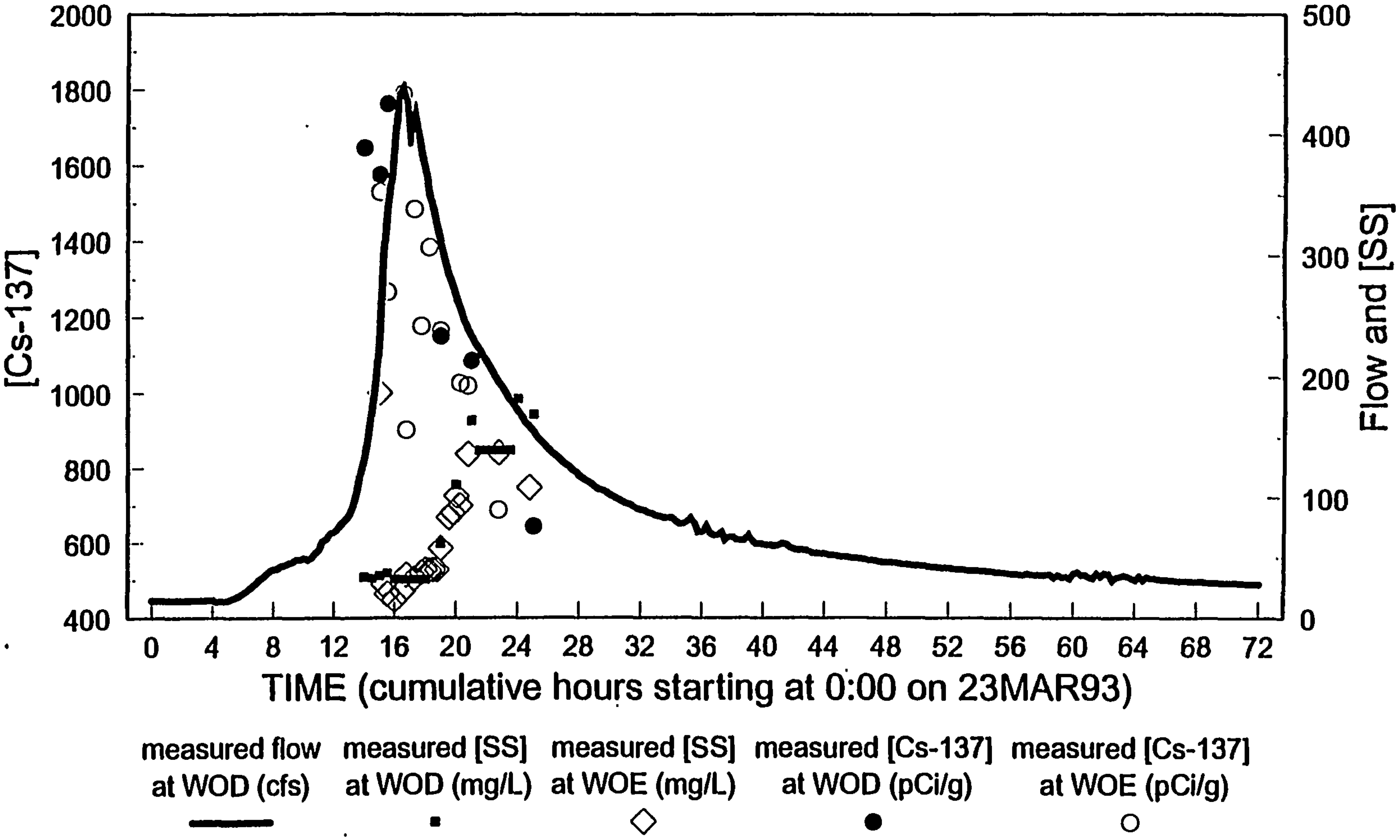

Figure $: Overlay of WOE values onto plot of WOD measured values for the 23MAR93 storm. WOE data moved 1.5 hours for best representation of WOE passing loads (see end of spreadsheet for more details).

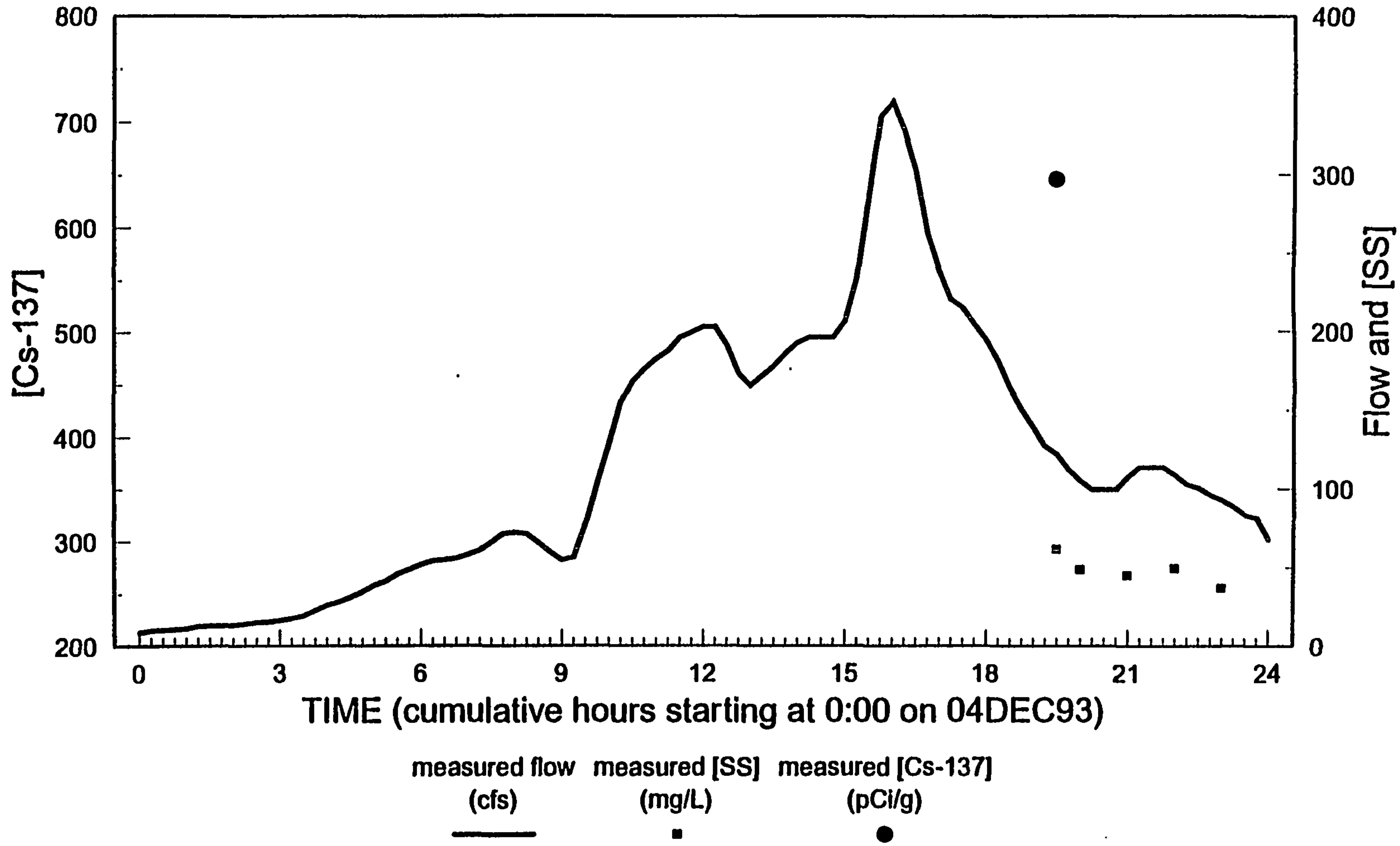

Figure $: Suspended sediment concentration, Cs-137 concentration, and flow for the 04DEC93 storm sampled at the 7500 Bridge site (GS3).

Storm 2. 04DEC93

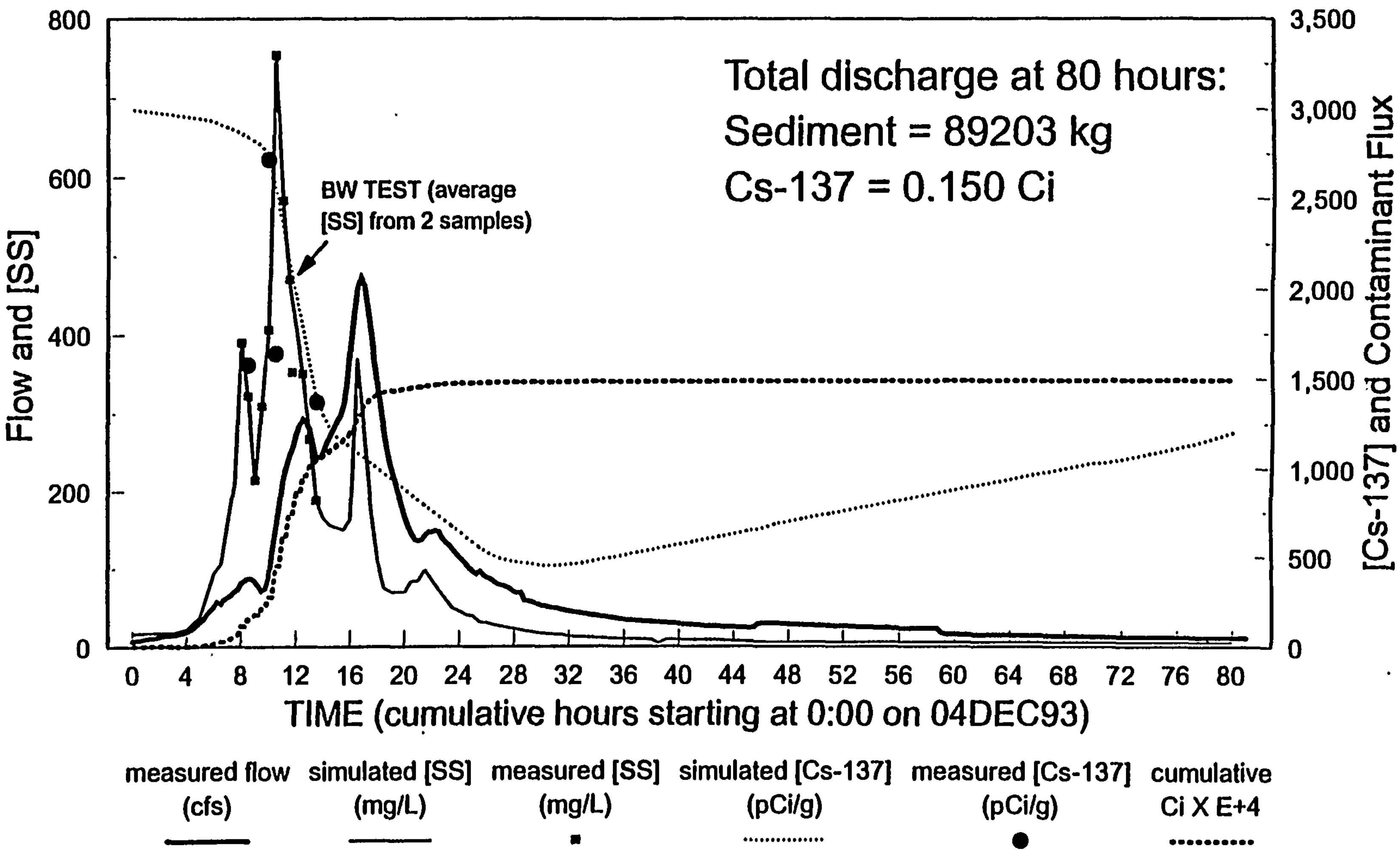

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 04DEC93 storm sampled upstream from the White Oak weir pool (MS3).

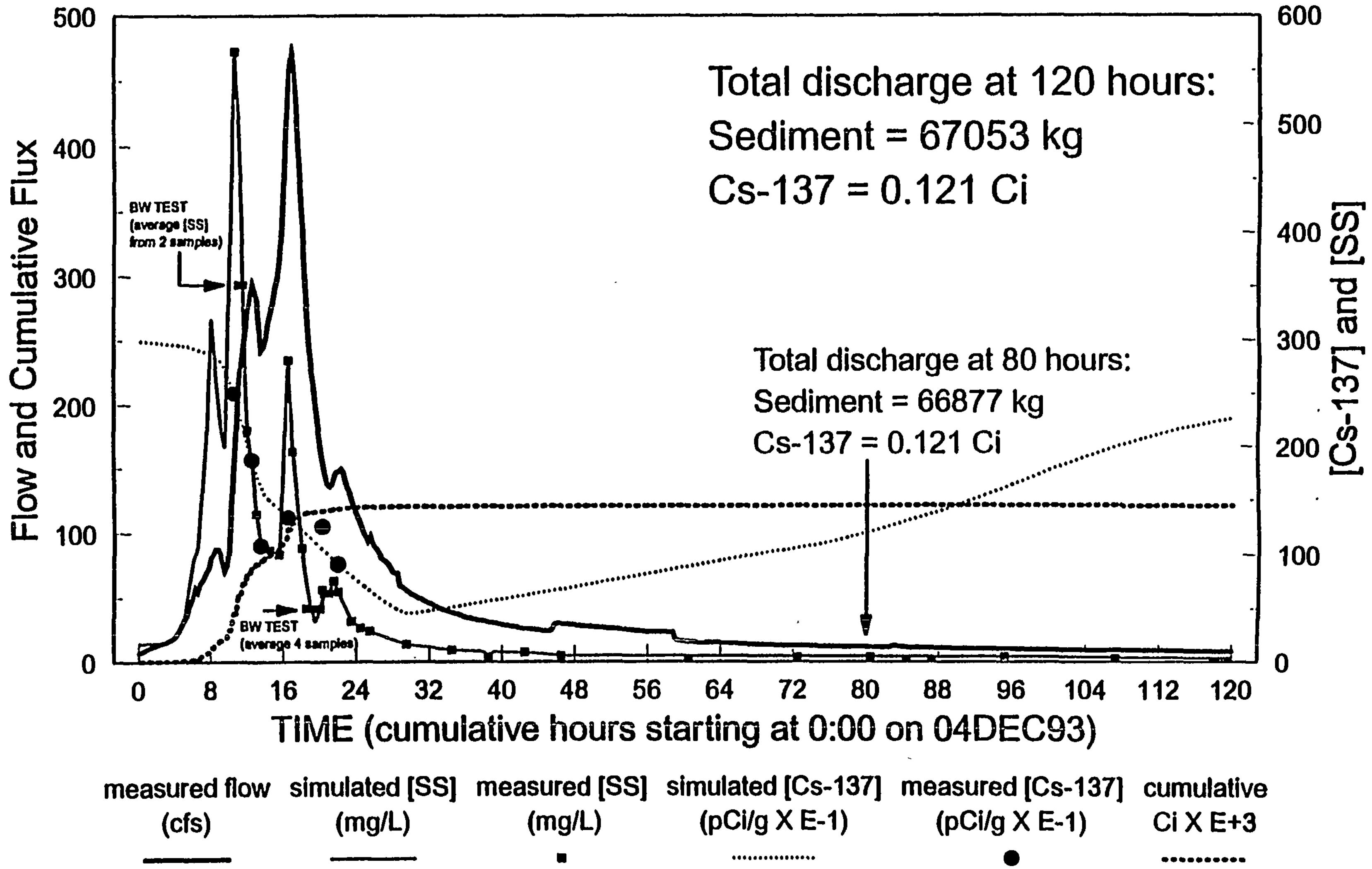

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 04DEC93 storm sampled downstream from the White Oak weir pool (MS3).

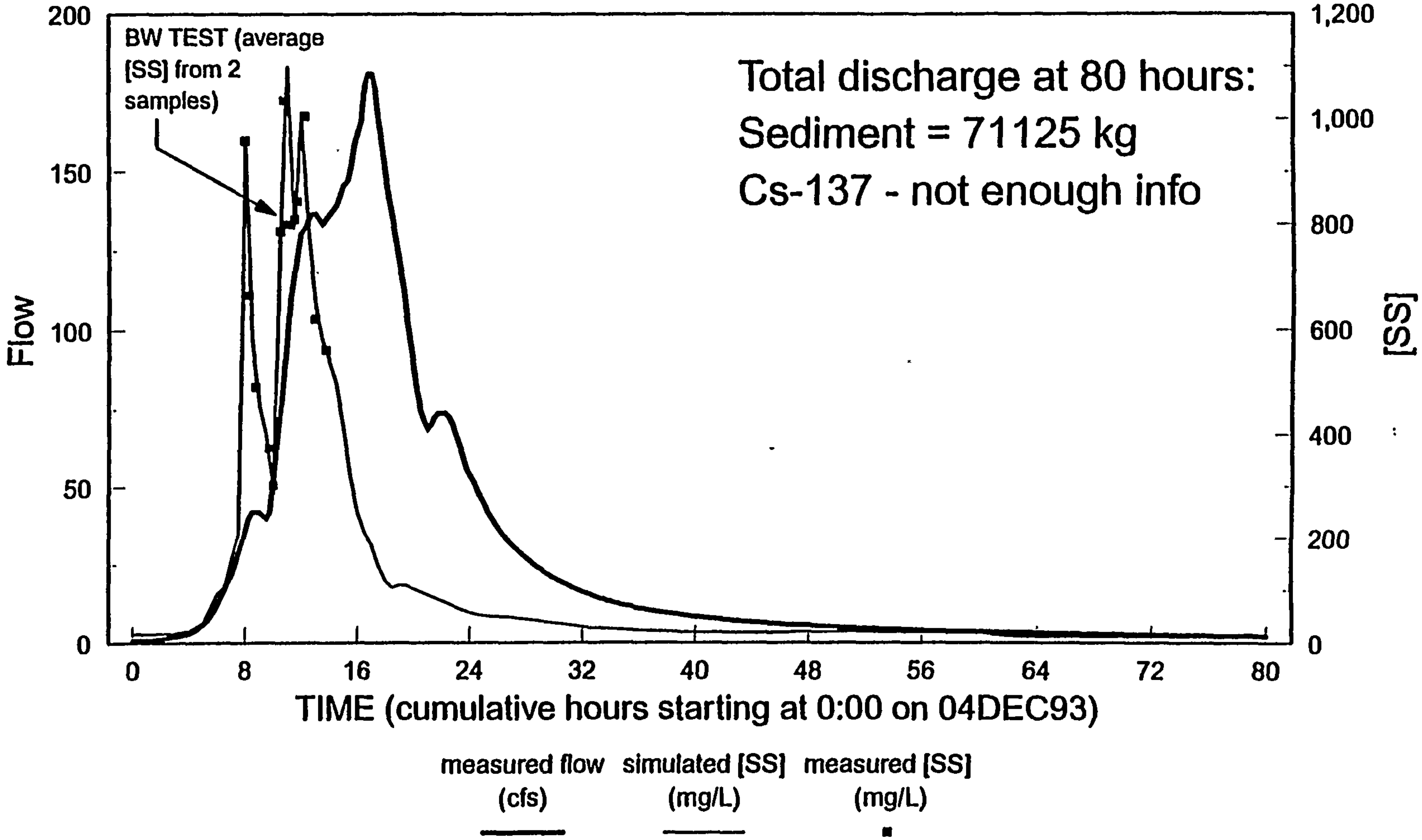

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 04DEC93 storm sampled upstream from the Melton Branch weir pool (MS4).

