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Report Follows

ASSESSMENT OF IN-STREAM PROCESSES IN URBAN STREAMS FOR DEVELOPMENT OF SEDIMENT TOTAL MAXIMUM DAILY LOADS

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ABSTRACT

The North Peachtree Creek drainage basin located in DeKalb County, Georgia, has been subject to rapid urban development over the last several decades and suffers impaired water quality as a consequence. Urbanization results in increased washload to the stream due to runoff from construction sites that are inadequately protected by erosion control measures. In addition, the runoff volume and peak discharge increase due to an increase in impervious area on the watershed. The result is a loss of equilibrium in the sediment regime of the stream characterized by increased bank erosion and lateral migration of the stream. Because the stream cannot transport the increased sediment load caused by urbanization, changes in cross-section and plan-form (meandering) occur and the stream becomes biologically impaired by sediment. Section 303(d) of the Clean Water Act requires the establishment of TMDLs (total maximum daily loads) for quantifying allowable sediment loads where excess sediment loads threaten the biological integrity of streams. However, the development of TMDLs for sediment is complex because of various in-stream processes that contribute to the problem as well as upstream sources of sediment such as erosion. This study focuses on field data collection using existing technology but in an expanded and more comprehensive manner for resolving some longstanding problems with the measurement of sediment discharge in streams. The field sampling site at Century Boulevard has been established and equipped with an Isco 6700 water quality sampler that has provided a field record of automatically sampled suspended sediment concentration (SSC) of point water samples over a wide range of storm events in terms of magnitude and time distribution. These samples have also been analyzed for turbidity and grain size distribution in particular cases. This sampling has shown that a strong relationship exists between SSC of the fine fraction of the sediment and turbidity at the sampling location ($R^2 = 0.976$). These point samples have also been coupled with intensive sampling of the stream bed and banks for comparing grain size distributions and turbidity characteristics. Depth-integrated sampling is currently being performed during storm events in order to develop an empirical relationship between total sediment discharge and the point measurements of suspended sediment concentration. These findings show that turbidity measurement can be coupled with other sediment transport measurement techniques to provide more accurate data and help identify sources of and changes in sediment input. Continuing research involving the use of depth-integrated samplers along with additional laboratory analyses will provide a more definitive procedure for coupling automatic point samplers with continuous turbidity measurement for accurate estimation of sediment loads.

CHAPTER I

INTRODUCTION

The North Peachtree Creek drainage basin located in DeKalb County, Georgia, has been subject to rapid urban development over the last several decades and suffers impaired water quality as a consequence. Urbanization produces eroded sediment in the form of washload due to runoff from construction sites that are inadequately protected by erosion control measures. Following construction, the runoff volume and peak discharge increase due to an increase in impervious area on the watershed as paved parking lots and manicured landscapes replace undeveloped natural areas. The result is permanent alteration of the hydrologic and hydraulic response of the stream accompanied by loss of equilibrium in the sediment regime. Because the stream cannot transport the increased sediment load caused by urbanization, changes in cross-section and plan-form (meandering) occur and the stream becomes biologically impaired by sediment.

Consequences of such changes in stream sediment regime include increased bank erosion and associated lateral migration of the stream, along with sediment deposition along the stream in areas of low velocity. This process results in degradation and loss of aquatic habitat and spawning areas, inhibition of photosynthesis due to turbidity in the water column, increased water treatment costs, loss of storage capacity in water supply reservoirs, and transport of contaminants associated with the fine-grained silt- and clay-sized sediment. Such impairment of water quality is addressed by Section 303(d) of the Clean Water Act, which requires the establishment of TMDLs (total maximum daily loads) for quantifying allowable pollutant loads for stream reaches in which the biological integrity of the stream is threatened. However, the development of TMDLs for sediment is complex because of various in-stream processes that contribute to the total sediment load as well as upstream sources of sediment such as erosion. Furthermore, measuring natural sediment loads for comparison with loads in impaired watersheds is not a straightforward process. Sediment moves both from upland watershed sources and within the stream system during large storm events, and then is redeposited so that it becomes a potential source for resuspension in succeeding storm events. In urban streams, sediment loads include sediment from surface erosion at construction sites and at other locations in the watershed, as well as eroded material from the stream bed and banks.

Previous research on the relative contribution of sediment sources in Peachtree Creek revealed that in the 1970s and 1980s, when the Atlanta area was experiencing rapid urbanization, approximately 53 percent of the sediment discharge was due to erosion of the watershed, while 47 percent was due to erosion of the channel and floodplain (Weber, 2000). By the 1990s, when urbanization had decreased, 44 percent of the sediment discharge was due to erosion of the watershed and 56 percent of the sediment discharge was due to channel and floodplain erosion. In addition, the sediment discharge in the 1970s was 75,500 tons/year, it increased during the 1980s to 88,400 tons/year, and then decreased to 74,200 tons/year in the 1990s. The changes in sediment yield and the relative contribution of sediment sources were due to changes in land use in the Peachtree Creek Basin. These changes highlight the effects that construction activities had on the sediment budget of Peachtree Creek and the subsequent changes in channel geometry that occurred, and continue to occur, as Peachtree Creek adjusts to reach equilibrium. These changes also make it difficult to identify sediment sources through field sampling alone.

For these reasons, locating sediment sources and measuring sediment loads are challenging problems that require solution for effective establishment of sediment TMDLs and sediment source controls.

Currently, the measurement of sediment loads in streams involves the use of:

(1) programmable point samplers that pump water samples (for later measurement of suspended sediment concentration) at specified time intervals from the stream with simultaneous measurement of stage;

(2) sensors for the continuous measurement of turbidity as a surrogate parameter for suspended sediment concentration;

(3) manual depth-integrating samplers that collect samples over several stream verticals to obtain the average cross-sectional suspended sediment concentration;

(4) velocity meters for establishing the stage-discharge relationship for the stream at the sampling cross section.

These techniques may be used in several combinations in order to estimate sediment discharge and the resultant sediment load, which is defined as the mass of sediment transported for a specified time interval such as a day, month, or year. In fact, the time interval is of considerable importance in developing sediment TMDLs. Average annual sediment loads can be measured by using a combination of depth-integrated sampling and discharge measurement using the flow-duration method. Storm-event sediment loads, however, may be more important in determining sediment TMDLs, especially in urban watersheds in which significant quantities of sediment are transported by large infrequent storm events. In this case, a pumping sampler or a continuous turbidity sensor in combination with discharge measurement may be required. The problems introduced by these methods include transforming a point measurement of suspended sediment concentration to a cross-sectional average, and determining a calibration relationship between turbidity and suspended sediment concentration. The latter calibration depends on the percentage of fine sediments in the suspended sediment in the stream. The fine sediments are the primary contributors to turbidity, but the percentage of fine sediments and their resultant turbidity depend on the magnitude of the discharge and the sediment sources as well as the sediment mineralogy and presence of additional suspended matter such as organics.

This study focuses on field data collection using existing technology but in an expanded and more comprehensive manner for resolving some of the longstanding problems associated with the measurement of sediment discharge and sediment loads in streams for the purpose of establishing sediment TMDLs and sediment controls. In previous research, a field sampling site at Century Boulevard on the North Fork of Peachtree Creek has been established and equipped with an Isco 6700 automatic water quality sampler that has provided a field record of automatically sampled suspended sediment concentration (SSC) of point water samples over a wide range of storm events with respect to magnitude and time distribution. These samples have also been analyzed for turbidity and grain size distribution in particular cases. Sediment samples from the streambed and banks in the vicinity of the automatic sampler and in upstream locations have been collected and analyzed. Depth-integrated sampling is currently being performed during storm events in order to develop an empirical relationship between total sediment discharge and the point measurements of suspended sediment concentration from the Isco sampler. This phase of the research is intended to establish the contribution of the fine fraction of suspended sediment to turbidity and to develop a methodology for separately estimating fine and coarse sediment loads during storm events. In a second phase of the research, numerical modeling will be used in combination with point measures of suspended sediment concentration to develop reliable measures of total cross-sectional sediment discharge.

This report summarizes the results obtained so far in phase one of the research. Chapter II is a review of the current literature related to measurement of suspended sediment discharge. Field sampling techniques and experimental laboratory procedures are given in Chapter III. Results and discussion are found in Chapter IV, and the final chapter provides a summary and conclusions.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Accurate measurement of fluvial sediment transport is necessary for effectively assessing the geomorphic and environmental health of any river or stream. This data is difficult to collect, however, because suspended sediment varies greatly both spatially and temporally, and sampling methods are labor-intensive and time consuming. Surrogate measurements of stream parameters that correlate with sediment concentration are often used and may offer satisfactory results. Turbidity is one of the most notable surrogates since it can be measured continuously and with little comparative cost. Turbidity has been used to effectively assess and predict sediment concentration for such uses as stream bank erosion analysis and contaminated sediment transport monitoring.

2.2 Importance of Suspended Sediment Monitoring

Suspended sediment affects nearly every aspect of a riparian environment. During periods of high flow, sediment erodes from stream banks and is lifted from the streambed and carried downstream. Deposition of such sediment often occurs at an undesirable location such as in a reservoir or near an in-stream hydraulic structure, thereby decreasing storage volume or otherwise impeding flow. Thus, design and maintenance of such structures requires an understanding of the deposition tendencies of suspended sediment and accurate quantitative measures of sediment volumes. Sediment discharge, the measure of the amount of sediment that passes a specific point in the stream per unit time, is often calculated for this purpose. A related quantity is the dry weight of sediment that is transported over a specified time interval, which is referred to as sediment load. Over the last two decades suspended sediment data have been used in such fields as contaminated sediment management, stream restoration, environmental quality, and geomorphic classification (Gray, 2002). The environmental concerns associated with suspended sediment are such that the U.S. Environmental Protection Agency (1998) identifies sediment as the single most widespread cause of impairment in the Nation's streams, rivers, lakes, reservoirs, ponds, and estuaries (Gray et al., 2000). Fine sediment (< 64 µm) in suspension contributes turbidity that harms biological activities. By reducing light penetration in the water column, suspended sediment impairs photosynthesis and limits spawning areas. In addition to biological impacts, sediment also acts as a vehicle for carrying harmful chemicals and trace elements downstream (Grayson et al., 1996; Faye et al., 1978). These concerns initiated the Total Maximum Daily Load (TMDL) program, set forth by the EPA. This program, established by the Clean Water Act, section 303, regulates the total amount of pollutant that a body of water can receive from all sources and still meet water quality standards. Observation of the TMDL program requires accurate measurements of suspended sediment discharge.

The TMDL program also involves allocation of pollutant to each contributing point and non-point source. Accordingly, monitoring sediment transport is very helpful in establishing the sediment's origin. Stream bank erosion and lateral migration can be examined during peak periods of sediment transport to identify causes of erosion and establish preventive measures for future erosion (Green et al., 1999). Fluvial sediment is the result of both watershed and bank erosion, and the balance is dictated by land use.

Urban areas are characterized by impervious pavement and structures and storm drainage systems that carry away most runoff. In addition, exposed land is routinely landscaped so that its absorptive capabilities are minimal. The result is a series of point discharges instead of the sheet flow that would occur naturally. This causes exaggerated peak discharges into streams during storms and resulting amplified channel erosion. Whereas urban streams experience significant stream bank erosion, agricultural areas involve mostly watershed erosion. The exposed land associated with cultivation, livestock feeding areas, grazing pastures, and fields of row crops is highly susceptible to sheet erosion during storm events. This process contributes to sediment loads in nearby streams, although such non-point discharges cause minimal channel erosion (Faye et al., 1978).

2.3 Need For Surrogate Technologies in Suspended Sediment Monitoring

Direct sampling of fluvial suspended sediment is a labor-intensive, costly procedure that is subject to several sources of error. Additionally, because suspended sediment concentration varies temporally and spatially in a stream cross-section, single point measurements are not sufficient for quantifying sediment loads. Experiments have shown that point measurements underestimate sediment loads (Horowitz et al., 1990). To account for this variability, calibrated depth- and point-integrating isokinetic samplers are employed. These samplers are used in conjunction with the Equal-Discharge Increment or Equal-Width Increment Methods to provide a representative sample. This procedure was established by the Federal Interagency Sedimentation Project (FISP), a subordinate of the Subcommittee on Sedimentation that began in 1938 (Gray, 2002). Because this time-tested standard procedure for sampling suspended sediment produces reliable data, these data are often coupled with surrogate measurements for gauging their effectiveness. The procedure is difficult to conduct, however, as it requires sampling during periods of high stream flow, which coincide with storm events. The sampling equipment is unwieldy and archaic by modern standards, and the sampling procedures require a team of trained staff for proper implementation. In addition, the samples produced require extensive laboratory analysis, making reliable data costly to produce.

The laboratory analysis that follows field sampling is subject to error such that, in spite of carefully executed sampling procedures, the resulting data can be skewed or otherwise unrepresentative. A common error lies in the discrepancy between the two laboratory methods used for measuring sediment concentration in a sample. The Total Suspended Solids (TSS) procedure, set forth by the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation (1995), was designed for analyzing wastewater effluent samples but has also been used for measuring sediment concentration in stream samples. The procedure involves filtering an aliquot of the sample under the assumption that it is representative of the entire sample. Withdrawal of the representative aliquot is often difficult, particularly when large particles that settle quickly constitute much of the sediment in the sample. This inherent bias in the TSS procedure produces unreliable results that do not accurately represent the concentration of sediment within a sample. In comparison, the Suspended Sediment Concentration (SSC) test presented by the American Society of Testing and Materials involves measuring the entire sample to obtain total sediment mass. This is accomplished through evaporation, filtration, or wet-sieve filtration, and produces reliable results that are a true measure of the concentration of solid material in a stream sample. Because the entire sample is measured, the SSC procedure is not affected by particle size and related settling velocities of particles. In order to quantify the differences between the two methods, the U.S. Geological Survey (2000) conducted an analysis of 3,235 paired TSS and SSC data taken from many different regions in the Nation. The study found that the TSS method was essentially unreliable for analyzing natural water samples, and TSS values demonstrated particle size bias by underestimating the sediment concentration when the sand-sized material exceeded about a quarter of the total sediment dry weight. In spite of the fundamental differences between the two procedures, investigators have commonly used the terms TSS and SSC interchangeably, an erroneous practice that has produced unreliable data. The study concluded that the SSC method should be used exclusively for measuring sediment concentration in natural-water samples to prevent error in laboratory analyses (Gray et al., 2000).

