D.C. DEPARTMENT OF HEALTH
Environmental Health Administration
Bureau of Environmental Quality
Water Quality Division

DISTRICT OF COLUMBIA

FINAL
TOTAL MAXIMUM DAILY LOADS

FOR

ORGANICS

IN

TIDAL BASIN AND WASHINGTON SHIP CHANNEL

DECEMBER 2004

Government of the
District of Columbia
Anthony A. Williams, Mayor

DISTRICT OF COLUMBIA

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WATER QUALITY DIVISION

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INTRODUCTION

Section 303(d) (1)(A) of the Federal Clean Water Act (CWA) states:

> *Each state shall identify those waters within its boundaries for which the effluent limitations required by section 301(b) (1)(A) and section 301(b)(1)(B) are not stringent enough to implement any water quality standards applicable to such waters. The State shall establish a priority ranking for such waters taking into account the severity of the pollution and the uses to be made of such waters.*

Further, Section 303(d) (1)(C) states:

> *Each state shall establish for the waters identified in paragraph (1)(A) of this subsection, and in accordance with the priority ranking, the total maximum daily load, for those pollutants which the Administrator identifies under section 304(a)(2) as suitable for such calculations. Such load shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality.*

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies, which are exceeding water quality standards.

In 1996, the District of Columbia (DC), developed a list of impaired waters that did not or were not expected to meet water quality standards as required by Section 303(d)(1)(A). This list, submitted to the Environmental Protection Agency every two years, is known as the Section 303(d) list. This list of impaired waters was revised in 1998 and 2002 based on additional water quality monitoring data. EPA, subsequently, approved each list. The Section 303(d) list of impaired waters contains a priority list of those waters that are the most polluted. This priority listing is used to determine which waterbodies are in critical need of immediate attention. For each of the listed waters, states are required to develop a Total Maximum Daily Load (TMDL), which establishes the maximum amount of a pollutant that a waterbody can receive without violating water quality standards and allocates that load to all significant sources. Pollutants above the allocated loads must be eliminated. By following the TMDL process, states can establish water-quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources. The Tidal Basin and the Washington Ship Channel are listed on DC's 303(d) lists for organics impairment. The TMDLs developed herein are for organics in the Tidal Basin and the Washington Ship Channel.

CHEMICALS OF CONCERN

Because of lack of data in the Tidal Basin and the Washington Ship Channel, the list of organic chemicals of concern were determined from data derived from fish tissue[1] and sediment[3] analysis in the Anacostia River. Table 1 presents the results of this assessment.

A recent data assessment study identified potential chemicals of concerns in Rock Creek (LTI, 2003). Based on the study, several likely chemicals have been identified, which included chlordane, DDT, endosulfan, heptachlor epoxide, hexachlorobenzene, total PAHs, and total PCBs. Therefore, listed chemicals in Table 1 are considered comprehensive to address organics in the Tidal Basin and the Washington Ship Channel.

Table1: Fish Tissue and Sediment Data Exceeding Screening Values

Organics	Anacostia Fish tissue Data[1] (ppm)	EPA Screening Value[2] (ppm)	Anacostia Sediment Data (ppm dw)	Sediment Screening value (ppm dw)
Chlordane	0.338	0.114	0.1699	0.00324
DDT	0.375	0.117	0.3194	0.00528
Dieldrin	0.0315	0.0025	N/A	N/A
Heptachlor Epoxide	0.0080	0.00439	NA	NA
Total PAHs	0.151	0.00547	97.878	1.61
Total PCBs	2.49	0.020	1.629	0.0598

Notes: N/A Data not Available.

1. U.S. FWS. 2001. Analysis of Contaminant Concentrations in Fish Tissue Collected from the Waters of the District of Columbia. Final Report. Publication number CBFO-C01-01, Chesapeake Bay Field Office, Annapolis, MD.
2. U.S. EPA 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1, Fish Sampling and Analysis, Third edition. EPA 823-B-00-007, Office of Water, Washington D.C.
3. Data Assessment Report Anacostia River Sediments Patrick Center for Environmental Research, The Academy of Natural Sciences of Philadelphia, KQS Report Number 134-01R01. Appendix II. September 2000.
4. MacDonald, D.D., C.G. Ingersoll and T.A. Berger. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. *Arch. Environ. Contam. Toxicol.* 29-31.

DESIGNATED BENEFICIAL USES

Categories of DC surface water designated beneficial uses and water quality standards are contained in District of Columbia Water Quality Standards, Title 21 of the District of Columbia Municipal Regulations, Chapter 11 (DC WQS, Effective January 24, 2003). Section 1101.1 states:

> *For the purposes of water quality standards, the surface waters of the District shall be classified on the basis of their (i) current uses, and (ii) future uses to which the waters will be restored.*

The categories of beneficial uses that were used to determine Water Quality standards for the surface waters of the District are as follows:

Category of Use	Class of Water
Primary contact recreation……………………………………………	A
Secondary contact recreation and aesthetic enjoyment…………………	B
Protection and propagation of fish, shellfish, and wildlife ……………..	C
Protection of human health related to consumption of fish and shellfish	D
Navigation ………………………………………………………………	E

The table below identifies the current use and designated beneficial uses of the waters of the Tidal Basin and the Washington Ship Channel.

Waterbody	Current Use					Designated Use				
	A	B	C	D	E	A	B	C	D	E
Tidal Basin		✓	✓	✓	✓	✓	✓	✓	✓	✓
Washington Ship Channel		✓	✓	✓	✓	✓	✓	✓	✓	✓

Where, Current use means the use which is generally and usually met in the waterbody at the present time in spite of the numeric criteria for that use not being met sometimes; and Designated use means the use specified for the waterbody in the water quality standards whether or not it is being attained.

APPLICABLE D.C.WATER QUALITY STANDARDS

Narrative Criteria

The District of Columbia's Water Quality Standards include narrative and numeric criteria that were written to protect existing and designated uses.

Section 1104.1 states several narrative criteria designed to protect the existing and designated uses:

> *The surface waters of the District shall be free from substances attributable to point or nonpoint sources discharged in amounts that do any one of the following:*
>
> 1. *Settle to form objectionable deposits;*
> 2. *Float as debris, scum, oil, or other matter to form nuisances;*
> 3. *Produce objectionable odor, color, taste, or turbidity;*
> 4. *Cause injury to, are toxic to or produce adverse physiological or behavioral changes in humans, plants, or animals;*
> 5. *Produce undesirable or nuisance aquatic life or result in the dominance of nuisance species; or*
> 6. *Impair the biological community which naturally occurs in the waters or depends on the waters for their survival and propagation.*

Numerical Criteria

Table 2: WQS Section 1104.7 Table 3 Organics Numerical Criteria

Constituent – Organics[1]	*Criteria for Classes (ug/L)*		
	C		D
	CCC Four Day Average	*CMC* One Hour Average	30 Day Average
Chlordane	0.004	2.4	0.00059
DDE	0.001	1.1	0.00059
DDD	0.001	1.1	0.00059
DDT	0.001	1.1	0.00059
Dieldrin	0.0019	2.5	0.00014
Heptachlor Epoxide	0.0038	0.52	0.00011
PAH 1[2]	50	N/A	14000
PAH 2[3]	400	N/A	0.031
PAH 3[4]	N/A	N/A	0.031
Total PCBs	0.014	N/A	0.000045

N/A – Not Applicable
Notes:

1. WQS for PAH1, 2 and 3 were based on a conservative assumption that applicable water quality standards are the most stringent standard for a single PAH in the group. For example, the Class D water quality standard for fluoranthene, pyrene, benz[a]anthracene, and chrysene are 370, 11000, 0.031, and 0.031 ug/l, respectively. Therefore the most stringent of the individual standards, 0.031 ug/l is given in Table 2 as the Class D standard for PAH2.

2. PAH1, is the sum of six 2 and 3-ring PAHs, naphthalene, 2-methyl napthalene, acenapthylene, acenapthene, fluorene, and phenanthrene.

3. PAH2, consists of the four 4-ring PAHs, fluoranthene, pyrene, benz[a]anthracene, and chrysene.

4. PAH3, consists of the six 5 and 6-ring PAHS, benzo[k]fluoranthene, benzo[a]pyrene, perylene, indeno[1,2,3-c,d]pyrene, benzo[g,h,i]perylene, and dibenz[a,h+ac]anthracene.

