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STORM-RELATED SUSPENDED PARTICULATE MATTER IN LITTLE WESTHAM CREEK

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Abstract

Properties of a watershed regulate the amount of suspended particulate matter (SPM) in a stream. The present study examined relationships between storm-related SPM and impervious area and tree cover in the suburban watershed of Little Westham Creek, Richmond, Virginia during Summer and early Fall, 1999. SPM concentration, SPM discharge, and turbidity due to clay, silt and sand, and the areas of impervious surface and tree stand cover in the watershed were measured at three sites. SPM concentration, SPM discharge, and turbidity due to clay were greater upstream than downstream. The percentages of watershed area covered by impervious surfaces and tree stands also were greater upstream than downstream. SPM was most likely associated with impervious area, not tree cover.

I certify that I have read this thesis and find that, in scope and quality, it satisfies the requirements for the degree of Master of Science.

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STORM-RELATED SUSPENDED PARTICULATE MATTER IN LITTLE WESTHAM CREEK

By

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Introduction

General background

Watershed properties such as slope (Whipple *et al.* 1981, Rosgen 1994), land use characteristics (Klein 1979, Whipple *et al.* 1981, Lenat & Crawford 1994), and soil type (Renard *et al.* 1997) regulate the amount of storm-related suspended particulate matter (SPM) carried by a stream. SPM in a stream is material, organic or inorganic, that is lifted up anywhere in a watershed and remains in suspension in the water column.

Increased amounts of SPM can have negative environmental implications to the aquatic environment such as scouring, phosphorus loading, and sedimentation (Horne & Goldman 1994). Scouring of streambeds destroys habitat for benthic invertebrates. Phosphorus loading can cause algal blooms. Sedimentation caused by the settling of SPM clogs the gills of some organisms and blocks sunlight from submerged vegetation.

SPM in general can be added to water from either increased surface runoff outside the stream or from increased water discharge in the stream. Increased surface runoff can directly add SPM from anywhere in the watershed when surfaces are exposed, or it can indirectly add SPM by increasing water discharge. Increased water discharge in the stream can add SPM from bank-cutting erosion, bed scouring, and resuspending previously deposited sediment.

Quantities of SPM can follow trends along the length of a stream. Headwaters of a stream have steep slopes, dense canopy cover, and low discharge (Leopold 1964, Rosgen 1994). Steep slopes increase SPM by scouring (Rosgen 1994). Dense riparian vegetation filters SPM (Minore & Weatherly 1994), and lower discharge decreases SPM

(Leopold 1964). As one looks downstream from the headwaters, riparian vegetation decreases and more light is available to the stream (Minore & Weatherly 1994). This light allows production of autotrophic biomass, increasing organic SPM (Solo-Gabriele *et al.* 1997). Width, depth and discharge also increase downstream (Leopold 1964). Discharge is directly proportional to SPM in the stream (Leopold 1994, Warren & Zimmerman 1994, Jago & Mahamod 1999). Downstream areas have gentler slopes, less dense canopy, and increased discharge (Leopold 1964, Rosgen 1994). Gentler slopes produce less SPM from stream scouring than steeper ones (Rosgen 1994). Less dense canopy (Karr & Schlosser 1978) and increased discharge (Leopold 1994) can cause increased SPM. According to the river continuum concept, organic SPM follows a gradient with course particulate matter near the headwaters and fine particulate matter farther downstream (Vannote *et al.* 1980).

SPM-related variations in a stream's watershed can also exhibit a heterogeneous distribution. Riparian vegetation can be found in patches (Elliot *et al.* 1997), and vegetation outside riparian zones, such as woodlots on banktops, can be patchy and remove SPM from surface runoff (Karr & Schlosser 1978). Trees from woodlots also decrease SPM by providing overhead cover from raindrops directly striking erodible soils (Marsh 1991). Benthic macroinvertebrates require spatial heterogeneity of in-stream vegetation (Kaenel *et al.* 1998). Local geomorphology such as substrate type can be independent of location along the stream gradient (Huryn & Wallace 1987). The amount of SPM produced in that case would be dependent on features of the substrate, not the location along the gradient.

Land use

Variations in land use characteristics in a watershed such as earth-disturbing activities, slope, bank stability, impervious surfaces, and vegetative cover can affect SPM in a stream. Agriculture and urban development remove vegetative cover and disturb soil, contributing SPM to nearby streams (Lenat & Crawford 1994, Lamberti & Berg 1995). Longer, steeper side slopes tend to increase the erosion potential of surface runoff velocity. Increasing surface runoff can increase SPM if not filtered by vegetated buffers (Karr & Schlosser 1978). Steeper slopes within the stream channel can cause scouring and stream channelization (Whipple 1981, Rosgen 1994). Stream channelization inputs SPM to streams with bank-cutting erosion (Karr & Schlosser 1978, Trimble 1997). Impervious area also affects SPM yield to a stream. Surfaces impervious to water drain quickly (Simmons & Reynolds 1982). When much of the watershed is impervious, surface runoff water is increased (Klein 1979). Increased velocity and volume of surface runoff provides energy necessary for eroding particles from exposed surfaces and carrying SPM. Once the surface runoff reaches the stream, it is translated to increased water discharge. The increase of water discharge provides energy to additionally increase SPM with the resuspension of sediment previously deposited in the channel (Cardenas *et al.* 1995).

Suburban watersheds

Suburbanization of a watershed includes removal of vegetation followed by development of impervious surface areas such as roads, parking lots, and roofs. Tree cover decreases banktop surface runoff water in the immediate area. Based on many long-term studies of forestry practices, Karr & Schlosser (1978) found that riparian vegetation such as trees directly filter SPM out of surface runoff water. Impervious areas dramatically increase the amount of surface runoff during storms (Tourbier & Westmacott 1977, Klein 1979). When this increased runoff reaches bare earth, it has energy to erode soil and increase SPM. As stated earlier, once increased surface runoff reaches a stream it is translated to increased stream water discharge, also with energy to increase SPM.

Environmental Implications to Westhampton Lake

During storm events, high turbidity has been found in Westhampton Lake at the University of Richmond, Virginia and its feeder stream (Bishop 1982), and this poses a serious sediment problem in the lake (Bishop 1998). Sedimentation in Westhampton Lake is so severe that in 1994 it was recommended that the lake be dredged every two years for the next ten at a total cost of $155,000 (App.1).

Westhampton Lake acts like a stormwater detention basin. It decreases the velocity of influent water, causing SPM to settle out. The northeast corner of the lake exemplifies this settling process where an accumulation of sediment is evident from Little Westham Creek (LWC), the major tributary of the lake.

Many problems arise in the lake because of sediment. Fine sediment remains suspended for long periods, blocking light necessary for photosynthesis by submerged aquatic plants. It also clogs gills of fish and other organisms (Horne & Goldman 1994). Moreover, phosphorus bound to clay particles (*e.g.* Carnigan & Vaithiyanathan 1999) can be released to cause unsightly algal blooms (Miller *et al.* 1978), as observed in Westhampton Lake in the spring and summer (Bishop 1982).

Westhampton Lake is influenced by its watershed features, and because LWC delivers most of the water to the lake, the need is apparent to study sediment transport properties of the stream. LWC consists of a mainstem and eastern branch (Fig.1). A field observation by the author indicated that major sources of SPM in the creek appeared to be sediment trapped immediately upstream of a small dam on the mainstem where it meets the eastern branch and highly erodible banks at the headwaters and near the mouth of the eastern branch. Closer observation of deposited sediment in the bed and turbidity during a storm event indicated that the eastern branch produces much of the sediment (transported in the form of SPM) to the lake.

The present study focuses on relationships between storm-related SPM and impervious area and tree cover. Impervious area was chosen because it is easy to quantify from digitized data and because in guidelines for managing stormwater quality, Henrico County (1997) uses percent impervious area on a site to compute pollutant removal requirements for development activities. Guidelines for computing pollutant removal requirements and acceptable design criteria for best management practices (BMPs) to meet the requirements are detailed in the County's Stormwater Quality Guidelines manual. (Keith O. White, P.E., pers. comm.). Tree cover was chosen for study because it is also easily quantified from digitized data and because of its ability to buffer streams from SPM. In general, impervious area is positively associated with SPM, and tree cover is negatively so.

Objective

The main goal of the current study was to compare quantities of storm-related SPM along LWC's eastern branch. Three study sites were chosen to represent upstream, middle, and downstream reaches of stream. Data from three sites and multiple storm events were used to determine if SPM differs along the length of the stream. SPM characteristics examined were water discharge, SPM concentration, SPM discharge, and turbidity associated with sand, silt, and clay.

Possible impacts of percent impervious area and percent tree cover on SPM were also examined. Two logical explanations for observing a larger quantity of SPM at a site were examined: decreased tree cover, increased impervious area. The null hypothesis was no detectable differences among stream reaches.

Materials and Methods

Field

Study Sites

Three sampling sites were chosen on the eastern branch of Little Westham Creek (Fig.1). Site A was near the headwaters, Site B at about midpoint of the stream, and Site C at the lower portion before it merges with the mainstem and enters the lake. Site A was chosen because of its proximity to the highly erodable headwaters. Site B was chosen because of its presence in a predominately forested area below Site A. Site C was chosen because it was adjacent to residential lawns with few trees below Site B.

Watershed area, stream length, impervious area, and area covered by stands of trees were determined using ArcView GIS 3.2 and digital data provided by Henrico County with accuracy ± 0.61 m (Frauenfelder 1999). Watershed area above each site was determined by tabulating the area of a polygon bounded by the topographic watershed boundary. Stream length was determined as the distance of each site from the headwaters. Impervious area and tree cover were determined with data digitized from aerial photographs (Frauenfelder 1999). Impervious area was defined as the area in each watershed covered by digitized roads, building footprints, and parking lots. Tree cover was considered as the area in each watershed covered by stands of trees.

Stream water samples and measurements of stream stage were taken during storm events with significant rainfall between June 17 and September 16, 1999. Grab samples of stream water were taken to characterize particle size distributions and concentration of SPM. Stream stage was monitored to provide an estimate of water discharge.

Stream water samples

Water samples were collected using methods similar to those of Clesceri *et al.* (1998). The modification was that the plastic bottles were not wide-mouthed, and water was stored in Whirlpaks (125 ml, Nasco) rather than plastic bottles. Grab samples were collected using a plastic, 250 ml bottle facing upstream with the center of the 2 cm diameter mouth at a fixed position 3 cm from the streambed in the center of the current. After filling most of the bottle, it was shaken for a few seconds to homogenize the sample. About 100 ml was poured into a Whirlpak and kept refrigerated until laboratory analysis. Time and stream water stage were recorded for each sample.

Measuring water discharge

A water stage-discharge relationship was established by monitoring the water discharge at 4-7 different flow stages as the water level dropped. An empirical relationship between stage and discharge was developed to allow monitoring of water discharge by measuring stream stage. Water discharges estimates for each site had the general form:

$$Q=10^{\log_{10}(ST-SZF)B+A} \qquad \text{eq. (1)}$$

where: Q was the predicted water discharge ($m^3 s^{-1}$), ST was the field measured stream stage depth (cm), SZF was the stage at zero flow (cm), B was the slope and A was the intercept. Actual measurements of stage were adjusted by subtracting the stage at zero flow before predicting water discharge. Values of SZF, A and B were estimated using Microsoft Excel's Solver program to minimize the sum of squares of predicted discharge.

Water discharge ($m^3 s^{-1}$) was measured using methods of Rantz (1982). Time and stage (cm) were recorded at beginning and end of the discharge measurement to make sure that flow was steady while measurements were taken. If flow was not steady, mean flow during the measurement was used for the estimate. Cloth measuring tape fastened to stakes was stretched across a level weir to form a transect across each site (App. 2). Distance was measured (facing upstream) from the left bank water's edge and to the right bank water's edge. Intermediate measures were taken at 0.2-m intervals, dividing the stream into subsections.

At each vertical substation along the transect, water depth (cm) and mean velocity ($m s^{-1}$) were recorded. Depth was measured using a USGS top-setting wading rod, and velocity using a flowmeter at six-tenths depth from the surface (Marsh-McBirney Flow-Mate). The flowmeter was factory calibrated with precision to the nearest 0.01 $m s^{-1}$ with accuracy at ± 2 % of actual flow. Measuring the velocity at six-tenths depth gave mean velocity of the water column (Leopold et al. 1964, Gordon *et al.* 1993).

Water discharge for each substation along the transect was calculated using the following general form:

$$Q = d\,w\,v \qquad \text{eq. (2)}$$

where: Q was water discharge ($m^3 s^{-1}$) of the subsection, d was stream water depth (m) of the subsection, w was subsection width (m), and v was mean velocity ($m s^{-1}$).

Summing the discharges of all subsections of the transect yielded total water discharge of the stream site at the measured stage of flow.

During a non-storm event, a bucket-filling method was used to estimate discharge at a very low stage. Buckets of a known volume (7 l) were arranged to catch water as it came over the transect weir. The given volume (m^3) divided by the time (s) it took to fill yielded an estimate of discharge ($m^3 \ s^{-1}$) into each bucket. Summing discharges from all the buckets along the transect gave an estimate of total discharge for the stream site over the weir at that stage.

Rainfall

A rain gauge (5" Taylor) was placed at each study site where rain could fall directly into the gauge unobstructed by trees. The number of inches of water in the gauge was recorded ± 0.05 in each time a water sample was taken until rainfall had stopped. Total accumulations per storm were compared to data from the internet (Accuweather). The author's observations of rain pattern and rainfall duration also were noted.

Laboratory

Dry weight

Within 1-5 days of collection, water samples were analyzed for total suspended solids (TSS) according to a modification of methods by Clesceri et al. (1998). The modification was that before drying in an oven SPM was settled using centrifugation and drawing off most of the water (see below) instead of glass-filtering. (Glass-filtering was omitted because it was thought to remove some smaller particles with significant turbidity such as fine clays. Centrifugation was necessary because the original design used settling volume as a measure of SPM.) Total dissolved solids left in the tubes before drying in the oven were assumed negligible to the total dry weight.

Refrigerated stream water samples were warmed to room temperature. Whirlpaks were shaken to homogenize the sample and 15 ml of sample water were poured into a graduated centrifuge tube. The water sample remaining in each Whirlpak after TSS analysis was frozen for later analysis.

Water in the centrifuge tubes was allowed to settle for 10 min so most of the TSS settled out (Clesceri *et al.* 1998). Tubes were centrifuged for 5-10 min at 2500 rpm. Most of the water was then drawn off using a pipette without disturbing the settled matter. Tubes were dried on a rack in an oven at 130° C. After only dry SPM was left, the dry weight (g) using a digital balance was recorded with precision to the nearest 0.001 g and accuracy ± 0.003 g due to air currents. Weight of a centrifuge tube containing SPM was compared to a recent measure of the same tube when empty to determine SPM dry weight.