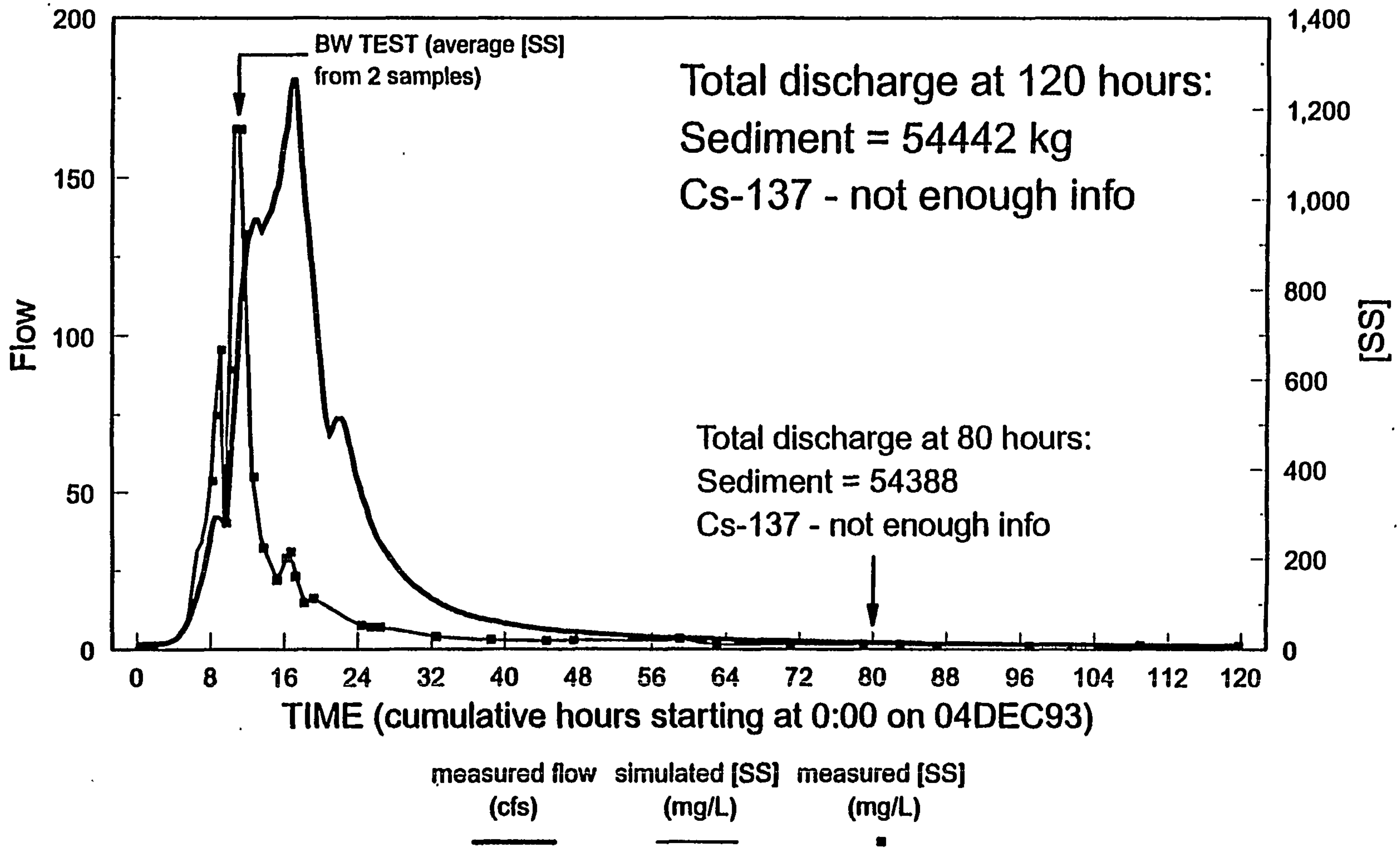

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 04DEC93 storm sampled downstream from the Melton Branch weir pool (MS4).

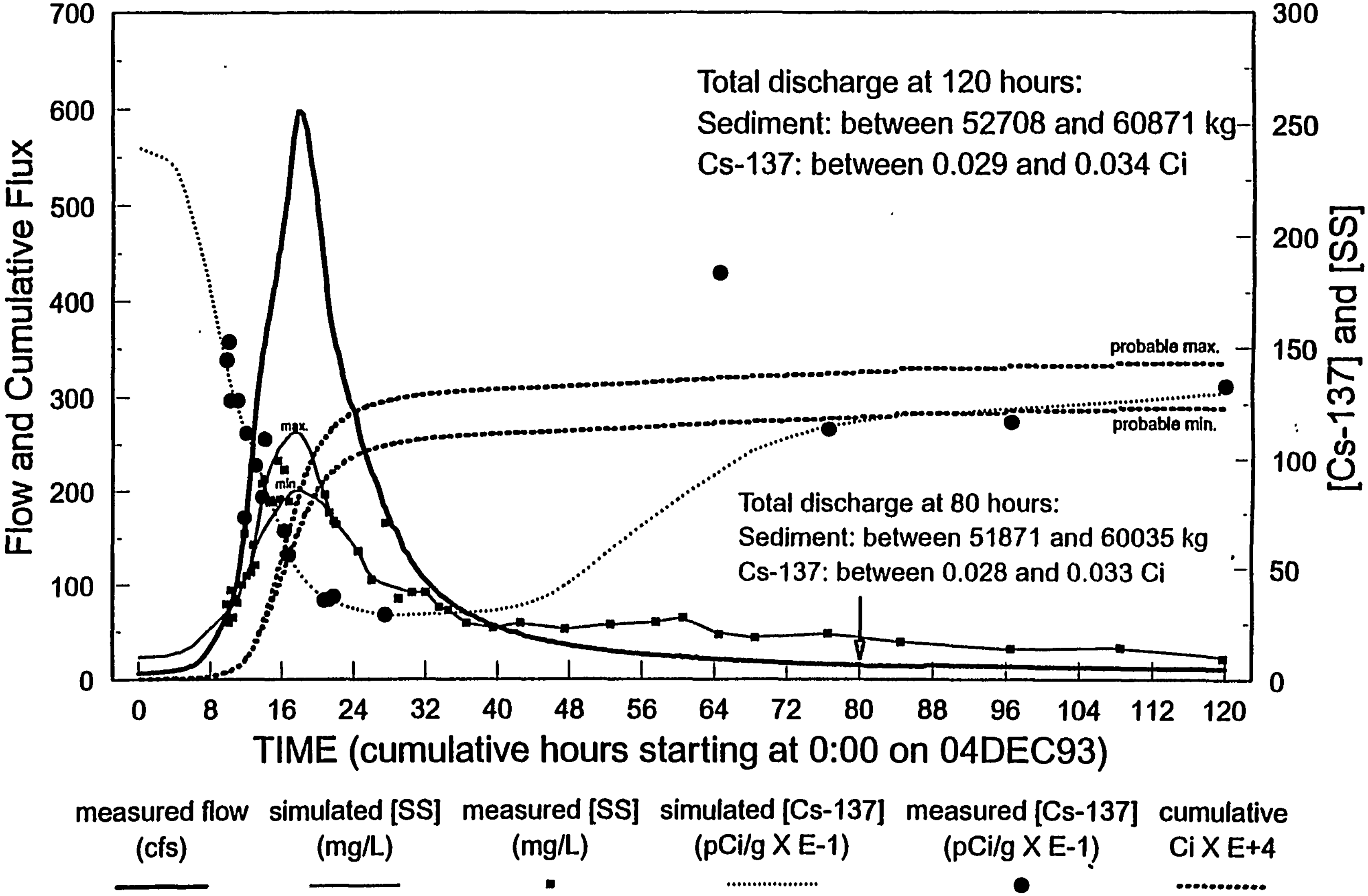

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 04DEC93 storm sampled at White Oak Dam (MS5).

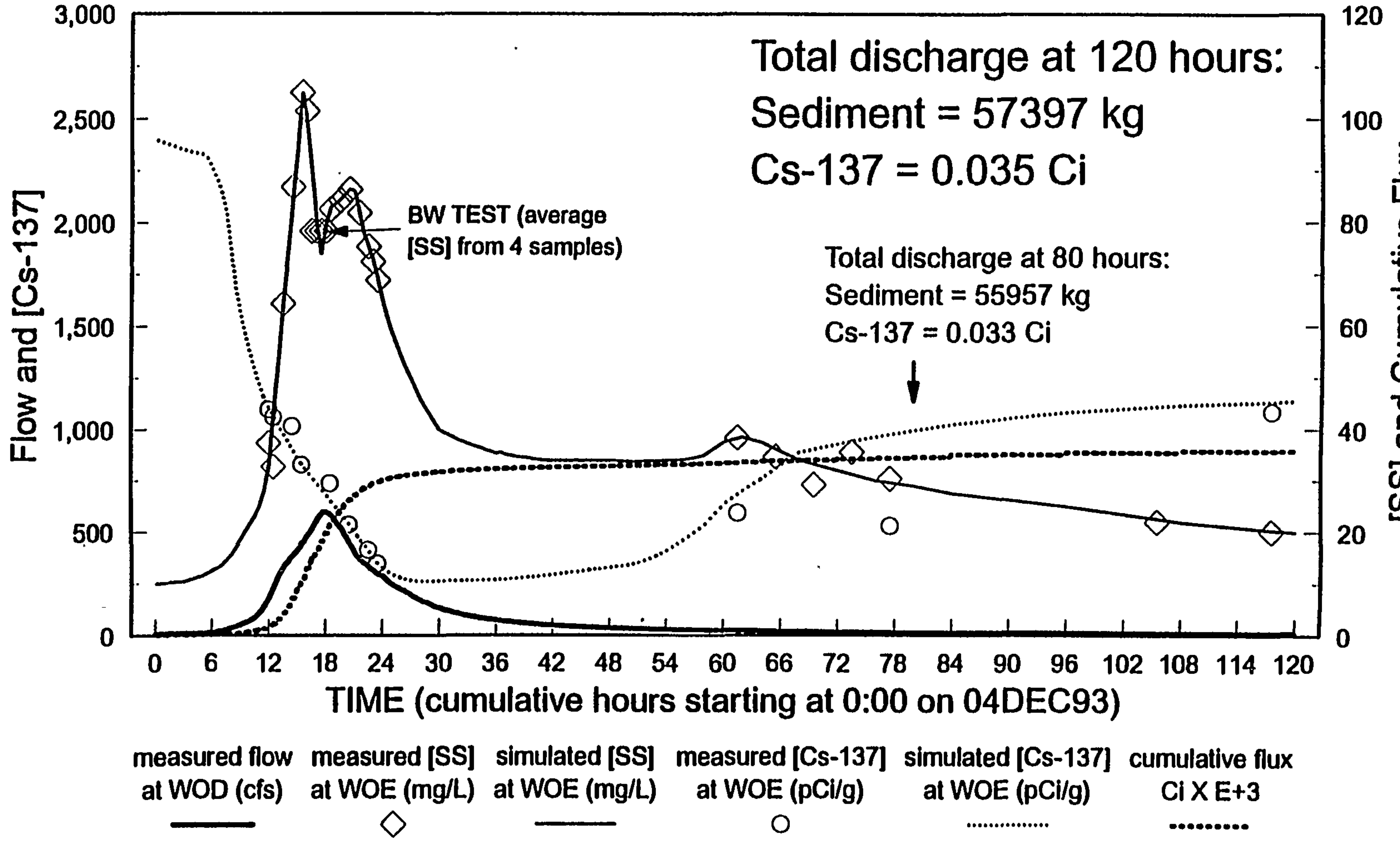

Figure $: Plot used to estimate WOE passing loads for the 04DEC93 storm by using measured flow from WOD (WOE data moved 1.5 hours to provide best comparative fit with WOD data).

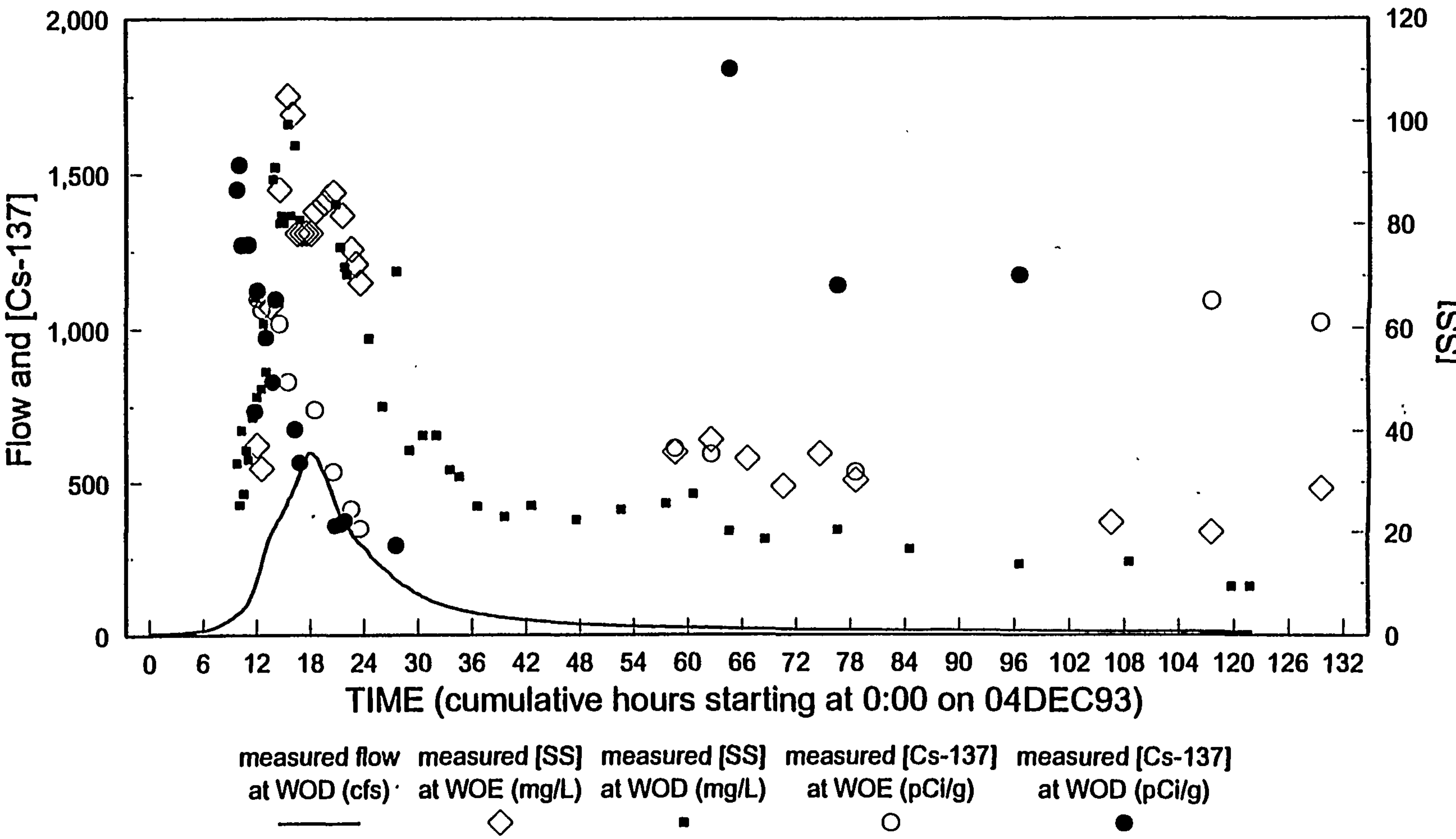

Figure $: Overlay of WOE values onto plot of WOD measured values for the 04DEC93 storm. WOE data moved 1.5 hours for best representation of WOE passing loads (see end of spreadsheet for more details).

Storm 3. 10FEB94

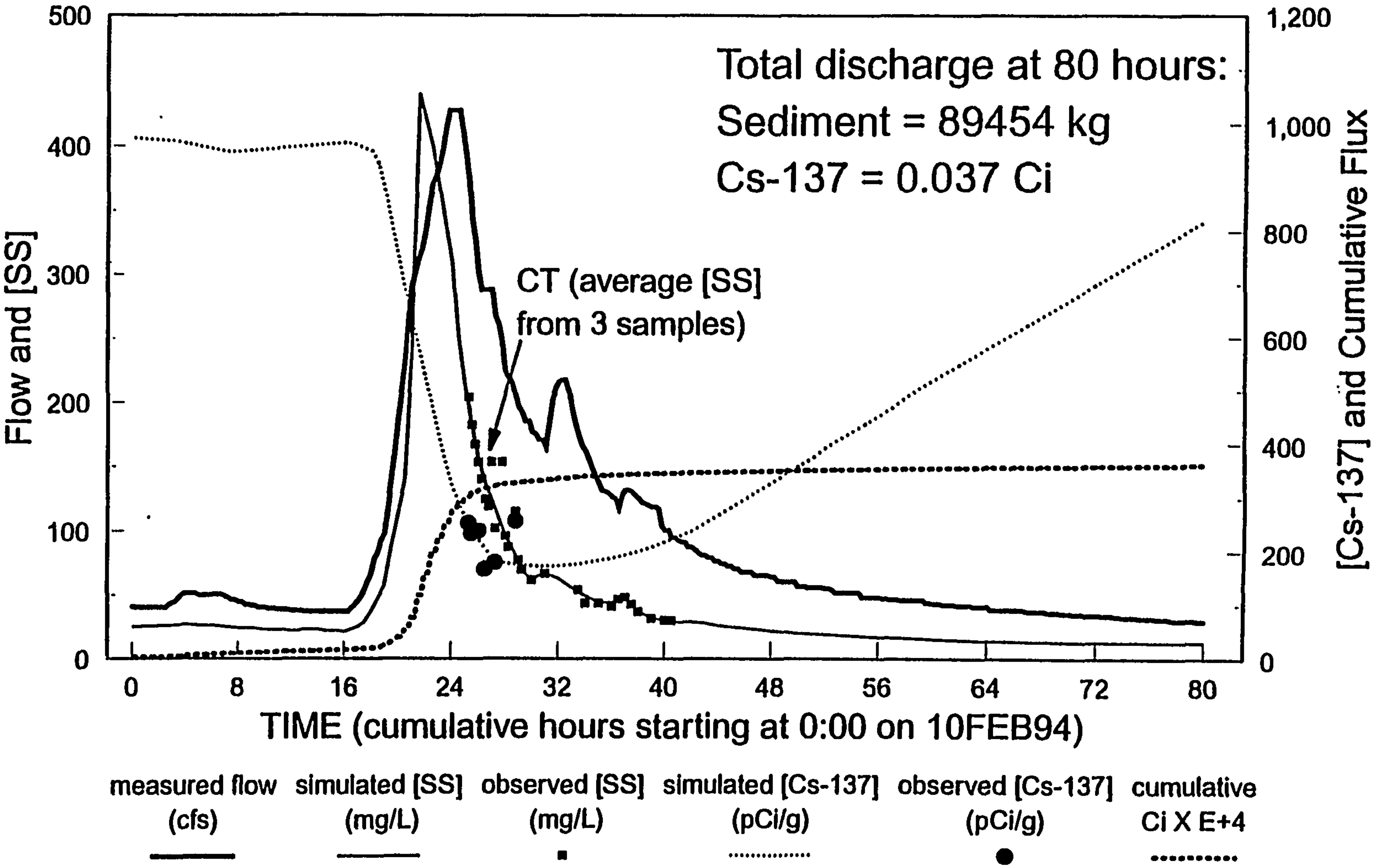

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 10FEB94 storm sampled at the 7500 Bridge site (GS3).

