SEDIMENT STORAGE AND TRANSPORT IN THE MAINSTEM POTOMAC RIVER BETWEEN POINT OF ROCKS AND SENECA DAM

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Prepared by:
Interstate Commission on the Potomac River Basin

Leslie L. Shoemaker
Technical Services Unit Staff

and

Andrew J. Miller, Ph.D
University of Maryland, Baltimore County

Interstate Commission on the Potomac River Basin
Paul Eastman, Executive Director
Suite 300
6110 Executive Blvd.
Rockville, Maryland 20852

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EXECUTIVE SUMMARY

The objectives of this study were to examine the processes and magnitude of sediment transport and storage between Point of Rocks and Seneca Dam. The effect of the dynamics of sediment movement on incremental reductions in upstream sediment load were also addressed.

- Only a small fraction of the total eroded material within a watershed appears at the watershed outlet during the span of a year. Sediment delivery ratio is related to the size of the watershed. The factors which cause the difference between sediment production and delivery are the processes of transport and storage of sediment. Quantifying the amount of storage within the system will help determine the improvements that can be anticipated from the implementation of nonpoint source control programs focusing on sediment control.

- The study area examined is the reach between Point of Rocks and Seneca Dam. Although a small component of the Potomac River Basin as a whole, the study reach forms the crucial link between the upstream watersheds and the Potomac Estuary.

- Data analysis of upstream versus downstream suspended sediment loads (the Potomac River at Point of Rocks and the Monocacy River versus the Potomac River at Chain Bridge), collected by USGS during water years 1979-1981, indicated time varying storage of sediment in the study reach.

- The nature of the stored material indicated by this analysis was unknown, but if comprised predominantly of silt and clay, storage could have significant implications for the transport of associated nutrients.

- The examination of this three year data set also indicated that the intervening drainage (not accounted for by Point of Rocks and the Monocacy River at Jug Bridge) has a very high effective sediment yield. The sediment produced by this intervening drainage has the least distance to travel to reach the Potomac Estuary. Programs which target sediment controls should include this area.

- The in-channel storage of fine grained sediment observed during the field survey (June-August 1985) did not indicate significant storage of silt and clay during this period when compared with the average annual load at Chain Bridge (approximately 2% of the average annual load).

- Combined channel-bottom and channel-margin storage of silt and clay during the period of the field survey was equivalent to a larger percentage (7.7%) of the average annual suspended-sediment load at Chain Bridge.

- Despite frequent exchange of thin layers of sediment between the channel margins and the river, the characteristic residence time of sediment stored in channel margins is longer than the characteristic residence time of sediment stored on the channel bottom. The longer residence time causes a longer time lag between input at the source and delivery at the lower end of the reach. The quantity of sediment involved is not large enough for this time lag to have an important effect on the total delivery of sediment and nutrients to tidewater.

- Because of the relatively small quantity of silt and clay size sediment measured in the field, the large storage observed in the analysis of the USGS data is probably due also to stored sand and the combined error of the 3 stations. If sand comprises a significant portion of the larger storage the question of its transport time is no longer pertinent to the transport of nutrients.

- When sediment storage data are combined with measured values of phosphorus, the total extractable phosphorus in margin storage represents 1.6% of the 1984 phosphorus load and 2.0% of the 1983 phosphorus load. Total in-channel storage, the most easily mobilized storage component, when compared with phosphorus loads measured at Chain Bridge, result in 0.4% of the 1984 load and 0.5% of the 1983 load.

I. INTRODUCTION

This report describes the characteristics and magnitudes of sediment storage in the mainstem Potomac River between Point of Rocks and Seneca Dam (Figure 1). The motivation for this investigation is the need to determine the effects of upstream nonpoint source control practices on the quality of the receiving waters of the Potomac Estuary.

The processes which deliver sediment and associated nutrients will be examined in detail. Emphasis will be placed on transport processes in the mainstem of the Potomac River. Transport processes have been suggested (Smith and Shoemaker, 1984) to have significant impact on the attenuation of sediment delivery to the Potomac Estuary. The section of the mainstem studied in this report provides detailed data on one section of the river. By closely examining this component of the sediment transport process and related storage we can better explain the magnitude of these processes.

An example is used below to illustrate the magnitude of sediment delivery. Since agricultural best management practices (BMPs) are by and large oriented to erosion control as a means to control sediment associated nutrients the discussion will focus on sediment transport.

When management programs are applied on a field site, or numerous field sites, several questions arise as to the impact of these programs downstream. If, as in the case of Maryland's existing program, nonpoint source (NPS) control measures are applied to high nutrient contributing sites, within high priority watersheds, what will be the overall reduction in nutrient loads to the receiving waters? What is the connection between an increment of reduction on a farmer's field and an increment of reduction at the watershed outlet? When can NPS managers expect to observe the results of their efforts at the watershed level?

To illustrate the processes of sediment movement let us briefly examine the Monocacy River basin, a sub-basin of the Potomac River. If best management practices applied throughout the Monocacy River watershed would reduce total sediment loss from fields in an average year by 20%, what would be the overall reduction for the watershed if measured at Frederick near the watershed outlet?

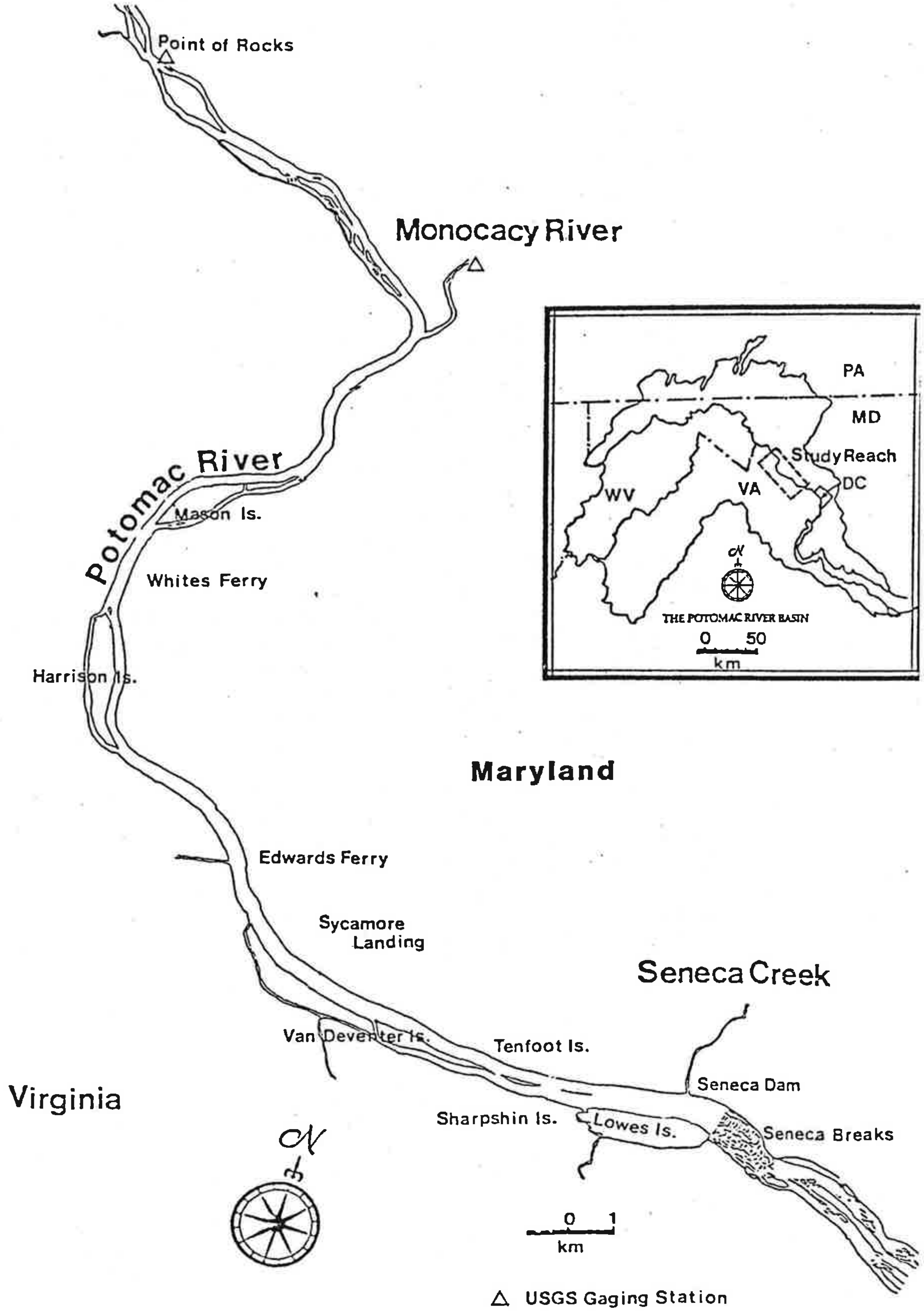


Figure 1: Study Area and Location of Gaging Stations

The graph shown in Figure 2 indicates roughly what the relationship between watershed size and sediment delivery is on an average year. On a watershed level only a small fraction of the total eroded material appears at the watershed outlet during the span of a year. Using a standard empirical relationship such as this, for the 817 mi2 (2116 km2) watershed of the Monocacy River at Frederick, the delivery ratio would be less than 4%. This suggests that a 20% reduction at the field level would result in a much smaller quantity of sediment reduction on an average year when measured at the watershed outlet. The implication is that for large watersheds the control of one ton of sediment at the field level will result in a much smaller reduction at the watershed level.

The factors which cause the difference between sediment yield and sediment delivery are the processes of transport and storage of sediment. Since transport is occurring throughout the period when NPS controls are being implemented, reductions in downstream water quality will be delayed for some period of time and will depend on the size of the watershed. This delay could be described as the inertia of the system.

A detailed discussion of the indications of basin wide storage in the Potomac River basin is contained in Smith and Shoemaker (1984). The problem of quantifying the amount of inertia in the system remains. Sediment in transport is residing at the edges of fields, on hillslopes, on floodplains, in small streams, larger streams, and finally in the mainstem of the river. How much is trapped for long periods of time is impossible to guess, but sediment is constantly being exchanged between these sites as it moves in a stepwise fashion through the system.

The Potomac River above tidewater drains an area of 11,560 mi2 encompassing portions of the Piedmont, Blue Ridge, Great Valley, Valley and Ridge, and Appalachian Plateau physiographic provinces in Maryland, Virginia, West Virginia, and Pennsylvania. Mean annual suspended sediment load is approximately 1.34 million tonnes (Feltz and Herb, 1978). Although local areas within each of the provinces have high sediment yields as a result of mining, logging, or agriculture, average sediment yield from the Piedmont drainage is more than twice as high as from the remainder of the drainage area when measured in tonnes/km2. Intensive agriculture and expanding urban and suburban development are largely responsible for these high sediment yields, and the associated nutrient loads carried down to the tidewater from both point sources and nonpoint sources are cause for major concern over the impact of upstream activities or estuarine water quality.

The U. S. Geological Survey (USGS) maintains stream gages throughout the basin and some of these have sediment discharge records as well as water discharge records. There is a gage at

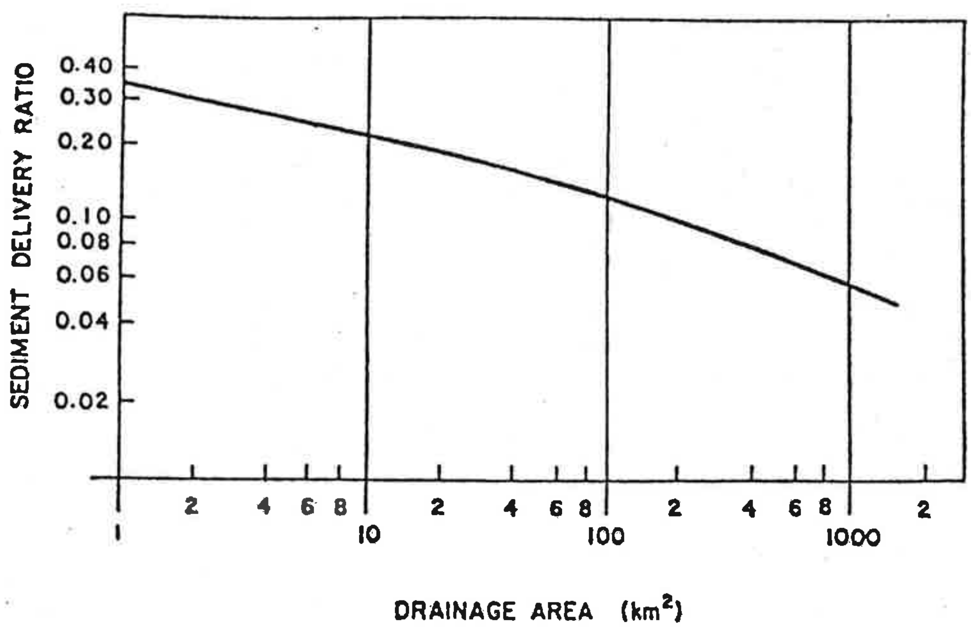


Figure 2: Sediment Delivery Ratio (Vanoni, 1975)

Point of Rocks, where the Potomac leaves the Blue Ridge and enters the Piedmont, and at Washington, D. C. where the Potomac reaches tidewater (Figure 1). The gauge on the Monocacy River near Frederick monitors approximately 7.0% of the upper Potomac River drainage, or 43% of the intervening drainage area between Point of Rocks and Washington, D.C. At both the Monocacy River near Frederick and the Potomac River at Point of Rocks, the USGS has collected daily suspended sediment data since 1960. The Potomac River at Chain Bridge was monitored by USGS for daily suspended sediment load for a three year period (water years 1979-1981).

The Piedmont reach of the Potomac River is generally a wide shallow bedrock floored channel with numerous boulders and cobbles. The banks are mostly alluvial, but bedrock walls are present on one side or the other at many locations. Islands are common throughout this reach of the river, which has characteristics of both meandering and braided channel patterns. Many of the islands have bedrock cores, but the internal structure of most of the islands has not yet been investigated. The river has a stepped profile, with alternating rapids and pooled reaches, the most prominent step or series of steps is located at Great Falls.

Although the Potomac River does not fit the paradigm of an alluvial river (Schumm, 1977), the presence of fine-grained alluvium in the banks and on many of the islands suggests some capacity for storage of fine-grained sediment. Storage of fine-grained sediment on the channel floor appears unlikely. However, an examination of suspended sediment records raises questions about whether transient channel storage of a portion of the suspended sediment load of the river may occur.

This report examines the transport and storage within the mainstem of the Potomac River between Point of Rocks and Seneca Dam. Clearly this is only one link in the chain of transport from field site to estuary. The report focuses on this area for several reasons:

- Since the Monocacy River is considered a major contributor to the sediment load at Chain Bridge, the mainstem of the Potomac River forms the crucial link between the Monocacy River and the Potomac Estuary.

- Comparison of long term sediment data available at Point of Rocks and Chain Bridge on the Potomac River and the Monocacy River at Jug Bridge, suggests time varying storage in the mainstem of the Potomac River.

- The combined results of the field study and the sediment data analysis allow us to develop a more complete picture of sediment storage. The field survey data represent a 3 month period during the summer low flow regime. The data from the field study must therefore be interpreted as a "snapshot" of the mainstem storage during this flow regime influenced by this summer's antecedent conditions, such as size of spring floods. Repeated field surveys would be required to portray the variations shown in the data analysis of Section II. The long term monitoring data available allow us to augment the field survey data.

An analysis of the USGS suspended sediment records is presented in the following section. The storage indicated by the data analysis is examined and the variability of the data addressed. Section III describes the geology and geomorphology of the area and the associated processes which transport and store sediment. The major types of storage sites are described and related to field reconnaissance data. Sections IV through V describe the methodology and techniques used to assess sediment storage in the field. The discussion and results are covered in Sections VI and VII. Field data are used to develop a sediment storage budget for the mainstem Potomac River. Conclusions are presented in Section VIII.

II. ANALYSIS OF USGS SUSPENDED SEDIMENT DATA

Daily suspended sediment data for the Potomac River at Point of Rocks and for the Monocacy River near Frederick have been collected by the U.S. Geological Survey since the 1961 Water Year. During Water Years 1979-1981, daily suspended sediment data also were collected on the Potomac River at Chain Bridge just up stream of Washington, D.C. (U.S.G.S., 1979-1981). The drainage area of the Potomac at Chain Bridge is 11,560 mi2. Drainage areas above the gages at Point of Rocks and at Frederick are 9651 mi2 and 817 mi2, respectively. Together these two stations cover 90.6% of the drainage area contributing to the flow of water and sediment past Chain Bridge. Because of this, the records from these three stations provide a useful data set for analyzing trends in sediment yield and for comparing the mass of sediment passing the upstream gages with the mass measured at Chain Bridge.

The Potomac River above Point of Rocks drains the Appalachian Plateau, Valley and Ridge, Great Valley, and the west side of the Blue Ridge physiographic province. With the exception of the Great Valley, which is heavily agricultural, these provinces typically are forested and have lower sediment yields (measured in tons/mi2) than the downstream Piedmont portion of the basin (Table 1). The Monocacy River near Frederick drains a basin located primarily in the Piedmont, with diverse rock types, predominantly agricultural land use, and an increasing amount of urbanization. The east side of the Blue Ridge also drains to the Monocacy River, but this portion of the basin probably contributes a relatively small percentage of the sediment load measured at the gage near Frederick.

Monthly sediment and water discharge records for Point of Rocks and the Monocacy River near Frederick have been added together to create an artificial station record (hereafter referred to as station PRMon) for comparison with Chain Bridge. Monthly water discharge values for PRMon and for Chain Bridge are plotted against time in Figure 3, and sediment discharge values are similarly plotted in Figure 4. As one would expect, the water discharge plots are quite similar, with the higher values for Chain Bridge reflecting the additional drainage area. Because of sampling problems that affect measurement of suspended sediment load and because of the natural variability in sediment transport, it is also to be expected that the fit would not be as close for sediment discharge. However, a surprising feature of Figure 4 is that, for the month with the largest sediment and water discharge in the three-year period, the combined sediment load passing the two upstream stations

Figure 3: Monthly Discharge

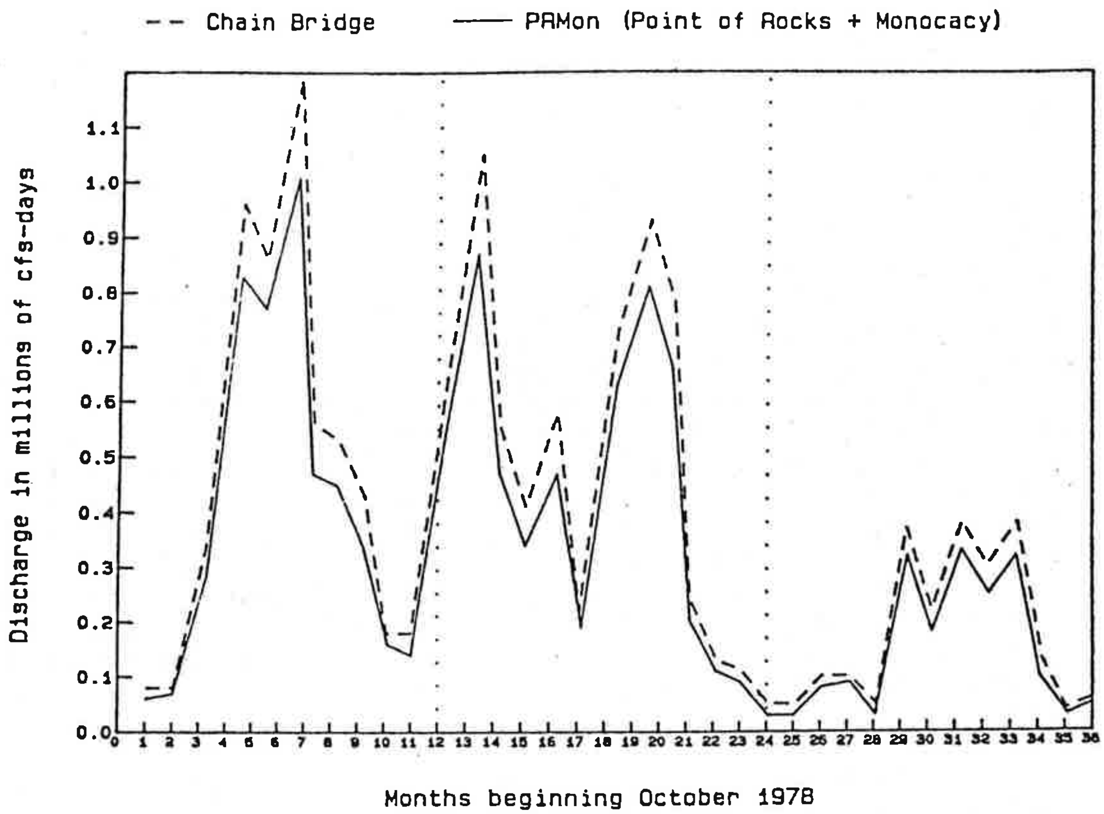
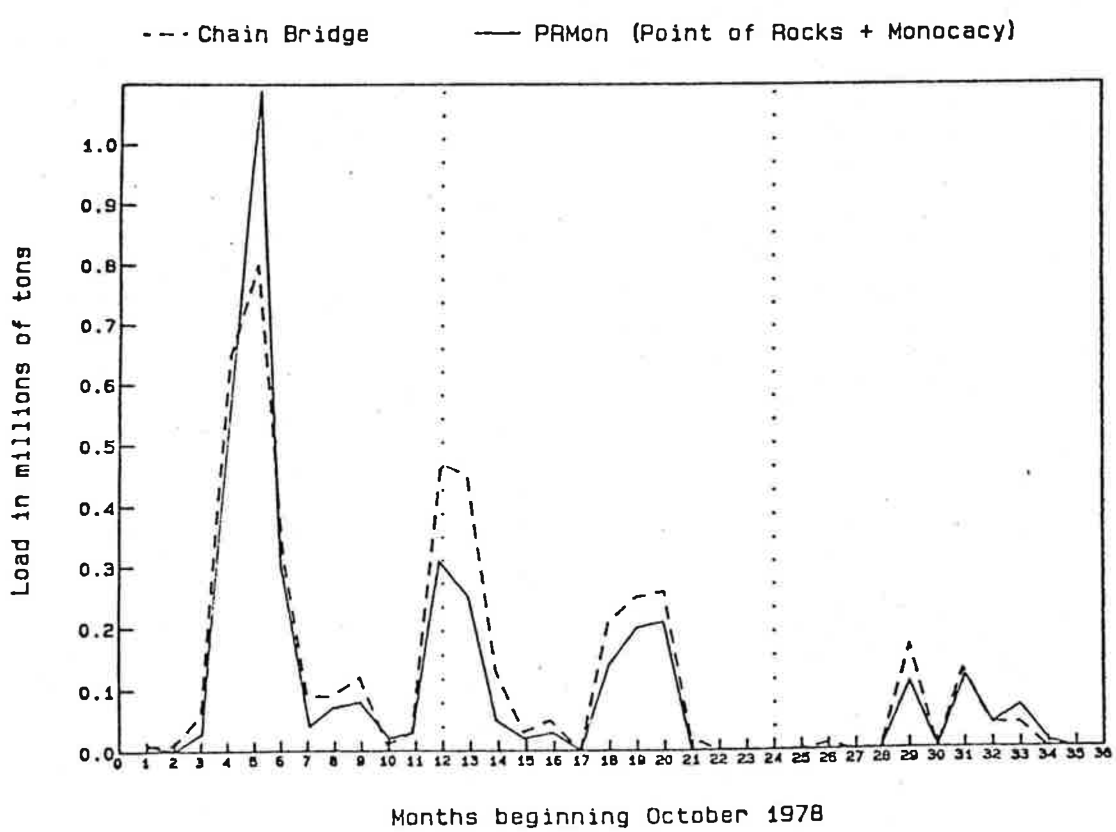


