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IMPORTANCE OF SEDIMENT SIZE CLASS INFORMATION FOR MODELING PARTICLE BOUND CONTAMINANT TRANSPORT DURING FLOODS

A Thesis

Presented for the

Master of Science

Degree

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detailed explanation of sediment and contaminant interactions.

Abstract

In this study, the effects that chemical pre-treatment of a suspended sediment sample have when modeling particle-bound contaminant transport were examined. To accomplish this, lake bed samples contaminated with cesium-137 were resuspended and analyzed for grain size distribution using the newly developed Settling Column Test. Three samples were pre-treated differently to see the effects pre-treatment have on the grain size distribution. The first sample tested was the control, undergoing no chemical pre-treatment. The second was dispersed with sodium bicarbonate, while the third was treated with hydrogen peroxide to oxidize and remove organics. The samples were then tested for cesium-137 concentrations per size class. Results from the laboratory testing showed that using sodium bicarbonate as a dispersant causes no difference in contaminant to grain size distribution results. However, removal of organics by oxidation causes an increase in the percent of clays.

Results from these tests were used to adjust initially identical Hydrological Simulation Program-Fortran (HSPF) parameter sets representing the White Oak Creek Watershed in Oak Ridge, Tennessee. The HSPF parameter sets were used to simulate particle-bound contaminant transport. Once adjustment of the HSPF input files was complete, the HSPF simulated five years of precipitation data including two

hypothetical one-hundred year frequency storm events. These simulations showed that using a hydrogen peroxide treated sample to adjust the HSPF parameters yielded results which differ from the control, or "natural" sample results, although the difference is considered to be minor for the comparative simulations reported here.

Table of Contents

Chapter Page

1. Introduction....1
   - -Scope And Objectives....2
   - -Background of Study....3

2. Background/Literature Search....8
   - 2.1 Grain Size Class Separation Methods....8
     - -Pipette Test....10
     - -Bottom Withdrawal Method....12
     - -Centrifugation....13
     - -Filtration....14
     - -Settling Column Test....16
   - 2.2 The Relationship of Sediment and Cs-137....21
   - 2.3 Hydrological Simulation Program-Fortran (HSPF)....23
     - -Physical Representations....24
     - -Information Processing within the HSPF....28
     - -HSPF Jobs and Runs....30
     - -HSPF Input File Format....31
     - -Sediment Transport Modeling with HSPF....39

3. Laboratory Procedures....43
   - 3.1 Limitations of the Settling Column Test....43
     - -Testing for Maximum and Minimum Allowable Initial Weights....44
     - -Test for a Time Delay from Sample Collection to Processing....49
   - 3.2 Obtaining Contaminated Suspended Sediment Samples....50
   - 3.3 Use of a Dispersant in Laboratory Testing...52
   - 3.4 Removal of Organics from Suspended Sediment Samples....54

4. Modeling with the Hydrological Simulation Program-Fortran (HSPF)....57
   - 4.1 HSPF Input File Representing the White Oak Creek Watershed....58
   - 4.2 Model Calibration Techniques....60
   - 4.3 Suspended Sediment Calibration....66
   - 4.4 Cesium-137 Calibration....68

5. Findings and Summary of Results....70
   - 5.1 Laboratory Results....70
   - 5.2 Modeling Results....75

6. Conclusions and Recommendations....78
   - 6.1 The Dispersed Test Comparison....78
   - 6.2 Oxidation of Organics and the Increase of Clay....79

Table of Contents (cont)

Chapter Page

6.3 Contaminant Transport Daily Values During Extreme Storms.....80

6.4 Recommendations for Modeling Contaminant Transport.....81

References.....83

Appendices.....87

Appendix A: Control Input File.....88

Appendix B: Oxidized Input File.....106

Vita.....124

List of Tables

Table		Page
2.1	Fall Times for the Settling Column Test	19
2.2	Sections of the PERLND Block	34
2.3	Sections of the IMPLND Block	35
2.4	Sections of the RCHRES Block	36
4.1	Target and Obtained Output Parameters	63
4.2	Model Validation	65
5.1	Size Fractions by Sample and Size Class	72
5.2	Comparison of Control and Dispersed Cs-137 Concentrations	73
5.3	Comparison of Control and Oxidized Cs-137 Concentrations	75
5.4	Modeling Results: 24 Hour Storm Load	77

List of Figures

Figure		Page
1.1	White Oak Creek Watershed	5
2.1	Nodes, Zones, and Elements	26
2.2	Directed and Non-Directed Graphs	27
2.3	Overview of the HSPF Software	29
2.4	Schematic of Data Flow for a Single Run	32
3.1	Location of Bearden Creek Sample	45
3.2	Total Weight vs. Size Class Weight	47
3.3	Location of White Oak Lake Sample	51
4.1	HSPF Modeling Scheme of White Oak Creek Watershed and Channel Reaches	59
4.2	HSPF Modeling Scheme of Simplified Watershed	61

Chapter 1

Introduction

Hydrologic transport modeling is one of the most important tools used by engineers to determine risks associated with watershed contaminants. The need exists for modelers to have a good understanding of the natural relationship between contaminants and particle size classes to model contaminant processes properly. Work previously performed has shown that certain trends seem to exist in contaminant to size class distributions, but test results vary due to different testing methods. An obvious reason for the inconsistency is testing of samples with different physical and mineralogical makeup (i.e., organic, particle shape, colloidal aggregation, etc.). Another suspected reason is the different types of pre-treatment performed on the sample. The two most common means of pre-treatment are the introduction of a dispersant to a suspended sediment sample and/or the removal of organic content by means of oxidation. Chemical alteration of samples containing particle reactive contaminants could yield unrepresentative results when attempting to model natural processes in a system. Results from a "natural" (or non-chemically altered) sample should best represent real life processes in a system. The objective of this study is to determine if models adjusted by using chemically altered or "natural" contaminant

to grain size fraction results, cause significant differences in forecasted results. The "natural" sample will be considered the control sample in this study.

An important factor in modeling particle-bound contaminant transport is the particle size of the sediment being transported. Small particles, such as clay, are much more easily transported than larger silt or sand particles. Therefore, it is necessary to have accurate particle size information prior to estimating sediment transport and particle-bound contaminant transport.

Many contaminants are transported by means of binding with sediments. Examples include pesticides, heavy metals, and some radionuclides. In this study, the main contaminant observed is the radionuclide cesium-137 (Cs-137) due to its documented extensiveness in the White Oak Creek watershed in Oak Ridge, Tennessee. The watershed is contaminated from more than fifty years of radioactive waste disposal at the Oak Ridge National Laboratory (Sobocinski et al., 1990). Although the data used for this investigation comes from the White Oak Creek Watershed, conceptual conclusions should be applicable to other areas where particle-bound contaminant transport is important.

Scope and Objectives

The purpose of this study is to demonstrate the importance of knowing the "natural" relationships between

particle-bound contaminants and size class distribution when modeling particle-bound contaminant transport. To accomplish this, a lake bed sample from White Oak Lake containing Cs-137 was resuspended in filtered stream water and separated into size classes. The grain size distribution testing was performed on a (1) "natural" (non-chemically altered), (2) a dispersed sample, and (3) a sample that has undergone organic removal. Cs-137 concentrations (pCi/g) were determined for each size class. The contaminant to grain size class relationship results were then used to adjust a computer model to match the "natural" (the control) sample, the dispersed sample, and the sample treated to remove organics. A Hydrological Simulation Program-Fortran (HSPF) computer model input file representing the White Oak Creek watershed was used to determine the sensitivity that sample pre-treatment has when modeling particle-bound contaminant transport loads.

Background of Study

Due to past waste disposal at the Oak Ridge National Laboratory (ORNL) in Oak Ridge Tennessee, many of the surrounding watersheds have become contaminated with radioactive materials. One main radionuclide of concern is cesium-137 (Cs-137) because of its abundance in the watershed, its potential to move off site, and its persistent

30.17 year half-life. Cesium-137 is referred to as a particle-bound contaminant, meaning it will attach itself to sediment and be transported though a hydrologic system with the sediment. Details of the bond between cesium and clay particles are discussed in Chapter II.

One watershed, which has been contaminated is the White Oak Creek Watershed (shown in Figure 1.1). The watershed consists of White Oak Creek, Melton Branch Creek, and several minor feeder tributaries, which eventually empty into the Clinch River. The Clinch River, a major tributary of the Tennessee River, is a vital waterway in East Tennessee and is used for recreation and water supply. Therefore, risk associated with off-site transport of particle reactive contaminants such as Cs-137 is a concern. White Oak Dam (WOD) was constructed approximately 0.6 miles upstream from the Clinch River in the 1950's to form White Oak Lake (Tschantz, 1987). White Oak Lake (WOL) is the primary sink for capturing contaminated suspended sediment before it enters the Clinch River. After years of sediment deposition, the lake has acquired a significant amount of Cs-137 laden sediment. Contaminated sediment that fills the bottom of the lake and resides along the banks and floodplains of White Oak Creek is now being investigated to determine if off-site risk could occur from scouring during a flood event. The possibility exists, that with enough tractive force during a flood, the lake bed could scour and lose much of the

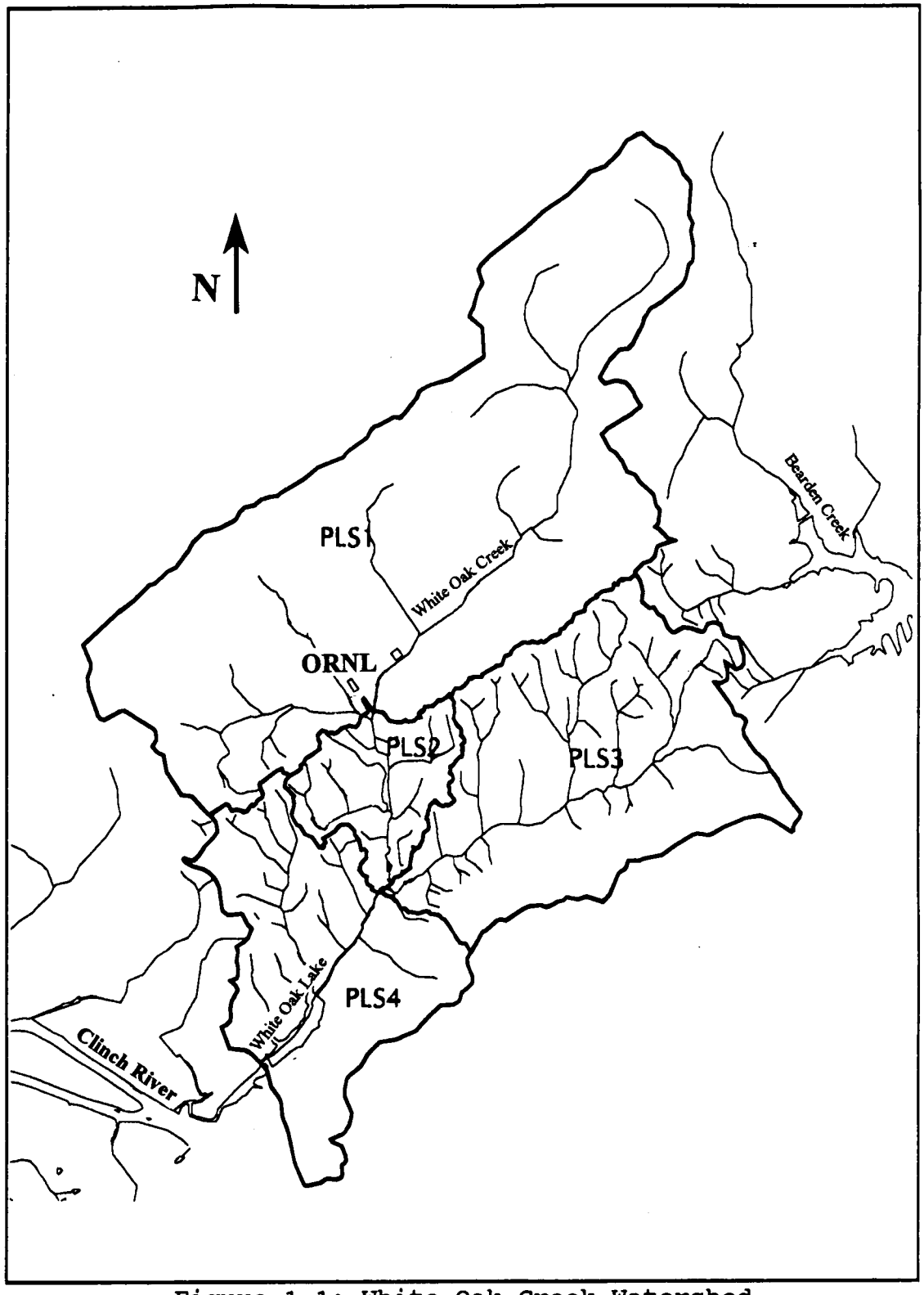

Figure 1.1: White Oak Creek Watershed

contaminated sediment that has been deposited there over the years. If this were to occur, the off-site release would cause human and environmental risks.

Oak Ridge National Laboratory's Environmental Restoration group formed a task team to quantify the risk associated with off-site contaminant transport during storms. This team is referred to as the Sediment Transport Task Team. A general procedure of the task team is as follows:

1. Field Work: collecting various types of samples from the White Oak Creek Watershed, including storm water samples

2. Laboratory Work: processing and analyzing the samples collected from the field to calibrate a computer model
3. Modeling: Using the Hydrological Simulation Program-Fortran (HSPF: EPA, 1984) along with all the data collected to determine the off-site risks associated with an assumed flood events

The HSPF was chosen for use in this study because of its ability to handle streamflow generation, flood routing, sediment transport, and contaminant-sediment interaction (Fontaine, 1991). Also, HSPF is well documented and is being used for a variety of applications at ORNL.

Important data requirements of the HSPF input file are the grain size distribution of the suspended sediment and the

amount of Cs-137 found in the grain size fractions. This need led to the development of a grain size distribution test called the Settling Column Test, which uses Stoke's law for settling velocity as a means for physically distinguishing grain size classes. This test is discussed in Section 2.1.

After the Settling Column Test was developed, the HSPF modelers were concerned with the effects laboratory pre-treatments had on grain size distribution results. Suspicion arose that certain types of pre-treatment of a suspended sediment sample could alter the observed relationship between grain size class and contaminant concentration per size class. One important purpose of this study is to answer questions about the effects of pre-treatment on a suspended sediment sample and relate these effects to (simulated) sediment transport.

Chapter 2

Background/Literature Search

2.1 Grain Size Class Separation Methods

The objective of the literature search is to find a grain size distribution procedure meeting the following criteria:

1. The procedure has to physically separate and characterize the grain size classes (clay, silt, and sand) required for HSPF. This separation is necessary to allow further testing of the separated samples for contamination concentration (pCi/g) per individual size class. Several tests studied do not give physically separated size classes. Grain size ranges are usually 0-4 μm for clay, 4 to 63 μm for silt, and 63-125 μm for sand.

2. The procedure should yield particle size ranges within each size class that are acceptable input for the Hydrological Simulation Program-Fortran (HSPF) computer model.

3. The test must be accurate. Comparison of results

with other grain size separation tests can be the only means of measuring relative accuracy.

4. The test should be reasonably inexpensive, simple to perform, and have a high degree of reproducibility in order to obtain the most natural grain size distribution possible.

5. A non destructive test is desired. The methods of grain size separation should be the least destructive to the natural soil structure as possible.

A literature search indicates that most procedures for determining grain size distribution involve Stoke's Law, which gives fall velocity of particles in a fluid medium. Assuming spherical particles, fall velocity defined by Stoke's Law is:

$$V=\frac{2(\rho_s-\rho_f)gr^2}{9\mu}$$

where: V=fall velocity of the particles in centimeters per second
r=radius of spheres (particles)in centimeters
μ=dynamic viscosity of the fluid in dyne seconds per centimeter

g=acceleration due to gravity
ρ_s=density of sphere in grams per cubic centimeter
ρ_f=density of fluid in grams per cubic centimeter

Several grain size distribution methods that use Stoke's Law include the pipette test, the bottom withdrawal test, centrifugation, and the Settling Column Test.

Pipette Test

A commonly used test for grain size class separation is the pipette test, which utilizes Stoke's Law for determining settling velocity. The procedure involves placing suspended sediment sample into a 1000 ml graduated cylinder and uses both a chemical dispersant and a mechanical mixer. At selected times and at a depth of 20 cm from the surface, 20 ml portions of the sample are drawn off using a pipette (Guy, 1969) The 20 ml portions are dried in an oven for one hour and weighed. The weight of the silt plus clay is determined by taking the initial 20 ml sample's dry weight and multiplying it by 50 (since 20 ml is 1/50 of the entire sample). The amount of sand (>63 μm) is then equal to the total amount of the sample minus the weight of the silt plus clay portion. To obtain size class information on a sample, the following calculation steps are performed (Guy, 1969):

1. Subtract 1/50 of the weight of the dispersant from each 20 ml withdrawal.
2. To determine the amount of material of a certain

size and finer, multiply the weight of the desired size's withdrawal and multiply it by 50. This will yield a weight representing a size class plus all finer size classes.

3. To calculate the weight of an individual size range, subtract the weight of all the samples in that particular size range and finer (as found in step 2) from the total weight of the sample in the size range immediately larger than the one in question.
4. At this point, sequential size fractions can be found from dividing the weight found in step 3 by the total weight of the sample.

This method is considered an accurate means of determining grain size distribution (Allen, 1981; Follmer and Beavers, 1973; Beavers and Jones, 1966). However, a problem develops when trying to determine contaminant per size class. The pipette test yields heterogeneous size fractions (the size fraction of interest plus subsequent size fractions) making accurate contamination counts per size class difficult. Therefore, modeling particle-bound contaminant transport with data collected from the pipette test would prove ineffective because of inaccurate contaminant to grain size distribution information.

Bottom Withdrawal Method

The bottom withdrawal method is another procedure for determining grain size distribution that relies on Stoke' Law for calculating settling velocity (Allen, 1981). It involves placing the suspended sediment sample into a bottom withdrawal tube that is a glass tube equipped with a volumetric scale and a quick-acting outlet at the lower end. Samples are poured into the top of the tube, mixed, and withdrawn from the bottom opening using a control, usually a clamp. The sample is mixed by tilting the tube from side to side for several minutes. Some researchers in conjunction also use chemical dispersants with the mechanical dispersion. At predetermined time intervals, the sample is withdrawn at 10 cm column height fractions. These withdrawals are then filtered, dried, and weighed. A plot called the Odem curve is then used to determine grain size class separation. The curve is plotted on an arithmetic graph having settling time as the ordinate and percent in suspension as the abscissa. Data points obtained from the bottom withdrawal method are plotted on the graph. From the fall time point on the curve relative to the grain size in question, a tangent is drawn to the ordinate. This value is read as percent finer than the given size class (Guy, 1969).

This is a widely used method and is considered an accurate means of determining grain size distribution of a sample. Nevertheless, as with the pipette test, the

individual fractions obtained from the bottom withdrawal method are heterogeneous, thus making accurate analysis of contaminants versus grain size class impossible.

Tests performed at the Oak Ridge National Laboratory have shown that using a dispersant with the bottom withdrawal method alters the grain size distribution when compared with a "natural" sample (Moore, 1994). This information supports the hypothesis that use of a dispersant while testing for grain size distribution can cause a variation in contaminant transport modeling inputs, but this cannot be proved directly from the bottom withdrawal test because of the heterogeneous size fractions.

Centrifugation

Another type of grain size separation is centrifugation. Several different operating procedures involve the use of a centrifuge, but the theory behind centrifugation remains constant. Grain size classes are separated by centrifuging a sample and decanting of the supernatant at predetermined times. These times are different for each type of centrifuge, but can be calculated by relating the force above gravity that acts upon different diameter particles to the rotations per minute. Once a fall velocity is found for each size class desired, a time can be found from the distance it would take for all particles greater than the one in question to settle out of suspension. To quantify the

amount of sediment in each size class, the respective decants are run through a filtering system to pull out all suspended sediments. Once all of the suspended sediment has been filtered out, a grain size distribution can be determined from the individual size class weights and the total sample weight.

Although this method seems to have a high degree of reproducibility (Allen, 1981), there are several reasons that this method may not be a good choice when the "natural" soil size classes are needed. Smaller, dense particles are sedimented or aggregated with larger particles of lower density (Salbu, 1985), thus complicating the grain size class separation. It is believed that the force of the centrifuge could alter the natural soil structure by either causing cohesive materials to compact into denser than natural particles or by breaking up less cohesive material. Consequently, the settling times for all size classes would be significantly decreased for coalescent particles, thus reducing the amount of time in which natural flocs could occur. Centrifugation also has a higher potential for cross contamination than most other grain size separation procedures, which can be a great concern when dealing with samples containing radioactive contamination.

