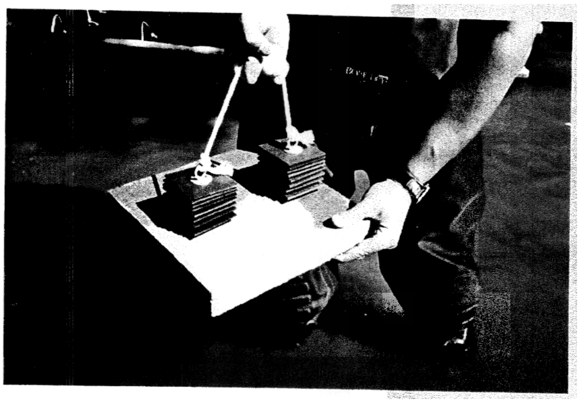
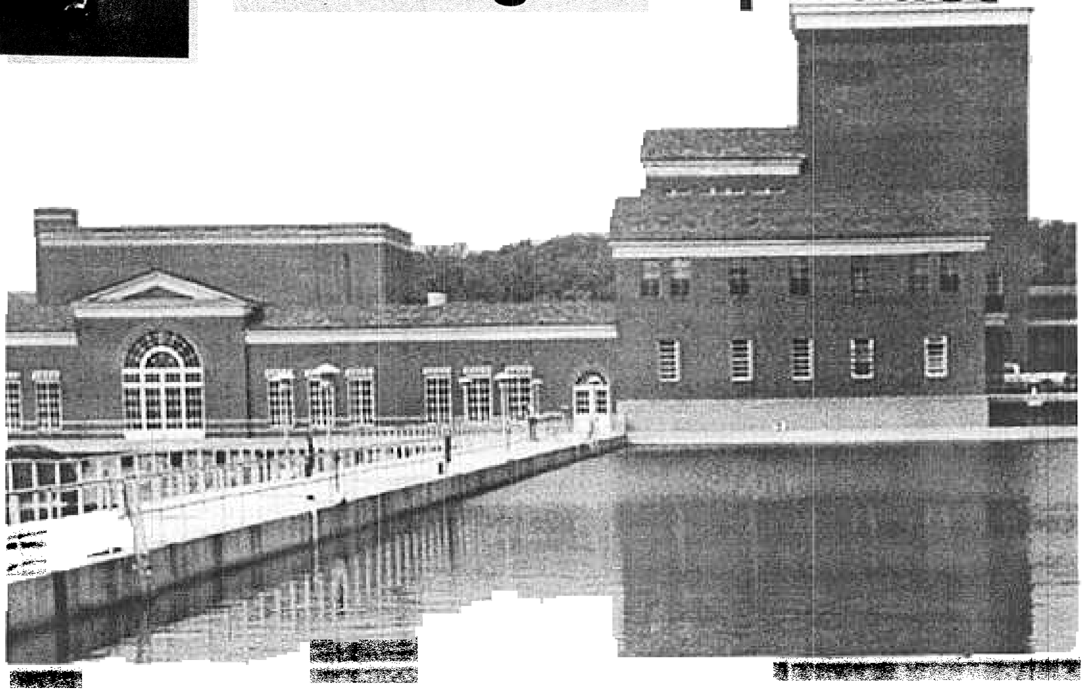


Water Quality Studies in the Vicinity of the Washington Aqueduct



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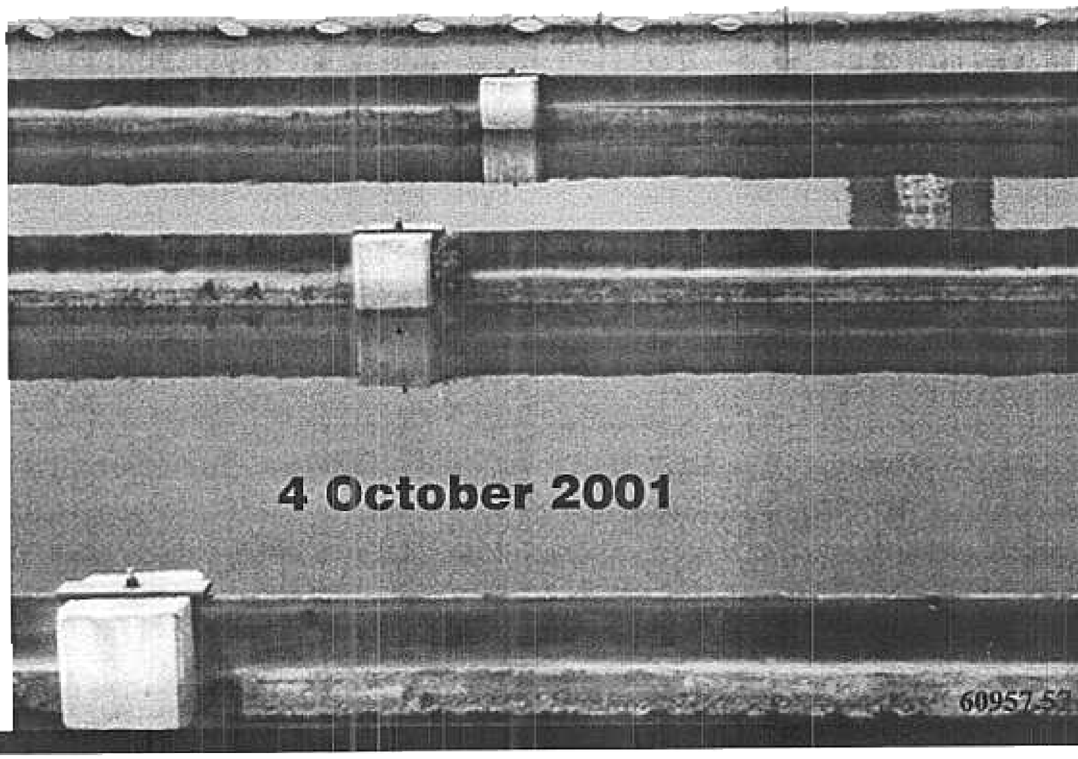

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EXECUTIVE SUMMARY

The Washington Aqueduct produces drinking water for approximately one million citizens in the District of Columbia, Arlington County, VA, and the City of Falls Church, VA. Raw river water is obtained from the Great Falls Raw Water Intake or the Little Falls Pumping Station on the Potomac River. This water flows through the Dalecarlia Reservoir and is then diverted for settling to either the Dalecarlia plant or the Georgetown Reservoirs. As allowed in the Aqueduct's NPDES permit, residual solids from the Dalecarlia plant sedimentation basins are periodically discharged to the Potomac River through Outfall 002, which is located upstream of Chain Bridge. Residuals from Georgetown Reservoir Basins 1 and 2 are periodically discharged to the Potomac River via Outfalls 003 and 004.

A water quality study was developed to respond to technical issues raised by staff from U.S. EPA and the District of Columbia's Department of Health. A study plan (dated 24 June 1999) was developed and approved by U.S. EPA. This report presents the results from those studies and includes discussions of: effluent dilution and fate modeling, effluent toxicity testing and chemical characterizations, discussions of fisheries issues, and the results of a field program to evaluate the benthic macroinvertebrate community. The findings from these efforts are summarized below.

Effluent Fate and Transport Modeling

A key part of the program was to quantify the dilution of the Aqueduct discharges in the Potomac River, and to examine the fate of released solids as they travel downstream. Modeling studies used the Surfacewater Modeling System (SMS), and the modeled area extended 8.0 km from Outfall 002 (upstream of Chain Bridge) to below Roosevelt Island.

Plume mapping studies were conducted at Outfall 002 (Dalecarlia Basin) and Outfall 003 (Georgetown Reservoir). At each outfall, a Rhodamine WT dye-tracer study was performed on the day the reservoir was being drawn down, and a turbidity study was performed the following day during a solids clean-out event.

- At Outfall 002, 22 percent of the total solids released passed beyond the downstream end of the model during a 24-hr run. The resulting depositional footprint estimated using the SED2D model was 1-mm thick[1] in the vicinity of the Outfall 002, and decreased to approximately 0.02 mm downstream in the vicinity of Roosevelt Island.

[1] One millimeter = 0.03937 inches which is approximately 1/25th of an inch.

- From Outfall 003, approximately 13 percent of the discharged solids passed beyond the downstream end of the model during a 24-hr run. SED2D indicated that the resulting depositional footprint typically exceeded 1 mm in the first 350 m, exceeded 0.2 mm for approximately 2,500 m along the shallow near-shore region downstream, and decreased to approximately 0.05 mm in the vicinity of Roosevelt Island.

- To put the Aqueduct releases into perspective, daily Potomac River flows and total suspended solids (TSS) loads measured at Little Falls (upstream) were obtained for the 20-year period, 1980 to 1999. The median (natural) suspended load in the Potomac River for this period was 218,000 kg/day. The 25 May 2000 discharge event from Dalecarlia Basin 3 released approximately 17,800 kg of solids, a value which is exceeded on 90 percent of the days each year by the daily mass of solids in the Potomac River passing Little Falls. The 3 May 2000 discharge event from Georgetown Reservoir released an estimated 153,600 kg of solids. This solids loading from Georgetown Reservoir is exceeded on 55 to 60 percent of the days each year by the daily mass of solids passing Little Falls.

- Based on current regulatory guidance, a chronic mixing zone dilution factor for Outfall 002 (at the permitted river flow of 153 cms) is approximately 51. Using U.S. EPA's 1-hr float time approach, the acute dilution factor is calculated to be 169 in this rapidly moving portion of the Potomac River. The complete mix dilution factor for Outfall 002 would be a factor of 1,160.

- At Outfall 003 (Georgetown Reservoir) the chronic mixing zone dilution factor is 4.3. The 1-hr average exposure approach used to determine the acute criterion results in a dilution factor of approximately 2.3. The complete mix dilution factor would be a factor of 136. These Outfall 003 dilution factors could be increased by outfall modifications.

Toxicity Testing

Acute and chronic toxicity tests were performed on effluents collected from the Dalecarlia and Georgetown facilities during normal periodic cleaning operations. As described in the Study Plan, toxicity tests were conducted on three different fractions of the Aqueduct effluent: whole effluent samples (using acute toxicity tests); supernatant from the settled whole effluent (using chronic toxicity tests); and the settled solids portion of the whole effluent (using benthic tests).

- The acute test results indicate that (with one exception) the whole effluent samples collected for the preliminary testing and for Rounds #1 through #4, were <u>not</u> acutely toxic to the test organisms. The 48- and 96-hour LC50 values were >100 percent effluent (TUa <1.0) for the waterflea (*D. magna)*, the fathead minnow (*P. promelas)* and the striped bass *(M. saxatilis)*. One fathead minnow test showed some level of dose-related acute toxicity which resulted in a 96-hour LC50 value of 29.3 percent effluent.

- The chronic toxicity test results showed that in two of the four rounds, the effluent was not chronically toxic. In the other two rounds, the lowest 7-day chronic value (ChV) for a fish or invertebrate was 35.4 percent effluent. Similarly, the Dynamac (1992) study concluded "*that the effluent released from the sampled sedimentation basins had no effect on either mortality or growth of fathead minnows.*"

- For the benthic testing, the 10-day LC50 values (based on *survival*) from the four rounds of testing were >100 percent sample, but the effluent concentration causing a reduction in growth (the IC25 value) ranged from 6.9 to 32.8 percent effluent.

Interpretation of these effluent toxicity test results is complicated by the fact that these tests continuously expose the test organisms in the laboratory to a series of effluent concentrations for 2 to 10 days (depending upon the test). In contrast, water column exposure to the Aqueduct plume is a transient phenomenon that lasts for perhaps 4-8 hours.

Effluent Chemical Characterization

The study summarized the recent chemistry data collected and analyzed by the Aqueduct, and generated additional effluent chemistry data as part of the toxicity testing program. Total aluminum concentrations for the Dalecarlia and Georgetown basins averaged 2,273 and 1,510 mg/L, respectively, for the period 1997-2001. EA Engineering's data included both total <u>and</u> dissolved aluminum, and indicated that the percentage of *dissolved* aluminum is considerably less than one percent of the total aluminum value in the effluent samples. Although total aluminum concentrations are high, effluent toxicity testing indicates that the aluminum in the effluent samples is not highly bioavailable or toxic.

Fisheries Issues

Life history information for each of the key species in the Study Plan was assembled and presented in the report, followed by discussions of the potential effects of Aqueduct discharges on the fish community. The report indicates that *potential* impacts to the fishery would be primarily restricted to young life stages of some of the fish species of concern. Juvenile and adult fish would be expected to avoid the discharges if stressed. Larvae, and particularly eggs, however, would be less able to avoid the sediment plume in the discharge areas.

Risks to young life stages of fish from the discharges would be from suspended solids (either in the water column or deposited on the substrate) and elevated aluminum concentrations. Studies from this water quality program indicate that a substantial quantity of solids fall to the substrate within a reasonably small area near the discharge (primarily from Outfall 003), and there could be moderate risk to several fish species of concern from sediment discharges when these young life stages are present. The primary risk would be from deposition of suspended solids onto eggs and larvae (causing smothering and reduced oxygen levels), which could affect survival. However, the area potentially affected represents a small portion of the Aqueduct study area.

Management options to minimize potential impacts on fishery resources are also discussed in the report. These include:

- Eliminating discharges between 15 February and 15 June of each year to avoid spawning and nursery periods, which would require a revision to the existing river flow restriction in the NPDES permit

- Reducing the river flow threshold (below which Aqueduct discharges cannot take place) by 20 percent

- Cleaning and discharging solids more slowly using more dilution water to reduce effluent concentrations and maximize the assimilative capacity into the River

- Negotiating an agreement with the EPA and pertinent resource agencies to allow discharges during the spring on an emergency basis

Benthic Macroinvertebrate Studies

Benthic effects were evaluated using an artificial substrate device called a Hester-Dendy unit, which allows bottom dwelling organisms to colonize square plates. These organisms are then evaluated to characterize the species and numbers of organisms that colonize the units. The study design used these Hester-Dendy units to allow comparisons between upstream (reference) and downstream benthic organism communities; <u>and</u> to compare the post-discharge benthic data to the before discharge data. The observations and conclusions from this study are as follows:

- The substrate in the study area consists of areas of boulders, bedrock, sand and mud. Large bedrock formations were evident along the shoreline and also out in mid-river where they were above the water surface during low tide. The softer sediments are in patches between or on these rock substrate areas. Sediments are continually redistributed following medium to high river flow events, which was confirmed by our observations of sediment deposition during the Hester-Dendy study.

- Based on the pre- and post-discharge collections, a very large load of sediment naturally moves through this segment of the Potomac River during times of increased flows, and deposits in the wider, slower current velocity segments of the river. This was evident at the downstream stations *as well as* the upstream reference station (UP-1). These large sediment loads, which resulted before the Georgetown basin discharge event, compromised the resulting dataset that was collected using the Hester-Dendy sampling approach. So much sediment covered some of the Hester-Dendy units that organisms could not colonize the samplers resulting in lower than expected numbers of benthic organisms and taxa. These low numbers of organisms affect the ability to draw strong conclusions from the dataset both from upstream versus downstream and pre- versus post-discharge perspectives.

- The benthic community that was collected in the Hester-Dendy study consisted of tolerant species, which is a consequence of the rigorous naturally occurring environmental conditions they are exposed to on a periodic but regular basis. It is clear that a large natural sediment load is transported through this area, and that the benthic community is adapted to these conditions. As an example, based upon a 19 year historical dataset, the <u>upper</u> 10th percentile daily sediment load value measured at the upstream end of the study area is approximately 157 times higher than the sediment load released from a typical discharge at Outfall 003, and 1,358 times higher than the sediment load released from a typical discharge at Outfall 002.

  Based on our observations during this benthic study, interpretation of existing river and discharge sediment load data, and supporting information from past studies, intermittent Dalecarlia and Georgetown discharge events are not expected to have a substantial or cumulative impact on the tolerant benthic community present in this reach of the Potomac River.

1. INTRODUCTION

The Washington Aqueduct produces drinking water for approximately one million citizens living, working and visiting in the District of Columbia, Arlington County, VA, and the City of Falls Church, VA and its service area. A division of the Baltimore District, U.S. Army Corps of Engineers, the Aqueduct is a federally owned and operated public water supply agency that produces an average of 180 million gallons on water per day at two treatment plants located in the District of Columbia (the Dalecarlia and McMillan WTPs). The Aqueduct was designed constructed by the COE, and has been in continuous operation since 1859.

The study area is shown in Figure 1-1. Raw river water is obtained for both plants from the Great Falls Raw Water Intake or the Little Falls Pumping Station on the Potomac River. The water flows through the Dalecarlia Reservoir and is then diverted for settling to either the Dalecarlia plant or the Georgetown Reservoirs. Residual solids from the Dalecarlia plant sedimentation basins are periodically discharged to the Potomac River through Outfall 002 which is located upstream of Chain Bridge. Residuals from the McMillan plant are generated in the Georgetown Reservoir Basins 1 and 2. Those residuals are periodically discharged into the Potomac River via Outfalls 003 and 004 (Figure 1-1). These discharges are allowed in the Aqueduct's NPDES permit.

The timing of these residual discharges is dictated by a number of factors. If permit conditions are satisfied (e.g., acceptably high river level and/or ambient turbidity condition), then a sedimentation basin is usually discharged based on a general frequency (e.g., 3 or 4 times a year at Dalecarlia, and twice a year at Georgetown).

To allow U.S. EPA Region 3 to draft the Aqueduct's new NPDES permit, a water quality study plan was developed to be responsive to a series of specific technical issues raised by staff from U.S. EPA and the District of Columbia's Department of Health. A formal study plan (dated 24 June 1999) was developed and formally approved by U.S. EPA [Included as Appendix C]. This report presents the results from those studies. Chapter 2 describes the effluent dilution and fate modeling studies that were conducted. The results of the effluent toxicity testing and chemical characterization work are presented in Chapters 3 and 4. Discussions of fisheries issues and the results of the field program to evaluate the benthic macroinvertebrate community are presented in Sections 5 and 6. A summary of the program results and conclusions from these water quality studies are in Section 7.

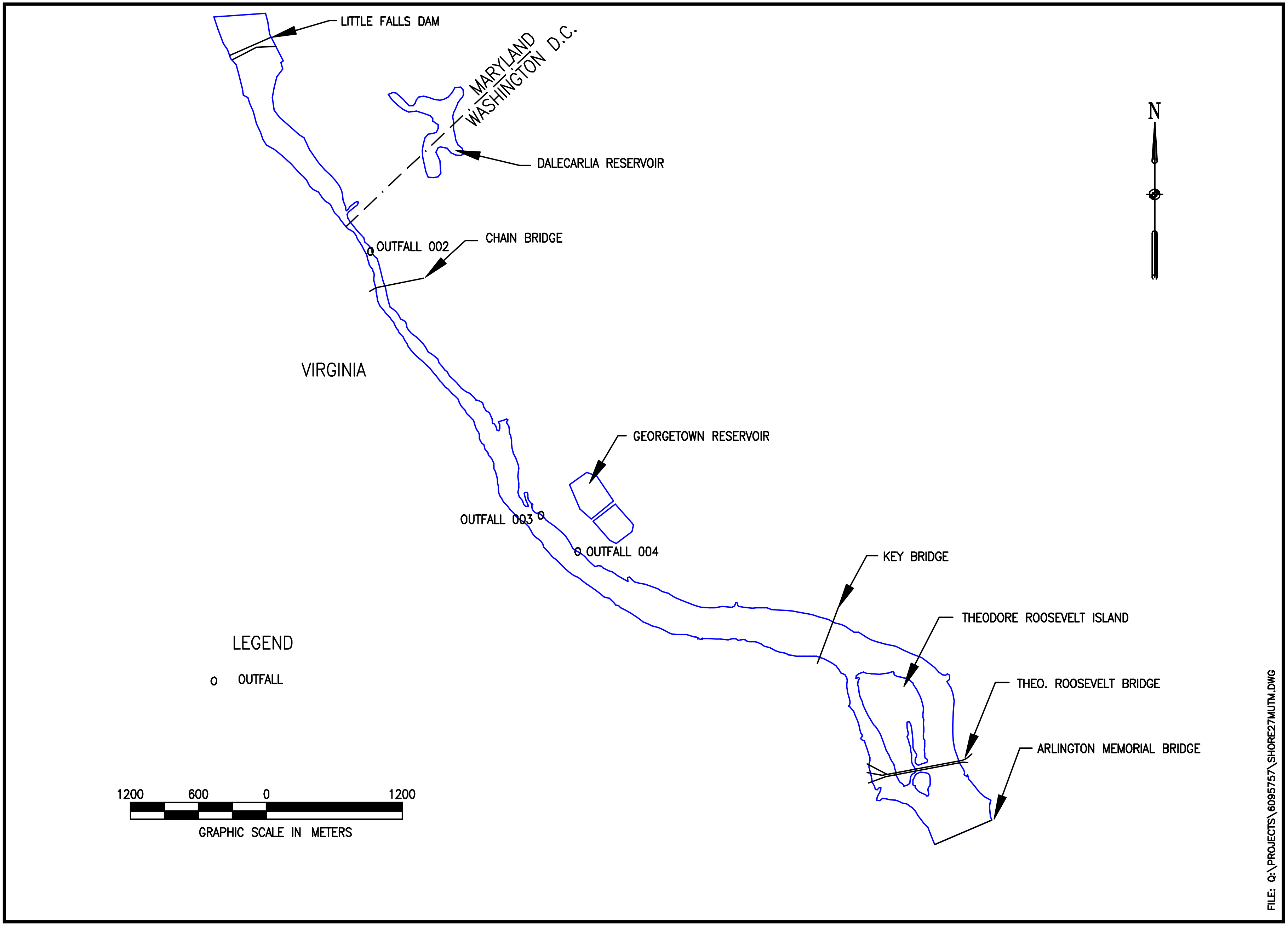


Figure 1–1. Study Area for the Washington Aqueduct Water Quality Studies.

2. EFFLUENT FATE AND TRANSPORT MODELING

A hydrodynamic model of the Potomac River was developed to simulate both river flow and the suspended solids discharge plume from the Washington Aqueduct outfalls. The primary objective of the modeling was to determine acute and chronic dilution factors as a function of effluent loading and river flow. A secondary goal was to model the fate of the released solids as they are transported downstream. The modeling used the Surfacewater Modeling System (SMS), which includes the U.S. Army COE – supported models RMA2, RMA4, and SED2D (see Section 2.2). To provide the necessary data for model development and calibration, field studies were performed including:

- A bathymetry survey of this river segment to provide cross-sectional geometry for model development

- Dye-tracer and turbidity plume mapping surveys during solids discharge events at Dalecarlia (Outfall 002) and Georgetown Reservoir (Outfall 003) to provide data sets for model calibration

A summary discussion of the results of the field surveys is presented and Section 2.1 and a summary discussion of the development of the Potomac River model is presented in Section 2.2. A more detailed discussion of the field surveys and model calibration is provided in Appendix B. The application of the calibrated model to simulations addressing the fate of the released solids and mixing zone issues is provided in Section 2.3.

2.1 FIELD STUDIES

A bathymetry survey of the Potomac River area included in the model was performed on 6-7 April 2000. During the same two days, cross-sectional velocity measurements were collected along two transects. At Outfall 003 from Georgetown Reservoir, a dye-tracer plume mapping survey was performed on 2 May 2000 and a turbidity mapping survey was performed on 3 May 2000 in conjunction with a suspended solids discharge event. At Outfall 002 from Dalecarlia Basin, a dye-tracer plume mapping survey was performed on 24 May 2000 and a turbidity mapping survey was performed on 25 May 2000 in conjunction with a suspended solids discharge event from Dalecarlia Basin 3. During the 3 May and 25 May 2000 turbidity studies, river and effluent water samples were collected that were analyzed for total and dissolved aluminum and TSS. Each of these field studies is addressed below.

2.1.1 Bathymetry Survey

A bathymetry survey of the Potomac River was conducted during 6-7 April 2000 extending for a 7.5-km distance from Memorial Bridge, upstream to Chain Bridge. A more detailed discussion of the bathymetry survey is provided in Appendix B.1.1. During these two days, depth data were measured along a total of 46 transects, which are illustrated in Figure B.1-1. The survey boat was equipped with a depth sounder and a global positioning system (GPS). The positioning and depth data were recorded at a 1-second interval to a laptop computer used onboard the survey boat as a data logger.

Water elevations during the bathymetry survey were recorded using an ENDECO 1029 water level recorder. The water level recorder was deployed in the vicinity of Outfall 003. The observed water elevations were used to adjust the depth measurements recorded during the surveys to mean low water (MLW).

The bathymetry data used in the model was augmented with hydrographic survey data collected by the National Ocean Service (NOS). In 1976 and 1977, NOS conducted surveys H9478 and H9488, which covered portions of the area included in the Potomac River model. In general, the bathymetry data measured during the 6-7 April survey provided adequate representation of the site. The NOS data were used to augment the survey data in the vicinity of Roosevelt Island and the downstream section of the model between Roosevelt Island and Memorial Bridge.

2.1.2 Cross-Sectional Velocity Survey

On 6 and 7 April 2000, cross-sectional velocities were measured along two transects downstream from Outfall 003. The velocity survey was performed to provide data to use during model calibration to adjust channel friction coefficients. A more detailed discussion of the cross-sectional velocity survey is provided in Appendix B.1.2.

The velocity data were measured along two transects: Transect B3 located approximately 400-m downstream of Outfall 003 and Transect B4 located approximately 1,700-m downstream in a broader section of the river (Figure B.1-1). The velocity surveys on both 6 and 7 April 2000 took place during an ebb tide. At Transect B3, measurements were made at five stations spaced evenly across the river. At Transect B4, 6-7 stations were used. At each station, velocity readings were made at 0.6-m (2-ft) intervals down to a 3.7-m (12-ft) depth. The velocity data are provided in Table B.1-1. At Transect B3, vertical average velocities were typically 10-20 cm/sec off-channel towards the left bank, and maximum vertical average velocities of 42-59 cm/sec were present in the channel. At Transect B4, the velocity distribution was more uniform across the river and was typically 20-30 cm/sec away from the near-shore stations.

The velocity survey data was used during model calibration to adjust the model's channel friction coefficients, which determine the lateral velocity distribution. The velocity data will be displayed in figures as part of model calibration in Section B.2.2.