2.4 Existing and Emerging Surrogate Technologies

Several surrogate measurements are commonly employed to avoid the difficult and costly procedure of sampling suspended sediment directly. Traditional surrogates such as stream discharge offer somewhat acceptable results but can suffer from large uncertainties in predicted suspended sediment concentration, especially if fine sediment is a significant proportion of the total size distribution. Emerging technologies such as laser diffraction and acoustic backscatter measurements show promise but are costly and are yet to experience widespread use.

Stream discharge as a surrogate parameter can be paired with measured sediment concentration for development of a discharge vs. suspended sediment concentration relationship, or sediment rating curve. This relationship can be used in conjunction with the stage-discharge relationship of a particular reach, allowing sediment discharge predictions to be made from water surface elevation measurements. This process is based on the idea that as stream flow increases, shear stresses on the streambed and banks also increase, causing erosion and suspension of sediment particles. Accordingly, as discharge increases, mean particle size of the suspended sediment increases in a similar fashion. Intensive calibration of a particular river section can yield acceptable results such that stage can be used to predict sediment loads and grain size distributions. Oftentimes, when precision is required or when such calibration is not practical, stream discharge is not a suitable measurement. Once the calibrations are established, however, the method is essentially free of cost. For this reason it is often used with other surrogates as a comparison or for filling in potential gaps in data sets caused by equipment failure (Green et al., 1999). Sediment rating curves using a power function that relates suspended sediment concentration and stream discharge have been used for more than 60 years. In general, this approach underestimates highs and overestimates lows (Horowitz, 2002). Thus, rating curves should be used for analyzing portions of storm events rather than entire events (Lewis, 2002).

Many technically advanced methods for monitoring sediment discharge are currently being developed or tested, and several have been used successfully on a limited basis. These devices employ measuring principles such as differential density, optical transmission, nuclear, laser diffraction, and acoustic backscatter intensity. The ideal surrogate technology would involve a direct relationship with suspended sediment and/or particle size distribution that could be monitored and recorded automatically in a fashion representative of the entire cross-section for any river in any flow situation (Gray, 2002). Although this technology does not yet exist, two of the most promising instruments involve laser diffraction and acoustic backscatter intensity. Both apparatuses have been field tested and yielded effective results in certain situations.

Laser diffraction devices, unlike many other instruments, are unaffected by changes in grain-size or particle color and refractive index. The apparatus uses technology based on the Mie theory model for light scattering physics by generating a collimated beam and collecting the beam with a receiving lens. As a particle passes through this beam and blocks light waves, some waves enter the particle while others are diffracted around it. The angular scattering caused by the particle leaves a distinctive silhouette that appears identical to an aperture of the same diameter. This diffractive signature can be used to indicate the grain-size. As this process occurs at an in-stream gauging station, stream flow passes through the instrument such that the summation of the analysis of each particle gives the grain-size distribution and the suspended sediment concentration of the stream flow. This can be accomplished isokinetically using a recently developed low drag vehicle that encloses a laser diffraction instrument. The unit measures free-stream velocity and adjusts withdrawal using an internal flow-assistance pump. It also records sampling depth using pressure transducers (Agrawal and Pottsmith, 2002). The Grand Canyon Monitoring and Research Center tested one such instrument beginning July 19, 2001. The particular unit was designed to detect particles over a size range of 1.3 to 250 µm. Investigators made 720 point measurements with the device and

13 samples using traditional isokinetic methods integrated across the cross-section. Preliminary results indicated that the laser diffraction instrument accurately tracked the sand concentration and its variance with increasing flow. Median grain size data from the two sample sets were also in good agreement (Melis et al., 2002). The variability in measurement that laser diffraction instruments offer reinforces the advantage of continuous monitoring.

A common limitation among optical sensors is their vulnerability to biological fouling, a substantial concern in the stream environment. Acoustical measurements are not affected by fouling and can also be used for measuring suspended sediment. Acoustic instruments have been widely used for measuring in-stream flow velocity and have recently also been employed for measurement of sediment concentration using acoustic backscatter intensity. These devices apply the principles of sound scattering from small particles for estimation of suspended sediment. Calculations include adjustments for ensonified volume, source level, two-way transmission loss, and volume scattering strength, a parameter affected by particle shape, size, density, rigidity, compressibility, and acoustic wavelength. The transmission loss of the water is based on the water's acoustic frequency, salinity, temperature, and pressure. The idea behind surrogate measurements is to simplify sediment monitoring, however, so measurement of all characteristics is not practical. A reduced form of the calculations involves a simplified exponential equation that relates sediment concentration to relative backscatter. The major limitation of this technology is its inaccurate response to changes in concentration and particle size distribution, a restraint common to single-frequency instruments. An inherent mismatch of frequency versus particle size also exists.

Although the limiting effects can be minimized through extensive calibration, acoustic sensors are most sensitive to large particles and do not respond well to the frequency range that corresponds to clay-sized particle distributions. In spite of its response to certain particle sizes, acoustic backscatter technology has the advantage of providing a data profile rather than a point measurement. The measurement process is also much less intrusive to the stream environment than are many other instruments. Like all surrogate measurements, significant calibration must be conducted before accurate predictions can be made (Gartner, 2002).

A final surrogate that has been used very successfully is turbidity measurement. The relationship between suspended sediment concentration and turbidity is based on the supposition that the cloudiness of a water sample is directly related to the concentration of sediment particles suspended in the sample. Accordingly, turbidity meters quantify suspended sediment by measuring the scattering or attenuation of a beam of light through a water sample and using this measure by relating it to a particular mass of suspended material. Using turbidity measurement as a surrogate for suspended sediment concentration is a process that, like other surrogates, requires significant calibration. Site-specific regression analyses produce relationships that can be used for prediction of sediment loads. Turbidity measurement can be accomplished in several ways. Grab samples can be taken and subsequently analyzed in a laboratory for turbidity and suspended sediment concentration. This process can be used for calibrating the site such that after calibration the sediment concentration tests can be replaced with turbidity measurements (Wass and Leeks, 2002). A more advanced procedure involves *in situ* turbidity probes that continuously monitor turbidity. A data logger records the turbidity measurements, which are converted to sediment concentration using the predetermined regression relationships. *In situ* turbidity probes require considerable maintenance since they can often be rendered ineffective by debris flowing downstream and are highly susceptible to biological fouling (Lewis, 2002). Both methods have been used extensively and, coupled with discharge measurements, can provide very accurate sediment load estimations.

There are also two major types of turbidity meters. Attenuation turbidimeters measure the loss of intensity of a light beam across a known distance of a sample. Nephelometric turbidimeters measure scattered light by detecting the beam at an angle from its origin. Turbidimeters are standardized with a substance of known turbidity, with the most common being formazine. However, in spite of standardization, the two types of instruments respond differently when measuring the turbidity caused by suspended sediment particles. Fluvial sediment is a mixture of grain sizes originating from various minerals, and this aggregation responds differently than formazine (Gippel, 1995). As a result, most turbidity measurements are instrument-specific (Pfannkuche and Schmidt, 2003).

While the use of turbidity as a surrogate for suspended sediment concentration has yielded successful results in numerous studies, it has several limitations. As mentioned previously, the relationship between turbidity and suspended sediment is very site-specific. Organic particles also contribute to turbidity in the water column and can skew suspended sediment data derived from turbidity measurements (Weigel, 1984). The predominant limitations to accurate turbidity measurement involve changes in particle shape and particle color. Each mineral that is represented in a particular stream sample has distinctive optical properties that respond differently to a light source. Particle color can contribute to as much as ten percent error, and nephelometric turbidity is particularly vulnerable to water color since light attenuates differently through various colors, although a near infrared light source can minimize this problem (Gippel, 1995). The shape of sediment particles affects the attenuation or scattering of light through a sample as well. This combination of sediment properties reinforces the importance of developing site-specific relationships between turbidity and suspended sediment since each site has its own unique sediment characteristics. Another considerable limitation in turbidity measurement is particle size. The relationship between turbidity and suspended sediment is based on the principle that each sediment particle contributes to the overall cloudiness of a sample. Fine sediment causes high attenuation in turbidity measurements (Brasington and Richards, 2000), but when coarse sediment particles (> 64 µm) constitute a significant portion of a sample, turbidity measurement becomes difficult since these large particles settle very quickly and therefore do not contribute to turbidity readings. And, as sediment concentration measurement involves the weight of sediment within a sample volume and large particles constitute a considerable fraction of the sediment weight, omission of large particles substantially skews sediment concentration data. For this reason, application of turbidity as a surrogate is most appropriate when fine clay-sized sediment particles compose most of the sample.

2.5 Applications of Turbidity Monitoring

The development of site-specific calibration curves for use in relating turbidity and suspended sediment concentration is the most important part of successfully using turbidity as a surrogate. Although the relationship is mostly uniform during periods of low flow, suspended sediment flux is highly variable in space and time and is difficult to quantify with single point measurements. In fact, during periods of high flow, turbidity varies for a given suspended sediment concentration. To prevent correlation error, numerous events during varying flow conditions must be incorporated in the data set. Storm events that yield the highest variation in sediment flux should be especially targeted. Turbidity data should be scrutinized to identify possible errors and periods of extended fouling should be omitted. Secondary relationships, such as between flow and suspended sediment, can serve as a check and, when turbidity data is missing, be used to form a piecewise model (Lewis, 2002).

More than two decades ago, a U.S. Geological Survey report noted that turbidity values should not be used to determine numeric values for suspended sediment concentration (Faye et al., 1978). Since then, however, turbidity has been used successfully for measuring stream bank erosion, nutrient and contaminant transport, and sediment loads. One study of the Namoi River in New South Wales, Australia measured flow and turbidity at continuous 15 minute intervals at 12 monitoring stations for predicting sediment concentrations and loads related to stream bank erosion (Green et al., 1999). Britain's Land-Ocean Interaction Study (LOIS) included establishing site-specific relationships of suspended sediment and turbidity in ten major tributaries of the River Humber. Least-squares linear regression analyses yielded correlation coefficients between 0.827 and 0.917. The success of this relationship can be partly attributed to the favorable conditions present for turbidity monitoring, namely that fine sediment constituted 96.4 percent of the total sediment. The turbidity measurements were made in conjunction with depth-integrated sampling. The turbidity-suspended sediment relationship was well established and provided sufficient data for estimating sediment loads and sediment flux (Wass and Leeks, 1999). The German Federal Institute of Hydrology investigated the relationship between suspended particulate matter and turbidity along the Elbe River (Pfannkuche and Schmidt, 2003). This study involved a total of 1405 measurements of turbidity, suspended particulate matter, and flow taken between June 1996 and February 2001. The measurements were adversely affected by large streambed particles and water color, and measurement error was found to increase with increasing flow. The effectiveness of turbidity as a surrogate was shown in an investigation of the Kansas River and Little Arkansas River in which twenty samples were collected at eight stream gauging stations between 1998 and 2001 (Christensen et al., 2002). The Kansas River sites yielded a coefficient of determination of 0.987 between the two parameters, and the relationship between suspended sediment and turbidity in the Little Arkansas River allowed prediction of sediment loads within six percent accuracy. Although the Kansas River was affected by a series of reservoir releases during the sampling period, the median particle size for the test sites was 95 percent fines, very favorable conditions for turbidity measurement.

Contaminated sediment can also be traced using turbidity data. The Ecuadorian Meteorological Institute investigated metal contamination in the Puyango River Basin in southern Ecuador (Tarras-Wahlberg and Lane, 2003). Forty-four samples were used to develop a calibration curve of nephelometric turbidity versus suspended solids with a coefficient of determination of 0.98. This study also included investigations of the turbidity profile that concluded the difference between near-bottom samples and surface waters only varied from six to eight percent. Grayson et al. investigated the Latrobe River in southeast Australia for suspended sediment concentration and total phosphorous using turbidity measurements during storm events (1996). The research was motivated by the poor correlation between river discharge and suspended sediment concentration and fine sediment was presumed to be key in the transport of phosphorous. Turbidity, sediment concentration, and total phosphorous data were collected during storm events of varying intensities. Although the *in situ* turbidity sensors detected that peaks in stage and sediment concentration were sometimes out of phase, the study revealed that turbidity and sediment concentration were linearly related and that turbidity probes were effective for estimating transported material with predictive capabilities generally greater than eighty percent.

2.6 Summary

Turbidity has proven to be an effective surrogate for suspended sediment concentration measurement in some cases. When compared to isokinetic suspended sediment sampling, it is cost effective and provides accuracy that is acceptable in most situations. The relationship between turbidity and suspended sediment concentration should be established through extensive sampling in order to produce dependable calibration curves. These site-specific calibrations are the most important part of the process, and when done correctly, sediment discharge estimates can be made with considerable accuracy. The method is more effective than the relationship between discharge and suspended sediment concentration (Christensen et al., 2002; Grayson et al., 1996). Turbidity like all other surrogate measurements currently employed to predict suspended sediment concentration has various limitations, but site-specific calibration is used in an attempt to overcome the limitations. In particular, when fine sediment constitutes a significant portion of transported sediment, turbidity offers high predictability of sediment concentration. Consequently, accuracy in turbidity measurement decreases with increasing suspended sediment grain sizes. In addition, the use of continuous turbidity monitoring suffers from translating a point measurement of turbidity to a suspended sediment discharge for the entire cross section. As a result, turbidity as a surrogate is particularly problematic in streams that have a mixture of fine and coarse sediment that changes with the size of the storm and with time during the same storm. Although turbidity does not provide absolute measures, the level of predictability that turbidity measurement affords is particularly attractive when compared to the other costly or otherwise highly inaccurate methods available if the limitations just described can be overcome.

