CALIBRATION OF THE TAM/WASP SEDIMENT TRANSPORT MODEL - FINAL REPORT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

Sediment has long been a pollutant of concern in the Anacostia River. High sedimentation rates in the river have created conditions that are detrimental to the health of the benthic macroinvertibrate and fish communities, have effectively inhibited the growth of submerged aquatic vegetation in the tidal river and contributed to low oxygen levels in the water column, and have necessitated regular and costly dredging of the navigation channel. Currently, the portion of the tidal Anacostia located in the District of Columbia is listed on the District's 303(d) list of impaired water bodies for not meeting water quality standards for constituents including suspended sediments.

The new version of the TAM/WASP sediment transport model described in this report is based on the TAM/WASP modeling framework developed by the Interstate Commission on the Potomac River Basin (ICPRB) for use by the District Columbia in its determination of Total Maximum Daily Load (TMDL) allocations for the tidal portion of the Anacostia River. This framework consists of a series of one-dimensional models which simulate hydrodynamic processes, constituent load inputs, and chemical and physical processes which play a role in the fate and transport of pollutants in the river. The hydrodynamic component of the modeling framework, based on the Tidal Anacostia Model (TAM) originally developed by the Metropolitan Washington Council of Governments, was recently modified by ICPRB to include tidal embayments, and the original 15 segment geometry was replaced by a 35 segment geometry computed by the National Oceanographic and Atmospheric Administration (NOAA). The water quality component of the sediment transport model, based on the US Environmental Protection Agency's Water Analysis Simulation Program (WASP) model has been modified by ICPRB to simulate velocity-dependent deposition and resuspension of solids.

The TAM/WASP sediment transport model predicts changes over time of water column and river bed sediment concentrations in the tidal portion of the Anacostia River by simulating the inputs of flows and sediment loads to the tidal river, the action of tidally driven flows, the advective and dispersive transport of suspended sediments, and the processes of sediment deposition and resuspension. The model tracks three sediment size fractions (fine-grained, medium-grained, and coarse-grained), where total sediment is assumed to be the sum of the three size fractions. Flow and load inputs from two of the watershed's major drainage areas, the Northeast Branch and the Northwest Branch, are estimated from flow monitoring and water quality monitoring data collected at two U.S. Geological Service gaging stations. Flow and load inputs to the tidal drainage area, from combined sewer overflows (CSO) and separate storm sewer outfalls along the tidal river, the Watts Branch and Lower Beaverdam tributaries of the tidal river, and several additional minor tributaries, are computed by a variety of means based on land use information for over 30 sub-sheds of the tidal drainage area. Fine-grained and medium-grained sediment fractions are treated in the model as cohesive sediments, with deposition and resuspension rates computed at each time step as a function of bed shear stress, similar to the approach employed in the HSPF model and the Army Corp of Engineer's HEC-6 model. To simulate the transport of the coarse-grained sediment fraction, a simple power law method is used.

The model calibration time period, January 1, 1988 through December 31, 1990, was chosen because these three years have been found to represent fairly typical hydrology for the region, including a relatively wet year, a relatively dry year, and a relatively average year. The TAM/WASP sediment transport model simulates the transport of sediments based upon a relatively small set of model parameters, including the critical bed shear stress for erosion, the critical shear stress for deposition, and the zero-flow settling velocity. Transport properties are also dependent on flow velocities, which are simulated for each segment at each model time step.

Because of the relatively low flow velocities believed to occur in the tidal Anacostia River, the river has been characterized as a primarily depositional environment. Measured flow velocities over a tidal cycle during non-storm conditions are in the range of 0 to 0.3 m/sec. Flow velocities are lowest in the stretch of the river downstream of the 11th Street bridge, and in this area fine-grain sediments predominate. Model-simulated flow velocities over the course of the three-year calibration period are generally less than 0.5 m/sec, and at no time during the years, 1988 through 1990, did the model predict a flow velocity greater than 0.85 m/sec.

Calibration results show that the TAM/WASP sediment transport model can simulate water column total suspended solids (TSS) concentrations during the calibration time period reasonably well, with model-predicted storm peak concentrations generally in the range of 150 to 250 mg/L, consistent with high values in the calibration data set, and non-storm concentrations generally in the range of 5 to 30 mg/L, consistent with available data. As a verification of the ability of the model to simulate sediment transport dynamics in the tidal river, the model performed well in predicting the spatial pattern of the sediment grain size distribution in the surficial sediment bed. Overall, model estimates of the daily TSS loads to the tidal river may be somewhat low, based on empirical estimates of sediment accumulation rates and on estimates by other studies.

CHAPTER 1: INTRODUCTION

1.1. Background

Sediment has long been a pollutant of concern in the Anacostia River. Estimates of the historical annual sediment load to the tidal portion of the river have been in the range of 46,000 tons (Warner et al., 1997) to 138,000 tons (Century Engineering, 1981). This high sediment load has created conditions that are detrimental to the health of the benthic macroinvertibrate and fish communities, and has effectively inhibited the growth of submerged aquatic vegetation in the tidal river, contributing to low oxygen levels in the water column. The high sedimentation rates have also necessitated regular and costly dredging of the navigation channel. According to U.S. Army Corps of Engineers Annual Reports, over 2,000,000 cubic meters (m^3) of sediment were dredged from the Anacostia and Washington Shipping Channel in the period between 1936 and 1986 (Scatena, 1986). Currently, the portion of the tidal Anacostia located in the District of Columbia is listed on the District's 303(d) list of impaired water bodies for not meeting water quality standards for constituents including suspended sediments.

The Anacostia River watershed encompasses an area of approximately 176 square miles (mi^2) in the District of Columbia and Maryland. The watershed lies within two physiographic provinces, the Piedmont Plateau and the Coastal Plain, whose division runs approximately along the Montgomery/Prince Georges County line. The upper northwestern portion of the watershed lies within the Piedmont Plateau province, characterized by steep stream valleys and well-drained loamy soils underlain by metamorphic rock. The remainder of the basin lies within the Coastal Plain province, a wedge-shaped mass of primarily unconsolidated sediments drained by slowly meandering streams. The location of the watershed and its three major drainage areas, the Northeast Branch, the Northwest Branch and the tidal drainage areas, are depicted in Figure 1-1. The drainage areas of the Northwest and Northeast Branches, 53 mi^2 and 76 mi^2, respectively, comprise approximately 73% of the total area of the watershed. The Anacostia River begins in Bladensburg, Maryland, at the confluence of its two major tributaries, the Northwest Branch and the Northeast Branch, and flows a distance of approximately 8.4 miles before it discharges into the Potomac River in Washington, DC. Because of its location in the Washington metropolitan area, the majority of the watershed is highly urbanized, with a population of 804,500 in 1990 and a projected population of 838,100 by the year 2010 (Warner et al., 1997). An analysis of GIS layers prepared by the Metropolitan Washington Council of Governments (MWCOG), indicates that land use in the watershed is approximately 43% residential, 11% industrial/commercial, and 27% forest or wetlands, with 22.5% of the area of the watershed covered by impervious surfaces (see Shepp et al., 2000).

The Anacostia River is actually an estuary, with tidal influence extending some distance into the Northeast and the Northwest Branches, approximately to the US Geological Survey (USGS) gage stations 01649500 at Riverdale Road, and 0165100 at Queens Chapel Road (see Figure 1-1). However, water in the tidal portion of the river is fresh water, with negligible values of salinity. The variation in the river's water surface elevation over a tidal cycle is approximately 3 feet. From an analysis by the National Oceanographic and Atmospheric Administration (NOAA) of sounding data taken by the US Army Corps of Engineers prior to a 1999 dredging project combined with additional bathymetry data taken by the Navy in the summer of 2000 (George Graettinger, NOAA, private communication), the volume of the tidal portion of the river at mean tide is approximately 10,000,000 m^3, with a surface area of approximately 3,300,000 square meters (m^2). The width of the river varies from approximately 60 meters (m) in some upstream reaches to approximately 500 m near the confluence with the Potomac, and average depths across the channel transects vary from approximately 1.2 m upstream of Bladensburg to about 5.6 m just downstream of the South Capital Street Bridge. The average daily combined discharge of the Northeast and Northwest Branches into the tidal river is approximately 370,000 m^3. During non-storm conditions, measured flow velocities during the tidal cycle have been in the range of 0 to 0.3 m/sec (Katz et al., 2000; Schultz and Velinsky, 2001).

1.2. TAM/WASP Modeling Framework

The TAM/WASP sediment transport model is based on the TAM/WASP modeling framework developed by ICPRB for use by the District Columbia in its determination of TMDL allocations for the tidal portion of the Anacostia River. This framework consists of a series of one-dimensional models which simulate hydrodynamic processes, constituent load inputs, and chemical and physical processes which play a role in the fate and transport of pollutants in the river. The hydrodynamic component of the modeling framework makes use of the hydrodynamic portion of the Tidal Anacostia Model (TAM) model (Sullivan and Brown, 1988), which was developed in the 1980's by the Metropolitan Washington Council of Governments (MWCOG), and is based on the Virginia Institute of Marine Science's Hydrodynamic Ecosystem Model (VIMS, 1985). The water quality component of the framework incorporates the EPA's Water Analysis Simulation Program (WASP) model (Ambrose et al., 1993), which has been modified by ICPRB to simulate certain additional processes. A 15 segment version of the TAM/WASP modeling framework, referred to in this report as TAM/WASP Version 1, was used in the construction of a eutrophication model for the tidal river, based on the WASP5 submodule, EUTRO, which was enhanced to simulate the process of sediment diagenesis (Mandel and Schultz, 2000). This model was completed by ICPRB in the spring of 2000 and has been used by the District to develop load allocations for the TMDL to meet dissolved oxygen water quality standards. A 35 segment version of the TAM/WASP modeling framework, described in this report and referred to as TAM/WASP Version 2, incorporates modifications to the TAM hydrodynamic component to include a new 35 segment geometry computed by NOAA and tidal embayments, as described in Appendix A. The current model segmentation is depicted in Figure 1-2. The TAM/WASP sediment transport modeling package is based on the WASP sub-module, TOXI5, which was modified by ICPRB to simulate velocity-dependent deposition and resuspension of solids. This model will be used by the District to assist in the development of TMDL load allocations for sediment, and also will be used by the Anacostia Watershed Toxics Alliance (AWTA) to evaluate potential scenarios for remediation of sediments contaminated by toxic chemicals.

The TAM/WASP sediment transport model predicts changes over time of water column and river bed sediment concentrations in the tidal portion of the Anacostia River by simulating the inputs of flows and sediment loads to the tidal river, the action of tidally driven flows, the advective and dispersive transport of suspended sediments, and the processes of sediment erosion and deposition. The model tracks three sediment size fractions (fine-grained, medium-grained, and coarse-grained), where total sediment is assumed to be the sum of the three size fractions. Flow and load inputs from two of the watershed's major drainage areas, the Northeast Branch and the Northwest Branch, are estimated from flow monitoring and water quality monitoring data at the U.S. Geological Service gaging stations at Riverdale Road on the Northeast Branch (Station 01649500) and at Queens Chapel Road on the Northwest Branch (Station 01651000) (see Figure 1-1). Flow and load inputs to the tidal drainage area, from combined sewer overflows (CSO) and separate storm sewer outfalls along the tidal river, the Watts Branch and Lower Beaverdam tributaries of the tidal river, and several additional minor tributaries, are computed by a variety of means based on land use information for over 30 sub-sheds of the tidal drainage area.

1.3. TAM/WASP Sediment Transport Dynamics

The WASP model allows the simulation of transport of up to three sediment grain size fractions. In the calibration runs of TAM/WASP, the three sediment size fractions modeled are:

Frac1 - coarse-grained sediments:	sand and gravel (grain sizes > 120 μm)
Frac2 - medium-grained sediments:	silt and very fine sand (grain sizes between 30 μm and 120 μm)
Frac3 - fine-grained sediments:	clay and very fine silt (grain sizes < 30 μm)

In TAM/WASP Version 1, a new capability was added to TOXIWASP by ICPRB to allow simulation of sediment transport based on model hydrodynamics (Mandel and Schultz, 2000). This capability has undergone further development in TAM/WASP Version 2, in order to support the use of the model for the prediction of fate and transport of toxic chemicals. The fine-grained and medium-grained sediment fractions are treated in TAM/WASP as cohesive sediments, and the algorithms governing their transport follow the approach developed by Partheniades (1962) and Krone (1962), which has frequently been employed in other models, such as the Hydrologic Simulation Program FORTRAN, (HSPF) model (Bicknell et al. 1993) and the Army Corps of Engineer’s HEC-6. To model the transport of the coarse-grained sediment fraction, two methods used in HSPF for implementing sand transport have also been incorporated by ICPRB into WASP, a simple power law method and Colby’s method (Colby, 1964). The algorithms governing sediment transport dynamics in TAM/WASP Version 2 are described below.

1.3.1. Transport of Fine-Grained and Medium-Grained Sediment Fractions

The erosion and deposition of cohesive sediments is a function of bed shear stress. The erosion of silt and clay occurs when shear stress exceeds a critical shear stress and is proportional to the extent it exceeds the critical shear stress. Similarly, the deposition of cohesive sediment occurs when shear stress is less than a critical threshold--distinct from the critical shear stress for erosion--and occurs in proportion to the drop in shear stress below the threshold.

Bed shear stress, τ_b, is calculated by the following equation:

$$\tau_b = \gamma * R * S \qquad \textbf{(1.1)}$$

where

τ_b	= bed shear stress (N/m^2)
γ	= the weight of water (9806 N*m/s)
R	= hydraulic radius (m)
S	= the slope of the energy grade line.

The slope of the energy grade line is determined by solving Manning's equation

$$S = \frac{V^2 * n^2}{R^{4/3}} \qquad \textbf{(1.2)}$$

where

V	= average flow velocity in the segment (m/s)
n	= Manning's roughness factor.

Thus, the relationship between bed shear stress and flow velocity is

$$V = \frac{R^{1/6}\ \tau_b^{1/2}}{n\ \gamma^{1/2}} \qquad \textbf{(1.3)}$$

For a cohesive sediment, deposition occurs if τ_b is less than τ_d, the threshold for deposition. Thus, the rate of deposition is given by

$$\begin{aligned} M_d &= 0, & \tau_b > \tau_d \\ &= C_{WC} * A * V_s * (1 - \tau_b / \tau_d), & \tau_b < \tau_d \end{aligned} \qquad \textbf{(1.4)}$$

where

C_{WC}	= concentration of sediment size fraction in water column segment (mg/l)
M_d	= mass of sediment size fraction deposited (g/d)
A	= area of the sediment bed in segment (m^2)
V_s	= settling velocity at zero flow (m/d)
τ_d	= critical shear stress threshold for deposition.

Erosion occurs if τ_b is greater than τ_c, the critical shear stress. The rate of erosion is given by

$$M_e = C_S * A * V_e * (\tau_b / \tau_c - 1), \quad \tau_b > \tau_d$$
$$= 0, \qquad \tau_b < \tau_d \tag{1.5}$$

where

- M_e = mass of sediment size fraction eroded (g/d)
- C_S = concentration of sediment size fraction in bed sediment segment (g/m^3)
- A = area of sediment bed in segment (m^2).
- V_e = erosion velocity constant (m/d)
- τ_c = critical shear stress threshold for erosion.

The area of each of the sediment bed segments, A, are input by the user. Sediment size fraction concentrations are computed by WASP. Average segment depths, hydraulic radii, and segment velocities are taken from WASP and ultimately derived from the TAM hydrodynamic program. Distinct values of the settling velocity, erosion velocity constant, critical shear stress, and the deposition threshold are entered by the user for fine-grained and medium-grained sediment fractions.

1.3.2. Transport of Coarse-Grained Sediment Fraction

The transport of coarse-grained sediments (i.e., sand and gravel) is modeled by determining the carrying capacity of the flow, which in turn is dependent on the flow's hydrodynamic properties. If flow conditions change so that the carrying capacity exceeds the concentration of sand currently being transported, additional sand will be eroded from the bed. If the concentration of sand exceeds its carrying capacity, sand will be deposited. Two methods of calculating the transport capacity were implemented into WASP by ICPRB: a simple power function method and Colby's method.

In the power function method, the transport capacity for coarse-grained sediments, C_p, (mg/l), is given as a simple power function of the velocity

$$C_p = k_s * V^{k_e} \tag{1.6}$$

where

- k_s, k_e = user-determined constants
- V = average segment flow velocity (m/s)

Alternately, the transport of coarse-grained sediments can be modeled using the Colby method.

Colby (1964) developed a series of curves, based on empirical studies and dimensional analysis, which predicts sand transport on the basis of average velocity, the median particle size of sand in the bed, water temperature, hydraulic radius, and the concentration of silt and clay in the water column. The HSPF model contains a subroutine that computationally instantiates Colby's analysis. This subroutine was adapted for use in WASP. The advantage of Colby's method is that it corrects sand transport capacity for the presence of finer-grain material. This may be important in a system like the tidal Anacostia, where the transport of silt and clay predominates.

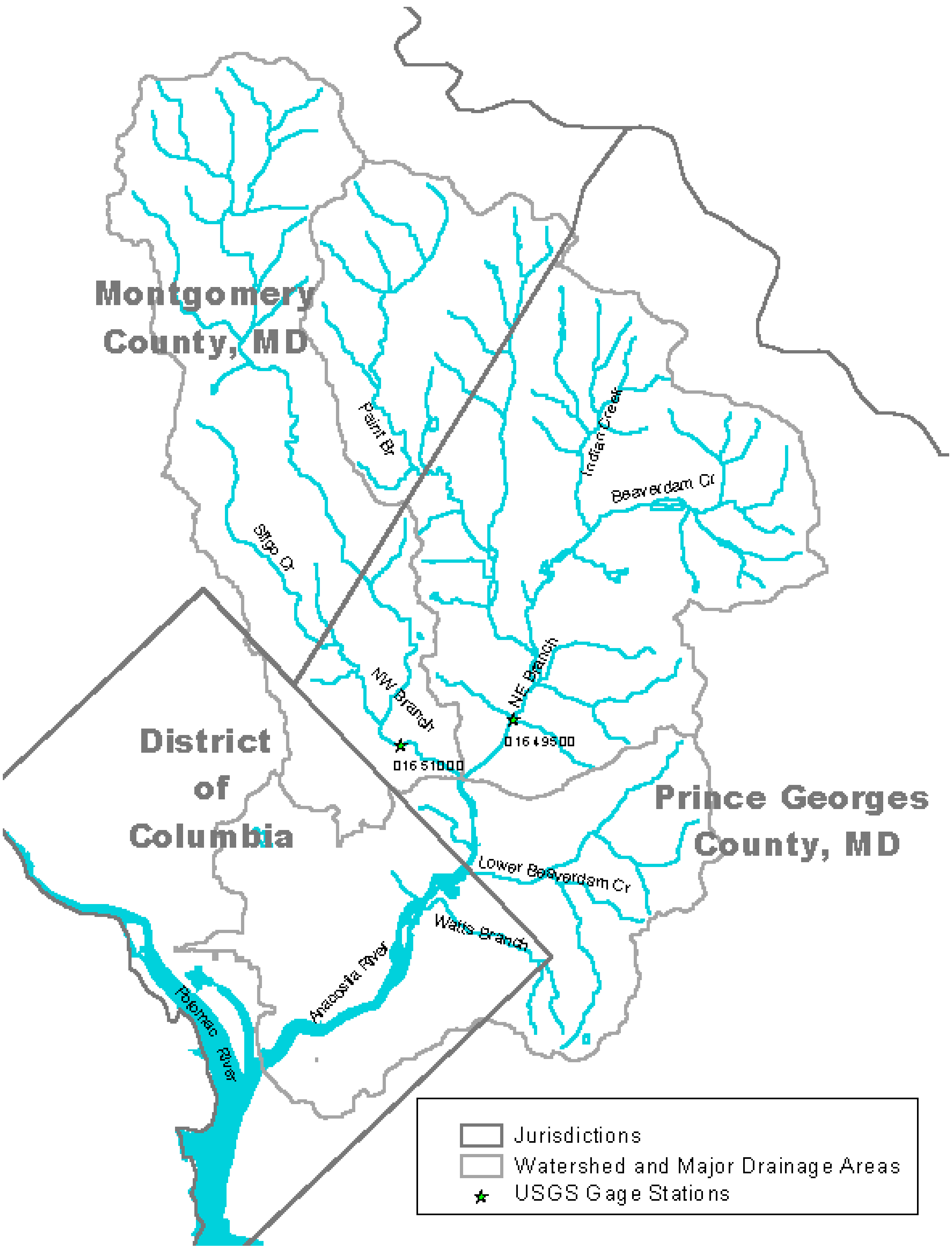

Figure 1-1. Anacostia River Watershed and Major Drainage Areas

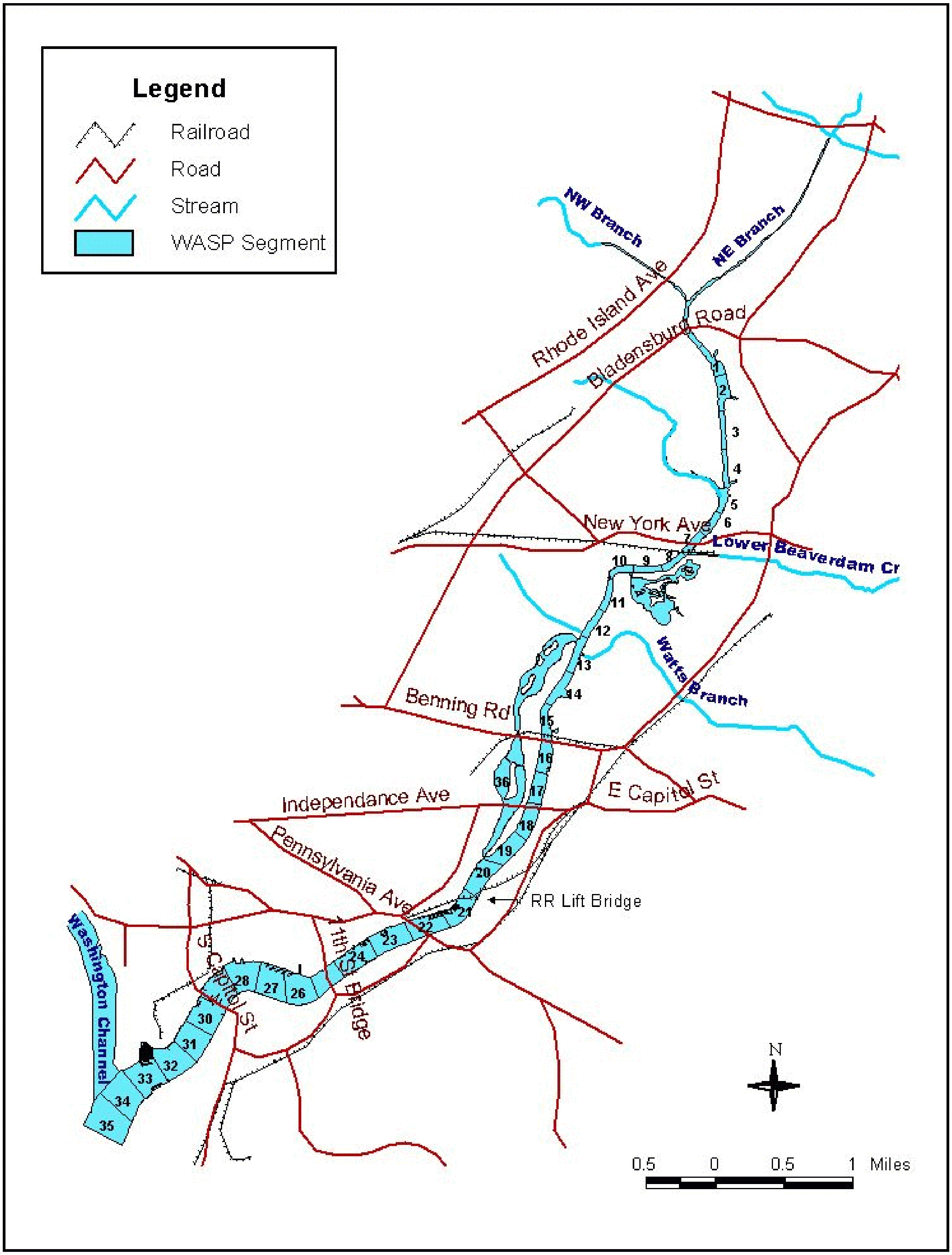

Figure 1-2. TAM/WASP Sediment Transport Model Segmentation

CHAPTER 2: MODEL INPUTS

The TAM/WASP sediment transport model for the tidal Anacostia River predicts concentrations of each of three sediment grain size fractions in the model's water column and river bed sediment segments by simulating the inputs of flows and sediment loads to the tidal river, the action of tidally driven flows, the advective and dispersive transport of suspended sediments, and the processes of sediment erosion and deposition.

2.1. Inputs for the TAM Hydrodynamic Model

The TAM hydrodynamic component of the TAM/WASP sediment transport model simulates water depths and flow velocities based on equations for continuity and momentum conservation (Sullivan and Brown, 1988). The primary hydrodynamic inputs are the model segment geometry, daily tidal gage heights near the downstream boundary of the model, the daily discharges of the two upstream tributaries, the Northeast and Northwest Branches, and daily discharges into each model segment from the tidal drainage area (see Figure 1-1). Each of these inputs is described in detail below.

2.1.1. Model Segment Geometry

The ICPRB's TAM/WASP Version 2 sediment transport model represents the tidal portion of the Anacostia River as a one-dimensional system of 35 segments, extending from the Bladensburg Road bridge in Prince Georges County, MD, to the Anacostia's confluence with the Potomac in Washington, DC (see Figure 1-2). Additionally, WASP model segment 36, representing Kingman Lake, adjoins segment 19. (Kingman Lake is represented as a tidal embayment to segment 19 in the TAM hydrodynamic model.) Each of the 36 water column segments is underlain by a sediment segment, as shown schematically in Figure 2-1. Sediment segment 72 underlies the water column segment 36, representing Kingman Lake, not represented in Figure 2-1. Segment geometry inputs to the TAM hydrodynamic component of the model are based on estimates of the average length, width, and depth of each of the water column segments. Segment length and width estimates were obtained using the geographical information system (GIS) representation of the tidal river recently prepared by NOAA for AWTA, based primarily on the National Capitol Parks - East GIS layer of the Anacostia River. Average mean-tide segment depth estimates were provided by NOAA (George Graettinger, NOAA, private communication) based on 1999 depth sounding data provided by the U.S. Army Corps of Engineers (US ACE) (US ACE, 1999) and an additional data set collected in the summer of 2000 for AWTA by the SPAWARs data collection team (see Katz et al., 2000). NOAA used the ESRI Arcview Spatial Analyst software interpolation capabilities to estimate river depths at each point on a 10 ft by 10 ft grid. Average segment depths were then computed by averaging depths at all grid points within the segment.