Filtration

Filtration is a simple means of separating a suspended

sediment sample into different size classes. It involves pouring the suspended sediment mixture through small filters (weighed before testing) of various sizes. A sample is passed first through the largest filter to catch the largest size fraction in question, then through subsequent filters. The filters are then dried, weighed, and the original weight is subtracted to determine the individual size class weights. The total sample weight can be calculated by summing the individual size weights, which allows for percentage tabulations.

The tendency for the extremely small filters to clog proves a disadvantage to filtration. Also, the sample is drawn through the filters by a vacuum pump that lends the possibility of breaking up naturally occurring flocs. If performed to its greatest accuracy, filtration provides information on the absolute instead of effective particle size. Absolute particle size refers to the actual measured size of a particle, regardless of whether it has flocculated with other particles. Effective particle size consists of composite particles that are due to flocculation (Walling and Woodward, 1993). In a natural system, the effective particle size is what governs a particle's settling behavior. Therefore, filtration does not yield information relating to the "natural" behavior of a suspended particle.

Settling Column Test

It was determined by the Sediment Transport Task Team at the Oak Ridge National Laboratory that a method that physically separates the grain size classes was needed if proper contaminant transport modeling was to be accomplished (Moore et al., 1994). The team needed a test that would give reliable results for input into the HSPF computer model. The criteria for the test included the need for homogeneous size class fractions that contain enough mass to be analyzed for radionuclide contamination. A method described by Loring and Rantala (1992) was modified by the team to yield results for use in the contaminant transport modeling of the White Oak Creek Watershed. Modification included changing the fall times using Stoke's Law to represent the particle sizes to be used in HSPF. The method, now referred to as the "Settling Column Test" (CT), separates suspended sediment samples into the following four size classes: clay (0-4 μm), fine silt (4-16 μm), coarse silt (16-63 μm), and sand (63-125 μm).

The procedure for the Settling Column Test involves Stoke's Law and decantation. The suspended sediment sample is analyzed by the Settling Column Test in the following fourteen steps (Martin Marietta Energy Systems, Inc., 1994):

1. Allow the raw field suspended sediment sample to set for 24 hours in a 1000 ml graduated cylinder.

2. The cylinder is to have a zero reference mark 2.5 cm from the bottom. Also, reference marks are to be located at 5 cm and 30 cm above the zero line.

3. After settling for 24 hours, almost all of the sediment will have settled to the bottom. The clear liquid can be decanted down to approximately a 5 cm depth. This decanted portion of the sample is filtered and counted as part of the clay fraction.

4. The remainder of the sediment in the cylinder is sieved through a series of 250 μm, a 125 μm and 63 μm sieves. The amount of material collected between the 125 μm and 63 μm sieves is counted as sand. The reason for using a 250 and 125 μm sieve is to keep the smaller 63 μm sieve from clogging with larger particles during the sieving process.

5. The sample portion which passes through the sieves is placed back into the 1000 ml graduated

cylinder. At this point the sample should only contain coarse silts, fine silts, and clays. The surface of the sediment mixture is to be at or above the 5 cm reference line.

6. The temperature of the suspended sediment sample is observed and used to calculate water density, which will affect the fall velocity. This temperature is entered into Table 2.1 and the corresponding time in the column for the clay fraction (<4 μm) is read to determine the time interval before the first clay decant.

7. The sample is then mixed for 5 minutes using a hand-held mixing rod to ensure a homogeneous mixture at the beginning of the time interval. When the mixing is done, the time interval found from Table 2.1 is started.

8. After the time interval has passed, the supernatant is decanted down to 5 cm below the initial surface of the liquid. This decant should contain only particles behaving as a clay sized particle, according to Stoke's Law. This decant is filtered and counted as a part of the clay

Table 2.1: Fall Times for the Settling Column Test

	Size Class	
	Clay	**Fine Silt**
	<0.004 mm	<0.016 mm
Temp (Celsius)		
10	1hr 18min	29min 15sec
11	1hr 16min	28min 27sec
12	1hr 14min	27min 41sec
13	1hr 12min	26min 56sec
14	1hr 10min	26min 13sec
15	1hr 8min	25min 32sec
16	1hr 6.5min	24min 53sec
17	1hr 5min	24min 15sec
18	1hr 3min	23min 39sec
19	1hr 1.5min	23min 4sec
20	1hr	22min 30sec
21	58.5min	21min 57sec
22	57.0min	21min 24sec
23	55.5min	20min 51sec
24	54.0min	20min 18sec

fraction.

9. Sediment free water is then added to the mixture to fill the graduated cylinder to the 5 cm reference line, the sample is mixed, and the time interval is started again.

10. This process is continued until the supernatant is almost completely free of visible sediment. At this point all of the clays are removed from the sediment, and fine silt and coarse silt should be all that remain in suspension.

11. Now sediment free water is added until the surface reaches the 30 cm mark. The temperature is measured again and the withdrawal time is determined from Table 2.1. The time interval under the fine silt column (<16 mm) is then noted.

12. The process for decanting the fine silts is the same as the process for the clays, but the time intervals will be shorter and the reference mark for the surface is at 30 cm above the zero line.

13. Once the decanted supernatant comes off clear, all of the fine silts have been removed. At this

point, all that should be left in the graduated cylinder is coarse silt (16 mm to 63 mm). The remaining sediment fraction is then filtered, dried, and counted as coarse silt.

14. When all of the filters are dried and weighed, the suspended sediments total weight and individual size class weights are tabulated.

Once the procedure is complete, separated homogeneous size fractions capable of being analyzed for contamination can be obtained.

2.2 The Relationship of Sediment and Cs-137

Cesium-137 is referred to as a particle-bound contaminant. When it is released into a hydrologic system, frequently it attaches to a sediment particle. Previous studies concerning the behavior of particle-bound radionuclides in a watershed have shown that Cs-137 often attaches itself to the clay fraction of soils more abundantly than to silts or sands. Lomenick and Tamura (1965) found that fine and medium clay absorb more than ten times the quantity of cesium-137 per gram than coarse and medium silts. They reported that 84% of the Cs-137 detected in their total sample was found in the clay fraction. This indicates that

the clay fraction is the most important size class when considering contamination counts for modeling.

Before discussing the way that Cs-137 attaches itself, or absorbs to clay particle, an explanation concerning the structure of the clay particle is necessary. The minerals that compose clays are generally illite, kaolinite, and montmorillonite. Other minerals are also found in the make up of clay particles, but are found usually in insignificant amounts. Two different structures that are associated with the clay minerals making up the clay particles. They are, according to Graf (1984) after Grim (1962):

> One unit consists of two sheets of closely packed oxygens or hydroxyls in which aluminum, iron, or magnesium are embedded in octahedral coordination, so that they are equidistant from six oxygens or hydroxyls....
>
> The second unit is built of silica tetrahedrons. In each tetrahedron, a silicon atom is equidistant from four oxygens or hydroxyls, if needed to balance the structure, arranged in the form of a tetrahedron with a silica atom at the center. The silica tetrahedral groups are arranged to form a hexagonal network, which is repeated indefinitely to form a sheet....

Clay particles are primarily composed of one or both types of structures, forming a lattice structure. Of the three main minerals that clays are composed of, illite is

the main carrier of cesium (Lomerick and Tamura, 1965). The other minerals, kaolinite and montmorillonite, usually contain only trace amounts of cesium.

Cesium fixation to a clay particle's lattice structure occurs at several different locations (Jacobs and Tamura, 1960): (1) On the sides of the clay surface. These locations on the sides of the particle surface tend not to be permanent, They are easily exchangeable sites for cesium and other cations. (2) On the edges of the clay mineral lattice. These sites seem to be more permanent than the surface sites. (3) Interlayer sites in which the cesium is trapped during lattice collapse. Cs-137 will be permanently fixed at these interlayer sites.

The fact that the clay fraction is the main carrier of cesium-137 makes it the most important of the grain sizes when modeling particle-bound contaminant transport. Consequently, understanding the effects that different types of laboratory pre-treatment have on the behavior of the clay fraction is important and necessary.

2.3 Hydrological Simulation Program-Fortran (HSPF)

The Hydrological Simulation Program-Fortran (HSPF) (EPA, 1984) was developed for the U.S. Environmental Protection Agency for water resource modeling. It was designed to help modelers effectively organize vast resources of data required

for accurate hydrologic modeling, such as this study. HSPF allows the user to continuously simulate most hydrologic, sediment transport, and water quality processes in a fresh-water system.

Physical Representations

The HSPF views the physical layout of a system (i.e., a watershed) as divided into elements, which consist of nodes and zones. A node represents a point in space. It can consist of particular values of a spatially varied function such as cross sectional area of a channel, flow, and water surface elevation. A zone illustrates a small portion of the real world. A zone will usually use nodes as boundary conditions. As an example, consider a channel reach with known cross sectional areas at an upstream and downstream location. Nodes would consist of the information at the upstream and downstream locations, such as cross sectional area, flow, and such. The reach between the nodes would be represented as a zone, consisting of such information as storage. The zone receives inflow and discharges outflow; these actions are referred to as fluxes. The relationship between nodes and zones is similar to that of a definite integral of a function and the limits of integration (EPA, 1984).

An element comprises nodes and/or zones. No set rules explain the grouping of nodes and zones to form elements. The

user must group them to best represent the system being modeled. Elements called segments are used to model the response of the land phase of the hydrologic cycle.

Segments are portions of land which are assumed to be homogenous. A segment that comprises a pervious surface is called a Pervious Land Segment (PLS). PLSs are comprised entirely of zones; they have no nodes. A PLS is a segment that would consist of such information as infiltration rate, precipitation data, evaporation data, and similar information pertaining to pervious land. Graphical representation of nodes, zones, elements, and Pervious Land Segments are illustrated in Figure 2.1.

Elements of similar nature are usually grouped together in what is called a processing unit (PU). Any element that cannot be simulated alone must be grouped into a PU with the other elements with which it is interacting. Having processing units with only one element in it is possible, however. The HSPF performs most efficiently when simulating one processing unit for the desired range before moving on to the next PU. The summation of all the processing units in a given run is called a network. Processing units must be linked together sequentially, in what is called a directed graph. Figure 2.2 shows directed and non-directed graphs. A directed graph can contain no cycles or bidirectional fluxes.

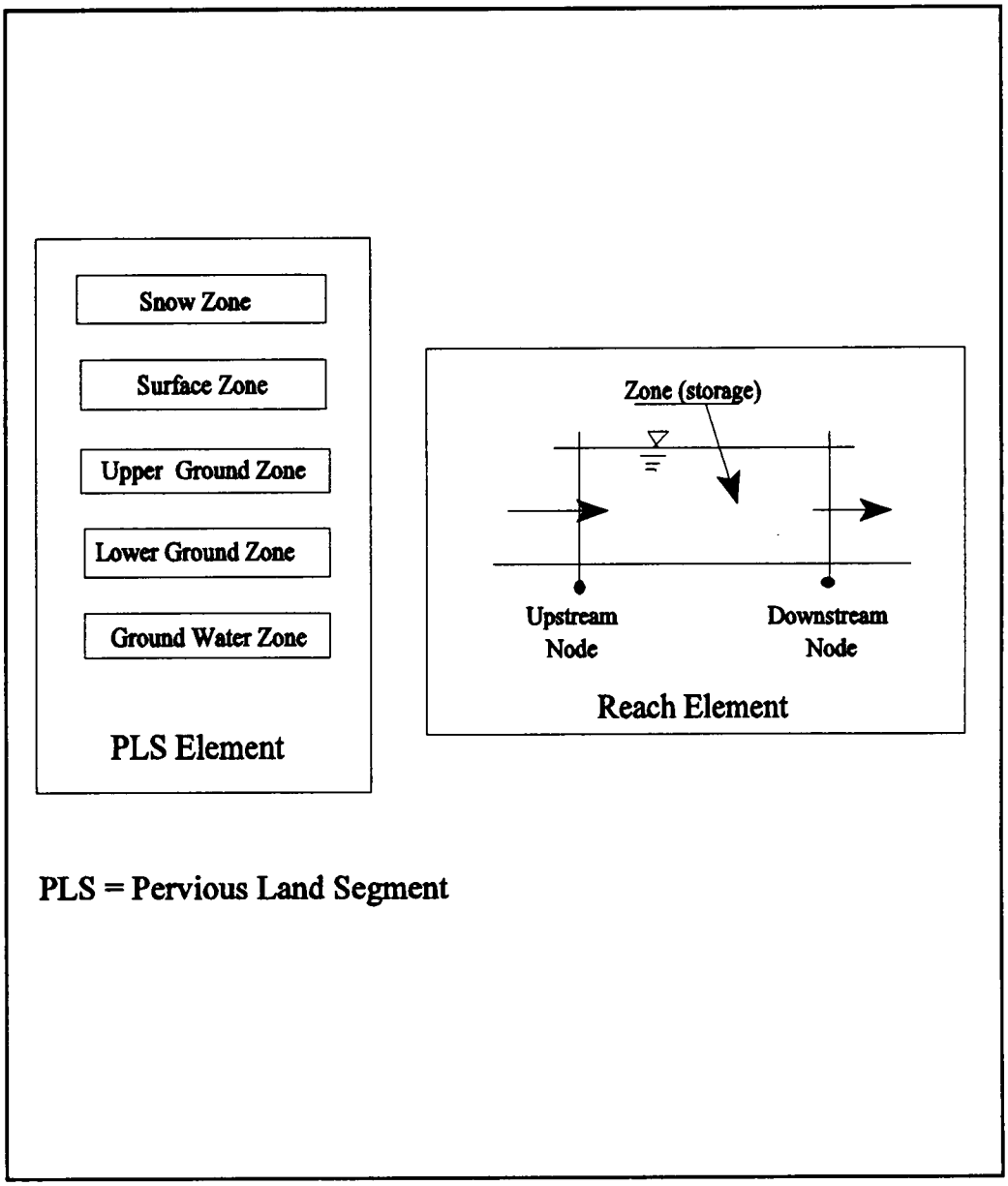

Figure 2.1: Nodes, zones, and elements

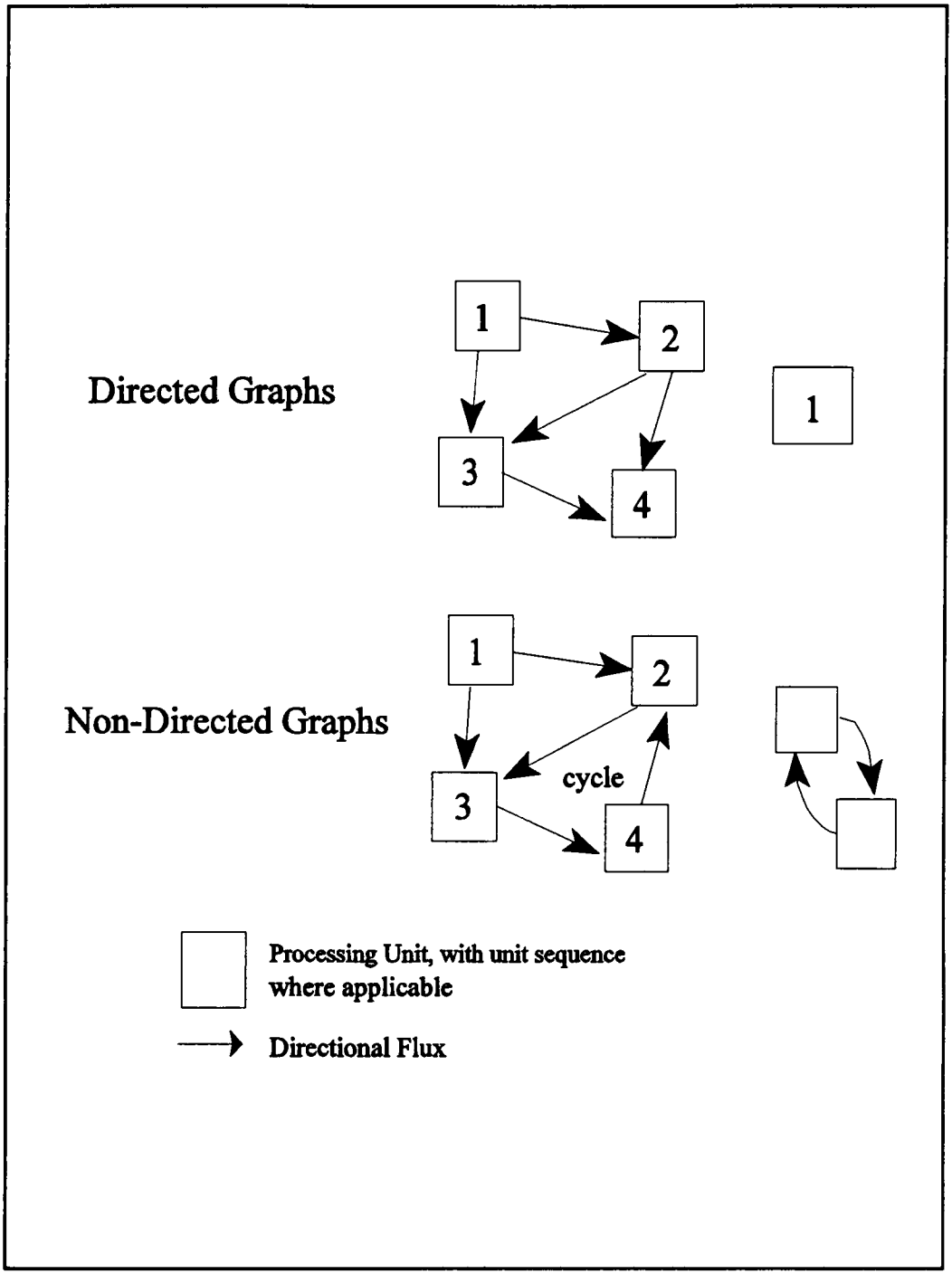

Figure 2.2: Directed and Non-Directed Graphs

Information Processing within the HSPF

An HSPF simulation run can be viewed as a group of operations performed in sequence. The graphical representation of an operation is shown in Figure 2.3 as the operations supervisor, the get time series, the put time series, and the operating modules group (ie., module 1, module 1+i, module n). The main activity of an operation is performed by the operating modules (OM) group. They function from an input time series for a specified time to generate a set of output time series. The time series data, which are viewed as an "internal scratch pad" (INPAD), all have the same time interval and duration. The operating module receives the internal scratch pad with time series data, performs its specified operation, and then returns output to the operations supervisor. The physical time corresponding to the time series data is called the "internal scratch pad span" (INSPAN).

An operation uses three types of time series storage. They include the time series store (TSS), sequential files, and the internal scratch pad. The time series store is the main storage location for time series data. It is viewed by the HSPF as a large file found on a disc. It can be divided into smaller data sets, which are self-contained. Sequential files contain a sequential data set, such as punch cards, magnetic tape, a sequential disk file, or a line printer (EPA 1984). The internal scratch pad is used when more than one

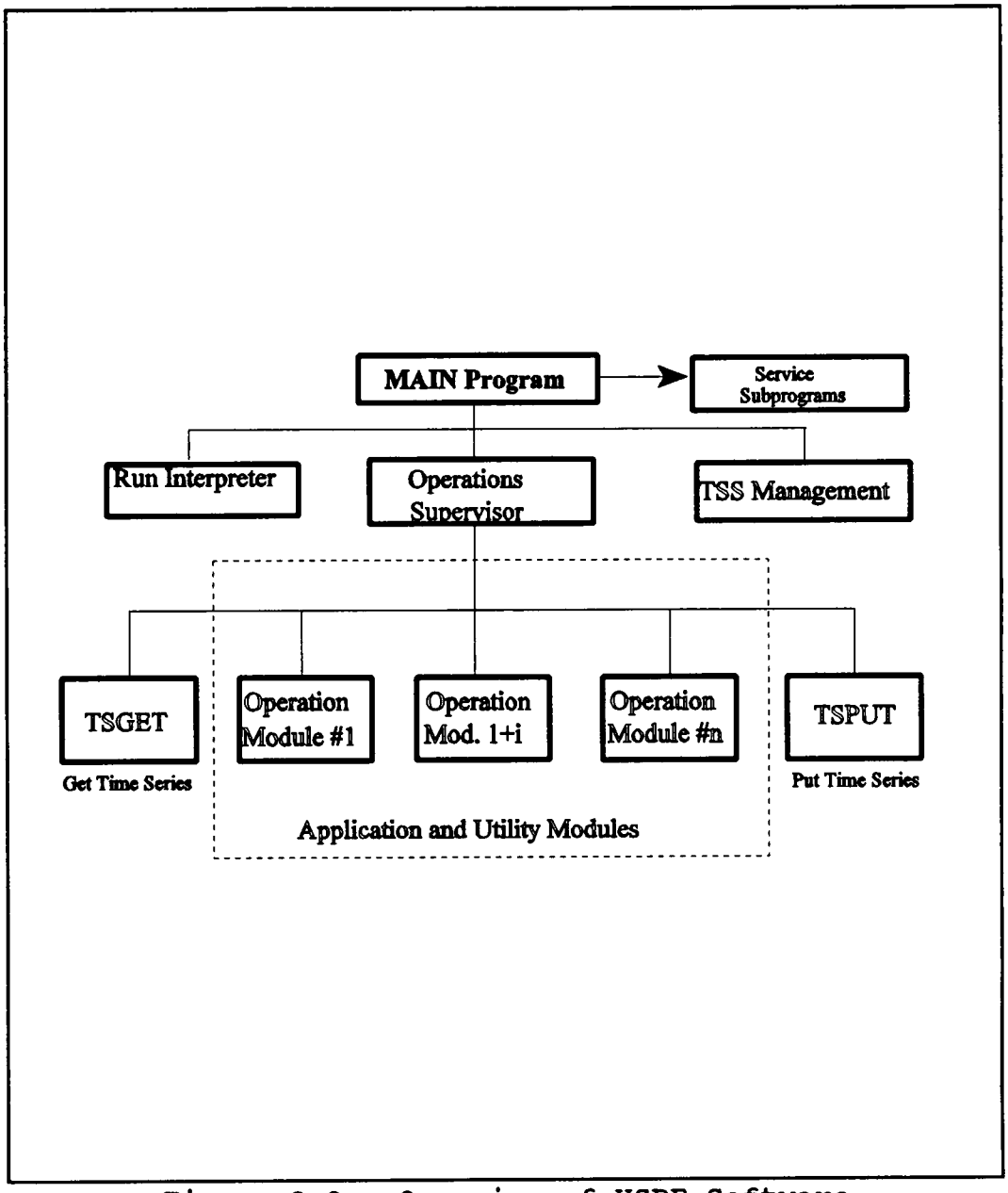

Figure 2.3: Overview of HSPF Software

operation in a sequence use the same time step.