WATERSHED

The Washington Ship channel along with the Tidal Basin are man made waterbodies located in the southwest section of Washington D.C. along the Potomac River. The Tidal Basin was built in the late 19th century by the Army Corps of Engineers as a part of the comprehensive management of the Potomac River and land development of Washington D.C. The main function of the Tidal Basin is to flush the Washington Ship Channel with the freshwater from the Potomac River. Two sets of floodgates exist in the flushing system, one linking the Tidal Basin and the Potomac River, and the other linking the Tidal Basin and the Washington Ship Channel. Freshwater flows into the Tidal Basin through the flap gates when the tidal elevation changes and the elevation in the Potomac River is higher than that in the Tidal Basin. In the same way, the freshwater flushes into the Washington Ship Channel as the water surface elevation becomes higher in the Tidal Basin. The purpose of the gates is to direct flow from the Potomac River to the Tidal

Basin then to the Washington Ship Channel. The Tidal Basin is shallow with an average depth of around 6.5 feet (2 meters) and a surface area of about 0.15 square miles (0.4 km2). The Washington Ship Channel is about 400 feet (122 meters) wide and the depth varies from 3 feet (1 meter) to 26 feet (8 meter) (Velinsky et al. 1994). Figure 1 shows the Ship Channel and the Tidal Basin.

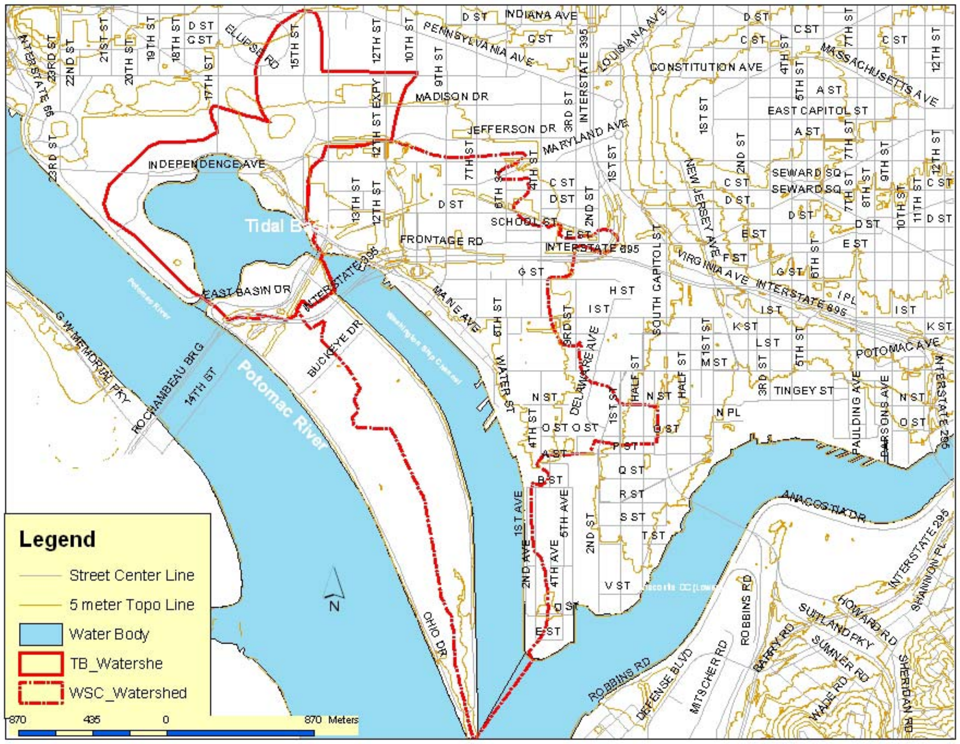

Figure 1: Tidal Basin and Washington Ship Channel

As shown in Figure 2, the land use in the Tidal Basin watershed is dominated by parklands/grass areas covering about 43 percent of the watershed. The Basin itself covers about 30 percent, and the remaining areas being used mainly for commercial/government offices. The land use around the Washington Ship Channel is dominated by government/commercial/residential uses along the northern bank of the waterbody covering about 53 percent of the watershed (see Figure 3). The area along the southern bank is characterized by recreational grass and parklands, with the Channel itself covering about 25 percent of the watershed. The Channel, along the northern banks between the Tidal Basin and Fort McNair, is used as docking for small personal and large commercial touring boats. There is a large fish market and series of seafood restaurants along the docking areas.

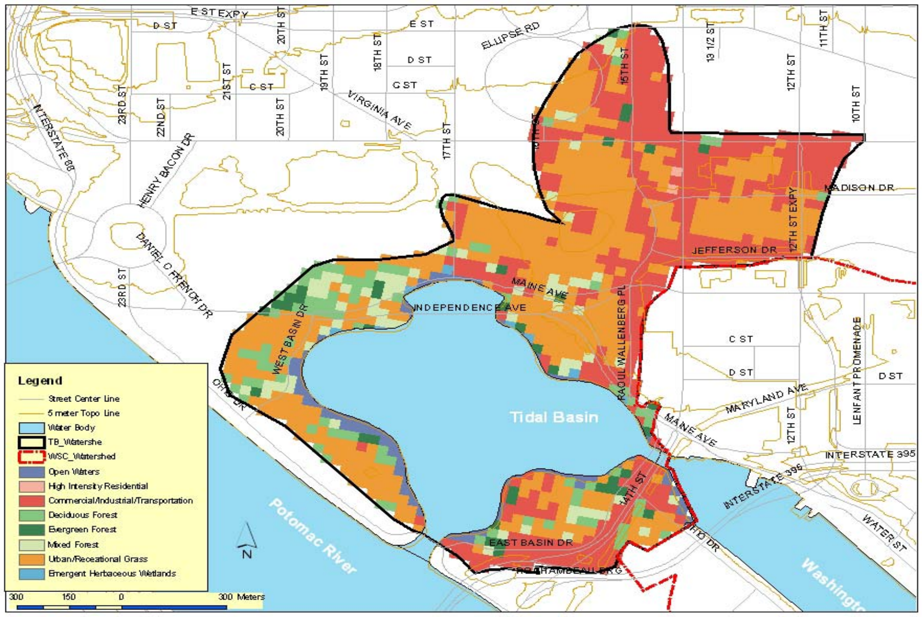

Figure 2: Landuse in the Tidal Basin Watershed

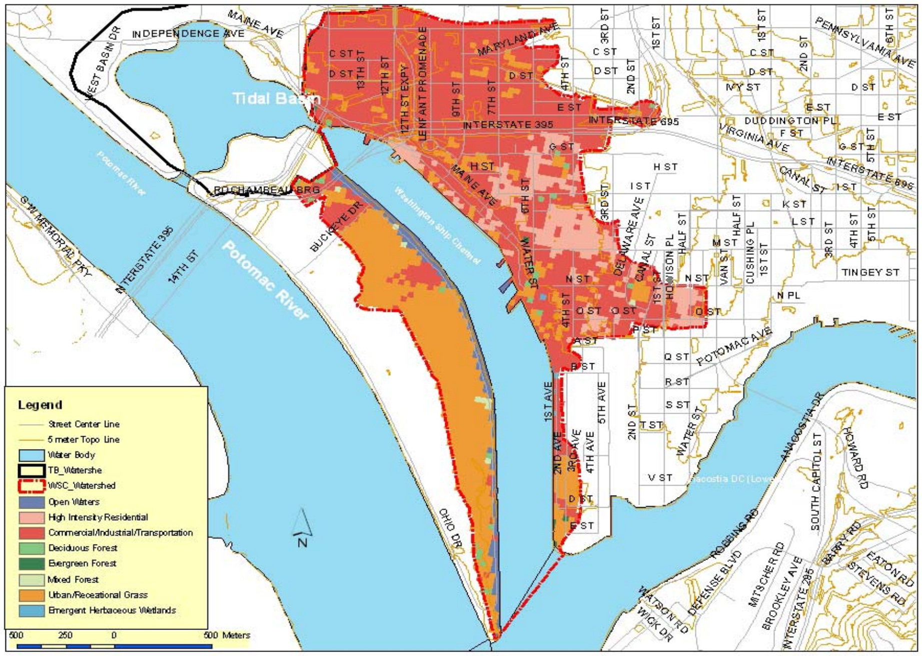

Figure 3: Landuse in the Washington Ship Channel Watershed

SOURCE ASSESSMENT

Within the District of Columbia, there are three different networks for conveying wastewater. Originally, a combined sewer system was installed which collected both sanitary waste and storm water and transported the flow to the wastewater treatment plant. When storm water caused the combined flow to exceed the pipe capacity leading to the treatment plant, the excess flow was discharged, untreated, through the combined sewer outfalls to the rivers. Approximately one third of the District of Columbia is served by the combined sewer system. The remaining two thirds of the District of Columbia is served by a separate system where one pipe network (separate sanitary sewage system) collects sanitary sewage that is transported to the Blue Plains wastewater treatment plant in the southeast corner of the District and another pipe network (separate storm sewer system) collects storm water that is transported and discharged to the nearest stream channel.