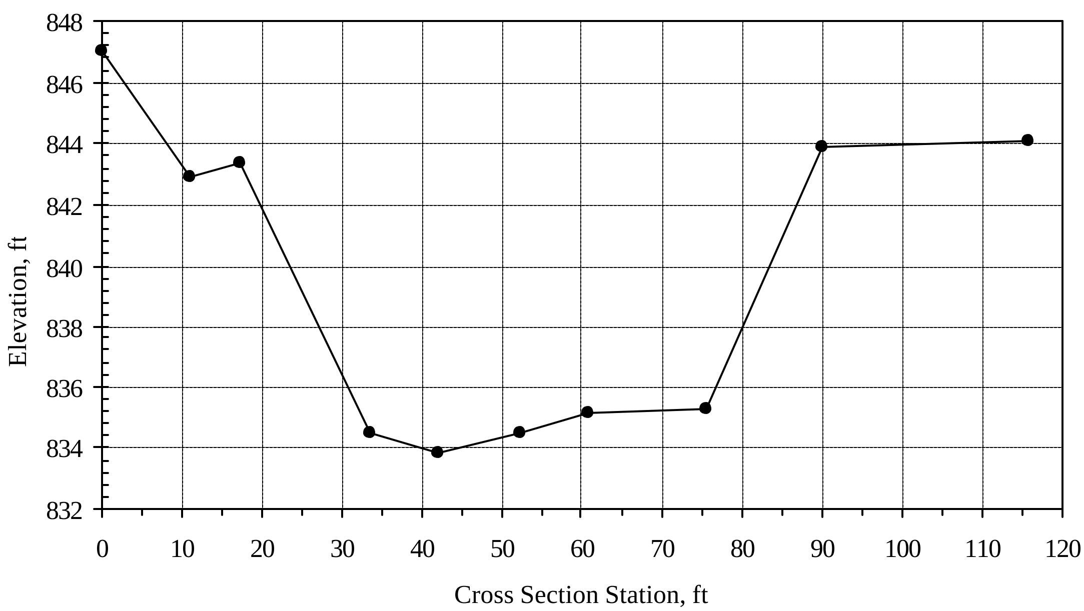
CHAPTER III

EXPERIMENTAL METHODS

3.1 Introduction

The data for this research were provided through field sampling and subsequent laboratory analysis. Field sampling was conducted at Century Boulevard in DeKalb County, Georgia, located in metro Atlanta. The North Fork Peachtree Creek at this bridge crossing, shown in Figure 3.1, is approximately 50 feet wide with a bank-full depth of approximately 8 feet. Storm event samples were collected at this location using an automatic point sampler and a depth-integrated sampler. Sediment samples were collected at multiple locations in the immediate vicinity of the sampling equipment as well as several upstream sites. Laboratory analyses subsequent to field sampling explored the concentration of sediment in a water sample, the turbidity of the sample caused by suspended sediment particles, and the particle size distribution of sediment in the sample.

a) Sampling location shown at base flow. Image taken looking downstream.



b) Surveyed cross section at sampling location looking downstream.

Figure 4.1 Sampling location: North Fork Peachtree Creek at Century Blvd.

3.2 Point Sampling

Point sampling was performed using a portable water quality sampler manufactured by Isco, Inc. (6700 series, full-size portable unit). The programmable unit, which includes a sampling pump with 24 one-liter bottles, was positioned in the floodplain. The suction line and an attached submerged strainer to withdraw water samples was located in the stream in the deepest part of the cross section on the left side looking downstream. The strainer was fixed at 1 ft above the streambed. Stage was measured directly above the strainer on the end of the suction line using an ultrasonic device attached to a bridge pier. The Isco unit continuously logged stage data at 5-minute intervals and was triggered to pump water samples by an increase in stage of 1 ft above the base level. After being activated, the sampler withdrew water samples with volumes ranging from 500-1000 mL and deposited each individual sample sequentially in one of the 24 bottles located within the sampling unit. Sampling was performed at an interval of 30 minutes and continued until the stage decreased below 1 ft or until the 24 sampling bottles were filled, providing the potential for 12 hours of sampling.

Following a storm event, the filled sample bottles were retrieved from the unit and replaced with empty bottles. An Isco 581 rapid transfer device was used to download data from the Isco unit. This information was then downloaded to a laboratory computer and written to a spreadsheet. The stage and time data were used to construct a storm hydrograph, and the time data were used to establish the timing of each sample relative to the hydrograph. The water samples subsequently underwent a variety of laboratory tests that provided information regarding the characteristics of the sediment present in the samples. In most applications, the contents of each sampling bottle were analyzed individually; in specific cases, however, samples were combined based on their relative locations in the storm hydrograph to provide fewer samples of larger volumes.

3.3 Depth-Integrated Sampling

Depth-integrated isokinetic sampling was used to acquire water samples representative of the entire stream cross section. A US D-77 depth-integrating suspended sediment sampler was utilized for collecting such samples. The sampler was equipped with a 5/16-inch intake nozzle attached to a 3-liter sampling bottle. The sampler was deployed into North Fork Peachtree Creek from the Century Boulevard bridge crossing. This was accomplished using a specially designed apparatus constructed in the Georgia Tech hydraulics laboratory, which used a telescoping boom and winch attached to a service vehicle truck ladder rack. The selected sampling scheme involved collecting depth-integrated samples at equally spaced stream verticals in the cross section. Stations at 10-ft intervals, beginning at 10 ft from left bank, were established and marked on the concrete bridge railing. This scheme provided five equal increments and the sampler was deployed at each of the four verticals that separated the respective increments. The same transit velocity was used for all verticals and was kept uniform within each vertical. This method allowed the sample volume to be determined only by the stream velocity and the corresponding depth at each vertical. A separate sampler bottle was used at each vertical, and the representative samples resulted from combining the partial samples collected at each vertical.

3.4 Soil Sample Collection

Soil samples were taken at several upstream locations. Stream banks experiencing active erosion were first identified. Then a sample was taken above the elevation of the base flow water surface at each location. The samples were approximately 150 g in mass and were taken to the laboratory in individual resealable plastic bags. Photographs of each location were also taken to aid in identifying each sample.

3.5 Suspended Sediment Concentration (SSC) Measurement

Suspended sediment concentration (SSC) analyses were performed in accordance with standard test method ASTM D 3977-97 Test Method B. The procedure consisted of measuring the volume of the sample, and then filtering the entire sample through a glass-fiber filtration disk. The sample volume was measured by agitating the sample and transferring it to a 1000 mL graduated cylinder. The sample was then filtered through a Whatman type 934-AH glass-fiber disk with 1.5 µm pore spaces and a diameter of 22 mm. Filtration was assisted by a vacuum system. After the entire sediment-water sample was filtered through the filtration disk, the disk and remaining sediment were oven-dried and then weighed. Calculation of suspended sediment concentration of the sample in mg/L was accomplished using the measured volume of the sample and the dry mass of sediment obtained from the measured weights of the filtration disk before and after filtration.

3.6 Percent Fine Sediment Measurement

The process of measuring percent fine sediment is identical to the above procedure for measuring suspended sediment concentration with an additional step. After measuring the volume of the sample, the sample was passed through an ASTM standard number 230 sieve (63 μm mesh openings) and collected in a container beneath the sieve. The sediment remaining on the sieve was thoroughly rinsed and the rinse water was also collected in the underlying container. The remaining coarse sediment was then rinsed from the sieve into a separate container. Both containers were then filtered through separate glass-fiber disks. This enabled calculation of fines-only SSC and total SSC, both in mg/L.

3.7 Turbidity Measurement

Turbidity was measured using an HF Scientific, Inc. Micro 100 laboratory turbidimeter equipped with a pour-through apparatus that enables turbidity measurement of a water sample of any volume. When storm event samples were measured for turbidity, their concentration was scrupulously maintained by not adding any rinse water when transferring between containers. The sample was thoroughly agitated before and during the process of pouring into the turbidimeter receptacle. The turbidity value was recorded after the turbidimeter reading stabilized.

For specific cases, the turbidity of a sample was measured after the coarse sediment had been removed. This was accomplished by pouring the entire sample through an ASTM standard number 230 sieve (63 μm mesh openings) and collecting the resulting mixture of water and fine sediment. This mixture was then poured through the turbidimeter and the value was recorded.

3.8 Particle Size Analysis

Particle size analysis was conducted in accordance with standard test method ASTM D 422-63. For storm event samples and bed sediment control samples, only the sieve analysis portion of the test was performed. For several control samples conducted with upstream soil samples, hydrometer analysis was also performed to provide a more exact and complete grain size distribution.

<u>Sieve Analysis</u>

Sieve analysis was performed on various sediment samples. The test requires a dry sediment sample of a known weight and a nest of sieves that encompass the range of sediment sizes in the sample. The weight of each sieve is measured and recorded before stacking the sieves in ascending order of size. The entire sediment sample is then poured into the top of the nest, the lid and pan are secured, and the nest is placed in a shaking device that jars and agitates the sieves for a length of time. Following shaking, each sieve is weighed so that the weight of sediment retained on each sieve can be determined. This data can then be plotted to provide information regarding the distribution of sediment sizes within the sample, and it leads to calculation of important sediment transport variables such as median grain size.

<u>Hydrometer Analysis</u>

Hydrometer analyses were performed using an ASTM 152H hydrometer conforming to the requirements enumerated in Specifications E 100. A dispersing-agent solution of sodium hexametaphosphate and distilled water was used to minimize the presence of interparticle bonds during the hydrometer analysis. After the sample was prepared in the 1000 mL sedimentation cylinder, the hydrometer was placed in the sample and readings were taken at time intervals of 2, 5, 15, 30, 60, 250, and 1440 minutes.

CHAPTER IV

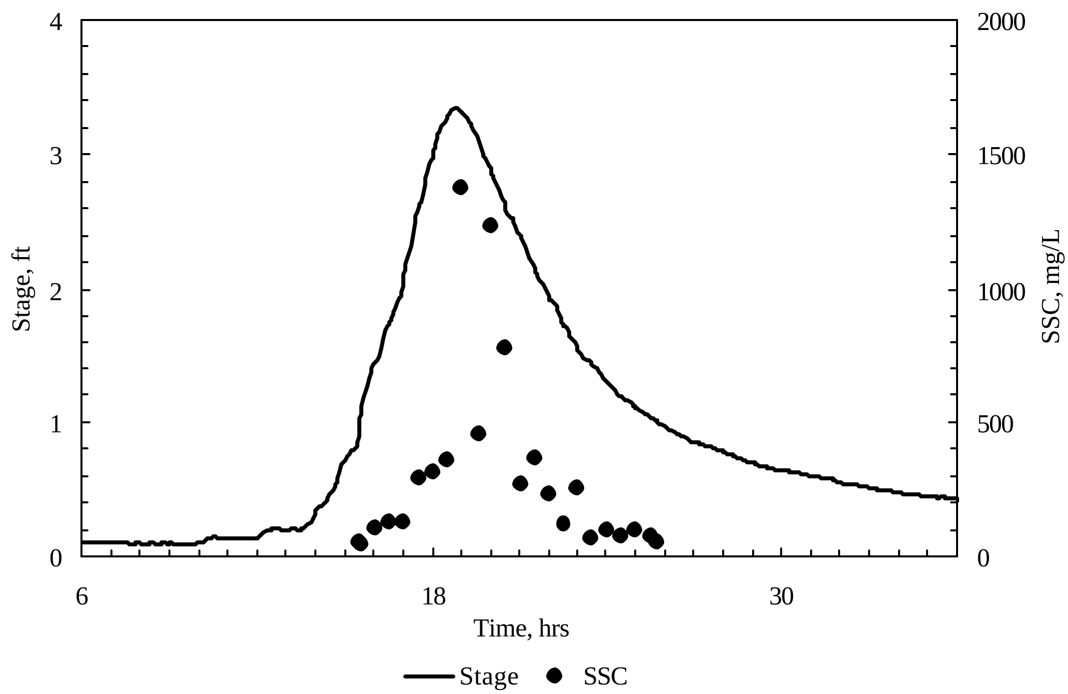
RESULTS AND ANALYSIS

4.1 Introduction

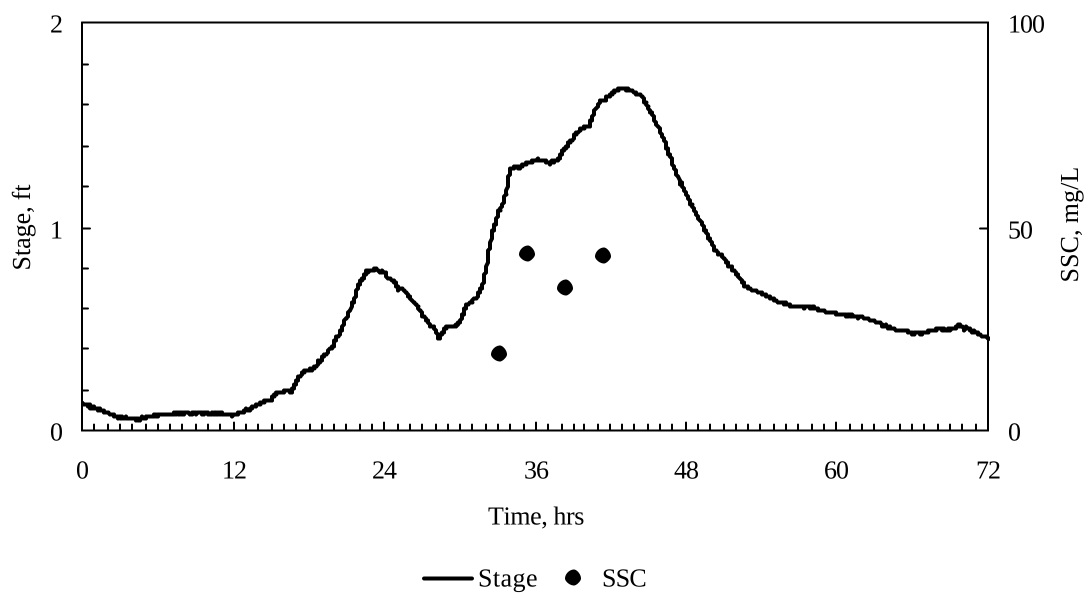
The data displayed and discussed in this section were collected from October 2003 through June 2004. During this time, point sampling was accomplished automatically during notable storm events, multiple sediment samples were taken from the stream bed and banks, and equipment for conducting depth-integrated sampling was designed, fabricated, and tested. Depth-integrated sampling is scheduled for the summer months of 2004, during which time frontal thunderstorms that contribute significant stage increase are prevalent in the Atlanta metro area.

