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Sediment Characterization of Coastal Lagoons and Bays, Virginian Province

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NOAA NATIONAL ESTUARINE INVENTORY:

SUPPLEMENT

SEDIMENT CHARACTERIZATION OF CHESAPEAKE BAY AND ITS TRIBUTARIES

NATIONAL ESTUARINE INVENTORY: SUPPLEMENT

SEDIMENT CHARACTERIZATION OF THE CHESAPEAKE BAY AND ITS TRIBUTARIES, VIRGINIAN PROVINCE

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PROJECT DESCRIPTION

NOAA's National Estuarine Inventory (NEI) is a series of related activities of the Office of Oceanography and Marine Assessment (OMA), National Oceanic and Atmospheric Administration (NOAA) that aims to develop a national estuarine data base and assessment capability. Initiated in June 1983 as part of NOAA's program of strategic assessments, the broad goal of the NEI is to build a comprehensive computerized data base for evaluating the health and status of the Nation's estuaries. It aims to bring estuaries into focus as a national resource base. Without a systematic set of data with common coordinates, units and classifications, it is difficult to analyze or compare estuaries, to assess their regional influence and to generate useful information in the form of sediment charts or desk-top atlas summaries.

Development of the NEI data base is an evolving process. Additional characteristics and estuaries are being added to the inventory and refinements made after the data are assessed. All information is being incorporated into the NEI through NOAA's Geographical Information System (GIS).

In May 1990 the Sediment and Contaminant Inventory (SCI) was initiated to develop a comprehensive information base on the distribution of bottom sediments and their contaminants. The project is one component of the National Estuarine Inventory. It will be used in conjunction with other NOAA data bases, e.g. the National Coastal Wetlands Inventory, the National Coastal Pollutant Discharge Inventory, and Estuarine Living Marine Resources to make comparisons and rankings. The project is sponsored jointly by the National Oceanic and Atmospheric Administration (NOAA), Strategic Assessment Branch of the Ocean Assessments Division and the Environmental Protection Agency (EPA), Environmental Monitoring and Assessment Program (EMAP) and it is conducted in cooperation with the Virginia Institute of Marine Science. In this report sediment and contaminant data are compiled for eight estuarine systems in the Chesapeake Bay region.

The Sediment and Contaminant Inventory (SCI) makes available a new computer data base and it characterizes the essential and typical sedimentological features of each system. This is one step in the compilation of a regional synthesis, thus bridging the gap between site specific studies and a regional data base. The ultimate goal of the data base is to learn the status of sediment contamination in the Nation's estuaries. It shows what data exist, where it comes from and where the gaps are that need to be filled. The data are organized into systematic data sets that are easily retrievable by modern computers.

The data sets are of special use to test the spatial representativeness of National Status and Trends (NST) and EMAP monitoring sites and to evaluate the susceptibility of different estuaries to pollutants associated with sediments. They facilitate grouping characteristics of individual estuaries into a regional compilation to show the extent and magnitude of sediment contamination that biota are exposed to. The data sets will be available to a variety of users through traditional hard copy media or through a desk top computer system as NOAA's Coastal Ocean Management Planning and Assessment System (COMPAS). This system should improve our ability to address plans, and compare alternatives, for modifications to estuaries or their watersheds. NOAA will ensure that the products are useful and available to coastal resource managers.

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EXPLANATION

Selection of Estuaries

The estuarine systems selected are from the NOAA National Estuarine Inventory in the EMAP Virginian Province (Figure 1). The principal spatial unit of each system is the estuarine drainage area (EDA) defined in the NEI data atlas (U.S. NOAA, 1985). The sediment and contaminant distributions embrace the estuarine bottom area, i.e. from the head of tides to the mouth where the estuary meets the ocean, bay or sound as determined by physiographic features (U.S. NOAA, 1985). Data coverage embraces whole estuaries and far-field contaminant distributions. Chart scales are greater than 1:80,000 and chart units larger than one square kilometer.

Sources of Information

Data on bottom sediment characteristics and contaminant distributions come from a variety of existing sources: computer files, published and unpublished literature including masters theses, doctoral dissertations and laboratory file data. The data come in many forms: e.g. tabulations, computer tapes, graphs and charts of distributions. Data entered into the data base come from references considered primary sources whereas general information used to characterize the sediments and to interpret sedimentary processes come from references considered secondary sources. Data sources are provided with each characterization summary.

Data Base Organization

The data were selected to provide the most up-to-date and comprehensive spatial coverage of estuarine bottom sediments. They mainly consist of laboratory processed data obtained from analysis of samples or cores collected at individual stations. For certain estuaries however, sediment information is available only as charted distributions. Where laboratory processed data is not available, either from individual stations or charted distributions, bottom notations from National Ocean Survey charts are used.

The sediment data were organized and processed into systematic data sets in digital form through a sequence of steps illustrated in Figure 2. (1) Once the data are identified and acquired, they are (2) inventoried and documented by bibliographic references, then (3) sorted by location, parameter and by spatial coverage, and (4) assessed for quality, i.e. completeness, consistency for compilation into chart "mosaics," (5) selected for inclusion in the data base with priority given to the best available and mappable laboratory processed data. Then, (6a) the point station data are reduced to common units and digitized in GIS (Geographic Information System) using either a Numonics NUM 2200 unit or a PC Quattro Pro spreadsheet. They are digitized by data source, sample number, geographic coordinate, parameter; textural distributions are classified into percent mud and the Shepard classification (Shepard, 1954). The PC used is a NEC Powermat 3865X personal computer equipped with Map Info Map File Import/Export package. Alternately, (6b) the chart distributions are scaled to a standard NOS chart, transferred to a mylar overlay and digitized by NOAA's Arc Info unit using the GIS and a SPANS (Spatial Analysis System of Tydac) plotting package. The digitized and classified data are then (7) plotted as "test" charts that serve to validate data in the data base. The resulting distributions from steps 6b and 7 are then examined for consistency, verified and (8) stored in a computer file. (9) The file data are processed by making digital contour plots for the desk-top atlas and (10) the output verified and reassessed for quality.

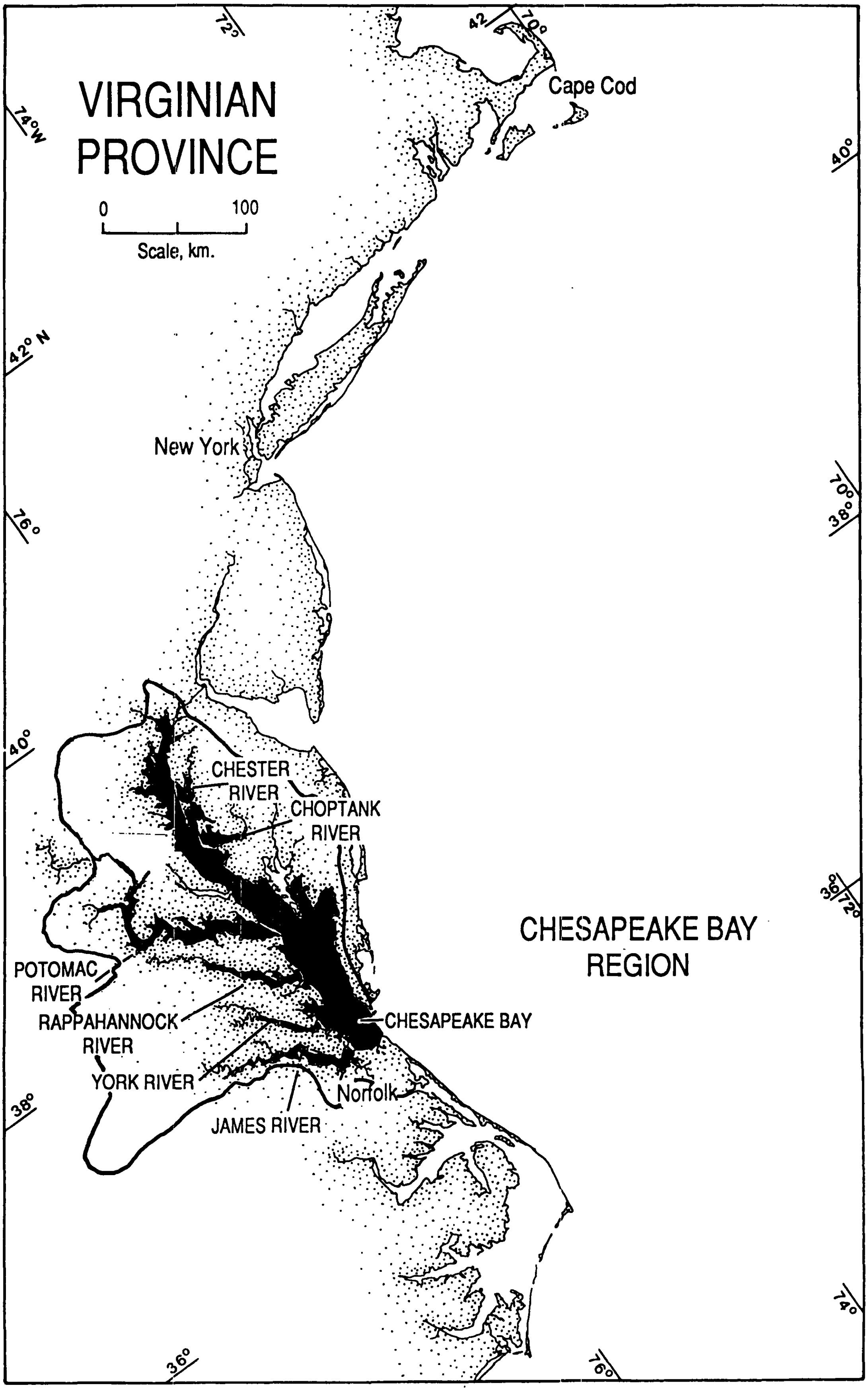


Figure 1. Location of estuarine systems characterized and included in the NEI data base from the Chesapeake Bay region of the Virginia Province. Estuarine drainage area of the Chesapeake Bay, bold line.

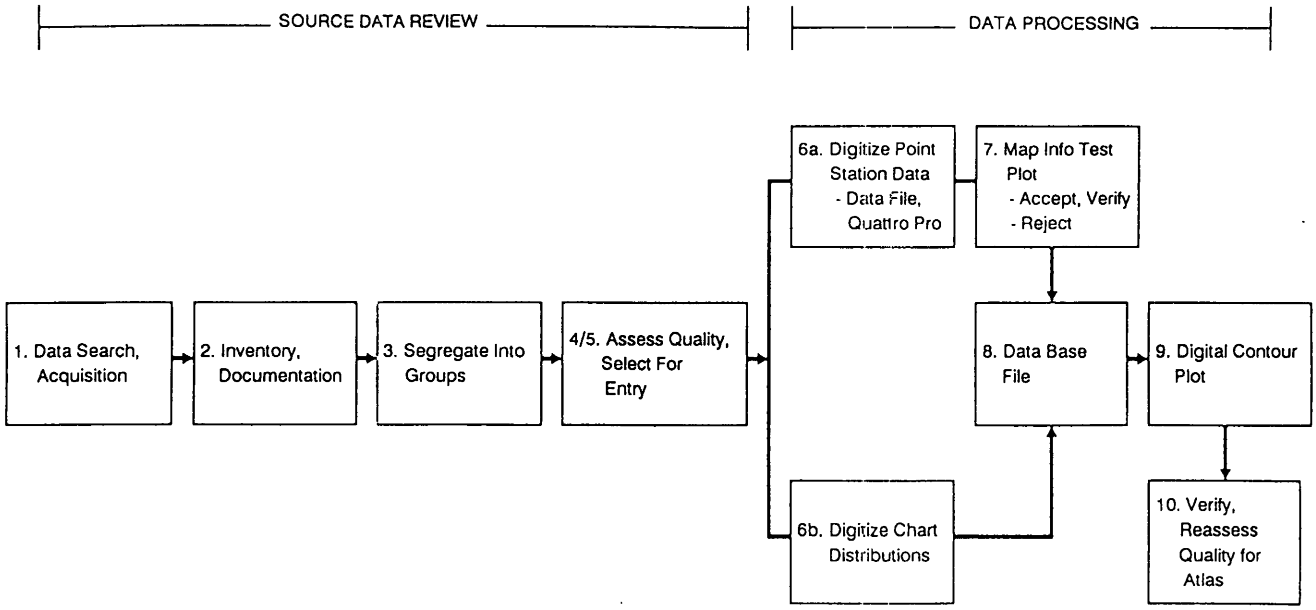


Figure 2. Scheme of organization and processing data into a computer data base and desk-top atlas.

Data Quality

The data used are the best available mappable data for each estuary. The relative scientific certainty of the data is assessed, after initial sorting of source data and after test plotting, at two levels: (1) by data source and (2) their "mappability." Appendix 1 shows the organization of data quality, criteria used and weighting scales. The overall, or aggregate, quality is estimated by averaging the two levels of certainty after normalizing to 100 (Table 1). For example, the overall data for Chesapeake Bay is rated "highly certain." It is all laboratory processed data using standard techniques and inter-laboratory calibration; it has a high sampling density (5 - 7 stations/10 km^2 and seven additional measured parameters which also have a high sampling density. The two data sets cover more than 90% of the bay and they are consistent by virtue of similar laboratory techniques, sampling density, sampling design and multiple parameters. The data is backed by older multiple laboratory processed coverage (e.g. Ryan, 1953 and Shideler, 1975).

Sediment Parameters

Sediment texture is mainly derived from laboratory mechanical analyses of sediment size. In several estuaries however, e.g. which lack laboratory processed data, sediment distributions are derived from NOS chart notations, i.e. the classes "mud," "sand" and "other." Sediment texture is mainly expressed as weight percent clay, silt, sand and gravel with textural classes following the standard Wentworth grade scale. Field sampling, laboratory processing and statistics of the size distributions often vary with investigator but no attempt has been made to modify the original data except to convert units. Readers should refer to the original data sources for procedural details. For estuaries lacking data expressed as clay, silt and sand percent, the percentage of sand and of "mud" (i.e. silt plus clay) is used. Alternately, data for the statistical parameters mean, median or modal diameters are used. Where textural data from several reliable data sources are available, the most compatible data are used.

Table 1. Data Quality Weightings by Source and by Mappability of Textural Parameters

	DATA SOURCE QUALITY								MAPPABILITY							AGGREGATE QUALITY	
NEI System	ID	S1	S2	S3	S4	SS	ST	SQ	M1	M2	M3	M4	MS	MT	MQ	AQ	DATA QUALITY
Chesapeake Bay/	1	3	3	2	4	1	13	87									
Tangier/Pokomoke	2	3	3	2	5	1	14	93									
									3	3	3	1	1	11			
	AVERAGE							90							92	91	HIGHLY CERTAIN
Potomac R.	1	3	3	2	2	0	10	67									
									1	3	3	1	0	8			
	AVERAGE							67							67	67	FAIRLY CERTAIN
Rappahannock R.	1	3	3	1	2	1	10	67									
	2	3	2	1	1	1	8	53									
	3	3	2	2	2	0	9	60									
	4	1	0	2	2	0	5	33									
									2	3	2	1	1	9			
	AVERAGE							53							75	64	FAIRLY CERTAIN
York R.	1	3	3	2	1	0	9	60									
	2	3	2	1	1	0	7	47									
	3	3	2	1	1	0	7	47									
	4	3	3	2	2	1	11	73									
	5	3	2	2	5	0	12	80									
									1	1	1	1	0	4			
	AVERAGE							57							33	56	FAIRLY CERTAIN
James R.	1	3	3	2	2	1	11	73									
	2	3	2	2	2	1	10	67									
	3	3	2	2	1	1	9	60									
	4	3	3	1	1	0	8	53									
									2	3	2	2	1	10			
	AVERAGE							63							83	73	MODERATELY CERTAIN
Choptank R.	1	3	3	2	4	1	13	87									
	2	1	0	1	3	0	5	33									
									3	3	2	1	1	10			
	AVERAGE							60							83	71	MODERATELY CERTAIN
Chester R.	1	3	2	2	3	0	11										
									2	3	3	2	0	10			
	AVERAGE							73							83	78	MODERATELY CERTAIN

KEY:

DATA SOURCE QUALITY

ID:	SOURCE ID*
S1:	DATA FORMS
S2:	DEGREE OF LAB PROCESSING
S3:	DOCUMENTATION
S4:	SAMPLING DENSITY
SS:	ADDITIONAL PARAMETERS
ST:	SUM OF THE WEIGHTINGS
SQ:	NORMALIZED WEIGHTING

* Number corresponds to reference in characterization summary for each system

MAPPABILITY

M1:	SAMPLING DENSITY
M2:	SPATIAL COVERAGE
M3:	CONSISTENCY
M4:	TEMPORAL COVERAGE
MS:	ADDITIONAL PARAMETERS
MT:	SUM OF THE WEIGHTINGS
MQ:	NORMALIZED WEIGHTING

AGGREGATE QUALITY

AQ (SCALE)	DATA QUALITY
Over 85	HIGHLY CERTAIN
70 - 85	MODERATELY CERTAIN
55 - 70	FAIRLY CERTAIN
40 - 55	REASONABLE INFERENCE
Below 40	DOUBTFUL

Organic matter reflects the incomplete oxidation of organic tissues of plants and animals stored in the sediments. Organic matter produced in an estuary includes plankton, grass, plant detritus and fecal material whereas organic matter supplied from external sources as banks and streams includes tree leaves, wood fragments and sewage. Total carbon (carbonate plus organic carbon) is usually measured by high temperature combustion in an induction furnace. Organic carbon may also be measured by high combustion after removal of carbonate by acid digestion (e.g. Hobbs, 1983). Organic matter is usually found by weight loss after oxidation such as treatment with hydrogen peroxide or loss-on-ignition (e.g. Moncure and Nichols, 1968). Since organic carbon represents about half of the total organic matter, organic matter percentages are also derived by multiplying organic carbon values of the original data by a factor of 1.8 following Bader (1954, 1955). Sediment organic carbon and/or organic matter are linearly related to the nitrogen content with ratios of about 11 to 13 (Bader, 1955). These parameters therefore, are an indication of eutrophic substances.

Water content of the sediments represents the weight percentage of water in a given sediment mass to the wet weight of sediment. It is usually determined by weight loss after drying. Water content is inversely proportional to grain size and bulk density, and directly proportional to porosity (Bennett and Lambert, 1971).

Short-term rates of sedimentation spanning decades (< 150 years B.P.) are determined from either bathymetric changes or geochronology. Bathymetric changes are measurements of shoaling or deepening of the bottom between successive depth surveys (Shepard, 1953). These changes reveal spatial patterns of sedimentation rate but are usually not as precise as radiometric measurements of sediment age with depth in sediment cores, e.g. ^{210}Pb and ^{137}Cs (Officer et al., 1984). The ^{210}Pb measurements reveal temporal variations with depth and are sensitive to local variations. Another method utilizes the abundance of pollen grains (Brush, 1986) in cores relative to average rates of sedimentation within a radiocarbon-dated depth interval. Where most sediment accumulates in dredged channels, maintenance dredging records of depth changes also provide useful data.

Mass Balance and Storage Efficiency

The status of sediment sources and losses is given by:

$$\underset{\text{(sources)}}{Mi} = \underset{\text{(losses or removal)}}{Ms + Me}$$

Assuming steady state over the long-term then the input flux, Mi, must equal the output flux, Me, and the flux to the bed, Ms. Biogenic production (P) and consumption (C) are neglected since they are usually small. The sources and losses of sediment vary with investigator, and with methodology or data uncertainties. Thus, a range of estimates is presented. The storage efficiency, Si, is the ability of an estuary to retain and accumulate sediment delivered to it (Nichols, 1986). This is expressed as a ratio of the mass rate of accumulation to the rate of input over a given time. Thus:

$$Si = Ms/Mi$$

The storage efficiency ratio is referred to the fluvial input mass which is usually known. Therefore, a ratio of one implies the amount of sediment accumulated is equivalent to the amount supplied by the river(s). A ratio greater than one implies an estuary stores more sediment than supplied by its rivers whereas a ratio less than one implies the estuary stores an amount less than the total fluvial input, a situation when fluvial sediment is transported through an estuary.

Sediment Pollution Index

To facilitate intercomparison of sedimentary attributes of estuaries within the region, a weighted index is devised. This is based on five sediment parameters commonly associated with polluted sediments. Thus, the sediment pollution index, SPI, is formulated:

$$SPI = f\ (M_{ud},\ A_c,\ \bar{O}_m,\ \overline{W}_c,\ Si)$$

where M_{ud} is the percent area of mud (> 40% silt plus clay) based on a percentage of the whole estuary area; A_c is the percentage area of sedimentation (accumulation) (e.g. > 3.0 mm/yr, or as specified) in mud zones; $\bar{O}_m$ is the percentage mean organic matter of all available samples in an estuary, $\overline{W}_c$ is the percentage mean water content of all available samples in an estuary; Si is the sediment storage efficiency in percent. To obtain comparability, the five values of each parameter are normalized by setting the maximum value of each parameter to 100. Finally, the resultant percentages are summed for each system and further transformed by setting the highest SPI value to 100. The result is a ranking of a given estuary in terms of its potential sediment pollution (Table 2).

Contamination Status

Trace metals are used as "sample" contaminants because available information on metals is relatively good. Metal data, i.e. the mean and range of total concentrations (weight per weight) in bottom sediments, is derived from state, federal and academic sources compiled by the Chesapeake Bay Program (U.S. EPA, 1983a, 1983b). The metals selected are those with known affinities for sediment (Förstner and Wittmann, 1979). The concentrations reported are from determinations of bulk sediment samples and thus contain variations due to grain size. Data analyzed by size fractions are often contained in the original source data. Most metals are analyzed by either laboratory acid extractions or fusions but the efficiency of analysis varies with technique and investigator.

To compare metal concentrations from different estuaries in a uniform way, and in the context of contamination status, a contamination factor is formulated following U.S. EPA (1983a). This factor expresses the degree of enrichment of single metals compared to a natural background concentration, i.e. either the minimum asymptotic value in a sediment core representing a pre-polluted concentration level, or an average geochemical background, i.e. Wedepohl metal concentration, representing the concentration in fossil sediments. The contamination factor, C_f, is calculated from:

$$C_f = Co - Cp/Cp$$

where Co is the observed surface metal concentration and Cp is the predicted metal concentration or pre-polluted background concentration. The factors are

Table 2. Sediment data indicating the sediment pollution index of 6 Chesapeake estuaries. Values are normalized to 100. For definition of terms, see text.

ESTUARY	Mud % Area	Ac % Area	$\overline{O}m$	$\overline{W}c$	$Si \times 100$	SPI
Chesapeake Bay[3]	60	84	91	69	17	87
James River	100	55	51	71	13	78
Potomac River	90	100	71	91[2]	18	100
Rappahannock River	84	58	76[4]	100	32	95
York River	44	91	100	76	43	96
Choptank River	63	51[1]	47	79	100	92

[1] Percent of area covered in lower estuary

[2] Estimated by Knebel et al. (1981)

[3] Northern Chesapeake Bay only, landward of Potomac River entrance, from Kerhin et al. 1988

[4] From Boon and MacIntyre (1968)

averages of all available samples in a given estuary or in a given estuary segment. If the C_f exceeds 1.0 the metal concentrations exceed the natural Chesapeake Bay sediment by 100%.

