CHARACTERIZING EROSION PROCESSES AND SEDIMENT YIELDS ON CONSTRUCTION SITES

by

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A THESIS

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ABSTRACT

This research investigated specific characteristics of construction sites that may affect erosion processes and sediment yields. The data collected were compared with models that compute runoff loading rates for individual rain events.

The objective of this research was to choose several construction sites with a variety of conditions that can affect erosion processes and sediment yields. Stormwater runoff samples were taken during various intervals of the rain event. These samples were analyzed for a variety of parameters, such as turbidity, suspended solids, total solids, and particle size distributions. The characteristics of each construction site, such as soil type, topography, percentage of area disturbed, drainage area, and erosion controls, were recorded. Rainfall data, such as intensity, total accumulation, and duration of each observed event, were also collected. The data were then analyzed to determine factors that affect erosion processes and sediment yields on construction sites. The information collected was also compared with models that calculate erosion rates of particulates for an individual rain event.

The results of the research determined that high concentrations of suspended solids occurred during periods of high rain intensity. Examination of the particle sizes for all runoff samples revealed that they were very small (median size approximately 5 μm). These small particles are difficult to remove from runoff with conventional erosion controls. This fact indicates the need for prevention of the erosion process at the source.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

CHAPTER

APPENDICES

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Stormwater runoff from construction sites has been identified as a major contributor of sediment to streams and rivers (Pitt, 1990). The sediment may also contain a variety of pollutants that can degrade receiving waters (Pitt, 1990). Characterizing the effects of rain events and site attributes on sediment loadings is an important step towards determining what controls will be effective.

Characterizing the sediment found in the runoff from a variety of disturbed areas may determine what types of controls will have the greatest benefit. Construction site erosion runoff characteristics of most importance are total solids, suspended solids, dissolved solids, turbidity, and particle size distributions. Testing the runoff for a variety of these characteristics provides information that may help to explain erosion processes, quantify the sediment yield, and assist in the design of erosion controls. The runoff and construction site characteristics will then be used in physically-based models and compared with empirical models that predict soil erosion and sediment yields. Conclusions from the results of these models and further analysis of the data will be used to investigate the effectiveness of sediment controls under a variety of conditions. Once specific controls are proven effective, they may be applied to design criteria for erosion and sediment controls on construction sites. If the effectiveness of the sediment and erosion controls can be documented with actual field data and calibrated models, the implementation and enforcement of ordinances related to erosion and sediment controls on construction sites will be supported by physical evidence. The criteria in these ordinances will make it possible for engineers and contractors to carefully plan erosion and sediment controls that effectively minimize the impact of disturbed area on construction sites.

Detailed information on actual runoff parameters from construction sites is very limited at this time. This study investigated erosion and sediment characteristics of construction sites that have not been extensively researched in the past. The need for this study is important because many models that predict the effects of erosion and sedimentation have been based on assumptions with little or no physical data to calibrate the models for construction site conditions. Monitoring data from construction sites may confirm or disprove assumptions that models have been based upon or discover anomalies in these models that should be considered.

This study is a preliminary investigation into the relationships between the rain characteristics, the site characteristics, and the sediment characteristics in stormwater runoff from construction sites. An attempt was made to specifically address the following questions.

1. What are the typical sediment characteristics in stormwater runoff from construction sites?

2. What site conditions affect the sediment characteristics?

3. How do the collected data compare with existing sediment loading models?

Seventy samples were collected at five construction sites during nine rain events. Turbidity, suspended solids, dissolved solids, and particle size distributions were determined for each sample.

During this research, a variety of site conditions that affect erosion and sediment yields were observed. Characteristics such as soil type, topography, and percentage of drainage area disturbed were recorded for each site. Rainfall data were collected from the National Weather Service for each rain event in the study.

Calculated suspended sediment loads were compared with existing models. Scatter plots, probability plots, and statistical analyses were used to characterize the runoff data and to identify the rain and site conditions that have significant effects on sediment loading in construction site stormwater runoff.

CHAPTER 2

LITERATURE REVIEW

2.1 Problems Caused by Construction Site Runoff

Erosion caused by rainfall and runoff from disturbed areas of construction sites can have a dramatic impact on receiving waters (Pitt, 1990). Compacted and vegetated soil is transformed into easily erodible sediment. Covering, compacting, vegetating, or using other types of erosion controls can reduce soil losses and sedimentation to the downstream areas to a minimum. Controlling this sediment is crucial since the runoff can carry sediment and other contaminants off the site and into a receiving water system. Soils naturally have nutrients and other organic matter that are easily transported in the sediment and dissolved into the runoff. The transported soil may also contain organics, nutrients, and toxic metals, along with other contaminants from materials being used on the construction sites such as oils and fuel (Pitt, 1990). Controlling the sediment and these contaminants can prevent the discharge of these substances into surface waters, groundwater, and water supplies.

2.2 Erosion Process

Several factors affect the erosion process. Site conditions such as soil types, surface characteristics, and land slope determine the degree to which soil can be detached from the ground surface. These conditions can be modeled to determine the sediment loading rates for individual sites and rainfall events. Rainfall energy and intensity is a significant factor in the erosion process. The annual rainfall erosion index is shown in Figure 2.1 (Wischmeier and Smith, 1978); these values can be used to calculate average annual erosion losses. The highest values are observed in the southeast region. Local erosion losses from construction sites have the potential to be the highest in the nation due to high rainfall energy and intensity.

Researchers have performed extensive studies on the mechanisms of the soil erosion process caused by rainfall. These studies have produced many conclusions to define each mechanism of the erosion process. Most of these studies agree that the basic components of the soil erosion process from rainfall are the detachment and transport of soil particles from rainfall impacts and overland flow.

2.2.1 Splash Mechanisms

In simulated rainfall studies, Haung (1982) was able to determine the significant forces of raindrop impacts on soil surfaces. Haung concluded that the impact of a raindrop caused compressive stresses to the surface and the shearing forces from the lateral jet. These two basic mechanisms of raindrop impact were considered significant factors in the soil detachment process. Haung also concluded that the jetting velocity from the lateral forces was two times greater than the velocity of the impact. The outflow jet caused both compression of the material surface and cracks under tension. The lateral jet stream was believed to be the critical mechanism of the raindrop-soil detachment process. Important soil characteristics for the detachment process were surface deformation, shearing stresses, and surface microrelief.

In another study, Haung (1983) demonstrated that continued deformities to a soil surface from raindrop impacts increased soil detachment. The microrelief of the soil surface was a significant factor in the amount of soil detachment from raindrop impacts. Simulated raindrop impacts in the study also revealed that soil materials with a low modulus of elasticity had greater deformation. When lateral jets caused by raindrop impacts traveled across irregular surface deformations, material was detached from the surface. These surface deformations were determined to be sides of impact cavities or irregularities on the granular material. As more cavities were formed by raindrop impacts, the lateral jets of new raindrop impacts detached, increasing amounts of material due to the increasing irregularity of the soil surface. This information indicates that a brief storm event does not have the ability to erode a soil surface as much as an event with a longer rainfall duration. The longer event duration can deform the surface of the soil causing increased particle detachment.

2.2.2 Thin Water Layer

The erosion process can be increased by a thin water layer flowing over the soil surface. Ferreira and Singer (1985) reported that a combination of rainfall impact and shallow overland flow resulted in more soil loss than either mechanism by itself. The effective depth of this water layer is quite small. A water layer only one third the diameter of a raindrop can produce more than twice the amount of sediment transport than that resulting from either rainfall or overland flow alone. Given this information, one may conclude that a brief storm event may not form a layer of water over the soil to effectively enhance the erosion process. Deep water layers, however, reduce site erosion because the water absorbs some of the raindrop energy before it can impact the ground surface.

2.3 Universal Soil Loss Equation (USLE)

Researchers have attempted to develop quantitative relationships between factors such as slope, rainfall characteristics, physical soil properties, vegetative cover, and other erosion controls that influence soil erosion and sediment transport. Musgrave (1947) examined soil loss measurements for approximately 40,000 storms on test plots in the United States. His findings indicate that soil erosion losses depend on soil erodability, runoff length and slope, the maximum 30-minute intensity of rainfall, and a cover factor. Additional studies led to the development of the Universal Soil Loss Equation (USLE). The USLE was developed to predict long term average soil losses in runoff from fields with specified crop management practices (Wischmeier, 1972). The major factors in the USLE are A (the soil loss per unit area), R (the rainfall erodability factor), K (the soil-erodability factor), LS (the slope length-steepness factor shown in Figure 2.2), C (the crop management or soil cover factor), and P (conservation practices):

$$A = R*K*LS*C*P.$$

The rainfall erodability factor can be evaluated for an individual storm using the rainfall energy (E) times the maximum 30-minute intensity of rainfall (I_{30}) for the event (Wischmeier, 1959):

$$R = E*I_{30}/100.$$

The kinetic energy for the event E is given by

$$E = 916 + 331 \log_{10} (I)$$

in which I is the average rainfall intensity for the event.

2.4 Sediment-Delivery Ratio

The sediment-delivery ratio is a percentage of the eroded material that reaches the outfall of a drainage basin. The ratio of the observed sediment yield and the predicted gross erosion of a drainage basin are dependent on drainage area, watershed slope, drainage density, and runoff (Gottschalk, 1964). Frenette (1986) observed that increased drainage area increases the probability that sediment particles will be trapped. Therefore, the sediment-delivery ratio decreases with increasing drainage area.

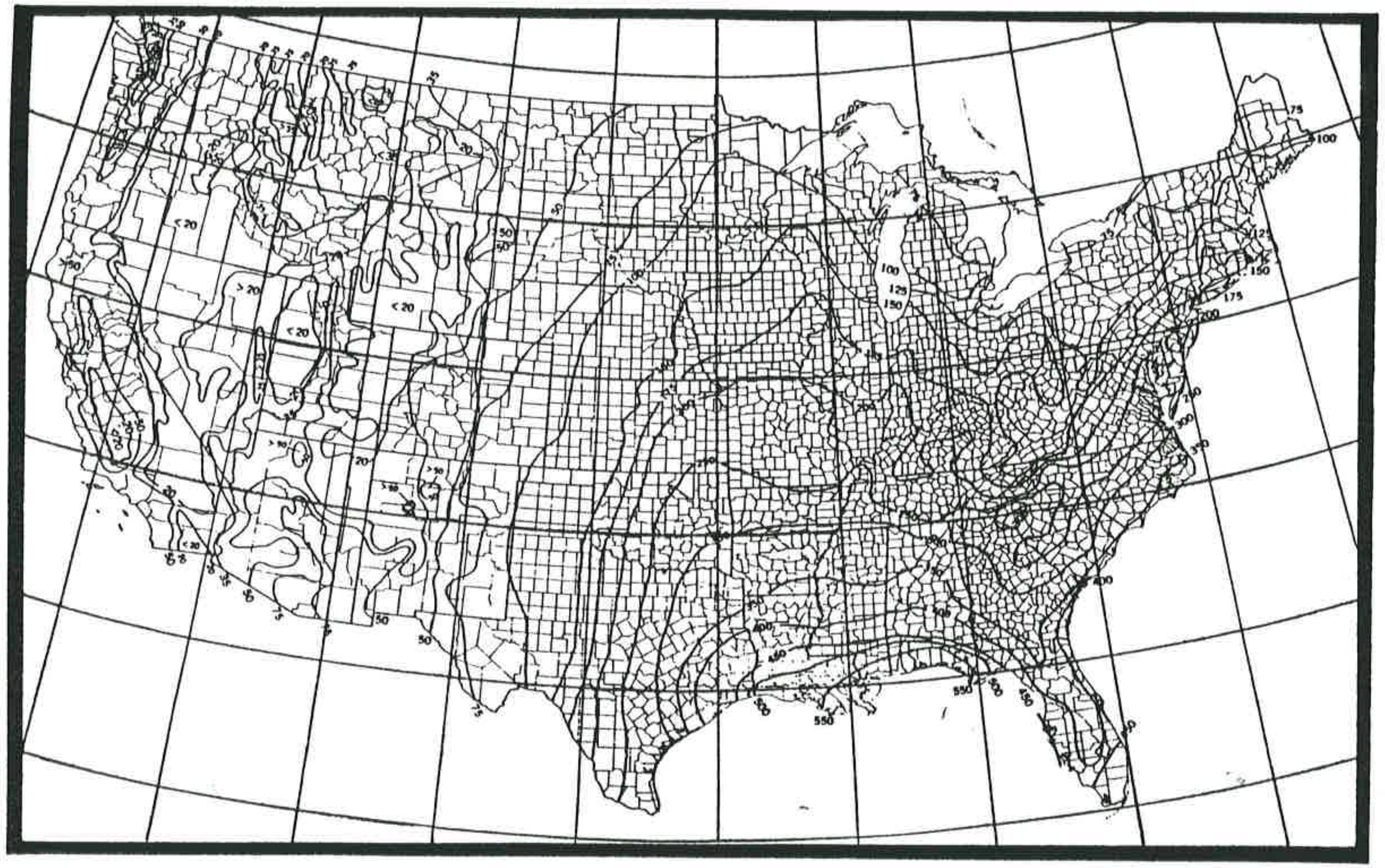
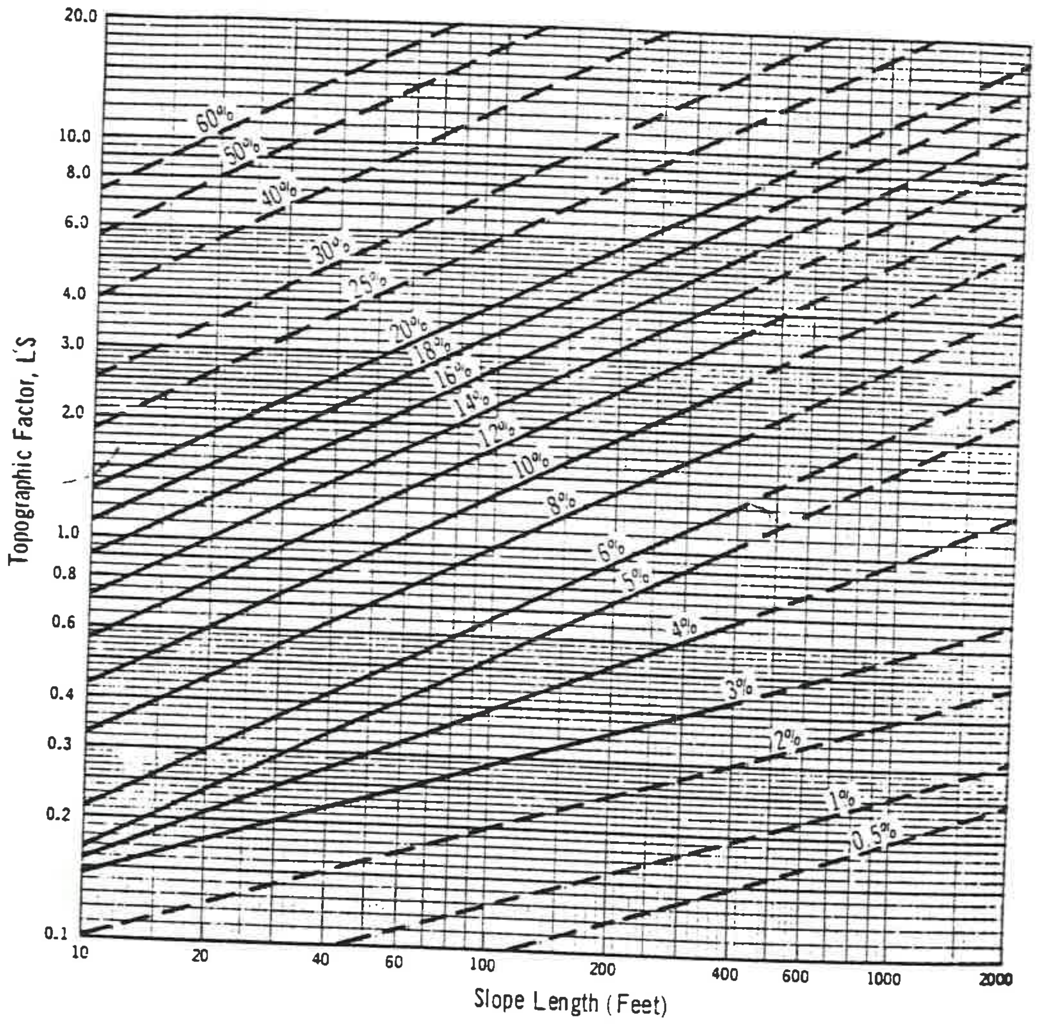


Figure 2.1 Average Annual Values of the Rainfall Erosion Index R
(Wischmeier and Smith 1978)



*The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available. The curves were derived by the formula:

$$LS = \left(\frac{\lambda}{72.6}\right)^{m} \left(\frac{430x^2 + 30x + 0.43}{6.613}\right)$$

where λ = field slope length in feet and $m = 0.5$ if $s = 5\%$ or greater, 0.4 if $s = 4\%$, and 0.3 if $s = 3\%$ or less; and $x = \sin\theta$. θ is the angle of slope in degrees.

Figure 2.2 Slope-effect Chart
(Topographic Factor, LS), (SCS, 1977)

CHAPTER 3

METHOD OF ANALYSIS

3.1 Sampling

Runoff samples were manually collected in glass bottles with teflon lined caps. To keep the data consistent, each sample was collected in the center of the flow at mid-depth in order to accurately compare the observed results with other rain events or sample locations. Samples were then stored at 4°C. No samples were held more than seven days prior to testing for gravimetric analysis and turbidity.

3.2 Sample Preparation and Analysis

Analytical methods for the gravimetric analysis, turbidity measurements, and determination of particle size distributions were followed according to "Standard Methods for Examination of Water and Wastewater" (American Public Health Association, 1995). Method 2540 B was used to determine the total solids, method 2540 B for suspended solids, method 2540 C for dissolved solids, method 2130 B for turbidity, and method 2560 B for particle size distributions. Sample preparation techniques and procedures for laboratory analysis are discussed in the following sections.

3.2.1 Gravimetric Analysis

Approximately 200-mL of sample was split for this analysis by pouring the sample back and forth between two jars. The sample splitting process was complete when the sample had been evenly mixed and an equal amount of sample volume remained in each jar. Since most of the samples had high concentrations of solids, a magnetic stirrer was used to keep the solids suspended in the sample. A beaker was placed on top of the stirrer mechanism and a magnetic stir bar was placed in the bottom of the beaker. The sample was then added and stirred at low speed to minimize currents of stratified particle sizes. A pipet with a wide opening was used to extract and measure the desired amount of sample for the total and suspended solids analyses.

In order to determine the suspended solid concentrations for a given sample, a standard glass fiber filter was placed in a filtering apparatus, washed three times successively with 20-mL of distilled water, placed in an aluminum dish, and dried between 103 and 105°C for at least one hour. The filter was then cooled in a desiccator and weighed. The filter was then placed back onto the filtering apparatus and the pipeted sample run through the filter. An initial visual observation was made of the sample when the solids were settled to determine how much sample could be run through the filter without clogging. If no visible solids were observed in the jar, 100-mL of sample was used. If solids were visible in the bottom of the jar, 50-mL of the sample was used. If a large quantity of solids was observed in the jar, 25-mL of sample was used. The filter was then placed back onto the aluminum dish, dried, cooled in the desiccator, and weighed. The difference between the recorded weights of the dried filter and dish before and after the sample was divided by the volume of the sample to obtain the concentration of suspended solids in the given sample.

In order to determine the concentration of total solids in a given sample, a clean crucible was heated between 103 and 105°C for at least 1 hour. The crucible was then placed in a desiccator until it reached room temperature. The crucible was then weighed. The prepared sample was pipeted into the crucible. The amount of sample volume used was equal to the amount used for the suspended solids analysis. The crucible was then dried at a temperature between 103 and 105°C, cooled in a desiccator, and weighed. The difference between the recorded weights of the dried crucible before and after the added sample was divided by the volume of sample to obtain the concentration of total solids in the given sample.

Total dissolved solids for a given sample were calculated by subtracting the suspended solids concentration from the total solids concentration.

3.2.2 Measuring Turbidity

Each sample was prepared in a similar manner as described in the gravimetric analysis section using the stirring mechanism and pipet. The undiluted sample was pipeted into a sample cell, and a turbidity reading was taken and recorded. If the turbidimeter had little or no response to the undiluted sample due to high opacity, the sample was diluted to determine the appropriate turbidity reading. The sample was diluted successively at a 1:2 ratio and the turbidity reading recorded until the turbidity values represented a straight line function with respect to each dilution factor. The straight line function values were then extrapolated to obtain an undiluted value for the sample.

3.2.3 Particle Size Distributions

The Coulter Counter particle size analyzer was not available when the samples were taken. A procedure was determined to use the filter from the suspended solids analysis for the particle size distribution procedure.

Each filter was stored in a small plastic covered petri-dish tray. In order to dislodge the particles from the filter, 5-mL of Cole-Parmer Isoton II solution was pipeted onto the filter. The filter and solution were allowed to sit for 24 hours to rehydrate the particles. The filter was then placed in a 100-mL beaker where distilled water was added to equal the original amount of sample passed through the filter. The beaker was then placed into an ultrasonic cleaning device filled with water to a depth of 2 inches. The solution was then agitated for five minutes to further dislodge the particles from the filter. A portion of the sample solution, usually 1-mL, was pipeted into 99-mL of Isoton II solution in preparation for the Coulter Counter Multisizer IIe. The prepared sample was pumped through the 200 micrometer orifice (3.6 to 128 μm particle size range) of the Coulter Counter for a period of 150 seconds. The interruption in current through the orifice was recorded by the Coulter Counter on 256 channels corresponding to various particle diameters. If the percentage of coincidence was greater than 10%, the original sample solution was diluted from 1-mL to 0.5-mL. Further dilutions were made if the percentage of coincidence was still greater than 10%. The procedure was repeated for the 50 micrometer orifice (0.95 to 33 μm particle size range).

CHAPTER 4

SITE DESCRIPTIONS AND CONDITIONS

4.1 Site Locations

Samples were collected from five construction sites in Vestavia Hills and Homewood, Alabama, suburbs of Birmingham. Table 4.1 indicates the site locations by section, township, range, and nearest street name. Figure 4.1 illustrates the site locations on a vicinity map.

4.2 Site Descriptions

The sample identification number did not always correspond to a particular sampling point due to sampling order or lack of runoff. Tables 4.2-4.6 match the sample point number to the sample identification number for each sample site.

Sites V and S are portions of the same townhouse development. These sites are relatively large with steep slopes on the perimeter of the site. The soil was observed to be composed predominantly of fine clay. Both these sites used silt fencing to control sediment in concentrated flow from drainage areas greater than 5 Acres. Site S drained into an open channel where attempts to control the sediment with silt fencing had been unsuccessful due to the large flows in the channel. Site V drains the eastern perimeter of the site. Attempts to divert runoff along the slope with a diversion ditch had been fairly successful, but the diversion channels running down the slope were not stabilized adequately. Runoff from a comparably large drainage area flowed through a small ditch that contained damaged and poorly maintained silt fencing.

Site I was a small area being developed into a church site. The site was relatively flat except for a slope on the northern perimeter. The observed soil consisted of clay and sand. No erosion controls were present at this site.

Site C was a bank expansion on a small lot. The site had gentle slopes with a brown soil consisting of sand and clay. Silt fencing was installed at the perimeter of the site. Unfortunately a majority of the disturbed area did not drain through the filter fencing. Most of the disturbed area drained directly into an unprotected storm inlet or onto a paved parking area.

Site T was being developed for a small medical office building. The entire site was moderately sloped with brownish soil consisting of clay and sand. Hay bales and silt fencing were installed around the storm drain inlets and ditches, but were poorly maintained.

4.3 Rainfall Data

Hourly precipitation measurements were obtained from the National Weather Service located approximately 1.2-1.8 km (2-3 miles) from the test sites (NOAA, 1989). Table 4.7

contains a summary of the rainfall information obtained for each sampling event.

4.4 Site Drainage

The drainage area for each site was determined based on site topography. Figures 4.2 and 4.3 illustrate the site locations and their surrounding topography. The Birmingham South quadrangle topographic map compiled by the United States Geological Survey (Photorevised 1978) was used to determine the size of the drainage areas for each construction site. The percentage of the drainage area disturbed by construction was obtained by comparing the area of the construction site with the total upstream drainage area from the sampling location.

4.5 Soil Characteristics

The soil types for each construction site were determined by locating the site on Jefferson County soil survey maps published by the Soil Conservation Service (1982). These maps contain map symbols that relate to specific soil types and characteristics. Figures 4.4 and 4.5 illustrate the site locations and map symbols on the soil survey maps. Once the soil type was determined by the classification codes, information for that particular soil type was provided in the soil survey report. The hydrologic group for each site was recorded from the soil survey for each site. The subsoil erosion factors were selected from the survey since the surface layer of the land was removed by the construction activity.

For sites V, S, and C, the map symbol indicated that these sites were in an urban land category, which means the land had been altered by development. An assumption to use the surrounding soil classification was made to assess the soil types in these areas.

Sites V , S, and I contain both Bodine and Birmingham soils. These soil types indicate that the sites are steep, well drained, and moderately permeable. The surface layer is cherty or cobbly loam, and the subsoil is a clay loam. The hydrologic group for this area is B, indicating that the soil is well drained. The erosion factor (K) for the subsoil is 0.28, reflecting soils from steep slopes and fine clay material. Site I also contains Allen soils which have a fine sandy loam surface layer and a sandy clay loam. The hydrologic group for Allen soils is still B, but the erosion factor (K) is 0.20 due to the sandy clay subsoil and typical topography.

Sites C and T contain Gorgas soils. This soil group indicates that the sites reside in areas with steep slopes and are well drained. The surface soil is a brown fine sandy loam, and the subsoil is a strong dark brown sandy loam. The hydrologic group for this soil is D due to the low water capacity. The erosion factor (K) is 0.17 since the soil does not contain a predominant fine clay composition.