The estimates of model segment lengths, widths, depths, surface areas, and volumes used in TAM/WASP Version 2 are given in Table 2-1. The tidal portions of the Northeast and Northwest Branches, the tidal portions of Dueling Creek, Lower Beaverdam Creek, Kenilworth Marsh, Hickey Run, Watts Branch, and Kingman Lake, respectively, are treated in the

TAM/WASP Version 2 hydrodynamic program as side embayments of the main channel portions of segments 1, 5, 7, 10, 12, 13, and 19, respectively, as described in Appendix A. Treated as such, these tidal embayment areas contribute to the surface area receiving and discharging flow, but do not distort the main channel segment cross-sectional areas used to compute flow velocity/discharge relationships. In the corresponding WASP model geometry, the surface areas and volumes of the tidal portions of the Northeast and Northwest Branches, Dueling Creek, Lower Beaverdam Creek, Kenilworth Marsh, Hickey Run, Watts Branch, respectively, are included in the surface areas and volumes of segments 1, 5, 7, 10, 12 and 13, respectively, and Kingman Lake is treated as a separate segment, WASP segment 36, adjoining segment 19.

It should be noted that the model segment geometry given in Table 2-1 differs from the 15 segment geometry used in TAM/WASP Model Version 1 (Mandel and Schultz, 2000), and also differs slightly from the 35 segment geometry developed by LimnoTech, Inc. (LTI) (Scott Hinz, LTI, private communication) for the extension of the TAM/WASP model currently being used to model dissolved oxygen in the DC Water and Sewer Authority (WASA) Long Term Control Plan (LTCP) project. LTI's segment geometry was based on the USGS's depiction of the river shorelines in its River Reach File, Version 3, and the ACE's 1999 sounding data. The total model river volume at mean tide in TAM/WASP Version 2 is approximately 10,000,000 cubic meters (m^3), compared to approximately 9,400,000 m^3 in the LTI/WASA model, a difference of 6%. The total model river surface area is approximately 3,300,000 square meters (m^2) in the ICPRB TAM/WASP V2 model, versus approximately 2,500,000 m^2 in the LTI/WASA model, a difference of about 24%.

Table 2-1. TAM/WASP Version 2 Segment Geometry

WASP Segment Number	Main Channel Length (m)	Main Channel Width (m)	Segment Depth (m from MSL)	Main Channel Surface Area (m^2)	Side Embayment Surface Area (m^2)	Total Segment Surface Area (m^2)	Total Segment Volume (m^3)
1	415	98.5	1.50	40,898	109,499	150,397	225,595
2	425	119.1	1.16	50,636	0	50,636	58,974
3	450	58.0	2.21	26,090	0	26,090	57,634
4	442	63.3	2.17	27,993	0	27,993	60,790
5	312	93.0	1.90	29,031	27,607	56,638	107,672
6	305	92.6	1.86	28,246	0	28,246	52,621
7	320	90.3	1.83	28,910	10,059	38,969	71,399
8	315	74.4	2.06	23,424	0	23,424	48,159
9	330	74.2	2.08	24,485	0	24,485	50,841
10	312	77.4	2.02	24,163	188,181	212,343	429,707
11	405	73.1	2.12	29,605	0	29,605	62,862
12	370	86.0	1.78	31,814	1,816	33,630	59,946
13	445	96.7	1.50	43,021	1,106	44,126	66,311
14	445	113.7	1.33	50,606	0	50,606	67,539
15	453	105.3	1.92	47,681	0	47,681	91,427
16	375	146.1	1.84	54,799	0	54,799	100,967
17	375	157.5	1.50	59,057	0	59,057	88,644
18	425	164.3	1.30	69,840	0	69,840	91,030
19	435	185.0	1.33	80,459	250,000	80,459	107,235
20	440	205.4	1.92	90,378	0	90,378	173,920
21	440	199.4	1.97	87,758	0	87,758	173,103
22	455	218.8	1.98	99,535	0	99,535	197,156
23	460	242.5	2.05	111,543	0	111,543	228,666
24	460	235.8	3.43	108,481	0	108,481	371,704
25	365	218.3	4.31	79,676	0	79,676	343,557
26	353	340.3	4.58	120,140	0	120,140	550,304
27	323	353.4	5.10	114,137	0	114,137	582,039
28	335	348.3	5.28	116,693	0	116,693	616,495
29	335	347.4	5.10	116,383	0	116,383	593,380
30	335	351.2	5.61	117,642	0	117,642	660,057
31	320	368.2	5.36	117,829	0	117,829	631,411
32	355	376.8	4.81	133,762	0	133,762	642,905
33	365	415.2	4.25	151,554	0	151,554	644,722
34	340	447.0	4.25	151,978	0	151,978	645,249
35	350	507.9	4.25	177,761	0	177,761	756,277
36			1.32	250,000	0	250,000	330,000

2.1.2. Tidal Gage Height Data

Hourly tidal heights were obtained from NOAA for Station 8594900, "Washington, Potomac River, DC", which is located in the Washington Ship Channel. Tidal heights were downloaded from the NOAA website, in units of meters, from the vertical datum, MLLW (mean lower low water) for the tidal epoch, 1960 to 1978. Tidal heights were converted to units of feet from MSL (mean sea level, local) for input into the TAM hydrodynamic routine by means of the conversion formula

$$MSLHeight = MLLWHeight * 3.281 - 1.56 \qquad \textbf{(2.1)}$$

There were three periods when no data was available:

1. September 17, 1988, 7:00 PM - September 29, 1988, 12:00 PM
2. January 23, 1989, 7:00 PM - March 10, 1989, 4:00 PM
3. December 31, 1993, 7:00 PM - December 31, 1993, 11:00 PM

As was done in the original version of TAM/WASP (Mandel and Schultz, 2000), in the first two cases, data was reused from the previous year, and in the third case, data from the previous day was reused.

On the second half of day 11/21/89, and on days 5/24/90, 5/25/90, and 5/26/90, one foot was added to each hourly tide height because of the extremely low tides which occurred during these time periods. This was done to avoid de-watering of some model segments, a condition which cannot be handled in the current TAM/WASP framework.

2.1.3. Daily Flow Inputs

Water flows into the tidal portion of Anacostia from many sources: from the Northeast Branch and Northwest Branch upstream tributaries, from CSO and separate storm sewer outfalls, from the Watts Branch, Lower Beaverdam Creek and other tidal tributaries, from direct drainage (i.e., overland flow from areas adjacent to the river banks), and from ground water discharge. These flows are represented in TAM/WASP as daily flow inputs into each of the model segments. Flow estimates from the two major drainage areas upstream of the tidal river, the Northeast Branch and Northwest Branch drainage areas, are obtained directly from USGS gage station data. Flow inputs from other portions of the watershed were computed based on a delineation of sub-sheds of the Anacostia tidal drainage area by MWCOG (see Shepp et al., 2000), as depicted in Figure 2-2, and on an estimation of direct drainage sub-shed boundaries by ICPRB based on NOAA's new depiction of the TAM/WASP. The locations of sub-shed outfalls relative to TAM/WASP segment boundaries, and the identification of sub-sheds associated with outfalls, given in Table 2-2, were determined by ICPRB using best engineering judgement based on partial information obtained from GIS layers prepared for the District Government by LTI in 1995 (LTI, 1995) and the DC Sewerage System map (WASA, 1986). Due to incomplete information, all of the outfalls believed to be associated with sub-shed 10 were lumped into segment 25 for modeling purposes.

Daily flow inputs for each segment were computed using the results of a land use analysis, given in Tables 2-3 and 2-4, and a time series of daily flows for each land use type produced by an HSPF watershed model of the Watts Branch sub-shed, which was taken to be representative of conditions in the tidal drainage area.

Upstream Flows

The USGS maintains two surface-water discharge stations on the non-tidal Anacostia River, Station 01649500 on the Northeast Branch at Riverdale Road and Station 01651000 on the Northwest Branch at Queens Chapel Road. These stations are approximately at the head-of-tide on each of the branches. Daily discharge data in cubic feet per second (cfs) from each of the stations was used to calculate flow from the non-tidal portion of the Anacostia River, the Northeast and Northwest Branch drainage areas. The sum of the Northeast and Northwest Branch discharges was multiplied by 1.02, as was done in the past use of TAM, to account for the contribution from the area between the gages and the beginning of the first model segment, at the Bladensburg Bridge.

CSO Flows

An extensive data collection and modeling effort for the combined sewer system in support of the WASA's Long Term Control Plan has recently been completed (WASA, 2000; MWCOG, 2001b). Model simulation results from this effort were made available to ICPRB by MWCOG (Andrea Ryon, MWCOG, private communication) to support construction of CSO flow inputs for the current version of the TAM/WASP model. Simulation results contained in a file from MWCOG/WASA named cso_b1.ana, containing estimates of daily CSO flows and TSS loads to individual TAM/WASP segments, based on 1988-1990 hydrology and describing the CSO system "without Phase I Controls"[1], were used in the TAM/WASP sediment transport model calibration runs.

Watts Branch Flows

A BASINS model of the Watts Branch has been developed by ICPRB (Mandel and Schultz, 2000). The HSPF model produced in BASINS, which was calibrated against the daily stream flow record from the USGS surface-water discharge station 01651800 on the Watts Branch, was used to predict daily flows. The calibration time period was 1992-1995. The MWCOG GIS layer of Anacostia sub-watersheds was used for the delineation of the Watts Branch watershed. Land use coverages were imported into BASINS from MWCOG's Anacostia Land Use/Land Cover Data GIS layer, which was developed from a 1990 Maryland Office of Planning Land Use/Land Cover data layer and the District of Columbia Office of Planning's 1992 Generalized Land Use Map.

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[1]The combined sewer system Phase I controls, including the Northeast Boundary Sewer Swirl concentrator and a system of inflatable dams, were completed sometime in 1990 as part of an earlier program by WASA to address the CSO problem.

Table 2-2. Sub-basins of the Tidal Portion of the Anacostia Watershed

Sub-Shed ID	Sub-shed Description	Model Segment*	Bank	Type**	Outfall Description***
1	Fort Lincoln	10	West	SSTrib	66" diameter outfall located 200' east from eastern-most part of S Dakota Ave ramp to NY Ave
2	Hickey Run	12	West	SSTrib	open channel
3	Langston North	36	West	SSTrib	NA
4	Langston South	36	West	SSTrib	48" corrugated metal pipe located southeast of M St and Maryland Ave
5	Spingam High School	36	West	SSTrib	4' 6" diameter outfall located 150' north of Benning Rd Br
6	Oklahoma Ave	36	West	SSTrib	54" diameter outfall located 700' north of E Capitol St Br
7	RFK Stadium	36	West	SSTrib	6' x 5' outfall located 500' north of E Capitol St Br
8	NE Boundary Sewer	20	West	CSO	15' 6" x 8' 6" outfall adjacent to service drive behind Swirl Facility and DC General
9	Barney Circle	22	West	CSO	4' 6" x 9' outfall at Barney Circle and PA Ave
10	Area North of Navy Yard	23	West	CSO	6' x 5' outfall at M and Water Streets
		25	West	CSO	5' diameter outfall at 12th and O Streets, SE
		26	West	CSO	2' 6" x 3' 9", or 4' outfall on Navy Yard property, just upstream of the 5 piers, from narrow channel
		27	West	CSO	6' 3" diameter outfall on Navy Yard property, just downstream of the 5 piers
11	6th Street area	27	West	SSTrib	13' x 18' outfall (Paul Miller, private communication)
12	B St/New Jersey Ave/Tiber Creek	28	West	CSO	8' x 7' outfall (B St/NJ Ave) located at Main St. and O St. Pump Station
		28	West	CSO	4' 6" x 4' 3" outfall in SE Federal Center, aligned with 4th Street
		28	West	CSO	15' diameter outfall (B St/NJ Ave) located at Main St. and O St. Pump Station
		28	West	CSO	12' x 10' 6" outfall (relief sewer) located at Main St. and O St. Pump Station
		28	West	CSO	10' x 12' 6" outfall (Tiber Cr.) located at Main St. and O St. Pump Station
		28	West	CSO	54" diameter outfall (Canal St.) located at Main St. and O St. Pump Station

Sub-Shed ID	Sub-shed Description	Model Segment*	Bank	Type**	Outfall Description***
13	First Street	29	West	SSTrib	60" diameter outfall located 1000' north of Douglass Bridge and 600' south of Main Sewerage Pumping Station
14	Buzzard Point	32	West	SSTrib	7' 6" x 6' outfall located 1400' north of Greenleaf Point, 400' north of marina area
15	Nash Run via Kenilworth	10	East	SSTrib	NA
16	Watts Branch	13	East	Watts	open channel
17	Clay Street	16	East	SSTrib	10' x 7' outfall 1400' north of E. Capital St. Bridge
18	Piney Run area	18	East	SSTrib	21' x 7.5' outfall just south of East Capital St. Bridge
19	Ely's Run	18	East	SSTrib	90" diameter outfall located 1200' south of E. Capital St. Bridge
20	Fort Dupont	19	East	SSTrib	8' x 6' outfall located 1440' north of Conrail Bridge overpass
21	Pope Branch	20	East	SSTrib	concrete outfall located 2000' north of Sousa Bridge, and 400' south of RR Br
22	Texas Ave Tributary	21	East	SSTrib	6' 9" x 6' outfall located 1200' north of Sousa Bridge, referred to as Naylor Run
		21	East	SSTrib	42" diameter outfall located 1100' north of Sousa Bridge
23	Pennsylvania Ave	22	East	SSTrib	72" diameter outfall located 600' north of Sousa Bridge
24	22nd Street area	22	East	SSTrib	42" diameter outfall located 150' south of Sousa Bridge, referred to as Young
25	Naylor Road area	23	East	SSTrib	8' x 6' outfall located 1600' south of Sousa Bridge and 800' north of Anacostia Recreation Center
26	Fort Stanton	24	East	SSTrib	6' x 6' outfall located 1100' north of 12th St. Bridge and 300' south of Anacostia Pool and Recreation Center
27	Old Anacostia	25	East	CSO	2' 6" x 8' / 5' x 12' outfall located between 11th St and Anacostia Bridges
		25	East	CSO	4' x 4' outfall located at Good Hope Rd and Welsh Memorial Bridge
		26	East	CSO	6' x 5' 3" outfall across from Navy Yard
28	Suitland/Stickfoot	27	East	SSTrib	11' diameter outfall located 1000' upstream of Main Sewerage Pumping Station

Sub-Shed ID	Sub-shed Description	Model Segment*	Bank	Type**	Outfall Description***
29	Poplar Point/Howard	30	East	CSO	5' x 5' 5" outfall (bypass sewer) located at Howard Rd and Robbins Rd
30	I-295/St. Elizabeth's Hospital (south)	30	East	SSTrib	90" diameter outfall located 400' south of Douglas Bridge across river from Capital Ave
33	Lower Beaverdam	7	East	LBD	open channel
35	Dueling Creek	5	West	SSTrib	open channel

* Based on ICPRB's best engineering judgement using partial information from GIS layers produced by LTI (see LTI, 1995) and the DC Sewerage System map (WASA, 1986).

** SSTrib = separate sewer system and minor tributaries; CSO = combined sewer overflow; Watts = Watts Branch; LBD = Lower Beaverdam Creek.

*** Based on ICPRB's best engineering judgement using partial information from GIS layers produced by LTI (see LTI, 1995) and the DC Sewerage System map (WASA, 1986); NA = not available.

Table 2-3. Results of Land Use Analysis of Tidal Drainage Area

Subshed	Total Area	Impervious Area	Urban Pervious Area	Forested Pervious
1	141	65	75	0
2	1130	415	714	0
3	48	4	45	0
4	97	22	75	0
5	27	16	11	0
6	53	19	33	0
7	69	13	56	0
8	4200	2145	2055	0
9	33	13	19	0
10	547	244	302	0
11	16	7	9	0
12	1845	994	851	0
13	24	22	2	0
14	146	97	50	0
15	465	163	302	0
16	2470	821	1425	224
17	503	202	301	0
18	808	242	566	0
19	131	48	83	0
20	434	47	388	0
21	262	52	210	0
22	216	48	168	0
23	205	58	148	0
24	36	14	22	0
25	140	54	87	0
26	367	132	235	0
27	286	103	184	0
28	550	223	327	0
29	35	21	14	0
30	346	155	191	0
33	10466	3864	4709	1893
35	838	229	609	0

Table 2-4. Results of Land Use Analysis of Direct Drainage Sub-Sheds

Segment	East Bank Direct Drainage Areas:				West Bank Direct Drainage Areas:			
	Area	Urban Impervious	Urban Pervious	Forested Pervious	Area	Urban Impervious	Urban Pervious	Forested Pervious
1	88	54	34	0	16	4	12	0
2	310	139	132	39	114	32	80	2
3	97	52	16	29	42	3	33	6
4	97	46	32	20	23	2	15	6
5	98	27	69	3	11	1	8	1
6	29	6	23	0	18	1	17	0
7	10	1	9	0	36	3	34	0
8	5	0	5	0	24	4	21	0
9	6	0	5	0	35	5	31	0
10	214	21	193	0	61	12	49	0
11	26	2	24	0	24	2	22	0
12	17	1	15	0	17	1	16	0
13	55	21	33	0	11	1	10	0
14	110	49	61	0	13	1	12	0
15	35	15	20	0	16	1	15	0
16	22	5	17	0	15	1	13	0
17	43	15	29	0	11	1	11	0
18	50	14	35	0	13	1	12	0
19	42	14	29	0	386	35	351	0
20	61	16	45	0	41	15	26	0
21	63	12	51	0	47	10	37	0
22	34	5	29	0	43	6	37	0
23	45	4	40	0	27	10	18	0
24	37	3	34	0	44	23	21	0
25	33	2	30	0	30	14	16	0
26	61	5	56	0	52	23	29	0
27	58	6	52	0	35	14	22	0
28	27	2	25	0	50	21	29	0
29	25	2	23	0	51	29	22	0
30	27	5	22	0	46	27	19	0
31	52	22	30	0	29	13	16	0
32	68	30	38	0	22	6	16	0
33	86	42	44	0	15	1	14	0

Lower Beaverdam Creek Flows

Prince George's County has had Tetra Tech, Inc. develop an HSPF model of the Lower Beaverdam Creek. The model was used to calculate the daily flow from Lower Beaverdam Creek. The only change made was to use meteorological data from Reagan National Airport for the period 1985-2000.

Flows from other tributaries, storm sewers, and direct drainage to the tidal Anacostia River

The flow from other tributaries, storm sewers, and the direct drainage to the tidal Anacostia River was calculated using the output from the HSPF model for the Watts Branch. The HSPF model can calculate daily flow from each land use type represented in the model. Three distinct land use types were represented: (1) impervious land, (2) pervious forested land, and (3) non-forested urban pervious land, i.e., lawns and other areas covered with turf. MWCOG supplied information needed to estimate of the amount of each type of land use in the drainage area for each model segment within the District. Similar calculations were made for the direct drainage to the tidal Anacostia in Maryland. Tables 2-3 and 2-4 show the amount of each land use type in the various drainage areas for each segment. Daily flow into each segment was calculated as the product of the flow per unit area from each land use type, as determined from the Watts Branch HSPF model, and the area of that type in the segment's drainage.

2.2. Inputs for the TAM/WASP Sediment Transport Model

The TOXIWASP component of the TAM/WASP Sediment Transport Model simulates changes in sediment concentrations in both the water column and the bed sediment by simulating the processes of advective transport, dispersive transport, deposition and erosion. The model classifies sediments into three categories according to grain size:

Frac1 - coarse-grained material:	sand and gravel (grain sizes > 120 μm)
Frac2 - medium-grained material:	silt and very fine sand (grain sizes between 30 and 120 μm)
Frac3 - fine-grained material:	clay and very fine silt (grain sizes < 30 μm)

2.2.1. Load Inputs

Daily sediment load values for input into TOXIWASP were estimated from available tributary, separate storm sewer, and CSO monitoring data for TSS. Because no monitoring data is available to determine the relative proportions of the individual sediment size fractions in sediment loads entering the river, the proportion of each size fraction to TSS was estimated from the bed sediment grain size data collected recently by GeoSea Consulting, Ltd. for the AWTA (Hill and McLaren, 2000). Based on the GeoSea data set, the relative proportion of the three size fractions residing in the river bed is:

Frac1:	0.22
Frac2:	0.24
Frac3:	0.54

In initial calibration runs, the proportions given above were used to estimate the daily loads of the individual size fractions based on the daily TSS loads estimated from monitoring data. During the calibration process, the relative proportions of the individual size fractions in the sediment loads were adjusted to account for the fact that a significant amount of fine-grained material appears to be exported from the tidal river (see Chapter 3).

Daily loads of TSS were calculated by multiplying daily flow volumes by daily concentration estimates. Details concerning the methods used to estimate sediment loads for each of the river's sediment sources are given below.

Upstream Loads

Daily sediment loads for the Northeast and Northwest Branches were estimated based on monitoring data collected in 1999 and 2000 as part of the WASA LTCP program. The following provisional event mean concentrations (EMC) for TSS were provided by MWCOG (T. J. Murphy, MWCOG, private communication).

NE Branch Provisional Non-storm EMC:	7 mg/L
NE Branch Storm Provisional EMC:	475 mg/L
NW Branch Provisional Non-storm EMC:	2 mg/L
NW Branch Provisional Storm EMC:	293 mg/L

The MWCOG/WASA LTCP upstream storm and non-storm provisional EMCs given above were used to estimate TSS storm and non-storm concentrations in initial calibration runs. During the calibration process, storm concentrations were reduced to 85% of the values above (see Chapter 3).

Daily TSS loads from the Northeast Branch and Northwest Branch were estimated by multiplying daily flow values by TSS concentration estimates. Daily flow values obtained from USGS gage data were first separated into base flow and storm flow components using the USGS hydrograph separation program, HYSEP, using the local minimum method. Then the total daily upstream TSS load was computed by summing the loads from four components as follows:

Total Daily TSS Load = (NE Baseflow)*(NE Non-storm Concentration) **(2.2)**
+ (NE Stormflow)*(NE Storm Concentration)
+ (NW Baseflow)*(NW Non-storm Concentration)
+ (NW Stormflow)*(NW Storm Concentration)

Watts Branch Loads

Daily TSS loads from the Watts Branch tributary were estimated by multiplying Watts Branch daily flows by estimates of Watts Branch TSS concentrations. The ICPRB HSPF model of the Watts Branch was used to generate a time series of daily storm flows and non-storm flows for each of the three land use types discussed above for the Watts Branch sub-shed. Because no storm flow monitoring data for TSS is available for Watts Branch, a storm TSS concentration of 227 mg/L was used, based on the MWCOG Pope Branch open channel result (Shepp et al., 2000). A non-storm TSS concentration of 6 mg/L for the Watts Branch was estimated from available DC DOH routine monitoring data for station TWB01 (time period 4/20/82 to 12/9/97) by computing the median value of the non-storm data (where the criteria for non-storm conditions was no precipitation recorded at National Airport on the day of and the day preceding the sampling event).

Lower Beaverdam Creek Loads

Output from the Prince Georges County/Tetra Tech HSPF model of Lower Beaverdam Creek was used to generate daily TSS loads from Lower Beaverdam.

CSO Loads

Simulation results contained in the file from MWCOG/WASA named cso_b1.ana, were used as estimates of daily CSO TSS loads to TAM/WASP for model calibration runs. These daily load estimates are based on 1988-1990 hydrology and a CSO system "without Phase I Controls".

Loads from Separate Storm Sewers and Other Tributaries

The sediment loads from other tributaries, storm sewers, and the direct drainage to the tidal Anacostia River were calculated using the flow estimates for each of the tidal drainage basin sub-sheds, based on the Watts Branch HSPF model daily flow output (see discussion in Section 2.1.3). Daily non-storm and storm flows for each sub-shed were then multiplied by estimates of TSS concentrations for the sub-shed. Storm and non-storm TSS concentrations used to compute daily load inputs from the separate sewer system and minor tributaries sub-sheds are given in Table 2-5. The use of the TSS storm concentration of 227 mg/L for Nash Run, Fort Dupont, Pope Branch follows the MWCOG designation of these sub-sheds as primarily open channel systems, and the MWCOG-estimated storm concentration for these systems based on Pope Branch monitoring data (Shepp et al., 2000). The use of the TSS storm concentration of 94 mg/L for the remaining sub-sheds listed in Table 2-5 is based on recent WASA LTCP provisional results (T.J. Murphy, MWCOG, private communication). This value is not significantly different from the TSS storm concentration value of 86 mg/L suggested for these sub-sheds by Shepp et al. (Shepp et al., 2000). A TSS storm concentration of 94 mg/L and non-storm concentration of 0 mg/L were used to calculate daily loads from the direct drainage areas.

2.2.2. Downstream Boundary Conditions

The TAM/WASP sediment transport model requires that the user input a time series of downstream boundary conditions for each of the three sediment size fractions, representing daily average water column concentrations of each of the suspended sediment size fractions in the Potomac River. Constant boundary condition values of 0 mg/L for coarse-grained sediment, 2 mg/L of medium-grained sediment, and 12 mg/L of fine-grained sediment were used for initial calibration runs. These values are based on an average TSS concentration of 14 mg/L from available DC DOH routine monitoring data at Station ANA29, near the confluence of the Anacostia and the Potomac River, and an average relative suspended sediment size fraction composition of 0% coarse-grained / 14% medium-grained / 86% fine-grained found in samples taken at Station ANA29 by the Academy of Natural Sciences (Schultz and Velinsky, 2001). These boundary condition values were adjusted during the calibration process to 0 mg/L for coarse-grained sediment, 2 mg/L of medium-grained sediment, and 20 mg/L of fine-grained sediment, as discussed in Chapter 3.