When C_f factors for several metals are added an index of contamination, C_I, is derived. This index accounts for the total sediment contamination within an estuary as indicated by selected metals. This index gives equal weight to all metals regardless of absolute abundance but has no ecological significance. It does not take into account large local increases near outfalls or industrial sites. From the range of C_I values, three ranks are defined:

< 4, "Normal" indicating less than 400% enrichment;
4-14, "Enriched" indicating 400 to 1400% enrichment;
> 14, "Polluted" indicating more than 1400% enrichment.

The contamination factors and index are useful indicators of potential problem areas in the region.

Pollution Susceptibility

The relative status of estuaries is further characterized by their susceptibility to pollution, i.e. the potential for pollution as determined by hydraulic characteristics and by the exposure to anthropogenic activities in the watershed. Following Biggs et al. (1989) the susceptibility characteristics are:

1. Hydraulic Character - HL

   Hydraulic loading which is the contaminant handling capacity of a system based on the volume and flushing. It includes both freshwater and tidal flushing and indicates how well an estuary can dilute or transport contaminants. When hydraulic loading is low flushing is sluggish and the estuary tends to retain contaminants.

2. Stratification - STRAT

   Estuaries with strong vertical salinity gradients are likely to develop hypoxia or anoxia and to recycle nutrients more efficiently than homogeneous systems.

3. Population/Estuary Surface Area - P/EA

   This ratio expresses the estuary loads of anthropogenic substances likely to result from watershed activity particularly point sources. When P/EA is high, nutrient loads to the estuary may be high.

4. Agriculture Workers/Estuary Surface Area - AG/EA

   This ratio expresses the estuary loads of anthropogenic substances likely to result from watershed activity particularly non-point sources. When AG/EA is high, nutrient and toxic loads to the estuary may be high.

5. Chemical Workers + Population and Estuary Area - C + P EA

   This relation expresses the estuary loads of anthropogenic substances likely to result from watershed activity, particularly point sources. When these values are high, toxic loads to the estuary may be high.

The parameters "3," "4," and "5" are ratios of the anthropogenic watershed activity to the hydraulic loading, parameter "1". They express the concentrations of pollutants that could result considering the given load to the system and the systems ability to flush that load to sea. The relative ranking, high, medium and low, in the characterization summaries is based on comparison of 78 U.S. estuaries from the National Estuarine Inventory (Biggs et al., 1989).

SEDIMENT CHARACTERIZATION

M120 CHESAPEAKE BAY
including Tangier
and Pocomoke Sounds

Description

The Chesapeake Bay is the largest estuary on the U.S. east coast and one of the largest in the world. It drains a watershed of 71,250 km^2 in the Susquehanna basin and covers a surface area of 6,500 km^2 without the tributaries. The bay is 290 km long and has a width of 4 to 48 km. Although the maximum depth reaches 53 m in the central sector, the mean depth is only 8.4 m and thus the bay overall is relatively shallow. Its width/depth ratio is large, 3,000.

Configuration and Bathymetry

The bay's configuration is highly dendritic and indented with numerous tributaries and creeks that lead headward to streams. The shoreline, which extends 13,000 km, is shaped into a classic ria coast. This pattern evolved during Pleistocene lowered sea level when the ancestral Susquehanna River incised coastal plain deposits of Pleistocene and Tertiary age[11]. As sea level rose in response to meltwaters and receding Pleistocene glaciers about 9,000 years ago, it began to flood the river valley and drown the margins[7]. The present-day Chesapeake Bay is broadly shaped into a slightly sinuous funnel with an axial channel flanked by broad shoals. Deep parts reflect the unfilled ancestral Susquehanna River channel whereas shallow parts reflect the drowned river flood plain. As the bay evolved the bathymetry has been slowly modified by sediment infilling, by shore erosion and by man through dredging and disposal.

From a geologic perspective, the bay is relatively young, born less than 9,000 years ago, when it was submerged by "flooding" of the sea[7]. Its life span is a function of the rate of change of submergence versus the rate of sediment accumulation. Submergence has slowed from approximately 12.5 mm/year between 7,000 to 9,000 years ago[7], to approximately 1.6 mm/year in the last 4,000 years[9]. Tide gage records in the last 40 to 80 years show submergence continues today but it is faster in the northern bay, approximately 4.0 mm/year, than in the bay mouth where it is approximately 3.0 mm/year[7,10]. Marsh deposits have largely kept pace with sea level rise in the last 3,000 years except locally[21]. In the central bay channel however, accretion lags sea level rise inasmuch as the channel is not filled today. Submergence in this zone compensates for the rate of sediment accretion thus prolonging the bay's lifespan.

Sediment Sources

Sediments are supplied to the bay from three major sources, the Susquehanna River drainage basin, shores and marine areas. Additionally, organisms as oysters and diatoms, contribute minor amounts of skeletal debris[2]. The northern bay receives about 1.1 to 2.0 x 10^6 metric tons/year of mud, or 52 to 95% of the total fine sediment influx, from the Susquehanna River[13,15]. During normal years about 50% of the fluvial load is delivered during short periods of spring freshet. However, during two hurricanes, Agnes and Eloise, about 40 million tons were discharged[20]. This represents about 20 to 40 years of normal influx. Sediment input is amplified by intense farming and soil erosion. An estimated seven tons of soil per acre of cropland are eroded every year.

Shore erosion by waves supplies about 0.6 x 10^6 tons/year of silt and clay. Erosion rates average about 0.3 m/year being faster on the exposed islands (up to 10 m yr^{-1}), southern and western shores averaging 0.9 m yr^{-1}, than elsewhere[3]. The relative importance of shore supply increases seaward through the northern bay[2]. Additionally, an estimated 0.4 x 10^6 tons/year of fine sediment is supplied to the southern bay by landward transport from marine areas[19]. However, bulk of the input to the southern bay is sand. Of the total bay sedimentation an estimated 61% is fluvial-derived fine sediment and 39% is marine-derived coarse sediment[15].

Pathways

Within the bay fine-grained sediment is cycled in the estuarine circulation. Fluvial sediment entering the northern bay from the Susquehanna River is transported: (1) seaward through freshwater reaches near the river mouth; (2) seaward through the upper estuarine layer, an efflux route, and downward by settling into the lower layer; (3) landward through the lower estuarine layer return flow, or reflux route, to the inner salt limit where it is retained for long periods in the turbidity maximum zone. This zone migrates about 40 to 55 km seaward from its normal position during river floods[20]. Small amounts of fine sediment are supplied to the bay via landward flow through the mouth. This route also carries large amounts of sand into the southern bay[15]. Additionally, sand is carried into the bay mouth by southward progradation of the southern end of the Delmarva Peninsula and from the shelf nearshore zone via longshore and coastal drift[6]. Sand is also released inside the bay by shore erosion particularly in the Smith and Tangier Islands area. This sand reportedly[14] is transported via longshore and local currents and deposited on broad shoals south of the islands.

Bottom Sediments

The pattern of sediment texture (Figure 3A and 3B) is marked by an abundance of mud in the northern bay and an abundance of sand in the southern bay near the bay mouth[4,14,17,18]. This estuary-wide pattern reflects nearness to contrasting fluvial and marine sources. Between these two types in the main channel of the central bay off the Rappahannock River, there are admixtures of sand, silt and clay. Mean size of channel sediments generally decreases seaward from about 0.24 mm in the Susquehanna Flats to 0.002 mm size off Kent Island and the Choptank River mouth[14]. Farther seaward from the Rappahannock River mouth, mean size generally increases toward the bay mouth to about 0.25 to 0.50 mm[4]. This trend reflects less energetic conditions in deep central parts of the channel floor than near the bay head or mouth.

Across the central bay, sand covers shallow margins whereas silty clay or clayey silt dominates in the channel[4,14]. In between a transition of mixed sediments often occurs in a narrow zone. The sand is produced by either shore erosion and/or wave winnowing of fine sediment from the shoals. Whereas the sand remains on the shoals as a lag deposit, fines move to less energetic zones either in deep central parts of the bay or protected marginal embayments. The central bay therefore is a trap for mud winnowed from the margins or supplied from the Susquehanna River, or from major tributaries during extreme river floods.

Organic Matter

Percentages of organic matter (derived by multiplying concentrations of organic carbon by 1.8) are greater in sediments of the northern bay than in the southern bay. They decrease seaward from 21% near the Susquehanna River entrance, the likely source of natural and anthropogenic organic matter (e.g. coal) to 2.8% off the Potomac River mouth[14]. In the southern bay organic matter averages 2.0% and is less than 1.0% in sandy sediments around the mouth[4]. The percentages are closely related to weight percent clay in the sediments which in turn, varies directly with water depth[4]. Organic matter is scarce in sandy zones of active wave and current energy.

Other Characteristics

Sedimentary structures displayed in X-radiographs show that the degree of bioturbation approximately follows the salinity gradient with the least bioturbation at the bay head and greatest at the mouth[16]. Laminations are preserved in zones of fast sedimentation in the turbidity maximum zone (about 40 km seaward of the bay head) and in the deep basin, between Baltimore and the Potomac mouth. This basin is seasonally anoxic below a depth of about 16 m. The clay mineral kaolinite is relatively common in the northern bay while chlorite and illite are relatively common in the southern bay.

Sinks

The main depocenter of mud sedimentation lies in the axial channel of the turbidity maximum zone of the northern bay (Figure 3A)[4,15]. Rates of sedimentation mainly range 3.8 to 15.5 mm/year in the turbidity maximum zone (but locally reach 80 mm/yr), 0.7 to 3.6 mm/year in the central bay and 1.9 to 12.2 mm/year in the southern bay. Locally rates reach more than 300 mm/year in dredged channels. This distribution suggests the bay is filling from the ends of the system, i.e. close to the sources of sediment[15]. In the depocenter sedimentation is encouraged by high suspended sediment concentrations of the turbidity maximum and by entrapment in the near-bottom current null zone. Settling is enhanced by biological agglomeration of fine particles by filter-feeding zooplankton. Elsewhere, sedimentation is induced in less energetic zones in the main channel of central bay marginal bays and reentrants. Flood-borne sedimentation makes up about 25 to 50% of the bottom deposits in the northern bay above Annapolis[20]. Sedimentation rates therefore, are variable with time depending on the frequency of river flooding. The sinks are also sites of toxic metal and chlorinated hydrocarbon contamination. The depth of contamination is likely greater in the sinks than elsewhere by virtue of fast sedimentation.

The zones of high sedimentation rate in the turbidity maximum zone and harbors like Baltimore require frequent dredging to maintain shipping channels at depths of 10.7 to 15.2 m. Material is disposed either along channel margins, in diked containments, or in open water of natural channels such as near Kent Island, Maryland, or Wolf Trap, Virginia.

Historical sedimentation rates show little estuary-wide change associated with European settlement or with intensive urban construction activities beginning in the 1950s[5]. Most man-induced sediment input is deposited at the head of sub-tributaries and thus only small amounts reach the bay mainstem. Although much sediment is released by man's activities in the watershed, it is mainly stored in river valleys or reservoirs and will take decades or centuries to reach the main bay.

Mass Balance

The northern bay, landward of the Potomac River mouth, receives an estimated 1.1 to 2.0 million metric tons of fine sediment annually from the river, about 0.6 million tons/year from shores and about 0.4 million tons/year of fine sediment from the southern bay and marine areas[13,15]. Altogether this amounts to 2.1 to 3.0 million metric tons/year. Accumulation of mud in sinks is in the range of 2.9 to 3.3 million metric tons/year[13]. Therefore, storage efficiency ranges 1.0 to 1.6. The northern bay stores an amount of fine sediment equivalent to the total river input plus sediment from other sources.

Contamination Status

The bay receives trace metals from human and natural sources through rivers, the atmosphere, urban runoff and municipal and industrial discharges[23]. The Susquehanna River is a dominant input pathway for Cd, Co, Ni, and Zn, while the atmosphere is important for Pb and Zn[22]. The river is important because of its substantial metal loadings, its large discharge of water and sediment that flow directly into the bay head. This contrasts to the James and Potomac Rivers that discharge into estuaries where sediments and metals are trapped thus limiting the supply to the main bay[12].

The turbidity maximum zone, between the Patapsco River and Susquehanna Flats, is a major sink for Cu, Pb and Zn. Mean concentrations are 33, 41 and 226 $\mu g/g$, respectively[22]. Enrichment factors (Cf) for most metals except Cr are two or greater. As expected the highest contamination factors come from heavily industrialized Baltimore Harbor, e.g. Cd (64), Cu (27), Pb (19) and Zn (6)[22]. In the bay mainstem enrichment factors for most metals decrease seaward from the turbidity maximum zone. Although the Patapsco River, Baltimore, is an area of major contamination, localized increases that reflect seaward transport out of the Patapsco are limited to the western bay shore. Secondary metal sinks occur in less energetic zones, e.g. in the central bay axial channel off Kent Island and mouths of tributaries as off the Potomac River, where sedimentation is relatively fast[12].

In terms of the contamination index, the combined factors yield mean indices of 12, 6 and -4 in upper, middle and lower bay segments, respectively[22]. These segments therefore, can be characterized as "enriched" and "normal," respectively.

The sediment pollution index for the northern bay ranks 87 on a scale of 100. It is affected by substantial percentages of mud and mud sedimentation area, and high organic matter.

In terms of pollution susceptibility among the nation's estuaries, the Chesapeake Bay ranks relatively high[1]. Although the anthropogenic toxic loading, C + P EA is moderate, with low population densities (< 100) of chemical and metal workers, the bay's ability to flush prospective toxic loads to sea is relatively low. This probably reflects high particle retention close to major source inputs like Baltimore Harbor.

Bottom Sediment Charts

The bottom sediments of the Chesapeake Bay mainstem have been thoroughly surveyed in 1978-1980 by two compatible investigations from grab samples and selected 1-m cores collected on a 1.0 to 1.4 km grid[4,14]. Navigation was provided by Raydist or Loran-C systems.

The distribution of mud abundance, Figure 4A, is broadly classified into three groups: (1) less than 40%; (2) 40 to 80%; (3) greater than 80%. This classification displays major patterns suitable for recognizing dominant features and for interpretation of sediment processes. The chart was compiled by using a minimum mappable unit of 9 km^2 and smoothing isolines. Therefore, isolated patches less than 9 km^2 are not shown. Greater detail can be acquired by mapping the original data at larger scales and smaller class intervals.

The distribution of sedimentation zones is based on sedimentation rates obtained from radiometric aging of a limited number of cores in mud zones (> 40%)[8,15]. Lateral boundaries of these zones at greater than 3 mm/yr generally parallel the mud isolines or bathymetry and are approximate.

Figure 3B shows the broad distribution of sediment types based on the Shepard classification (triangle). The chart was compiled by using a minimum mappable unit of 9 km^2 and smoothing boundaries. Because of the small, page-size scale, narrow transition zones of texture, such as occur between shoals and the channel, are not represented. For greater detail the original data should be mapped at a larger scale.

For sources of information and explanation of data in the sediment inventory summary, see the text discussion.

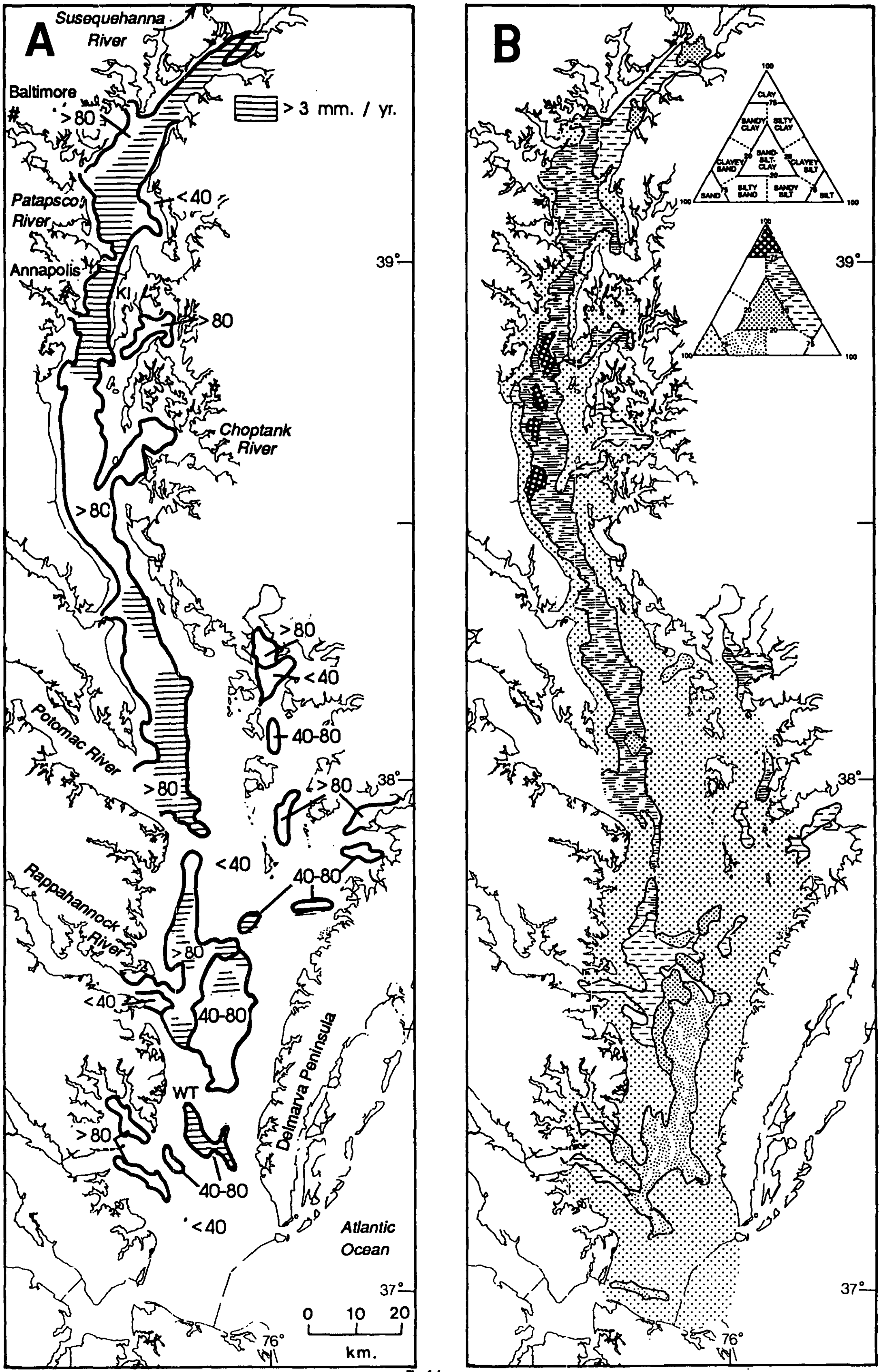


Figure 3. A. Distribution of percent mud[3,14], isolines; and zones of sedimentation rate in mud zones (> 40% mud) greater than 3 mm/yr, shaded, boundaries approximate. KI is Kent Island; WT is Wolf Trap.
B. Distribution of sediment texture following the Shepard classification.

SEDIMENT INVENTORY

M120 CHESAPEAKE BAY

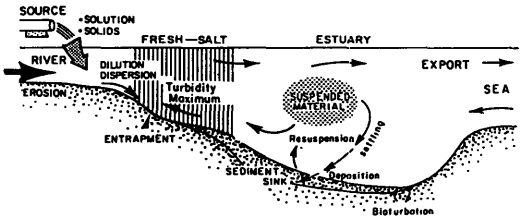
Drainage and Morphology

Drainage Area, Km^2 (Susquehanna River)	71,250
Total Drainage Area, Km^2	160,000
Average River Inflow, m ^{3}/s	1,110
Length, Km	290
Average Depth, m	8.4
Average Width, Km	25
Width/Depth Ratio	3,000
Surface Area, Km^2	6,500
Sinuosity	1.09

Sources, Northern Bay

	Tons/yr x 10^6	Relative Strength, %
River	1.1-2.0	52-95
Shores	0.6	20-30
Marine	0.4	13-20
Total	2.1 to 3.0	

Pathways



Relative strength

Strong	Weak
➔	→

Submergence Rates

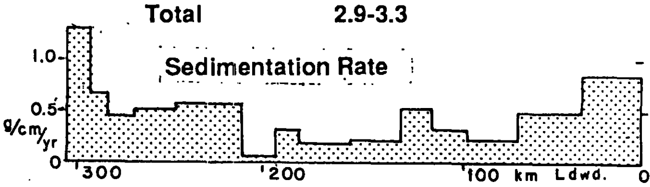
Short-term, mm/yr	3.0 to 4.0
Long-term, mm/yr (0-4,000 yrs BP.)	1.6

Data Quality, Bottom Sediment Texture

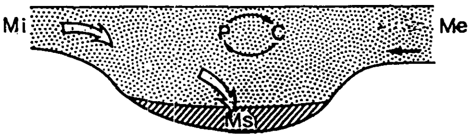
Highly Certain

Sinks, Northern Bay

	Tons/yr x 10^6	Relative Strength, %
Channel & Floor	2.7-3.1	94
Marsh, Swamp	0.2	6
Total	2.9-3.3	



Mass Balance, Northern Bay



Mi (Source)	=	Ms + Me (Loss)
2.1	=	2.9 - 0.8 x 10^6 tons/yr
3.0	=	3.3 - 0.3 x 10^6 tons/yr

Storage Efficiency: $Si = \frac{Ms}{\Sigma Mi} = 1.0$ to 1.6

Bottom Sediments

	Mean	Std. Dev.
Water Content, percent	40.5	25.0
Organic Matter, percent	2.7	0.5

Percent Mud Area, M_{ud}	36
Percent Sedimentation Area, A_c (>3 mm/yr)	14
Percent Sand Area	64

Dominant Pattern:

Lateral	• Channel mud bordered by broad sand shoals
Longitudinal	• Channel, sand at extreme head, mud in upper and middle estuary, sand at mouth; tripartite pattern

Contamination Status, Explanation

Contaminant loading data come from NOAA's National Coastal Pollutant Discharge Inventory[23]. They include total loadings, particulate and dissolved, natural and anthropogenic from both the fluvial drainage (~ 1987) and the estuarine drainage area (EDA) (~ 1982) that drains directly into the estuary. The loadings also include discharges from both point and non-point sources.

The percentage distribution of metal loadings by type of source in the pie diagrams includes both point and nonpoint sources within the estuarine drainage areas.