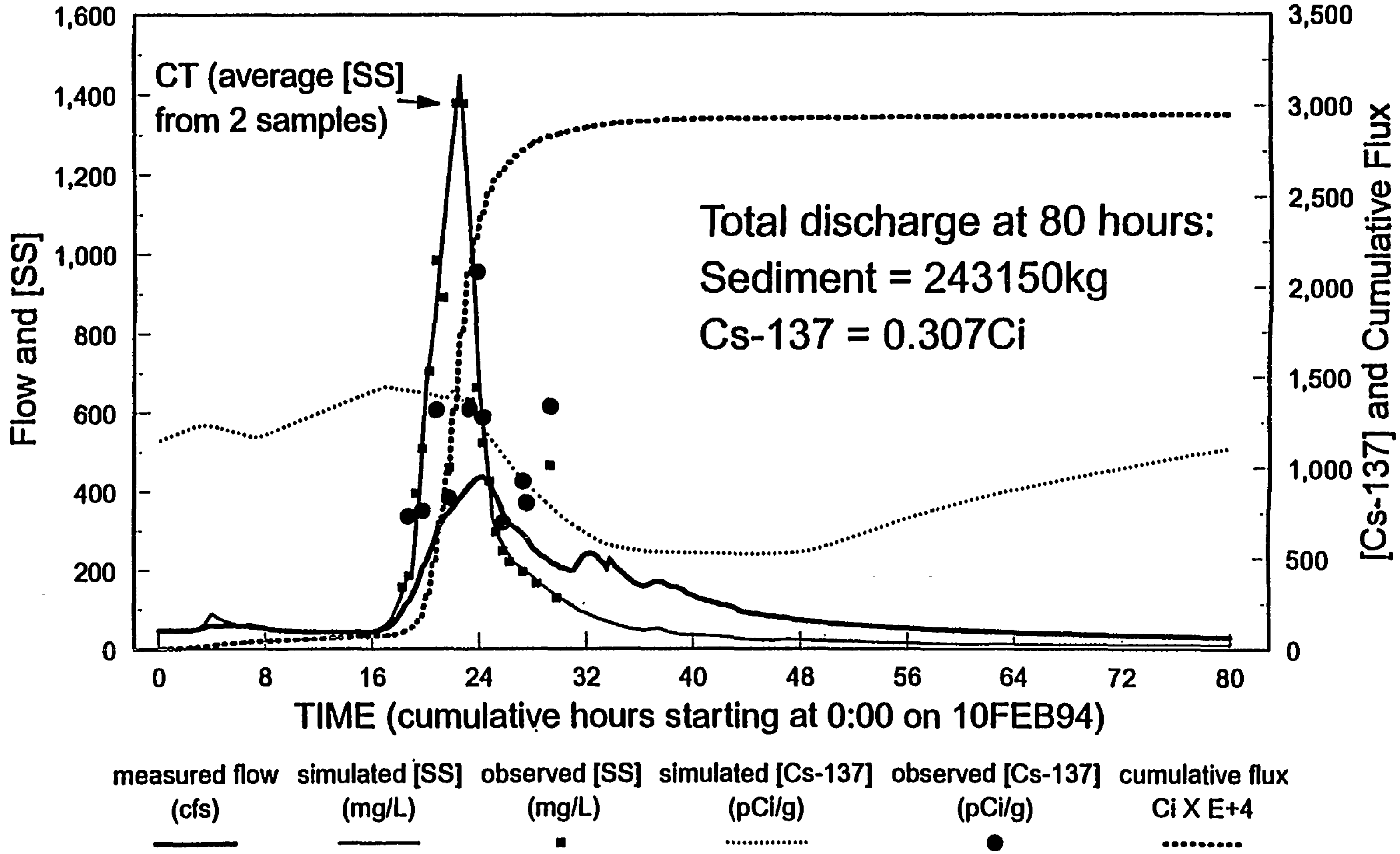

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 10FEB94 storm sampled upstream from the White Oak weir pool (MS3).

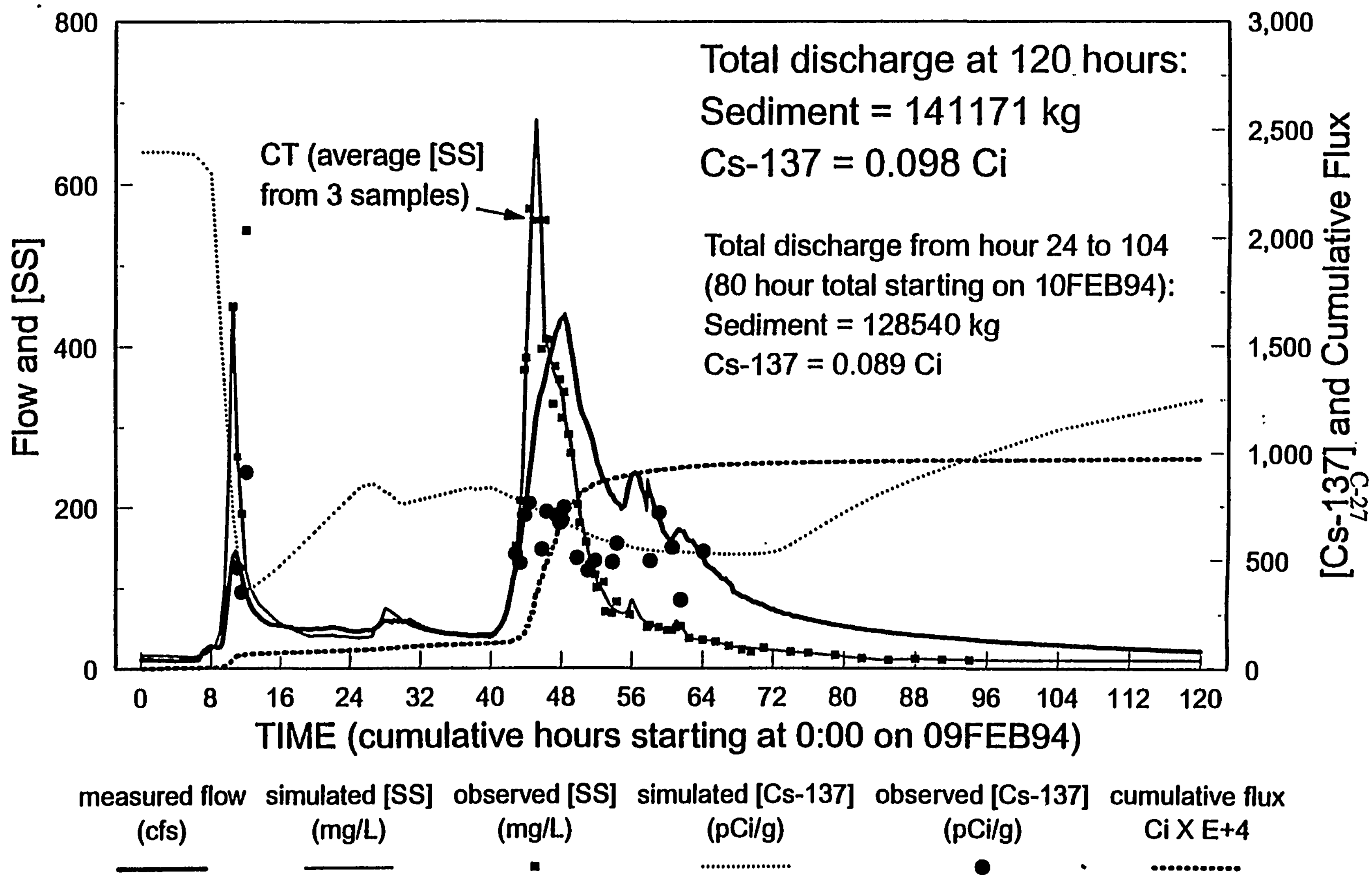

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 10FEB94 storm sampled downstream from the White Oak weir pool (MS3).

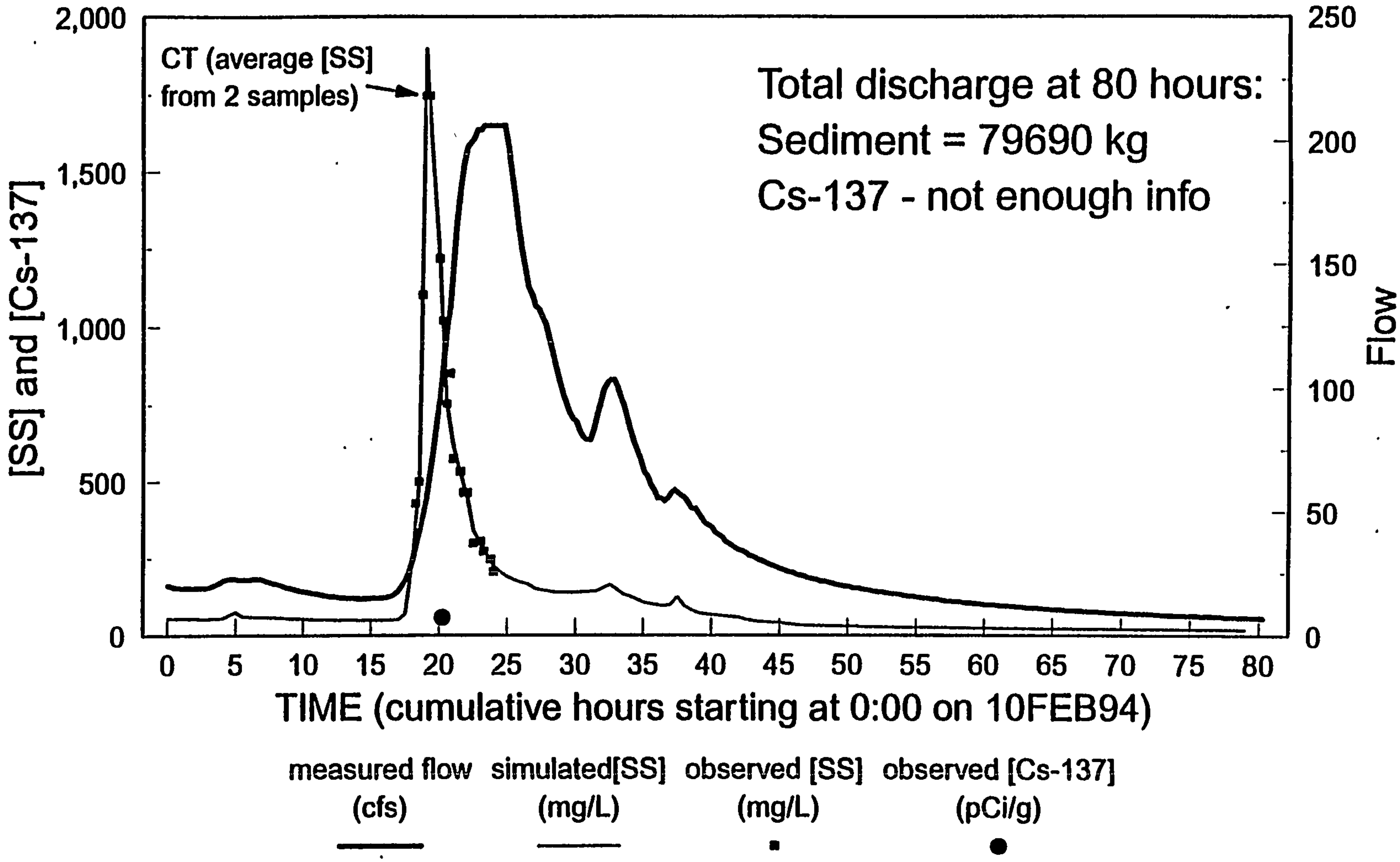

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 10FEB94 storm sampled upstream from the Melton Branch weir pool (MS4).

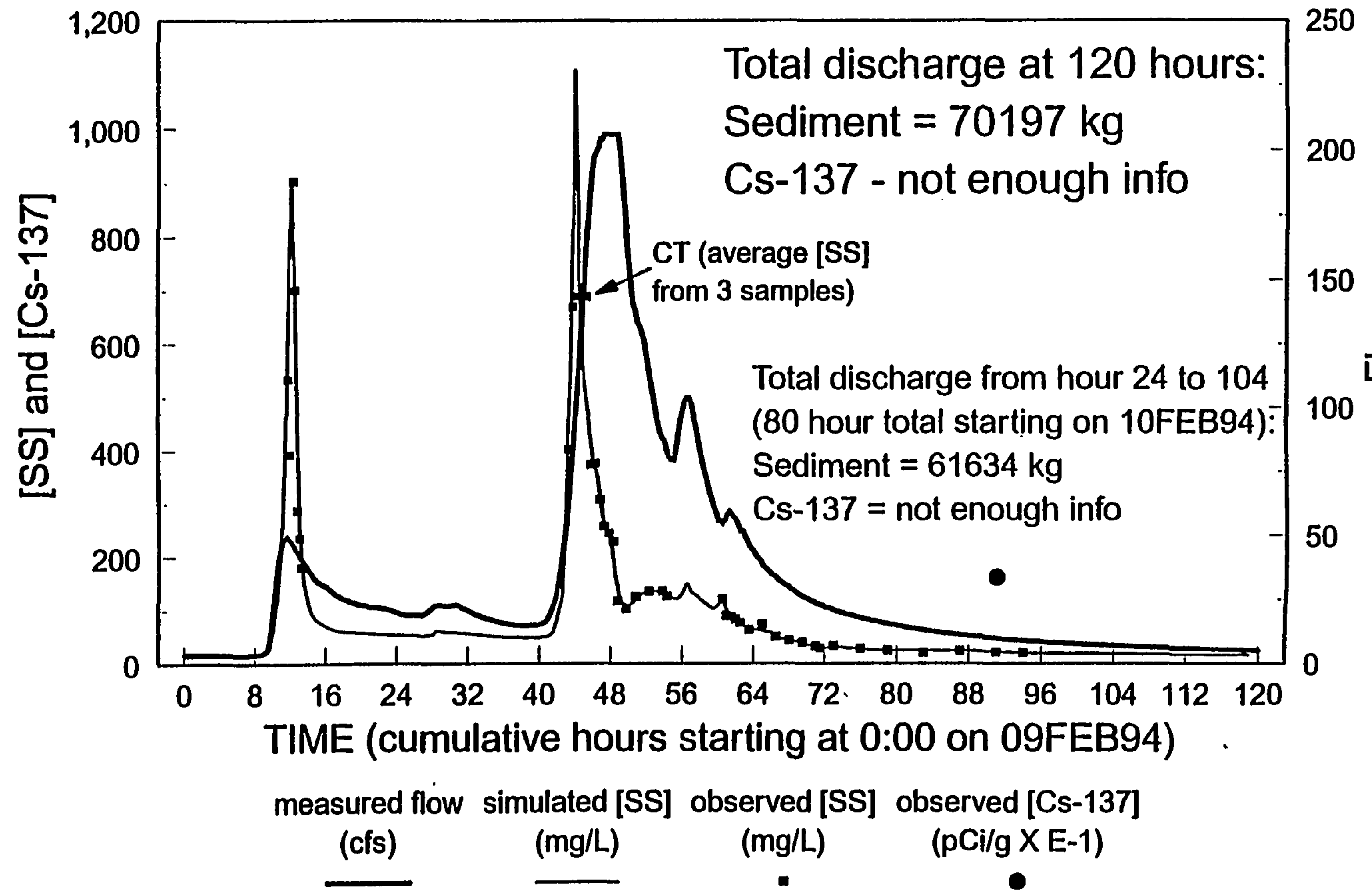

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 10FEB94 storm sampled downstream from the Melton Branch weir pool (MS4).

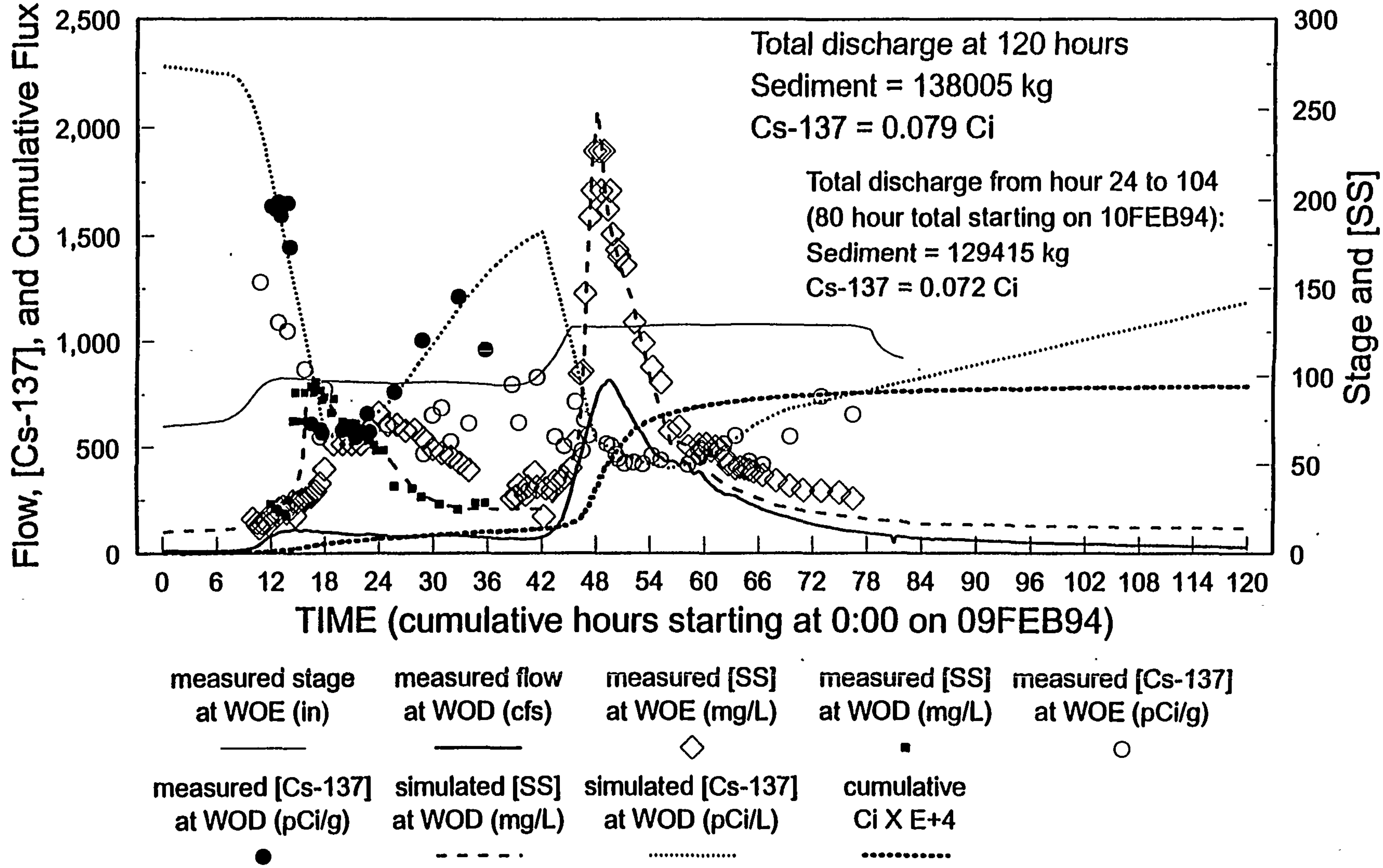

Figure $: Spreadsheet used to calculated [SS] and [Cs-137] at WOD after hour 36 by using data from the WOE sampling site. WOE data moved up 2 hours to account for travel time (see end of spreadsheet for more details).