The rest of the organization of HSPF software is also shown in Figure 2.3. The following is a description of the various functions in the hierarchy:

The *run interpreter* is a set of subprograms designed to interpret the *users control input*. It interprets the order in which the operations of HSPF will be performed. It also controls the initial conditions and other parameters for each operation, and it creates an instruction file to keep the time series correct between operations.

The *operations supervisor* is a subroutine, which utilizes information from the run interpreter. It is responsible for calling up the proper application of utility modules. It passes the correct parameters and variables from the run interpreter to the modules.

The *time series store management* modules manipulate data in the time series store, while the time series management system (TSMS) refers to all modules that only manipulate or store time series. The TSMS includes the TSS management functions, the get time series function (TSGET), and the put time series function (TSPUT).

HSPF Jobs and Runs

A job is the work performed by HSPF in response to a complete set of Users Control Input and consists of one or more runs (EPA, 1984). A run is considered a set of one or

more operations that all perform within the same time span. Figure 2.4 shows the operational process of a single run. The sequence of events in Figure 2.4 is as follows (EPA, 1984).

1. Operation 1 is performed until its output rows in the INPAD are full.
2. Data is transferred from those full rows to other time series storage areas.
3. Steps 1 and 2 are repeated for operations 1-4 in INGRP1.
4. Steps 1, 2, and 3 are repeated until the run span is complete.
5. The INPAD is reconfigured and works on operations 5-11 proceeds as stated in steps 1-4. This is done for INGRP2 and then INGRP3.

HSPF Input File Format

The HSPF computer model contains many different input parameters to represent the natural world. The input parameters needed to represent the natural world varies depending upon what is to be modeled, so not all these parameters are required. This allows the user to create an input file representing almost any possible hydrologic or contaminant transport system.

Three main modules, or blocks, which are used to physically describe a system. These are the PERLND block

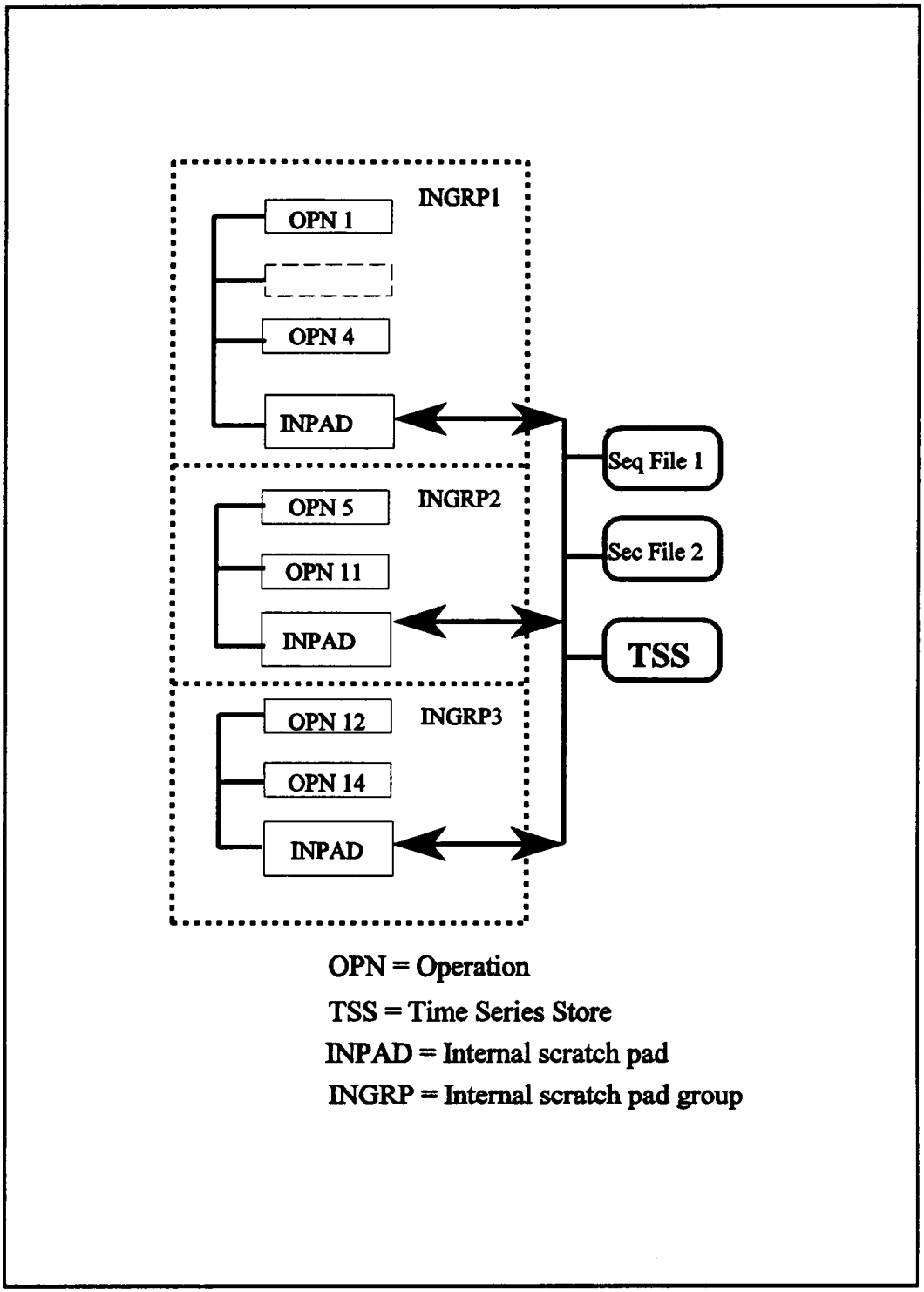

Figure 2.4: Schematic of Data Flow for a Single Run

(pervious land segment), the IMPLND block (impervious land segment), and the RCHRES block (free-flowing reach or mixed reservoir). Each of these blocks contains many optional parameters, which cover a broad range of hydrologic possibilities. Copies of the input files used for this study can be found in Appendices A and B.

Within each of the PERLND, IMPLND, and RCHRES blocks are sections that can be used to customize an input file to represent a hydrologic system. Tables 2.2, 2.3, and 2.4 show how each section in the main blocks is used. Usually, a system will be broken into several different pervious and impervious land segments, connected by different reaches. Containing multiple geographic representations is not necessary for an output file if only a small portion of the natural world is being modeled. The HSPF can model either a pervious or impervious land segment; likewise, it can model a free-flowing reach or reservoir. The modeler must decide how many different "pieces" the natural system should be broken down into and how the pieces should be connected.

The manner in which the different blocks of a system are linked together is programmed in the NETWORK block. The NETWORK block input asks for a parameter, its current location (block and section), and where the modeler would like the parameter to be applied. For example, the NETWORK block can take all of the calculated runoff from pervious land segment number 1 (PLS 1) and connect it with reach

Table 2.2 Sections of the PERLND block

Section Name	Brief Descripition
ATEMP	Correct Air Temperature for Elevation Difference
SNOW	Simulate Accumulation and Melting of Snow and Ice
PWATER *	Simulate Water Budget for a Pervious Land Segment
SEDMNT *	Simulate Production and Removal of Sediment
PSTEMP	Estimate Soil Temperatures
PWTGAS	Estimate Water Temperature and Dissolved Gas Concentrations
PQUAL *	Simulate Quality Constituents Using Simple Relationships with Sediment and Water Yield
MSTLAY	Estimate Moisture Content of Soil Layers and Fractional Fluxes
PEST	Simulate Pesticide Behavior in Detail
NITR	Simulate Nitrogen Behavior in Detail
PHOS	Simulate Phosphorous Behavior in Detail
TRACER	Simulate Movement of a Tracer

* indicates if section was used in this study

Table 2.3 Sections of the IMPLND block

Section Name	Brief Descripition
IWATER	Simulate the Water Budget for an Impervious Land Segment
SOLIDS	Simulate Accumulation and Removal of Solids
IWTGAS	Estimate Water Temperature and Dissolved Gas Concentrations
IQUAL	Simulate Washoff of Quality Constituents Using Simple Relationships with Solids and Water Yield.

* indicates if section was used in this study

Table 2.4 Sections of the RCHRES block

Section Name	Brief Descripition
HYDR *	Simulate Hydraulic Behavior
ADCALC *	Prepare to Simulate Advection of Fully Entrained Constituents
CONS	Simulate Conservative Constituents
HTRCH	Simulate Heat Exchange and Water Temperature
SEDTRN *	Simulate Behavior of Inorganic Sediment
GQUAL *	Simulate Behavior of a Generalized Quality Constituent
RQUAL	Simulate Constituents Involved in Biochemical Transformations

* indicates if section was used in this study

number 1 (RCHRES 1) as inflow from upstream. The NETWORK block allows any type of data to be routed this way, such as sediment, water quality, and hydraulic parameters. It also allows for the data to be input into another block that is established to create a graphical display in the output. This is accomplished by sending data into the DISPLY (display) block, which allows the modeler to customize the desired output.

The input used for time series information (i.e., precipitation data) used to be stored in an HSPF TSS file, but the file was cumbersome and difficult to use. The WDM (Watershed Data Management) file has replaced the TSS due to its ease. The WDM file is created using the ANNIE program (USGS, 1990). Types of information that can be stored and processed in a WDM file are precipitation, evaporation, infiltration, soil temperatures, or virtually any type of time series data. These time series data sets can contain time steps of one second to one year, and cover a period of one hour to one century. So it can be seen that time step series files can be quite cumbersome to manage. WDM's are used along with the ANNIE program to make huge time series data sets more manageable. In many cases data for WDM files can be downloaded from other sources to reduce the time spent manipulating large quantities of data into a format the HSPF can use. Usually only one WDM file is used with an HSPF run, but this file contains many different types of information.

Each different type of information is contained in a separate data set number (DSN). For example, the precipitation data may be stored in DSN #45 while the evaporation data may be in DSN #3. A WDM file can handle up to 32,000 data sets.

The EXT SOURCES (external sources) block is used to tell the program which data set number (DSN) in a WDM file is to be used. The EXT SOURCES block is usually used to call a multiple of different data sets from a WDM using the data set numbers as a marker. The EXT SOURCES is also used to specify the type of data being read from the WDM's different data sets, such as PRCP (precipitation), EVAP (evaporation), and TEMP (temperature). This block also allows for a multiplication factor to be used with incoming data sets to account for any data manipulation needs, such as conversions from English to metric.

WDM files can also be used as a location for output data collection from the HSPF. This is an option that can be used along with or instead of the previously mentioned DISPLY block. Using a WDM file as an output receiver can be accomplished using the NETWORK block to send information to a specified WDM data set. This data set is constructed using the COPY block. Once a run is complete, and the output has been sent to the desired WDM file, ANNIE can be used to create graphical plots of chosen HSPF output.

Sediment Transport Modeling with HSPF

The HSPF computer model allows the user to simulate sediment transport using a variety of input descriptions. Sediment transport can be modeled as coming from a pervious land segment (PLS), an impervious land segment, or as moving though a reach.

In a pervious land segment, sediment movement depends on several influences, such as wash-off, overland scour, man-made influences, rainfall splash, ground cover, and atmospheric fallout. These parameters are input in the SEDMNT section of the PERLND block. The equations used to produce and remove sediment are based on the Agricultural Runoff Management (ARM) and NPS models (EPA, 1984). Most of the equation input parameters are capable of being considered monthly to allow for seasonal changes on sediment transport.

HSPF also allows the user to model both dissolved and particle-bound contaminants coming off a pervious land segment. Input for values concerning contaminant movement in a PLS are entered in the PQUAL section of the PERLND block. HSPF will handle constituent movement that is associated with sediment, overland flow, interflow, and groundwater flow.

Several factors influence the way in which HSPF will model sediment transport through a reach. Variables include sediment inflow into the reach, suspended storage, deposition or scour of the bed, and total bed storage. The purpose of

the SEDTRN section of the RCHRES (reach) block is to simulate the transport, deposition, and scour of sediment in reaches and reservoirs. Within the SEDTRN section, sediment is broken down into 3 size fractions: sand, silt, and clay. The size range used for each fraction is specified by the modeler. For each of the 3 size fractions, the initial suspended sediment concentration (mg/L) and the percent of each in the initial bed composition is needed for input.

The behavior of sand in the reach can be modeled by the Toffaleti equation, the Colby equation, or a power function. Input parameters for sands include the effective diameter of sand particles (D_{50} usually), the settling velocity in still water, and the density of the sand. If using the power function for sand transport, a coefficient (KSAND) and exponent (EXPSND) for the function must also be input.

Silt and clay within the reach are modeled similarly. The information required for silt and clay include mean particle diameter within a size class (D_{50}), settling velocity in still water, density, critical shear stress for deposition and for scour, and the erodibility coefficient.

HSPF assumes that the scour or deposition of sediment does not affect the hydraulic properties of the channel (EPA, 1984). Also, it assumes that each of the three size classes will deposit in different locations within the reach. Because of this, armoring is not modeled. Lateral movement of bed sediments is also ignored.

A variety of constituents can be modeled within the RCHRES block. Through a combination of optional input parameters in the GQUAL section, any constituent can be modeled. Of interest for this study is the manner in which HSPF models particle-bound contaminant transport. To model particle-bound contaminants, the user must input the way in which it is distributed on the sediment. The amount of contaminant per size fraction must be entered for both the suspended sediment and the bed load sediment, equating to six size fractions (sand, silt, and clay for both suspended and bed sediment). Values for absorption and desorbtion rates must be entered for these six fractions. HSPF also allows for a first order decay rate to be considered. In this study, however, the decay rate will not be considered for cesium-137, because it has such a long half life (30.17 years) relative to the reach travel time (hours). Therefore, the Cs-137 concentration in the watershed will not significantly change over the run length due to decay.

The documentation of HSPF states that the SEDTRN section of the RCHRES module asks for input pertaining to inorganic sediment. Within the HSPF documentation, no reference is made to modeling organic material in reaches or free-flowing reservoirs. However, inorganic and/or organic sediment can be modeled in the SEDMNT section of the PERLND module. Since a pervious land segment (PERLND module) is usually followed by a reach or reservoir (RCHRES module), it appears that

there is an inconsistency. This inconsistency is that organics can be modeled coming off a pervious land segment (PLS) but cannot be modeled flowing through a reach. However, if it is believed that organics play an important role in the sediment transport within a reach or reservoir, they can be accounted for in the input as inorganic material. For inorganic material transport modeling, the total densities of the sediment would have to be adjusted to account for the inorganic/organic mixture.

Chapter 3

Laboratory Procedures

The Settling Column Test (Moore et al, 1994) was chosen for use in this study due to its ability to produce homogeneous grain size classes necessary for contaminant analysis. A previous comparison study indicates the grain size class results from the column test compared well with commonly used grain size distribution procedures (Moore et al, 1994). The settling column test compared well with the bottom withdrawal procedure and the pipette test.

3.1 Limitations of the Settling Column Test

Limitations of the settling column test had not been fully explored by the developers, therefore, a study of the limitations was performed on the test to verify the validity of its use. One question arising with the settling column test is the maximum and minimum mass size that could be tested accurately. Also in question was the length of time a refrigerated sample could sit without altering the soil size classes.

Identical suspended sediment samples were needed in order to test the limitations of the settling column test. In order to obtain identical samples, a clean stream bed core

(no contaminants) was taken from Bearden Creek in Oak Ridge (see Figure 3.1 for location). A single core sample was taken because is was capable of being converted into many identical suspended sediment samples. This was accomplished by first mixing the core sample mechanically to ensure a homogeneous mixture of grain sizes throughout the core. The core was split into several samples with mass ranges from 0.13 to 5.4 grams. Each split was then suspended in deionized distilled water. At this point, samples containing various mass weights of identical grain size distribution were available for testing the limitations of the settling column test.

Testing for Maximum and Minimum Allowable Initial Weights

Historically, the minimum mass a grain size distribution procedure will allow for accurate measurement is 0.5 grams of sediment (the bottom withdrawal procedure, which operates with approx. 500 ml of suspended sediment sample). In this investigation of the limitations of the settling column test, the lowest weight of sediment used was 0.1267 grams and the largest was 5.3932 grams. A total of eighteen suspended sediment samples between the two maximum and minimum weights all taken from the same Bearden Creek core was used in this study to determine the limiting sizes that could be used with accuracy. It was found that after separating all the samples into the four desired size classes that there is

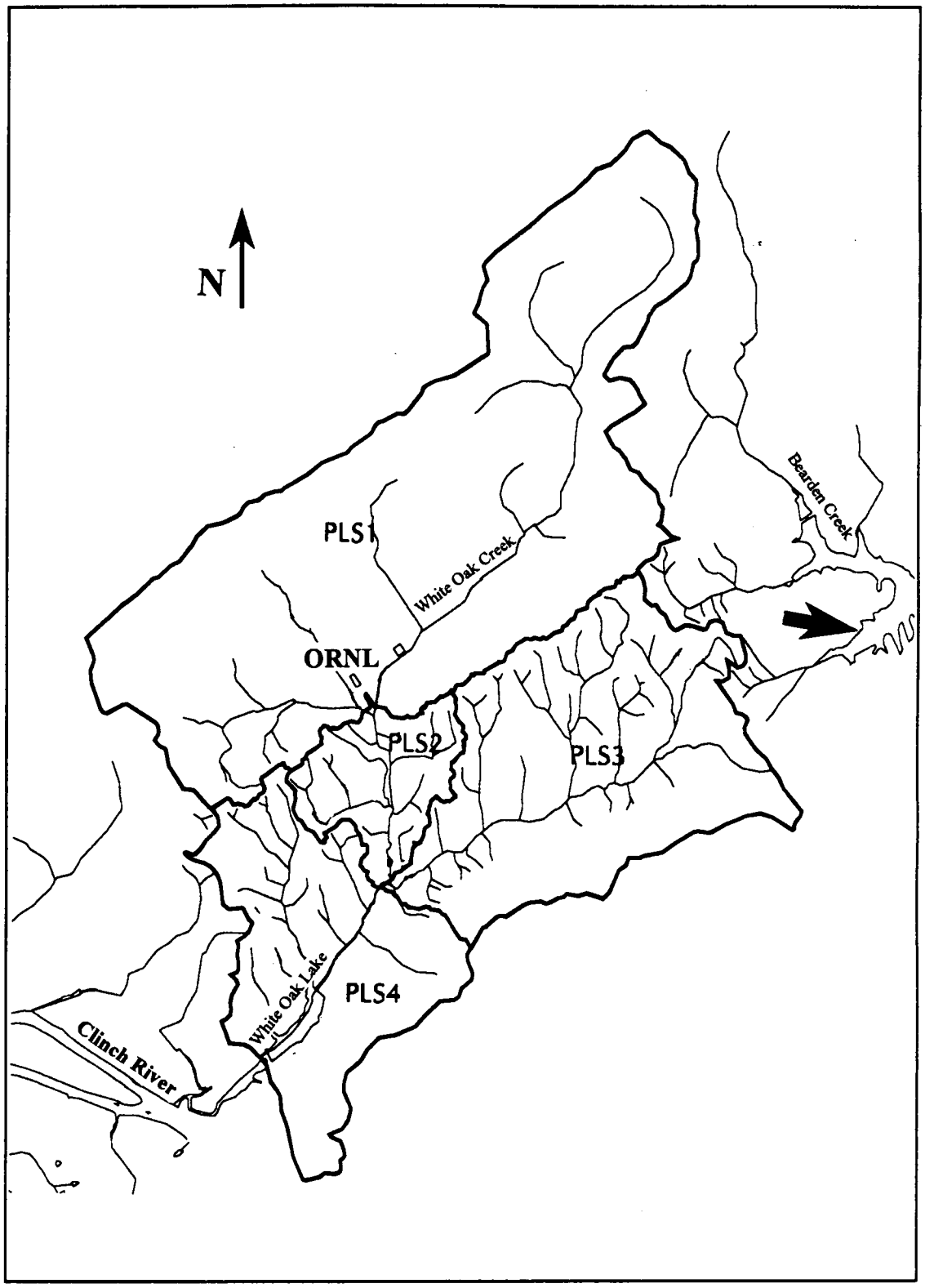

Figure 3.1: Location of Bearden Creek Sample (sample location marked with arrow)

statistically no difference between the two high and low weight ranges.