Sediment concentrations are total concentrations in the uppermost bottom sediments. The mean, minimum and maximum values of the sediment concentrations, as well as the contamination factors are for the total estuary. The distributions of these parameters in the upper, middle and lower estuary are geometric mean values in segments of the bay, chartlet, lower right. Summary inventory and status sheets are available in the desk-top atlas.

CONTAMINATION STATUS

M120 CHESAPEAKE BAY

Contaminant Loading, tons/yr*

	Cu	Pb	Zn
River	297	1270	808
Industry	25	40	82
Wastewater	13	15	57
Atmosphere	27	19	478
Crop Runoff	5	3	12
Urban Runoff	19	78	87
Total	386	1425	1524

Sediment Concentration, μg/g, total estuary

	Cu	Pb	Zn
Mean	13	24	116
Minimum	0.1	3	9
Maximum	94	116	553

Contamination Factor, Cf

	Cu	Pb	Zn
Mean	1	1	0
Minimum	-1	-1	-2
Maximum	7	6	4

Contamination Index, C_I

Mean 5

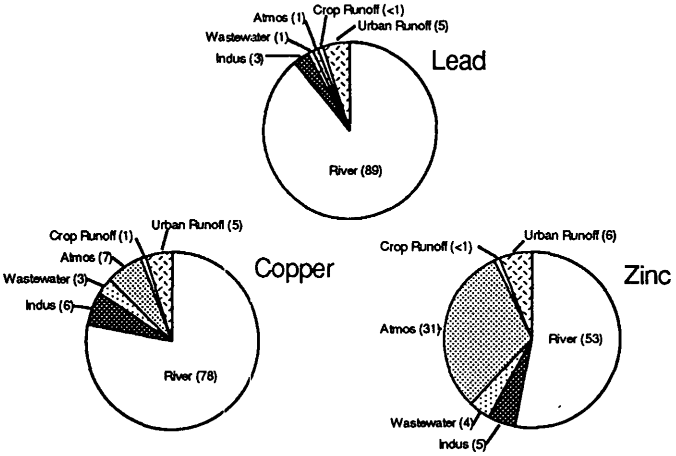
Sediment Pollution Index, SPI*

SPI: 87

Pollution Susceptibility

High because of low flushing ability and high anthropogenic metal activity

Percentage of Metal Load*



Distribution of Concentration, mean, μg/g

	Upper	Middle	Lower → Seaward
Cu	▨ 33	□ 16	□ 6
Pb	▨ 41	□ 18	□ 12
Zn	▨ 226	□ 97	□ 26

Distribution of C_f, mean

	Upper	Middle	Lower → Seaward
Cu	▨ 2	□ 1	□ -0.6
Pb	▨ 2	□ 1	□ -0.2
Zn	□ 1	□ 0.5	□ -1

Distribution of C_I

Upper	Middle	Lower → Seaward
▨ 12	▨ 6	□ -4

■ Polluted ▨ Enriched □ Normal

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*Northern Chesapeake Bay and Susquehanna River

Chesapeake Bay References

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5. Brush, 1990
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* Primary data source reference

M120b POTOMAC RIVER

Description

The Potomac River, known as "The Nation's River," is the second largest tributary contributor of freshwater to Chesapeake Bay. Its drainage basin occupies 37,800 km^2 traversing five physiographic provinces from the Appalachian Plateau seaward to the Coastal Plain. Each province differs in topography, rainfall, soil type, stream pattern and climate. Thus, basin sediment yield is highly variable. The Potomac River is a "flashy" river because it is prone to numerous peak discharges. About four million people live in the basin of which three million live in the Washington D.C. area[7]. There are significant inputs of toxics and nutrients above and below the Fall Zone. Sediments are of concern not only as a carrier of nutrients, primarily phosphorous, but because of historic soil erosion between 1840 and 1920 and urban erosion in 1960. Erosion has resulted in filling of channels and harbors with loss of port facilities, degraded water quality and loss of suitable substrate for shellfish production. Additionally, fine sediments on the estuary floor are a potential sink for high nutrient loads supplied from the Metropolitan Washington area.

The Potomac is the longest and broadest tributary entering Chesapeake Bay. It is 187 km long from the mouth to the head-of-tides at the Fall Zone. Its width increases seaward from less than 0.5 km at the head to 11 km at the mouth. Since the estuary is relatively shallow, 7.0 m deep on the average, the width depth ratio is large, 1460.

Configuration and Bathymetry

The Potomac estuary is broadly shaped by drowned Pleistocene topography inherited from erosion of coastal plain deposits. This relic "floor" is buried by as much as 40 m of sandy and silty fluvial and estuarine sediments of Holocene age (< 10,000 yrs)[6]. From its head to its mouth the estuary forms one large gently meandering funnel with a sinuosity of 1.47. Along the estuary three hydrologic zones are recognized[4]: (1) a freshwater river zone or upper estuary from the Fall Zone to near Quantico, (2) a middle estuary transition zone between fresh and brackish water from Quantico to Morgantown, (3) a lower estuary brackish and saline zone between Morgantown and the mouth. Across the estuary with increasing depth four geomorphic units are recognized[2]: (1) shoreline flats, (2) smooth flats, (3) irregular slopes and (4) channels. Cross profiles of the lower estuary are broadly U-shaped with an axial channel bordered by long slopes. This contrasts to V-shaped profiles in the river zone which reflects the ancestral river channel. In the vicinity of Morgantown the slopes at 3 to 6 m depth are interrupted by isolated knolls and ridges representing oyster bars overlying relic sand bars[6].

The bathymetry is locally modified by dredged channels cut through shoals in the axial channel to 7.3 m deep at five places for a total length of 24 km. This allows ships with drafts less than 7.3 m to reach Washington, D.C. Many short channels cut 1.8 to 2.1 m deep allow passage into tributary creeks and small harbors[7].

The shoreline with its numerous tributary rivers, creeks and embayments traverses 1,804 km exceeding the axial length of the estuary 10 fold[7]. The shore is backed by bluffs 5 to 50 m high. Marshes and swamps, which are scattered throughout the margins and heads of tributaries, occupy 96 km^2 which is equivalent to 7% of the total estuary surface area.

Sediment Sources

The Potomac River estuary receives sediment from three major sources, the river drainage basin, shores and marine areas including Chesapeake Bay. Additionally, organisms, e.g. oysters, contribute minor amounts of shell. The river supplies about 1.4×10^6 m tons/year on the average or 55% of the total fine sediment input (silt and clay)[10]. Most of the annual sediment load is discharged during a few days of the year. Approximately 90% of the annual load is discharged in 10% of the time. Additionally, about 0.9×10^6 m tons/year or 37% are supplied from the tributaries but this load is largely retained within the tributary creeks[2]. Shore erosion supplies approximately 0.1 to 0.2×10^6 m tons/year or 3 to 8% of the total annual fine sediment input, with and without the tributary inputs[10]. Forty percent of the erodable material is silt and clay[10]. Erosion rates average 0.46 m/year along the southwest (Virginia) shore and 0.36 m/year along the northeast (Maryland) shore[10]. The relative importance of shore material generally increases seaward; that is away from the fluvial source and toward the mouth where wave fetch increases as the estuary widens[4]. An estimated 0.01 to 0.4×10^6 m tons/year, or about 0.3 to 14% of the total fine sediment load, is supplied from marine areas as Chesapeake Bay, by landward transport. The smaller value is calculated by box modeling at normal river inflow[10], whereas the greater value assumes rates are similar to the James and Rappahannock mouths with landward transport is proportional to values determined by Schubel and Carter[11].

Pathways

Once fine sediments are supplied to the estuary they are cycled by the estuarine circulation[4]. For fluvial sediment and material eroded from the freshwater upper estuary, the pathway is: (1) seaward through the upper estuary; (2) seaward through the upper estuarine layer of the transition zone and brackish zone of the middle and upper estuary and downward by settling into the lower layer; (3) landward through the lower estuarine layer to the inner salt water limit. Much fine sediment is resuspended and retained for long periods in the turbidity maximum zone between Morgantown and Maryland Point (23 km landward of Morgantown). During high river inflow the maximum extends 40 km seaward of Morgantown and surface concentrations reach 100 mg/l[12]. Contaminants sorbed to fine particle may be expected to follow the three pathways. Small amounts are added to the estuary from different sources to balance amounts removed or that accumulate on the floor. Prior to accumulation however, suspended sediment goes through repeated tidal cycles of settling, deposition and resuspension. By exchanging sediment between the bed and overlying water, contaminants can react with particles or be released from the bed to the water. On shoals exposed to long wave fetch in the middle and lower estuary, wind waves also resuspend bottom sediments and thus facilitate transport of fine sediment to deep water or to protected reentrants.

Tributaries of the Potomac are essentially closed systems. Most sediment and nutrients are retained with the tributaries and thus, they are not significant sources affecting the main estuary[2].

Bottom Sediments

Silty clay dominates the axial channel throughout the estuary except near the head[4] (Figures 4A, 4B). Mean particle size of channel sediments is minimal in the transition zone and inner lower estuary, 75 to 110 km landward. This includes patches of pure clay (Figure 4B). Sand to mud ratios in channel and slope sediments are variable and higher near the head (140 km landward) (e.g. ~ 70:30) than in the transition zone. Across the lower estuary, mud on the channel floor passes landward into mixtures of sand, silt or clay on irregular slopes. In contrast, moderately well-sorted sand dominates shoreline flats. Particle size generally increases with decreasing water depth; the greatest increase occurs between the 5 and 10 m depth[4]. This textural transition reflects nearness to the sand source, the shore banks, and the energy distribution of waves. Waves not only winnow fines from shoals but allow deposition in deep water where energy is weak.

Organic Matter

Percentages of organic matter derived from organic carbon measurements, average 3.2% for the entire estuary[4]. Concentrations are high (> 50%) in silt from the river zone channel. In contrast, they are relatively low (< 0.6%) in sand from the shoreline flats and irregular slopes of the middle and lower estuary. The river zone is the main sink for organic matter and nutrients. This zone has substantial sedimentation and it is close to the fluvial source and to sewage treatment plants in the Washington, D.C. area. With distance away from these sources, organic matter tends to accumulate more with the fine particles[4].

Sinks

The main depocenter of mud sedimentation lies in the inner part of the lower estuary between Morgantown and Nomini Bay[5,6] (Figure 7A). An estimated 8 to 18 mm/year of sediment are deposited. The depocenter is close to the turbidity maximum and the inner limit of salty water during high river inflow[12]. Fast sedimentation is encouraged by high suspended sediment concentrations in the turbidity maximum and by entrapment in the near-bottom null zone. Substantial sedimentation occurs in the river zone, 120 to 180 km landward, where rates in the channel range 6.2 to 7.3 mm/year. Sedimentation is facilitated by decreased competence of river inflow which affects bedload during high discharge[4] and affects suspended load during normal discharge. Elsewhere the heads of tributaries such as Port Tobacco are sites of fast sedimentation[2]. Fast sedimentation, with rates > 110 mm/year, is induced by accelerated erosion caused by historic tobacco farming[2]. Despite accelerated input caused by farming, as well as by construction activity in the Washington, D.C. area, there is no significant effect on sedimentation in the main estuary[2]. Most effects are confined to marsh building and seaward migration of the heads of navigation in the tributaries.

The Potomac River system is depositional and undergoing submergence. Rates of submergence in the last 3,000 years are approximately 1.3[6] to 1.6 mm/year. Short-term rates in the last 40 to 80 years, are approximately 2.2 to 4.1 mm/year increasing seaward from the transition zone to the mouth[3]. Whereas marsh accretion has largely kept pace with sea level rise in the last 3,000 years channel accretion near the mouth has lagged relative sea-level rise inasmuch as it is not filled to capacity today.

Mass Balance

The Potomac receives an estimated 2.4 to 2.9 x 10^6 m tons/year of fine sediment annually including material from the river, tributaries, shores and marine areas. Accumulation in sinks amounts to approximately 3.7 x 10^6 m tons/year. Therefore, there is an imbalance with an "excess" accumulation of 0.8 to 1.3 x 10^6 m tons/year greater than the source input. This may reflect an underestimate of the fluvial input because sediment discharge measurements during major floods are lacking.

The storage efficiency ratio ranges 1.3 to 1.5. This indicates the estuary stores an amount of fine sediment equal to the entire river input in addition to sediment from other sources as shores and marine areas.

Contamination Status

The large population center in the metropolitan Washington, D.C. area has created numerous point sources of metal contamination. These include nine major sewage treatment plants, a number of industrial sites and power plants, besides urban runoff and local stream sources. Approximately half of the Potomac's nutrient load comes from the Washington, D.C. area including point and nonpoint sources, whereas the other half comes from above the Fall Zone, mainly agricultural areas. Sixty-six percent of the Pb and 51% of the Zn come from above the Fall Zone whereas 63% of the Cd and 59% of the Cu come from the estuarine drainage area below the Fall Zone[14].

The river zone between Quantico and the Fall Zone is a major sink for Cu, Pb and Zn[8]. Mean concentrations in this zone are 29, 44 and 211 μg/g respectively[13]. Enrichment factors (Cf) for Cu, Pb and Zn are 2 to 3 and generally decrease seaward from the river zone toward the mouth[8,13]. This reflects anthropogenic inputs from the Washington, D.C. area. In terms of contamination index, the combined factors yield a mean of 15.3 in river (upper estuary)[13]. This zone therefore, can be characterized as polluted with more than 1400% enrichment.

The Potomac has the highest sediment pollution index, 100, of the six systems in the Chesapeake region. It is affected by relatively large areas of percentage mud and sedimentation.

In terms of pollution susceptibility among the nation's estuaries, the Potomac ranks high because of its low ability to flush prospective toxic loads[1]. Additionally, it has a relatively high population density including high percentages of agricultural, chemical and metal workers relative to estuary surface area.

Bottom Sediment Charts

Bottom sediments of the Potomac River estuary have been sampled by U.S. Geological Survey investigators[4] in 1978-1981. Positioning was accomplished by a combination of Radar and Loran, or by dead reckoning in some locations. Most stations were occupied along cross transects extending from bank to bank.

The distribution of mud abundance, Figure 4A, is broadly classified into three groups: (1) less than 40%; (2) 40 to 80%; (3) greater than 80%. This classification displays major patterns suitable for recognizing dominant features and for interpretation of sediment processes. The chart was compiled by drawing isolines between values along cross transects paralleling the bathymetry and the patterns charted by Lippson *et al.*, 1979. A minimum mappable unit of 3 km^2 was used and therefore small isolated patches, common in the upper estuary, are not shown. Greater detail can be obtained by mapping the original data at larger scales and smaller class intervals.

The distribution of sedimentation zones is based on sedimentation rates obtained from radiometric aging of a limited number cores in mud zones (> 40%)[2,4]. Lateral boundaries of these zones at > 4 mm/yr generally parallel the mud isolines and bathymetry and are approximate.

Figure 3B shows the broad distribution of sediment types based on the Shepard classification (triangle). The chart was compiled by using a minimum mappable unit of 3 km^2 and smoothing boundaries. Because of the small, page-size scale, narrow transition zones of texture, such as occur between shoals and the channel, are not represented. For greater detail the original data should be mapped at a larger scale.

For sources of information and explanation of data in the sediment inventory summary, see the text discussion.

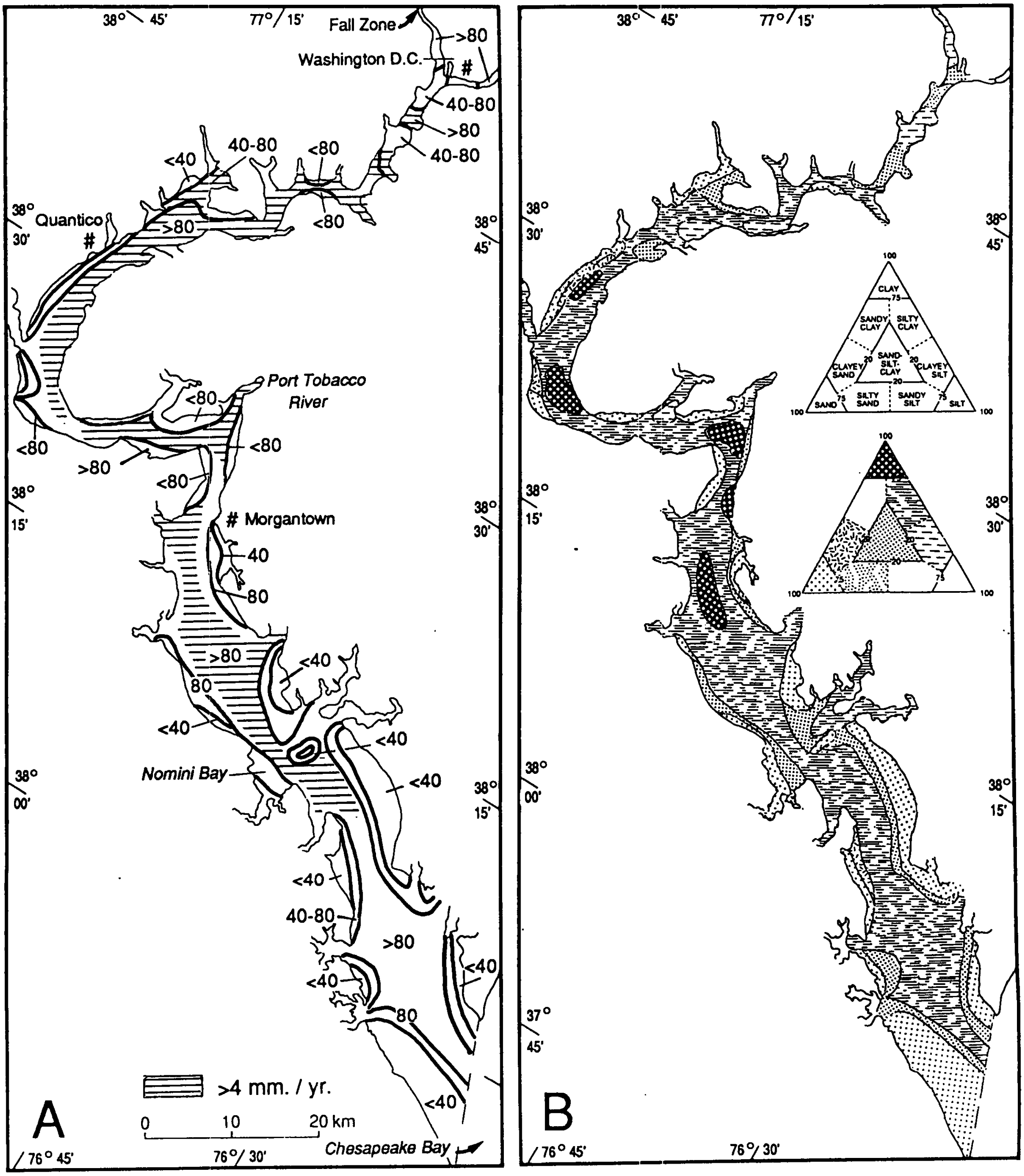


Figure 4. A. Distribution of percent mud, isolines; and zones of sedimentation rate in mud zones (> 40% mud) greater than 4 mm/yr, shaded, boundaries approximate.

B. Distribution of sediment texture following the Shepard classification.

SEDIMENT INVENTORY

M120b POTOMAC RIVER

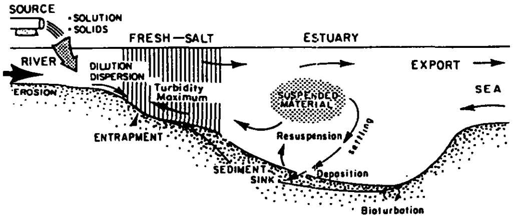
Drainage and Morphology

Total Drainage Area, Km^2	37,800
Average River Inflow, m^3/s	500
Length, Km	187
Average Depth, m	7.0
Average Width, Km	10.2
Width/Depth Ratio	1,460
Surface Area, Km^2	1,250
Sinuosity	1.47

Sources

	Tons/yr x 10^6	Relative Strength, %
River	1.4	57
Tributaries	0.9	37
Shores	0.1-0.2	3-8
Marine	0.01-0.4	~0.3
Total	2.4 - 2.9	

Pathways



Relative strength	➘	→
	Strong	Weak

Submergence Rates

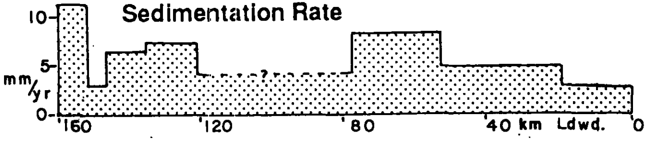
Short-term, mm/yr	2.2 to 4.1
Long-term, mm/yr (0-4,000 yrs BP.)	1.3 to 1.6

Data Quality, Bottom Sediment Texture

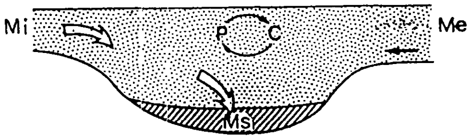
Fairly Certain

Sinks

	Tons/yr x 10^6	Relative Strength, %
Main Channel	2.7	73
Tributaries	0.9	24
Marsh, Swamp	0.1	3
Total	3.7	



Mass Balance



Mi (Source)	=	Ms + Me (Loss)
2.4	=	3.7 - 1.3 x 10^6tons/yr
2.9	=	3.7 - 0.8 x 10^6tons/yr

Storage Efficiency: $Si = \frac{Ms}{\Sigma Mi} = 1.3 \text{ to } 1.5$

Bottom Sediments

	Mean	Std. Dev.
Water Content, percent	62	—
Organic Matter, percent	3.2	1.9

Percent Mud Area, M_{ud}	79.4
Percent Sedimentation Area, A_c (>4 mm/yr)	30.9
Percent Sand Area	20.6

Dominant Pattern:

Lateral	• Channel mud bordered by admixtures on slopes and sand marginal flats
Longitudinal	• Channel coarse-grained near head; fine-grained, mud in middle and lower estuary

Contamination Status, Explanation

Contaminant loading data come from NOAA's National Coastal Pollutant Discharge Inventory[14]. They include total loadings, particulate and dissolved, natural and anthropogenic from both the fluvial drainage (~ 1987) and the estuarine drainage area (EDA) (~ 1982) that drains directly into the estuary. The loadings also include discharges from both point and non-point sources.

The percentage distribution of metal loadings by type of source in the pie diagrams includes both point and nonpoint sources within the estuarine drainage areas.

Sediment concentrations are total concentrations in the uppermost bottom sediments. The mean, minimum and maximum values of the sediment concentrations, as well as the contamination factors are for the total estuary. The distributions of these parameters in the upper, middle and lower estuary are geometric mean values in segments of the bay, chartlet, lower right. Summary inventory and status sheets are available in the desk-top atlas.