Figure 4: Monthly Sediment Load



exceeds the amount passing Chain Bridge by nearly 300,000 tons. It should be noted that the differences shown do not account for the additional sediment yield of the drainage area between the upstream stations and Chain Bridge. If this additional sediment were added to the sediment load from station PRMon, the discrepancy with Chain Bridge would be even larger. There are several other months for which the upstream sediment load exceeds that measured at Chain Bridge, although the discrepancies noted for these months do not approach the magnitude of the difference observed in February 1979.

The plot also shows that, in some months, the 90.6% of the basin area monitored by combined station PRMon accounts for less than half of the sediment passing Chain Bridge. If water and sediment discharge from combined station PRMon are expressed as percentage of water or of sediment discharge at Chain Bridge (Figure 5), it becomes clear that the relative contribution of PRMon to the water discharge at Chain Bridge is quite steady, whereas the relative contribution of PRMon to sediment discharge at Chain Bridge is highly variable. This plot exaggerates the importance of small differences in sediment load measured during low-flow months; nevertheless the pattern suggests that the area between the upstream gages and the gage at Chain Bridge plays an important role in fluctuations in sediment delivery to Chain Bridge.

In order to model the difference between sediment discharge patterns at PRMon and at Chain Bridge, we next make the assumption that, by subtracting monthly values of sediment load and cumulative water discharge at PRMon from those at Chain Bridge, we can create an artificial record (hereafter called station X) representing the drainage area downstream of Point of Rocks and Frederick. Examination of storm records at Point of Rocks, Frederick, and Chain Bridge leads us to the conclusion that the time lag between upstream and downstream stations does not tend to shift storm-period sediment load from one month to the next. Simple linear regression of monthly discharge values for station X against monthly discharge values at Point of Rocks produces a relationship with an r2 value of 0.91; a similar regression on monthly discharge of the Monocacy at Frederick gives an r2 of .88, and multiple linear regression on both stations gives an r2 value of .97. However, regressions involving monthly sediment loads yield r2 values of only 0.09, 0.13, and 0.51 respectively. We can infer from these results that Station X is similar to the two upstream gages with respect to the pattern of water discharge, but the sediment picture is less clear.

If we normalize the water and sediment discharge records, dividing by drainage area for each station, we can plot data for Point of Rocks, Monocacy, and Station X all at the same scale. Figure 6 shows such plots covering the period between September 1978 and December 1979. For most of the period shown, water discharge per unit of drainage area is higher for station X than

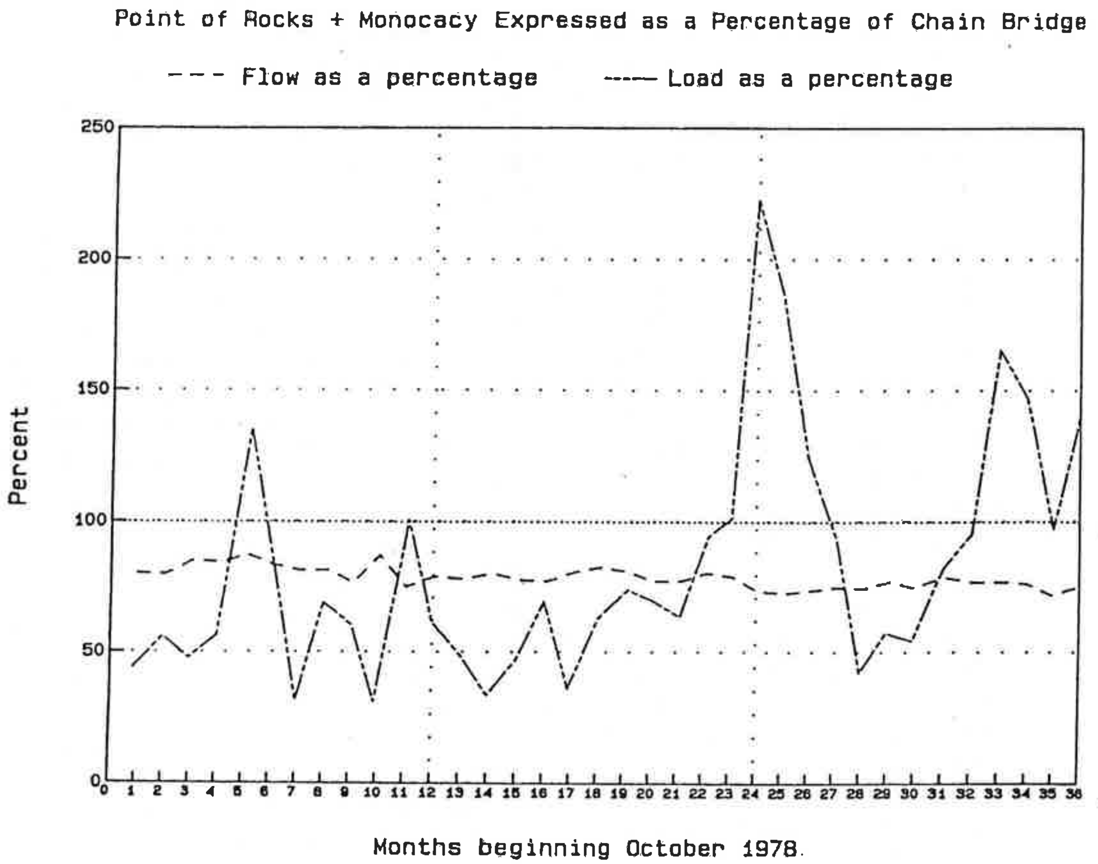


FIGURE 5: Percentage of Water and Sediment Discharge at Chain Bridge

for either the Monocacy River or the Potomac River at Point of Rocks. The pattern differs in detail but is similar in broad outline to those at the other two stations. The pattern of sediment yield, however, is anomalous. The peak values of monthly sediment yield are much higher than at either of the other stations, and this trend is even more striking if comparisons are made using individual storm hydrographs. Most striking, of course, is the large negative value of sediment yield for February 1979, which results from the fact that measured suspended sediment load at Chain Bridge was lower during that month than measured sediment load for the combined PRMon station.

In order to explain the behavior of Station X, we need to consider it as a signal with three components. The first component is the water and sediment discharge derived from 9.4% of the Potomac River basin above Chain Bridge. The second component is an error term: Station X is a linear combination of the records from three gages, and therefore its variance should be larger than the variance of the records at any of those stations. This is particularly true for sediment, as sediment data generally are subject to larger uncertainties than water discharge data. The third component reflects the role of the channel system as either a source or sink for suspended sediment. Conceivably the negative sediment yield for February 1979 represents channel and/or floodplain storage of sediment derived from upstream. Similarly the peaks in January, September and October 1979 may be partially attributable to remobilization of sediment from storage in the area between the upstream and downstream gages.

The suspended sediment records are products of standard USGS procedures for calculating sediment discharge (Porterfield, 1972). Sediment samples typically are taken on a daily basis by an observer who lives near the station and are forwarded to the USGS for analysis. These point samples are supplemented periodically by multiple-bottle samples taken at a series of verticals along the river channel. During high flow an attempt is made to obtain several samples per day. USGS office procedures mandate that the daily hydrograph be split into shorter periods for calculations of increments of the daily water and sediment discharge during periods of varying flow and sediment concentration. These values are then summed; the published daily mean flow and sediment concentration for flood periods are calculated as weighted averages.

There are several sources of uncertainty that may affect the results. First, most samples are taken at a single point; incomplete mixing in the cross section may cause spatial variability in sediment concentration that cannot be assessed by a point sample. Some stations, such as Chain Bridge, have hydraulic characteristics that promote better mixing than others. Second, there is inherent variability in the samples themselves. Two samples obtained at the same time in the same place may on occasion have concentrations that differ by several hundred mg/l. It is not always possible to tell whether one of the samples was tainted by sampling or measurement error, and therefore the use of these samples is subject to the judgement of the person drawing the sediment concentration curve. Third the temporal distribution of samples does not necessarily conform to the shape of the hydrograph. Samples are rarely taken at night and, although special emphasis is placed on frequent sampling at or near peak flow, logistical problems during floods sometimes prevent adequate sampling. If the peak was missed or if samples in the vicinity of the flood peak are sparse, the person drawing the sediment concentration curve must use his or her best judgement to estimate the shape of the curve. The range of possible sediment discharge estimates may be very wide under such circumstances; but only one value will be published. Finally, there are some periods of one or more days when no sediment samples are available, either because the observer was not present or because the sample was accidently spilled in the lab or in transit. This occurs more often during periods of low flow than during floods, but samples sometimes are missing for the first part of the rising limb of the hydrograph. When this happens, values of sediment concentrations are interpolated from a scatterplot of sediment concentration versus discharge, based on previous samples taken at the same station. Although separate plots are compiled for each season and for the rising and falling limbs, the range of scatter still may be considerable.

The cumulative impact of all of these sources of error on the accuracy of the results has not yet been assessed. An analysis of records for several floods at Chain Bridge, Point of Rocks and Frederick is currently in progress. It is important to remember that the quality of the data may vary from one event to the next. Although there are multiple sources of error, this fact should not be interpreted as a blanket statement about the reliability of the results. It is certainly possible that discrepencies such as those observed at Station X are attributable to the uncertainty in the sediment data, but this uncertainty must be assessed on a case-by-case basis. The results of the analysis currently in progress will be published in a journal article, as there is a need for discussion of this type in the literature.

Despite the uncertainties inherent in the Station X record, the average sediment yield for water years 1979-81 is reasonably close to the value one might expect if the signal were assumed to represent the drainage area between Point of Rocks and Chain Bridge. Estimates of sediment yield for basins within the Potomac River drainage were made by Wark and Keller (1963). Their results, shown in Table 1, are compared with 1979-81 averages for the Potomac River at Point of Rocks and the Monocacy River at Frederick. (The average sediment yield at

Station X for 1979-81 is based on the difference between Chain Bridge and the other two stations.) Four sub-basins within the drainage area assigned to Station X were analyzed by Wark and Keller. The combined drainage area of these basins is 501 mi2 and includes almost half of the drainage area between Point of Rocks and Chain Bridge. The weighted average sediment yield for these four basins is 297 tons/mi2. This compares favorably with the 1979-81 average of 262 tons/mi2 for Station X.

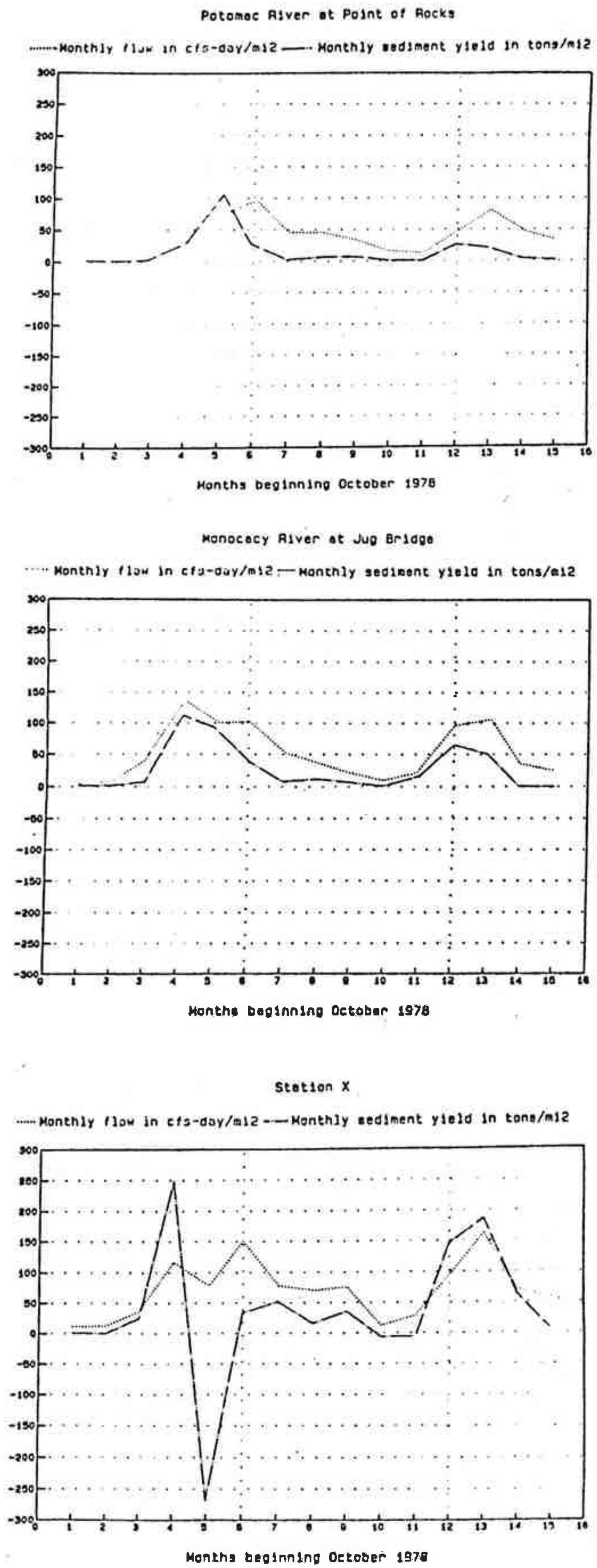
Table 1. Sediment Yield Data from Wark and Keller (1963) Compared with Sediment Yields Based on Water Years 1979-1981.

Station	Wark and Keller	Water Years 1979-1981
Point of Rocks	113 tons/mi2	106 tons/mi2
Monocacy at Frederick	327 tons/mi2	239 tons/mi2
Goose Creek	290 tons/mi2	
Seneca Creek	320 tons/mi2	
Difficult Run	280 tons/mi2	
Watts Branch	516 tons/mi2	
Weighted average	297 tons/mi2	
Station X		262 tons/mi2

Portions of the drainage area assigned to Station X are located within the Monocacy River basin downstream of Frederick; other portions are located in areas of similar land cover and land use, and all of the area assigned to Station X is within the Piedmont. This area is more heavily urbanized than the Monocacy River basin above Frederick and may have a flashier hydrologic response, but in our opinion it is not unreasonable to assume that the pattern of sediment discharge is similar to that observed on the Monocacy River. If we use this assumption to model the expected temporal pattern of sediment discharge for Station X, we may then be able to identify how the actual record departs from the expected pattern.

We assume that the relation between monthly discharge and sediment yields at Frederick can be applied to the monthly discharge at Station X in order to produce a simple regression line relating discharge in cfs/mi2 to sediment yield in tons/mi2. Monthly discharge values for Station X were

Figure 6: Sediment Load and Discharge per Square Mile



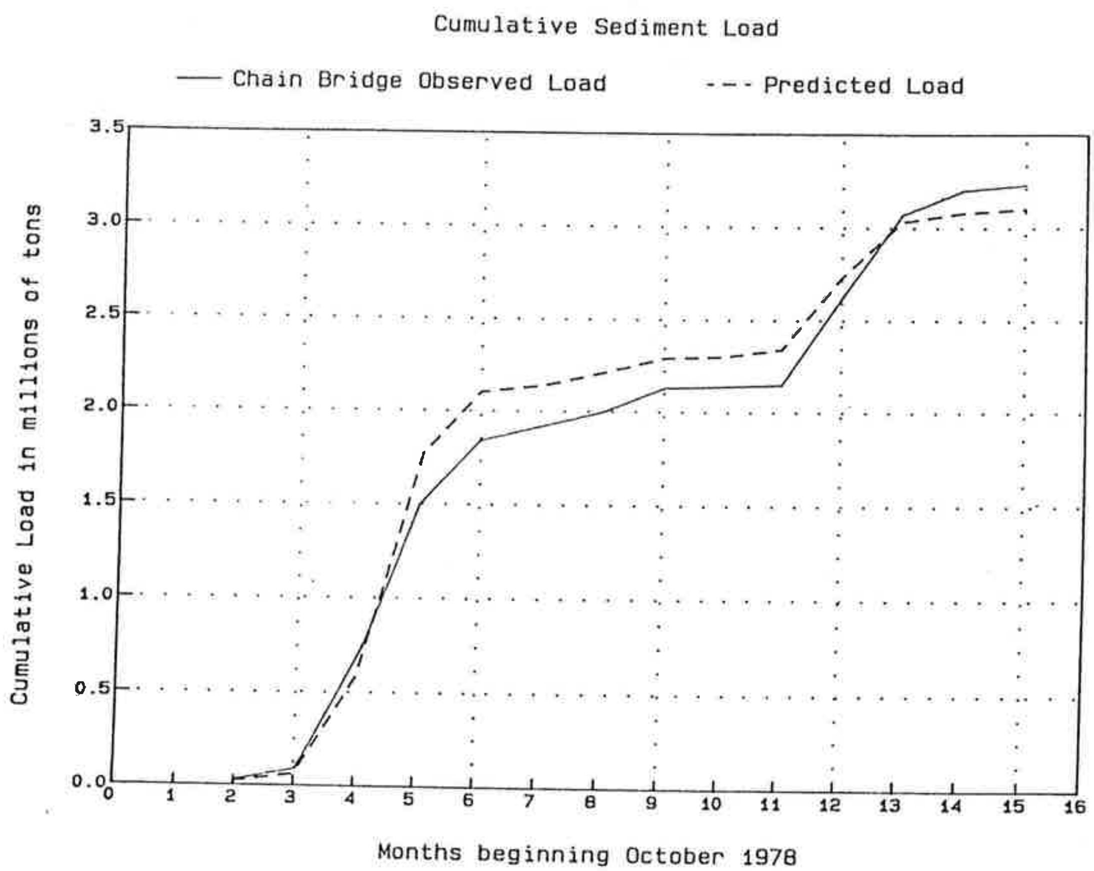


FIGURE 7: Cumulative Sediment Load vs. Time

substituted into the resulting linear equation, and predicted monthly sediment loads were calculated by multiplying the result by the drainage area of Station X. The sum of the predicted loads for 1979-81 gives us the average predicted sediment yield of 284 tons/mi2. The relatively close agreement between actual (262 tons/mi2) and predicted (284 tons/mi2) sediment yield suggests that, regardless or errors or uncertainties for individual events in the record, the total amount of sediment contributed by Station X can be estimated using the assumptions stated above.

Cumulative sediment load at Chain Bridge is plotted against time in Figure 7. A synthetic or predicted Chain Bridge record, calculated as the sum of sediment loads at Point of Rocks and Frederick and predicted sediment load at Station X, is also plotted on the same figure. Comparison of the two curves suggests that, during 1979, a large volume of sediment went into storage upstream of Chain Bridge during February and remained in storage for most of the next 6 to 8 months. High flows occurring in September and October appear to have remobilized this sediment.