2.1.3 Field Methodology and Physical Site Conditions

Basin/reservoir cleanings are typically a two-step process. The overlying water is released to the river on the first day (usually a 6-14 hour period), and then the solids are hosed or pushed out on the morning of the second day (usually a 3-4 hour period). Plume mapping surveys were performed at Outfalls 002 and 003 in conjunction with suspended solids discharge events. On the day preceding the reservoir clean-out, the overlying water in the reservoir is discharged to the river to provide access. The dye-tracer studies were performed during this 6-14 hour drawdown period. The dye study can only be performed during the reservoir drawdown when relatively clean water is being discharged because the suspended sediment masks the fluorometer reading at high TSS values and provides a false positive at lower TSS levels. During the dye study, Rhodamine WT dye was injected into the discharge flow for an approximately 6-hour period. The discharge flow present on the day of the reservoir drawdown was typically several times higher than the flow used during the actual solids clean-out event. The release of dye for a several hour period allows the resulting dye distribution in the Potomac River to simulate both the build-up and subsequent diffusion of the suspended solids release. During the surveys, the plume mapping transects were repeated approximately every 1.5 to 2 hours. In addition, during each dye and turbidity study, at least one full mapping survey was performed after the discharge was turned off.

The transects used during the plume mapping surveys are listed in Table 2.1-1 and illustrated in Figure 2.1-1. Table 2.1-1 includes the distance of each transect downstream from Outfalls 002 and 003. During the 2-3 May 2000 surveys at Outfall 003 (Georgetown Reservoir), Transects 7 to 20 were used. Transect 7 was the upstream background transect, and Transect 8 was located at Outfall 003. During the 24-25 May 2000 surveys at Outfall 002 (Dalecarlia Basin), Transects 1 to 20 were used, excluding Transects 8 and 9, which were closely spaced specifically for the previous Outfall 003 survey.

The following section summarizes the field methodology used during the surveys. A more detailed discussion is provided in Appendix B.1.3.

During the dye surveys, a 20-percent solution of rhodamine WT dye was injected into the reservoir outflow using a precision metering pump. The dye plume mapping surveys were performed using a boat equipped with a Turner Designs Model 10 fluorometer set up in the flow-through mode. The fluorometer sampling hose was mounted to a strut on the side of the boat at a fixed 0.3-m depth. The fluorometer readings were recorded at 1-second intervals with a Campbell CR10 data logger as the boat moved continuously along the survey transects. The survey boat was also equipped with a GPS system that also recorded continuously at a 1-second interval. The fluorometer was calibrated at the end of the survey day using site water for the calibration dilutions. The resulting instrument calibration was used to convert the fluorometer reading to concentrations in part per billion (ppb).

The turbidity plume mapping surveys were performed in a similar manner as the dye survey by continuously recording data as the boat moved along survey transects. A Coastal MacroLite with an OBS-3 turbidity sensor was mounted on a fixed strut at a 0.3-m depth. The turbidity values were recorded continuously at 2-second intervals to a lap-top computer. The survey boat also contained a GPS system that recorded at 1-second intervals.

An ENDECO 1029 water level recorder was deployed in the vicinity of Outfall 003 for the duration of the dye and turbidity plume mapping studies.

2-3 May 2000 (Outfall 003) – Georgetown Reservoir

On 2 and 3 May 2000, both the dye and turbidity studies started during an early ebb tide and the last survey was performed near or just following low slack water. The tide heights during the dye and turbidity plume mapping surveys are provided in Figures B.1-5 and B.1-6 which also indicate the duration of the discharge event and the times of each survey. Potomac River flows at the USGS gage at Little Falls are displayed in Figure B.1-7 for the 2-3 May 2000 period. During the 2 May 2000 dye study, river flow decreased from approximately 305 cms to 300 cms, and during the 3 May 2000 turbidity study, river flow decreased from 272 cms to 266 cms.

24-25 May 2000 (Outfall 002) – Dalecarlia Basin 3

On 24 and 25 May 2000, the dye and turbidity studies started during an early flood tide and the last survey was performed during the following ebb tide. It should be noted that at the Potomac River flow conditions associated with these studies, the river current does not reverse direction during a flood tide, but only slows up. The tide heights during the dye and turbidity plume mapping surveys are provided in Figures B.1-8 and B.1-9, which also indicate the duration of the discharge event and the times of each survey. Potomac River flows at the USGS gage at Little Falls are displayed in Figure B.1-10 for the 24-25 May 2000 period. River flows during the 24-25 May 2000 period were significantly lower than during 2-3 May 2000. During the 24 May 2000 dye study, river flow increased from approximately 160 cms to 170 cms, and during the 25 May 2000 turbidity study, river flow increased from 190 cms to 215 cms.

2.1.4 Water Chemistry Data

River Water Chemistry Data

Surface water samples were collected as part of the turbidity plume mapping surveys on 3 May 2000 at Outfall 003, and 25 May 2000 at Outfall 002. These samples were analyzed for total suspended solids (TSS), dissolved aluminum, and total aluminum. In addition, a turbidity reading was made onboard the boat at the time of sample collection.

The water chemistry samples were collected along the same transects used for the turbidity mapping surveys (Figure 2.1-1). However, because of the time required to collect and process each sample, only approximately every-other transect was employed. On 3 May 2000 (Outfall 003), Transects 7, 9, 11, 12, 13, 14, and 16 were used. On 25 May 2000 (Outfall 002), Transects 1, 4, 6, 9, 12, and 14 were used. A left and right sample was collected at the upstream Transects 1, 4, and 7 where the river is narrower, and a left, middle, and right sample was collected downstream where the river is wider. At each outfall, three sets of water chemistry samples were collected during the period that the four turbidity plume mapping surveys were performed. A total of 43 water samples were collected at river stations during the 3 May 2000 survey, and a total of 42 water sample were collected during the 25 May 2000 survey.

The water chemistry results from the 3 May 2000 turbidity study at Outfall 003 (Georgetown Reservoir) are provided in Table B.1-3 and the results for the 25 May 2000 study at Outfall 002 (Dalecarlia Basin 3) are provided in Table B.1-4. These tables provide concentrations for dissolved and total aluminum, TSS, and turbidity. A more detailed discussion of the water chemistry data is provided in Appendix B.1.5, including the relationship between dissolved and total aluminum (Figure B.1-11) and between total Al and TSS (Figure B.1-12). The water chemistry data indicates that dissolved Al in the sampled surface waters has a concentration of approximately 100-150 μg/L, which does not noticeably increase as the total Al concentrations increase from approximately 500 μg/L to 3,000 μg/L. Both the Outfall 002 and Outfall 003 studies display a linear relationship between total Al and TSS, with total Al increasing from approximately zero to 2.5 mg/L (2,500 μg/L), as TSS increases from approximately zero to 30 mg/L.

Relationship Between TSS and Turbidity

The relationship between TSS and turbidity was examined to provide a method to convert the readings from the probe used on the survey boat during the turbidity plume mapping surveys to TSS concentrations. The relationship between TSS and turbidity displayed by the 85 water chemistry samples collected during the 3 and 25 May 2000 surveys was evaluated. Figure 2.1-2 indicates that a linear relationship exists with the following regression equation ($R^2 = 0.76$):

$$\text{TSS (mg/L)} = 1.541 \text{ Turbidity(NTU)} - 2.40$$

The above equation relates turbidity as measured by the Hach turbidity meter on the water chemistry sampling boat to TSS. An additional data set was examined to relate values obtained from the turbidity probe used on the plume mapping boat to the Hach meter measurements. During the turbidity surveys, 13 grab samples were collected next to the turbidity probe on the plume mapping boat, which were then processed with the Hach turbidity meter. Based on these samples, the relationship between turbidity as measured by the turbidity probe and the Hach meter is provided in Figure B.1-14. The relationship between the two turbidity sensors was combined with the relationship between turbidity and TSS to provide an equation to convert the survey turbidity data to TSS. An examination of the turbidity data during the two surveys indicated a slight shift in the intercept for NTU resulting in the following expressions:

$$\text{TSS (mg/L)} = 1.541 \text{ Turbidity} - 20.9 \quad \text{3 May 2000 (Outfall 003)}$$
$$\text{TSS (mg/L)} = 1.541 \text{ Turbidity} - 17.8 \quad \text{25 May 2000 (Outfall 002)}$$

In the above equations, turbidity is the value measure by the turbidity probe on the plume survey boat.

Effluent Water Chemistry Data

Effluent water chemistry samples were collected periodically from the reservoir discharge during the 2-3 May and 24-25 May 2000 studies. Similar to the river water chemistry samples, the effluent samples were analyzed for TSS and total and dissolved aluminum. The results of effluent water chemistry samples collected during the reservoir drawdown and during the suspended solids discharge on the following day are provided in Table B.1-5. At Outfall 003

(Georgetown Reservoir), TSS values were <2.5 mg/L during the drawdown phase and total aluminum concentrations ranged from 187 to 233 μg/L. During the solids discharge on the following day, TSS values ranged from 4,700 mg/L to 12,300 mg/L, with two additional values of less than 1,000 mg/L that most probably are associated with temporary lulls in the clean out. During the solids release on 3 May 2000, total effluent aluminum concentrations ranged from 26 to 1,300 mg/L.

At Outfall 002 (Dalcarlia Basin), TSS concentrations were low during most of the 24 May 2000 basin drawdown (<5 mg/L), although TSS increased near the end as the basin elevation reached bottom. During the solids discharge on the following day (25 May 2000), TSS concentrations ranged from 4,600 to 16,500 mg/L before dropping off to 235 mg/L at the end of the discharge event. Total aluminum concentrations during the discharge event ranged from 1,020 to 1,810 mg/L and decreased to 28.1 mg/L at the end.

2.1.5 Particle Size Distribution

The size of the particles in the effluent is an important factor in the modeling of solid's transport and deposition in the Potomac River. As discussed below, particle size distributions were determined using several methods to address the characteristics of the floc that is produced in the water treatment process.

Standard ASTM Particle Distribution

During the suspended solids discharge events, sediment samples were collected from the bottom of each reservoir. On 3 May 2000, a sediment sample was collected from Georgetown Reservoir, and on 25 May 2000, two samples were collected from Dalecarlia Basin 3. Each sample was a composite of material collected from two locations. A particle size analysis was performed on each sample and the results are provided in Table B.1-6. The two Dalecarlia samples were very similar and an average distribution was calculated. Based on particle size, the Georgetown sample was 50.2 % sand, 31.6% silt, and 18.2% clay. The averaged Dalecarlia sample contained more sand and less clay and silt than the Georgetown sample. The Dalecarlia fractions were 81.3% sand, 12.4 % silt, and 6.3% clay. Since the water for both reservoirs is drawn from the same location in the Potomac River, there is no apparent reason for the particle size fractions to differ except possibly for natural seasonal variation over the period of time since the previous clean out. The Georgetown and averaged Dalecarlia data were combined to provide a composite particle size distribution that is considered to be representative of typical conditions. The composite sample was 65.7 % sand, 22.0 % silt, and 12.3 % clay (Table B.1-6).

Particle Characteristics of Floc

The composite particle size distribution for sediment samples from the Georgetown and Dalecarlia Reservoirs does not reflect the presence of the floc resulting from the addition of alum in the treatment process. The ASTM hydrometer and sieve methodology for determining particle size uses sodium hexametaphosphate as a de-floccing agent. The resulting size distribution, therefore, reflects the underlying particles, but not the aggregated particles forming the floc. On 5 March 2001, an additional sediment sample was obtained from the bottom of a Dalecarlia basin during a clean-out event. This sample was subject to a hydrometer test without the use of a de-floccing agent. This test is described in Appendix B.1.6.

In a standard hydrometer test, the particle velocity is related to a particle diameter according to Stokes' law and assuming a spherical particle with a density associated with the dry sample. However, a floc is composed of a collection of particles and the floc also has a very high moisture content. Tambo and Watanabe (1979) presented a paper on the physical characteristics of flocs including results from experimental studies with aluminum flocs. The paper provided a settling velocity equation for a non-spherical aluminum floc particle and a relationship for floc density as a function of floc diameter (see Appendix B.1.6). Using this information, floc diameters associated with the settling velocities resulting from the hydrometer test were calculated and provided in Table B.1-7. The range of settling velocities in Table B.1-7 corresponds to a range of floc diameters of approximately 0.03 to 0.4 mm. A spherical sand or silt particle would require a diameter 4-10 times smaller in order to posses a similar settling velocity.

The particle characteristic data presented in this section will be analyzed further in Section 2.2.4 when constructing particle distributions for model simulations.

2.1.6 Plume Surveys at Outfall 003 (Georgetown Reservoir)

A dye-tracer plume mapping study was performed at Outfall 003 on 2 May 2000 while the Georgetown Reservoir was being drawn down. The following day (3 May), a turbidity plume mapping study was performed during and for several hours after a suspended solids discharge event. As discussed in Section 2.1.3, both studies took place primarily during an ebb tide.

Dye Plume Mapping Surveys (2 May 2000)

On 2 May 2000, a 20-percent solution of Rhodamine WT dye was injected into the reservoir outflow starting at 0749 hours and continued until 1406 hours. During the period of dye injection, three effluent samples were collected at the concrete outfall structure near the river at approximately 1-hour intervals and analyzed for discharge dye concentration. The discharge flow was calculated from the dye injection rate and the observed effluent concentrations (Table B.1-8). The average discharge flow based on the three samples was 3.46 cms (79 mgd).

The transects used during the dye survey were listed in Table 2.1-1 and illustrated in Figure 2.1-1. Outfall 003 is located at Transect 8 and Transect 7 (150-m upstream of Outfall 003) was used for background. The times of the five dye plume mapping surveys are summarized in the following table.

2 May 2000 – Outfall 003

Survey	Time (hrs)
Dye Injection	0749 - 1406
Survey 1	0820 – 0915
Survey 2	1009 – 1117
Survey 3	1134 – 1235
Survey 4	1338 – 1448
Survey 5	1509 - 1631

The dye concentration data recorded along each transect are provided in Appendix Figures A.1-1 to A.1-14 for Transects 7 to 20. The minimum, maximum, and mean dye concentrations along each transect are summarized in Table B.1-9. An examination of Table B.1-9 indicates that the leading edge of the dye plume arrived downstream at Transects 10, 13, and 16 respectively during the first three surveys. By survey 5, dye had just arrived at Transect 20 (5.05 km downstream from Outfall 003), 8.5 hours after the initiation of dye injection. A more detailed discussion of the results of the 2 May 2000 dye study at Outfall 003 is provided in Appendix B.1.7.

A plume map displaying dilution contours was constructed from the dye survey data for the 500-m region downstream from Outfall 003 (Transects 8-11). The dilution contours were based on the average dye concentrations during surveys 2 and 3, which were performed before the termination of dye injection. The discharge dye concentration during this period was 20.7 ppb based on an average of survey values in the vicinity of the discharge. The resulting dilution contour map (Figure 2.1-3) indicates that the contour for a dilution factor of 5 extended 120 m, and a dilution factor of 10 extended approximately 380 m. The arc of the factor of 5-dilution contour delineates the approximate offshore extent of the eddy that was located downstream of the outfall. A dilution factor of 20 extended beyond Transect 11, which was 480-m downstream.

Turbidity Plume Mapping Surveys (3 May 2000)

On 3 May 2000, the suspended solids discharge event lasted for 3.5 hours, from approximately 1000 hours to 1330 hours. The effluent samples collected and analyzed for aluminum and TSS were previously presented in Table B.1-5. Three of the effluent samples had TSS concentrations that varied between 4,500 mg/L and 12,300 mg/L. Between 1120 and 1250 hours there appeared to be a lull in the clean-out and TSS values were temporarily less than 1,000 mg/L.

The transects used during the turbidity surveys were listed in Table 2.1-1 and illustrated in Figure 2.1-1. The times of the four turbidity mapping surveys are summarized in the following table.

3 May 2000 – Outfall 003

Survey	Time (hour)
Clean out	1000 - 1330
Survey 1	1018 - 1050
Survey 2	1118 - 1222
Survey 3	1301 - 1352
Survey 4	1527 - 1622

Outfall 003 is located at Transect 8 and Transect 7, 150-m upstream of Outfall 003, was used for background. During the surveys, transects were performed through Transect 17, just upstream of Key Bridge. The turbidity data recorded along each transect are provided in Appendix Figures A.2-1 to A.1-11 at Transects 7 to 17. The relationship between turbidity and TSS developed in Section 2.1.4 was used to transform the turbidity survey data into TSS. The TSS values are presented in the appendix figures by the addition of a second axis. The resulting minimum, maximum, and mean TSS concentrations along each transect are summarized in Table B.1-10.

Background TSS levels at Transect 7 were typically 6-8 mg/L during the 4 surveys (Figure A.2-1). At outfall 003 (Transect 8), a maximum value of 2,164 mg/L was measured during survey 2. At Transects 9 and 10, maximum TSS concentrations of 43-86 mg/L were present during surveys

1-3 and values decreased by survey 4, which was started approximately 2-hours after the clean-out was completed.

Downstream of Transect 12 (Figures A.2-6 to A.2-11), there were no clearly evident TSS plume features. This contrasts with the previous day's dye survey when a plume was present with maximum concentrations along the near shore, extending both laterally and in a downstream direction. A more detailed description of the turbidity plume results is provided in Appendix B.1.7.

A contoured map of TSS values is provided in Figure 2.1-4 for the 450-m reach from Outfall 003 to Transect 11. The data set used for the figure is a composite of the highest turbidity values along each of these four transects during the four surveys (Figures A.2-2 to A.2-5). The turbidity values were converted to TSS using the relationship developed in Section 2.1.4. The resulting TSS values were 2,000 mg/L at the outfall, decreasing to maximum values of 85 mg/L at Transect 9 (70 m), 48 mg/L at Transect 10 (200 m), and 43 mg/L at Transect 11 (480 m). The 48-mg/L TSS value at Transect 10 (200 m) corresponds to a dilution factor slightly above 40:1. The high suspended loads discharged from Outfall 003 are dissipated in the river at a higher rate than would be indicated by the dye study. In Figure 2.1-3, the maximum dye concentration at Transect 10 corresponded to a dilution factor of 10:1, a factor of four smaller than that determined using the TSS plume data. The increased dilution observed in the turbidity survey may result in part from settling and stratification of TSS in the water column. The turbidity probe used for the plume mapping surveys was mounted in the upper portion of the water column. It is likely that higher TSS concentrations were present in the lower portion of the water column.

2.1.7 Plume Surveys at Outfall 002 (Dalecarlia Basin)

A dye tracer plume mapping survey was performed at Outfall 002 on 24 May 2000 while the Dalecarlia Basin was being drawn down. The following day, 25 May 2000, a turbidity plume mapping survey was performed during and for several hours after a suspended solids discharge event associated with the basin clean out. As discussed in Section 2.1.3, both studies primarily took place during a flood and early ebb tide.

Dye Plume Mapping Surveys (24 May 2000)

On 24 May 2000, a 20-percent solution of Rhodamine WT dye was injected into the outflow from Dalecarlia Basin 3 starting at 0809 hours and continuing to 1415 hours. During the period of dye injection, 11 effluent samples were collected at a manhole several hundred meters from the injection point at approximately 30-minute intervals. The dye injection rate determined from the scale readings and the measured effluent concentrations are provided in Table B.1-11. The discharge flow was calculated from the dye injection rate and the observed effluent concentrations (Table B.1-11). The average discharge flow from the 11 samples was 1.75 cms.

The discharge flow from Dalecarlia was also calculated based on the observed drawdown of Basin 3. Between 0805 hours and 1340 hours, the basin's elevation decreased 5.92 m (19.42 ft). This level change, coupled with the basin area of 5,888 m^2 yields an average discharge flow of 1.73 cms (39.6 mgd). This discharge flow is in excellent agreement with the 1.75-cms value calculated from the dye injection rate and the 1.73-cms flow value was used in subsequent analysis.

The transects used during the dye surveys were listed in Table 2.1-1 and illustrated in Figure 2.1-1. The times of the five dye plume mapping surveys are summarized in the following table.

24 May 2000 – Outfall 002

Survey	Time (hrs)
Dye Injection	0809 – 1415
Survey 1	0842 – 0902
Survey 2	0950 – 1029
Survey 3	1107 – 1249
Survey 4	1338 – 1509
Survey 5	1555 – 1728

Outfall 002 is located approximately 520-m upstream from Transect 1 in a relatively narrow and high velocity portion of the river. Transect 1, just below Chain Bridge was considered to be the farthest upstream location that was safe for performing lateral plume mapping surveys. Each survey was performed progressively farther downstream and surveys 4 and 5 were performed to Transect 20 at Memorial Bridge. The dye concentration data recorded along each transect are provided in Appendix Figures A.3-1 to A.3-18 at Transects 1 to 20. The minimum, maximum, and mean dye concentration along each transect is summarized in Table B.1-12.

The mean transect concentrations in Table B.1-12 indicate that the downstream leading edge of the dye plume reached Transects 4, 7, and 12 respectively during the first 3 surveys. By survey 5 the dye arrived at Transect 17 (Key Bridge, 5.7 km downstream of Outfall 002), 9-hrs after the beginning of dye injection. Figure A.3-1 displays the dye build up at Transect 1 during the survey period. At this first transect, 520-m downstream of Outfall 002, the dye was already well mixed with a small concentration gradient increasing from left to right bank. Downstream at Transect 6 (Figure A.2-6) and Transect 10 (Figure A.2-8) the river widens out and the study results show a faster build-up of dye on the right bank (main channel) and the subsequent buildup of dye on the shallower left side of the river during later surveys. A more detailed discussion of the 24 May 2000 dye study results at Outfall 002 are provided in Appendix B.1.8.

Between surveys 3 and 4 during the 24 May 2000 dye study at Outfall 002, the survey boat was able to travel upstream of Transect 1 and perform several mapping transects in the vicinity of the discharge. The time interval between surveys 3 and 4 was near high water and the river currents upstream of Transect 1 were less than at other times during the study. The resulting dilution contour map is presented in Figure 2.1-5. During this survey (1322-1339-hrs) the discharge dye concentration was 34.2 ppb. Figure 2.1-5 indicates that the 10, 30, and 40 fold dilution contours were approximately 85-m, 135-m, and 190-m downstream of Outfall 002 along the discharge (left) bank. Downstream of the outfall, there was a very sharp lateral gradient as the dye mixed from the quieter back eddy formed in the lee of the shoreline protrusion at the discharge into the high velocity and turbulent flow coming from Little Falls. Within the 200-m region included in the dilution contour map, the plume gradually mixed across the remaining width of the river.

Turbidity Plume Mapping Surveys (25 May 2000)

On 25 May 2000, the suspended solids discharge event lasted for 3.5 hours, from approximately 0830 hours to 1200 hours. The effluent samples collected and analyzed for aluminum and TSS were previously presented in Table B.1-5. Four of the five effluent samples had TSS concentrations that varied between 4,600 mg/L and 16,500 mg/L.

The transects used during the turbidity survey were listed in Table 2.1-1 and illustrated in Figure 2.1-1. The times of the 4 turbidity mapping surveys are summarized in the following table.

25 May 2000 – Outfall 002

Survey	Time (hour)
Clean out	0830 – 1200
Survey 1	0907 – 1006
Survey 2	1101 – 1148
Survey 3	1259 – 1345
Survey 4	1445 – 1532

During all 4 surveys, transects were performed downstream to Transect 14. Although it was not possible to perform an upstream background transect, turbidity values at the downstream transects, ahead of the turbidity plume indicate background levels. The turbidity data recorded along each transect are provided in Appendix Figures A.4-1 to A.4-10 at Transects 1 to 14. The relationship between turbidity and TSS developed in Section 2.1.4 was used to create a second axis on these figures to display TSS. The minimum, maximum, and mean TSS concentrations along each transect are summarized in Table B.1-13.

Examination of Table B.1-13 indicates that TSS levels of 3-6 mg/L at Transects 12 and 14 during surveys 1 and 2 were most likely representative of background levels. During surveys 1 and 2, the highest TSS concentration along Transects 1 to 4 was 25.1 mg/L, and transect average concentrations varied between 11.4 and 18.5 mg/L. A more detailed description of the 25 May 2000 turbidity study results at Outfall 002 is provided in Appendix B.1.8.