CONTAMINATION STATUS

M120b POTOMAC RIVER

Contaminant Loading, tons/yr

	Cu	Pb	Zn
River	185	570	634
Industry	4	5	6
Wastewater	24	28	104
Atmosphere	7	8	214
Crop Runoff	3	2	7
Urban Runoff	28	121	114
Total	251	734	1079

Sediment Concentration, µg/g, total estuary

	Cu	Pb	Zn
Mean	25	36	202
Minimum	0	4	0
Maximum	64	450	1062

Contamination Factor, Cf

	Cu	Pb	Zn
Mean	2	3	3
Minimum	-1	-0.8	-0.6
Maximum	6	25	10

Contamination Index, C_I

Mean 10

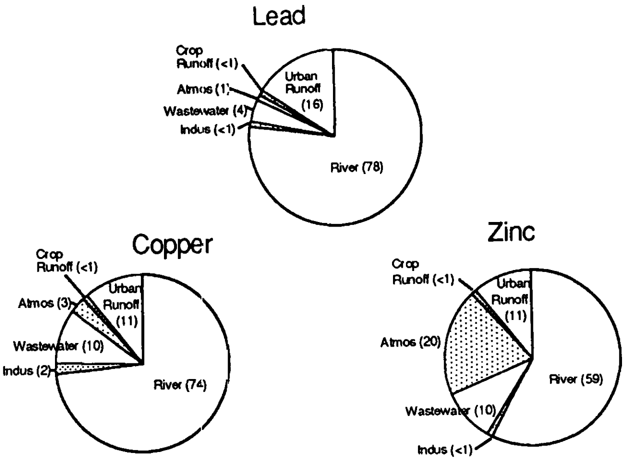
Sediment Pollution Index, SPI

SPI: 100

Pollution Susceptibility

High due to low flushing ability and high anthropogenic metal activity

Percentage of Metal Load



Distribution of Concentration, mean, µg/g

	Upper	Middle	Lower → Seaward
Cu	□ 29	□ 28	□ 17
Pb	▨ 44	□ 28	□ 23
Zn	▨ 211	▨ 325	□ 128

Distribution of Cf, mean

	Upper	Middle	Lower → Seaward
Cu	□ 3	□ 2	□ 1
Pb	▨ 5	□ 2	□ 0.8
Zn	□ 3	□ 4	□ 2

Distribution of C_I

Upper	Middle	Lower → Seaward
■ 15	□ —	□ 5

■ Polluted ▨ Enriched □ Normal

Potomac River References

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* Primary data source reference

M120c RAPPAHANNOCK RIVER

Description

The Rappahannock River is one of five major tributary estuaries leading into the western margin of Chesapeake Bay. The river rises on the eastern slope of the Blue Ridge Mountains and drains 6,970 km^2 of upland in the Piedmont and coastal plain provinces. Sixty-three percent of the basin is forested and 35% is covered by cropland and pasture. The name Rappahannock means rise and fall of water referring to the tide. Tidal influence extends from the mouth to the Fall Zone at Fredericksburg, a distance of 173 km. Because of its long form the transit time of freshwater and fluvial sediment at average river inflow from the Fall Zone to the saline reaches, which extend 85 km landward from the mouth, is relatively long, weeks to months[14].

The Rappahannock is considered one of the least-impacted of the five western tributaries. It is not extensively modified by dams or dredging. Dredging is limited to 10 short lateral channels cut into tributary creeks and an axial channel cut into shoals at Tappahannock and between Port Royal and Fredericksburg to the 3.0 m depth. Industrial and municipal discharges are relatively low and localized, mainly at Fredericksburg, Tappahannock and Urbanna.

Configuration and Bathymetry

The Rappahannock River estuary is a drowned river valley formed about 7,000 years ago when sea level was 12 m lower than today. It is carved out of unconsolidated coastal plain sediments of Pleistocene and Tertiary age. The estuary is shaped into: (1) a meander zone extending seaward from the Fall Zone to Port Royal; (2) a narrow funnel zone from Port Royal to the mouth. The meander zone channel is V-shaped and its longitudinal profile is broken by deep holes on meander bends. The funnel zone consists of gentle meanders with a U-shaped axial channel bordered by wide shoals or shallow embayments. These features reflect the ancestral river channel and flood plain. The estuary is relatively shallow, 5.5 m, but channel depth reaches 23.5 m at 15 km landward of the mouth. The shoreline is backed by bluffs 4 to 45 m high and interrupted by small tributary creeks. Marshes border the creeks and they occupy point bars and meander necks seaward of Port Royal, an indication of progressive drowning of the estuary[11]. Bathymetry has been modified by sedimentation on the channel floor in middle and lower reaches, by shore and bank erosion, and locally by man through dredging and spoil disposal.

Sediment Sources

Sediments are supplied from the river, shores and marine areas. Additionally, shell-producing organisms, e.g. oysters and diatoms, contribute minor amounts of skeletal debris[6]. Rates of input are incompletely known and thus, limited to order-of-magnitude estimates. The river supplies approximately 0.3 x 10^6 m tons/year or 26% of the total fine sediment input. Most of the suspended load is delivered during short periods of river flood and freshet[12]. An estimated 85 to 90% of the annual sediment load is supplied in less than 10% of the time[14].

Shore erosion supplies approximately 0.3 x 10^6 m tons/year or 28% of the sediment assuming 26% of the erodable material is silt and clay[20]. Erosion rates average 0.3 m/year being two times greater on the southwest bank which is exposed to northeast storms, than on the northeast bank. An estimated 0.2 to 0.4 x 10^6 m tons/year or about 26 to 45% of the total fine sediment is supplied by landward transport from marine areas as Chesapeake Bay. The lesser value assumes the rates are similar to the James mouth with landward transport proportional to values determined by Schubel and Carter (1979)[17]. The greater value is derived from box model analysis of Officer and Nichols (1980)[15] using higher than average river inflow. This analysis may underestimate the input because it does not include net transport of resuspended sediment from the Bay. Sand is partly supplied from the river during floods, as bedload which constitutes less than 11% of the total load. For another part, it is supplied to marginal shoals by bank erosion[8].

Pathways and Cycling

Fine suspended sediment is cycled within the estuary by the estuarine circulation[13]. For fluvial sediment and material eroded from upper estuary banks the route is: (1) seaward through the freshwater reaches of the upper estuary; (2) seaward through the upper estuarine layer of the middle and lower estuary (Tappahannock to Windmill Point), and downward by settling into the lower layer; (3) landward through the lower estuarine layer to the inner salt water limit in the vicinity of Tappahannock. In this zone it is retained for long periods in the turbidity maximum zone. Because many contaminants are sorbed to fine particles, they likely follow the three pathways. Small amounts of sediment and contaminants are added to the estuary from different sources to balance amounts removed or amounts that go into storage on the floor.

Prior to storage in the deposits, suspended sediment goes through repeated tidal cycles of settling, deposition and resuspension[13]. Resuspension is most intense in the turbidity maximum zone where the highest tidal velocities occur. Suspended sediment concentrations in this zone vary 2 to 330 mg/l within 3.2 hours[13]. Additionally, mean concentrations vary from neap to spring tide range, 75 to 220 mg/l[14]. By exchanging sediment between the bed and overlying water, contaminants can react with particles or be released from the bed to the water.

Bottom Sediments

The textural patterns (Figures 5A and 5B) are dominated by silty clay in the middle estuary channel and clayey silt in the lower estuary channel[3,10]. Silt:clay ratios change seaward from 20:80 near the head to 70:30 near the mouth[2,9]. The size grading results from processes of sedimentation[9]. Across the lower estuary, sand on marginal shoals changes channelward to clayey sand or silty sand and then into clayey silt on the channel floor. Mud percentages increase with depth with the greatest increase on the edge of the shoals at the 4 to 6 m depth[7]. Sand is abundant in the meander zone close to its source in the river and banks[8]. This is also an energetic zone during floods and transport competence diminishes with distance seaward from the Fall Zone.

Organic matter percentages reach 12.7% in the lower estuary channel[16]. They diminish landward to 4.9% near Tappahannock and seaward to 8.6% at the mouth. Percentages remain relatively high, > 10%, in muddy channel sediments where sedimentation is relatively fast (> 20 mm/year, Figure 5A). Sedimentary structures in sediment from the meander zone result from short periods of river floods and long periods of normal tidal conditions. Floods produce gravel beds with scour and fill structures, erosional contacts at the base, discontinuities and indistinct large-scale cross-bedding with quartz pebble, wood fragments or silty laminations. In the funnel zone where energy conditions are lower and less diverse than in the meander zone, laminated mud bedding prevails especially where sediment accumulation rates are greater than about 30 mm/year. These alternate vertically with thick massive mud layers or irregular bioturbate layers representing biogenic activity under slow accumulation rates (< 10 to 20 mm/year)[16]. Bottom sediments are oxic in the upper 0.5 to 4.0 cm[11]. The clay minerals chlorite and feldspar are confined to the lower estuary while kaolinite, montmorillonite and vermiculite are abundant in the upper estuary[9].

Sinks

The main depocenter of mud sedimentation occurs in the lower estuary 8 to 30 km landward of the mouth (Figure 5A)[7]. This zone contains the major mass of sediment and has the fastest rates, e.g. up to 47 mm/year at 8 km landward. Relatively fast rates occur locally at 90 km landward. Fast sedimentation is encouraged by weak tidal currents and the relatively deep basin bathymetry. The depocenter is close to the mouth through which storm resuspended sediment from the Chesapeake Bay can be transported via landward flow. The total mass of fine sediment fill, which is estimated from bathymetric changes[7], amounts to 2.2 to 3.7 x 10^6 m tons/year. Additionally, about 0.11 to 0.17 x 10^6 m tons/year accumulate in marshes.

The sediments fill a system undergoing submergence. Rates have slowed from approximately 12.5 mm/year in an early phase (6,000 to 8,000 years BP) to approximately 1.6 mm/year in the last 4,000 years[4]. Short-term rates, 40 to 80 years, are faster and increase seaward from approximately 1.5 mm/year near Fredericksburg to 4.0 mm/year at the mouth[5]. Whereas marsh accretion has kept pace with relative sea level rise in the last 5,000 years, channel accretion has lagged relative sea level rise (submergence) inasmuch as it is not filled to capacity today.

Mass Balance

The Rappahannock receives an estimated 0.8 to 1.0 x 10^6 m tons/year of fine sediment annually including material from the river, shores and marine areas. Accumulation in sinks amounts to 2.3 to 3.8 x 10^6 m tons/year. Therefore, there is a substantial imbalance with an "excess" accumulation of 1.5 to 2.8 x 10^6 m tons/year greater than the total source input. This results mainly from large amounts of fill in the lower estuary. Since the fluvial and shore inputs account for most fill in the upper estuary, the "excess" in the lower estuary probably comes from seaward areas[7]. Moreover, models[15] may not fully account for likely high storm resuspensions transported through the mouth from Chesapeake Bay[7].

The storage efficiency ratio ranges 2.3 to 3.8. Values greater than one indicate the estuary stores an amount of fine sediment equal to the entire river input besides sediment from other sources as the shores and marine areas.

Contamination Status

The Rappahannock River basin is 96% rural; industrial and municipal discharges are low. Point source pollution from six sewage treatment plants at Fredericksburg, towns in the drainage basin, Tappahannock, and Urbanna, is largely controlled, but banks and flood plains that support agriculture are non-point sources of nutrients and pesticides. Fluvial inputs dominate the metal loads for Cu, Pb and Zn[19].

Mean metal concentrations are relatively low for Cu (15 μg/g), Pb (22 μg/g) and Zn (73 μg/g)[18]. Mean values for Cd however, are quite high (3 μg/g) in the lower estuary due to high Cd from natural sources in shore bluffs. Consequently, the mean contamination index is also high (31)[18] although anthropogenic inputs are small.

Of the six Chesapeake Systems the Rappahannock has a relatively high sediment pollution index (95). It is affected by a relatively large area of muddy sediment, substantial storage efficiency, and substantial areas of fast sedimentation accompanied by high water content.

In terms of pollution susceptibility the Rappahannock ranks high among the nation's estuaries because of its low ability to flush prospective toxic loads[1]. Its anthropogenic activity in the basin however, is relatively low.

Bottom Sediment Charts

The bottom sediments of the Rappahannock River have been sampled from time to time in five different investigations[3,7,8,10,16]. Stations are largely positioned by dead reckoning and some by Loran C. The textural patterns are a "mosaic" of data obtained between 1960 and 1981.

The distribution of mud abundance, Figure 5A, is broadly classified into three groups: (1) less than 40%; (2) 40 to 80%; (3) greater than 80%. This classification displays major patterns suitable for recognizing dominant features and for interpretation of sediment processes. The chart was compiled by using a minimum mappable unit of 3 km^2 and smoothing isolines. Greater detail can be acquired by mapping the original data at larger scales and smaller class intervals.

The distribution of sedimentation zones is based on historical bathymetric changes[7] supplemented by rates obtained from radiometric aging of a limited number of cores.

Figure 5B shows the broad distribution of sediment types based on the Shepard classification (triangle). The chart was compiled by using a minimum mappable unit of 3 km^2 and smoothing boundaries. Because of the small page-size scale, narrow transition zones of texture, such as occur between shoals and the channel, are not always represented. Greater detail can be obtained by mapping the original data at a larger scale.

For sources of information and explanation of data in the sediment inventory summary, see text discussion.

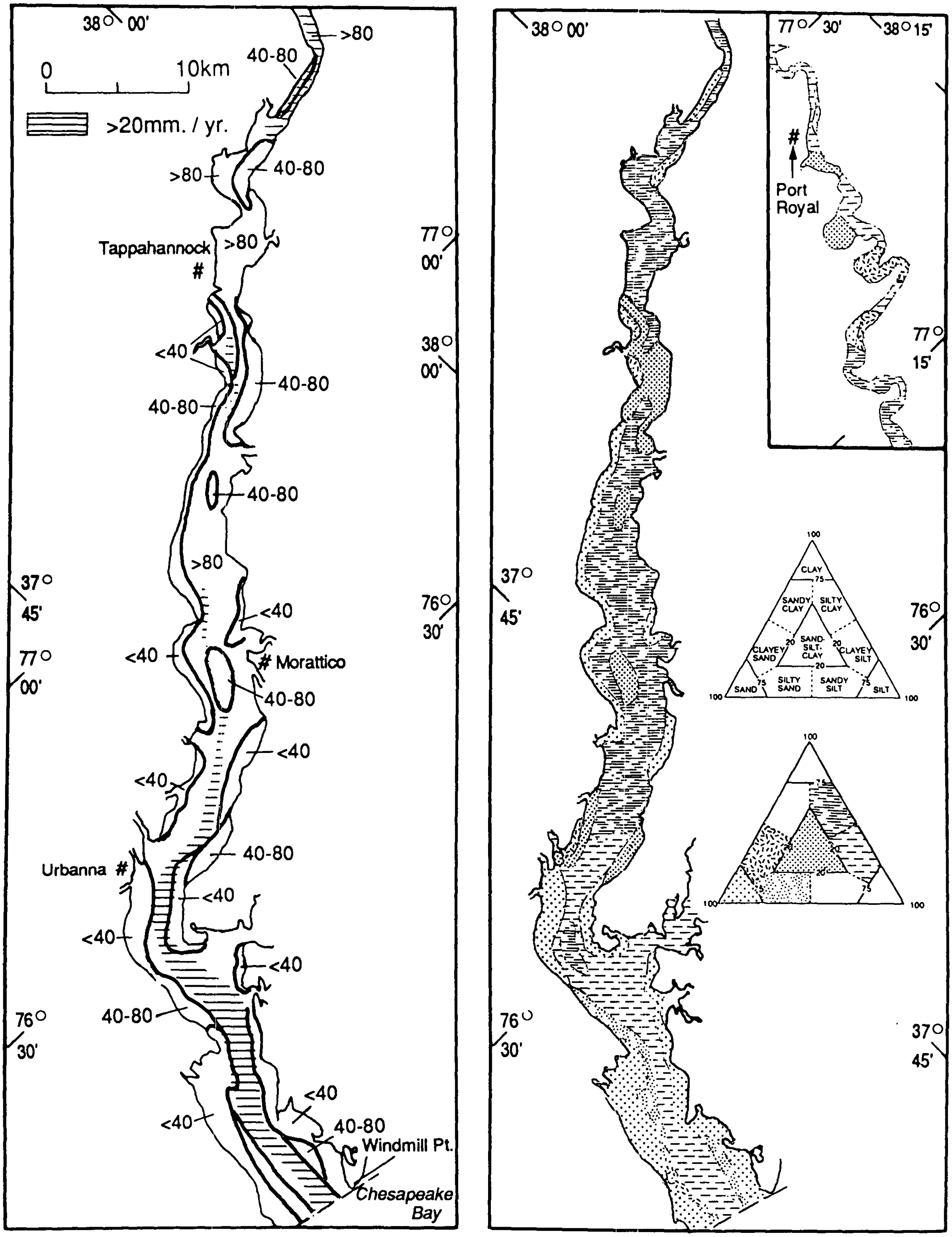


Figure 5. A. Distribution of percent mud, isolines; and zones of sedimentation in mud zones (> 40% mud) greater than 20 mm/yr, shaded, boundaries approximate.

B. Distribution of sediment texture following the Shepard classification.

SEDIMENT INVENTORY

M120c RAPPAHANNOCK RIVER

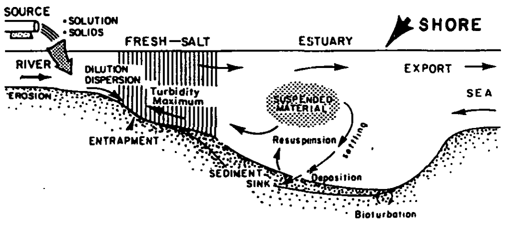
Drainage and Morphology

Total Drainage Area, Km^2	6,970
Average River Inflow, m^3/s	821
Length, Km	173
Average Depth, m	5.5
Average Width, Km	4.2
Width/Depth Ratio	760
Surface Area, Km^2	376
Sinuosity	1.59

Sources

	Tons/yr $\times 10^6$	Relative Strength, %
River	0.3	26
Shores	0.3	28
Marine	0.2-0.4	26-45
Production	≤ 0.02	< 1
Total	0.8-1.0	

Pathways



Relative strength	➤	→
	Strong	Weak

Submergence Rates

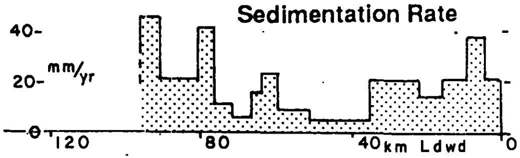
Short-term, mm/yr	1.5 to 4.0
Long-term, mm/yr (0-4,000 yrs BP.)	1.6

Data Quality, Bottom Sediment Texture

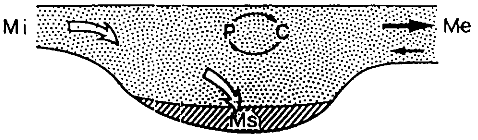
Fairly Certain

Sinks

	Tons/yr $\times 10^6$	Relative Strength, %
Channel	2.2-3.7	96
Marsh, Swamp	0.1	4
Total	2.3-3.8	



Mass Balance



Mi (Source)	=	Ms + Me (Loss)
0.8	=	2.3 - 1.5 x 10^6tons/yr
1.0	=	3.8 - 2.8 x 10^6tons/yr

Storage Efficiency: $Si = \frac{Ms}{\Sigma Mi} = 2.3$ to 3.8

Bottom Sediments

	Mean	Std. Dev.
Water Content, percent	68.1	10.1
Organic Matter, percent	10.7	2.4

Percent Mud Area, M_{ud}	73.7
Percent Sedimentation Area, A_c (>2 cm/yr)	17.9
Percent Sand Area	26.3

Dominant Pattern:

Lateral	• Channel mud bordered by sand shoals with scattered mud patches and oyster reefs
Longitudinal	• Channel Sand in extreme upper estuary; mud in middle and lower estuary

Contamination Status, Explanation

Contaminant loading data come from NOAA's National Coastal Pollutant Discharge Inventory[19]. They include total loadings, particulate and dissolved, natural and anthropogenic from both the fluvial drainage (~ 1987) and the estuarine drainage area (EDA) (~ 1982) that drains directly into the estuary. The loadings also include discharges from both point and non-point sources.

The percentage distribution of metal loadings by type of source in the pie diagrams includes both point and nonpoint sources within the estuarine drainage areas.

Sediment concentrations are total concentrations in the uppermost bottom sediments. The mean, minimum and maximum values of the sediment concentrations, as well as the contamination factors are for the total estuary. The distributions of these parameters are limited to geometric mean values in the lower estuary, chartlet, lower right. Summary inventory and status sheets are available in the desk-top atlas.

CONTAMINATION STATUS

M120c RAPPAHANNOCK RIVER

Contaminant Loading, tons/yr

	Cu	Pb	Zn
River	29	23	110
Industry	<1	8	16
Wastewater	6	<1	<1
Crop Runoff	3	3	4
Urban Runoff	7	<1	<1
Total	45	34	130

Sediment Concentration, µg/g, total estuary

	Cu	Pb	Zn
Mean	15	22	73
Minimum	0.6	1	4
Maximum	32	75	148

Contamination Factor, Cf

	Cu	Pb	Zn
Mean	0.8	1	-0.1
Minimum	-0.4	-0.6	-0.8
Maximum	3	4	0.3

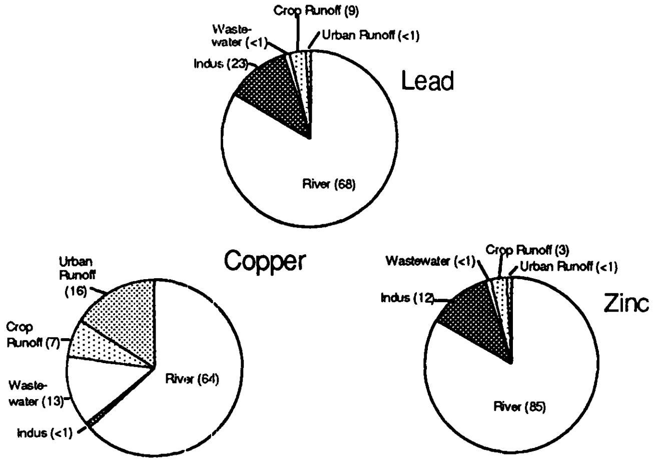
Sediment Pollution Index, SPI

SPI: 100

Pollution Susceptibility

High due to low flushing ability

Percentage of Metal Load

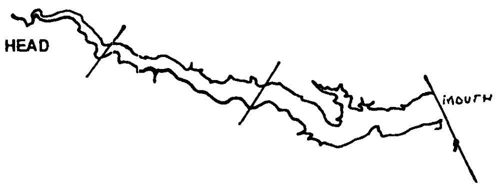


Distribution of Concentration, mean, µg/g

	Upper	Middle	Lower → Seaward
Cu	—	—	15
Pb	—	—	22
Zn	—	—	73

Distribution of Cf, mean

	Upper	Middle	Lower → Seaward
Cu	—	—	0.8
Pb	—	—	1
Zn	—	—	-0.5



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* Primary data source reference

M120d YORK RIVER

Description

The York River estuary is 55 km long from the mouth to West Point and remarkably straight landward of Gloucester Point. Farther landward the York divides into two prominent tributaries, the Pamunkey and Mattaponi Rivers which rise in the Piedmont province. The Pamunkey is tidal for 73 km landward of West Point and it is bordered by extensive salt marshes and freshwater woodland swamps. The Indian name "Pamunkee" reflects the high ground along shores behind marshes. The entire drainage basin occupies 6,900 km^2, the third smallest in the Chesapeake Bay drainage system. The basin is largely rural and more than 70% forested while the remainder is cropland or pasture.