This illustration does not prove that channel storage in the mainstem of the Potomac River has a significant effect on delivery of sediment to tidewater, but does suggest that storage and remobilization of sediment is worthy of further investigation. The discrepancies could affect calibration of computer models that route water, sediment, and nutrients down to the tidewater. The extent to which uncertainties in the sediment data influence these results is still under investigation.

Our primary goal in this study was to assess sediment storage characteristics of the mainstem Potomac River between the upstream and downstream gaging stations in order to see whether the amount of fine-grained sediment in storage is large enough to explain observed discrepancies in the sediment record. Examination of Figure 7 suggests that storage is transient and might have been large between February and August of 1979 and smaller in subsequent periods. Unfortunately we have no continuous records of sediment load at Chain Bridge after 1981 and therefore we do not have an estimated mass of sediment storage during the field collection period of the summer of 1985. The implications of our findings are discussed in greater detail at the conclusion of the report.

III. GEOLOGY AND GEOMORPHOLOGY OF THE STUDY AREA

The Potomac River carves a gap in Catoctin Mountain to enter the Piedmont at Point of Rocks. Between Point of Rocks and Seneca Creek the river traverses sedimentary rocks of the western Piedmont, an area of relatively low relief. Dominant rock types are the shales, sandstones, and conglomerates of the Triassic Newark group; a portion of the channel downstream of Point of Rocks and upstream of the Monocacy River is underlain by the Frederick limestone (Cleaves and others, 1968). At Seneca Creek the Newark Group contacts the Ijamsville phyllite, and downstream of here the Potomac crosses through metasedimentary and metavolcanic rocks of the eastern Piedmont, where relief is much steeper than in the western Piedmont. A rubble dam located 1 km downstream of Seneca Creek was built in 1823 to supply water to the C&O Canal. Although this dam has been breached, a section of it is still present on the left side of the channel, causing some ponding of the Potomac River immediately upstream. The ponded reach is known informally as Seneca pool. Below the dam, the Potomac is characterized by numerous falls and rapids, the steepest of which is Great Falls. Because of this sharp break in gradient, our investigations of sediment storage in the channel of the Potomac were restricted to the area upstream of the dam.

The Potomac River is constrained by bedrock at the upstream and downstream ends of the study reach, and is affected by local bedrock controls at various points within the study reach. Occasional outcrops of the New Oxford formation form steep rock walls bordering the right side of the channel, although most of the channel is bordered by alluvial floodplain deposits. A common rock type within the New Oxford formation is a limestone conglomerate; variable weathering of this conglomerate may be responsible for the patchy distribution of rock outcrops bordering the river. Bedrock ledges on the channel floor create steps in the profile of the river at several locations within the study reach, and these steps appear to play an important role in determining channel form and process. Because of these constraints, the Potomac channel may be described as "semi-controlled" (Schumm, 1985, p.7).

The channel of the Potomac displays aspects of both meandering and braided patterns. Multiple channel islands are found in the reach between Point of Rocks and the Monocacy River. Fewer islands are present below the confluence, although those that are present tend to be quite large. The straight reach above the Monocacy gives way to a low-sinuosity meandering reach extending downstream a short distance past Edwards Ferry; from here to the dam the channel follows a straight course divided by a set of individual channel islands extending almost to Seneca Creek. The braided pattern resumes as the channel steepens immediately below the dam.

Because of the presence of bedrock controls, the Potomac does not fit Schumm's (1977) definition of an alluvial channel. However, its morphology may be described in terms used by Schumm to classify alluvial channels. Bankfull width-depth ratio through much of the study reach is typically greater than 40. The channel bottom typically consists of gravel, cobbles and boulders over bedrock, with sand and finer particle sizes at relatively scattered locations. In an alluvial river this combination of width-depth ratio and particle size, together with low sinuosity, would be characteristic of a channel that carries large amounts of bedload, and the steeper reaches of such a channel might contain active braid bars composed of sand or gravel.

Despite the presence of features reminiscent of braided bedload rivers, the Potomac delivers sediment to tidewater that consists mostly of silt and clay, and the alluvial banks of the Potomac have high silt-clay content. Although they may have bedrock cores, many of the islands in the reaches described above as braided also are characterized by large amounts of silt and clay exposed in their banks. A bank exposure on Harrison Island, one of the large channel islands in the meandering portion of the study reach, reveals 7 m of laminated sandy silt with only modest textural variations. This layer of sediment appears to have formed by overbank floodplain sedimentation.

A report by Commonwealth Associates (1980) suggests that the late Pleistocene Potomac River in the vicinity of Seneca Creek was a braided channel carrying coarser load than the alluvial silts carried by the modern Potomac. According to the chronology of this report, by 15,000 B.P. the Potomac was a meandering channel in the process of reworking the deposits left behind by the braided channel. Between 11,000 and 10,000 years ago the meandering course was abandoned and the Potomac incised a straight channel into the alluvial deposits; since then there have been at least two episodes of floodplain alluviation with subsequent channel incision. Thus the mixed characteristics of the Potomac River reflect a complex history of environmental change. The details of this history throughout the remainder of the study reach have not been examined.

Described below are several geomorphic surfaces bordering the river channel at different elevations which have some significance for sediment storage and/or remobilization at high flows (Figure 8).

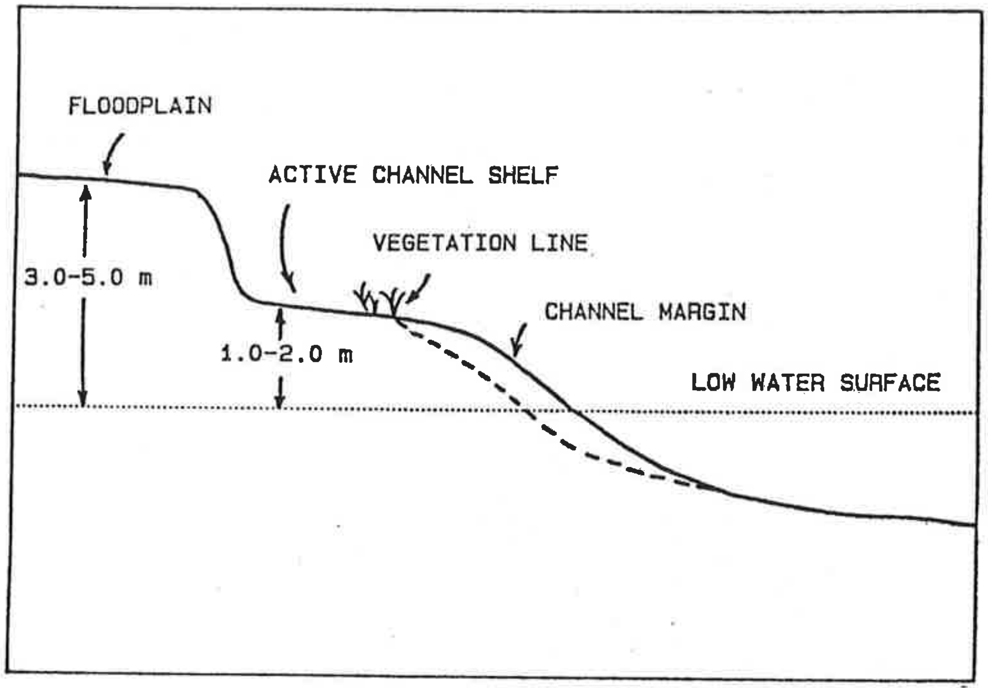


Figure 8: Schematic of Topographic Surfaces Bordering River (Approximately 4:1 vertical exaggeration.)

A low bench elevated 1.0-2.0 meters above low water, corresponds to the active channel shelf described by Osterkamp and Hupp (1984). The active channel shelf is defined as a surface below the floodplain level that is inundated between 5 and 20% of the time. There is no doubt that this surface is underwater during the annual spring freshet on the Potomac River, even when the surface of the floodplain is not reached by the crest stage. One of the field sites described by Osterkamp and Hupp (1984) is located at Algonkian Regional Park, on the right bank of the Potomac River at the lower end of our study reach. At this location the active channel shelf is described as being 10 m wide and the floodplain is described as having a width of 1,900 m.

This feature is bounded by a scarp leading up to the floodplain, which is typically 3.0-5.0 meters above low water. A higher terrace level is found at elevations 7.0-8.5 meters above low water. The larger channel islands have flat upper surfaces corresponding to this level.

Commonwealth Associates (1980) show the locations of several ancient meander scars left by the Potomac River at the lower end of the study reach. This abandoned meander belt includes some areas at the elevation of the floodplain level and some areas at the elevation of the terrace level. Higher terraces have also been identified along the Potomac River, but these are outside the scope of our study.

III.1 Variations in Width, Depth, and Slope

The width of open water in the channel as depicted on USGS topographic quadrangles is quite stable from Point of Rocks almost down to Edwards Ferry, varying between 240 and 320 m. From Edwards Ferry, which is located opposite the confluence with Goose Creek, the channel widens as one moves downstream: the total width of open water between the left and right bank (excluding islands) reaches 450 m at Van Deventer Island and reaches 650 m below Seneca Creek. Ponding above the rubble dam cannot account for more than a small percentage of the widening of the channel. The distance between the left and right banks in the braided reach below the dam ranges between 650 and 1000 m, with an open water width ranging between 500 and 650 m.
A water-surface profile collected for this study in August 1985 (Figure 9) shows that the channel descends steeply from Point of Rocks to the confluence with the Monocacy River, with an average gradient of 3.6 m/km. The average gradient between the Monocacy River and Seneca Creek is 0.09 m/km, but within this reach the profile consists of a series of steps reminiscent of a pool-riffle sequence. The channel reaches occupied by Mason and Harrison Islands have bedrock ledges at the upstream end of each island, and in each case the ledge causes ponding in the

undivided reach upstream. Water depths at low water range from a minimum of 0.3 m to a maximum of 3.0 m; water depth in the reaches where islands are present is shallower and surface current velocities are swifter (up to 0.85 m/s) than in undivided reaches of the channel (up to 0.30 m/s). Downstream of Harrison Island, the channel widens gradually and current velocities slacken (0.15-0.36 m/s) approaching Seneca Pool. Maximum water depth in Seneca Pool at low water is 2.2 m.

III.2 Qualitative Assessment of Sediment Storage

a) General Characteristics of the Study Reach

Our original conception of what we were looking for in the field was relatively simple. Based on our analysis of suspended sediment records, we thought that Seneca pool was behaving as a reservoir with fairly low trap efficiency and strong potential for resuspension of trapped sediments. Our work plan focused on detailed profiling, sampling, and analysis of bottom sediment stored in Seneca pool. Lacking detailed information on depth and water-surface slope, we were uncertain how far upstream the backwater of this reservoir and its associated deposits would extend.

Field reconnaissance revealed a situation that differed from our expectations. With few exceptions, the channel bottom throughout the study reach was a layer of gravel, cobbles and boulders over bedrock. Patches of sandy bottom or interstitial sands between cobbles and boulder, however, were not uncommon. The boulders often were large enough - and unpredictable enough in their location - that operation of a 6-horsepower outboard motor on shallow-water drive was a hazardous business in as much as 1 m of water. Even in pooled reaches, we seldom found more than a very thin film of silty material on the bottom. The only significant deposition of fine grained sediment in the channel proper was in the reach between Seneca Dam and Sharpshin Island and in the upstream reach between Whites Ferry and Mason Island. However, even here, the extent of these deposits, both longitudinally and laterally in the channel, was fairly limited. In Seneca pool the fine grained sediment was located left of the centerline of the channel; very little was found in the right half of the channel.

b) Channel Margin Storage

Reconnaissance also revealed that there were significant accumulations of sediment along the margins of the channel at some locations. Channel margin deposits typically were wedge-shaped prisms of silty sand or sandy silt extending out into the water, and they generally had level bottom surfaces underlain by gravel and cobbles. Some were extensions of mud beaches that sloped gently down from the level of the active channel shelf, and others were subaqueous deposits overlying gravel and cobbles at the base of the eroding bank. In either case the deposits become thinner and coarser with distance from the shore line, generally disappearing within 5-10 meters. The thickness of sediment at the waterline was sometimes in excess of 1.5 m. Multiple leaf litter layers in these deposits indicated episodic deposition, possibly extending over several seasonal cycles. A few sites had significant amounts of decaying organic material under anoxic conditions beneath the surface and these released gas bubbles when penetrated by a coring tube. Surficial sediment layers beneath the water line might consist of several inches of floc, or fluid mud with the general consistency of chocolate pudding, and this layer might also contain heavy concentrations of recent leaf litter. Where these beach deposits were unvegetated and contained little or no root material, we concluded that they were capable of being scoured and resuspended at high flow. Measured volumes of sediment in the larger of these prisms were on the order of 5 cubic meters per meter of shoreline, and in a few extraordinary cases they were even larger. If this amount of sediment were stored along the entire length of the study reach between the Monocacy River and Seneca Dam, we might account for several hundred thousand cubic meters of sediment.

The distribution of such large wedges of sediment along the channel margin was, in reality, rather patchy. At many sites along the shoreline we found similar deposits of smaller extent, amounting to 1 or 2 cubic meters per meter of shoreline. At locations where gravel bars formed a shallow platform extending into the water, we often found aquatic grasses growing in the water. Because of the damping effect of their stems on current velocity, these grasses had a tendency to trap sediment. However, the sediment deposited in such grass beds was composed primarily of fine sand and rarely accumulated in thicknesses of more than 10 cm. At other sites, instead of active deposition there was an eroding bank with tree roots exposed at the surface and gravel in the water at the base of the bank. Some of these sites had a thin layer of silty sand covering the gravel and extending 2 to 3 m away from the bank. Many other sites were intermediate in their characteristics: the surface sloping down into the water consisted of soft fine grained material that appeared to be an extension of the bank; or two layers were present, the top layer consisting of recently deposited sediment and the lower one consisting of bank material. In some cases there was no clear distinction between recently deposited sediment and older bank material. This is not particularly surprising in light of Osterkamp and Hupp's (1984) statement that "the fine material forming channel banks accumulates as a plastering during periods of rising stream stage (Osterkamp, 1981)" (p. 1098). In-place bank material was considered potentially available for scouring and resuspension when it was not bound by roots; criteria for assessing the volume of "available" sediment are discussed in a later section of this report.

Our observations indicated that these channel-margin storage areas were sites where deposition and resuspension could occur in quick succession, and perhaps during the same event. The landward edge of the prism of sediment under consideration was often marked as the limit of permanent woody vegetation. The vegetation line is located on the sloping surface leading up to the active channel shelf. On this slope and on the surface of the active channel shelf, there were generally mud deposits that had been left behind by the most recent high flow. The deposits covered the previous year's vegetation and formed discrete sediment units of 1 to 5 cm thickness, and they were penetrated by desiccation cracks. Some of these layers extended across the flooded surface and part of the way back down the beach, where they were truncated by tiny scarps that might have been cut by small waves lapping against the beach as flood waters receded. Some beaches exposed multiple layers of desiccated mud truncated by a set of scarplets at varying levels down the beach.

c) Overbank Sedimentation and Deposition

Overbank sedimentation occurs regularly on flat or sloping surfaces corresponding to the elevation of the active channel shelf. As the description above indicates, deposition on this surface is probably contemporaneous with deposition on the adjacent slope leading down to the channel margin. Overbank sedimentation on the floodplain does not occur quite as frequently and at many of our stations it was apparent that this year's spring flow had not reached the floodplain. However, desiccated layers of recently deposited overbank sediment were observed on several islands at elevations corresponding to the floodplain level. In one instance we noted that the side of the island was actively being scoured while new material was periodically deposited on the surface. Positive evidence for storage in the form of vertical accretion was found when we excavated the remains of a charcoal fire from the top of the bank of the island. A thin layer of baked brick-like sediment over the coal probably was formed when the fire was extinguished by having dirt shoveled over it. On top of this layer was a 15-20 cm deposit of brown sandy silt with some wood fragments and roots, which was itself covered by a layer of mud deposits from a recent high-flow event. No artifacts were found to date the fire, but the coal looked quite fresh. Evidence that such stored sediment may be remobilized from island locations was provided by the fact that the remains of this charcoal fire were exposed in the eroding bank; nobody builds a campfire on the edge of a steeply sloping bank, and therefore the island must have eroded at least 0.5 to 1 meter during the time since the charcoal was buried. Similar anecdotal evidence for storage and resuspension of sediment on low channel islands was provided at another location where we found an old shoe eroding out of the bank from beneath a tree root.

The greater lateral extent of the floodplain surface as compared with the active channel shelf makes it a potential sink (and a less likely source of resuspension) for sediment carried by flood flows. We had an opportunity to examine the effects of a large flood in November of 1985, and additional observations here and elsewhere along the Potomac River have been made by Scatena and Parkinson (1986) in a separate report to ICPRB. The flood clearly overtopped the terrace level, as indicated by debris and fine coatings of sediment about two meters above this surface. Near the bank this flow left deposits of sand and silt that typically were about 1 to 3 cm thick, but the thickness of the deposits declined rapidly with distance away from the river channel. Investigations in fields located several hundred meters back from the water's edge revealed the presence of thin, discontinuous silt lamina no more than 1 to 5 mm thick. Although some floods may leave behind more significant deposits, the amount of sediment deposited on the floodplain and on the higher terrace level in our study reach by this event was relatively small.

d) Tributary Mouths

Many of the smaller tributaries of the Potomac River tend to peak much earlier than the Potomac River during a flood event and are then inundated by rising water levels coming in from the mainstem. Substantial amounts of debris may be deposited in the tributary mouth as a result of this process. The resulting deposits are analogous to the slackwater deposits described by Kochel and Baker (1982), but they are associated with floods of low recurrence interval. Because they are located on the channel floor, they are not likely to be preserved. However, if baseflow in the tributary is low enough, even low flow on the Potomac River may cause backwater effects that prevent the immediate flushing of the channel. Flushing is most likely to occur as a result of a local convective storm that causes a rapid rise in the tributary without a corresponding rise in the main river. One such channel (Limestone Branch, entering the Potomac River on the right bank downstream of Mason Island) had accumulations of loose sediment in the channel mouth that were full of decaying organic litter and that reached thicknesses of 1.3 m in the center of a channel only 9 m wide. The natural bottom of this channel is covered by large blocks of limestone, and within 70 m upstream of the mouth the thickness of fine grained sediment covering the rock bottom had declined to less than 0.2 m.

Along pooled reaches of the main channel it is possible that some of the sediment stored at tributary mouths is not flushed at all and accumulated to form small slackwater deltas. Examination of topographic quadrangles of the study reach shows that several of the smaller tributaries entering the Potomac River along this reach have built small deltas along the shore line. Local variations in channel margin sediment storage may be associated with small deltas at tributary junctions.

e) Channel Islands

Along the margins of islands upstream of Seneca Pool there were often bars composed mostly of sand over a gravel platform and separated from the scarp leading up to the surface of the island by a shallow trough. Similar features were also found at some sites along the mainland in reaches occupied by islands. The upper surface of the bar was at the same elevation above low water as the active channel shelf. In many cases the bar surface was populated by mature trees, but the vegetation at the upstream end of the bar was much younger, indicating either that these bars are growing by accretion at the upstream end or that vegetation at the upstream end is frequently destroyed in floods. The trough generally was 5-10 m wide. In all cases the trough, elevated just above low water, intercepted the channel of the Potomac River at the upstream end of the bar. Large amounts of organic debris typically are entrained in flood waters entering this trough, and the organic debris has a tendency to become tangled in overhanging branches or wrapped around trees and shrubs growing in or along the margins of the trough. The resulting debris jam slows down flow in the trough and encourages deposition of fine-grained sediment from ponded flood waters. Continuation of this process could result in filling of the trough and may lead to island growth. Accumulation of sediment behind debris jams also occurs in some of the narrow channels between small islands in the braided reach upstream of the Monocacy River. We found large debris jams at the upstream ends of several islands, and in some cases the debris completely blocked a channel, trapping enough sediment to fill the channel. At one such site we also observed that flood flows had cut a new channel across one of the islands, remobilizing some of the sediment stored in the island.

Lintner (1983) describes the erosional and depositional effects of organic debris jams and ice jams on islands in the lower Susquehanna River, and he concludes that "while floods result in significant property damage, they appear to be principally depositional in nature" (p. 30). He also documents a 72% increase in island area between 1801 and 1929, followed by a further quadrupling in island area between 1929 and 1973 after closure of a dam to form a reservoir in his study area. Much of this growth occurred under different conditions than are prevalent in the Potomac River; the processes are similar, but we cannot presently assess their effects on annual sediment delivery in the Potomac. However, the islands are large reservoirs of sediment, and our field observations indicate that they actively exchange sediment with the river at high flow. Further study of their evolution will be required in order to determine whether they have any long-term impact on sediment delivery.

IV. METHODOLOGY

Within the constraints of a three month field effort to be carried out during a summer low flow regime, a field plan was developed to assess the fine grained sediment stored in the mainstem of the Potomac River. The study area was reduced to the reach between Point of Rocks and Seneca Breaks (See Figure 12), with primary effort to be concentrated on the area downstream of the confluence with the Monocacy River. The focus of the field study was chosen to coincide with the areas most likely to store significant quantities of fine grained sediment.