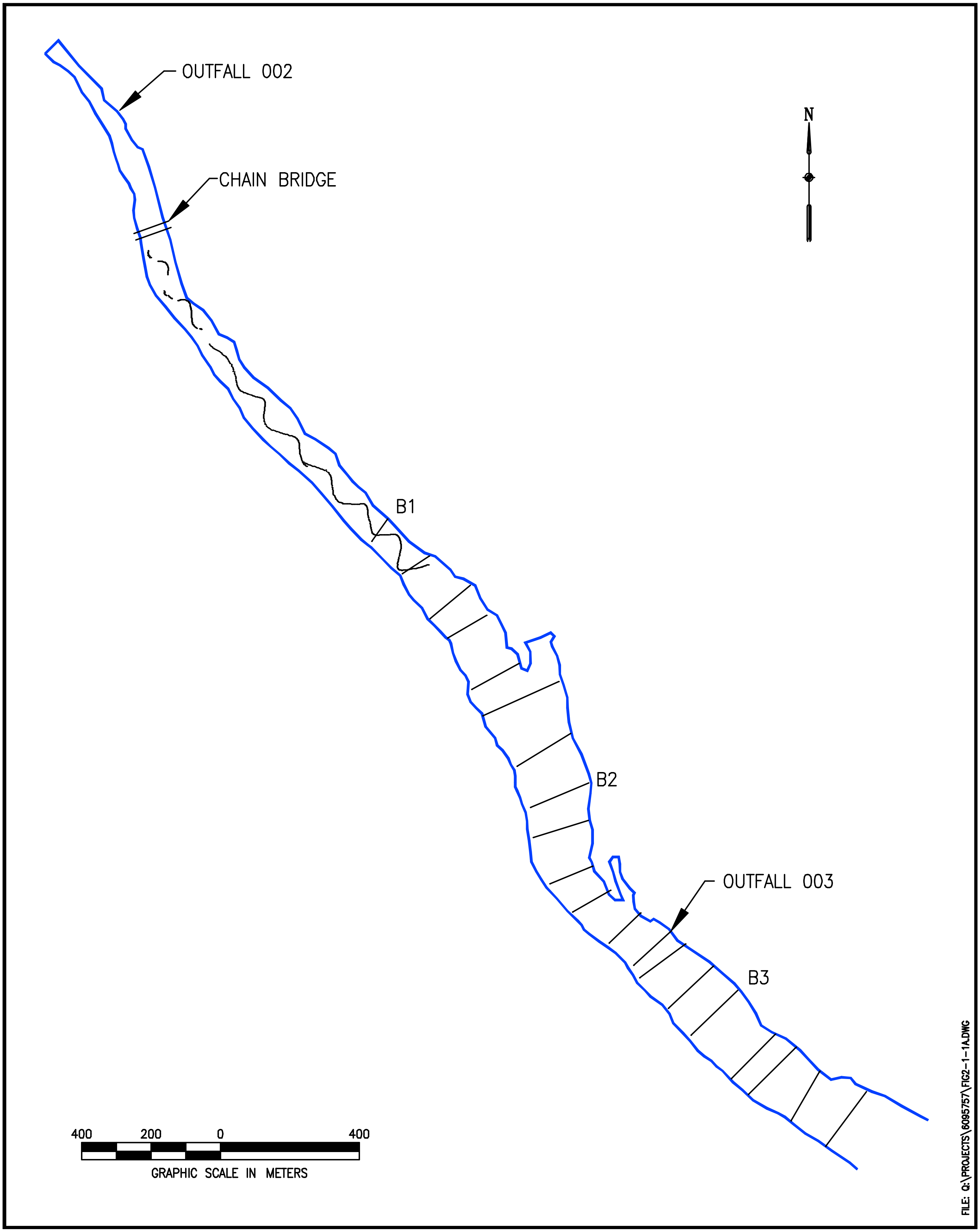


Figure 2.1-1A. Transects Used During the Bathymetry Study

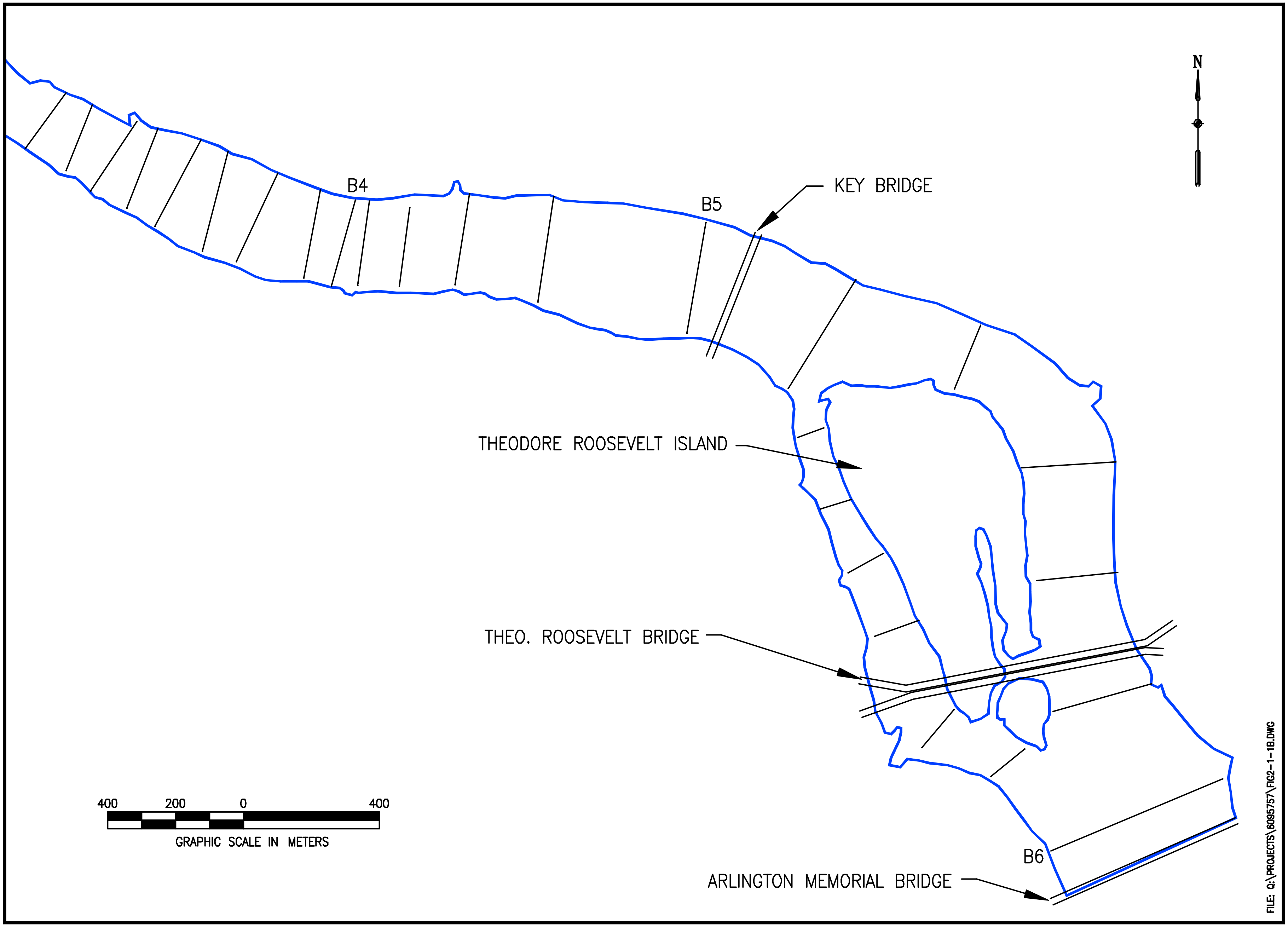
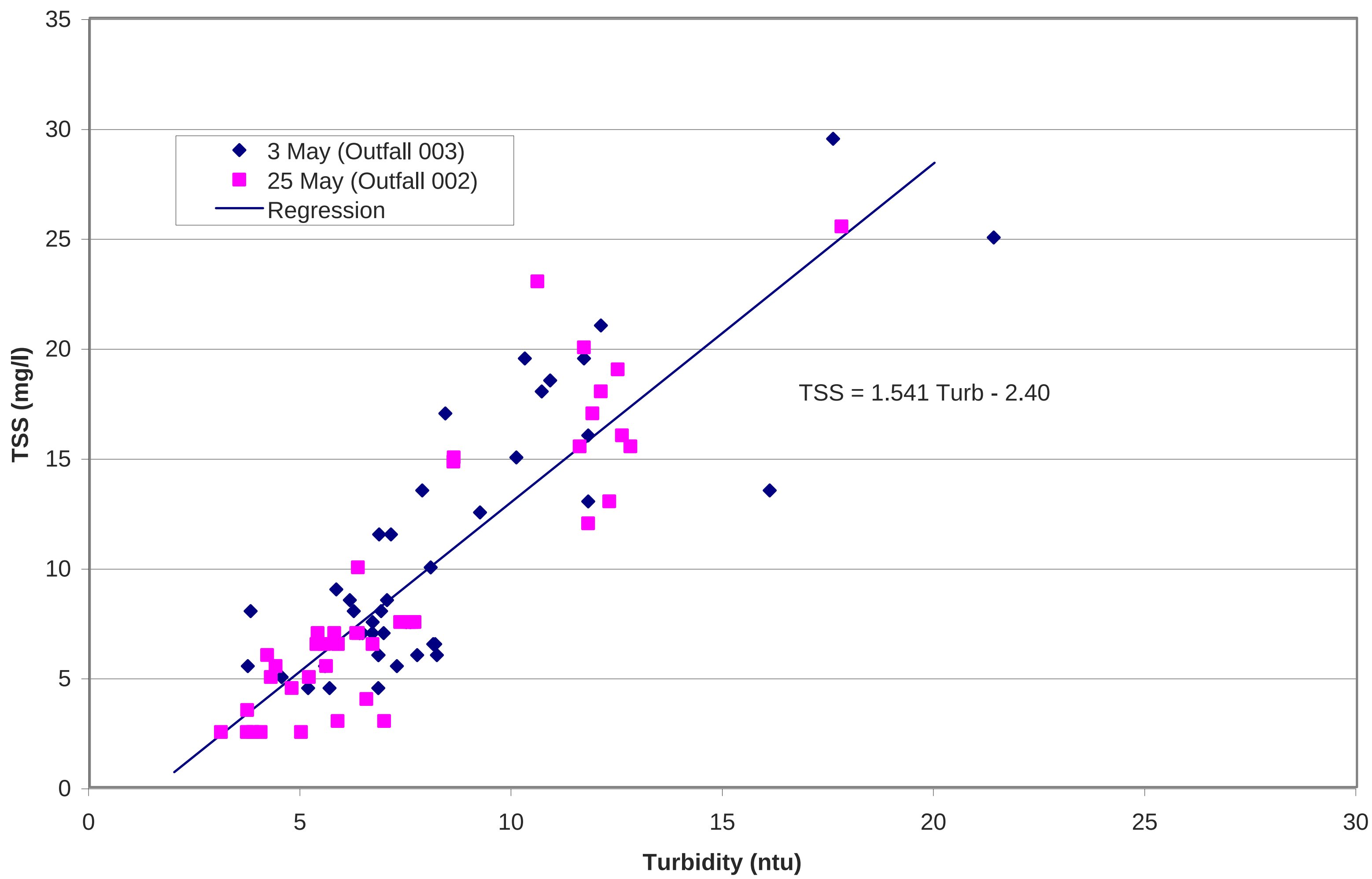


Figure B.1-1B. Transects Used During the Bathymetry Study

Figure 2.1-2 Relationship Between TSS and Turbidity in Water Samples Collected During the Turbidity Surveys at Outfalls 002 and 003



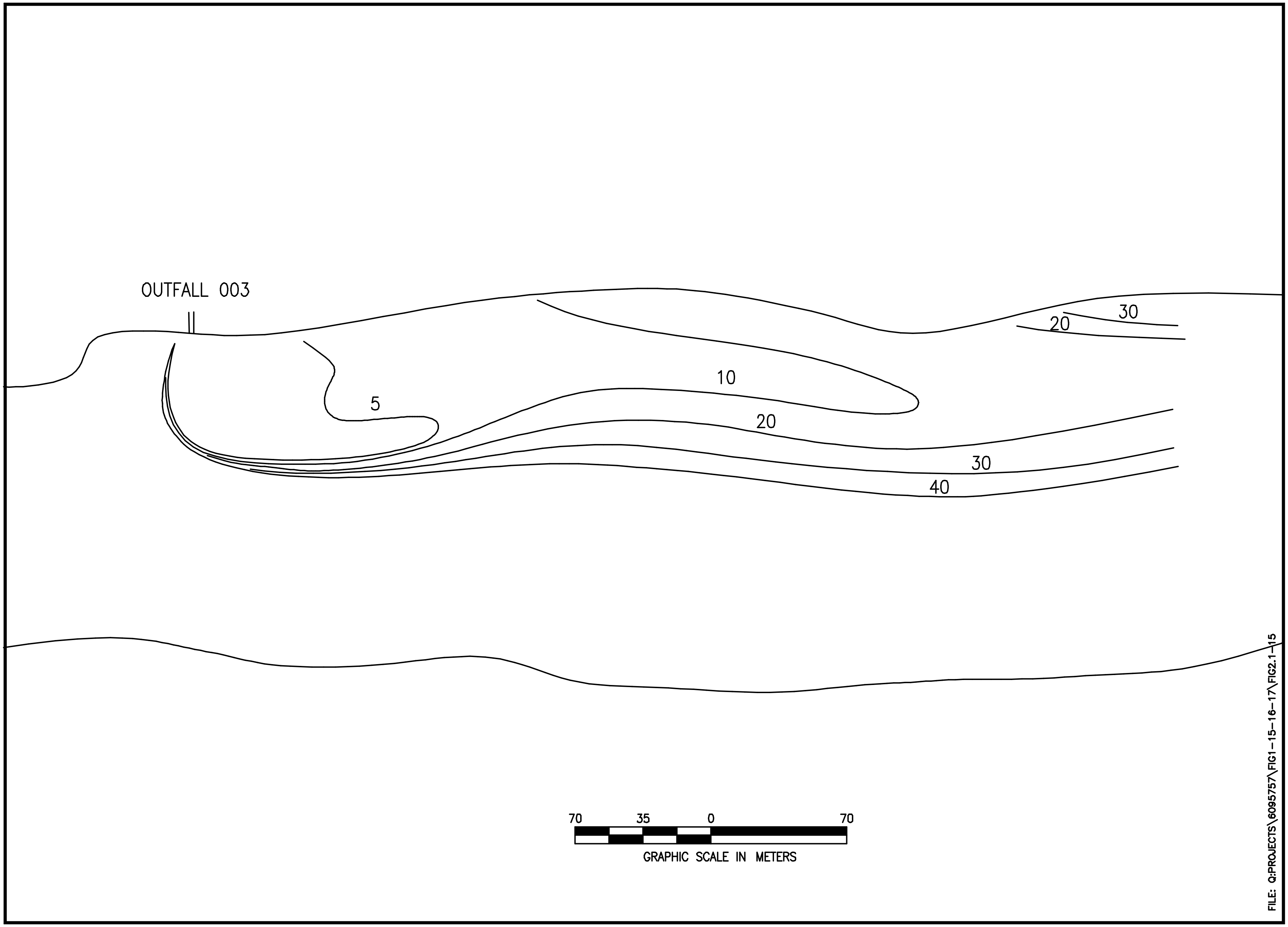
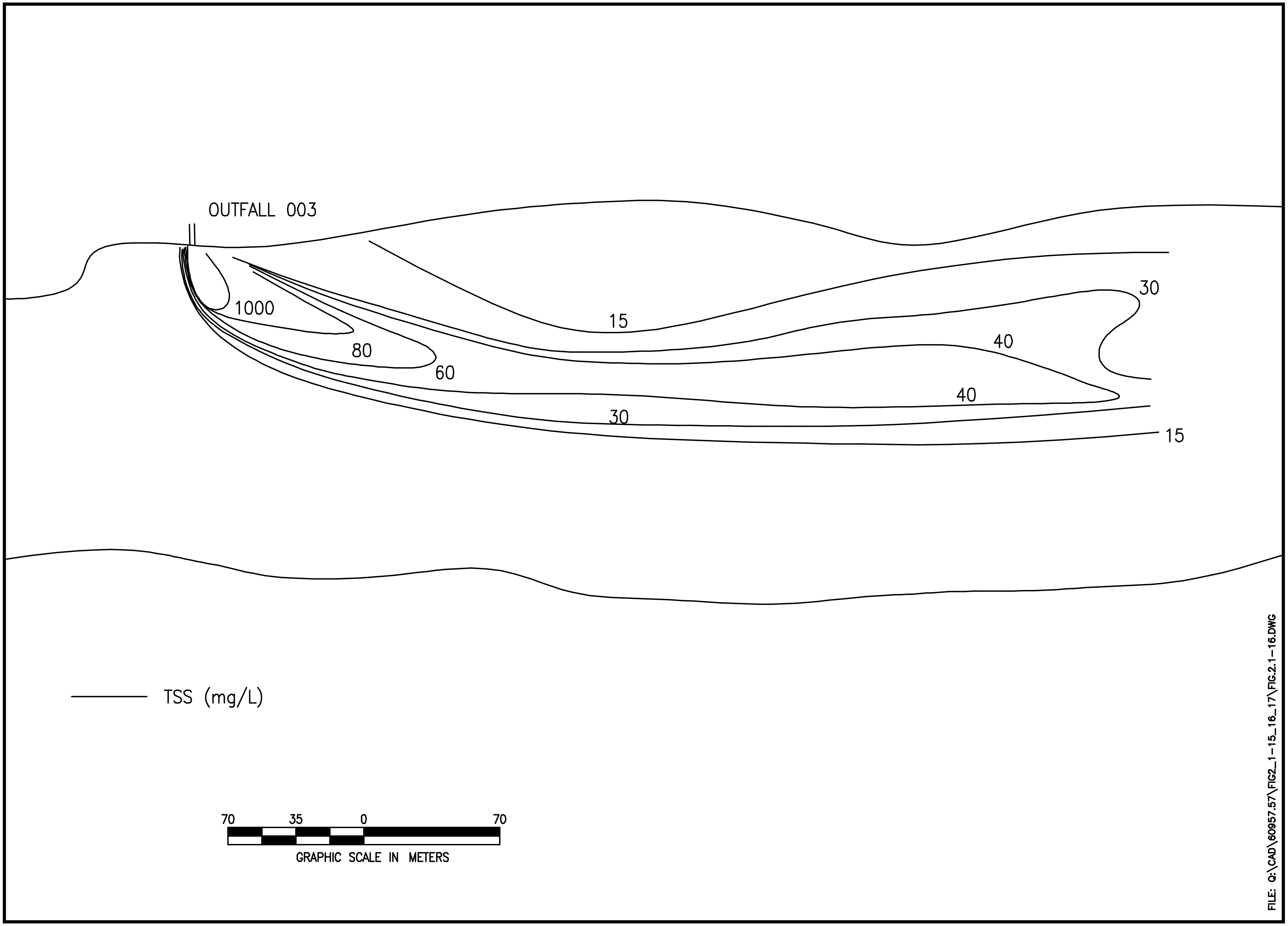


Figure 2.1-3. Average Dye Dilution Contours During Surveys 2 and 3 of the Outfall 003 Plume Mapping Survey, 2 May 2000



FILE: Q:\CAD\60957.57\FIG2_1-15_16_17\FIG.2.1-16.DWG

Figure 2.1-4. Maximum TSS Concentrations During the Turbidity Plume Mapping Surveys at Outfall 003, 3 May 2000

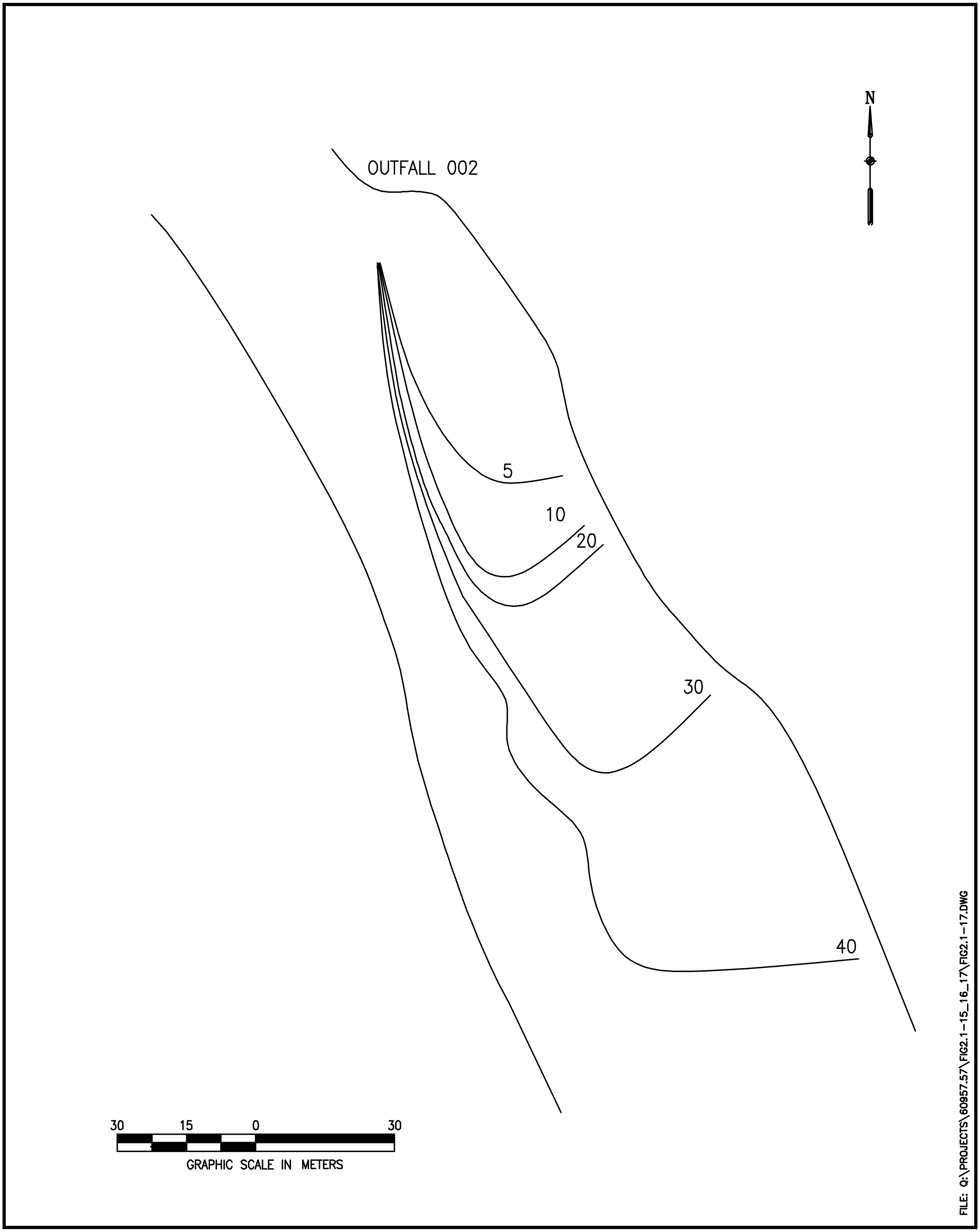


Figure 2.1–5. Dye Dillution Contours During the Outfall 002 Plume Mapping Survey, 24 May 2000(1320–1340 hrs.)

Table 2.1-1 Transects Used During the Dye and Turbidity Plume Mapping Surveys at Outfalls 002 and 003

Transect	Distance from 002 (m)	Distance from 003 (m)	Georgetown (003)		Dalecarlia (002)	
			Dye 2-May	Turbidity 3-May	Dye 24-May	Turbidity 25-May
1	520				x	x
2	790				x	x
3	1,150				x	x
4	1,560				x	x
5	1,880				x	x
6	2,280				x	x
7	2,780	-150	x	x	x	x
8	2,930	0	x	x		
9	3,000	70	x	x		
10	3,130	200	x	x	x	x
11	3,410	480	x	x	x	
12	3,830	900	x	x	x	x
13	4,320	1,390	x	x	x	
14	4,630	1,700	x	x	x	x
15	4,950	2,020	x	x	x	
16	5,190	2,260	x	x	x	
17	5,710	2,780	x	x	x	
18	6,640	3,710	x		x	
19	7,020	4,090	x		x	
20	7,980	5,050	x		x	

2.2 MODEL CALIBRATION

The model used to evaluate Aqueduct discharges to the Potomac River was the Surfacewater Modeling System (SMS), developed by BOSS International and Brigham Young University. SMS is a pre- and post-processor for surface water modeling and analysis. It includes interfaces with several numerical models including the U.S. Army Corps of Engineers, Waterways Experiment Station (WES) supported models RMA2, RMA4, and SED2D.

- RMA2 is a two-dimensional depth averaged finite-element hydrodynamic numerical model. It computes water surface elevations and horizontal components for free-surface flow in two-dimensional flow fields. RMA2 was used to provide a hydrodynamic solution for the modeled portion of the Potomac River. For the Aqueduct model, time-variable river flows were applied at the upstream model boundary, and time-variable tidal elevations were applied at the downstream model boundary. The resulting output file provides a flow velocity and a water surface elevation at each model node for each solution time step.

- RMA4 is a two-dimensional finite-element water quality model. The model simulates the advection-diffusion processes and treats pollutants either as conservative or nonconservative using first order decay. RMA4 uses the hydrodynamic solution file from RMA2 as an input file along with additional information on pollutant loadings and diffusion coefficients. As part of the Aqueduct model, RMA4 was used to simulate the discharge plumes resulting from the dye studies, while treating dye as a conservative tracer. The calibration of the Aqueduct model to the observed instream dye distribution was used to establish appropriate lateral and longitudinal diffusion coefficients.

- SED2D is a two-dimensional finite-element model for vertically averaged sediment transport in open channel flow. The model simulates both deposition and erosion and treats two sediment categories: 1) “noncohesive”, which is usually referred to as sand; and 2) “cohesive”, which is referred to as silt or clay. SED2D also uses the hydrodynamic solution file from RMA2 as an input file along with additional information including sediment loads, particle settling velocities, and shear stress for deposition and erosion. As part of the Aqueduct model, SED2D was used to model the suspended solids load during a reservoir clean-out event, and to simulate the resulting water column concentrations and the depositional patterns.

A more detailed discussion of the model calibration is provided in Appendix B.2.

2.2.1 Model Grid

The model domain was selected to extend from a location approximately 180-m upstream of Outfall 002, downstream past Roosevelt Island to Memorial Bridge. The total length of the model along the Potomac River was 8.0 km. The finite-element nature of RMA2 allows a variable model cell size to be used. Thus, a smaller element can be used in the vicinity of the outfalls where greater resolution is desired. The dynamic nature of the discharge flow entering transverse to the river flow and the accompanying large concentration gradients makes a smaller element size in the vicinity of the outfalls necessary for improved numerical stability. In the Aqueduct model, each of these far-field cells was typically 50-m long and 15 to 20-m wide. A much smaller element size was used in the vicinity of Outfalls 002 and 003. The model places nodes at the corner of each element and also mid-way along each side. The Aqueduct model contains a total of 2021 elements and 6281 nodes. For each model time step, the model solution files contains x and y velocity components, water surface elevations, and concentrations at each node. In general, the model was approximately 6 elements wide upstream in the vicinity of Outfall 002, increasing to 12 elements wide by Outfall 003. Between Outfall 003 and Roosevelt Island, the model maintained 12 elements across the river, although the element width varied with the river width resulting in curve-linear coordinates. A larger model element was used below Roosevelt Island approaching the downstream tidal boundary.

The finer model grid in the vicinity of Outfalls 002 and 003 are displayed in Figure 2.2-1. The smaller elements at Outfall 002 are approximately 5x5 m and the smaller elements at Outfall 003 are 5x7 m. The model grid used in the Potomac River beyond the vicinity of the outfalls is displayed in Figure 2.2-2, which extends from below Outfall 003 to the downstream end of the model at Arlington Memorial Bridge.

2.2.2 RMA2 Model Development

Model Boundaries

The RMA2 model was set-up using real-time data at the upstream and downstream boundaries. At the upstream boundary, the 15-minute USGS flow data was obtained at the Little Falls gage on days that field surveys were performed (Figures B.1-7 and B.1-10). At the downstream boundary the 5-min tide data obtained from the water level recorder deployed during each field survey was used.