4.2 Point Sampling

Point sampling using the Isco sampler produced a field record of automatically sampled point measurements of suspended sediment concentration. Storm events of varying intensities were sampled to provide an understanding of the sediment transport response of the stream in a variety of flow conditions. Figure 4.1 shows results from the two types of analyses of the point samples. Figure 4.1 a) displays the placement of individual suspended sediment concentration (SSC) data points on the stage hydrograph collected during a storm event of medium intensity on January 5, 2004. In contrast, Figure 4.1 b) shows a longer duration storm event on February 26, 2004 that has relatively low intensity and SSC data points that represent several sample bottles grouped together and located on the hydrograph time scale based on the average of their respective sampling times. The maximum value of SSC is nearly 1500 mg/L for the



a) Stage hydrograph and SSC for 1/05/04 storm event



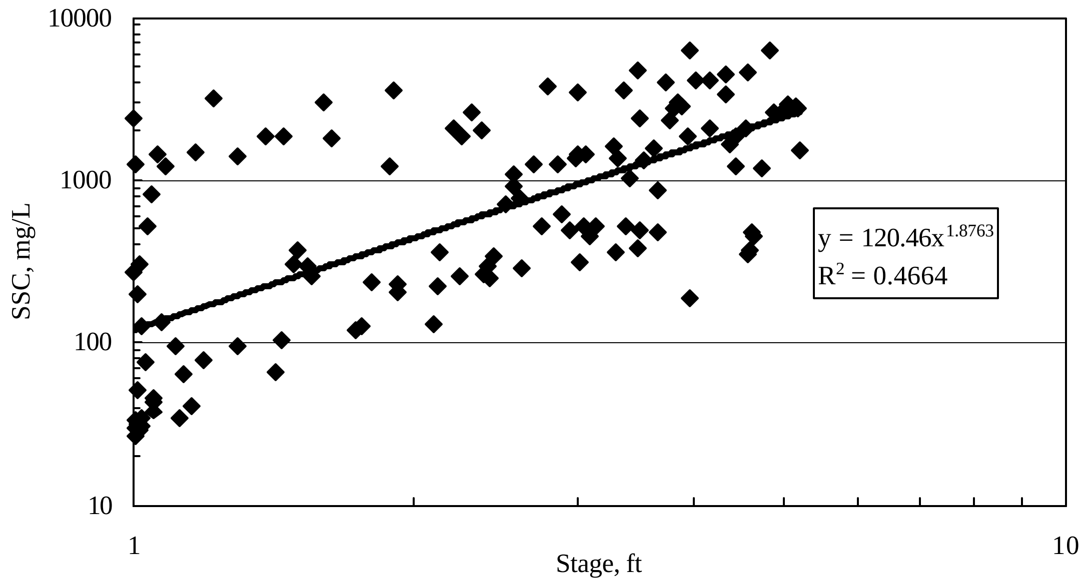
b) Stage hydrograph and grouped SSC for 2/26/04 storm event

Figure 4.1 Point sampling data for storms of varying intensities

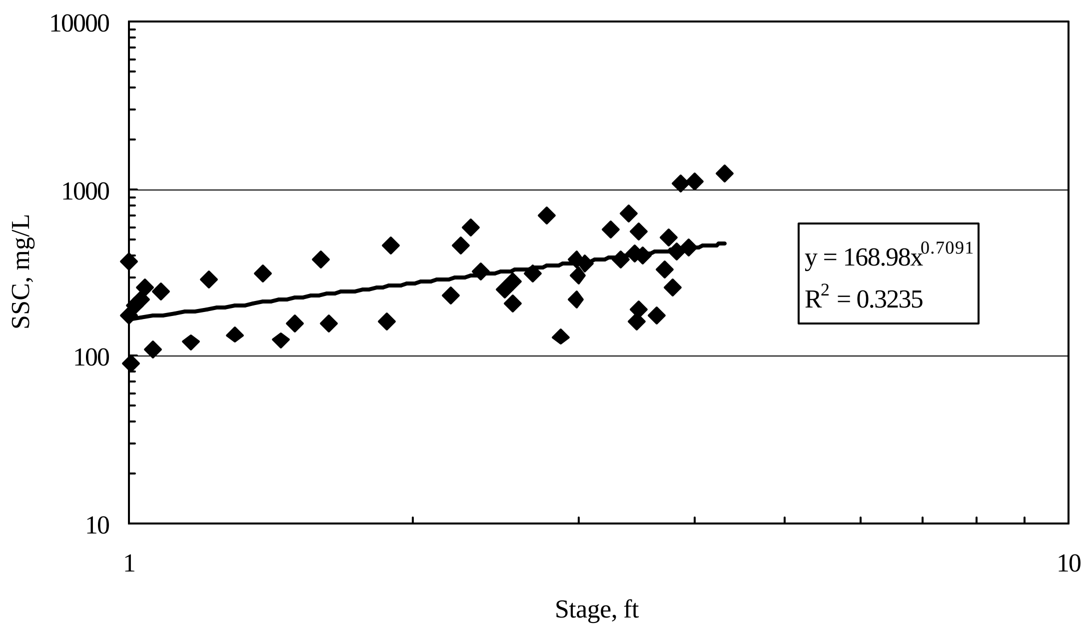
medium-intensity storm of Figure 4.1 a), but for the minor storm of Figure 4.1 b) the values of SSC are only of the order of 100 mg/L. Bankfull stage is approximately 8 ft, so neither of these storms is very large in magnitude by comparison. The entire field record of point sampling sinceOctober 2003 is included in the Appendix.

Sediment Rating Curves

Sediment transport data are often used to produce site-specific sediment rating curves that define the relationship between stage or discharge and SSC at a sampling location. However, due to the extreme variability in stage hydrograph response to storm events and the overall flashy nature of urban streams, the sediment rating curve, shown in Figure 4.2 a), revealed that a very poor relationship exists between stage and total SSC. A sediment rating curve relating stage and SSC of fine sediment, shown in Figure 4.2 b), also produced a weak relationship. The absence of a strong relationship in either case highlights the difficulty in quantifying sediment loads through point sampling and the high degree of temporal variability of sediment concentration that occurs in urban streams.



a) Log-log plot of stage and SSC data



b) Log-log plot of stage and fines-only SSC data

Figure 4.2 Logarithmic plots of paired stage and SSC data

Turbidity

The point samples from several storm events were analyzed for percent fines and the turbidity of the fine sediment only. This provided a graphical relationship between fine SSC and turbidity, as shown in Figure 4.3. This favorable relationship (R^2 = 0.976) indicates the strong correlation that exists between fine SSC and turbidity at the sampling location.

Grain Size Distribution

Sieve analysis was performed on point samples from selected storm events to provide insight into the range of sediment sizes in transport at the sampling location. A representative sample is shown in Figure 4.4 as a cumulative distribution plotted in lognormal form.

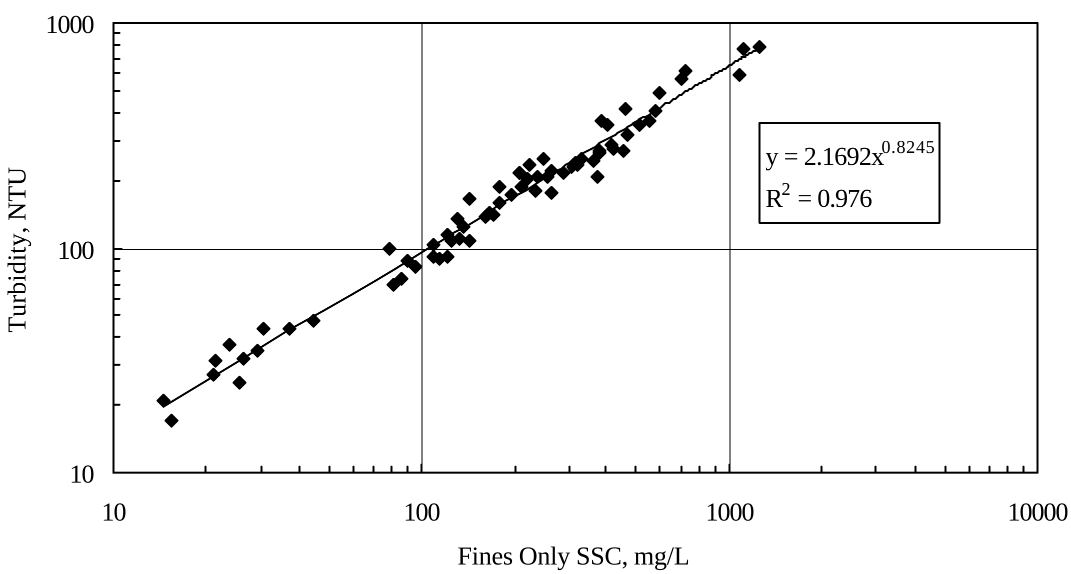


Figure 4.3 Log-log plot of fine SSC and turbidity for multiple storm events

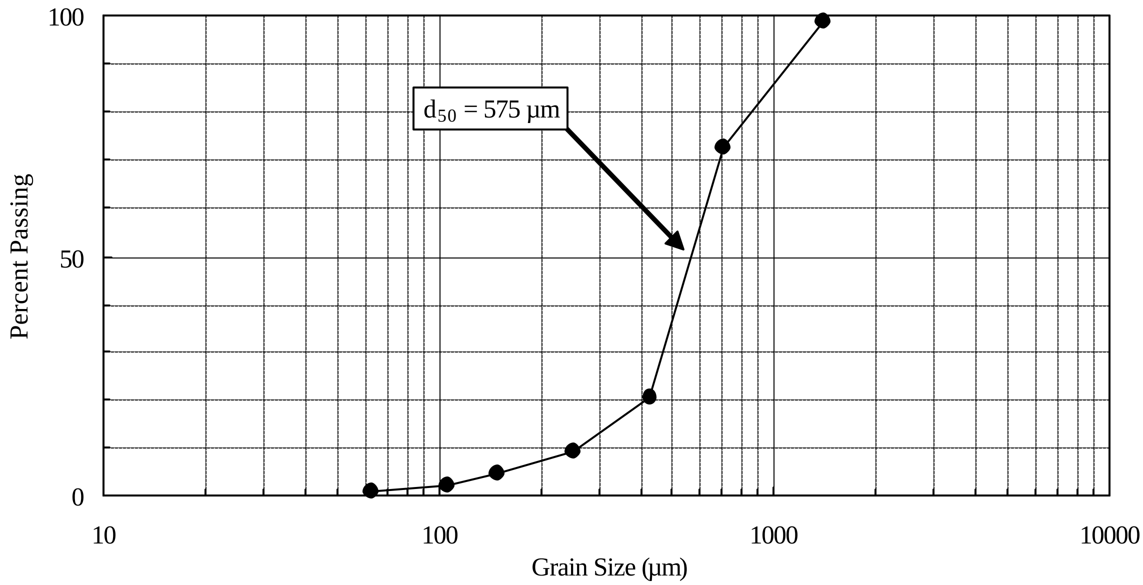


Figure 4.4 Grain size distribution of sediment from storm event on 2/03/04.

4.3 Sediment Samples

Sediment samples were collected from several sites in the vicinity of the sampling location and at a site approximately one mile upstream where severe bank erosion is actively occurring and presumably contributes significantly to the suspended sediment transported through the sampling location.

Stream Bed Samples

The stream bed was sampled in several locations adjacent to and upstream of the automatic sampler intake nozzle so that the bed sediment could be compared with the sediment collected by the sampler during a storm event. The storm event chosen for comparison was the largest event that occurred during the sampling period and which provided the most sediment in the point samples. This comparison, shown in Figure 4.5, reveals that although the two sediment samples are very similar, the sediment collected by the automatic sampler contains a larger percentage of fine sediment than the bed material. The median grain size of the automatically sampled sediment is approximately 60 µm smaller than the bed material. It is important to note, however, that the point samples from most storm events do not include enough sediment to perform a grain size analysis. In particular, smaller storm events include very high percentages of fine sediment. However, even samples from the selected event, which included the full range of grain sizes present in the stream, revealed the difference between the point samples and bed samples. The difference in median grain size can partially be explained by the bed armoring that occurs during high flows, along with the presence of large particles included in the bed material that are too heavy to be suspended from the bed and transported during most storm events. The difference in percent of fine sediment, however, represents additional sources of sediment that contribute to the sediment load but do not originate in the stream bed. The task of identifying these additional sources led to intensive sampling of the stream banks in areas where active erosion could be visually identified. As in bed sampling, bank samples were also taken in the immediate vicinity of the automatic sampler so that the effects of nearby sediment could also be identified.

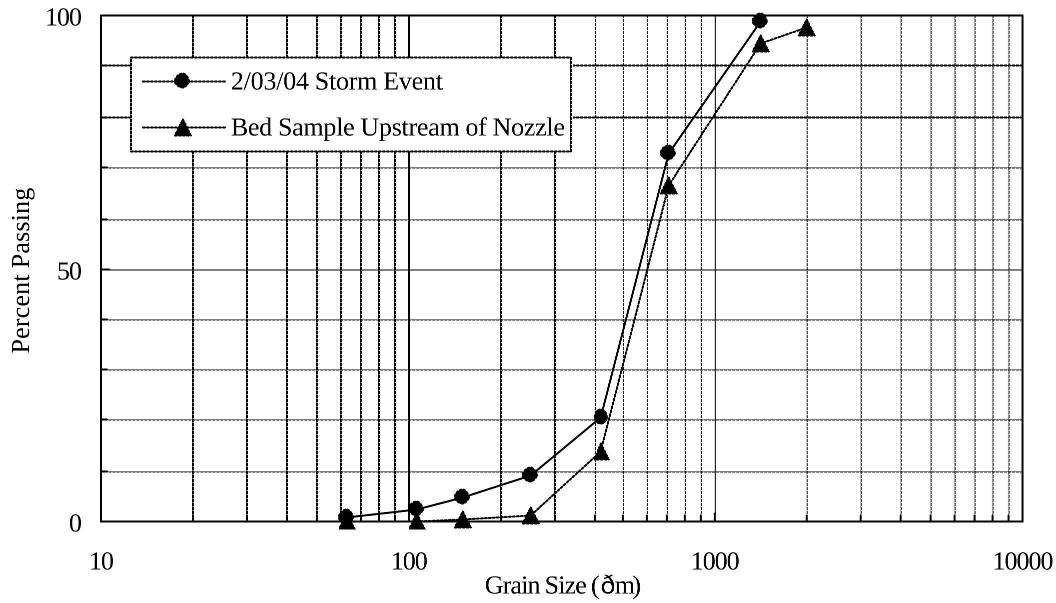


Figure 4.5 Comparison of bed sample with automatically sampled sediment

<u>Stream Bank Samples</u>

The stream banks were sampled approximately 100 ft upstream of the sampling site where native sediments unrelated to construction of the Century Blvd. bridge were found. The stream banks in this vicinity are stable due to the heavy vegetation in the floodplain and on the crest of the banks. However, significant bank erosion was identified approximately one mile upstream of the sampling site in a stream reach, shown in Figure 4.6, where the stream meanders sharply from its westward flow direction to a southwesterly direction. The banks in this area are vertical and are approximately 8-10 ft in height. The floodplain has been reduced in size due to the receding bank. The remains of the floodplain are perched atop the steep banks and consist of residential lawn area. The stream bed is heavily armored in this region and several deadfalls in the form of logs, tires, and other urban litter contribute to the significant bank scouring that takes place during each event.