To show that the eighteen samples from the same location statistically yielded the same results, proof of a linear fit between total weight of the samples and individual size class weights had to be established. This is illustrated by plotting the total weights of all size classes versus the separated size class weights (see Figure 3.2) As an example, the equation of the line for the clay size fraction would then be:

$$y = mx + b$$

Where: y = The amount of clay in the suspended sample (grams)

x = The total weight of the sediment in the suspended sediment sample (grams)

m = The percent (in decimal form) of the total weight that was found to be clay

b = The y intercept ($b \cong 0$ by regression)

To prove that a linear fit adequately represents the eighteen samples as the total weights change from the low to high range, data were put into both a linear equation and a quadratic equation. Then the equations were tested statistically to determine the level of probability of

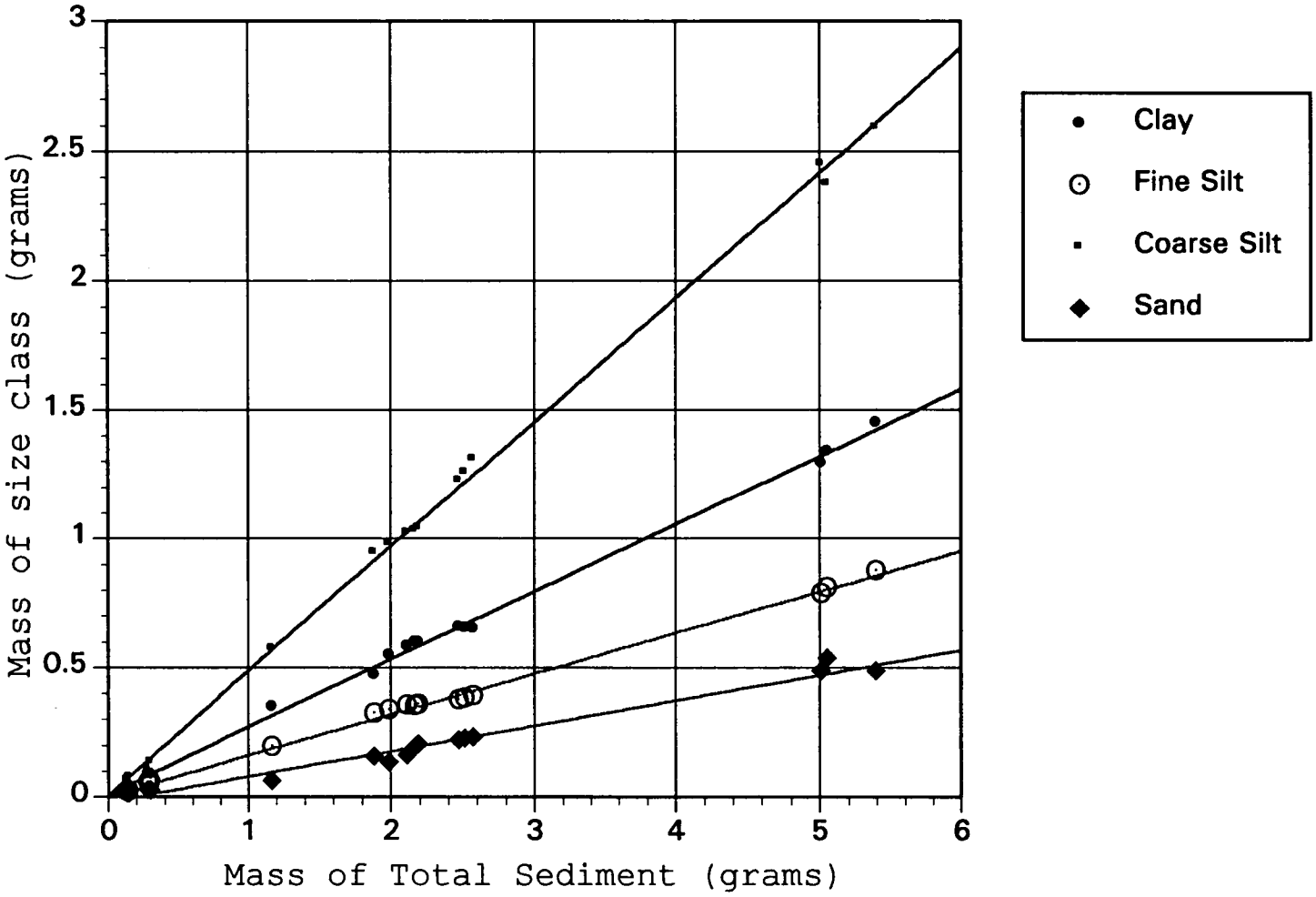

Figure 3.2 Total Weight vs. Size Class Weight

conformity. To do this, a value called the P factor was used. The P factor is the smallest level of significance (α) for which a hypothesis can be rejected (Larsen and Marx, 1981). The comparison of these two different types of equations show that the clay, fine silt, and coarse silt fractions all behave linearly with a P factor greater than 0.05. This is considered a very significant linear fit. However, the sand fraction showed evidence of conforming to a quadratic equation. However, the curvature of the sand equation is insignificant. Furthermore, the separation of the sand is not a part of the Settling Column Test. Sands are sieved out of the initial sample before the sample is even transferred to the 1 liter graduated cylinder. The only explanation for a variation in sand percentage is from an insufficient mixing of the initial core sample to allow the sands to be evenly distributed. Furthermore, since the percentage of sand found in the core taken from Bearden Creek is very small compared with the other size classes (8.41% average), any slight deviation between samples would be amplified when represented by a quadratic equation.

The actual maximum and minimum sediment weight that should be used were not found because all the sizes tested compared statistically. Since suspended sediment masses would seldom fall outside the 0.1267 grams to 5.3932 grams weight range, the settling column test can be used with

3.2 Obtaining Contaminated Suspended Sediment Samples

In order to determine the effects of pre-treatment when determining contaminant to size class relationships, suspended sediment samples had to be obtained for testing. For reasons of waste minimization practices and environmental and human safety issues, only one contaminated sample could be obtained from the White Oak Creek Watershed for use in this study. Ideally, one would want a suspended sediment sample taken during an extreme storm event, but because obtaining a storm event sample was not practical with the limited resources available, another option had to be utilized. Also required were several identical samples or one large sample capable of being separated into identical replicates. Beginning with identical samples when performing a comparison of results stemming from different laboratory procedures is necessary.

To accomplish the task of acquiring several identical suspended sediment samples, a core sample was taken from the bed of White Oak Lake near the mouth of White Oak Creek (see Figure 3.3). As with the Bearden Creek core sample, the contaminated sample from White Oak Lake was used to generate identical suspended sediment samples. The initial weights used to create suspended sediment samples were approximately 5.0 grams before sieving off the coarse sand fraction (d >

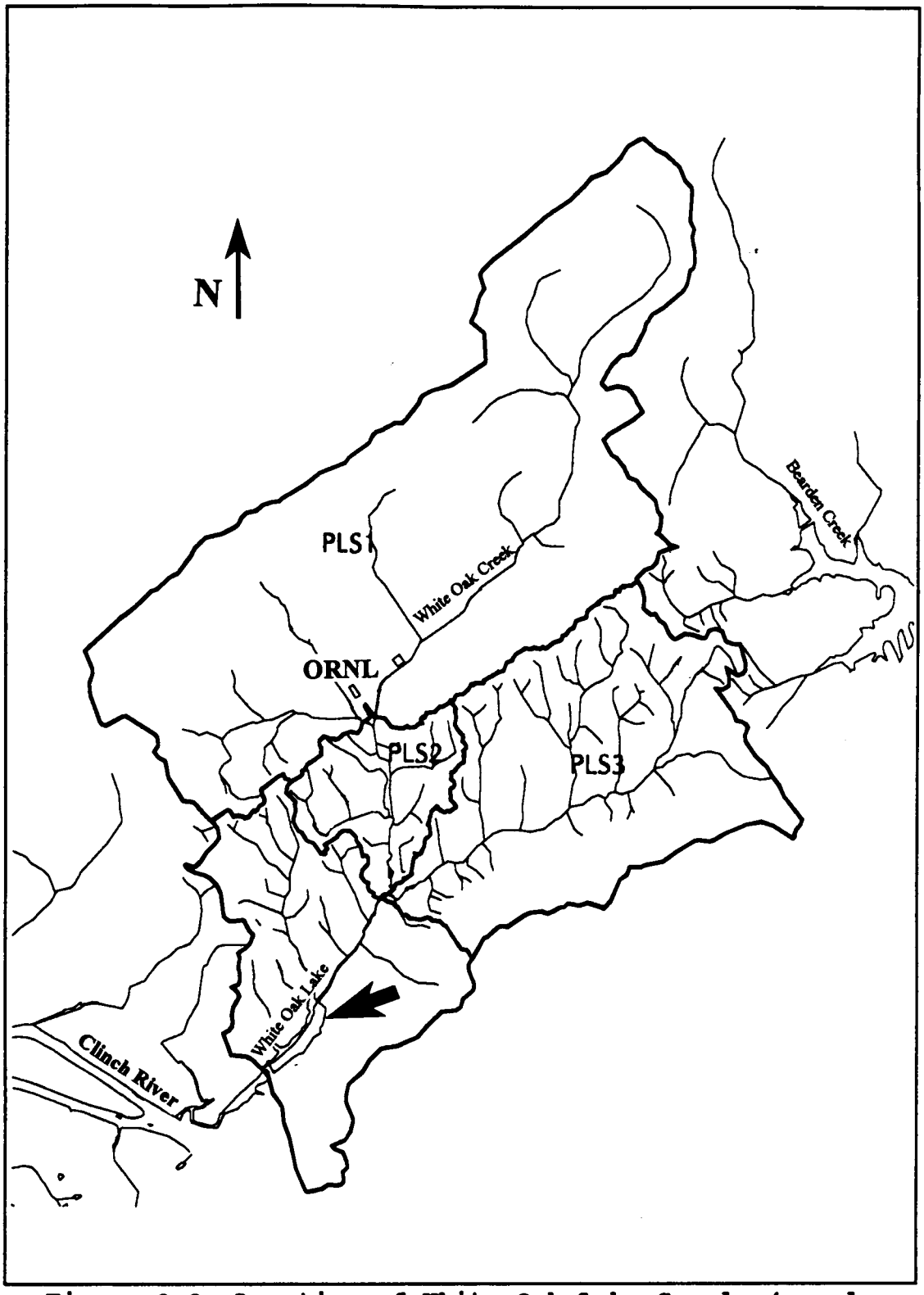

Figure 3.3: Location of White Oak Lake Sample (sample location marked with arrow)

125 μm). After the sieving of the larger materials was complete, an average weight of 2.90 grams of sediment was resuspended and used with the column test. This weight fell well within the range of allowable initial starting weights defined by the limitations testing.

3.3 Use of a Dispersant in Laboratory Testing

One of the most common pre-treatment methods for grain size class distribution analysis is the addition of a chemical dispersant. Dispersants are used to keep grain to grain sediment flocculation from occurring and to facilitate a complete mixture of the grain size classes. This is usually accomplished by forcing all of the sediment particles to be surrounded by a negative charge, thus causing them to repel one another. This effect, called the double layer theory, is discussed further in this chapter. The use of a dispersant was studied to determine the effects dispersants have on contaminant concentration in relation to grain size class when using the settling column test. The results were used to calibrate the HSPF computer model to detect the effect a dispersant may have when modeling particle bound contaminant transport.

To understand the effect a dispersant has on laboratory results of grain size distribution, first a control sample

had to be examined. This involved separating the grain size classes using the settling column test without any pre-treatment being performed on the suspended sediment sample. This control test was performed with three replicates to ensure accuracy of the procedure (sample ID's: 1218CT01, 1218CT02, and 1218CT03). These control samples are used for comparison with a dispersed sample and other means of laboratory pre-treatment.

The next step was to separate the grain size classes of a dispersed sample using the settling column test. Again, to ensure accuracy of the procedure, three replicates were run simultaneously (sample ID's: 1218CT04, 1218CT05, and 1218CT06). To disperse the sample, sodium bicarbonate was added to the suspended sediment sample until a pH of 9.5 was reached (Jackson, 1975). Reaching a pH of 9.5 is to ensure that enough sodium is in the solution to cause dispersion. Most cohesive sediment particles have a negative charge; this negative charge attracts a positive cloud around it. The positive cloud in turn attracts a negative cloud on top it. This phenomenon is usually referred to as the "double layer theory". Adding sodium bicarbonate strengthens the ionic layers of the outside negative cloud, making the particles with the strong negative cloud repel one another and thus causing dispersion (Jackson, 1975).

After the settling column test had been performed on both the control and dispersed sample, the concentration of

cesium-137 per size class was determined. To prepare the sample for contamination analysis, the filters that contain all of the dry sediment were separated into their respective size class. For each of the six tests performed to this point (three dispersed and three control), one filter contained sand, two contained fine silt, one contained coarse silt, and eight contained clays. After separation, the filters were placed into separate scintillation vials (approx. 20 ml plastic vials). Therefore, for each time the column test was performed, four vials contained the dry, separated size fractions. At the Gamma Counting Laboratory in the Environmental Science Division at ORNL, the samples were analyzed to determine the amount of gamma radiation each of the vials (one size fraction per vial) produce. Knowing the weight of the size fraction in each vial, the concentration of Cs-137 could then be determined in pCi/g (pico-Curies/gram). The end product of the procedure was the knowledge of the size class distribution, along with the percent of total contamination found within each size class.

3.4 Removal of Organics from Suspended Sediment Samples

Another common pre-treatment technique for grain size class distribution analysis is removing the organics. In many procedural documentations, removal of the organics is one of the first recommended steps after collecting a sample.

Frequently when a grain size distribution test is created, the developers are only interested in the grain size distribution of the sediment particles, not any organic material. When modeling particle bound cesium transport with results from a grain size distribution test in which the organics are removed, an inaccurate representation of the natural system can result, because cesium has been observed on organic material (Tamura, 1964). Due to this, the settling column test was performed on a base sample and a sample where organics were removed to see if contaminant variances would occur on predetermined size fractions.

Several different methods are available for removal of organics. These include addition of acids, heating to 800 degrees Celsius to combust organic material, and the addition of hydrogen peroxide (Jackson, 1975). In discussions with soil scientists at ORNL, it was found that using acids or heating the sample to extreme temperatures is considered potentially destructive to the inorganic soil structure and was therefore not used.

Hydrogen peroxide (30%) was used to remove organics from the suspended sediment samples (ID#s 1218CT07, 1218CT08, and 1218CT09) by oxidation. This was accomplished by adding small amounts of hydrogen peroxide (H_2O_2) to the samples. Applying a heat source of approximately 70° C (+/- 5°) sped up the oxidation process. The organics in the samples then "bubble out" of solution while dissolving. This bubbling

effect could be seen while this process was taking place due to the organic carbon reacting with the extra oxygen associated with hydrogen peroxide. Hydrogen peroxide was added until the bubbling of the organics no longer occurs. Once the removal of organics process was complete, the column test was performed on the three identical samples.

As with the dispersed and control sample, the separated size classes from the suspended sediment sample containing only inorganics were sent to the gamma counting lab for contamination concentration analysis.

Chapter 4

Modeling with the Hydrological Simulation Program-Fortran (HSPF)

Results from the laboratory tests were used to adjust a Hydrological Simulation Program-Fortran input file representing the White Oak Creek Watershed. This input file (developed by the Sediment Transport Task Team at the Oak Ridge National Laboratory) was modified to produce output compatible to the laboratory test results. The file was adjusted to match both the controlled laboratory results and the chemically altered results to one storm event (March 27, 1994). Although it was intended to use three different input files, one for each type of laboratory pre-treatment, only two input files were needed, because the control (or natural) sample and the dispersed sample yielded identical results (discussed in detail in Chapter 5). An input file representing the control sample and the oxidized sample were the only two used for the simulation.

Modeling results of interest are the variances in cumulative contaminant loads simulated as traveling off-site during an extreme event when using the different laboratory results to adjust the model. Contaminants discharged through reach 8 (location of White Oak Dam in the HSPF input file) will be considered as leaving off-site.

4.1 HSPF Input File Representing the White Oak Creek Watershed

The HSPF input file created for the White Oak Creek watershed was developed by the Sediment Transport Task team of the Environmental Sciences Division at the Oak Ridge National Laboratory. The watershed was divided into four pervious land segments (PLS) and seven reaches (See Figure 4.1). Continuous flow monitoring stations collect data at four sites. These sites are the 7500 Bridge, White Oak Creek weir (WOCW), Melon Branch weir (MBW), and White Oak Dam (WOD). At these sites, suspended sediment samples have been taken during major storm events both by automatic and manual sampling. These data were used by the Sediment Transport Modeling Task Team to calibrate the original HSPF input file.

The area was broken into the different subareas (PLSs and reaches) to group similar geographical and hydrologic features into defined regions. PLS 1 is the largest of the four pervious land segments. It consists of the Oak Ridge National Laboratory and some surrounding area. PLS 1 is the source of any contaminant discharged from the laboratory. PlS 2 and PLS 4 consists of contaminated waste disposal grounds and are believed to be the main contributors of contaminants to the watershed during storm events. The creek systems and lake found in the watershed were represented in the input file as 7 different reaches. Reaches 2 through 6

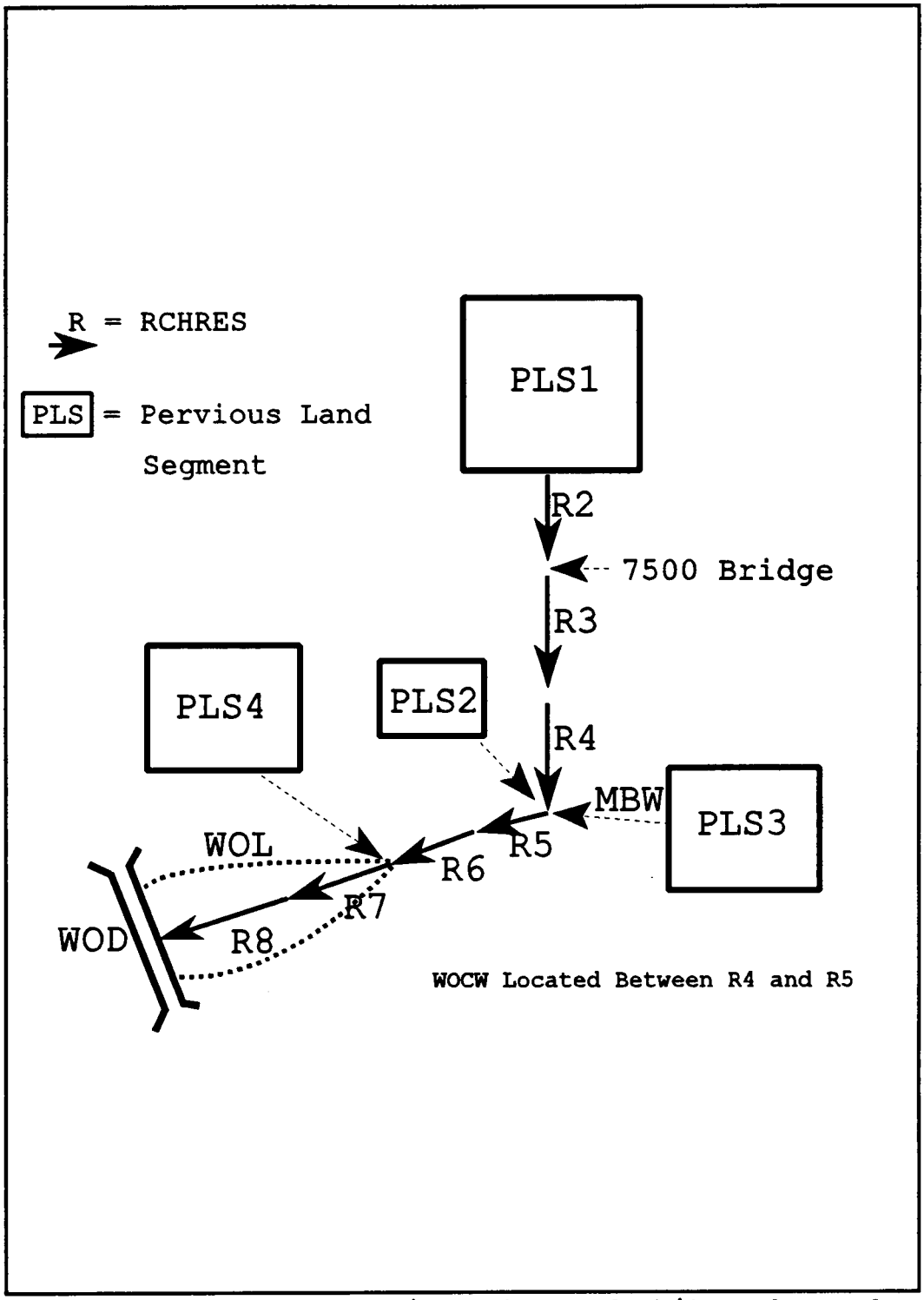

Figure 4.1: HSPF Modeling Scheme of White Oak Creek Watershed and Channel Reaches

represent the creeks and tributaries feeding into White Oak Lake, while reaches 7 and 8 represent the lake.