Empty centrifuge tube weight was recorded three times during the four months of TSS analysis to ensure accuracy. Differences in weights of the empty tubes were within the detection limits of the balance, and represented approximately 10 % of the maximum dry weight of SPM encountered.

Because of the small quantities of SPM in the tubes, instrumental error yielded a negative value for dry weight in 2.7% of the samples. Values with a negative dry weight were set to 0.000 g. Complete dryness was checked approximately once for each set of samples by comparing measured dry weights to dry weights after cooling and desiccating.

Turbidity

Within a few months of collection, samples were analyzed for turbidity. Frozen stream water samples were thawed to room temperature. Turbidity (NTU) was measured using a LaMotte 2020 Turbidimeter after shaking to homogenize and after diluting the sample to a readable level when necessary.

Measurements according to settling were taken at 0, 1, and 10 minutes to separately account for turbidity due to sand, silt, and clay. The heaviest particle, sand settled after 1 min, silt settled after 10 min, and the lightest particle, clay was the only particle remaining suspended after 10 min. Fifteen samples (10%) were lost because of Whirlpaks leaking and were not included in this analysis.

Data analysis

Data were normalized to properly characterize each site during each storm. For graphical analysis, actual routine grab sample times were normalized for duration of time for each storm by setting the first sample time equal to 0 min. Each stream property was normalized by the site's watershed area to discount the effect of larger watersheds having more SPM due to their larger relative size and not their land use (Cuthbert & Kalf 1993).

For statistical analysis, data from Storm 4 were omitted because measurements did not capture both the rising and falling limbs of the discharge versus time plot (hydrograph). For the remaining storms, water discharge, SPM concentration, SPM discharge, total turbidity, turbidity associated with sand, silt, and clay at each site were plotted versus duration. Area under the curve was estimated to give each variable's storm-wise yield to each site during sampling. Areas were estimated by summing for the entire range: the difference of two consecutive x-values multiplied by mean y-values between the two data points.

Means and standard deviations of each stream property were calculated. Using each storm as a block, sites were ranked and tested using a non-parametric Friedman's ANOVA method for randomized blocks (storms) to detect if there were differences among sites. If the null hypothesis of no differences among sites was rejected, a non-parametric equlivalent of Tukey's honestly-significant difference test (HSD) was used to determine which sites were significantly different. Levels of significance were set at $p<0.05$ for all statistical tests.

To estimate water discharge based on routine stream water stage measures, a calibration curve, or rating curve (Leopold et al. 1964) was plotted using data from the water discharge study. Water stage measurements were adjusted by SZF, the stage at which zero water would flow over the weir. Microsoft Excel's Solver program was used to determine the SZF, slope, and intercept of each site's least squares regression line by minimizing the sum of squared deviations (predicted discharge minus observed discharge).

Inserting field stream water stage measurements into the equation for the calibration curve converted field measures to water discharges. Only 9 % of the staff gauge measurements were outside the range of those used to develop the calibration curve.

Water discharge per watershed area (m^3 sec^{-1} km^{-2}) at each site was plotted versus time during each storm to produce a hydrograph. All storms were also compared in one plot for Site C to show variation among storms in water discharge. Means ± standard deviations and statistically significant differences of water discharge per storm (water yield hereafter) at each site were calculated and recorded.

SPM concentration per watershed area (kg m^{-3} km^{-2}) at each site was plotted versus time for each storm at each site to graphically visualize the concentration of SPM at each site as the storm progressed. SPM concentrations were calculated as dry weight per 15 ml sample. The concentration of SPM in each sample at each site was plotted versus time for each storm. All storms were also compared in one plot for Site C to show variation among storms in SPM concentration. Means ± standard deviations and statistically significant differences of SPM concentration per storm at each site were calculated and recorded.

SPM discharge per watershed area (kg min^{-1} km^{-2}) at each site was calculated for each sample at each site by multiplying water discharge by SPM concentration at each sample time in the entire cross section of water. SPM discharge gave an approximation of the flux of SPM going through a site at each sampling time during a storm. All storms were also compared in one plot of Site C to show variations among storms in SPM discharge. Means ± standard deviations and statistically significant differences of SPM discharge per storm (SPM yield hereafter) at each site were calculated and recorded.

SPM discharge was plotted versus water discharge to compare relationships at the three sites. A log-log relationship was used to normalize the data. Sites were compared using linear regression. Because there were not visual differences in lines, data were pooled for an overall correlation using a regression test. Linear regression provided a correlation coefficient and a p-value for statistical significance of the trend line.

Results

Values for drainage area, stream length, total impervious area, and total area of tree cover were smallest at Site A and largest at Site C (Table 1). Values for Site C were approximately twice those of Site A for drainage area, stream length, and impervious area. The percent impervious surface area and tree cover were greatest at Site A and least at Site C.

Rainfall patterns were similar at the three sites (Table 2). The amount of rain during a specific storm was similar at each site. Mean rainfall ranged from 1.6 (Storm 4) to 14.1 cm (Storm 5) among storms. Trends were the same when comparing the author's observed values to those collected from Accuweather, although absolute values differed. Rain patterns ranged from a light drizzle in Storm 1, to thunderstorms in Storms 2 and 3, and a hurricane in Storm 5. Unpublished data from smaller storms and baseline data did not yield any turbidity or dry weight, and were not included in the study.

Stream water stage-discharge relationships were developed for each site (Fig. 2). Values of r^2 were ≥ 0.96 at each site, indicating excellent fits (Table 3).

Sites were similar with respect to water discharge per watershed area (Fig. 3). Following a unimodal response, discharge generally increased to a peak then decreased over time. Measurements of water discharge started at and returned to base flow levels for Storms 1, 2 and 3, and started above base flow and returned to base flow levels for Storms 4 and 5. The first value for Storm 4 at Site B is probably an erroneous reading of the staff gauge. (The staff gauge measurement was believed to have been accidentally read 10 cm higher than observed because it is much higher than measures observed at the same site during the hurricane.) The system responded quickly to storm surges, returning to pre-storm levels within about an hour for all storms other than Storm 5 (Fig 3). Values of mean water yield were similar among sites (Table 4). Differences among storms produced large values for standard deviations. Sites were ranked for each storm separately in order to eliminate these storm effects. Differences in water yield were not statistically significant among sites (Table 5).

Temporal patterns in SPM concentrations per watershed area followed a general unimodal trend for Storms 1 and 3 (Fig. 4). Storm 2 was clearly bimodal. The peak at Site C lagged behind the other two sites in Storms 1 and 3. Storms 1-3 show SPM concentrations per watershed area starting at base levels and returning to base levels by the end of the sampling duration. See the last plot in Fig. 4 for a comparison of trends among storms. Mean SPM concentrations per watershed area per storm were greatest at Site A and smallest at Site C (Table 4). Differences in mean-ranked SPM concentration per storm between Sites A and C were statistically significant (Table 5).

Temporal patterns in SPM discharge per watershed area followed a unimodal trend for Storms 1 and 3 (Fig. 5). Storm 2 was bimodal. The peak at Site C lagged behind the other two sites in Storms 2 and 4. Storms 2-4 show measures starting at base levels and returning to base levels by the end of the sampling duration. The first value for Storm 4 at Site B is a visual outlier. See the last plot in Fig. 5 for a comparison of trends among storms. Mean SPM yield per watershed area was greatest at Site A and smallest at Site C (Table 4). Differences in mean-ranked SPM yield between Sites A and C were statistically significant (Table 5).

SPM discharge and water discharge were positively related (Fig. 6). Visual observations indicated similarities at each site. So, data were pooled to establish an overall correlation coefficient. There was a positive correlation of the log SPM discharge versus log water discharge plot with statistical significance ($r= 0.94$, $n=136$, $p<0.05$). Eq. 3 describes the regression line

$$SPM = 0.011Q^{1.64} \qquad \text{eq. (3)}$$

where: SPM = SPM discharge (kg h^{-1}), Q = water discharge ($m^3\, h^{-1}$), and the numerical values were least squares estimates of intercept and slope.

Mean total turbidities did not differ among sites (Tables 4&5). The three sites also did not differ with respect to turbidity associated with sand and silt (Tables 4&5), but turbidity associated with clay differed among sites (Table 4). Site A had more turbidity associated with clay than did Site C (Table 5).

Discussion

Findings

The null hypothesis that all sites were the same with regard to water discharge, SPM concentration, SPM discharge, total turbidity, and turbidity associated with sand, silt and clay was rejected. Significant differences were found between the uppermost and lowermost sites. Thus, comparisons discussed hereafter only involve Sites A and C. Site A had greater SPM concentration, SPM discharge, and turbidity associated with clay than did Site C.

LWC responded quickly to storm events. Solo-Gabriele *et al.* (1997) observed similar "quick storm flow" responses to an urban stream near Boston, Massachusetts. These flashy responses to rainfall events were attributed to storm-sewer flows, direct precipitation into the stream, and direct runoff into the channel. Slower responses were attributed from runoff higher in the watershed that takes time to reach the stream.

In suburban areas, vegetation is removed which exposes soil. The removal of trees is associated with an increase in surface runoff (Karr & Schlosser 1978) and SPM (Klein 1979). Trees slow down runoff to a stream, physically intercepting runoff and SPM (Gordon *et al.* 1993). The slowing of runoff to a stream further reduces SPM by reducing inputs from bank-cutting erosion (Trimble 1997), bed scouring (Whipple 1981), and resuspension of sediment (Cardenas *et al.* 1995). Trees also help cover soil from direct rainfall and help stabilize erodible banks (Gordon *et al.* 1993). Thus, one would expect areas in this watershed with higher percent tree cover to have decreased water discharges and SPM.

After trees are removed more impervious areas are developed. Increased impervious area along banktops directly shields soil from being picked up as SPM. However, in LWC's watershed, less than 30 % of the watershed is impervious. Because the entire watershed is not impervious, shielding effects are masked by other SPM contributing processes. Impervious areas increase surface runoff. The increased surface runoff has energy to erode pervious surfaces, increasing SPM. Not only does this directly add SPM to a stream, but it also increases water discharge, gaining energy to scour stream beds, resuspend sediment, and cut stream banks. Thus, one would expect areas in this watershed with greater percent impervious surfaces (≤ 30 %) to have increased water discharges and SPM.

In summary, one would expect impervious surfaces and trees to have opposite effects on SPM. Impervious surfaces would increase SPM and tree cover would decrease SPM.

Hypotheses

Based on assumptions about associations between SPM and land use, one can predict relationships between Sites A and C. The author proposes three hypotheses to explain relationships between SPM and land use. The first hypothesis (H1) assumes either that impervious area and tree cover have no effect on stream properties or that their effects cancel each other, so stream properties do not differ at Sites A and C. The second (H2) assumes that stream properties are associated with impervious area. Site A, with a greater percentage of impervious area would have yielded more water (Simmons &

Reynolds 1982) and more SPM (Klein 1979). The last hypothesis (H3) assumes stream properties are associated with tree cover. Knowing tree cover removal increases SPM (Karr & Schlosser 1978), it is assumed presence of tree cover would decrease in SPM. Thus Site A, with a greater percentage of tree cover would yield less water and less SPM.

Predictions of SPM associated properties based on the previous three hypotheses can help explain SPM contributing processes in LWC (Table 6). Because any detectable differences reject the null hypothesis, more weight needs to be given to differences when shown. So, when differences were observed, a hypothesis with many predictions matching field observations would best explain SPM yield to the stream.

Significant differences in SPM concentration, SPM discharge, and turbidity associated with clay among the upper and lower study sites were evident, so H1 can be rejected. Hubbard *et al.* (1990) suggested that compared to non-forested areas, areas with riparian buffer zones decreased runoff and SPM concentrations per unit area. This was not the case in the current study. Site A had both more tree cover and greater water discharge per watershed area, so H3 can be rejected because its predictions were never supported with observations.

In all three cases when differences between sites were observed, predictions of H2 matched the observed relationships. SPM might be delivered to the stream due to SPM contributing properties in Site A's watershed. Site A had a greater mean water yield per watershed area, which may have allowed more SPM to be carried (Leopold 1994, Jago & Mahamod 1999). Also, the runoff water added downstream of Site A may have been relatively void of SPM. This clean water may have diluted the samples at Site C. The effects of impervious area may have exceeded effects of trees.

Another study of LWC showed possible erosion "hot spots" upstream of Site A (Hillegass, unpub. MS.). Perhaps the buffering of SPM by trees was negligible compared to SPM additions within the stream. Perhaps most SPM was added due to stream channelization, scouring, and resuspension of sediment. Very steep, erodible banks upstream of Site A were observed before the study, as well as evidence of bedload transport throughout the length of the stream (personal observation). Stream channel erosion has been shown to be a major sediment source in urbanizing watersheds (Trimble 1997). Another study of LWC showed evidence of stream banks caving in during storms (Aunins, unpub. MS.). Resuspension of particulate matter could also have been an SPM producing factor (Cardenas *et al.* 1995).

The inability to distinguish differences in total turbidity and turbidity associated with sand and silt may also indicate that the type of SPM in the stream at Site A was not different from Site C. Similar characteristics of turbidity would be expected between sites if the consistency of the SPM were the same. This further supports the idea that SPM was all from one main source upstream of Site A, and it remained the main source between Sites A and B.

Limitations

The lack of large differences among sites in impervious area and tree cover may have led to difficulty in detecting relationships between watershed and SPM. Vandalism, grab sampling, complications in measuring water discharge, and low sample size may have also limited the ability to detect differences in SPM among sites (App.3).

Conclusion

The watershed of Site A tended to produce more storm-related SPM to the stream per watershed area than did the other sites. Thus, I conclude that the primary source of SPM in Little Westham Creek was upstream of Site A. A personal observation of steep, undercut banks and sediment in the bed indicated that the stream banks near the headwaters and just upstream of Site A were highly erodible. If there were no other significant sources of SPM to the stream, then one would expect SPM concentrations to be diluted as water moves downstream from the headwaters. The author proposes that the major source of SPM was upstream of Site A, within a reach starting at the headwaters and extending approximately 500 meters downstream.

To alleviate the sediment loading in Westhampton Lake, it needs to be determined which branch of LWC produces the most SPM to the lake. If the eastern branch produces most of the SPM to the lake, and with careful control and more detailed information on watershed properties, perhaps it can be shown that most of the sediment loading the upper extents of Westhampton Lake comes from the highly erodible banks near the headwaters. Restoration in this portion of stream might help resolve the sedimentation problem in the lake.

Recommendations

The current study provides information to Henrico County Public Works (specifically to Jeff Perry & Keith White) to help rank LWC among other streams in the new stream restoration program. If LWC is ranked high priority in need of restoration, perhaps Henrico County can restore water quality to the stream.