Configuration and Bathymetry

The York River estuary is a drowned river valley formed about 7,000 years ago. The principal bathymetric features consist of an axial channel flanked by broad shoals. These reflect the ancestral river channel and bordering flood plain. The estuary averages 6.6 m deep but channel depth reaches 24 m in the constricted zone at Gloucester Point. The shoreline is fringed by bluffs 5 to 30 m high and it is broken by small tributary creeks bordered by salt marsh. The bathymetry has been modified by sedimentation and local erosion of the channel floor, by shore erosion and by man through dredging. The main dredge cuts are at four pier facilities on the south bank of the lower estuary and shoals seaward from West Point for 1.6 km.

Sediment Sources

Sediments are supplied from three major sources, the river drainage basin, shores and marine areas. Rates of input are poorly known. Order-of-magnitude estimates however, indicate the river supplies approximately 0.22 x 10^6 m tons/year or 55% of the total fine sediment input (silt and clay). This assumes sediment yield per square kilometer from the drainage basin is similar to the Rappahannock basin. Shore erosion supplies about 0.05 x 10^6 m tons/year or 13% of the sediment assuming 22% of the material is silt and clay[15]. Erosion rates average 0.26 m/year being three times faster on the southwest bank, which is exposed to northeast storms, than on the northeast bank. Additionally, an estimated 0.13 x 10^6 m tons/year or 32% of the fine sediment is supplied from marine areas by landward transport. This assumes the rates of transport are similar to those of the James and Rappahannock mouth with landward transport proportional to values determined by Schubel and Carter (1979)[12].

Pathways and Cycling

Fine-grained sediment is cycled within the estuary by the estuarine circulation. For fluvial sediment the route is: (1) seaward through the freshwater reaches of the Mattaponi and Pamunkey Rivers; (2) seaward through the upper layer from about 20 km above West Point to the mouth, and downward by settling into the lower estuarine layer; (3) landward through the lower estuarine layer to the inner salt limit about 20 km above West Point. Because contaminants are sorbed to fine sediment, they cycle with the fine sediment. For example, pulp-mill effluent discharged at West Point, is sorbed to clay and silt, which may retain as much as 100 times their weight in effluents, is transported seaward through the upper York estuary during river floods[8]. But during normal river flows it is dispersed through the turbidity maximum zone 5 to 30 km landward of West Point[8].

Bottom Sediments

Silty clay and high percentages of mud are widely distributed in the channel of the middle and upper York River[9,11] (Figures 6A, 6B). The lower estuary channel contains patches of clayey silt and sand extends to the 20 m depth at Gloucester Point[4,5]. Across the middle and lower estuary, sand, which resides on marginal shoals, changes channelward to sand-silt-clay or silty sand and then to silty clay[2,5,11]. Mud percentages increase with depth with the greatest increase on the edge of the shoals at the 4 to 5 m depth. This transition reflects nearness to the sand source, the marginal banks, and the energy distribution of waves. The waves winnow fines from the shoals and allow deposition in deep water where energy is weak. Sand is more abundant on shoals around the mouth where the shoals are exposed to waves of Chesapeake Bay[5]. Oyster rock and shell are limited to the middle estuary[7]. Varied texture in the Pamunkey includes patches of clayey silt or clayey sand partly derived from the river interspersed with sand derived by local bank erosion.

Organic Matter

Percentages of organic matter are higher in muddy sediment of the lower Pamunkey (> 9.0%)[11], which is the source of organic detritus produced in marshes, than in sediments in the lower York (< 4.0%)[4]. Anthropogenic sources including historic coal-fired ships (prior to ~ 1920) and pulp-mill discharge at West Point.

Sedimentary structures in cores from the middle estuary channel near Clay Bank exhibit massive bioturbate layers alternating with regular layers. Individual layers show coarsening upward, a feature that suggests winnowing of coarse material from a mud matrix, or episodic input of sandy material eroded from banks.

Sinks

The main sink of mud accumulation occurs in the middle estuary 10 km landward of Clay Bank. Accumulation rates, estimated from depth changes between 1911 and 1938, reach 16.6 mm/year and average about 5.5 mm/year[3]. The main sink is close to the inner salt limit during river floods, a time when large fluvial sediment loads are delivered. Mass accumulation in the channel, estimated from bathymetric changes[3], amounts to about 0.56 to 0.69 x 10^6 m tons/year. Additionally, about 0.11 x 10^6 m tons/year accumulate in marshes assuming the marsh surface keeps pace with submergence, about 3.2 mm/year[6,10], and the marsh soil has a dry density of 0.30 tons/m^3.

Mass Balance

The total input of fine sediment amounts to about 0.4 x 10^6 m tons/year whereas the total accumulation in sinks amounts to about 0.67 to 0.80 x 10^6 m tons/year. Therefore, an amount equivalent to more than 100% of the total river input is stored. The storage efficiency ratio ranges 1.6 to 2.0 indicating that the York not only stores most of its fluvial input but large amounts of sediment from other sources, i.e. from shores and marine areas. Future fluvial inputs may be affected by Lake Anna constructed in 1978 for a nuclear power plant[13].

Contamination Status

The York River receives metal contaminants at ends of the system including municipal wastewater and a pulp and paper mill at West Point, a municipal outfall, power plant, Naval Weapons facility and oil refinery along the lower estuary. Fluvial inputs however, dominate the metal loads for Cu, Pb and Zn[14].

Mean metal concentrations based on scattered samples of bottom sediments exhibit higher values for Cu (36 $\mu g/g$), Pb (42 $\mu g/g$) and Zn (227 $\mu g/g$) near West Point[13] than in the lower York, i.e. Cu (11 $\mu g/g$), Pb (15 $\mu g/g$) and Zn (59 $\mu g/g$). In turn, mean contamination factors for these metals are moderately high near West Point, i.e. Cu (4.5), Pb (4.5) and Zn (2.5). These factors yield an estuary-wide contamination index of 12, a ranking of "enriched."[13]

The sediment pollution index is 96 on a scale of 100 for six systems in the Chesapeake system. It is influenced by a relatively high percentage organic matter and area of sedimentation.

In terms of pollution susceptibility among the nation's estuaries, the York River ranks high because of its low ability to flush prospective toxic loads[1]. Its anthropogenic activity, i.e. in terms of metal and chemical activity, however, is relatively low.

Bottom Sediment Charts

The bottom sediments of the York River have been sampled from time to time in five different investigations. Stations are largely positioned by dead reckoning and some by Loran C. The textural patterns are a "mosaic" of data obtained between 1971 and 1990. Most samples come from the channel whereas samples from the shoals of the middle estuary are scarce or nil.

The distribution of mud abundance, Figure 6A, is broadly classified into three groups: (1) less than 40%; (2) 40 to 80%; (3) greater than 80%. This classification displays major patterns suitable for recognizing dominant features and for interpretation of sediment processes. The chart was compiled by using a minimum mappable unit of 3 km^2 and smoothing isolines. Greater detail can be acquired by mapping the original data at larger scales and smaller class intervals.

Figure 6B shows the broad distribution of sediment types based on the Shepard classification (triangle). The chart was compiled by using a minimum mappable unit of 3 km^2 and smoothing boundaries. Because of the small page-size scale, narrow transition zones of texture, such as occur between shoals and the channel, are not always represented. Greater detail can be obtained by mapping the original data at a larger scale.

For sources of information and explanation of data in the sediment inventory summary, see text discussion.

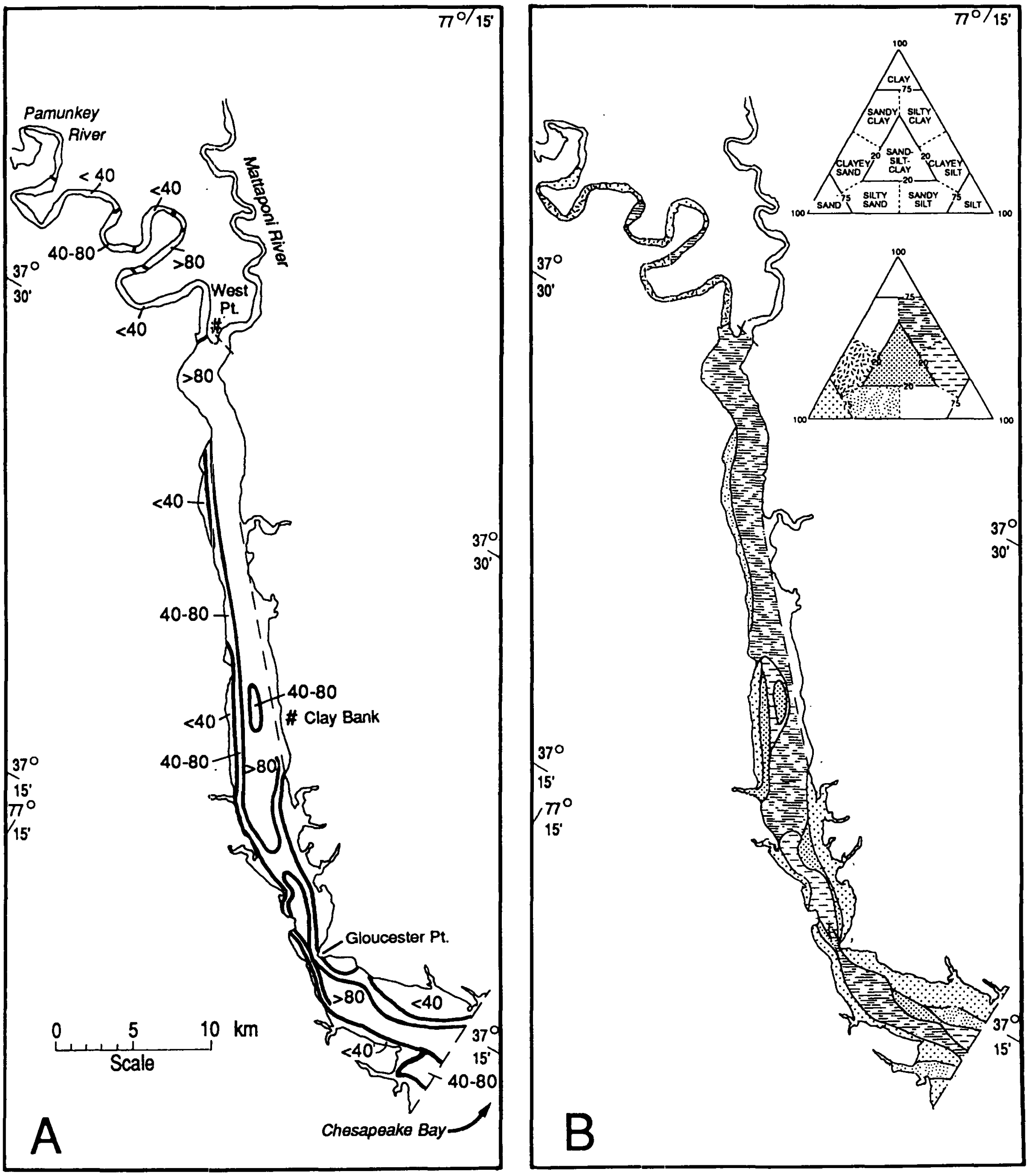


Figure 6. A. Distribution of percent mud, isolines.
B. Distribution of sediment texture following the Shepard classification.

SEDIMENT INVENTORY

M120d YORK RIVER

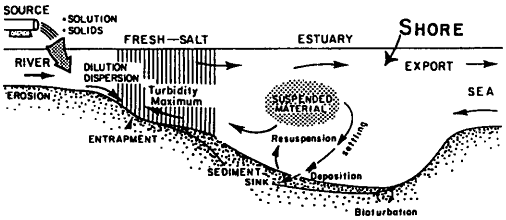
Drainage and Morphology

Total Drainage Area, Km^2	6900
Average River Inflow, m^3/s	71
Length, Km	55
Average Depth, m	6.6
Average Width, Km	3.8
Width/Depth Ratio	576
Surface Area, Km^2	192
Sinuosity	1.09

Sources

	Tons/yr x 10^6	Relative Strength, %
River	0.22	55
Shores	0.05	13
Marine	0.13	32
Total	0.40	

Pathways



Submergence Rates

Short-term, mm/yr	0 - 4.1
Long-term, mm/yr (0-4,000 yrs BP.)	1.2 - 1.6

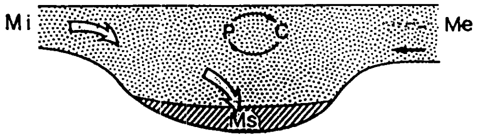
Data Quality, Bottom Sediment Texture

Fairly Certain

Sinks

	Tons/yr x 10^6	Relative Strength, %
Channel	0.56-0.69	83-86
Marsh, Swamp	0.11	14-17
Total	0.67-0.80	

Mass Balance



Mi (Source) = Ms + Me (Loss)

– 0,3

0.4 $\neq$ 0.7 to 0.8 x 10^{6}tons/yr

Storage Efficiency: $Si = \frac{Ms}{\Sigma Mi} = 1.6$ to 2.0

Bottom Sediments

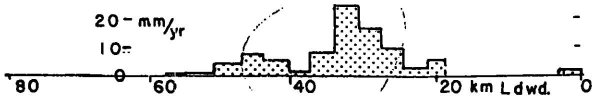
	Mean	Std. Dev.
Water Content, percent	—	—
Organic Matter, percent	4.5	2.3

Percent Mud Area, M_{ud}	61.4
Percent Sedimentation Area, A_c (>5 mm/yr)	28.2
Percent Sand Area	38.6

Dominant Pattern:

Lateral	• Channel mud bordered by sand shoals
Longitudinal	• Channel sand and mud upper estuary; mud with sand and silt patches in lower estuary

Sedimentation Rate



Contamination Status, Explanation

Contaminant loading data come from NOAA's National Coastal Pollutant Discharge Inventory[14]. They include total loadings, particulate and dissolved, natural and anthropogenic from both the fluvial drainage (~ 1987) and the estuarine drainage area (EDA) (~ 1982) that drains directly into the estuary. The loadings also include discharges from both point and non-point sources.

The percentage distribution of metal loadings by type of source in the pie diagrams includes both point and nonpoint sources within the estuarine drainage areas.

Sediment concentrations are total concentrations in the uppermost bottom sediments. The mean, minimum and maximum values of the sediment concentrations, as well as the contamination factors are for the total estuary. The distributions of these parameters in the upper, middle and lower estuary are geometric mean values in segments of the river, chartlet, lower right. Summary inventory and status sheets are available in the desk-top atlas.

CONTAMINATION STATUS

M120d YORK RIVER

Contaminant Loading, tons/yr

	Cu	Pb	Zn
River	16	22	236
Industry	6	7	12
Wastewater	<1	<1	<1
Crop Runoff	2	2	3
Urban Runoff	1	5	6
Total	26	37	258

Sediment Concentration, µg/g, total estuary

	Cu	Pb	Zn
Mean[1]	15	25	78
Minimum[1]	1	1	4
Maximum[1]	50	88	327

Contamination Factor, Cf

	Cu	Pb	Zn
Mean	3	3	2

Contamination Index, CI

Mean 12.3

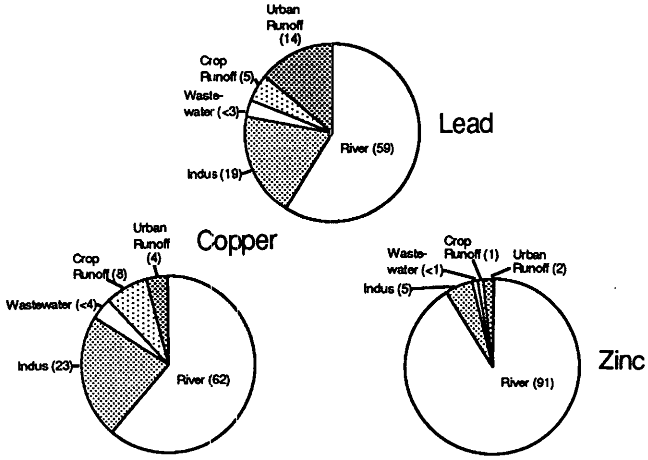
Sediment Pollution Index, SPI

SPI: 96

Pollution Susceptibility

High because of low flushing ability

Percentage of Metal Load



Distribution of Concentration, mean, µg/g

	Upper	Middle	Lower → Seaward
Cu	□ 36	□ 20	□ 11
Pb	□ 42	□ 40	□ 15
Zn	▨ 227	□ 172	□ 59

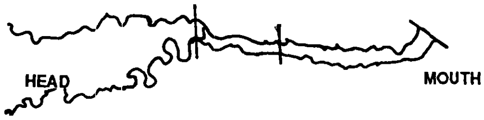
Distribution of Cf, mean

	Upper	Middle	Lower → Seaward
Cu	□ 5	□ 4	□ 0.001
Pb	□ 4	□ 5	□ 0.1
Zn	□ 3	□ 2	□ -0.8

Distribution of CI

Upper	Middle	Lower → Seaward
□ -4.3	■ 39	□ 2.3

■ Polluted ▨ Enriched □ Normal



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[1] Based on limited number of samples

York River References

1. Biggs et al., 1989
2. Boesch, 1971*
3. Brown et al., 1939
4. Byrne et al., 1982*
5. Carron, 1976*
6. Emery and Aubrey, 1991
7. Haven et al., 1981
8. Nelson, 1960
9. Nichols, unpublished, 1990*
10. Nichols, 1991
11. Schaffner, 1989*
12. Schubel and Carter, 1979
13. U.S. Environmental Protection Agency, 1983a
14. U.S. NOAA, National Coastal Pollutant Discharge Inventory, unpublished, 1982
15. Hardaway, 1992

* Primary data source reference

SEDIMENT CHARACTERIZATION

M120e JAMES RIVER

Description

The James River estuary is the southernmost tributary of Chesapeake Bay and the most turbid system in the region. Suspended sediment concentrations reach 300 mg/l. Its natural oyster rocks formerly were one of the best oyster seed-producing areas in the world. The estuary is a classic in a hydrodynamic context since the relationship between salt balance and density-driven estuarine circulation was tested in the James by Pritchard in 1952[16]. The estuary is 160 km long, has an average width of 5.1 km, a maximum depth of 28 m and a mean depth of 5.8 m. Its surface area and volume at mid-tide level are 611 km^2 and 2.5 km^3 respectively. The drainage basin embraces 26,400 km^2 and traverses four physiographic provinces from the Appalachian Mountains seaward to the Coastal Plain. About two million people live in the basin and there are significant inputs of toxics and nutrients.

Configuration and Bathymetry

The bathymetry is broadly shaped by the drowned Pleistocene topography inherited from erosion of coastal plain deposits of Pleistocene and Tertiary age[12]. Two morphological zones are recognized: (1) a narrow funnel zone extending from the mouth 116 km landward to Jordan Point; (2) a meander zone between Jordan Point and Richmond on the Fall Zone, 160 km landward of the mouth. The funnel consists of broad meanders with an axial channel bordered by wide shoals or shallow embayments. These features reflect the ancestral river channel and flood plain. The sinuosity ratio, i.e. ratio of channel length to valley length, is 1.23 in the funnel and 1.73 in the meander zone. The shoreline is indented by branching tributary creeks and fringed by bluffs 5 to 18 m high. The bathymetry has been modified by sedimentation on the channel floor, by growth of oyster reefs, by shore erosion and by man through dredging a 7.6 m-deep shipping channel and spoil disposal. Dredged channels cut through shoals of the middle and upper estuary including meander necks and laterally, 1.8 to 2.5 m deep, into selected tributary creeks. Maintenance dredging amounts to an estimated 0.4 x 10^6 m tons/year on the average.

Sediment Sources

Sediments are supplied from three major sources, the river, shores and marine areas. Benthic organisms contribute minor amounts of shell[7]. The river supplies about 77% of the total fine sediment input, i.e. 2.4 x 10^6 tons/year. The suspended load is delivered during short periods of river flood and freshet in the wet season, January to April. An estimated 90% of the annual load is delivered to the estuary in less than 11% of the time[10].

Shore erosion supplies about 0.3 x 10^6 m tons/year of fine sediment. Erosion rates average 0.4 m/year being three times faster on the southwest bank, which is exposed to northeast storms, than on the northeast bank. Additionally, an estimated 0.3 to 0.5 x 10^6 m tons/year of fine sediment are supplied from marine areas via landward flow through the lower estuarine layer. Sand is mainly supplied by bank erosion but small amounts come from Chesapeake Bay via longshore transport along entrance spits or via near-bottom currents through the mouth.

Pathways

Within the estuary fine-grained suspended sediment is cycled in the estuarine circulation. For river sediment the route is: (1) seaward through freshwater reaches of the upper estuary; (2) seaward through the upper estuarine layer, an efflux route, and downward by settling into the lower estuarine layer; (3) landward through the lower estuarine layer return flow or reflux route, to the inner salt limit where it is retained for long periods in the turbidity maximum zone[12]. A pronounced seasonal migration, or refluxing, likely occurs whereby fine sediment, which accumulates in the upper estuary during summer at low river inflow, is scoured by river currents during spring floods and redispersed seaward into the lower estuary[11]. Because contaminants are sorbed to sediment of fine size and large surface area, they cycle with fine sediment. Small amounts are added to the estuary from different sources to balance amounts removed from the estuary, or amounts that go into storage on the floor. For example, Kepone, a polychlorinated hydrocarbon released at Hopewell for nine years, was partly flushed through the estuary by strong seaward transport of river floods. An estimated 42 to 90% of the Kepone input however, was retained in the estuary by entrapment in the estuarine circulation and by seasonal refluxing of fine sediment[11].

Cycling

Suspended sediment supplied to the estuary undergoes repeated tidal cycles of settling, deposition and resuspension prior to storage in the deposits. As ebb or flood currents vary from nearly 0 at slack water to 60 cm/s near maximum current within 3.2 hours, suspended sediment concentrations in the turbidity maximum zone change from 75 to 300 mg/l[10]. By exchanging sediment between the bed and overlying water, contaminants can react with particles or be released to the water. In the resuspension process some sediments from different sources are mixed while others are fractionated depending on contrasts in their organic or inorganic composition.