TABLE 4.1 SITE LOCATION DESCRIPTIONS

Site	Section	Township	Range	Nearest street
C	19	18 South	2 West	Highway 31 and Park View Drive
T	19	18 South	2 West	Highway 31 and Shades Crest Road
V	14	18 South	3 West	Valley Avenue and Beacon Parkway
S	14	18 South	3 West	Valley Avenue and Beacon Parkway
I	14	18 South	3 West	Barcelona Court

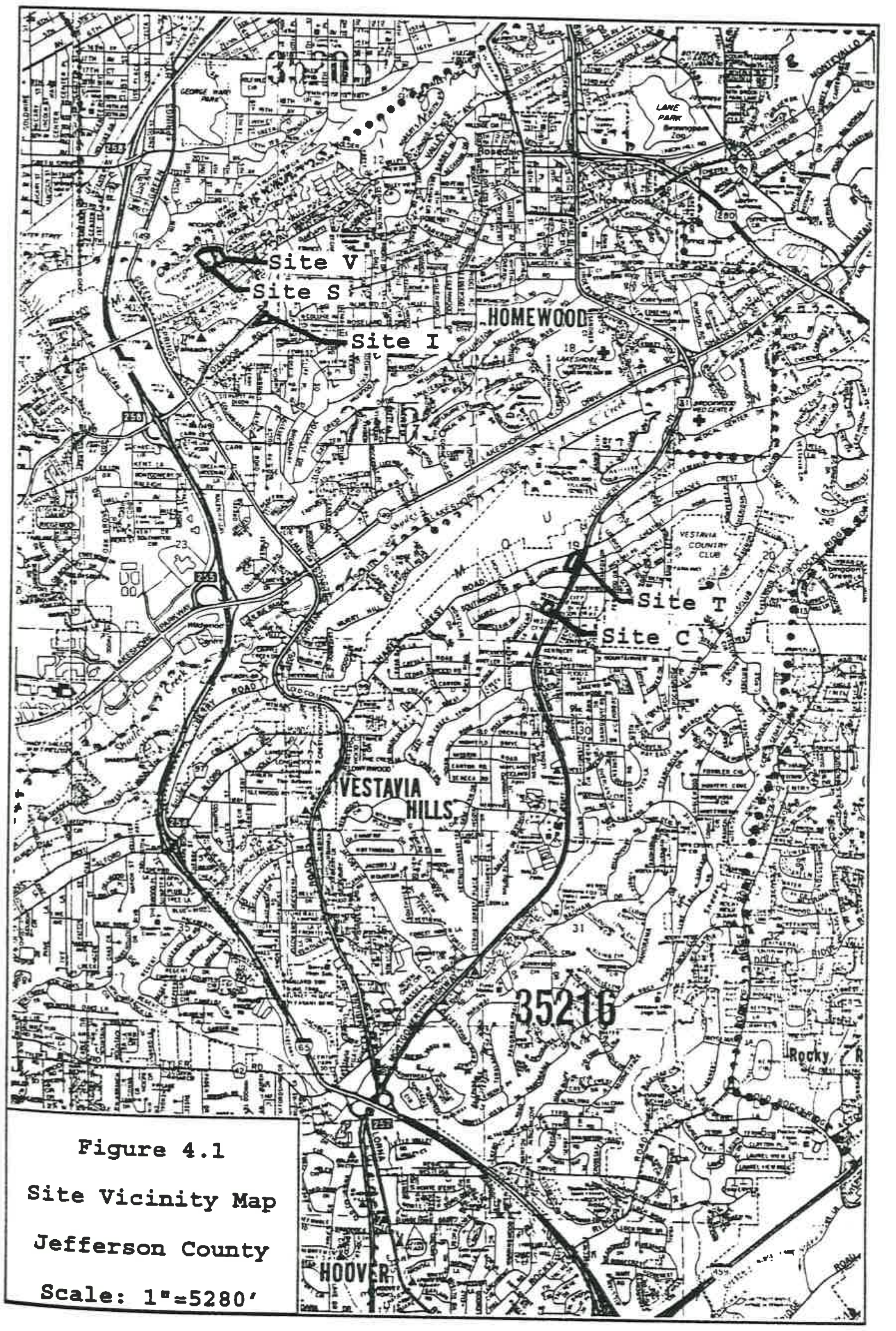


Figure 4.1

Site Vicinity Map

Jefferson County

Scale: 1"=5280'

TABLE 4.2 SAMPLES ACCORDING TO SAMPLE POINT FOR SITE V

Sample point	Sample ID
1	V2-6, V3-1
2	V1-3, V2-5, V3-2
3A	V1-1, V1-9, V2-1
3B	V1-5, V1-11, V2-3
3C	V1-7
4A	V1-2, V1-10, V2-2, V3-3
4B	V1-6, V1-12, V2-4
4C	V1-8
5	V1-5

TABLE 4.3 SAMPLES ACCORDING TO SAMPLE POINT FOR SITE S

Sample point	Sample ID
1A	S2-1, S3-1
1B	S2-2
2A	S2-3, S3-2
2B	S2-4
3A	S2-5, S3-3
3B	S2-6
4	S2-7
5	S2-8
6	S2-9

TABLE 4.4 SAMPLES ACCORDING TO SAMPLE POINT FOR SITE C

Sample point	Sample ID
1	C1-1, C2-1, C4-1, C6-1
2	C1-2, C2-2, C3-1, C4-2, C5-2, C6-2
3	C1-3, C2-3, C3-2, C4-5, C5-3, C6-3
4	C4-4
5A	C4-FB, C5-FB, C6-FB
5B	C1-5, C2-5, C6-5, C4-FA, C5-FA, C6-FA
6	C4-8

TABLE 4.5 SAMPLES ACCORDING TO SAMPLE POINT FOR SITE T

Sample point	Sample ID
1A	T1-1
1B	T1-2
2A	T1-3
2B	T1-4
3	T2-1
4	T2-2
5	T2-3

TABLE 4.6 SAMPLES ACCORDING TO SAMPLE POINT FOR SITE I

Sample point	Sample ID
1	I1-1
2	I1-2
3	I1-3

TABLE 4.7 RAIN EVENT DESCRIPTIONS

Site-event	Date	Time	Rain depth* (inches)	Peak hourly intensity* (inches/hour)	Average hourly intensity* (inches/hour)	Event duration (hours)	Observed intensity**
C-1	06/21/89	6:30 AM	1.72	0.75	0.215	8	Medium
C-2	06/21/89	7:15 AM	1.88	0.75	0.209	9	Medium
C-3	06/24/89	2:00 PM	0.58	0.58	0.580	1	High
C-4	06/28/89	5:45 PM	2.22	2.22	2.22	1	Medium
C-5	07/01/89	5:30 PM	0.50	0.26	0.25	2	Medium
V-1	07/01/89	6:00 PM	0.50	0.26	0.25	2	Medium
V-1A	07/01/89	6:30 PM	0.55	0.26	0.183	3	High
C-6	07/08/89	5:45 PM	0.56	0.56	0.56	1	Medium
V-2	07/08/89	6:45 PM	0.56	0.56	0.56	1	Low
I-1	07/08/89	7:00 PM	0.56	0.56	0.56	1	Low
S-2	07/14/89	12:30 PM	1.11	0.92	0.555	2	Medium
V-3	10/31/89	7:00 PM	0.28	0.28	0.28	1	Low
S-3	10/31/89	7:15 PM	0.28	0.28	0.28	1	Low
T-1	11/07/89	12:15 PM	0.53	0.53	0.26	2	Medium
T-2	01/20/90	5:50 PM	1.45	0.21	0.483	3	Medium

* Prior to sampling

** At time of sampling

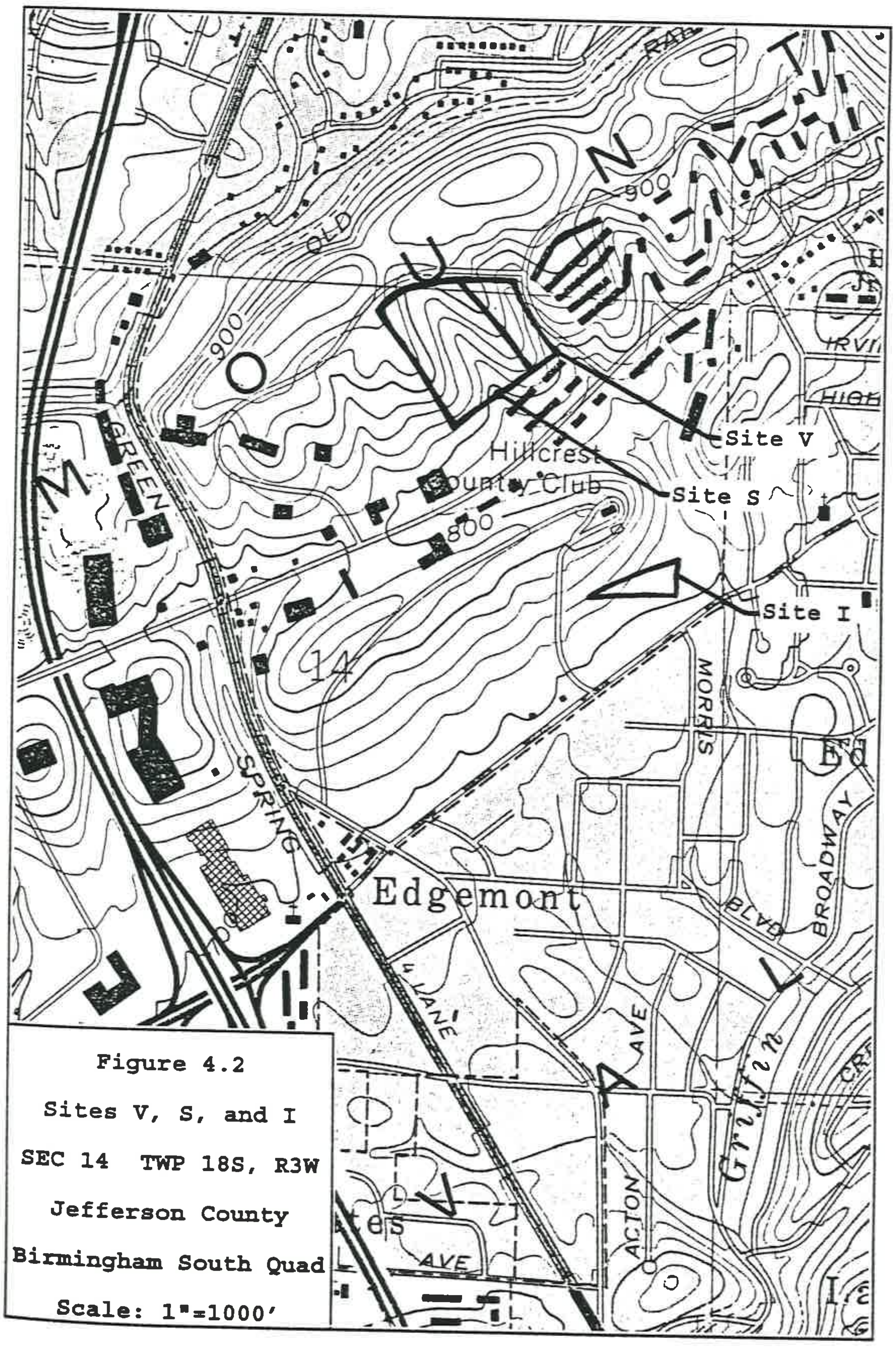


Figure 4.2

Sites V, S, and I

SEC 14 TWP 18S, R3W

Jefferson County

Birmingham South Quad

Scale: 1"=1000'

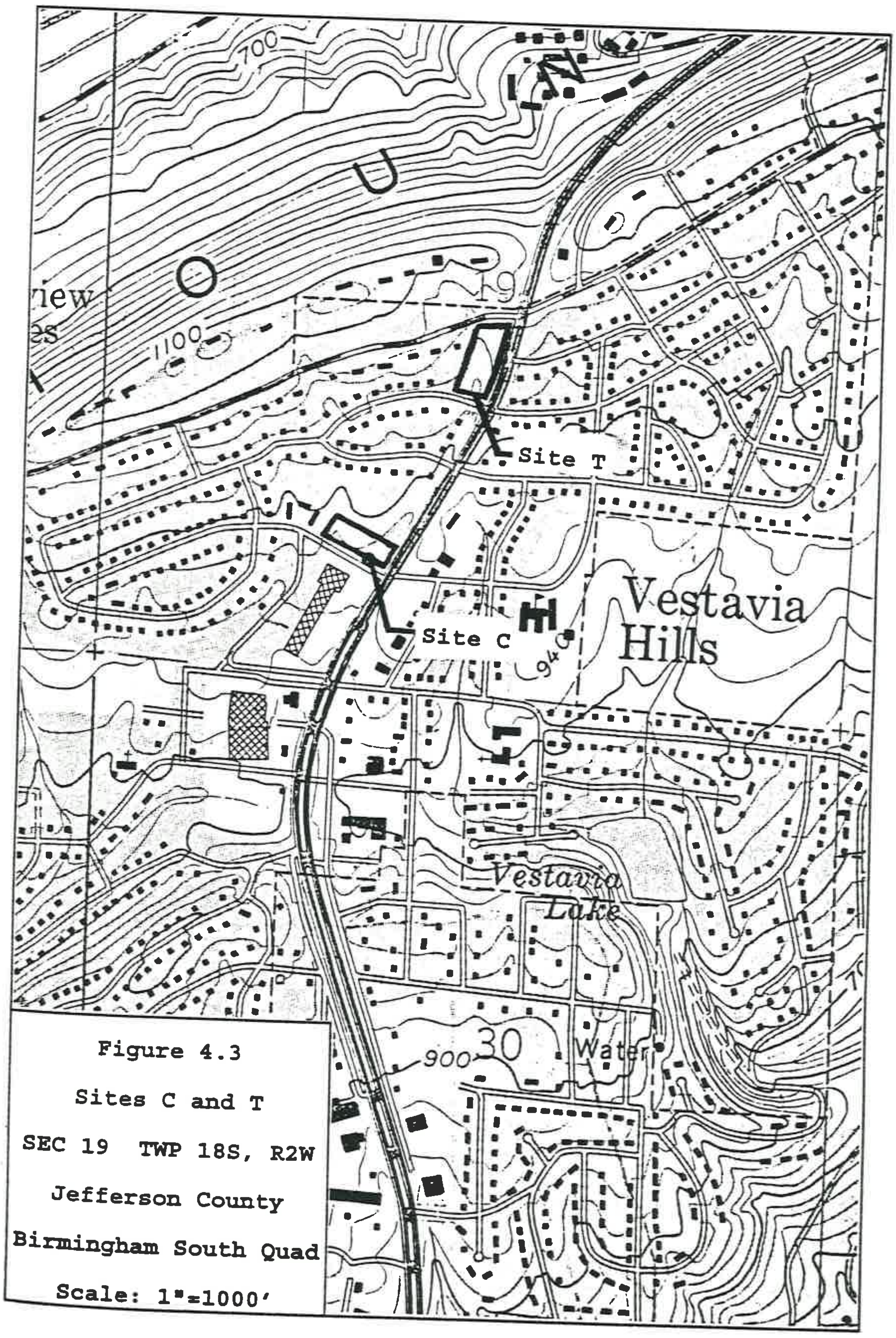


Figure 4.3

Sites C and T

SEC 19 TWP 18S, R2W

Jefferson County

Birmingham South Quad

Scale: 1"=1000'

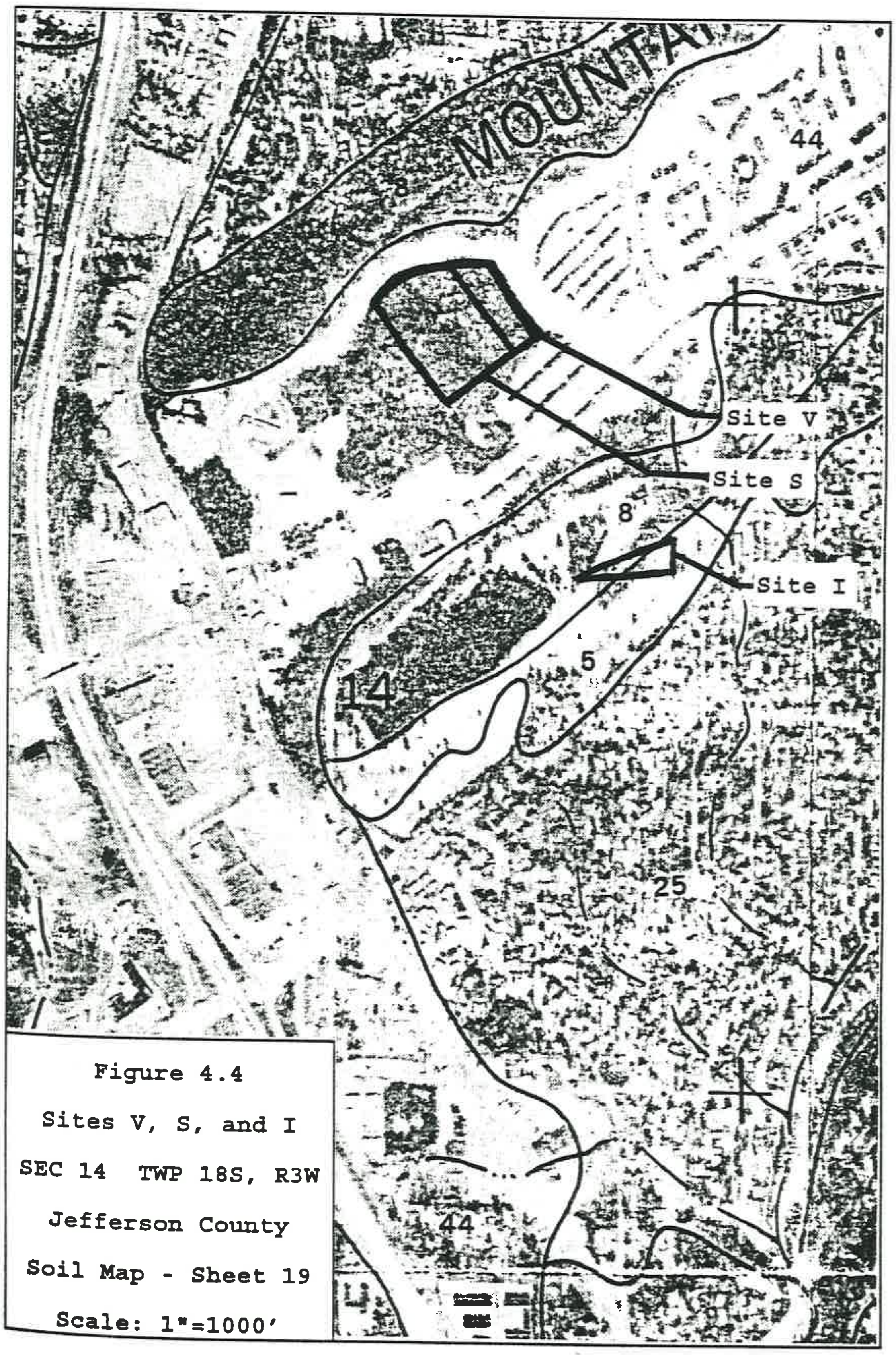


Figure 4.4

Sites V, S, and I

SEC 14 TWP 18S, R3W

Jefferson County

Soil Map - Sheet 19

Scale: 1"=1000'

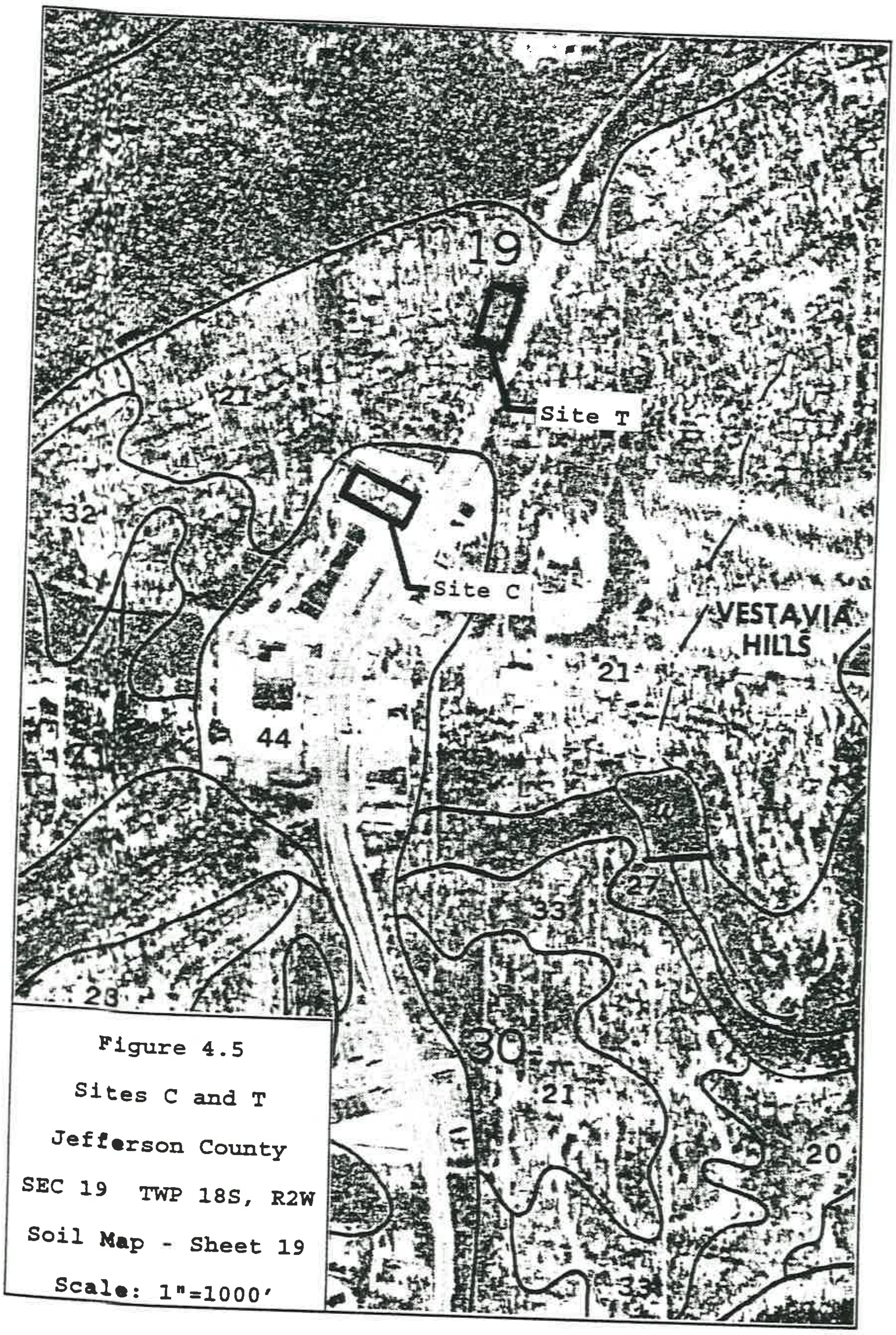


Figure 4.5

Sites C and T

Jefferson County

SEC 19 TWP 18S, R2W

Soil Map - Sheet 19

Scale: 1"=1000'

CHAPTER 5

ANALYTICAL RESULTS

5.1 Study Objectives

The primary objective of most construction site controls is to reduce sediment discharges. The main focus of this research was to discover which conditions caused significant variations in suspended sediment loadings. Exploratory data analysis was used to determine which site conditions and rainfall characteristics produced significant sediment loadings. Statistical analyses were also used to measure the variance of the data.

The sediment discharges were compared to modeled values using site specific conditions and rainfall data. The Universal Soil Loss Equation (USLE) was able to relate the rainfall energy with erosion processes. After the results from USLE were calculated, more statistical analyses were performed to examine other relationships between the site characteristics and other parameters. Conclusions about which site characteristics produced higher erosive forces and larger sediment yields were then made according to the results of this study.

5.2 Analysis Results

The following information presents the results from the analyses of 70 samples. Samples were collected from various locations under the different conditions as shown previously.

Table 5.1 presents the results of the gravimetric analysis, turbidity measurements, and particle size distribution data from the Coulter Counter particle size analyzer.

5.3 Exploratory Data and Statistical Results

The analytical data were evaluated using statistical methods, applied in calculations to determine the observed sediment loadings, and compared with predicted loadings.

The rainfall data used in this study may have introduced an appreciable amount of error since the observations were not at each site. The distance from the observed rainfall and the sites was relatively close (3-5 km), but Summer rain patterns (isolated afternoon showers) produce highly variable rains in the area. These showers can produce heavy downpours in one area with no precipitation less than 1 km away.

Observed on-site rainfall intensities were therefore used to categorize each storm event at the time of sampling. A rating of high (>1 in/hr), medium (about ¼ in/hr), and low (drizzle) was assigned to each storm event.

5.3.1 Suspended Solids

The monitoring study indicated that suspended solids concentrations were extremely variable (Table 5.2). Suspended solids concentrations spanned three orders of magnitude, ranging from 100 to over 27000 mg/L. The median suspended solids concentration was 4300 mg/L.

Probability distributions for all samples, for each site, and for each observed level of rain intensity are contained in Appendix A. The probability plot for all samples indicated a reasonably normal distribution of the suspended solids concentrations for this study. Each site displayed a similar degree of variability of suspended solids concentrations. An apparent strong relationship between suspended solids concentrations and rain intensity was observed. The median suspended solids concentration for low intensity storms was approximately 400 mg/L, almost 1900 mg/L for medium storms, and nearly 26000 mg/L for high intensity storms.

5.3.2 Turbidity and Suspended Solids

Turbidity values varied from 275 to over 50,000 turbidity units. The average turbidity was 3672 turbidity units. Turbidity and rainfall relationships similar to the suspended solids data were also observed for the turbidity data.

A weak linear relationship was observed between turbidity values and suspended solids concentrations. Figures 5.1-5.4 show the turbidity versus suspended solids plots grouped by site and observed rain intensity. The plots grouped by site showed no site variability. Any grouping of data was strictly related to the rain intensity during sampling. The relationship between turbidity, suspended solids, and rain intensity is illustrated by the stratification of rain intensity on Figures 4.3 and 4.4.

5.3.3 Particle Size Distributions

The particle size distributions of the sediment were almost entirely composed of extremely fine-grained particles, based on the 70 samples analyzed (Table 5.2). Average cumulative particle sizes were calculated using all 70 samples. Almost 90% of the samples had average particle sizes less than 20 micrometers. Nearly 50% of the samples had average particle sizes less than 5 micrometers.

Particle size distribution plots in Appendix B display the cumulative percent volume of particle sizes for all samples, sample sites, and observed rain intensity. An average particle size distribution for each site also revealed that 50% of all the particles were less than 5 micrometers except for Site I. The only samples taken at Site I were during a low intensity rainfall event and were not representative of an average storm event. All other sample sites had data from at least one medium intensity storm event. The average sample particle size distributions for three storm intensities revealed that 50% of all the particles were less than 3.5 micrometers for low intensity rainfall, less than 5 micrometers for medium intensity rainfall, and less than 8.5 micrometers for high intensity rainfall.

5.3.4 Observed Loadings

The observed sediment loading was calculated for each sample using an estimated runoff volume and the observed suspended solids concentrations from the sampling data. Runoff for an individual storm event was estimated using the Soil Conservation Service method TR-55 (SCS, 1986). Rainfall data used in these calculations were obtained from the National Weather Service observations in Homewood (NOAA, 1989). Table 5.3 presents the observed loading calculation parameters and results. The average observed sediment loading was 314 pounds per acre. Observed loadings varied from less than 1 to over 27,000 pounds per acre.

5.3.5 Predicted Loadings (USLE)

The Universal Soil Loss Equation (USLE) was used to predict sediment loadings for each sample location. Rainfall data used in these calculations were obtained from the National Weather Service observations in Homewood (NOAA, 1989). Table 5.3 presents the USLE loading calculation parameters and results. The average predicted sediment loading was nearly 11,000 pounds per acre. Predicted loadings varied from 332 to nearly 47,000 pounds per acre.

5.3.6 Sediment-Delivery Ratio

The sediment-delivery ratio was obtained by dividing the observed sediment loading by the predicted sediment loading. Table 5.4 presents the sediment-delivery ratio for each sample along with the total and disturbed drainage area for each sample site. The average sediment-delivery ratio was 0.23. Sediment-delivery ratios varied from 0.00001 to 2.88. The data were sorted by increasing sample site drainage area in Table 5.4 to illustrate a general trend that the sediment-delivery ratio decreases primarily with increasing drainage area. Sample site drainage area versus the sediment-delivery ratio is plotted in Figure 5.5. This plot displays a significant decrease in the sediment-delivery ratio when the sample site drainage area is greater than 1 acre for most sample sites. No apparent relationship was observed between percent area disturbed within the observed drainage areas and the sediment-delivery ratio.

5.3.7 Annual Sediment Loadings

Annual sediment loadings were calculated for construction sites using the observed suspended solids concentrations for low, medium, and high rain intensity for small, medium, and high rain accumulations respectively. Rainfall events used in these calculations were from Birmingham in 1976 (NOAA, 1976). The observed rainfall events for Birmingham in 1976 were determined to be an average rainfall year (Pitt and Durrans, 1995). Table 5.5

presents the predicted sediment loadings for each rain event classification and the predicted annual sediment loadings for the observed soils at the construction sites. Predicted annual sediment loading for type B soils is 44 tons/acre/year and 73 tons/acre/year for type D soils. Predicted sediment loadings for type B soils and type D soils are less than 1 ton/acre/year for all of the small (less than 0.26 inches) rainfall events combined, and approximately 1 ton/acre/year for all of the medium (0.25 to 1 inch) rainfall events combined. The sediment loadings from the large rainfall events (greater than 1 inch) were nearly equal to the total annual predicted loadings, which indicates that a majority of the sediment was transported during these storm events. Therefore, 20 out of the 112 events total per year are likely responsible for practically all of the annual erosion losses.