Water quality is low for the eastern branch of LWC. This study indicates the loading of SPM in the watershed of the upper 500 m of stream. Also during the study, there were no observations of fish or benthic invertebrates within the study reach. Minnows were observed in the mainstem during occasional visits (personal observation). Based on a small study in Spring 2000, benthic macroinvertebrate life approximately 10 m downstream of Site A in the eastern branch of LWC appears to be severely impaired as compared to a site of equal elevation in the mainstem (Jordan & Scott, unpub. MS.).

Residents in the study area informed the author of mysterious nighttime stream flushes filling the stream banks a couple of times per year during non-storm periods. Suspected sources of those flushes are either the water tanks at Triangle Shopping Center or the parking lot at Village Shopping Center. Both sites are connected to the headwaters area and have potential to produce large amounts of water to the stream. Visual observation of scouring below a stormwater pipe just below the water tanks indicates excessive discharge from the tanks. To stop this problem, water needs to be released in lower volume and over a longer duration of time. The author suggests construction of a discharge retention pond in the vicinity of the water tanks. This would not only prevent stream channelization, sediment resuspension, and bank erosion by slowing the velocity and volume of water, but it would also serve as a BMP to remove chlorine and other toxins before entering the stream. A stormwater retention pond could serve as a BMP downstream of Village Shopping Center, further helping water quality in the stream with the removal of pollutants and slower release of stormwater.

Along the first 500 m of stream, the banks are being severely eroded. One way to fix that problem would be to lay back the slope of the banks and vegetate them. The laying of riprap, gravel, or some biological alternative with root mats in the stream itself would prevent bed scouring and promote in-stream settling of SPM. The addition of riffle-pool complexes might allow more settling and provide habitat necessary for benthic macroinvertebrate life. Hopefully by minimizing SPM loading of the eastern branch within 500 m of the headwaters will restore water quality to the stream and help resolve the sedimentation problems of Westhampton Lake.

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Table 1. Properties of nested watersheds associated with study sites along Little Westham Creek.

Site	Watershed Area (km^2)	Stream Length (m)	Impervious Area[1] (km^2)	% Impervious Area[1] (%)	Tree Covered Area[2] (km^2)	% Tree Covered Area[2] (%)
A	0.241	555	0.071	30	0.060	25
B	0.307	744	0.082	27	0.072	24
C	0.605	1331	0.160	26	0.096	16

1. Impervious area was estimated with digitized data of area covered by roads, building footprints, and parking lots. 2. Tree cover was estimated with digitized data of area covered by stands of trees, mostly forested areas.

Table 2. Rainfall for each storm. Values are depths of rain (cm) that accumulated in rain gauges during the storms.

Date	Storm[1]	Rain gauge depth (cm)				Accuweather[3] (cm)	Type of Rainfall	Duration (h)
		A	B	C	Mean			
06/17/1999	1	2.0	2.0	1.3	1.8	0.2	Light Drizzle	1
06/29/1999	2	3.3	3.1	3.0	3.1	2.1	Severe T-Storm	4
06/30/1999	3	4.1	3.9	3.8	3.9	3.5	T-Storm	1
07/28/1999	4	1.6	1.6	1.6	1.6	0.4	Drizzle	3
09/16/1999	5	n/a[2]	15.2	13.0	14.1	12.3	Hurricane (Floyd)	60

1. Storm 4 was characterized in graphical figures, but omitted from statistical analysis.
2. n/a means data were not available. 3. Data from http://www.accuweather.com/adcbin/climo_local?nav=home#moremaps . All other measures observed by the author.

Table 3. Values for estimating water discharge based on stage of water measured in the field.

Site	# Samples	SZF	Slope	Intercept	r^2	Mean % Error
A	7	0.1	1.5	-2.4	0.96	0.82
B	4	-7.5	3.0	-4.7	0.99	1.02
C	5	-1.5	2.3	-3.3	1.00	0.71

Table 4. Stream properties at each site. Values represent accumulations throughout storms. Values: mean ± standard deviation in 10^3, and in parentheses, number of observations.

Stream Properties	Site A	 B	 C
Water Discharge (m^3 km^{-2})	8 ± 10 (4)	6 ± 9 (4)	6.± 8 (4)
SPM Concentration (kg min m^{-3} km^{-2})	0.7 ± 0.7 (4)	0.4 ± 0.4 (4)	0.2 ± 0.2 (4)
SPM Discharge (kg km^{-2})	9 ± 12 (4)	6 ± 8 (4)	5 ± 6 (4)
Turbidity (NTU min km^{-2})			
Total	357 ± 386 (4)	336 ± 308 (4)	150 ± 122 (4)
Sand	97 ± 106 (4)	94 ± 72 (4)	42 ± 32 (4)
Silt	132 ± 146 (4)	130 ± 128 (4)	58 ± 47 (4)
Clay	128 ± 134 (4)	112 ± 112 (4)	50 ± 47 (4)

Table 5. Mean ranks of sites for stream properties. Sites were ranked for each storm separately. Sites arranged left to right in order of low to high mean ranks from Friedman's test. Sites not connected by an underline were statistically different.

Property	Mean rank 1	2	3
Water discharge	C B		A
SPM concentration	C	B	A
SPM discharge	C	B	A
Turbidity			
Total	C	B A	
Sand	C	A	B
Silt	C	B A	
Clay	C	B	A

Table 6. Relationships of stream properties at Site A compared to Site C according to 1) no net effect of impervious area or tree cover on SPM, 2) SPM associated with % impervious area, 3) SPM associated with % tree cover. More weight given to differences when observed. Asterisks indicate where the prediction matches the observed relationship.

	Relation to watershed			
Stream Property per Area	1	2	3	Observed
Water discharge	A=C*	A>C	A<C	A=C
SPM concentration	A=C	A>C*	A<C	A>C
SPM discharge	A=C	A>C*	A<C	A>C
Turbidity				
Total	A=C*	A>C	A<C	A=C
Sand	A=C*	A>C	A<C	A=C
Silt	A=C*	A>C	A<C	A=C
Clay	A=C	A>C*	A<C	A>C

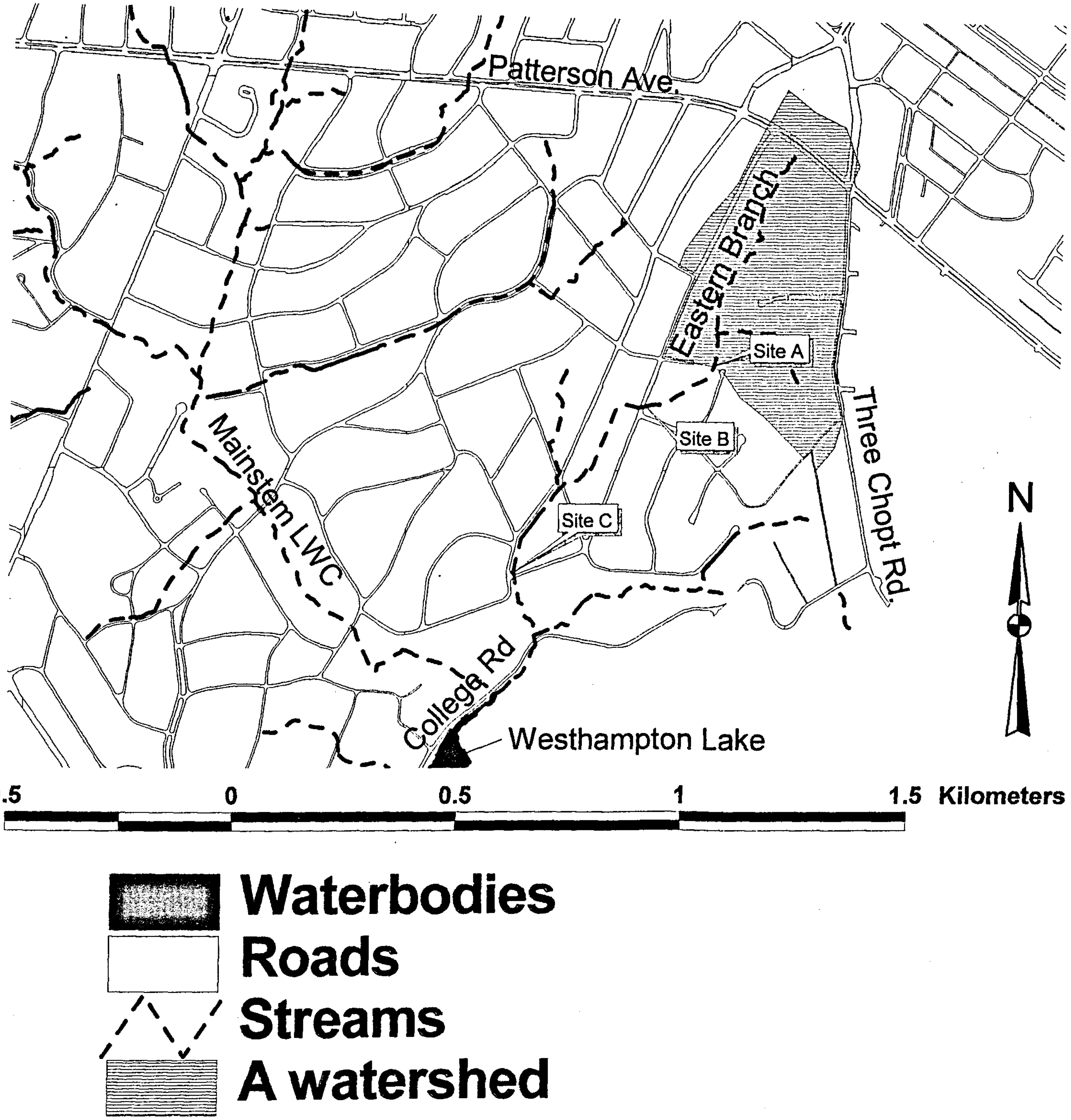


Fig.1a. Watershed of Site A along the eastern branch of Little Westham Creek.

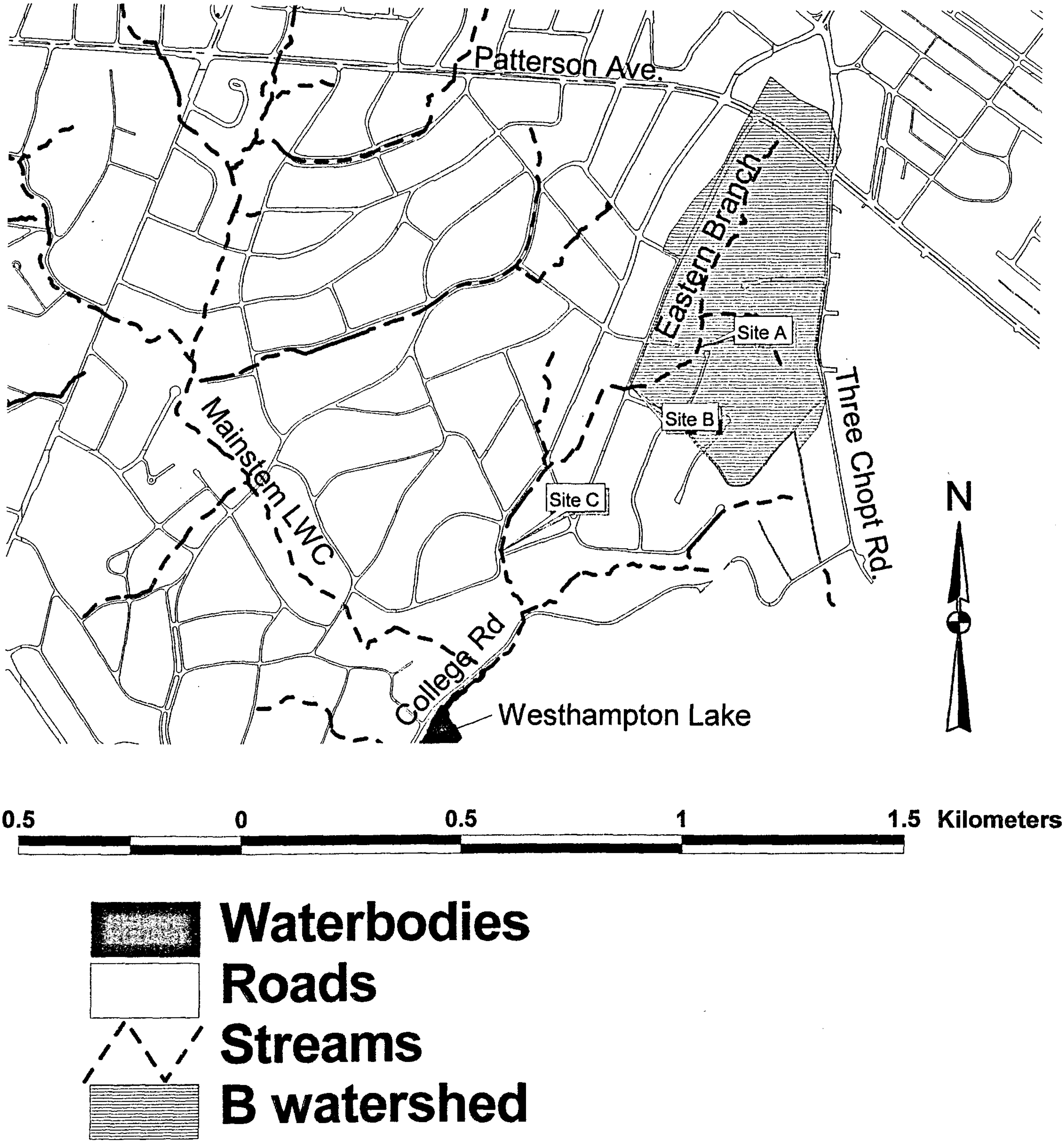


Fig.1b. Watershed of Site B along the eastern branch of Little Westham Creek.