Figure 4.6 Bank erosion approximately one mile upstream of sampling site

4.4 Turbidity and Fine Sediment

The relationship between suspended sediment concentration of fine sediment and the turbidity it produces is a parameter measured for all sediments sampled. The record of storm event samples provides a strong relationship between fine sediment concentration and turbidity, and the bed and bank samples were used to create suspensions for which turbidity and SSC fines could be measured and correlated. This was accomplished by removing all of the coarse sediment from each sample and then using the remaining fine sediment for turbidity measurement as described previously in

Chapter III. Comparing all of the soil types sampled as shown in Figure 4.7 and Table 4.1 indicates that each sample exhibits a unique relationship between SSC fines and turbidity that can serve as the signature or fingerprint of the sediment at that location.

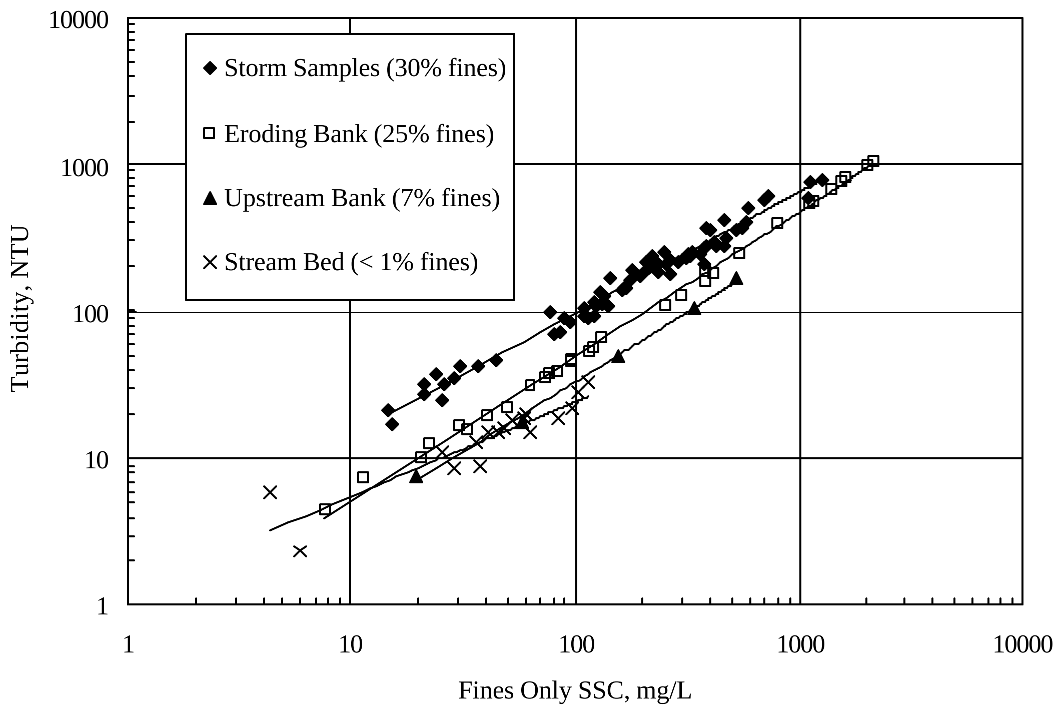


Figure 4.7 Comparison of turbidity signatures of sediment samples

Table 4.1 Comparison of turbidity signatures of sediment samples

Type of Sample	*Percent Fines*	*Regression Equation*	*R^2*
Storm Samples	30%	$NTU = 2.146(SSC)^{0.8251}$	0.9711
Eroding Bank	25%	$NTU = 0.545(SSC)^{0.9785}$	0.9974
Upstream Bank	7%	$NTU = 0.42(SSC)^{0.948}$	0.9972
Stream Bed	< 1%	$NTU = 1.279(SSC)^{0.6387}$	0.832

The initial motivation for exploring the relationship between SSC fines and turbidity was the attempt to locate the relative contributions of bed and bank sediment to the sediment found in the automatic sampler. Comparing the turbidity fingerprint of the fine sediment contained in the storm samples with that of the fine sediment sampled from the stream bed in Figure 4.7 shows that the two sediments are very dissimilar and thus proves that the bed sediment only constitutes a negligible fraction of the fine sediment in the automatic samples. Yet, as Figure 4.7 demonstrates, none of the bank samples match exactly the fine sediment found in the automatic samples. However, the eroding bank sediment is most similar, particularly in the upper portion of the relationship. The similarity between the automatically sampled sediment and the eroding bank sediment is indicative of eroding banks in the upstream channel contributing to the suspended sediment load.

The correlation between the percent of fine sediment in a sediment sample and the turbidity that it contributes is a separate relationship that was examined. Comparison of the sediment samples in Figure 4.7 and Table 4.1 indicates that the turbidity of a sample is highly dependent upon the percent of fine sediment that the entire sediment sample contains. Regression of each data set in Figure 4.7 reveals that an increasing percentage of fine sediment in a total sediment sample corresponds to increasing turbidity for a given fine sediment concentration created from that sediment. Said in a different way, a sediment with a high percentage of fine sediment in the total sample contributes more turbidity for a given fine sediment concentration than does the same concentration created using a sediment with a lesser percentage of fine sediment. The samples shown in Figure 4.7 include their respective percent fines shown as an average value of all samples collected at a given location.

The increasing turbidity at a given fines concentration with increasing percent of fine sediment is related to the median grain size of the sample. An increasing percentage of fine sediment correlates to a decreasing median grain size for the entire sample. Additionally, the median grain size of the fine sediment in the sample that remains after removing the coarse sediment decreases as.the median grain size of the entire sample decreases. Furthermore, the median grain size of a sediment is related to the number of individual sediment particles that constitute a measured weight of that sediment. And, since turbidity measures the attenuation or scattering of light through liquid, and because many very small particles contribute more turbidity than a few large particles, sediment with a relatively small median grain size contributes more turbidity for a given concentration than does a sediment with a larger median grain size.

This principle may also explain the discrepancy between turbidity signatures of the record of storm samples and the eroding bank samples. Because the percent fines of the storm samples is higher than the bank samples, the turbidity signature should be different. However, this does not mean that the eroding bank sediment is not the main source of fine sediment found in the storm samples. Once the sediment is scoured from the stream banks upstream, it is subject to the sediment transport capabilities of the stream reach. The stream velocity during storm flows is not sufficient to maintain the entire range of grain sizes in suspension, and the sediment transport capacity of the stream reach requires that deposition of some of this sediment occurs. And since the eroded sediment must travel a significant distance before it reaches the sampling location, much of the coarser sediment particles are deposited and do not reach the sampling location. When the automatic sampler withdraws water from the stream, the fine sediment it collects includes very fine sediment particles from the eroding bank, and the coarse sediment consists mostly of coarse sand particles from the stream bed. In addition, Figure 4.7 shows that the turbidity signature of the storm samples and the turbidity signature of the eroding bank samples grow more similar with higher concentrations. The upper end of the relationship represents large storm events in which most of the sediment eroded upstream reached the sampling location without a larger percentage settling.

4.5 Turbidity and SSC

Although the relationship between turbidity and suspended fine sediment is well established, the need for accurate sediment discharge measurement requires that the entire range of sediment sizes be accounted for. Furthermore, when turbidity is used as a surrogate for monitoring suspended sediment transport, the relationship between turbidity and SSC must be established. As discussed in Chapter II, however, the relationship between turbidity and SSC includes error that in some cases can preclude the use of turbidity as an accurate surrogate measurement.

Previous research performed in 1999 at the sampling location provided a record of automatically sampled storm event samples that were measured for total suspended solids and turbidity using the same laboratory equipment as described in Chapter III. As discussed in Chapter II, measurement of total suspended solids, or TSS, involves removing a subsample from the total sample and measuring its characteristics under the assumption that it is representative of the entire sample. The relationship between TSS and turbidity is shown in Figure 4.8, along with the relationship between fine SSC and turbidity at the sampling location obtained in the present study. At low sediment concentrations, the two data sets are very similar and actually overlap. This region represents data that were collected at low stages where coarse sediment was absent or minimal in the storm samples. At high sediment concentrations, however, the two relationships diverge. This region represents large storm events during which coarse sediment is suspended and is highly concentrated in the storm samples. Additionally, the difference in the two relationships represents the effects of the coarse sediment on turbidity measurement.

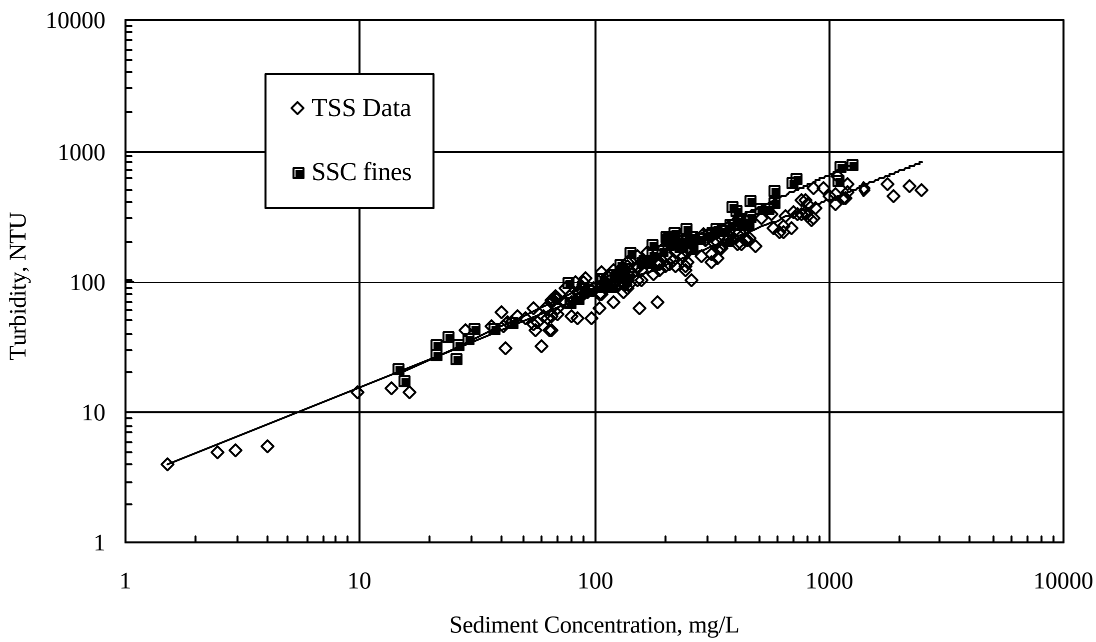


Figure 4.8 Comparison of fine SSC and TSS data.

Data from the sediment samples collected at the eroding upstream bank also show the effects of coarse sediment on turbidity measurement. Figure 4.9 shows the relationship between turbidity and total SSC obtained from the total sample, turbidity and fine SSC measured separately for the separated fine fraction, and a third data set representing the turbidity caused by each total SSC measurement multiplied by the percent fine sediment in the total sample. The third data set does not represent separate measured values, but multiplying total SSC by the percent fine sediment in the sample is a way to isolate the effects of the coarse sediment on turbidity measurement of the entire sample. Figure 4.9 then shows that the amount of additional turbidity contributed by the coarse sediment is small.

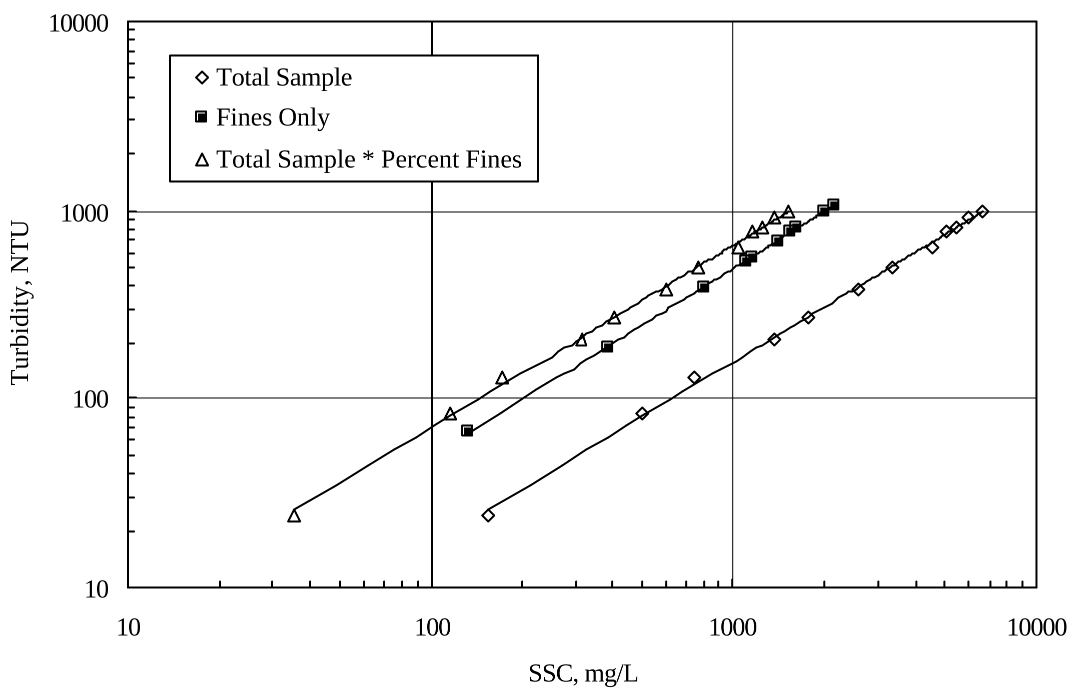


Figure 4.9 Effects of grain size on turbidity measurement.

4.6 Depth-Integrated Sampling

The depth-integrated sampling scheduled for the summer months of 2004 will provide insight into the spatial distribution of sediment in the sampling location stream cross section. This data will be coupled with the point measurements of SSC collected by the automatic sampler to determine the relationship between the point measurements and the concentration of sediment in the entire cross section. The point measurement of SSC will also be coupled with the Rouse suspended sediment distribution calculations (Sturm, 2001) for the coarse sediment fraction along with the shear stress distribution to obtain discharge of the coarse fraction.

4.7 Summary

By combining automated point sampling and depth-integrated sampling, a more accurate method for predicting coarse sediment loads will be developed as discussed above. In addition, a methodology will be developed that takes advantage of the strong correlation that exists between turbidity and fine SSC for predicting transport of fine sediment, including their sources and sinks. Since fine SSC determined from turbidity measurements can be assumed uniform over the entire cross section, measurement of both fine and coarse sediment can be accomplished at different times during the storm as the proportion of fine and coarse sediment changes. This approach will provide a more accurate method for establishing sediment TMDLs in urban streams but will not be limited by sediment size or sampler location as are feasible current methods. As a result, many of the limitations involved in measuring and enforcing sediment TMDLs will be overcome.