The input file representing the White Oak Creek Watershed was modified to a more simplistic system. Sedimentation processes in White Oak Creek were "turned off". Details of the modification are discussed in Section 4.3. The creek represented by the simplified input file only conveyed sediment from the pervious land segments to White Oak Lake. Figure 4.2 shows the modeling scheme of the input file representing the simplified watershed. Reaches 2 through 6 are omitted because scour and deposition are not simulated in White Oak Creek.

The WDM (watershed data management) file used for the White Oak Creek watershed consisted of five years of actual data collected from January 1, 1990 to December 31, 1994. Contained within this WDM file was precipitation, water temperature, daily pan evaporation, and flow data.

4.2 Model Calibration Techniques

Adjustment of the HSPF input file involved modifying model parameters so that two types of output parameters match the target values found by laboratory experiment. Two parameters that had to be matched were (1) the size class distribution of the suspended sediment and (2) the percent of the total cesium-137 found on each size fraction.

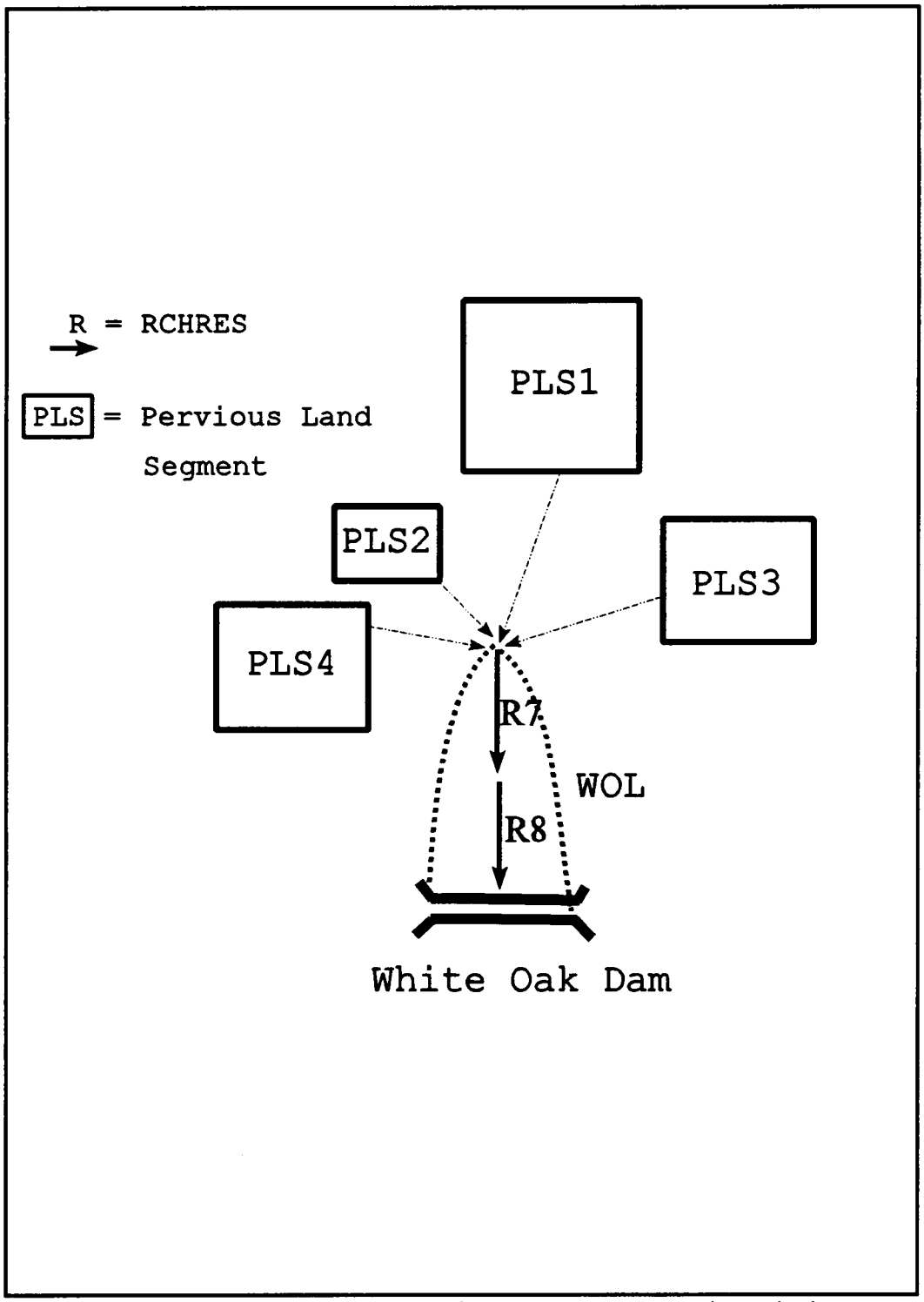

Figure 4.2: HSPF Modeling Scheme of Simplified Watershed

HSPF breaks sediment into three different size classes: sand, silt, and clay. The Settling Column Test divides sediment into four size classes: sand, coarse silt, fine silt, and clay. To model the Settling Column Test results with HSPF, the fine silt and coarse silt findings from the Settling Column Test were combined to represent the HSPF's silt fraction.

A large storm event was chosen to be the target for adjustment of the model parameters. For calibration, the objective was to match two output variables: average daily sediment discharge and total daily cesium discharge to the values measured in the lakebed sample. A large storm was needed because sand transport would have to be simulated, and sand is seldom transported during base flow conditions. A 10-year frequency storm event that occurred on March 27, 1994 was chosen as the calibration target day. Since observed input was from the beginning of 1990, the model was used to perform more than four years of simulation before March 27, 1994. This helped ensure that the model was no longer under the influence of initial conditions.

First the model parameters were adjusted in order to match the grain size distribution of the suspended sediment concentration because this output variable directly affects the other output parameter which needed to be matched: the percent of cesium-137 per size class. Table 4.1 shows the accuracy of the model parameter adjustment by comparing the

Table 4.1: Target and Obtained Output Parameters

March 27, 1994 Storm

Natural Sample:

	Percent of Total Suspended Sediment	
	Target	Obtained
Clay	24.7	25.8
Silt	69.0	67.9
Sand	6.3	6.2
Σ =	100.0	99.9

	Percent of Cesium per Size Class	
	Target	Obtained
Clay	51.0	51.5
Silt	43.9	43.8
Sand	5.1	4.7
Σ =	100.0	100.0

Oxidized Organics Sample:

	Percent of Total Suspended Sediment	
	Target	Obtained
Clay	30.2	30.9
Silt	65.8	65.0
Sand	3.9	4.1
Σ =	99.9	100.0

	Percent of Cesium per Size Class	
	Target	Obtained
Clay	60.0	60.0
Silt	38.4	39.0
Sand	1.7	2.0
Σ =	100.1	101.0

Percentages not totaling exactly 100% due to rounding

laboratory results (target output) with the actual simulated output.

To validate the manner in which the model was adjusted, modeling results from the second largest 1994 storm were examined (February 11, 1994). As Table 4.1 shows, the output for the March 27, 1994 storm matches closely with the target values. Comparing the simulated output from the February 11, 1994 storm with the target laboratory values showed that the model adjustment yielded fairly consistent results for large storms. Table 4.2 compares the output from the February 11, 1994 storm with the target values. The differences between the target output and obtained output for the February 11, 1994 storm were not as accurate as the March 27, 1994 storm results, but were still fairly consistent. The largest deviation from the target result was 5.9% occurring with the percent of sands simulated by the control input file. This indicates that the adjusted model is fairly consistent in yielding target values during high flow conditions. However, when using the model with low flow conditions, an unrealistically high amount of sediment was simulated as being transported, indicating the model was inaccurate for low flow conditions. The fact that the model yields unrealistic results during low flows was not of concern in this study since extreme flows (100 year events) were used to produce results for comparison.

Table 4.2: Model Validation

Febuary 11, 1994 Storm

Natural Sample:

	Percent of Total Suspended Sediment	
	Target	Obtained
Clay	24.7	20.4
Silt	69.0	67.4
Sand	6.3	12.2
Σ =	100.0	100.0

	Percent of Cesium per Size Class	
	Target	Obtained
Clay	51.0	47.5
Silt	43.9	46.2
Sand	5.1	6.3
Σ =	100.0	100.0

Oxidized Organics Sample:

	Percent of Total Suspended Sediment	
	Target	Obtained
Clay	30.2	26.3
Silt	65.8	65.1
Sand	3.9	8.6
Σ =	99.9	100.0

	Percent of Cesium per Size Class	
	Target	Obtained
Clay	60.0	56.6
Silt	38.4	40.5
Sand	1.7	2.9
Σ =	100.1	100.0

Percentages not totaling exactly 100% due to rounding

4.3 Suspended Sediment Calibration

An average daily suspended sediment concentration on March 27, 1994 was chosen to be the target value to match. The output of the HSPF can be made to display the total average daily suspended sediment concentrations, and also the individual concentrations of sand, silt, and clay. This portion of the output was the focus of the suspended sediment adjustment. On March 27, 1994 the output was made to match the grain size distributions found in the laboratory. Two input files that were initially identical were adjusted to fit both the natural laboratory results and the chemically altered results.

To help minimize the fluctuation of the suspended sediment concentration simulated leaving the watershed, the sedimentation processes occurring in the reaches upstream from White Oak Lake were "turned off". Making the critical bed shear stress for scour extremely high and the shear stress for deposition extremely low accomplished this. White Oak Lake (Reaches 7 & 8) and the pervious land segments were the only places where sediment activity occurred. To adjust the model output to the target grain size distribution of suspended sediment, the shear stresses for both scour and deposition in the lake (reaches 7 & 8) were modified. The critical bed shear stresses for both scour and deposition only effect silt and clay behavior. Within HSPF, the silt

and clay size fractions are given separate critical shear stress values in the SEDTRN section of the RCHRES block.

As discussed in section 2.3, sand transport in HSPF can be modeled by (1) the Toffaleti method, (2) the Colby method, or (3) a power function. When attempted, the Toffaleti method yielded unreasonable sand transport results. The power function method was chosen for use in this simulation because it is fairly simple to adjust for sand transport. The actual power function used in both the natural and chemically altered input files is defined as:

$$PSAND = KSAND * AVVELE^{EXPSND}$$

Where: PSAND = potential sand load (mg/l)
KSAND = coefficient (input parameter)
EXPSND = exponent (input parameter)
AVVELE = average channel velocity (ft/sec)

Values that yielded the adjusted output from this equation were KSAND equal to 110.0 for the "natural" input file and KSAND equal to 64.0 for the input file representing the chemically altered test. The value of EXPSND was 0.80 for both input files.

By raising or lowering the given critical shear stresses for deposition and scour in the input file for silts and clays, the suspended sediment grain size distribution for silts and clays leaving White Oak Lake could be obtained.

4.4 Cesium-137 Calibration

After the adjustment of the suspended sediment's grain size distribution was complete, the Cs-137 concentration adjustment could begin. Cs-137 input concentrations were modified to match the percentage of total daily value of Cs-137 on each size class for the March 27, 1994. The percentage of the cesium simulated on each size class was adjusted to match both the natural and the chemically altered laboratory results.

To adjust the cesium concentrations, the amount of contaminant per size class coming from the pervious land segments was adjusted. HSPF distributes the percent of total cesium per size class in a PLS by dividing the PLS's total acreage. If, for example, a PLS of 100 acres is to be simulated with 20% of the cesium being associated with the sand fraction, 30% with the silt, and 50% with the clay fraction, the input file would be adjusted as follows: In the NETWORK block of the input file, the user would input 20 acres of the PLS (20% of 100 acres) contributing to the cesium found on the sand fraction, 30 acres for the silt fraction of cesium, and 50 acres for the clay fraction of cesium. These were the parameters that were adjusted in both input files so that the output from these files would match the percent of cesium found per size class in the laboratory testing. The output was in the form of mCi (milli-Curies) of

cesium-137 passing from reach 8 per day per size class. From this, a percentage of Cs-137 per size class could be calculated.

Of the four pervious land segments, PLS 3 is the only one that is not simulated as contributing any Cs-137 to the system. This is because only minute traces of Cs-137 contamination have been observed as coming from PLS 3. The other three PLSs (PLS 1, 2, and 4) were all adjusted simultaneously using the same acreage percentages to yield the target output. For the input file representing the controlled laboratory sample, 22% of the PLS's area was simulated as contributing cesium to the sand fraction, 21% contributed to the silt fraction, and 58% contributed to the clay fraction. For the chemically altered input file, 15% of the PLS's area contributed to the sand fraction, 22% to the silt fraction, and 63% to the clay fraction. With these contributing percentages of the PLSs, the model output for cesium concentration per size class was then adjusted to the target values (Table 4.1)

Complete input files for both the control and chemically altered tests can be found in Appendices A and B.

Chapter 5

Findings and Summary of Results

The end result of this study is to find the effects that pre-treatment of a suspended sediment sample has on modeling of particle-bound contaminant transport. Within this process are intermediate findings, the laboratory results, which should be discussed before moving onto modeling results.

5.1 Laboratory Results

As previously explained, the Settling Column Test was performed on three different types of pre-treated samples, all having three replicates. First, a control (natural) sample was examined with the Settling Column Test. No pre-treatment techniques were used on the control sample. Second, a sample that was dispersed with sodium bicarbonate was examined. Third, a sample which had undergone a removal of organics procedure was tested.

Three replicates were performed for each sample, making a total of nine different settling column test runs. Averages of the results from the three replicates within each group were the values used to compare laboratory results. These averages were used when adjusting the HSPF input files.

Two laboratory results were found for each sample tested. The settling column test found the grain size

distribution each sample, and the Gamma Counting Laboratory determined the amount of Cs-137 found on each size fraction (in pCi/g). From the contamination count on each size class, a total count could be determined and thus, the percent of total cesium per size class was calculated.

After analysis was complete, the control sample and the dispersed sample were found to not be statistically different in both grain size distribution and percent of Cs-137 per size class (see Tables 5.1 & 5.2). To conclude that the samples were not statistically different, the three replicates used for each type of sample were averaged, and the standard deviation was computed. Then the averages of two different samples were using a Student t test for standard deviation. Using the Student t test, a hypothesis and a null hypothesis had to be established and examined. The null hypothesis was that the two averages were the same, and the hypothesis was that the two averages were different. After performing the Student t test, the null hypothesis could not be rejected with a P factor greater than 0.01, indicating the control and dispersed results statistically were not significantly different. Assistance for the statistical analysis performed in this study was provided by John Beauchamp at the Oak Ridge National Laboratory (Beauchamp, 1995).

The sample in which the organics were oxidized did show some differences in both grain size distribution and percent

Table 5.1:Size Fractions (%) by Sample and Size Class

1. **Control Sample**			(No Pre-treatment)	
	CLAY	FINE SILT	COARSE SILT	SAND
1218CT01	25.04	21.84	47.08	6.05
1218CT02	24.65	21.04	48.1	6.21
1218CT03	24.32	20.64	48.28	6.77
Average	**24.67**	**21.17**	**47.82**	**6.34**
Std. Dev	0.360	0.611	0.647	0.378

2. **Dispersed Sample**			(Sodium Bicarbonate)	
	CLAY	FINE SILT	COARSE SILT	SAND
1218CT04	24.76	21.96	47.11	6.17
1218CT05	25.22	22.78	45.33	6.67
1218CT06	24.79	22.19	46.31	6.71
Average	**24.92**	**22.31**	**46.25**	**6.52**
Std. Dev	0.257	0.423	0.892	0.301

3. **Oxidized Sample**			(Hydrogen Peroxide)	
	CLAY	FINE SILT	COARSE SILT	SAND
1218CT07	30.17	21.95	44.28	3.59
1218CT08	30.08	22.21	43.51	4.2
1218CT09	30.48	21.95	43.57	3.99
Average	**30.24**	**22.04**	**43.79**	**3.93**
Std. Dev	0.210	0.150	0.428	0.310

*For Standard Deviations, n = 3

Note: 0-4 micrometers = Clay
4-16 micrometers = Fine Silt
16-62 micrometers = Coarse Silt
63-125 micrometers = Sand

Table 5.2: Comparison of Control and Dispersed Cs-137 Concentrations

1. Control Sample

	% Cs-137	Std.Dev
Clay	**51.01**	1.39
Fine Silt	**18.92**	0.40
Coarse Sil	**24.95**	1.05
Sand	**5.13**	0.51

n = 3

2. Dispersed Sample

	% Cs-137	Std.Dev
Clay	**52.05**	1.43
Fine Silt	**18.93**	0.92
Coarse Sil	**23.46**	0.20
Sand	**5.56**	0.50

n = 3

of Cs-137 per size class (see Table 5.3). Results from the oxidized sample show a 5.57% increase in the amount of clays in the sample. This increase was facilitated by the decrease in both the sand and silt size fractions. The percent of Cs-137 found per size class increased by 8.96% in the clay fraction, decreased by 5.50% in the silt fraction, and decreased by 3.46% in the sand fraction. Reasons for this change due to oxidation of organics are discussed in Chapter 6.

5.2 Modeling Results

Modeling results found in this study are not to be taken as representing an actual scenario of an extreme storm occurring within the White Oak Creek Watershed. Results found from the different input files were used for comparison purposes. The reader is discouraged from drawing any conclusions from the individual results found.

Initially, laboratory results from each of the three samples tested were going to be used as a basis for adjustment of the HSPF input files, making a total of three input files. Because the control and the chemically dispersed samples yielded the same results, only the control and the oxidized organics sample were used to adjust the model. Therefore, two initially identical input files for the White Oak Creek watershed were adjusted for the March 27,

Table 5.2: Comparison of Control and Oxidized Cs-137 Concentrations

1. Control Sample

	% Cs-137	Std.Dev
Clay	**51.01**	1.39
Fine Sil	**18.92**	0.40
Coarse S	**24.95**	1.05
Sand	**5.13**	0.51

n = 3

2. Oxidized Sample

	% Cs-137	Std.Dev
Clay	**59.97**	0.73
Fine Sil	**19.13**	0.38
Coarse S	**19.23**	0.79
Sand	**1.67**	0.53

n = 3

1994 storm.

After model adjustment was complete, a different five year precipitation file was used as the time series precipitation data for both input files. This precipitation file included all the actual precipitation data from January 1, 1990 to the December 31, 1993, but the year of 1994 consisted of simulated rainfall. The simulated year includes some real rain data, but also includes two one-hundred year storms. The one-hundred year storms were simulated as occurring on May 5 and June 1, 1994.

When comparing the one-hundred year storm results from the two adjusted input files, the file representing the oxidized organics sample showed slightly more cesium leaving the system than the controlled sample input file showed. For the assumed 100-year storm event of May 5, 1994, the increase in cesium was only 4.6%, from 2150 mCi/day for the control input file to 2250 mCi/day for the oxidized organics input file. On June 1, the increase was 5.0%, going from 1550 mCi/day for the control input file to 1630 mCi/day for the oxidized organics input file. See Table 5.4 for a summary of daily modeling results.