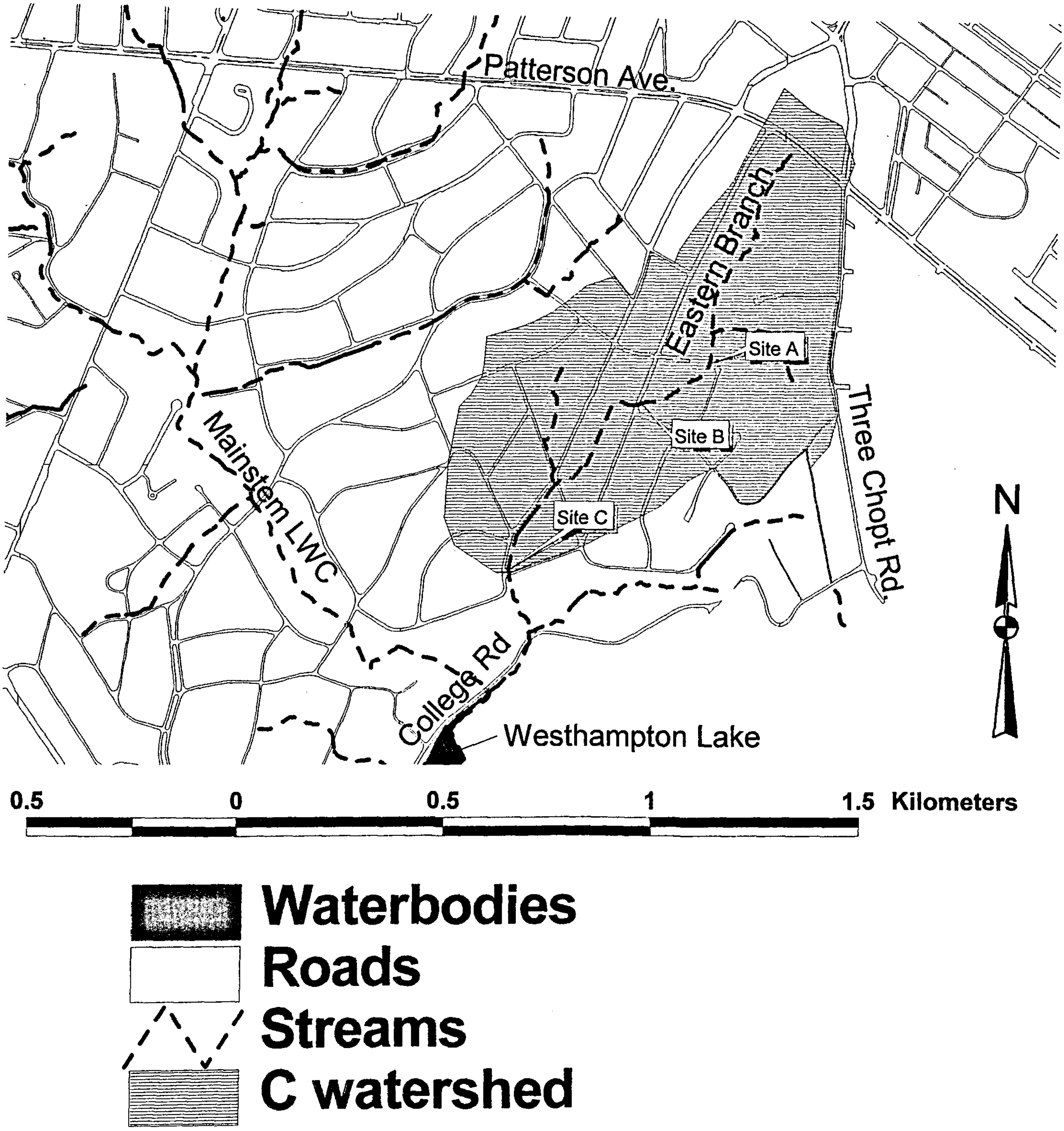


Fig.1c. Watershed of Site C along the eastern branch of Little Westham Creek.

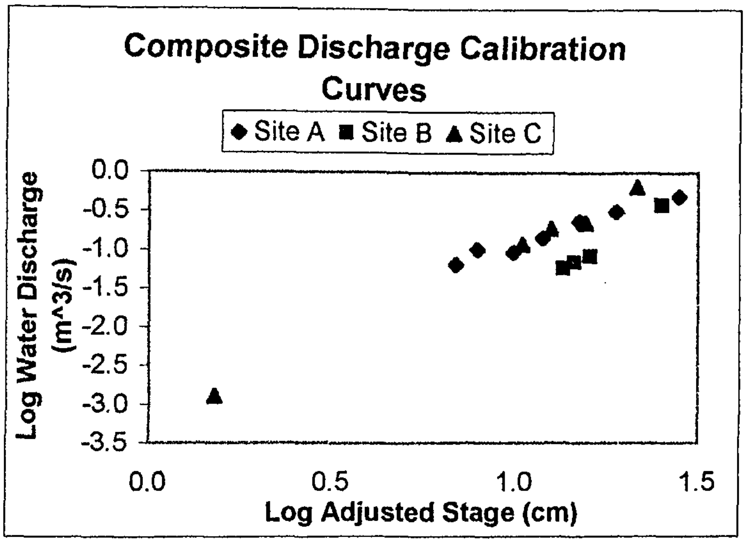


Fig 2. Log water discharge ($m^3 s^{-1}$) versus log adjusted stage (cm). Stage has been adjusted to account for the actual stage where there is zero flow over the weir.

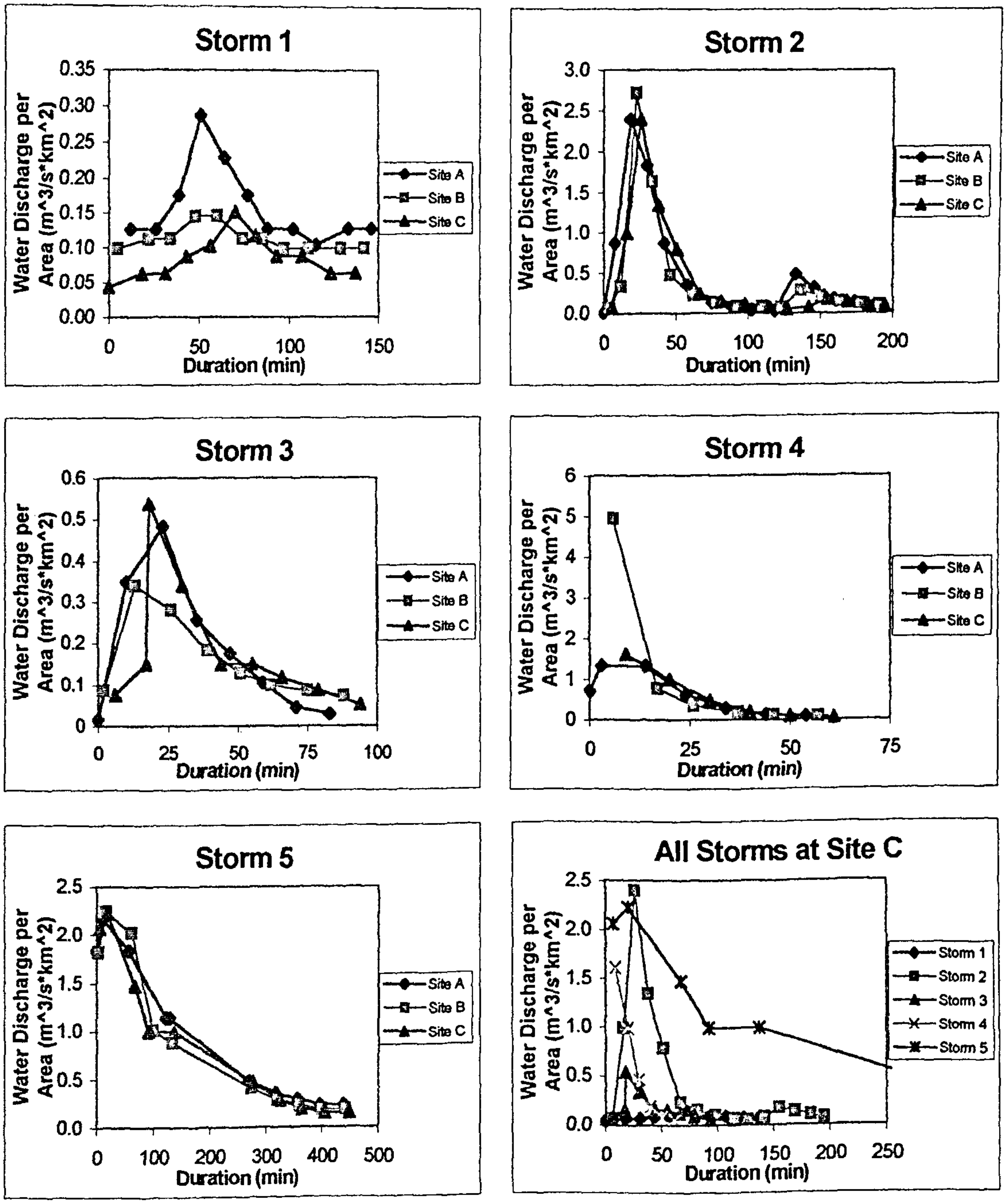


Fig.3. Water discharge per watershed area for each storm (m^3 sec^{-1} km^{-2}). The last plot summarizes water discharge from all the storms at Site C.

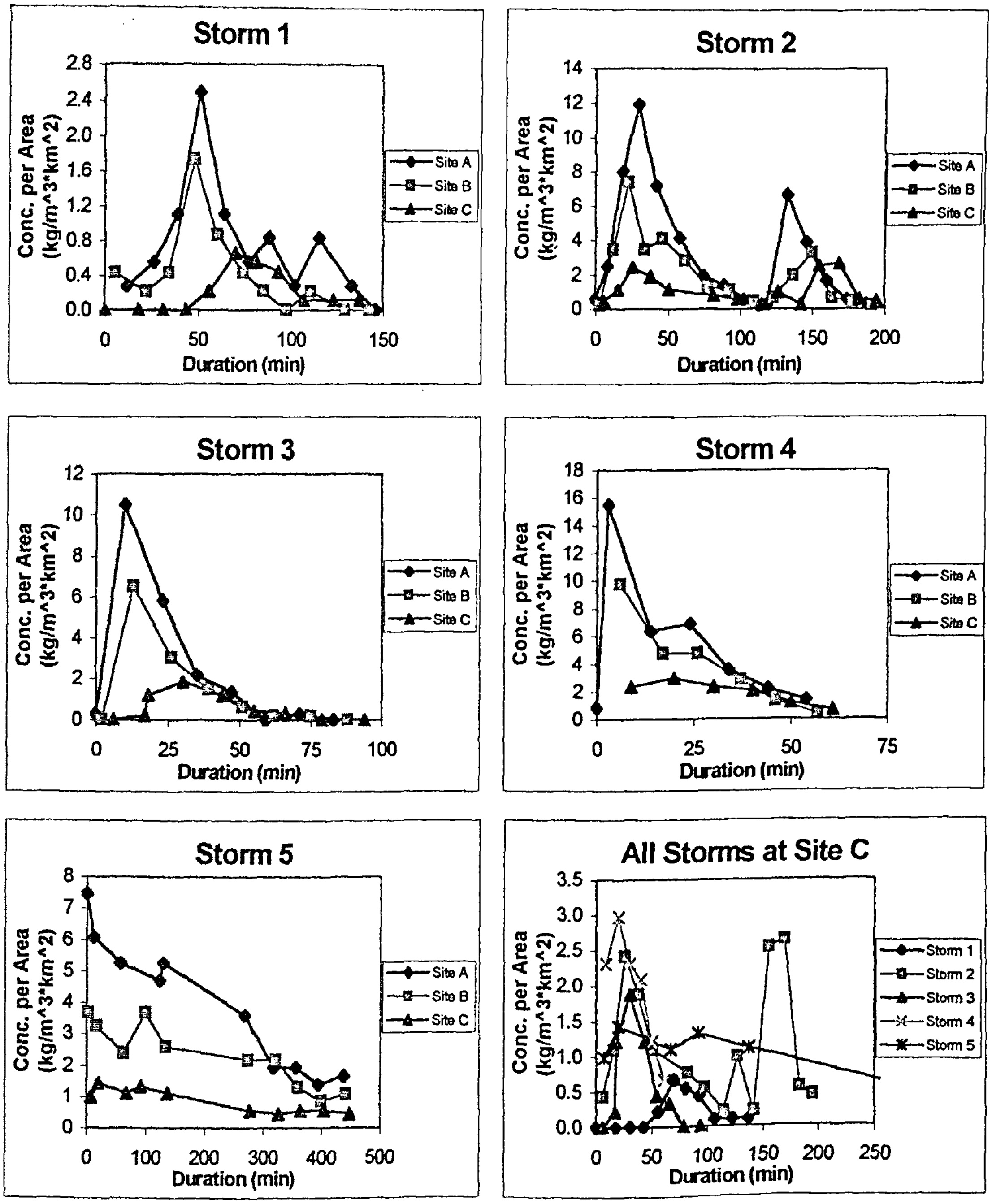
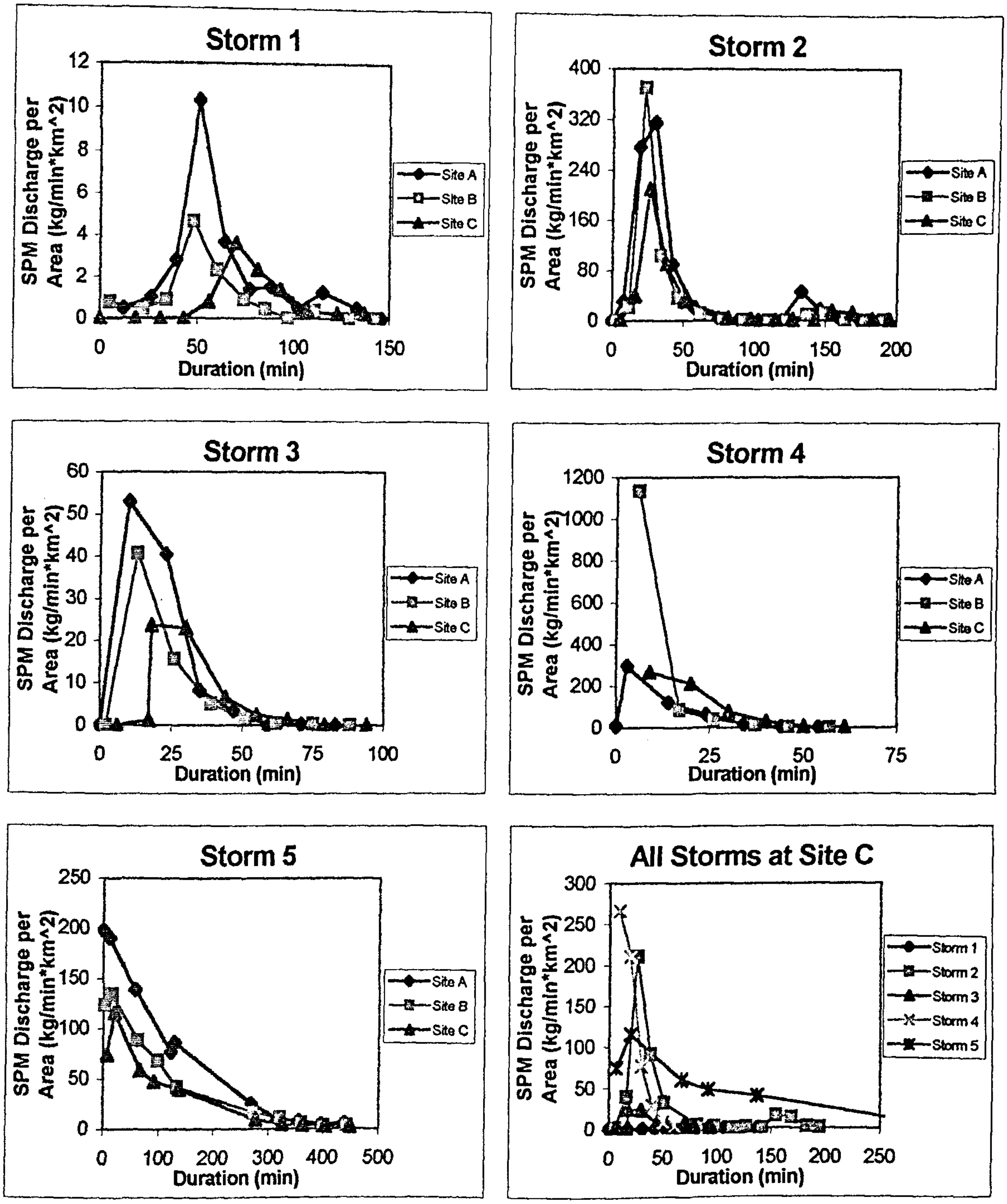


Fig.4. SPM concentrations per watershed area (kg m^{-3} km^{-2}) for each storm. The last plot summarizes SPM concentrations from all the storms at Site C.