Bottom Sediments

The sediment texture (Figures 7A, 7B) is dominated by an abundance of mud, mainly silty clay in the main channel, embayments, tributary creek mouths and in abandoned meander loops of the meander zone[3,12]. Mean grain size is minimal in the central funnel zone and increases along the channel both landward and seaward[9]. Sand is abundant near the mouth and near the head in the meander zone. These variations exhibit a threefold longitudinal or tripartite distribution, sand-mud-sand.

Across the central estuary funnel, sand covers marginal shoals but passes channelward into admixtures of sand-silt-clay with oyster shells. In deep water mud dominates the channel floor except in seaward reaches where mud is mixed with sand[2]. The lateral transition from sand, or sandy admixtures, to mud, with water depth is usually abrupt[12].

The textural distribution broadly reflects the energy distribution. Sediments from energetic ends of the system, where river floods and storm waves are intense, are coarser-grained and better sorted than sediments from the central, less energetic sector of weak tides.

Organic Matter

Percentages of organic matter are greater in the upper estuary (> 4%) than in the lower estuary (< 2%)[9,18]. They generally decrease away from the river which is likely the main source of natural and anthropogenic organic matter; e.g. marshes and nutrient-rich sewage discharges. Substantial percentages, 2 to 4%, occur around anthropogenic sources at the mouth of lower tributaries, e.g. Elizabeth and Nansemond Rivers. Organic matter is relatively low (< 2%) in sandy sediments near the mouth and along margins.

Other Characteristics

Radiographic examination of sedimentary structures from the meander zone, a zone subject to river flooding, reveals numerous physical bedforms including sandy cross laminations, scour, fill and discontinuities. In the estuary funnel the degree of bioturbation varies from 10 to 99% with laminated mud bedding in the river-influenced upper sector particularly, where sedimentation is fast (> 30 mm/yr)[17]. In the middle and lower estuary where sedimentation rates are moderate to low (< 30 mm/yr) biogenic mixing is active and sediments are massive or irregularly layered[4]. Bottom sediments are oxic in the upper one to four cm[6]. The clay minerals kaolinite, dioctahedral and vermiculite are common in the upper estuary whereas chlorite, montmorillonite and illite are relatively abundant in the lower estuary[9].

Sinks

The main depocenter of mud sedimentation occurs in the mid-estuary funnel at Burwell Bay (Figure 4A)[11,13,21]. Approximately 110 mm/year of sediment are deposited on the average. Fast sedimentation is encouraged by high suspended sediment concentrations in the turbidity maximum, weak tidal currents and by entrapment in the near-bottom current null zone. This depocenter is close to the core of the turbidity maximum and the inner limit of salty water, during high river inflow when major fluvial sediment loads are delivered. Elsewhere, relatively fast sedimentation is localized in less energetic zones, i.e. the main channel, the shipping channel and tributary creek mouths. The sinks are sites of major Kepone contamination as well as sites for radionuclide accumulation[8,14]. The depth of contamination is greater in the sinks than elsewhere by virtue of fast sedimentation[11].

The sediments fill a system undergoing submergence. Rates have slowed from approximately 12.5 mm/year in an early phase (6,000 to 8,000 years BP) to approximately 1.6 mm/year in the last 4,000 years[5]. Short-term rates, 40 to 80 years, are generally faster and increase seaward from approximately 1.0 mm/year near Hopewell to 4.3 mm/year near the mouth. Marsh accretion has kept pace with relative sea-level rise in the last 5,000 years but channel accretion seems to have lagged relative sea-level rise inasmuch as it is not filled to capacity today[12].

Mass Balance

The James receives an estimated 2.4 x 10^6 tons of fine sediment annually from the river, about 0.3 x 10^6 tons from shore erosion and 0.3 to 0.5 x 10^6 tons from marine areas. Accumulation in sinks, including marshes, amounts to 2.0 to 3.1 x 10^6 tons annually. Therefore, an estimated 64 to 100% of the total fluvial input is retained[11,13]. The storage efficiency ratio ranges from 0.8 to 1.0. The lesser value indicates about 60% of the input is stored in the estuary whereas

40% can escape through the mouth, a likely pathway during river floods. The greater value indicates the estuary stores an amount of fine sediment equivalent to the total river input plus sediment from other sources.

Contamination Status

The James receives contaminants from industrial and municipal discharges located at ends of the system, i.e. in the upper estuary below the Fall Zone (Richmond and Hopewell), and in the lower estuary (Hampton Roads, Elizabeth and Nansemond Rivers)[20]. River inputs dominate the metal loads of Cu, Pb and Zn.

The sediment pollution index is 78 on a scale of 100 for six Chesapeake systems. It is affected by relatively large percentage area of mud compared to other systems in the Chesapeake region.

Mean metal concentrations in the sediments exhibit relatively high values for Cd (3 μg/g) and substantial concentrations of Cu (6 μg/g), Pb (34 μg/g) and Zn (188 μg/g)[19]. Concentrations are highest in the seaward sector, including Hampton Roads and the Elizabeth River, least in the middle sector and intermediate in the landward river-influenced sector. Mean contamination factors for the entire estuary are very high for Cd (49) and moderately high for Cu, Pb and Zn (4 to 5)[18]. The high contamination factors are mainly influenced by high anthropogenic concentrations in Hampton Roads. These factors yield an estuary-wide contamination index of 69, a ranking of "polluted." Pollution susceptibility ranks high because flushing of toxic loads is relatively sluggish[1].

Bottom Sediment Charts

The bottom sediments of the James River have been sampled from time to time in four different investigations[3,9,12,18]. Stations are largely positioned by dead reckoning and some by Loran C in the lower estuary. The textural patterns are a "mosaic" of data obtained between 1968 and 1990.

The distribution of mud abundance, Figure 7A, is broadly classified into three groups: (1) less than 40%; (2) 40 to 80%; (3) greater than 80%. This classification displays major patterns suitable for recognizing dominant features and for interpretation of sediment processes. The chart was compiled by using a minimum mappable unit of 2.5 km^2 and smoothing isolines. Greater detail can be acquired by mapping the original data at larger scales and smaller class intervals.

The distribution of sedimentation zones is based on historical bathymetric changes supplemented by rates obtained from radiometric aging of a limited number of cores[13,17].

Figure 7B shows the broad distribution of sediment types based on the Shepard classification (triangle). The chart was compiled by using a minimum mappable unit of 1.5 km^2 and smoothing boundaries. Because of the small page-size scale, narrow transition zones of texture, such as occur between shoals and the channel, are not always represented. Greater detail can be obtained by mapping the original data at a larger scale.

For sources of information and explanation of data in the sediment inventory summary, see text discussion.

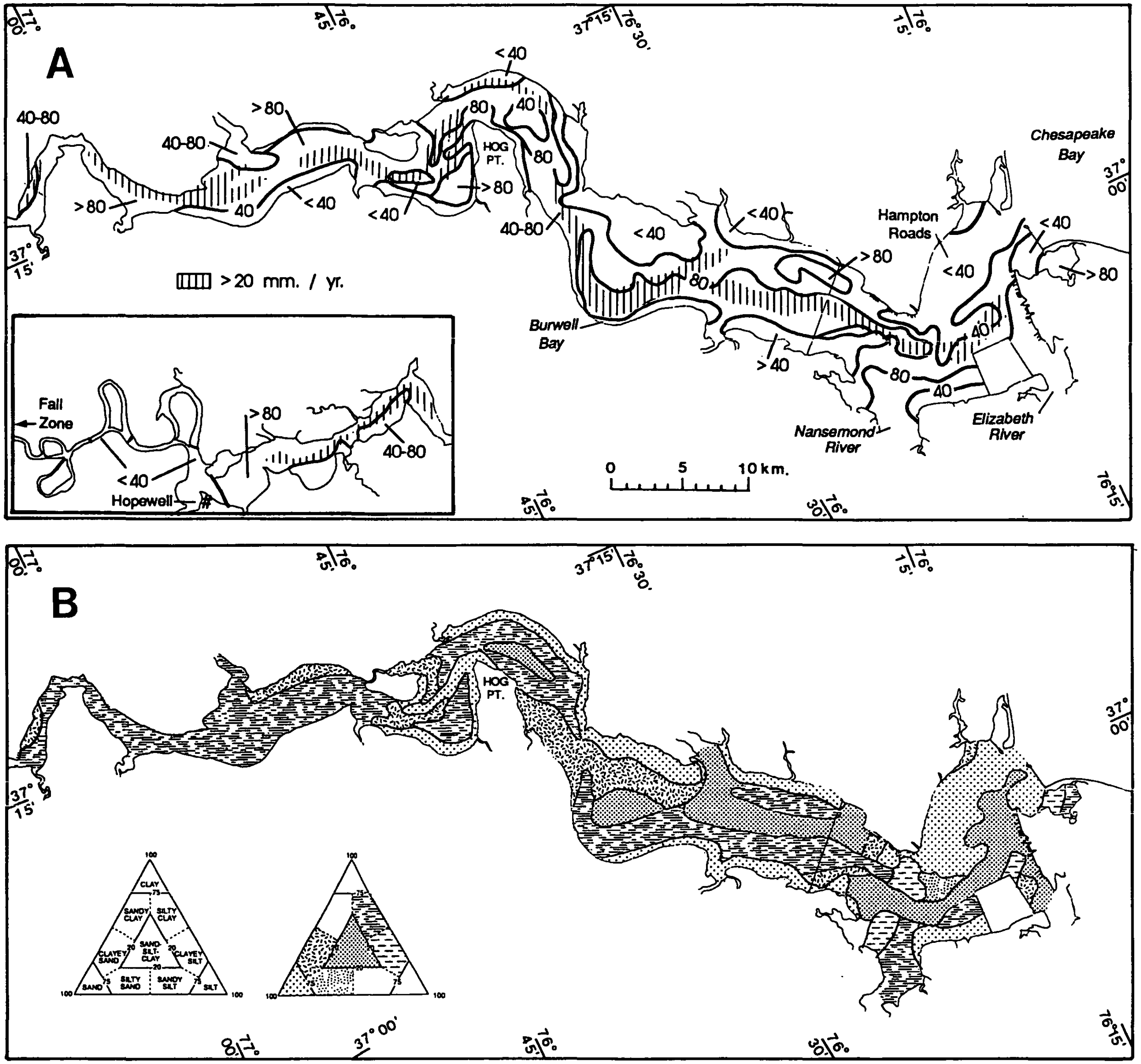


Figure 7. A. Distribution of percent mud, isolines; and zones of sedimentation where rates exceed > 20 mm/yr in mud zones (> 40%).

B. Distribution of sediment texture following the Shepard classification.

SEDIMENT INVENTORY

M120e JAMES RIVER

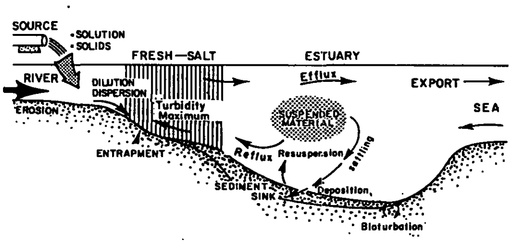
Drainage and Morphology

Total Drainage Area, Km^2	26,400
Average River Inflow, m^3/s	213
Length, Km	161
Average Depth, m	5.8
Average Width, Km	5.1
Width/Depth Ratio	879
Surface Area, Km^2	611
Sinuosity	1.23 to 1.73

Sources

	Tons/yr x 10^6	Relative Strength, %
River	2.4	77
Shores	0.3	9
Marine	0.4	13
Production	< 0.02	< 1
Total	3.1	

Pathways



Relative strength	➞	→
	Strong	Weak

Submergence Rates

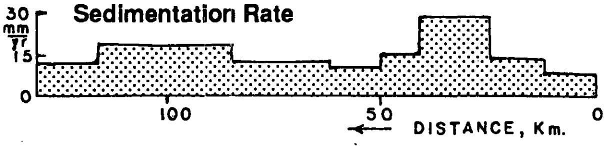
Short-term, mm/yr	0 to 4.3
Long-term, mm/yr (0-4,000 yrs BP.)	1.6

Data Quality, Bottom Sediment Texture

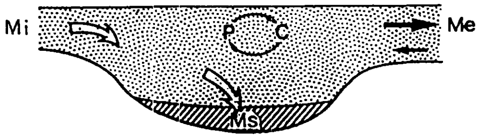
Moderately Certain

Sinks

	Tons/yr x 10^6	Relative Strength, %
Natural Channels	1.5-2.6	75-84
Shipping Channels	0.4	20-13
Marsh, Swamp	0.1	5-3
Total	2.0-3.1	



Mass Balance



Mi + P	=	Ms + C + Me
(Source)		(Loss)
3.1	=	2.0 + 1.1 x 10^6tons/yr

Storage Efficiency: $Si = \frac{Ms}{\Sigma Mi}$ =0.6 to 1.0

Bottom Sediments

	Mean	Std. Dev.
Water Content, percent	47.6	18.8
Organic Matter, percent	2.3	1.8

Percent Mud Area, M_{ud}	87.5
Percent Sedimentation Area, A_c (>2 cm/yr)	16.9
Percent Sand Area	12.5

Dominant Pattern:

Lateral	• Channel mud bordered by sand shoals with scattered mud patches and oyster reefs
Longitudinal	• Tripartite pattern Channel, sand-mud-sand

Contamination Status, Explanation

Contaminant loading data come from NOAA's National Coastal Pollutant Discharge Inventory[14]. They include total loadings, particulate and dissolved, natural and anthropogenic from both the fluvial drainage (~ 1987) and the estuarine drainage area (EDA) (~ 1982) that drains directly into the estuary. The loadings also include discharges from both point and non-point sources.

The percentage distribution of metal loadings by type of source in the pie diagrams includes both point and nonpoint sources within the estuarine drainage areas.

Sediment concentrations are total concentrations in the uppermost bottom sediments. The mean, minimum and maximum values of the sediment concentrations, as well as the contamination factors are for the total estuary. The distributions of these parameters in the upper, middle and lower estuary are geometric mean values in segments of the river, chartlet, lower right. Summary inventory and status sheets are available in the desk-top atlas.

CONTAMINATION STATUS

M120e JAMES RIVER

Contaminant Loading, tons/yr

	Cu	Pb	Zn
River	135	214	802
Industry	14	11	31
Wastewater	13	12	46
Atmosphere	2	3	162
Crop Runoff	9	1	8
Urban Runoff	24	100	107
Total	197	341	1156

Sediment Concentration, µg/g, total estuary

	Cu	Pb	Zn
Mean	6	34	188
Minimum	0.4	0.2	0.4
Maximum	336	563	7750

Contamination Factor, Cf

	Cu	Pb	Zn
Mean	4	4	5
Minimum	-3	-2	-3
Maximum	79	111	490

Contamination Index, C_I

Mean	69

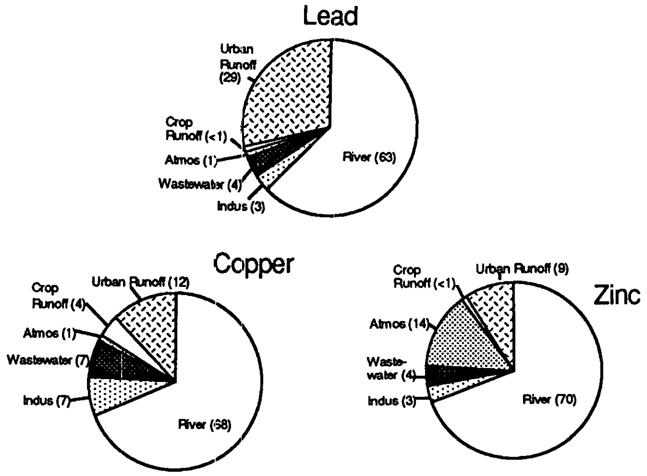
Sediment Pollution Index, SPI

SPI:	78

Pollution Susceptibility

High because of low flushing ability and high anthropogenic metal activity

Percentage of Metal Load



Distribution of Concentration, mean, µg/g

	Upper	Middle	Lower → Seaward
Cu	☐ 20	☐ 27	▨ 26
Pb	☐ 23	☐ 34	▨ 36
Zn	▨ 118	☐ 149	▨ 217

Distribution of C_f, mean

	Upper	Middle	Lower → Seaward
Cu	☐ 2	☐ 2	▨ 5
Pb	☐ 1	☐ 1	▨ 6
Zn	☐ 1	☐ 1	▨ 9

Distribution of C_I

Upper	Middle	Lower → Seaward
▨ 12	☐ -4	■ 76

■ Polluted ▨ Enriched ☐ Normal

James River References

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4. Diaz, 1989
5. Emery and Aubrey, 1991
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7. Haven et al., 1981
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13. Nichols et al., 1991
14. Officer and Nichols, 1980
15. Olsen et al., 1986
16. Pritchard, 1952
17. Schaffner et al., 1987
18. Trotman and Nichols, 1978*
19. U.S. Environmental Protection Agency, 1983a
20. U.S. NOAA, National Coastal Pollutant Discharge Inventory, unpublished, 1982
21. Wong and May, 1984

* Primary data source reference

M120f CHESTER RIVER

Description

The Chester River estuary, Maryland, leads into northern Chesapeake Bay from the northern Delmarva Peninsula. It lies within the coastal plain and drains a relatively small (1,140 km^2), flat to gently rolling rural terrain. Basin soils are fertile and have long been farmed; about 70% of the basin is cropland whereas the remainder is mainly forested[2]. Urban and industrial land use is relatively small but increased significantly between 1975 and 1990. Although the main river extends 82 km, the inner limit of tide extends only 68 km landward of the mouth, i.e. to Millington, Maryland[2].

Configuration and Bathymetry

The bathymetry is shaped into a narrow axial channel flanked by broad submerged terraces which support the principal shell fisheries. In lower reaches, seaward of Spaniard Point, the channel averages 6 m deep but it is interrupted by a series of basins 15 to 18 m deep[4]. The deepest basin, 18 m deep, lies 20 km landward of the mouth, i.e. east of Eastern Neck Island[2]. In the upper estuary the natural channel is navigable to Chestertown at the 4 m depth.

The submerged terraces at about 2 m and at 5 to 6 m are mainly depositional features that fill and smooth an older irregular erosion surface buried beneath recent deposits[4]. The shoreline is submergent reflecting the old, drowned fluvial drainage. In lower reaches the shore is indented by tributary creeks and modified by erosion of headlands and formation of spits. Freshwater wetlands fringe the extreme upper estuary while salt marshes border some creeks as well as Eastern Neck Island and low headlands of the lower estuary. Dredging is limited to shallow cuts in the mouth, the head of a few tributary creeks and across shoals to Kent Island Narrows.

Sediment Sources

Although the rates of fluvial input of fine sediment have not been measured in the Chester River, they are probably low, like the Choptank River; possibly on the order of 0.03×10^6 tons/year. This is because of the low terrain and rural character of the drainage basin.

Shores exhibit extensive erosion[2]. Reportedly, more than 90% of the shoreline is receding at 0.3 to 3.0 m per year. This is mainly caused by waves with a large fetch in the lower estuary. Additionally, percolation and seepage of ground water promote bank failure[2]. Although the volume and mass of material eroded has not been measured, shore erosion is likely a primary source of fine sediment to the estuary.

Exchange with Chesapeake Bay is active but rates are unknown. Landward flow through the lower layer at the mouth is indicated by current measurements[2]. Landward transport of fine sediment is also evidenced by clay mineralogy. Chlorite is common to the Bay but rare in the Chester drainage basin. The Chester is influenced by flooding of the Susquehanna River in the northern Bay. It receives high concentrations of suspended material, and adsorped contaminates, during floods by both advection and diffusion[5].

Pathways

Within the estuary suspended sediment is distributed according to its particle size and the local energy regime. The shore zones contain both coarse and fine sediment. Whereas the silt and clay components are washed out, resuspended by wave action and carried channelward across the broad terraces, the coarse sediments reside close to their source along shores or on terraces. For fluvial sediment the main route is seaward through freshwater reaches of the upper estuary. During high inflow, some deposition occurs in the channel just seaward of Spaniard Point. For fine sediment from Chesapeake Bay, the main route is landward through the mouth in the lower estuarine layer. The presence of contaminants, PCBs, DDT and chlordane in fine sediment of the Chester indicates landward transport from the Susquehanna River and northern Bay, the chief source[2]. Prior to accumulation the sediment undergoes repeated tidal cycles of settling, deposition and resuspension. Small amounts of sediment are added to the estuary from the river; shores and Chesapeake Bay, to balance amounts that accumulate on the floor.

Bottom Sediments

The bottom sediments are distributed according to particle size and the energy regime. Marginal shoals are covered by coarse to fine sand and low percentages of mud. The silt and clay are winnowed by wave resuspension and redistributed channelward by tidal or wind-driven currents[4]. The remaining sand therefore, reflects an energetic regime. In contrast, mud, mainly silty clay, covers the channel floor from the mouth to the head. The channel is a depositional sink for fines supplied from the shoals as well as from the river or Chesapeake Bay. Seismic profiling reveals the mud is quite thick based and overlies an older erosional surface[4]. Across the lower estuary, mud on the channel floor passes landward into mixtures of sand-silt-clay on slopes. This textural transition, which occurs between 1.8 and 5.0 m depth, reflects the distribution of wave energy and tidal mixing of different source sediments, i.e. shores, river and Chesapeake Bay.

Sinks

Fine sediment accumulates in two zones: (1) the middle estuary, just seaward of Spaniard Point which receives locally derived, and probably some fluvial material, forming a clastic wedge; (2) the estuary mouth which receives sediment from the Chesapeake Bay and adjacent estuary shoals forming a clastic wedge. The deep channel basins exist because sedimentation rates are relatively low compared to accumulation in the clastic wedges[4]. They are unfilled remnants inherited from the old river channel. The absolute rates of accumulation are unknown.

The sediments fill a submergent system. Rates of submergence are approximately 1.3 mm/yr in the last 4,000 years[3] and about 3.5 mm/yr in the last 40 to 80 years[1]. Whereas the marshes have kept pace with relative sea level rise in the last 4,000 years, infilling of the channel floor in the lower estuary has lagged the rise because of slow sedimentation rates.

Lacking data for sediment influx and accumulation rates precludes estimates of mass balance or storage efficiency. However, as a first approximation the relative strength of the terms, with a dominance of shore input and accumulation in the channel, is likely similar to the Choptank described in the following section.

Contamination Status

The Chester River has a small urban, industrial and agriculture input of metals. Although fluvial and upstream sources are unknown, the estuary receives on the average each year an estimated 1.7 tons of Cu, 3.1 tons of Pb and 5.9 tons of Zn[7]. Additionally, sewage treatment plants, though regulated, and numerous marinas near Kent Island, contribute substantial amounts of phosphorous and nitrogen[6]. Mean metal concentrations in the whole estuary are about 9 to 15 μg/g for Cu; 19 to 31 μg/g for Pb and 70 to 138 μg/g for Zn[2,5]. Concentrations are relatively high in major sedimentation zones near the mouth and in the middle estuary just seaward of Spaniard Point. They are relatively low in lower estuary basins where sedimentation is relatively low. Mean contamination factors for the entire estuary are low or negative, e.g. -0.03 for Cu, 0.6 for Pb and -0.03 for Zn[5].