As mentioned previously, the initial plan included an intensive survey of the Seneca pool area. Seneca pool, a ponded reach behind a low head dam was assumed to act as a reservoir, storing sediment in this area. At low flow the backwater of the Seneca pool reaches up to Sycamore Landing or even further to Edwards Ferry. The water is deeper and the velocities slower than further upstream. During the initial project development stage, field surveys indicated that Seneca pool was not behaving as a reservoir of sediment storage as had been anticipated. Although sediment was stored in substantial quantities along the channel margin of the left bank, no thick accumulations of fine grained sediment were observed in the center of the channel.

Significant channel margin accumulations were not, however, localized in the Seneca pool area, but also occurred in what appeared to be low velocity reaches near Edwards Ferry, Sycamore Landing, Whites Ferry and the mouth of the Monocacy. The emphasis of the field survey was redistributed to the study area as a whole, with a greater emphasis on channel margin assessment and less emphasis on in-channel storage.

In order to assess the magnitude of storage three major tasks were defined:

- A longitudinal profile survey was carried out to determine the change in water surface slope in the study area. Changes in slope in most cases indicate the relative water velocities and the associated storage of sediment.
- To augment the profile information a detailed survey was carried out of the channel margins. More emphasis was placed on the areas between the confluence of the Monocacy and Seneca pool. Margin surveys included not only the measurement of the sediment depth, but also sample collection to determine particle size distribution. Because

of the nutrient carrying capacities of silt and clay size sediment the study focused on this fine grained fraction.

- Seven cross-sections were established at representative reaches of the river. Each cross-section was to include: the shape of the channel, current velocities, the types of sediment stored, and water depths. Sites were marked to allow reexamination at future times.

- To better describe the magnitude of phosphorus transported in the sediment, samples were taken in three types of storage areas; marsh grass areas, channel margin material, and silty floc. Three representative sites were chosen for each type and a total of 28 samples were delivered to the Occoquan Lab. (Results of phosphorus data analysis and assessment of results are presented in Appendix E).

- The information provided by this analysis will allow us to evaluate the magnitude of stored phosphorus associated with the fine grained sediment, as well as its enrichment in comparison with the sediment load at Chain Bridge.

- Floodplain cores were taken for pollen analysis to determine the long term historic floodplain deposition. Unfortunately, the dry summer conditions caused the areas chosen for sampling to be dried out and the cores proved inappropriate for pollen analysis. Floodplain storage and deposition is described in the results section and observations made after the November 1985 flood are included.

The survey was carried out using the procedures outlined in the following section.

V. FIELD SURVEY TECHNIQUES

V.1 Longitudinal Profile of Water Surface Elevations

The surveying of the profile began at the Point of Rocks gaging station, which has a bolt marking a fixed elevation reference mark of 212.90 feet above sea level. (Gary Fisher, USGS, personal communication) The profile measurements were made using a total station, an electronic distance meter with a theodolite, which has the ability to measure up to 3 km distance accurately to 1/100 of a meter, and horizontal and vertical angles to 3 seconds. The measurements were carried out during a 4 day period during which both flow and temperature were stable. Flow stage at Point of Rocks varied from 1.11 to 1.28 feet throughout this period.

The observations were carried out in series, with one station designated as "fixed" while the other station moved to the next location downstream. The total station (TS) was one station, the other was the prism, which receives the light signal from the station thereby locating the distance traveled. The prism was referenced to the actual water elevation with each sighting. Each reading included: distance in meters, vertical elevation change, horizontal deviation from north, and vertical distance from water surface. North was located with a Brunton compass reading. All subsequent horizontal angles were referenced to the north. Sightings were generally on the order of 1000-1500 meters apart depending on line of sight. Sightings were made on the right or left bank, the assumption being made that the water surface elevation remained level at a cross-section. This was verified during the surveying of cross-sections described in Section V.3.

The longitudinal profile was connected to a reference mark located on the Seneca Aqueduct. The cross-sections were also surveyed and their location plotted on the profile. Reference points were surveyed so that the profile could be related to other flows.

The changes in elevation described by the surveying were calculated. Elevation changes were corrected for errors caused by angle of refraction and earth curvature using two methods. The following formula was used to calculate the size of the correction required for each sighting (Pugh, 1975).

$$\text{Correction} = (0.5 - Ri)\ (D2)/R$$

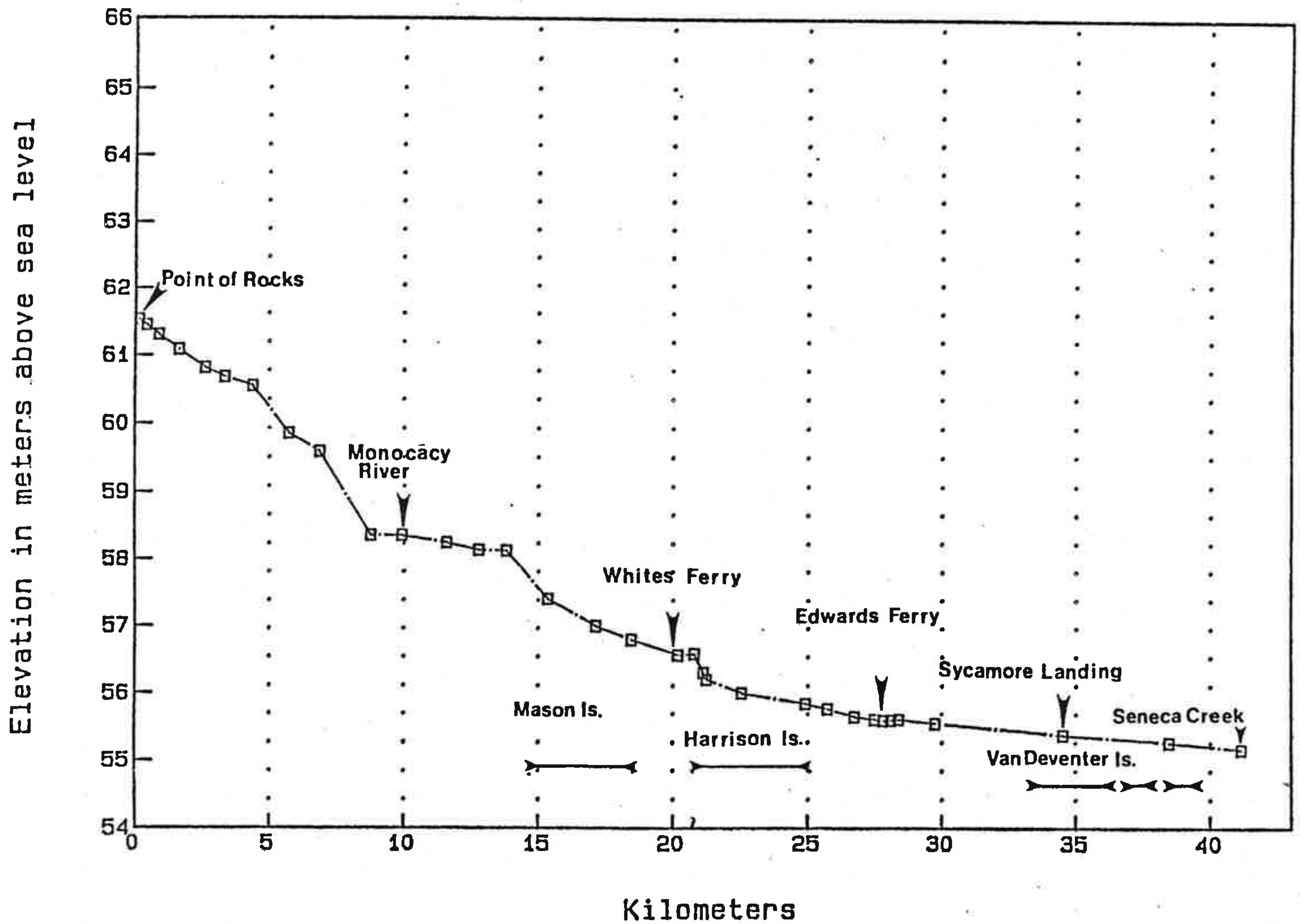


Figure 9: Longitudinal Water-Surface Profile from Point of Rocks to Seneca Creek

Where Ri is the index of refraction, approximately .07, D is the distance of the sighting, and R is the radius of the earth.

The corrections between a pair of symmetrical observations, one upstream, one downstream at similar distances, will cancel each other out. When pairs of observations are of similar distances, errors can therefore be easily removed.

The location of the TS and prism locations were plotted on topographic maps using the distance and horizontal readings. Since measured distances included sightings across the channel, the distances were remeasured on the topographic maps with a digitizer to reflect actual distance along the center of the channel. The new distances, slightly shorter than before, were plotted with the final elevation values on the longitudinal profile (Figure 9).

V.2 Margin Storage

a) Assessment

The entire shoreline within the study area was examined at 126 individual sites for margin storage. Figures 10a and 10b shows the locations of the sites visited. Examinations were made of the right and left banks as well as the banks of the larger islands. Included in the survey were sites of potential storage such as island tails, eddies and slackwater areas.

At each site observations were made of the nature of the bank, and slope of beach. If sediment accumulations were of sufficient depth (>2 centimeters) to warrant measurement a more detailed examination was carried out.

At each of these sites the following measurements were taken:

- Depth of sediment and water depth, at the water line and at 3 foot intervals out into the river, to a total of approximately 18 feet. Total distance measured depended on depth of water and amount of measurable sediment.

- Depth of channel margin sediment landward from the waterline and extending up to the active channel shelf, in 3 to 6 foot intervals. Slope of the active channel shelf was measured in 6 foot intervals. The location of the vegetation line was noted.

- The types of sediment found were described and when representative sediment samples were taken for particle size analysis. The results of the analysis were used to place the sediment stored into broad categories relating to particle size distribution.

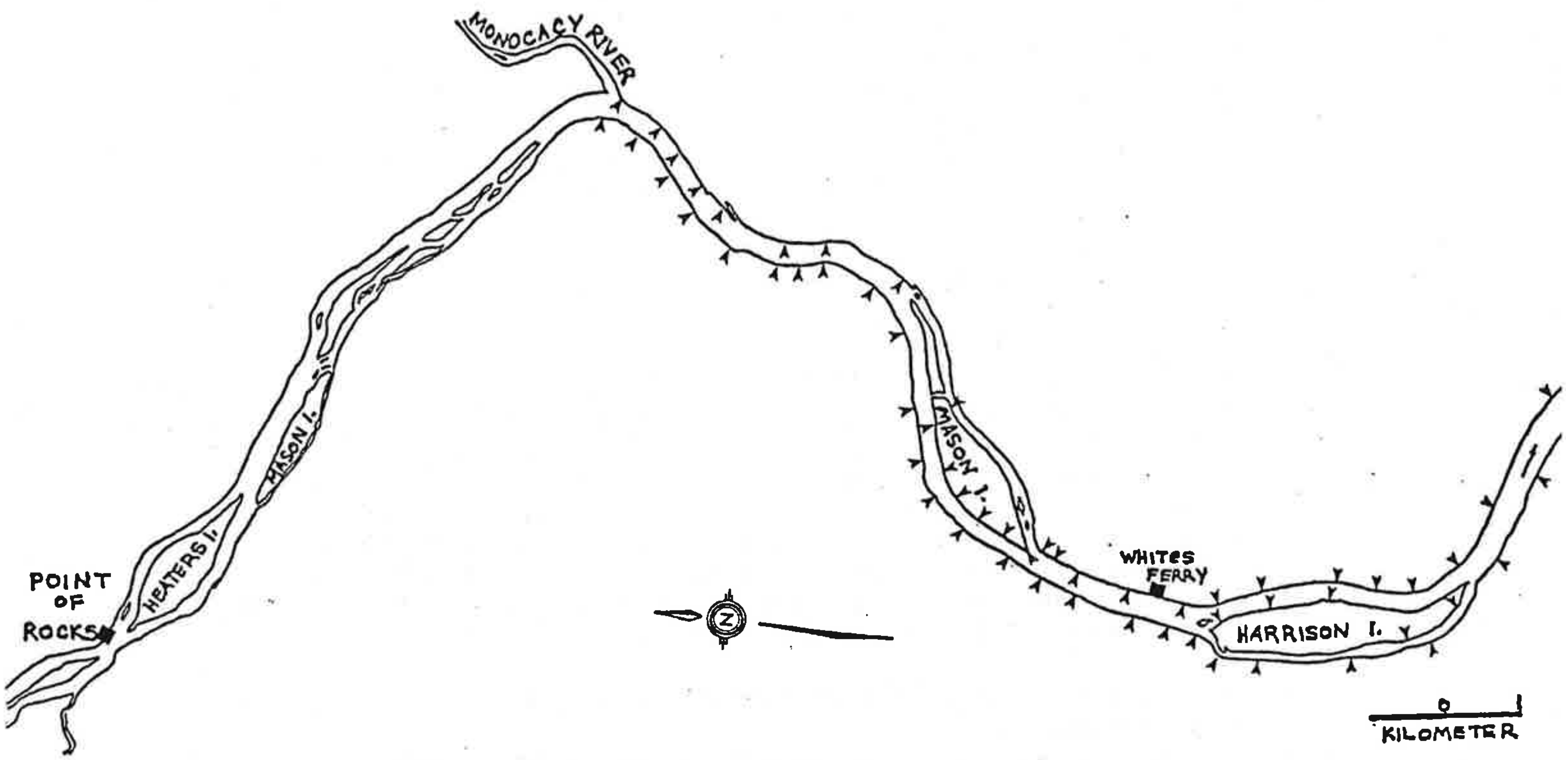


Figure 10a: Point of Rocks to just upstream of Edwards Ferry

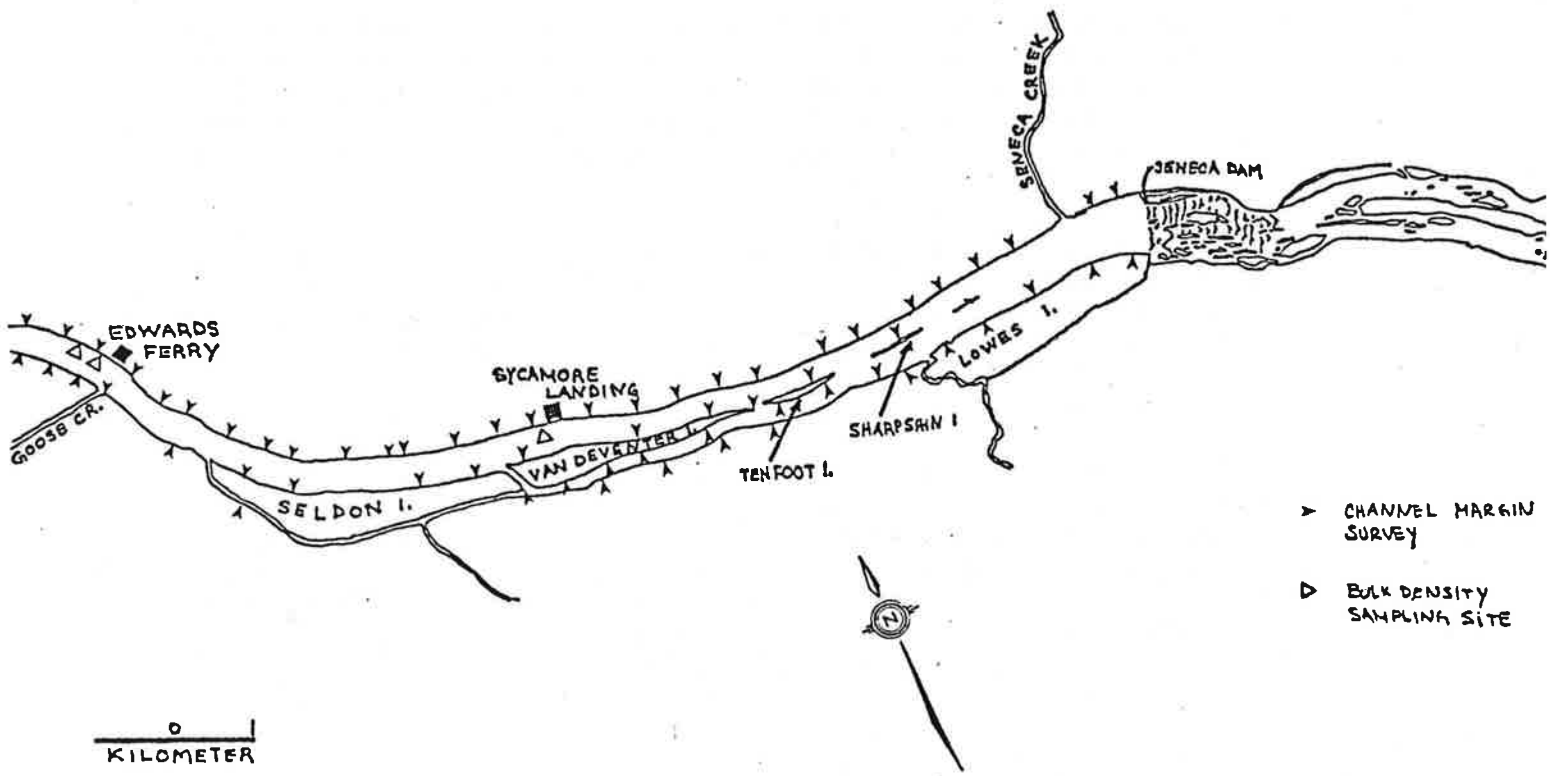


Figure 10b: Potomac River from Edwards Ferry to Seneca Dam

Sediment thickness measurements were made with a soil sampling core or with a SCS sediment spud. Included with the depth measurements were descriptions of texture, layering, ease of penetration, and indicators of age of deposits. Depths of 1.5 meters were considered maximum. At depths beyond this the sampling device was virtually impossible to retrieve. Particle size samples were taken with a soil sampling core, grab samples, or for deeper water with a ponar dredge.

b) Sample Collection and Processing

Particle-size analysis was performed on 68 sediment samples for the primary purpose of determining silt-clay content. The standard sieve-pipet method was used, following guidelines approved by EPA for use by the Maryland Geological Survey in analyzing sediment samples from Chesapeake Bay (Darlene Wells, Maryland Geological Survey, personal communication). References describing the sieve-pipet method include Guy(1969) and Plumb (1981). Our analysis differed from the method used by the Maryland Geological Survey in the following respects:

(1) We did not treat the sediment with HCl for removal of carbonates.

(2) We used a mechanical mixer rather than an ultrasonic probe to insure dispersion of the particles following addition of a solution of sodium metaphosphate as a dispersing agent.

(3) We used the pipet analysis only to distinguish the clay fraction from the silt fraction and did not attempt to specify the complete distribution of particle sizes. Sieving was used only to separate the silt-clay fraction and to separate the very fine sand fraction from the coarser particle sizes.

Maximum sand content for any sample was 94.0% and maximum silt-clay content was 99.4%; most of the samples had a silt-clay content between 33% and 70%, and most of the silt-clay fraction of these samples typically was silt. The results of the particle-size analyses are presented in Table 2 of Appendix A. In order to estimate the silt-clay fraction of sediments stored along the margins and on the bottom of the channel, we devised a set of categories based on subjective determinations of sediment characteristics at our field sites. Sediment samples falling within the same category were analyzed for particle size, and an average particle-size distribution for the category was determined by averaging the results of these analyses. Categories were developed based on descriptions in the field notes. The mean silt-clay content for each category is listed in Table 2:

Table 2. Mean silt-clay content for sediment types

Sediment type	Percent silt-clay	Number of samples
Sand, traces of silt and organic material	21.95	8
Muddy sand	33.33	11
Silty sand	48.36	13
Sand with clay fragments or mud balls	54.45	4
Silty floc	67.38	7
Loam	67.67	15
Silt loam	84.91	8

In order to assess the unit mass of sediment stored along the channel margin at each station, the appropriate bulk density class and particle-size data for the type of sediment described in the field notes were multiplied by the measured volume. The same method was used for channel-bottom sediment. In many cases the prism of sediment was subdivided into smaller volumes that were assigned to different bulk density classes or sediment types; wherever this was done, all calculations were performed separately for each subdivision and the results were summed to derive a total unit mass and a silt-clay mass for the station.

c) Bulk Density Samples

An additional set of samples were collected for bulk density analysis. The location of the sample sites are marked on Figure 10a and 10b. At each site three samples were collected. The sites represented the major categories of stored sediment found: channel margins, one more sandy, the other more silty, and one example of dense channel margin material with a higher clay content.

A standard soil density coring device was used, and uniform size sleeves were used to contain the undisturbed sample. The samples were sealed with plastic caps, and weighed within 12 hours of collection. They were dried at 70 degrees centigrade for 72 hours and reweighed.

The completely submerged material, such as sandy and silty floc, was not sampled due to the difficulty in procuring an undisturbed sample. Values were estimated using standard literature (Hakanson and Jansson, 1983; Chow, 1964).

The bulk density values are used to estimate mass from volume measurements. The categories used for describing bulk density groups are different from the particle size categories described in Table 2. Bulk density categories are predominantly dependent on water content, amount of compaction, and to a lesser degree composition. In particular, when material is dry and compacted differences in particle size cause only small variations in bulk density. However, when wet, material with a high percentage of fine-grained particles has a relatively lower bulk density than coaser grained material.