Storm 1

Storm 2

Storm 3

Storm 4

Storm 5

All Storms at Site C

Fig.5. SPM discharges per watershed area (kg min^{-1} km^{-2}) for each storm. The last plot summarizes SPM discharge from all the storms at Site C.

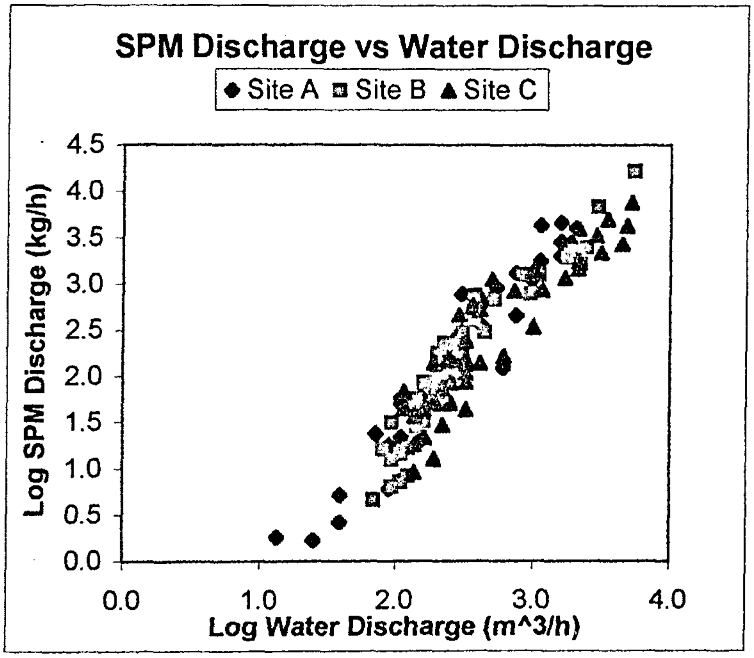
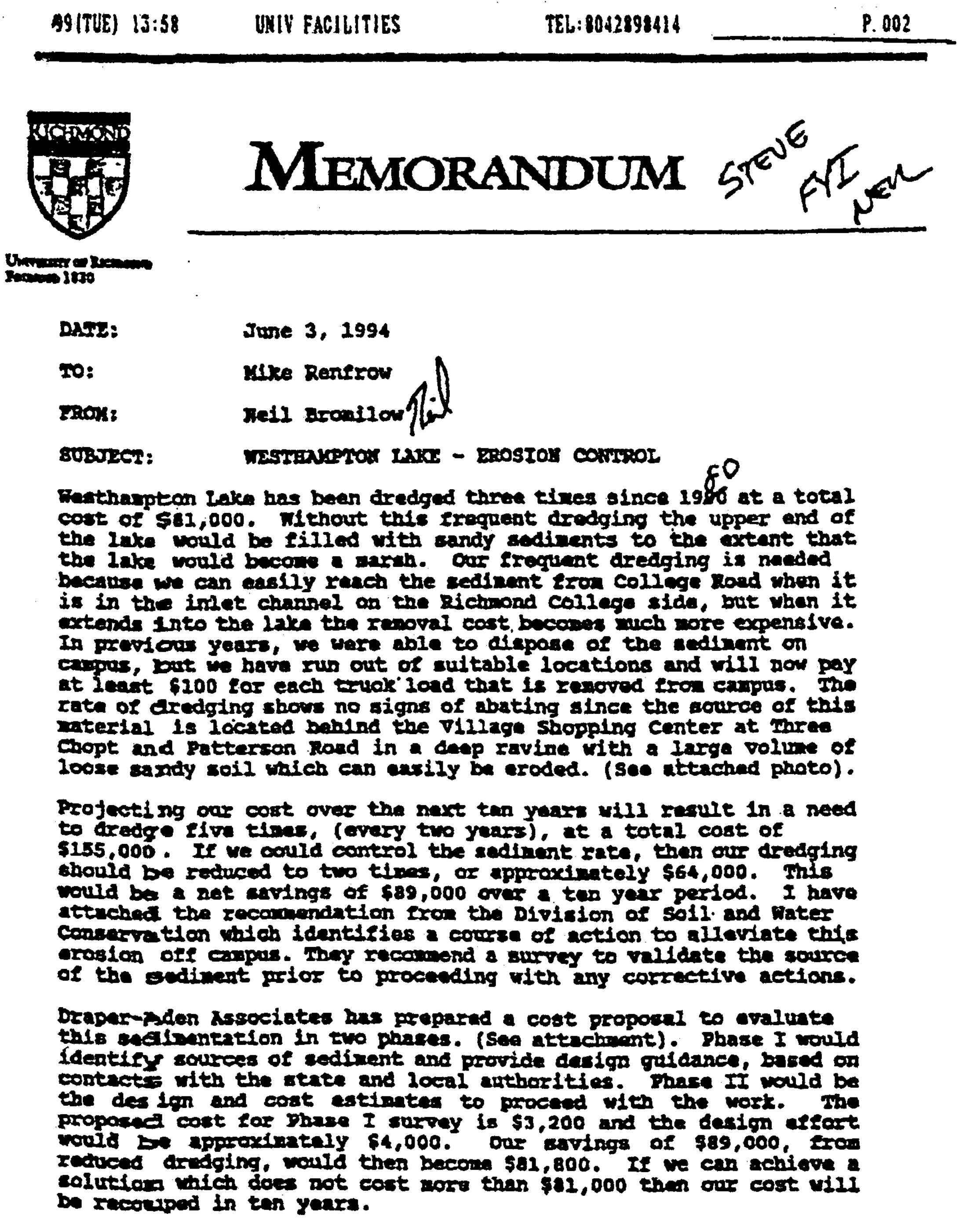


Fig.6. SPM discharge (kg h^{-1}) as a function of water discharge (m^3 h^{-1}) for each site.

Appendix 1. Letter to Mike Renfrow concerning the cost of dredging Westhampton Lake and stopping sediment at its source behind Village Shopping Center, the headwaters of Little Westham Creek's eastern branch.



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University of Richmond
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MEMORANDUM

STEVE FYI NEIL

DATE: June 3, 1994

TO: Mike Renfrow

FROM: Neil Bromilow Neil

SUBJECT: WESTHAMPTON LAKE - EROSION CONTROL

Westhampton Lake has been dredged three times since 1986 80 at a total cost of $81,000. Without this frequent dredging the upper end of the lake would be filled with sandy sediments to the extent that the lake would become a marsh. Our frequent dredging is needed because we can easily reach the sediment from College Road when it is in the inlet channel on the Richmond College side, but when it extends into the lake the removal cost becomes much more expensive. In previous years, we were able to dispose of the sediment on campus, but we have run out of suitable locations and will now pay at least $100 for each truck load that is removed from campus. The rate of dredging shows no signs of abating since the source of this material is located behind the Village Shopping Center at Three Chopt and Patterson Road in a deep ravine with a large volume of loose sandy soil which can easily be eroded. (See attached photo).

Projecting our cost over the next ten years will result in a need to dredge five times, (every two years), at a total cost of $155,000. If we could control the sediment rate, then our dredging should be reduced to two times, or approximately $64,000. This would be a net savings of $89,000 over a ten year period. I have attached the recommendation from the Division of Soil and Water Conservation which identifies a course of action to alleviate this erosion off campus. They recommend a survey to validate the source of the sediment prior to proceeding with any corrective actions.

Draper-Aden Associates has prepared a cost proposal to evaluate this sedimentation in two phases. (See attachment). Phase I would identify sources of sediment and provide design guidance, based on contacts with the state and local authorities. Phase II would be the design and cost estimates to proceed with the work. The proposed cost for Phase I survey is $3,200 and the design effort would be approximately $4,000. Our savings of $89,000, from reduced dredging, would then become $81,800. If we can achieve a solution which does not cost more than $81,000 then our cost will be recouped in ten years.

1

WESTHAMPTON LAKE - EROSION CONTROL
June 3, 1994

I recommend that we pursue the following course of action:

- o Authorize Draper-Aden to proceed with Phase I which will identify the source and quantities of sediment coming into the lake for a cost of $3,200.
- o Present this information to Henrico County Public Works officials with the intention that they would construct the erosion control facilities, but we would donate the funds to do it. This is necessary since we do not have contractual status in the ravine behind the Village Shopping Center where this work needs to be done.
- o This design and survey should be accomplished in the next 12 months, with funding being initiated in the summer of 1995. This will reduce the cost of the next scheduled dredging.

NFB:jej

Appendix 2. Theoretical cross-section of a stream transect for measuring water discharge from Gordon *et al.* (1993). Mean velocity was measured at 0.6D from the water surface, standard for smaller streams. Only the mean velocity was measured at each vertical because time was limited by quickly diminishing flows. Verticals were evenly spaced at 0.2 m when possible.

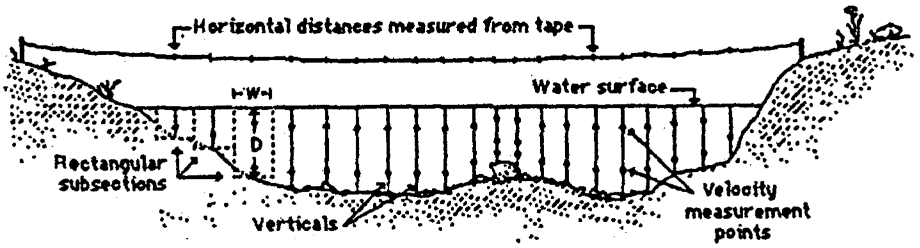


Figure 5.18. Definition of terms used in computing discharge from current meter measurements (see text). Note variable spacing of verticals

Appendix 3. Limitations of the study and ideas for future study.

Limitations

Only one stream was studied, but a control stream could have better shown effects of similar landscape properties. A study stream with greater differences in impervious area and tree cover may have shown better relationships between those watershed properties and SPM. Because differences were so small among sites (Table 1), statistical power may have been low. Sites with greater differences among sites in percent impervious area and percent tree cover may have provided higher statistical power.

Also, sites were not truly independent. Water and SPM passed through Site A and continued in the stream past Sites B and C. The statistical tests used assume independent samples. When studying nested sites along a stream, even though sites have different watershed properties, they are not exclusive of each other. This is a major assumption in the current study.

Vandalism may have caused problems with detecting differences in SPM among sites. This study was done in a residential area, prone to vandalism and intermittent creek modification. One rain gauge was stolen, some were filled up when it did not rain, and some were emptied when it had rained. Children were suspected to have been tampering with rain gauges. This would have misrepresented the relationships of rainfall per storm and SPM per storm. A small dam had been built within two meters upstream of Site A before two of the storms. These dams could have impeded flow at low flows, and added extra SPM at higher flows, because they washed out at high flows. A study with a control in an area with limited access to the watershed could have prohibited unwanted interference. Also, storm-sewer water and groundwater were not taken into consideration in this analysis. Therefore, the sources of water in the study may not have all been from within the drainage area drawn from a topographical map. Water from unidentified sources may have had watershed properties not counted for in this study, causing poor relationships between watershed properties and SPM characteristics.

Water discharge sampling error may have caused difficulty in detecting differences in SPM. Water discharge estimates were sometimes greater than 25 % in error. Staff gauges were not in deep, broad pools because there were not any such pools nearby and out of site from potential vandals. The stream was narrow, so the number of sampling points along a transect were limited. Optimally there should be at least 20 sampling points along a transect at a v-notch weir (Rantz 1982, Clesceri *et al.* 1998). Instead, weirs already present in the stream were chosen. These weirs were not v-notched, and were not completely even along the bottom. Also, rocks and other obstacles were sometimes on the weir or directly upstream which may have impeded flow. Error in discharge measures may have yielded falsely high or low water discharges and therefore SPM discharges.

Grab sampling stream water may have caused difficulty in detecting differences in SPM among sites. Martin *et al* (1992) found that surface grab samples underestimated concentrations of SPM as compared to flow-weighted composite samples (independent of stream velocity upon sampler intake). Using grab samples may have underestimated SPM concentrations. This effect may have been magnified because samples were taken with a small mouth bottle rather than a wide mouth bottle. Grab samples for this study were taken near the bottom of flow because depths were less than 5 cm at base flow. Because sand is the heaviest constituent of SPM able to fit in the sample bottle, it is found closest to the stream bed. Lighter particles may have been homogeneously distributed in the water column. This may have made the samples falsely heavy for TSS, overestimating SPM concentration. Also, stream samples were taken in series rather than at the same time for all sites. The water samples were taken approximately every ten minutes at each site. Because LWC responded quickly to storm events, more frequent sampling may have been needed. This could have better distinguished curves of the hydrographs and sedigraphs, providing better estimates of storm-wise yields. Additionally, SPM analysis should have been done within a few days of the storm (Clesceri *et al.* 1998). Due to a turbidity meter breaking, turbidity measures had to be taken on previously frozen samples. Freezing the samples may have caused particles to bind that were not originally bound together. This may have caused errors in turbidity estimates, making it difficult to detect differences among sites.