Eddy Viscosity

The principal calibration parameters in RMA2 are eddy viscosity and channel roughness. Eddy viscosity (E) controls the fluid momentum transfer between water masses moving at different speeds. The eddy viscosity in the Aqueduct model was based upon a Peclet number. The Peclet number defines the relationship between velocity, elemental length, fluid density, and eddy viscosity. For a specified Peclet number, the eddy viscosity varies throughout the model in proportion to variation in velocity and element size. As the Peclet number is increased, the eddy viscosity decreases. A Peclet number of 20 was determined to provide numerical stability in the RMA2 model over a range of flow and tidal conditions.

Cross-Sectional River Velocity

The Manning's coefficient option was selected for determining channel roughness in the RMA2 model. The RMA2 model was executed for 6 and 7 April 2000 and the resulting velocities along Transects B3 and B4 were compared to observations. This comparison is illustrated in Figure B.2-3 for Transect B3 and Figure B.2-4 for Transect B4. The Manning's distribution selected for use in the model has the following form.

River Depth (m)	Manning's Coefficient
.5	0.047
2	0.035
4	0.030
6	0.027
10	0.024
14	0.023
16	0.021

2.2.3 Calibration of Diffusion to the Dye Survey Data (RMA4)

Longitudinal and lateral diffusion were calibrated by fitting RMA2/RMA4 to the dye plume mapping data obtained on 2 May 2000 at Outfall 003 (Georgetown Reservoir) and 24 May 2000 at Outfall 002 (Dalecarlia Basin).

On 2 May 2000 (Outfall 003, Georgetown Reservoir), the model was started at 0600 hour (near high slack) approximately 2.0 hours before Outfall 003 was turned on and the initiation of dye injection. The average discharge flow during the reservoir drawdown was 3.46 cms and discharge dye concentrations during the 6-hour dye release varied between 14.2 ppb and 21.2 ppb (Table B.1-8).

On 24 May 2000 (Outfall 002, Dalecarlia Basin), the model was started at 0600 hour (near low slack) approximately 2.0 hours before Outfall 002 was turned on and the initiation of dye injection. The average discharge flow during the reservoir drawdown was 1.73 cms and during the 6-hour dye release, discharge dye concentrations varied between 18.1 ppb and 34.2 ppb (Table B.1-10).

Diffusion coefficients were selected using a model option that automatically generates a value at every time step for each element based on the element size and average current velocity. The calculated diffusion value is scaled by a factor input by the user. A x-direction scale factor of 0.2 was used for the entire Aqueduct model. A value that was within the recommended range. The y-direction diffusion coefficient is set as a fraction of the x-direction diffusion coefficient. In order to fit the RMA4 model to the dye plume mapping data during the calibration process it was necessary for the y-direction diffusion scale factor to vary between several regions.

Beyond the vicinity of Outfalls 002 and 003, a y-direction scale factor of 0.15 was used throughout the model (region 1). Downstream of Outfall 002 the y-direction scale factor was increased to 0.7 for a 420-m reach in order to obtain the lateral nearly mixed condition observed at Transect 1 (region 2). The y-direction scale factor was increased in two regions associated with Outfall 003. The first being a 40x40-m region directly in front of Outfall 003 (region 3), and the second region extended 620-m downstream and approximately 80-m offshore along the shallow near shore zone (region 4). The two regions associated with Outfall 003 were not needed during the Outfall 002 simulations. The model parameters used in the resulting four regions of the model are summarized in the following table.

Region	**Peclet**	**x-Dir Scaling**	**y-Direction Scaling**	
			002 Simulation	**003 Simulation**
1) Main Model	20	0.20	0.15	0.15
2) Downstream 002	20	0.20	0.70	0.70
3) Adjacent 003	20	0.20	0.15	0.40
4) Downstream 003	20	0.20	0.15	0.25

A comparison of predicted and observed dye concentrations at the survey transects for the 2 May 2000 Outfall 003 study (Georgetown Reservoir) are provided in Figures B.2-5 and B.2-6. A comparison of predicted and observed dye concentrations for the 24 May 2000 Outfall 002 study (Dalecarlia Basin) are provided in Figures B.2-7 to B.2-9. A discussion of the goodness-of-fit of the predicted and observed dye concentrations at the transects represented in these figures is provided in Appendix B.2.3. In general, the agreement between t model predictions and observations were considered to be very good.

2.2.4 Modeling the Suspended Solids Plume (SED2D)

The suspended solids discharge from the Georgetown Reservoir (Outfall 003, 3 May 2000) and Dalecarlia Basin (Outfall 002, 25 May2000) were modeled with SED2D. SED2D requires the RMA2 hydrodynamic output file, diffusion coefficients, and the particle characteristics of the material being discharged. Diffusion in SED2D was parameterized to match the values selected in RMA4 based on the dye study surveys.

Particle Characteristics

The composite particle size distribution based on sediment samples collected during this project from the Georgetown and Dalecarlia Reservoirs indicated that the material was 65.7 % sand, 22.0 % silt, and 12.3 % clay (Table B.1-6). However, this particle distribution does not reflect the presence of the floc resulting from the addition of alum in the water treatment process. An analysis of particle size without using a de-floccing agent (which is typically used in particle size determinations) yielded a much narrower range of particle size with an absence of the finer clays (Table B.1-7).

Modeling the discharged material as a single particle classification (floc) was not considered to be realistic because considerations of all the available data indicated that a coarser and finer material were also likely to be present. Based upon a discussion in Appendix B.2.4, three particle classifications were selected for simulation with SED2D: sand 25%, floc 65%, and silt 10 %.

The particle size distribution from the ASTM settling tests and the particle scenario selected for the model are compared in the following table.

ASTM Test Results				Model Scenario		
Material	**Dia (mm)**	**ASTM (%)**	**Floc (%)**	**Material**	**Dia (mm)**	**Percent**
Sand	> 0.05	65.7	88.2	Sand	> 0.05	25
Silt	0.002-0.05	22.0	11.8	Floc	> 0.05	65
Clay	< 0.002	12.3	0	Silt	< 0.05	10

SED2D provides different mechanisms for the simulation of noncohesive particles (sand) and cohesive particles (silt and clay). The floc was modeled using the cohesive particle mechanism. For sand, the model requires the particle diameter, settling velocity, and material density. For a cohesive particle, the model requires settling velocity and shear stresses for deposition and erosion. SED2D calculates a bottom shear stress as a function of velocity and channel friction at each location in the model. The bottom shear stress must be below the depositional shear stress for a particle to be deposited. If the bottom shear stress increases above the erosional shear stress, a particle will be resuspended.

The relationship between particle size, shear stress, and other physical site conditions effecting sediment transport is under active investigation by the U.S. Army Engineer Waterways Experiment Station (WES) and other investigators. Based upon a review of the particle data and sediment characteristics (see Appendix B.2.4), the following particle attributes were used in the model.

Particle Characteristics

Parameter	**Sand**		**Parameter**	**Floc**	**Silt**
Diameter (mm)	0.05		Diameter (mm)	.05	.002
Settling Vel.(m/sec)	0.00208		Settling Vel. (m/sec)	2.4E-4	8.2E-5
Density (gm/cm^3)	2.5		Shear Stress (newton/m^2)	0.1	0.1

SED2D Model Execution

SED2D was executed three time for each of the two outfalls to provide model simulations for the sand, floc, and silt particle classes. The water column TSS concentrations for the three particle classes were summed at each model node to provide composite TSS concentrations. In general, the TSS discharge concentration was modeled as being 10,000 mg/L using a 0.132-cms flow at Dalecarlia Basin and a 1.138-cms flow at Georgetown Reservoir. A 3.5-hour suspended solids discharge event was modeled at both outfalls.

A summary of the total mass included in the discharge scenario at each outfall is provided in the following table.

Mass of Discharged Solids (kg)

Material	Outfall 002 (Dalecarlia)	Outfall 003 (Georgetown)
Sand	4,455	38,407
Floc	11,583	99,860
Silt	1,782	15,363
Total	17,820	153,630

The surface area of Georgetown Reservoir (66,425 m^2) is approximately 11 times greater than the surface area of Dalecarlia Basin 3 (5,897 m^2). The increase in mass of solids discharged at Outfall 003 is approximately proportional to the increase in reservoir size.

A frequency distribution of suspended load at Chain Bridge, based on historical USGS data, is presented in Chapter 4 (Section 4.3.2, Table 4-5). The 17,820-kg discharged solids mass at Outfall 002 is less than a lower 10-percentile value of the daily Potomac River suspended load. The 153,630-kg discharged solids mass at Outfall 003 is between a 40- and 45-percentile of daily Potomac River suspended load.

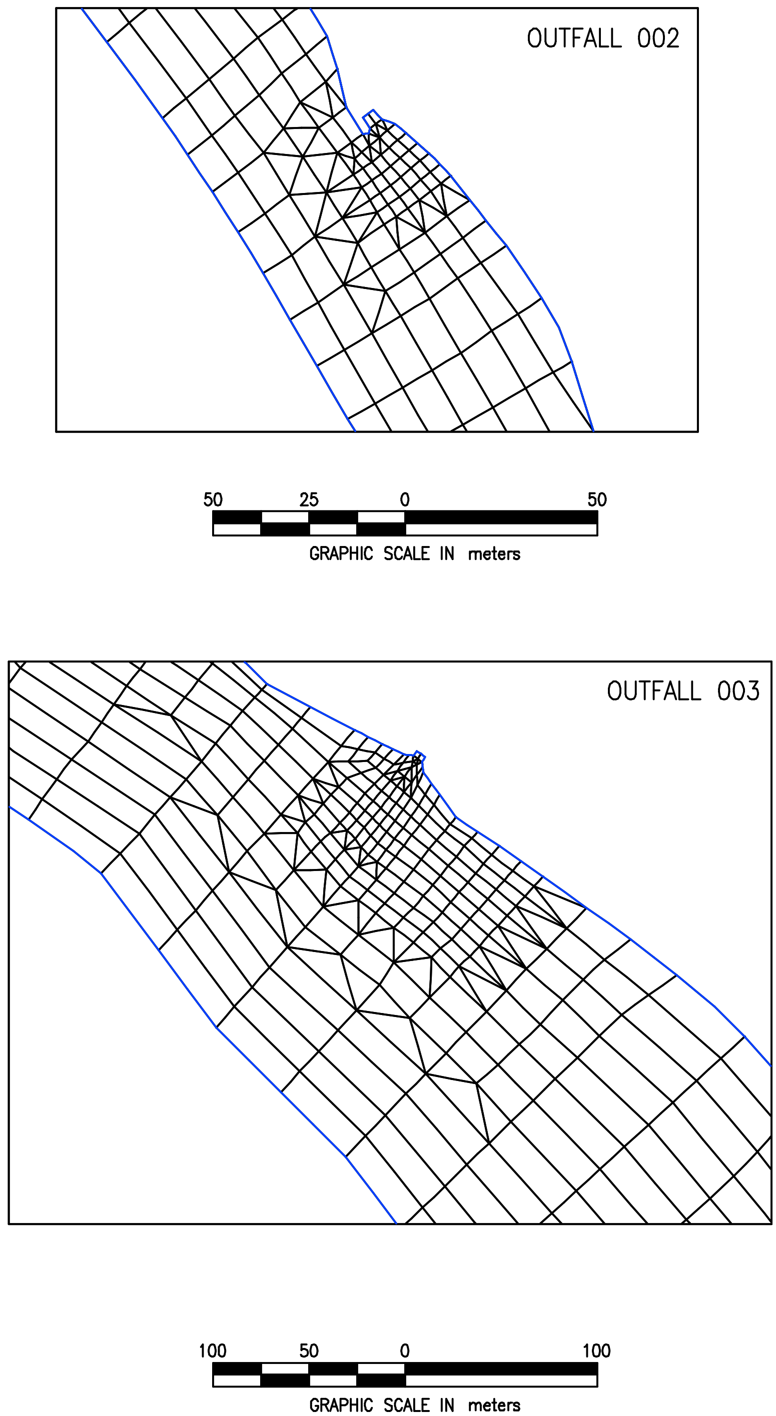
A comparison between observed surface and predicted TSS values is provided in Figures B.2-12 and B.2-13 for Outfall 002 from Dalecarlia Basin, and in Figures B.2-14 and B.2-15 for Outfall 003 from Georgetown Reservoir. The SED2D model output only contained the TSS loadings from the outfalls and did not include the natural background concentrations in the Potomac River. This was done to allow the model to illustrate the incremental increase in TSS concentration directly associated with operations at the reservoirs. However, to make comparisons to the observed survey data, a background TSS concentration was added to the model predictions when generating the figures. The background concentrations were selected based upon examination of the survey data. For the 3 May 2000 survey at Outfall 003, a background TSS concentration of 8 mg/L was used at Transects 10 to 14, decreasing to 6 mg/L at Transect 16. For the 25 May 2000 survey at Outfall 002, a background TSS concentration of 8 mg/L was used at Transects 1 to 8, decreasing to 6 mg/L at Transect 10, and 3 mg/L at Transect 12.

Figure B.2-12 for Dalecarlia Basin displays good agreement between predicted and observed TSS concentrations downstream from Outfall 002 at Transects 1 and 4 during surveys 2, 3, and

4. Surveys 3 and 4 were performed after the solids clean-out event had ended and TSS concentration were decreasing to background levels.

Figure B.2-14 for Georgetown Reservoir provides results at Transect 11 (480-m downstream from Outfall 003) and Transect 12 (900-m downstream). At Transect 11, the decrease in TSS concentrations near the left bank and the sharp delineation of the plume width at approximately one-half the river width were well represented by the model. The lower near-shore concentrations and a higher off-shore plume centerline were features associated with the back-eddy formed downstream of the outfall. The lower observed concentrations during survey 3, the time of maximum plume build-up, were attributed to water column stratification. Before coming well mixed, the higher density suspended solids plume is concentrated in the lower portion of the water column, resulting in higher water column average TSS concentrations than would be observed with a near surface probe.

A more detailed discussion of the comparison of the observed and predicted TSS values at Outfalls 002 and 003 is provided in Appendix B.2.4.



FILE: Q:\PROJECTS\6095757\JYOST\FIG2-2-1.DWG

Figure 2.2-1. Near-Field Model Grid Used at Outfalls 002 and 003

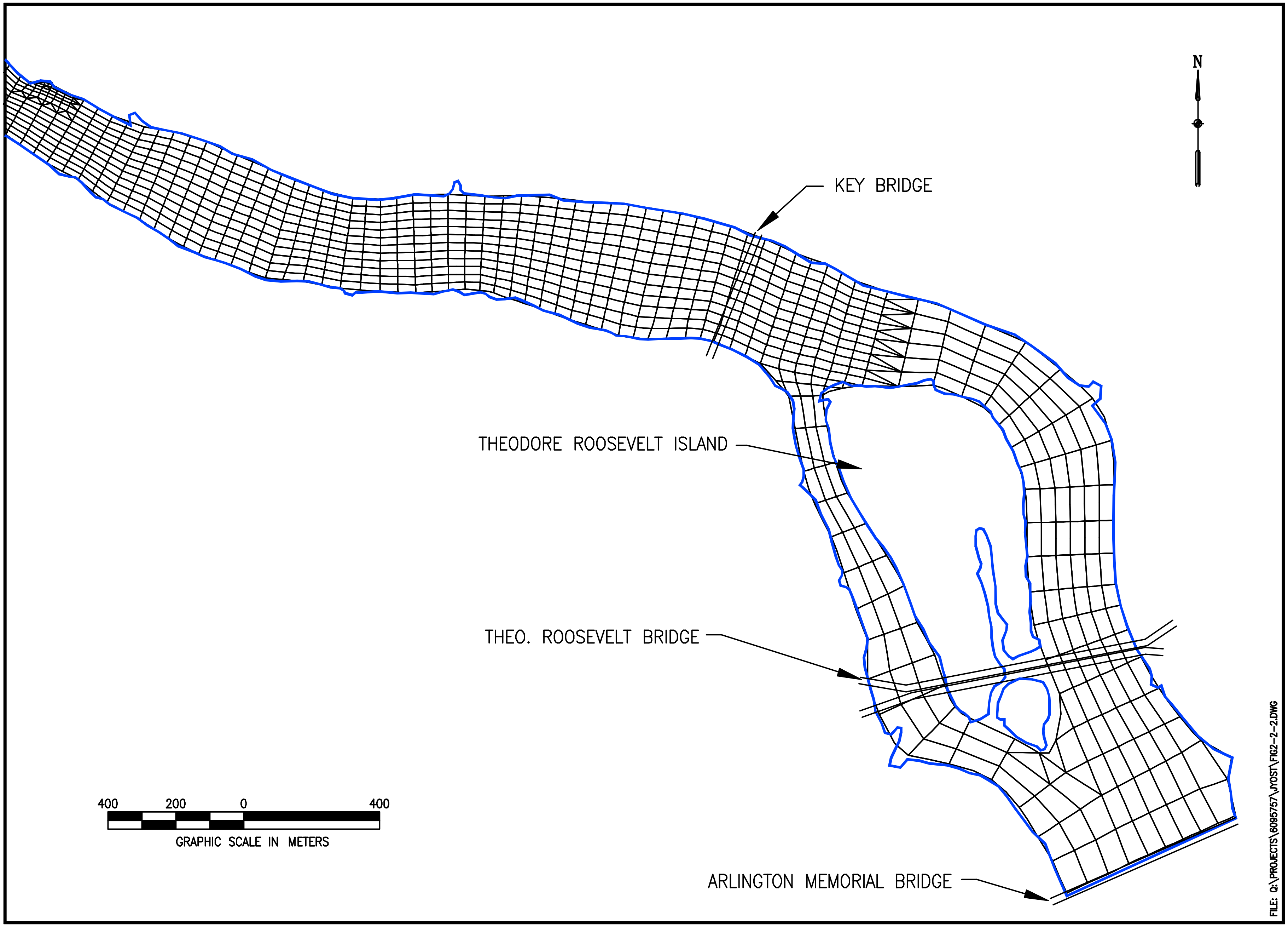


Figure 2.2–2. Model Grid Used in the Downstream Portion of the Potomac River Model

2.3 SUSPENDED SOLIDS FATE AND MIXING ZONE DILUTION FACTORS

The SMS model was used to examine the fate of the solids during the Outfall 002 and Outfall 003 discharge events and to determine mixing zone dimensions associated with a range of dilution factors at each outfall. The model runs performed during calibration typically extended 6 hours beyond the end of the solids discharge event. At the end of these runs, suspended solids were still present in the water column and the plume had not progressed beyond the downstream end of the model. The solids discharge events at Outfalls 002 and 003 were re-executed using a 24-hour model run. This a1lowed the suspended solids mass in the water column resulting from the discharge event to approach zero as a result of deposition and the remnant plume passing beyond the downstream end of the model.

2.3.1 Suspended Solids Fate at Outfall 002

The total TSS concentrations in the water column were determined by summing the results for the sand, floc, and silt from the 24-hour model runs at each model node and time step. The resulting time history of the individual components and of the total suspended solids was used to examine the fate of the discharged material in the Potomac River. The text and figures in the following sections do not include the natural background Potomac River TSS concentrations, but only display the incremental increase associated with the discharges. The background TSS concentrations were typically 6-8 mg/L, and under wet weather conditions, TSS concentrations commonly range up to 100 mg/L.

The distribution of suspended and deposited solids during a 24-hour model run at Outfall 002 is summarized in Figure 2.3-1 and Table 2.3-1. The time scale in the figure and table starts at the beginning of the clean-out event. The discharge event occurred between 0.0 and 3.5 hours. The fraction of suspended solids associated with sand reached zero at 7.5-hours, 4-hours after the end of the discharge event, and the suspended fraction associated with floc and silt approached zero by 21.5-hours, 18-hours after the end of the discharge event. The decrease in the curve representing the total solids mass in the system (both suspended and deposited) between approximately 12 and 20 hours represents the remnant suspended plume passing beyond the downstream end of the model. Based on the model, approximately 4,400 kg (22 percent) of the total mass discharged from Outfall 002 passed beyond the downstream end of the model in 24 hours.

The modeled TSS plumes in the Potomac River are provided in Figures 2.3-2, 2.3-3, and 2.3-4 at times corresponding to the end of the solids discharge event, and 2 hours, and 4 hours following the event. The comparison of observed and predicted results in Section 2.2.4 indicated that the TSS plume very quickly becomes fully mixed.

- At the end of the discharge event (Figure 2.3-2), the leading edge of the plume (the 2-mg/L TSS contour) had reached a location approximately 3,400-m downstream of Outfall 002 and the 10 mg/L TSS was confined to within 350-m of the outfall.

- As shown in Figure 2.3-3, the TSS plume 2-hours following the end of the solids discharge event, as defined by the 1-mg/L contour, had a total length of 2,600 m, centered at a location 3,400 m downstream of Outfall 002 (centered approximately at the location of Outfall 003). After 2-hours, the discharged suspended solids had been flushed out of the 2,000-m reach downstream of Outfall 002 and the maximum TSS concentrations in the remaining plume were less than 6 mg/L.

- The TSS plume 4-hours following the end of the solids discharge event had a length of approximately 2,300-m between the leading and trailing 1-mg/L contours (Figure 2.3-4). The center of mass of the remnant plume was approximately 4,600 m downstream of Outfall 002 and the maximum suspended TSS concentration was less than 5 mg/L.

The maximum extent of the depositional footprint resulting from the discharge event is represented by conditions at the end of the 24-hour model run, when the suspended solids concentrations approach zero. The resulting mass of sand, floc, and silt deposited to the bed at each model node was converted to a thickness. The bed thickness associated with a deposited mass is dependent on the depositional density of the material. The SMS model assumes that sand has a porosity of 0.4, resulting in a density of 1,500 gm/L. The depositional density of floc and silt is much lower due to a high water content and an expected range is 200-500 gm/L. A density of 200 gm/L corresponds to a porosity of 0.92. The bed thickness associated with sand and two densities associated with floc and silt are provided in the following table for a range mass deposition.

Bed Thickness (mm)

Deposition (gm/m^2)	Sand 1,500 gm/L	Floc and Silt 200 gm/L	Floc and Silt 500 gm/L
5	0.0033	0.025	0.010
10	0.0067	0.05	0.020
20	0.013	0.10	0.040
50	0.033	0.25	0.10
100	0.067	0.50	0.20
500	0.33	1.0	0.40

To be conservative, the total deposited thickness at each model node was calculated assuming that the depositional density was 1,500 mg/L for sand, and 200 gm/L for floc and silt.

The depositional footprint from a solids discharge event at Outfall 002 is provided in Figure 2.3-5 (a, b). A figure is presented for two river reaches to provide coverage of the entire model domain. Figure 2.3-5a displays deposition in the higher velocity, more confined Potomac River reach downstream of Outfall 002. At Outfall 002, there is a depositional zone extending approximately 400 m along the lower velocity discharge bank. Just below the outfall, deposition exceeds 0.1 mm, while the remainder of the 400-m region typically exceeded 0.01 mm. At the slight bend in the vicinity of Transect 1, there was a 250-m reach with very low deposition (< 0.01 mm). Immediately downstream of this low deposition region, deposition increased to greater than 0.02 mm, and tapered off to 0.01 mm approximately 2,000 m downstream of the outfall. The higher deposition that occurred downstream of the bend at Transect 1 was associated with sand, resulting from the channel velocity decreasing due to both a widening and deepening of the channel compared to the more confined channel adjacent to the outfall.

Figure 2.3-5b displays the depositional pattern in the downstream half of the model domain. Upstream of Roosevelt Island, deposition was typically 0.03 mm. In the vicinity of Roosevelt Island, deposition exceeded 0.02 mm in the main channel on the east side of the island, and was less than 0.01 mm in the smaller channel on the west side of the island.

2.3.2 Suspended Solids Fate at Outfall 003

The total TSS concentrations in the water column at Outfall 003 were determined by summing the results for the sand, floc, and silt from the 24-hour model runs at each model node and time step. The resulting time history of the individual components and of the total suspended solids was used to examine the fate of the discharged material. The text and figures in the following sections do not include the natural background Potomac River TSS concentrations, but only display the incremental increase associated with the discharges.

The distribution of suspended and deposited solids during a 24-hour model run at Outfall 003 is summarized in Figure 2.3-6 and Table 2.3-2. The fraction of suspended solids associated with sand reached zero at 6.5-hours, 3-hours after the end of the discharge event, and the suspended fraction associated with floc and silt neared zero by 22-hours, 18.5-hours after the end of the discharge event.   The decrease in the curve representing the total solids mass in the system (both suspended and deposited) between approximately 9 and 20 hours represents the remnant suspended plume passing beyond the downstream end of the model. Approximately 20,000 kg (13 percent) of the total mass discharged passed beyond the downstream end of the model.

The modeled TSS plumes in the Potomac River are provided in Figures 2.3-7, 2.3-8, and 2.3-9 at times corresponding to the end of the solids discharge event, and 2 hours, and 4 hours following the event.

- At the end of the discharge event (Figure 2.3-7), the 5-mg/L TSS contour had reached a location approximately 2,000 m downstream of Outfall 003 and the 100-mg/L TSS contour was confined to within 350 m of the outfall. The higher TSS contours extended along the discharge bank (left bank) and a 5-mg/L contour was in the vicinity of the main channel towards the right bank.

- Two-hours following the end of the solids discharge event (Figure 2.3-8), the 2-mg/L TSS contour extended approximately 3,700 m downstream, reaching the vicinity of Roosevelt Island. TSS concentrations in the vicinity of Outfall 003, which exceeded 1,000 mg/L during the discharge event had decreased to less than 100 mg/L. The 20-mg/L contour, which extended 1,000 m at the end of the discharge event (Figure 2.3-7), now reached a downstream distance of approximately 1,500 m, although it was confined to the narrower near-shore zone.

- At 4-hours following the end of the solids discharge event (Figure 2.3-9) the 2-mg/L contour had moved only about 600-m downstream from it’s 2-hr location. This relatively small downstream movement resulted from low Potomac River velocities near high tide and the beginning of flood. A remnant suspended TSS plume of less than 10 mg/L still existed along the shallow near-shore region downstream of Outfall 003. However, TSS concentrations along the main channel on the right half of the river had been flushed out for a 1,500-m distance downstream of the outfall.

Model results at the 22-hour time step with a near zero suspended solids concentration, represents the maximum extent of the depositional footprint resulting from the discharge event at Outfall 003. The resulting deposited mass at each model node for the three material classes were converted to thickness assuming a depositional density of 1,500 mg/L for sand and 200 gm/L for floc and silt, as discussed in the previous section.