5.3.8 Analysis of Variance

ANOVA was used to determine if site soil conditions, rain conditions, or their interactions had significant effects on the observed suspended solids concentrations and average particle sizes. No differences due to soil conditions either alone or interacting with rain were noted in the ANOVA results.

One-way ANOVA tests were performed using SigmaStat Version 1 (Jandel Corporation) to detect any effects on suspended solids concentrations or particle sizes due to sandy or clay soil conditions on the sites or due to medium or high intensity rainfall during sampling. One of the ANOVA results is the probability (P) that at least one category of the factor being tested is different from the others. A summary of the one-way ANOVA test results are shown in Table 5.6. Tests were performed by examining rain intensity effects on sandy soils and clayey soils separately. A two-way ANOVA was not possible because of missing sample data for low intensity rain events on sandy soils. The sandy soil ANOVA included medium and high intensity rain categories, while the clayey soil ANOVA included low, medium, and high intensity categories. Observed P values ranged from less than 0.0001 to 0.844. The lower the P value, the more likely that at least one of the levels of the factor being tested had a significant effect on the observed condition. Typically, a P value of 0.05, or less, is used to indicate significant differences. Calculated probability values did not indicate that the observed variabilities in suspended solid concentrations and average particle sizes were due to site soil conditions. Both sandy soil and clay soil groupings had P values ranging from 0.058 to 0.844, therefore indicating insignificant effects on the suspended solids concentrations and the average particle sizes. The one-way ANOVA found very significant effects due to rain intensity. Values for P for medium and high rain intensity groupings ranged from less than 0.0001 to 0.0192. A two-way ANOVA was also performed, but only for medium and high rain intensities for the sandy and clayey soil sites, to evaluate the interactive effects of rain intensity and soil types on suspended solids concentrations and average particle sizes. Values for P for the combination of soil types and rain intensity were 0.956 for suspended solids concentrations and 0.852 for average particle sizes. These results indicate that the combined interactive effects of soil types and rain intensity had no significant effect on suspended solid concentrations and average particle sizes. The only significant factor effecting suspended solids concentrations or average particle sizes was rain intensity.

5.3.9 Statistical Comparisons for Erosion Control Effects

Several samples were taken before and after hay bales and silt fencing erosion control structures. Tables 5.7-5.10 present the observed data taken before and after these erosion controls for each site.

The paired t-test and signed rank tests were performed using SigmaStat Version 1 (Jandel Corporation) on observed data taken before and after erosion controls on each site to determine if any reduction in turbidity values, suspended solids concentrations, or average particle sizes occurred from silt fencing or hay bale erosion controls. The t-test evaluated the distributions of the observed data. If the distribution was not normal, a signed rank test was conducted. Each test result concluded that any beneficial effects that occurred from the erosion control were not great enough to exclude the possibility that the difference was due to chance. A summary of the test results are shown in Table 5.11. Only one control on site T resulted in a P value less than 0.05. However, in this case, the suspended solids concentrations actually increased significantly after the hay bale control.

5.3.10 Linear Regression

Plots of the observed turbidity values versus suspended solids concentrations indicated a weak linear relationship. Linear regression was performed on turbidity values versus suspended solids concentrations using SigmaStat Version 1 (Jandel Corporation). Probability values for high, medium, and low intensity categories for turbidity values and suspended solids concentrations are listed in Table 5.12. Regression equations for low, medium, and high intensity categories are as follows:

TSS Low = -9.29 + (0.724 * Turbidity Low) ($r^2 = 0.84$)

TSS Medium = 1124.9 + (0.724 * Turbidity Medium) ($r^2 = 0.16$)

TSS High = 22885 + (0.085 * Turbidity High) ($r^2 = 0.18$)

The equation coefficients suggest only a weak linear relationship for medium and high intensity groupings. Only the low intensity rainfall coefficients indicate a statistically significant relationship between turbidity values and suspended solids concentrations.

TABLE 5.1 ANALYSIS RESULTS

Site	Sample	Total solids	Total suspended solids	Total dissolved solids	Turbidity	Cumulative volume	Particle size percent greater than size indicated (µm)		
		(mg/L)	(mg/L)	(mg/L)	(NTU)	µm³/mL	90%	50%	10%
C1	C1-1	750	403	348	640	28248326	1.2	2.2	9.9
C1	C2-1	950	104	846	440	19254590	1.2	3.0	16.5
C1	C4-1	1830	1494	336	1420	82317408	1.2	3.1	15.9
C1	C6-1	1366	1160	206	1420	99539128	1.2	2.5	10.9
C2	C1-2	10184	8824	1360	1100	1.10e+08	1.3	3.6	38.0
C2	C2-2	10118	9190	928	1460	1.90e+08	1.3	3.4	22.5
C2	C3-1	36372	27008	9364	8800	2.49e+09	1.7	6.6	17.3
C2	C4-2	4556	3932	624	2480	3.50e+08	1.4	6.0	29.7
C2	C5-2	2488	2280	208	600	1.33e+08	1.3	4.0	18.4
C2	C6-2	30040	20870	9170	4120	4.50e+08	1.5	7.0	38.0
C3	C1-3	414	236	178	310	20710588	1.2	2.4	13.6
C3	C2-3	342	222	120	275	21595472	1.2	2.4	9.2
C3	C4-5	3446	2772	674	720	1.60e+08	2.3	17.1	44.8
C3	C5-3	1060	886	174	750	1.38e+08	1.3	3.9	18.7
C3	C6-3	4512	2818	1694	2880	2.48e+08	1.3	4.8	16.2

TABLE 5.1 ANALYSIS RESULTS (CONTINUED)

Site	Sample	Total solids	Total suspended solids	Total dissolved solids	Turbidity	Cumulative volume	Particle size percent greater than size indicated (µm)		
		(mg/L)	(mg/L)	(mg/L)	(NTU)	$\mu m^3/mL$	90%	50%	10%
C4	C3-2	33178	24322	8856	4320	9.35e+08	1.6	6.5	19.0
C4	C4-4	2658	1994	664	720	1.98e+08	1.4	6.9	18.9
C5	C1-5	592	106	486	375	14739156	1.3	4.0	56.0
C5	C2-5	438	128	310	350	25857568	1.2	2.8	16.3
C5	C6-5	1040	808	232	760	1.14e+08	1.3	3.7	13.7
C5A	C4-FB	1970	1744	226	1900	86612816	1.2	3.1	16.7
C5A	C5-FB	1992	1784	208	1480	1.17e+08	1.2	2.5	16.3
C5A	C6-FB	2392	1366	1026	3040	1.29e+08	1.3	3.8	17.3
C5B	C4-FA	57502	2272	55230	2060	1.63e+08	1.3	3.7	14.0
C5B	C5-FA	1976	1450	526	2320	53042004	1.2	1.8	13.8
C5B	C6-FA	2976	1824	1152	2200	2.02e+08	1.3	4.1	13.9
C8	C4-8	8084	7564	520	370	1.32e+09	1.4	4.0	12.0
I1	I1-1	872	500	372	1100	39507088	1.2	1.9	5.5
I2	I1-2	1076	714	362	1220	41936328	1.1	1.7	4.5
I3	I1-3	1716	1376	340	2000	1.30e+08	1.2	2.2	8.3
S1	S3-1	344	220	124	420	32155894	1.2	2.6	14.8

TABLE 5.1 ANALYSIS RESULTS (CONTINUED)

Site	Sample	Total solids	Total suspended solids	Total dissolved solids	Turbidity	Cumulative volume	Particle size percent greater than size indicated (μm)		
		(mg/L)	(mg/L)	(mg/L)	(NTU)	μm³/mL	90%	50%	10%
S1A	S2-1	5256	5192	64	4520	6.70e+08	1.7	17.1	56.0
S1B	S2-2	4116	3892	224	3720	2.20e+08	1.6	9.3	35.9
S2	S3-2	338	208	130	405	30706008	1.2	3.0	21.0
S2A	S2-3	3524	3268	256	3680	1.60e+08	1.4	5.6	22.6
S2B	S2-4	3208	3140	68	3560	1.80e+08	1.4	7.4	31.5
S3	S3-3	370	246	124	450	27210544	1.2	2.2	8.3
S3A	S2-5	5416	4920	496	4080	2.40e+08	1.5	9.3	38.1
S3B	S2-6	4217	3996	221	4080	4.10e+08	1.7	15.3	42.4
S7	S2-7	3956	3760	196	3520	1.73e+08	1.3	4.8	25.3
S8	S2-8	3268	3024	244	3450	2.10e+08	1.4	7.0	22.5
S9	S2-9	4124	3532	592	3776	4.07e+08	1.4	4.6	19.7
T1A	T1-1	1660	1480	180	1700	1.42e+08	1.3	3.3	15.8
T1B	T1-2	2264	1946	318	2080	2.44e+08	1.3	3.9	15.4

TABLE 5.1 ANALYSIS RESULTS (CONTINUED)

Site	Sample	Total solids	Total suspended solids	Total dissolved solids	Turbidity	Cumulative volume	Particle size percent greater than size indicated (µm)		
							90%	50%	10%
		(mg/L)	(mg/L)	(mg/L)	(NTU)	µm³/mL			
T2A	T1-3	2240	2024	220	2020	2.88e+08	1.3	3.9	16.5
T2B	T1-4	3008	2552	456	2200	1.36e+08	1.2	2.8	19.3
T3	T2-1	7730	7320	410	4400	---------	-----	-----	----
T4	T2-2	4175	3088	1088	1560	---------	-----	-----	----
T5	T2-3	1170	1020	150	370	---------	-----	-----	----
V1	V2-6	578	406	172	640	69626800	1.3	3.4	20.0
V1	V3-1	574	434	140	820	47057404	1.2	2.9	13.5
V2	V1-3	1452	1368	84	1792	92612904	1.3	2.9	17.1
V2	V2-5	556	396	160	620	66441836	1.3	2.8	14.1
V2	V3-2	564	410	154	790	77044528	1.3	4.0	16.5
V3A	V1-1	1532	1504	28	1496	1.50e+08	1.3	5.6	18.7
V3A	V1-9	26736	26354	382	37120	4.10e+09	1.8	10.3	20.7
V3A	V2-1	818	672	146	940	1.12e+08	1.3	2.8	10.6

TABLE 5.1 ANALYSIS RESULTS (CONTINUED)

Site	Sample	Total solids	Total suspended solids	Total dissolved solids	Turbidity	Cumulative volume	Particle size percent greater than size indicated (μm)		
		(mg/L)	(mg/L)	(mg/L)	(NTU)	μm³/mL	90%	50%	10%
V3B	V1-11	25988	25616	372	27392	4.70e+09	2.1	11.0	38.1
V3B	V1-12	21576	21452	124	20480	2.30e+09	1.7	7.4	35.9
V3B	V2-3	684	498	186	750	70453416	1.3	3.3	15.6
V3C	V1-7	1340	1244	96	1696	72017840	1.3	4.5	26.7
V4A	V1-10	27296	27452	156	50176	4.94e+09	1.8	9.9	23.1
V4A	V1-2	2004	1892	112	2000	1.35e+08	1.3	3.4	17.9
V4A	V2-2	690	504	186	800	1.15e+08	1.4	4.1	16.8
V4A	V3-3	574	392	182	830	66334292	1.3	3.5	19.4
V4B	V1-6	1388	1288	100	1584	89483456	1.3	6.3	23.9
V4B	V2-4	406	207	136	500	47095028	1.3	3.0	15.3
V4C	V1-8	1764	1616	148	2016	55569964	1.2	2.0	15.0
V5	V1-4	1328	1180	148	1472	65464316	1.3	4.0	22.6
V5	V1-5	1352	1284	68	1520	78548408	1.2	4.5	16.8

TABLE 5.2 ANALYTICAL DATA SUMMARY

	Total solids	Total suspended solids	Total dissolved solids	Turbidity	Cumulative volume	Particle size percent greater than size indicated (μm)		
	(mg/L)	(mg/L)	(mg/L)	(NTU)	μm^3/mL	90%	50%	10%
Minimum value	338	104	28	275	14739156	1.1	1.7	4.5
Maximum value	57502	27452	55230	50176	4938040000	2.3	17.1	56.0
Average value	5807	4302	1508	3672	434817762	1.4	4.9	20.7
Standard deviation	10448	7173	6764	8072	1005505804	0.2	3.3	10.7
Coefficient of variation	1.8	1.7	4.5	2.2	2.3	0.2	0.7	0.5

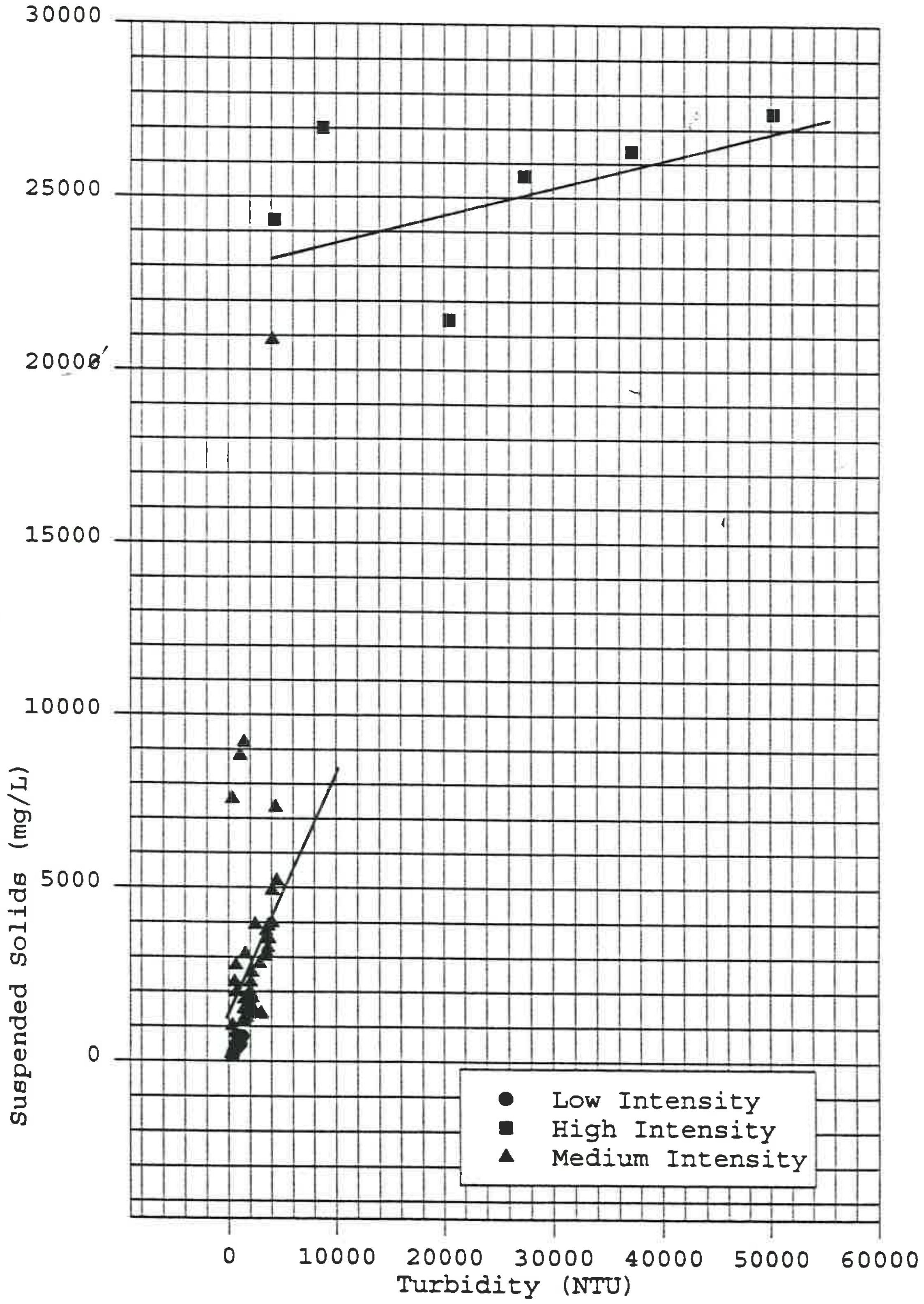


Figure 5.1 Turbidity vs Suspended Solids for all Samples

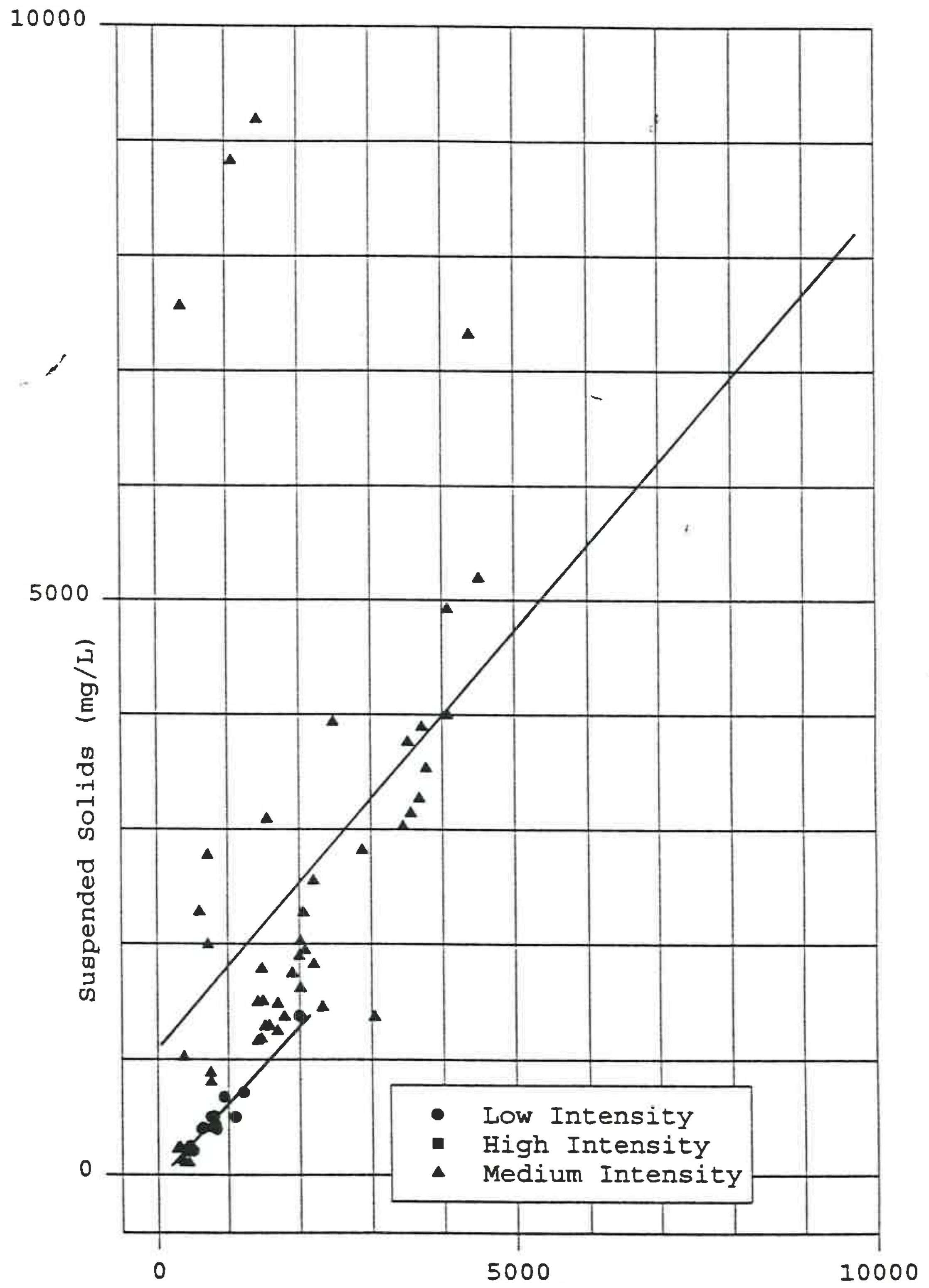


Figure 5.2 Turbidity vs Suspended Solids for a Selected Range of Samples

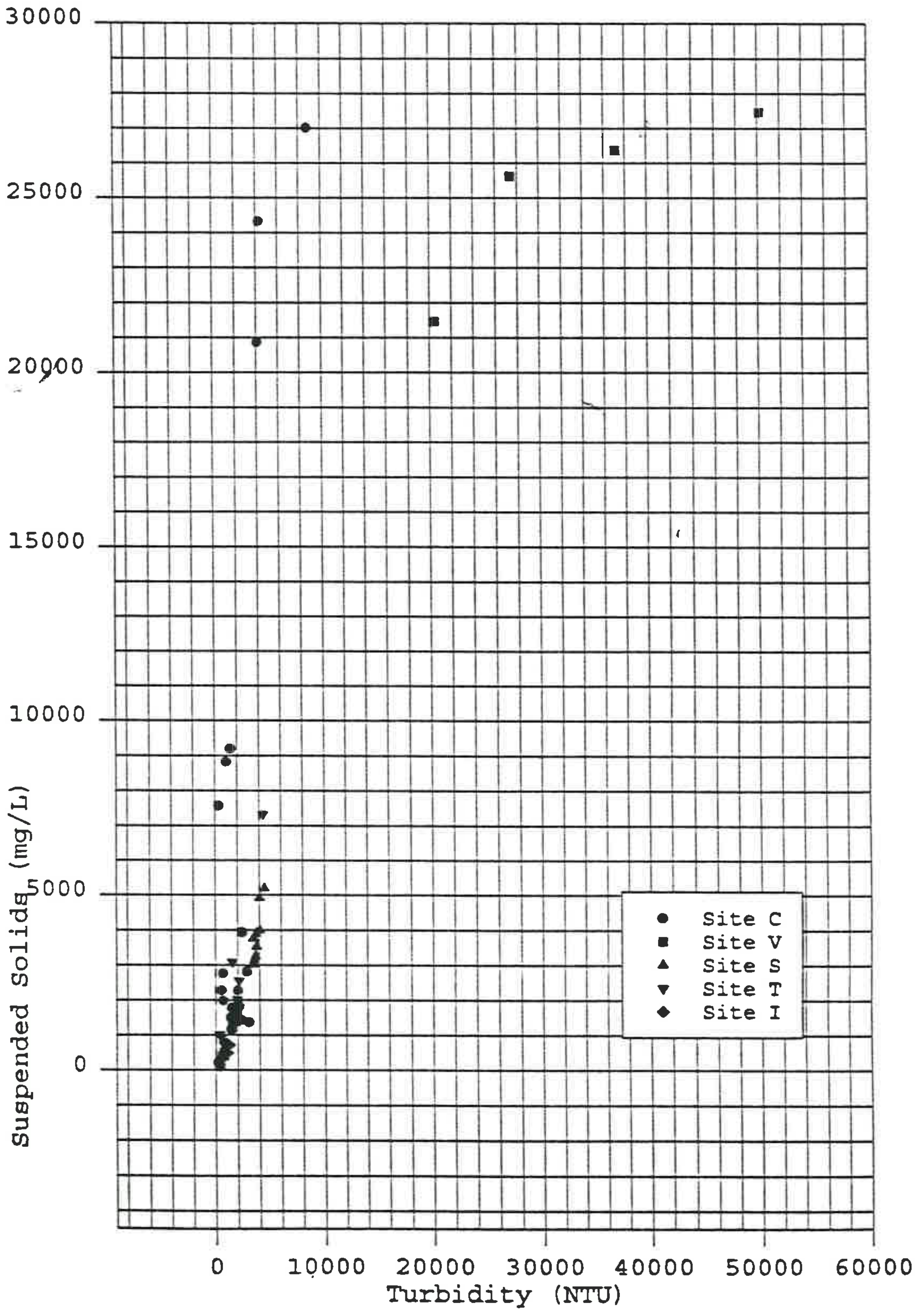


Figure 5.3 Turbidity vs Suspended Solids for all Samples

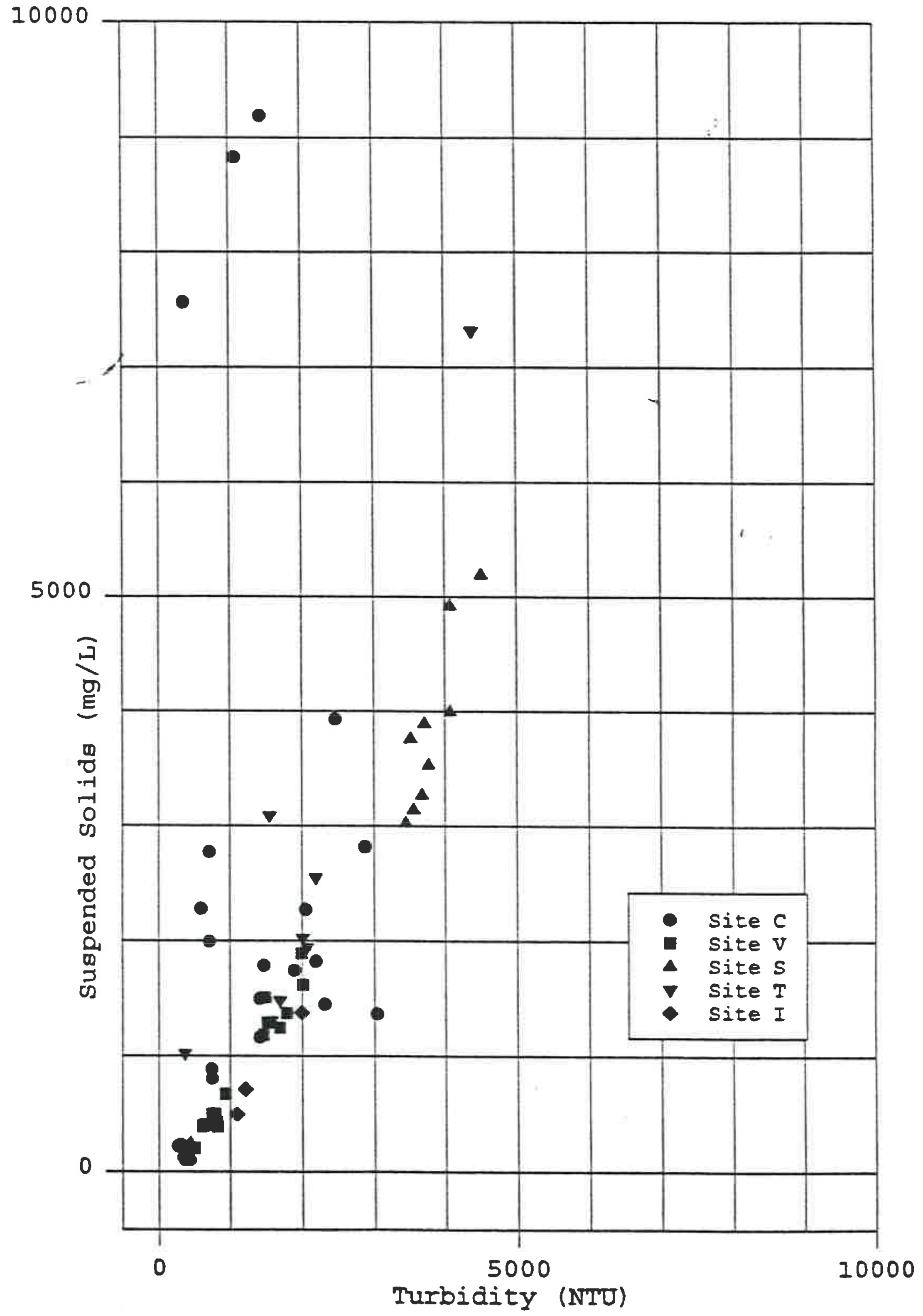


Figure 5.4 Turbidity vs Suspended Solids for a Selected Range of Samples

TABLE 5.3 SEDIMENT LOADING PARAMETERS

Site	Sample	k	Soil type	L	S	LS	r USLE	USLE load	Suspended solids	R SCS	CN	Observed load
				(ft)				(lbs/ac)	(mg/l)	(in)		(lbs/ac)
C1	C1-1	0.17	D	900	3	0.56	7.82	1489	402.5	1.137	94	103
C1	C2-1	0.17	D	900	3	0.56	7.77	1480	104	1.284	94	30
C1	C4-1	0.17	D	900	3	0.56	34.32	6535	1494	1.603	94	541
C1	C6-1	0.17	D	900	3	0.56	6.99	1332	1160	0.175	94	46
C2	C1-2	0.17	D	200	3	0.35	7.82	930	8824	1.137	94	2268
C2	C2-2	0.17	D	200	3	0.35	7.77	925	9190	1.284	94	2669
C2	C3-1	0.17	D	200	3	0.35	7.29	867	27008	0.188	94	1145
C2	C4-2	0.17	D	200	3	0.35	34.32	4084	3932	1.603	94	1425
C2	C5-2	0.17	D	200	3	0.35	2.80	333	2280	0.137	94	71
C2	C6-2	0.17	D	200	3	0.35	6.99	832	20870	0.175	94	824
C3	C1-3	0.17	D	200	3	0.35	7.82	930	236	1.137	94	61
C3	C2-3	0.17	D	200	3	0.35	7.77	925	222	1.284	94	64
C3	C4-5	0.17	D	200	3	0.35	34.32	4084	2772	1.603	94	1005
C3	C5-3	0.17	D	200	3	0.35	2.80	333	886	0.137	94	27
C3	C6-3	0.17	D	200	3	0.35	6.99	832	2818	0.175	94	111
C4	C3-2	0.17	D	200	3	0.35	7.29	867	24322	0.188	94	1032