Low sample size may also have caused difficulty in detecting differences in SPM among sites. A study of rainstorms in every season over a few years would have been preferred. There could have been seasonal effects on SPM. Fine particulate organic matter can be more prevalent in SPM estimates in summer (Wallace *et al.* 1991). This may have yielded higher SPM measures as compared to storms in other seasons. Also, with a larger number of samples there could have been more replicates for statistical analysis. With year-round sampling, perhaps storms could be separated by rainfall intensity and duration. There were a small number of samples in the study (5 storms) due to the drought in the Richmond area in summer 1999. The lack of replication and separation of storms made it necessary to use non-parametric statistical tests, which generally have lower statistical power than normal-theory tests. Differences among sites in water yield, total turbidity, and turbidity associated with sand and silt may have been detected had more powerful tests been appropriate.

Future study

This study provides good baseline data for further analysis. Future studies may include control streams with less accessibility by the public and with more detectable differences in watershed properties. The goal of the current study was to compare storm-related SPM at three sites along one stream. If one wanted to determine whether tree cover and impervious area had effects on storm-related SPM, a study with a different design would be necessary. For instance, one stream could consist of completely forested area, another with mostly impervious area, and another with tree cover removed and no impervious area. Those conditions might better determine effects of tree cover and impervious area on storm-related SPM in a stream. In addition, studying many streams in a similar area of similar size, flow, and climatic conditions and varying tree cover and impervious area would give the experiment replication necessary to significantly determine effects of tree cover and impervious area on SPM.

Attention should also be taken to stormwater pipe inputs and their sources. Sites might be chosen farther apart so that the effects of varying watershed properties could be magnified. Watershed properties such as slope and soil erodibility might be taken into consideration. Water samples might be taken synchronously and more frequently within a storm. More storms should be measured, and sampled for as long as a year or more. Staff gauges might be located in deeper, broader pools, and water discharges could be calibrated with more detail. Site-specific turbidity could be calibrated, and possibly used as a measure of SPM concentration to reduce time-intensive lab analysis.

Appendix 4. Raw data for stream properties.

Sample					Turbidity			t0	t1	t10		Settlement		Dry Weight			
Storm	Storm date	Site	Time	St.Ga.Dpth	Temp	Sample	Vial	Turbidity	Turbidity	Turbidity	Dilution	@1min	@10min	Tube+Sed.	Tube	Tube	
(#)	mm/dd/yyyy	(#)	(24h)	(cm)	(C)	(#)	(#)	(NTU)	(NTU)	(NTU)	(X)	(ml)	(ml)	(g)	(#)	(g)	
2	06/17/1999	A	1348	4	24	1	4	9	7.4	4.4	1	0	0	11.587	1	11.586	
2	06/17/1999	A	1402	4	24	2	1	11	8.8	4.5	1	0	0.01	11.734	2	11.732	
2	06/17/1999	A	1416	6	24	3	2	96	65	30	1	0.01	0.07	11.947	3	11.943	
2	06/17/1999	A	1427	7	24	4	4	280	190	85	1	0.02	0.09	11.854	4	11.845	
2	06/17/1999	A	1440	6	24	5	3	140	110	45	1	0.01	0.03	11.764	5	11.760	
2	06/17/1999	A	1453	5	24	6	1	50	39	19	1	0.01	0.01	11.827	24	11.825	
2	06/17/1999	A	1504	4	24	7	2	45	34	17	1	0	0.01	11.953	7	11.950	
2	06/17/1999	A	1518	4	24	8	4	20	15	8.4	1	0	0.01	11.712	8	11.711	
2	06/17/1999	A	1531	3.5	24	9	3	18	12	6.6	1	0	0	11.824	9	11.821	
2	06/17/1999	A	1549	4	24	10	1	12	9.2	5.3	1	0	0.01	11.913	10	11.912	
2	06/17/1999	A	1602	4	24	11	2	10	8.9	6.1	1	0	0	11.737	11	11.737	
2	06/17/1999	B	1341	3.5	23.8	1	3	9	6.9	4.1	1	0	0	11.588	1	11.586	
2	06/17/1999	B	1358	4	24	2	2	9.1	7.4	4.7	1	0	0	11.733	2	11.732	
2	06/17/1999	B	1410	4	LOST	3	LOST	LOST	LOST	LOST	1	0	0.01	11.945	3	11.943	
2	06/17/1999	B	1424	5	24	4	4	190	130	55	1	0.05	0.1	11.853	4	11.845	
2	06/17/1999	B	1436	6	24	5	1	190	130	60	1	0.01	0.1	11.764	5	11.760	
2	06/17/1999	B	1450	4	24	6	3	110	75	33	1	0.01	0.07	11.764	6	11.752	
2	06/17/1999	B	1501	4	24.5	7	2	65	40	20	1	0.01	0.01	11.951	7	11.950	
2	06/17/1999	B	1513	3.5	24.2	8	4	50	32	17	1	0	0.01	11.711	8	11.711	
2	06/17/1999	B	1527	3.5	24.5	9	3	19	11	6.6	1	0	0.01	11.822	9	11.821	
2	06/17/1999	B	1545	3.5	24.5	10	2	13	11	6.3	1	0	0	11.912	10	11.912	
2	06/17/1999	B	1558	3.5	24.5	11	1	12	9.2	4.9	1	0	0	11.737	11	11.737	
2	06/17/1999	C	1336	4	23.8	1	1	4.8	4.5	3.6	1	0	0	11.633	12	11.635	
2	06/17/1999	C	1354	5	24	2	4	6.4	5.5	3.9	1	0	0	11.743	13	11.743	
2	06/17/1999	C	1407	5	23.5	3	3	6.5	5	3.7	1	0	0	11.718	14	11.719	
2	06/17/1999	C	1419	6	23.8	4	2	15	13	6.3	1	0	0	11.801	15	11.801	
2	06/17/1999	C	1432	6.5	24	5	1	26	19	11	1	0	0.03	11.784	16	11.782	
2	06/17/1999	C	1446	8	24	6	4	220	170	75	1	0.02	0.1	11.733	17	11.727	
2	06/17/1999	C	1457	7	24	7	3	270	190	80	1	0.01	0.08	12.023	18	12.018	
2	06/17/1999	C	1509	6	24	8	2	95	85	45	1	0.01	0.07	11.807	19	11.803	
2	06/17/1999	C	1523	6	23	9	1	45	32	16	1	0.01	0.03	11.679	20	11.678	
2	06/17/1999	C	1539	6	24	10	4	20	16	8.6	1	0	0.02	11.926	21	11.925	
2	06/17/1999	C	1563	5	24	11	3	12	9.5	4.5	1	0	0.01	11.857	22	11.856	
3	06/29/1999	A	1952	1	24	1	3	50	25	9	1	0.01	0.06	11.763	5	11.761	
3	06/29/1999	A	2000	15	24	2	4	290	140	60	1	0.03	0.10	11.836	24	11.827	
3	06/29/1999	A	2011	30	23.5	3	4	330	220	110	5	0.10	0.17	11.963	7	11.964	
3	06/29/1999	A	2022	26	24	4	3	310	190	100	5	0.09	0.15	11.757	8	11.714	
3	06/29/1999	A	2034	15	24	5	1	170	120	55	5	0.06	0.12	11.861	9	11.825	
3	06/29/1999	A	2050	8	LOST	6	LOST	LOST	LOST	LOST	LOST	0.05	0.10	11.931	10	11.916	
3	06/29/1999	A	2107	4	24	7	4	450	400	280	1	0.01	0.06	11.747	11	11.740	
3	06/29/1999	A	2121	3	24	8	3	500	400	240	1	0.01	0.07	11.643	12	11.638	
3	06/29/1999	A	2136	2	LOST	9	LOST	LOST	LOST	LOST	LOST	0.01	0.02	11.591	1	11.589	
3	06/29/1999	A	2151	1.5	24.5	10	1	95	80	50	1	0.01	0.01	11.736	2	11.734	
3	06/29/1999	A	2205	10	LOST	11	LOST	LOST	LOST	LOST	LOST	0.08	0.13	11.970	3	11.948	
3	06/29/1999	A	2218	7.5	LOST	12	LOST	LOST	LOST	LOST	LOST	0.03	0.10	11.862	4	11.848	
3	06/29/1999	A	2232	5	LOST	13	LOST	LOST	LOST	LOST	LOST	0.02	0.08	11.767	5	11.761	
3	06/29/1999	A	2246	4	23.5	14	4	330	280	150	1	0.01	0.06	11.829	24	11.827	
3	06/29/1999	A	2300	3.5	LOST	15	LOST	LOST	LOST	LOST	LOST	0.01	0.02	11.955	7	11.954	
3	06/29/1999	B	1955	2	24	1	2	25	9.2	3.6	5	0.02	0.05	11.943	23	11.942	
3	06/29/1999	B	2004	9	LOST	2	LOST	LOST	LOST	LOST	LOST	0.09	0.17	11.760	2	11.734	
3	06/29/1999	B	2015	25	24	3	1	220	190	100	5	0.09	0.18	11.960	3	11.946	
3	06/29/1999	B	2026	20	24	4	3	280	160	70	5	0.06	0.14	11.864	4	11.848	
3	06/29/1999	B	2038	11	LOST	5	LOST	LOST	LOST	LOST	LOST	0.05	0.12	11.780	5	11.761	
3	06/29/1999	B	2054	7	LOST	6	LOST	LOST	LOST	LOST	LOST	0.07	0.10	11.840	24	11.827	
3	06/29/1999	B	2110	4.5	24	7	2	180	120	55	5	0.01	0.08	11.960	7	11.954	
3	06/29/1999	B	2125	3	24	8	1	80	40	22	5	0.01	0.06	11.719	8	11.714	
3	06/29/1999	B	2142	3	24	9	4	40	23	12	5	0.01	0.02	11.827	9	11.825	
3	06/29/1999	B	2155	2.5	24	10	3	110	80	40	1	0.01	0.02	11.919	10	11.916	
3	06/29/1999	B	2209	8	LOST	11	LOST	LOST	LOST	LOST	LOST	0.02	0.09	11.749	11	11.740	
3	06/29/1999	B	2222	6.5	24	12	2	140	95	40	5	0.03	0.09	11.653	12	11.638	
3	06/29/1999	B	2236	5	LOST	13	LOST	LOST	LOST	LOST	LOST	0.01	0.08	11.750	13	11.747	
3	06/29/1999	B	2250	4	24	14	1	70	45	21	5	0.01	0.06	11.725	14	11.723	
3	06/29/1999	B	2303	3.5	LOST	15	LOST	LOST	LOST	LOST	LOST	0.01	0.03	11.805	15	11.804	
3	06/29/1999	C	1958	5	25	1	1	45	28	9.3	5	0.03	0.10	11.789	16	11.785	
3	06/29/1999	C	2006	20	24	2	2	55	18	6	5	0.03	0.12	11.738	17	11.728	
3	06/29/1999	C	2018	30	25	3	1	370	270	110	5	0.07	0.15	12.044	18	12.022	
3	06/29/1999	C	2030	23	25	4	2	160	100	37	5	0.07	0.14	11.823	19	11.806	
3	06/29/1999	C	2043	18	25	5	3	190	150	85	5	0.01	0.11	11.692	20	11.682	
3	06/29/1999	C	2059	10	25.6	6	2	450	310	150	5	0.05	0.16	11.893	22	11.860	-Whirlpak leaked, Sample omitted from Conc&Turb
3	06/29/1999	C	2114	8	24	7	1	120	65	24	5	0.01	0.09	11.935	21	11.928	
3	06/29/1999	C	2130	6.5	25	8	1	330	250	120	5	0.01	0.03	11.947	23	11.942	
3	06/29/1999	C	2147	6	25	9	2	40	24	14	5	0.01	0.03	11.736	2	11.734	
3	06/29/1999	C	2159	4.5	25	10	3	75	60	25	3	0.01	0.03	11.956	3	11.946	
3	06/29/1999	C	2214	5.5	25	11	1	50	17	6	5	0.01	0.03	11.850	4	11.848	
3	06/29/1999	C	2227	8.5	25	12	2	390	280	110	5	0.03	0.06	11.784	5	11.761	
3	06/29/1999	C	2241	7.5	24	13	1	18	8.1	4.9	11.5	0.08	0.12	11.861	24	11.827	
3	06/29/1999	C	2256	6.5	25.5	14	3	110	65	25	5	0.01	0.08	11.959	7	11.954	
3	06/29/1999	C	2307	5.5	25	15	1	150	100	31	5	0.01	0.03	11.718	8	11.714	
4	06/30/1999	A	1221	1	14	1	2	5.7	2.5	1.8	5	0.00	0.01	11.943	23	11.942	
4	06/30/1999	A	1231	8	22	2	3	290	230	110	5	0.09	0.18	11.772	2	11.734	
4	06/30/1999	A	1244	10	20	3	1	60	45	18	5	0.10	0.12	11.967	3	11.946	
4	06/30/1999	A	1256	6.5	23	4	2	380	270	130	1	0.04	0.08	11.856	4	11.848	
4	06/30/1999	A	1308	5	18.5	5	2	22	14	7.3	5	0.01	0.05	11.766	5	11.761	
4	06/30/1999	A	1320	3.5	21	6	3	8.6	7	4.1	5	0.01	0.02	11.827	24	11.827	
4	06/30/1999	A	1332	2	24	7	3	80	65	30	1	0.01	0.02	11.955	7	11.954	
4	06/30/1999	A	1344	1.5	22	8	1	27	21	10	1	0.01	0.01	11.714	8	11.714	
4	06/30/1999	B	1223	3	24	1	3	65	31	18	1	0.01	0.01	11.826	9	11.825	
4	06/30/1999	B	1234	9	24	2	1	320	230	95	5	0.08	0.17	11.946	10	11.916	
4	06/30/1999	B	1247	8	24	3	2	260	170	75	5	0.04	0.11	11.754	11	11.740	
4	06/30/1999	B	1300	6	24	4	1	190	110	60	5	0.03	0.08	11.645	12	11.638	
4	06/30/1999	B	1312	4.5	24	5	3	70	50	28	5	0.01	0.05	11.750	13	11.747	
4	06/30/1999	B	1323	3.5	24	6		130	110	65	1	0.01	0.04	11.724	14	11.723	
4	06/30/1999	B	1336	3	24	7	2	110	85	40	1	0.01	0.01	11.805	15	11.804	
4	06/30/1999	B	1349	2.5	24	8	3	66	40	16	1	0.01	0.01	11.785	16	11.786	
4	06/30/1999	C	1227	5.5	25	1	2	70	28	8.8	1	0.01	0.02	11.941	23	11.942	
4	06/30/1999	C	1238	8	25	2	3	25	9.1	4.4	5	0.01	0.05	11.736	2	11.734	