Bottom Sediment Charts

Bottom sediments of the Chester River have been sampled at 102 stations with a sampling density of 4 km/10km^2 in a special study by Palmer (1974)[4]. Stations were positioned by sextant sights. The distribution of mud abundance, shown as bold isolines, Figure 8A, is broadly classified into three groups: (1) less than 40%; (2) 40 to 80%; (3) greater than 80%. This classification displays major patterns suitable for recognizing dominant features and for interpretation of sediment processes. The chart was compiled by using a minimum mappable unit of 0.5 km^2 and smoothing isolines. Therefore, isolated patches less than 0.5 km^2 are not shown. Greater detail can be acquired by mapping the original data at larger scales and smaller class intervals.

Figure 8B shows the broad distribution of sediment types based on the Shepard classification (triangle). The chart was compiled by using a minimum mappable unit of 0.5 km^2 and smoothing boundaries. For greater detail the original data should be mapped at a larger scale.

For sources of information and explanation of data in the sediment inventory summary, see text.

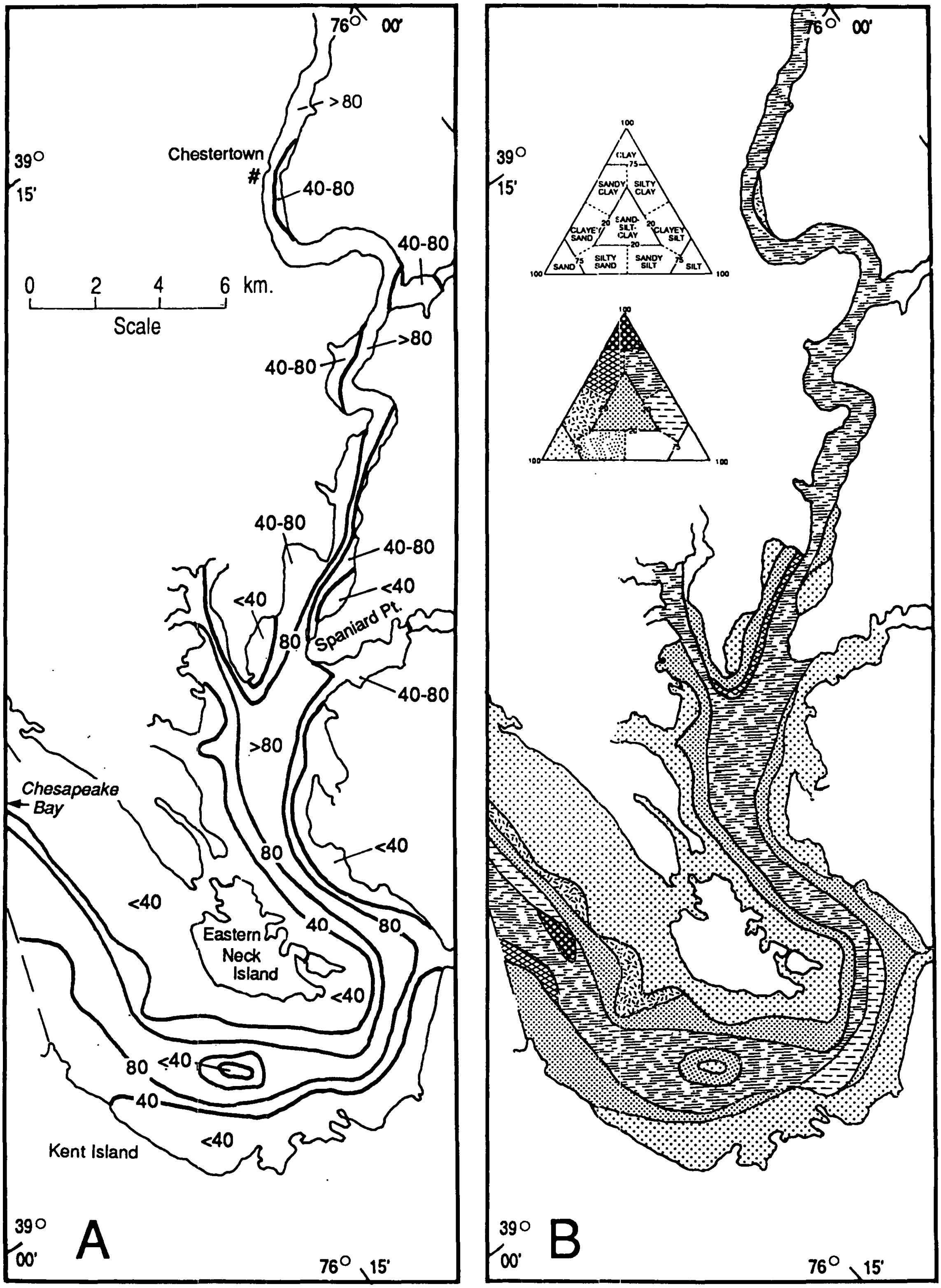


Figure 8. A. Distribution of percent mud, isolines.
B. Distribution of sediment texture following the Shepard classification.

SEDIMENT INVENTORY

M120f CHESTER RIVER

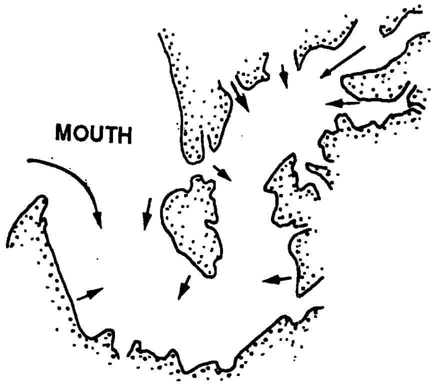
Drainage and Morphology

Total Drainage Area, Km^2	1,140
Average River Inflow, m^3/s	1.9
Length, Km	82
Average Depth, m	4.3
Average Width, Km	2.6
Width/Depth Ratio	604
Surface Area, Km^2	148
Sinuosity	1.45

Sources

	Relative Strength
River	Low
Shores	High
Marine	Low
Production	

Pathways



Submergence Rates

Short-term, mm/yr	1.3
Long-term, mm/yr (0-4,000 yrs BP.)	3.5

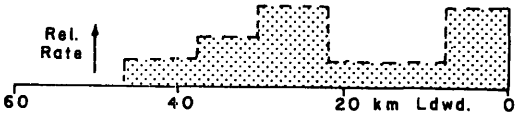
Data Quality, Bottom Sediment Texture

Moderately Certain

Sinks

	Relative Strength
Channel, middle estuary	High
Channel, mouth	High
Marsh, swamp	Low

Sedimentation Rate, schematic



Bottom Sediments

	Mean	Std. Dev.
Water Content, percent	—	—
Organic Matter, percent	—	—

Percent Mud Area, M$_{ud}$	58
Percent Sedimentation Area, A$_c$ (>5 mm/yr)	—
Percent Sand Area	42

Dominant Pattern:

Lateral	• Channel mud bordered by sand shoals
Longitudinal	• Channel mud in lower, middle and upper estuary

Chester River References

1. Emery and Aubrey, 1991
2. Clarke et al., 1972*
3. Kraft and Belknap, 1986
4. Palmer, 1974
5. Stumpf, 1988
6. U.S. EPA, Chesapeake Bay Program, 1983a
7. U.S. NOAA, Strategic Assessment Branch, 1990

* Primary data source reference

M120g CHOPTANK RIVER

Description

The Choptank River estuary, Maryland, leads into Chesapeake Bay from the central Delmarva Peninsula. It lies entirely within the coastal plain and drains a relatively small (2330 km^2) flat and rural terrain. Sixty-two percent of the area is agricultural land, 33% forest and 5% residential, urban or wetlands. The river and estuary extend 109 km making it the longest river in Delmarva. But the inner limit of the tide extends to Greensboro, Maryland, 70 km landward of the mouth. Compared to the western shore tributaries of Chesapeake Bay, however, the Choptank is relatively short and wide at the mouth. Although the estuary averages 4 m deep overall[7], its maximum depth is 26.2 m in the axial channel near Chlora Point (Figure 8).

Configuration and Bathymetry

The bathymetry is broadly shaped into an axial channel 3 to 17 m deep, flanked by wide submerged terraces at the 1.5 to 2.1 m depth and also at the 3.7 to 4.0 m depth[2]. The terraces are both erosional and depositional and their depths vary with exposure to storm waves[2]. The shoreline is submergent reflecting the old drowned fluvial drainage. In the lower estuary it is indented by branching tributary creeks and modified by erosion of headlands and formation of spits. Extensive freshwater wetlands and salt marshes border the upper estuary and act as potential sinks for fluvial sediment[11]. Dredging is limited to a few cuts in tributary creeks, through axial channel bars near the head and across Tilghman Island at Knapps Narrows[10].

Sediment Sources

Because of the lower erosion potential of flat terrain and the rural character of the drainage basin, fluvial input of fine sediment is relatively low, less than 0.05 x 10^6 m tons/year[11]. Before settlement and farming in the basin, fluvial inputs were only 0.008 x 10^6 m tons/year. Therefore, 80% of the present day inputs may be attributed to human use[11].

Shore erosion is the primary source of fine sediment to the estuary. Erosion for the period 1939 and 1980 amounts to about 19 x 10^4 m^3/year or 0.37 m tons/year with slightly higher rates in the lower estuary (seaward of Chlora Point) than in the upper estuary (landward of Cambridge)[11]. Shore erosion therefore, contributes seven times more sediment than fluvial input. High erosion rates are attributed to the large wave fetch across the lower estuary and the poor consolidation of strata along the shores[11].

At the mouth fine sediment exchange with Chesapeake Bay is relatively low. Seaward transport is approximately 0.08 x 10^6 m tons/year[11]. This is twice the landward transport (0.04 x 10^6 m tons/year) with a resultant net seaward transport of approximately 0.04 x 10^6 m tons/year or about 3 to 10% of the total sediment input[11]. Export through the mouth contrasts with input through the mouth of the western shore tributaries which mainly serve as net sinks for Chesapeake Bay sediments. Export is encouraged by the relatively high suspended sediment concentrations maintained in the lower estuary by shore erosion and by tidal resuspension[11].

Pathways

Within the estuary suspended sediment is cycled in the estuarine circulation. The estuary is partially to well-mixed and the inner limit of salt intrusion resides between Dover Bridge and Denton, Maryland (Figure 8)[11]. For river sediment the route is seaward through the freshwater reaches of the upper estuary and deposition in brackish parts of the upper estuary. For shore eroded sediment the route is channelward from shores and marginal flats toward the channel[2]. Prior to accumulation the sediment undergoes repeated tidal cycles of settling, deposition and resuspension.

On an average daily basis, tide and wind action resuspend an estimated 0.08 metric tons of fine sediment[11]. By exchange of sediment between the bed and overlying water, contaminants can react with particles or be released to the water. Small amounts of sediment are added to the estuary from the river or shores to balance amounts exported or that go into storage on the floor.

Bottom Sediments

The textural pattern is dominated by mud, mainly clayey silt, in the lower estuary channel below a depth of 5.5 m; sand prevails at shoaler depths[4] (Figure 9). Mud floors the upper estuary channel[9]. Between Cabin Creek and Chlora Point mud covers the channel below 1.8 m depth while sand covers shoals at lesser depths[9]. The textural distribution broadly reflects the sediment sources and the energy distribution. Sand is derived from the shores by wave reworking of Pleistocene deposits. Where shoals are exposed to wave action sand is winnowed of silt and some clays. In the lower estuary mud is deposited in deep, less energetic zones of the channel where wave action and currents are weak. In the upper estuary, in contrast, mud is derived from the river and largely retained in upper reaches[11].

Organic matter averages 1.8% and ranges from less than 0.1% to 3.2%[4]. Percentages are higher in muddy sediments (> 2.5%), especially in depositional zones, than in sandy sediments (< 0.9%)[3].

Sinks

Sediment accumulation rates diminish seaward in the channel from 7.9 mm/year near Cabin Creek to 1.5 mm/year near the mouth[11]. The mass of sediment accumulated however, is greater in the lower estuary than the upper estuary because of the greater bottom area of accumulation. Sedimentation of silt and clay mainly occurs in the middle and upper estuary channel or in bordering marshes. In the lower estuary however, sedimentation patterns are irregular[2]. Most sediments accumulate on slopes off eroding headlands at depths of 5 to 10 m[2].

The sediments fill a submergent system. Rates of submergence are approximately 1.3[5] to 1.6 mm/year in the last 4,000 years, and about 4.2 mm/year in the last 40 to 80 years[1]. Whereas the marshes have largely kept pace with relative sea level rise in the last 5,000 years, infilling of the channel floor in the middle estuary has lagged the rise, inasmuch as the channel is not filled to capacity today.

Mass Balance

The Choptank receives an estimated 0.46 m tons of fine sediment annually from all sources including the river, shores and marine areas[11]. Accumulation in natural channels and slopes amounts to 0.37 to 0.45 x 10^6 m tons/year while export through the mouth is about 0.09 m tons/year[11]. Therefore, the sources nearly balance the losses. The storage efficiency ratio is relatively high, 7.4 to 9.0, because the estuary not only stores an amount equivalent to the total river input but also a large amount from other sources, mainly from shores.

Contamination Status

Although the Choptank River lacks intense urbanization it receives substantial inputs of nutrients and small amounts of toxic metals. The chief problem, nitrogen enrichment, is caused by nonpoint source runoff from cropland. Metal wastes are introduced from sewage treatment plants and urban runoff at Cambridge and Greensboro as well as from cropland and small industrial discharges. On the average each year the loading is 0.4 tons Cd, 2.6 tons Cu, 3.5 tons Pb and 8.4 tons Zn[8]. Mean metal concentrations in the lower estuary are within a normal range, e.g. Cu, 26 μg/g; Pb, 3 μg/g and Zn, 121 μg/g[6]. Data are lacking for the middle and upper estuary. Mean contamination factors for the lower estuary are low or negative, e.g. 1 for Cu, -0.9 for Pb and 0.1 for Zn[6]. These factors yield a contamination index of 2.8 for the lower estuary, a ranking of "normal." The sediment pollution index is 92 on a scale of 100 for six Chesapeake systems. It is affected by a relatively high sediment storage efficiency compared to other systems.

Bottom Sediment Charts

The bottom sediments of the lower Choptank River seaward of Chlora Point have been sampled by the Maryland Geological Survey[4] on a 1.0 km grid. The upper estuary sediments are known from bottom notations of the U.S. Coast and Geodetic Survey[9]. Stations by the Maryland Geological Survey were positioned by Raydist and Loran C systems.

The distribution of sediments is broadly classified into two groups: (1) mud, taken as greater than 40% in the lower estuary, and (2) sand, taken as greater than 60% in the lower estuary. In the upper estuary the bottom notations, "mud" or "silt" and "clay" and "sand" are used. This classification displays major patterns suitable for recognizing dominant features. Greater detail can be acquired in the lower estuary by mapping the original data at larger scales and smaller class intervals, and by utilizing the Shepard classification.

For sources of information and explanation of data in the sediment inventory summary, see text discussion.

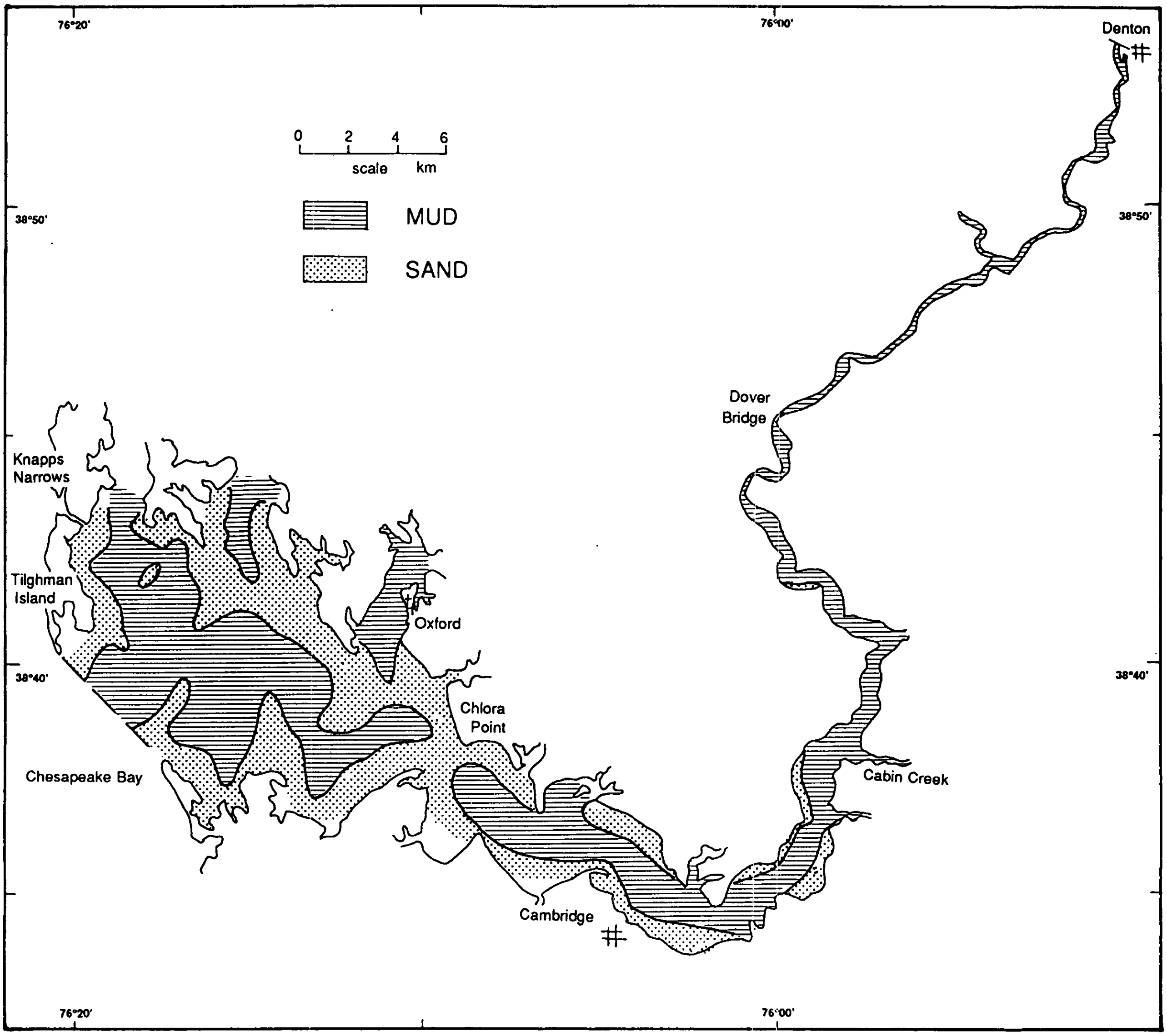


Figure 9. Distribution of mud and sand in the Choptank River estuary.

SEDIMENT INVENTORY

M120g CHOPTANK RIVER

Drainage and Morphology

Total Drainage Area, Km^2	2330
Average River Inflow, m^3/s	3.7
Length, Km	109
Average Depth, m	4.0
Average Width, Km	2.3
Width/Depth Ratio	575
Surface Area, Km^2	285
Sinuosity	2.9

Sources

	Tons/yr x 10^6	Relative Strength, %
River	0.05	11
Shores	0.37	79
Marine	0.04	3-10
Total	0.46	

Pathways

Submergence Rates

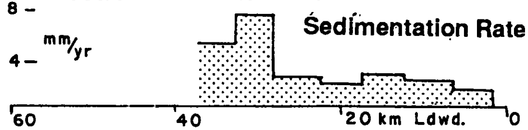
Short-term, mm/yr	4.2
Long-term, mm/yr (0-4,000 yrs BP.)	1.3 to 1.6

Data Quality, Bottom Sediment Texture

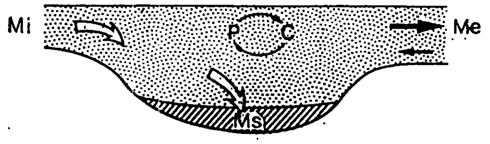
Moderately Certain

Sinks

	Tons/yr x 10^6	Relative Strength, %
Natural Channels and Slopes	0.37-0.45	100
Export to Chesapeake Bay	0.09	
Total	0.46 - 0.54	



Mass Balance



Mi (Source)	=	Ms + Me (Loss)
0.46	=	0.37 to 0.09 x 10^{6}tons/yr
0.54	=	0.45 to 0.09 x 10^{6}tons/yr

Storage Efficiency: $Si = \frac{Ms}{\Sigma Mi} = 7.4$ to 9.0

Bottom Sediments

	Mean	Std. Dev.
Water Content, percent	54	—
Organic Matter, percent[1]	1.8	0.7

Percent Mud Area, M$_{ud}$	56
Percent Sedimentation Area, A$_c$[1]	16
Percent Sand Area	44

Dominant Pattern:

Lateral	• Channel mud bordered by sand shoals in lower and middle estuary
Longitudinal	• Channel mud in upper, middle and lower estuary

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[1] Lower and middle estuary only

Contamination Status, Explanation

Contaminant loading data come from NOAA's National Coastal Pollutant Discharge Inventory[8]. They include total loadings, particulate and dissolved, natural and anthropogenic from both the fluvial drainage (~ 1987) and the estuarine drainage area (EDA) (~ 1982) that drains directly into the estuary. The loadings also include discharges from both point and non-point sources.

The percentage distribution of metal loadings by type of source in the pie diagrams includes both point and nonpoint sources within the estuarine drainage areas.

Sediment concentrations are total concentrations in the uppermost bottom sediments. The mean, minimum and maximum values of the sediment concentrations, as well as the contamination factors are for the total estuary. Summary inventory and status sheets are available in the desk-top atlas.