The resulting depositional footprint from a solids discharge event at Outfall 003 is provided in Figure 2.3-10. The depositional zone immediately in front of Outfall 003 exceeded 20 mm and the 5-mm contour extended approximately 200-m downstream, and a 1-mm contour extended approximately 350-m downstream. The 0.2-mm depositional contour extended 2,500-m downstream along the left bank. There was minimal deposition within the main channel for the first 800-m downstream from Outfall 003. Between 800-m and 2,000-m downstream, deposition of 0.05-0.10 mm was present near the right bank, and deposition along the main channel typically did not exceed 0.01 mm. In the vicinity of Roosevelt Island, deposition of typically 0.05 mm was present in the main channel along the east side of the island, and deposition of 0.01-0.02 mm was present in the smaller channel on the west side of the island.

2.3.3 Mixing Zones

Section 1105.7 of the D.C. DOH's regulations allow for mixing zones where it is demonstrated that a small area of impact "will not adversely affect the waterbody as a whole." Within the estuary, paragraph (f) of the District's regulations states that "the maximum cross sectional area occupied by a mixing zone for chronic water quality criteria shall not exceed ten percent (10%) of the numerical value of the cross-sectional area of the waterway, and the width of the mixing zone shall not occupy more than one third (1/3) of the width of the waterway. Paragraph (i) states that the mixing zone shall be sized by using the EPA guidance (EPA's TSD) and approved by the Director.

Section 4.4.4 of EPA's TSD provides several alternative approaches for determining the size of an acute mixing zone with the goal of "preventing lethality or other acute effects" (p.71). "Lethality [and other acute effects] is a function of the magnitude of pollutant concentrations and the duration an organism is exposed to those concentrations." As an alternative, the Agency states that the mixing zone can be sized such that a drifting organism would not be exposed to 1-hour average concentrations exceeding the acute criterion, or would not receive harmful exposure when evaluated by other valid toxicological analysis, and discussed in TSD Section 2.2.2" (p. 72). This approach is often termed the one-hour float time.

The Aqueduct model was executed for three river flow scenarios to determine mixing zone characteristics (width, cross-sectional area) and the 1-hour float time associated with both Outfalls 002 and 003. Washington Aqueduct's existing permit limits solid discharge events to times when river flows are above a 3.47-ft gage height, which corresponds to 153 cms (5,400 cfs). In addition to the 153-cms river flow scenario, a river flow of 100 cms and 250 cms was selected to illustrate a range of river conditions. Potomac River flows greater than 153 cms occur less than 30 percent of the time during July, and less than 20 percent of the time during August to October. The Aqueduct must therefore clean all of it's reservoirs and basins during the spring in order to last until the next opportunity in the late fall. The 100-cms river flow condition was performed to illustrate the possibility of discharging during lower summer flows, and thus avoiding more critical biological conditions in the spring. For each river flow scenario, the model was executed using a mean tide range and outfall flows corresponding to the flow used during the 3 May 2000 and 24 May 2000 discharge events (0.132 cms at Outfall 002 and 1.138 cms at Outfall 003). The model was executed using a conservative dye tracer in order to provide dilution contours.

Plume dimensions associated with various dilution contours were summarized during a mid-ebb tide and during a mid-flood tide. Since a Potomac River flow reversal does not take place within the modeled flow range, a slack tide condition does not occur. The resulting range of river velocities is bracketed by the mid-ebb and mid-flood condition. The downstream distance to each dilution contour was determined by measuring dimensions on graphical output generated by SMS. At each outfall, a cross-section was selected just downstream of the discharge that exhibited maximum width. A computer program processed the predicted dye concentrations along this cross-section to develop a table of plume widths and cross-sectional areas. The cross-sectional analysis program accounts for lower near-shore concentrations when the plume centerline is not shore attached. The dilution associated with a 1-hr average float time was also determined. A computer program was used that searched along each set of lateral nodes in the model grid downstream of the discharge to identify the location of the maximum concentration (minimum dilution). The concentration exposure history of a particle was calculated along this maximum centerline concentration using the velocity field associated with the node of maximum concentration. The results of this dilution analysis are provided in Tables 2.3-3 and 2.3-4 for Outfall 002 and in Table 2.3-5 and 2.3-6 for Outfall 003.

Outfall 002

Table 2.3-3 provides dilution factors for Outfall 002 (0.132 cms) under three river flow scenarios during an ebb and flood tide. Dilution contours at Outfall 002 for an ebb tide scenario are illustrated in Figure 2.3-11 at a 153-cms river flow. The 0.132-cms flow at Outfall 002 has a maximum dilution factor of 1,160 when fully mixed into a 153-cms river flow. At a 153-cms river flow, the available dilution factor increased from 50 to 100 as the downstream distance increased from 29.1 m to 54.2 m. At a lower river flow of 100 cms, the distance necessary for a dilution factor of 50 increased from 29.1 to 36.1 m, while at a higher river flow of 250 cms, the distance decreased to 10.7 m. During a flood tide, dilution contours occurred at approximately a 10 percent shorter distance for all three river flow scenarios.

The dilution contours in Figure 2.3-11 can be compared to the dye plume map that was generated during the 24 May 2000 dye study (Figure 2.1-5). In Figure 2.1-5, the factor of 40 dilution contour extended approximately 180-m downstream, considerably farther than the 54-m distance for the 100-dilution contour in Figure 2.3-11. It must be remembered that during the dye study (which occurred during the basin decant process), the discharge flow was 1.73 cms, while during the reservoir clean-out, the discharge flow was only 0.132 cms. With some approximation, the two scenarios can be scaled by the 13.1 ratio between their discharge flows. This would indicate that the 100-dilution contour at the solids discharge flow (0.132 cms) is similar to the 7.6-dilution contour during the dye study (1.73 cms). With this consideration, the two dilution contour figures are in reasonable agreement.

The dilution factor associated with a 1-hr average exposure time (acute mixing zone) was 169 at a 153-cms river flow. The 1-hr average dilution factor decreased to 109 for a 100-cms river flow and increased to 282 for a 250-cms river flow. During a flood tide, the 1-hr average dilution was reduced slightly with a value of 156 for the 153-cms river flow scenario (Table 2.3-3).

Table 2.3-4 provides plume widths and cross-sectional areas at Outfall 002 during an ebb tide for three river flows, and for a range of dilution factors. The cross-sectional analysis was performed at transects 3-m and 7-m downstream of the outfall. At the 153-cms and 250-cms river flows, the 3-m transect had larger plume widths and these results were used in the table. At the lower 100-cms river flow, the 3-m transect had larger plume widths at dilution factors below 30 and the 7-m transect had larger plume widths above a dilution factor of 30.

With respect to the D.C.DOH criteria for plume width (33.3 percent) and cross-sectional area (10 percent), a chronic mixing zone at Outfall 002 is limited by it’s cross-sectional area. At a river flow of 153-cms, 10 percent of the cross-sectional area is associated with a dilution factor of approximately 51, and is equivalent to 18.6 percent of the river width. At a river flow of 250-cms, 10 percent of the cross-sectional area increases to a dilution factor greater than 80, while at a lower 100-cms river flow, the 10-percent criteria is met by a dilution factor of 33.

Outfall 003

Table 2.3-5 provides dilution factors for Outfall 003 under three river flow scenarios during an ebb and flood tide. Dilution contours at Outfall 003 for an ebb tide scenario are illustrated in Figure 2.3-12 at a 153-cms river flow. The 1.138-cms flow at Outfall 003 has a maximum dilution factor of 136 when fully mixed into a 153-cms river flow (Table 2.3-5). During an ebb tide and at a 153-cms river flow, the downstream plume length was 302 m for a dilution contour of 20 and 488 m for a dilution factor of 40. At a 100-cms river flow, downstream distances were slightly shorter, 293 m to a dilution contour of 20. At a higher 250-cms river flow, downstream distances were slightly shorter at dilution factors less 30, reflecting greater initial dilution in the higher river flow. At larger dilution factors of 40 to 50, the downstream distance increased due to the more rapid plume transport at the higher river velocities. During a flood tide, downstream distances were slightly shorter. For example, at a 153-cms river flow the distance for a dilution factor of 20 decreased from 302 m during ebb tide to 284 m during flood tide.

The dilution contours in Figure 2.3-12 (1.138 cms) can be compared to Figure 2.1-3 generated during the 2 May 2000 dye plume mapping study (3.46 cms). The river flow during the 2 May 2000 dye study was 300-cms, slightly larger than the 250-cms model scenario. The two figures exhibit similar plume widths, indicating that plume width is more dependent on the width of the shallow near-shore zone than to discharge flow. In Figure 2.1-3, the downstream distances to the 10-dilution contour was 380 m, respectively, while in Table 2.3-5 for a 250-cms river flow, the 10-dilution contour was at a distance of 176 m. The shorter plume length predicted by the model is consistent with how one would expect the plume to respond when the discharge flow was reduced from the higher 3.46-cms value present during the reservoir decant process to the lower 1.138-ms flow associated with the reservoir clean-out.

The dilution factor for an acute mixing zone associated with a 1-hr average exposure time was 2.33 during an ebb tide and 2.31 during a flood tide at a 153-cms river flow. The 1-hr average dilution for the ebb tide scenario decreased to 2.16 for the lower 100-cms river flow, and increased to 2.65 for a 250-cms river flow. For the flood tide scenarios, the 1-hr average dilutions were nearly identical to the ebb tide results.

Plume widths and cross-sectional areas at Outfall 003 are provided in Table 2.3-6 during an ebb tide for three river flows, and for a range of dilution factors. The dilution contours illustrated in Figure 2.3-12 indicate a sharp lateral gradient in plume width at approximately 40 percent of the river width, the boundary between the shallower near-shore region and the deeper channel. At a transect 90-m downstream of Outfall 003 and for a 153-cms river flow scenario, plume widths increased from 22.4 percent to 43.7 percent of the river as the dilution factor increased from 5 to 50. The corresponding plume cross-sectional areas increased from 12.4 percent for a dilution of 5, to 20.6 percent for a dilution of 50.

With respect to the D.C.DOH criteria for plume width (33.3 percent) and cross-sectional area (10 percent), a chronic mixing zone at Outfall 003 is limited by it's cross-sectional area. At a river flow of 153-cms, 10 percent of the cross-sectional area is associated with a dilution factor of 4.3, while the 33.3 percent width criteria corresponds to a larger dilution factor of 8.1. At a 100-cms river flow, the dilution factor for a 10-percent cross-sectional criteria decreases to slightly less than 4.0, while at a higher 250-cms river flow, the chronic dilution factor increases to 4.7.

Outfall 003 Mixing Zone for TSS

The dilution factors provided in Table 2.3-6 were based on model runs using a conservative tracer. This approach underestimates the available dilution associated with a substance whose water column concentration is influenced by settling. This reduction in water column concentration could be of importance when making comparisons to surface water quality criteria for parameters such as total aluminum. The 153-cms model scenario executed in the previous section for a conservative tracer was also executed in SED2D for a 10,000 mg/L, 3.5 hour, clean-out event. The resulting TSS concentrations from combining the sand, floc, and silt particle classes were used to calculate plume widths, cross-sectional areas, and 1-hour average exposure concentrations. The resulting plume dimensions are summarized in the following table.

Dimensions for a TSS Plume, 153-cms River Flow

Dilution	Width (m)	Width (%)	Cross-Section (m^2)	Cross-Section (%)
20	9.6	5.5	37.4	3.2
25	22.5	12.8	85.9	7.3
30	29.7	16.9	112	9.5
35	34.5	19.6	130	11.0
40	38.5	21.9	142	12.1
50	44.2	25.1	162	13.7

For a 10-percent cross-sectional area criteria associated with a chronic mixing zone, the allowed dilution factor increased from 4.3 for a conservative tracer (Table 2.3-6) to 31.6 based on TSS and including settling. The acute dilution factor associated with a 1-hour average exposure time increased to 8.1 for the TSS plume.

Alternative Outfall 003 Location

The dilution available at Outfall 003 is limited by it's shoreline location, which impedes mixing with the Potomac River flow beyond the shallower shore zone. To illustrate an alternate Outfall 003 location, the Aqueduct model was executed with the discharge placed off shore. For this example, rather than modeling an actual discharge structure, an equivalent mass loading was added to a model element approximately 200-m in front of the existing shoreline Outfall. At this location, the MLW Potomac River depth was approximately 2 m. A 1.138-cms discharge flow coupled with a 10,000 mg/L TSS concentration results in a mass loading of 11.38 kg/sec. This mass loading was applied to the 200-m offshore model element for a 3.5 hour period during the 153-cms river flow, ebb tide scenario. The resulting plume for a conservative tracer at the end of the 3.5-hour discharge event was processed for plume dimensions and 1-hour average exposure concentrations. A dilution factor for a chronic mixing zone based upon a 10-percent cross-sectional area criteria was 18.6, and a dilution factor for an acute mixing zone based upon a 1-hour average exposure period was 8.4.

2.3.4 Effluent Fate and Transport Modeling Summary

Per an EPA-approved Study Plan (24 June 1999), a hydrodynamic model of the Potomac River was developed to simulate the discharge from Washington Aqueduct outfalls to determine acute and chronic dilution factors and to examine the fate of released solids as they travel downstream. The modeling used the Surfacewater Modeling System (SMS) which includes the U.S. Army

COE – supported models RMA2, RMA4, and SED2D. The model extended 8.0 km from Outfall 002, upstream of Chain Bridge, downstream to below Roosevelt Island and contained a total of 2,021 elements and 6,281 nodes. The field studies used for model calibration and model results for mixing zone and deposition issues are summarized below.

- A bathymetry survey was performed along a total of 46 transects to provide channel geometry for the model.

- Plume mapping studies were conducted at Outfall 002 (Dalecarlia Basin) and Outfall 003 (Georgetown Reservoir). At each outfall, a dye-tracer study was performed on the day the reservoir was being drawn down, and a turbidity study was performed the following day during a solids clean-out event.

- At Outfall 002, 22 percent of the total mass discharged passed beyond the downstream end of the model during a 24-hr run. The resulting depositional footprint estimated using the SED2D model was 1-mm thick in the vicinity of the Outfall 002 and decreased to approximately 0.02 mm downstream in the vicinity of Roosevelt Island.

- At Outfall 003, 13 percent of the total mass discharged passed beyond the downstream end of the model during a 24-hr run. SED2D indicated that the resulting depositional footprint typically exceeded 1 mm in the first 350 m, exceeded 0.2 mm for 2,500 m along the shallow near-shore region downstream, and decreased to approximately 0.05 mm in the vicinity of Roosevelt Island.

- A chronic mixing zone at Outfall 002 (at the permitted river flow of 153 cms) is limited by the 10 % cross-section criterion at a dilution factor of 51. Using the 1-hr float time approach, the acute dilution factor is calculated to be 169.

- At Outfall 003 (Georgetown Reservoir) the chronic mixing zone is limited by the 10% cross-section criterion at a dilution factor of 4.3. The 1-hr average exposure associated with acute criterion results in a dilution factor of 2.33.

- At Outfall 003, acute and chronic dilution factors increase when calculated using TSS rather than a conservative dye tracer. The resulting chromic mixing zone dilution factor was 31.6 and the acute dilution factor (1-hour average exposure) was 8.1.

- Relocation of Outfall 003 a distance 200-m offshore resulted in an acute (1-hour average exposure) dilution factor of 8.4 and a chronic (10% cross-section) dilution factor of 18.6 (conservative dye tracer).

2.4 REFERENCES

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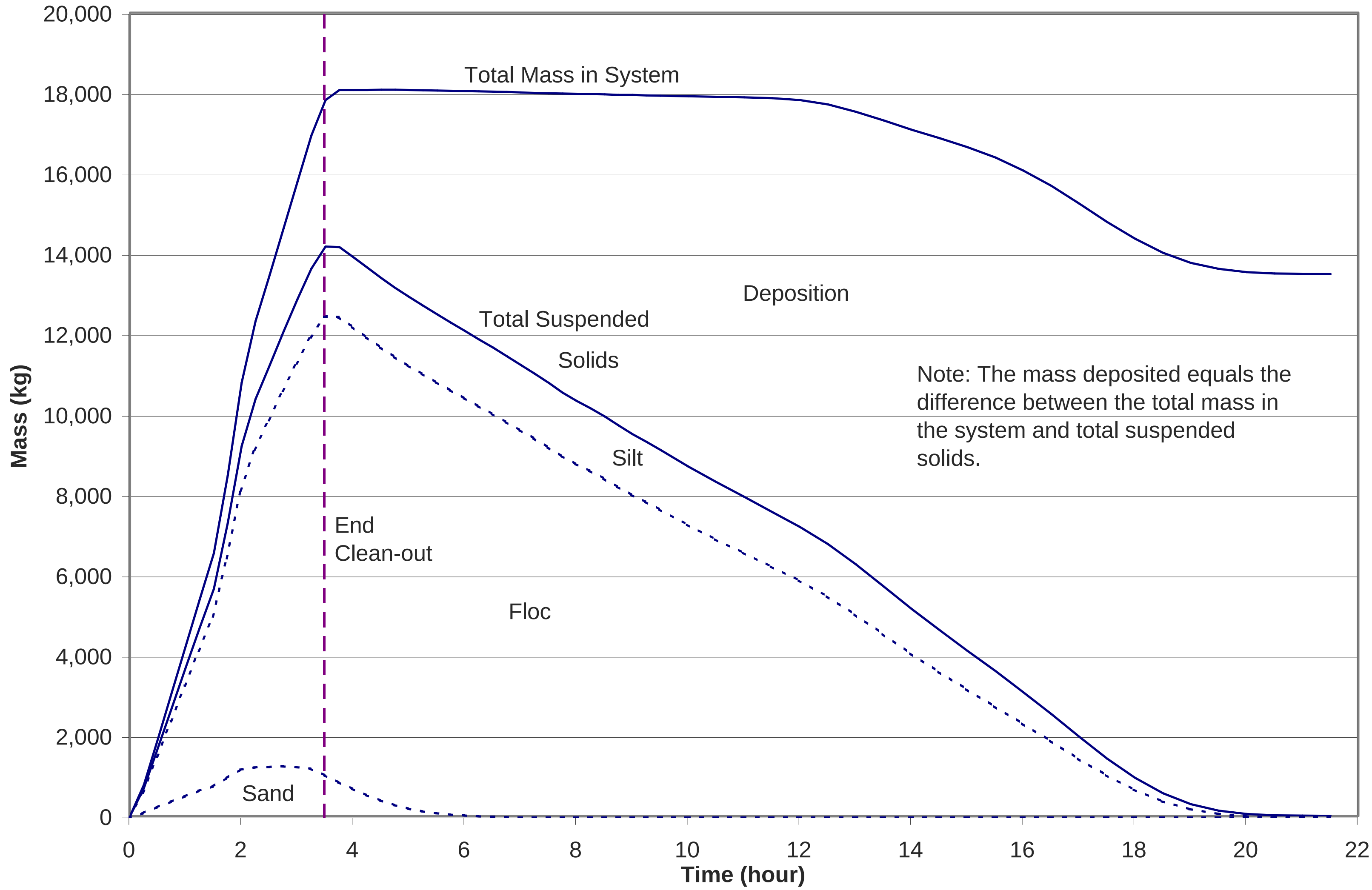
Teeter, Allen M., and E. Clark McNair, Jr. 1993. *Size Dependence in Fine-Grained Sediment Transport, Dredging Research Technical Notes*. DRP-1-11. U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.

Figure 2.3-1 The Incremental Mass Associated with Suspended Sand, Floc, and Silt, the Mass Deposited, and the Total Mass in the System, 25 May 2000, Outfall 002



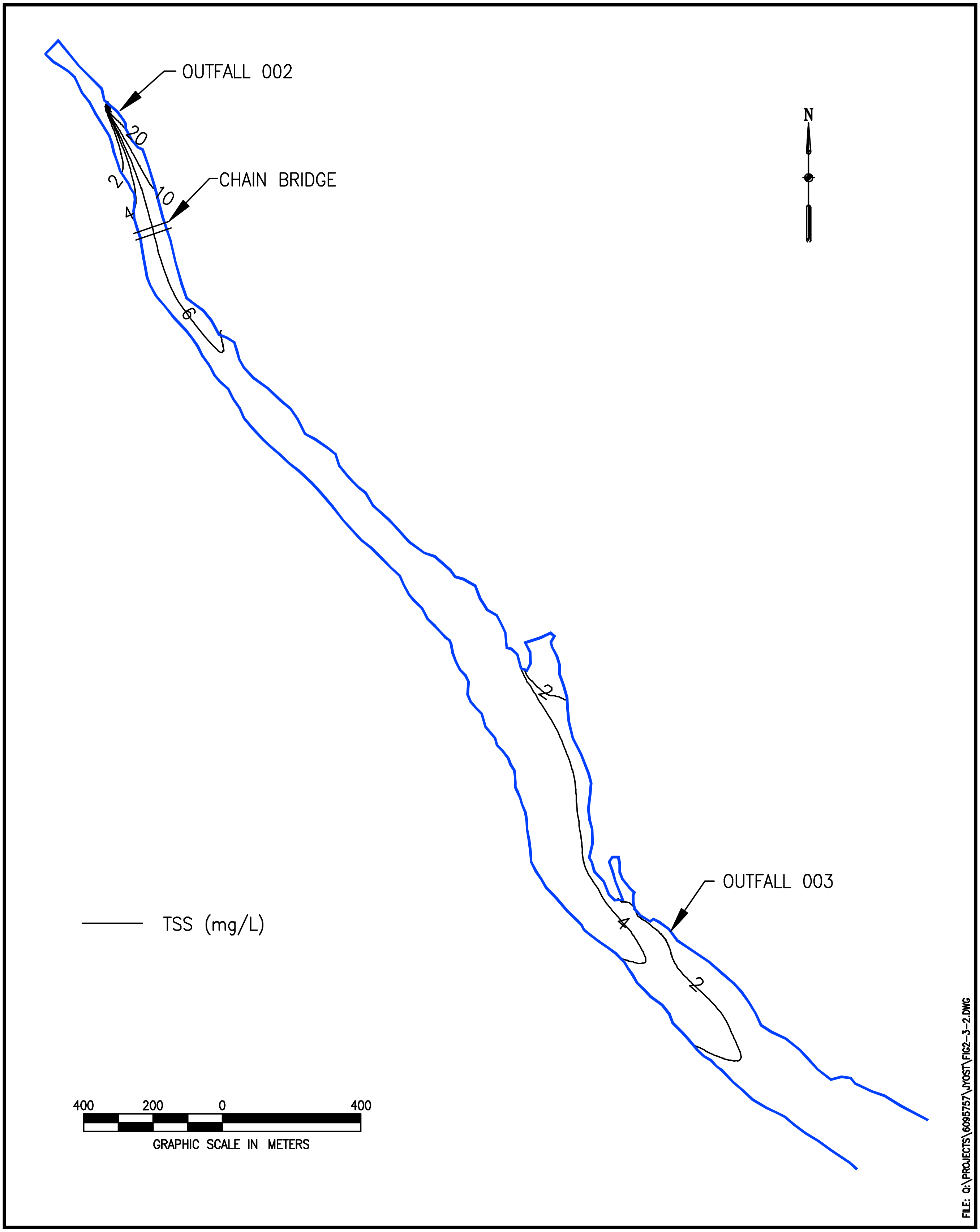


Figure 2.3-2. Predicted TSS Concentrations in the Potomac River at the End of the Solids Release From Outfall 002, 25 May 2000

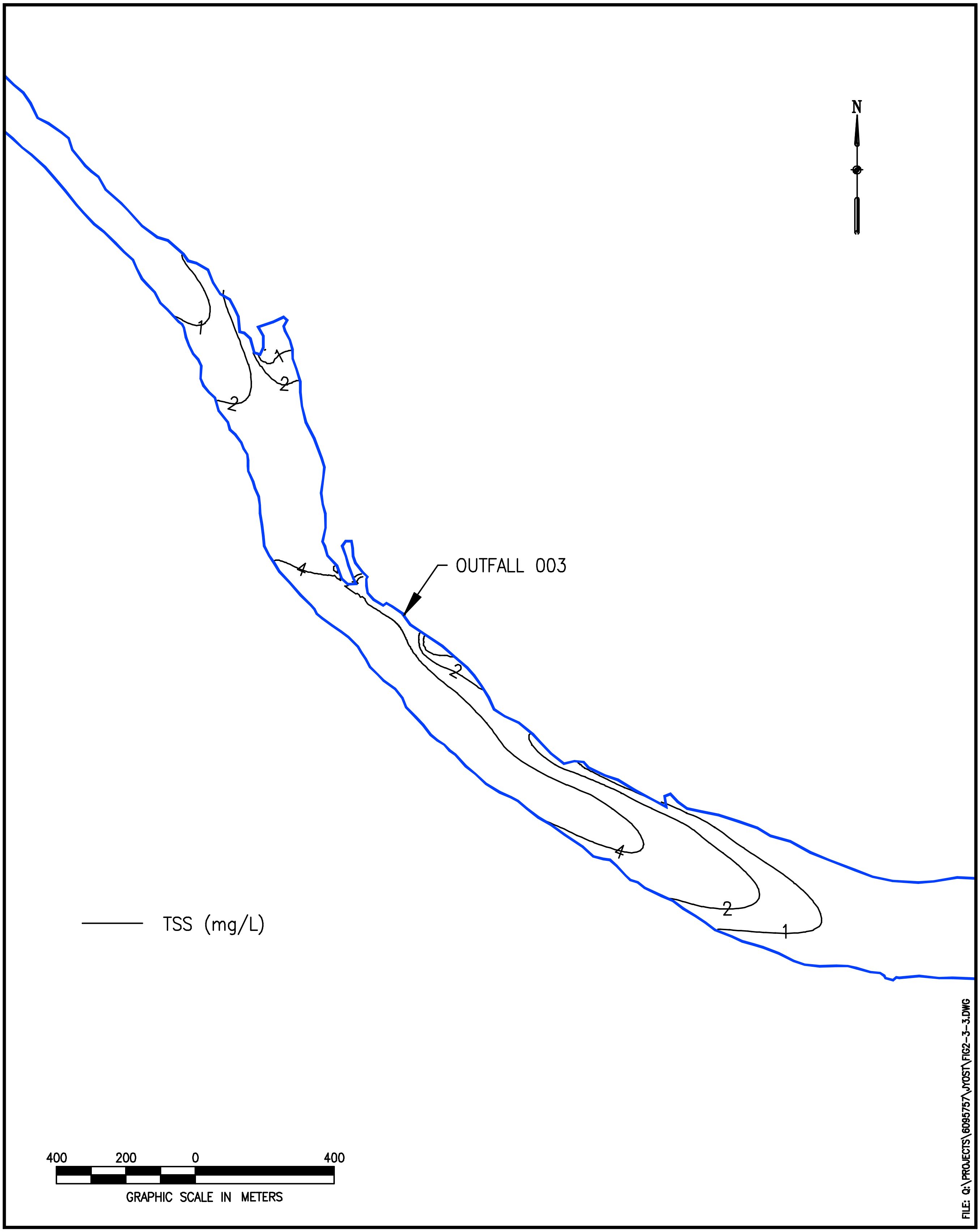


Figure 2.3-3. Predicted TSS Concentrations in the Potomac River 2 Hours After the End of the Solids Release From Outfall 002, 25 May 2000