Table 2-5. TSS Non-storm and Storm Concentration Values for Tidal Drainage Area Sub-sheds

Sub-shed	Description	TSS Non-storm Concentration (mg/L)	TSS Storm Concentration (mg/L)	Source of Estimate
1	Fort Lincoln	2	94	MWCOG/WASA LTCP
2	Hickey Run	2	94	MWCOG/WASA LTCP
3	Langston North	0	94	MWCOG/WASA LTCP
4	Langston South	0	94	MWCOG/WASA LTCP
5	Spingam High School	0	94	MWCOG/WASA LTCP
6	Oklahoma Ave	0	94	MWCOG/WASA LTCP
7	RFK Stadium	0	94	MWCOG/WASA LTCP
11	6th St	0	94	MWCOG/WASA LTCP
13	First St	0	94	MWCOG/WASA LTCP
14	Buzzard Point	0	94	MWCOG/WASA LTCP
15	Nash Run via Kenilworth	2	227	MWCOG Open Channel (from Pope Branch)
17	Clay St	0	94	MWCOG/WASA LTCP
18	Piney Run	0	94	MWCOG/WASA LTCP
19	Ely's Run	0	94	MWCOG/WASA LTCP
20	Fort Dupont	2	227	MWCOG Open Channel (from Pope Branch)
21	Pope Branch	2	227	MWCOG Open Channel (from Pope Branch)
22	Texas Ave	0	94	MWCOG/WASA LTCP
23	Pennsylvania Ave	0	94	MWCOG/WASA LTCP
24	22nd St	0	94	MWCOG/WASA LTCP
25	Naylor Rd	0	94	MWCOG/WASA LTCP
26	Fort Stanton	0	94	MWCOG/WASA LTCP
28	Suitland Pkway/St Elizabeth	0	94	MWCOG/WASA LTCP
30	I295/St Elizabeths	0	94	MWCOG/WASA LTCP
35	Dueling Cr	2	94	MWCOG/WASA LTCP

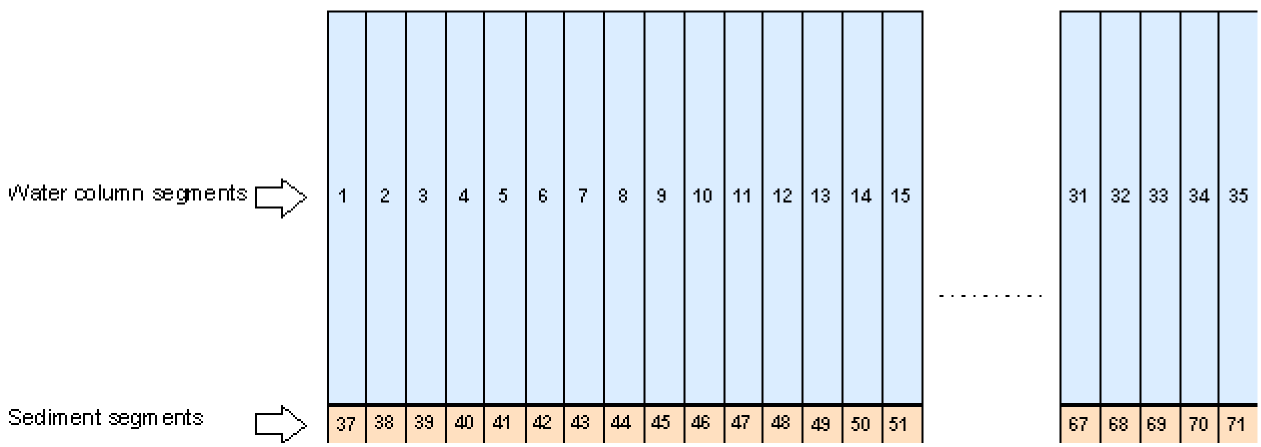

Figure 2-1. Schematic Representation of Location of Sediment Segment Underlying Water Column Segments

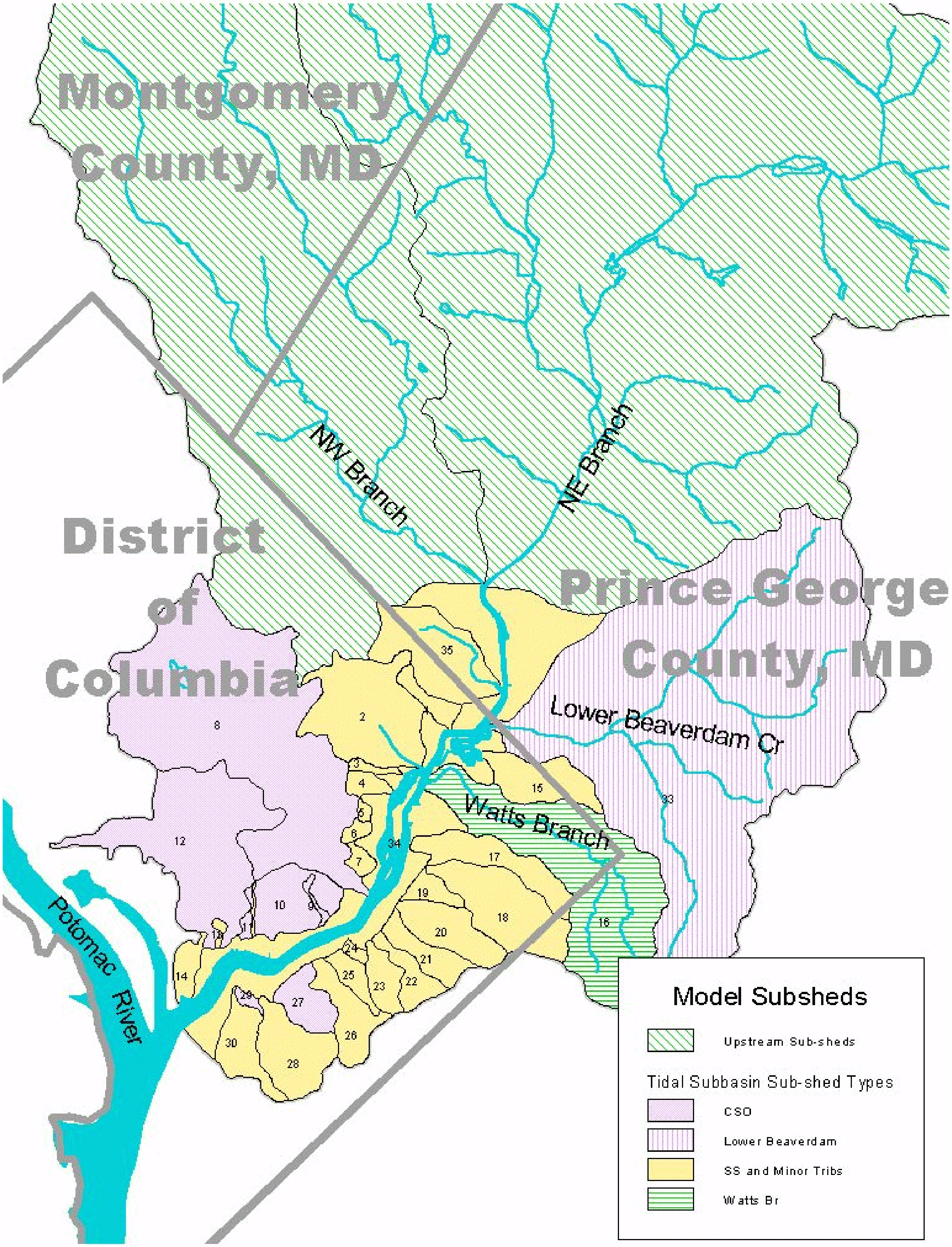

Figure 2-2. Sub-Sheds of the Tidal Drainage Area

CHAPTER 3: MODEL CALIBRATION

The TAM/WASP sediment transport model simulates the transport of sediments based on the set of simple algorithms discussed in Section 1.3. As can be seen from equations (1.1) through (1.6), the model-simulated sediment transport processes of erosion and deposition are dependent upon a relatively small set of model parameters, including the critical bed shear stress for erosion, τ_c , the critical shear stress for deposition, τ_d , and the zero-flow settling velocity, V_s. Transport properties are also dependent on model flow velocities, V, which are simulated for each segment at each model time step (with time step = 1/200 day for model calibration runs) by the TAM hydrodynamic model.

Calibration of the TAM/WASP sediment transport model was primarily accomplished by adjusting model parameters, listed in Table 3-1, until a reasonable match was found between model predictions and empirical data. As discussed below, some adjustments were also made to other model inputs. The values of model parameters given in Table 3-1 were set uniformly for all model segments, with the exception of segment 1. The calibration time period was January 1, 1988 through December 31, 1990. This calibration time period was chosen because these three years have been found to represent fairly typical hydrology for the region, including a relatively wet year, a relatively dry year, and a relatively average year (Mandel and Schultz, 2000). In order to allow the model to approach steady-state conditions, a preliminary model run was made with the initial bed sediment size fraction concentrations set uniformly at Frac1 = 33.3%, Frac2 = 33.3%, Frac3 = 33.3%. Using the WASP "RESART" file option, the three-year calibration run was then run using the initial conditions created by the preliminary run. A discussion of the model-simulated hydrodynamics, the data sets relied upon for the calibration, and considerations made during the calibration process is given below.

Table 3-1. TAM/WASP Sediment Transport Model Final Calibration Parameter Values

Model Parameter	WASP Variable Name	Frac1	Frac2	Frac3
V_s = settling velocity at zero flow (m/d)	SETV	NA	20.0	2.0
τ_d = critical shear stress threshold for deposition (N/m^2)	TAUD	NA	0.02	0.02
V_e = erosion velocity constant (m/d)	EROSV	NA	0.00004	0.00001
τ_c = critical shear stress threshold for erosion (N/m^2)	TAUC	NA	0.20	0.10
k_e = user-determined constant	EXSAND	4.0	NA	NA
k_s, = user-determined constant	KSAND	50.0	NA	NA

3.1 Summary of Model-Simulated Hydrodynamics

Because of the relatively low flow velocities believed to occur in the tidal Anacostia River, the river has been characterized as a primarily depositional environment. Measured flow velocities over a tidal cycle during non-storm conditions are in the range of 0 to 0.3 m/sec (Katz et al., 2000; Schultz and Velinsky, 2001). Flow velocities are lowest in the stretch of the river downstream of the 11th Street bridge, and in this area fine-grain sediments predominate.

Hydrodynamics in the TAM/WASP sediment transport model is simulated by a 35 segment version of the TAM model, which predicts flow velocities and water surface elevations at each model time step. A cumulative distribution of model-predicted flow velocities at WASP model transects for each time step (200 time steps per day) of the 1988-1990 calibration run is given in Table 3-2 (where transect n is the boundary between model segment (n-1) and model segment n). From this table, it can be seen that flow velocities are generally less than 0.5 m/sec, and at no time during the years, 1988 through 1990, did the model predict a flow velocity greater than 0.85 m/sec. From the cumulative velocity distribution, the approximate median velocities for the calibration run can be computed. These median velocities are graphed in Figure 3-1. From this graph it is evident that flow velocities in the tidal river are greatest mid-river, with the highest median velocities occurring in the two stretches of the river represented by model segments 11 through 14 and segments 18 and 19.

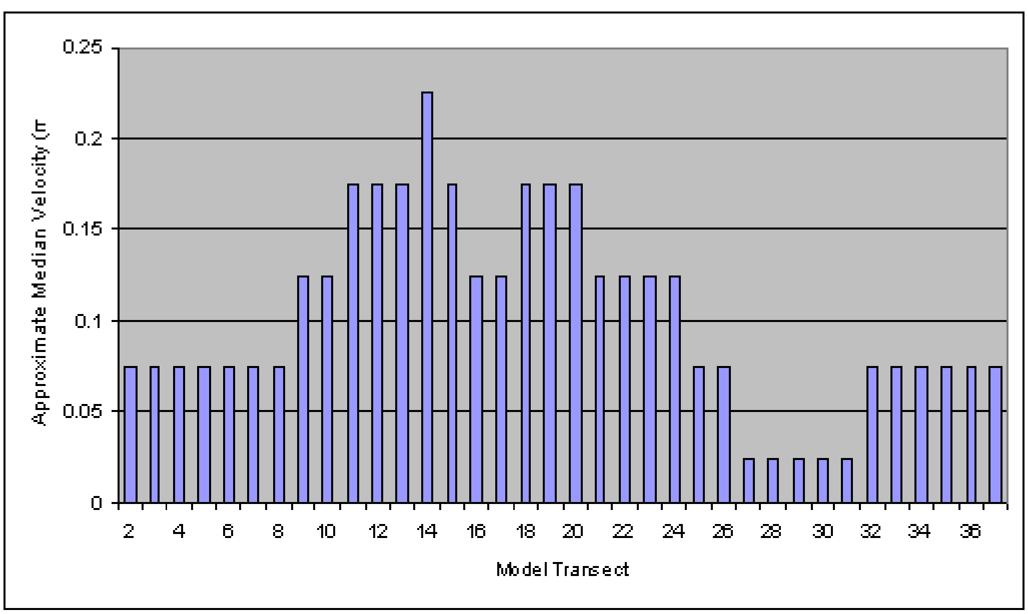

Figure 3-1. Approximate Median Flow Velocities for Calibration Run

The characterization of the river as primarily depositional is consistent with preliminary comparisons of model-predicted bed sediment grain size composition versus empirical data. During certain initial calibration runs, the simulation of erosion processes for cohesive sediment fractions (i.e. fine-grained and medium-grained material) was turned off, and the resulting model predictions of bed sediment composition compared quite well to existing data.

3.2. Data Sets Used in Calibration

The calibration of the TAM/WASP sediment transport model was based on model runs for the three-year time period, 1988 - 1990. Model simulation results were compared to TSS monitoring data for this time period, available from the DC Department of Health (DC DOH) routine monitoring program and from a special study by MWCOG done in 1988 through 1991 in conjunction with the District's abatement program for the combined sewer overflow problem. In addition, information from several other studies was used to assist in the determination of appropriate calibration parameters. The data sets used in model calibration are described below.

3.2.1. Data from the DC DOH Ambient Monitoring Program

Water quality in the tidal portion of the Anacostia River is routinely monitored by the DC DOH, which maintains a system of 29 water quality monitoring stations in the tidal portion of the Anacostia River. The District's Anacostia River stations range from ANA01, at the New York Avenue bridge near the District line, to ANA29, at the Anacostia's confluence with the Potomac River. The locations of the stations are described in Table 3-3 and depicted in Figure 3-2. At the present time, water quality data for stations ANA01 through ANA29 are available for the time period January 1984 through December 1998, and data for the relatively new station, ANA30, are available for the period April 1990 through December 1998. Comprehensive monitoring at this network of stations has generally taken place one day each month, including in-situ field measurements at most monitoring stations, and collection of grab samples at selected monitoring stations. An additional set of field measurements have generally been made on a second date of each month. Regular monthly sampling has also been conducted by the Maryland Department of Natural Resources (MDDNR) at a monitoring station located at the Bladensburg Road Bridge (ANA0082) beginning in January 1986. Water quality data for all stations listed in Table 3-3 was obtained from the Chesapeake Bay Program's water quality database available online via www.chesapeakebay.net.

Table 3-2. Cumulative Distribution of Predicted Flow Velocities (m/sec) at Model Transects, for Three-Year Calibration Run

WASP Transect	0.0 to 0.05	0.05 to 0.10	0.10 to 0.15	0.15 to 0.20	0.20 to 0.25	0.25 to 0.30	0.30 to 0.35	0.35 to 0.40	0.40 to 0.45	0.45 to 0.50	0.50 to 0.55	0.55 to 0.60	0.60 to 0.65	0.65 to 0.70	0.70 to 0.75	0.75 to 0.80	0.80 to 0.85	> 0.85
2	72870	121539	15288	4795	2308	1292	529	179	0	1	0	38	161	0	0	0	0	0
3	70915	128681	12973	3618	1609	741	262	1	0	1	1	29	149	20	0	0	0	0
4	45335	134376	29757	5035	2022	1470	505	298	2	0	0	1	1	1	21	92	84	0
5	52116	136395	23955	3800	1629	640	264	1	0	1	2	1	85	111	0	0	0	0
6	43505	136074	32419	4675	1614	487	25	2	0	2	30	123	44	0	0	0	0	0
7	35563	124212	47615	8962	1671	615	160	2	1	1	15	74	109	0	0	0	0	0
8	28110	84741	79812	19609	3928	1687	617	294	2	0	2	1	20	66	111	0	0	0
9	24629	65023	92387	25858	7611	1863	1002	270	156	1	0	2	2	19	55	109	13	0
10	23361	57928	95915	28414	9634	2097	1028	267	155	1	1	2	1	22	57	105	12	0
11	15021	23664	52559	73527	29322	15541	6910	1919	319	16	3	2	9	17	46	59	66	0
12	14276	21318	45447	71825	36629	17112	8872	2842	384	92	3	2	10	18	45	51	74	0
13	13118	18271	35257	60949	52715	20054	12212	4985	1057	179	2	3	17	15	45	43	78	0
14	12321	16388	29040	48169	60796	27622	14888	7197	2028	253	97	8	15	18	45	40	75	0
15	14273	20591	39627	64698	48154	19486	9355	2297	247	72	15	13	39	35	51	47	0	0
16	19075	33765	71743	63454	22503	7555	641	63	20	29	44	57	51	0	0	0	0	0
17	19779	34835	71068	64257	22367	6134	358	19	29	46	54	54	0	0	0	0	0	0
18	16384	24091	43635	66386	45255	17885	4872	247	69	41	31	45	59	0	0	0	0	0
19	15914	22235	37947	57155	54163	23405	7271	630	110	39	30	39	55	7	0	0	0	0
20	18704	26111	43076	62811	45552	18072	4390	157	34	49	44	0	0	0	0	0	0	0
21	22825	35025	61446	66285	26304	6775	214	38	86	2	0	0	0	0	0	0	0	0
22	22954	34550	59364	66614	27708	7396	298	34	82	0	0	0	0	0	0	0	0	0
23	24950	38602	66470	62573	22418	3831	65	91	0	0	0	0	0	0	0	0	0	0
24	35913	68818	85824	26115	2221	107	2	0	0	0	0	0	0	0	0	0	0	0
25	50700	106156	56354	5681	109	0	0	0	0	0	0	0	0	0	0	0	0	0
26	82113	122455	14336	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	124495	93575	930	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	130369	88063	568	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	117812	99378	1810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	115199	101479	2322	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	116439	100350	2211	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	101136	111652	6212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	86025	118669	14297	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	82150	119289	17539	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	89200	117116	12674	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	90543	116182	12267	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3-3. Tidal Anacostia River Water Quality Monitoring Stations

Station	Description of Station Location[a]	WASP
ANA0082	Anacostia River bridge on Bladensburg Road	1
ANA01	New York Avenue bridge, 50 m upstream of westbound bridge	7
ANA02	Aquatic Gardens near middle river bend	8
ANA03	Aquatic Gardens inlet, upstream side	9
ANA04	National Arboretum, 200 m downstream of river bend	10
ANA05	Hickey Hill, 200 m upstream of Hickey Run	11
ANA06	Kingman Lake, downstream side	13
ANA07	Upstream of Benning Road PEPCO power plant	14
ANA08	Benning Road power plant, southern most stack	15
ANA09	Kingman Island, across from gazebo on east bank	16
ANA10	Upstream of East Capital Street bridge	17
ANA11	Kingman Island south at daymarker #5	18
ANA12	Kingman Lake outlet, upstream side	19
ANA13	Railroad bridge, 50 m downstream of bridge	20
ANA14	Pennsylvania Avenue, marina south dock	22
ANA15	Pennsylvania Avenue south, 100 m downstream of bridge	22
ANA16	Anacostia Park pool across from marina flagpole	23
ANA17	11th Street bridge on upstream side	25
ANA18	Navy Yard east, 200 m west of 11th street bridge	25
ANA19	Navy Yard, across from east pier	26
ANA20	Navy Yard west, next to west pier	28
ANA21	100 m north of South Capitol Street bridge	29
ANA22	300 m south of South Capitol Street bridge	30
ANA23	Buzzard Point power plant, between fl#3 and nun #2	31
ANA24	Buzzard Point marina, south of east dock	32
ANA25	Greenleaf Point, approximately 100 m south of can #1	33
ANA27	Hains Point, 100 m north of n #2	34
ANA29	At red and green flasher near Potomac confluence	35
ANA30	Across the Anacostia River main navigational channel, across the most	1

[a]From the Chesapeake Bay Program's Water Quality Database, Station Information.

3.2.2. MWCOG/OWML 1988-91 data collection associated with the Combined Sewer Overflow abatement program

During the time period, July 1988 through June 1991, MWCOG undertook a data collection effort in conjunction with the District's abatement program for the combined sewer overflow problem. Both baseline and wet weather longitudinal water quality data were collected at selected monitoring stations in the tidal Anacostia by the subcontractor, Occoquan Water Monitoring Laboratory (OWML). The 1988-1991 MWCOG/OMWL data contains longitudinal sample sets, consisting typically of concentrations of constituents of interest, including TSS, at eight to ten monitoring stations along the length of the tidal Anacostia, at selected dates in the summer and fall, with much of the longitudinal data taken during wet weather conditions. Additional data was taken during OWML's routine maintenance visits to the Benning Road Bridge and Seafarers' Marina continuous monitoring stations. For a detailed description of the 1988-1991 MWCOG/OMWL data, the reader is referred to the report by Nemura et al (1991).

3.2.3. ANS/ICPRB Sediment Study

A joint project by the Academy of Natural Sciences (ANS) and ICPRB to provide data to aid in the understanding of sediment transport dynamics in the tidal Anacostia River was recently completed (Schultz and Velinsky, 2001). Water column samples were collected at two locations over a tidal cycle on two separated occasions to provide fixed point time series data, and were also collected from ten sampling stations on four separate occasions to provide longitudinal profile data. The water column samples were analyzed for flow velocity, TSS, total organic carbon (TOC), particle grain size distributions, and additional water quality parameters. Also, surficial bed sediment samples were collected from 128 locations and analyzed for particle grain size distributions and organic carbon and organic nitrogen content. The ANS/ICPRB sediment study provides the only data available on the particle size fraction composition of suspended sediment in the Anacostia.

Results of the ANS/ICPRB study were used in the calibration to assist in the determination of the relative magnitudes of parameters governing suspension and deposition of medium-grained versus fine-grained material. The study found that measured TSS concentrations in samples collected over a tidal cycle near Kenilworth Marsh during non-storm conditions ranged from 7 to 30 mg/L on 7/7/99 and ranged from 8 to 15 mg/L on 11/9/99. TSS concentrations in samples collected over a tidal cycle near the Navy Yard ranged from 6 to 19 mg/L on 7/8/99 and ranged from 10 to 17 mg/L on 11/10/99. These results demonstrate that tidal flow velocities produce significant resuspension of sediment in the Anacostia. The ANS/ICPRB study also investigated the relationship between flow velocity and TSS concentrations in the river during non-storm conditions, and concluded that the critical velocity for resuspension of fine silt (0 to 30 μm) material was likely in the range of 5 to 15 cm/sec. No critical velocity for resuspension of larger particle sizes (> 30 μm) could be determined within the range of flow velocities represented by the data.

The ANS data set also contains valuable information on concentrations of particle size fractions in the water column. In the longitudinal profile data, the percentage of medium-grained particles (30 to 120 μm) to total measured particles (2 to 120 μm) ranged from 2% to more than 34%, with a mean of 13% and a standard deviation of 8%. The amount of coarse-grained material (> 120 μm) present in the water column was judged to be negligible.

3.2.4. GeoSea Bed Sediment Grain Size Analysis Data

In the summer of 2000, the Anacostia Watershed Toxics Alliance (AWTA) sponsored a project to characterize the grain size distribution of the surficial bed sediments of the Anacostia (Hill and McKlaren, 2000). The AWTA subcontractor, GeoSea, collected and analyzed over 600 sediment samples. For each sample, the size distribution of particles greater than 1 mm was determined by dry sieving at 0.5 ϕ intervals[2]. The size distribution of particles less than 1mm was analyzed with a Malvern Mastersizer 2000 laser particle sizer, based on principles of light defraction.

ICPRB used ESRI's ArcView and Spatial Analyst software to estimate from GeoSea data the average percentages in each model segment of the model's three particle size categories: size fraction 1 (> 120 μm), size fraction 2 (between 30 and 120 μm); and size fraction 3 (< 30 μm). The results of this analysis, given in Table 3-4, were compared with model simulation results to assist in the determination of model calibration parameters (see Section 3.3).

[2] ϕ(phi) is the unit of measure most commonly used in sediment size distributions where ϕ is defined as $\phi = -\log(D)/\log 2$, where D = particle diameter (mm).

Table 3-4. Sediment Bed Particle Size Fraction Distribution Estimated From Empirical Data

Segment	Size Fraction 1 Average Percentage by Weight	Size Fraction 2 Average Percentage by Weight	Size Fraction 3 Average Percentage by Weight
0	99.1	0.2	0.2
1	94.3	2.7	2.8
2	43.6	24.3	31.4
3	17.7	33.4	48.3
4	37.1	31.2	30.5
5	20.6	30.8	47.6
6	18.3	31.1	49.9
7	28.8	26.4	44.1
8	45.0	28.6	25.6
9	36.9	22.5	40.3
10	49.8	17.1	32.2
11	37.0	20.0	42.2
12	28.6	22.0	48.4
13	66.9	13.6	18.8
14	54.8	18.3	26.0
15	35.5	23.0	40.9
16	23.3	30.5	45.6
17	38.1	26.0	35.3
18	39.0	24.8	35.4
19	34.5	27.2	37.5
20	32.6	27.5	39.2
21	36.1	24.9	38.3
22	20.2	30.1	48.7
23	24.4	34.9	39.8
24	15.3	30.2	53.7
25	9.9	26.9	62.5
26	5.7	22.4	71.3
27	11.0	20.7	67.7
28	13.7	20.4	65.0
29	18.7	20.3	60.2
30	7.5	17.7	73.9
31	3.6	17.9	77.8
32	3.5	19.1	76.5
33	5.6	21.6	72.2
34	7.7	23.8	67.7
35	11.4	25.6	62.1

3.3. Determination of Model Calibration Parameters

Model calibration runs were made for the time period January 1, 1988 through December 31, 1990, and predicted TSS water column concentrations were compared with available data from the DC DOH routine monitoring program and the MWCOG/OWML 1988-1991 data collection effort. Initial segment concentrations for the calibration run were obtained from the last day segment concentrations of a preliminary model run which was made in order to allow the model to approach steady-state conditions. The preliminary run, also based on the 1988-1991 time period, was made with the initial bed sediment size fraction concentrations set uniformly at Frac1 = 33.3%, Frac2 = 33.3%, Frac3 = 33.3%. Because the depth of the bed sediment segment was set at only 1 centimeter, the final bed sediment size fraction concentrations of the preliminary run were reasonably close to steady state values and reasonably close to empirical data. Final calibrated model simulation results are compared with TSS water column monitoring data in Figures 3-3, 3-4, 3-5, and 3-6 for model segments 7, 15, 22, and 29. During the calibration process, comparisons were also made between model predictions of bed sediment size fraction concentrations and the GeoSea bed sediment grain size distribution results given in Table 3-4. The calibrated model predictions of bed sediment segment size fraction concentrations on the last day of the calibration run compared with corresponding grain size fraction composition from the GeoSea data appear in Figure 3-7. Final calibration parameters are given in Table 3-1. Considerations influencing selection of calibration parameters, as well as adjustments made to model input loads during the calibration process, are discussed below.