CHAPTER V

CONCLUSIONS

The effects of urbanization on urban streams are well documented and the quality of these streams has come under scrutiny by numerous government agencies in recent years. Of major importance in assessing and improving the quality of such streams is a thorough understanding of its sediment transport characteristics, including sediment sources and accurate quantification of sediment loads. The Total Maximum Daily Load (TMDL) program seeks to accomplish these tasks but suffers from lack of accurate, feasible data collection methods.

5.1 Project Summary

This study has employed existing technology to address many of the longstanding problems with collecting sediment transport data in an effort to develop a new methodology for gathering accurate and inexpensive data for establishing and maintaining sediment TMDLs.

Automated point sampling has provided a field record of point measurements of suspended sediment concentration (SSC). This sampling has shown that a strong relationship exists between SSC of the fine fraction of the sediment and turbidity at the sampling location (R^2 = 0.976). These point samples have also been coupled with intensive sampling of the stream bed and banks for comparing grain size distributions and turbidity characteristics. This has provided insight into the effects of sediment sizes on turbidity measurement and is being used to develop a method of identifying and quantifying suspended fine sediment. This methodology will also be useful in tracking sediment sources and increasing accountability for developers to employ effective erosion control measures. The outcome of the this work will be particularly beneficial in applications where fine sediment impairment is a concern due to its contribution to the transport of attached contaminants, silting of spawning areas, and inhibition of photosynthesis and aesthetic quality.

5.2 Continuing Research

Depth-integrated sampling is currently being performed and will provide suspended sediment concentration data for the entire stream cross section at the sampling location. The depth-integrated sampling data will also be combined with field record of point measurements of SSC, calculation of the Rouse distribution of suspended sediment, and calculation of shear stress distribution for correlating point measurements with the cross sectional distribution of suspended sediment.

5.2 Expected Research Outcomes

Combining point sampling and depth-integrated sampling will yield a more accurate method for predicting coarse sediment loads. In addition, a methodology that takes advantage of the strong correlation that exists between turbidity and fine SSC for predicting transport of fine sediment, including their sources and sinks, will be developed. These two related research goals will produce a method that will capable of measuring both fine and coarse sediment at different times during storm events. Temporal changes in sediment transport present a major hurdle that can be overcome by measuring both fine and coarse sediment as the proportion of fine and coarse sediment changes during a storm hydrograph. This approach will provide a more accurate method for establishing sediment TMDLs in urban streams but will not be limited by sediment size or sampler location as are current methods. As a result, many of the limitations involved in measuring and enforcing sediment TMDLs will be overcome.

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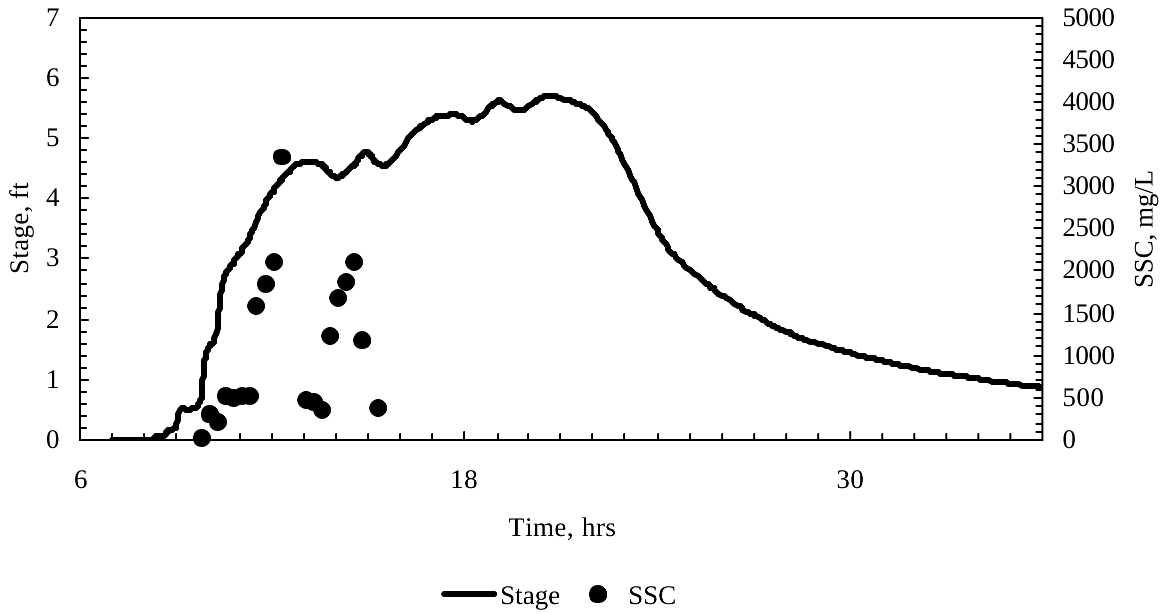
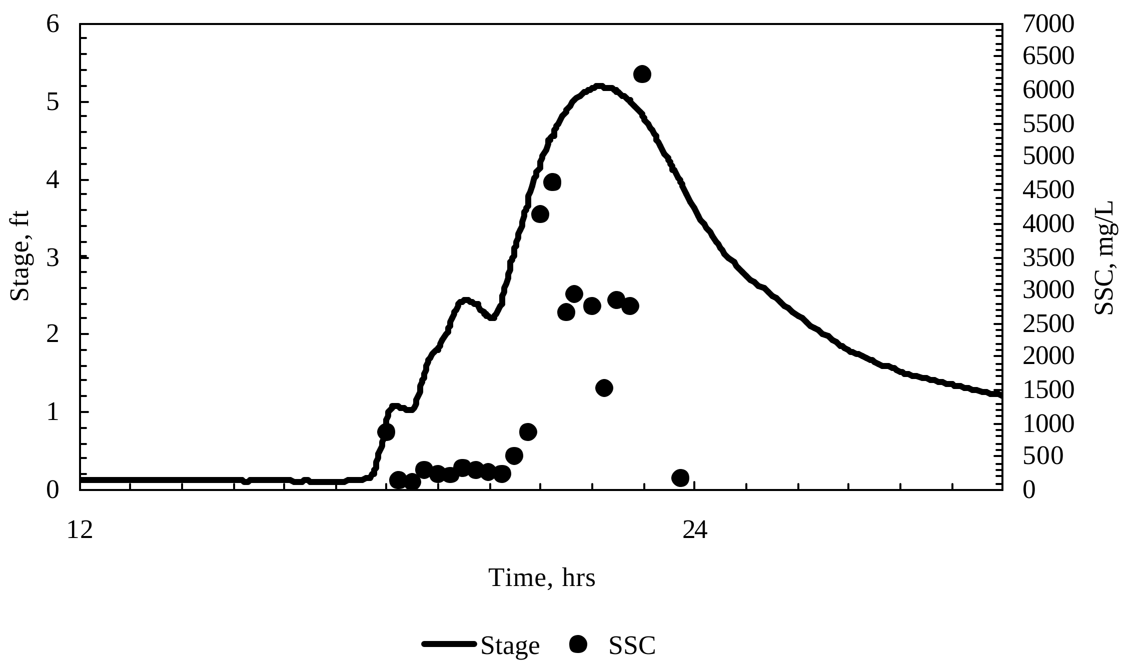
APPENDIX

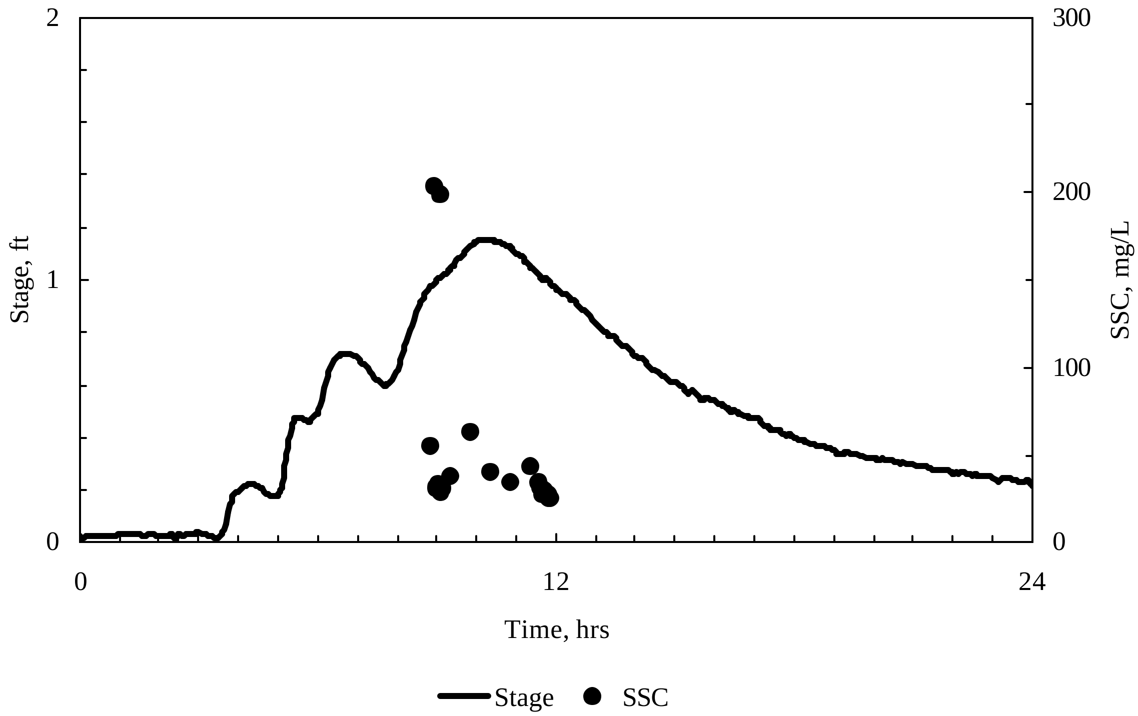
FIELD RECORD OF STORM EVENT POINT SAMPLING



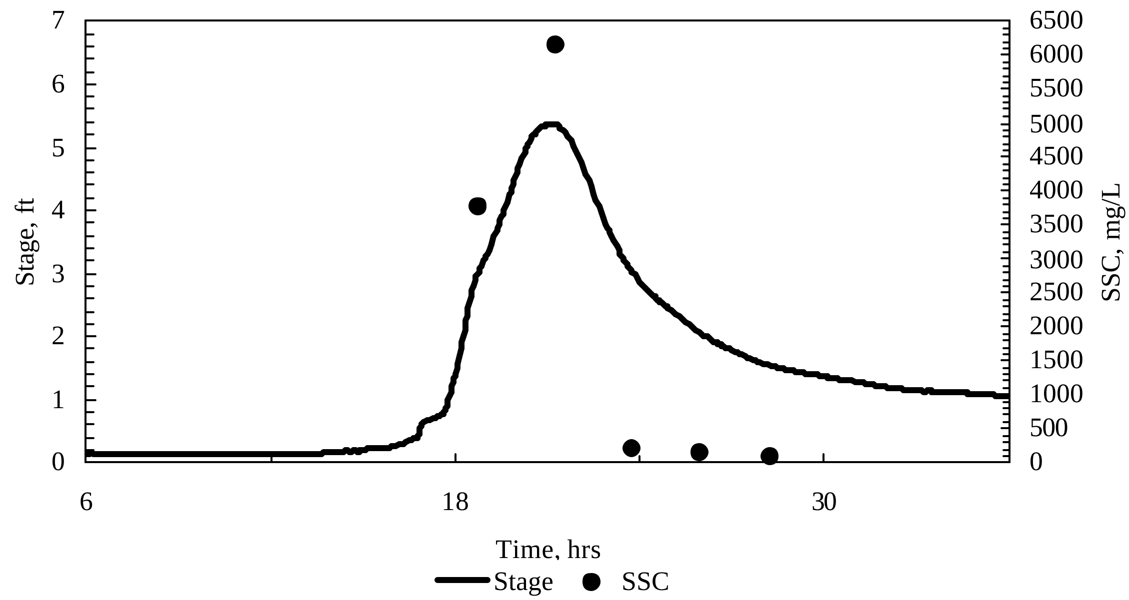
Hydrograph and SSC from 10/26/03 storm event



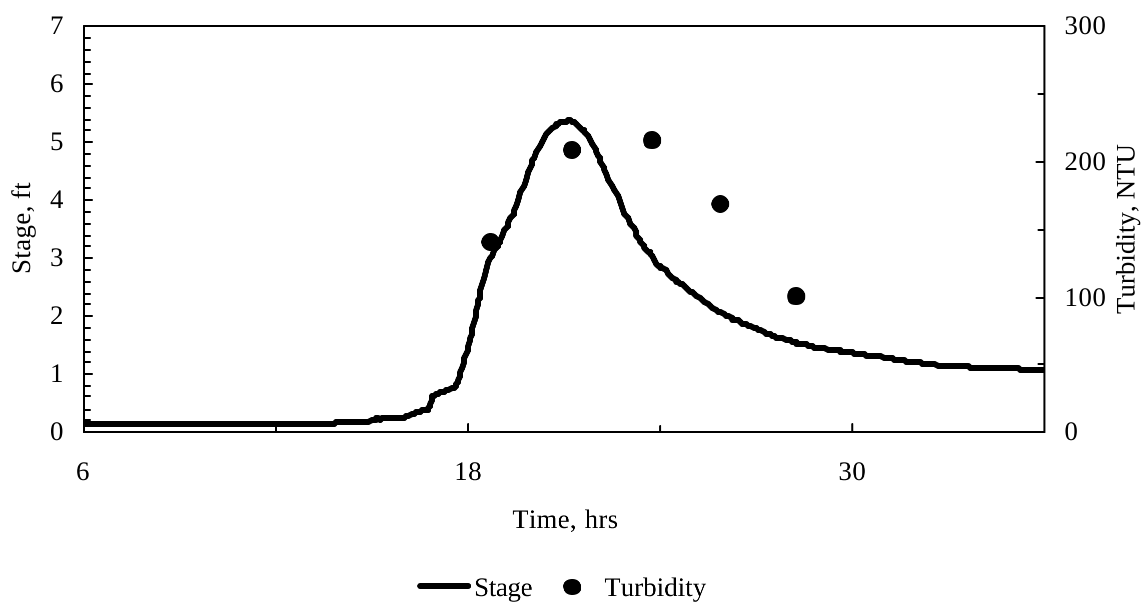
Hydrograph and SSC from 11/05/03 storm event