Table 5.4: Modeling Results: 24 Hour Storm Load

[SS] = Average 24 hour Suspended Sediment in mg/l
[Cs-137] =24 Hour Cs-137 Load in mCi/day

Control Input File

	May 5, 100-yr storm		June 1, 100-yr storm	
	[SS]	[Cs-137]	[SS]	[Cs-137]
Sand	33.3	44.2	30.2	27.1
Silt	553.7	913.7	850.3	631.3
Clay	169.2	1189.3	149.9	889.3
Total	756.1	2147.2	1030.4	1547.7

Oxidized Input File

	May 5, 100-yr storm		June 1, 100-yr storm	
	[SS]	[Cs-137]	[SS]	[Cs-137]
Sand	19.4	22.0	17.6	14.2
Silt	412.0	905.0	475.5	626.8
Clay	175.1	1317.7	154.6	985.4
Total	606.5	2244.7	647.6	1626.4

Chapter 6

Conclusions and Recommendations

Two conclusions were found during the laboratory portion of this study, which merit discussion. First, using sodium bicarbonate as a dispersing agent with the Settling Column Test will not change the results of the test when compared to not using a dispersant. Second, when using hydrogen peroxide to oxidize organics in a sample, the Settling Column Test does alter the test results. The difference, as noted in Chapter 5, is that the relative amount of clays increase when the organics are oxidized. Differences found when using hydrogen peroxide were the basis for the calibration of the HSPF input file.

After adjusting the HSPF input file and using the simulated precipitation containing the two extreme events, the relative cesium-137 transport results could be compared. The simulated cesium transported during extreme storm events was only slightly affected (<5.0%) by using the two different laboratory results for model adjustment.

6.1 The Dispersed Test Comparison

When using sodium bicarbonate as a dispersing agent, no difference was seen when compared with the control sample's results of grain size distribution or percent of Cs-137 per

size class. It was expected that the dispersing agent would prevent flocculation of the clay material, thus keeping it in suspension longer. If this had occurred, a larger amount of the clay size fraction would have been seen. It is believed that the reason that this did not occur was due to the mechanical dispersion that takes place between decants during the Settling Column Test. The mechanical mixing appears to disperse a sample enough that it matches results obtained from a chemically dispersed sample.

6.2 Oxidation of Organics and the Increase of Clay

When comparing the results between the control sample and the oxidized organics sample, a difference in the percent of the clay size fraction was seen. The increase occurred with the sample that was oxidized with hydrogen peroxide to remove the organics. The clay size fraction of the control sample was 24.67% of the grain size distribution whereas the percent of clays in the oxidized sample were 30.24%. This increase in the amount of clays seen in the grain size distribution comes from a decrease of about 3% of the silts and about 2% of the sands.

In a conversation with T. Tamura (Tamura, 1995), the reasons for an increase in the clay size fraction were discussed. Apparently, many clay particles are "stuck" to larger sand and silt particles by organic material.

Therefore, when organics are not removed from a sample, the clays attached to the larger particles behave as the large particles do, and act as silts or sands in the settling column test. When the organics are removed from a sample, the clays are released and are then capable of being counted in the clay size fraction. This will cause an increase in the amount of clays counted, and a decrease in silts and sands counted.

6.3 Contaminant Transport Daily Values During Extreme Storms

To calculate the difference in results of the two HSPF input files during an extreme storm event, the daily values for cesium-137 discharged during the simulated 100-year storms were compared. The amount of simulated Cs-137 transported off-site during the extreme events was slightly higher for the input file representing the oxidized organics laboratory sample. A cesium-137 increase of 4.6% was seen during the first simulated 100-yr storm (May 5), and an increase of 5.0% during the second 100-yr storm (June 1). When looking at the breakdown of the amount of Cs-137 being transported per size class, the increase of the contaminant is evidently due to the increase of Cs-137 found on the clay fraction.

The increase in the amount of cesium-137 found on the clay fraction for the oxidized organics input file is

apparently directly related to the higher clay values used during calibration of the model. The input file was calibrated for approximately a 5% increase in the amount of clays and approximately a 9% increase in Cs-137 found on the clay fraction. This adjustment was made during a 10-year storm. Evidently, when a 100-year storm is applied to an input file adjusted for a 10-year storm, little change from the initial daily Cs-137 concentrations occurs.

6.4 Recommendations for Modeling Contaminant Transport

To obtain particle bound contaminant transport modeling results that most closely simulate what is happening in the real world, the modeler needs data that most resembles what naturally occurs. As shown from this study, pre-treatment of suspended sediment samples prior to grain size distributions can cause varied laboratory results. If these results are used to adjust a model, depending upon what type of output is in question, a difference in modeling results can be seen.

Since the modeling results vary only slightly (<5.0%) when comparing the daily values for particle bound contaminant transport for extreme storm events, it seems that oxidation of organics prior to grain size distribution testing is of little significance. Therefore, if oxidation is desirable for laboratory purposes, it would not cause any significant inaccuracies in the modeling of average daily

values during floods.

The best way to calibrate a model to simulate contaminant transport is to use the most natural input data obtainable. This would mean using no pre-treatment techniques when performing the settling column test. Also, when calibrating an input file to match the contaminant to grain size classes, the time frame that is desired as an output should be considered. The input file should be calibrated to simulate the proper time frame of results in question.

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Appendices

Appendix A
The Control HSPF Input File

```
RUN

GLOBAL
 HSPF VERSION 10.0:  Calibrated to match natural laboratory conditions.
 ***Calibrated for 10-year frequency storm event.
 ***NO scour or deposition in reaches 2-6
 START      1990/01/01      END    1994/12/31
 RUN INTERP OUTPUT LEVEL   3
 RESUME    0 RUN    1 TSSFL   15
END GLOBAL


FILES
<FILE>  <UN#>***<----FILE NAME---------------------------------------->
WDM       21   e:wocdat.wdm
            01   testb.out

MESSU     22   echo.out
            65   testnat.d65
            66   testnat.d65
INFO      23   HSPINF.DA
ERROR     24   HSPERR.DA
WARN      25   HSPWRN.DA
END FILES

OPN SEQUENCE
  INGRP           INDELT  0:30
    PERLND     1
    RCHRES     2
    RCHRES     3
    RCHRES     4
    PERLND     2
    PERLND     3
    RCHRES     5
    RCHRES     6
    PERLND     4
    RCHRES     7
    RCHRES     8
    DISPLY    63
    DISPLY    64
    DISPLY    65
    DISPLY    66
    DISPLY    67
```

```
    DISPLY     68
    DISPLY     69
  END INGRP
END OPN SEQUENCE

PERLND
 ACTIVITY
  <PLS >        Active Sections (1=Active; 0=Inactive)          ***
  # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS
TRAC ***
  1   2            0      1      1      0      0      1
  3                0      1      1      0      0      0
  4                0      1      1      0      0      1
 END ACTIVITY


 PRINT-INFO
  <PLS >        Print-flags  (4=MTH., 3=DAY, 2=PIVL)        *** PIVL  PYR
  # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS
TRAC      ***
  1                        4      4                  4                  1    12
  2   4                    4      4                  4                  1    12
 END PRINT-INFO

 GEN-INFO
  <PLS ><-------Name------->NBLKS  Unit-systems      Printer ***
  # -  #                              User   t-series  Engl Metr ***
                                              in  out            ***
  1     WOC u/s 7500 br.            1    1      1     1      1     0
  2     WOC 7500 Br. -MS3           1    1      1     1      1     0
  3     MB u/s MS4                  1    1      1     1      1     0
  4     MS 3/4 conf.-WOD            1    1      1     1      1     0
 END GEN-INFO



 *** Section PWATER ***

 PWAT-PARM1
  <PLS >  PWATER variable monthly parameter value flags ***
  # -  # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE   ***
  1   4      0      0      0      1      0      0      0      0      1
 END PWAT-PARM1
```

```
PWAT-PARM2
 <PLS > *** PWATER input info: Part 2
 # - # ***FOREST LZSN   INFILT    LSUR   SLSUR  KVARY AGWRC
 1          0.1 5.0043     .08     250.   0.14    0.0  0.9777
 2          0.1  13.00     .08     250.   0.14    0.0  0.9990
 3          0.2  13.00     .08     250.   0.14    0.0  0.9883
 4          0.4  13.00     .08     250.   0.14    0.0  0.9990
END PWAT-PARM2


PWAT-PARM3
 <PLS > *** PWATER input info: Part 3
 # - # ***PETMAX  PETMIN INFEXP INFILD DEEPFR BASETP AGWETP
 1  2        40.     35.    2.0    2.0    0.0    0.0    0.0
 3           40.     35.    2.0    2.0    0.1   0.15    0.0
 4           40.     35.    2.0    2.0    0.2   0.25    0.0
END PWAT-PARM3

PWAT-PARM4
 <PLS >    PWATER input info: Part 4                      ***
 # - #    CEPSC     UZSN     NSUR    INTFW     IRC    LZETP  ***
 1          .05     .851      0.3   2.2954  0.3000   0.3000
 2          .05       1.      0.3       .5  0.3000   0.3000
 3          .15    .5677      0.3   7.0000  0.3253   0.3000
 4          .20    .9999      0.3    .5000  0.3000   0.3333
END PWAT-PARM4

MON-INTERCEP
 <PLS>  Only required if VCSFG=1 in PWAT-PARM1              ***
 # - #  Interception storage capacity at start of each month ***
  *** JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
 1  4 .01 0.01 0.03 0.08 0.12 0.12 0.12 0.12 0.12 0.06 0.03 0.01
END MON-INTERCEP

MON-UZSN
 <PLS>  Only required if VUZFG=1 in PWAT-PARM1              ***
 # - #  Upper zone storage at start of each month      ***
  *** JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
 1  4  0.4  0.5  0.6  0.8  1.0  1.0  1.0  0.9  0.7  0.6  0.5  0.4
END MON-UZSN

MON-MANNING
```

```
 <PLS >  Only required if VNNFG=1 in PWAT-PARM1                ***
 # -  #  Manning's n for overland flow at start of each month      ***
  ***  JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 1   4 0.30 0.30  0.30 0.30  0.27 0.25 0.25  0.25 0.25 0.25 0.35 0.33
END MON-MANNING

MON-LZETPARM
 <PLS >  Only required if VLEFG=1 in PWAT-PARM1                ***
 # -  #  Lower zone ET parameter at start of each month          ***
  ***  JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 1   4   .2   .2   .2   .3   .4   .4   .4   .3   .3   .2   .2   .2
END MON-LZETPARM

PWAT-STATE1
 <PLS > *** Initial conditions at start of simulation
 # -  # ***  CEPS     SURS      UZS     IFWS      LZS     AGWS     GWVS
 1   4            0.       0.      0.8     0.05     10.8      7.0       0.
END PWAT-STATE1

*** SECTION SEDMNT ***

SED-PARM1
 <PLS > ***
 # -  #  CRV VSIV SDOP ***
 1   4    0    0    0
END SED-PARM1

SED-PARM2
 <PLS > ***
 # -  #    SMPF    KRER    JRER   AFFIX   COVER    NVSI ***
 1   4       1.0     0.08     1.9    .010     0.5     0.0
END SED-PARM2

SED-PARM3
 <PLS > ***
 # -  #    KSER    JSER    KGER    JGER ***
 1   4       0.1     1.3      .1     1.1
END SED-PARM3

MON-COVER
 <PLS >  Monthly values for erosion-related land cover         ***
 # -  # JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 1   4  .17  .13  .09  .06  .01  .03  .43  .67  .77  .61  .26  .21
```

```
END MON-COVER

SED-STOR
 <PLS > Detached sediment storage (tons/acre)          ***
 # - #   BLOCK1     BLK2     BLK3     BLK4     BLK5 ***
 1   4     0.0
END SED-STOR


*** Section PQUAL ***

NQUALS
 <PLS >     ***
 # - #NQUAL ***
 1   2        1
 4            1
END NQUALS

QUAL-PROPS
 <PLS >*** Identifiers and flags
 # - #<qualid>***QTID QSD VPFW VPFS QSO VQO QIFW VIQC QAGW
 1   4 Cs-137       mCi     1                  1            1            1
END QUAL-PROPS

QUAL-INPUT
 <PLS > Storage on surface and nonseasonal parameters              ***
 # - #    SQO   POTFW POTFS ACQOP SQOLIM WSQOP IOQC    AOQC
 1                  .2      2.3                        1.0E-10  1.0E-10
 2                  .3      1.4                        1.0E-10  1.0E-10
 4                  .2      1.4                        1.0E-10  1.0E-10
END QUAL-INPUT


*** Section PSTEMP ***

PSTEMP-PARM2
 <PLS >                                                          ***
 # - #    ASLT     BSLT    ULTP1    ULTP2    LGTP1    LGTP2 ***
***  1     14.5     .365      1.2      4.0      1.2      6.0
END PSTEMP-PARM2

*** Section PWTGAS ***
```

```
 PWT-PARM2
  <PLS >                                                    ***
  # - #    ELEV   IDOXP   ICO2P   ADOXP   ACO2P ***
***  1      500.      6.     .05       5.     .05
 END PWT-PARM2
END PERLND


RCHRES
 ACTIVITY
  RCHRES  Active Sections (1=Active; 0=Inactive)        ***
  # -  # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
  2         1    1    0    0    1    1    0    0    0    0
  3  8      1    1    0    0    1    1    0    0    0    0
 END ACTIVITY

 PRINT-INFO
  RCHRES  Print-flags                                                    ***
  # - # HYDR ADCA CONS HEAT SED GQL OXRX NUTR PLNK PHCB
                                                    PIVL PYR ***
  2  8     4    4    4    4    4    4    4    4    4    4
                                                       1   12
 END PRINT-INFO

 GEN-INFO
  RCHRES<-------Name------->Nexit  Unit Systems  Printer     ***
  # - #                            User t-series  Engl Metr LKFG ***
                                       in  out          ***
  2    2.21-2.18 7500 WEIR          1   1   1    1     1    0
  3    2.18-1.9 INT. POND           1   1   1    1     1    0
  4    1.90-1.63 MS3                1   1   1    1     1    0
  5    1.62-1.40                    1   1   1    1     1    0
  6    1.40-1.18 U/S WOL            1   1   1    1     1    0    0
  7    1.18-0.83 MID WOL            1   1   1    1     1    0    1
  8    0.83-0.60 WOD                1   1   1    1     1    0    1
 END GEN-INFO

 *** Section HYDR ***
```

```
HYDR-PARM1
 RCHRES  Flags for HYDR section                                    ***
 # - #  VC A1 A2 A3  ODFVFG for each    ODGTFG for each ***
        FG FG FG FG       possible  exit        possible  exit ***
                           1 2 3 4 5            1 2 3 4 5 ***

 2  8       1   1  1     4
END HYDR-PARM1

HYDR-PARM2
 RCHRES ***  (note 2/21/4 - the db50 here is used for sand transport
     ***   while the diam. for sand under SAND_PM below is ignored)
 # - #   FTABNO     LEN    DELTH    STCOR     KS     DB50 ***
 2         2        0.03      0.1              . 0      .01
 3         3        0.28      6.1              .0     0.01
 4         4         .28      3.6              .0     0.01
 5         5         .22      4.3              .0     0.01
 6         6        0.22      1.2              .0     0.01
 7         7        0.35      2.5              .0    0.008
 8         8         .23      1.6              .0    0.008
END HYDR-PARM2

HYDR-INIT
 RCHRES  Initial conditions for HYDR section    ***
 # - #     VOL    Initial  value  of COLIND *** Initial  value  of OUTDGT
      (ac-ft)         for  each  possible  exit *** for  each  possible  exit
                 EX1  EX2  EX3  EX4  EX5 ***  EX1  EX2  EX3  EX4  EX5
 2        .03     4.0
 3        .30     4.0
 4        .40     4.0
 5        .20     4.0
 6        .70     4.0
 7        4.0     4.0
 8        3.5     4.0
END HYDR-INIT
```

*** Section SEDTRN ***

```
SANDFG
 RCHRES    ***
 # - # SDFG ***
 2  8      3
END SANDFG

SED-GENPARM
 RCHRES  BEDWID   BEDWRN    POR ***
 # - #                       ***
 2  4      30.      10.      .5
 5  6      40.      11.      .5
 7        500.      20.      .5
 8        600.      20.      .5
END SED-GENPARM

SAND-PM
*** (note D here should match DB50 in hydr-parm2 above)
 RCHRES     D      W     RHO   KSAND   EXPSND ***
 # - #                        ***
 2  3     .03     3.2    2.65     1.0      1.0
 4  6     .02     2.4    2.65     1.0      1.0
 7  8    .008     .47    2.65   110.0      0.80
END SAND-PM

SILT-CLAY-PM
 RCHRES     D      W     RHO   TAUCD   TAUCS     M ***
 # - #(silt)                                     ***
 2  2   .00063  .0091     2.2  0.000001 10000000  .6
 3  3   .00063  .0091     2.2  0.000001 10000000  .6
 4  4   .00063  .0091     2.2  0.000001 10000000  .6
 5  5   .00063  .0091     2.2  0.000001 10000000  .6
 6  6   .00063  .0091     2.2  0.000001 10000000  .6
 7  7   .00063   .022     2.2   5.95E-5  5.96E-5  .7
 8  8   .00063   .022     2.2   5.95E-5  5.96E-5  .7
END SILT-CLAY-PM
```

```
SILT-CLAY-PM
 RCHRES      D       W      RHO    TAUCD    TAUCS       M ***
 # -  #(clay)                                  ***
 2   2    .000079  .00011      2.0   0.000001  10000000     .6
 3   3    .000079   .0011      2.0   0.000001  10000000     .6
 4   4    .000079   .0011      2.0   0.000001  10000000     .6
 5   5    .000079   .0011      2.0   0.000001  10000000     .6
 6   6    .000079   .0011      2.0   0.000001  10000000     .6
 7   7    .000079   .0041      2.0    .000300    .000301     .7
 8   8    .000079   .0041      2.0    .000300    .000301     .7
END SILT-CLAY-PM

SSED-INIT
 RCHRES    Suspended sed concs (mg/l) ***
 # -  #     Sand     Silt     Clay  ***
 2   8        1.      15.      15.
END SSED-INIT

BED-INIT
 RCHRES   BEDDEP  Initial bed composition      ***
 # -  #     (ft)     Sand     Silt     Clay ***
 2   2      3.        .5       .3       .2
 3   4      3.        .5       .3       .2
 5   6      3.        .4       .4       .2
 7   8      4.        .2       .5       .3
END BED-INIT

*** Section GQUAL ***

GQ-GENDATA
 RCHRES NGQL TPFG PHFG ROFG CDFG SDFG PYFG  LAT ***
 # -  #                          ***
 2   8          1      1                        1
END GQ-GENDATA

GQ-QALDATA
 RCHRES<-------GQID------->    DQAL   CONCID    CONV    QTYID ***
 # -  #                                  ***
 2   8      Cs-137                3.4E-7        mCi      .035      mCi
END GQ-QALDATA


GQ-QALFG
```

```
 RCHRES HDRL OXID PHOT VOLT BIOD  GEN SDAS ***
 # - #                    ***
 2   8                                    1
END GQ-QALFG


GQ-GENDECAY
 RCHRES   FSTDEC    THFST ***
 # - #             ***
 1   1
END GQ-GENDECAY

GQ-SEDDECAY
 RCHRES   KSUSP   THSUSP    KBED    THBED ***
 # - #                    ***
 1   1
END GQ-SEDDECAY

GQ-KD
 RCHRES            Partition coefficients              ***
 # -  # ADPM(1,1) ADPM(2,1) ADPM(3,1) ADPM(4,1) ADPM(5,1)
                                        ADPM(6,1)
 2   8       3.e-4       3.e-2       3.e-2       3.e-4       3.e-2
                                                         3.e-2
END GQ-KD

GQ-ADRATE
*** this is adsorption rate in 1/day
 RCHRES       Adsorption/desorption rate parameters          ***
 # -  # ADPM(1,2) ADPM(2,2) ADPM(3,2) ADPM(4,2) ADPM(5,2 )
                                       ADPM(6,2) ***
 2   8          1.          1.          1.          1.          1.
                                                              1.
END GQ-ADRATE

GQ-SEDCONC
 RCHRES   SQAL1    SQAL2    SQAL3    SQAL4    SQAL5    SQAL6 ***
 # - #                                ***
 2   8      5.E-10    5.E-10    5.E-10    5.E-10    5.E-10    5.E-10
END GQ-SEDCONC

GQ-VALUES
 RCHRES   TWAT   PHVAL    ROC    CLD   SDCNC    PHY ***
```

```
  # - #                                          ***
  1   8
 END GQ-VALUES

END RCHRES

DISPLY
 DISPLY-INFO1
*** # -  #<----------Title------->TRAN PIVL DIG1FIL1 PYRDIG2 FIL2YEND
  63    Total [SS] rch8 (mg/l)  AVER          2    1    1    1   65    12
  64    Clay [SS] rch8 (mg/l)   AVER          2    1    1    1   65    12
  65    Silt [SS] rch8 (mg/l)   AVER          2    1    1    1   65    12
  66    Sand [SS] rch8 (mg/l)   AVER          2    1    1    1   65    12
  67    Cs-137 sand rch8 (mCi/) SUM           2    4    1    2   65    12
  68    Cs-137 silt rch8 (mCi/) SUM           2    4    1    2   65    12
  69    Cs-137 clay rch8 (mCi/) SUM           2    4    1    2   65    12
 END DISPLY-INFO1
END DISPLY

PLTGEN
 PLOTINFO
  # -  # FILE  NPT  NMN LABL  PYR PIVL ***
  1         51          2          12    1
  2         52          1          12   24
 END PLOTINFO

 GEN-LABELS
  # -  #<----------------Title----------------->  ***   <------Y axis------>
  1    SIMULATED FLOW (hr)                          CFS
  2    simulated flow (daily)                       cfs
 END GEN-LABELS

 SCALING
  # -  #     YMIN      YMAX     IVLIN ***
  1   2          0.       2000.       20.
 END SCALING

 CURV-DATA       (first curve)
         <-Curve label--> Line Intg  Col Tran ***
  # -  #                  type  eqv code code ***
  1   2   SIM OVERLANDFLOW   0        AVER
 END CURV-DATA
```

```
 CURV-DATA       (second curve)
        <-Curve label--> Line Intg  Col Tran ***
  # -  #                 type  eqv code code ***
   1   2   SIM STREAMFLOW     0         AVER
 END CURV-DATA
END PLTGEN

FTABLES
 FTABLE    8
ROWS COLS ***  MI.  0.83 TO 0.6
  9   4

   DEPTH     AREA   VOLUME   OUTLET   ***
    (FT)  (ACRES)  (AC-FT)    DISCH   ***
                    (CFS)    ***
    .000     .000     .0000    .0000
   10.40     9.0       61.0    300.0
   11.90    10.0       75.0    700.0
   13.20    10.0       88.0   1200.0
   13.60    10.0       92.0   1400.0
   14.20    10.0       99.0   1700.0
   15.30    11.0      110.0   2170.0
   20.80    12.0      173.0  12150.0
   23.40    12.0      205.0  23800.0
 END FTABLE  8

 FTABLE    7
ROWS COLS ***  MI.  1.18 TO 0.83
  9   4

   DEPTH     AREA   VOLUME   OUTLET ***
    (FT)  (ACRES)  (AC-FT)    DISCH ***
                    (CFS) ***
    .000     .000     .0000    .0000
   7.40     17.0       66.0    281.0
   8.90     17.0       92.0    657.0
  10.21     18.0      115.0   1130.0
  10.61     18.0      122.0   1320.0
  11.21     19.0      132.0   1590.0
  12.32     19.0      154.0   2170.0
  17.93     22.0      274.0  11700.0
  20.71     25.0      346.0  22800.0
 END FTABLE  7
```