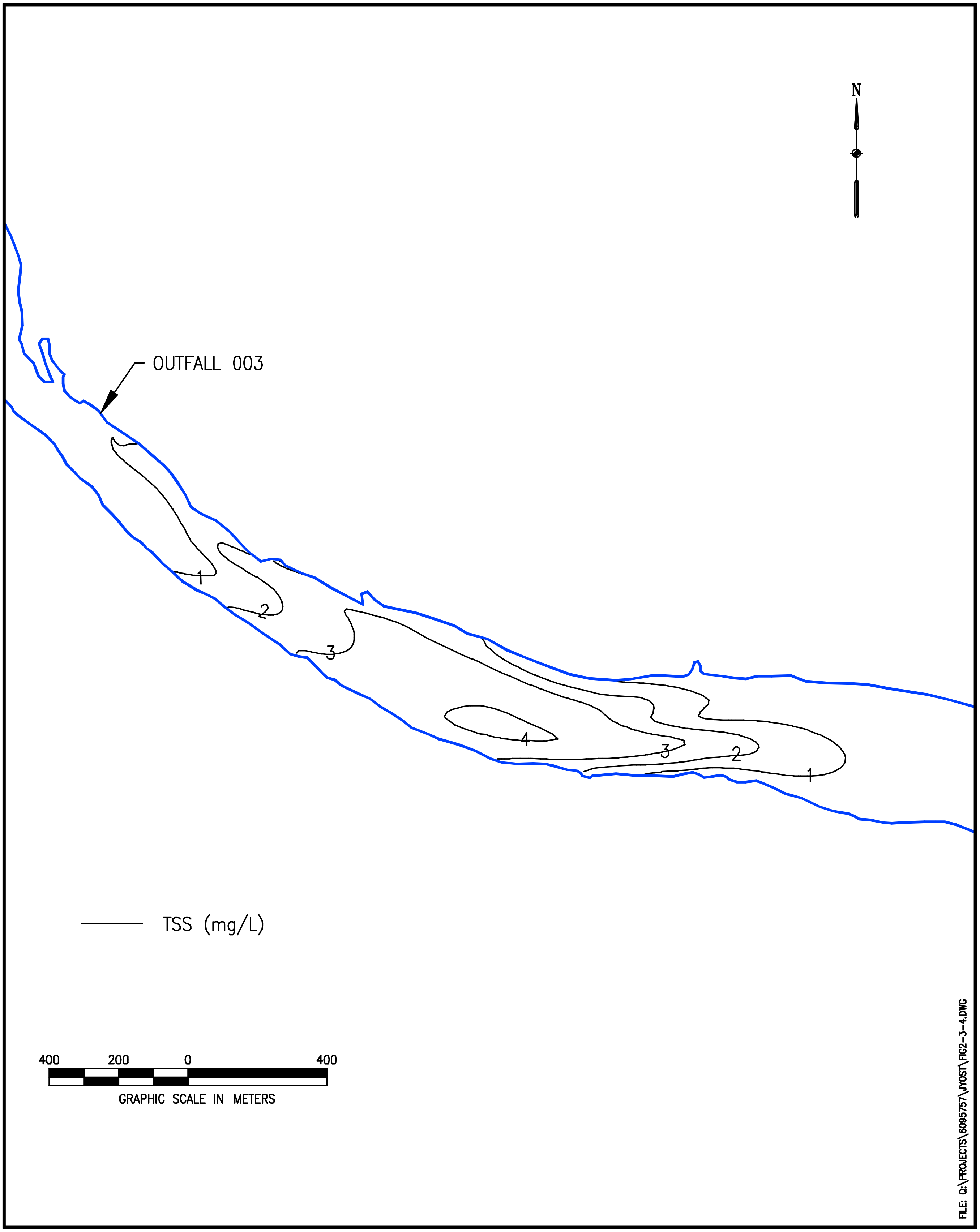


Figure 2.3-4. Predicted TSS Concentrations in the Potomac River
4 Hours After the End of the Solids Release From Outfall 002, 25 May 2000

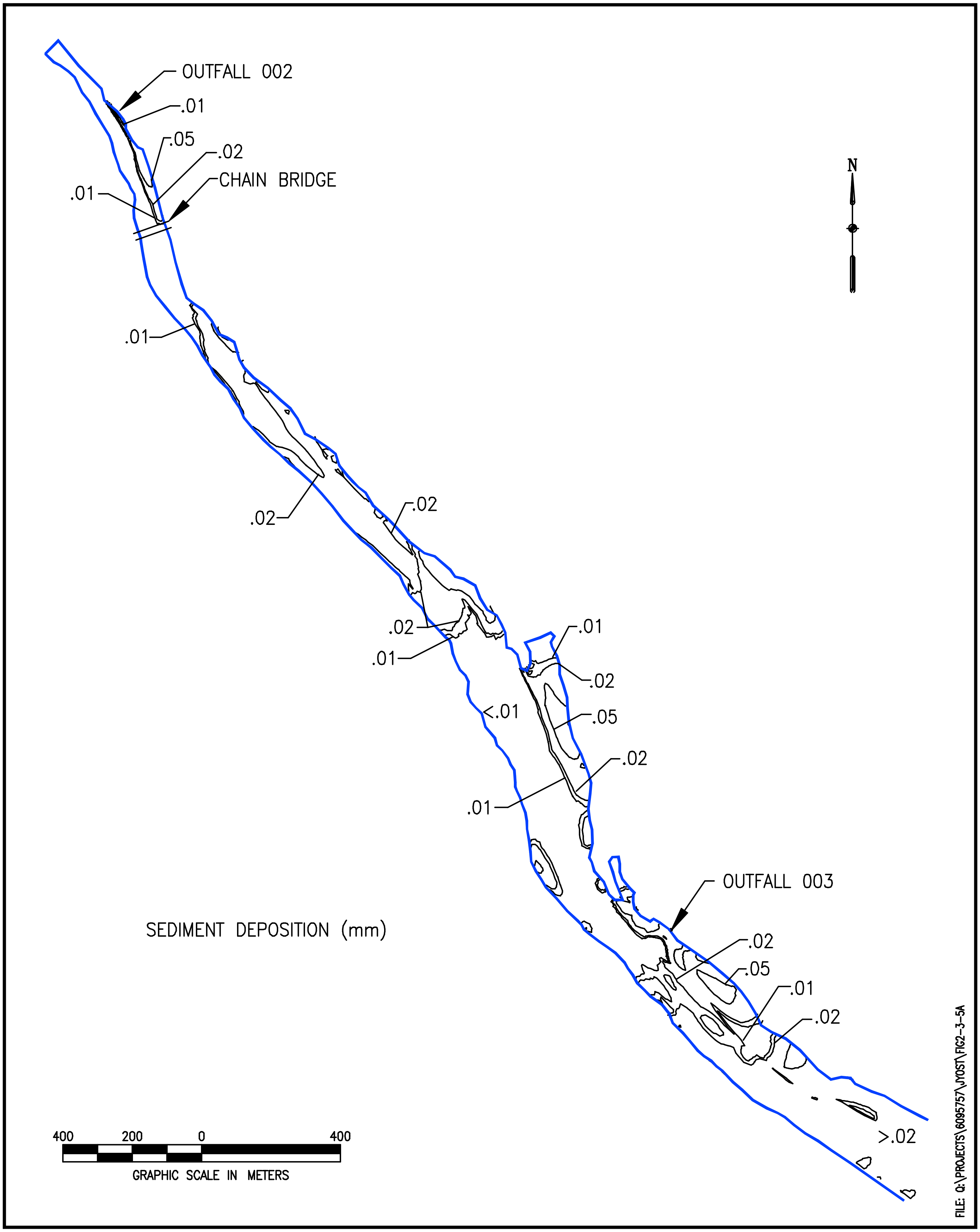


Figure 2.3-5A. Predicted Sediment Deposition Associated with a Clean-Out Event at Outfall 002, 25 May 2000, Upstream

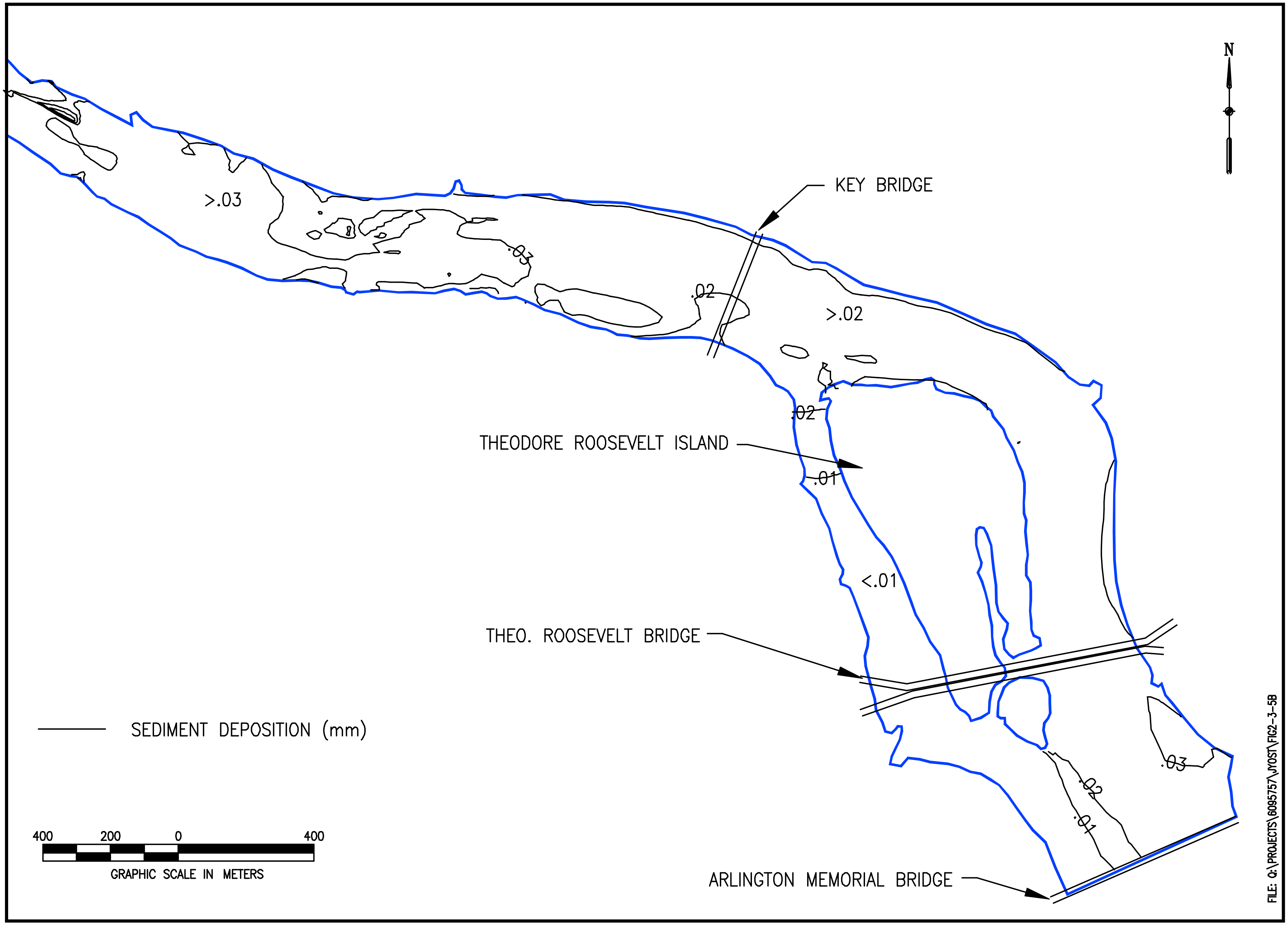
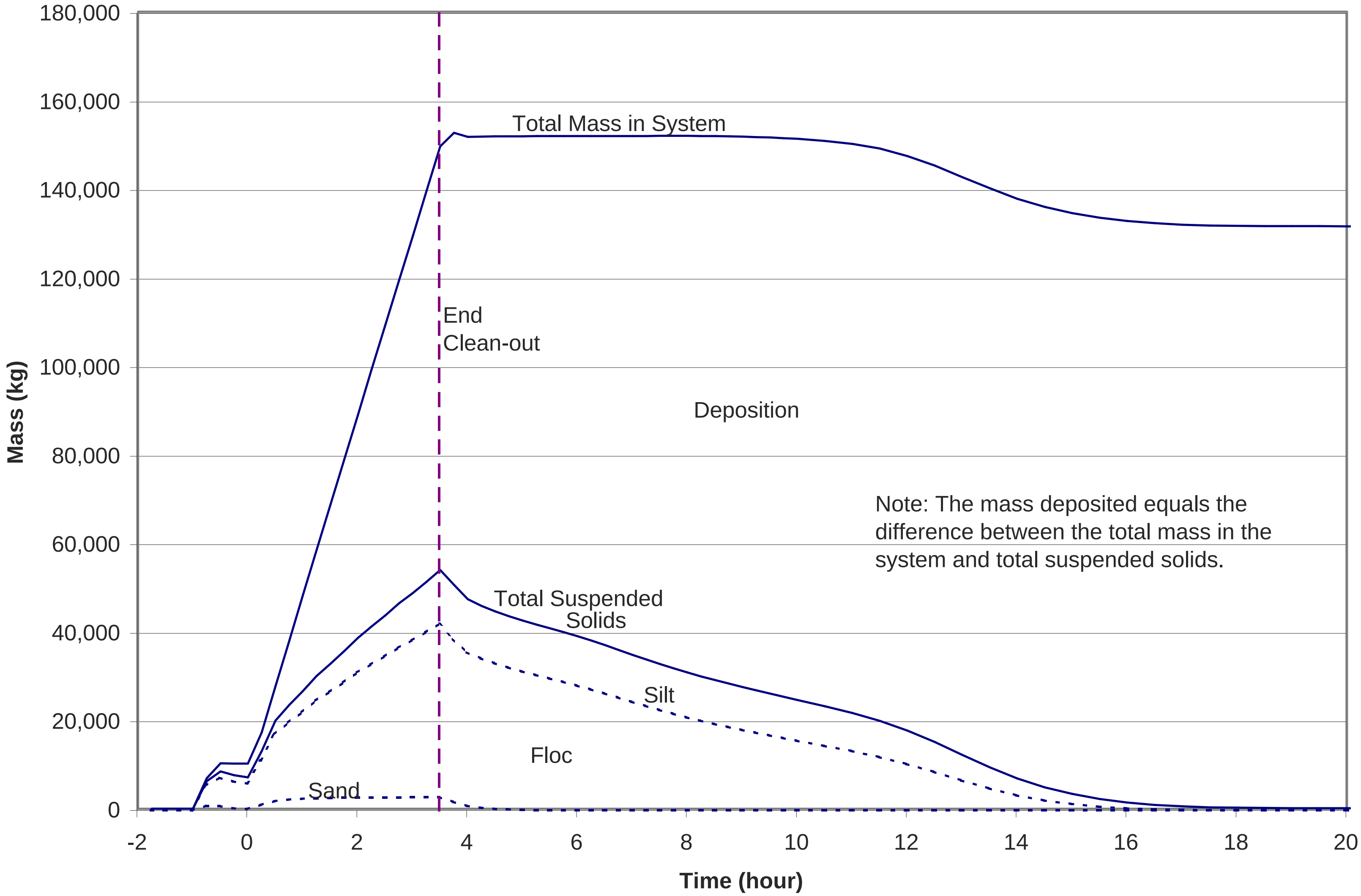


Figure 2.3-5B. Predicted Sediment Deposition Associated With a Clean-Out Event at Outfall 002, 25 May 2000, Downstream

Figure 2.3-6 The Incremental Mass Associated with Suspended Sand, Floc, and Silt, the Mass Deposited, and the Total Mass in the System, 3 May 2000, Outfall 003 Mass



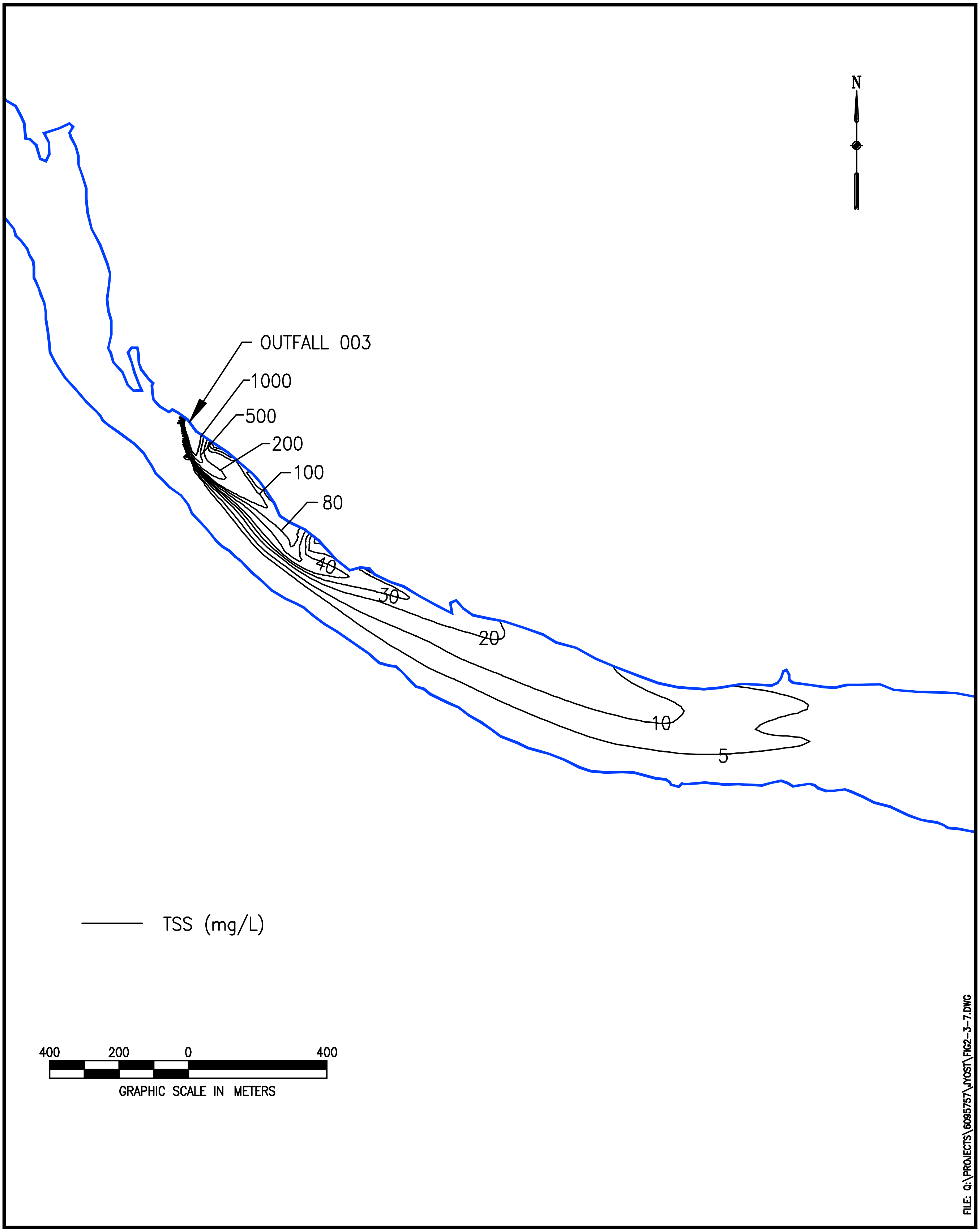


Figure 2.3-7. Predicted TSS Concentrations in the Potomac River at the End of the Solids Release From Outfall 003, 3 May 2000

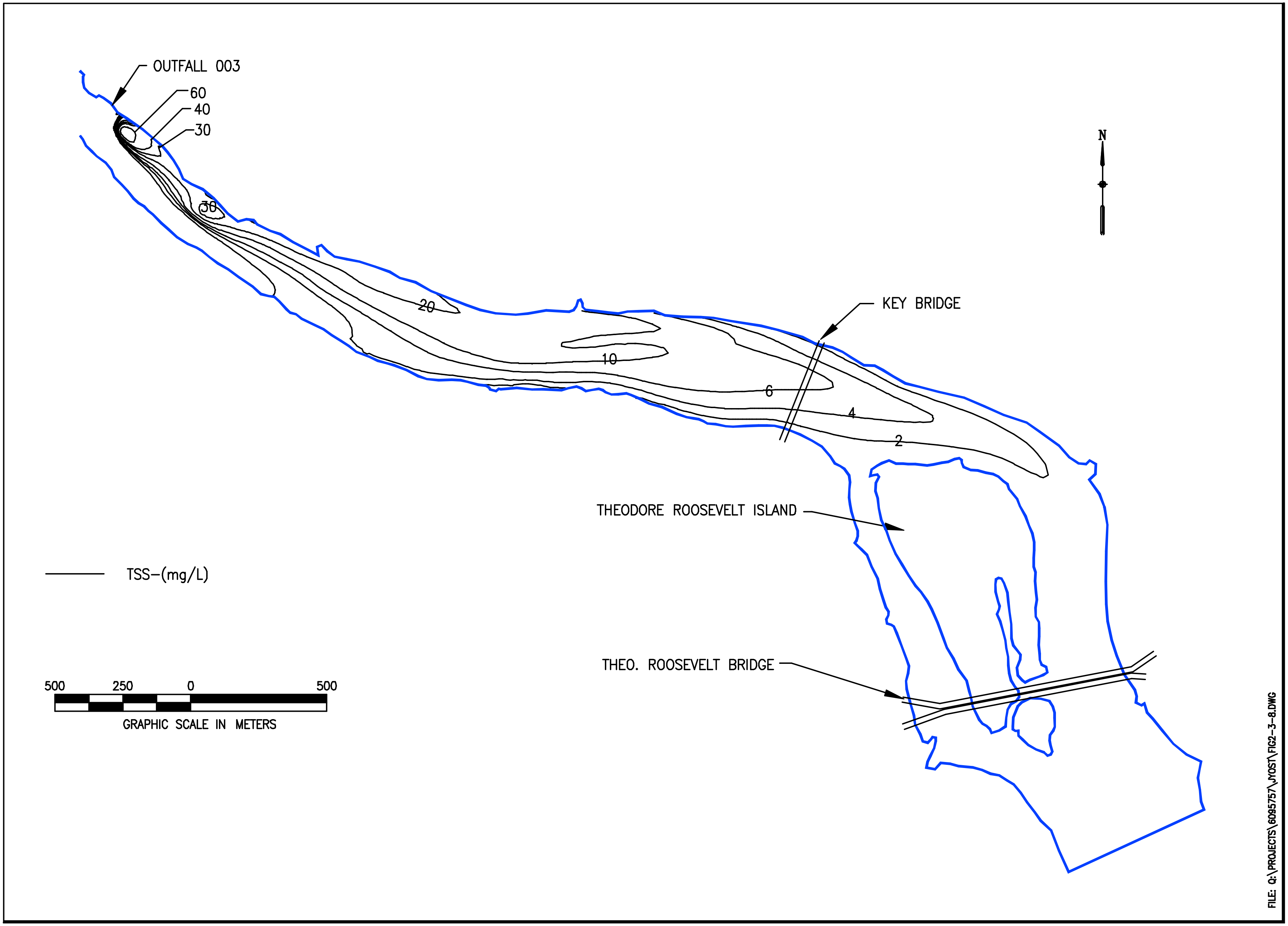


Figure 2.3–8. Predicted TSS Concentrations in the Potomac River 2 Hours
After the End of the Solids Release From Outfall 003, 3 May 2000