3.3.1. Initial Model Setup

In the calibration runs the TOXIWASP model option of variable bed volume was used, where the initial depth of the surficial sediment layer was set at 1 cm. The shallow depth of the sediment bed layer made the bed concentrations more responsive to changes which occurred over the course of the calibration run. As discussed above, initial bed sediment size fraction concentrations on the first day of a three-year preliminary run were set at Frac1 = Frac2 = Frac3 for all segments. Final segment concentrations produced by the preliminary run were used as initial segment concentrations for the calibration run. Anacostia River sediment density was assumed to be 2.5 gm/cm^3 , typical of Chesapeake Bay sediments (Velinsky et al., 1997), and porosity was assumed to be 0.6. A longitudinal dispersion coefficient of 1.3 m^2/sec was used in the model, based on results of the analysis of a dye study conducted by LTI (MWCOG, 2001a).

3.3.2. Calibration Parameters for Settling and Resuspension of Cohesive Sediments

In the TAM/WASP sediment transport model, the simulation of sediment deposition processes for cohesive sediments (fine-grained and medium-grained material) is governed by equation (1.4). No deposition occurs when bed shear stress is greater than a critical value, τ_d, and the settling velocity is a product of the zero-flow settling velocity, V_s, and a factor dependent on bed shear stress, $(1 - \tau_b/\tau_d)$. In initial calibration runs, model-predicted TSS peaks during storms were too high, and the zero-flow settling velocity, V_s, was increased to 20 m/day for medium-grained material and 2 m/day for fine-grained material in order to reduce most of the TSS peaks to values consistent with high values in the measured data set, i.e. on the order of 200 mg/L. The calibration values for V_s are within the range of suggested settling velocities based on particle size (Ambrose et al., 1993). However, though settling velocities had to be set high enough to produce reasonably low TSS peaks during storms, adjustments also had to be made to model parameters in order to match the relatively high TSS concentrations measured during non-storm periods. It was found that this could be done while maintaining a reasonable match to sediment bed sediment composition data by setting τ_d, the critical shear stress threshold for deposition, to the value of 0.02 N/m^2 for both fine-grained and medium-grained material (corresponding to threshold velocity for deposition of approximately 0.05 to 0.06 m/sec).

Sediment erosion, or resuspension, processes are modeled by equation (1.5). Erosion only occurs when bed shear stress is greater than a critical value, τ_c, and the erosion velocity is a product of a constant multiplicative factor, V_e, and a factor dependent on bed shear stress, $(\tau_b/\tau_c - 1)$. Note that the multiplicative factor, V_e, represents the erosion velocity when bed shear stress is two times the value of critical shear stress threshold. The critical shear threshold for erosion was set at 0.20 for medium-grained material (corresponding to a threshold velocity of approximately 0.17 to 0.20 m/sec) and 0.10 for fine-grained material (corresponding to a threshold velocity of approximately 0.12 to 0.14 m/sec). This is consistent with the results found in the ANS/ICPRB sediment study, noted above. The erosion velocity constant multiplicative factors, V_e, were set at relatively low values of 0.004 cm/day for medium-grained material and 0.001 cm/day for fine-grained material. The model erosion parameters, τ_c and V_e, were primarily determined by comparing model-predicted bed sediment composition with bed sediment data (Figure 3-7). It can be seen from the cumulative velocity distribution (Table 3-2) and from Figure 3-1 that model-predicted flow velocities are greatest in segments 11 through 14 and segments 18 and 19. This is also evident in Figure 3-7, where it can be seen that the medium and fine-grained sediment fractions are preferentially eroded from these segments. When the magnitude of erosion processes was set too high, too much fine and medium-grained material was eroded from this area of the river, leading to concentrations of fine and medium-grained material in the sediment bed that were too low.

The ANS/ICPRB study found that the percentage of medium-grained solids to total solids in the water column was roughly 10%. Calibration run results predicted the average percentage of medium-grained solids in the water column to be rather low, at approximately 5%. Attempts during the calibration to adjust parameters governing the settling and resuspension in order to increase the proportion of medium to fine-grained material in the water column led to unacceptably high TSS storm peaks.

Model calibration parameters, given in Table 3-1, were set uniformly along the entire length of the tidal river, with the exception of segment 1. A separate set of calibration parameters was used for segment 1 because it contains a large area, upstream of the Bladensburg Bridge, which was treated in the hydrodynamic model as a tidal embayment. Therefore, the simulation of flow velocities in segment 1 was probably poor, and changes were made to segment 1 calibration parameters to improve the match to bed sediment composition data. In segment 1, the calibration parameters governing the settling and resuspension of cohesive sediments were as follows: $\tau_{d,\ frac2} = 0.02$; $V_{s,\ frac2} = 20.0$; $\tau_{d,\ frac3} = 0.01$; $V_{s,\ frac3} = 1.0$; $\tau_{c,\ frac2} = 0.04$; $V_{e,\ frac2} = 0.00008$; $\tau_{c,\ frac3} = 0.02$; $V_{e,\ frac3} = 0.00002$.

3.3.3. Calibration Parameters for the Transport of Coarse-Grained Material

The transport of coarse-grained material, i.e. sands and gravels, is modeled with a simple power law function for the carrying capacity of the flow, C_p. The other model option, which is to use the Colby method to compute carrying capacity, was found to be inappropriate for the range of flow velocities occurring in the calibration run. For each segment at each time step, the carrying capacity is computed, and a calculation is made of the amount of material that must be transferred between the water column segment and the underlying bed segment such that the concentration of coarse-grained material, Frac1, is adjusted to the carrying capacity. The transfer of the calculated amount of material is then made over the subsequent four time steps. (The transfer is done over four time steps in order to maintain numerical stability.) The two calibration parameters in the power law function, k_s and k_e were set at 50.0 and 4.0, respectively, in order to best match the data on bed sediment composition and to maintain very low Frac1 water column concentrations throughout most of the three-year calibration run, consistent with the findings of the ANS/ICPRB study. In the calibrated model, only one storm event led to significant sand concentrations, that is, Frac1 concentrations > 2 mg/L, in the water column segments of the mid and lower river. This event occurred on 5/7/89. Because, to the knowledge of the author, almost no data on sand concentrations exists, it is not possible at this time to verify model predictions concerning the transport of coarse-grained material for this day or other days of the calibration run.

In segment 1, which, as discussed above, is treated differently from the other segments, the calibration parameters governing the transport of sand and gravel were set at $k_s = 500.0$ and $k_e = 3.0$.

3.3.4. Other Calibration Adjustments

Other adjustments were made to model inputs during the calibration process. Adjustments were made to upstream storm concentrations, to input load size fraction proportions, and to downstream boundary conditions.

Because TSS storm peaks were judged to be too high during initial calibration runs, the storm concentration values used to compute Northeast and Northwest Branch storm loads were reduced 15% from the provisional EMC values from MWCOG from the WASA/LTCP data. The values used in the final calibration were:

NE Branch Storm Concentration:	404 mg/L
NW Branch Storm Concentration:	249 mg/L

Because, to the knowledge of the author, no monitoring data exists to allow the determination of the size fraction concentrations of sediment loads, the initial relative proportions of the input loads size fractions were estimated from bed sediment data, as discussed in Section 2.2.1. Because, according to model simulation results, a significant amount of fine-grained material (Frac3) is exported to the Potomac River, the relative proportion of the three size fractions in model input loads was adjusted to include more fine-grained material. The relative proportions of the three sized fractions in input loads used in the final calibration were:

Frac1:	0.17
Frac2:	0.15
Frac3:	0.68

Downstream boundary conditions were initially set based on average TSS concentrations from DC DOH routine monitoring data and relative suspended sediment size fraction composition from ANS/ICPRB data, as discussed in Section 2.2.2. During the calibration process, downstream boundary conditions were changed to: 0 mg/L for coarse-grained sediment, 2 mg/L of medium-grained sediment, and 20 mg/L of fine-grained sediment. These values produced a better match of model simulation results to bed sediment composition data. Because the DC DOH routine monitoring data contains little storm data, the computed average TSS concentration at ANA29 of 12 mg/L may underpredict the impact of the TSS levels in the Potomac River.