FTABLE 6
ROWS COLS *** MI. 1.40 TO 1.18
9 4

DEPTH (FT)	AREA (ACRES)	VOLUME (AC-FT)	OUTLET DISCH (CFS) ***
.000	.000	.0000	.0000
3.33	7.0	12.0	254.0
4.82	9.0	23.0	593.0
6.13	10.0	36.0	1030.0
6.54	11.0	41.0	1210.0
7.14	11.0	47.0	1440.0
8.25	12.0	59.0	1975.0
14.37	14.0	146.0	10900.0
17.69	16.0	201.0	21500.0

END FTABLE 6

FTABLE 5
ROWS COLS *** MI. 1.62 TO 1.40
9 4

DEPTH (FT)	AREA (ACRES)	VOLUME (AC-FT)	OUTLET DISCH (CFS) ***
.000	.000	.0000	.0000
3.08	2.0	3.0	239.0
4.39	4.0	7.0	557.0
5.82	7.0	14.0	975.0
6.21	8.0	16.0	1140.0
6.74	9.0	20.0	1360.0
7.77	10.0	29.0	1850.0
14.41	14.0	109.0	10500.0
18.39	15.0	167.0	20700.0

END FTABLE 5

FTABLE 4
ROWS COLS *** MI. 1.90 TO 1.63
9 4

DEPTH (FT)	AREA (ACRES)	VOLUME (AC-FT)	OUTLET DISCH (CFS) ***

```
  .000     .000        .0000    .0000
  4.07     4.0          8.0     223.0
  4.61     5.0         11.0     519.0
  5.30     7.0         16.0     920.0
  5.49     7.0         17.0    1070.0
  5.74     7.0         19.0    1260.0
  6.53     8.0         23.0    1730.0
 15.03    12.0        103.0   10100.0
 18.64    12.0        149.0   19800.0
END FTABLE  4

FTABLE    3
ROWS COLS ***  MI.  2.18 TO 1.90
  9   4

  DEPTH     AREA    VOLUME    OUTLET   ***
  (FT)   (ACRES)  (AC-FT)     DISCH   ***
                    (CFS)     ***
  .000     .000        .0000    .0000
  3.63     6.0          6.5     223.0
  5.33     7.0         17.0     519.0
  6.65     7.0         27.0     920.0
  7.01     7.0         30.0    1070.0
  7.41     7.0         32.0    1260.0
  8.22     7.0         38.0    1730.0
 15.52    14.0        102.0   10100.0
 19.50    16.0        156.0   19800.0
END FTABLE  3

FTABLE    2
ROWS COLS ***  MI.  2.21 TO 2.18
  9   4

  DEPTH     AREA    VOLUME    OUTLET   ***
  (FT)   (ACRES)  (AC-FT)     DISCH   ***
                    (CFS)     ***
  .000     .000        .0000    .0000
  5.43     0.2          0.5     176.0
  6.66     0.2          1.0     410.0
  7.48     0.3          1.2     760.0
  7.78     0.3          1.3     910.0
  8.00     0.3          1.5    1025.0
  8.68     0.4          1.9    1425.0
```

```
  15.53     1.0        4.0   9000.0
  19.87     1.0        8.0  17750.0
 END FTABLE  2

 FTABLE    1
ROWS COLS ***   ( mile 2.55 TO 2.21  in woc)
  9   4

   DEPTH    AREA   VOLUME   OUTLET   ***
   (FT)  (ACRES)  (AC-FT)    DISCH   ***
                   (CFS)    ***
   .000     .000     .0000    .0000
   3.69     2.8         5.5   176.0
   5.08     2.8        11.0   410.0
   6.30     3.7        13.8   760.0
   6.77     3.7        14.7   910.0
   7.24     3.7        17.5  1025.0
   8.74     4.6        22.1  1425.0
  17.82    14.0       109.0  9000.0
  21.11    17.0       174.0 17750.0
 END FTABLE  1
END FTABLES

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols>
<-Grp><-Member->***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #      <Name>***
WDM     51 PRCP    ENGLZERO        DIV  PERLND   1   1 EXTNL  PREC
WDM     52 PRCP    ENGLZERO        DIV  PERLND   2   2 EXTNL  PREC
WDM     53 PRCP    ENGLZERO        DIV  PERLND   3   3 EXTNL  PREC
WDM     53 PRCP    ENGLZERO        DIV  PERLND   1   4 EXTNL  PREC
WDM     40 EVAP    ENGLZERO .007 DIV  PERLND   1   4 EXTNL  PETINP
WDM     41 TEMP    ENGLZERO          RCHRES   1   8 HTRCH  TW
END EXT SOURCES

NETWORK
  *** PLS areas IN AC. : (1) 2099,  (2) 204.8, (3) 960, (4) 672
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->
***
<Name>   #      <Name> # #<-factor->strg <Name>   #   #      <Name> # #  ***
PERLND   1 PQUAL  IOQUAL      2099.     RCHRES   2    INFLOW IDQAL
PERLND   1 PQUAL  AOQUAL      2099.     RCHRES   2    INFLOW IDQAL
PERLND   1 PWATER PERO       174.93     RCHRES   2    EXTNL  IVOL
```

```
PERLND  1 SEDMNT SOSED     524.8   RCHRES  2   INFLOW ISED  1
PERLND  1 SEDMNT SOSED     839.6   RCHRES  2   INFLOW ISED  2
PERLND  1 SEDMNT SOSED     734.6   RCHRES  2   INFLOW ISED  3
PERLND  1 PQUAL  SCRQS     462.00  RCHRES  2   INFLOW ISQAL1
PERLND  1 PQUAL  SCRQS     441.00  RCHRES  2   INFLOW ISQAL2
PERLND  1 PQUAL  SCRQS    1197.00  RCHRES  2   INFLOW ISQAL3
PERLND  2 PWATER PERO       17.07  RCHRES  5    EXTNL  IVOL
PERLND  2 SEDMNT SOSED      51.2   RCHRES  5   INFLOW ISED  1
PERLND  2 SEDMNT SOSED      81.9   RCHRES  5   INFLOW ISED  2
PERLND  2 SEDMNT SOSED      71.7   RCHRES  5   INFLOW ISED  3
PERLND  2 PQUAL  SCRQS      45.06  RCHRES  5   INFLOW ISQAL 1
PERLND  2 PQUAL  SCRQS      43.01  RCHRES  5   INFLOW ISQAL 2
PERLND  2 PQUAL  SCRQS     116.74  RCHRES  5   INFLOW ISQAL3
PERLND  3 PWATER PERO       80.00  RCHRES  5   EXTNL  IVOL
PERLND  3 SEDMNT SOSED       240.  RCHRES  5   INFLOW ISED  1
PERLND  3 SEDMNT SOSED       384.  RCHRES  5   INFLOW ISED  2
PERLND  3 SEDMNT SOSED       336.  RCHRES  5   INFLOW ISED  3
PERLND  3 PQUAL  SCRQS        0.   RCHRES  5   INFLOW ISQAL  1
PERLND  3 PQUAL  SCRQS        0.   RCHRES  5   INFLOW ISQAL  2
PERLND  3 PQUAL  SCRQS        0.   RCHRES  5   INFLOW ISQAL  3
PERLND  4 PWATER PERO       56.00  RCHRES  7   EXTNL  IVOL
PERLND  4 SEDMNT SOSED       168.  RCHRES  7   INFLOW ISED  1
PERLND  4 SEDMNT SOSED      268.8  RCHRES  7   INFLOW ISED  2
PERLND  4 SEDMNT SOSED      235.2  RCHRES  7   INFLOW ISED  3
PERLND  4 PQUAL  SCRQS     147.84  RCHRES  7   INFLOW ISQAL1
PERLND  4 PQUAL  SCRQS     141.12  RCHRES  7   INFLOW ISQAL2
PERLND  4 PQUAL  SCRQS     383.04  RCHRES  7   INFLOW ISQAL3
RCHRES  2 ROFLOW              1.    RCHRES  3   INFLOW
RCHRES  3 ROFLOW              1.    RCHRES  4   INFLOW
RCHRES  4 ROFLOW              1.    RCHRES  5   INFLOW
RCHRES  5 ROFLOW              1.    RCHRES  6   INFLOW
RCHRES  6 ROFLOW              1.    RCHRES  7   INFLOW
RCHRES  7 ROFLOW              1.    RCHRES  8   INFLOW
RCHRES  8 SEDTRN SSED  4 1    1.   DISPLY 63   INPUT  TIMSER
RCHRES  8 SEDTRN SSED  3 1    1.   DISPLY 64   INPUT  TIMSER
RCHRES  8 SEDTRN SSED  2 1    1.   DISPLY 65   INPUT  TIMSER
RCHRES  8 SEDTRN SSED  1 1    1.   DISPLY 66   INPUT  TIMSER
RCHRES  8 GQUAL  ROSQAL 1      1.   DISPLY 67   INPUT  TIMSER
RCHRES  8 GQUAL  ROSQAL 2      1.   DISPLY 68   INPUT  TIMSER
RCHRES  8 GQUAL  ROSQAL 3      1.   DISPLY 69   INPUT  TIMSER
END NETWORK

EXT TARGETS
```

```
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr
Amd ***
<Name>  x      <Name> x x<-factor->strg <Name>  x <Name>qf  tem strg strg***
COPY    1 OUTPUT MEAN  1            WDM   112 FLOW   ENGL    REPL
COPY    2 OUTPUT MEAN  1            WDM   122 FLOW   ENGL    REPL
COPY    3 OUTPUT MEAN  1            WDM   132 FLOW   ENGL    REPL
COPY    4 OUTPUT MEAN  1            WDM   142 FLOW   ENGL    REPL
END EXT TARGETS

END RUN
```

Appendix B
The Oxidized HSPF Input File

```
RUN

GLOBAL
 HSPF VERSION 10.0:  Calibrated to match Oxidized laboratory conditions.
 ***Calibrated for 10-year frequency storm event.
 ***NO scour or deposition in reaches 2-6
 START      1990/01/01      END    1994/12/31
 RUN INTERP OUTPUT LEVEL   3
 RESUME    0 RUN     1 TSSFL    15
END GLOBAL


FILES
<FILE>  <UN#>***<----FILE NAME---------------------------------------->
WDM       21   e:wocdat.wdm
            01   testb.out

MESSU     22   echo.out
            65   testnat.d65
            66   testnat.d65
INFO      23   HSPINF.DA
ERROR     24   HSPERR.DA
WARN      25   HSPWRN.DA
END FILES

OPN SEQUENCE
   INGRP           INDELT  0:30
     PERLND      1
     RCHRES      2
     RCHRES      3
     RCHRES      4
     PERLND      2
     PERLND      3
     RCHRES      5
     RCHRES      6
     PERLND      4
     RCHRES      7
     RCHRES      8
     DISPLY     63
     DISPLY     64
     DISPLY     65
     DISPLY     66
     DISPLY     67
```

```
    DISPLY     68
    DISPLY     69
  END INGRP
END OPN SEQUENCE

PERLND
 ACTIVITY
  <PLS >        Active Sections (1=Active; 0=Inactive)          ***
  # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS
TRAC ***
  1   2            0      1      1      0      0      1
  3                0      1      1      0      0      0
  4                0      1      1      0      0      1
 END ACTIVITY


 PRINT-INFO
  <PLS >        Print-flags  (4=MTH., 3=DAY, 2=PIVL)        *** PIVL  PYR
  # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS
TRAC      ***
  1                        4      4                  4                  1    12
  2   4                    4      4                  4                  1    12
 END PRINT-INFO

 GEN-INFO
  <PLS ><-------Name------->NBLKS  Unit-systems      Printer ***
  # -  #                              User   t-series  Engl Metr ***
                                              in  out            ***
  1     WOC u/s 7500 br.            1    1     1     1     1     0
  2     WOC 7500 Br. -MS3           1    1     1     1     1     0
  3     MB u/s MS4                  1    1     1     1     1     0
  4     MS 3/4 conf.-WOD            1    1     1     1     1     0
 END GEN-INFO



 *** Section PWATER ***

 PWAT-PARM1
  <PLS >  PWATER variable monthly parameter value flags ***
  # -  # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE   ***
  1   4      0      0      0      1      0      0      0      0      1
 END PWAT-PARM1
```

```
PWAT-PARM2
 <PLS > *** PWATER input info: Part 2
 # - # ***FOREST LZSN   INFILT    LSUR    SLSUR   KVARY AGWRC
 1          0.1 5.0043      .08     250.     0.14     0.0 0.9777
 2          0.1  13.00      .08     250.     0.14     0.0 0.9990
 3          0.2  13.00      .08     250.     0.14     0.0 0.9883
 4          0.4  13.00      .08     250.     0.14     0.0 0.9990
END PWAT-PARM2


PWAT-PARM3
 <PLS > *** PWATER input info: Part 3
 # - # ***PETMAX  PETMIN INFEXP INFILD DEEPFR BASETP AGWETP
 1  2        40.     35.    2.0    2.0    0.0    0.0    0.0
 3           40.     35.    2.0    2.0    0.1   0.15    0.0
 4           40.     35.    2.0    2.0    0.2   0.25    0.0
END PWAT-PARM3

PWAT-PARM4
 <PLS >    PWATER input info: Part 4                        ***
 # - #    CEPSC     UZSN     NSUR    INTFW     IRC    LZETP  ***
 1          .05     .851      0.3   2.2954  0.3000   0.3000
 2          .05       1.      0.3       .5  0.3000   0.3000
 3          .15    .5677      0.3   7.0000  0.3253   0.3000
 4          .20    .9999      0.3    .5000  0.3000   0.3333
END PWAT-PARM4

MON-INTERCEP
 <PLS>  Only required if VCSFG=1 in PWAT-PARM1              ***
 # - #  Interception storage capacity at start of each month ***
  *** JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
 1  4  .01 0.01 0.03 0.08 0.12 0.12 0.12 0.12 0.12 0.06 0.03 0.01
END MON-INTERCEP

MON-UZSN
 <PLS>  Only required if VUZFG=1 in PWAT-PARM1              ***
 # - #  Upper zone storage at start of each month      ***
  *** JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
 1  4  0.4  0.5  0.6  0.8  1.0  1.0  1.0  0.9  0.7  0.6  0.5  0.4
END MON-UZSN

MON-MANNING
```

```
 <PLS > Only required if VNNFG=1 in PWAT-PARM1                    ***
 # - # Manning's n for overland flow at start of each month      ***
  *** JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 1  4 0.30 0.30  0.30 0.30  0.27 0.25 0.25  0.25 0.25 0.25 0.35 0.33
END MON-MANNING

MON-LZETPARM
 <PLS > Only required if VLEFG=1 in PWAT-PARM1                    ***
 # - # Lower zone ET parameter at start of each month          ***
  *** JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 1  4   .2   .2   .2   .3   .4   .4   .4   .3   .3   .2   .2   .2
END MON-LZETPARM

PWAT-STATE1
 <PLS > *** Initial conditions at start of simulation
 # - # *** CEPS    SURS    UZS    IFWS    LZS    AGWS    GWVS
 1  4          0.      0.     0.8     0.05   10.8      7.0       0.
END PWAT-STATE1

*** SECTION SEDMNT ***

SED-PARM1
 <PLS > ***
 # - # CRV VSIV SDOP ***
 1  4    0    0    0
END SED-PARM1

SED-PARM2
 <PLS > ***
 # - #    SMPF    KRER    JRER    AFFIX   COVER    NVSI ***
 1  4       1.0     0.08     1.9     .010       0.5      0.0
END SED-PARM2

SED-PARM3
 <PLS > ***
 # - #    KSER    JSER    KGER    JGER ***
 1  4       0.1     1.3      .1      1.1
END SED-PARM3

MON-COVER
 <PLS > Monthly values for erosion-related land cover          ***
 # - # JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 1  4  .17  .13   .09  .06   .01  .03  .43  .67  .77  .61  .26  .21
```

```
END MON-COVER

SED-STOR
 <PLS > Detached sediment storage (tons/acre)        ***
 # - #   BLOCK1     BLK2     BLK3     BLK4     BLK5 ***
 1   4     0.0
END SED-STOR


*** Section PQUAL ***

NQUALS
 <PLS >     ***
 # - #NQUAL ***
 1   2        1
 4            1
END NQUALS

QUAL-PROPS
 <PLS >*** Identifiers and flags
 # - #<qualid>***QTID QSD VPFW VPFS QSO VQO QIFW VIQC QAGW
 1   4 Cs-137       mCi     1                  1            1            1
END QUAL-PROPS

QUAL-INPUT
 <PLS > Storage on surface and nonseasonal parameters              ***
 # - #    SQO   POTFW POTFS ACQOP SQOLIM WSQOP IOQC    AOQC
 1                  .2      2.3                        1.0E-10  1.0E-10
 2                  .3      1.4                        1.0E-10  1.0E-10
 4                  .2      1.4                        1.0E-10  1.0E-10
END QUAL-INPUT


*** Section PSTEMP ***

PSTEMP-PARM2
 <PLS >                                                          ***
 # - #    ASLT     BSLT     ULTP1    ULTP2    LGTP1    LGTP2 ***
***  1     14.5     .365       1.2       4.0       1.2       6.0
END PSTEMP-PARM2

*** Section PWTGAS ***
```

```
 PWT-PARM2
  <PLS >                                                    ***
  # - #    ELEV    IDOXP    ICO2P    ADOXP    ACO2P ***
***  1      500.       6.       .05        5.       .05
 END PWT-PARM2
END PERLND


RCHRES
 ACTIVITY
  RCHRES  Active Sections (1=Active; 0=Inactive)        ***
  # - # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
  2        1     1     0     0     1     1     0     0     0     0
  3  8     1     1     0     0     1     1     0     0     0     0
 END ACTIVITY

 PRINT-INFO
  RCHRES  Print-flags                                                ***
  # - # HYDR ADCA CONS HEAT SED GQL OXRX NUTR PLNK PHCB
                                                  PIVL PYR ***
  2  8     4     4     4     4     4     4     4     4     4     4
                                                        1    12
 END PRINT-INFO

 GEN-INFO
  RCHRES<-------Name------->Nexit  Unit Systems  Printer     ***
  # - #                          User t-series  Engl Metr LKFG ***
                                      in  out          ***
  2   2.21-2.18 7500 WEIR        1  1   1   1    1    0
  3   2.18-1.9 INT. POND         1  1   1   1    1    0
  4   1.90-1.63 MS3              1  1   1   1    1    0
  5   1.62-1.40                  1  1   1   1    1    0
  6   1.40-1.18 U/S WOL          1  1   1   1    1    0    0
  7   1.18-0.83 MID WOL          1  1   1   1    1    0    1
  8   0.83-0.60 WOD              1  1   1   1    1    0    1
 END GEN-INFO

 *** Section HYDR ***
```

```
HYDR-PARM1
 RCHRES  Flags for HYDR section                                    ***
 # - #  VC A1 A2 A3  ODFVFG for each    ODGTFG for each ***
        FG FG FG FG       possible  exit        possible  exit ***
                            1 2 3 4 5           1 2 3 4 5 ***

 2  8       1   1 1     4
END HYDR-PARM1

HYDR-PARM2
 RCHRES ***  (note 2/21/4 - the db50 here is used for sand transport
     ***   while the diam. for sand under SAND_PM below is ignored)
 # - #   FTABNO     LEN    DELTH    STCOR     KS    DB50 ***
 2         2        0.03      0.1              .0      .01
 3         3        0.28      6.1              .0     0.01
 4         4         .28      3.6              .0     0.01
 5         5         .22      4.3              .0     0.01
 6         6        0.22      1.2              .0     0.01
 7         7        0.35      2.5              .0    0.008
 8         8         .23      1.6              .0    0.008
END HYDR-PARM2

HYDR-INIT
 RCHRES  Initial conditions for HYDR section    ***
 # - #     VOL    Initial  value  of COLIND *** Initial  value  of OUTDGT
      (ac-ft)          for  each  possible  exit *** for  each  possible  exit
                 EX1  EX2  EX3  EX4  EX5 ***  EX1  EX2  EX3  EX4  EX5
 2        .03     4.0
 3        .30     4.0
 4        .40     4.0
 5        .20     4.0
 6        .70     4.0
 7        4.0     4.0
 8        3.5     4.0
END HYDR-INIT
```