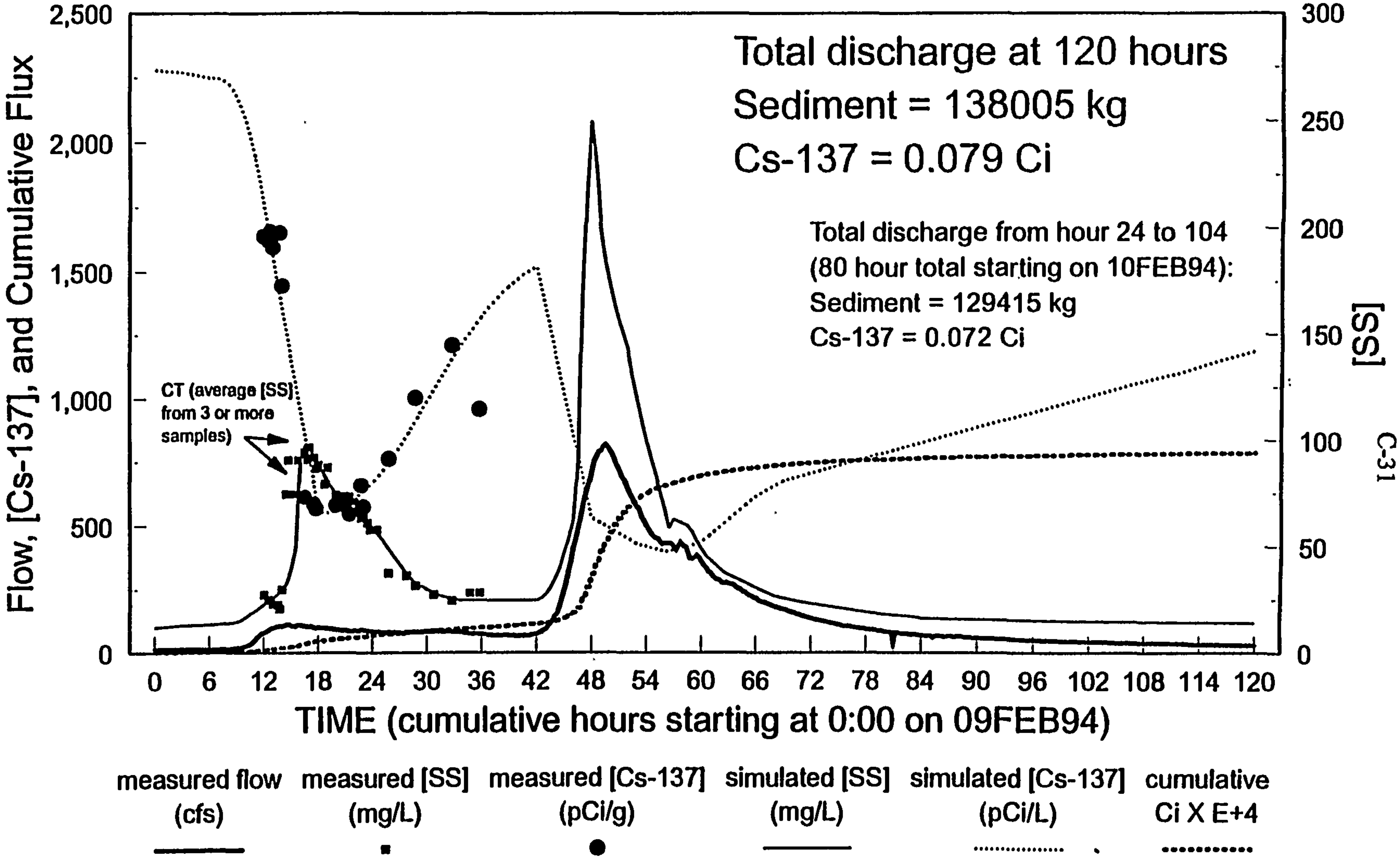

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 10FEB94 storm sampled at White Oak Dam (MS5).

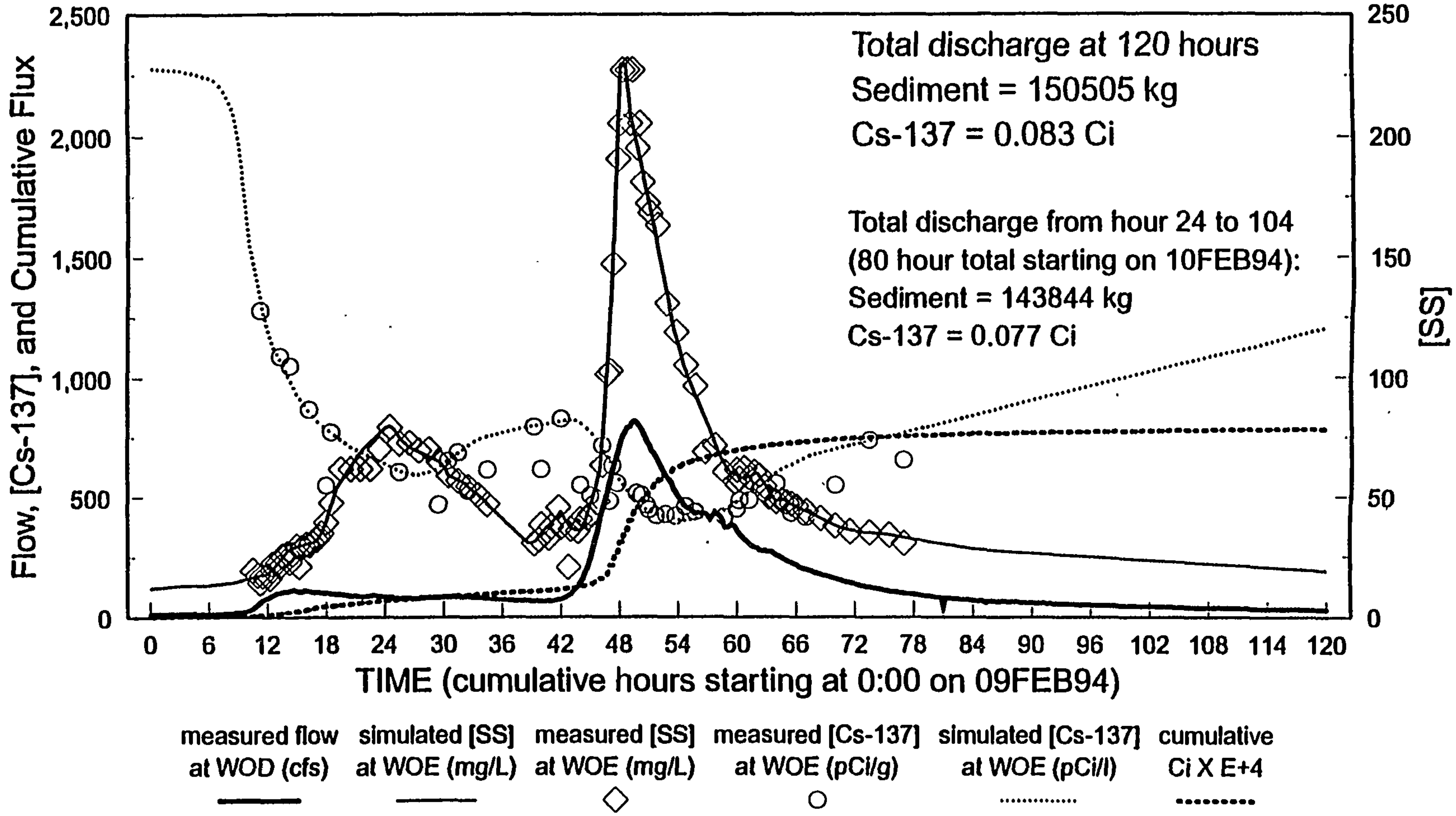

Figure $: Plot used to estimate WOE passing loads for the 10FEB94 storm by using measured flow from WOD (WOE data moved 1.5 hours to provide best comparative fit for the large storm on the 10th).

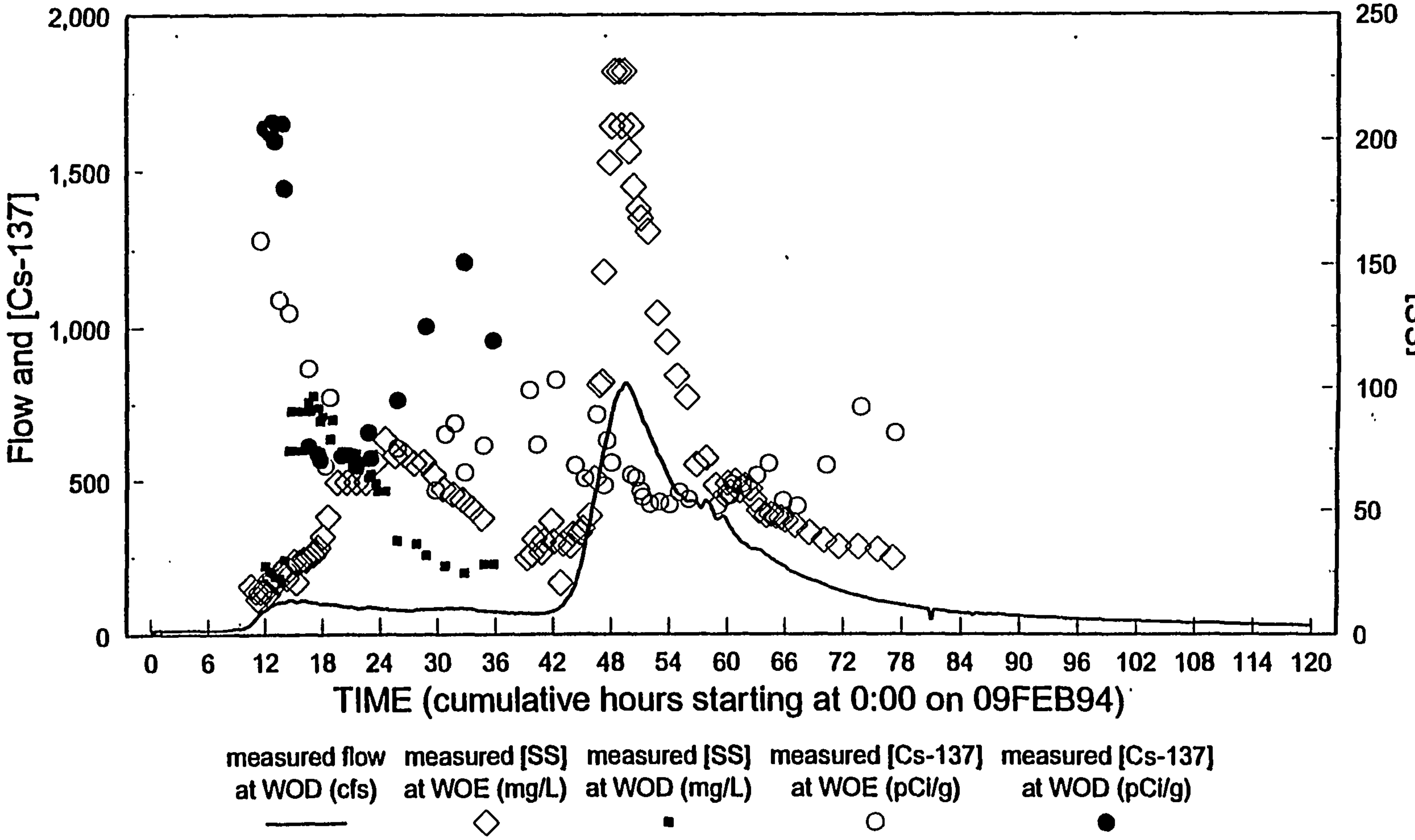

Figure $: Overlay of WOE values onto plot of WOD measured values for the 10FEB94 storm. WOE data moved 1.5 hours for best representation of WOE passing loads (see end of spreadsheet for more details).

Storm 4. 27MAR94

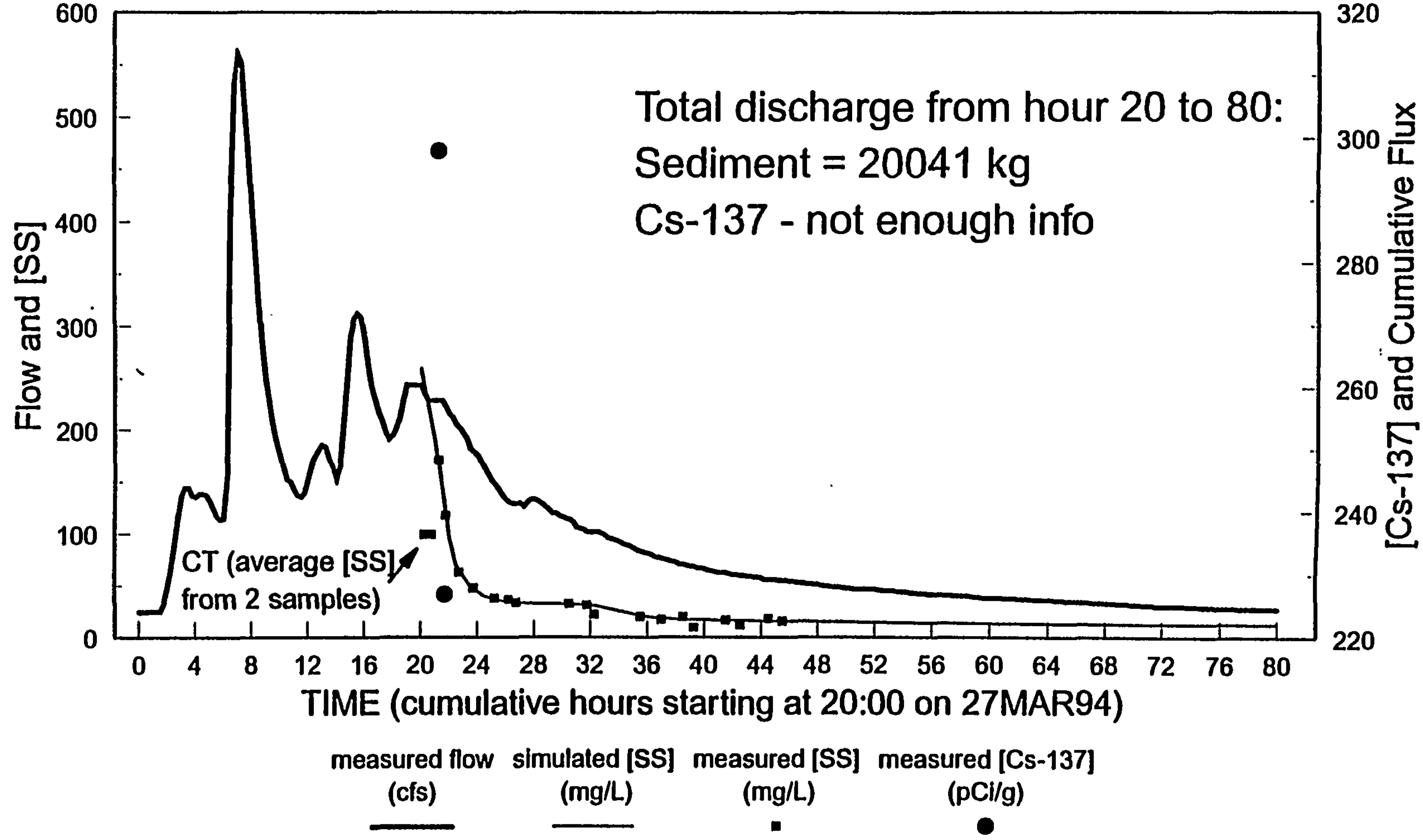

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 27MAR94 storm sampled at the 7500 Bridge site (GS3).

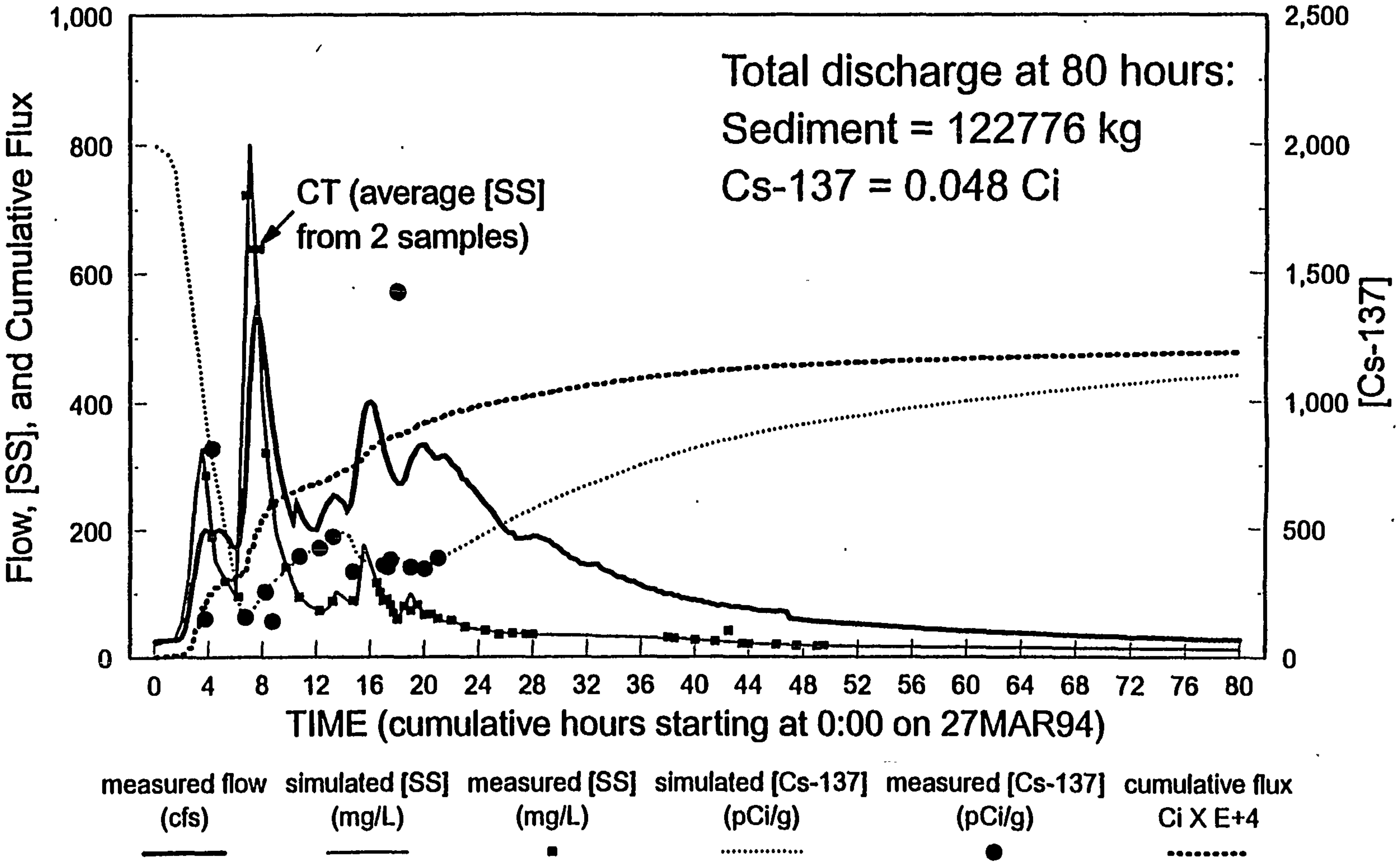

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 27MAR94 storm sampled downstream from the White Oak weir pool (MS3).