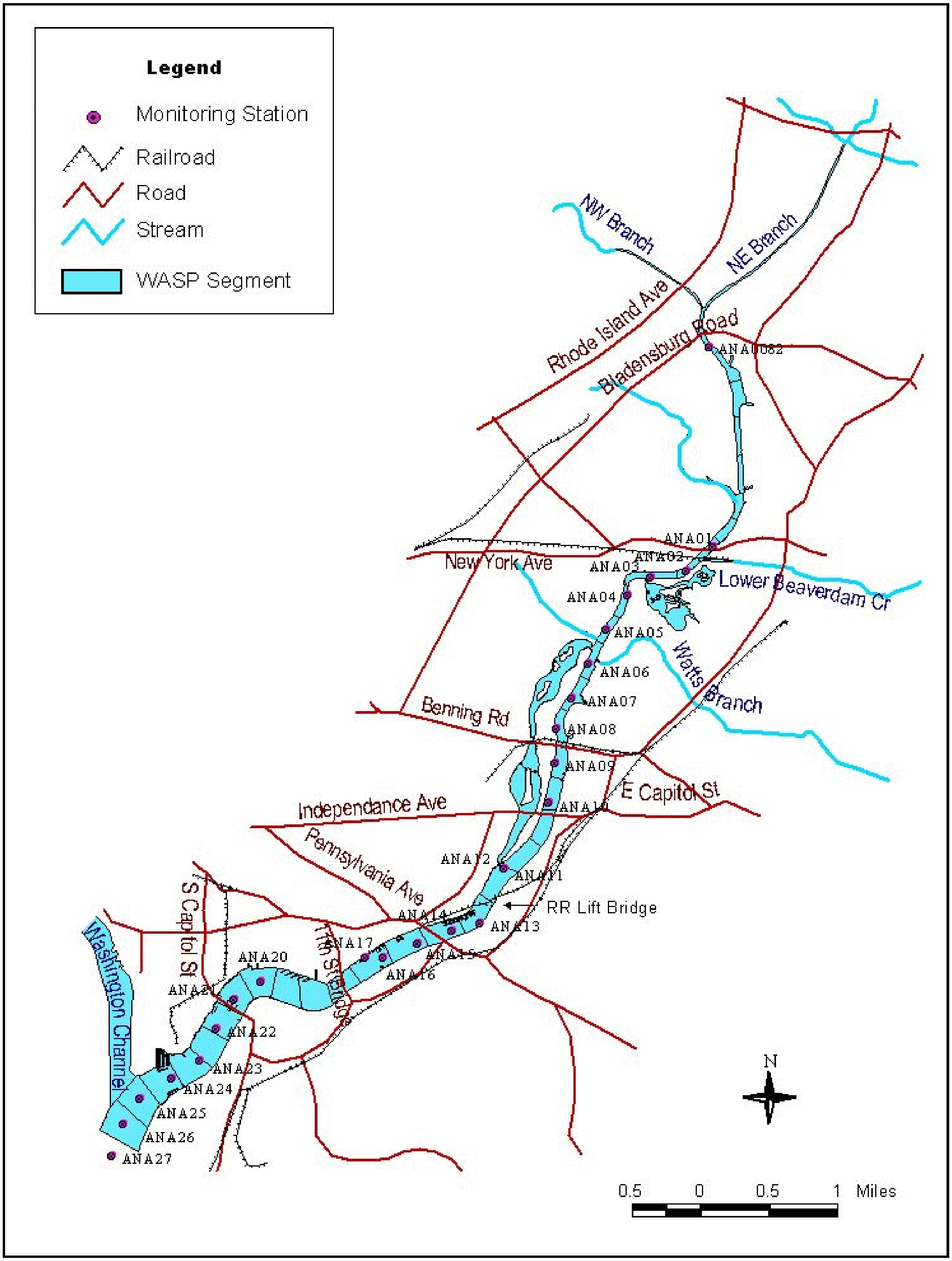

Figure 3-2. Location of DC DOH Water Quality Monitoring Stations

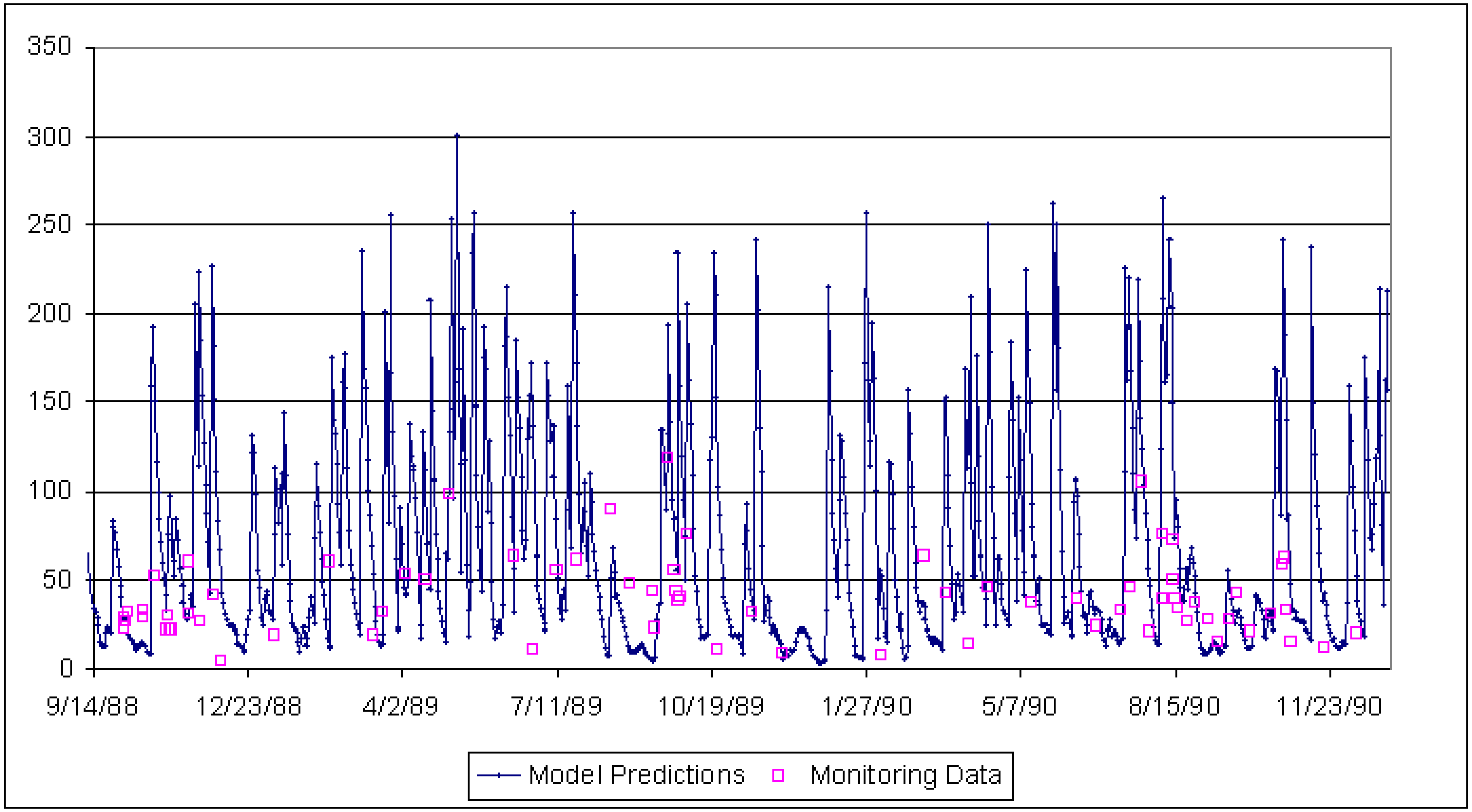

Figure 3-3. Predicted Versus Measured TSS Concentrations (mg/L) at Segment 7

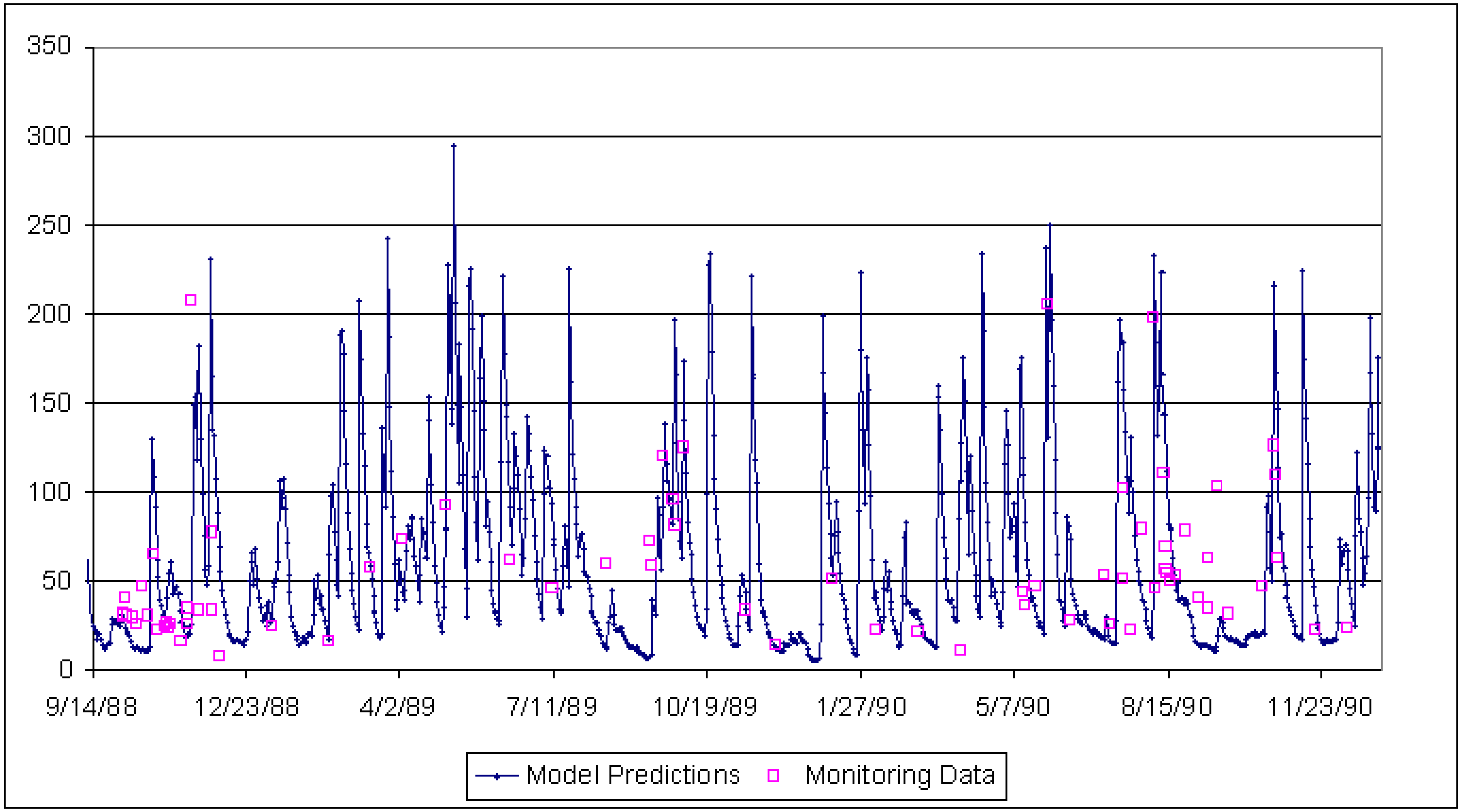

Figure 3-4. Predicted Versus Measured TSS Concentrations (mg/L) at Segment 15

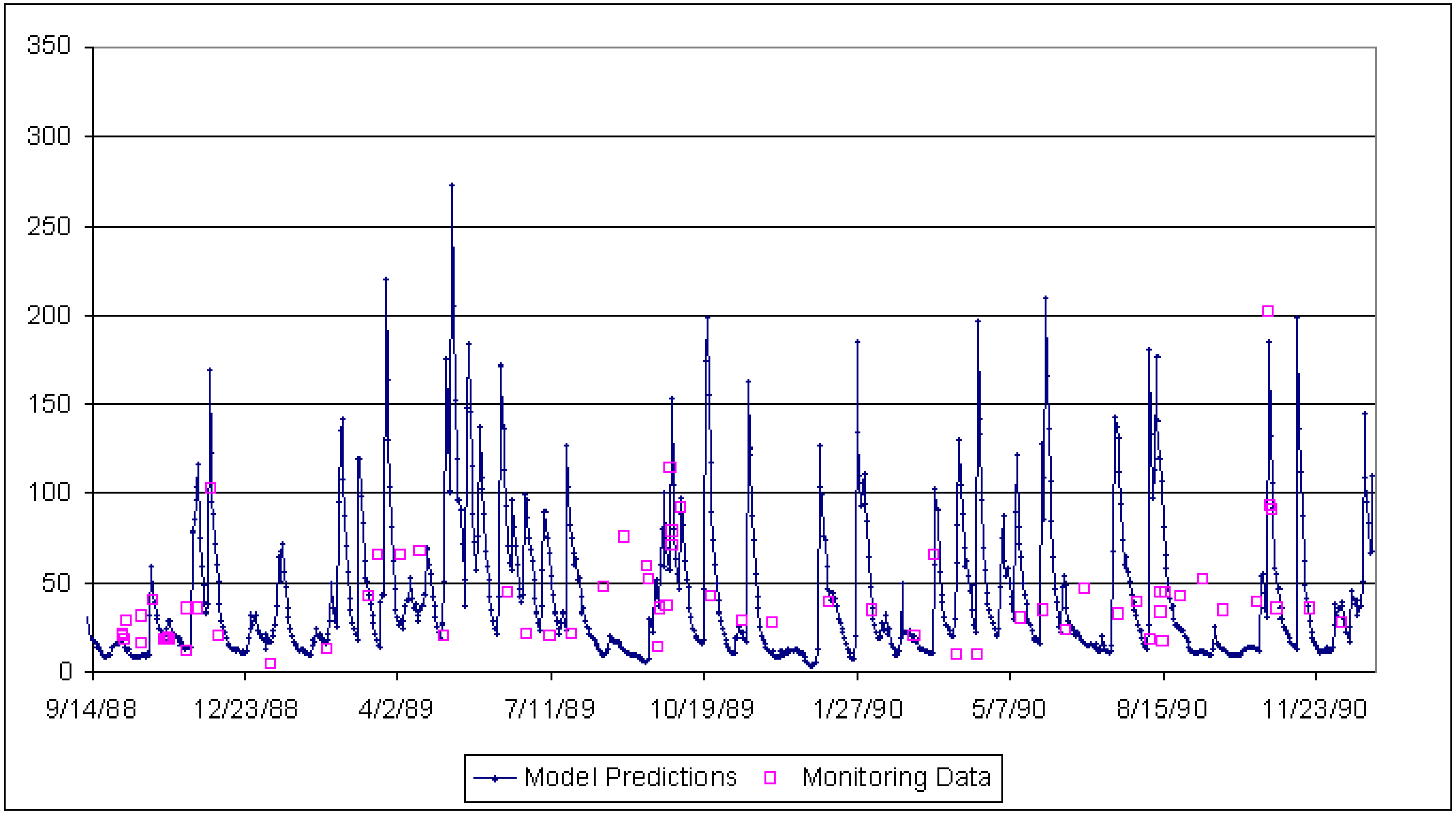

Figure 3-5. Predicted Versus Measured TSS Concentrations (mg/L) at Segment 22

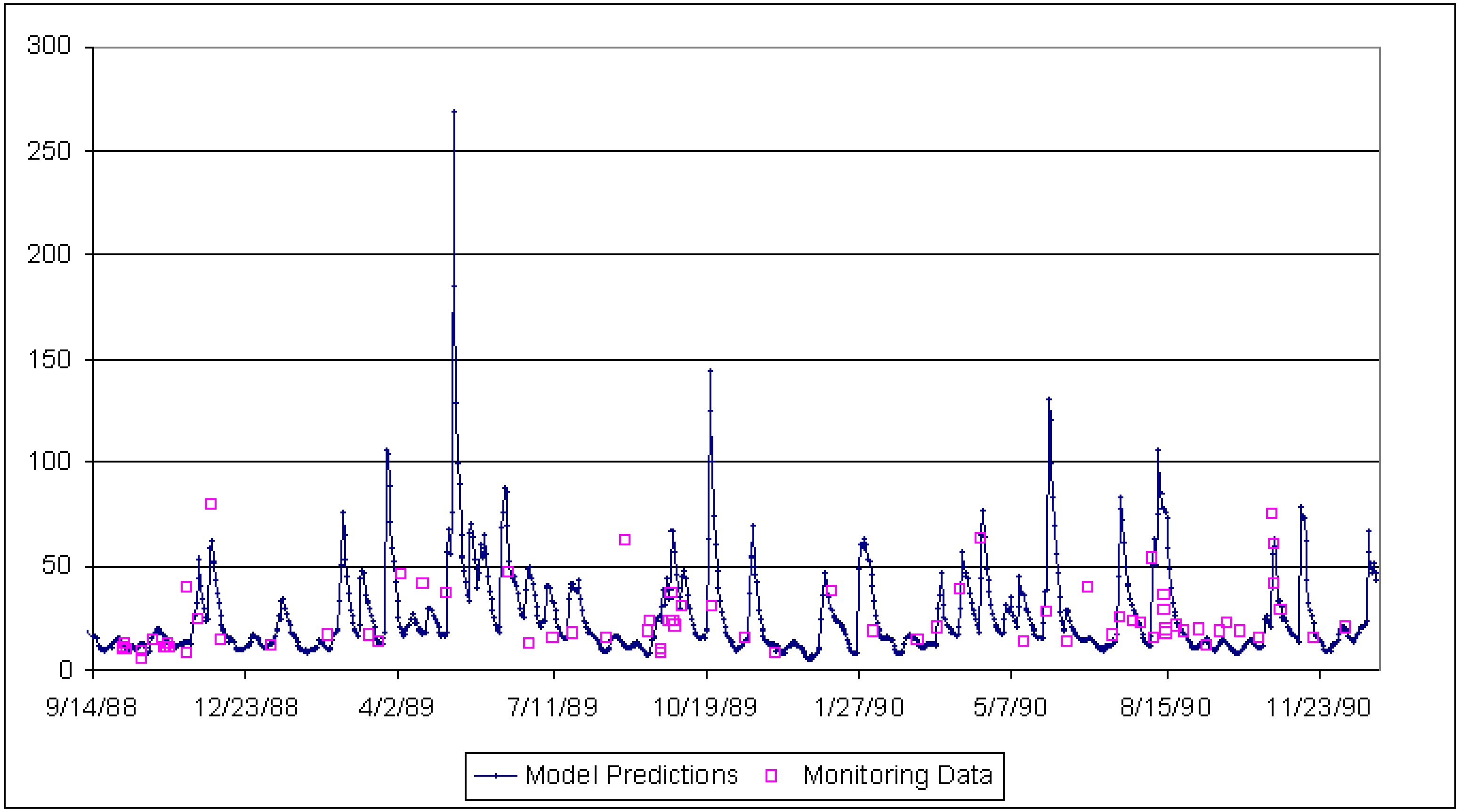

Figure 3-6. Predicted Versus Measured TSS Concentrations (mg/L) at Segment 29

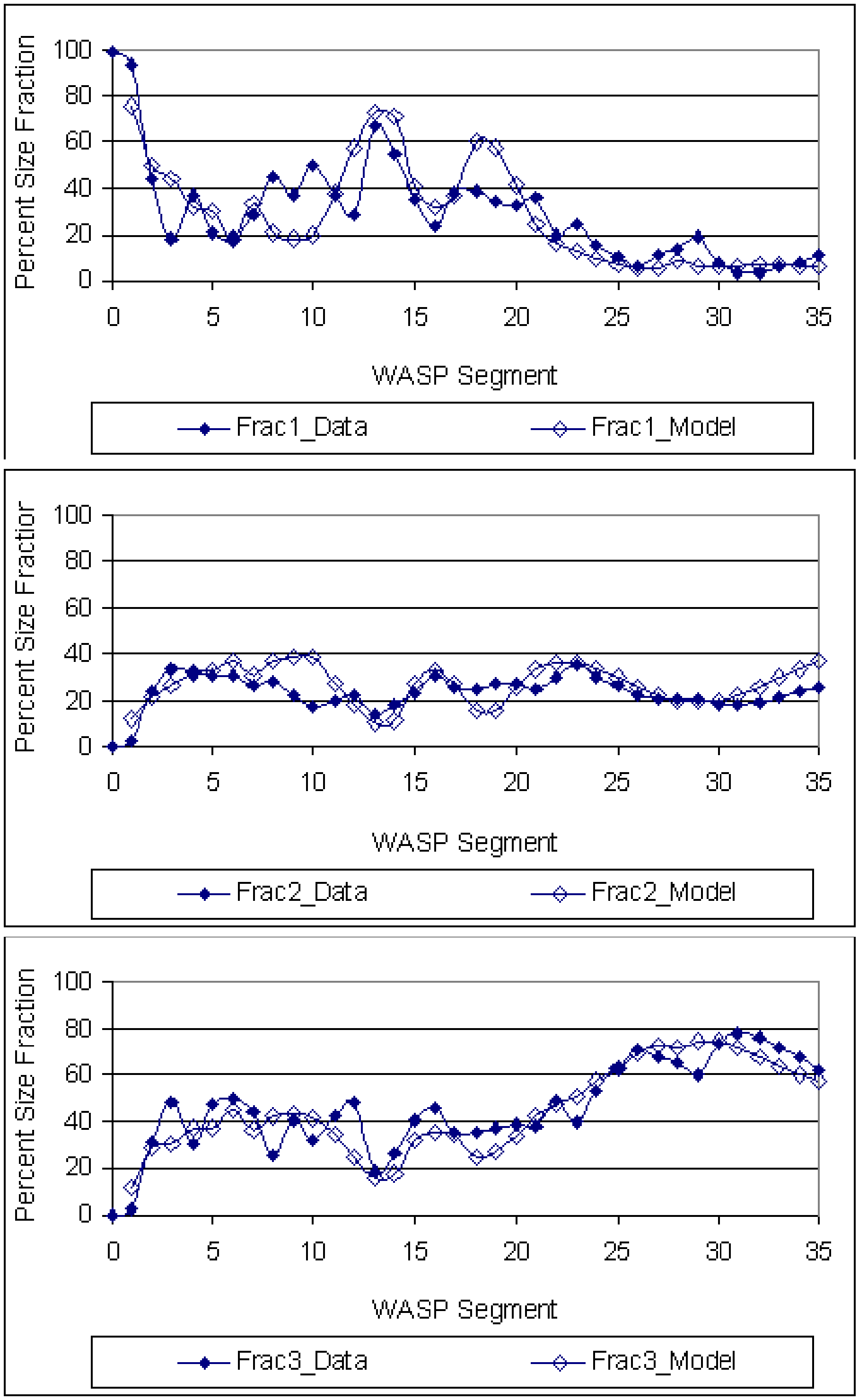

Figure 3-7. Model-Predicted Bed Sediment Size Fraction Composition at End of Six-Year Run, Versus Measured Results

3.4. Sensitivity Tests

The following tests were run to examine the sensitivity of the TAM/WASP sediment transport model to changes in model inputs and model parameters.

3.4.1. Sensitivity to Changes in Upstream Loads

To examine the response of model-predicted water column TSS concentrations to changes in upstream loads, daily TSS loads from the Northeast and Northwest Branch tributaries were halved. The results appear in Figures 3-8 to 3-11. Because upstream sources appear to contribute the majority of TSS loads to the tidal river, model response to changes in upstream loads was pronounced. When upstream loads were halved, TSS storm peaks dropped by nearly ½, even in segment 29 in the lower river. The effect of the change on non-storm TSS values was smaller.

3.4.2. Sensitivity to Changes in Certain Loads from the Tidal Drainage AreaSeparate Sewer System, CSO, and Minor Tributary Loads

The response of model-predicted water column TSS concentrations to changes in tidal drainage area sources was investigated by halving daily TSS loads from the separate sewer system and minor tributary sub-sheds and the combined sewer system sub-sheds in the tidal drainage area (see Tables 2-2 and 2-3). The results appear in Figures 3-12 to 3-15. Model response to this change was small, consistent with the fact that the model-estimated contributions from these sources is relatively small (see Section 3.5).

3.4.3. Sensitivity to Changes in Erosion Parameters

In order to better understand the impact of simulated erosion processes on model results, all erosion processes were effectively turned off by setting τ_c, the critical shear stress threshold for erosion, to 9.2 N/m^2, corresponding to a critical velocity threshold of greater than 1 m/sec. Since the simulated flow velocity at no time exceeded 1 m/sec during the calibration period, no erosion was simulated during this sensitivity run. Results appear in Figures 3-16 to 3-19. It can be seen that erosion makes a minor contribution to TSS storm peaks, adding from about 1 to up to 26 mg/L to TSS concentrations. However, it appears that erosion processes often double model-predicted TSS concentrations during non-storm periods in the upper and middle portions of the river. Only in the lower river segment 29, where from Table 3-2 it can be seen that flow velocities rarely exceeded the critical velocity for erosion, did simulated erosion processes have a fairly minor impact on predicted TSS concentrations.

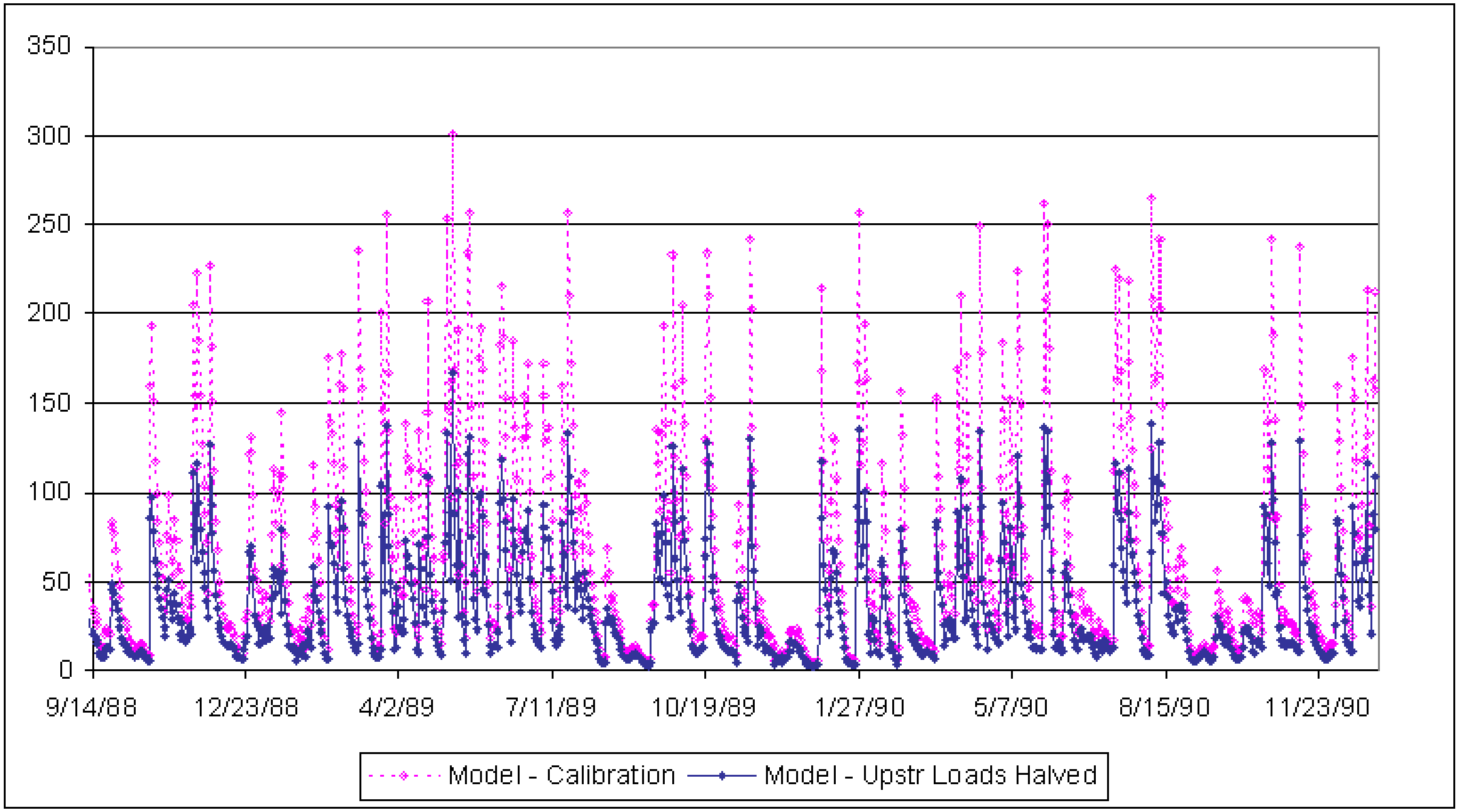

Figure 3-8. Sensitivity Test: TSS Concentrations (mg/L) at Segment 7 with Upstream Loads Halved

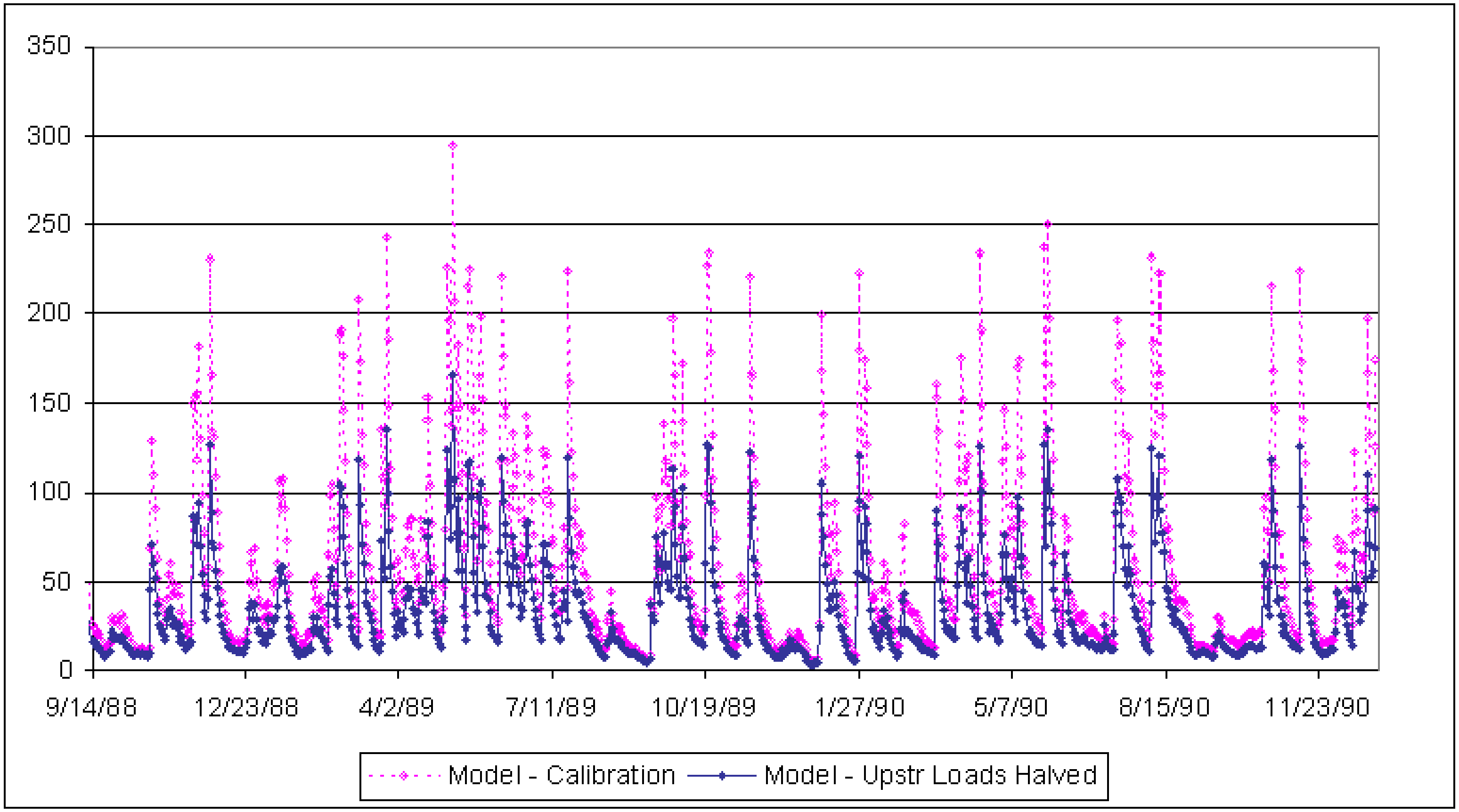

Figure 3-9. Sensitivity Test: TSS Concentrations (mg/L) at Segment 15 with Upstream Loads Halved

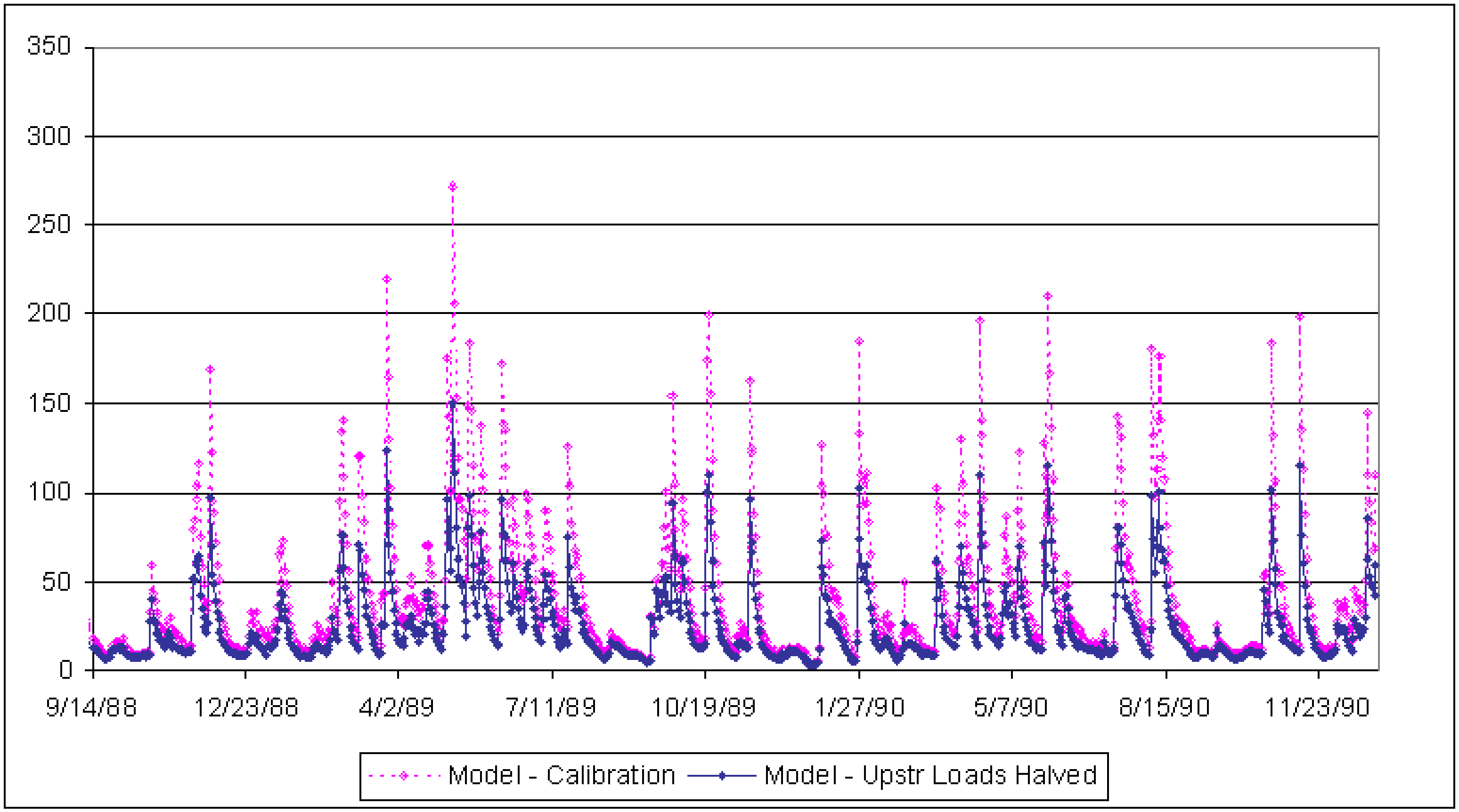

Figure 3-10. Sensitivity Test: TSS Concentrations (mg/L) at Segment 22 with Upstream Loads Halved

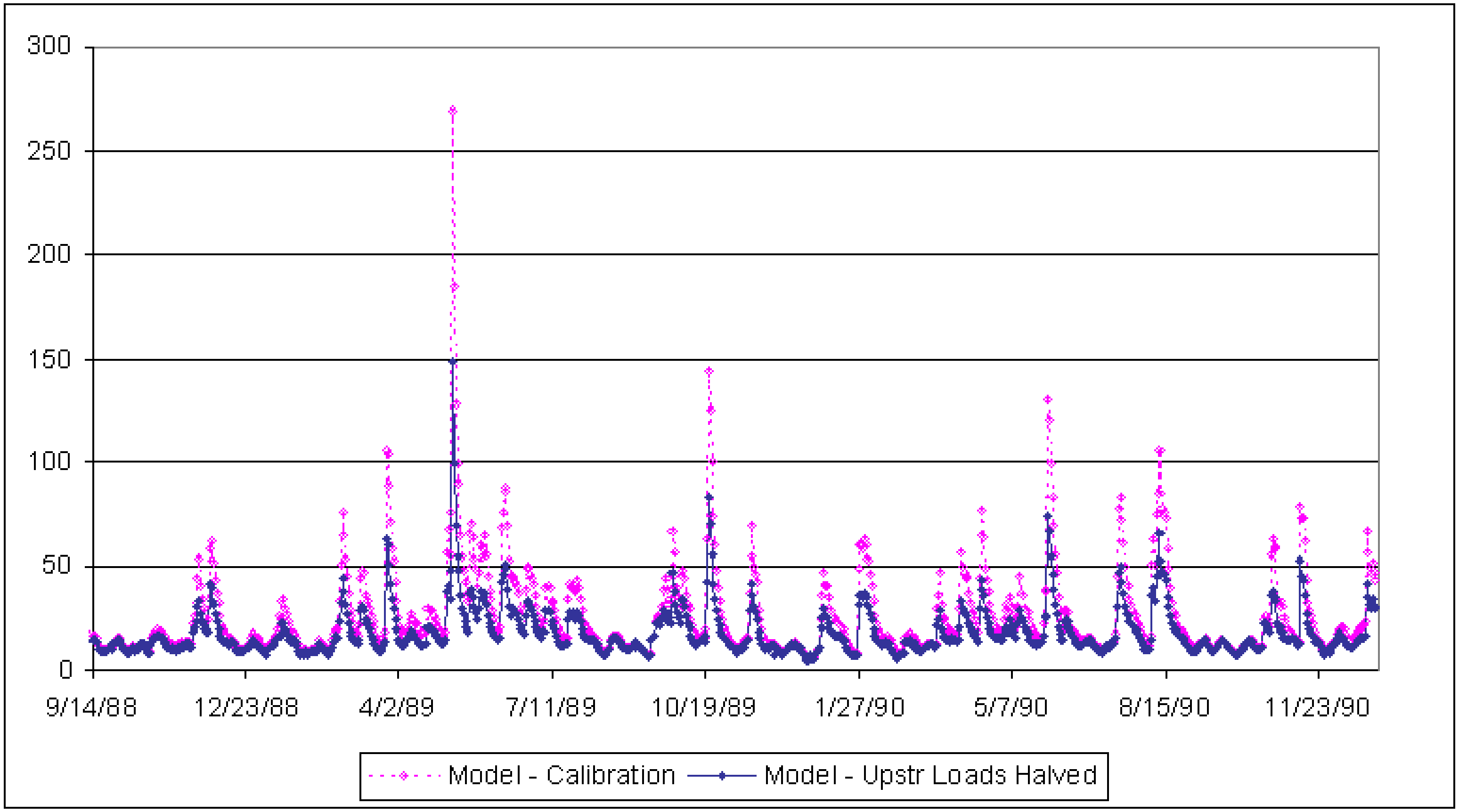

Figure 3-11. Sensitivity Test: TSS Concentrations (mg/L) at Segment 29 with Upstream Loads Halved

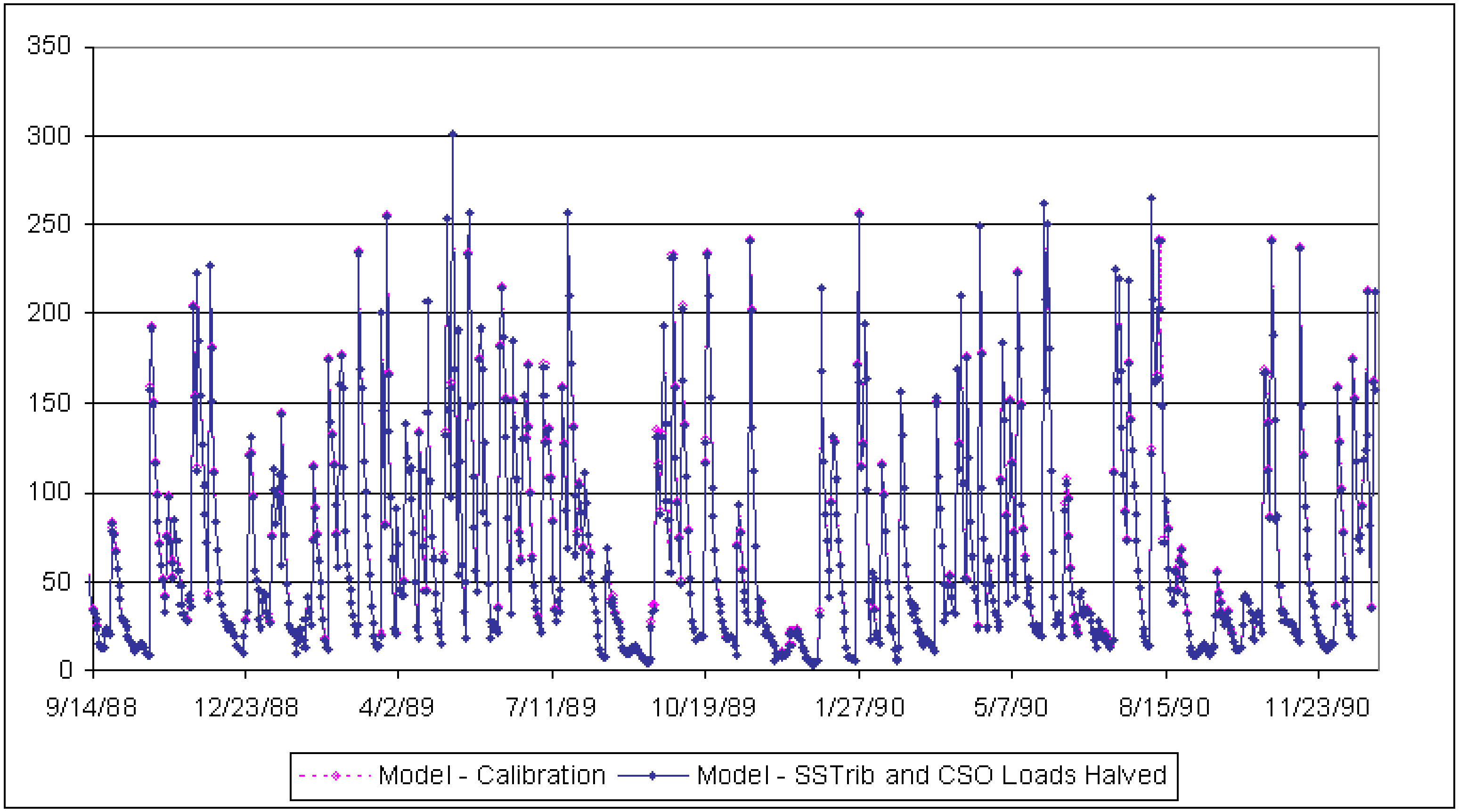

Figure 3-12. Sensitivity Test: TSS Concentrations (mg/L) at Segment 7 with Separate Sewer System, Minor Tributary, and CSO Loads Halved