TABLE 5.3 SEDIMENT LOADING PARAMETERS (CONTINUED)

Site	Sample	k	Soil type	L	S	LS	r USLE	USLE load	Suspended solids	R SCS	CN	Observed load
				(ft)				(lbs/ac)	(mg/l)	(in)		(lbs/ac)
C4	C4-4	0.17	D	200	3	0.35	34.32	4084	1994	1.603	94	723
C5	C1-5	0.17	D	200	3	0.35	7.82	930	106	1.137	94	27
C5	C2-5	0.17	D	200	3	0.35	7.77	925	128	1.284	94	37
C5	C6-5	0.17	D	200	3	0.35	6.99	832	808	0.175	94	32
C5A	C4-FB	0.17	D	200	3	0.35	34.32	4084	1744	1.603	94	632
C5A	C5-FB	0.17	D	200	3	0.35	2.80	333	1784	0.137	94	55
C5A	C6-FB	0.17	D	200	3	0.35	6.99	832	1366	0.175	94	54
C5B	C4-FA	0.17	D	200	3	0.35	34.32	4084	2272	1.603	94	823
C5B	C5-FA	0.17	D	200	3	0.35	2.80	333	1450	0.137	94	45
C5B	C6-FA	0.17	D	200	3	0.35	6.99	832	1824	0.175	94	72
C8	C4-8	0.17	D	200	3	0.35	34.32	4084	7564	1.603	94	2742
I1	I1-1	0.28	B	600	5	1.29	6.99	5053	500	0.030	86	3
I2	I1-2	0.28	B	220	2	0.25	6.99	979	714	0.030	86	5
I3	I1-3	0.28	B	350	5	0.97	6.99	3799	1376	0.030	86	9
S1	S3-1	0.28	B	1320	12.9	7.2	2.66	10726	220	0.001	86	0

TABLE 5.3 SEDIMENT LOADING PARAMETERS (CONTINUED)

Site	Sample	k	Soil type	L	S	LS	r USLE	USLE load	Suspended solids	R SCS	CN	Observed load
				(ft)				(lbs/ac)	(mg/l)	(in)		(lbs/ac)
S1A	S2-1	0.28	B	1320	12.9	7.2	11.47	46258	5192	0.255	86	299
S1B	S2-2	0.28	B	1320	12.9	7.2	11.47	46258	3892	0.255	86	224
S2	S3-2	0.28	B	1410	12.6	7.3	2.66	10875	208	0.001	86	0
S2A	S2-3	0.28	B	1410	12.6	7.3	11.47	46901	3268	0.255	86	188
S2B	S2-4	0.28	B	1410	12.6	7.3	11.47	46901	3140	0.255	86	181
S3	S3-3	0.28	B	1500	12.2	7.1	2.66	10577	246	0.001	86	0
S3A	S2-5	0.28	B	1500	12.2	7.1	11.47	45616	4920	0.255	86	284
S3B	S2-6	0.28	B	1500	12.2	7.1	11.47	45616	3996	0.255	86	230
S7	S2-7	0.28	B	1580	11.8	7.2	11.47	46258	3760	0.255	86	217
S8	S2-8	0.28	B	1580	11.8	7.2	11.47	46258	3024	0.255	86	174
S9	S2-9	0.28	B	1580	11.8	7.2	11.47	46258	3532	0.255	86	204
T1A	T1-1	0.17	D	232	3.9	0.53	5.76	1039	1480	0.156	94	52
T1B	T1-2	0.17	D	232	3.9	0.53	5.76	1039	1946	0.156	94	68
T2A	T1-3	0.17	D	165	4.2	0.52	5.76	1019	2024	0.156	94	71
T2B	T1-4	0.17	D	165	4.2	0.52	5.76	1019	2552	0.156	94	90

TABLE 5.3 SEDIMENT LOADING PARAMETERS (CONTINUED)

Site	Sample	k	Soil type	L	S	LS	r USLE	USLE load	Suspended solids	R SCS	CN	Observed load
				(ft)				(lbs/ac)	(mg/l)	(in)		(lbs/ac)
T3	T2-1	0.17	D	330	5	0.95	2.56	826	7320	0.892	94	1476
T4	T2-2	0.17	D	300	3	0.4	2.56	348	3087.5	0.892	94	623
T5	T2-3	0.17	D	330	5	0.95	2.56	826	1020	0.892	94	206
V1	V2-6	0.28	B	470	14.8	5.3	6.99	20759	406	0.030	86	3
V1	V3-1	0.28	B	470	14.8	5.3	2.66	7895	434	0.001	86	0
V2	V1-3	0.28	B	470	14.8	5.3	2.80	8296	1368	0.017	86	5
V2	V2-5	0.28	B	470	14.8	5.3	6.99	20759	396	0.030	86	3
V2	V3-2	0.28	B	470	14.8	5.3	2.66	7895	410	0.001	86	0
V3A	V1-1	0.28	B	470	14.8	5.3	2.80	8296	1504	0.017	86	6
V3A	V1-9	0.28	B	470	14.8	5.3	2.80	8296	26354	0.027	86	162
V3A	V2-1	0.28	B	470	14.8	5.3	6.99	20759	672	0.030	86	4
V3B	V1-11	0.28	B	470	14.8	5.3	2.80	8296	25616	0.027	86	157
V3B	V1-12	0.28	B	630	13	5.1	2.80	7983	21452	0.027	86	132
V3B	V2-3	0.28	B	470	14.8	5.3	6.99	20759	498	0.030	86	3
V3C	V1-7	0.28	B	470	14.8	5.3	2.80	8296	1244	0.017	86	5

TABLE 5.3 SEDIMENT LOADING PARAMETERS (CONTINUED)

Site	Sample	k	Soil type	L	S	LS	r USLE	USLE load	Suspended solids	R SCS	CN	Observed load
				(ft)				(lbs/ac)	(mg/l)	(in)		(lbs/ac)
V4A	V1-10	0.28	B	630	13	5.1	2.80	7983	27452	0.027	86	169
V4A	V1-2	0.28	B	630	13	5.1	2.80	7983	1892	0.017	86	7
V4A	V2-2	0.28	B	630	13	5.1	6.99	19976	504	0.030	86	3
V4A	V3-3	0.28	B	630	13	5.1	2.66	7597	392	0.001	86	0
V4B	V1-6	0.28	B	630	13	5.1	2.80	7983	1288	0.017	86	5
V4B	V2-4	0.28	B	630	13	5.1	6.99	19976	207	0.030	86	1
V4C	V1-8	0.28	B	630	13	5.1	2.80	7983	1616	0.017	86	6
V5	V1-4	0.28	B	630	13	5.1	2.80	7983	1180	0.017	86	5
V5	V1-5	0.28	B	470	14.8	5.3	2.80	8296	1284	0.017	86	5

TABLE 5.4 SEDIMENT LOADING SUMMARY

Site	Sample	Observed loading	USLE load	Total drainage area	Drainage area disturbed	% Drainage area disturbed	Sediment-delivery ratio
		(lbs/ac)	(lbs/ac)	(Ac)	(Ac)		
C5B	C4-FA	823	4084	0.3	0.3	74%	0.20163
C5A	C5-FB	55	333	0.3	0.3	74%	0.16633
C5A	C4-FB	632	4084	0.3	0.3	74%	0.15477
C5B	C5-FA	45	333	0.3	0.3	74%	0.13519
C5B	C6-FA	72	832	0.3	0.3	74%	0.08649
C5A	C6-FB	54	832	0.3	0.3	74%	0.06478
C5	C2-5	37	925	0.3	0.3	74%	0.04018
C5	C6-5	32	832	0.3	0.3	74%	0.03832
C5	C1-5	27	930	0.3	0.3	74%	0.02927
I2	I1-2	5	979	0.4	0.4	100%	0.00486
T5	T2-3	206	826	0.4	0.4	100%	0.24911
C4	C3-2	1032	867	0.5	0.4	76%	1.18944
C3	C4-5	1005	4084	0.5	0.4	76%	0.24600
C4	C4-4	723	4084	0.5	0.4	76%	0.17696
C3	C6-3	111	832	0.5	0.4	76%	0.13363
C3	C5-3	27	333	0.5	0.4	76%	0.08260

TABLE 5.4 SEDIMENT LOADING SUMMARY (CONTINUED)

Site	Sample	Observed loading	USLE load	Total drainage area	Drainage area disturbed	% Drainage area disturbed	Sediment-delivery ratio
		(lbs/ac)	(lbs/ac)	(Ac)	(Ac)		
C3	C2-3	64	925	0.5	0.4	76%	0.06969
C3	C1-3	61	930	0.5	0.4	76%	0.06518
C2	C2-2	2669	925	0.6	0.3	53%	2.88486
C2	C1-2	2268	930	0.6	0.3	53%	2.43694
C2	C3-1	1145	867	0.6	0.3	53%	1.32079
C2	C6-2	824	832	0.6	0.3	53%	0.98966
C2	C4-2	1425	4084	0.6	0.3	53%	0.34895
C2	C5-2	71	333	0.6	0.3	53%	0.21257
T4	T2-2	623	348	0.7	0.7	100%	1.79087
T1B	T1-2	68	1039	0.8	0.8	100%	0.06588
T1A	T1-1	52	1039	0.8	0.8	100%	0.05010
T2B	T1-4	90	1019	0.9	0.9	100%	0.08806
T2A	T1-3	71	1019	0.9	0.9	100%	0.06984
T3	T2-1	1476	826	1.0	1.0	100%	1.78774
I1	I1-1	3	5053	1.4	1.4	100%	0.00066
I3	I1-3	9	3799	1.6	1.6	100%	0.00242

TABLE 5.4 SEDIMENT LOADING SUMMARY (CONTINUED)

Site	Sample	Observed loading	USLE load	Total drainage area	Drainage area disturbed	% Drainage area disturbed	Sediment-delivery ratio
		(lbs/ac)	(lbs/ac)	(Ac)	(Ac)		
C8	C4-8	2742	4084	2.3	1.3	57%	0.67127
V3A	V1-9	162	8296	3.0	3.0	100%	0.01953
V3B	V1-11	157	8296	3.0	3.0	100%	0.01898
V3A	V1-1	6	8296	3.0	3.0	100%	0.00069
V2	V1-3	5	8296	3.0	3.0	100%	0.00063
V5	V1-5	5	8296	3.0	3.0	100%	0.00059
V3C	V1-7	5	8296	3.0	3.0	100%	0.00057
V3A	V2-1	4	20759	3.0	3.0	100%	0.00022
V3B	V2-3	3	20759	3.0	3.0	100%	0.00016
V1	V2-6	3	20759	3.0	3.0	100%	0.00013
V2	V2-5	3	20759	3.0	3.0	100%	0.00013
V1	V3-1	0.13	7895	3.0	3.0	100%	0.00002
V2	V3-2	0.12	7895	3.0	3.0	100%	0.00002
C1	C4-1	541	6535	4.1	0.3	6%	0.08287
C1	C1-1	103	1489	4.1	0.3	6%	0.06947
C1	C6-1	46	1332	4.1	0.3	6%	0.03438

TABLE 5.4 SEDIMENT LOADING SUMMARY (CONTINUED)

Site	Sample	Observed loading	USLE load	Total drainage area	Drainage area disturbed	% Drainage area disturbed	Sediment-delivery ratio
		(lbs/ac)	(lbs/ac)	(Ac)	(Ac)		
C1	C2-1	30	1480	4.1	0.3	6%	0.02040
V5	V1-4	5	7983	4.2	4.2	100%	0.00056
V4A	V1-10	169	7983	7.2	7.2	100%	0.02114
V3B	V1-12	132	7983	7.2	7.2	100%	0.01652
V4A	V1-2	7	7983	7.2	7.2	100%	0.00090
V4C	V1-8	6	7983	7.2	7.2	100%	0.00077
V4B	V1-6	5	7983	7.2	7.2	100%	0.00062
V4A	V2-2	3	19976	7.2	7.2	100%	0.00017
V4B	V2-4	1	19976	7.2	7.2	100%	0.00007
V4A	V3-3	0.12	7597	7.2	7.2	100%	0.00002
S1A	S2-1	299	46258	11.2	8.6	77%	0.00647
S1B	S2-2	224	46258	11.2	8.6	77%	0.00485
S1	S3-1	0.07	10726	11.2	8.6	77%	0.00001
S2A	S2-3	188	46901	12.4	9.6	77%	0.00402
S2B	S2-4	181	46901	12.4	9.6	77%	0.00386
S2	S3-2	0.06	10875	12.4	9.6	77%	0.00001

TABLE 5.4 SEDIMENT LOADING SUMMARY (CONTINUED)

Site	Sample	Observed loading	USLE load	Total drainage area	Drainage area disturbed	% Drainage area disturbed	Sediment-delivery ratio
		(lbs/ac)	(lbs/ac)	(Ac)	(Ac)		
S3A	S2-5	284	45616	13.9	10.5	75%	0.00622
S3B	S2-6	230	45616	13.9	10.5	75%	0.00505
S3	S3-3	0.07	10577	13.9	10.5	75%	0.00001
S7	S2-7	217	46258	16.2	10.6	66%	0.00469
S9	S2-9	204	46258	16.2	10.6	66%	0.00440
S8	S2-8	174	46258	16.2	10.6	66%	0.00377

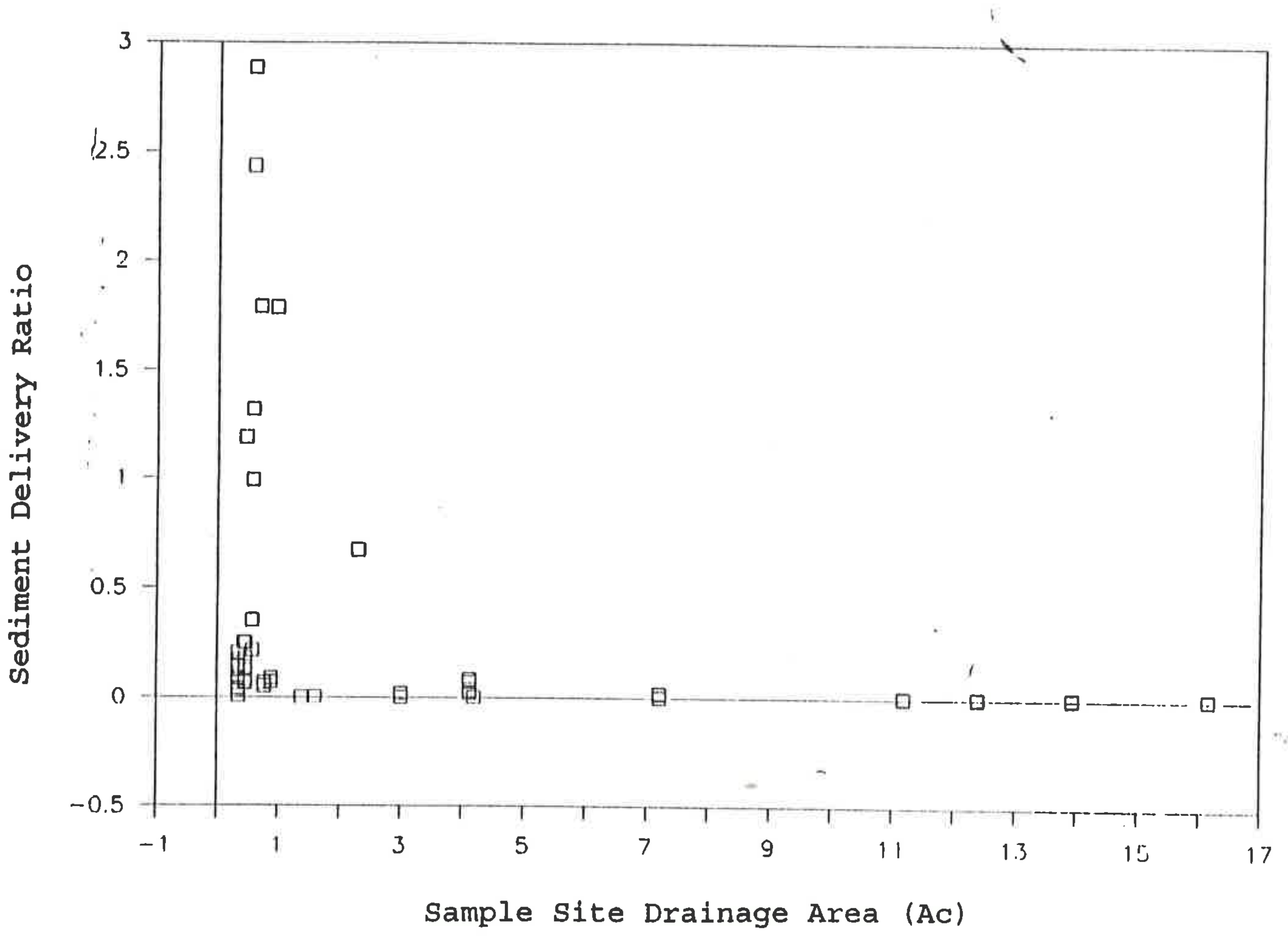


Figure 5.5 Sample Site Drainage Area (Ac) vs the Sediment Delivery Ratio

TABLE 5.5 PREDICTED TOTAL ANNUAL LOADINGS FOR BIRMINGHAM 1976 RAINFALL DATA

		Type B soils CN=86		Type D soils CN=94	
	Annual rain depth	Predicted annual runoff	Predicted annual loading	Predicted annual runoff	Predicted annual loading
	(inches)	(inches)	(tons/acre/year)	(inches)	(tons/acre/year)
Total annual	55.2	16.4	44.4	30.0	73.6
Small rain events	3.1	0.00	0.000	0.1	0.003
Medium rain events	15.9	1.3	0.3	5.1	1.1
Large rain events	36.2	15.1	44.1	24.8	72.5

TABLE 5.6 ONE-WAY ANOVA P RESULTS

	Rain intensity for sandy soils	**Rain intensity** for clay soils	**Soils** for medium intensity rain	**Soils** for high intensity rain
Total suspended solids	0.0192	<0.0001	0.208	0.844
Average particle size	0.0064	<0.0001	0.190	0.058

TABLE 5.7 SILT FENCING AT SITE C

	Before	After	Before	After	Before	After
Sample	C4-FB	C4-FA	C5-FB	C5-FA	C6-FB	C6-FA
Total suspended solids (mg/L)	1744	2272	1784	1450	1366	1824
Turbidity (NTU)	1900	2060	1480	1450	3040	2200
Average particle size (μm)	3.1	3.7	2.5	1.8	3.8	4.1

TABLE 5.8 SILT FENCING AT SITE S

	Before	After	Before	After	Before	After
Sample	S2-1	S2-2	S2-3	S2-4	S2-5	S2-6
Total suspended solids (mg/L)	5192	3892	3268	3140	4920	3996
Turbidity (NTU)	4520	3720	3680	3560	4080	4080
Average particle size (μm)	17.1	9.3	5.6	7.4	9.3	15.3

TABLE 5.9 SILT FENCING AT SITE V

	Before	After	Before	After	Before	After		
Sample	V1-1	V1-2	V1-5	V1-6	V1-7	V1-8		
Total suspended solids (mg/L)	1504	1892	1284	1288	1244	1616		
Turbidity (NTU)	1496	2000	1520	1584	1696	2016		
Average particle size (μm)	5.6	3.4	4.5	6.3	4.5	2.0		

	Before	After	Before	After	Before	After	Before	After
Sample	V1-9	V1-10	V1-11	V1-12	V2-1	V2-2	V2-3	V2-4
Total suspended solids (mg/L)	26354	27452	25616	20480	672	504	498	207
Turbidity (NTU)	37120	50176	27392	20480	940	800	750	500
Average particle size (μm)	10.3	9.9	11.0	7.4	2.8	4.1	3.3	3.0

TABLE 5.10 HAY BALES AT SITE T

	Before	After	Before	After
Sample	T1-1	T1-2	T1-3	T1-4
Total suspended solids (mg/L)	1480	1946	2024	2200
Turbidity (NTU)	1700	2020	2080	2200
Average particle size (μm)	3.3	3.9	3.9	2.8

TABLE 5.11 PAIRED TEST P RESULTS FOR EROSION CONTROLS

	Site C	Site T	Site V	Site S	All Sites
Total suspended solids	0.514	0.040	0.813	0.151	0.804
Turbidity	0.923	0.218	0.688	0.343	0.241
Average particle size	0.8819	0.818	0.310	1.00	0.634

TABLE 5.12 SIGNIFICANCE OF EQUATION COEFFICIENTS RELATING TURBIDITY AND SUSPENDED SOLIDS (P VALUES)

Equation coefficients	Low intensity	Medium intensity	High intensity
Constant	0.89	0.04	<0.0001
Ratio	<0.0001	0.003	0.19

SUMMARY AND CONCLUSIONS

6.1 Major Findings

The following major findings were established during these analyses:

1. The probability plots of suspended solids concentrations for all samples indicated a reasonably normal distribution of suspended solids concentrations for this study. This indicates that there were no significant gaps in the data due to rain or site conditions.

2. Levels of suspended solids and turbidity measured in runoff from construction sites spanned three orders of magnitude, with median values of 1508 mg/L and 3672 turbidity units, respectively. A weak direct relationship was observed when turbidity versus suspended solids was plotted for medium and high rain intensity groupings. A statistically significant relationship was observed for low rain intensity conditions.

3. The observed rainfall intensity estimates at the sites during sampling were much more applicable than the National Weather Service data from the distant weather monitoring location. Observed rainfall intensities were therefore used to categorize each storm event at the time

of sampling. The rainfall data from the National Weather Service provided only a gross estimate of the storm event. The data was not adequate for determinations used to compare variations in sediment loads for individual storm events.

4. Particle size distributions for all samples showed that the sediment in the runoff was almost entirely composed of very fine-grained material (clay-sized particles). The average particle size for all samples was approximately 5 micrometers with most of the variability due to observed rainfall intensity.

5. The influence of rain intensity clearly affected the suspended solids concentrations, turbidity values, and average particle sizes. Significant differences between high, medium, and low intensity rainfall were demonstrated on probability plots, particle size distribution plots, turbidity versus suspended solids plots, and ANOVA calculations.

6. Site soil and control practices did not significantly influence the observed runoff quality data. Probability plots, particle size distribution plots, and ANOVA results concluded that site conditions such as sandy versus clay soils were not a significant factor. Variability in the observed data at all sites was primarily due to rain intensity at the time of sampling.

7. Sediment loading calculations for all samples revealed that the sediment-delivery ratio generally decreased with increasing drainage area. Significant decreases were observed in the sediment-delivery ratio when the drainage area was greater than 1 acre for most sample sites. The "percent of area disturbed" value within the drainage basins had no observed effect on the sediment-delivery ratio.

8. Statistical comparison tests determined that changes in the observed data due to erosion controls such as hay bales and silt fencing were no greater than those expected due to chance. These results indicate that the observed hay bales and silt fencing were not effective in controlling average particle sizes or suspended solids concentrations. Coarser grained material was observed to be trapped by these on-site controls, but the majority of the transported sediment particles, which are fine-grained, cannot be controlled by hay bales and silt fencing.

6.2 Conclusions

The objective of this study was to collect basic data on the concentration and particle size distribution of suspended solids in runoff from construction sites and discover factors that influence the sediment loadings.

The results of the research determined that large concentrations of suspended solids occurred mostly during high rain intensities. Rainfall kinetic energy, associated mainly with peak rain intensity, was the driving mechanism for the erosion process. Site characteristics such as physical soil properties and slopes may have been important factors, but they were not shown to be significant during these tests, possibly because of the overwhelming effects of rain intensity. Predicted annual sediment loadings using the observed suspended solids concentrations and 112 rainfall events from an average rainfall year indicated that most all of the erosion was due to 20 of the 112 storm events which had the largest rainfall accumulations.

The observed and predicted sediment loadings for all samples demonstrated that the sediment-delivery ratio decreases primarily with increasing drainage area. Particles detached in bare upland areas were trapped in vegetated areas downstream. Site conditions such as irregular surfaces, erosion controls, and standing water encourage runoff to slow down and pond. The result of this process increases the entrapment and settling of particles. Given these conditions, it is likely that entrapped particles increase with the size of the drainage area.

Particle size distributions for the runoff samples showed that a majority of the sediment contained extremely fine-grained particles. Examination for all runoff samples revealed that the average particle sizes were very small (median size approximately 5 μm). These small particles are difficult to remove using conventional erosion controls. This fact emphasizes the importance of prevention of the erosion process at the source. Soil cover practices such as mulching or temporary vegetation reduce the initial erosion process, therefore decreasing the sediment loading.

Preventive measures are the best erosion control practices. Limiting the amount of disturbed area at a construction site by clearing only portions of land in active construction phases, rather than clearing the entire site at the beginning of the project, can decrease the potential for rain to erode bare soil surfaces. Erosion controls such as silt fencing and hay bales can reduce the transport of coarse grained sediment, but a majority of the particles will not be entrapped by these structures. The key to reducing sediment loads from construction sites is surface treatment and, most of all, careful planning to reduce the amount of land disturbance to active construction phases.