Table 3: Mean bulk density values for sediment types

Dry, compacted material	1.25
Dry, cohesive material	1.13
Loose, dry material	0.97
Wet, sandy deposits	0.97
Wet, silty, sandy floc	0.75*
Silty floc (submerged)	0.40*

* Estimate based on literature

c) Calculation of Margin Storage

Each margin survey visit was plotted to reflect the prisms of sediment stored and the unit volume calculated in m3/m (see Figure 11). The data described in the section above were used to indicate the availability of the stored sediment and the various textures and densities. The prisms of sediment were each subdivided into volumes that were assigned separate particle-size and density classes at sites where our field observations indicated that these characteristics varied within the prism. The area of each prism was then calculated. The data on each site was then entered into a spreadsheet program and the unit mass of sand, silt and clay for each site calculated. To calculate mass throughout a reach the values were averaged between sites and multiplied by the distance along the shoreline. The masses were then summed for all reaches to generate total storage along the channel margins.

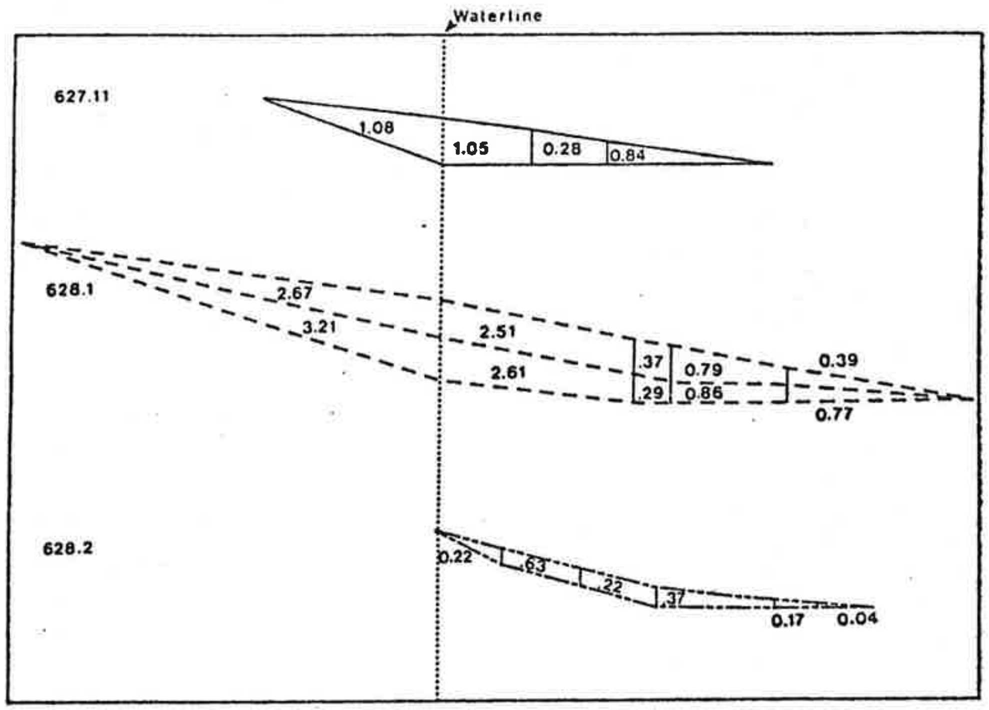


Figure 11: Sample Plotsof Channel Margin Storage (in m^3/m), see Appendix B for additional calculations.

V.3 Cross-section Monitoring

Seven sites for cross-sections were chosen in representative reaches of the channel (Figure 12). The furthest upstream cross-section was located along Mason Island in a steep, rocky reach. The second was located just below Mason Island, in a deeper section, with higher sediment storage characteristics. The third, was located along Harrison Island in another rocky, shallow area. Cross-section 4 was located near Sycamore Landing, an area which we believed close to the beginning of the Seneca pool backwater. Section 5 was located between Tenfoot and Sharpshin Islands, in Seneca pool. Sections 6 and 7 were located in the widest regions of Seneca pool, just upstream and downstream of the mouth of Seneca Creek.

Each cross-section was surveyed using the total station (TS). The TS, set up on one bank, was used to establish the 0 line, perpendicular to the flow of the river. The TS was used to orient all sightings on this 0 line. Both banks were surveyed up to the flat level or topographic level whenever possible. Observations were made of the general character of the banks, and the features of the terraces or floodplain.

In order to measure the shape of the channel bottom a boat was used to set 5 to 8 floats, with the aide of the TS, along the 0 line. The boat was then anchored, front and back at each float. From the boat the following measurements were made: depth of water, surface water velocity, depth of fine grained sediment or type of bottom material. Samples were taken for particle size analysis whenever sufficient quantities of fine grained sediment were encountered. The TS was used to measure the distance from the fixed markers to the shoreline. To generate a continuous picture of the shape of the river bottom, a fathometer trace was run, across the section at a constant velocity. The location of each float was marked off on the trace to scale distances more accurately.

Each section was marked with lag bolts, spray paint and metal stakes. The markers were surveyed with the section, and also relocated during the surveying of the longitudinal profile.

The Marsh-McBirny current meter failed during measurement of the first cross-section. Subsequently, surface water velocities were measured over a 14 foot distance with floats and a stopwatch. Each measurement was replicated three times, with the average used as the final value. On the final section high winds made even this impossible. Equipment problems were also encountered with the fathometer traces. Several breakdowns occurred and some traces were unusable because of reflections from large rocks in the channel. The detail from the fathometer trace was only added in 3 of the 7 sections. However, the measured points were still deemed adequate to define the general characteristics of the channel.

The information acquired was plotted to show the channel characteristics. The velocities are listed above each section (Figure 13).

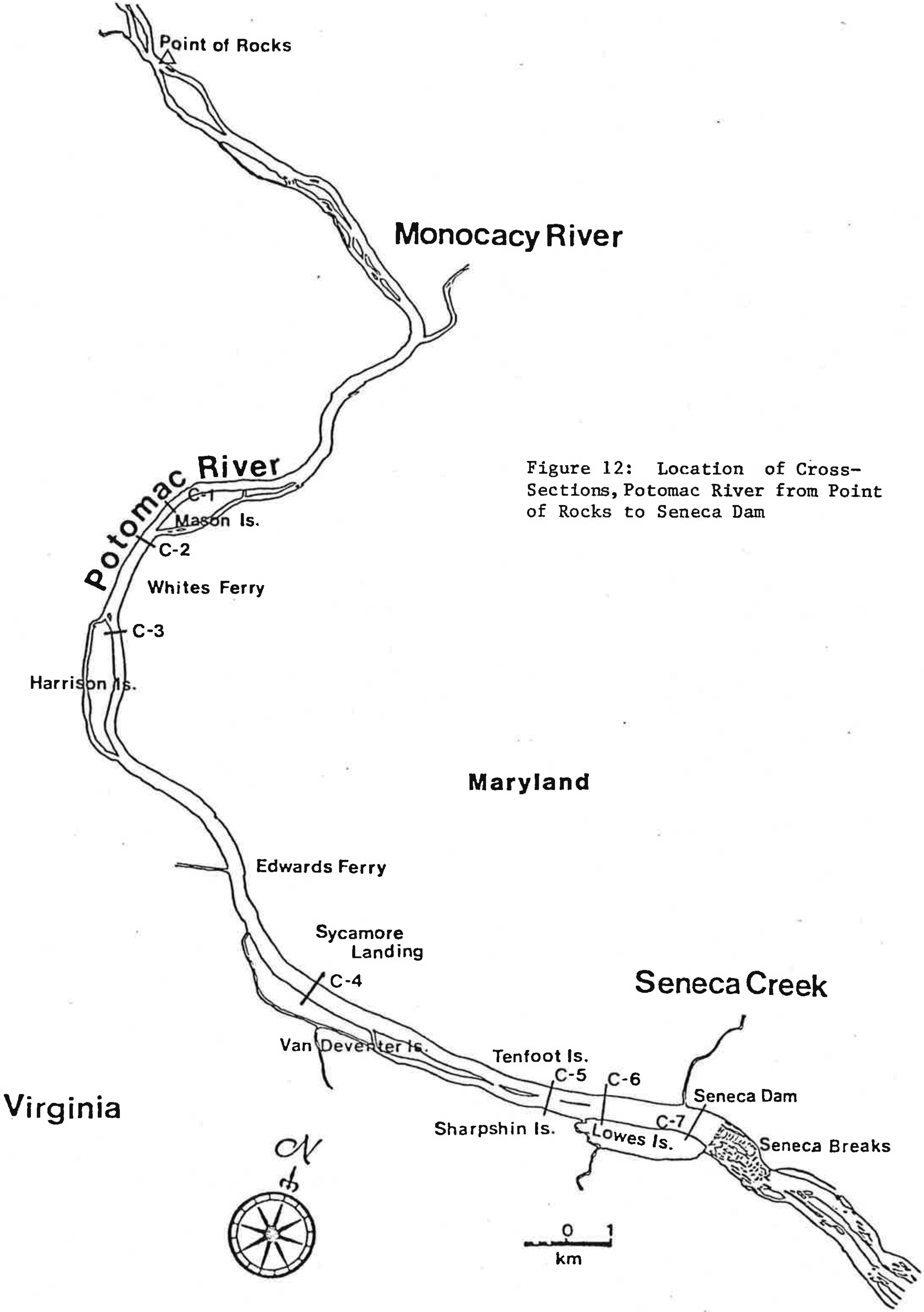
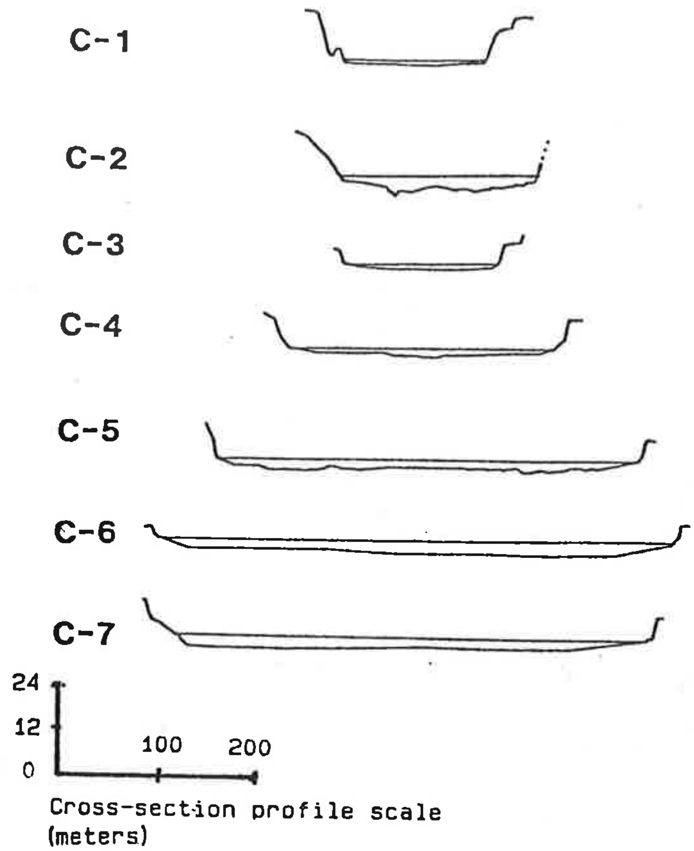


Figure 12: Location of Cross-Sections, Potomac River from Point of Rocks to Seneca Dam



Cross Section	Date	Stage* at Point of Rocks (feet)	Average Velocity (m/s)	Maximum Depth (m)
C-1	7/29/85	1.49	0.66	1.10
C-2	7/30/85	1.49	0.27	2.36
C-3	7/31/85	1.52	0.64	0.96
C-4	8/01/85	1.45	0.31	1.33
C-5	8/01/86	1.45	0.18	1.47
C-6	8/09/86	1.41	0.17	1.89
C-7	8/02/86	1.45	--	2.21

* Stage of 1.4 equivalent to 2800 cfs.

Figure 13: Cross-section Profiles, Average Velocities and Depths

VI. RESULTS

VI.1 In-Channel Storage of Sediment

In order to assess storage of fine grained sediment on the channel bottom we surveyed three cross sections in the reach between Mason and Harrison Islands, and four cross sections between Sycamore Landing and Seneca Dam (Figure 12). The cross sections are shown in Figure 13, and surface velocities are indicated for several points on each cross section. As we have already noted, virtually no fine grained sediment was found on the channel bottom through most of the study reach. Of our seven cross sections, the two sections closest to Seneca Dam and the single section between Whites Ferry and Mason Island stored measurable amounts of fine grained sediment. At section C-7, the closest to the dam, a maximum sediment thickness of 0.71 m was measured at the left channel margin. The sediment deposited along the channel margin consisted predominantly of silty sand. This deposit, which thinned with distance from the left side of the channel, was considered as part of the channel margin storage budget. At distances of 30 to 75 m from the left edge of the water we recovered an average of 0.24 m of soft silty floc from the bottom of the channel. This material gradually thinned and became coarser with increasing distance from the left bank; at 194 m we found a mixture of silty floc and fine sand on the bottom with a total thickness of only 0.05 m. From here to the right edge of the cross section (total width 624 m) the thickness of mixed sand and silt above the rocky bed varied between 0.0 and 0.08 m. The relative lack of sediment storage on the right side of the channel may be explained by the fact that remains of the dam extend from the left bank but no longer extend across the right half of the channel. Much of the fine grained sediment stored in this reach may well be derived from Seneca Creek, which is located immediately upstream along the left bank.

Using measured sediment thicknesses we estimated that the total volume of sediment stored in this cross section, exclusive of the channel margin deposits, was 36.6 cubic meters per meter of channel length. Assuming an average bulk density of 0.4 g/cm3 for the soft silty floc and 0.75 g/cm3 for the sandier material, we estimate the mass of sediment was 18.2 tonnes per meter of channel length, of which 11.3 comprised the silt and clay fraction.

Section C-6 had a thick margin deposit along the left bank, but at sites within the channel we found no more than 0.05 m of mixed sand and silty floc over a mixture of coarse sand, gravel, and cobbles. Average thickness of the surface layer was only about 1 to 2 cm, resulting in a total volume of 7.7 m3/m of channel.

Assuming that section C-7 is characteristic of the lower 500 m of channel and that an average of the two sections can be used to characterize the 1130 m of channel between them, we estimate a total storage mass of 23,700 tonnes of sand, silt and clay. An estimated 15,300 tons fall into the silt and clay particle size range. The sand fraction of the material described here includes only the sand fraction of the fine grained sediment. The total mass of sand in the bottom sediment greatly exceeds the mass of fine grained bottom material.

At section C-5 there is essentially no storage of fine grained sediment in the channel, as is the case further upstream. If we assume that the 2300 m reach between sections C-5 and C-6 has a storage mass equivalent to the average of the two sections multiplied by the length of the reach, we can budget an additional 6700 tonnes of bottom sediment, including 3200 tonnes of silt and clay. Thus our total figure for channel bottom storage of fine grained sediment in Seneca pool amounts to 30,400 tonnes, including 18,500 tonnes of silt and clay.

At section C-2, a short distance below Mason Island, a modest amount of fine grained sediment was identified on the channel bottom near the left bank. As was true at section C-7, a large margin deposit was present along the left side of the channel. The maximum thickness of mud, about 0.15 m, was located in the deepest part of the channel, at a water depth of slightly more than 3.0 m. There was no more than a trace of silty material in the right half of the cross section. The total volume of fine grained sediment on the channel bottom was estimated to be about 13.3 m3/m of channel, and the equivalent total mass of silt and clay was calculated as 5.3 and 3.6 tonnes, respectively. There were substantial medium and coarse sand deposits on the bottom in this reach; and as was true in Seneca pool, the total mass of sand present far exceeds the sand component of the fine grained sediment.

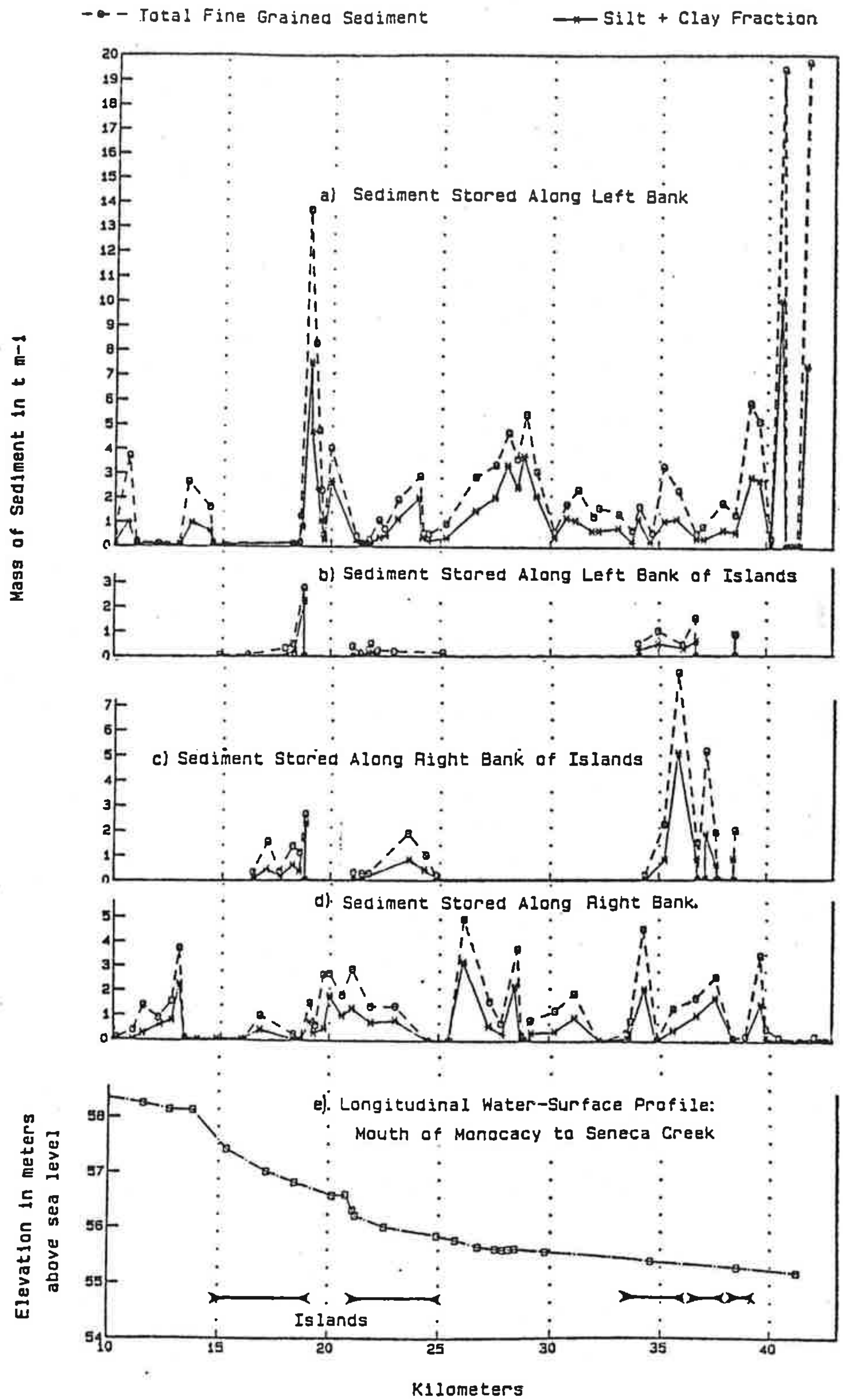
The reach between the downstream tip of Mason Island and the upstream tip of Harrison Island is about 2 km long. If we assume the figures obtained at the cross section as applicable to the entire reach, the estimated total mass of fine grained sediment (mixed fine sand, silt and clay) amounts to 10,600 tonnes, with the silt clay fraction accounting for 7,200 tonnes.

If these figures are added to those calculated for Seneca pool, we arrive at a total mass of fine grained sediment stored in the bottom amounting to about 41,000 tonnes, including 25,700 tonnes of silt and clay.

VI.2 Sediment Storage along Channel Margins

Using the methods described earlier in this report, we made measurements of the volume of sediment stored along the margins

Figure 14: Longitudinal Water-Surface Profile from Mouth of Monocacy to Seneca Creek with Masses of Sediment Stored along the Left, Right and Island Channel Margins.



of the channel at 126 locations between the mouth of the Monocacy River and Seneca Dam. The data gathered were combined with particle size and density information to calculate masses of sediment stored along the channel margins and to calculate the mass of silt and clay contained in this material. The longitudinal distribution of total mass and of the silt clay fraction are plotted in Figure 12; with the left and right sides of the channel and the left and right banks of major channel islands, all plotted on parallel axes. This figure also includes a plot of the longitudinal water surface profile, and the locations of major islands are indicated on the profile. Careful reading of this figure supports our initial impression that variations in water surface slope and current velocity were inversely related to variations in the amount of fine grained sediment stored along channel margins. Particularly upstream of Edwards Ferry, steep gradients, rapid velocities, and relatively small masses of sediment stored along channel margins were associated with the presence of channel islands. Gentle gradients, slower velocities, and larger masses of sediment in margin storage were associated with reaches without islands.

We estimate the total mass of fine grained sediment stored in the channel margin deposits to be 149,479 tonnes, with the silt clay fraction accounting for 76,796 tonnes.