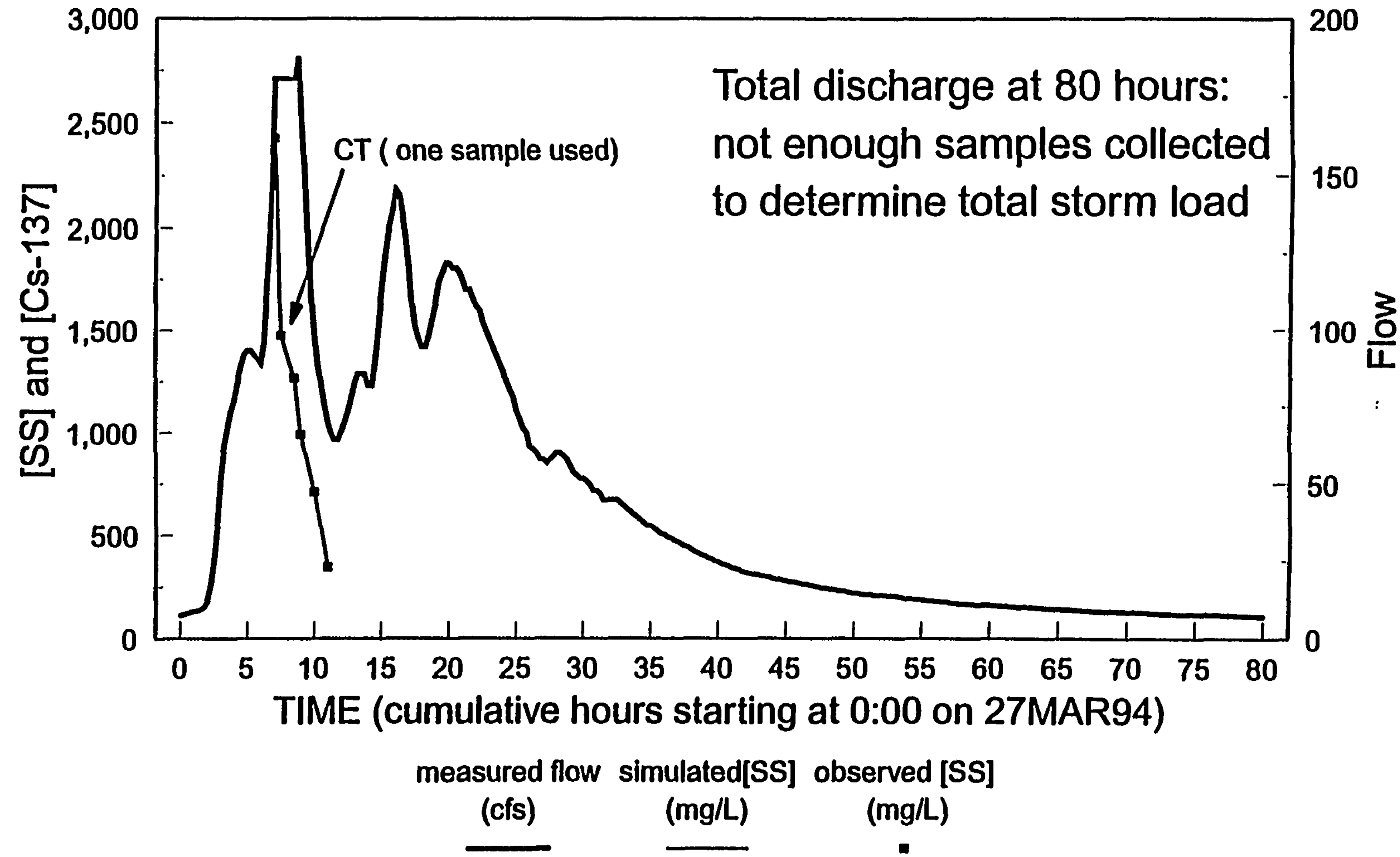

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 27MAR94 storm sampled upstream from the Melton Branch weir pool (MS4).

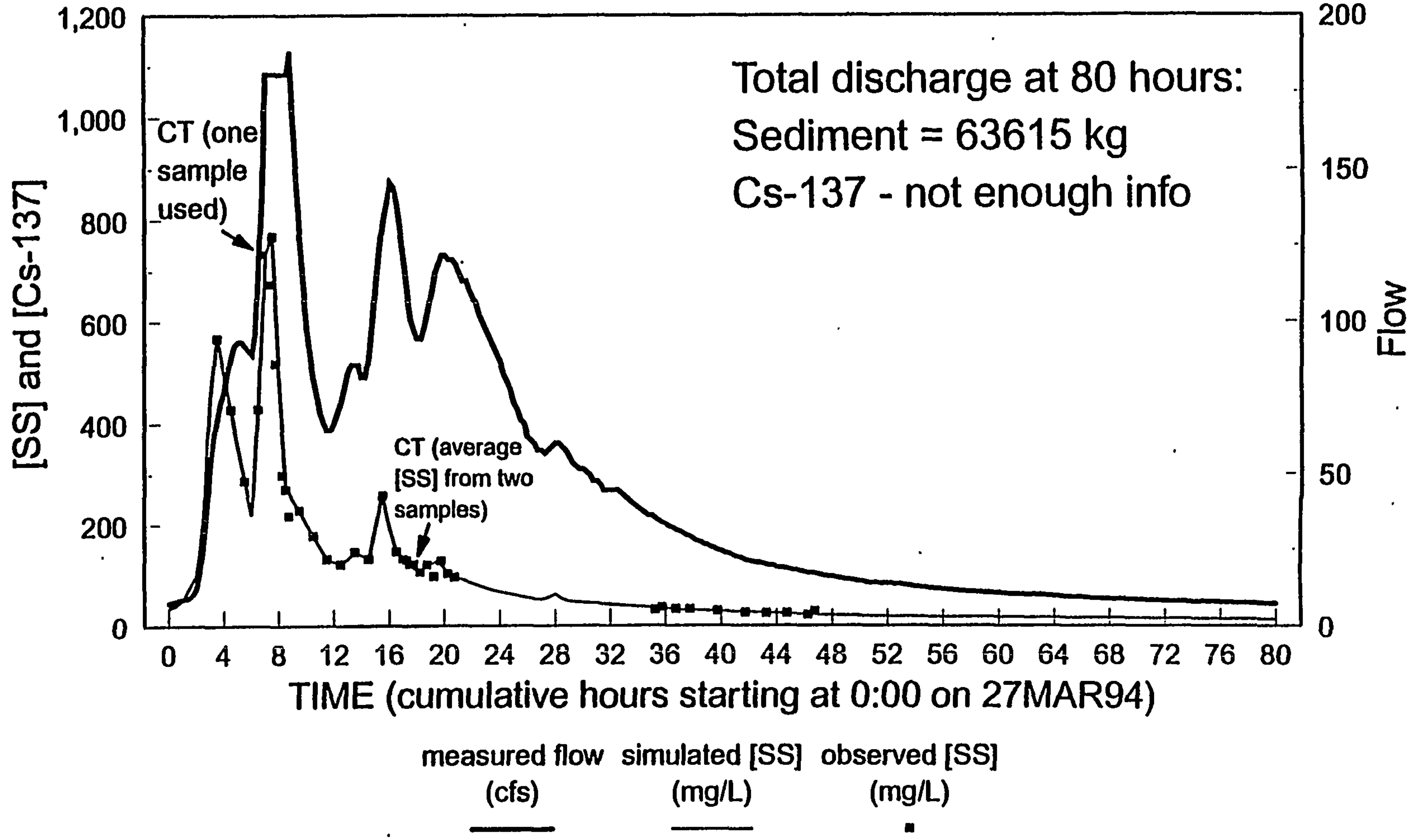

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 27MAR94 storm sampled downstream from the Melton Branch weir pool (MS4).

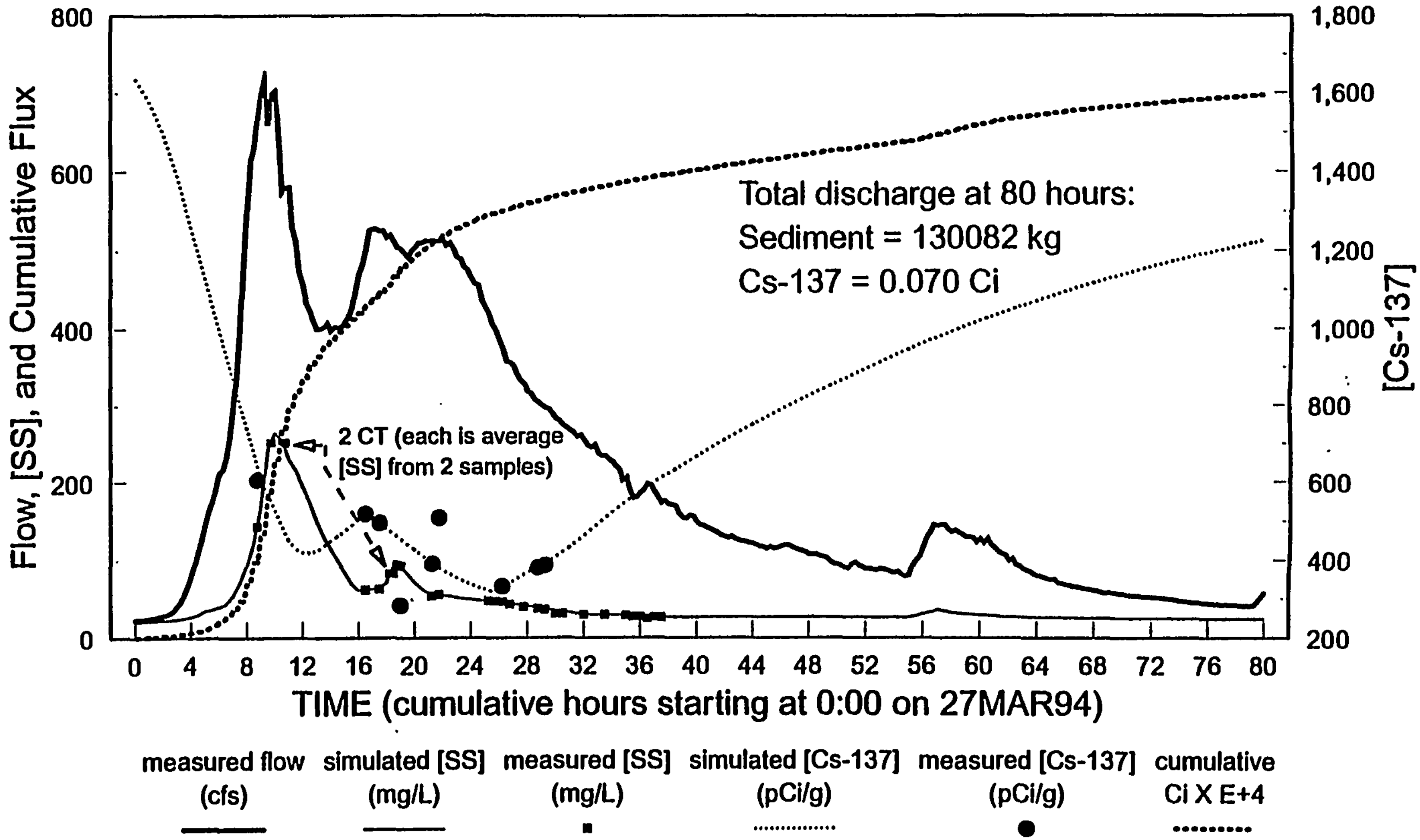

Figure $: Discharge and transport of suspended sediments ([SS]) and Cs-137 for the 27MAR94 storm sampled at White Oak Dam.

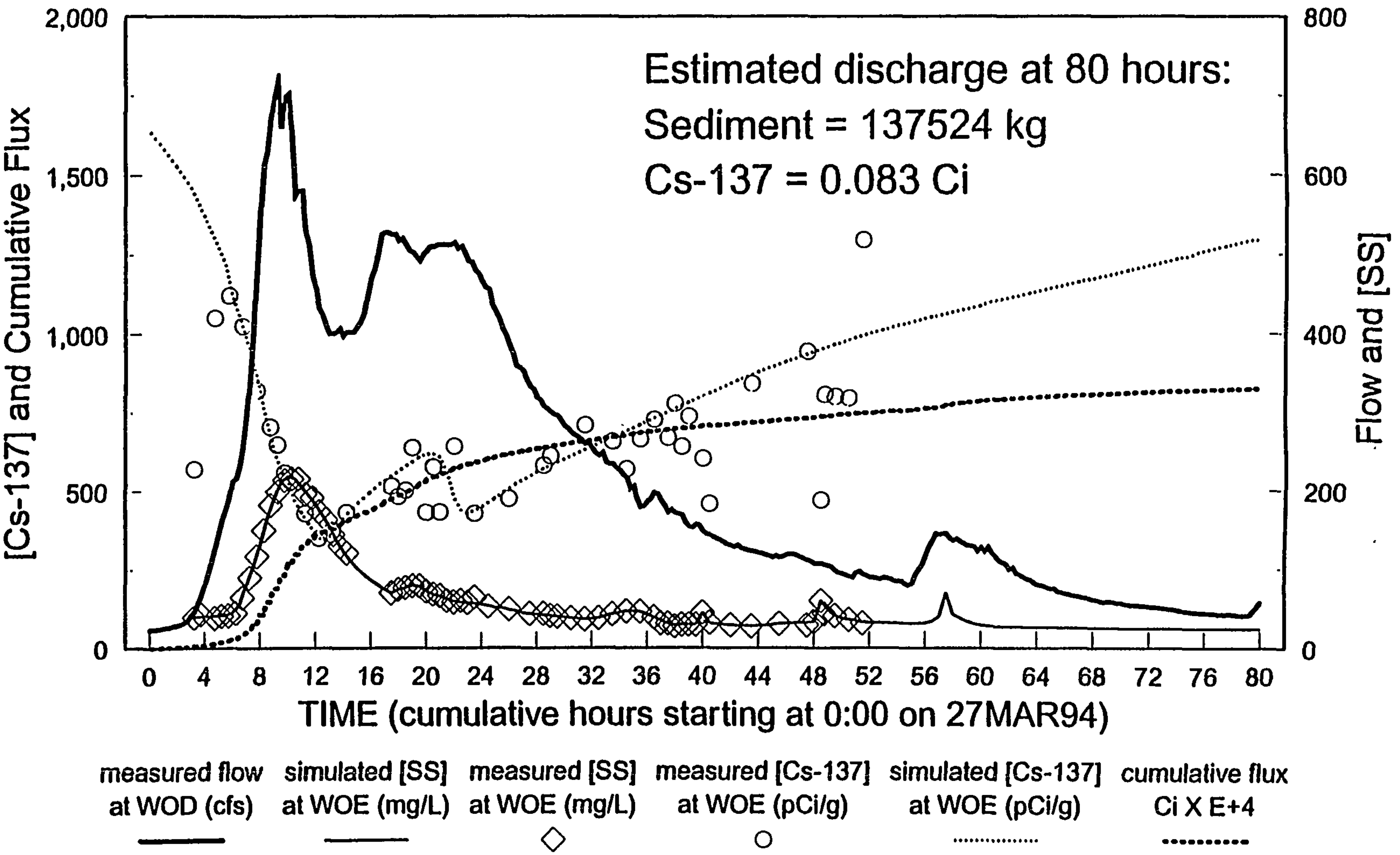

Figure $: Plot used to estimate WOE passing loads for the 27MAR94 storm by using measured flow from WOD (WOE data moved 1.5 hours to provide best comparative fit with WOD flow).

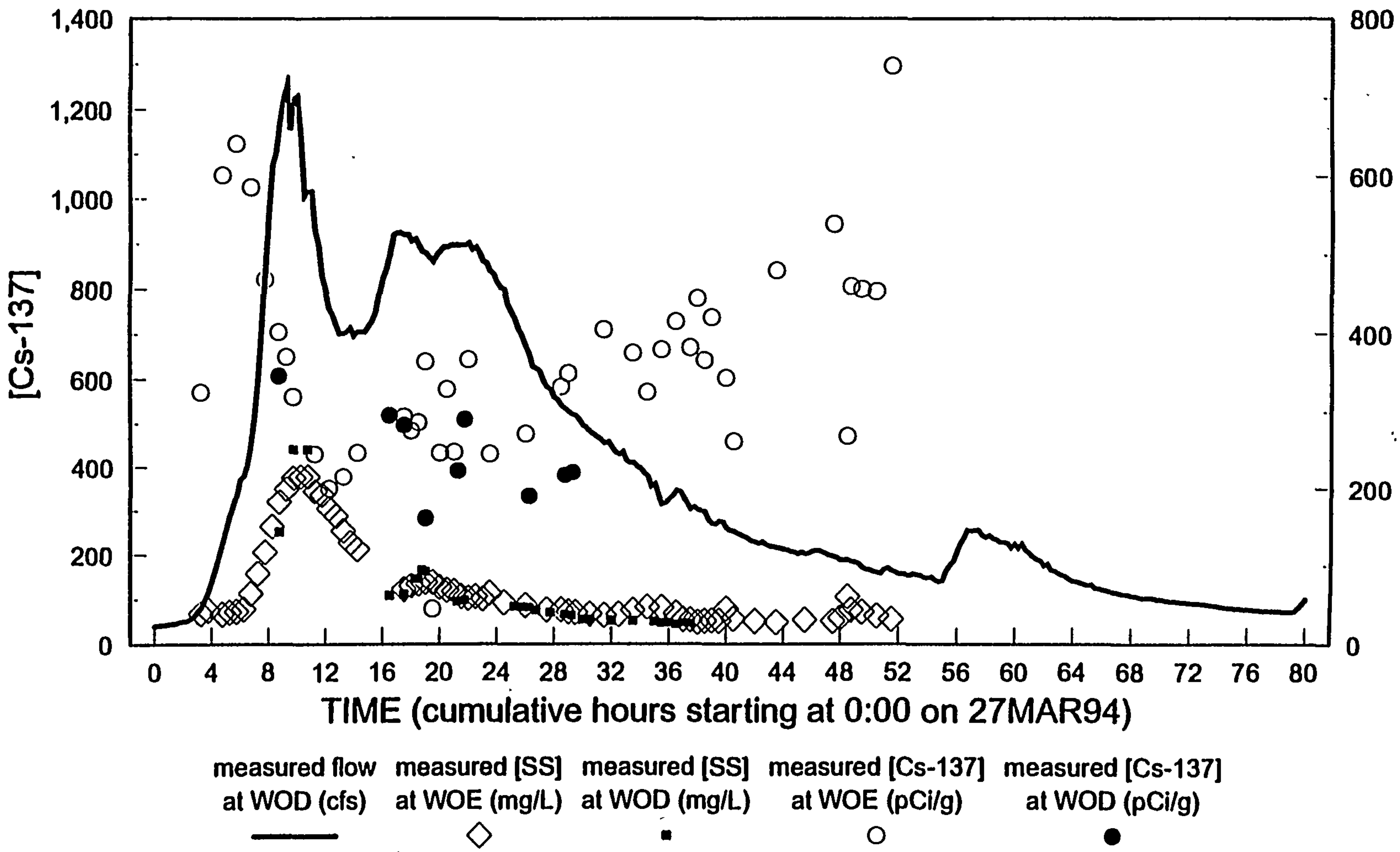

Figure $: Overlay of WOE values onto plot of WOD measured values for the 27MAR94 storm. WOE data moved 1.5 hours for best representation of WOE passing loads (see end of spreadsheet for more details).