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APPENDIX A
SUSPENDED SOLIDS PROBABILITY PLOTS

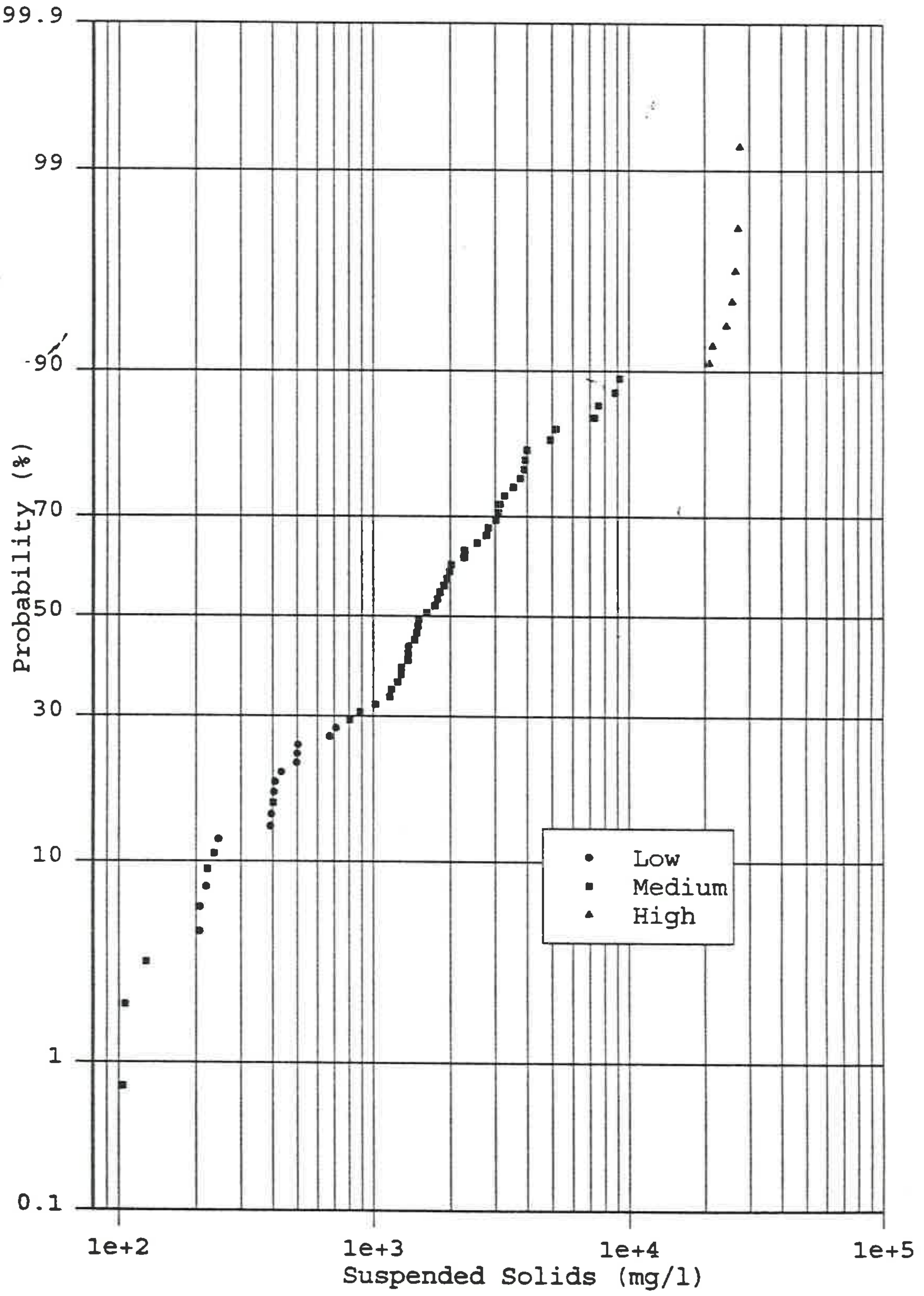

Figure A.1 Probability Plot for All Samples

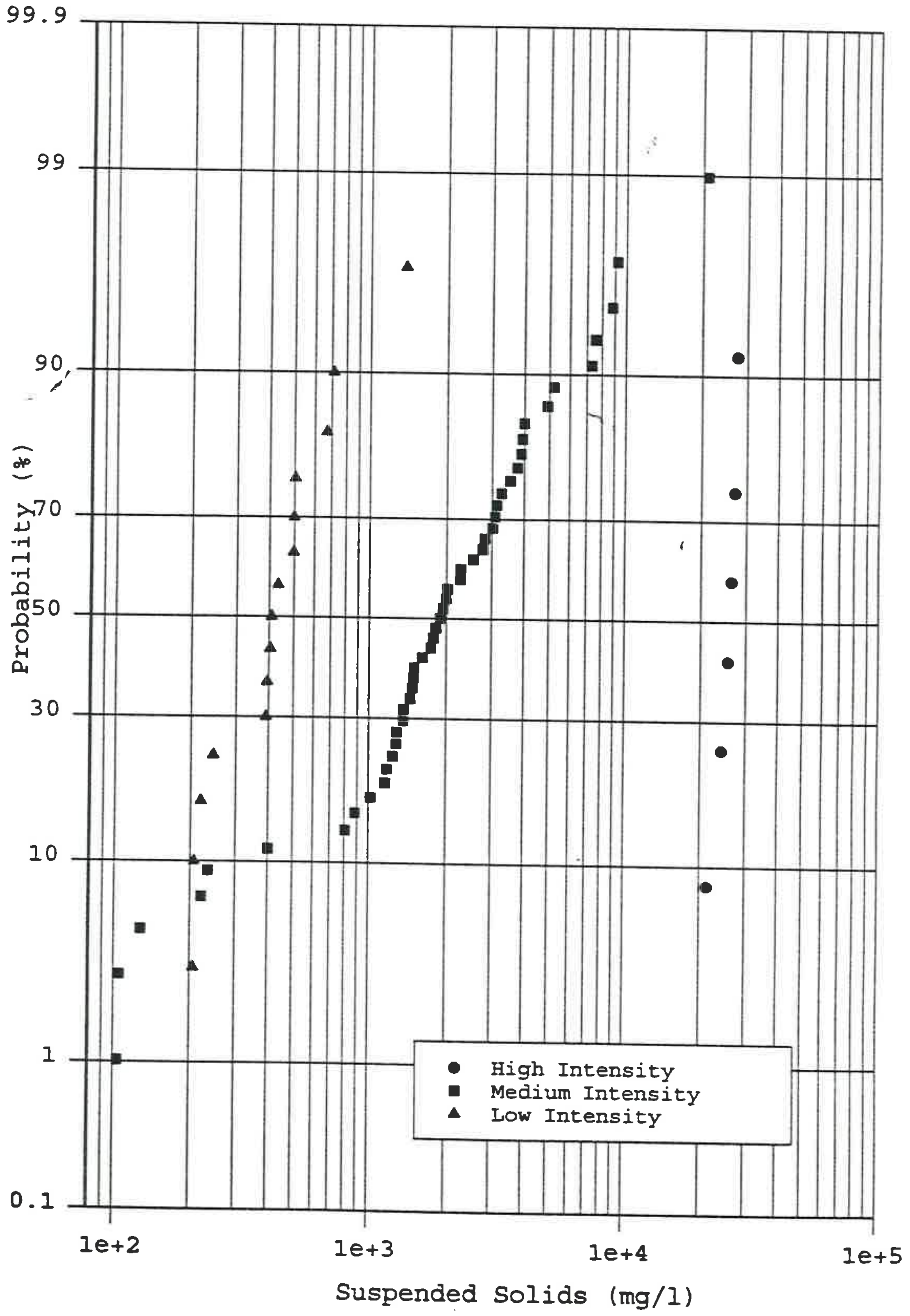

Figure A.2 Probability Plots Grouped by Rain Intensity

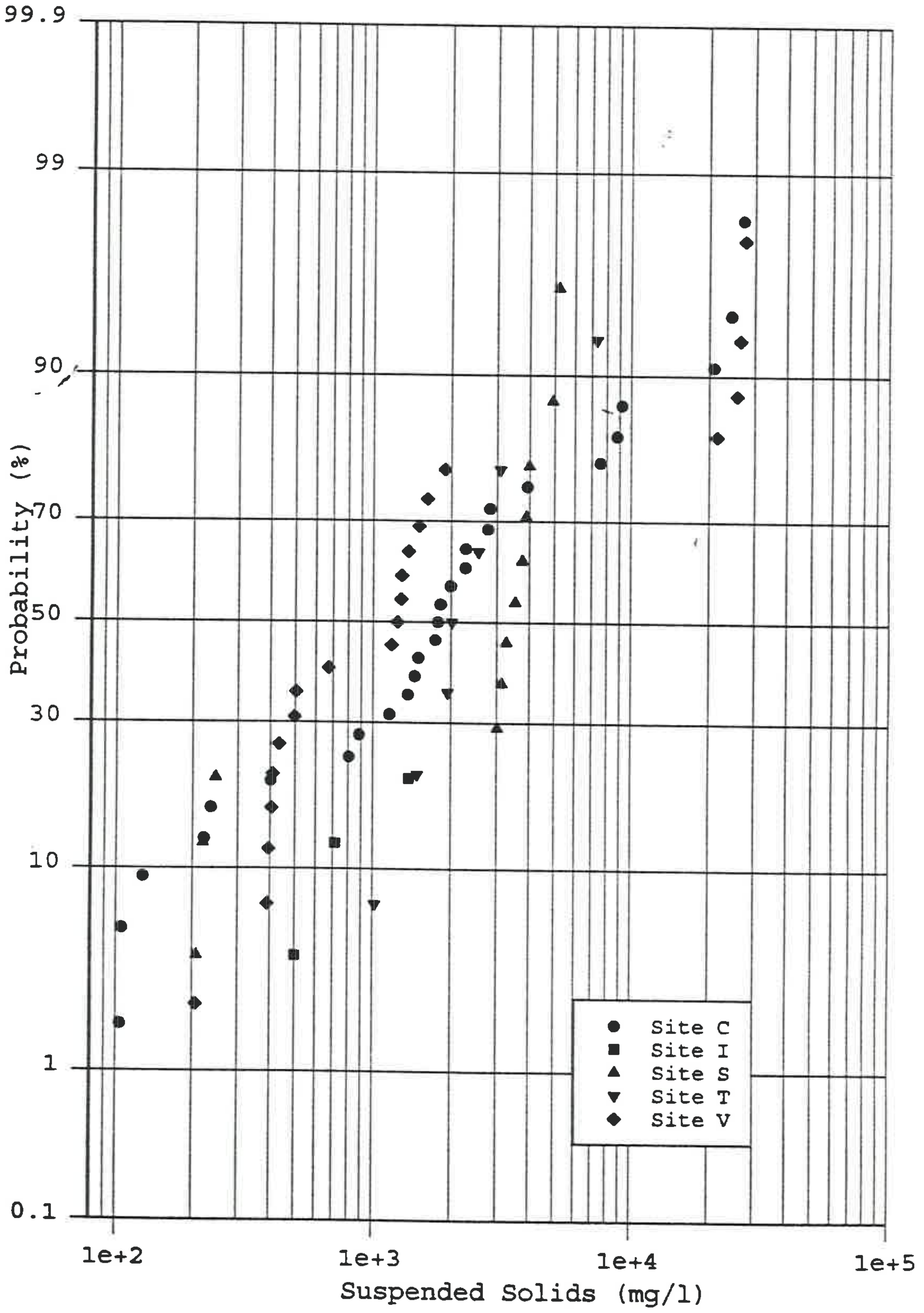

Figure A.3 Probability Plots Grouped by Site

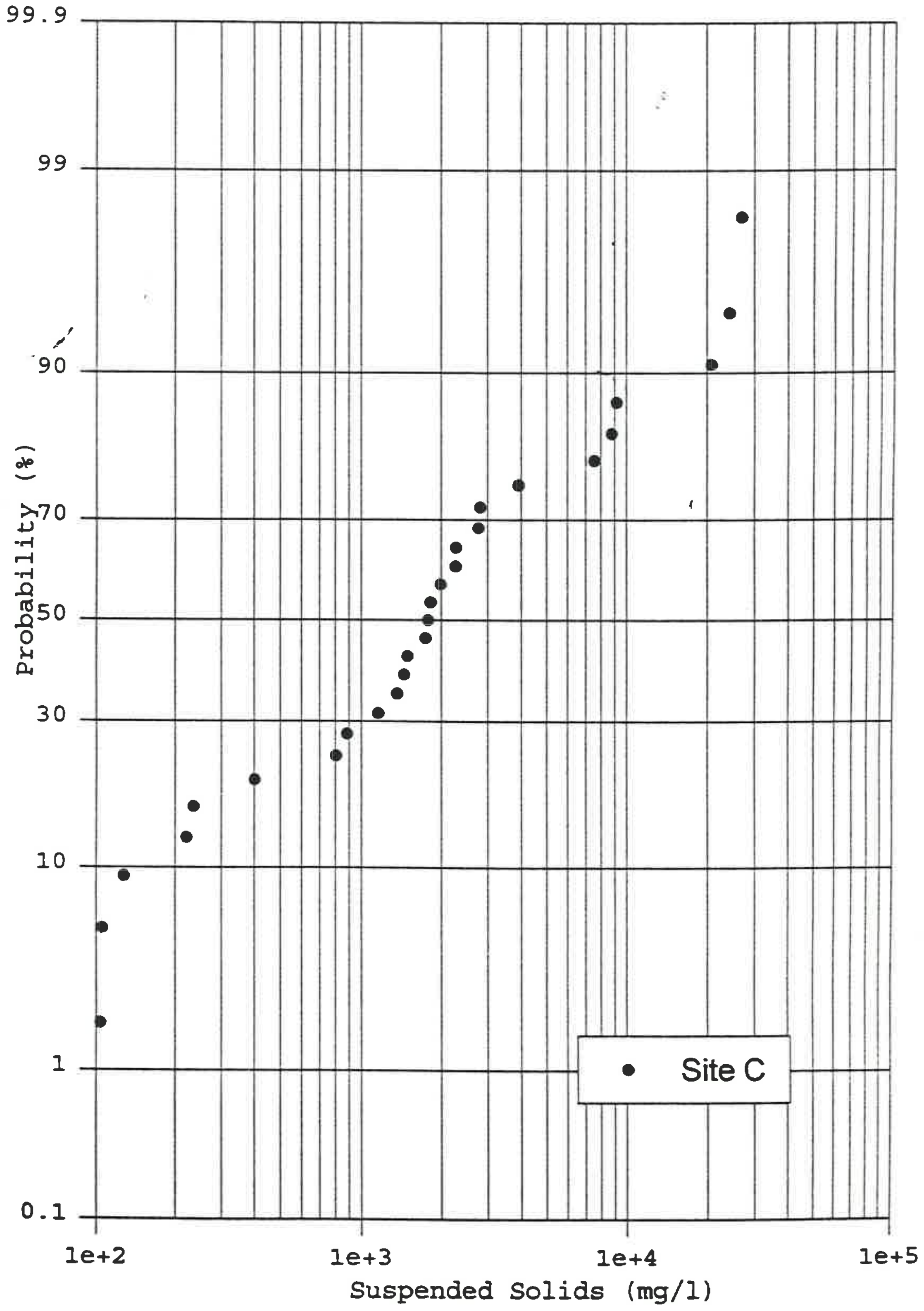

Figure A.4 Probability Plot for Site C

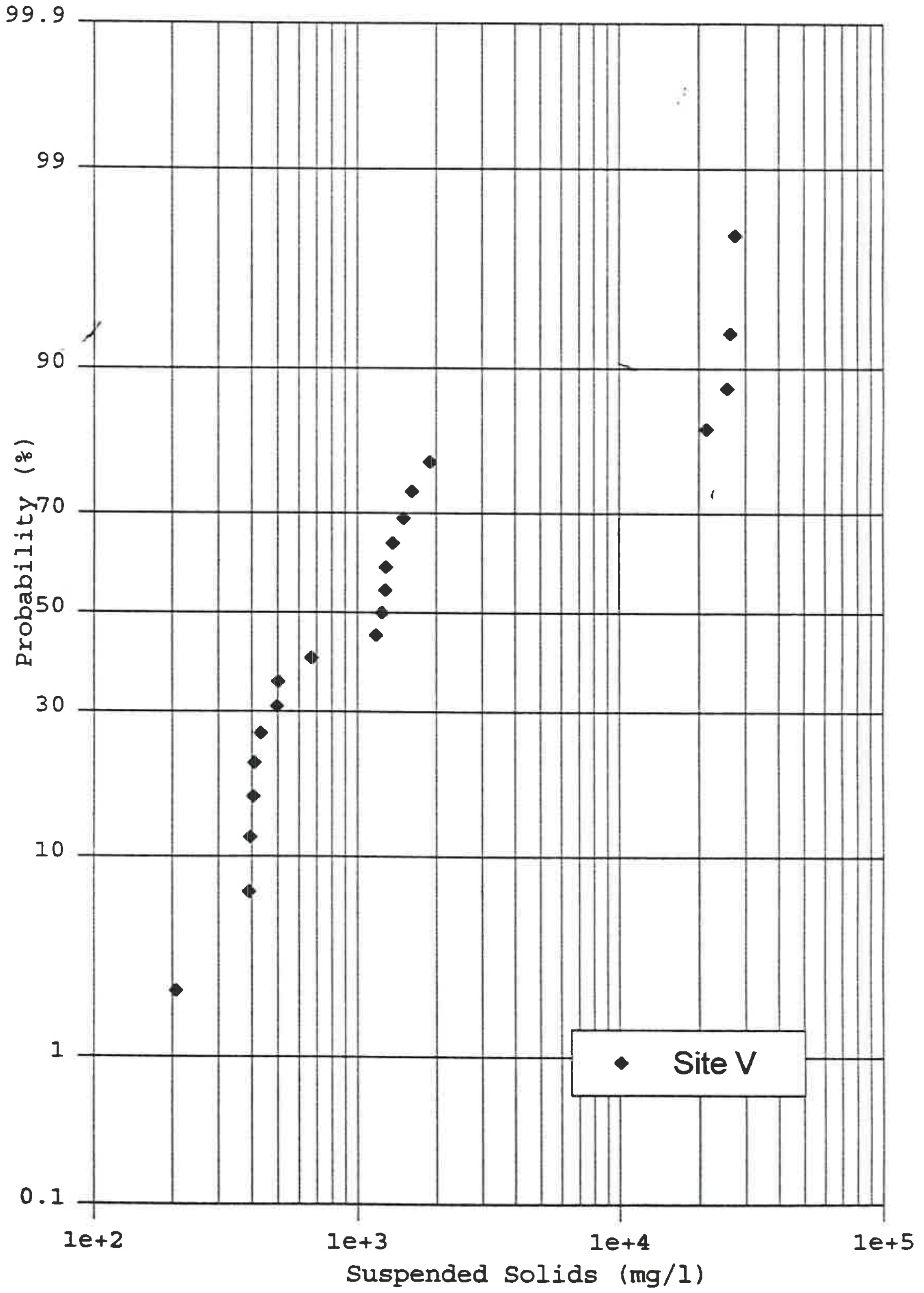

Figure A.5 Probability Plot for Site V

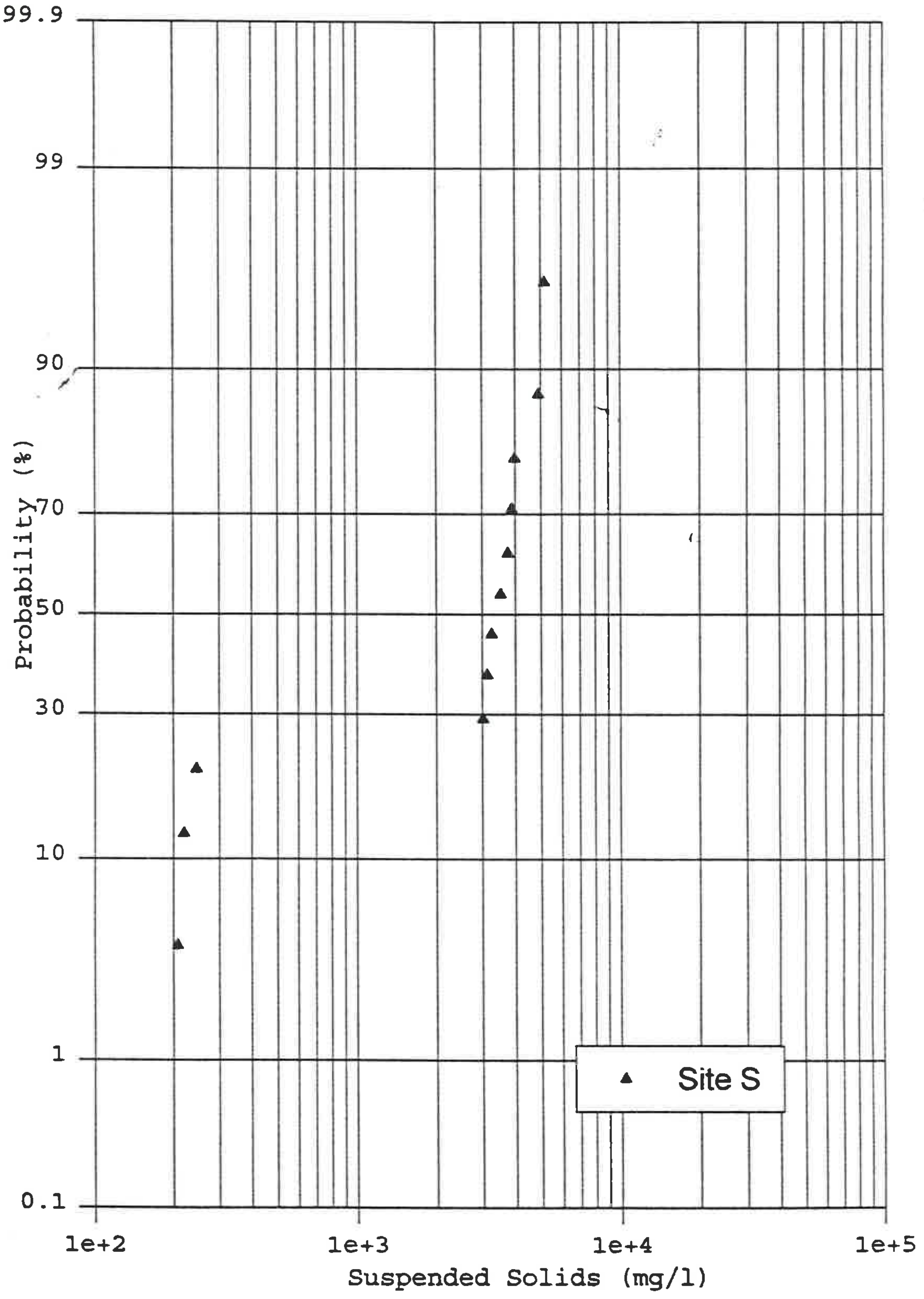

Figure A.6 Probability Plot for Site S

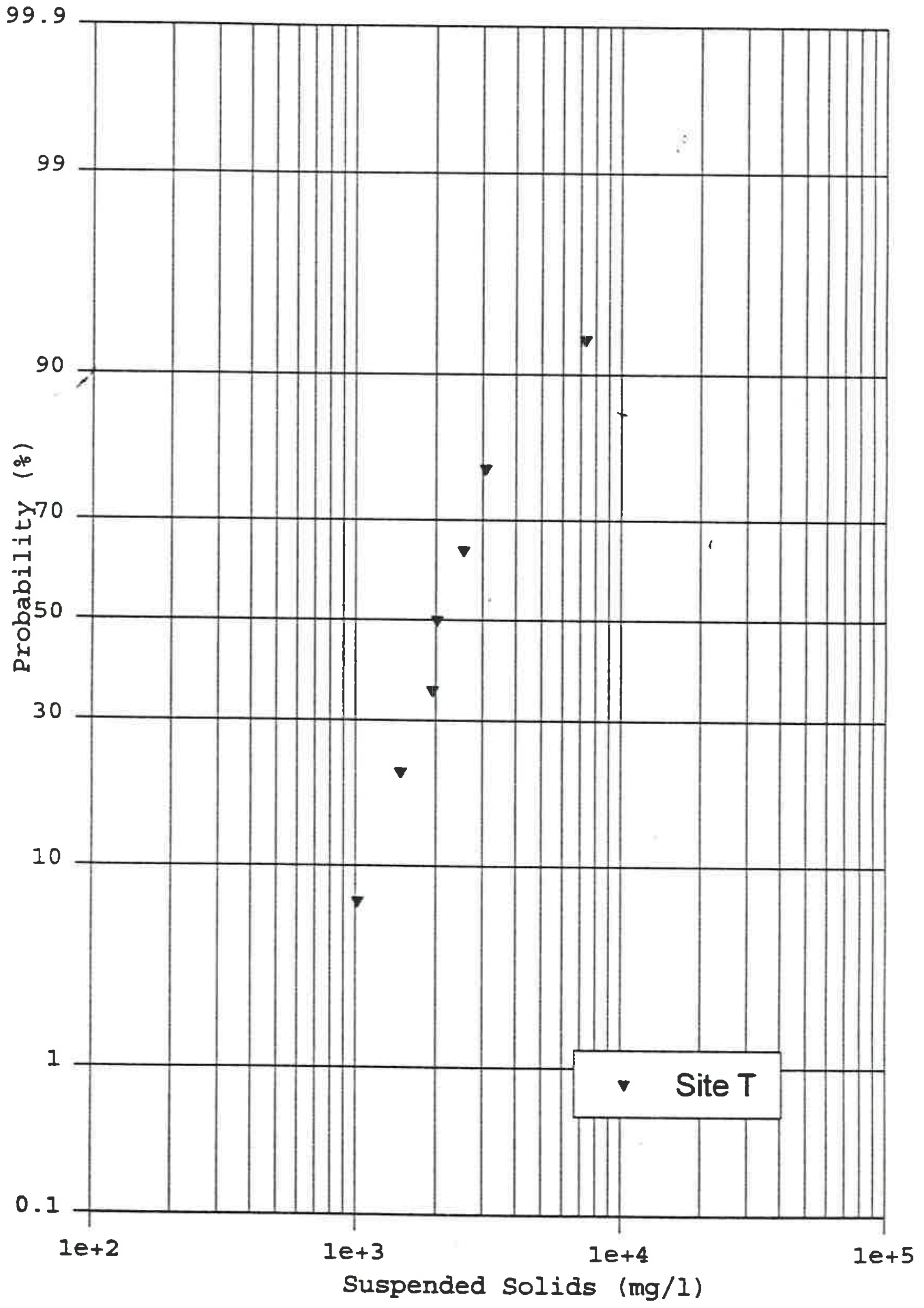

Figure A.7 Probability Plot for Site T

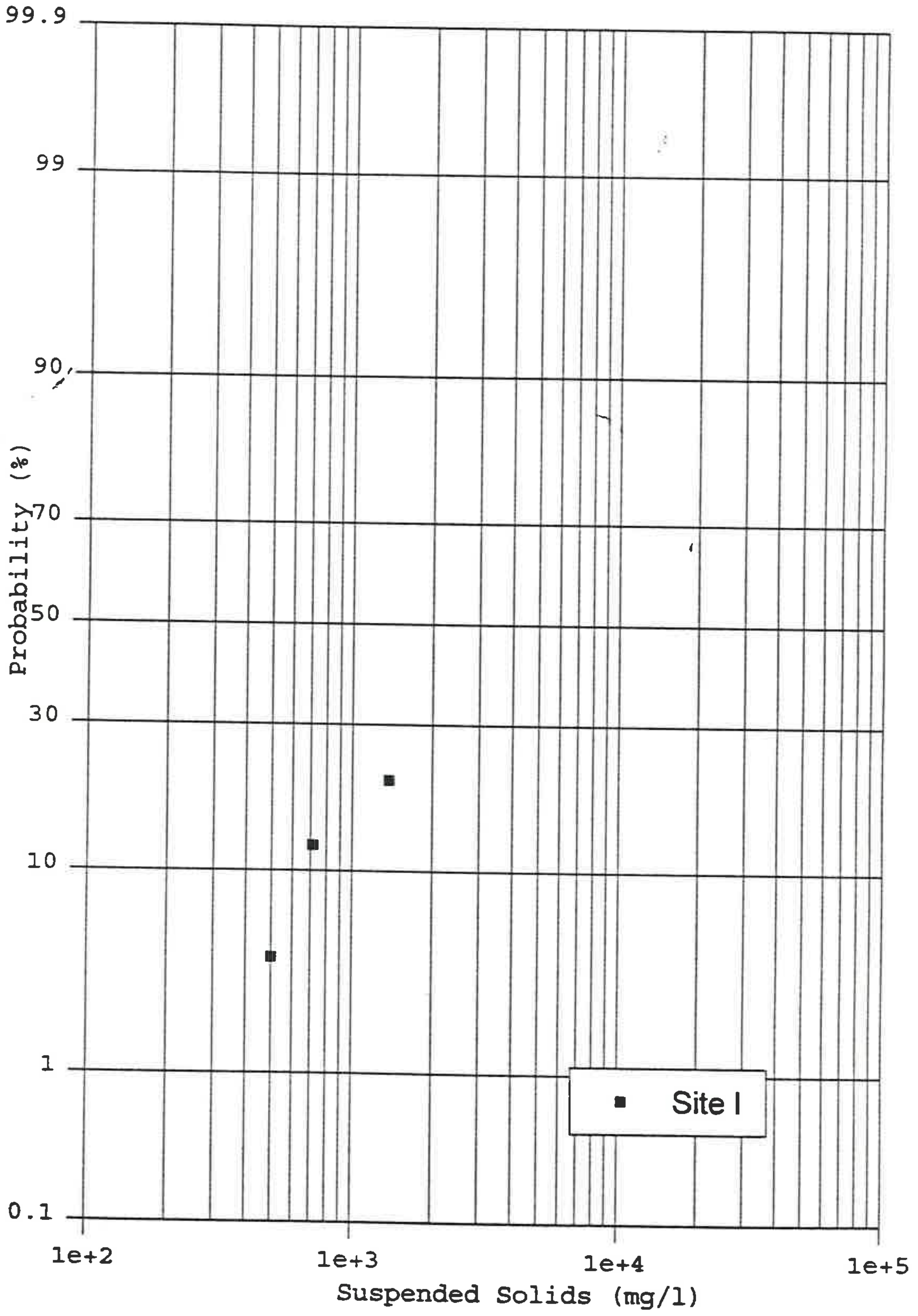

Figure A.8 Probability Plot for Site I

APPENDIX B
PARTICLE SIZE DISTRIBUTION PLOTS

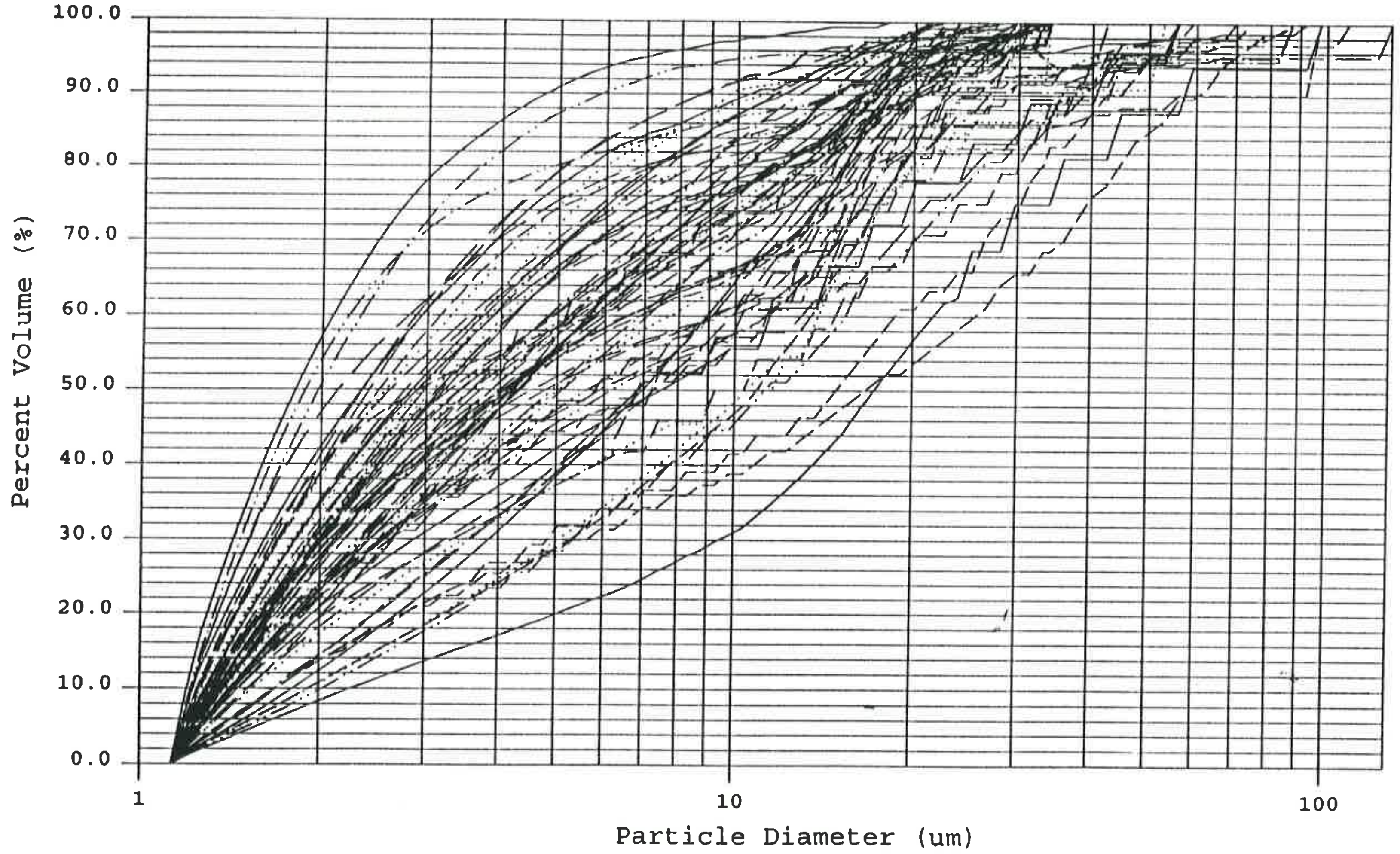