The Washington Ship Channel and the Tidal Basin is served by the separate storm system as shown in Figure 4. Separate storm water networks collect storm water from streets and parking lots. Collected storm runoffs are then directly discharged to nearby rivers or

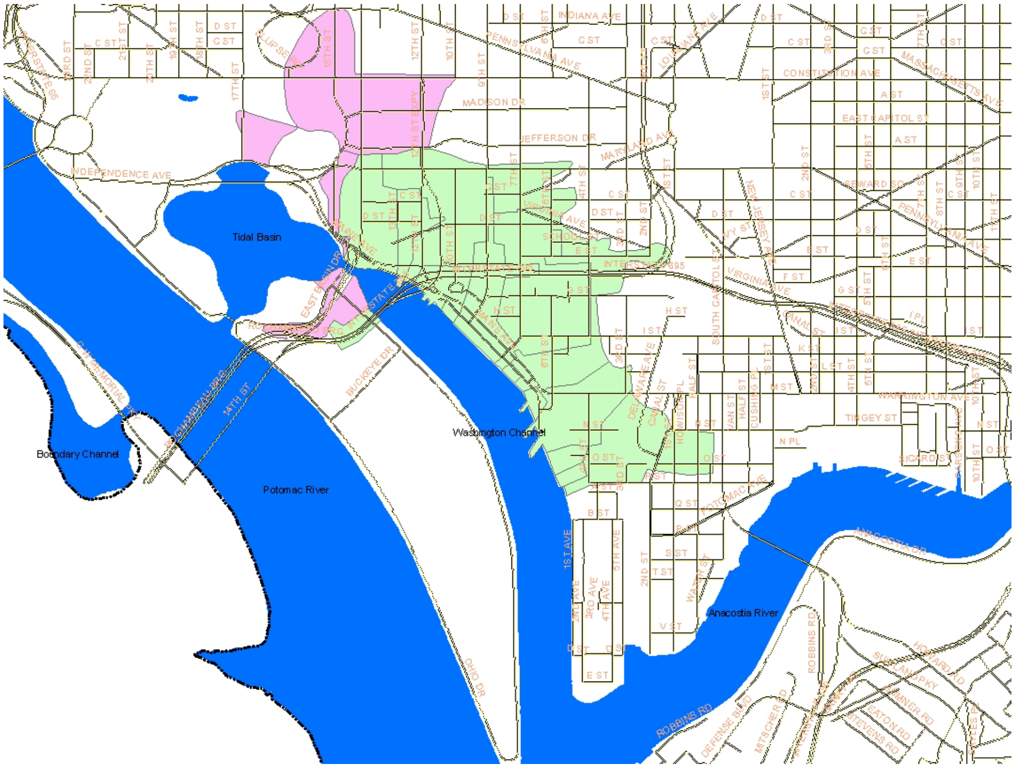

Figure 4. Separate Storm Sewer Areas in the Tidal Basin and Washington Ship Channel Watersheds

streams. There are six storm sewers discharging into the Tidal Basin and nine storm sewers draining into the Washington Ship Channel. There are no combined sewer overflow outfalls in the waterbodies.

Direct runoffs from parklands flanking the water bodies and not serviced by storm water sewers also occur along the Tidal Basin and the Ship Channel. Therefore, during wet weather events, there is a combination of direct storm water runoff and storm water being carried by pipes to the waterbodies. Historically considered nonpoint source, storm water runoff discharged from separate storm sewer systems (SSWS) are permitted under the National Pollution Discharge Elimination System (NPDES).

In addition to storm and direct runoffs, the Tidal Basin and the Ship Channel are affected by water quality conditions in the Potomac and the Anacostia Rivers because of direct hydraulic connections.

TMDL TECHNICAL APPROACH

TMDL End Points

For this TMDL analysis, the numeric criteria described in the "Applicable D.C. water Quality Standards" section were used to achieve load allocations for the Tidal Basin and the Ship Channel.

Seasonal Variations and Critical Conditions

Because of the natural variability in rainfall and storm water runoff, developing a daily load is not an effective means of determining the assimilative capacity of the receiving waters. Rather, looking at total loads over a range of conditions is a more relevant way to determine the maximum allowable loads. A statistical analysis of rainfall records over a period of fifty years was conducted and a dry year, a wet year, and an average rainfall year, were identified based on total annual rainfall and other factors such as average intensity and number of events per year (DCWASA, 2002). The consecutive years of 1988, 1989, and 1990, represent a relatively dry year, a wet year, and an average precipitation year, respectively. These three years were considered the period of record for determining compliance with the water quality standards for the TMDL analysis. Determination of compliance with the water quality standards was based on the frequency of violations as calculated by the model for these three years.

Modeling

A model was developed for the Tidal Basin and the Ship Channel to simulate organics. The model used the same framework as what was used to simulate fecal coliform bacteria in the waterbodies (Lung, 2003). A brief description of the model is included in Appendix A. Because of very limited data, the model was based on simplified conservative assumptions. It was developed using EFDC, a three-dimensional model capable of simulating hydrodynamics, sediment transport and water quality using a curvilinear-orthogonal grid for a waterbody. The model grid for the Tidal Basin and the Ship Channel is shown in Figure 5.

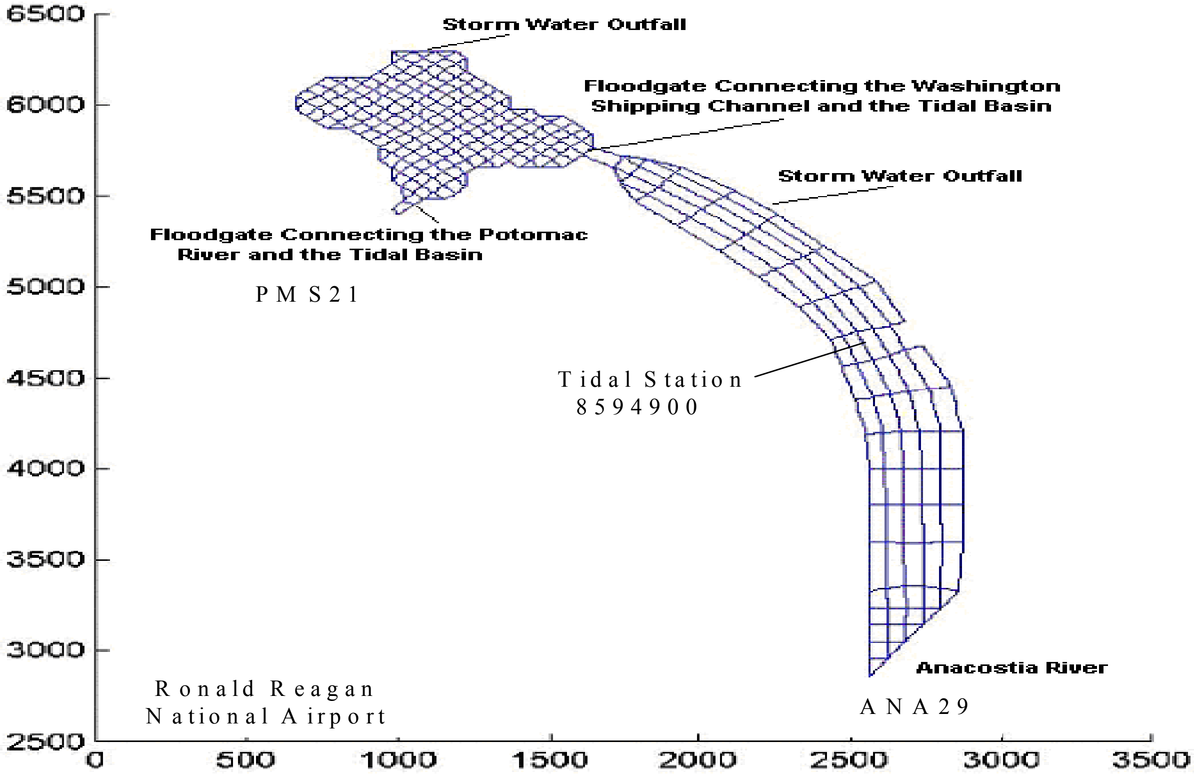

Figure 5: Hydrodynamic Grid of the Tidal Basin and Washington Ship Channel

The model input includes runoffs from the separate storm water system and direct runoffs from park areas. No illicit discharges are simulated in the model. The separate storm water and direct runoff loads were calculated using event mean concentrations of the chemicals of concerns and the modeled flow volume over the period of analysis. Boundary conditions at the upstream link between the Tidal Basin and the Potomac River and the downstream link between the Washington Ship Channel and the Anacostia River were also simulated in the model. The model was run for three different years (1988, 1989, 1990) and the model outputs were checked at selected locations such as close proximity to storm water outfalls, where maximum concentrations may occur.