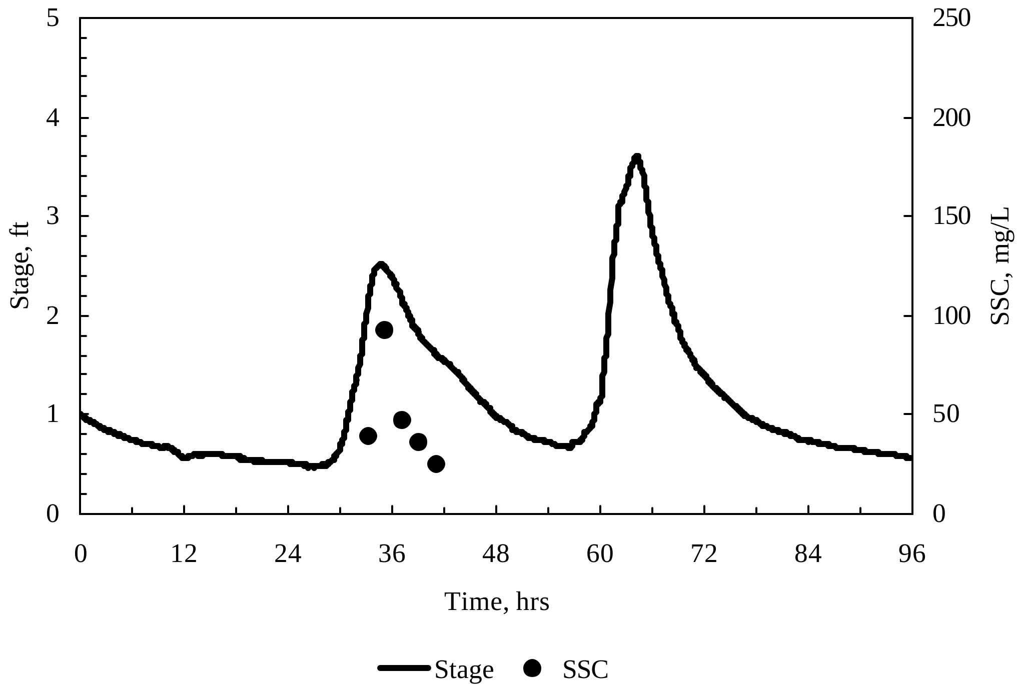
Hydrograph and SSC from 11/17/03 storm event



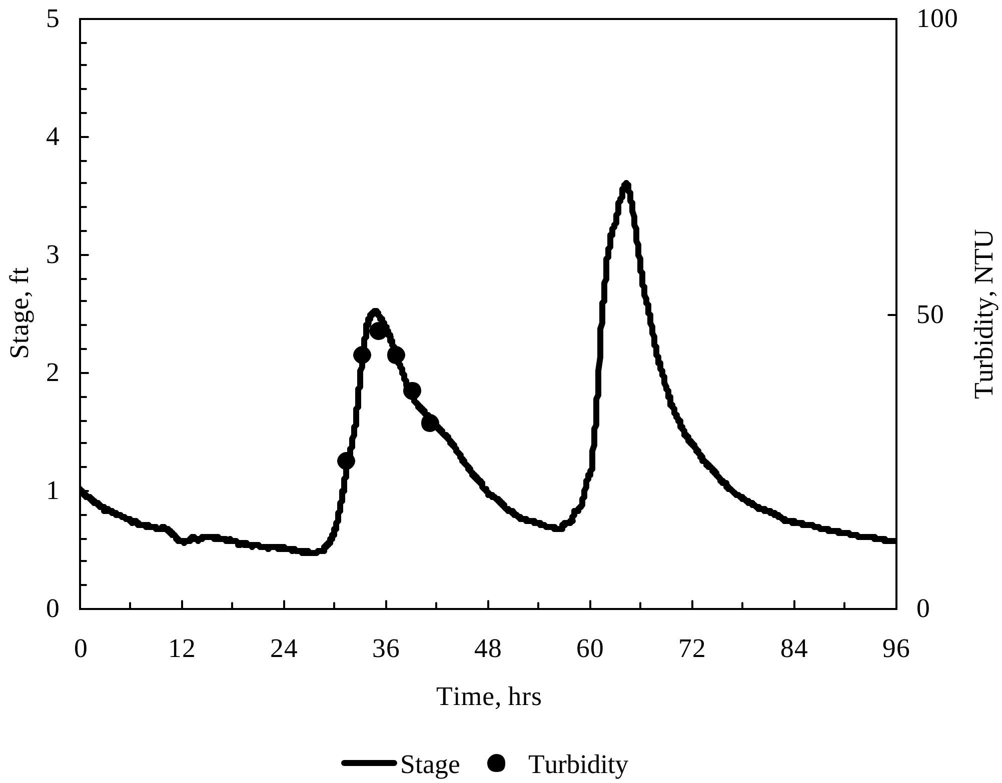
Hydrograph and grouped SSC from 2/03/04 storm event



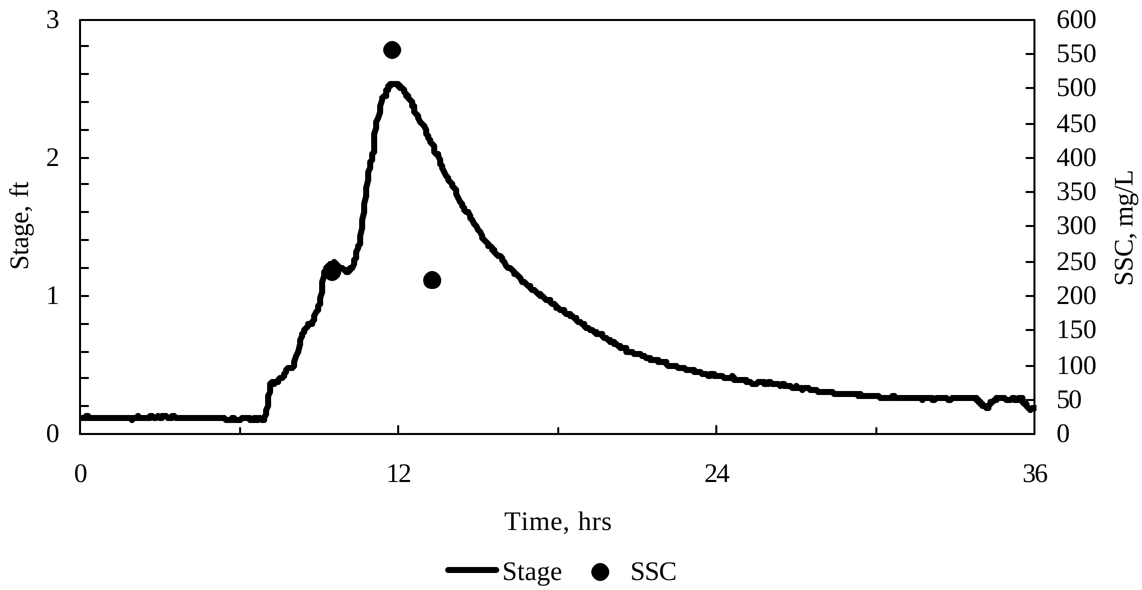
Hydrograph and grouped turbidity from 2/03/04 storm event



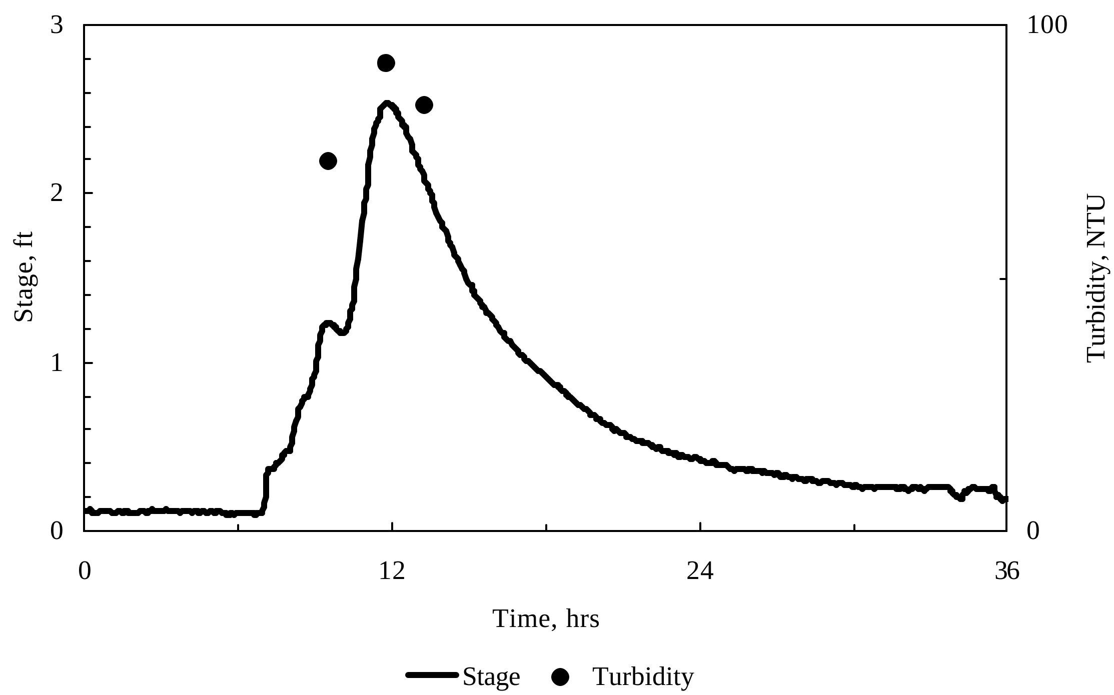
Hydrograph and grouped SSC from 2/14/04 storm event



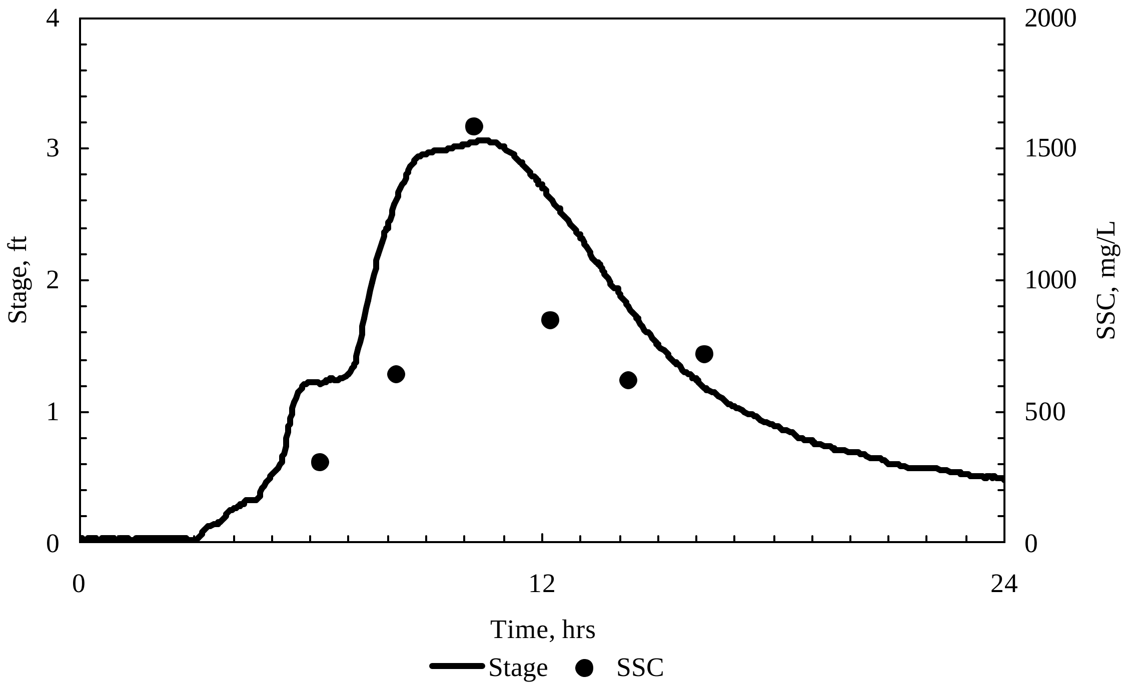
Hydrograph and grouped turbidity from 2/14/04 storm event



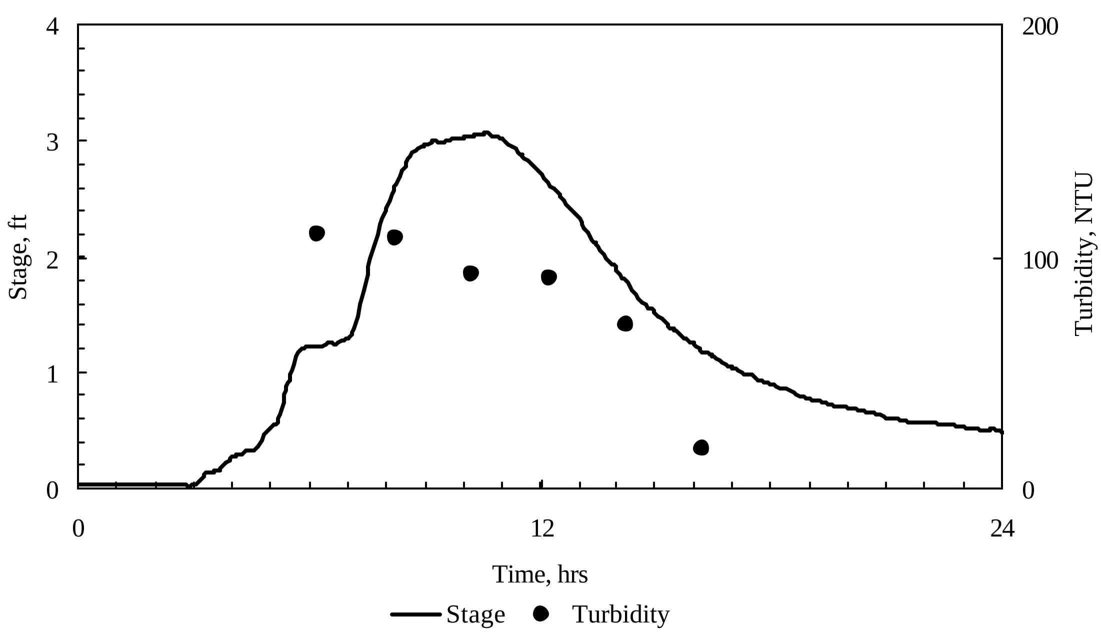
Hydrograph and grouped SSC from 3/06/04 storm event