Differences in the total storage and in the average mass per meter of shoreline are indicated in Table 4 for the left bank, right bank and island shorelines. The left bank has the largest amount of storage, which on average includes about twice as much sediment per meter of shoreline as the right bank. The island shorelines have the smallest total and average amount of storage, although there are local exceptions to this trend.

We have also compared the storage of sediment in channel margin deposits upstream and downstream of Edwards Ferry. Slightly more than 40% of the total is stored above Edwards Ferry; for the left bank, right bank, and island banks, storage above Edwards Ferry account for 37.7%, 57.3% and 30.0% of the total, respectively. Average storage per meter of channel for all shorelines combined is 4.6 tonnes per meter, and below Edwards Ferry the average is 6.3 tonnes per meter. The difference between these two reaches is evident in the figures for the left bank (1.7 vs 3.5 tonnes per meter) and for island shorelines (0.6 vs 2.0 tonnes per meter) but there is virtually no difference between the two reaches along the right bank (1.26 vs 1.27 tonnes per meter). There is surprisingly little sediment stored along the right bank throughout the study reach; we have no strong evidence to indicate why this should be so.

There are three primary locations with extremely large volumes of sediment in storage along the channel margins, and all three are on the left bank. The first site is just below the downstream end of Mason Island; the second site is located between the downstream tip of Harrison Island and Edwards Ferry; and the third site is at the downstream end of Seneca pool.

Table 4: Summary of Sediment Storage

	Shoreline Length (m)	Total Mass (tonnes)	Mass/meter of shoreline (tonnes/m)	Silt/Clay Mass (tonnes)	Silt/Clay mass/meter of shoreline (tonnes/m)
I: Mouth of Monocacy to Edwards Ferry					
Left Bank	18,032	28,901	1.66	15,436	0.86
Right Bank	19,167	24,179	1.26	13,660	0.71
Islands	15,550	8,692	0.56	3,828	0.25
Total	18,380	61,772	3.36	32,931	1.79
II. Edwards Ferry to Seneca Dam					
Left Bank	13,866	48,737	3.52	23,692	1.71
Right Bank	14,653	18,749	1.27	10,201	0.71
Islands	10,244	20,221	1.97	9,974	0.97
Total	13,935	87,707	6.29	43,867	3.15
III. Totals for Study Reach: Mouth of Monocacy to Seneca Dam					
Left Bank	32,482	77,638	2.39	39,128	1.20
Right Bank	33,820	42,928	1.27	23,861	0.71
Islands	25,880	28,913	1.12	13,809	0.53
Total	32,315	149,479	4.63	76,796	2.38

As discussed above, deposition of fine grained sediment along channel margins seem to be associated with channel transitions where gradient and flow velocity decrease; thus we see larger volumes of stored sediment downstream of islands and entering pooled backwater reaches. At the downstream end of Mason Island (Figure 10b) the narrower thread of flow rejoins the mainstem from behind Mason Island at the left side of the channel. At the junction and for a short distance downstream there are deposits of medium and coarse sand in deep water, and along the left bank we find large volumes of channel margin storage. Two possible mechanisms may be advanced to explain this pattern:

- At high flow, water emerging from the narrow channel behind the island enters the main stem as a jet. Because of the angle of entry, the higher velocity flow is diverted toward the right bank. As the main body of flow separates from the left bank, a boundary layer is formed where a low velocity reverse eddy allows sediment entrained from the main flow to settle out of suspension. Scouring occurs beneath the main thread of flow. Experimental studies by Mosely (1976; cited by Schumm, 1977) demonstrate that this type of mechanism may occur at tributary junctions.

- As the flow emerging from behind the island encounters the main stem, ponding occurs, allowing any sand in suspension to settle out at the location where gradient and velocity drop suddenly.

We have not carried out detailed surveys of the bottom profile, velocity or sediment characteristics at this site to verify or disprove either of these hypotheses.

Local variations in the amount of stored sediment elsewhere along the shoreline may be related to inflow of small tributary channels, to irregularities in the shape of the shoreline (causing alteration in flow patterns along the shore), and to the effects of human activities. An example of the latter effect would be seen at sites where a portion of the C & O canal was built immediately adjacent to the river and the canal embankment has been stabilized by emplacement of rock walls along the bank.

VI.3 Overbank Sedimentation

Previous sections of the report describe the three major sets of geomorphic surfaces that were found bordering the channel above the low water level. Evidence for deposition occurring on the active channel shelf and floodplain surfaces has also been discussed. We did not make a detailed survey of overbank sediment thicknesses, but our observations allow us to make an order of magnitude estimate to assess the relative importance of overbank sedimentation. Where recent overbank sediment was observed, typical thicknesses ranged from 0.02 to 0.05 m of sandy silty material, with discontinuous silty mud drapes no more than a few millimeters thick. Spring 1985 high flows apparently did not deposit sediment on the floodplain but did leave deposits on the active channel shelf. If we assume that the surface extends back about 5.0 m from the water's edge and that a uniform thickness of 2 cm is deposited along island and mainland shorelines throughout the entire reach, we calculate a total volume of about 9,070 m3 of sediment. Assuming further that this sediment has an average bulk density of 1.0 g/cm3 and a silt clay content of 50%, we arrive at a total mass of 9,070 tonnes and a silt clay mass of 4,535 tonnes.

Overbank sedimentation on the floodplain surface may not occur every year but probably occurs on average every two years. Observations of the results of the November 1985 flood, described earlier, lead us to believe that layers of sediment as thick as 0.02 m probably would extend no further back from the waters edge than 10 or 20 m in most floods. This would at least double the estimate of total sediment deposited to between 18,000 and 36,000 tonnes. If we further assume that thickness declines gradually to a negligible trace at 100 m from the channel, we might increase our estimate of overbank sedimentation from 0.2 m3/m of channel to about 1.0 m3/m of channel length, thus increasing the estimate of total overbank storage from 9,100 to 91,000 tonnes.

Other favorable sites for deposition of overbank sediment can be found at tributary junctions. At the confluence of the Monocacy and the Potomac Rivers and at the confluence of Seneca Creek and the Potomac River, the November 1985 flood left a layer of mud that was 0.05 to 0.1 m thick covering floodplain areas immediately upstream of the aqueduct. Similar deposits, more extensive than our estimated average, were found along the Potomac shoreline at Edwards Ferry. We have not attempted to account for these deposits separately in our estimate.

Some islands in the study reach have upper surfaces no higher than the average floodplain level, about 3 to 4 meters above the low water. We cannot say with any assurance how much sediment might be stored on island surfaces, particularly considering the complexity of the processes involved in island sedimentation and erosion; however, given the large surface area occupied by islands in the study reach, we believe they may play a more important role in storage of sediment than does the floodplain level of the mainland. Because islands are more readily subjected to scouring and bank erosion, they may also return stored material to the river more readily than the floodplain surfaces along the mainland do. In this regard it is also worth noting that sediment stored on the active channel shelf that slopes down toward the river, also is more likely to be remobilized than sediment at higher elevations on the floodplain surface. The active channel shelf, of course, merges with the zone where channel margin deposits are located, with the border being marked at the limit of permanent vegetation.

VI.4 Small Tributaries

Based on our foray into the mouth of Limestone Branch (discussed in Section III.2) we have made an estimate of the volume of fine grained sediment ponded on the day of our visit. We estimate a maximum volume of 350 m3; assuming that this very loose material had a bulk density of 0.4 g/cm3, we calculate a total mass of 140 tonnes, of which about 90 to 95 tonnes would be silt and clay. If there were 100 such tributaries along the study reach we might budget a total of 14,000 tonnes. However, although similar deposits were found in several other small tributaries, they were usually smaller in volume. Larger tributaries like Goose Creek have a greater ability to flush their mouths of fine grained sediment under normal flow conditions. Thus for the purposes of this report we assume that storage at tributary mouths can be neglected. Despite this statement, it is entirely possible that some of the larger tributaries (such as Goose Creek and Seneca Creek) store substantial amounts of sediment in their channels, and there may well be more fine grained sediment stored upstream in these channels than there is in the channel of the Potomac River. Spot checks indicated that the mouth of Goose Creek was sandy, with only traces of silt on the bottom and the mouth of the Monocacy appeared to have even less fine grained sediment. On the other hand, we did notice that there was mud in the channel of Seneca Creek upstream of the aqueduct, although we did not make measurements there.

VI.5 Summary of Sediment Storage

In calculating a total mass of fine grained sediment storage in the study reach (mouth of Monocacy to Seneca Dam), we make use of the following results (all results are rounded to the nearest 1,000 tonnes). See also Table 5.

- Channel bottom storage amounts to 41,000 tonnes, including 26,000 tonnes of silt and clay.
- Channel margin storage amounts to 149,000 tonnes, including 77,000 tonnes of silt and clay.
- Overbank storage on the active channel shelf amounts to 9,000 tonnes, including 5,000 tonnes of silt and clay.
- Additional overbank storage on floodplain may amount to 9,000 tonnes (after subtracting the amount already budgeted for the active channel shelf), with estimates ranging as high as an additional 82,000 tonnes. Associated silt clay estimates would be 5,000 to 41,000 tonnes.

TABLE 5: Summary of sediment storage investigations

Geomorphic setting	Mass of fine-grained sediment Total (t)	Silt + Clay (t)	Comments
Channel bottom	41,000	26,000	Mass in storage, summer 1985. Channel-bottom muds probably have residence time <1 year. Amount in storage may be highly variable over time.
Channel margin	149,000	77,000	Mass in storage, summer 1985. Surface layers probably have residence time <1 year; deeper layers remobilized infrequently. Probably no more than 20% annual turnover.
Active channel shelf	9,000	4,500	Estimated mass of layer of fresh sediment draped over surface. Residence time uncertain, but longer than surface layers of channel-margin deposits.
Flood plain	109,000	54,000	Estimated mass of layer of fresh sediment deposited in November 1985 flood (recurrence interval = 25 years). Similar amount deposited in February 1984 flood (recurrence interval = 10 years). Residence time could be decades to centuries.
Channel islands	no data	no data	Historical changes in islands may affect long-term sediment delivery.
Tributary mouths	no data	no data	Ponding by flood water may cause temporary storage of slackwater deposits. Probable residence time of days to months.

- Storage on channel island surfaces, other than what is included in the above category, has not been estimated.

- The islands may play an important role in storage and remobilization of fluvial sediment, but we do not have enough information to quantify this role.

- Small tributaries are assumed to provide a negligible amount of sediment from storage at their confluence with the mainstem, as observed at Limestone Branch. However, the general type of storage of fine grained sediment in tributary channels and throughout tributary basins has not been addressed. This category of storage may be very large but is outside the scope of this study.

- Because the overbank sediment figures are event based and do not reflect either the total magnitude of storage at any one time or the amount of sediment available for resuspension, they are not truly comparable with the channel bottom and channel margin estimates. If we sum the latter two categories, the total amount is 190,000 tonnes, including 102,000 tonnes of silt and clay. If we were to consider one year's accumulation of flood deposition on the active channel shelf these numbers would increase by small amounts; if we were to add the larger floodplain estimate, the totals would come to 281,000 tonnes and 148,000 tonnes respectively.

VII. DISCUSSION

Our goal in this study was to see whether the amount of fine-grained sediment stored in the mainstem Potomac River between Point of Rocks and Seneca Dam was large enough to explain the discrepancies observed in the sediment record (Section II). We use the term "fine-grained sediment" to refer to variably cohesive sediment deposits that contain a significant silt-clay component. In many cases these deposits also contain a large component of sand (Table 2), which consists primarily of fine sand. Therefore we refer to the silt-clay component of the fine-grained sediment as a fraction of the total amount of fine-grained sediment. Suspended sediment measured at gages in the Potomac River is composed primarily of silt and clay, but also includes a sand component.

The average annual sediment load at Chain Bridge for the three years of record (1979-1981) is 1.47 million tons, or 1.33 million tonnes. Silt and clay in channel-bottom storage were estimated to be 26,000 tonnes, or just under 2% of the annual load of the Potomac at Chain Bridge. The total fine-grained sediment figure for channel-bottom storage (41,000 tonnes) represents 3.1% of the annual load. Clearly the hypothesis that channel-bottom storage in Seneca Pool accounts for the discrepancy in the data collected from 1979 to 1981 is not supported by these results. The evidence supporting the storage hypothesis appears to show that the amount of storage can vary dramatically over short time periods, and therefore it is possible that the amount of fine-grained sediment stored in the channel was much larger following the high flow of February 1979 than it was in the summer of 1985. However, we have no evidence that would allow us to verify or to reject this possibility.

The combined values for channel-bottom and channel-margin storage are considerably larger. The silt-clay component of the fine-grained sediment (102,000 tonnes) amounts to 7.7% and the total amount of fine-grained sediment (190,000 tonnes) amount to 14.3% of the average annual suspended sediment load at Chain Bridge. The combined mass of fine-grained sediment stored in channel-bottom and channel-margin deposits measured in summer 1985 is about two-thirds the size of the discrepancy between the sediment loads at Chain Bridge and station PRMon for February 1979 (295,000 tons of 268,000 tonnes). If we assume that the additional drainage area between the upstream and downstream gages contributes sediment as modeled in section II (see top of page 12), the size of the discrepancy increases to 406,000 tons or 368,000 tonnes; the mass of fine-grained sediment in channel-bottom and channel margin storage in summer 1985 is equivalent to about half of this amount.

Channel margin deposits are not as readily mobilized as channel bottom deposits, but they are subject to scouring and deposition at various stages of the flood hydrograph. Evidence of active exchange of sediment between the Potomac River and its channel margin deposits was observed at many of our field sites (Section III.2 (c)). Given the dynamic nature of the system and the active exchange of sediment between the channel margins and the main body of the flow, it is not unreasonable to suppose that the amount of fine-grained sediment in storage after the high flow of February 1979 could have been twice as large as in summer 1985. Some of the shoreline locations that were sites of bank erosion in summer 1985 may have had channel margin deposits at some time in the past. Unfortunately our "snapshot" of existing conditions does not allow us to see what the system actually looked like in the past.

The characteristics of existing channel margin deposits do allow us some additional insight into this question, however. Although some of the thicker wedges of sediment were relatively soft and unconsolidated, others were denser and contained multiple layers of leaf litter; in some cases we found buried roots of plants that had grown on the surface of the deposit in the past. Deposits fitting the latter description appear to have been laid down over a period of time longer that a single season. Although their age cannot be placed exactly, the stratigraphy of these deposits indicates that multiple high-flow events contributed to their formation over a period of years. Removal of the surficial layers of these deposits can occur to varying degrees as they are scoured by the river at stages higher than base flow, but complete remobilization of sediment stored in channel margins would require a catastrophic event. Such events do occur on occasion. The November 1985 flood was such an event in parts of the West Virginia drainage of the Potomac River, but its effects were not severe in the vicinity of our study reach.

The pattern of apparent storage and remobilization in 1979 (Figure 7, Section II) would require deposition of up to 368,000 tonnes in a single event that occurred in February and removal of a comparable amount of sediment by several moderately high discharge events the following fall. Such rapid changes in storage, particularly given the size of flow responsible for remobilization, are not consistent with the characteristics of the channel margin deposits observed in the field and are not completely attributable to variations in channel margin storage.

There are other forms of sediment storage that may contribute to the pattern shown in Figure 7. Channel storage and resuspension of sand may account for a significant component of the discrepancy in the sediment discharge records. Five suspended-sediment samples collected at Chain Bridge on February 27, 1979, the peak-discharge day for the 3 years of record (average discharge 201,000 cfs) had an average sand content of 15.6%. A sample collected two days earlier at Point of Rocks, on the rising limb of the hydrograph (instantaneous discharge 92,800 cfs), had a sand content of 20%. Particle-size data from suspended-sediment samples generally are poorly correlated with flow, and there are not enough samples from this event to allow estimation of a separate mass balance for sand, but the amount of sand traveling in suspension during this event and at flow levels grater than about 70,000 cfs is large enough to merit consideration as a component of the storage-resuspension budget. An analysis of particle-size distribution of suspended-sediment samples at Chain Bridge and Point of Rocks was included in Washington Area Council of Government's examination of the upper Potomac River (WA-COG), 1984). They suggest that sand may be accumulating in the channel below Point of Rocks at low or medium flow, with resuspension occurring during high-flow events. Depending upon the characteristics of the flood wave and the hydraulic conditions prevailing in the channel in any given event, it is also possible that significant amounts of sand are deposited in the study reach during some high-flow events and that sand is resuspended during other high-flow events.

Although our field survey did not include measurement of sand deposits with negligible amount of interstitial silt and clay, our reconnaissance of channel conditions indicated that there is a large volume of sand distributed throughout the study reach, even though most of the river bottom is composed of coarser particle sizes. This sand is available for resuspension at high flow. Because sand is not associated with nutrient transport to the same extent as the silt-clay fraction of the suspended load, storage and resuspension of sand in the river channel is of little concern from the perspective of those responsible for managing nutrient loads delivered to tidewater.

Geomorphic surfaces above the level of the channel proper can serve as sinks for fine-grained sediment during high-flow events. According to our estimates, however, the active channel shelf (Section III.2 (b), Section VI.3) accounts for a very modest amount of sediment. By considering storage on both the floodplain and the active channel shelf, we may account for up to 91,000 tonnes of storage during a single event. But the floodplain is inundated less frequently than the active channel shelf and the sediment stored in the floodplain is remobilized slowly, primarily by bank erosion. Thus overbank sedimentation can account for some loss of sediment between the upstream and downstream gages, but subsequent resuspension is unlikely to come from the floodplain surface.

Channel islands may play an important role in storage and remobilization of fine-grained sediment. Islands are large reservoirs of fine-grained sediment and are highly dynamic in their interactions with the main body of flow during flood events, as described in Section II.3 (e) of this report. The development of a separate sediment budget for islands was beyond the scope of this report, although the estimates of channel margin storage and overbank sedimentation include islands.

Storage also may occur at the mouths of major tributaries to the Potomac River as a result of ponding by a flood wave traveling along the main stem. Much of the sediment deposited at tributary sites probably can be resuspended fairly easily after passage of the flood and would not remain in storage for long. If much of the sediment yield of Piedmont tributaries was trapped at tributary mouths by the February 1979 high flow, this could help to explain part of the discrepancy between estimated sediment discharge and measured sediment discharge at Chain Bridge during this month. Resuspension could have occurred in a series of storms during the following months.

From the preceding discussion it becomes clear that the concept of a single, readily identifiable storage reservoir for fine-grained sediment in Seneca Pool or elsewhere in the study reach does not adequately explain the pattern of apparent storage and remobilization shown in Figure 7. There are multiple reservoirs of fine-grained sediment, all of which may be partially responsible for this pattern, and it is likely that sand stored in the channel also accounts for a significant percentage of the storage and remobilization of sediment. Channel-bottom storage in the main stem and in tributary mouths probably has a very short characteristic residence time, but much of the sediment deposited along channel margins, on the active channel shelf and the floodplain, and on islands will remain in storage for periods longer than a few months. Sediment lost to the river by deposition at these sites may be replaced by sediment derived from bank erosion in subsequent events.

There are also phenomena other than sediment storage and remobilization that may be partially responsible for the observed pattern of sediment discharge:

1) Suspended-sediment sampling is subject to error, because incomplete mixing produces spatial variations in concentration across the channel and because suspended sediment concentrations at high flow experience temporal variations that may not be captured by a small number of samples. Although we have no data to evaluate the magnitude of error in the sediment records, we note that a comparison of three stations with independent measurements has variance equal to the sum of the variances at those three stations. An unknown portion of the apparent storage and remobilization of sediment may therefore be attributable to sampling error.

2) Previous statements in Section II of this report (p. 9) point out that the difference between sediment load measured at Chain Bridge and the combined sediment loads measured at Point of Rocks and Frederick should be considered as a signal with three parts: storage and resuspension between

stations, sampling error, and sediment discharge from smaller tributaries entering the Potomac above Chain Bridge ("station X"). Although the apparent loss of sediment between Point of Rocks and Chain Bridge in February 1979 cannot be attributed to these tributaries, some of the excess sediment appearing at Chain Bridge in other months may not be sediment remobilized from storage in the study reach but may instead be derived from extremely high sediment yields in some of these tributary basins. Whether or not this is true, our examination of the sediment data strongly suggests that, taken as a group, these tributaries contribute more suspended sediment to the Potomac River at Chain Bridge than does the Monocacy River above Frederick. In targeting the Monocacy basin as a priority area for nonpoint source controls, we should consider the possibility that other Piedmont tributaries are also important source areas for nonpoint pollution.

Characteristic amounts and residence times of sediment storage within a large watershed like the Potomac remain to be fully explained. As indicated in the Introduction (section I), a general relationship between drainage area and sediment delivery ration has been described and is often referred to in the literature. The processes that cause delivery to lag behind erosion also are known. But the precise timing and location of these processes have not been quantified. The survey described in this report focuses on only one small piece of the sediment delivery problem. Transport processes active in the main stem between Point of Rocks and Chain Bridge have some effect on the delivery of sediment to Chain Bridge, although this effect appears to be relatively small with respect to fine-grained sediment. The role of sediment storage and resuspension throughout the remainder of the watershed may prove far more important than sediment storage in this relatively short section of the mainstem.