TOTAL MAXIMUM DAILY LOAD AND ALLOCATION

Wasteload and Load Allocation, and Margins of Safety

There are no combined sewer outfalls in the Tidal Basin and the Washington Ship Channel; however, both waterbodies receive discharges from separate storm sewers. They also receive direct runoffs from park areas not served by the sewer systems.

The following table shows the existing loads and allowable organics TMDLs that met the applicable water quality standards. An explicit margin of safety equal to ten percent of the TMDL load has been considered for the allocation for all the constituents, except PCBs. For PCBs, load reduction is 99.67 percent for both waterbodies. The total allowable loads reflect the reductions needed in order to meet all numeric water quality standards described earlier.

For both the Tidal Basin and the Washington Ship Channel, the following reductions were required to meet the water quality standards: Chlordane at 63.99%; DDD at 0%; DDE at 73.38%; DDT at 89.65%; Dieldrin at 0%; Heptachlor Epoxide at 31.03%; PAH 1 at 0%; PAH 2 at 95.53%; and PAH 3 at 93.06%. For the TMDL analysis, it was assumed that the boundaries between the Potomac River and the Tidal Basin; and between the Anacostia River and the Ship Channel meet the lowest numeric standard of each constituent at all time.

Existing and allocated loads for organics in the Tidal Basin (pounds per average year)

Constituent	Tidal Basin Existing Load			TMDL	10% MOS	Storm Water	Direct Runoff
	Storm Water	Direct Runoff	Total Load				
Chlordane	1.228E-02	9.945E-03	2.222E-02	8.003E-03	8.003E-04	3.980E-03	3.223E-03
DDD	3.747E-03	3.035E-03	6.782E-03	6.782E-03	6.782E-04	3.372E-03	2.732E-03
DDE	1.661E-02	1.346E-02	3.007E-02	8.003E-03	8.003E-04	3.980E-03	3.223E-03
DDT	4.272E-02	3.460E-02	7.732E-02	8.003E-03	8.003E-04	3.980E-03	3.223E-03
Dieldrin	3.622E-04	2.934E-04	6.556E-04	6.556E-04	6.556E-05	3.260E-04	2.641E-04
Heptachlor Epoxide	1.195E-03	9.682E-04	2.164E-03	1.492E-03	1.492E-04	7.419E-04	6.010E-04
PAH1	8.225E-01	6.662E-01	1.489E+00	1.489E+00	1.489E-01	7.403E-01	5.996E-01
PAH2	5.195E+00	4.208E+00	9.404E+00	4.205E-01	4.205E-02	2.091E-01	1.694E-01
PAH3	3.350E+00	2.713E+00	6.063E+00	4.205E-01	4.205E-02	2.091E-01	1.694E-01

Existing and allocated loads for organics in the Ship Channel (pounds per average year)

Constituent	**Washington Ship Channel Existing Load**			**TMDL**	**10% MOS**	**Storm Water**	**Direct Runoff**
	Storm Water	**Direct Runoff**	**Total Load**				
Chlordane	4.058E-02	1.704E-02	5.762E-02	2.075E-02	2.075E-03	1.315E-02	5.524E-03
DDD	1.238E-02	5.201E-03	1.758E-02	1.758E-02	1.758E-03	1.115E-02	4.681E-03
DDE	5.490E-02	2.306E-02	7.796E-02	2.075E-02	2.075E-03	1.315E-02	5.524E-03
DDT	1.412E-01	5.929E-02	2.005E-01	2.075E-02	2.075E-03	1.315E-02	5.524E-03
Dieldrin	1.197E-03	5.028E-04	1.700E-03	1.700E-03	1.700E-04	1.077E-03	4.525E-04
Heptachlor Epoxide	3.950E-03	1.659E-03	5.609E-03	3.869E-03	3.869E-04	2.452E-03	1.030E-03
PAH1	2.718E+00	1.142E+00	3.860E+00	3.860E+00	3.860E-01	2.446E+00	1.027E+00
PAH2	1.717E+01	7.211E+00	2.438E+01	1.090E+00	1.090E-01	6.910E-01	2.902E-01
PAH3	1.107E+01	4.650E+00	1.572E+01	1.090E+00	1.090E-01	6.910E-01	2.902E-01

For allocating PCB loads among sources, existing land-based loads and watershed atmospheric deposition loads of PCBs were calculated. Atmospheric deposition is expected to decrease over time since the production and use of PCBs was banned in the 1970s. The releases from unidentified land sources are accounted for in the model by the storm water loads. Existing loads were calculated using the EFDC model for the Tidal Basin and the Ship Channel. Available atmospheric deposition loads for the tributaries were based on average annual atmospheric deposition flux provided by Chesapeake Bay Program data (Chesapeake Bay Program, 1999). Total PCB loads for sources other than atmospheric loads (i.e., land-based) were determined by subtracting atmospheric loads from existing loads in the watershed (see Appendix B for detailed calculations). For the Tidal Basin and the Ship Channel, 99.67 percent reductions of the PCB existing loads are required to meet water quality standards.

Existing and allocated loads for PCBs in the Tidal Basin (pounds per average year)

	Existing Load			**Atmospheric Load**	**TMDL (Land-Based Source)**	**Storm Water (Land-Based Source)**	**Direct Runoff (Land-Based Source)**
	Storm Water	**Direct Runoff**	**Total**				
TPCB	1.007E-01	8.155E-02	1.822E-01	1.025E-02	5.675E-04	3.141E-04	2.534E-04

Existing and allocated loads for PCBs in the Ship Channel (pounds per average year)

	Existing Load			**Atmospheric Load**	**TMDL (Land-Based Source)**	**Storm Water (Land-Based Source)**	**Direct Runoff (Land-Based Source)**
	Storm Water	**Direct Runoff**	**Total**				
TPCB	3.327E-01	1.397E-01	4.724E-01	5.147E-02	1.389E-03	9.788E-04	4.104E-04

REASONABLE ASSURANCE

There are several programs in place in the District of Columbia to control the effects of storm water runoff and promote prevention and control of nonpoint source pollution. The source control measures described in the following will help reduce toxics pollution of the District of Columbia waters.

Storm Water Load Reductions

The District of Columbia Water Pollution Control Act (DC Law 5-188) authorizes the establishment of the District's Water Quality Standards (21 DCMR, Chapter 10) and the control of sources of pollution such as storm water management (21 DCMR, Chapter 5).

The DC Department of Health has an extensive storm water management, sediment, and erosion control program for construction activities. It also has a Nonpoint Source Management Plan to address the reduction of nonpoint source pollution (D.C. Department of Health, 2002).

A number of activities to reduce pollutant runoff are carried out as part of the Municipal Separate Storm Sewer Permit (MS4) for the District of Columbia. The most pertinent of these are contained in the storm water management plan. The plan provides additional mechanisms for achieving the load reductions needed.

Major currently operating programs in DC that reduce loads are as follows:

1. Street sweeping programs by the Department of Public Works.
2. Requirements for storm water treatment on all new development and earth disturbing activities such as road construction.
3. Regulatory programs restricting illegal discharges to storm sewers and enforcing the erosion control laws.
4. Environmental education and citizen outreach programs to reduce pollution causing activities.
5. DC WASA has launched a citywide Sanitary Sewer System Investigation. The activities under this program will eliminate infiltration of sanitary sewer to the storm water system.

Federal lands encompass a major portion of the Tidal Basin and the Washington Ship Channel watersheds. The federal facilities such as the National Park Service will need to develop storm water management plans to reduce their loads and implement those plans.

In terms of legacy compounds such as PCBs, many of these compounds are banned from widespread use and/or strictly regulated under the Toxics Substances Control Act (TSCA). As toxics and other pollutants are associated with particles and washes to streams during wet weather conditions, different storm water management initiatives, including BMPs that reduce suspended solids loads to the receiving water bodies will, in turn, reduce toxics pollution.