Figure B.1 Particle Size Distributions for All Sample Points

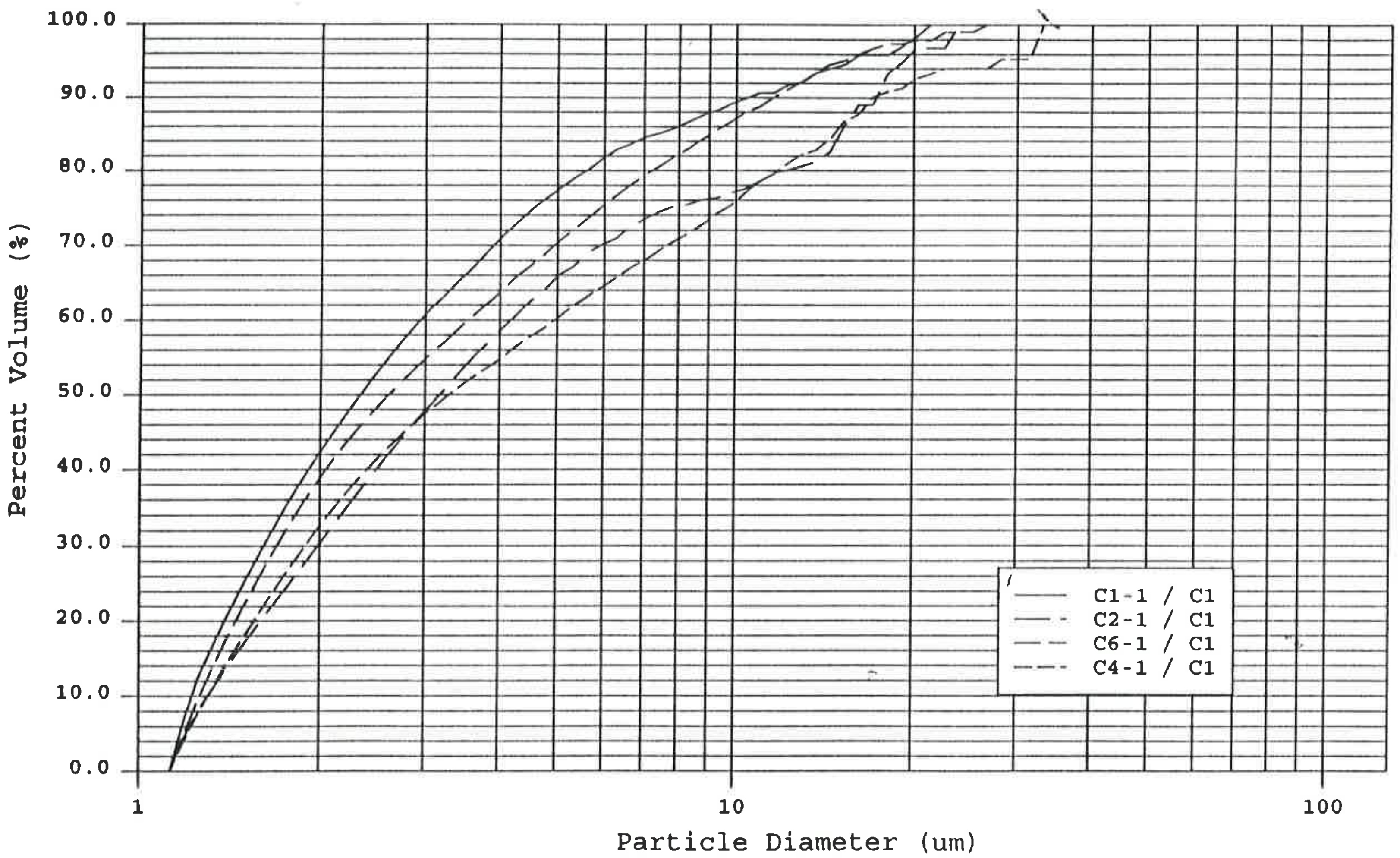

Figure B.2 Particle Size Distributions for Sample Point C1

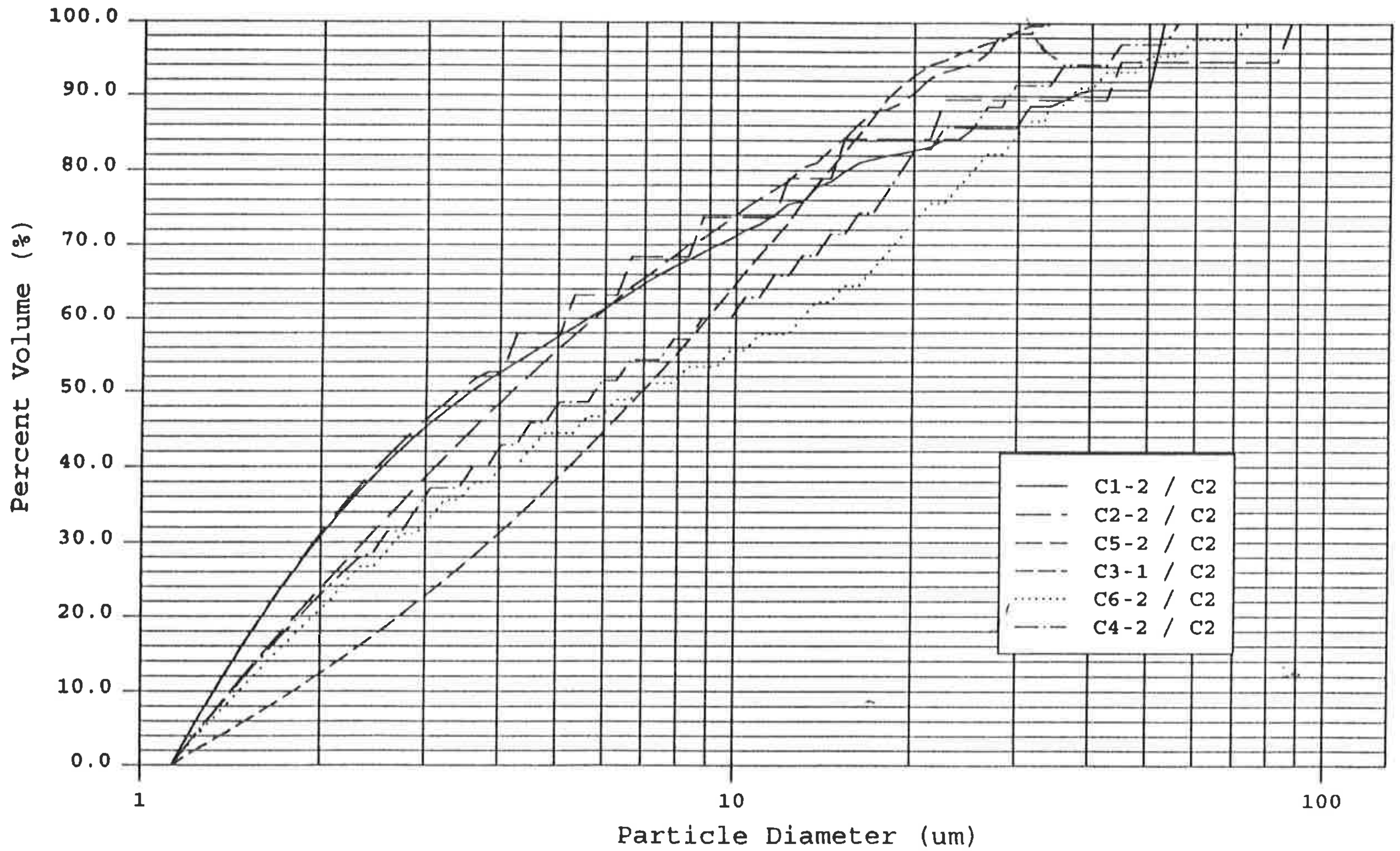

Figure B.3 Particle Size Distributions for Sample Point C2

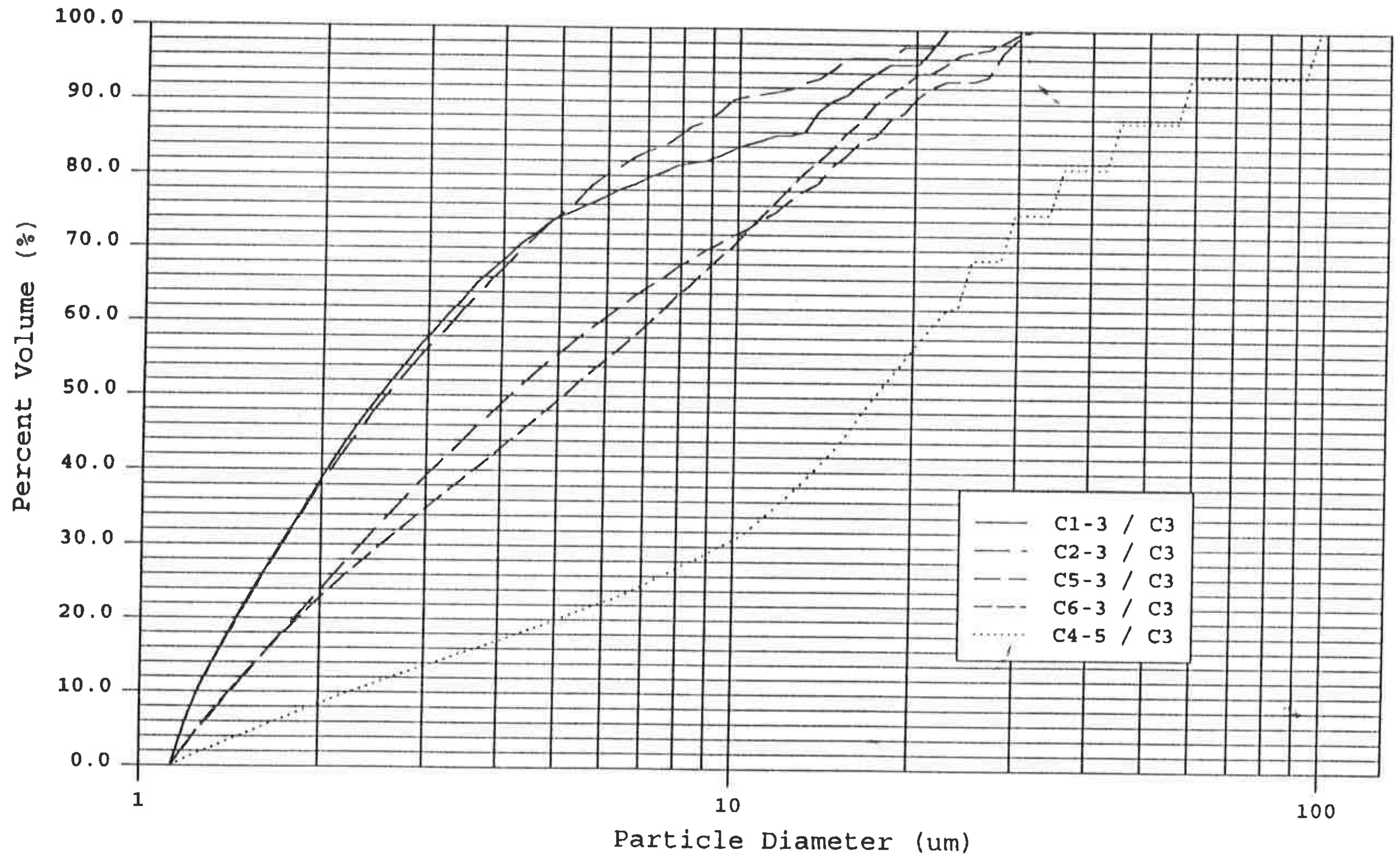

Figure B.4 Particle Size Distributions for Sample Point C3

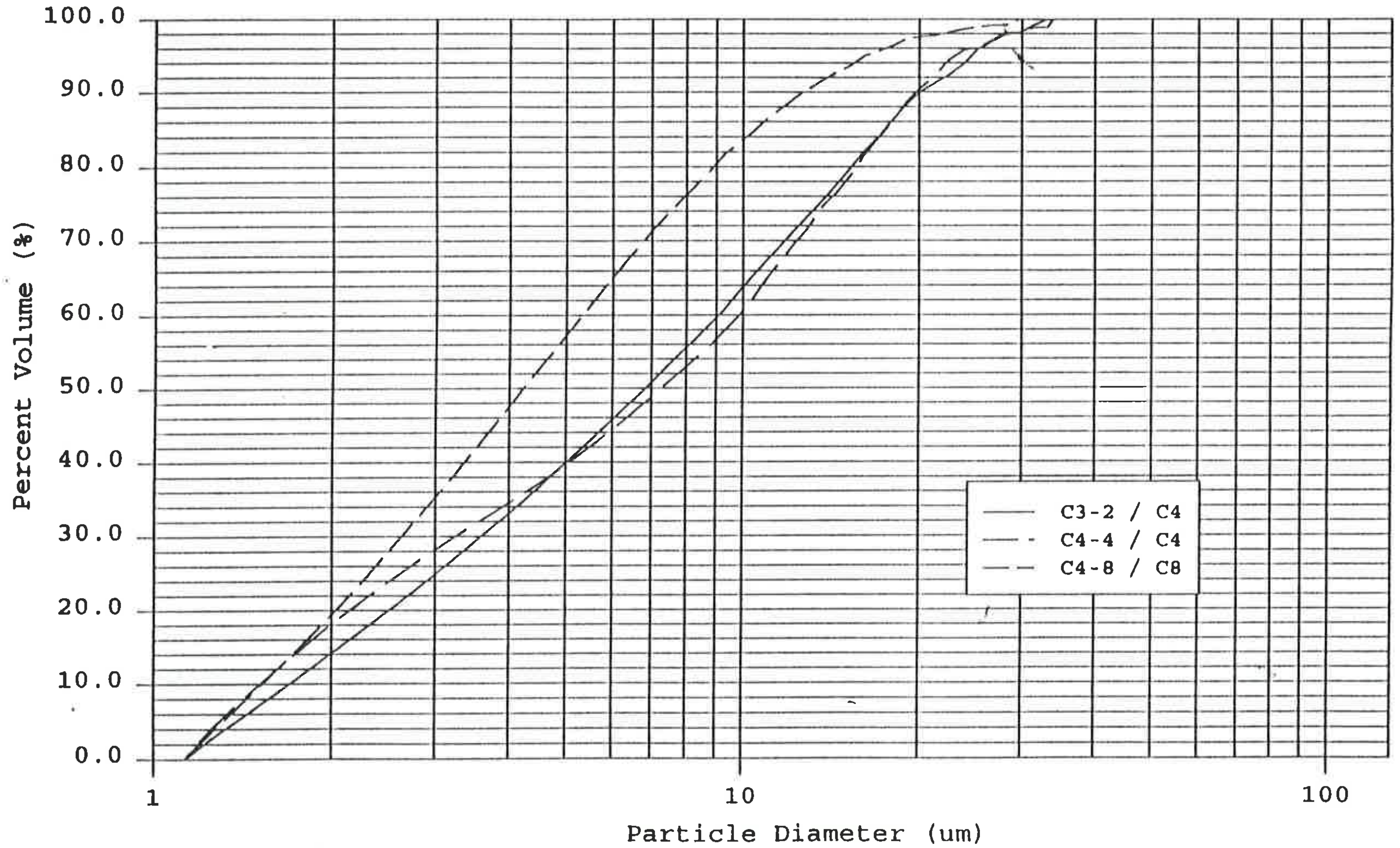

Figure B.5 Particle Size Distributions for Sample Points C4 & C8

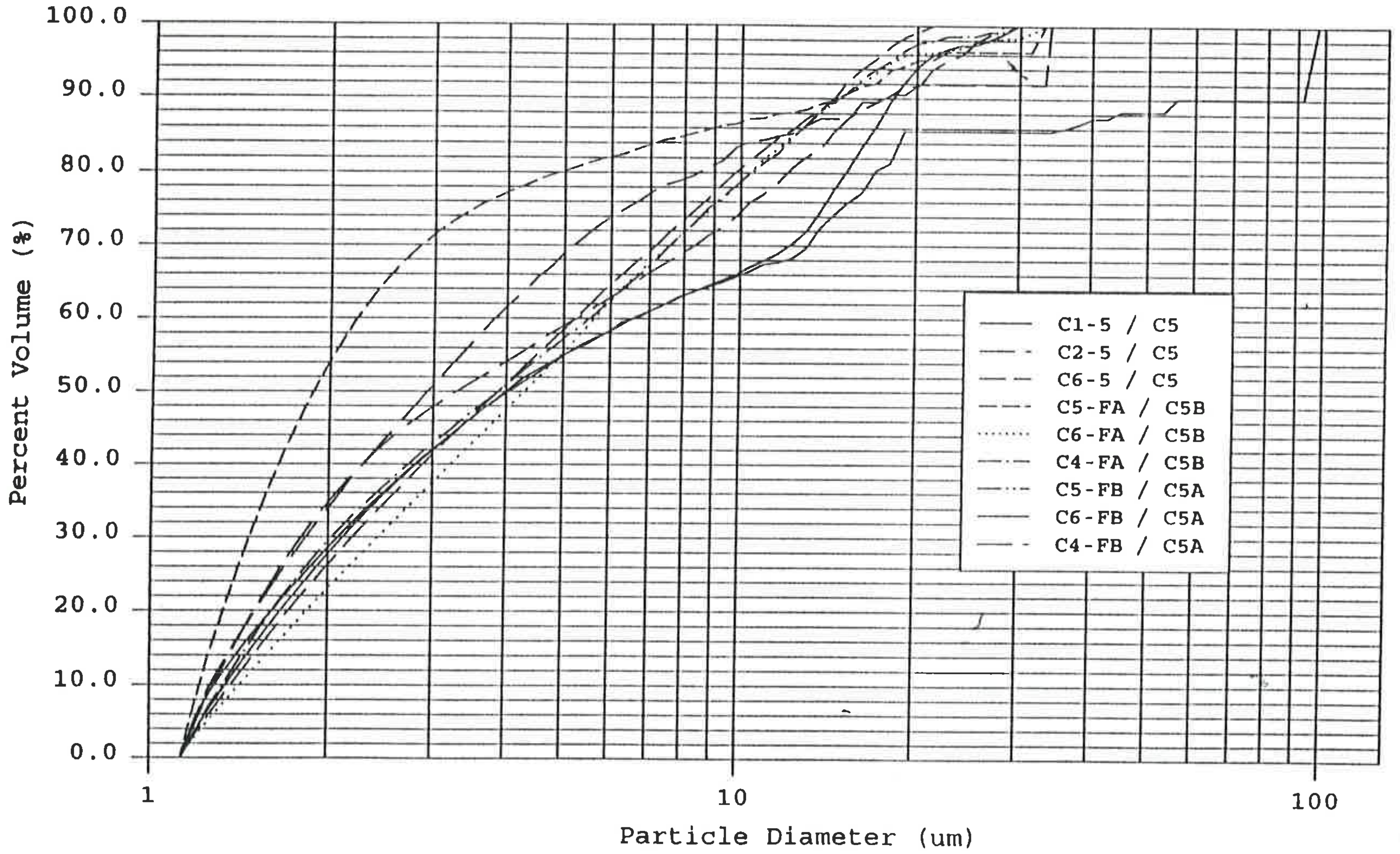

Figure B.6 Particle Size Distributions for Sample Point C5

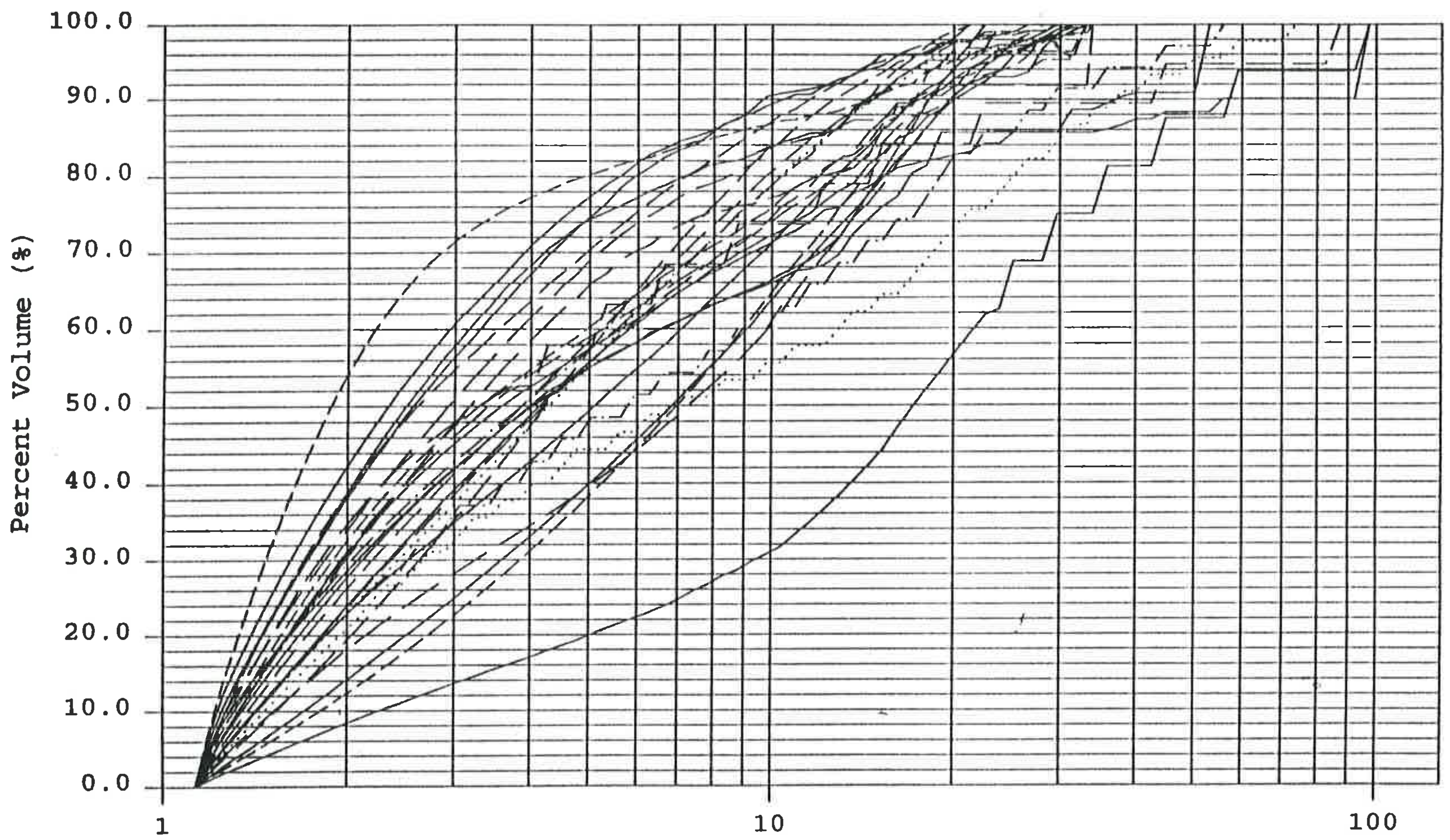

Figure B.7 Particle Size Distributions for Site C

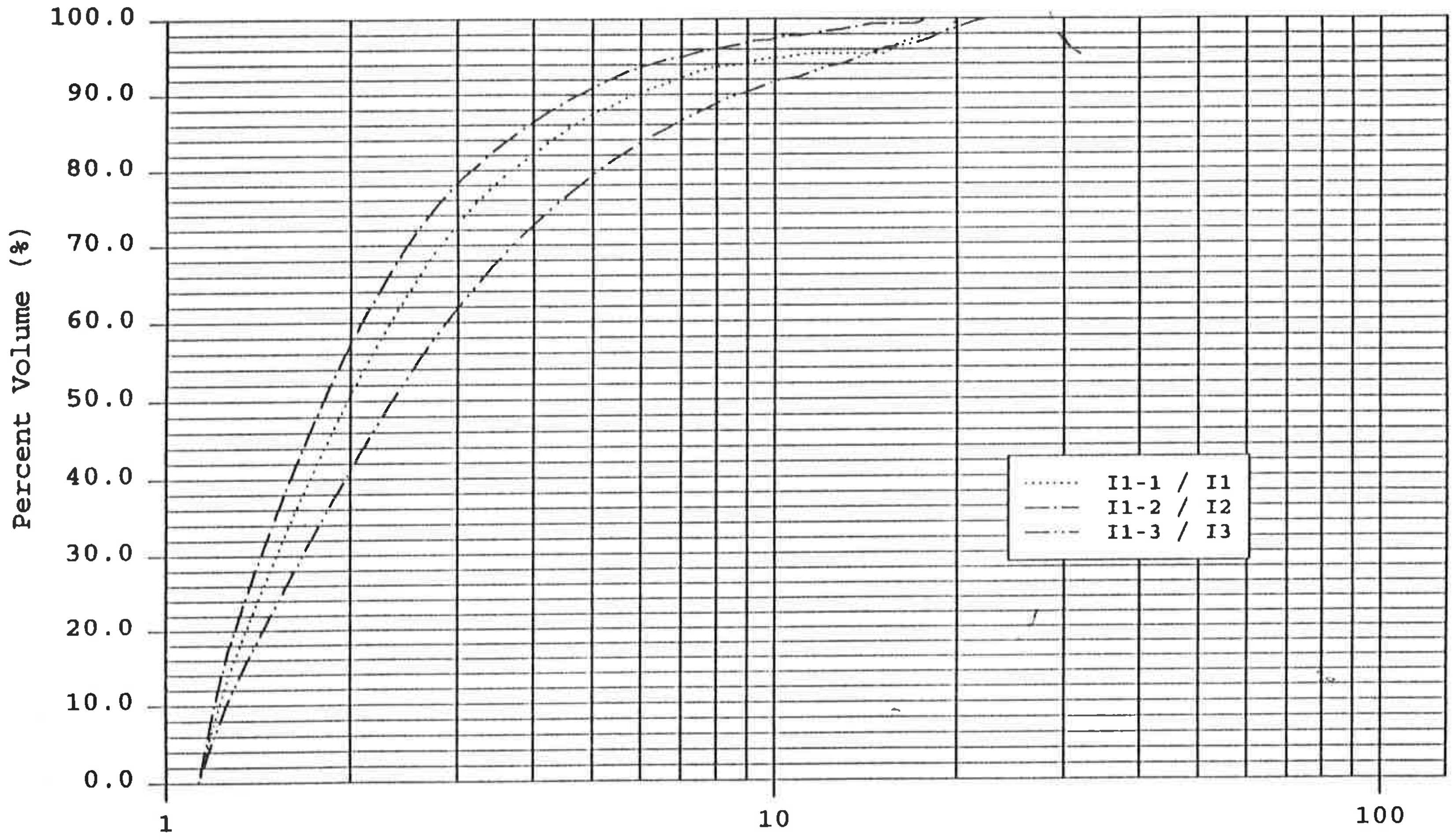

Figure B.8 Particle Size Distributions for Site I

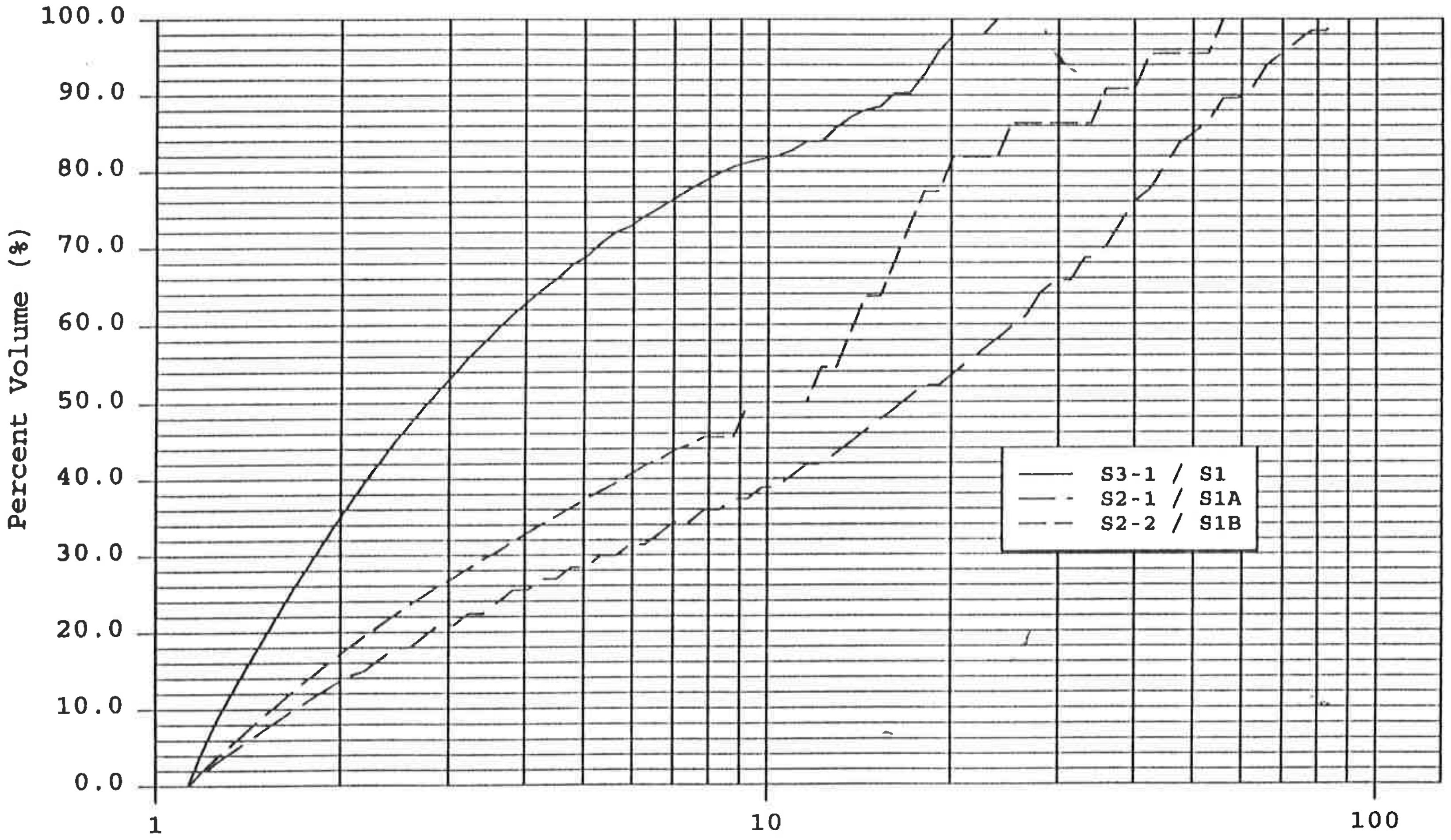

Figure B.9 Particle Size Distributions for Sample Point S1