4	06/30/1999	C	1239	15	24	3	3	120	40	12	6	0.06	0.11	11.957	3	11.946
4	06/30/1999	C	1251	12	25	4	3	320	190	70	6	0.04	0.15	11.865	4	11.848
4	06/30/1999	C	1305	8	24.5	5	1	70	45	14	6	0.02	0.10	11.772	6	11.761
4	06/30/1999	C	1316	8	25	6	2	160	100	40	5	0.02	0.09	11.831	24	11.827
4	06/30/1999	C	1327	7	25.5	7	3	60	33	16	6	0.01	0.06	11.957	7	11.954
4	06/30/1999	C	1340	6	25	8	1	75	60	29	6	0.01	0.03	11.714	8	11.714
4	06/30/1999	C	1355	4.5	25	9	2	19	12	7.5	6	0.01	0.01	11.626	9	11.626
6	07/28/1999	A	2004	13	23	1	1	190	95	33	5	0.01	0.08	11.945	23	11.942
6	07/28/1999	A	2007	20	LOST	2	LOST	LOST	LOST	LOST	LOST	0.10	0.19	11.790	2	11.734
6	07/28/1999	A	2018	20	22.9	3	3	250	180	90	5	0.07	0.10	11.969	3	11.946
6	07/28/1999	A	2028	12	LOST	4	LOST	LOST	LOST	LOST	LOST	0.06	0.11	11.873	4	11.848
6	07/28/1999	A	2038	7	23	5	2	140	120	55	5	0.01	0.06	11.774	6	11.761
6	07/28/1999	A	2048	4	24	6	2	460	370	230	5	0.01	0.06	11.835	24	11.827
6	07/28/1999	A	2058	3	23	7	4	380	280	150	1	0.01	0.04	11.959	7	11.954
6	07/28/1999	B	2010	32	23	1	4	360	250	120	5	0.07	0.19	11.759	8	11.714
6	07/28/1999	B	2021	14	23	2	1	600	340	190	6	0.04	0.10	11.847	9	11.825
6	07/28/1999	B	2030	9	23	3	2	390	280	155	6	0.05	0.10	11.938	10	11.916
6	07/28/1999	B	2041	6	23.6	4	3	140	110	65	5	0.04	0.06	11.753	11	11.740
6	07/28/1999	B	2050	4	23.2	5	4	80	66	30	5	0.01	0.07	11.644	12	11.638
6	07/28/1999	B	2101	3	23.5	6	1	65	55	23	6	0.01	0.08	11.749	13	11.747
6	07/28/1999	C	2013	25	25	1	4	160	75	29	5	0.09	0.13	11.806	16	11.785
6	07/28/1999	C	2024	20	24.8	2	2	190	130	60	5	0.07	0.13	11.765	17	11.728
6	07/28/1999	C	2034	14	25	3	3	130	90	36	6	0.05	0.11	12.043	18	12.022
6	07/28/1999	C	2044	9	24.5	4	1	160	130	70	5	0.05	0.09	11.825	19	11.806
6	07/28/1999	C	2054	6	24.5	5	3	100	90	50	5	0.03	0.06	11.693	20	11.682
6	07/28/1999	C	2105	4.5	24.5	6	n/a	95	70	35	5	0.01	0.07	11.934	21	11.928
7	09/16/1999	A	914	25	22	1	3	400	280	140	5	0.07	0.09	11.761	2	11.734
7	09/16/1999	A	926	28	22	2	4	130	95	50	5	0.07	0.09	11.968	3	11.946
7	09/16/1999	A	1011	25	22	3	2	110	85	34	5	0.05	0.06	11.867	4	11.848
7	09/16/1999	A	1116	18	22	4	1	110	80	40	5	0.04	0.07	11.778	5	11.761
7	09/16/1999	A	1123	18	22	5	3	140	95	45	5	0.04	0.08	11.961	23	11.942
7	09/16/1999	A	1343	10	22.6	6	4	95	65	32	6	0.04	0.05	11.693	20	11.680
7	09/16/1999	A	1431	8	22.5	7	3	50	40	18	5	0.02	0.04	11.961	7	11.954
7	09/16/1999	A	1510	7	23	8	1	70	55	23	5	0.02	0.05	11.722	8	11.715
7	09/16/1999	A	1550	6	23.5	9	1	45	40	21	6	0.01	0.02	11.830	9	11.825
7	09/16/1999	A	1632	6	24	10	3	38	33	17	5	0.01	0.04	11.921	10	11.915
7	09/16/1999	B	917	21	23	1	1	200	120	65	6	0.03	0.10	11.757	11	11.740
7	09/16/1999	B	930	23	23.5	2	2	190	130	60	5	0.02	0.10	11.760	13	11.745
7	09/16/1999	B	1016	22	24	3	3	100	80	38	5	0.03	0.11	11.734	14	11.723
7	09/16/1999	B	1053	16	23	4	1	190	190	95	5	0.01	0.10	11.820	15	11.803
7	09/16/1999	B	1127	16	24	5	2	90	70	31	5	0.02	0.09	11.797	16	11.785
7	09/16/1999	B	1347	10	23.5	6	3	120	80	37	6	0.04	0.06	11.738	17	11.728
7	09/16/1999	B	1436	8	24	7	1	70	65	35	6	0.01	0.07	12.032	18	12.022
7	09/16/1999	B	1514	7	24	8	2	75	60	17	6	0.01	0.06	11.812	19	11.806
7	09/16/1999	B	1554	6	23.5	9	3	210	160	70	1	0.01	0.04	11.931	21	11.927
7	09/16/1999	B	1636	6	24	10	1	240	190	60	1	0.01	0.02	11.863	22	11.858
7	09/16/1999	C	921	28	23	1	1	450	370	190	5	0.01	0.06	11.951	23	11.942
7	09/16/1999	C	934	29	23	2	2	750	600	340	6	0.01	0.08	11.747	2	11.734
7	09/16/1999	C	1021	24	23	3	3	400	320	170	5	0.02	0.06	11.956	3	11.946
7	09/16/1999	C	1046	20	23	4	1	450	300	120	5	0.03	0.06	11.860	4	11.848
7	09/16/1999	C	1131	20	23	5	4	450	350	180	6	0.02	0.07	11.771	5	11.761
7	09/16/1999	C	1351	14	23	6	2	280	210	110	6	0.01	0.07	11.831	24	11.826
7	09/16/1999	C	1440	11	23	7	3	370	280	140	5	0.01	0.04	11.958	7	11.954
7	09/16/1999	C	1518	9	23	8	1	280	250	130	5	0.01	0.04	11.720	8	11.715
7	09/16/1999	C	1559	8	23	9	4	170	140	80	6	0.01	0.02	11.830	9	11.826
7	09/16/1999	C	1643	8	23	10	2	110	95	60	6	0.00	0.01	11.919	10	11.915

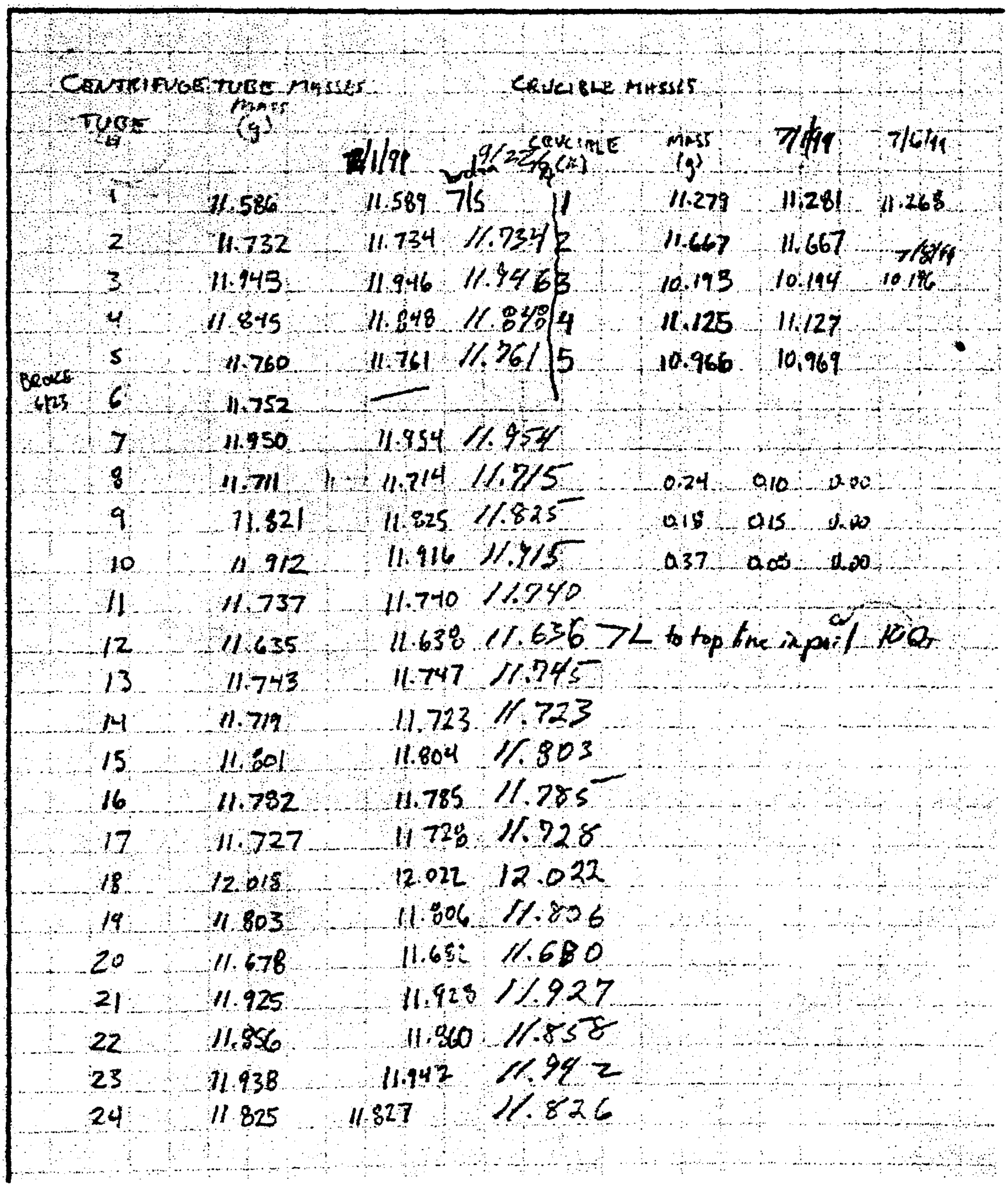
Appendix 5. Raw rain data.

Storm	Site	Time (24h)	Time (min after 1331)	Height (inches)	
2	A	1348	19	0.05	*note: Storm 1 not used
		1403	32	0.05	
		1416	45	0.05+	
		1428	57	0.05+	
		1441	70	0.05+	
		1537	126	0.08	
			(min after 1331)		
2	B	1331	0	0.00	
		1354	23	0.05	
		1411	40	0.05+	
		1425	54	0.05+	
		1437	66	0.05+	
		1547	136	0.08	
			(min after 1331)		
2	C	1331	0	0.00	
		1353	22	0.05	
		1408	37	0.05	
		1420	49	0.05+	
		1433	62	0.05+	
			(min after 1950)		
3	A	1952	2	0.30	
		2000	10	0.75	
		2012	22	1.00	
		2023	33	1.10	
		2035	45	1.15	
		2051	61	1.15	
		2137	106	1.15	
		2152	121	1.20	
		2206	135	1.25	
		2219	148	1.25	
		2233	162	1.25	
		2247	176	1.28	
			(min after 1950)		
3	B	1955	5	0.40	
		2005	15	0.80	
		2015	25	1.00	
		2027	37	1.05	
		2039	49	1.10	
		2055	65	1.10	
		2138	108	1.10	
		2156	126	1.15	
		2210	140	1.20	
		2224	154	1.20	
		2239	169	1.20	
		2251	181	1.23	
			(min after 1950)		
3	C	1958	8	0.60	
		2008	18	0.90	
		2019	29	1.00	
		2031	41	1.05	

		2044	54	1.05
		2100	70	1.05
		2145	115	1.08
		2200	130	1.15
		2213	143	1.15
		2228	158	1.18
		2242	172	1.18
		2256	186	1.18
			(min after 1220)	
4	A	1221	1	1.50
		1232	12	1.58
		1245	25	1.58
		1257	37	1.60
		1345	85	1.60
		1400	100	1.60
			(min after 1220)	
4	B	1224	4	1.50
		1235	15	1.53
		1248	28	1.53
		1301	41	1.53
		1350	90	1.53
			(min after 1220)	
4	C	1228	8	1.48
		1239	19	1.48
		1252	32	1.48
		1305	45	1.48
		1355	95	1.49
			(min after 1720)	
5	A	1729	9	0.02
		1747	27	0.02
		1814	54	0.02
		1834	74	0.02
		1846	86	0.05
		1858	98	0.05
		1911	111	0.05
			(min after 1720)	
5	B	1733	13	0.02
		1752	32	0.02
		1818	58	0.02
		1838	78	0.05
		1851	91	0.05
		1902	102	0.05
		1916	116	0.05
			(min after 1720)	
5	C	1737	17	0.02
		1755	35	0.02
		1821	61	0.02
		1842	82	0.05
		1854	94	0.05
		1906	106	0.05
		1918	118	0.05
			(min after 2000)	
6	A	2005	5	0.55
		2019	19	0.60
		2059	59	0.63
			(min after 2000)	
6	B	2011	11	0.60
		2021	21	0.60
		2102	62	0.63
			(min after 2000)	
6	C	2014	14	0.60
		2024	24	0.60
		2106	66	0.63

			(min after 0830)		
7	A	835		4.75	
		915		0.30	emptied
		927		0.35	
		1011		0.62	
		1116		0.85	
		1123		0.85	
		1343		0.15	kids suspected to have dumped gauge
		1431		0.15	
		1510		0.15	
		1550		0.15	
		1632		0.15	
			(min after 0830)		
7	B	840		4.75	
		918		0.30	emptied
		931		0.38	
		1016		0.62	
		1053		0.75	
		1127		0.85	
		1347		1.25	
		1435		1.25	didn't read carefully enough?
		1514		1.23	
		1554		1.23	
		1636		1.23	
			(min after 0830)		
7	C	830		4.00	
		922		0.33	emptied
		935		0.40	
		1021		0.60	
		1046		0.66	
		1131		0.80	
		1351		1.10	
		1440		1.10	
		1518		1.10	
		1559		1.10	
		1643		1.10	

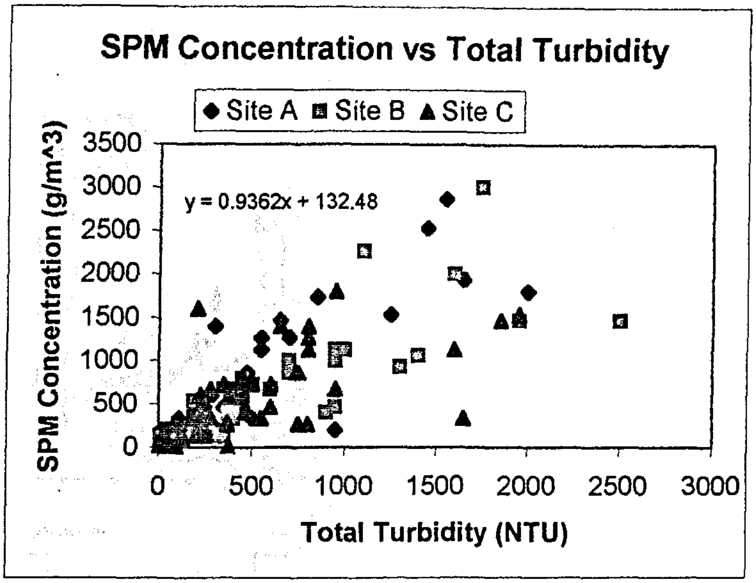
Appendix 6. Weights of centrifuge tubes measured three times during TSS analysis. Mean difference was approximately ± 0.003 g, within the detection limits of the balance.