CONTAMINATION STATUS

M120g CHOPTANK RIVER

Contaminant Loading, tons/yr

	Cu	Pb	Zn
River	1.1	0.5	2.9
Industry	<.1	<.1	0.1
Wastewater	0.6	0.5	2.5
Crop Runoff	0.4	0.6	1.1
Urban Runoff	0.4	1.7	1.8
Total	2.6	3.5	8.4

Sediment Concentration, $\mu g/g$*

	Cu	Pb	Zn
Mean	26	3	121

Contamination Factor, Cf *

	Cu	Pb	Zn
Mean	1	-0.9	0.1

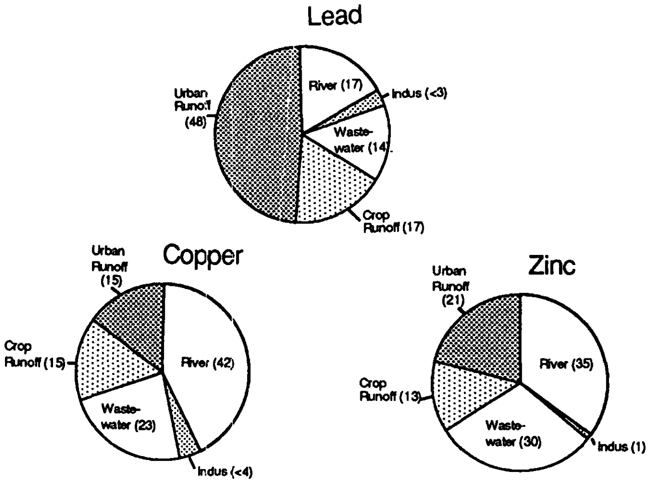
Contamination Index, CI *

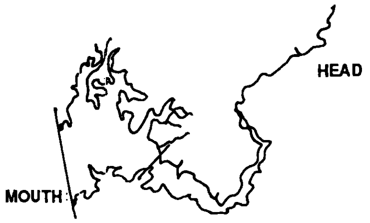
Mean 2.8

Sediment Pollution Index, SPI

SPI: 92

Percentage of Metal Load





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*Lower estuary only

Choptank River References

1. Emery and Aubrey, 1991
2. Jordan, 1961
3. Kofoed and Gorsline, 1966
4. Kerhin et al., 1988*
5. Kraft and Belknap, 1986
6. U.S. EPA, Chesapeake Bay Program, 1983a
7. U.S. NOAA, Strategic Assessment Branch, 1990
8. U.S. NOAA, National Coastal Pollution Discharge Inventory, unpublished, 1982
9. U.S. National Ocean Survey, Charts #12266, #12268*

10 Yarbro et al., 1981

11. Yarbro et al., 1983

* Primary data source reference

COMPARISON OF ESTUARIES

Comparison of the six estuaries selected for study highlights differences and similarities in their sediment character and related contaminant status (Table 3). Of note, fluvial input of fine sediment is the strongest term in the Chesapeake Bay mainstem, Potomac River and the James River. In contrast, input from marine areas is weak in all systems except the York River. Shore-derived material is dominant in the Rappahannock and Choptank. It overwhelms fluvial input by 3.5:1 and 7:1 in each system respectively. Despite the strong fluvial input in the James and Potomac Rivers, shore erosion becomes increasingly important in seaward zones as the estuary widens and wave exposure increases.

Depocenters of fast sedimentation in western shore tributaries, the James and Potomac (Table 3), lie in the middle estuary, a zone close to the turbidity maximum and near-bottom null zone during high river inflow when most fine sediment is supplied. In contrast, low fluvial input systems like the Choptank have secondary depocenters in upper reaches. The Chesapeake Bay mainstem, the longest system, has depocenters at ends of the system, close to major sources (i.e. river, mud; mouth sand) and zones where energy is reduced inward toward the central Bay.

Whereas all systems exhibit lateral tripartite patterns, i.e. sand-mud-sand in lower and middle reaches (Table 3), the longitudinal tripartite pattern occurs only in the Chesapeake Bay, James and to a lesser extent in the York River. This evolves from relatively high energy at ends of the system which give rise to coarse sediment and low tidal energy in middle reaches which encourages mud deposition. The other tributaries lack the seaward sand member because they join Chesapeake Bay in zones where mud prevails.

Storage efficiency (Si) is moderate to high in systems with low fluvial input and moderate to high sediment accumulation rates, e.g. the Choptank, York and Rappahannock Rivers (Table 3). These systems have relatively low hydraulic flow ratios reflecting low river inflow relative to tidal mixing. The James River has the lowest storage efficiency because high fluvial discharge during floods allows partial escape of some fine sediment.

All the systems have a relatively high pollution susceptibility in terms of hydraulic loading (Table 3). This means they have a large accommodative capacity to retain pollutants which is attributed to low flushing ability. Systems with substantial anthropogenic activity in watersheds, e.g. Chesapeake Bay, Potomac and James Rivers, are particularly susceptible to adverse effects. This is substantiated by moderate to high contamination index (Ci) values for metals, i.e. 5 to 69 (except in the York), indicating either enrichment or pollution.

GENERALITIES

Although estuaries are typically variable and each estuary has characteristics that differ from all others, the sediment processes are similar in kind throughout most systems. Therefore, it is possible to formulate generalities, which apply to most systems in the region. They serve as a norm for recognizing unexpected deviations. They provide a first-order guide to predicting the fate of contaminated sediments in lesser known similar systems.

Table 3. Comparison of sediment sources, sinks, selected sediment characteristics and contaminant index in systems of the Chesapeake region.

FEATURE		CHESAPEAKE BAY	POTOMAC RIVER	RAPPAHANNOCK RIVER	YORK RIVER	JAMES RIVER	CHOPTANK RIVER
SOURCES	Fluvial	█	█	—	▬	█	—
	Shores	▬	—	█	▬	—	█
	Marine	—	—	—	▬	—	—
SINK	Sedimentation Area, (%)	—	▬	—	▬	—	—
	Depocenter(s)	Upper and Lower (mud) (sand)	Middle	Upper and Lower	Middle	Middle	Upper and Middle
SEDIMENT CHARACTER	Mud Area, (%)	▬	█	█	▬	█	█
	Organic Matter, (%)	- - -	█□█	█□█	█□█	- - -	- - -
	Pattern -Longitudinal	Tripartite	Dupartite	Dupartite	Near-Tripartite	Tripartite	Dupartite
	-Lateral	Tripartite	Tripartite	Tripartite	Tripartite	Tripartite	Tripartite
INDEX FACTOR	S_i	- - -	- - -	█□█	- - -	⋯	█□█
	SPI	▬	█	█	█	—	□
	C_i	▒	▒		▒	█	
	Pollution Susceptibility -Hydraulic Ld.	█	█	█	█	█	
	-Anthropogenic Activity	█	█	—	—	█	

Source, Sink, Mud Area, Sedimentation Area	█ >60%	▬ 20 - 60%	— <20%
Depocenter	Position in estuary		
Organic Matter, (%) Storage Efficiency, S_i	█□█ >3%	- - - 1.3 - 3%	⋯ <1.3%

Sediment Pattern: Dupartite is sand-mud (upper-middle and lower)
Tripartite is sand-mud-sand (upper-middle-lower)

Sediment Pollution Index, SPI	█ >90%	▬ 80 - 90%	— <80%
Contamination Index for Metals, C_i	█ >14% Polluted	▒ 4 - 14 Enriched	□ <4 Normal

1. The estuaries are submergent. As a consequence they are net sediment sinks and storage efficiency of fine sediment is high. The estuaries are largely unfilled with sediment (except the James) and thus have a capacity to assimilate sediment in the axial channel.

2. Submergence leads to shore erosion. Shores supply a portionately large amount of material in systems with relatively low fluvial input. Shore input increases seaward as the estuary widens and exposure to wave action increases.

3. Estuarine sediments are mixtures derived from multiple sources including rivers, shores and marine areas. The dominance of a particular source depends on the supply rates and the exclusion of other sources.

4. Fluvial fine sediment is dispersed by the estuarine circulation following three routes: (a) seaward through freshwater reaches, (b) seaward through the upper estuarine layer and downward by settling, (c) landward through the lower layer. Dispersion of fluvial contaminants follows two modes: (a) a near-field distribution with decreasing contaminant concentrations downstream from the source governed by mixing and dilution with less contaminated sediment. (b) a far-field distribution with peak contaminant concentrations in the middle estuary governed by hydraulic entrapment, particle selectivity of hydrodynamic processes and by rapid sedimentation. Whereas contaminant concentrations are highest near the source, the greatest mass resides in far-field sinks.

5. In systems with a strong shore supply (weak fluvial input), fine sediment is released by direct erosion of bluffs, and secondarily by winnowing and resuspension of fines from marginal shoals. It is dispersed channelward by wind drift, tidal or secondary currents.

6. Fine sediment, mud and organic matter which generally bear most contaminants, accumulate in less energetic far-field zones, i.e. the main channel of middle or lower reaches and locally in dredged channels, protected reentrants, tributary creek mouths and marshes where sedimentation is fast. Sediment goes through three process regimes with distance channelward: (a) erosion, (b) transport and (c) accumulation. Prior to accumulation fine sediment goes through many cycles of settling, deposition and resuspension. This allows a long particle residence time in the water column and resultant particle-chemical interactions.

7. Accumulation and storage in the channel is encouraged by low flushing ability of the estuaries and by particle settling and entrapment processes like the estuarine circulation. Since the salt intrusion is retained within the estuaries at all stages of river inflow, direct by-passing of fluvial material to the ocean is limited.

8. The ultimate fate of contaminated sediment is burial in sinks where movement is negligible and concentrations are diminished by vertical mixing with less contaminated sediment, e.g. through bioturbation. Rapid burial reduces exposure of benthic organisms.

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James River:

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Appendix 1

Table 1. Organization of data quality and criteria used for assessment of scientific certainty of data in the database.

1. DATA SOURCE QUALITY

(1) Data Forms

Data produced by laboratory analysis of sediment texture (e.g. wet-sieving, pipetting, hydrometer and settling tube analysis, etc.) is considered the highest quality. Numeric values (e.g. tables, computer files) are considered to produce a better data set than isopleths or charted distributions. NOS bottom notations or field descriptions are considered the lowest quality.

	Weight
A. Laboratory Processed	
- Available as measured values	3
- Available as isopleths or charted distributions	2
B. Non-Laboratory Processed	
- NOS bottom notations or visual description	1

(2) Degree of Laboratory Processing

Laboratory processed data in terms of percent sand-silt-clay, which enables Shepard's classification of sediment texture, has priority over statistical parameters (e.g. mean, median, mode, sorting, etc.). The percent mud or sand/mud ratio, which is usually measured by wet sieving, is also considered to have lower quality than percent sand-silt-clay.

A. Percent Sand-Silt-Clay	2
B. Percent Mud, Mean, or Median	1

(3) Documentation

Published data that has been peer-reviewed is regarded highly certain. Semi-published "grey" literature, including technical reports, theses, or dissertations are not peer-reviewed and regarded as lesser quality.

A. Published	3
B. Semi-published "Grey" Literature, Tech. Reports, Theses, or Dissertation	2
C. Unpublished Field Data	1

(4) Spatial Sampling Density

Sampling density is determined by the number of stations per 10 km^2. This is the most important factor affecting source data quality. The critical values of 1,3,5, and 7 are set by testing the data for the Chesapeake Bay and its tributaries.

A.	> 7 stations / 10 km^2	5
B.	5 - 7 stations / 10 km^2	4
C.	3 - 5 stations / 10 km^2	3
D.	1 - 3 stations / 10 km^2	2
E.	< 1 stations / 10 km^2	1

(5) Additional Parameters other than texture

The textural parameters are often interrelated to other measured parameters (e.g. organic content, water content, etc.). Whenever these additional parameters are measured and abundant, the data quality is more assured.

A.	Available other parameters	1

The data source quality weightings are normalized by dividing by 15 (the maximum number of points) and scaled to 100%.

2. MAPPABILITY

(1) Sampling Density

When several sets of source data are used to map an estuary, the sampling density in terms of the whole estuary is important to decide the mappability. The values of 3 and 7 stations/10 km^2 are set by testing the data for the Chesapeake Bay and its tributaries.

		Weight
A.	> 7 stations / 10 km^2	3
B.	3 - 7 stations / 10 km^2	2
C.	< 3 stations / 10 km^2	1

(2) Spatial Coverage

The end product of the computer processing is a chart that shows the distribution of values by parameter from one or several data sources. The coverage in terms of percent of the whole estuary is used to assure the certainty of data representation.

A. > 80 %	3
B. 60 - 80 %	2
C. < 60 %	1

(3) Consistency, Number and Compatibility of data sets

Variations of different data sources in time and space are important in producing consistent composite charts. The best chart consists of a single data source that covers the whole estuary at one time. The smaller is the number of data sources in a composite, the better the mappability.

A. 1 - 2	3
B. 3 - 4	2
C. > 4	1

(4) Temporal Coverage

Multiple coverage of the same area at several times strengthens the reliability of a chart.

A. Over two data sets	2
B. Less than two data sets	1

(5) Additional Parameters other than texture

The distribution of additional parameters strengthens the reliability of a chart since many parameters are interrelated to grain size.

A. Other parameters available	1

The data mappability weightings are normalized by dividing by 12 (the maximum number of points) and scaled to 100%.

3. AGGREGATE QUALITY

Normalized weightings of all data source quality values and mappability values are then averaged and assigned descriptors.

(1) > 85 Highly Certain - Excellent Data Set and Mappability

(2) 71 - 85 Moderately Certain - Good Data Set and Mappability

(3) 56 - 70 Fairly Certain - Fair Data Set and Fair Mappability

(4) 40 - 55 Reasonable Inference - Fair Data Set and Reasonable Mappability

(5) < 40 Doubtful - Rejected Data Set

Appendix 2. Index to data sources and data content in the database.

SYSTEM	SOURCE				SAMPLING		AVAILABILITY	
	Author	Year	SOURCE ID	TOTAL STATIONS	DENSITY PER 10 km^2	SPATIAL COVERAGE	Source	Form
Chesapeake Bay	Byrne, R.J., et al.	1982	1 (sed) [1]	1993	5-7		VIMS	Tape
	Kerhin, R.T., et al.	1983	2 (sed) [1]	4052	7		VIMS	Tape
	Helz, G.R., et al.	1983	(met) [1]				EPA	Tape
	Total Stations			6045		>80%		
Chester River	Clarke, W.D. and Palmer, H.D.	1972		86 [3]	3-5	>80%	MD DNR [4]	Graphs
Choptank River	Kerhin, R.T., et al.	1983	1	280	5-7		VIMS	Tape
	NOS Bottom Notations [2]		2	211	3-5		NOAA	Tape
	Total Stations			491		>80%		
James River	Byrne, R.J., et al.	1982	1	110	1-3		VIMS	Tape
	Moncure, R. and Nichols, M.M.	1968	2	155	1-3		VIMS	Numeric
	Trotman, R. and Nichols, M.M.	1978	3	58	<1		VIMS	Numeric
	Nichols, M.M.	1990	4	16	<1		VIMS	Numeric
	Total Stations			339		>80%		
Potomac River	Glenn, J.L.	1988	(sed) [1]	275	1-3	>80%	USGS	Numeric
	Martin, E.A., et al.	1981	(met) [1]	35			USGS	Numeric
	Total Stations			310				
Rappahannock River	Nelson, B.W.	1961 f	1	48	1-3		(author)	Numeric
	Schaffner, L.	1981 f	2	11	<1		VIMS	Numeric
	Natale, C.J.	1982	3	50	1-3		VIMS	Graphs
	Ellison, R., et al.	1965	4	69	1-3		VIMS	Desc
	Total Stations			178		>80%		
York River	Boesch, D.F.	1971	1	8	<1		VIMS	Numeric
	Schaffner, L.	1989 f	2	6	<1		VIMS	Numeric
	Nichols, M.	1990 f	3	18	<1		VIMS	Numeric
	Byrne, R.J., et al.	1982	4	22	1-3		VIMS	Tape
	Carron, M.	1976	5	30	>7		VIMS	Numeric
	Total Stations			84		>80%		

KEY

'f' after year means work is unpublished file data.

Sampling density is number of stations per km^2, from S4, Data Source Quality, Table 1.

Spatial coverage is in terms of percent of whole estuary, from M2, Mappability, Table 1.

All forms listed refer to hard copy, except for "Tape" which means data is on magnetic tape or diskette. "Desc" indicates data contains descriptions based on visual examination of samples.

[1] Sediment and metals data in separate files.

[2] NOS bottom notations from National Ocean survey charts 12266 and 12268; data for Upper Choptank R. estuary only.

[3] Three surveys, two sampling dates.

[4] Maryland Department of Natural Resources.

SYSTEM	SOURCE		SOURCE ID	TEXTURAL PARAMETERS							
	Author	Year		Gravel %	Sand %	Silt %	Clay %	Mud %	Class ID	Shepard Class	NOS Notations
Chesapeake Bay	Byrne, R.J., et al.	1982	1 (sed)[1]								
	Kerhin, R.T., et al.	1983	2 (sed)[1]								
	Helz, G.R., et al.	1983	(met)[1]								
	Total Stations			6045	6045	6045	6045	6045	6045	6045	
Chester River	Clarke, W.D. and Palmer, H.D.	1972			86	86	86	86	86	86	
Choptank River	Kerhin, R.T., et al.	1983	1								
	NOS Bottom Notations[2]		2								
	Total Stations			280	280	280	280	280	280	280	211
James River	Byrne, R.J., et al.	1982	1								
	Moncure, R. and Nichols, M.M.	1968	2								
	Trotman, R. and Nichols, M.M.	1978	3								
	Nichols, M.M.	1990	4								
	Total Stations			339	339	339	339	339	339	339	
Potomac River	Glenn, J.L.	1988	(sed)[1]								
	Martin, E.A., et al.	1981	(met)[1]								
	Total Stations			275	275	275	275	275	275	275	
Rappahannock River	Nelson, B.W.	1961 f	1								
	Schaffner, L.	1981 f	2								
	Natale, C.J.	1982	3								
	Ellison, R., et al.	1965	4								
	Total Stations				109	109	109	109	178	178	
York River	Boesch, D.F.	1971	1								
	Schaffner, L.	1989 f	2								
	Nichols, M.	1990 f	3								
	Byrne, R.J., et al.	1982	4								
	Carron, M.	1976	5								
	Total Stations			54[3]	84[3]	84	84	84	54	54	

Appendix 2

KEY
'f' after year means work is unpublished file data.

[1] Sediment and metals data in separate files.

[2] NOS bottom notations from National Ocean survey charts 12266 and 12268; data for Upper Choptank R. estuary only.

[3] Gravel portion included with sand for source ID 5.

SYSTEM	SOURCE		SOURCE ID	METALS CONCENTRATIONS						
	Author	Year		Cd	Cu	Fe	Mn	Ni	Pb	Zn
Chesapeake Bay	Byrne, R.J., et al.	1982	1 (sed)[1]							
	Kerhin, R.T., et al.	1983	2 (sed)[1]							
	Helz, G.R., et al.	1983	(met)[1]							
	Total Stations			138	175	183	181	181	179	177
Chester River	Clarke, W.D. and Palmer, H.D.	1972								
Choptank River	Kerhin, R.T., et al.	1983	1							
	NOS Bottom Notations[2]		2							
	Total Stations									
James River	Byrne, R.J., et al.	1982	1							
	Moncure, R. and Nichols, M.M.	1968	2							
	Trotman, R. and Nichols, M.M.	1978	3							
	Nichols, M.M.	1990	4							
	Total Stations									
Potomac River	Glenn, J.L.	1988	(sed)[1]							
	Martin, E.A., et al.	1981	(met)[1]							
	Total Stations			35	35	23	23		35	35
Rappahannock River	Nelson, B.W.	1961 f	1							
	Schaffner, L.	1981 f	2							
	Natale, C.J.	1982	3							
	Ellison, R., et al.	1965	4							
	Total Stations									
York River	Boesch, D.F.	1971	1							
	Schaffner, L.	1989 f	2							
	Nichols, M.	1990 f	3							
	Byrne, R.J., et al.	1982	4							
	Carron, M.	1976	5							
	Total Stations									

KEY

'f' after year means work is unpublished file data.

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[1] Sediment and metals data in separate files.

[2] NOS bottom notations from National Ocean survey charts 12266 and 12268; data for Upper Choptank R. estuary only.

SYSTEM	SOURCE		SOURCE ID	STATISTICAL PARAMETERS			OTHER PARAMETERS			
	Author	Year		Mean	Median	Sorting	Water Content	Total Carbon	Organic Carbon	Organic Matter
Chesapeake Bay	Byrne, R.J., et al.	1982	1 (sed)[1]							
	Kerhin, R.T., et al.	1983	2 (sed)[1]							
	Helz, G.R., et al.	1983	(met)[1]							
	Total Stations						4822	1629		1690
Chester River	Clarke, W.D. and Palmer, H.D.	1972								
Choptank River	Kerhin, R.T., et al.	1983	1							
	NOS Bottom Notations[2]		2							
	Total Stations						275	39		38
James River	Byrne, R.J., et al.	1982	1							
	Moncure, R. and Nichols, M.M.	1968	2							
	Trotman, R. and Nichols, M.M.	1978	3							
	Nichols, M.M.	1990	4							
	Total Stations						92			134
Potomac River	Glenn, J.L.	1988	(sed)[1]							
	Martin, E.A., et al.	1981	(met)[1]							
	Total Stations			212	212	212			137	137
Rappahannock River	Nelson, B.W.	1961 f	1							
	Schaffner, L.	1981 f	2							
	Natale, C.J.	1982	3							
	Ellison, R., et al.	1965	4							
	Total Stations			43			58			11
York River	Boesch, D.F.	1971	1							
	Schaffner, L.	1989 f	2							
	Nichols, M.	1990 f	3							
	Byrne, R.J., et al.	1982	4							
	Carron, M.	1976	5							
	Total Stations									27

KEY
'f' after year means work is unpublished file data.

[1] Sediment and metals data in separate files.

[2] NOS bottom notations from National Ocean survey charts 12266 and 12268; data for Upper Choptank R. estuary only.

Appendix 2

SYSTEM	SOURCE		TOTAL STATIONS	ADDITIONAL PARAMETERS AVAILABLE
	Author	Year		
Chesapeake Bay	Byrne, R.J., et al.	1982	1993	grain size statistics, tot. carbon, tot. org. carbon, sulfur
	Kerhin, R.T., et al.	1983	4052	
	Helz, G.R., et al.	1983		
	Total Stations		6045	
Chester River	Clarke, W.D. and Palmer, H.D.	1972	86	
Choptank River	Kerhin, R.T., et al.	1983	280	
	NOS Bottom Notations		211	
	Total Stations		491	
James River	Byrne, R.J., et al.	1982	110	grain size statistics, tot. carbon, tot. org. carbon, sulfur
	Moncure, R. and Nichols, M.M.	1968	155	shell%, munsell color, depth of oxidation, minerals, pH, Eh
	Trotman, R. and Nichols, M.M.	1978	58	mean, median, std. deviation, density, organic content, Kepone conc.
	Nichols, M.M.	1990	16	
	Total Stations		339	
Potomac River	Glenn, J.L.	1988	275	geomorphologic units
	Martin, E.A., et al.	1981	35	
	Total Stations		310	
Rappahannock River	Nelson, B.W.	1961 f	48	
	Schaffner, L.	1981 f	11	
	Natale, C.J.	1982	50	
	Ellison, R., et al.	1965	69	
	Total Stations		178	
York River	Boesch, D.F.	1971	8	median, organic carbon
	Schaffner, L.	1989 f	6	
	Nichols, M.	1990 f	18	
	Byrne, R.J., et al.	1982	22	grain size statistics, water content, tot. carbon, tot. org. carbon, sulfur
	Carron, M.	1976	30	
	Total Stations		84	

KEY

'f' after year means work is unpublished file data.