VIII. CONCLUSIONS

The objectives of this study were to examine the processes and magnitude of sediment transport and storage between Point of Rocks and Seneca Dam. The effect of the dynamics of sediment movement on incremental reductions in upstream sediment load were also addressed. The major conclusions of this study are as follows:

- Data analysis of upstream versus downstream suspended sediment loads (the Potomac River at Point of Rocks and the Monocacy River versus the Potomac River at Chain Bridge), collected by USGS during water years 1979-1981, indicated time varying storage of sediment in the study reach.

- The nature of the stored material indicated by this analysis was unknown, but if comprised predominantly of silt and clay, storage could have significant implications for the transport of associated nutrients.

- The examination of this three year data set also indicated that the intervening drainage (not accounted for by Point of Rocks and the Monocacy River at Jug Bridge) has a very high effective sediment yield. The sediment produced by this intervening drainage has the least distance to travel to reach the Potomac Estuary. Programs which target sediment controls should preferentially include this area.

- The in-channel storage of fine grained sediment observed during the field survey (June-August 1985) did not indicate significant storage of silt and clay during this period when compared with the average annual load at Chain Bridge (approximately 2% of the average annual load).

- Combined channel-bottom and channel-margin storage of silt and clay during the period of the field survey was equivalent to a larger percentage (7.7%) of the average annual suspended-sediment load at Chain Bridge.

- Despite frequent exchange of thin layers of sediment between the channel margins and the river, the characteristic residence time of sediment stored in channel margins is longer than the characteristic residence time of sediment stored on the channel bottom. The longer residence time causes a longer time lag between input at the source and delivery at the lower end of the reach. The quantity of sediment involved is not large enough for this time lag to have an important effect on the total delivery of sediment and nutrients to tidewater.

- Because of the relatively small quantity of silt and clay size sediment measured in the field, the large storage observed in the analysis of the USGS data is probably due also to stored sand and the combined error of the 3 stations. If sand comprises a significant portion of the larger storage the question of its transport time is no longer pertinent to the transport of nutrients.

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APPENDIX A

PARTICLE SIZE ANALYSIS RESULTS

Station Number	Water Content	Fine Sand and Larger	Very Fine Sand	Silt	Clay
618.011	.861	8.7	16.9	57.2	17.1
618.012	.776	22.6	16.9	46.0	14.5
618.013	.667	24.2	16.6	45.6	13.6
618.014	.585	37.2	26.0	28.6	8.3
618.015	.543	8.6	8.3	69.8	13.2
619.011	.481	15.5	10.7	36.5	37.3
619.021	.651	52.2	13.4	25.5	8.9
619.031	.581	58.8	15.4	18.7	7.1
619.032	1.128	44.1	18.5	27.0	10.4
625.011	.965	46.5	10.6	34.4	8.5
625.012	1.087	18.0	10.9	54.9	16.2
Sec1Sta1	.573	56.2	18.1	15.6	10.0
Sec1Sta1	.530	25.8	35.8	31.1	7.2
Sec1Sta2	.657	32.2	5.2	49.4	13.2
Sec1Sta3A	.723	15.1	7.4	58.2	19.2
Sec1Sta3B	.574	61.2	10.4	16.5	11.9
Sec1Sta5	.406	75.3	4.1	15.5	5.2
626.011	.528	5.3	9.4	67.0	18.3
626.052	.574	19.8	21.8	44.9	13.5
627.012	.548	19.8	14.1	51.0	15.2
627.051	.689	16.8	9.3	57.6	16.3
627.101	.518	41.3	17.4	31.4	9.9
628.061	.654	43.2	18.8	28.1	10.0
703.011	.887	38.0	15.3	39.0	7.7
703.012	.595	1.1	6.1	75.3	17.5
703.021	.595	66.1	9.0	20.5	4.4
703.051	.676	40.9	13.1	34.2	11.7
705.021	.132	20.5	21.0	40.3	18.2
705.022	.175	24.7	9.7	39.6	26.0
708.041	.524	48.1	26.5	19.1	6.3
709.011	.496	4.1	9.3	65.8	20.8
709.012	.986	17.3	18.0	44.2	20.5
709.041	.657	11.3	13.7	56.3	18.7
709.051	.936	16.9	153.	486.	141.
709.091	.580	38.5	155.	345.	114.
709.111	.403	9.2	89.	636.	183.
715.021	.474	55.4	156.	231.	59.
715.031	.579	37.2	164.	381.	83.
715.061	.526	26.3	123.	475.	139.
715.062	.841	23.6	164.	460.	140.
715.081	.755	32.2	231.	355.	92.
717.011	1.612	1.0	17.	735.	238.
718.011	.620	8.7	103.	640.	170.
718.012	.572	70.8	78.	186.	28.
718.071	1.125	24.4	153.	469.	134.

Station Number	Water Content	Fine Sand and Larger	Very Fine Sand	Silt	Clay
718.081	.866	29.2	140.	431.	137.
718.151	.612	15.9	175.	527.	139.
719.011	.666	28.1	250.	353.	116.
719.101	.813	14.0	172.	519.	169.
719.111	.877	23.8	216.	415.	132.
719.141	.423	28.8	166.	431.	115.
723.011	.275	34.3	189.	322.	145.
723.012	.960	17.3	239.	435.	153.
723.091	.490	13.8	95.	586.	181.
723.092	.664	60.6	142.	165.	87.
723.121	.801	26.6	265.	367.	101.
723.131	.360	6.3	55.	711.	170.
724.031	.727	17.6	190.	481.	153.
724.041	.506	55.5	208.	183.	53.
724.061	.657	34.4	197.	351.	108.
724.131	.548	45.1	162.	294.	93.
731.151	.260	25.6	100.	502.	141.
801.011	.328	40.7	96.	389.	108.
801.012	.512	10.1	94.	650.	156.
801.021	.670	58.4	16.3	20.3	4.9
801.022	.989	11.0	16.7	57.1	15.2
801.023	.275	92.4	1.6	4.5	1.5
802.011	.409	0.3	0.4	77.0	22.4

APPENDIX B: CHANNEL MARGIN STORAGE

1. Mass in tonnes between stations
2. Mass in tonnes/meter of shoreline

Right Bank below Monocacy River

Numbers listed below are totals for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
718.030		0.00						
	373.00		183.36	39.87	61.18	21.68	82.85	306.08
718.040		373.00						
	765.00		139.68	46.75	79.96	26.47	106.42	292.85
718.050		1138.00						
	410.00		233.46	64.83	98.36	33.29	131.64	429.93
703.050		1548.00						
	780.00		391.83	141.34	350.80	118.44	469.24	1002.41
718.060		2328.00						
	545.00		177.15	112.87	346.37	111.65	458.02	748.03
718.080		2873.00						
	215.00		154.84	93.11	270.24	79.18	349.41	597.37
718.070		3088.00						
	305.00		144.42	90.84	279.03	79.84	358.87	594.14
718.090		3393.00						
	710.00		3.58	2.90	10.21	3.18	13.40	19.87
718.100		4103.00						
	815.00		0.00	0.00	0.00	0.00	0.00	0.00
718.110		4918.00						
	1140.00		5.34	4.32	15.23	4.74	19.97	29.63
718.120		6058.00						
	841.00		104.68	71.91	256.67	81.02	337.69	514.27
718.130		6899.00						
	1650.00		332.53	220.46	653.53	202.49	856.03	1409.02
718.140		8549.00						
	295.00		31.15	19.70	39.05	11.42	50.46	101.31
627.070		8844.00						
	540.00		131.36	87.63	192.43	61.68	254.11	473.11
627.080		9384.00						
	200.00		66.75	42.14	98.03	31.30	129.33	238.23
627.100		9584.00						
	405.00		424.47	95.57	168.65	56.58	225.23	745.27
627.110		9989.00						

Numbers listed below are totals for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
	365.00		432.48	143.06	353.12	131.73	484.85	1060.39
718.150		10354.00						
	448.00		218.04	175.08	517.02	190.42	707.44	1100.56
719.010		10802.00						
	557.00		441.27	238.94	553.44	187.63	741.07	1421.28
719.020		11359.00						
	840.00		572.95	299.55	777.05	247.65	1024.70	1897.21
719.040		12199.00						
	1033.00		278.18	220.58	800.38	246.50	1046.88	1545.64
719.050		13232.00						
	1452.00		213.26	171.52	628.30	196.04	824.35	1209.13
719.080		14684.00						
	1005.00		29.77	13.18	79.48	20.76	100.25	143.20
719.090		15689.00						
	791.00		449.41	328.14	991.58	363.70	1355.29	2132.83
719.100		16480.00						
	913.00		756.87	520.81	1379.93	490.19	1870.12	3147.79
719.110		17393.00						
	630.00		269.30	160.61	309.62	91.36	400.98	830.89
719.120		18023.00						
	638.00		382.32	271.15	669.13	226.97	896.09	1549.56
719.130		18661.00						
	261.00		140.78	100.50	250.12	85.66	335.78	577.05
626.010		18922.00						
	245.00		19.64	12.26	23.16	6.72	29.88	61.78
Goose Creek		19167.00						
	168.00		23.17	15.41	38.01	12.98	50.99	89.57
723.070		19335.00						
	1056.00		452.57	234.00	493.64	158.71	652.35	1338.92
723.080		20391.00						
	950.00		552.30	277.46	645.28	224.36	869.64	1699.39
723.090		21341.00						
	1182.00		353.39	199.65	545.69	201.54	747.22	1300.26
723.100		22523.00						
	1249.00		54.38	51.38	248.99	74.86	323.85	429.61
723.110		23772.00						

Numbers listed below are totals for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
	802.00		156.82	110.87	319.61	95.01	414.62	682.30
723.120		24574.00						
	588.00		555.58	349.05	675.08	196.68	871.77	1776.40
724.060		25162.00						
	736.00		586.38	369.72	738.73	213.10	951.82	1907.92
724.070		25898.00						
	780.00		221.39	129.84	283.68	81.80	365.48	716.71
724.080		26678.00						
	953.00		423.05	288.16	738.24	251.87	990.11	1701.32
724.090		27631.00						
	910.00		391.33	338.87	1111.67	414.63	1526.30	2256.50
724.100		28541.00						
	917.00		322.77	247.54	747.04	275.21	1022.25	1592.56
724.110		29458.00						
	606.00		115.96	54.67	117.62	36.63	154.25	324.89
723.060		30064.00						
	665.00		501.89	272.25	522.43	155.93	678.36	1452.51
723.050		30729.00						
	241.00		187.71	103.59	201.63	61.35	262.98	554.28
723.040		30970.00						
	652.00		179.55	60.04	130.64	45.05	175.69	415.28
723.030		31622.00						
	1006.00		154.96	27.60	37.87	13.47	51.34	233.90
723.020		32628.00						
	568.00		87.09	22.91	40.81	13.63	54.44	164.44
723.010		33196.00						
	388.00		59.49	15.65	27.88	9.31	37.19	112.33
625.010		33584.00						
	236.00		0.00	0.00	0.00	0.00	0.00	0.00
Seneca Breaks		33820.00						
Total			12108.66	6958.28	17916.60	5944.39	23860.99	42927.93

Island Banks below Monocacy River

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance (m)	Cumdist (m)	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
Mason Island, west side								
Tip		0.00						
	1750.00		358.63	114.11	176.90	59.25	236.16	708.75
628.070		1750.00						
	644.00		331.63	105.52	163.59	54.79	218.38	655.40
628.060		2394.00						
	458.00		231.50	73.66	114.20	38.25	152.45	457.52
628.050		2852.00						
	513.00		164.21	87.91	160.94	47.77	208.70	460.88
628.040		3365.00						
	325.00		169.40	76.49	134.20	41.06	175.27	421.17
628.030		3690.00						
	215.00		96.37	45.65	219.10	58.59	277.68	419.70
627.060		3905.00						
Mason Island, east side								
Tip		0.00						
	1402.00		0.00	0.00	0.00	0.00	0.00	0.00
618.020		1402.00						
	1702.00		119.49	38.02	58.94	19.74	78.69	236.15
628.023		3104.00						
	157.00		31.88	10.14	15.72	5.27	20.99	63.00
618.010		3261.00						
	512.00		146.92	82.42	481.02	125.87	606.90	836.28
627.060		3773.00						

Distance in meters

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
Harrison Island, west side								
Tip		0.00						
	390.00		74.00	23.55	36.50	12.23	48.73	146.25
708.011		390.00						
	460.00		61.43	27.48	63.84	23.25	87.10	176.00
719.030		850.00						
	1170.00		471.66	240.30	474.96	151.79	626.75	1338.77
719.060		2020.00						
	1237.00		689.47	334.87	598.96	180.75	779.70	1804.16
719.070		3257.00						
	412.00		106.74	46.23	78.81	24.41	103.22	256.20
619.030		3669.00						
	320.00		42.34	11.09	13.46	5.11	18.58	72.00
Tip		3989.00						
Harrison Island, east side								
708.010		0.00						
	490.00		48.35	15.38	23.85	7.99	31.84	95.55
705.020		490.00						
	212.00		7.37	1.31	1.80	0.64	2.44	11.13
708.020		702.00						
	87.00		16.80	3.68	5.33	1.84	7.17	27.65
705.050		789.00						
	315.00		65.77	20.14	22.93	7.81	30.74	116.64
708.040		1104.00						
	665.00		61.35	27.34	27.03	8.99	36.02	124.69
708.070		1769.00						
	2200.00		133.58	42.50	65.89	22.07	87.96	264.00
807.000		3969.00						

Distance in meters

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
Van Deventer Island, north side								
Tip		0.00						
	244.00		29.52	19.83	54.64	15.05	69.69	119.07
723.130		244.00						
	1132.00		311.08	145.31	325.20	97.99	423.19	879.62
723.140		1376.00						
	1455.00		488.65	220.29	423.86	131.34	555.20	1264.18
724.010		2831.00						
	422.00		200.79	79.04	139.00	42.20	181.20	461.08
724.022		3253.00						
Van Deventer Island, south side								
Tip		0.00						
	659.00		10.36	10.90	70.43	18.68	89.10	110.38
724.05		659.00						
	980.00		501.09	193.87	383.99	116.47	500.45	1195.50
724.04		1639.00						
	973.00		1403.91	795.15	2136.19	779.90	2916.09	5115.11
724.03		2612.00						
	847.00		946.39	623.87	1836.91	683.72	2520.62	4090.80
724.02		3459.00						
Tenfoot Island, north side								
Tip		0.00						
	650.00		0.00	0.00	0.00	0.00	0.00	0.00
724.14		650.00						
	350.00		0.00	0.00	0.00	0.00	0.00	0.00
Tip		1000.00						

Distance in meters

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
Tenfoot Island, south side								
Tip								
	213.00		588.85	180.87	289.80	94.12	383.92	1153.57
724.13		213.00						
	673.00		1281.87	382.15	614.55	198.61	813.16	2477.11
724.12		886.00						
	161.00		168.23	46.13	74.99	23.88	98.87	313.24
Tip		1047.00						
Sharpshin Island								
724.15	1485.00	1485.00	1027.31	591.31	1099.43	322.75	1422.19	3041.28
Total		25880.00	10386.94	4716.53	10386.97	3422.17	13809.14	28912.82

Left Bank below Monocacy River

Distance in meters

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
718.020		0.00						
	536.00		676.79	141.99	228.51	81.98	310.49	1129.27
718.010		536.00						
	345.00		395.83	78.73	127.45	46.19	173.65	648.20
703.040		881.00						
	1100.00		0.00	0.00	0.00	0.00	0.00	0.00
703.310		1981.00						
	836.00		2.58	1.61	3.04	0.88	3.92	8.11
703.030		2817.00						
	583.00		353.94	129.20	225.12	68.64	293.76	776.90
703.020		3400.00						
	1047.00		966.63	377.84	658.36	201.40	859.76	2204.23
703.010		4447.00						
	180.00		57.46	25.42	44.33	13.62	57.95	140.83
618.030		4627.00						
	3532.00		29.46	18.39	34.75	10.09	44.84	92.70
628.022		8159.00						
	111.00		0.93	0.58	1.09	0.32	1.41	2.91
628.021		8270.00						
	175.00		19.37	15.70	55.30	17.22	72.52	107.59
628.020		8445.00						
	132.00		264.87	162.39	418.44	135.99	554.43	981.69
628.010		8577.00						
	365.00		1079.30	686.12	1685.58	556.06	2241.64	4007.06
627.050		8942.00						
	330.00		600.81	401.33	885.69	283.65	1169.34	2171.48
627.040		9272.00						
	172.00		195.91	122.77	235.20	68.43	303.63	622.31
627.030		9444.00						
	207.00		81.82	52.38	113.30	32.42	145.72	279.92
627.020		9651.00						

Distance in meters

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
627.010	325.00	9976.00	121.00	106.42	361.38	134.02	495.40	722.82
705.030	1140.00	11116.00	474.54	395.55	1240.31	465.51	1705.82	2575.92
708.030	106.00	11222.00	8.02	5.25	12.83	4.23	17.06	30.33
705.040	134.00	11356.00	2.13	1.86	6.05	2.31	8.36	12.35
708.050	320.00	11676.00	15.93	8.82	22.55	7.02	29.58	54.32
708.060	438.00	12114.00	151.45	53.32	94.83	31.03	125.86	330.63
708.080	250.00	12364.00	101.03	36.54	85.02	25.99	111.01	248.58
708.090	740.00	13104.00	214.91	137.79	484.58	136.53	621.11	973.81
708.100	745.00	13849.00	300.45	249.39	918.20	296.55	1214.75	1764.60
708.110	234.00	14083.00	62.55	51.77	209.92	70.51	280.43	394.75
708.120	250.00	14333.00	32.77	18.41	56.34	15.44	71.78	122.96
708.130	750.00	15083.00	191.64	108.31	200.63	59.06	259.69	559.64
719.140	1357.00	16440.00	858.65	518.19	990.45	289.84	1280.29	2657.13
626.030	1334.00	17774.00	1162.69	779.17	1732.86	556.38	2289.24	4231.10
626.020	258.00	18032.00	196.81	158.85	515.26	177.52	692.79	1048.44
709.010	408.00	18440.00	271.93	242.96	877.13	315.68	1192.81	1707.70
709.020	324.00	18764.00	255.71	223.27	725.95	276.60	1002.56	1481.54
709.030	620.00	19384.00	464.45	405.52	1318.54	502.39	1820.93	2690.89

Distance in meters

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
	746.00		244.97	213.89	695.46	264.98	960.44	1419.30
709.040		20130.00						
	694.00		142.91	124.78	405.73	154.59	560.32	828.01
709.050		20824.00						
	373.00		208.49	135.05	318.77	107.67	426.43	769.97
709.060		21197.00						
	687.00		383.55	224.60	480.16	150.23	630.39	1238.54
709.070		21884.00						
	559.00		246.64	137.35	303.32	97.21	400.53	784.51
709.080		22443.00						
	638.00		308.62	174.95	360.40	104.36	464.75	948.32
709.090		23081.00						
	488.00		193.85	85.51	180.04	52.81	232.85	512.21
709.100		23569.00						
	458.00		168.14	63.51	243.46	67.14	310.60	542.26
709.110		24027.00						
	646.00		194.34	91.93	356.01	96.78	452.80	739.06
715.010		24673.00						
	468.00		516.78	139.21	220.71	71.74	292.45	948.44
715.020		25141.00						
	674.00		884.68	313.48	560.95	174.04	734.98	1933.14
715.030		25815.00						
	876.00		369.07	238.80	522.17	152.29	674.46	1282.33
715.040		26691.00						
	400.00		102.50	49.52	105.78	31.54	137.33	289.34
715.050		27091.00						
	904.00		507.82	172.61	370.27	128.23	498.51	1178.94
715.060		27995.00						
	507.00		299.64	126.68	271.36	88.93	360.28	786.60
715.070		28502.00						
	758.00		877.00	547.51	1034.30	300.25	1334.55	2759.06
715.080		29260.00						
	306.00		530.12	320.84	654.48	203.70	858.18	1709.15
715.090		29566.00						
	640.00		503.28	293.05	654.77	218.75	873.53	1669.85
724.160		30206.00						

Distance in meters

Numbers listed below indicate total for shoreline between stations
Mass of sediment in tonnes

Station	Distance	Cumdist	Fine sand	VFS	Silt	Clay	(Si + Cl)	Total mass
	558.00		1626.47	990.76	2121.48	682.25	2803.73	5420.96
809.010		30764.00						
	200.00		585.62	355.95	761.70	244.97	1006.67	1948.25
809.011		30964.00						
	485.00		6.44	2.05	3.18	1.06	4.24	12.73
Seneca Creek Mouth		31449.00						
	85.00		1.13	0.36	0.56	0.19	0.74	2.23
809.012		31534.00						
	364.00		1252.85	1003.63	1060.48	286.06	1346.53	3603.01
802.010		31898.00						
	584.00		4004.63	3215.49	3395.20	915.33	4310.53	11530.65
Rubble dam		32482.00						
Total			23771.89	14737.36	29649.74	9478.61	39128.35	77637.61