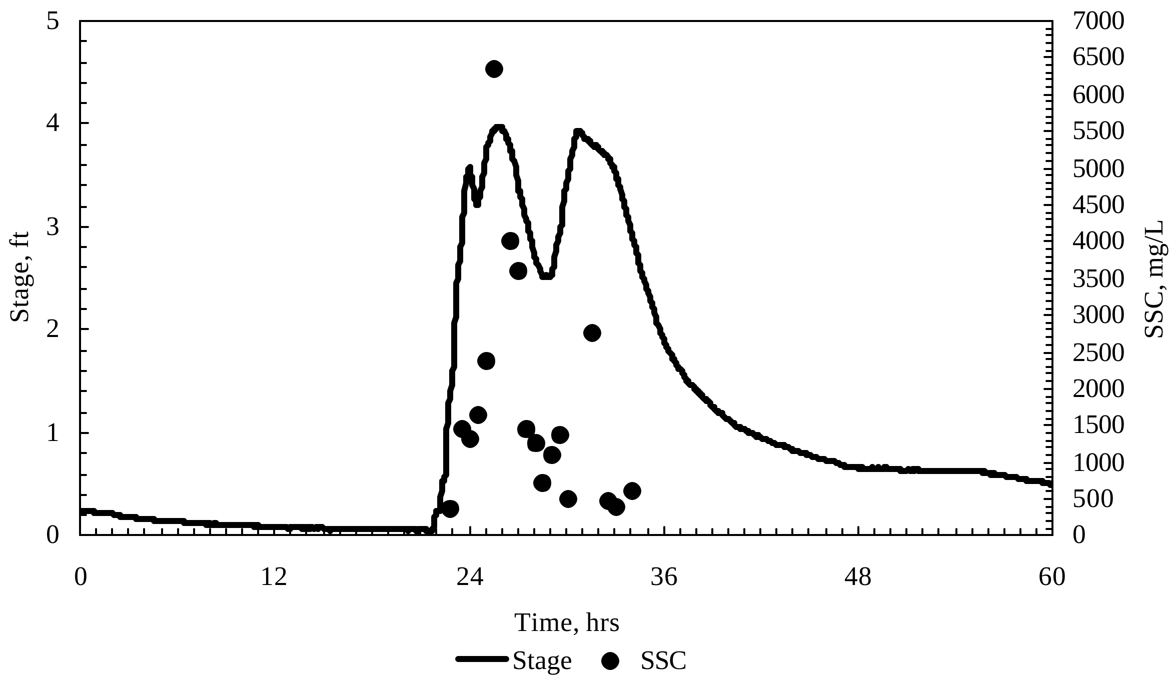
Hydrograph and grouped turbidity from 3/06/04 storm event



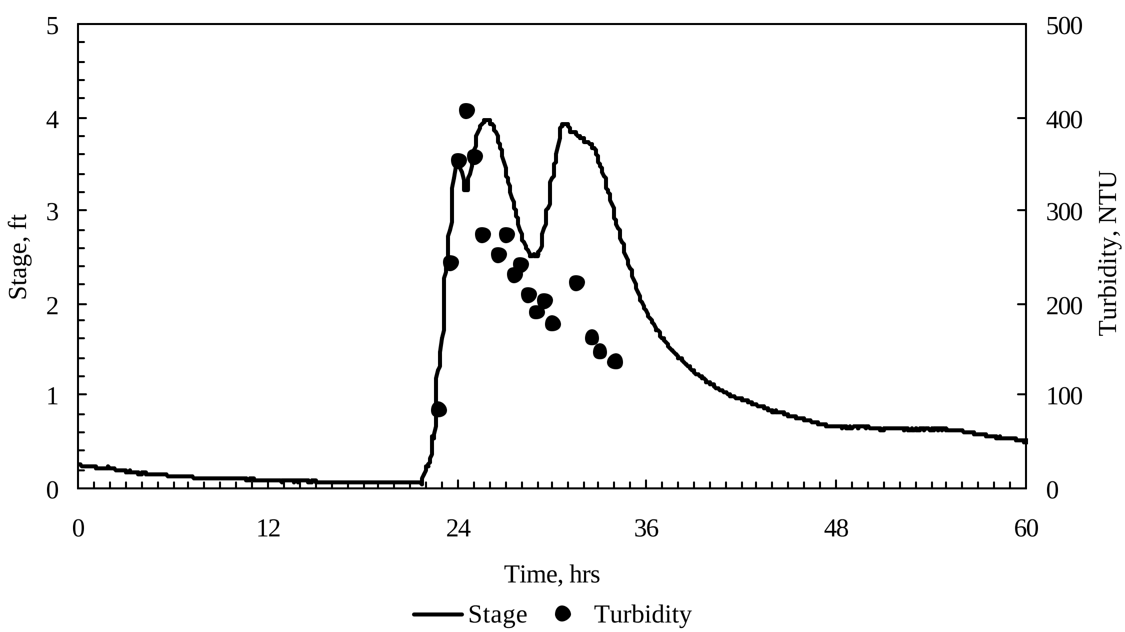
Hydrograph and grouped SSC from 3/30/04 storm event



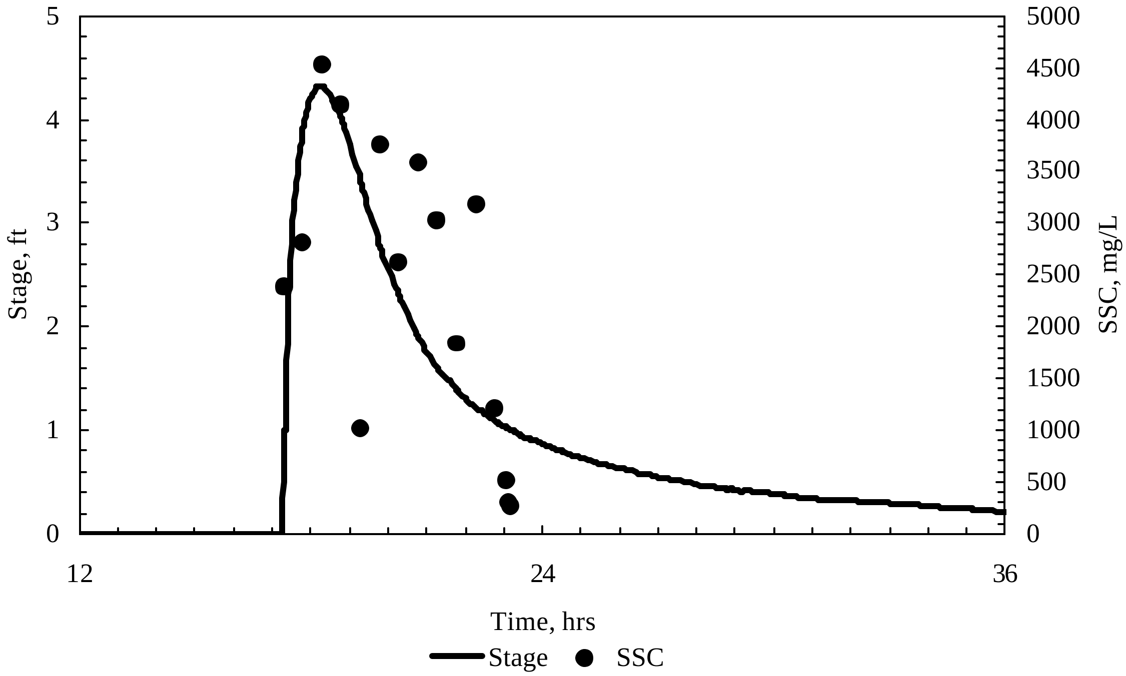
Hydrograph and grouped turbidity from 3/30/04 storm event



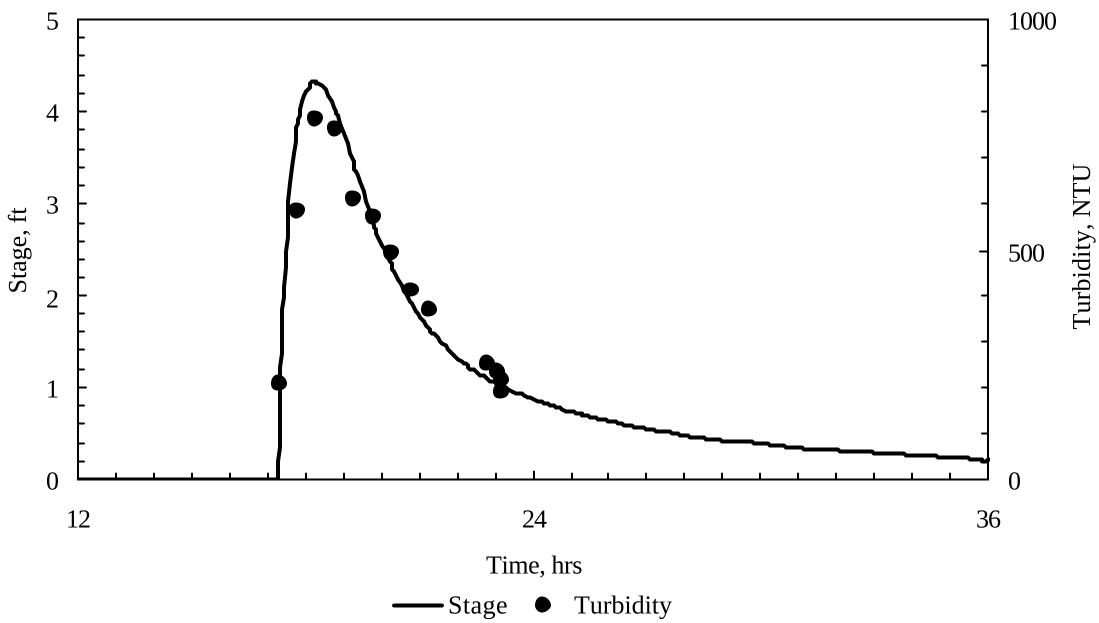
Hydrograph and SSC from 4/13/04 storm event



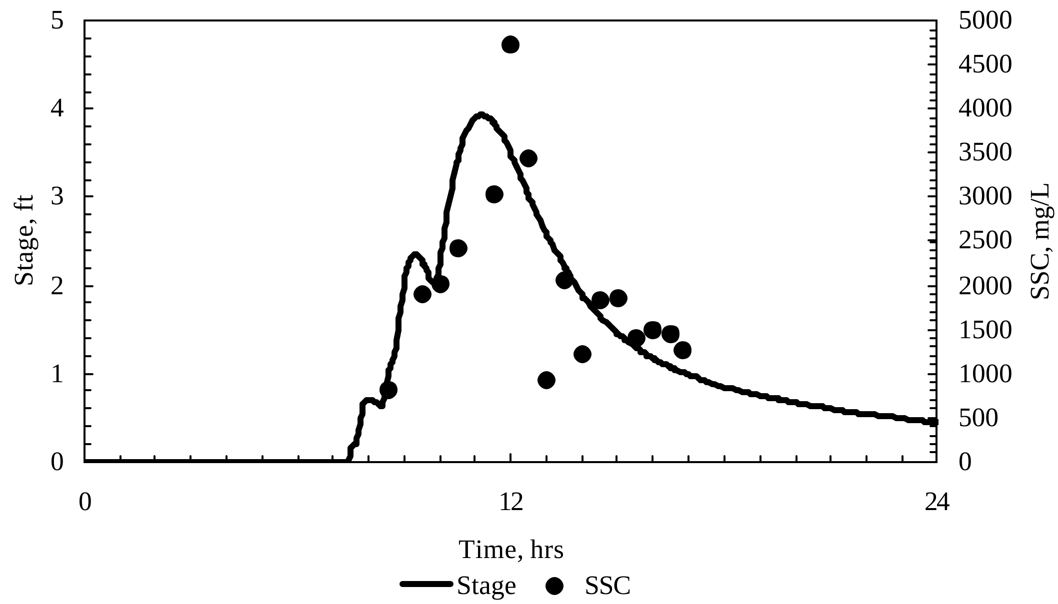
Hydrograph and turbidity from 4/13/04 storm event



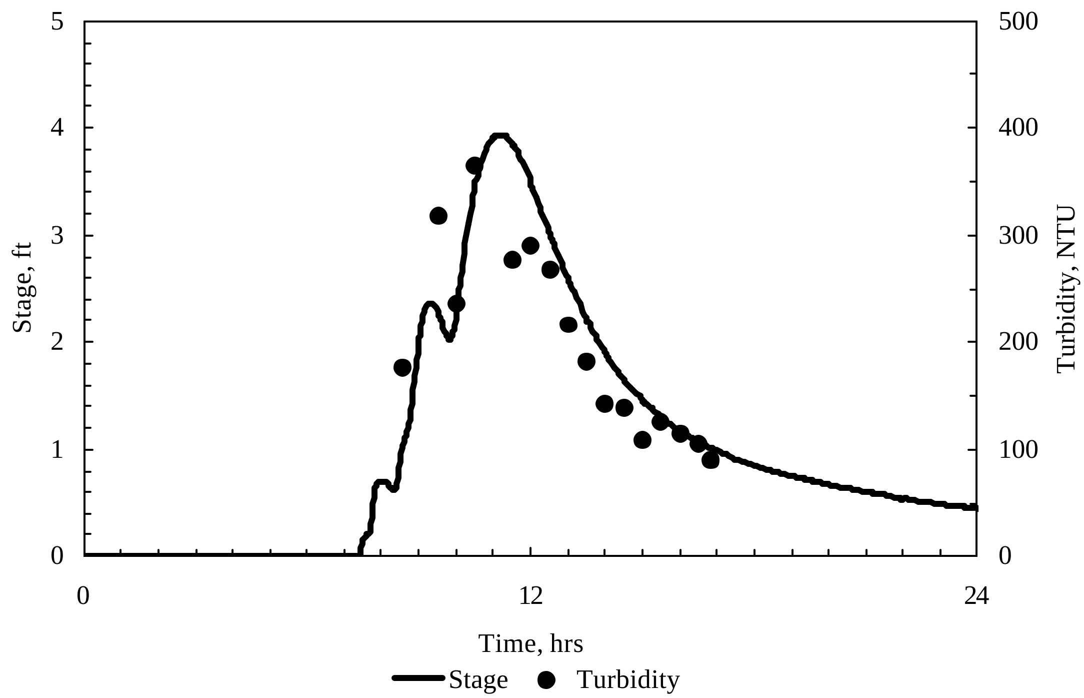
Hydrograph and SSC from 5/22/04 storm event



Hydrograph and turbidity from 5/22/04 storm event



Hydrograph and SSC from 5/31/04 storm event



Hydrograph and turbidity from 5/31/04 storm event