Storm 5. 08MAR95

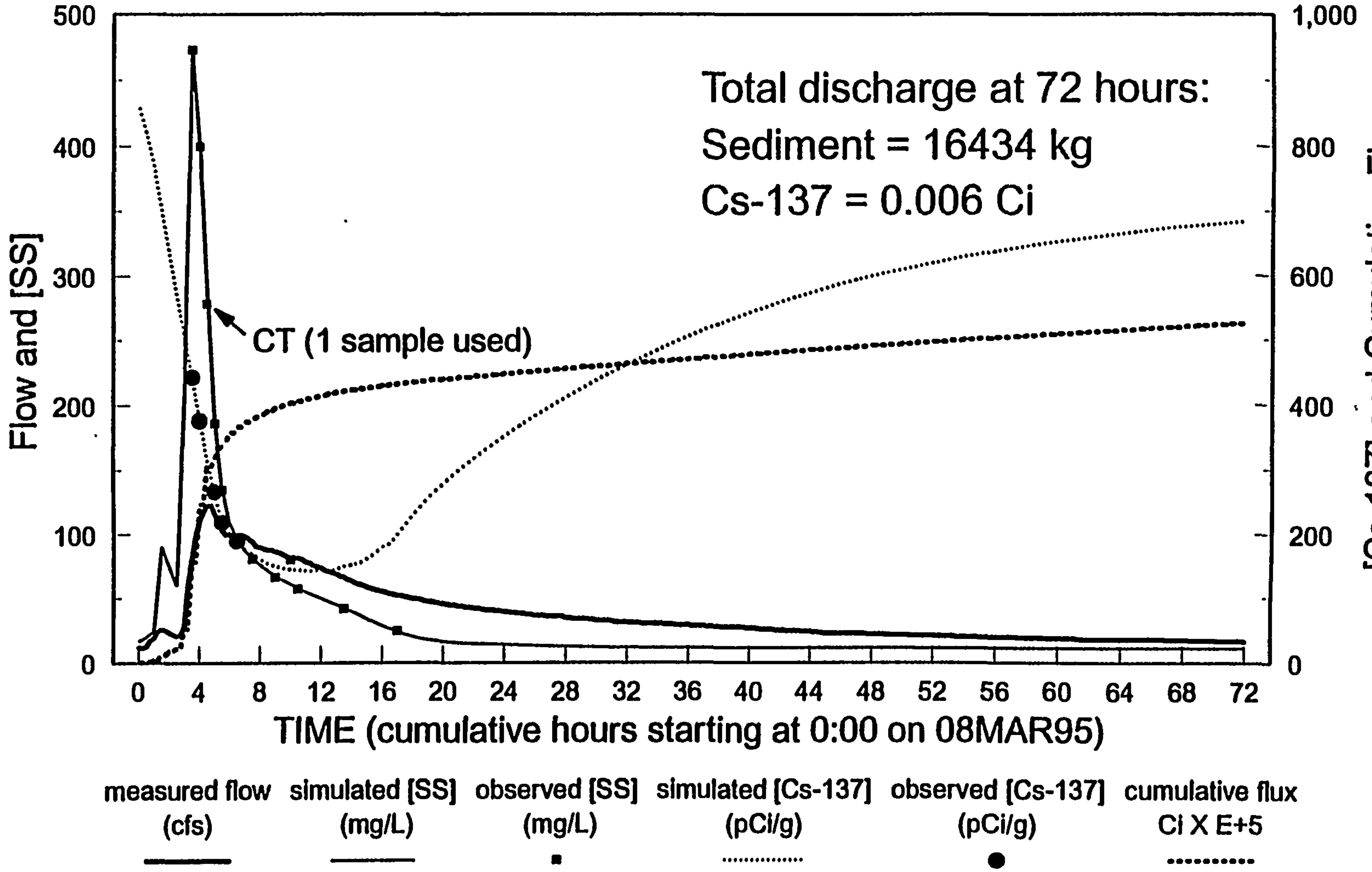

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 08MAR95 storm sampled at the 7500 Bridge site (GS3).

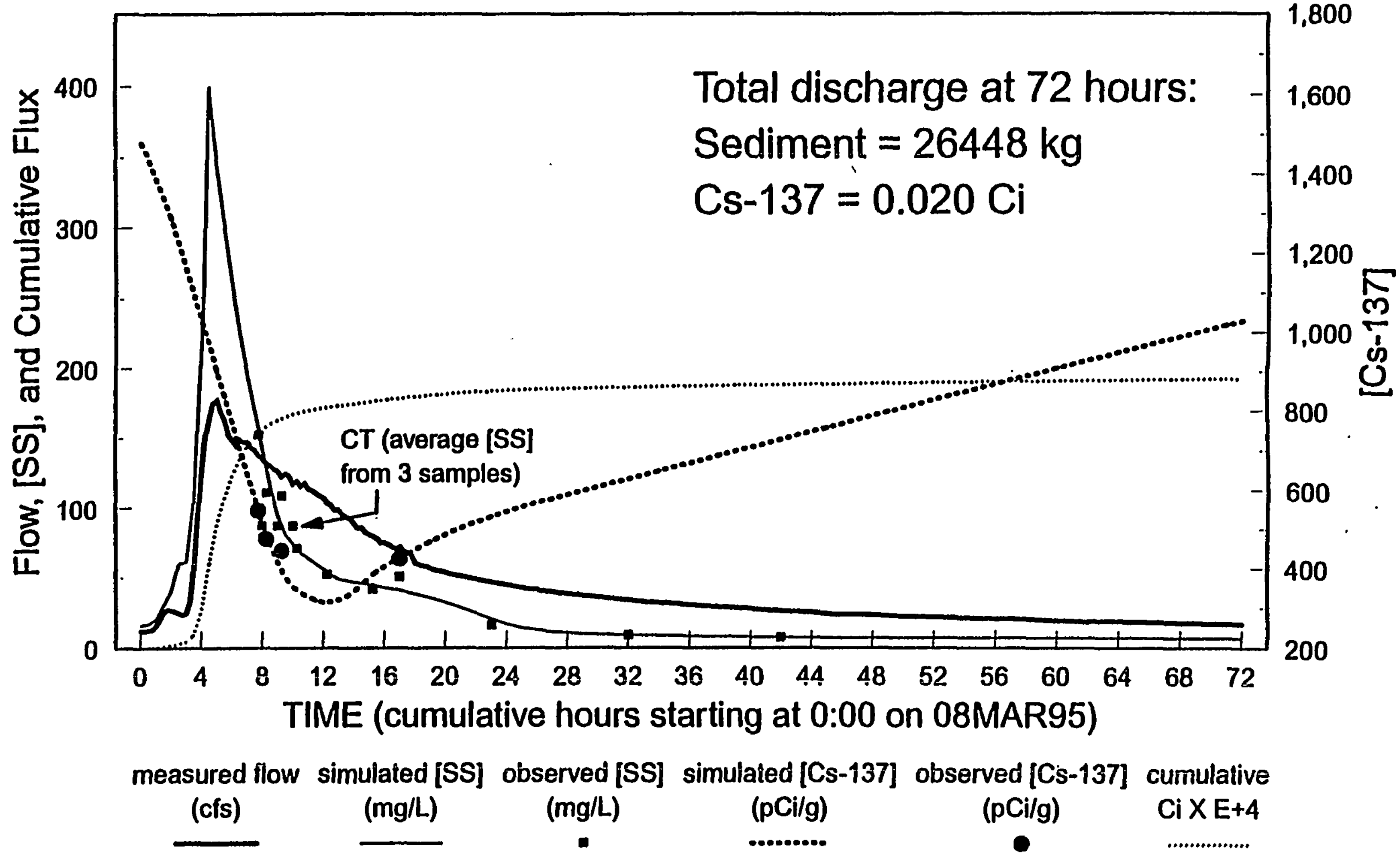

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 08MAR95 storm sampled downstream from the White Oak weir pool (MS3).

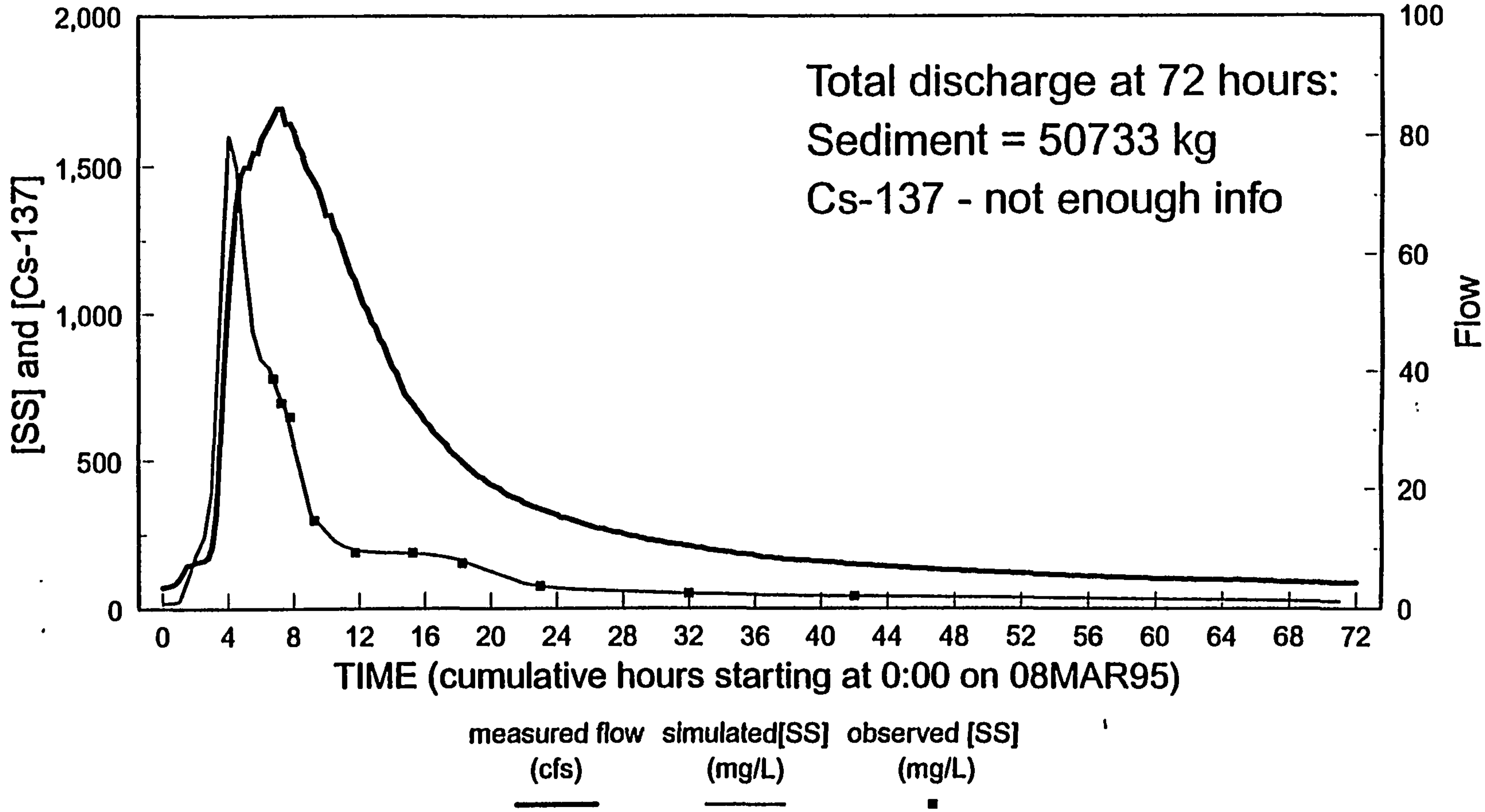

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 08MAR95 storm sampled upstream from the Melton Branch weir pool (MS4).

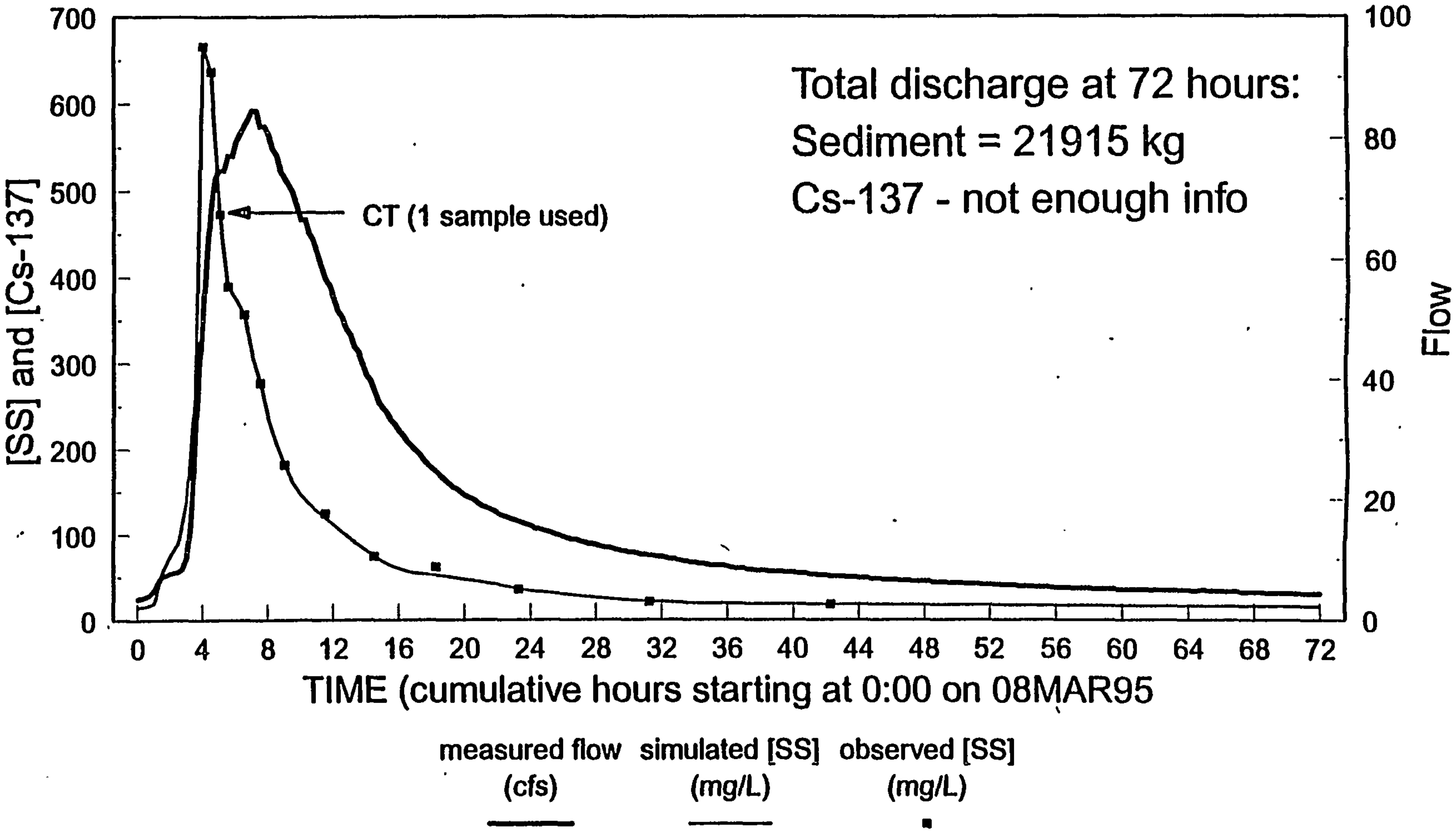

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 08MAR95 storm sampled downstream from the Melton Branch weir pool (MS4).

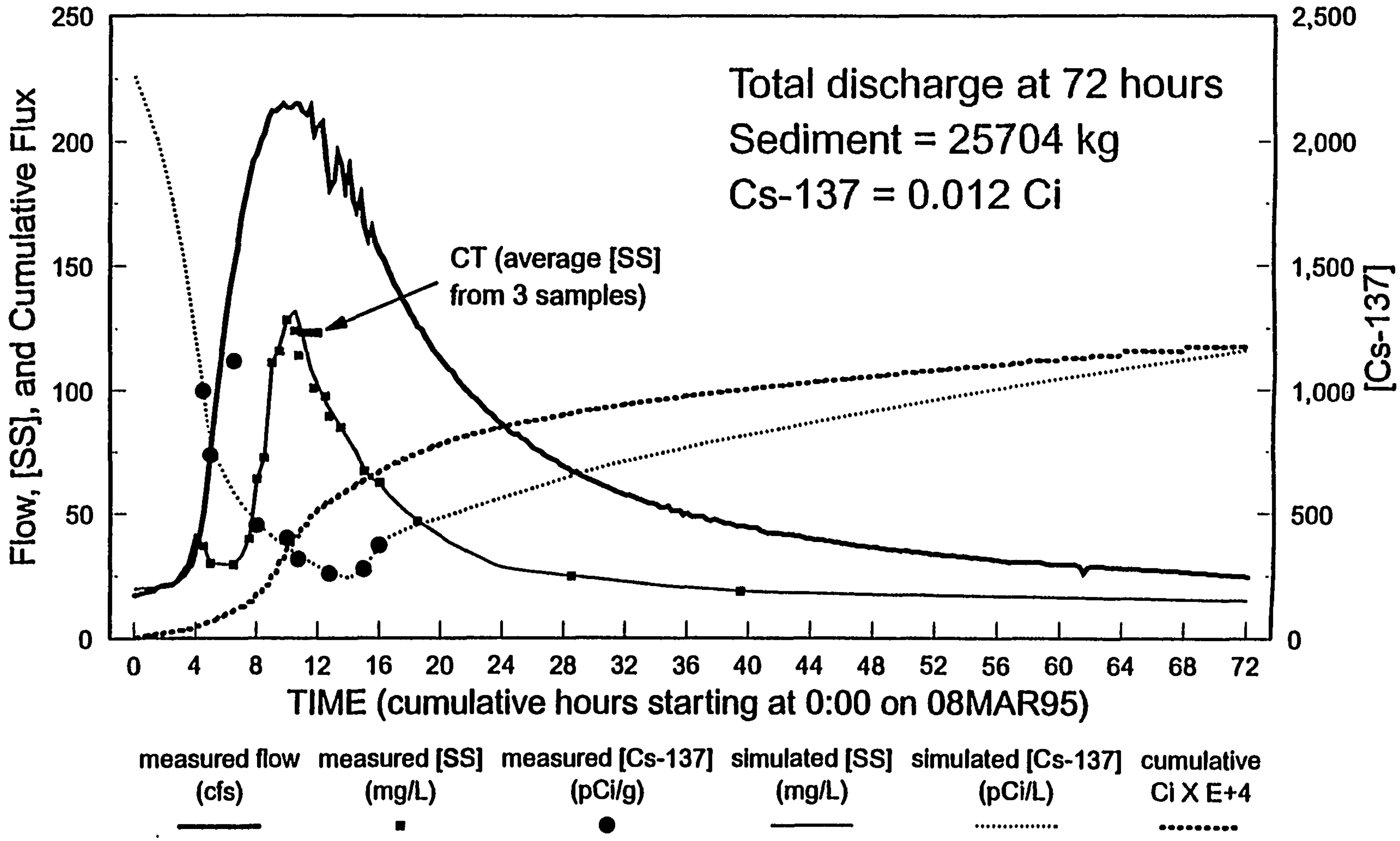

Figure $: Discharge and transport of suspended sediments and Cs-137 for the 08MAR95 storm sampled at White Oak Dam (MS5).