Right Bank below Monocacy River

Mass of sediment in tonnes/m of shoreline

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
718.030	0.90	0.18	0.26	0.09	0.35	1.43
718.040	0.08	0.03	0.07	0.02	0.09	0.21
718.050	0.28	0.09	0.14	0.05	0.18	0.56
703.050	0.86	0.23	0.34	0.12	0.46	1.54
718.060	0.15	0.14	0.56	0.19	0.75	1.03
718.080	0.50	0.28	0.71	0.22	0.93	1.72
718.070	0.94	0.59	1.80	0.51	2.32	3.84
718.090	0.01	0.01	0.03	0.01	0.04	0.06
718.100	0.00	0.00	0.00	0.00	0.00	0.00
718.110	0.00	0.00	0.00	0.00	0.00	0.00
718.120	0.01	0.01	0.03	0.01	0.04	0.05
718.130	0.24	0.16	0.58	0.18	0.77	1.17
718.140	0.16	0.10	0.21	0.06	0.27	0.54
627.070	0.05	0.03	0.06	0.02	0.07	0.15
627.080	0.44	0.29	0.66	0.21	0.87	1.60
627.100	0.23	0.13	0.32	0.10	0.42	0.78
627.110	1.87	0.35	0.51	0.18	0.69	2.90
718.150	0.50	0.44	1.43	0.54	1.97	2.91
719.010	0.47	0.34	0.88	0.31	1.19	2.00
719.020	1.11	0.51	1.11	0.37	1.47	3.10
719.040	0.25	0.20	0.75	0.22	0.97	1.42
719.050	0.29	0.23	0.80	0.25	1.06	1.58
719.080	0.01	0.01	0.06	0.02	0.08	0.09
719.090	0.05	0.02	0.10	0.03	0.12	0.20

Mass of sediment in tonnes/m of shoreline

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
719.100	1.08	0.81	2.41	0.89	3.30	5.20
719.110	0.57	0.33	0.61	0.18	0.79	1.70
719.120	0.28	0.18	0.37	0.11	0.48	0.94
719.130	0.92	0.67	1.73	0.60	2.33	3.92
626.010	0.16	0.10	0.19	0.05	0.24	0.50
Goose Creek						
723.070	0.28	0.18	0.45	0.15	0.61	1.07
723.080	0.58	0.26	0.48	0.15	0.63	1.47
723.090	0.58	0.32	0.88	0.33	1.20	2.11
723.100	0.02	0.01	0.05	0.01	0.06	0.09
723.110	0.07	0.07	0.35	0.11	0.46	0.60
723.120	0.32	0.21	0.45	0.13	0.58	1.11
724.060	1.57	0.98	1.85	0.54	2.39	4.94
724.070	0.02	0.03	0.16	0.04	0.20	0.25
724.080	0.54	0.31	0.57	0.17	0.74	1.59
724.090	0.34	0.30	0.98	0.36	1.34	1.98
724.100	0.52	0.45	1.46	0.55	2.02	2.98
724.110	0.19	0.09	0.16	0.05	0.21	0.49
723.060	0.19	0.09	0.22	0.07	0.29	0.58
723.050	1.32	0.73	1.35	0.40	1.75	3.79
723.040	0.24	0.13	0.33	0.11	0.44	0.81
723.030	0.31	0.05	0.08	0.03	0.10	0.47
723.020	0.00	0.00	0.00	0.00	0.00	0.00
723.010	0.31	0.08	0.14	0.05	0.19	0.58
625.010	0.00	0.00	0.00	0.00	0.00	0.00
Seneca Breaks						

Island Banks below Monocacy River

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
	Mass of sediment in tonnes/m of shoreline					
Mason Island, west side						
Tip						
628.070	0.20	0.07	0.10	0.03	0.13	0.41
628.060	0.82	0.26	0.41	0.14	0.54	1.63
628.050	0.19	0.06	0.09	0.03	0.12	0.37
628.040	0.45	0.28	0.54	0.16	0.69	1.43
628.030	0.59	0.19	0.29	0.10	0.39	1.16
627.060	0.31	0.24	1.75	0.45	2.20	2.74
Mason Island, east side						
Tip						
618.020	0.00	0.00	0.00	0.00	0.00	0.00
628.023	0.14	0.04	0.07	0.02	0.09	0.28
618.010	0.27	0.08	0.13	0.04	0.17	0.53
627.060	0.31	0.24	1.75	0.45	2.20	2.74
Harrison Island, west side						
Tip	0.19	0.06	0.09	0.03	0.12	0.38
708.011	0.19	0.06	0.09	0.03	0.12	0.38
719.030	0.08	0.06	0.18	0.07	0.25	0.39
719.060	0.73	0.35	0.63	0.19	0.82	1.90
719.070	0.39	0.19	0.34	0.10	0.44	1.02
619.030	0.13	0.03	0.04	0.02	0.06	0.23
Tip						

Mass of sediment in tonnes/m of shoreline

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
Harrison Island, east side						
708.010	0.20	0.06	0.10	0.03	0.13	0.39
705.020	0.00	0.00	0.00	0.00	0.00	0.00
708.020	0.07	0.01	0.02	0.01	0.02	0.11
705.050	0.32	0.07	0.11	0.04	0.14	0.53
708.040	0.10	0.06	0.04	0.01	0.05	0.21
708.070	0.08	0.03	0.04	0.01	0.05	0.17
807.000	0.04	0.01	0.02	0.01	0.02	0.08
Van Deventer Island, north side						
Tip						
723.130	0.12	0.08	0.22	0.06	0.29	0.49
723.140	0.43	0.18	0.35	0.11	0.46	1.07
724.010	0.24	0.13	0.23	0.07	0.30	0.67
724.022	0.71	0.25	0.43	0.13	0.56	1.51
Van Deventer Island, south side						
Tip						
724.050	0.02	0.02	0.11	0.03	0.14	0.17
724.040	1.01	0.38	0.68	0.21	0.89	2.27
724.030	1.88	1.26	3.71	1.39	5.11	8.24
724.020	0.36	0.22	0.62	0.22	0.84	1.42
Tenfoot Island, north side						
Tip						
724.140	0.00	0.00	0.00	0.00	0.00	0.00
Tip						

Mass of sediment in tonnes/m of shoreline

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
Tenfoot Island, south side						
Tip						
724.130	2.76	0.85	1.36	0.44	1.80	5.42
724.120	1.04	0.29	0.47	0.15	0.61	1.95
Tip						
Sharpshin Island						
724.150	0.69	0.40	0.74	0.22	0.96	2.05

Left Bank below Monocacy River

Mass of sediment in tonnes/m of shoreline

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
718.020	0.23	0.07	0.11	0.04	0.15	0.46
718.010	2.29	0.46	0.74	0.27	1.01	3.76
703.040	0.00	0.00	0.00	0.00	0.00	0.00
703.310	0.00	0.00	0.00	0.00	0.00	0.00
703.030	0.01	.00	0.01	.00	0.01	0.02
703.020	1.21	0.44	0.77	0.23	1.00	2.65
703.010	0.64	0.28	0.49	0.15	0.64	1.56
618.030	0.00	0.00	0.00	0.00	0.00	0.00
628.022	0.02	0.01	0.02	0.01	0.03	0.05
628.021	0.00	0.00	0.00	0.00	0.00	0.00
628.020	0.22	0.18	0.63	0.20	0.83	1.23
628.010	3.79	2.28	5.71	1.86	7.57	13.65
627.050	2.12	1.48	3.53	1.18	4.71	8.31
627.040	1.52	0.95	1.84	0.54	2.38	4.85
627.030	0.76	0.47	0.90	0.26	1.15	2.39
627.020	0.03	0.03	0.20	0.05	0.25	0.32
627.010	0.71	0.62	2.02	0.77	2.80	4.13
705.030	0.12	0.07	0.15	0.05	0.20	0.39
708.030	0.03	0.03	0.09	0.03	0.12	0.18
705.040	0.00	0.00	0.00	0.00	0.00	0.00
708.050	0.10	0.06	0.14	0.04	0.18	0.34
708.060	0.59	0.19	0.29	0.10	0.39	1.17
708.080	0.22	0.10	0.39	0.11	0.50	0.82
708.090	0.36	0.27	0.92	0.26	1.18	1.81

Mass of sediment in tonnes/m of shoreline

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
708.100	0.44	0.40	1.54	0.54	2.08	2.92
708.110	0.09	0.04	0.25	0.07	0.32	0.45
708.120	0.17	0.11	0.20	0.06	0.26	0.53
708.130	0.34	0.18	0.34	0.10	0.43	0.96
719.140	0.92	0.58	1.12	0.33	1.45	2.96
626.030	0.82	0.59	1.47	0.51	1.98	3.39
626.020	0.71	0.64	2.52	0.87	3.39	4.74
709.010	0.63	0.55	1.78	0.68	2.46	3.63
709.020	0.95	0.83	2.70	1.03	3.73	5.52
709.030	0.55	0.48	1.55	0.59	2.14	3.16
709.040	0.11	0.10	0.31	0.12	0.43	0.64
709.050	0.30	0.26	0.86	0.33	1.18	1.75
709.060	0.82	0.46	0.85	0.25	1.10	2.38
709.070	0.30	0.19	0.54	0.19	0.73	1.22
709.080	0.58	0.30	0.54	0.16	0.70	1.58
709.090	0.39	0.25	0.59	0.17	0.75	1.39
709.100	0.41	0.10	0.15	0.05	0.20	0.71
709.110	0.32	0.18	0.91	0.24	1.16	1.66
715.010	0.28	0.11	0.19	0.06	0.25	0.63
715.020	1.93	0.49	0.75	0.25	1.00	3.42
715.030	0.69	0.44	0.91	0.27	1.18	2.31
715.040	0.15	0.10	0.28	0.08	0.36	0.61
715.050	0.36	0.15	0.25	0.08	0.32	0.83
715.060	0.76	0.24	0.57	0.21	0.78	1.78
715.070	0.42	0.26	0.50	0.14	0.64	1.33

Mass of sediment in tonnes/m of shoreline

Station	Fine Sand	VFS	Silt	Clay	(Si+Cl)	Total
715.080	1.89	1.18	2.23	0.65	2.88	5.95
715.090	1.57	0.92	2.05	0.68	2.73	5.22
724.160	0.00	0.00	0.00	0.00	0.00	0.00
809.010	5.83	3.55	7.60	2.45	10.05	19.43
809.011	0.03	0.01	0.01	.00	0.02	0.05
Seneca Creek Mouth						
809.012	0.03	0.01	0.01	.00	0.02	0.05
802.010	6.86	5.51	5.81	1.57	7.38	19.76
Rubble dam - Seneca Breaks						

APPENDIX C

BULK DENSITY SAMPLING RESULTS

Sample Number	Bulk Density g/cm3
1.1	1.12
1.2	1.08
1.3	1.19
2.1	1.05
2.2	1.00
2.3	0.87
3.1	1.30
3.2	1.19
3.3	1.25

APPENDIX D

LONGITUDINAL WATER-SURFACE PROFILE

Table 1: Longitudinal Water-Surface Profile: Point of Rocks to Seneca Creek

Station Number	Elevation (m above sea level)	Cumulative Distance (m)	Comments
Reference Mark	64.89	0	Reference elevation on Point of Rocks Gage.
1	61.51	0	Water level at Gage
2	61.46	359.8	
3	61.29	845.9	
4	61.09	1554.0	
5	60.80	2581.2	
6	60.64	3322.5	
7	60.49	4409.9	
8	59.85	5654.9	
9	59.57	6847.9	
10	58.54	8771.5	
11	58.34	9806.2	
12	58.29	11494.0	Mouth of Monocacy
13	58.17	12798.5	
14	58.23	13795.8	
15	57.44	15242.4	
16	57.07	17152.6	
17	56.82	18488.4	
18	56.79	19131.5	
19	56.68	20297.5	White's Ferry
20	56.70	20859.2	
21	56.41	21127.6	
22	56.34	21332.6	
23	56.11	22608.6	
24	55.95	25178.7	
25	55.88	25815.0	
26	55.78	26498.8	
27	55.70	27584.4	
28	55.71	27833.4	
29	55.70	28186.4	Edward's Ferry
30	55.70	28433.4	
31	55.75	29959.4	
32	55.50	34331.4	
33	55.40	38353.4	
34	55.30	41072.4	Seneca Creek

APPENDIX E

RESULTS AND ANALYSIS OF PHOSPHORUS SAMPLING

Sediment samples were collected at nine sites within the study region and submitted to the Occoquan Water Monitoring Laboratory for nutrient analysis. The resulting information is used to estimate the general availability of phosphorus within the sediment storage areas and to estimate the contribution that these sources may have to the phosphorus load in the Potomac River.

Total phosphorus (mg P/ g sediment) and NaOH extractable phosphorus (mg P/ g sediment) values were obtained for each sample. The first measure is commonly used in water quality monitoring and indicates the presence of phosphorus in soluble, particulate, organic and inorganic forms. In the context of soil testing, it is still a measure of the presence of phosphorus in any of the listed forms (ASTM (1985)), but is an overestimate of the phosphorus available for uptake into the water column. The second measure (Chang and Jackson (1958)) is a better indicator of the 'available' phosphorus. This measure includes the fractions of phosphorus which are saloid bound, iron bound, and aluminum bound. A summary of the results of the analysis is shown in Table 1 in which the reported values are averages of the three values obtained at each site (except site 3 for which four samples were taken).

Table 1: Phosphorous Analysis of Sediment Samples

Sediment Sample Area	Total Phosphorous (mg P/ g)	NaOH Extractable Phosphorous (mg P/ g)
1	0.74	0.28
2	0.77	0.27
3	0.35	0.11
4	0.75	0.20
5	0.38	0.11
6	0.86	0.32
7	0.60	0.23
8	0.82	0.29
9	0.53	0.12

Based on the physical characteristics of the sites which are detailed in Table 2, the samples may be divided into three general categories. This allows the examination of how phosphorus concentrations may vary with sediment type. The three categories are beach accumulation (samples 1, 4, 6, and 7), in-channel storage (samples 2 and 8), and marsh grasses and island tails (samples 3, 5, and 9). The phosphorus concentrations are relatively consistent within a category with the beach accumulation sediments exhibiting the widest range of concentrations for both measures of phosphorus (0.60 - 0.86 and 0.20 - 0.32). Given this wide range, it is difficult to differentiate between beach accumulation and in-channel storage based on phosphorus data. The NaOH extractable phosphorus concentrations of the marsh grass and island tail areas are remarkably consistent in addition to being the lowest in magnitude; this is as expected since these areas are comprised primarily of gravel and fine sand.

Table 2: Description of Sediment Samples Collected for Nutrient Analysis

1.1-1.3	Left bank approximately 1000 feet downstream of Mason Island. The material is fairly recent bank material, with layering of sedmient and organics. The samples were collected with a soil core.
2.1-2.3	Same location as above. Samples were collected 6 feet from the waterline from the top 6 inches of surface floc. The material is very loose, soft and silty. Some organic matter is mixed in.
3.1-3.4	Between Mason Island and the left bank at the tail of a small island. Predominately gravel and fine sand with organics. The sampling location is typical of marsh grass accumulations. Sample 3.3 seemed to have an unusual amount of organics so a fourth sample 3.4 was collected. There was a layer of fines deposited on the surface.
4.1-4.3	Right bank near tip of Harrison Island. Cows probably have access to the shoreline here. Cores were taken of the beach material. Layered with organics.
5.1-5.3	Tip of Harrison Island. Grab samples taken along the edge of marsh grasses. Gravel and fines mixed with organics.

6.1-6.3 Left bank approximately 300 feet downstream of Edwards Ferry. Cores taken of layered beach material.

7.1-7.3 Left bank downstream of Sycamore Landing. Cores of newly layered beach material.

8.1-8.3 Left bank downstream of Seneca Creek. Samples of thick silty floc taken with a ponar dredge.

9.1-9.3 Right bank near Seneca Dam. Grab samples taken typical of marsh grass accumulations.

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* Data listing provided by Occoquan lab has been added to the appendix.

These general categories correspond to the types of sediment storage defined earlier in this report. That is, beach accumulation is typical of what has been described as channel margin storage, and in-channel storage is employed as defined earlier. The third category, marsh grass samples, were taken for comparison purposes here and are not referenced otherwise in the report.

The sediment samples were grouped by category and one value of each measure of phosphorus was obtained to characterize channel margin storage and in-channel storage:

Storage Type	Total Phosphorous (mg P/g)	NaOH Extractable Phosphorous (mg P/g)
Channel Margin	0.74	0.26
In-channel	0.80	0.28

Using the tonnes (148,750 tonnes in channel margin storage and 41,000 tonnes in in-channel storage) of total sediment storage reported in Section VI for the study reach (the mouth of Monocacy to Seneca Dam), estimates of phosphorus loads were calculated for total phosphorus and NaOH extractable phosphorus. The estimates are:

Storage Type	Total Phosphorus (lbs)	NaOH Extractable Phosphorus (lbs)
Channel Margin	242,700	85,600
In-channel	72,300	25,300
Total	315,000	110,900

The load for NaOH extractable phosphorus (the better indicator of 'available' phosphorus) was compared with historical total annual phosphorus loads at Chain Bridge (MWCOG (1985)); a load of 110,900 lbs. represents 1.6% of the 1984 phosphorus load (6.98 million lbs.) and 2% of the 1983 phosphorus load (5.58 million lbs.). That is, if the phosphorus available in the study reach was mobilized at one point in time, the contribution to the annual load is fairly small. This comparison is intended only as a general indication of the phosphorus contained in the sediments, however. Phosphorus is continuously adsorbed by the sediments and desorbed from the sediments with varying flow conditions and varying nutrient concentrations in the water column.

Another view of the phosphorus contribution from sediment storage areas results from relating the phosphorus fraction of the stored sediments to the phosphorus fraction of the suspended sediments in the river. The latter fractions, derived from measurements at Chain Bridge (MWCOG (1985)), are 1.51 mg P/g for 1984 and 1.23 mg P/g for 1983. These values suggest that if 1985 phosphorus conditions were similar to the two preceding years that the sediment storage areas are relatively depleted of phosphorus relative to the sediments in the passing water. Furthermore, the summer months of 1984 exhibit even higher phosphorus fractions in the water column as is shown below:

Month	Particulate Phosphorus (mg P/ g)
June	2.67
July	2.00
August	1.62

The sediment storage areas do not appear to be significant sources of phosphorus in the summer months, in particular.

References

ASTM, 1985 Annual Book of ASTM Standards, Method D4183-82, 1985.

Chang, S. C. and M. L. Jackson, "Fractionalization of Soil Phosphorous," Soil Science, Vol. 84, 1958, pp. 133.

Metropolitan Washington Council of Governments, Potomac River Water Quality 1984, Water Resources Planning Board, 1985.

OWML

M E M O R A N D U M

TO: Cameron Wiegand

FROM: Tom Grizzard

RE: Data Transmittal and Methods - Potomac River Sediments

DATE: 28 January, 1986

Please find attached the analytical results from the Potomac River Sediments delivered by ICPRB personnel. The data reported are all on a dry weight basis.

The methods employed were as follow:

- Volatile Solids - Method 209F, Standard Methods, 16th Edition, APHA, 1985.
- Total P - Method D4183-82, 1985 Annual Book of ASTM Standards, ASTM, 1985.
- NaOH Extractable P - "Fractionation of Soil Phosphorus", Soil Science, S. C. Chang and M. L. Jackson, vol. 84, pp. 133, 1958

Please note that the NaOH-extractable P includes the following fractions:

- Saloid Bound P
- Iron Bound P
- Aluminum Bound P

The NaOH fraction may be used as a reasonable indicator of the P fractions which might ultimately become available from the sediments under varying conditions of anaerobiosis, elevated pH, and concentration gradient.

Please give me a call if you would like further explanations of the forms represented by these fractions. I apologize for our tardiness in getting these finished data to you. The analyses were completed some time back, and they have been sitting on disk since early October, 1985.

POTOMAC RIVER SEDIMENTS - PHOSPHORUS FRACTIONATION

MWCOG I.D.	OWML LABID	VOLATILE SOLIDS (%)	TOTAL P PO4-P mg/g	NaOH - P PO4-P mg/g
1.1	3373	7.24	0.68	0.26
1.2	3374	6.31	0.69	0.26
1.3	3375	7.89	0.86	0.31
2.1	3376	9.08	0.81	0.29
2.2	3377	6.99	0.66	0.27
2.3	3378	8.60	0.83	0.25
3.1	3379	1.83	0.35	0.11
3.2	3380	3.20	0.39	0.13
3.3	3381	2.59	0.33	0.11
3.4	3382	1.67	0.32	0.10
4.1	3383	8.96	0.73	0.19
4.2	3384	9.50	0.72	0.18
4.3	3385	9.32	0.79	0.22
5.1	3386	3.11	0.32	0.09
5.2	3387	3.82	0.37	0.13
5.3	3388	5.50	0.44	0.12
6.1	3389	7.86	0.77	0.29
6.2	3390	7.91	0.91	0.34
6.3	3391	7.79	0.91	0.33
7.1	3392	8.46	0.57	0.19
7.2	3393	7.35	0.54	0.20
7.3	3394	7.69	0.68	0.29
8.1	3395	8.48	0.80	0.30
8.2	3396	9.32	0.92	0.28
8.3	3397	7.71	0.74	0.29
9.1	3398	6.22	0.52	0.12
9.2	3399	7.95	0.57	0.14
9.3	3400	7.41	0.49	0.10