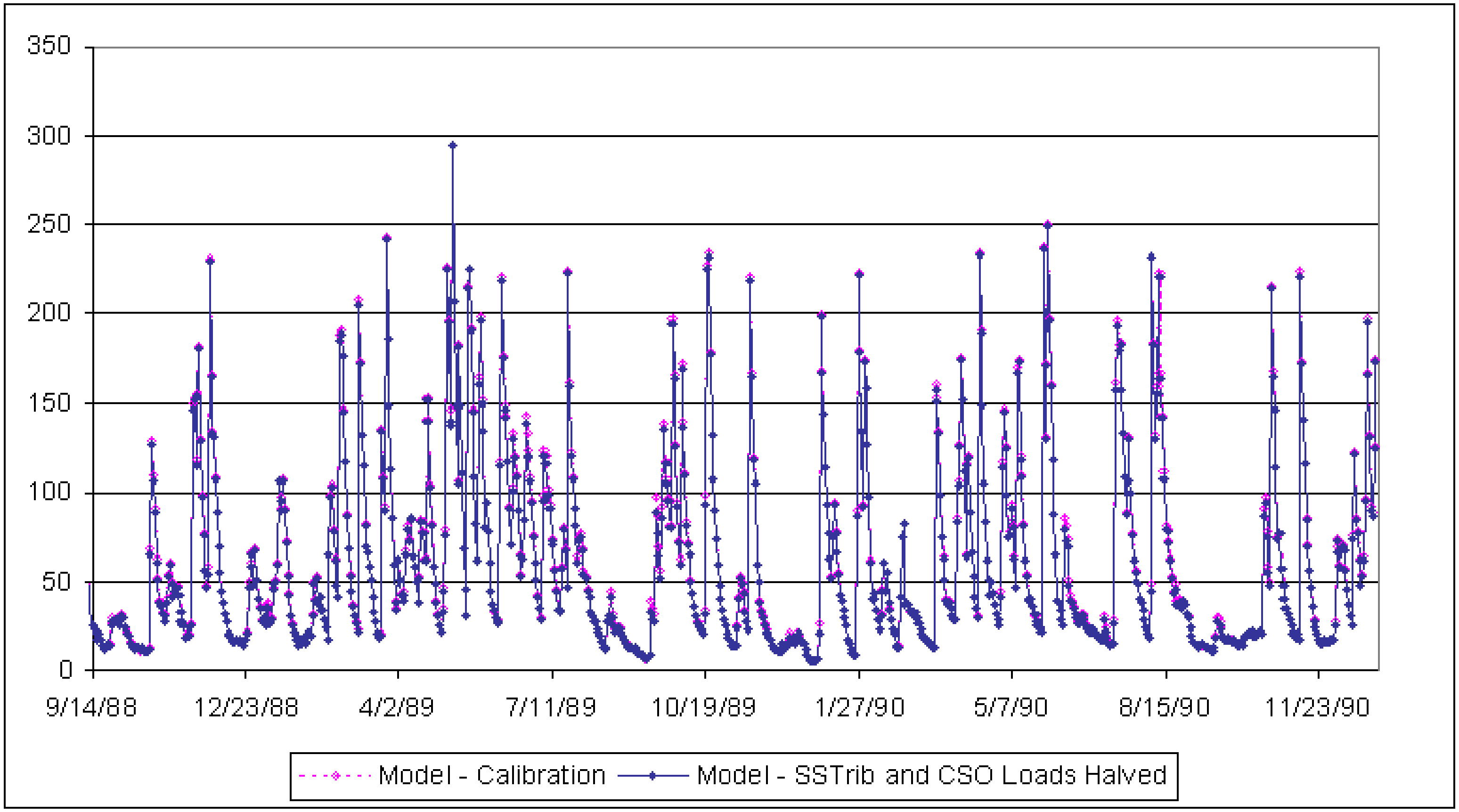

Figure 3-13. Sensitivity Test: TSS Concentrations (mg/L) at Segment 15 with Separate Sewer System, Minor Tributary, and CSO Loads Halved

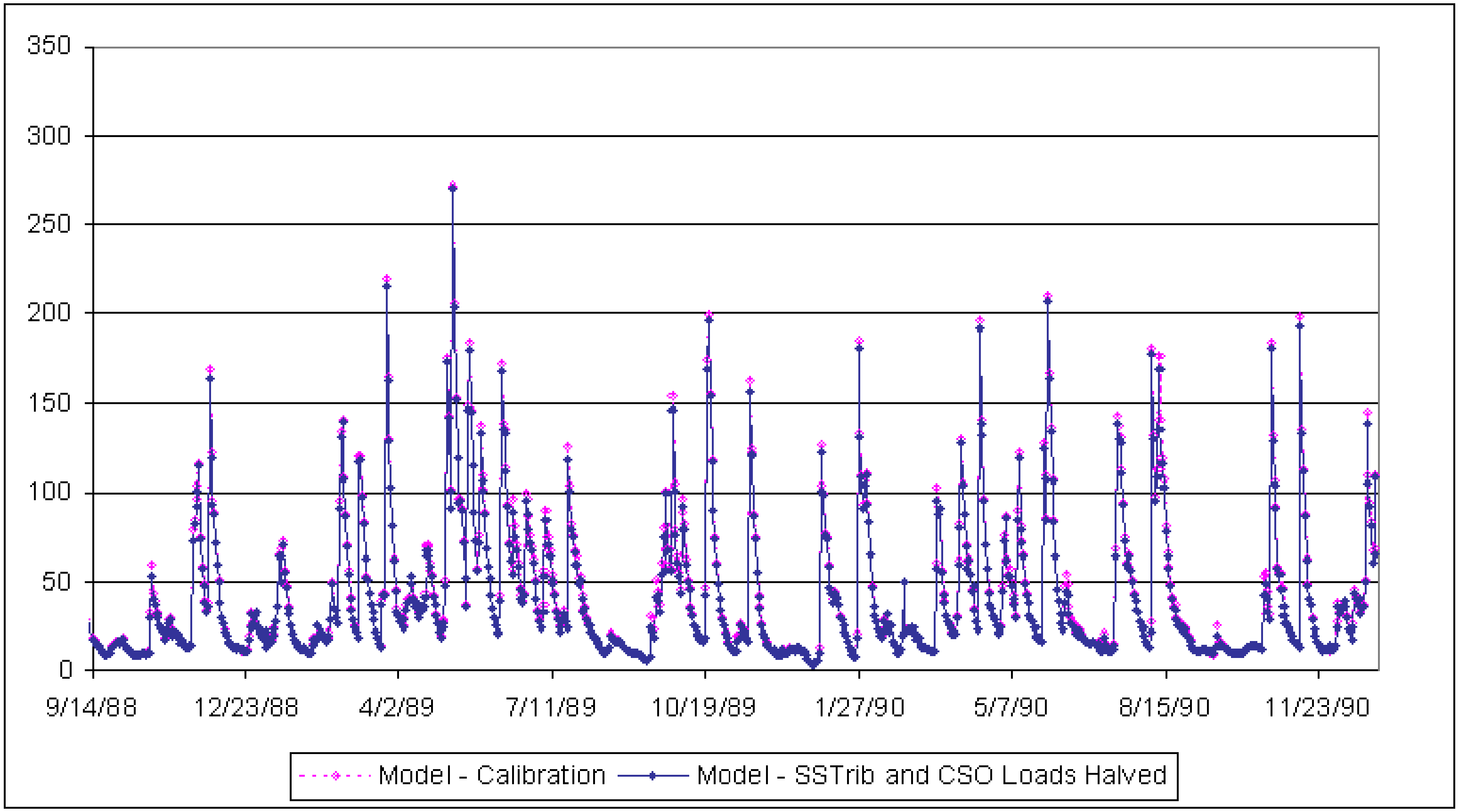

Figure 3-14. Sensitivity Test: TSS Concentrations (mg/L) at Segment 22 with Separate Sewer System, Minor Tributary, and CSO Loads Halved

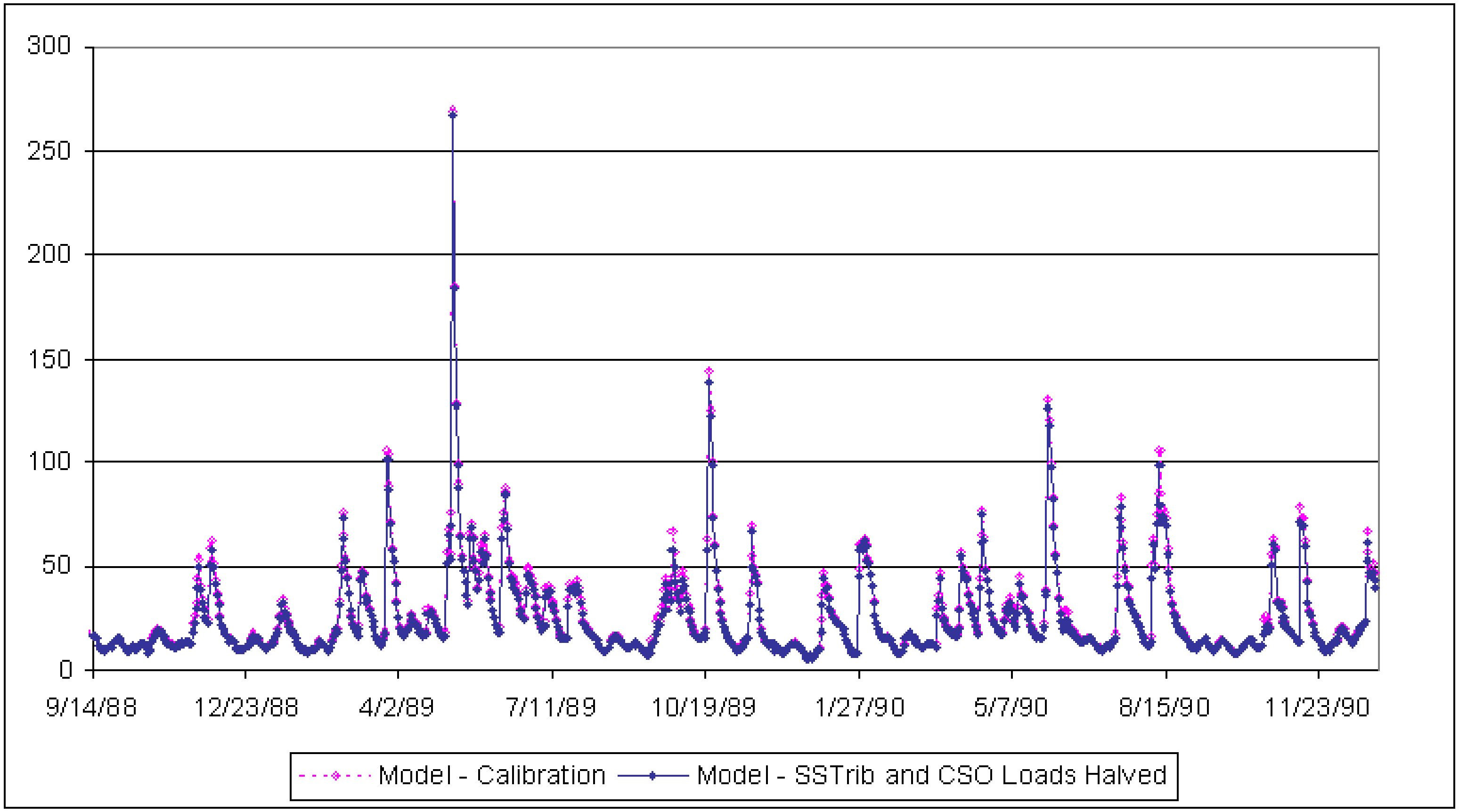

Figure 3-15. Sensitivity Test: TSS Concentrations (mg/L) at Segment 29 with Separate Sewer System, Minor Tributary, and CSO Loads Halved

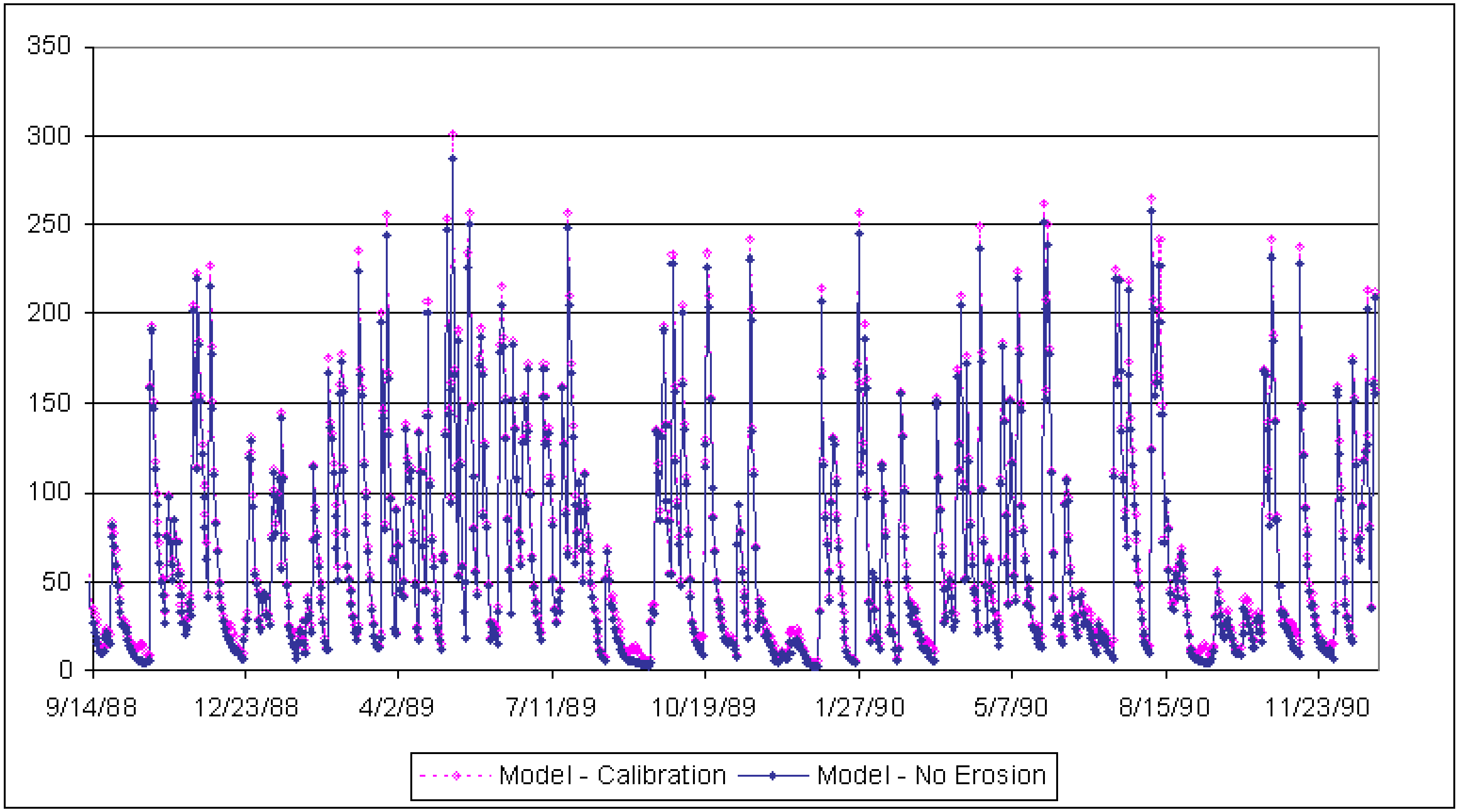

Figure 3-16. Sensitivity Test: TSS Concentrations (mg/L) at Segment 7 with Erosion Turned Off

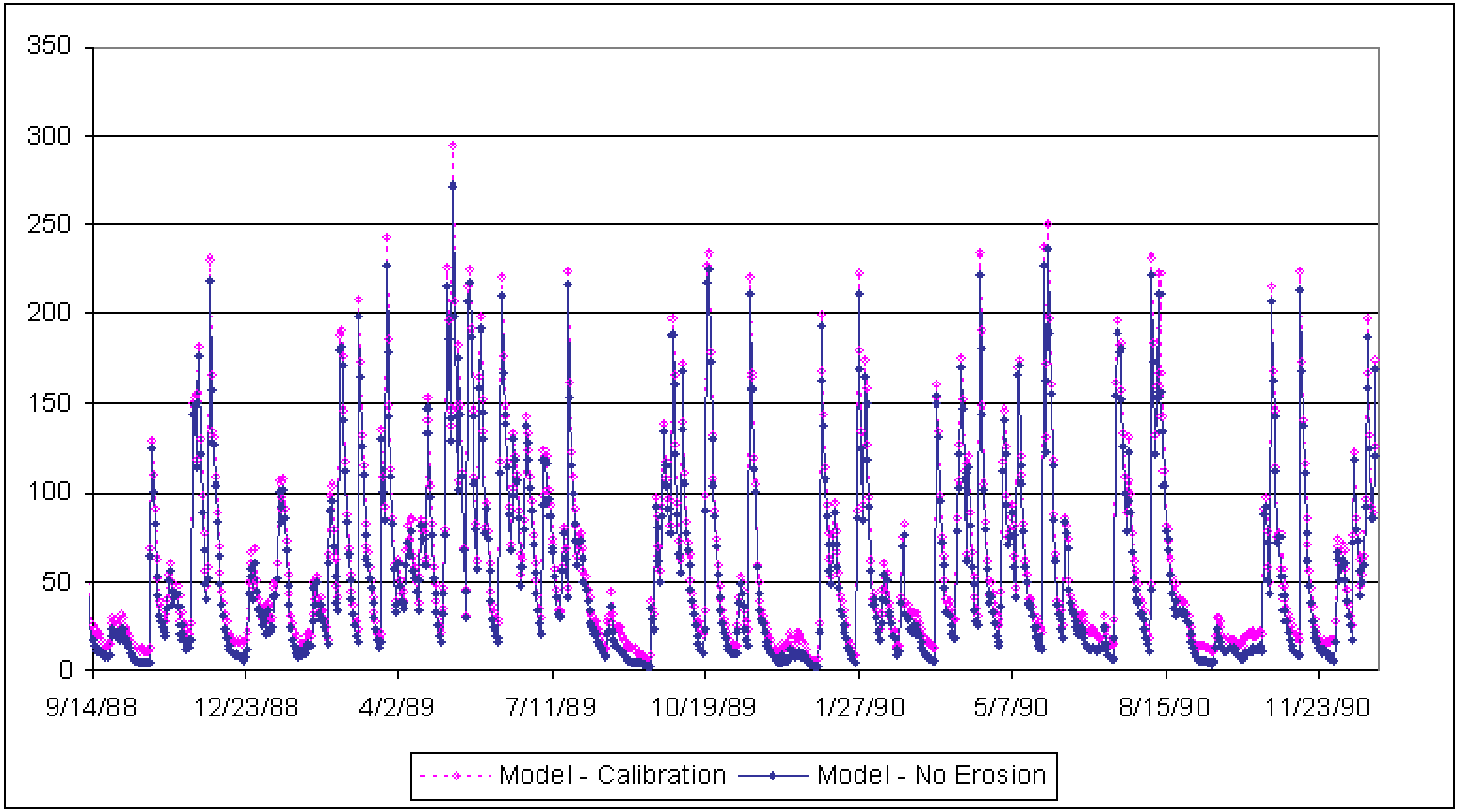

Figure 3-17. Sensitivity Test: TSS Concentrations (mg/L) at Segment 15 with Erosion Turned Off

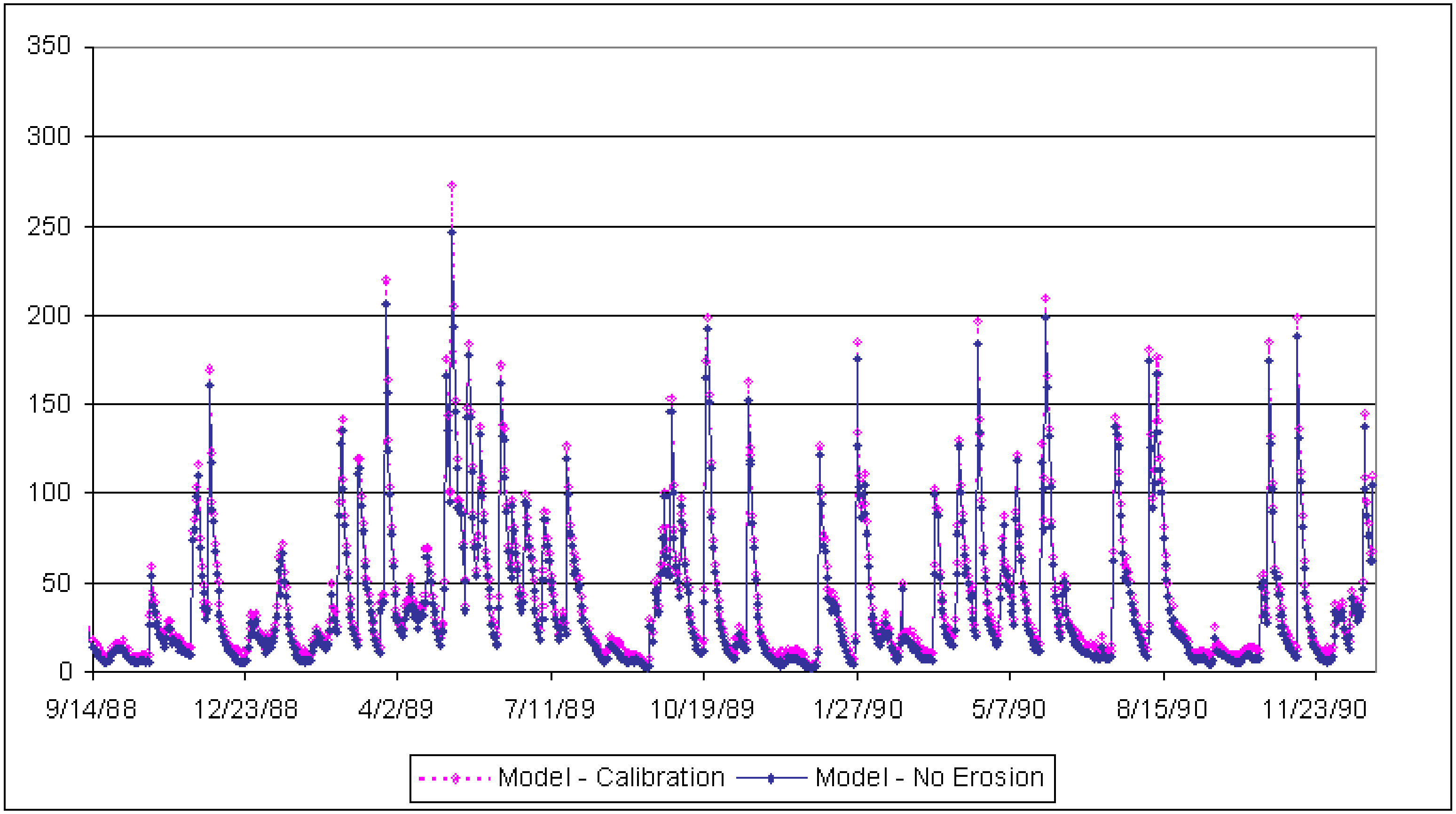

Figure 3-18. Sensitivity Test: TSS Concentrations (mg/L) at Segment 22 with Erosion Turned Off

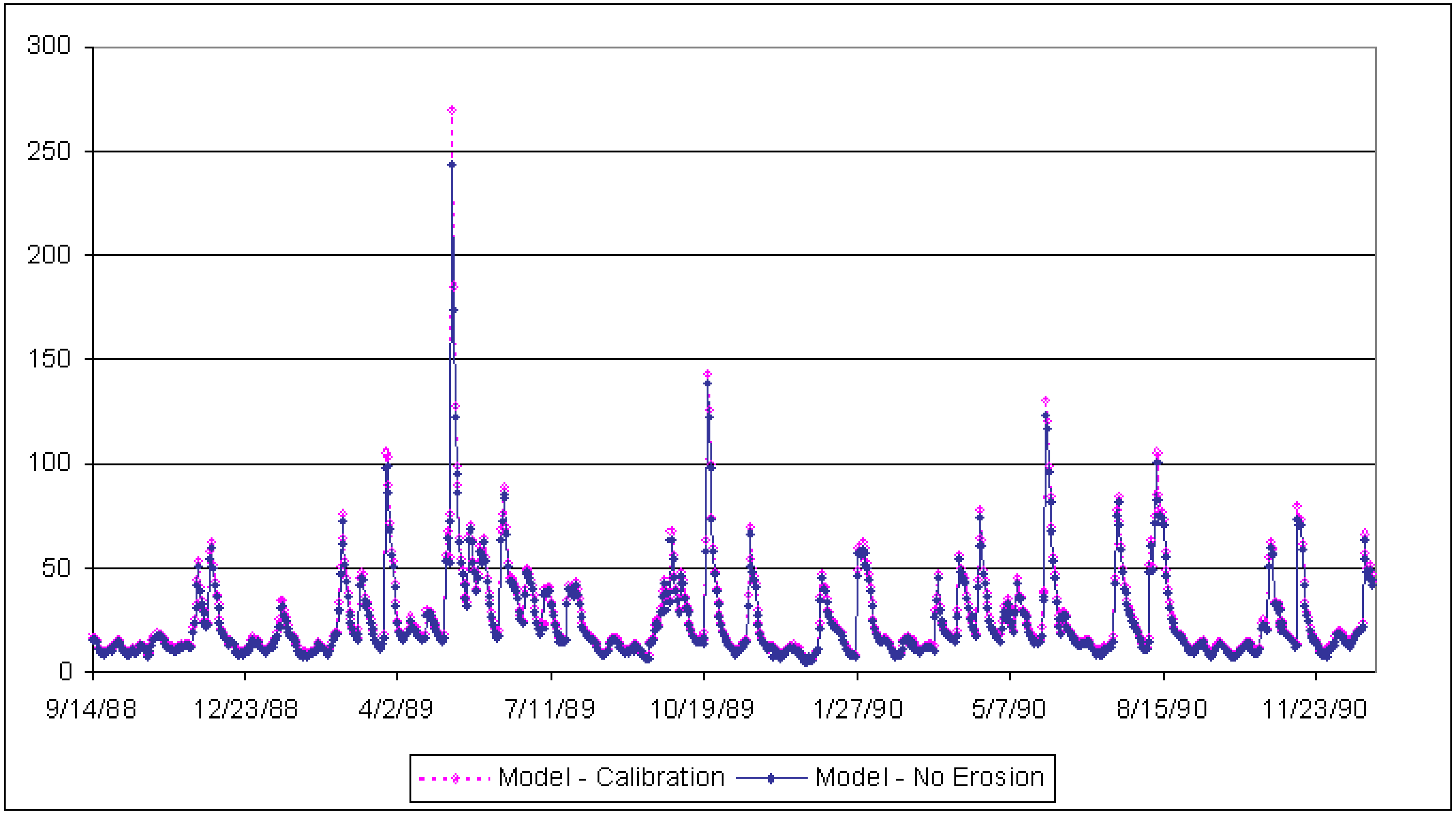

Figure 3-19. Sensitivity Test: TSS Concentrations (mg/L) at Segment 29 with Erosion Turned Off

CHAPTER 4: SUMMARY OF RESULTS

4.1. Summary of Model Inputs

A summary of the final calibration run flow inputs and TSS load inputs for the five major types of model drainage areas appears in Table 4-1. The average annual flow input percentages are quite close to the corresponding drainage area percentages, with the exception of Lower Beaverdam Creek and the CSO sub-sheds. The CSO flows are from WASA estimates assuming "historical" (1988-90) system conditions. The CSO sub-sheds are expected to contribute less flow than would be estimated from their relative areas, because a portion of the runoff from the CSO sub-shed is carried to the Blue Plains sewage treatment plant.