*** Section SEDTRN ***

```
SANDFG
 RCHRES    ***
 # -  # SDFG ***
 2   8      3
END SANDFG

SED-GENPARM
 RCHRES   BEDWID    BEDWRN     POR ***
 # -  #                          ***
 2   4       30.        10.     .5
 5   6       40.        11.     .5
 7          500.        20.     .5
 8          600.        20.     .5
END SED-GENPARM

SAND-PM
***  (note D here should match DB50 in hydr-parm2 above)
 RCHRES      D      W     RHO    KSAND   EXPSND ***
 # -  #                          ***
 2   3     .03    3.2    2.65      1.0      1.0
 4   6     .02    2.4    2.65      1.0      1.0
 7   8    .008    .47    2.65     64.0     0.80
END SAND-PM

SILT-CLAY-PM
 RCHRES      D      W     RHO   TAUCD    TAUCS      M ***
 # -  #(silt)                                      ***
 2   2  .00063  .0091     2.2  0.000001 10000000   .6
 3   3  .00063  .0091     2.2  0.000001 10000000   .6
 4   4  .00063  .0091     2.2  0.000001 10000000   .6
 5   5  .00063  .0091     2.2  0.000001 10000000   .6
 6   6  .00063  .0091     2.2  0.000001 10000000   .6
 7   7  .00063   .022     2.2  0.000067 0.000068   .7
 8   8  .00063   .022     2.2  0.000067 0.000068   .7
END SILT-CLAY-PM
```

```
SILT-CLAY-PM
 RCHRES      D       W      RHO    TAUCD    TAUCS       M ***
 # -  #(clay)                                  ***
 2   2    .000079  .00011     2.0   0.000001  10000000    .6
 3   3    .000079   .0011     2.0   0.000001  10000000    .6
 4   4    .000079   .0011     2.0   0.000001  10000000    .6
 5   5    .000079   .0011     2.0   0.000001  10000000    .6
 6   6    .000079   .0011     2.0   0.000001  10000000    .6
 7   7    .000079   .0041     2.0    .000252    .000253    .7
 8   8    .000079   .0041     2.0    .000252    .000253    .7
END SILT-CLAY-PM

SSED-INIT
 RCHRES    Suspended sed concs (mg/l) ***
 # -  #     Sand     Silt     Clay  ***
 2   8        1.      15.      15.
END SSED-INIT

BED-INIT
 RCHRES   BEDDEP  Initial bed composition      ***
 # -  #     (ft)     Sand     Silt     Clay ***
 2   2      3.        .5       .3       .2
 3   4      3.        .5       .3       .2
 5   6      3.        .4       .4       .2
 7   8      4.        .2       .5       .3
END BED-INIT

*** Section GQUAL ***

GQ-GENDATA
 RCHRES NGQL TPFG PHFG ROFG CDFG SDFG PYFG  LAT ***
 # -  #                          ***
 2   8          1     1                        1
END GQ-GENDATA

GQ-QALDATA
 RCHRES<-------GQID------->    DQAL   CONCID    CONV    QTYID ***
 # -  #                                  ***
 2   8      Cs-137              3.4E-7       mCi      .035      mCi
END GQ-QALDATA


GQ-QALFG
```

```
 RCHRES HDRL OXID PHOT VOLT BIOD  GEN SDAS ***
 # - #                      ***
 2   8                                      1
END GQ-QALFG


GQ-GENDECAY
 RCHRES   FSTDEC    THFST ***
 # - #             ***
 1   1
END GQ-GENDECAY

GQ-SEDDECAY
 RCHRES   KSUSP   THSUSP    KBED    THBED ***
 # - #                     ***
 1   1
END GQ-SEDDECAY

GQ-KD
 RCHRES            Partition coefficients              ***
 # - # ADPM(1,1) ADPM(2,1) ADPM(3,1) ADPM(4,1) ADPM(5,1)
                                        ADPM(6,1)
 2   8       3.e-4       3.e-2       3.e-2       3.e-4       3.e-2
                                                         3.e-2
END GQ-KD

GQ-ADRATE
*** this is adsorption rate in 1/day
 RCHRES       Adsorption/desorption rate parameters          ***
 # - # ADPM(1,2) ADPM(2,2) ADPM(3,2) ADPM(4,2) ADPM(5,2 )
                                      ADPM(6,2) ***
 2   8          1.          1.          1.          1.          1.
                                                             1.
END GQ-ADRATE

GQ-SEDCONC
 RCHRES   SQAL1   SQAL2   SQAL3   SQAL4   SQAL5   SQAL6 ***
 # - #                             ***
 2   8       5.E-10    5.E-10    5.E-10    5.E-10    5.E-10    5.E-10
END GQ-SEDCONC

GQ-VALUES
 RCHRES   TWAT   PHVAL    ROC    CLD   SDCNC    PHY ***
```

```
  # - #                                          ***
  1   8
 END GQ-VALUES

END RCHRES

DISPLY
 DISPLY-INFO1
*** # -  #<----------Title------->TRAN PIVL DIG1FIL1 PYRDIG2 FIL2YEND
  63    Total [SS] rch8 (mg/l)  AVER          2    1    1    1   65    12
  64    Clay [SS] rch8 (mg/l)   AVER          2    1    1    1   65    12
  65    Silt [SS] rch8 (mg/l)   AVER          2    1    1    1   65    12
  66    Sand [SS] rch8 (mg/l)   AVER          2    1    1    1   65    12
  67    Cs-137 sand rch8 (mCi/) SUM           2    4    1    2   65    12
  68    Cs-137 silt rch8 (mCi/) SUM           2    4    1    2   65    12
  69    Cs-137 clay rch8 (mCi/) SUM           2    4    1    2   65    12
 END DISPLY-INFO1
END DISPLY

PLTGEN
 PLOTINFO
  # -  # FILE  NPT  NMN LABL  PYR PIVL ***
  1         51          2          12    1
  2         52          1          12   24
 END PLOTINFO

 GEN-LABELS
  # -  #<----------------Title----------------->  ***   <------Y axis------>
  1    SIMULATED FLOW (hr)                          CFS
  2    simulated flow (daily)                       cfs
 END GEN-LABELS

 SCALING
  # -  #     YMIN     YMAX     IVLIN ***
  1   2          0.       2000.       20.
 END SCALING

 CURV-DATA       (first curve)
         <-Curve label--> Line Intg  Col Tran ***
  # -  #                   type  eqv code code ***
  1   2   SIM OVERLANDFLOW   0         AVER
 END CURV-DATA
```

```
 CURV-DATA       (second curve)
        <-Curve label--> Line Intg  Col Tran ***
  # - #                 type  eqv code code ***
   1   2   SIM STREAMFLOW     0         AVER
 END CURV-DATA
END PLTGEN

FTABLES
 FTABLE    8
ROWS COLS ***  MI.  0.83 TO 0.6
  9   4

   DEPTH     AREA   VOLUME   OUTLET    ***
    (FT)  (ACRES)  (AC-FT)    DISCH    ***
                     (CFS)    ***
    .000     .000      .0000    .0000
   10.40     9.0         61.0   300.0
   11.90     10.0        75.0   700.0
   13.20     10.0        88.0  1200.0
   13.60     10.0        92.0  1400.0
   14.20     10.0        99.0  1700.0
   15.30     11.0       110.0  2170.0
   20.80     12.0       173.0 12150.0
   23.40     12.0       205.0 23800.0
 END FTABLE  8

 FTABLE    7
ROWS COLS ***  MI.  1.18 TO 0.83
  9   4

   DEPTH     AREA   VOLUME   OUTLET ***
    (FT)  (ACRES)  (AC-FT)    DISCH ***
                     (CFS) ***
    .000     .000      .0000    .0000
    7.40     17.0        66.0   281.0
    8.90     17.0        92.0   657.0
   10.21     18.0       115.0  1130.0
   10.61     18.0       122.0  1320.0
   11.21     19.0       132.0  1590.0
   12.32     19.0       154.0  2170.0
   17.93     22.0       274.0 11700.0
   20.71     25.0       346.0 22800.0
 END FTABLE  7
```

FTABLE 6
ROWS COLS *** MI. 1.40 TO 1.18
9 4

DEPTH (FT)	AREA (ACRES)	VOLUME (AC-FT)	OUTLET DISCH (CFS) ***
.000	.000	.0000	.0000
3.33	7.0	12.0	254.0
4.82	9.0	23.0	593.0
6.13	10.0	36.0	1030.0
6.54	11.0	41.0	1210.0
7.14	11.0	47.0	1440.0
8.25	12.0	59.0	1975.0
14.37	14.0	146.0	10900.0
17.69	16.0	201.0	21500.0

END FTABLE 6

FTABLE 5
ROWS COLS *** MI. 1.62 TO 1.40
9 4

DEPTH (FT)	AREA (ACRES)	VOLUME (AC-FT)	OUTLET DISCH (CFS) ***
.000	.000	.0000	.0000
3.08	2.0	3.0	239.0
4.39	4.0	7.0	557.0
5.82	7.0	14.0	975.0
6.21	8.0	16.0	1140.0
6.74	9.0	20.0	1360.0
7.77	10.0	29.0	1850.0
14.41	14.0	109.0	10500.0
18.39	15.0	167.0	20700.0

END FTABLE 5

FTABLE 4
ROWS COLS *** MI. 1.90 TO 1.63
9 4

DEPTH (FT)	AREA (ACRES)	VOLUME (AC-FT)	OUTLET DISCH (CFS) ***

```
  .000    .000        .0000   .0000
  4.07    4.0           8.0   223.0
  4.61    5.0          11.0   519.0
  5.30    7.0          16.0   920.0
  5.49    7.0          17.0  1070.0
  5.74    7.0          19.0  1260.0
  6.53    8.0          23.0  1730.0
 15.03   12.0         103.0 10100.0
 18.64   12.0         149.0 19800.0
END FTABLE  4

FTABLE    3
ROWS COLS ***  MI.  2.18 TO 1.90
  9   4

  DEPTH    AREA   VOLUME   OUTLET   ***
  (FT)  (ACRES)  (AC-FT)   DISCH   ***
                  (CFS)   ***
  .000    .000        .0000   .0000
  3.63    6.0           6.5   223.0
  5.33    7.0          17.0   519.0
  6.65    7.0          27.0   920.0
  7.01    7.0          30.0  1070.0
  7.41    7.0          32.0  1260.0
  8.22    7.0          38.0  1730.0
 15.52   14.0         102.0 10100.0
 19.50   16.0         156.0 19800.0
END FTABLE  3

FTABLE    2
ROWS COLS ***   MI. 2.21 TO 2.18
  9   4

  DEPTH    AREA   VOLUME   OUTLET   ***
  (FT)  (ACRES)  (AC-FT)   DISCH   ***
                  (CFS)   ***
  .000    .000        .0000   .0000
  5.43    0.2           0.5   176.0
  6.66    0.2           1.0   410.0
  7.48    0.3           1.2   760.0
  7.78    0.3           1.3   910.0
  8.00    0.3          1.5   1025.0
  8.68    0.4          1.9   1425.0
```

```
  15.53     1.0        4.0   9000.0
  19.87     1.0        8.0  17750.0
 END FTABLE  2

 FTABLE    1
ROWS COLS ***  ( mile 2.55 TO 2.21  in woc)
  9   4

   DEPTH    AREA   VOLUME   OUTLET   ***
    (FT)  (ACRES)  (AC-FT)    DISCH   ***
                    (CFS)    ***
    .000     .000     .0000    .0000
    3.69     2.8       5.5     176.0
    5.08     2.8      11.0     410.0
    6.30     3.7      13.8     760.0
    6.77     3.7      14.7     910.0
    7.24     3.7      17.5    1025.0
    8.74     4.6      22.1    1425.0
   17.82    14.0     109.0    9000.0
   21.11    17.0     174.0   17750.0
 END FTABLE  1
END FTABLES

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols>
<-Grp><-Member->***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #      <Name>***
WDM     51 PRCP    ENGLZERO        DIV PERLND   1   1 EXTNL  PREC
WDM     52 PRCP    ENGLZERO        DIV PERLND   2   2 EXTNL  PREC
WDM     53 PRCP    ENGLZERO        DIV PERLND   3   3 EXTNL  PREC
WDM     53 PRCP    ENGLZERO        DIV PERLND   1   4 EXTNL  PREC
WDM     40 EVAP    ENGLZERO .007 DIV PERLND   1   4 EXTNL  PETINP
WDM     41 TEMP    ENGLZERO          RCHRES   1   8 HTRCH  TW
END EXT SOURCES

NETWORK
  *** PLS areas IN AC. : (1) 2099,  (2) 204.8, (3) 960, (4) 672
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->
***
<Name>   #      <Name> # #<-factor->strg <Name>   #   #      <Name> # #  ***
PERLND   1 PQUAL  IOQUAL      2099.    RCHRES   2    INFLOW IDQAL
PERLND   1 PQUAL  AOQUAL      2099.    RCHRES   2    INFLOW IDQAL
PERLND   1 PWATER PERO       174.93    RCHRES   2    EXTNL  IVOL
```

```
PERLND  1 SEDMNT SOSED     524.8   RCHRES  2   INFLOW ISED  1
PERLND  1 SEDMNT SOSED     839.6   RCHRES  2   INFLOW ISED  2
PERLND  1 SEDMNT SOSED     734.6   RCHRES  2   INFLOW ISED  3
PERLND  1 PQUAL  SCRQS     315.00  RCHRES  2   INFLOW ISQAL1
PERLND  1 PQUAL  SCRQS     462.00  RCHRES  2   INFLOW ISQAL2
PERLND  1 PQUAL  SCRQS    1323.00  RCHRES  2   INFLOW ISQAL3
PERLND  2 PWATER PERO       17.07  RCHRES  5    EXTNL  IVOL
PERLND  2 SEDMNT SOSED      51.2   RCHRES  5   INFLOW ISED  1
PERLND  2 SEDMNT SOSED      81.9   RCHRES  5   INFLOW ISED  2
PERLND  2 SEDMNT SOSED      71.7   RCHRES  5   INFLOW ISED  3
PERLND  2 PQUAL  SCRQS      30.72  RCHRES  5   INFLOW ISQAL 1
PERLND  2 PQUAL  SCRQS      45.06  RCHRES  5   INFLOW ISQAL 2
PERLND  2 PQUAL  SCRQS     129.02  RCHRES  5   INFLOW ISQAL3
PERLND  3 PWATER PERO       80.00  RCHRES  5   EXTNL  IVOL
PERLND  3 SEDMNT SOSED       240.  RCHRES  5   INFLOW ISED  1
PERLND  3 SEDMNT SOSED       384.  RCHRES  5   INFLOW ISED  2
PERLND  3 SEDMNT SOSED       336.  RCHRES  5   INFLOW ISED  3
PERLND  3 PQUAL  SCRQS        0.   RCHRES  5   INFLOW ISQAL  1
PERLND  3 PQUAL  SCRQS        0.   RCHRES  5   INFLOW ISQAL  2
PERLND  3 PQUAL  SCRQS        0.   RCHRES  5   INFLOW ISQAL  3
PERLND  4 PWATER PERO       56.00  RCHRES  7   EXTNL  IVOL
PERLND  4 SEDMNT SOSED       168.  RCHRES  7   INFLOW ISED  1
PERLND  4 SEDMNT SOSED      268.8  RCHRES  7   INFLOW ISED  2
PERLND  4 SEDMNT SOSED      235.2  RCHRES  7   INFLOW ISED  3
PERLND  4 PQUAL  SCRQS     100.82  RCHRES  7   INFLOW ISQAL1
PERLND  4 PQUAL  SCRQS     147.84  RCHRES  7   INFLOW ISQAL2
PERLND  4 PQUAL  SCRQS     423.36  RCHRES  7   INFLOW ISQAL3
RCHRES  2 ROFLOW              1.   RCHRES  3   INFLOW
RCHRES  3 ROFLOW              1.   RCHRES  4   INFLOW
RCHRES  4 ROFLOW              1.   RCHRES  5   INFLOW
RCHRES  5 ROFLOW              1.   RCHRES  6   INFLOW
RCHRES  6 ROFLOW              1.   RCHRES  7   INFLOW
RCHRES  7 ROFLOW              1.   RCHRES  8   INFLOW
RCHRES  8 SEDTRN SSED  4 1    1.   DISPLY 63   INPUT  TIMSER
RCHRES  8 SEDTRN SSED  3 1    1.   DISPLY 64   INPUT  TIMSER
RCHRES  8 SEDTRN SSED  2 1    1.   DISPLY 65   INPUT  TIMSER
RCHRES  8 SEDTRN SSED  1 1    1.   DISPLY 66   INPUT  TIMSER
RCHRES  8 GQUAL  ROSQAL 1     1.   DISPLY 67   INPUT  TIMSER
RCHRES  8 GQUAL  ROSQAL 2     1.   DISPLY 68   INPUT  TIMSER
RCHRES  8 GQUAL  ROSQAL 3     1.   DISPLY 69   INPUT  TIMSER
END NETWORK

EXT TARGETS
```

```
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr
Amd ***
<Name>  x      <Name> x x<-factor->strg <Name>  x <Name>qf  tem strg strg***
COPY     1 OUTPUT MEAN  1            WDM   112 FLOW    ENGL     REPL
COPY    2 OUTPUT MEAN  1            WDM   122 FLOW    ENGL     REPL
COPY    3 OUTPUT MEAN  1            WDM   132 FLOW    ENGL     REPL
COPY    4 OUTPUT MEAN  1            WDM   142 FLOW    ENGL     REPL
END EXT TARGETS

END RUN
```

Vita

Andrew Clevenger was born in Kingsport, Tennessee on November 2, 1970. He graduated from Sullivan South High School in Kingsport in June of 1989. In the fall of 1989 he entered the University of Tennessee, Knoxville and received his Bachelor of Science degree in Civil Engineering in December, 1993. In January, 1993, he entered the Environmental Engineering graduate program at the University of Tennessee. He is presently working at the Oak Ridge National Laboratory in Oak Ridge, Tennessee as a graduate research associate.