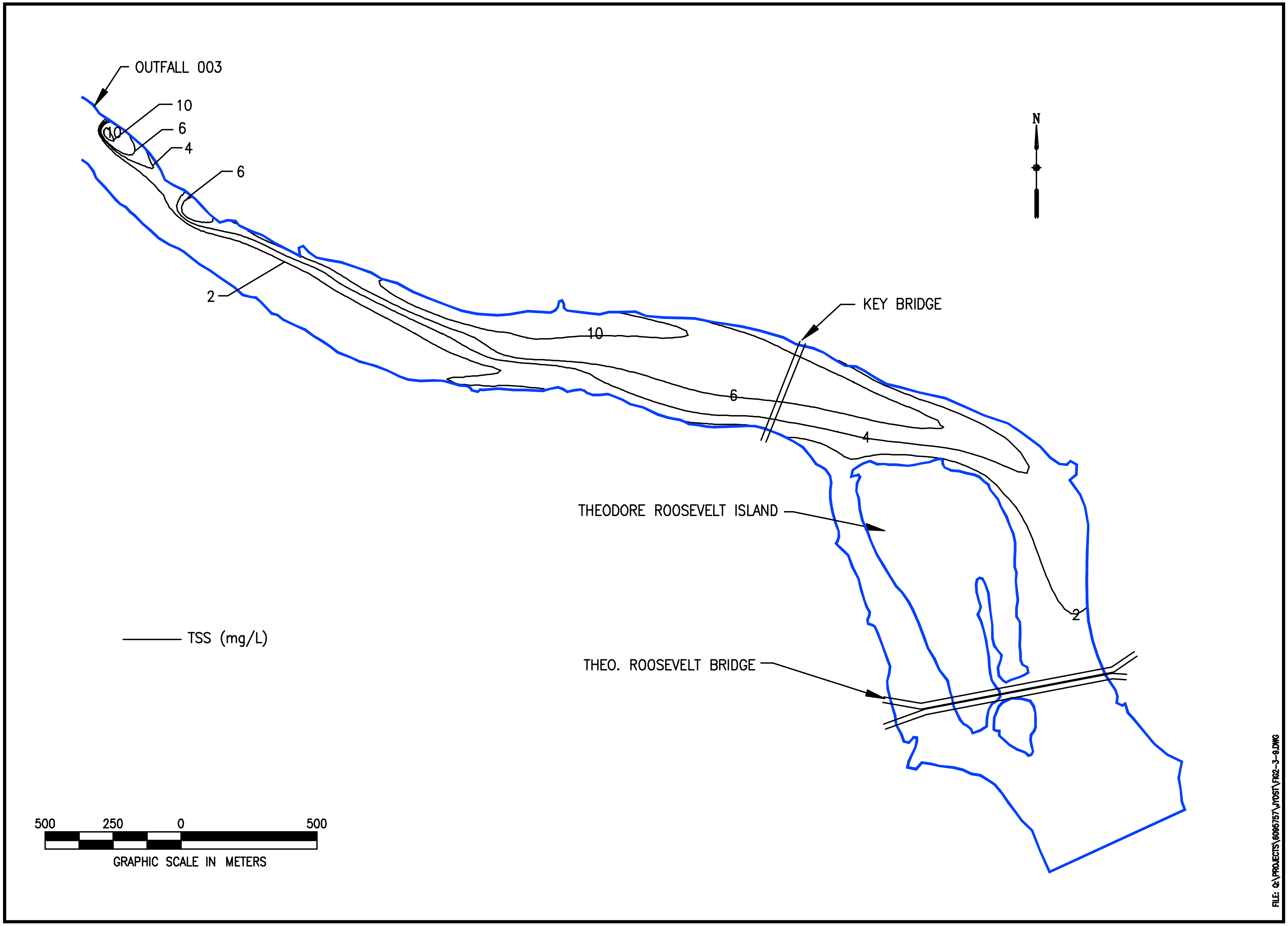


Figure 2.3–9. Predicted TSS Concentrations in the Potomac River 4 Hours After the End of the Solids Release From Outfall 003, 3 May 2000

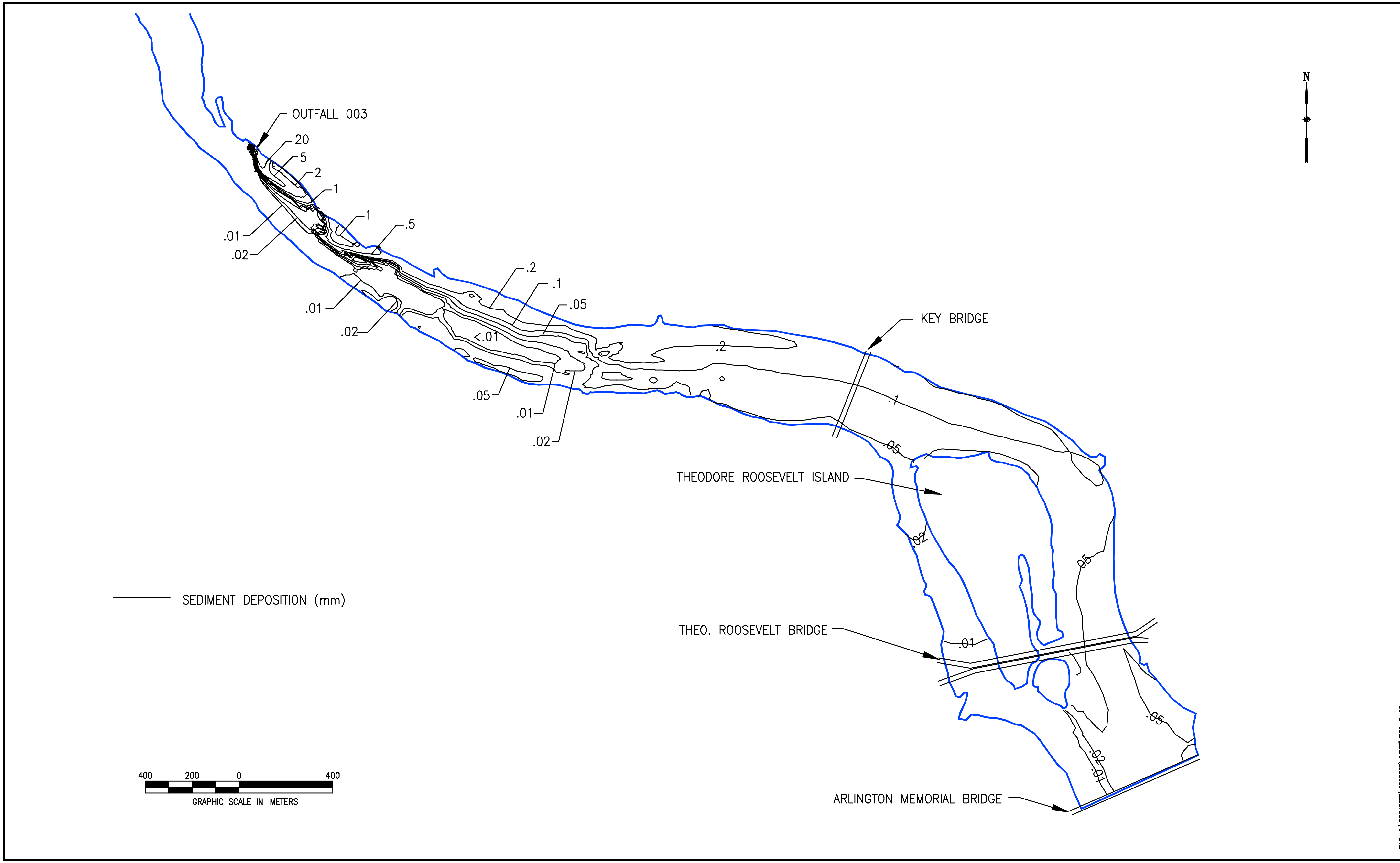


Figure 2.3-10. Predicted Sediment Deposition Associated With a Clean-Out Event at Outfall 003, 3 May 2000

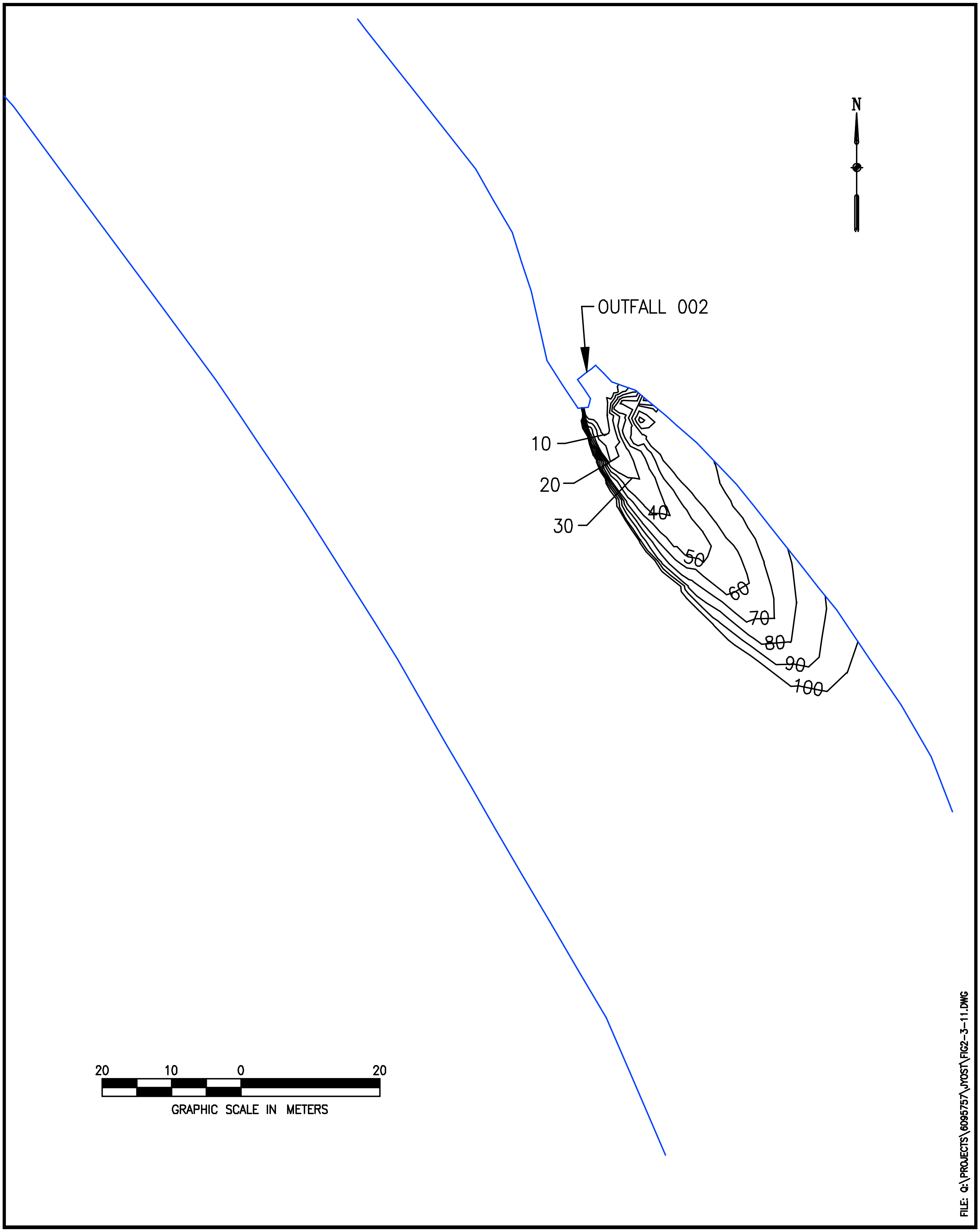


Figure 2.3-11. Predicted Dilution Contours at Outfall 002, 1.132-cms Discharge Flow, 153-cms River Flow

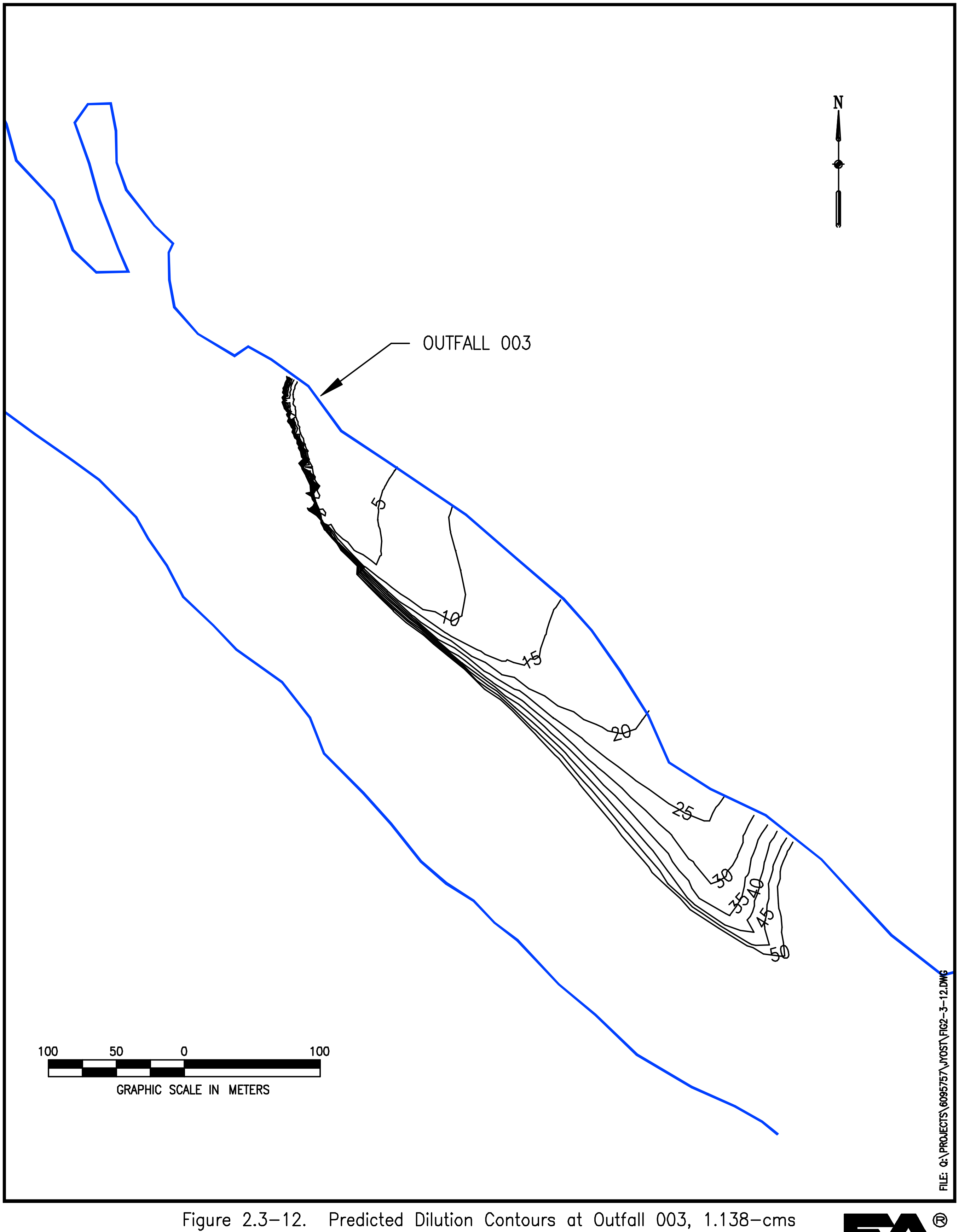


Figure 2.3-12. Predicted Dilution Contours at Outfall 003, 1.138-cms Discharge Flow, 153-cms River Flow

Table 2.3-1 Suspended and Deposited Solids Mass for the Sand, Floc, and Silt Particle Classes Present in the Aqueduct Model Domain, 25 May 2000, Outfall 002

	Mass (kg)								
	Sand		Floc		Silt		Total		
Hour	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Total
0.00	0	0	0	0	0	0	0	0	0
0.25	116	78	506	0	77	0	699	78	777
0.50	262	222	1,256	2	192	0	1,709	224	1,934
0.75	397	376	2,003	6	306	0	2,706	382	3,088
1.0	538	526	2,748	11	420	1	3,706	537	4,242
1.5	781	861	4,228	28	648	1	5,657	891	6,548
2.0	1,198	1,509	6,947	65	1,068	3	9,212	1,577	10,790
2.5	1,270	2,116	8,622	131	1,331	6	11,223	2,253	13,476
3.0	1,260	2,705	10,051	207	1,557	9	12,868	2,922	15,790
3.5	1,066	3,286	11,412	343	1,701	16	14,179	3,645	17,823
4.0	723	3,637	11,502	496	1,690	23	13,915	4,157	18,072
5.0	231	4,150	11,029	960	1,663	46	12,924	5,155	18,079
6.0	59	4,309	10,390	1,590	1,625	78	12,074	5,976	18,050
7.0	10	4,340	9,645	2,328	1,577	116	11,232	6,784	18,015
8.0	0	4,341	8,813	3,147	1,521	161	10,334	7,648	17,982
9.0	0	4,341	8,048	3,895	1,464	203	9,512	8,439	17,951
10.0	0	4,341	7,296	4,632	1,405	248	8,701	9,220	17,921
11.0	0	4,341	6,599	5,315	1,348	292	7,947	9,947	17,894
12.0	0	4,341	5,908	5,947	1,293	334	7,201	10,621	17,822
13.0	0	4,341	5,069	6,545	1,201	379	6,271	11,264	17,535
14.0	0	4,341	4,096	7,162	1,059	428	5,155	11,930	17,085
15.0	0	4,341	3,203	7,721	912	476	4,115	12,537	16,652
16.0	0	4,341	2,351	8,127	732	515	3,083	12,983	16,066
17.0	0	4,341	1,480	8,386	498	542	1,979	13,269	15,248
18.0	0	4,341	702	8,519	255	558	957	13,418	14,374
19.0	0	4,341	218	8,567	83	565	300	13,473	13,773
20.0	0	4,341	38	8,579	17	568	55	13,487	13,542
21.0	0	4,341	2	8,581	9	569	10	13,491	13,501
21.5	0	4,341	0	8,581	5	570	6	13,491	13,497

Note: Clean-out event from 0 to 3.5 hours.

Table 2.3-2 Suspended and Deposited Solids Mass for the Sand, Floc, and Silt Particle Classes Present in the Aqueduct Model Domain over Time, 3 May 2000, Outfall 003

Hour	Mass (kg)								
	Sand		Floc		Silt		Total		
	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Total
-1.00	0	0	0	0	0	0	0	0	0
-0.75	1,056	670	4,493	0	691	0	6,240	670	6,910
-0.50	1,002	1,555	6,385	306	1,017	11	8,403	1,872	10,275
-0.25	519	2,023	6,023	612	999	25	7,541	2,659	10,200
0.00	297	2,240	5,782	843	986	36	7,065	3,118	10,183
0.25	1,211	3,081	10,099	1,127	1,679	49	12,989	4,257	17,246
0.50	2,069	4,801	15,152	2,861	2,671	102	19,892	7,765	27,656
1.0	2,629	9,333	19,562	11,813	4,394	451	26,585	21,597	48,181
1.5	2,812	14,214	23,961	20,729	5,953	951	32,726	35,893	68,619
2.0	2,892	19,189	28,229	29,724	7,474	1,484	38,595	50,396	88,991
2.5	2,932	24,191	31,796	39,325	8,936	2,065	43,664	65,581	109,245
3.0	2,963	29,202	35,420	48,773	10,366	2,670	48,749	80,645	129,393
3.5	2,995	34,216	39,164	58,130	11,775	3,295	53,934	95,641	149,575
4.0	1,008	36,932	34,719	63,748	11,569	3,784	47,296	104,463	151,759
5.0	138	37,783	31,266	67,331	11,108	4,242	42,511	109,356	151,867
6.0	12	37,894	28,228	70,441	10,703	4,645	38,942	112,980	151,922
7.0	0	37,905	24,539	74,144	10,213	5,130	34,752	117,180	151,931
8.0	0	37,909	21,034	77,666	9,720	5,626	30,754	121,200	151,954
9.0	0	37,912	18,217	80,343	9,265	6,046	27,483	124,301	151,783
10.0	0	37,914	15,778	82,406	8,791	6,403	24,569	126,722	151,291
11.0	0	37,914	13,418	83,952	8,184	6,697	21,602	128,562	150,164
12.0	0	37,914	10,532	84,953	7,113	6,908	17,645	129,774	147,419
13.0	0	37,914	6,799	85,534	5,330	7,048	12,129	130,496	142,625
14.0	0	37,914	3,436	85,874	3,381	7,148	6,817	130,936	137,753
15.0	0	37,914	1,450	86,056	1,886	7,219	3,336	131,189	134,524
16.0	0	37,914	482	86,138	920	7,266	1,401	131,318	132,719
17.0	0	37,914	101	86,170	430	7,298	531	131,382	131,913
18.0	0	37,914	4	86,177	212	7,319	216	131,410	131,626
19.0	0	37,914	0	86,178	141	7,336	141	131,427	131,568
20.0	0	37,914	0	86,178	101	7,348	101	131,439	131,540
21.0	0	37,914	0	86,178	61	7,358	61	131,449	131,510
22.0	0	37,914	0	86,178	30	7,362	30	131,454	131,484

Note: Clean-out event from 0 to 3.5 hours with a prerelease.

Table 2.3-3 Downstream Distance to Dilution Contours and 1-Hour Average Dilution at Outfall 002 for a Range of Potomac River Flows, Dalecarlia Basin

Downstream Distance (m) to Dilution Contour for Range of River Flows

Dilution	Ebb Tide			Flood Tide		
	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
10	7.4	6.4	3.3	6.3	5.9	4.2
20	11.8	9.9	6.1	11.4	8.1	6.4
30	21.7	13.8	7.7	18.9	9.2	7.9
40	29.3	20.6	9.2	27.3	16.7	10.3
50	36.1	29.1	10.7	32.6	23.0	11.6
60	44.8	35.4	11.8	42.2	29.8	13.2
70	56.2	41.3	13.4	50.5	36.0	16.0
80	63.2	45.7	16.0	58.6	41.4	19.1
90	71.8	50.1	18.4	66.1	45.2	21.9
100	80.5	54.2	21.2	74.0	49.6	24.6

Dilution During 1-Hour Average Exposure

	Ebb Tide			Flood Tide		
	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
1-Hour	109	169	282	95	156	270
Full Mix	758	1160	1895	759	1160	1895

Note: Outfall 002 flow = 0.132 cms (3 mgd)

Table 2.3-4 Plume Width and Cross-Sectional Area at Transect 3-m Downstream of Outfall 002, Dalecarlia Basin

Dilution	Width		X-S Area	
	(m)	(%)	(m^2)	(%)
River Flow = 100 cms (Ebb Tide)				
10	3.7	7.4	7.5	4.0
15	5.1	10.1	10.0	5.4
20	5.8	11.5	11.4	6.1
25	8.6	17.0	15.9	8.5
30	8.6	17.1	16.1	8.6
35(a)	9.0	17.5	21.4	10.9
40(a)	10.5	20.5	24.4	12.5
45(a)	10.6	20.8	25.0	12.8
50(a)	10.8	21.1	25.4	13.0
River Flow = 153 cms (Ebb Tide)				
10	2.4	4.8	5.1	2.7
15	3.5	6.9	7.3	3.9
20	4.0	8.0	8.4	4.5
25	4.3	8.6	9.0	4.8
30	8.7	17.3	16.3	8.7
35	8.8	17.4	16.4	8.8
40	8.9	17.6	16.6	8.9
45	9.0	17.9	17.1	9.2
50	9.2	18.2	17.5	9.4
60(a)	11.1	21.8	26.8	13.6
River Flow = 250 cms (Ebb Tide)				
10	0.0	0.0	0.0	0.0
15	2.1	4.2	4.3	2.3
20	3.0	5.9	6.0	3.2
25	3.5	6.9	7.1	3.8
30	3.8	7.5	7.8	4.2
35	8.4	16.7	15.6	8.4
40	8.5	16.9	15.9	8.5
45	8.6	17.0	16.1	8.6
50	8.6	17.2	16.2	8.7
60	8.7	17.4	16.5	8.8
80	9.0	17.9	17.1	9.1

Note: Outfall 002 flow = 0.132 cms (3 mgd)
a) 7-m downstream transect.

Table 2.3-5 Downstream Distance to Dilution Contours and 1-Hour Average Dilution at Outfall 003 for a Range of Potomac River Flows, Georgetown Reservoir

Downstream Distance (m) to Dilution Contour for Range of River Flows

Dilution	Ebb Tide			Flood Tide		
	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
5	136	138	129	123	133	132
10	196	195	176	184	189	179
15	240	240	219	233	236	217
20	293	302	263	274	284	257
25	355	377	341	313	336	310
30	409	439	434	348	385	401
35	444	468	468	376	428	459
40	467	488	493	401	455	483
45	480	504	514	422	473	503
50	492	517	531	437	490	522

Dilution During 1-Hour Average Exposure

	Ebb Tide			Flood Tide		
	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
1-Hour	2.16	2.33	2.65	2.32	2.31	2.30
Full Mix	89	136	221	89	135	221

Note: Outfall 003 flow = 1.138 cms (26 mgd)

Table 2.3-6 Plume Width and Cross-Sectional Area at a Transect 90-m Downstream of Outfall 003, Georgetown Reservoir

Dilution	Width (m)	Width (%)	X-S Area (m^2)	X-S Area (%)
River Flow = 100 cms (Ebb Tide)				
4	34.4	19.6	120	11.1
5	52.6	29.9	157	14.5
10	70.8	40.3	187	17.3
15	73.5	41.8	203	18.7
20	75.1	42.7	212	19.6
25	76.1	43.2	218	20.1
30	76.7	43.6	221	20.4
35	77.2	43.9	224	20.7
40	77.5	44.0	226	20.9
45	77.8	44.2	227	21.0
50	78.0	44.3	229	21.1
River Flow = 153 cms (Ebb Tide)				
4	26.6	15.1	98	9.1
5	39.5	22.4	134	12.4
10	70.2	39.9	184	17.0
15	71.6	40.7	192	17.7
20	73.5	41.8	203	18.7
25	74.7	42.4	209	19.4
30	75.4	42.9	214	19.8
35	76.0	43.2	217	20.1
40	76.4	43.4	219	20.3
45	76.7	43.6	221	20.4
50	76.9	43.7	223	20.6
River Flow = 250 cms (Ebb Tide)				
4	23.5	13.4	85	7.8
5	34.9	19.9	118	10.9
10	67.5	38.4	170	15.7
15	69.1	39.3	178	16.5
20	69.9	39.7	183	16.9
25	70.4	40.0	185	17.1
30	70.7	40.2	187	17.3
35	71.0	40.3	188	17.4
40	71.1	40.4	189	17.5
45	71.8	40.8	193	17.8
50	72.5	41.2	197	18.2

Note: Outfall 003 flow = 1.138 cms (26 mgd)

3. EFFLUENT TOXICITY TESTING

3.1 INTRODUCTION

EA Engineering, Science, and Technology performed acute and chronic toxicity testing on residual solids discharged from the Dalecarlia and Georgetown facilities during normal cleaning operations. The toxicity testing program was conducted according to the "Study Plan for Washington Aqueduct Water Quality Studies" (dated 24 June 1999, and approved by U.S. EPA Region 3), which addresses laboratory testing to quantify of the toxicity of the effluents.

Effluent samples were collected from the Dalecarlia Basin #2 in September 1999, December 2000, April 2001, and May 2001, and from the Dalecarlia Basin #3 in May 2000. Effluent samples were collected from Georgetown Basin #2 in December 1999 and May 2000. Samples of upstream Potomac River water, and water from Dalecarlia Basin #2, were collected for use as dilution water. Sediment from the Potomac and Magothy Rivers were collected for use as control sediment.

As described in the Study Plan, toxicity tests were conducted on three fractions of the Aqueduct effluent:

- Whole effluent samples (acute toxicity tests)
- Supernatant from the settled whole effluent (chronic toxicity tests)
- Settled solids portion of the whole effluent (benthic tests)

Acute toxicity tests were performed with *Daphnia magna* (water flea), *Pimephales promelas* (fathead minnow), and *Morone saxatilis* (striped bass) as the test species. The objective of the acute toxicity testing was to determine whether the whole effluent samples were acutely toxic to the test species, based on survival, when compared to the river water control.