The model-estimated share of the annual TSS load contributed by the upstream tributaries, 87.7%, is significantly larger than the model-estimated annual upstream flow contribution, which is only 70.3 %. This is the case because the Northeast and Northwest Branch storm TSS concentrations used to compute daily loads, based on an analysis of provisional WASA/LTCP monitoring data and on calibration considerations, are significantly higher than estimated storm concentrations for the other types of sub-drainage areas. Because upstream loads make up such a large share of the model's total load inputs, model sensitivity to reductions in upstream loads is very pronounced, as demonstrated in Section 3.4.

Table 4-1. Model Input Summary

Drainage Area Type	Area (acres)	Area (%)	Average Annual Flow (1000 m^3)	Average Annual Flow (%)	Average Annual Load (1000 kg)	Average Annual Load (%)
Upstream Drainage Areas	77,800	72.0%	136,183	70.3%	27,642	87.7%
Tidal Drainage Area: Watts Branch	2,470	2.2%	4,987	2.6%	655	2.1%
Tidal Drainage Area: Lower Beaverdam	10,466	9.3%	23,390	12.1%	682	2.2%
Tidal Drainage Area: Separate Sewers and Minor Tributaries	10,501	10.0%	20,952	10.8%	1,223	3.9%
Tidal Drainage Area: CSOs	6,946	6.4%	8,129	4.2%	1,316	4.2%
Total Watershed	108,183	100.0%	193,640	100.0%	31,518	100.0%

According to WASP mass balance calculations for the calibration run, the average annual amount of sediment exported to the Potomac River via advection and dispersion processes is 3,529,000 kg, or approximately 11% of the average total annual load. Thus, according to model predictions, approximately 89% of the sediment entering the tidal river is retained. A graph of the load contributions of the five major types of model drainage areas, along with the contribution from advective and dispersive transport to the Potomac River, appears in Figure 4-1.

Results summarized in Table 4-1 suggest that TAM/WASP sediment load estimates are, in general, low. The average total annual TSS load estimated by the model, 31,518,000 kg, or approximately 35,000 tons, is somewhat lower than the estimate of 46,000 tons by Warner et al. (1997). The total annual upstream load estimated by TAM/WASP, 27,642,000 kg, or approximately 30,000 tons, is slightly less than 32,000 tons estimated by Warner and significantly less than the estimate of 50,000 tons from the preliminary calibration results of the non-tidal Anacostia HSPF model (Mandel and Manchester, 2001). Finally, the model's estimate of the annual TSS load from Lower Beaverdam Creek, 682,000 kg or approximately 750 tons, is dramatically lower than Warner's estimate of 8,102 tons, suggesting that the Lower Beaverdam Creek HSPF model used by TAM/WASP to estimate daily loads should be revisited.

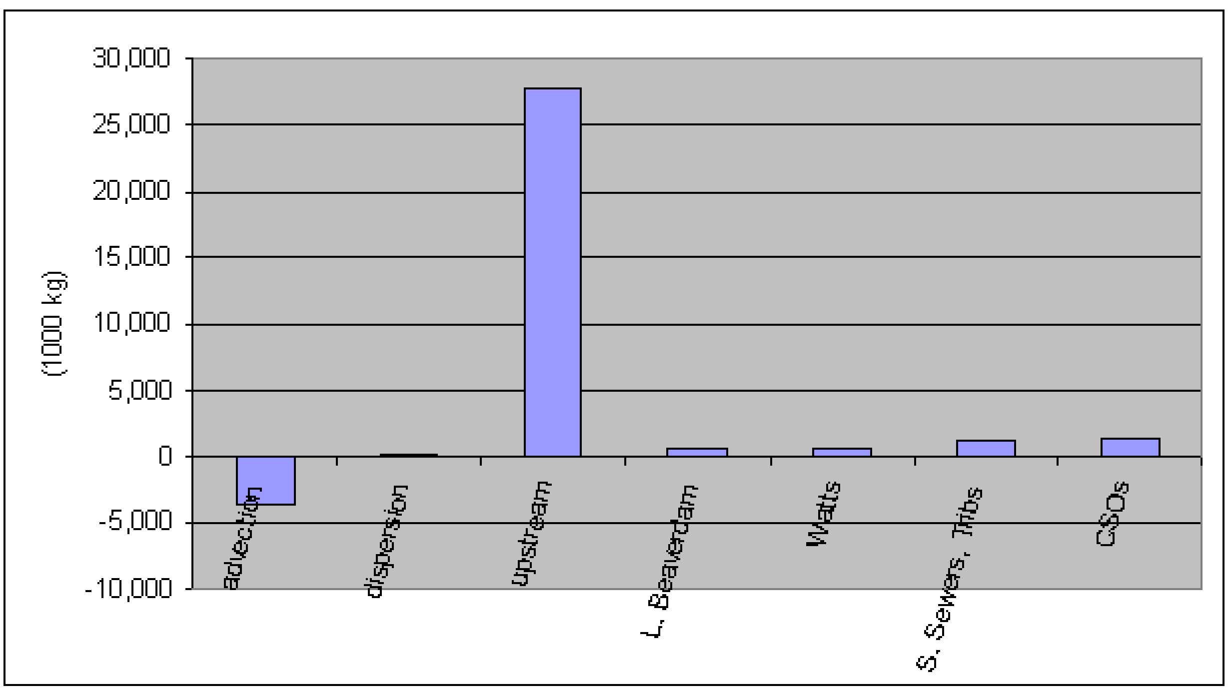

Figure 4-1. Model-Predicted Average Annual Sediment Contributions to Tidal Anacostia (including advection and dispersion from Potomac)

4.2. Summary of Sediment Accumulation Rates

The solid material which remains each year in the tidal river settles to the river bottom. Model-predicted sediment accumulation rates were computed from calibration run output, based on an assumed sediment density of 2.5 gm/cm^3 and porosity of 0.6. A graph of average annual sediment accumulation for each model bed sediment segment appears in Figure 4-2 (where segments are labeled by the number of the overlying water column segment). An overall average accumulation rate for the entire river bed was also computed to be 0.9 cm/year. Model-predicted accumulation rates are highest in the upper and lower portions of the river, ranging from 0.6 to almost 3 cm/yr in upstream segments 1 to 9, and from 0.6 to 1.3 cm/yr in downstream

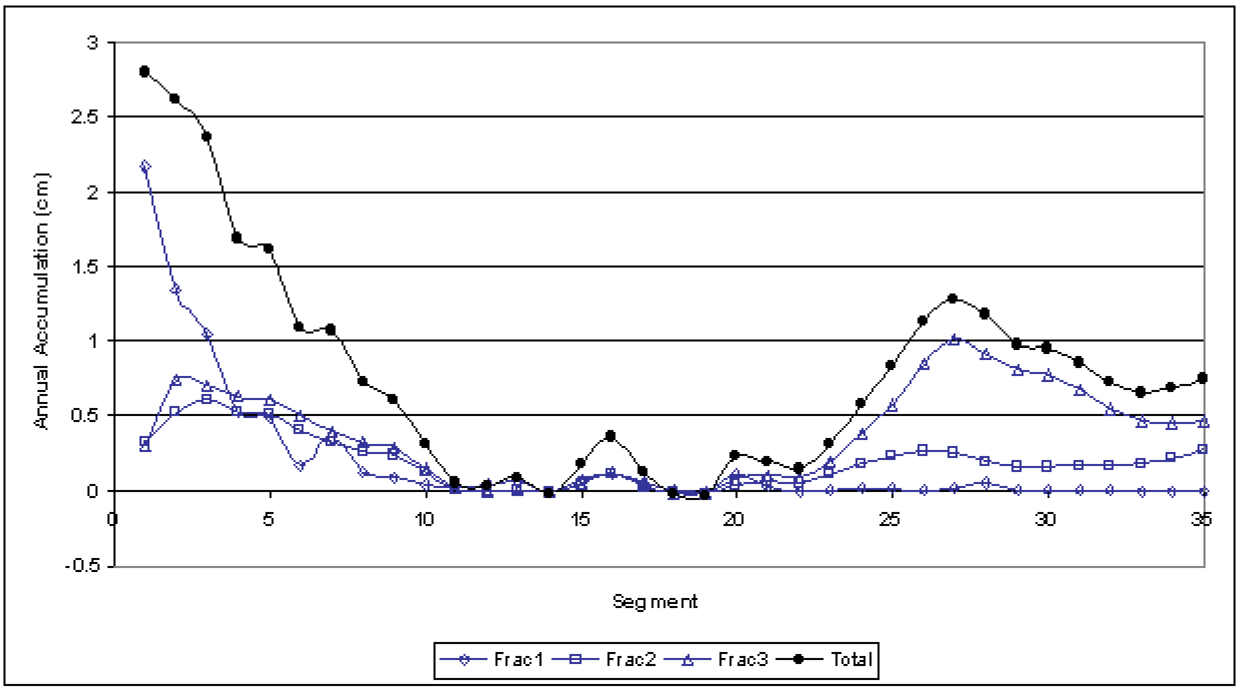

Figure 4-2. Model-Predicted Sediment Accumulation Rates from Calibration Run

segments 24 to 35. Mid-river segments 11, 12, 13, 14, 18, and 19, which, as discussed in Section 3.1, all have model-predicted median flow velocities of greater than 0.15 m/sec, are predicted to have no significant annual accumulation rates in their underlying bed sediment segments. The bed sediment segment beneath model segment 36, representing Kingman Lake (not represented in Figure 4-2), was predicted to have an annual accumulation rate of 1.8 cm/yr. Model-predicted sedimentation rates are somewhat low in comparison to rates estimated from empirical data. In a detailed study of sediment accumulation in the tidal Anacostia, Scatena (1986) estimated sedimentation rates of 1.2 to 9.1 cm/yr for the time period 1865 to 1985 and 1.5 to 5.1 cm/yr for the time interval 1972 to 1985. More recently, Velinsky et al. (1997) estimated sedimentation rates of approximately 1 to 2 cm/yr for the time period 1945 to 1995 based on analyses of ^{210}Pb in two sediment cores from the lower river. The low model-predicted sediment accumulation rates suggest that the model's estimated total annual TSS loads may be low. Alternatively, the higher sediment accumulation rates estimated from empirical data may be because sediment loads were higher during the earlier time periods upon which much of the empirical analysis is based.

4.3. Conclusion

Calibration results show that the TAM/WASP sediment transport model can simulate water column TSS concentrations during the calibration time period reasonably well, with model-predicted storm peak concentrations generally in the range of 150 to 250 mg/L, consistent with high values in the calibration data set, and non-storm concentrations generally in the range of 5 to 30 mg/L, consistent with the calibration data set and the results of the ANS/ICPRB study. The model tended to somewhat under-simulate water column concentrations of the medium-grained size fraction and over-simulate water column concentrations of the fine-grained size fraction.

As a verification of the ability of the model to simulate sediment transport dynamics in the tidal river, the model performed well in predicting the spatial pattern of sediment size fraction percentages in the surficial sediment bed. Table 4-2 gives some error statistics comparing model predictions of bed sediment grain size fraction percentages to the estimates from empirical data given in Table 3-4.

Table 4-2. Model Bed Sediment Size Fraction Distribution Prediction Error Statistics

Size Fraction	Average Difference	R^2
Frac1:	0.2	0.74
Frac2:	2.8	0.60
Frac3:	-2.2	0.80

Overall, model estimates of the daily TSS loads to the tidal river may be somewhat low, based on empirical estimates of sediment accumulation rates and on estimates by other studies.

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APPENDIX A: ICPRB ENHANCEMENTS TO THE TAM HYDRODYNAMIC MODEL

TAM/WASP Version 2 is based on a new version of the Tidal Anacostia Model (TAM) hydrodynamic model developed by the Interstate Commission on the Potomac River Basin (ICPRB) that uses a 35 segment geometry computed by staff at the National Oceanographic and Atmospheric Administration (NOAA), and represents tidal embayment areas such as Kenilworth Marsh and Kingman Lake as side embayments adjacent to main channel segments. This appendix documents the changes recently made to the TAM hydrodynamic model by ICPRB.

Background

In support of the District of Columbia's program to determine TMDL allocations for the District's portion of the Anacostia River, ICPRB developed a pair of one-dimensional models, the TAM/WASP eutrophication model and the TAM/WASP sediment transport model, to simulate the loading, fate and transport of pollutants in the tidal portion of the river. The original TAM/WASP models (Mandel and Schultz, 2000) were based on a 15 segment model geometry, using as their hydrodynamic component the Tidal Anacostia Model (TAM) originally developed by the Metropolitan Washington Council of Governments (MWCOG) in the mid-1980's (Sullivan and Brown, 1988) and based on the Virginia Institute of Marine Science's Hydrodynamic Ecosystem Model (HEM) (VIMS, 1985). On the basis of an analysis of a dye study conducted by LimnoTech, Inc. (LTI) in the summer of 2000 (LTI, 2000), LTI recommended that TAM/WASP be upgraded to 35 segments. LTI constructed a 35 segment version of the TAM/WASP eutrophication model and this model was used by the DC Water and Sewer Authority (DC WASA) in its Long Term Control Plan (LTCP) to evaluate potential

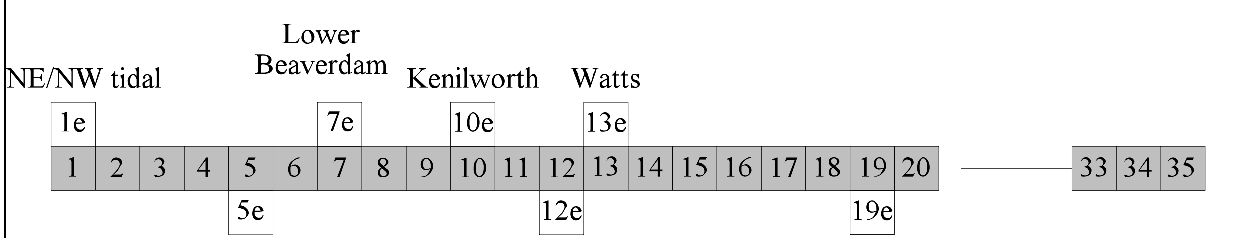

Figure 1. Schematic Representation of Model Segment Geometry, with Side Embayments

scenarios for addressing the District's combined sewer overflow problem. (DC WASA, 2001).

During 2001, ICPRB continued to develop the TAM/WASP sediment transport model in order to better support the District's TMDL effort for sediment, and also to provide a screening level toxics fate and transport model. Initially, ICPRB upgraded the TAM/WASP sediment transport model to 35 segments using geometry which was provided by LTI and which was based on a depiction of the river's shoreline from version 3 of the USGS's river reach files. However, a comparison of flow velocity measurements made by the Navy's SPAWAR vessel in the summer of 2000 (Katz et al., 2000) with predictions of the 35 segment TAM model using the LTI/WASA LTCP geometry gave poor results, with the TAM model significantly under-predicting peak flow velocities during a tidal cycle. Subsequently, ICPRB was able to improve the performance of the TAM hydrodynamic model by switching to a new 35 segment geometry computed by staff at NOAA, which was based on GIS data, using a more accurate depiction of the river's shoreline. The NOAA geometry also included Kingman Lake, Kenilworth Marsh, and other tidal embayment areas which were not represented in the LTI/WASA geometry, and has a total water surface area of approximately 3,300,000 square meters (m^2), which is about 24% greater than the total surface area of the LTI/WASA model. This increased surface area led to a significant increase in predicted peak flow velocities during a tidal cycle.

In order to implement NOAA's new 35 segment model geometry, which includes large tidal embayment areas such as Kingman Lake and Kenilworth Marsh, ICPRB made changes to the source code of the TAM hydrodynamic model to add the capability of representing side embayment areas. This capability was present in the original HEM model and has been used in other studies using HEM to simulate estuarine hydrodynamics (e.g. Kuo et al., 1994). By representing tidal embayment areas as side embayments, these additional areas of the Anacostia estuary contribute to the model surface area receiving and discharging flow, but do not distort the geometry of the main channel segment cross-sectional areas used to compute flow velocity/discharge relationships. ICPRB's new enhanced version of the TAM hydrodynamic model is described in more detail in the sections below.

Model Geometry

Model geometry for Version 2 of the TAM/WASP sediment transport model consists of a one-dimensional system of 35 segments, where each segment represents a portion of the tidal river's main channel, as pictured in Figure 1, with segment 1 representing the furthest upstream reach of the tidal river, near Bladensburg, and segment 35 representing the furthest downstream reach of the river, at its confluence with the Potomac. Additionally, main channel segments representing reaches of the river adjacent to tidal embayments have associated with them side embayment segments. As shown in Figure 1, the tidal portions of the Northeast and Northwest Branches, the tidal portions of Dueling Creek, Lower Beaverdam Creek, Kenilworth Marsh, Hickey Run, Watts Branch, and Kingman Lake, respectively, are represented in the Version 2 hydrodynamic program as side embayments, 1e, 5e, 7e, 10e, 12e, 13e, and 19e, of the main channel portions of segments 1, 5, 7, 10, 12, 13, and 19, respectively. (In the corresponding WASP model geometry of TAM/WASP, the surface areas and volumes of the tidal portions of the Northeast and

Northwest Branches, Dueling Creek, Lower Beaverdam Creek, Kenilworth Marsh, Hickey Run, and Watts Branch, respectively, are included in the surface areas and volumes of segments 1, 5, 7, 10, 12 and 13, respectively, and Kingman Lake, 19e, is treated as a separate segment, WASP segment 36, adjoining segment 19.)

TAM Hydrodynamic Model Finite Difference Solution

The TAM hydrodynamic model (Sullivan and Brown, 1988) is a one-dimensional model which simulates hydrodynamic processes based on the following equations of continuity and momentum conservation:

$$B \frac{\partial \eta}{\partial t} + \frac{\partial Q}{\partial x} = \bar{q} \qquad \textbf{(1a)}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = -gA\frac{\partial \eta}{\partial x} - gn^2 \frac{Q}{A} * |Q| R^{-\frac{4}{3}} + \frac{\tau_s}{\rho} * B + M \qquad \textbf{(1b)}$$

where

t	= time (s)
x	= distance along estuary axis (m)
B	= surface width of the estuary (m)
η	= surface elevation (m)
Q	= discharge (m^3/s)
$\bar{q}$	= lateral inflow per unit reach length (m^2/s)
A	= cross-sectional area (m^2)
g	= gravitational constant (m/s^2)
n	= Manning's friction coefficient ($s/m^{1/3}$)
R	= hydraulic radius (m)
τ_s	= surface shear stress (N/m^2)
ρ	= density of water (kg/m^3)
M	= momentum of lateral inflow (m^3/s^2)

The TAM model solves equations (1) using the finite difference method. In TAM/WASP Version 2, the system is discretized using the 35 segment model geometry described in the section above, with flows, Q_i, and cross-sectional areas, A_i, defined at each transect between segments, and water surface heights, η_i, and water surface areas, Sa_i, defined for each segment, as shown in Figure 2.

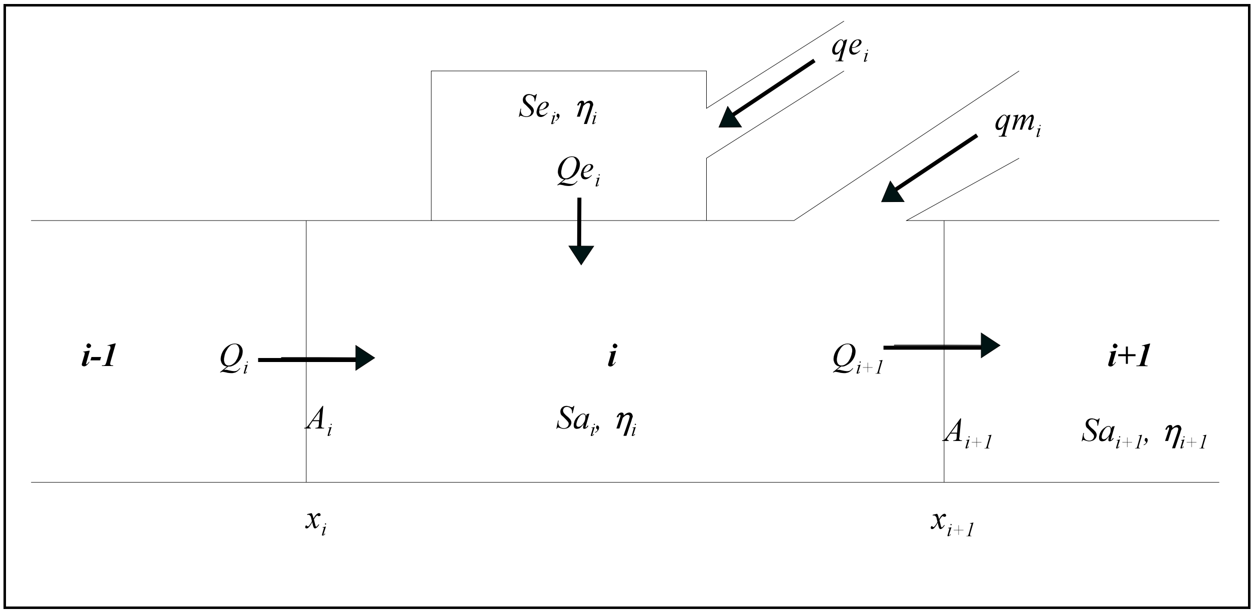

Figure 2. Schematic Representation of Model Discretization

Letting x_i represent the value of the spatial coordinate at the i^{th} transect, and integrating the continuity equation with respect to x, the following finite difference scheme can be obtained to approximate solutions of the system of hydrodynamic equations given above:

$$(Sa_i + Se_i)(\eta_i' - \eta_i) = \Delta t\, \beta (Q_i' - Q_{i+1}') + \Delta t\, \beta_c (Q_i - Q_{i+1}) + q_i \Delta t \qquad \textbf{(2a)}$$

$$\begin{aligned} Q_i' = Q_i &- \frac{\Delta t}{4\,\Delta x_i}\left[(Q_i + Q_{i+1})(U_i + U_{i+1}) - (Q_{i-1} + Q_i)(U_{i-1} + U_i)\right] \\ &- \frac{\Delta t}{\Delta x_i} A_i\, g\left[\alpha(\eta_i' - \eta_{i-1}') + \alpha_c(\eta_i - \eta_{i-1})\right] - \Delta t\, g\, n_i^2 \frac{Q_i' |U_i|}{R^{4/3}} \end{aligned} \qquad \textbf{(2b)}$$

where

Δt	=	time increment (s)
Δx_i	=	spatial increment (m)
A_i	=	cross-sectional area of transect i (m^2)
Q_i	=	flow across transect i (m^3/s)
η_i	=	surface water height of segment i (m)
Sai	=	water surface area of main channel segment i (m^2)
Se_i	=	water surface area of side embayment i (m^2)

qm_i = lateral inflow into main channel segment i (m^3/s)
qe_i = lateral inflow into side embayment i (m^3/s)
q_i = ($qm_i + qe_i$) = total lateral inflow into segment i (m^3/s)

and where primes denote functions evaluated at a later time step, e.g. $\eta_i' = \eta(x_i, t + \Delta t)$. Also, the weighting factors, α, α_c, β, and β_c, are constants which satisfy the conditions, $\alpha + \alpha_c = 1$ and $\beta + \beta_c = 1$. In addition, the flow across the boundary separating segment i from side embayment i, Q_i, satisfies the equation

$$Qe_i = qe_i - \frac{\partial \eta_i}{\partial t} Se_i \qquad \textbf{(3)}$$

The TAM model uses the weighting scheme defined by $\alpha_c = \beta_c = 0$, and thus the finite difference equations, (2), simplify to

$$SAM_i (\eta_i' - \eta_i) = \Delta t \, \beta (Q_i' - Q_{i+1}') + q_i \Delta t \qquad \textbf{(4a)}$$

$$Q_i' (1 + \Delta t \, g \, n_i^2 \frac{|U_i|}{R^{4/3}}) = Q_i - \frac{\Delta t}{4 \Delta x_i} [(Q_i + Q_{i+1})(U_i + U_{i+1}) - (Q_{i-1} + Q_i)(U_{i-1} + U_i)] - \frac{\Delta t}{\Delta x_i} A_i \, g \, \alpha (\eta_i' - \eta_{i-1}') \qquad \textbf{(4b)}$$

where the total surface area of segment i, including side embayment, is defined as $SAM_i = (Sa_i + Se_i)$.