CENTRIFUGE TUBE MASSES — CRUCIBLE MASSES

	TUBE #	MASS (g)	[illegible]/1/99	9/22/99	CRUCIBLE (#)	MASS (g)	7/1/99	7/6/99
	1	11.586	11.589	7/5	1	11.279	11.281	11.268
	2	11.732	11.734	11.734	2	11.667	11.667	7/8/99
	3	11.943	11.946	11.946	3	10.193	10.194	10.196
	4	11.845	11.848	11.848	4	11.125	11.127	
	5	11.760	11.761	11.761	5	10.966	10.969	
BROKE 6/23	6	11.752						
	7	11.950	11.954	11.954				
	8	11.711	11.714	11.715		0.24	0.10	0.00
	9	11.821	11.825	11.825		0.18	0.15	0.00
	10	11.912	11.916	11.915		0.37	0.05	0.00
	11	11.737	11.740	11.740				
	12	11.635	11.638	11.636	7L to top line in pail w/ [illegible]			
	13	11.743	11.747	11.745				
	14	11.719	11.723	11.723				
	15	11.801	11.804	11.803				
	16	11.782	11.785	11.785				
	17	11.727	11.728	11.728				
	18	12.018	12.022	12.022				
	19	11.803	11.806	11.806				
	20	11.678	11.682	11.680				
	21	11.925	11.928	11.927				
	22	11.856	11.860	11.858				
	23	11.938	11.942	11.942				
	24	11.825	11.827	11.826				

Appendix 7. Relationship of SPM concentration to total turbidity.

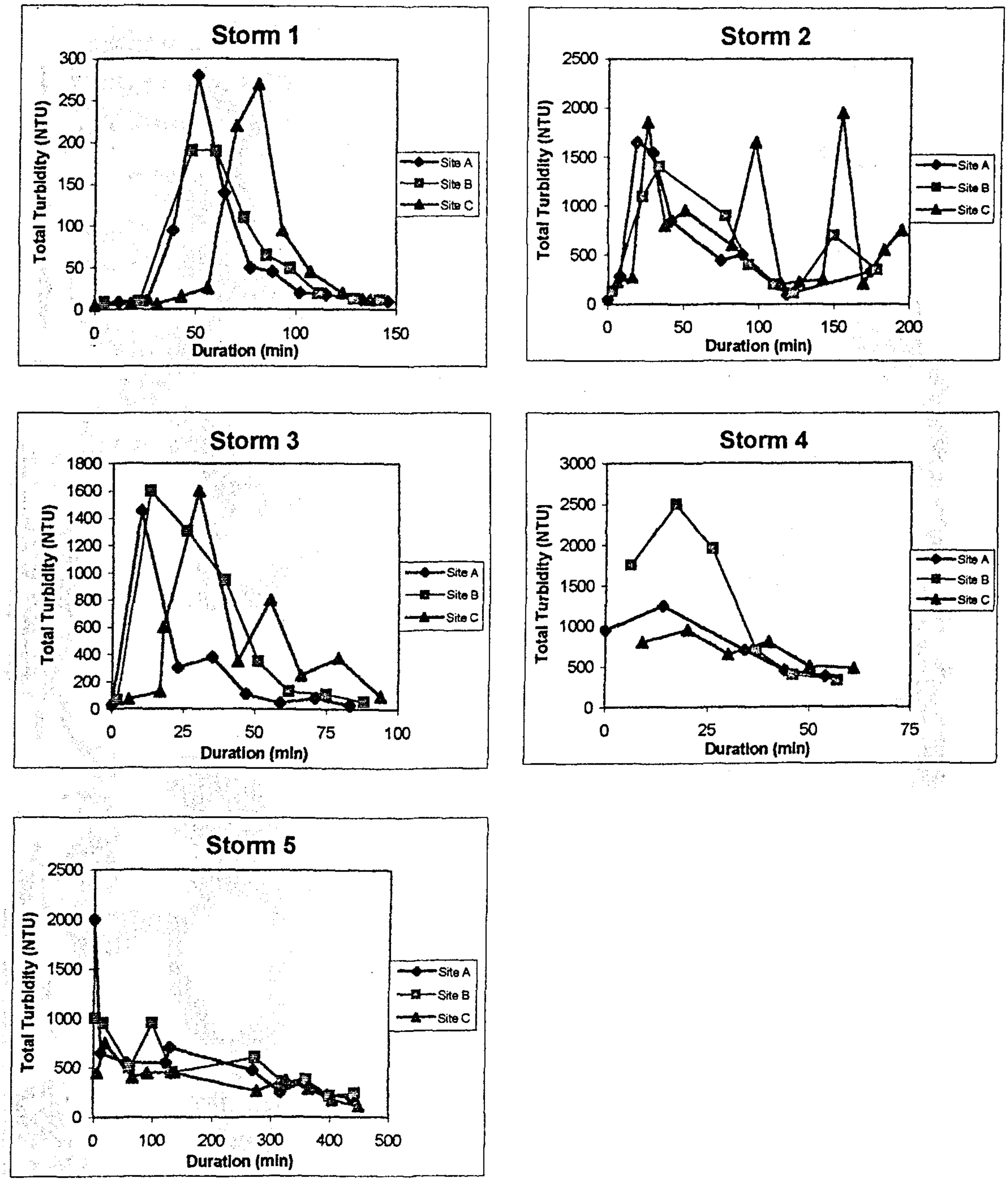


SPM concentration and total turbidity were positively related. The relationship of sediment concentration to total turbidity was visually similar among all three sites. Data were pooled to establish an overall correlation coefficient. There was a positive correlation of SPM concentration versus total turbidity plot with statistical significance ($r = 0.78$, $n=136$, $p<0.05$). Eq. 4 describes the regression line

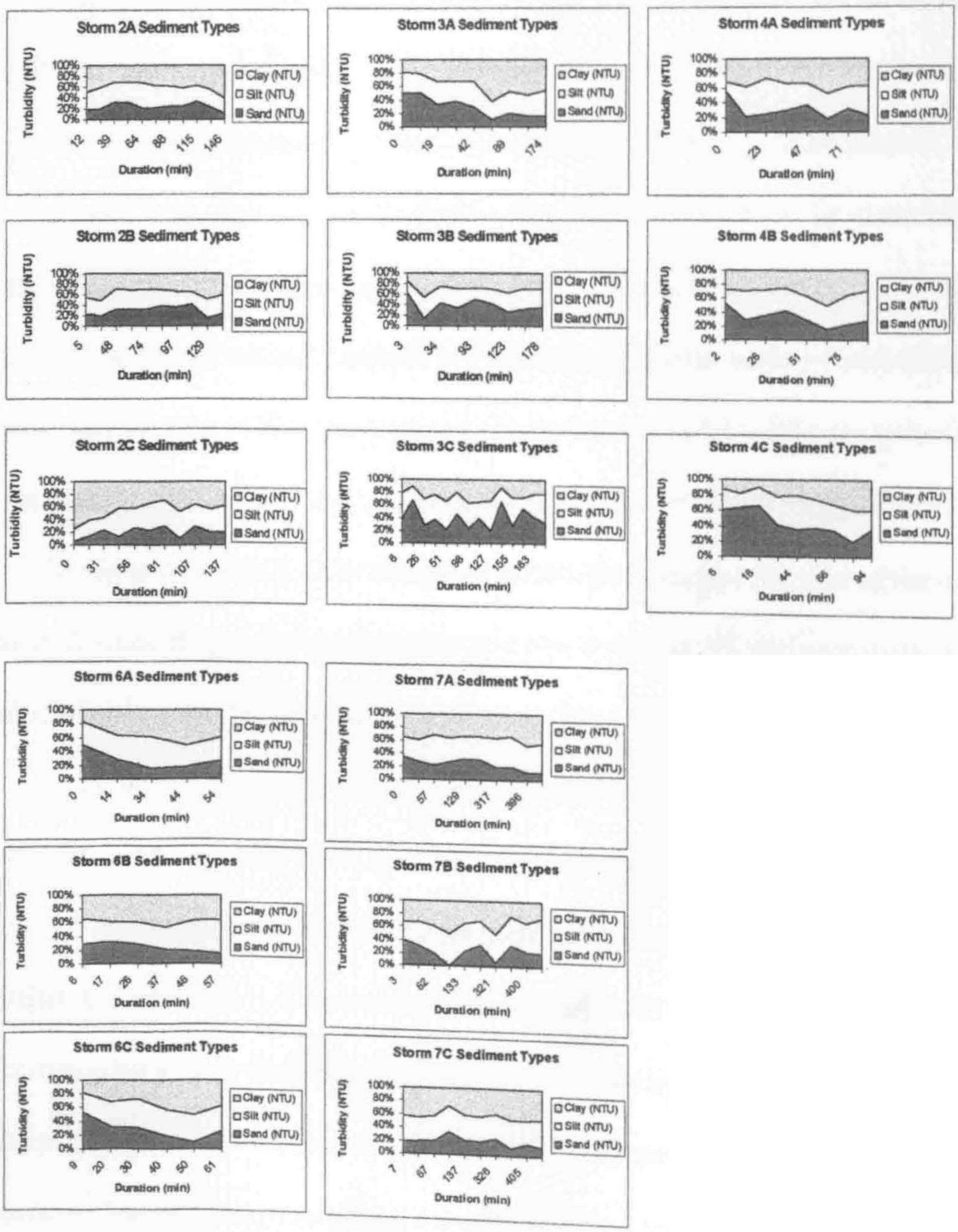
$$y = 0.9362x + 132.48 \qquad \text{eq. (4)}$$

where: Y was SPM concentration, and x was total turbidity.

Appendix 8. Total turbidity (NTU) versus duration (min) at each site for each storm.



Appendix 9. Sediment types as a fraction of total turbidity at each site for each storm. The thickness of each shaded area indicated percent contribution to the total turbidity attributed to sand, silt, and clay.



Appendix 10. Critique and appropriateness of statistical tests used.

In order to detect differences among sites, data were ranked according to storm in an attempt to eliminate the large variation among storms. Because storms ranged from small drizzles to a hurricane, there was much variation among storms that were likely to have masked differences among sites. The variables of interest, or treatments, were sites, not storms. Thus, storms were blocked to eliminate their effect on the comparison of sites. The specific statistical test used was Friedman's non-parametric ANOVA for randomized blocks without replication. This test ranks each variate (Site) within each block (Storm) (Zar 1999). For instance, the storm-wise SPM yield was ranked among sites during a particular storm, assigning the site with the lowest value of SPM yield a 1 and the highest value a 3. This was done for every storm, and the sum of the squares of the rank sums at each site were used to compute a statistic X^2, and compared to critical value of chi square for statistical significance (Zar 1999).

In the current study, it was only of interest whether there were differences among sites. Specific absolute values were not as important as the relative trends of the sites. Most of the assumptions of an ANOVA were avoided by using non-parametric statistics (Sokal & Rohlf 1981). Two assumptions that still held were sampling at the site was random according to the total distribution of possible samples representative of that site under that specific condition, and sampling was independent. Samples were indeed random. For instance, a sampling occasion at Site A had an equal chance of having a high, low, or intermediate value on the distribution of possible sample values representing that site (Gowan, pers. comm.). In other words, it was random as to how representative was that specific sample of Site A during that particular storm. Samples were also independent of each other. Whether a sample taken at Site A was on the high or low end of the distribution of possible samples taken at the site on that occasion did not affect the location on the sampling distribution at Site B (Gowan, pers. comm.).

If Friedman's test found significant differences, a non-parametric equivalent of Tukey's test of honestly significant differences (HSD) was used with ranked data to determine specifically which sites were different. Multiple comparisons in general compare differences among means between all possible pairs (Sokal & Rohlf 1981). In the case of the test used, it is conservative in the fact that it has low power to detect differences (Gowan, pers. comm.). In the current study, the assumption was made of preference for Type II error over Type I. The null hypothesis was only rejected when there were definite differences, and there was error by failing to reject the null hypothesis when it was actually false (Sokal & Rohlf 1981). In other words, the multiple comparisons test used in the current study fails to detect differences when they may actually exist. Thus, when differences were found, they were probably real differences.

The multiple comparisons test in the current study tests for significance by comparing the calculated q statistic, q, to the critical value for three variates (sites) with α=0.05 (Zar 1999). The q statistic is calculated for each pair using the following equation:

$$q = (R_B - R_B)\, SE^{-1} \qquad \text{eq. (4)}$$

where: q is the pair-wise q statistic, R_B is the larger rank sum of the pair, R_B is the smaller rank sum of the pair, and SE is the standard error.

Standard error is calculated using the following equation:

$$SE = (ba(a + 1)\ 12^{-1})^{0.5} \qquad \text{eq. (5)}$$

where: SE is the standard error for multiple comparison for non-parametric randomized blocks, a is the number of variates (sites), and b is the number of blocks (storms) (Zar 1999).

If the pair-wise calculated q is greater than the critical value, then the null hypothesis that the pair is the same is rejected (Zar 1999).

In the current study, this comparison was used on ranked data to test differences between sites. Differences were found between Sites A and C in SPM concentration, SPM discharge, and turbidity associated with clay. When the null hypothesis was rejected, Site A had larger values than Site C. Thus, the goal of comparing sites was obtained and the trends were supported with statistical significance.

Brief Autobiography

John R. Jordan, Jr., son of John and Brenda Jordan was born on June 25, 1976 in Richmond, Virginia. He grew up in Chesterfield County, Virginia and attended Midlothian High School in Midlothian, Virginia. After graduating in 1994 he continued his education at Randolph-Macon College. He graduated in May, 1998 with a Bachelor of Science degree in Biology and Environmental Studies. He enrolled in graduate school at University of Richmond in Fall 1998. This thesis completes his work for the Master of Science degree in Biology. He is currently employed as an environmental scientist at Jordan Consulting Engineers in Richmond, Virginia.