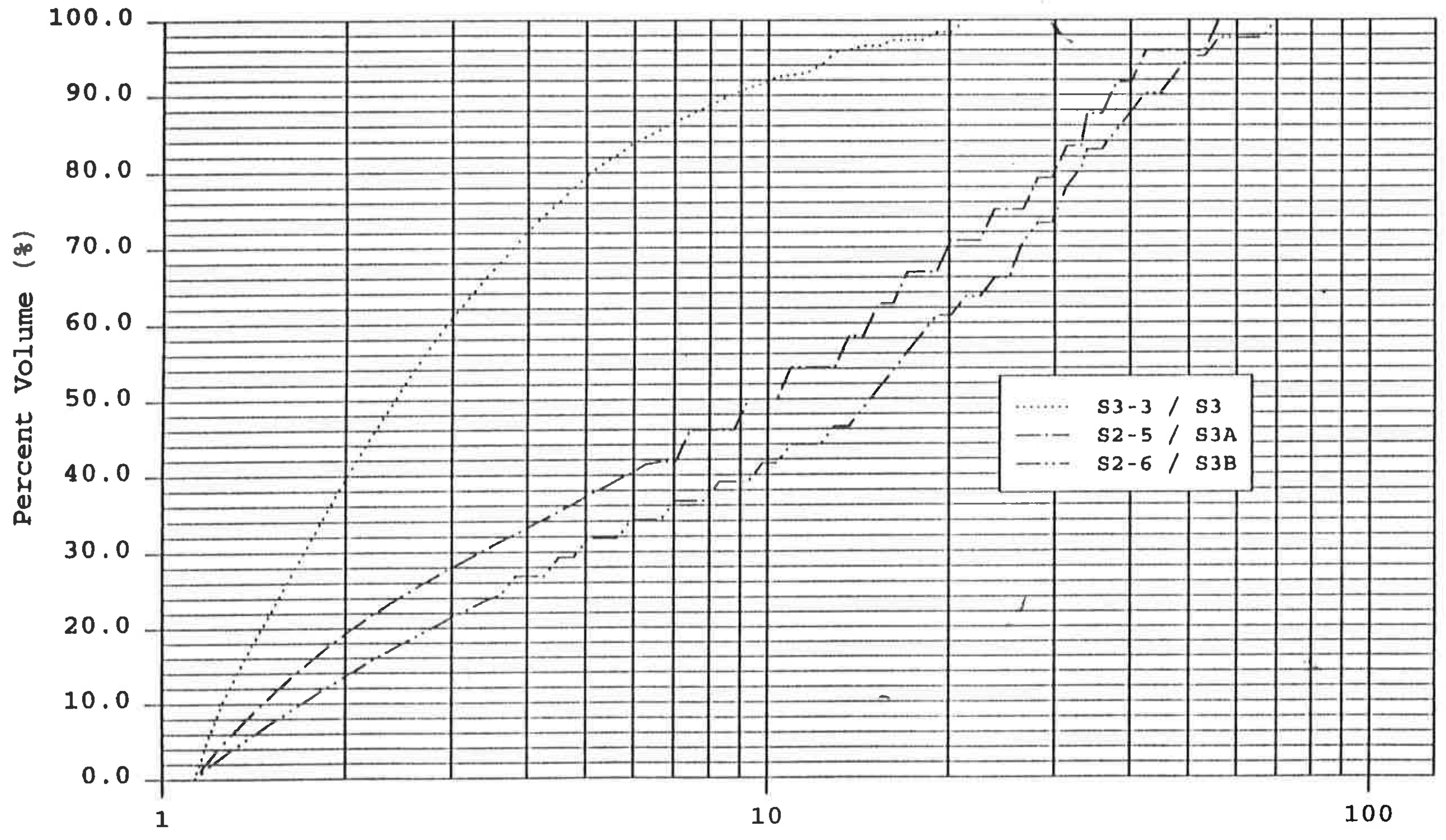

Figure B.10 Particle Size Distributions for Sample Point S3

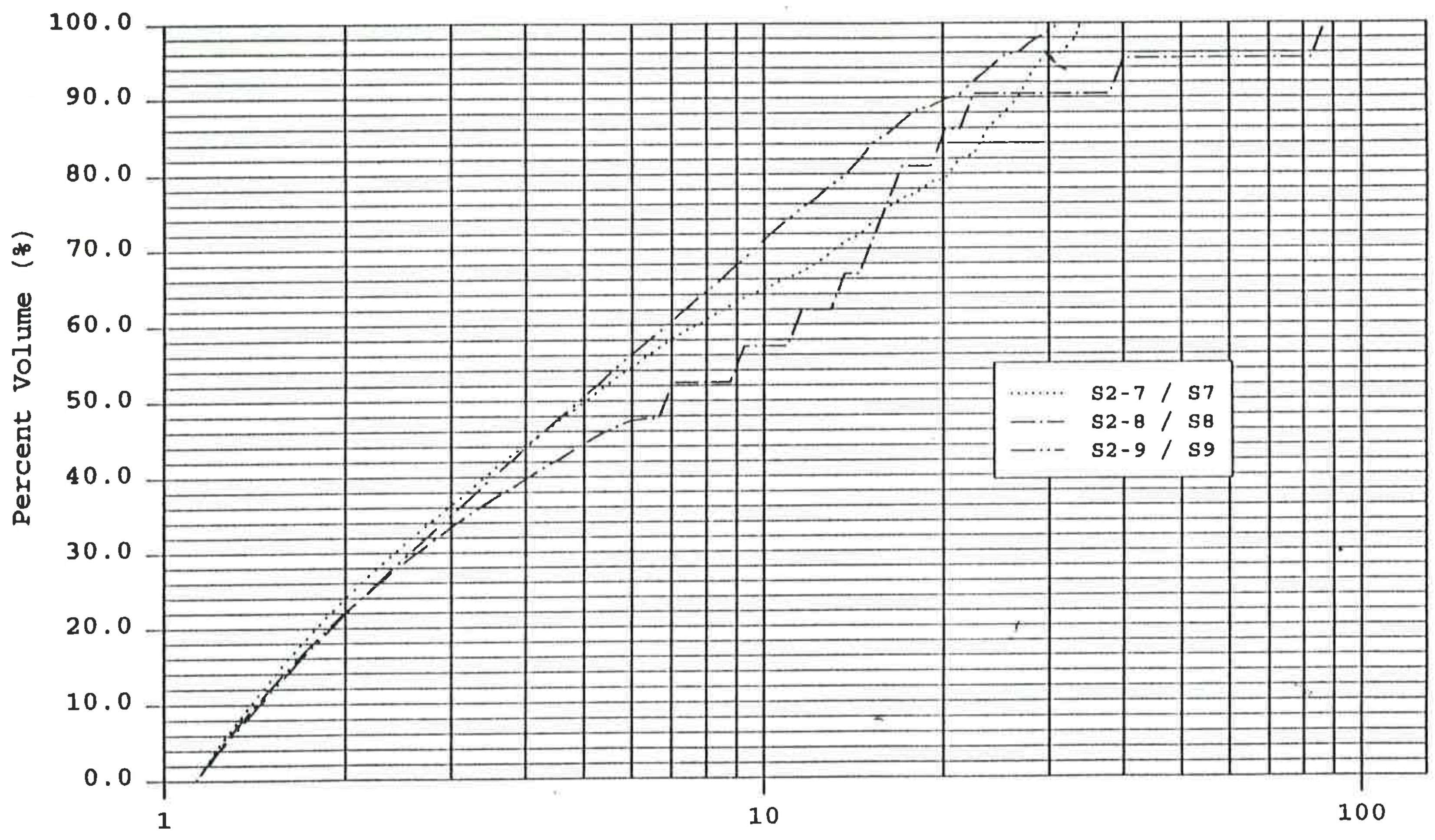

Figure B.11 Particle Size Distributions for Sample Points S7, S8, & S9

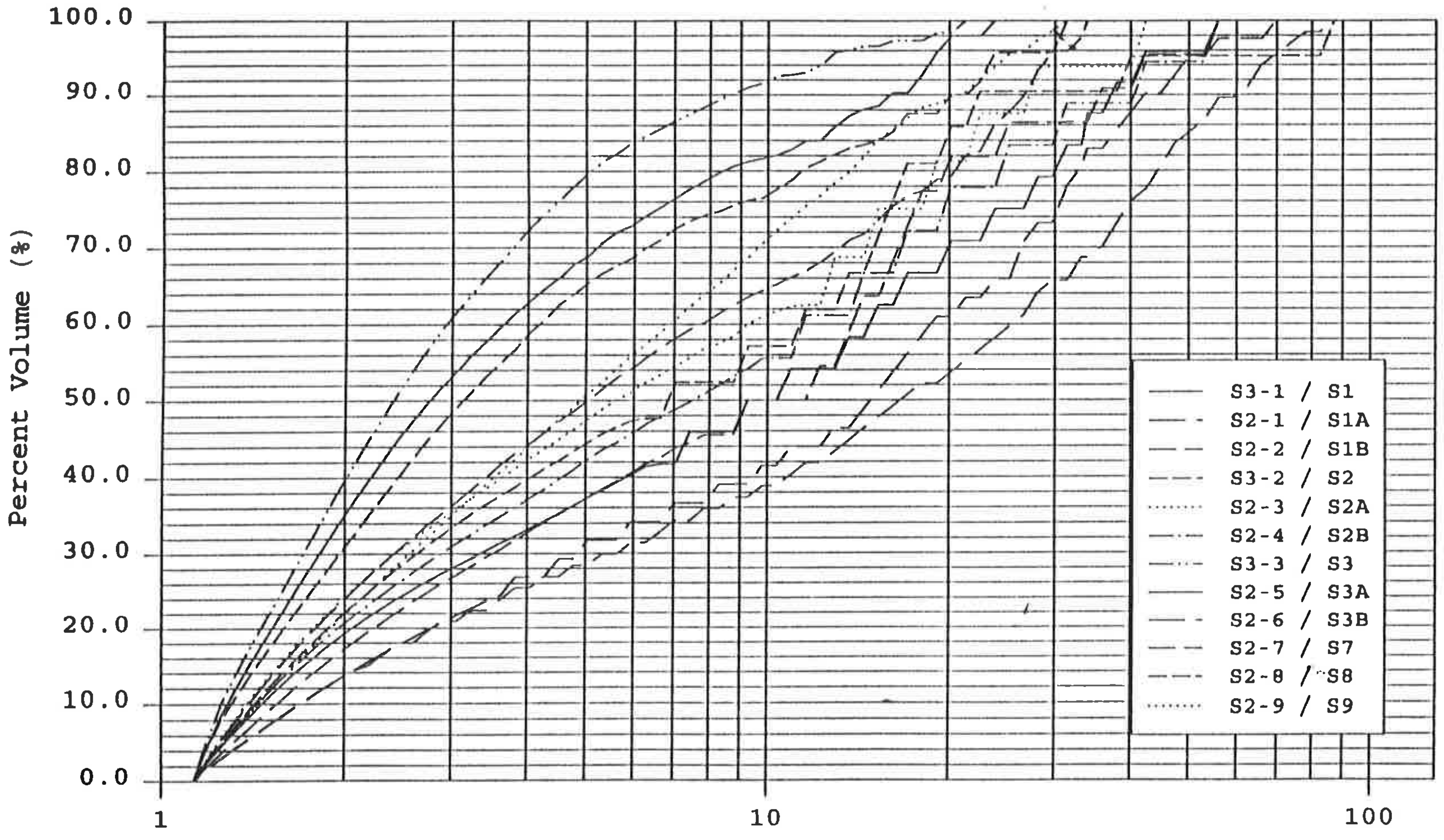

Figure B.12 Particle Size Distributions for Site S

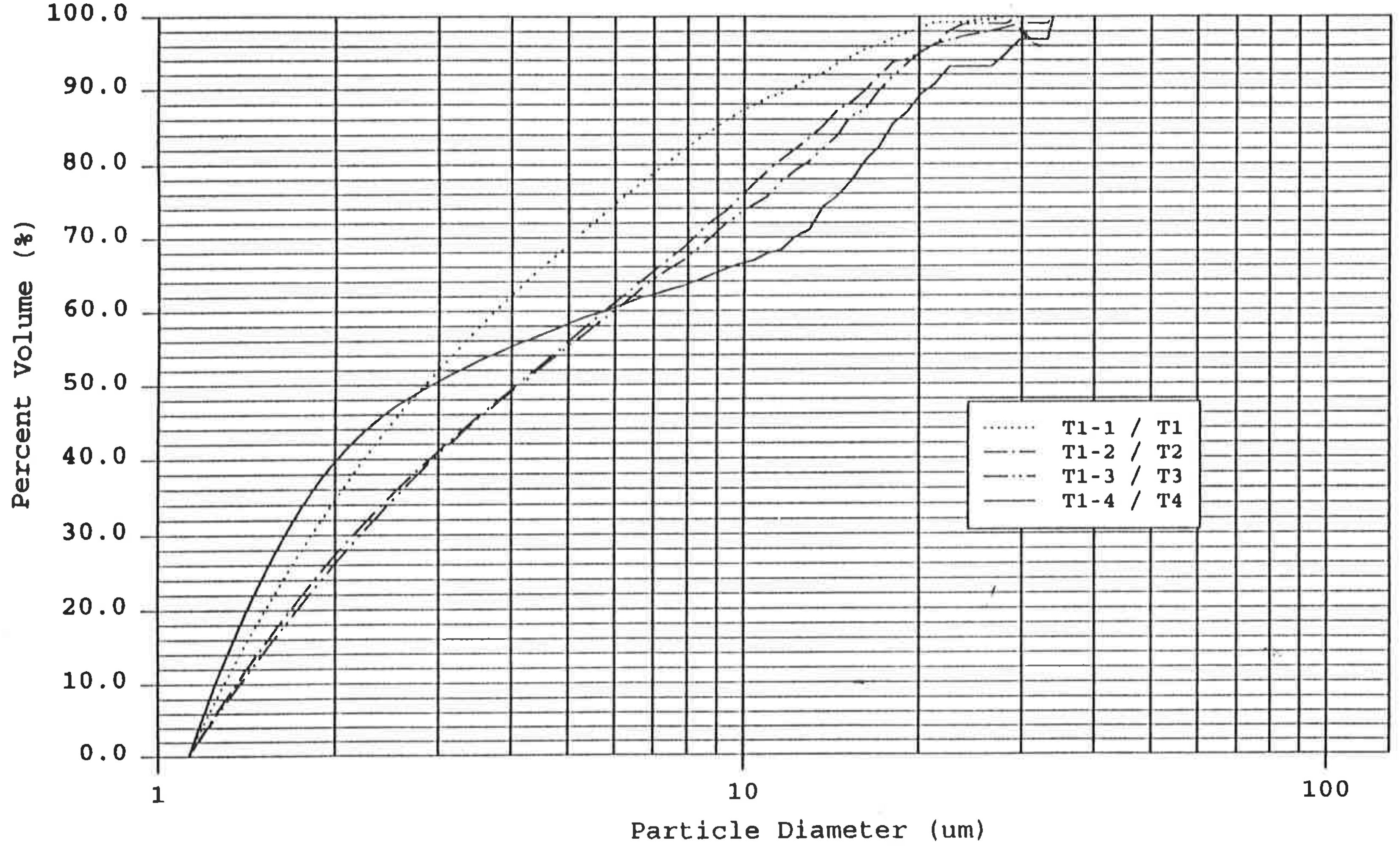

Figure B.13 Particle Size Distributions for Site T

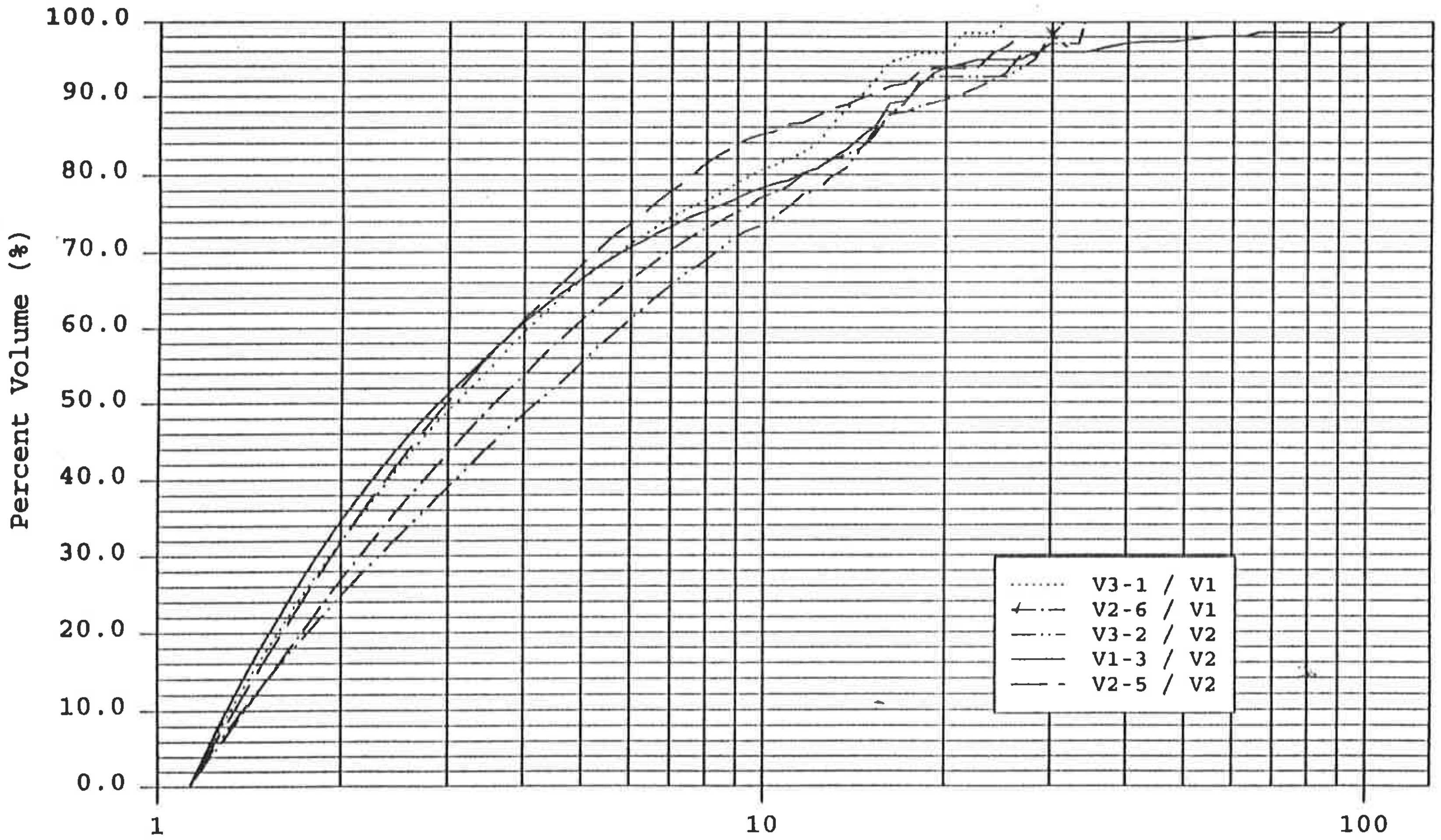

Figure B.14 Particle Size Distributions for Sample Points V1 & V2

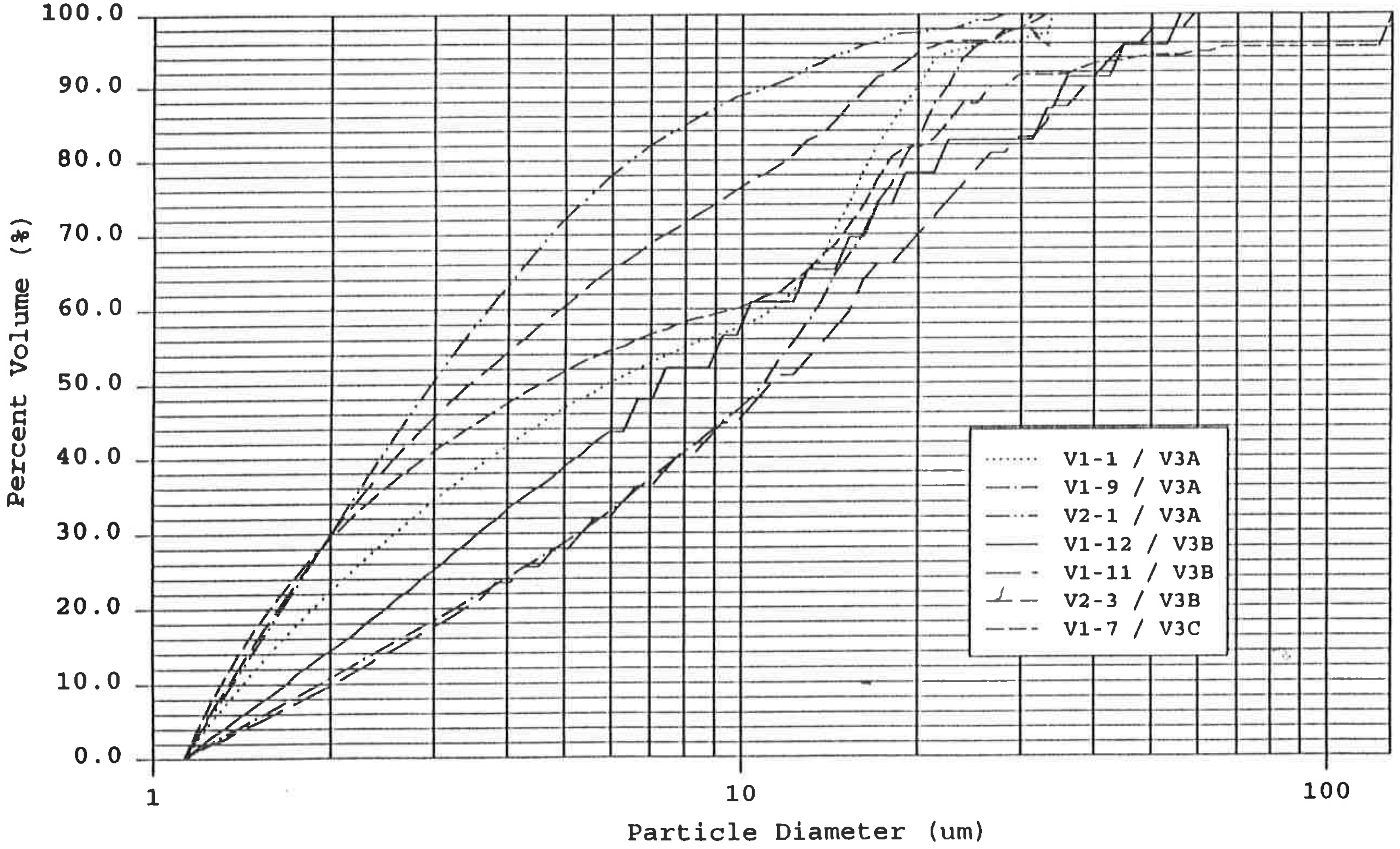

Figure B.15 Particle Size Distributions for Sample Point V3

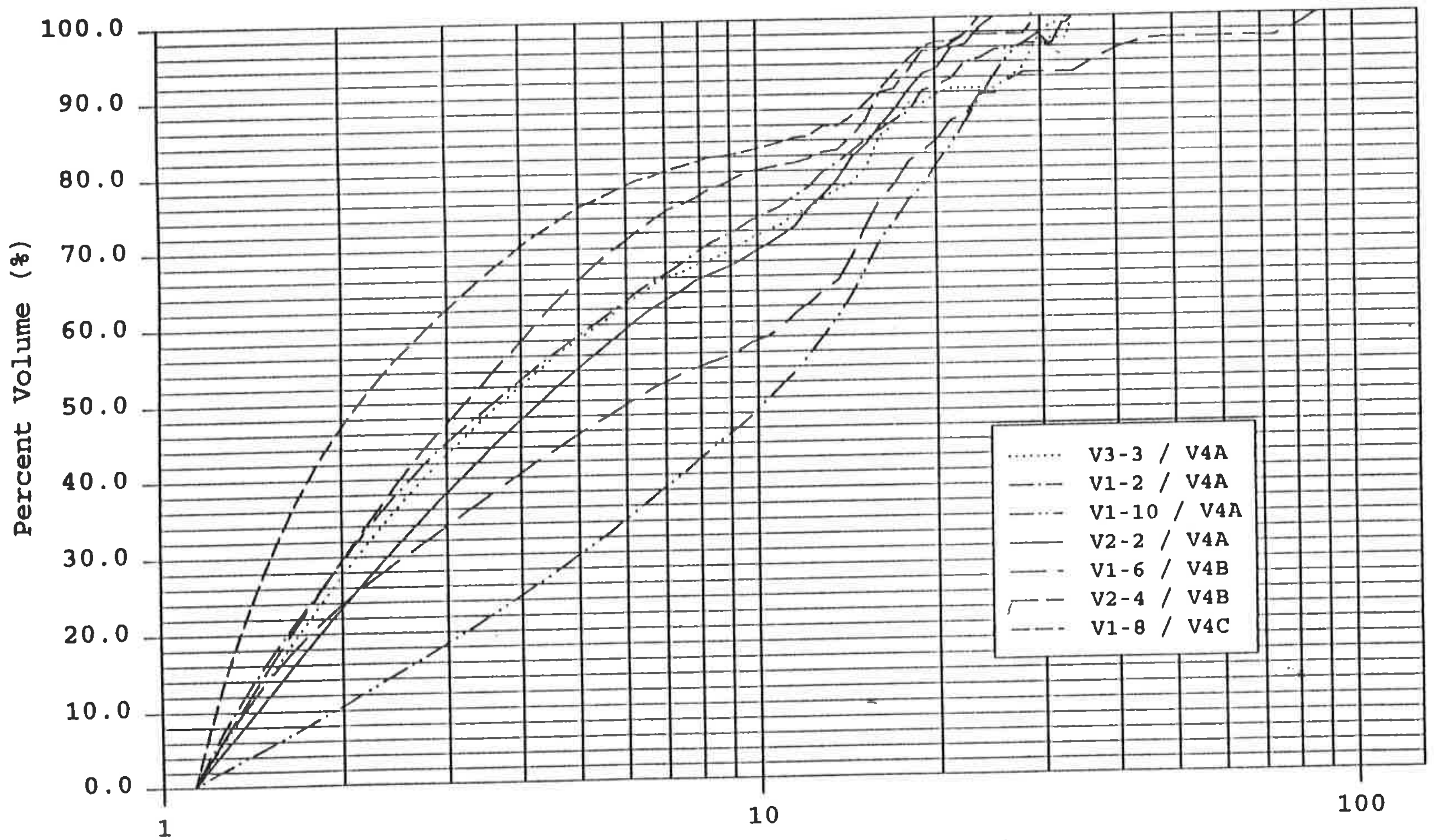

Figure B.16 Particle Size Distributions for Sample Point V4

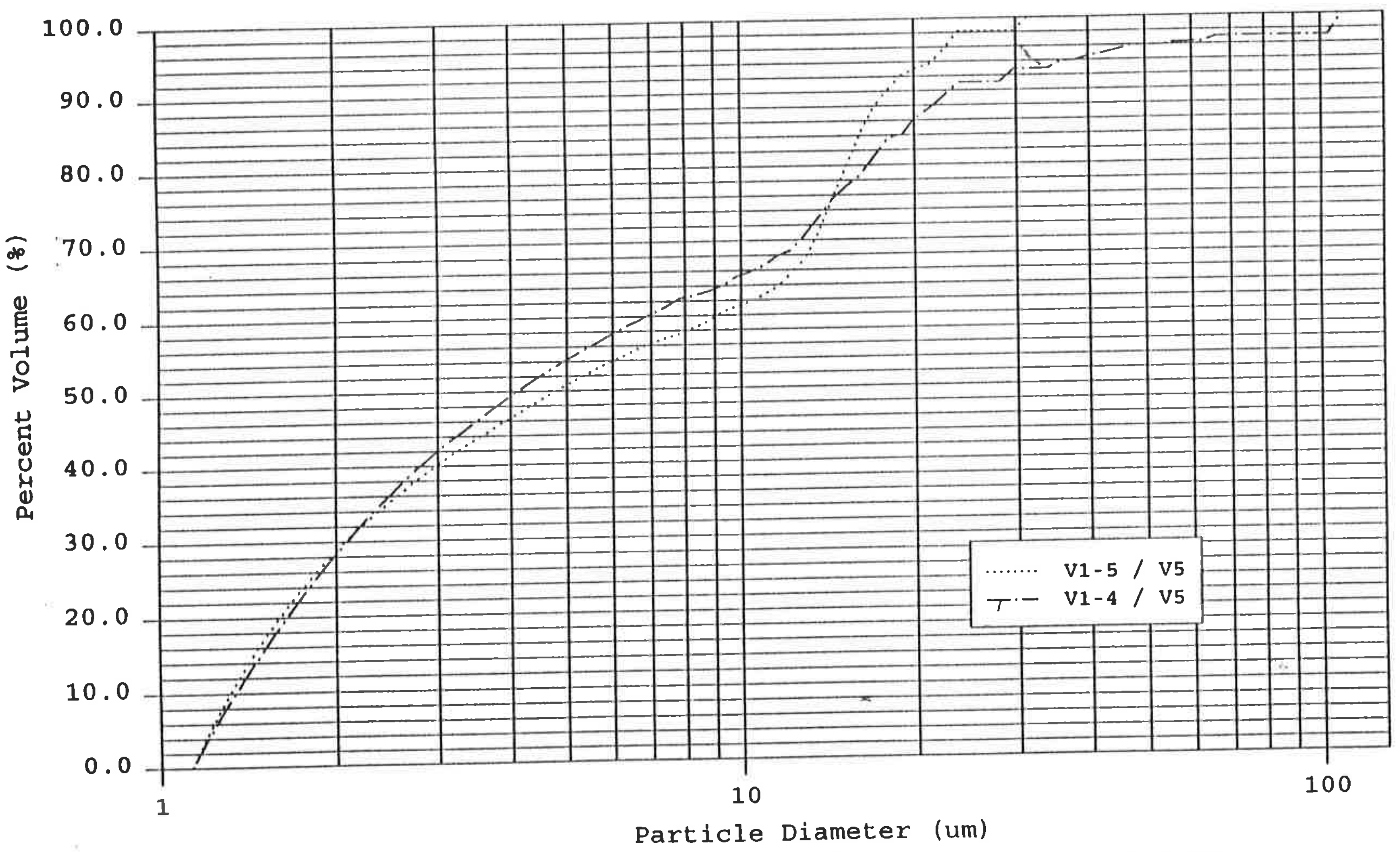

Figure B.17 Particle Size Distributions for Sample Point V5