NPDES Permits

Additional requirements, as necessary, will be added to all permits that are issued, reissued or modified by U.S. EPA and certified by DC DOH after the approval of this TMDL. Permits, as an EPA policy, are not reopened to incorporate TMDL requirements. However, in rare cases, a permit would be reopened, upon approval of a TMDL to incorporate necessary requirements of the TMDL, when egregious impacts to the environment are observed or if the permittee is determined to be a significant contributor and there is obvious environmental impact that needs immediate attention. Per EPA guidance, the requirements that will be incorporated into storm water permits are, in most cases, BMPs and not numeric effluent limits.

Each source/permit holder in a category will not be required to make the same reductions. Reductions will be determined on a facility-by-facility basis and, in most cases for storm water permit holders, reductions are required in the form of BMPs. EPA will give credit to facilities that are implementing BMPs at the time of permit re-issuance. BMPs will be required to be checked for effectiveness and if additional controls are needed, additional BMPs would be required upon permit reissuance.

Point source facilities that currently have no monitoring for certain TMDL parameters will not necessarily be considered to be a source. However, this will be determined as follows:

First, the facility may be asked to volunteer to monitor for that particular constituent in order to determine whether or not they are a source. Second, the permit may be modified upon reissuance to require monitoring for the constituent with no limit placed. Third the permit may be modified upon reissuance to require monitoring with a clause that if the parameter is detected at levels above the TMDL WLA then the facility must take measures to determine the particular source of the constituent and enact controls to reduce. Then if levels are not reduced the next permit may have limits. A fourth option, if a permittee refuses to take a voluntary sample, EPA can require sampling by issuing a 308 order.

Monitoring

The Department of Health maintains an ambient monitoring network that includes stations in the Potomac and Anacostia Rivers and Rock Creek, as well as in the Tidal Basin and the Washington Ship Channel. Because of lack of water column/sediment data on organics in the Tidal Basin and the Washington Ship Channel, the model developed for the TMDL analysis was based on simplified conservative assumptions. In order to conduct a more detailed analysis, a monitoring project will be initiated to collect organics data in the Tidal Basin and the Ship Channel in the 2005-2006 period. The data will then be used to revise the TMDLs in 2007.

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Appendix A

ORGANICS MODELING OF THE TIDAL BASIN AND THE WASHINGTON SHIP CHANNEL

The general framework of Environmental Fluid Dynamics Code (EFDC) model (Hamrick, 1992) was adopted in this study. The fate and transport of organics are modeled using the toxic module of EFDC. The EFDC model can be used to run hydrodynamics, sediment transport, eutrophication, and toxics coupled together. The flow field, mixing coefficients, salinity, and temperature are calculated by the hydrodynamics model in the EFDC model. Sediment transport model updates the suspended solids concentration.

The Tidal Basin (Figure 1) was built in the late 19th century by the Army Corps of Engineers as a part of the comprehensive management of the Potomac River and land development of Washington D.C.

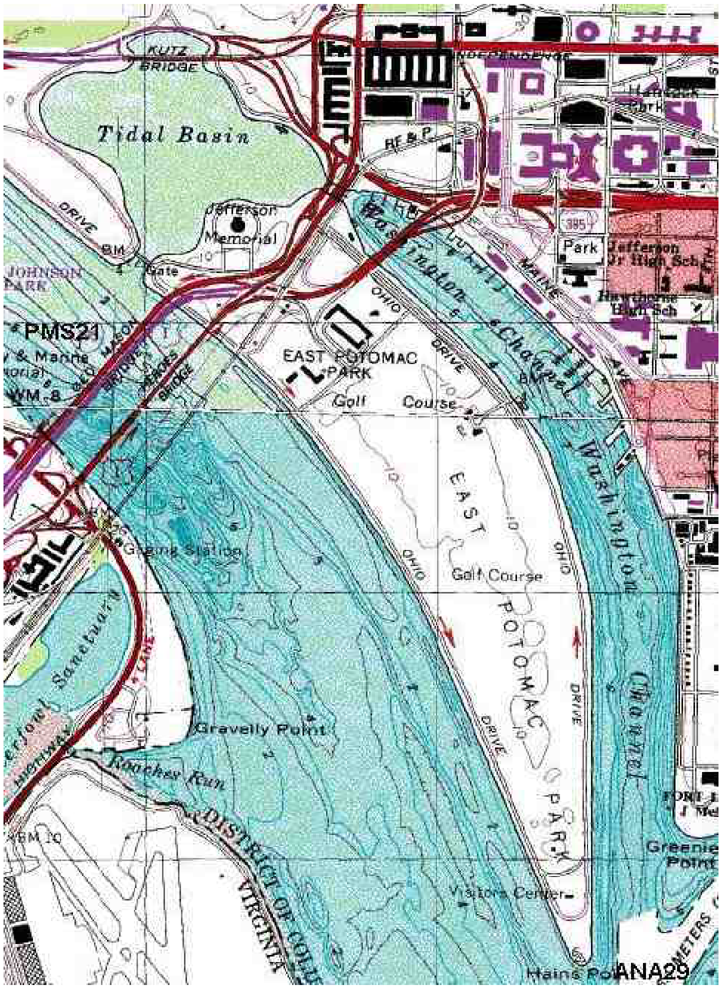

Figure 1: Tidal Basin and Washington Ship Channel

The main function of Tidal Basin is to flush the Washington Ship Channel with the freshwater from the Potomac River. Two floodgates exist in the system, one linking the Tidal Basin and the

Potomac River, and the other linking the Tidal Basin and Washington Ship Channel. Freshwater flows into the Tidal Basin through flap gate when the tidal elevation changes and the elevation in the Potomac River is higher than that in the Tidal Basin. In the same way, the freshwater flushes into the Washington Ship Channel as the water surface elevation becomes higher in the Tidal Basin. The direction of water flow is unidirectional from the Potomac River to the Tidal Basin then to the Washington Ship Channel. The Tidal Basin is shallow with an average depth of around 2 meters and a surface area of about 0.4 km^2. The Washington Ship Channel is about 122 meters wide and the depth varies from 1 meter to 8 meters (Velinsky et al. 1994). The flow field in the Tidal Basin and Washington Ship Channel is governed by the tidal fluctuation, floodgate operation, and wind.

Model Grid

Since the EFDC model is able to use orthogonal and curvilinear grid that matches the natural boundary of the water body, the Tidal Basin and the Washington Ship Channel were divided to 265 active cells fitting the boundary on the horizontal plane as shown in Figure 2. Each cell is further divided into two layers with equal depth, resulting in a three-dimensional grid. Because the EFDC model uses σ-coordinates in the vertical direction, the relative depth of each layer is 0.5. More about the process of grid generation can be found elsewhere (Lung, 2003).