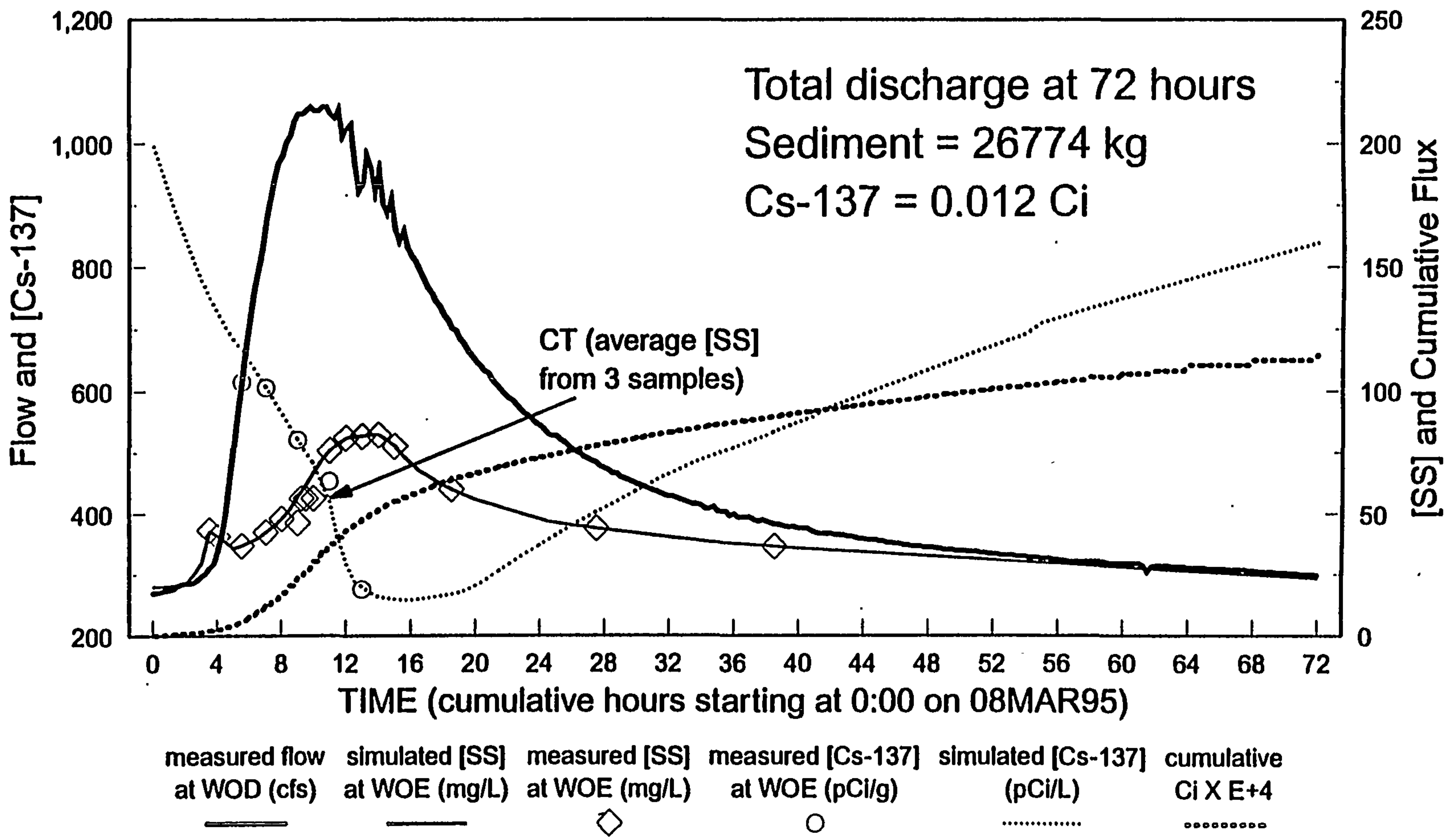

Figure $: Plot used to estimate WOE passing loads for the 08MAR95 storm by using measured flow from WOD (WOE data moved 1.5 hours to provide best comparative fit with WOD flow).

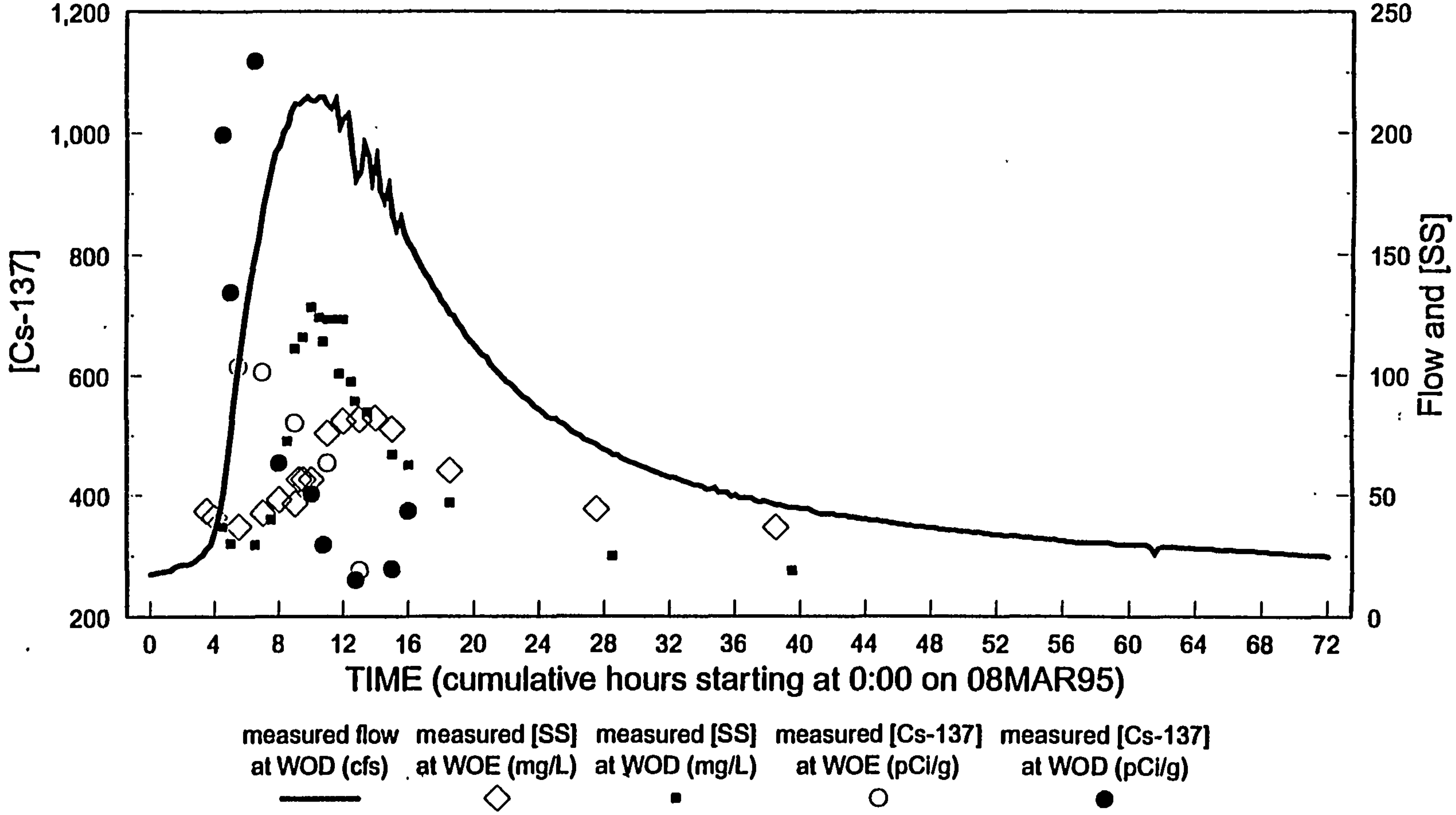

Figure $: Overlay of WOE values onto plot of WOD measured values for the 08MAR95 storm. WOE data moved 1.5 hours for best representation of WOE passing loads (see end of spreadsheet for more details).

Appendix D:

WATERSHED TRANSPORT MODELING SUPPORTING MATERIAL

APPENDIX IV. WATERSHED TRANSPORT MODELING SUPPORTING MATERIAL

This appendix is divided into sections covering key aspects to the watershed modeling subtask:

- HSPF Model parameters.
- Rainfall Input to the Model
- New Approach to Hydrologic Calibration

III.1 HSPF Model Parameters

Related physical processes: precipitation, evaporation, interception, infiltration, soil detachment /transport, overland runoff, interflow, groundwater, channel flow, water storage, solubility, radioactive decay, and adsorption/desorption. Processes for other type of water quality constituents involved in biochemical transformation such as dissolved oxygen, biochemical oxygen demand, nitrite, benthic algae, zooplankton, total inorganic carbon, pH, and carbon dioxide are beyond the scope of the work and were not considered in modeling.

Parameters and input data associated with the processes:

Overland runoff with sediment: precipitation and evaporation time series, drainage area, elevation, basin slope, land use, soil, and vegetation.

Hillslope contaminant transport: washoff and scour potency factors (ratio of constituent yield to sediment), concentration of constituents in interflow and groundwater, and storage of available contaminant on the surface.

Stream flow routing: channel cross sections, length, energy slope, median diameter of bed sediment, and roughness for each reach.

Sediment transport in channel: sediment sizes; fall velocity; bulk density; critical stresses for scour and deposition; and relationship between reach water surface area, depth, width, and water volume.

Channel contaminant transport: initial concentration of constituents; initial concentration of constituents on sand, silt, and clay in water (suspended) and bed; initial bed thickness (inventory in channel reach); initial composition of sand, silt, and clay in the bed material; and water temperature.

Decay processes: first-order decay rate, temperature correction coefficient, and decay rate for constituents adsorbed to suspended and bed sediments.

IV.2 RAINFALL INPUT TO THE MODEL

The watershed is subdivided into 4 Pervious Land Segments (PLSs). Rainfall from 6 gages is averaged according to the Thessen polygons shown in Fig. IV.1 and Table IV.1

[insert Fig IV.1, T. Polygons; Table IV.1 with polygon weights]
TABLE 3.2.2: Percentages used to develop precipitation weighted averages for each subcatchment in the WOC basin.

SUBCATCHMENT	PLS - 1 (2088 ac)	PLS - 2 (238 ac)	PLS - 3 (971 ac)	PLS - 4 (647 ac)
RAINGAGE AND PERCENT USED FOR WEIGHTED AVERAGE CALCULATIONS	1ST=51.58% SW7=22.79% RG1=18.00% SW4=05.22% ISH=02.41%	SW4=60.49% 1ST=39.51%	SW7=75.41% SW4=17.56%	49T=68.22% SW4=31.78%

IV.3 NEW APPROACH TO HYDROLOGIC CALIBRATIONS

A large number of parameters are required in the HSPF model. Some of the parameters can be determined from the measured in field or determined in laboratory. Others, however, must be determined in calibration processes. For instance, some of the parameters in the model, such as upper zone storage and lower zone storage, are not measurable which represent aggregation of several established variables because of the simplification in model governing equations and solution techniques. Therefore, the calibration is a key component in the modeling processes.

The conventional trial-and-error calibration procedure is cumbersome and results may not be satisfactory. Even for an experienced modelers, the calibration process may require 30 to 35% of the modeling efforts (Donigian et al. 1984). An improved method over the conventional trial-and-error method for calibration is expert system which is a collection of a set of rules based on experts' opinion to guide the selection of parameter values (Lumb et al. 1993, Johanson et al. 1984). The expert system, such as HYDRO-II developed by USGS, provides physically meaningful advice on which and how the parameters should be adjusted and helps less-experienced modelers understand simulation processes. However, such method requires manually calibrate the model step by step and, therefore, it is still less efficient and time consuming.

An optimization calibration method is to determine the parameters (control variables) by minimizing the performance function (simulated and observed runoff). The optimization calibration is highly automated calibration process therefore with high efficiency. However, the disadvantage of the method is that it is computational intensive and lack of physical understanding of parameters. Because the only criterion for determining the parameter value is to compare the improvement of numerical value of objective function while varying the control variables, the resultant parameters may by physically meaningless in some cases.

A new calibration methodology was devėloped by combining optimization with expert system to take advantages of both methods to overcome their drawbacks. The expert system incorporates calibration strategies (Lumb et al. 1993, and Donigian et al. 1984) with direct observations of the watershed's hydrologic behavior (Oakes et al. 1982) and determines the sequence in which to calibrate parameters. The nonlinear-optimization model (Lasdon and Waren 1989) determines the values of the parameters by minimizing the absolute difference between the computed and observed stream flow at the outlet of each pervious land segment. A FORTRAN computer code Optimization-Expert System Model (OPTCALI) was developed for the application of the new method. Three major components in OPTCALI are: (1) outer loop as an expert-system to determine which parameters to be calibrated, an inner loop consists of (2) an nonlinear optimizer and (3) the watershed simulator. Table IV.2 summarizes features of OPTCALI with respect to calibration strategies (phases), parameters and capabilities.

Table IV 2. Summary of OPTCALI

Items	Description
Major calibration phases	annual water balance, monthly or seasonal adjustment, low flow, storm flow, daily flow, and hourly flow.
Parameters	lower zone storage, infiltration capacity, groundwater recession rate, upper zone storage, interflow, interflow recession, and lower zone evapotranspiration
Land segment	Can calibrate for single and/or multiple land segments
Time	Can calibrate use one or more years of flow data records
Multiple gages	Can calibrate against multiple gage stations

[Insert Figure IV.2 Generalized flow chart of OPTCALI]

IV.3.1 Discussion of Parameters

The major calibration parameters are lower zone storage, infiltration capacity, groundwater recession rate, upper zone storage, interflow, interflow recession, and lower zone evapotranspiration

(Table IV.3).

Table IV.3 HSPF major hydrologic calibration arameters

HSPF Calibration Parameter	Description	Comments
LZSN	lower zone normial storage	LZSN is the major calibraton parameter affecting water balance. High LZSN value will incease infiltration and reduce water balance.
INFILT	infiltration capacity	Negatively affect water balance
AGWRC	groundwater recession rate	Can change the shape of low flow portion on hydrograph. Lower AGWRC value of will result in faster flow attenuation.
UZSN	upper zone storage	Can change the shape on lower portion of hydrograph for small storms.
INTFW	interflow	Can change the higher portioon (and peak) on hydrograph.
IRC	interflow recession	Can affect the slope of hydrograph (on upper portion).
LZETP	lower zone evapotranspiration	It is an index to the density of deep rooted vegetation.

IV.3.2 Calibration and Validation Results

The first three-year period of a five-year record of flows was used for model calibration and the last two years of data were used for model validation (without changing in model parameters for validation runs). Each subwatershed (i.e., PLS) was calibrated independently. Previous conventional trial-and-error calibration for White Oak Creek basin did not change parameter value for different subwatershed. In order to compare the new calibration method with the conventional one, OPTCALI was first run to calibrate model also assuming that parameter did not vary with subwatershed. Initial parameter values were those that resulted from the previous trial-and-error calibration. OPTCALI improved the annual water balance at the White Oak dam (outlet of the basin) by 400% over the best results from previous trial-and-error approach. However, the simulated flow runoff at the each subwatershed outlet, other than the White Oak Dam, does not match the observed flow data well, which indicates that the watershed is not hydrologically homogeneous. The spatial variation in rainfall runoff determines that each subwatershed (pervious land segment) must have its unique parameters. OPTCALI was used to recalibrate for each land segment independently in two phases. The only calibration parameter in Phase I was lower zone storage and the corresponding performance (objective) function was annual water balance. Starting at previous optimal parameter values as initial conditions, the resultant performance function (absolute difference in annual water discharge between the observed and simulated values) was improved by 29.2% in Phase I. Phase II lumped low flow, storm flow and seasonal adjustment together to determine the remaining calibration parameters. At the optimal solution, the performance function was further improved by 21.5%. Optimal parameters values are summarized Table IV.4.

Table IV.4 Summary of optimal HPSF parameters ouput from OPTCALI

PLS	Parameter	Lower bound	Initial value	Upper bound	Optimal value
1	LZSN	4.0	7.825	13.0	7.8249
	INFILT	0.01	0.08	1.5	0.08
	AGWRC	0.9	0.993	1	0.9652
	UZSN	0.1	0.8	1	0.903
	INTFW	0.5	4	7	2.0137
	IRC	0.1	0.3	0.6	0.3
	LZETP	0.1	0.3	0.8	0.1
2	LZSN	4.0	7.991	13.0	7.9913
	INFILT	0.01	0.08	1.5	0.08
	AGWRC	0.9	0.991	1	0.9999
	UZSN	0.1	0.8	1	0.1
	INTFW	0.5	4	7	2.2886
	IRC	0.1	0.3	0.6	0.3
	LZETP	0.1	0.3	0.8	0.8
3	LZSN	4.0	12.022	13.0	12.0221
	INFILT	0.01	0.08	1.5	0.08
	AGWRC	0.978	0.988	1	0.9906
	UZSN	0.1	0.8	1.0	0.5677
	INTFW	0.5	4	7	7
	IRC	0.1	0.3	0.6	0.3
	LZETP	0.1	0.3	0.6	0.3
4	LZSN	4.0	4.027	13.0	4.0266
	INFILT	0.01	0.08	1.5	0.08
	AGWRC	0.9	0.975	1	0.9999
	UZSN	0.1	0.8	1	1
	INTFW	0.5	4	7	0.5
	IRC	0.1	0.3	0.6	0.3
	LZETP	0.1	0.3	0.8	0.1

The good agreement between simulated and observed flows in the calibrated HSPF model is illustrated by the plot of weekly flows shown in Figure 4.8 and the goodnees of fit test in Figure Figure 4.9. The agreement between simulated and observed daily averaged flows is shown in Figures IV.3-5 for each subwatershed (PLS1, PLS2, and PLS3 respectively), and Figure 4.10 for whole watershed.