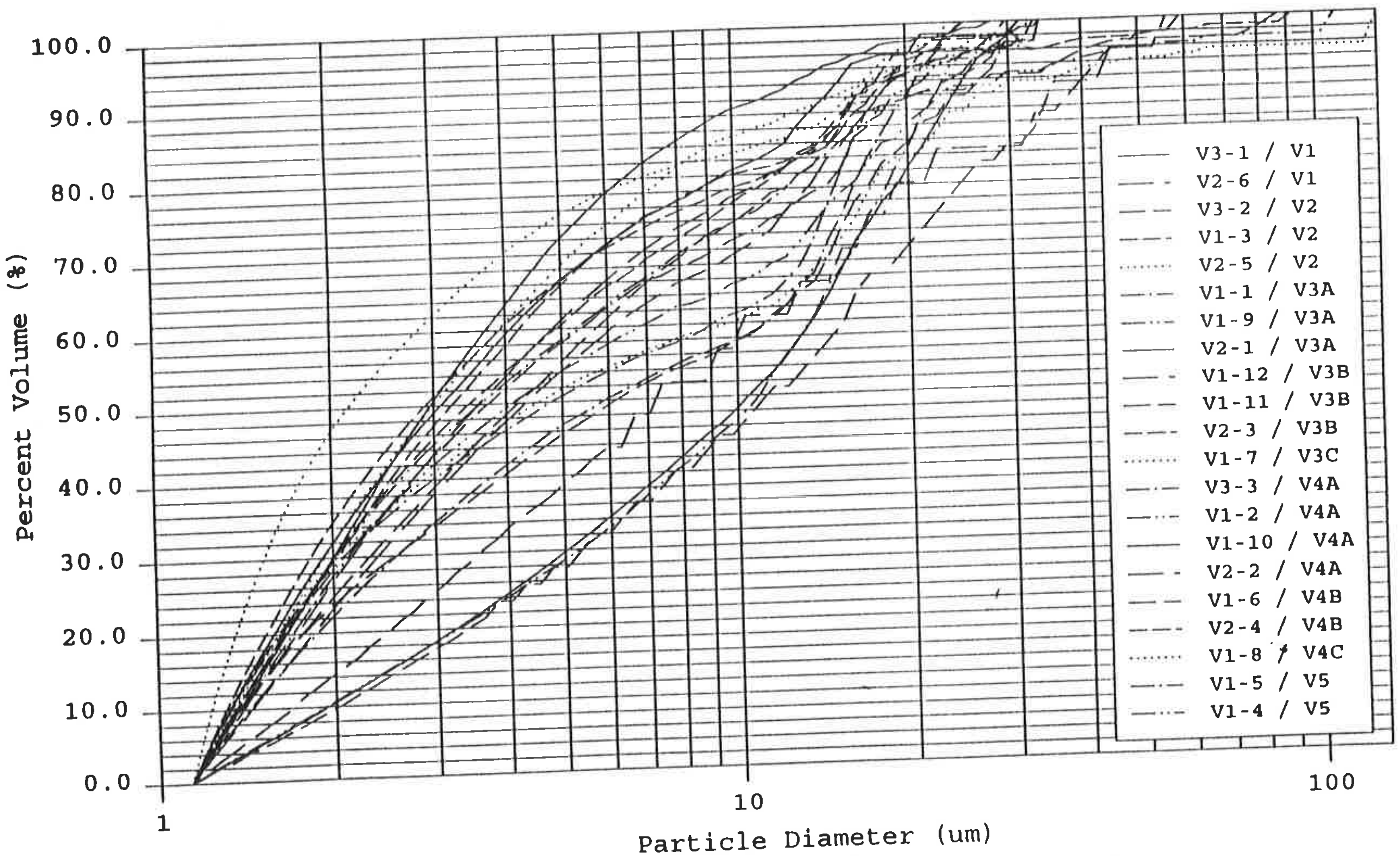

Figure B.18 Particle Size Distributions for Site V

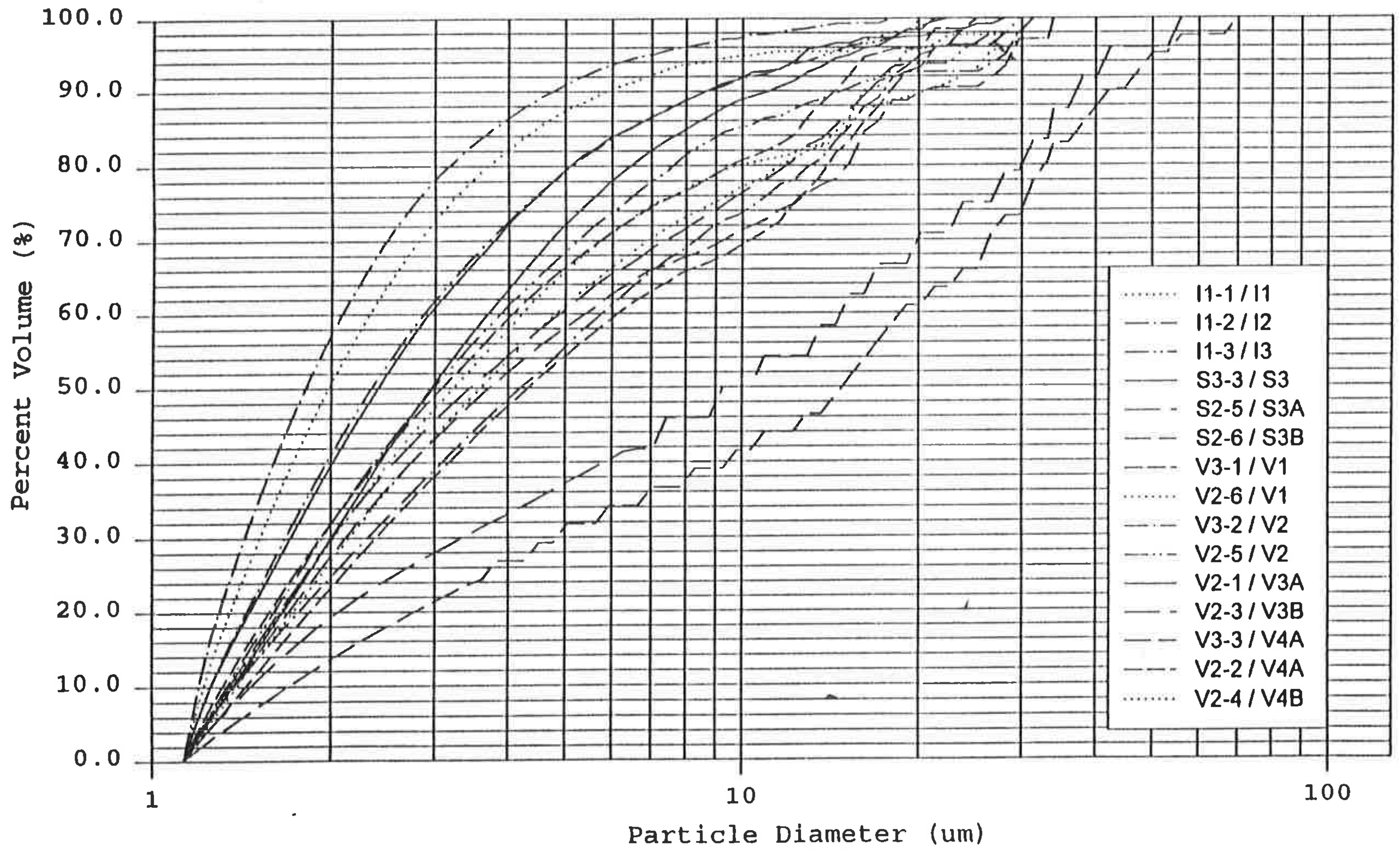

Figure B.19 Particle Size Distributions for Low Intensity Rainfall

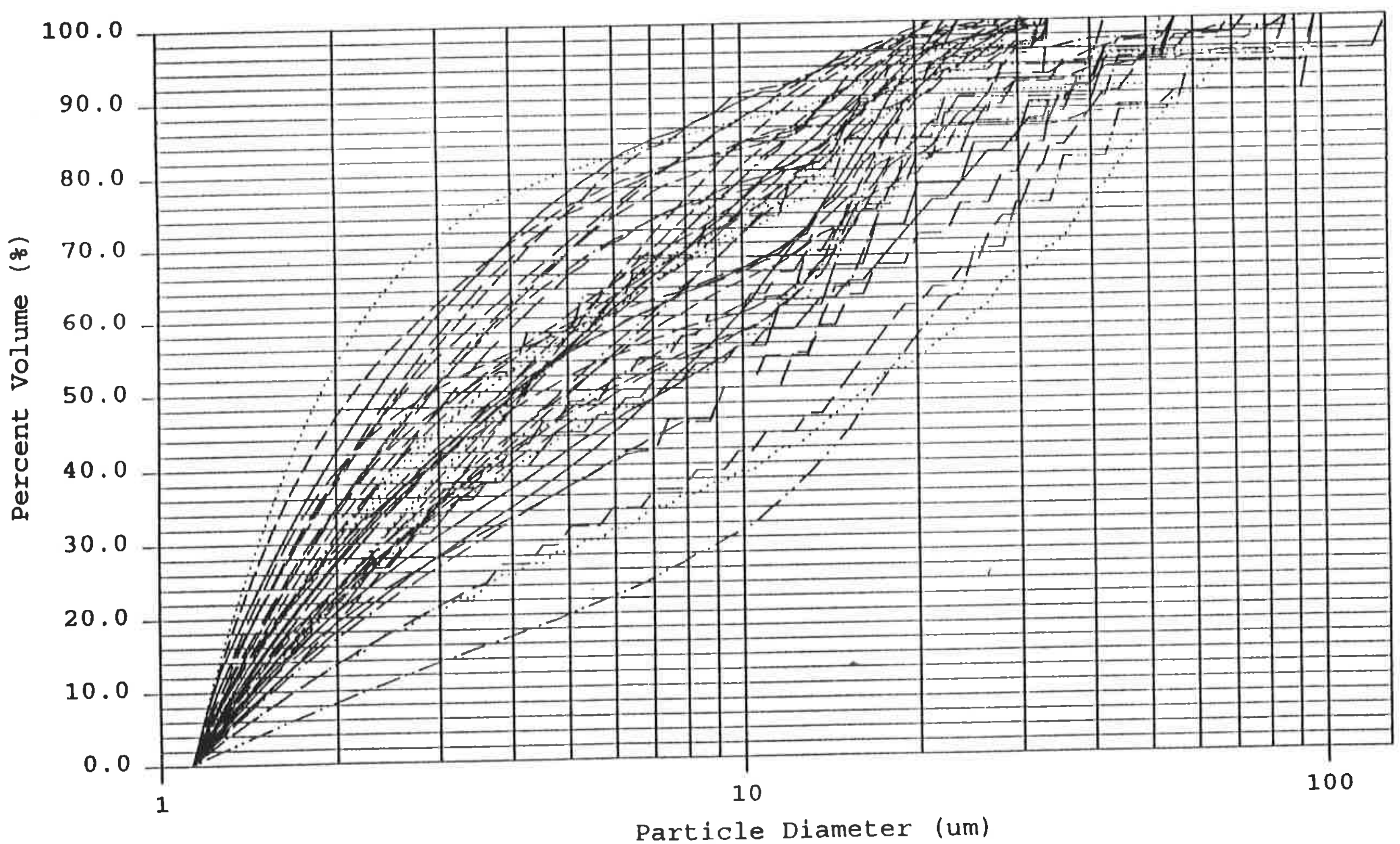

Figure B.20 Particle Size Distributions for Medium Intensity Rainfall

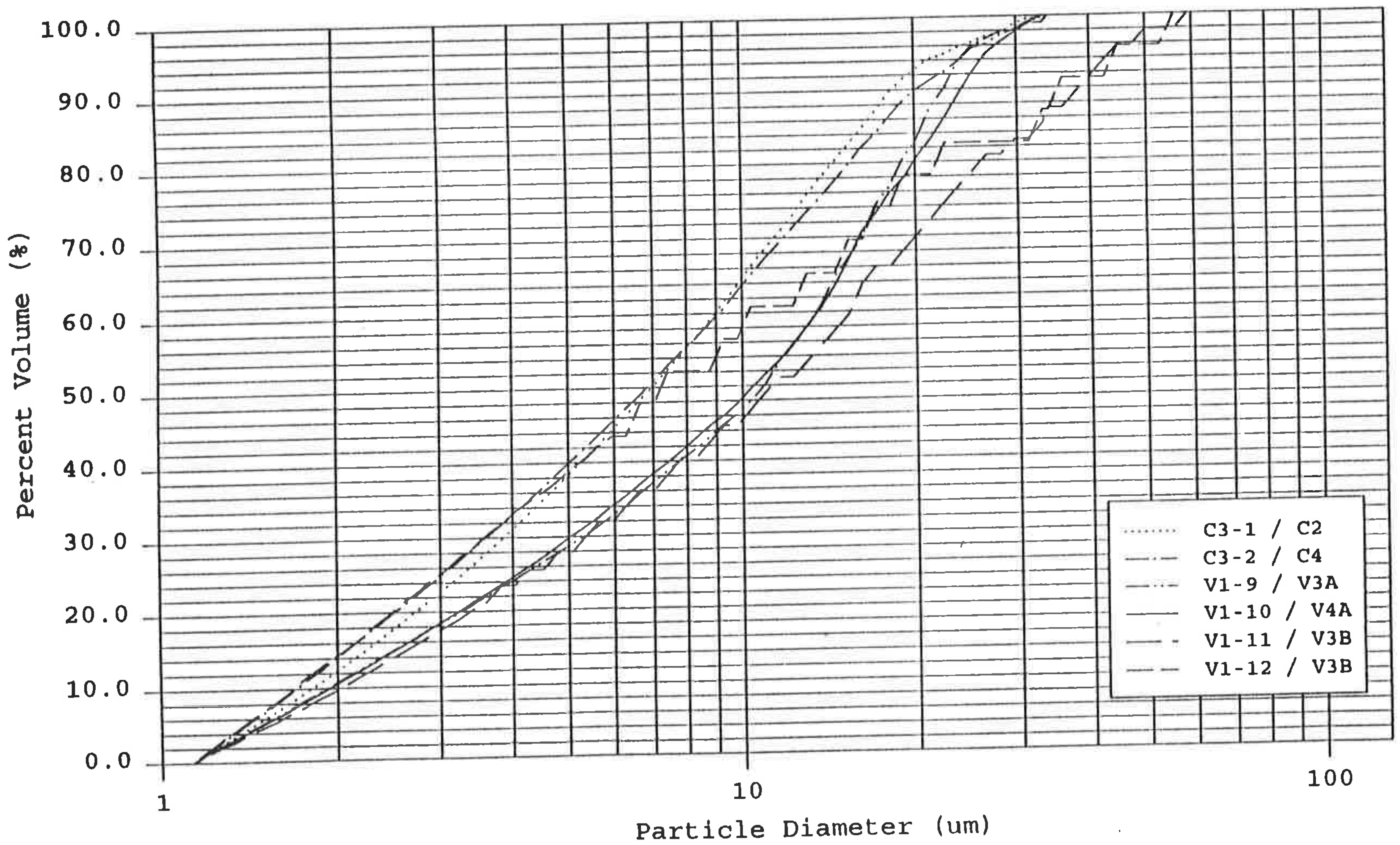

Figure B.21 Particle Size Distributions for High Intensity Rainfall

GRADUATE SCHOOL
UNIVERSITY OF ALABAMA AT BIRMINGHAM
THESIS APPROVAL FORM

Name of Candidate John Nelson

Major Subject Civil Engineering

Title of Thesis Characterizing Erosion Processes and Sediment Yields on Construction Sites

Thesis Committee:

Robert Pitt, Ph.D., **Chairman** Robert Pitt

Melinda M. Lalor, Ph.D.

Duane Castaneda, Ph.D.

Director of Graduate Program Fouad H. Fouad

Dean, UAB Graduate School Joan F. Lorden

Date 10/18/96