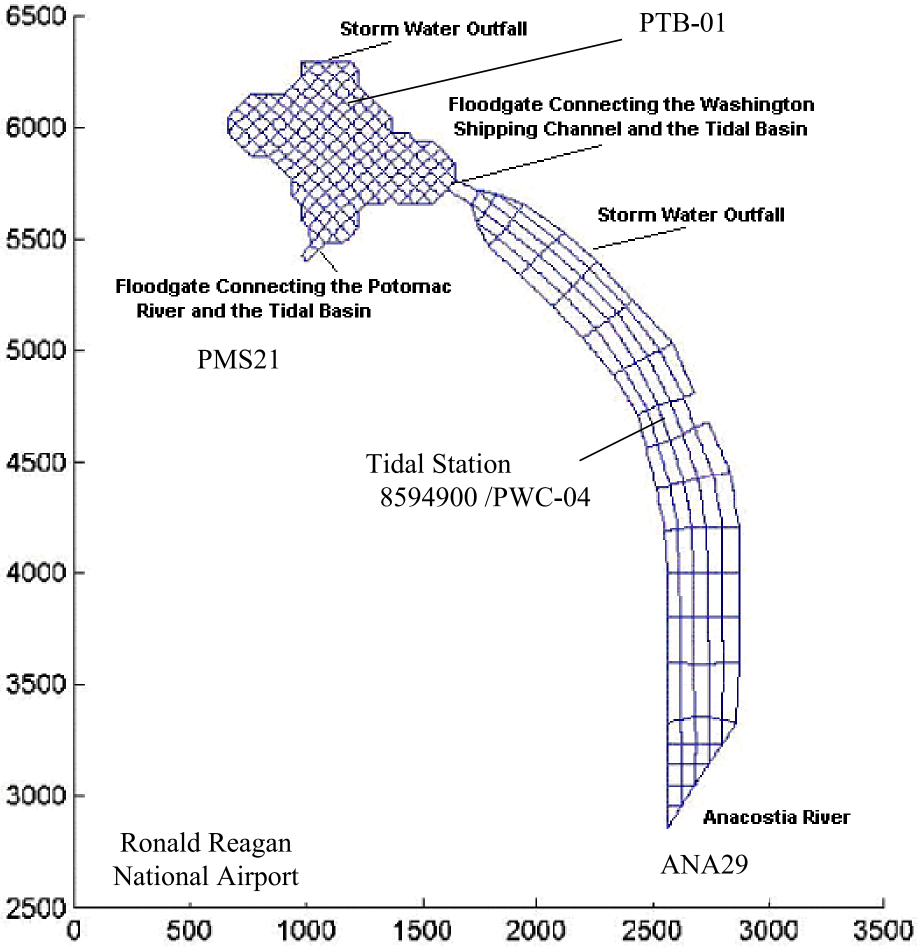

Figure 2: Hydrodynamic Grid of the Tidal Basin and Washington Ship Channel

Hydrodynamic and Sediment Transport Model

The hydrodynamic and sediment transport simulation in this study is obtained by running the EFDC model. The hydrodynamic component of EFDC solves the three-dimensional, time variable, viscous, incompressible, free surface flow governed by the Reynolds Equations. Some simplifications of the governing equations were achieved by applying a hydrostatic approximation, a Boussinesq approximation, and an eddy viscosity concept (Hamrick, 1992). Temperature and salinity are integrated in the hydrodynamics computation since water density is dependent on temperature and salinity. Wetting and drying of shallow areas because of water elevation variation is allowed in EFDC. The structure of the hydrodynamic component of EFDC is shown in Figure 3.

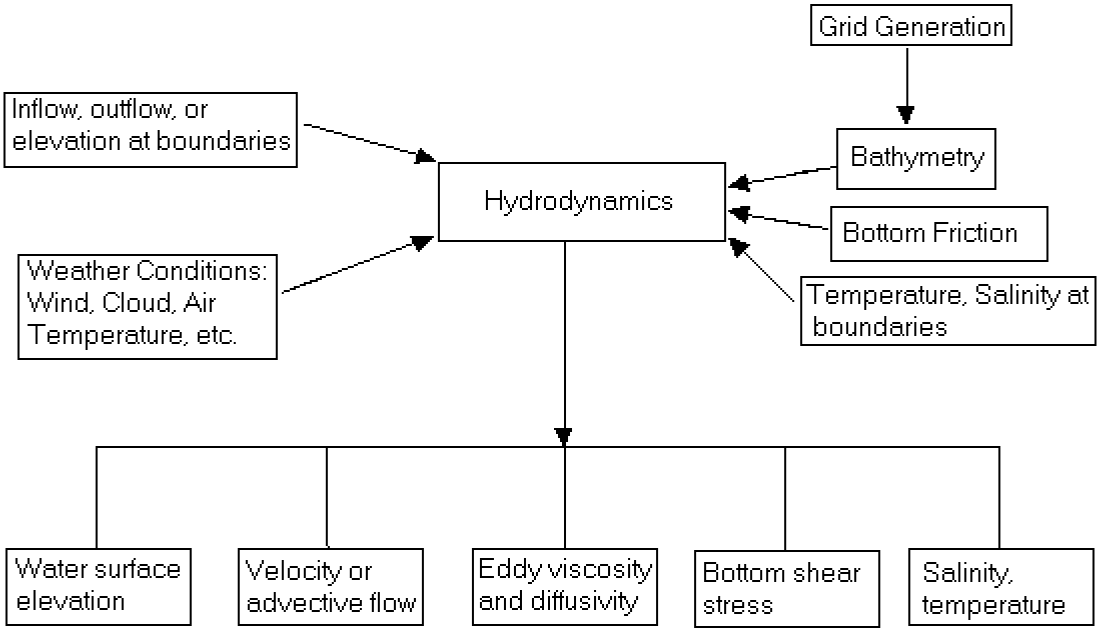

Figure 3: EFDC Hydrodynamic Model Framework (modified from Tetra Tech, 2002)

In addition to the hydrodynamics component, EFDC models sediment transport including both non-cohesive sediment, which considers bed load, and cohesive sediment. The cohesive sediment transport model uses the same advection-diffusion scheme to calculate the transport in the water column as other dissolved constituents with an extra settling term. The settling velocities can be quantified with various options from simple to complex depending on whether flocculation process is considered or not. A flocculation model can be activated to compute the flocculation effects of the fine particles. In the bottom of the surface waters, multiple layers can be assigned and several consolidation options are available. The details about the hydrodynamic and sediment transport model can be found in the EFDC manual (Hamrick, 1992).

Calibration of Hydrodynamics and Sediment Transport Models

To support the modeling analysis and calibrate the model, a large amount of data is required. For example, meteorological, tidal elevation, flap gate operation, and stormwater runoff data are needed for driving the hydrodynamic model. Similarly, water quality data are needed at the boundaries of the Tidal Basin and the Ship Channel with the Potomac and Anacostia Rivers. In order to calculate loads from storm water, TSS (total suspended solids) data for storm water are also required. The model was calibrated using the data for the year 1998. Following is a brief description of the data used in the study. Details of the data used in the study can be found elsewhere (Lung, 2003).

The meteorological data including the air pressure, wet bulb air temperature, dry bulb air temperature, cloud cover, wind speed and direction, and precipitation were directly obtained from the Reagan National Airport. The tidal elevation data were obtained from the NOAA tidal station in the Washington Ship Channel. Since the area of the modeling domain is very small, the differences between the two boundaries are minimal. For modeling the freshwater flushing of the Washington Ship Channel, the flood flap gate operation tables relating the water elevation differences and the flow rates are very important. Unfortunately, no information regarding the gate operation is currently available. Therefore, the gate operation tables were assumed and adjusted during the calibration of the water elevation in the Tidal Basin, which is to have the flushing process and not to have extremely high or low water elevation.

There are six separate storm sewers outfalls in the Tidal Basin and nine outfalls in the Washington Ship Channel. Storm water loads were calculated using event mean concentrations. The storm water runoff was estimated by multiplying the precipitation rate, infiltration loss percentage, and the drainage area. For TSS in the storm water, an event mean concentration (EMC) of 94 mg/L was used.

In addition to the data that drive the hydrodynamic modeling, water column suspended solids (TSS) data are needed for simulating and calibrating sediment transport processes. TSS data in the Potomac River, Anacostia River, the Tidal Basin, and the Washington Ship Channel were obtained from the Chesapeake Bay Program Website (www.chesapeakebay.net). The data from the Potomac and Anacostia Rivers were used as boundary conditions.

The hydrodynamics and sediment transport calculation are coupled in EFDC since the change of sediment bed depth will change the water depth and bottom bathymetry. The model was simulated for the entire period of year 1998 with a time step of 100 seconds. Figure 4 and 5 show both observed and simulated water surface elevations in the Washington Ship Channel for a day and for the entire year, respectively. Modeled water surface elevations in the Washington Ship Channel matches the observed elevation very well. No observed water surface elevations are available for the Tidal Basin. The change of the water surface elevation in the Tidal Basin is governed by the inflow through the floodgate from the Potomac River, precipitation, evaporation, storm water, and the outflow through the floodgate to the Washington Ship Channel. Figure 6 shows the modeled water surface elevation in the Tidal Basin, which is relatively stable with small fluctuations and reflects that the freshwater flushing into the Washington Ship Channel.

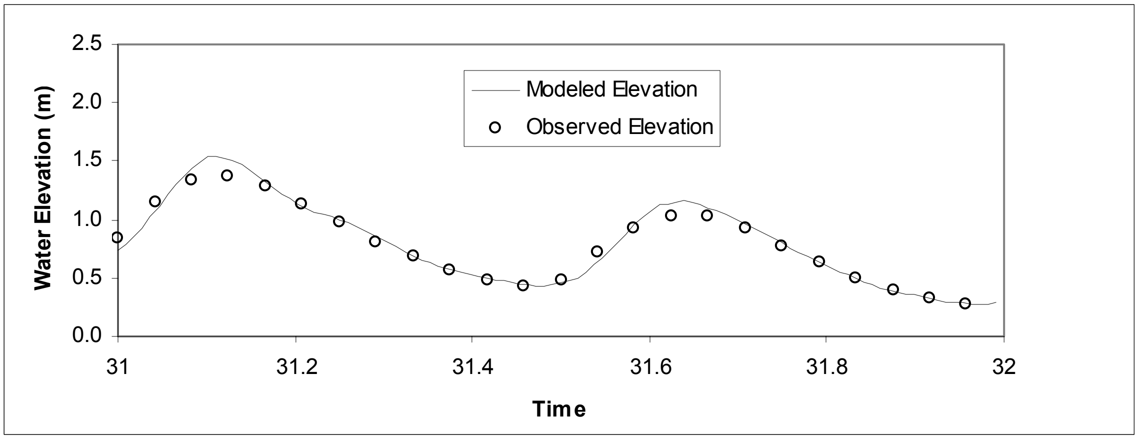

Figure 4: Observed and Modeled Water Surface Elevation in the Washington Ship Channel for a Day