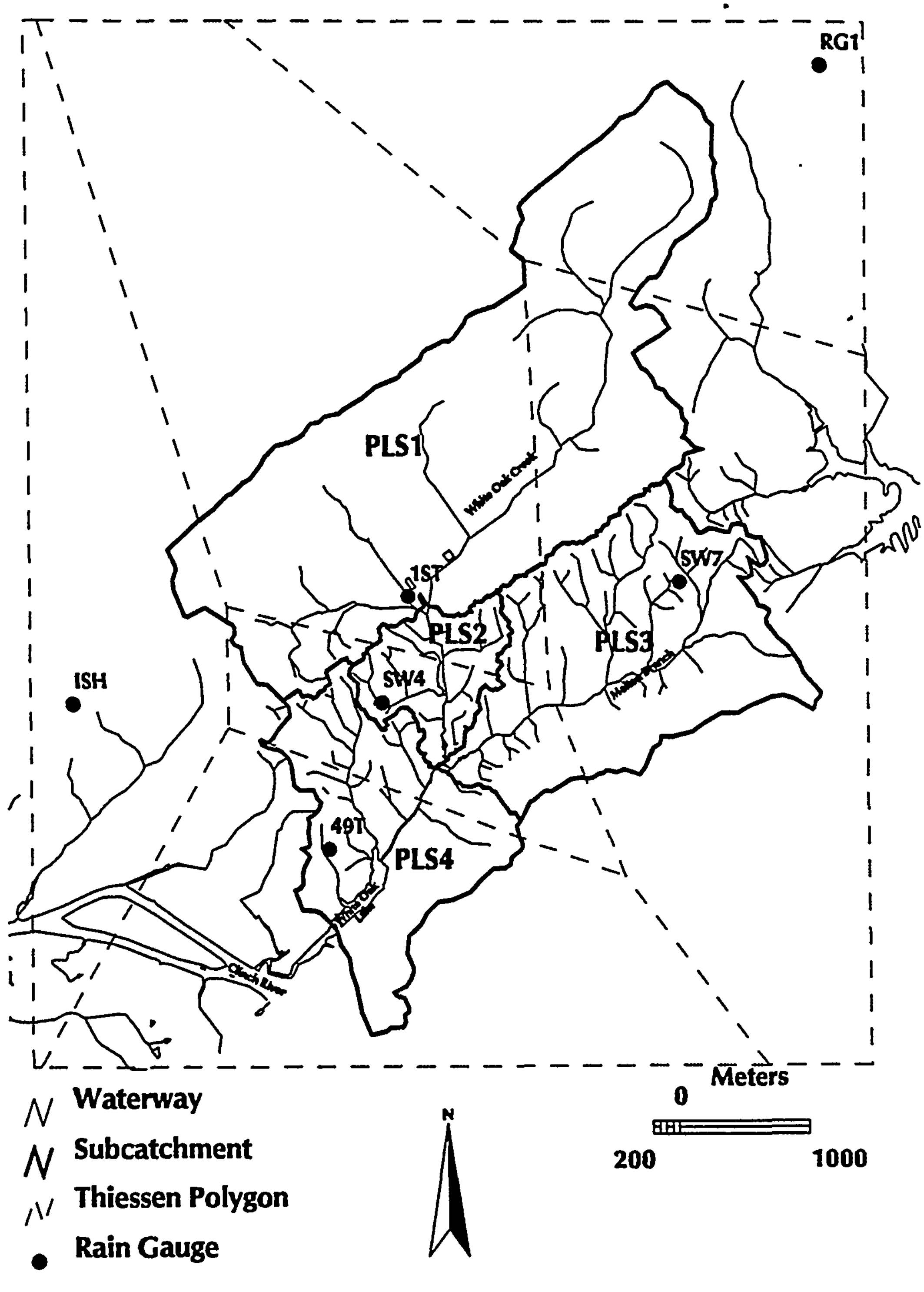

Fig. D-1. Locations of raingages and Thessen polygons to estimate rainfall for each subwatershed.

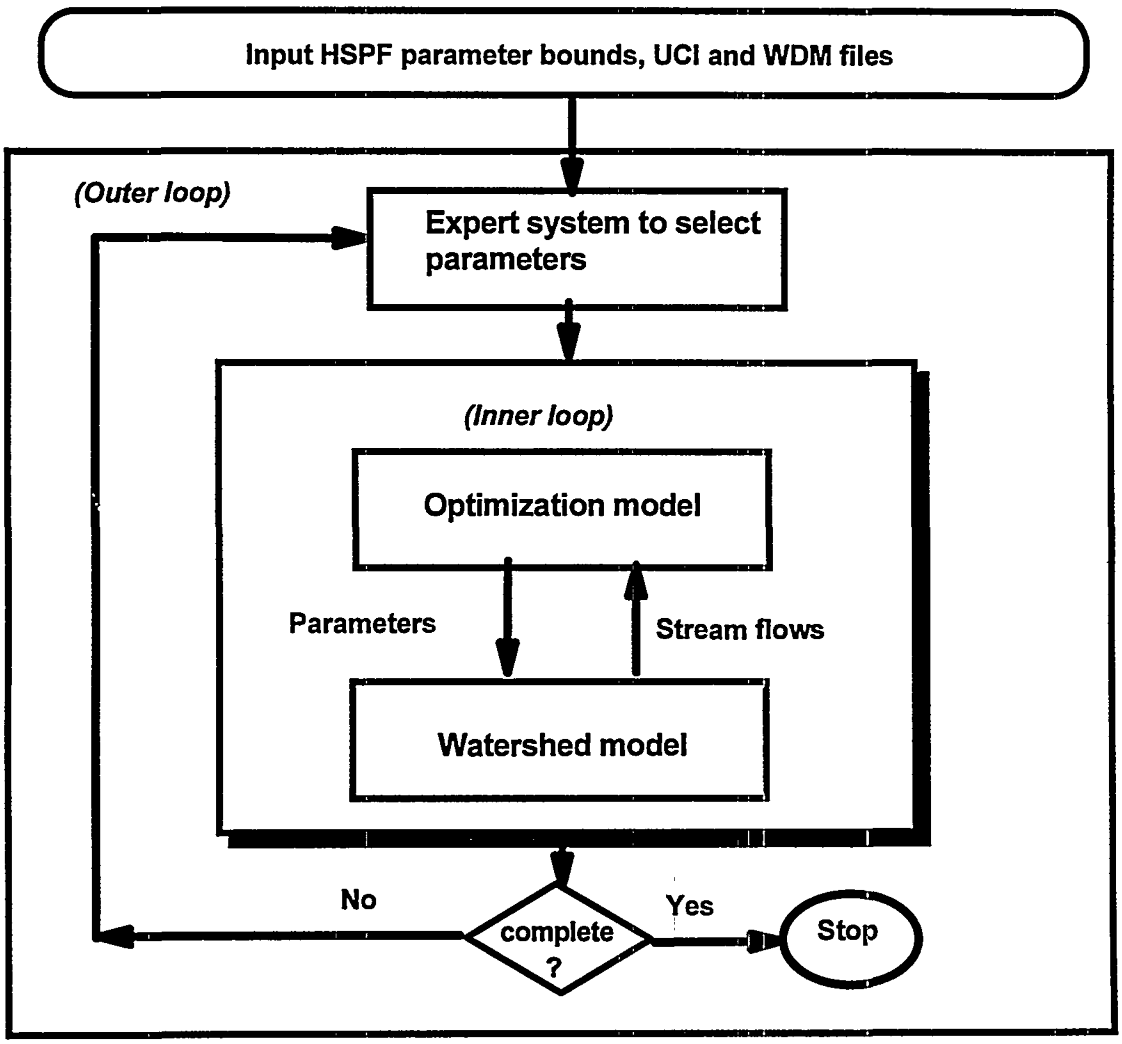

Fig. D-2. Generalized flowchart for OPTCALI.

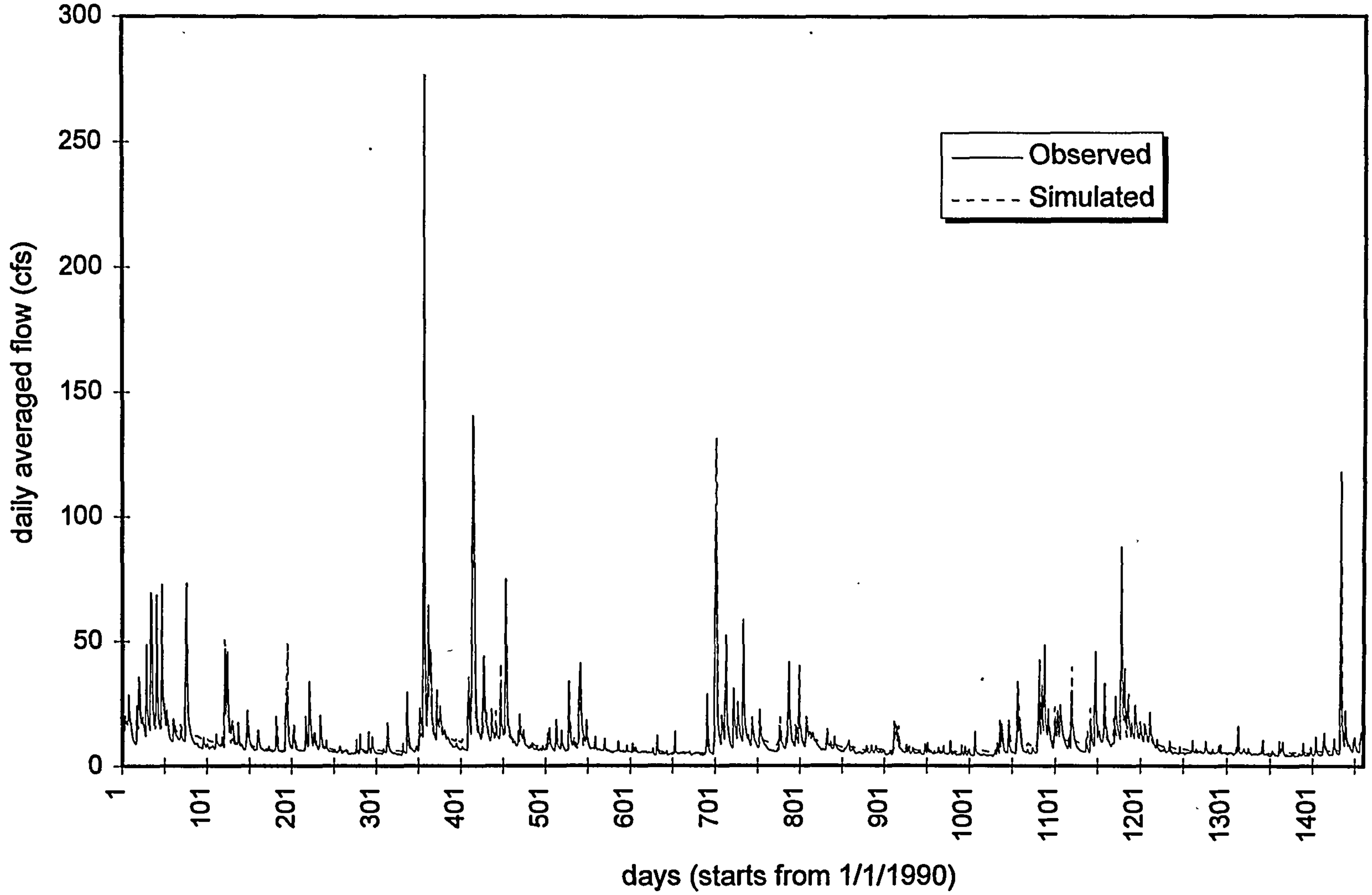

Fig. D-3. Comparison between observed and simulated flow at 7500 bridge.

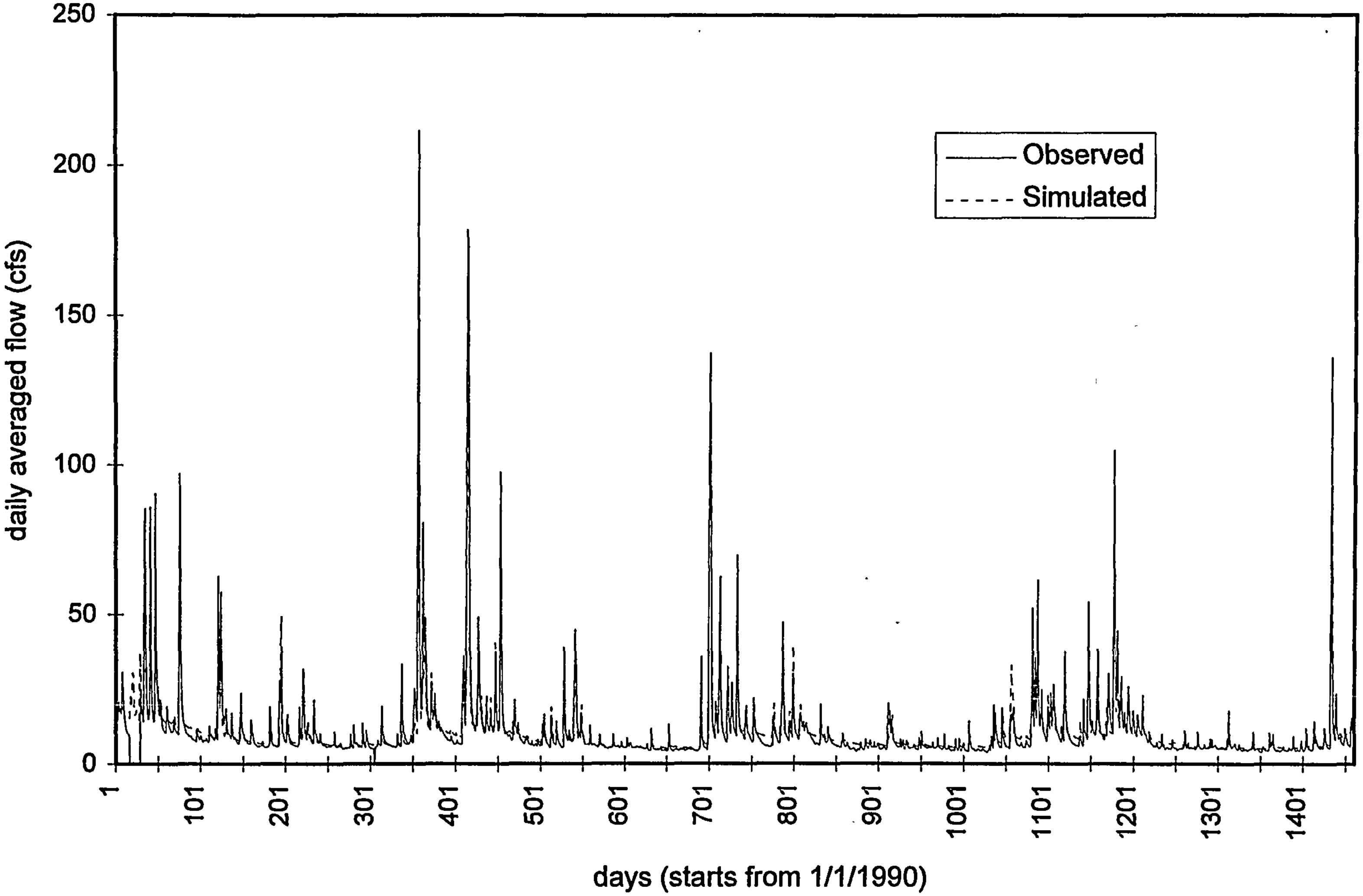

Fig. D-4. Comparison between observed and simulated flow at White Oak Creek Weir.

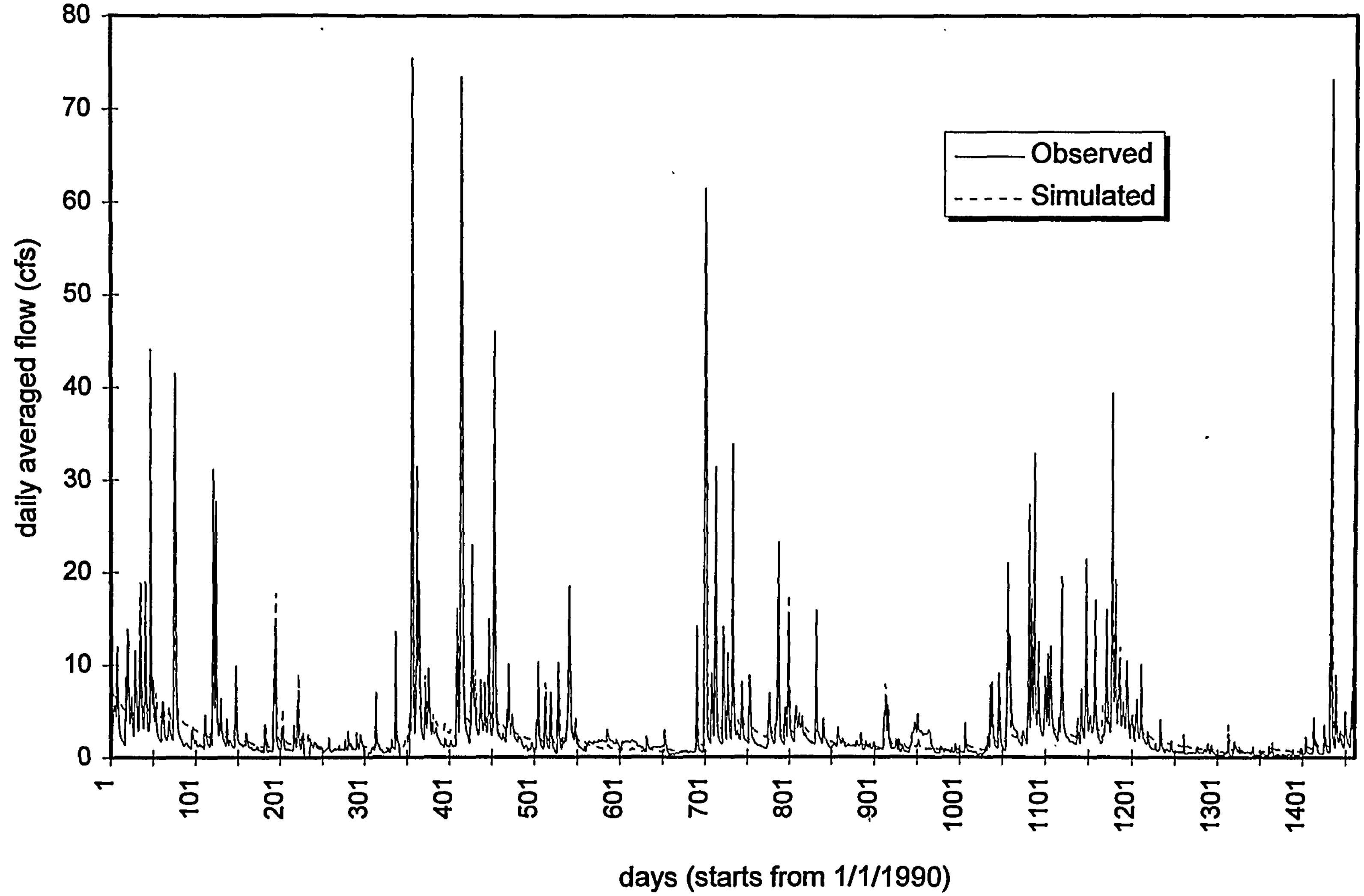

Fig. D-5. Comparison between observed and simulated flow at Melton Branch Weir.

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