Solving equation (4a) for Q_i' and substituting into equation (4b), one obtains,

$$[SAM_i + \frac{\Delta t^2 g A_i}{\Delta x_i FRIC_i} + \frac{\Delta t^2 g A_{i+1}}{\Delta x_{i+1} FRIC_{i+1}}] \eta_i'$$

$$= SAM_i \eta_i + \Delta t \frac{Q_i}{FRIC_i} - \Delta t \frac{Q_{i+1}}{FRIC_{i+1}} - \Delta t (\frac{CC Q_i}{FRIC_i} - \frac{CC Q_{i+1}}{FRIC_{i+1}}) \quad \textbf{(5)}$$

$$+ \frac{\Delta t_2 g A_i}{\Delta x_i FRIC_i} \eta_{i-1}' + \frac{\Delta t^2 g A_{i+1}}{\Delta x_{i+1} FRIC_{i+1}} \eta_{i+1}' + q_i \Delta t$$

where, for convenience, the following quantities have been defined:

$$FRIC_i = (1 + \Delta t \, g \, n_i^2 \frac{|U_i|}{R^{4/3}})$$

$$CC Q_i = \frac{\Delta t}{4 \Delta x_i} [(Q_i + Q_{i+1})(U_i + U_{i+1}) - (Q_{i-1} + Q_i)(U_{i-1} + U_i)] \quad \textbf{(6)}$$

In the original TAM code, equation (5), with (6), was implemented (Sullivan and Brown, 1988) but with no side embayment contributions to segment water surface areas, i.e., with $SAM_i = Sa_i$. In order to incorporate side embayments into the model, ICPRB changed the TAM source code to read the values of side embayment water surface areas, Se_i, from a model input file, and changed the definition of segment water surface areas from $SAM_i = Sa_i$ to $SAM_i = (Sa_i + Se_i)$.

Segment geometry inputs to the TAM hydrodynamic component of TAM/WASP Version 2 are based on estimates of the average length, width, and depth of each of the water column segments. Segment length and width estimates were obtained using the GIS representation of the tidal river recently prepared by NOAA for AWTA. Average mean-tide segment depth estimates were provided by NOAA (George Graettinger, NOAA, private communication) based on 1999 depth sounding data provided by the U.S. Army Corps of Engineers and an additional data set collected in the summer of 2000 for AWTA by the SPAWARs data collection team. NOAA used ESRI's Arcview Spatial Analyst software interpolation capabilities to estimate river depths at each point on a 10 ft by 10 ft grid. Average segment depths were then computed by averaging depths at all grid points within the segment. The estimates of model segment lengths, widths, depths, surface areas, and volumes used in TAM/WASP Version 2 are given in Table 1.

The model segment geometry given in Table 1 differs from the 15 segment geometry used in TAM/WASP Model Version 1 (Mandel and Schultz, 2000), and also differs slightly from the 35 segment geometry developed by LimnoTech, Inc. (LTI) (Scott Hinz, LTI, private communication) for the extension of the TAM/WASP model currently being used to model dissolved oxygen in the DC Water and Sewer Authority (WASA) Long Term Control Plan (LTCP) project. LTI's segment geometry was based on the USGSs depiction of the river shorelines in its River Reach File, Version 3, and the ACE's 1999 sounding data. The total model river volume at mean tide in TAM/WASP Version 2 is approximately 10,000,000 cubic meters (m^3), compared to approximately 9,400,000 m^3 in the LTI/WASA model, a difference of 6%. Due to model constraints, the depth of the side embayments are set equal to the depth of the corresponding main channel segments, which leads to an overestimation in model volume. The total model river surface area is approximately 3,300,000 square meters (m^2) in the ICPRB TAM/WASP V2 model, versus approximately 2,500,000 in the LTI/WASA model, a difference of about 24%.

Table 1. TAM/WASP Version 2 Segment Geometry

WASP Segment Number	Main Channel Length (m)	Main Channel Width (m)	Segment Depth (m from MSL)	Main Channel Surface Area (m^2)	Side Embayment Surface Area (m^2)	Total Segment Surface Area (m^2)	Total Segment Volume (m^3)
1	415	98.5	1.50	40,898	109,499	150,397	225,595
2	425	119.1	1.16	50,636	0	50,636	58,974
3	450	58.0	2.21	26,090	0	26,090	57,634
4	442	63.3	2.17	27,993	0	27,993	60,790
5	312	93.0	1.90	29,031	27,607	56,638	107,672
6	305	92.6	1.86	28,246	0	28,246	52,621
7	320	90.3	1.83	28,910	10,059	38,969	71,399
8	315	74.4	2.06	23,424	0	23,424	48,159
9	330	74.2	2.08	24,485	0	24,485	50,841
10	312	77.4	2.02	24,163	188,181	212,343	429,707
11	405	73.1	2.12	29,605	0	29,605	62,862
12	370	86.0	1.78	31,814	1,816	33,630	59,946
13	445	96.7	1.50	43,021	1,106	44,126	66,311
14	445	113.7	1.33	50,606	0	50,606	67,539
15	453	105.3	1.92	47,681	0	47,681	91,427
16	375	146.1	1.84	54,799	0	54,799	100,967
17	375	157.5	1.50	59,057	0	59,057	88,644
18	425	164.3	1.30	69,840	0	69,840	91,030
19	435	185.0	1.33	80,459	250,000	80,459	107,235
20	440	205.4	1.92	90,378	0	90,378	173,920
21	440	199.4	1.97	87,758	0	87,758	173,103
22	455	218.8	1.98	99,535	0	99,535	197,156
23	460	242.5	2.05	111,543	0	111,543	228,666
24	460	235.8	3.43	108,481	0	108,481	371,704
25	365	218.3	4.31	79,676	0	79,676	343,557
26	353	340.3	4.58	120,140	0	120,140	550,304
27	323	353.4	5.10	114,137	0	114,137	582,039
28	335	348.3	5.28	116,693	0	116,693	616,495
29	335	347.4	5.10	116,383	0	116,383	593,380
30	335	351.2	5.61	117,642	0	117,642	660,057
31	320	368.2	5.36	117,829	0	117,829	631,411
32	355	376.8	4.81	133,762	0	133,762	642,905
33	365	415.2	4.25	151,554	0	151,554	644,722
34	340	447.0	4.25	151,978	0	151,978	645,249
35	350	507.9	4.25	177,761	0	177,761	756,277

Model Verification: Velocity Predictions

In the summer of 2000, AWTA sponsored a data collection effort utilizing the Navy's Marine Environmental Survey Capability (MESC) deployed on the *ECOS* research vessel. A variety of physical and chemical measurements were made during the time period from July 5 to 21, 2000, including real-time flow velocity measurements at several locations along the river. (See Katz et al., 2000.) The TAM/WASP Version 2 TAM hydrodynamic model was run to simulate conditions in the tidal Anacostia during the time period July 6 through July 22, 2000, in order to compare model predictions with flow velocity measurement taken by the Navy using Acoustic Doppler Current Profiler (ADCP) devices. The ADCP's were set up to measure flow velocities throughout the entire water column in 1.5 meter bins from a depth of 1.7 meter to the river bottom, with flow averages available every 10 seconds. Comparison of the new enhanced TAM hydrodynamic model predictions with the depth-averaged along-channel flow velocities measured via the ADCP's are shown in Figures 4, 5, and 6. Model results match the measured flows quite well at the railroad lift bridge and the South Capital Street Bridge. In comparison to the ADCP data collected near the St. James Creek Marina, the model is still under-predicting peak flows during a tidal cycle by roughly 30%. Possible explanations for this discrepancy are the presence of structures related to the St. James Creek Marina, which may affect flow at this location, or the proximity to the Potomac, which may make the approximations of the one-dimensional model less valid.

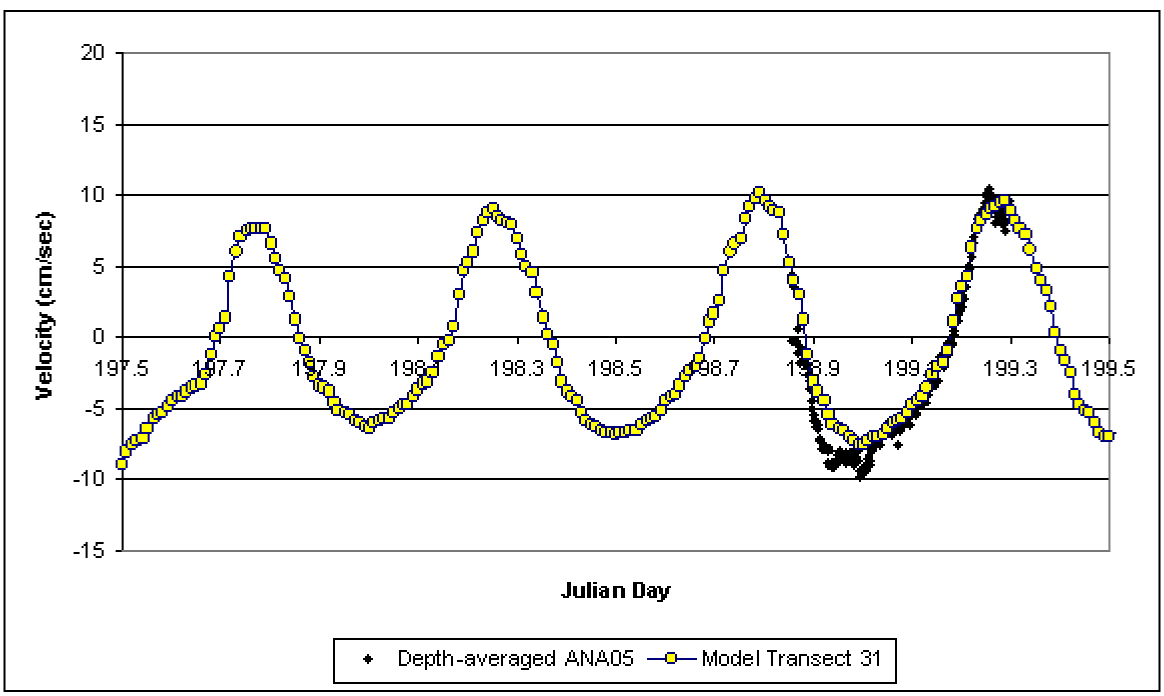

Figure 3. Comparison of Model-Predicted and Measured Flow Velocities at the South Capitol Street Bridge.

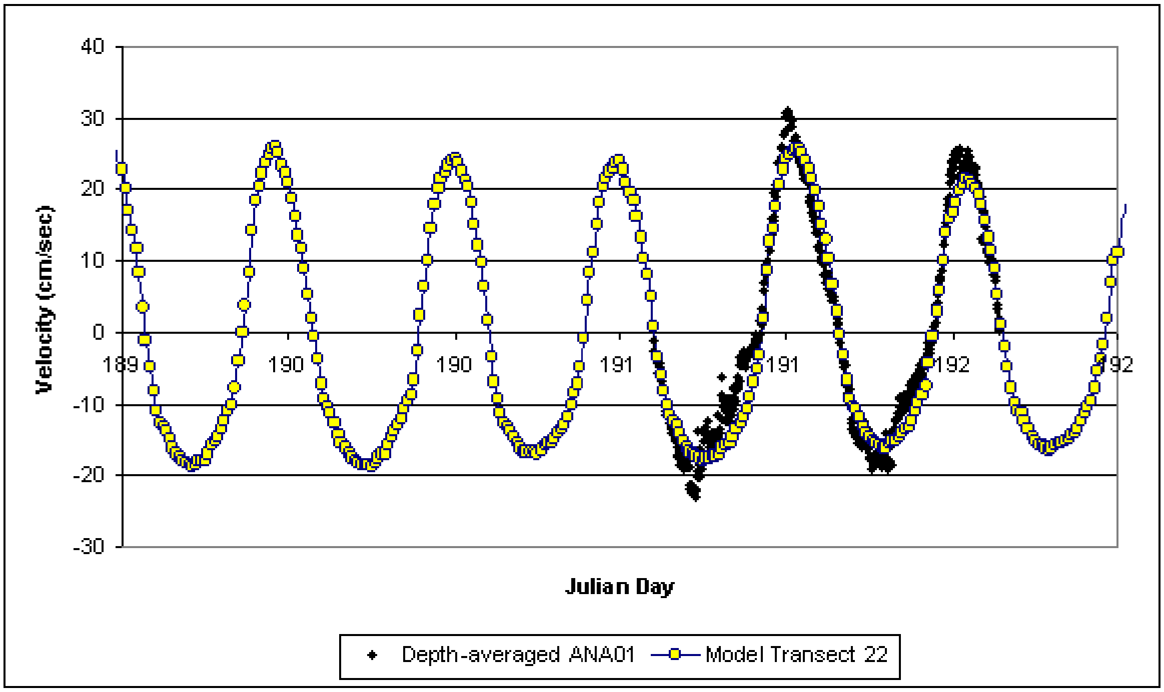

Figure 4. Comparison of Model-Predicted and Measured Flow Velocities at the Railroad Lift Bridge.

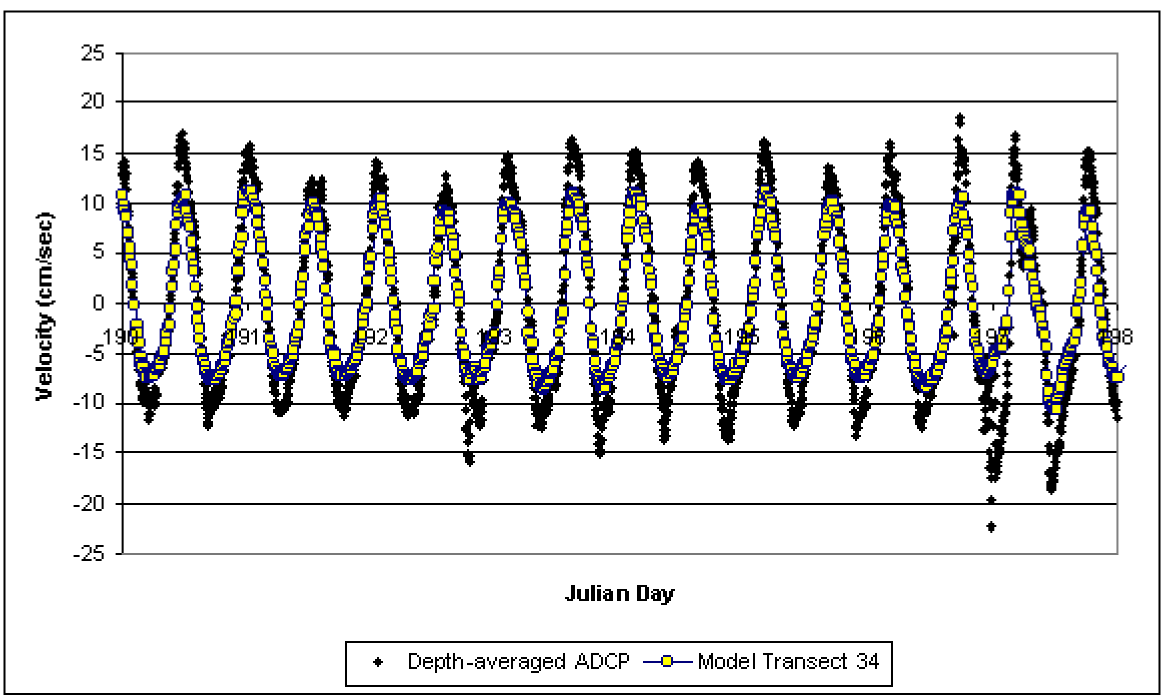

Figure 5. Comparison of Model-Predicted and Measured Flow Velocities at the St. James Creek Marina.

Model Verification: Summer 2000 Dye Study

In the summer of 2000, LTI conducted a dye study in the Anacostia for USEPA Region 3. The purpose of the study was to gather data on mixing and dispersion in the river to support TAM/WASP model development. A total of 18.2 gallons of a 20% solution of Intracid Rhodamine WT fluorescent tracing dye was injected mid-channel into the river at the Bladensburg Marina from June 6 through June 11, 2000. Dye concentrations were monitored twice daily at 18 sampling stations along the length river from Bladensburg Road to Haines Point. Monitoring stopped on June 23 when dye concentrations were found to be no longer detectable.

TAM/WASP Version 2 was used to simulate dye concentrations in the Anacostia from June 1 through June 30. Dye injection rates used were those reported by LTI (DC WASA, 2001), and the following other LTI assumptions were also used: a downstream boundary dye concentration of 0.1 mg/L, an upstream boundary concentration of 0.2 mg/L, a dispersion coefficient of 1.3 m^2/s, and a decay rate of zero. Best results were obtained when the WASP advection factor, ADFAC, was set to 0.25, a slightly different value than was used in the calibration of the sediment transport model.

The model simulates the location of the peak and the tidal variation of dye concentrations reasonably well. In Figure 6, a comparison is shown of predicted versus observed dye concentrations along the length of the river on three days: June 14, June 17, and June 20. Model predictions for June 17 and 20 are fairly good, though the model under-predicts upstream dye concentrations on June 14. Figure 7 show time series of predicted versus observed dye concentrations at five locations: New York Avenue, East Capitol Street Bridge, Sousa Bridge, 11th Street Bridge, and South Capitol Street Bridge. Model results again are fairly good at all but the most upstream location, New York Avenue. Comparing the performance of ICPRB's modified version of TAM with LTI's 35-segment version of TAM, results can be seen to be fairly similar, though the ICPRB model concentration predictions are somewhat lower than those of the LTI version. LTI hypothesized that the under-prediction of concentrations by TAM/WASP in the upstream portion of the river might be partially due to lack of complete lateral mixing of the dye plume in the early days of the study, and partially due to the inherent inaccuracies in representing a channel with side embayments with a one-dimensional model. Though ICPRB's version of the model does incorporate side embayments in the hydrodynamic portion of the model, all side embayments but Kingman Lake are still combined with main channel segments in the WASP component of the model. Also, because the necessity of using unrealistically high average depths for some of these combined segments, ICPRB's version of the model in some cases over-estimates segment volumes. This causes a dilution effect and an under-prediction of concentrations in some upstream areas of the river.

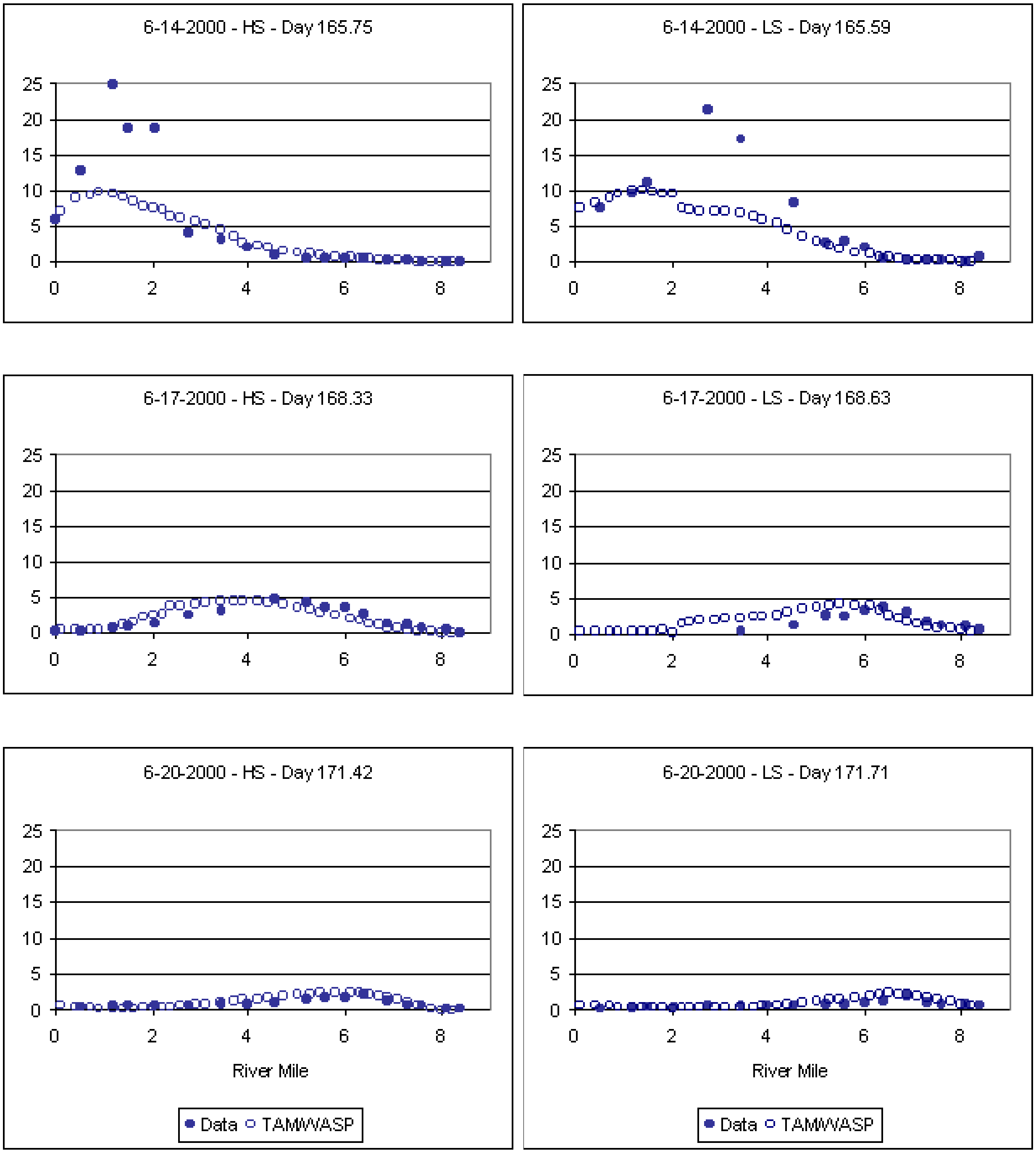

Figure 6. Comparison of Longitudinal Profile of Measured Versus Predicted Dye Concentrations (mg/L) at high slack tide (HS) and low slack tide (LS).

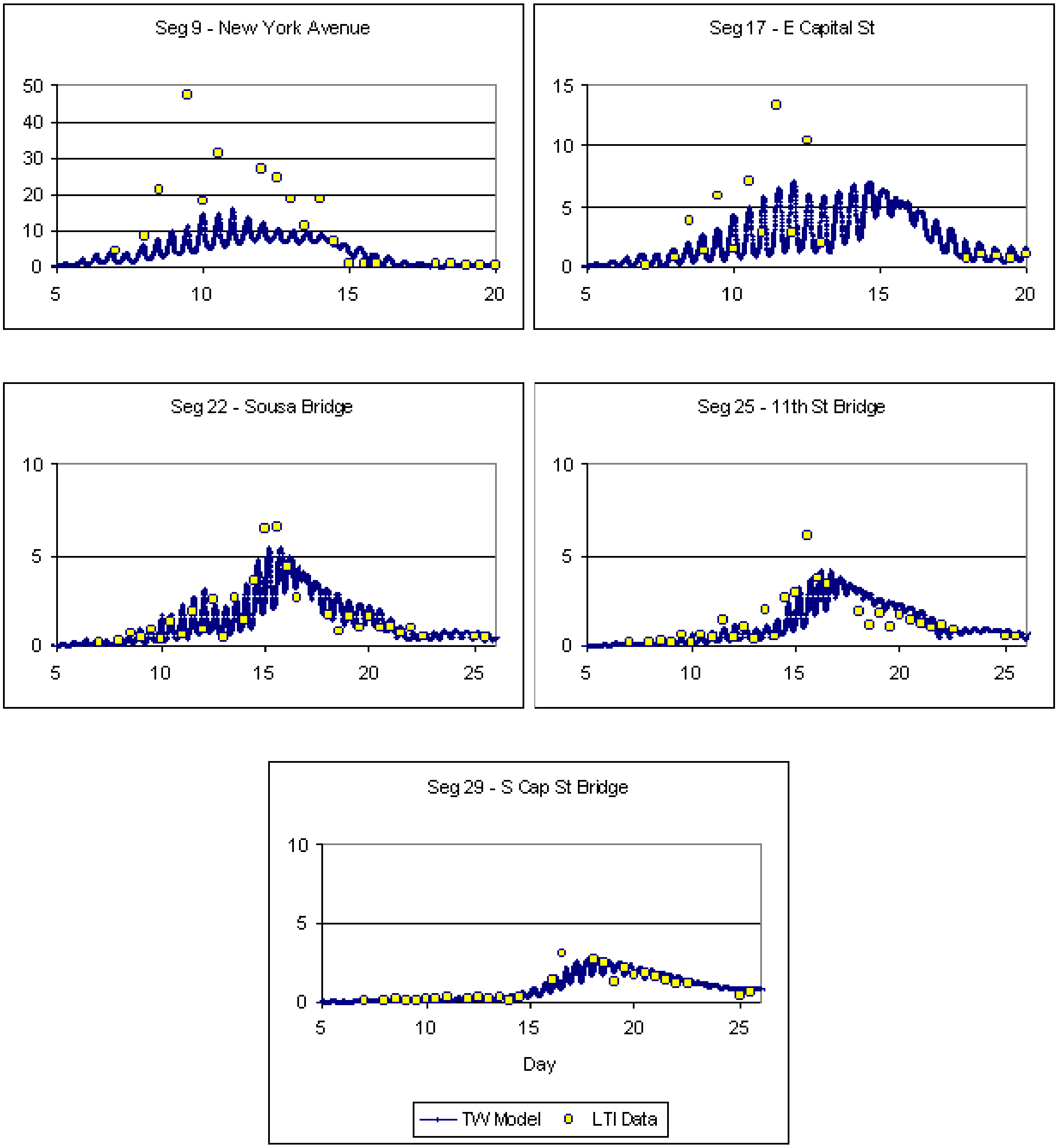

Figure 7. Comparison of Time Series of Measured Versus Predicted Dye Concentrations (mg/L).

Conclusion

ICPRB has developed a new version of the TAM hydrodynamic model which uses a 35 segment geometry computed by NOAA, and represents tidal embayment areas such as Kenilworth Marsh and Kingman Lake as side embayments adjacent to main channel segments. The model is based on the original 15 segment model developed by MWCOG and the Virginia Institute of Marine Science's HEM one-dimensional modeling framework. The number of model segments was increased from 15 to 35 following the recommendation that LTI made based on its summer 2000 dye study. The new segment geometry by NOAA was incorporated in order to improve model predictions of flow velocities in the channel. The NOAA geometry has a total water surface area of approximately 3,300,000 square meters (m^2), which is about 24% greater than the total surface area of the LTI/WASA model. This increased surface area leads to a significant increase in predicted peak flow velocities during a tidal cycle, allowing a better match between model flow predictions and available data.

ICPRB's new version of the TAM model was also coupled to the EPA's WASP water quality model and used to simulate the plume of dye in the river released in June, 2000 in LTI's study. Model predictions matched observations reasonably well, though not as well as in LTI's simulation of the plume made using their 35-segment version of the TAM model. This difference is probably due to the dilution caused by the greater river volume estimate used in the ICPRB version of the model.

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