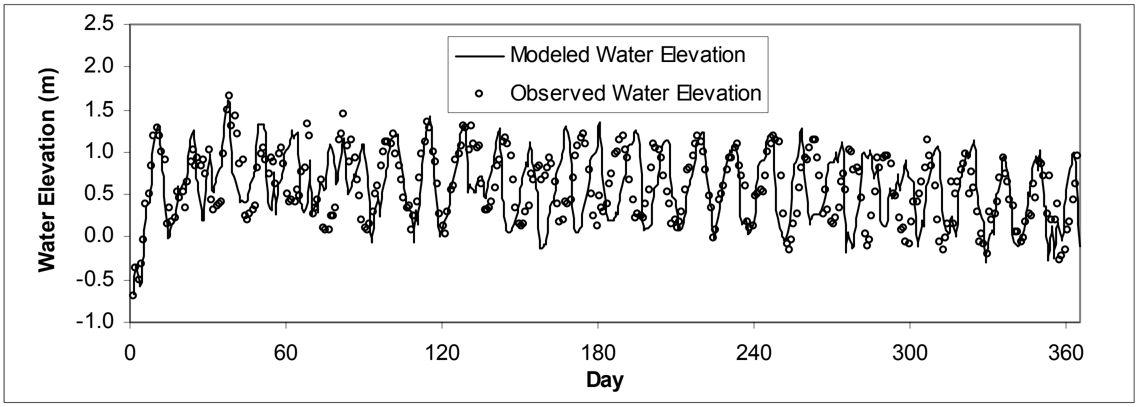

Figure 5: Observed and Modeled Water Surface Elevation in the Washington Ship Channel for Year 1998

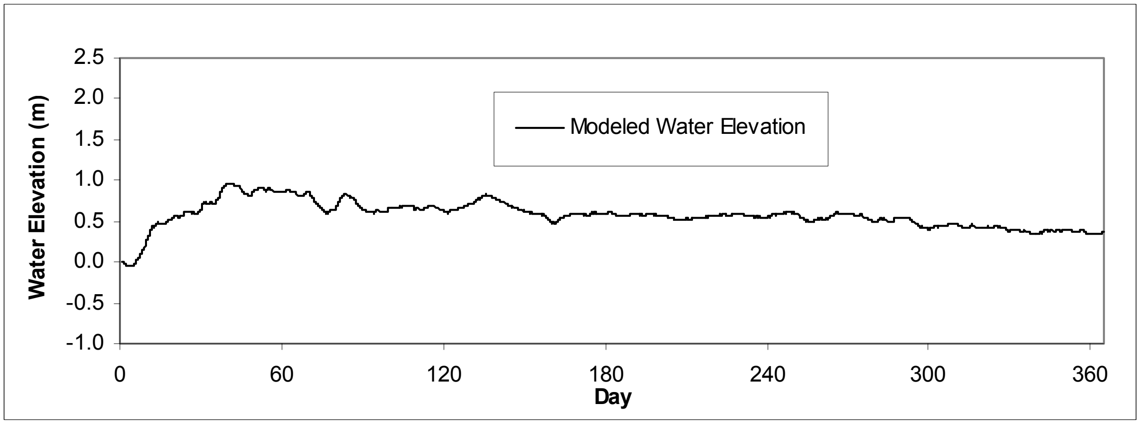

Figure 6: Modeled Water Surface Elevation in the Tidal Basin

Water temperature is also important in the determination of the water density for the hydrodynamics calculation. The modeled temperature results are almost identical to the observed temperature in the Ship Channel as shown in Figure 7. It also shows that the temperature in the Tidal Basin and the Washington Ship Channel do not show any significant spatial variations.

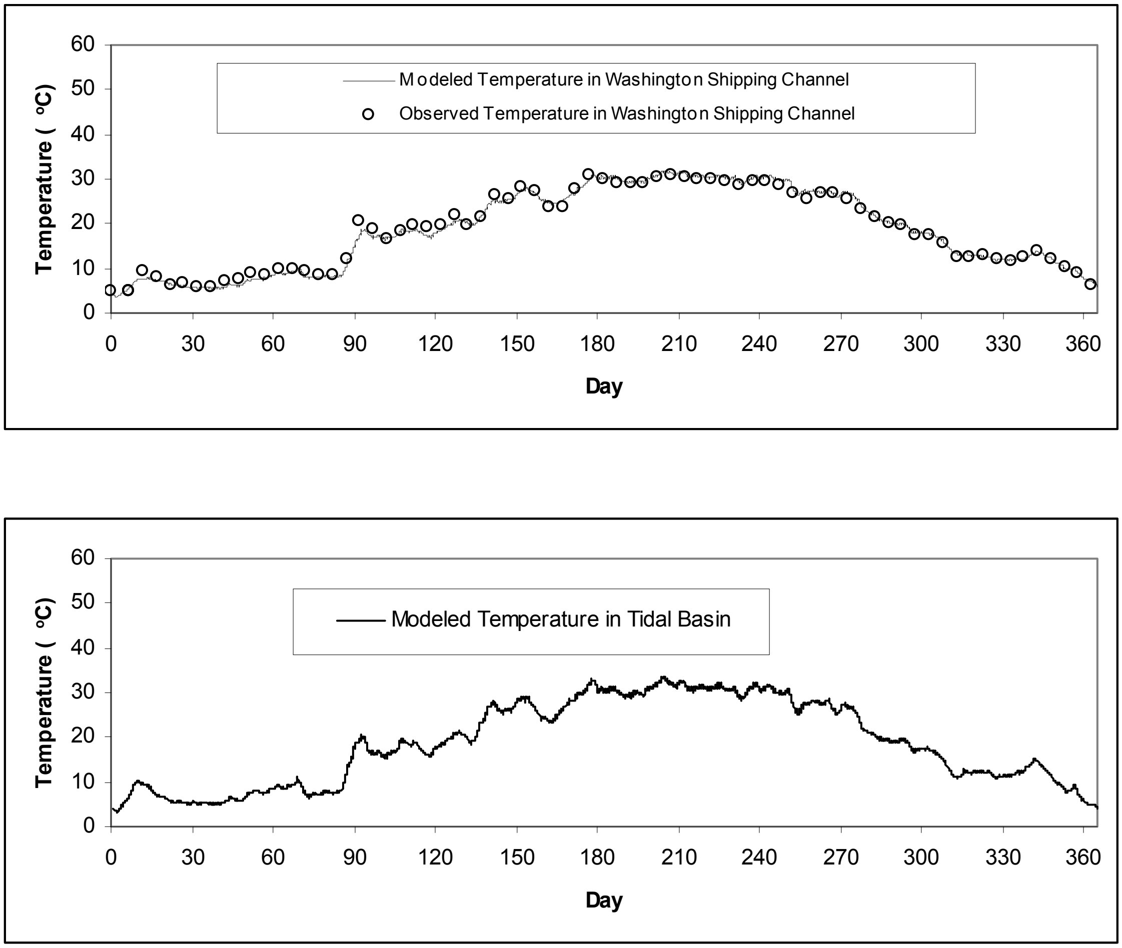

Figure 7: Comparison of Modeled and Observed Water Temperature in the Tidal Basin and Washington Ship Channel

To model the sediment transport, the properties of the sediment must be set. In this study, only cohesive sediment was considered since previous studies showed that the sediment in the bottom of the Tidal Basin and the Washington Ship Channel are mainly silt and clay. As there is no sediment bed depth data available, the initial sediment bed depth was assigned to be 50 cm to ensure that sufficient sediment is available for resuspension. The critical shear stress for deposition was considered 7.5×10^{-5} $(m/s)^2$ and the critical shear stress for resuspension was set equal to 1.0×10^{-4} $(m/s)^2$. The settling velocity was set to 5.0×10^{-6} m/s. The layer-averaged TSS results from the sediment transport model as well as the observed data are shown in Figures 8 and 9 for the Tidal Basin and Washington Ship Channel, respectively. The observed data are from station PTB-01 in the Tidal Basin and station PWC-04 in the Ship Channel. The modeled suspended solids showed that the spatial variation is high in both the Tidal Basin and the Washington Ship Channel.

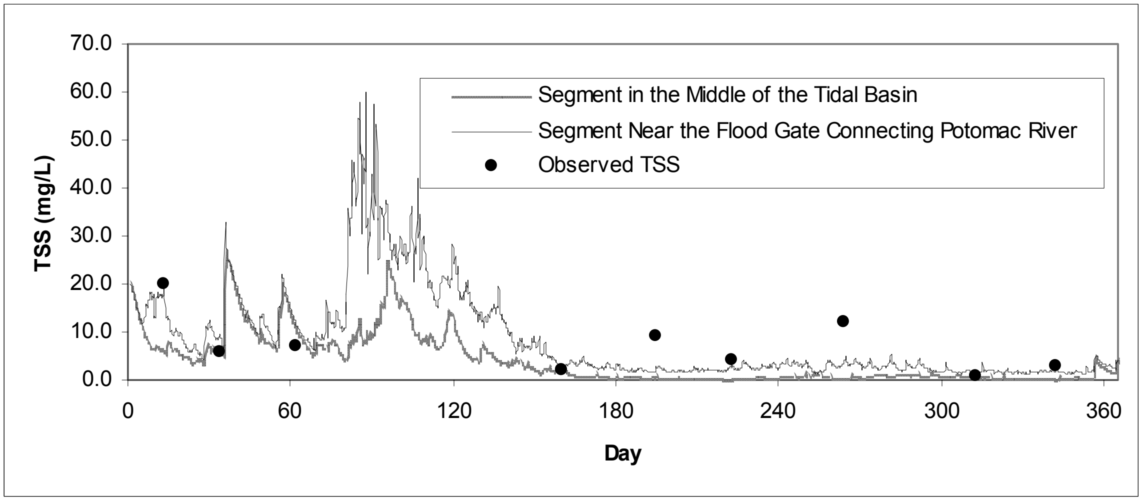

Figure 8: Modeled and Observed Suspended Solids Concentrations in the Tidal Basin

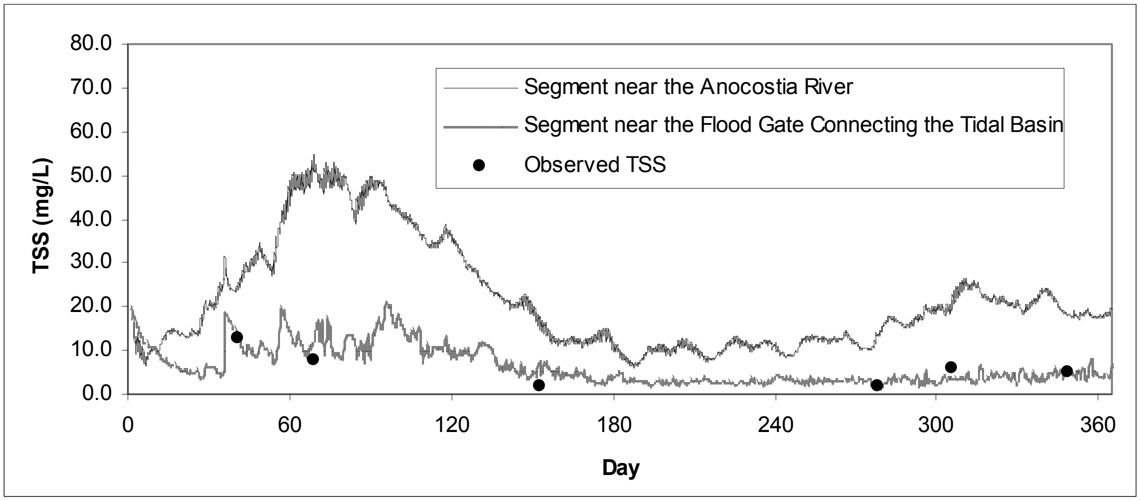

Figure 9: Modeled and Observed Suspended Solids in the Washington Ship Channel

ORGANICS MODEL

The fate and transport of organics are modeled using the toxic module of EFDC. The details of the theory and numerical algorithm for the toxic module can be seen elsewhere (Tetra Tech, 2002). A brief description of mechanisms and processes in the organic model is in the following. The model was simulated with inputs of storm water and direct runoffs from the watershed. The storm water and direct runoff loads were calculated by multiplying flows with an event mean concentration for an organic constituent. The event mean concentrations used for various organics are the same as what were used in the DC Small Tributaries Model (ICPRB, 2003). Because of lack of data, the model could not be calibrated and is based on simplified conservative assumptions.

Mass Transport

The organics are assumed to be mixed evenly with water. The advection-diffusion equation for dissolved materials is solved to model the mass transport of organics. Organics can get attached and transported with suspended solids, and mass transfer can occur across the air-water interface based on partition coefficients, temperature, suspended solids concentrations, and concentrations in the atmosphere.

In EFDC, the sorption of organics to suspended solids is calculated with a linear sorption assumption. Two options were provided to determine the fractions of dissolved and particulate organic concentrations. One is to directly calculate the fractions using a partition coefficient and suspended solid concentrations. An alternative method is to use the organic carbon content in the suspended solids. The particulate organics move along with suspended solids under settling, deposition, and resuspension processes. Mass transfer of the dissolved organics occurs at the air-water interface due to volatilization. The volatilization process of organics can be expressed using Henry's law. The air-water exchange flux can be obtained using Henry's constant, mass transfer velocity, and partial pressure in the air over the water. Since in many cases, organics are not abundant in the atmosphere, the calculation can be simplified as a one-way loss of organics from the water (Chapra, 1997). EFDC uses the simplified volatilization process and calculates the volatilization flux using a volatilization rate determined by the molecular weight of certain organics. In this case, air-water exchange of organics (including diffusion, wet deposition, dry deposition) were not considered. For this analysis, initial sediment concentrations are set to zero. Diffusion is the only exchange mechanism considered for sediment-water exchange in this approach. Sediment-water exchange of organics by deposition and resuspension were not considered. The lowest values of the water quality criteria for class C and D water were used as the concentrations of organics in the Anacostia and Potomac and as initial concentrations in the Tidal Basin and Ship Channel.

Reactions

Organics may transform or decay in the water column due to various processes such as hydrolysis, photolysis, and biodegradation. In EFDC, photolysis is solved explicitly using solar radiation intensity. The hydrolysis and biodegradation processes are lumped into a first-order decay rate. For this analysis, the organics are assumed as conservative materials and no chemical and biological reactions are considered.

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Appendix B

Tidal Basin and Washington Ship Channel PCB Atmospheric Deposition and Allocated Load

Allocated PCB Load = Existing Load – Available Atmospheric Deposition Load

Existing PCB loads for the Tidal Basin and the Washington Ship Channel were determined using the EFDC Model. The calculations performed to determine the Total Available PCB Atmospheric Loads to the watersheds are described in the following:

Available atmospheric load was determined using average annual atmospheric deposition flux in the Chesapeake Bay (Chesapeake Bay Program, 1999). The annual fluxes are:

Wet Urban Deposition = 8.3 ug/m2-year;
Dry Urban Deposition = 8.0 ug/m2-year; and
Total Wet-Dry Deposition = 16.3 ug/m2-year

The PCB atmospheric load for the Tidal Basin and the Washington Ship Channel watersheds were calculated by multiplying the total wet-dry flux rate by the watershed area to generate total annual atmospheric loading. This result was then multiplied by the watershed runoff coefficient to determine the available atmospheric load for the watershed.

The runoff coefficient was determined by using the following formula:
Runoff Coefficient = 0.05 + .009 * (percent imperviousness)

Percent imperviousness of the Tidal Basin and the Ship Channel watersheds

Waterbody	**Total Area (ac)**	**Impervious Area (ac)**	**Percent Imperviousness**
Tidal Basin	271	63.4	23.4
Washington Ship Channel	633	358.9	56.7

The PCB loadings for the Tidal Basin and the Washington Ship Channel are as follows:

Waterbody	Drainage Areas Sq Miles	Drainage Area Sq.Meters	Total Atmospheric Load (lbs/yr)	Runoff Coefficient	Available Atmospheric Load (lbs/yr)	Total DC Existing PCB Load (lbs/yr)	DC Existing Land-Based Load (lbs/yr)	TMDL (land-based source) (lbs/yr)	Allocated Storm Water (lbs/yr)	Allocated Direct Runoff (lbs/yr)
Tidal Basin	0.423	1096698	0.0393	0.261	1.025E-02	1.822E-01	1.720E-01	5.675E-04	3.141E-04	2.534E-04
Washington Ship Channel	0.989	2561660	0.0919	0.560	5.147E-02	4.724E-01	4.210E-01	1.389E-03	9.788E-04	4.104E-04