Chronic toxicity tests were performed on the suspended particulate phase (supernatant) using *Ceriodaphnia dubia* (water flea), *Pimephales promelas* (fathead minnow), and *Selenastrum capricornutum* (a freshwater algae) as the test species. The objective of the chronic toxicity testing was to determine whether the suspended particulate phase of the effluent was chronically toxic to the test species based on survival, reproduction (*C. dubia*), growth expressed as biomass (*P. promelas*), and cell growth expressed as cell density (*S. capricornutum*), when compared to the river water control.

Benthic toxicity tests were conducted with *Hyalella azteca* (freshwater amphipod) on the settled solids portion of the whole effluent layered over a control sediment. The objective of the benthic toxicity tests was to determine whether the settled effluent samples were toxic to *H. azteca* based on survival and growth (expressed as biomass) when compared to the control sediment.

The test organisms were exposed to a concentration series of 100, 50, 25, 12.5 and 6.25 percent of whole effluent, suspended particulate phase, or settled solids diluted with upstream Potomac River water.

Four rounds of toxicity testing were performed on the Washington Aqueduct samples. The first round of testing (Round #1), which also included preliminary acute toxicity testing, was conducted in September and December 1999. These results were presented in EA Report #3202. The results from Round #2 (May 2000), Round #3 (June 2000), and Round #4 (December 2000 - January 2001) were presented in EA Report #3626. The information included in these two reports has previously been discussed with U.S. EPA and U.S. Fish and Wildlife Service staff.. This report summarizes the data generated during the four rounds of testing and discusses the results from these toxicity tests.

3.2. METHODS AND MATERIALS

3.2.1 Sample Receipt

Discharge samples from the Dalecarlia and Georgetown basins, and samples of upstream Potomac River water, were collected by EA personnel, and hand-carried the same day to EA's Ecotoxicology Laboratory in Sparks, Maryland. At the time of the collection, bottles were also filled for chemical analyses. As specified in the Study Plan, the discharge samples were collected to be representative of the "worst-case" solids discharge concentrations that would exist during a discharge event (i.e., samples were collected at Dalecarlia when hose cleaning operations were pushing out the largest masses of solids, and at Georgetown when the front end loaders were actively pushing solids into the conduit from the deeper areas of the reservoir). Upon receipt at EA, the samples were visually inspected and compared against the chain-of-custody record. The samples were logged into the Ecotoxicology Laboratory Sample Log, and assigned a unique accession number. When not actively being processed, the samples were stored in a secured walk-in cooler in the dark at 4°C. A summary of sample collection and receipt information, along with sample descriptions, is presented in Table 3-1.

3.2.2 Test Organisms

The *Daphnia magna* (water flea) were obtained from EA's Culture Facility in Sparks, MD, and were cultured in moderately hard synthetic freshwater. The organism cultures were maintained in 8-inch culture bowls at 20°C with a 16-hour light/8-hour dark photoperiod, and fed according to EPA guidance (US EPA 1993). Gravid adults were isolated the evening before the test to ensure that neonates (young) produced were less than 24 hours old at test initiation.

Pimephales promelas (fathead minnows) were obtained from embryos spawned in EA's culture facility. Brood organisms were maintained in recirculating dechlorinated tap water at 23°C in 20-gallon aquaria. Eggs produced from the brood system were removed from the brood aquaria and placed into culture water at 25°C for the incubation period. Newly hatched larvae, less than 24 hours old, were used in the chronic toxicity testing. For use in the acute toxicity testing, the *P. promelas* larvae were gradually acclimated to 20°C and fed brine shrimp nauplii (*Artemia* sp., <24 hours old) a minimum of once daily. The larvae were 1-14 days old (hatched within a single 24-hour period) when used to initiate the acute toxicity tests.

Ceriodaphnia dubia (water fleas) were cultured at EA's culture facility in moderately hard synthetic fresh water, and maintained in an environmentally controlled room at 25°C with a 16-hour light/8-hour dark photoperiod. Organisms were fed daily a suspension of yeast/cereal leaves/trout chow supplemented with the algae *S. capricornutum* as described in US EPA (1994). Adults were maintained in individual 30-ml plastic cups (one brood female per culture cup) with a 15-ml volume. Gravid adults were re-isolated the evening before the initiation of the chronic toxicity testing to ensure that neonates produced were less than 24 hours old for test initiation. For use in the chronic toxicity testing, the less than 24-hour old neonates were released from broods of eight or more within an 8-hour period from the time of re-isolation.

Morone saxatilis (striped bass) were acquired from Horn Point Lab in Cambridge, Maryland, and from the Virginia State Fish Hatchery in Brookneal, Virginia.

Selenastrum capricornutum (freshwater algae) were cultured at EA's culture facility, following procedures detailed in US EPA (1994).

The *Hyalella azteca* (freshwater amphipod) were also obtained from EA's culture facility. The amphipods were cultured at 20°C in 10-gallon glass aquaria with a substrate of hardwood leaves and overlying water of dechlorinated municipal tap water. Prior to introduction into the aquaria, the leaves were pre-soaked or boiled to remove tannins. The cultures were fed Tetramin-B flake food weekly in addition to the hardwood leaves. For use in testing, 7-14 day old organisms were collected from the cultures and gradually acclimated to the test temperature (23°C).

3.2.3 Laboratory Control Waters and Control Sediments

The acute and chronic toxicity tests conducted on the whole effluent and suspended particulate phase included a laboratory water control, in addition to the Potomac River dilution water control.   The laboratory water used in the *D. magna* and *C. dubia* tests was moderately hard synthetic freshwater (hardness of 80-100 mg/L $CaCO_3$). Batches of this water were prepared per US EPA (1993) by passing deionized water through activated carbon, adding reagent grade chemicals and aerating overnight. The water was prepared at least 24 hours prior to use in testing, and kept under gentle aeration until needed. This water was also used to culture the *D. magna* and *C. dubia*.

Dechlorinated tap water was used as the laboratory control water for the *P. promelas* acute and chronic tests. Dechlorinated tap water, and moderately hard synthetic freshwater were also used as dilution water for several *M. saxatilis* acute tests. The source of the tap water was the City of Baltimore municipal water system. Upon entering the laboratory, the water passed through a high-capacity, activated-carbon filtration system to remove any possible contaminants such as chlorine and possible trace organic compounds. This water source has proven safe for aquatic organism toxicity testing at EA as evidenced by maintenance of the multigeneration *H. azteca*, and fathead minnow cultures with no evident loss of fecundity.

Natural Potomac River surficial sediment was used as the control sediment in all *H. azteca* toxicity testing, with the exception of the test performed on the effluent sample collected on 25 May 2000. These Potomac River “control sediments” were collected upstream of the Aqueduct discharges in the vicinity of Lock 5 near the C&O Canal Trail. Due to the inability to collect Potomac River sediment, caused by very high river flow, the benthic tests performed on the 25 May 2000 effluent sample utilized a control sediment collected from the Magothy River, Maryland. Sediment collected from the Magothy River has historically been non-toxic and is routinely utilized as a control sediment in EA’s toxicity tests. The overlying water in the *H. azteca* toxicity tests was dechlorinated tap water.

3.2.4 Toxicity Test Operations and Performance

The toxicity tests were performed following EA’s protocols (EA 1996) which are in accordance with US EPA guidance (1993, 1994, 2000). The test organisms were exposed for a designated period of time to a concentration series of 100, 50, 25, 12.5 and 6.25 percent test material and a dilution water control. The *D. magna*, *C. dubia*, and *P. promelas* acute and chronic toxicity tests also included a laboratory water control. Prior to preparation of test solutions, aliquots of effluent, dilution water, and laboratory control water or control sediment were brought to the desired test temperature. Test concentrations were prepared by measuring small volumes of sample in pipets, transferring to a graduated cylinder, and bringing to volume with dilution water.

3.2.4.1 Acute Toxicity Testing

Static acute toxicity tests were conducted on the whole effluent samples. The *D. magna*, *M. saxatilis*, and *P. promelas* acute toxicity tests were conducted in 250-ml glass beakers containing 200 ml of test solution. Each test concentration and control had two test replicates with ten organisms per replicate. At test initiation, ten organisms were randomly added to each replicate test chamber.

The acute toxicity tests were maintained at a target temperature of 20±1°C with a 16-hour light/8-hour dark photoperiod. Test duration was 48 hours for the *D. magna,* and 96 hours for the *P. promelas* and *M. saxatilis* acute toxicity tests. During the exposure period, the test solutions were gently aerated at a rate of approximately 100 bubbles per minute to achieve continuous mixing of the effluent. The organisms were not fed during the test. The test organisms were observed daily and the number of live organisms per replicate was recorded on data sheets. In addition, temperature, pH, dissolved oxygen, and conductivity were measured daily in each test concentration and control. At the end of the exposure period, the 48- or 96-hour median lethal concentration (LC50) was calculated if there was at least 50 percent mortality in the 100 percent test concentration. The Acute Toxic Units (TU_a) were calculated for each acute toxicity test based on the LC50 value [TU_a=100/LC50].

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3.2.4.2. Chronic Toxicity Testing

Chronic toxicity tests were conducted on the suspended particulate phase, which was prepared by stirring the whole effluent sample for thirty minutes and then allowing the sample to settle for sixty minutes. The supernatant was drawn off and used to prepare the test concentrations.

3.2.4.2.1. *Ceriodaphnia dubia* Chronic Toxicity Testing

The *C. dubia* chronic toxicity tests were conducted in 30-ml plastic cups with 15 ml of test solution per cup. Each test concentration and control had ten replicate cups with one organism per cup. To initiate the chronic toxicity test, one brood of eight of more *C. dubia* neonates was used per test row according to US EPA (1994) known parentage blocking technique. The organisms were fed daily during testing with 0.2 ml suspension of yeast/cereal leaves/trout chow supplemented with algae (*S. capricornutum*). The tests were maintained at 25±1°C with a 16-hour light/8-hour dark photoperiod.

The test solution was renewed (replaced) daily by carefully transferring the test organism from each test cup into a new cup containing freshly prepared test solution. During the daily transfer, observations of mortality were recorded along with neonate counts per replicate. Temperature, pH, dissolved oxygen, and conductivity measurements were recorded on each concentration at test initiation and termination, and daily on the test solutions before and after renewal. The *C. dubia* chronic toxicity tests were terminated when at least 60 percent of the surviving dilution water control organisms had produced three broods, with a mean of at least 15 neonates per control organism.

3.2.4.2.2. *Pimephales promelas* Chronic Toxicity Testing

The *P. promelas* chronic toxicity tests were conducted in 1-L polypropylene beakers, with each beaker containing 250 ml test solution. Each test concentration had four replicates of ten organisms, for a total of 40 organisms exposed per test concentration and control. The test solution in each beaker was renewed daily. The daily solution renewals were performed by siphoning 80 percent of the old test solution from each test chamber taking care to remove debris and uneaten food from the bottom of the chamber, and then slowly siphoning new test solution into the chamber. The tests were performed at 25±1°C with a 16-hour light/8-hour dark photoperiod. Observations of mortality were recorded daily. Temperature, pH, dissolved oxygen, and conductivity measurements were recorded on one replicate of each concentration at test initiation and termination, and daily on the test solutions before and after solution renewal. The *P. promelas* larvae were fed 0.15 to 0.25 ml (ration increased with age) of a 0.05 g/ml suspension of newly hatched brine shrimp nauplii (*Artemia* sp., less than 24 hours old) three times daily.

At the end of the 7-day exposure period, the surviving larvae were rinsed, and placed in pre-weighed, oven-dried aluminum pans (one pan per replicate) and dried at 100°C for a minimum of six hours. The total organism dry weight per replicate was divided by the number of exposed organisms to obtain a mean dry weight (biomass) for each replicate.

3.2.4.2.3. *Selenastrum capricornutum* testing

The 96-hour *S. capricorntum* chronic toxicity tests were conducted in 250-ml erlenmyer flasks with loose fitting metal lids. Each replicate chamber contained 100 ml of test solution. Each test concentration and control had three algal growth replicate test chambers, in addition to a fourth replicate designated for water quality monitoring. Prior to preparation of the test concentrations, the effluent suspended particulate phase and the Potomac River dilution water were spiked with nutrients without EDTA (US EPA 1994). Algal media without EDTA was used as the laboratory control for the *S. capricornutum* tests.   The spiked effluent and river water were passed through a 0.45 μm filter prior to preparation of the test dilutions. At test initiation, each replicate was innoculated with 1 ml of a 1,000,000 cell/ml concentration of *S. capricornutum*. The flasks were placed on a shaker table and the test solutions were oscillated continuously at 100 cpm during the 96-hour exposure period.   The chambers were maintained at a target temperature of 25±1°C, and were exposed to continuous illumination of 400±40 foot candles. Preparation of test dilutions and inoculum, and the inoculation of the test chambers, were performed using sterile procedures. Temperature and pH were monitored daily, and conductivity was measured at initiation and termination, in the water quality chambers. At test termination, cell growth was determined visually using a hemocytometer.

3.2.4.2.4. Statistical Analyses

The results of the chronic toxicity tests were statistically analyzed according to US EPA (1994) guidance to determine if any suspended particulate phase concentration was significantly different ($p=0.05$) from the dilution water control with respect to survival, reproduction (*C. dubia*), growth expressed as biomass (*P. promelas*), and cell growth expressed as cell density (*S. capricornutum).*   The short-term chronic toxicity test endpoints were expressed as the No Observed Effect Concentration (NOEC), the Lowest Observed Effect Concentration (LOEC), and the Chronic Value (ChV). The definitions of these chronic endpoints follow US EPA (1994) and are as follows:

- The <u>NOEC</u> is the highest concentration of toxicant to which organisms are exposed in a full or partial life-cycle test, which causes no statistically significant adverse effect on the observed parameter (usually hatchability, survival, growth, or reproduction).

- The LOEC is the lowest concentration of toxicant to which organisms are exposed in a full or partial life-cycle test, which causes a statistically significant adverse effect on the observed parameter (usually hatchability, survival, growth, or reproduction).

- The ChV is a value lying between the NOEC and the LOEC, derived by calculating the geometric mean of the NOEC and LOEC. The term is sometimes used interchangeably with Maximum Acceptable Toxicant Concentration (MATC).

The Chronic Toxic Units (TU_c) were calculated for each chronic toxicity test based on the ChV value [TU_c=100/ChV].

3.2.4.3. Benthic Toxicity Testing

The *H. azteca* benthic toxicity tests were conducted in 300-ml lipless glass beakers containing control sediment and test dilution. The tests were performed with eight replicates per test concentration and control. To prepare the test material, the whole effluent sample was diluted with upstream Potomac River water. The 100, 50, 25, 12.5, and 6.25 percent effluent dilutions were added to the test beakers and allowed to settle over the control sediment. The May 2000 *H. azteca* testing utilized 175 ml of dilution over 100 ml of sediment, while the December 2000 testing consisted of 225 ml dilution layered over 50 ml of sediment. The sediment and effluent dilutions were added to the chambers 24 hours prior to introduction of the test organisms. The beakers were left undisturbed overnight so as to allow any suspended sediment particles in the water column to settle. At test initiation, ten organisms were randomly introduced into each replicate beaker. The test chambers were placed in a water bath and maintained at the target temperature of 23±1°C with a 16-hour light/8-hour dark photoperiod. The *H. azteca* were fed 1 ml/replicate of YCT (a suspension of yeast, ground cereal leaves, and trout chow) daily.

The overlying water in the exposure chambers was renewed twice daily using a water delivery system (Zumwalt et al. 1994). Fresh dechlorinated tap water was slowly added to each replicate, displacing the water already in the beaker through a notch cut into the top of the beaker. The notch was sealed with fine mesh screen to prevent any organisms from being flushed out of the test chamber. Temperature, pH, dissolved oxygen, and conductivity measurements were recorded daily on the overlying water in one replicate of test concentration and control. The overlying water was gently aerated during the test, in such a way as to not disturb the settled solids.

At the end of the 10-day exposure period, the surviving organisms from each replicate were retrieved by screening through a 250 μm sieve. The number of surviving *H. azteca* from each replicate was recorded, and the organisms of each replicate were placed in a dried, pre-weighed tin and placed in a drying oven at 100°C for at least six hours. The tins were then removed from the oven, placed in a desiccator to cool, and each pan was weighed to the nearest 0.01 mg to determine a mean dry weight per replicate. The results of the 10-day *H. azteca* toxicity tests were statistically analyzed to calculate the IC25 and IC50 values. The inhibition concentration (ICp) is the point estimate of the toxicant concentration that would cause a given percent reduction in a non-quantal biological measurement such as fecundity or growth. For example, an IC25 would be the estimated concentration of toxicant that would cause a 25 percent reduction in biomass. The Acute Toxic Units (TU_a) were calculated based on the IC25 value [TU_a=100/IC25].

3.2.5. Reference Toxicant Tests

In conformance with EA's quality assurance/quality control program, reference toxicant tests were performed on the in-house cultured organisms and on the acquired organisms stocks. The results of each reference toxicant test were compared to EA's established control chart limits. The reference toxicants used for this study were sodium chloride (NaCl) for *C. dubia*, cadmium chloride ($CdCl_2$) for *P. promelas* used in the chronic toxicity tests, potassium chloride (KCl) for *D. magna*, *P. promelas* and *M. saxatilis* used in the acute toxicity tests, potassium dichromate ($K_2Cr_2O_7$) for *S. capricornutum*, and copper sulfate ($CuSO_4$) for *H. azteca*.

3.2.6. Archives

Original data sheets, records, memoranda, notes and computer printouts are archived at EA's Baltimore Office in Sparks, Maryland. These data will be retained for a period of 5 years unless a longer period of time is requested by the US Army Corps of Engineers - Baltimore District.

3.3. RESULTS

3.3.1 Acute Toxicity Testing

The results of the acute toxicity testing conducted on effluent samples discharged from the Washington Aqueduct facilities are summarized in Table 3-2. The test results indicate that (with one exception) the whole effluent samples collected for the preliminary testing and for Rounds #1 through #4, were not acutely toxic to the test organisms. The 48- and 96-hour LC50 values were >100 percent effluent (TUa <1.0) for *D. magna*, *P. promelas* and *M. saxatilis*. Although the *P. promelas* acute toxicity test conducted during Round #1 on the Georgetown #2 effluent had unacceptable control mortality, it appears that the sample has some level of dose-related acute toxicity which resulted in a 96-hour LC50 value of 29.3 percent effluent (Table 3-2).

The Study Plan included whole effluent acute toxicity testing using striped bass (*M. saxatilis*) prolarvae; and included a cautionary statement that:

> *"As ASTM Standard Guide E 1241-92 observes, "striped bass embryos and larvae are difficult to work with," the proposed aeration/mixing of the test solutions may not be an acceptable practice for the proposed striped bass prolarvae testing and the results will need to be interpreted with caution."*

As toxicity tests could only be conducted when discharges occur, which are in turn limited by Potomac River minimum flow requirements, substantial efforts were made by EA and Aqueduct staff to conduct this component of the acute toxicity testing program.

A minimum of ten acute toxicity tests were initiated with *M. saxatilis* on Aqueduct effluents, in addition to EA's QA program requirement that reference toxicant tests performed on each lot of acquired organisms. Further, two different sources of eggs and larvae were used (Horn Point Lab in Cambridge, Maryland, and the Virginia State Fish Hatchery in Brookneal, Virginia).

Only one *M. saxatilis* test had acceptable control survival (minimum of 90 percent control survival), per US EPA (1993) guidelines. The acceptable test was an unaerated reference toxicant test conducted in May 2000 (Round #2), using prolarvae. During the corresponding May 2000 test using the Georgetown #2 effluent, the test solutions were aerated throughout the 96-hour exposure period to maintain complete mixing of the effluent sample, per instructions from U.S. F&WS staff. It is EA's opinion that the gentle aeration caused excessive stress to the test organisms, resulting in >10 percent mortality in all effluent concentrations and in the control. Although the effluent test had unacceptable control mortality (40 percent), the results indicate that the effluent sample was not acutely toxic to the test organisms. More specifically, even though the May 2000 Georgetown #2 test had 40 percent mortality in the controls, survival in the 12.5, 25, 50 and 100 percent effluent exposure concentrations were 55%, 75%, 55% and 80 percent survival, respectively. Thus, the LC50 value is >100 percent effluent [<1.0 TUa], and that result is presented in Table 3-2. Due to limited seasonal availability, EA was unable to acquire additional lots of prolarvae in 2000.

The striped bass larvae acquired in Spring 2001 for subsequent toxicity testing had just begun to feed, and thus were more sensitive to stress from feeding problems and other conditions unrelated to effluent toxicity. The toxicity tests that were conducted with the organisms in the larval stage were performed both with and without aeration of test solutions, and with a variety of dilution/control waters, in efforts to achieve a successful test with reliable results. However, these tests all had high mortality across test concentrations, including the controls.

In our opinion, the unacceptable tests with *M. saxatilis* were a result of the age and sensitivity of available test organisms, and the aeration of the exposure solutions during testing. They were not caused by, nor indicate the presence of, acute toxicity associated with the Aqueduct effluent samples.

3.3.2 Chronic Toxicity Testing

Table 3-3 summarizes the results of the chronic toxicity tests performed on the suspended particulate phase of the discharge samples collected during Rounds #1 through #4. The Georgetown #2 sample collected on 1 December 1999 (Round #1) and the Dalecarlia #2 sample collected on 18 December 2000 (Round #4) were not chronically toxic to the three test species. The NOEC values for *C. dubia*, *P. promelas* and *S. capricornutum* were 100 percent effluent, and the chronic values (ChV) were >100 percent effluent.

There was some evidence of chronic toxicity associated with the effluent samples collected during Rounds #2 and #3. The Georgetown #2 sample collected on 3 May 2000, and the Dalecarlia #3 sample collected on 25 May 2000 were both chronically toxic to *C. dubia*. Although neither sample statistically (p=0.05) affected *C. dubia* survival, there was a significant adverse effect on reproduction in the higher concentrations of effluent. The NOEC for the Round #2 *C. dubia* test was 25 percent effluent, and the ChV was 35.4 percent effluent. For Round #3, the NOEC for *C. dubia* was 50 percent effluent and the ChV was 70.7 percent effluent.

During Rounds #2 and #3, the upstream Potomac River water, which was used as the control and dilution water for the *P. promelas* chronic toxicity tests, was toxic to the fathead minnow larvae, severely impacting both survival and growth of these test organisms. Exposure to the effluent samples produced a inverted dose response for both survival and growth, indicating that the effluent samples were not chronically toxic to the fathead minnow larvae (since there was no toxicity at the highest exposure concentrations (including 100 percent effluent).. The NOEC values for the Round #2 and #3 *P. promelas* chronic toxicity tests were 100 percent effluent (ChV >100 percent effluent).

In Round #2, the Georgetown #2 sample was chronically toxic to the *S. capricornutum*. Cell density was significantly affected in the higher concentrations of effluent, with a resulting NOEC of 12.5 percent effluent, and a ChV of 17.7 percent effluent. During Round #3, the Potomac River water (control/dilution water) was toxic to the algae, interfering with the evaluation of cell growth. Statistical analyses were inappropriate, and the toxicity of the Dalecarlia #3 sample could not be determined.

3.3.3. Benthic Toxicity Testing

A Summary of the benthic toxicity test results is presented in Table 3-4. The 10-day LC50 (survival) values from the four rounds of testing were >100 percent sample. The IC25 (growth) values ranged from 6.9 percent sample during Round #4, to 32.8 percent sample during Round #3. The Round #1 test had an IC25 of 13.9 percent sample, and the Round #2 test had an IC25 of 23.5 percent sample.

3.3.4. Reference Toxicant Testing

The results of the *C. dubia*, *D. magna*, *P. promelas*, *S. capricornutum*, and *H. azteca* reference toxicant tests were all valid and fell within the control chart limits, indicating that these organism cultures were of acceptable quality.

3.4 SUMMARY AND CONCLUSIONS

A series of acute and chronic toxicity testing was performed on effluents discharged from the Dalecarlia and Georgetown facilities during normal cleaning operations. As described in the Study Plan, toxicity tests were conducted on three fractions of the Aqueduct effluent: whole effluent samples (using acute toxicity tests); supernatant from the settled whole effluent (using chronic toxicity tests); and the settled solids portion of the whole effluent (using benthic tests). Note that the concentrations of *total* aluminum used in the toxicity tests are substantially greater than the concentrations to which organisms in the Potomac River would be exposed. This can be seen by comparing total and dissolved aluminum concentrations used in the toxicity tests (Table 4-3) with aluminum concentrations collected from the Potomac River during discharges from Outfall 002 (Table 2.1-4) and from Outfall 003 (Table 2.1-3). Recognize that the Table 4-3 concentration values are in mg/L (ppm), whereas the concentrations in Tables 2.1-3 and 2.1-4 are in µg/L (ppb). Similar comparisons of *dissolved* aluminum indicate that the concentrations used in the toxicity tests are (in almost all cases) higher than what were measured in the Potomac during discharge events.

The acute test results indicate that (with one exception) the whole effluent samples collected for the preliminary testing and for Rounds #1 through #4, were not acutely toxic to the test organisms. The 48- and 96-hour LC50 values were >100 percent effluent (TUa <1.0) for *D. magna*, *P. promelas* and *M. saxatilis*. One fathead minnow test showed some level of dose-related acute toxicity which resulted in a 96-hour LC50 value of 29.3 percent effluent.

The chronic toxicity test results showed that in two of the four rounds, the effluent was not chronically toxic. In the other two rounds, the lowest 7-day ChV for a fish or invertebrate was 35.4 percent effluent. It is noteworthy that 7-day chronic effluent toxicity tests were conducted and reported in the Dynamac (1992, p. 72) study which showed "*that the effluent released from the sampled sedimentation basins had no effect on either mortality or growth of fathead minnows. This result is consistent with observations at the basins, where the fish communities were clearly visible.*"

For the benthic testing, the 10-day LC50 (survival) values from the four rounds of testing were >100 percent sample, but the effluent concentration causing effects on growth (the IC25 value) ranged from 6.9 to 32.8 percent effluent.

Interpretation of these results is complicated by the fact that these tests continuously expose the test organisms to a series of effluent concentrations for 2 to 10 days (depending upon the test), whereas exposure to the Aqueduct plume is a transient phenomenon that lasts for perhaps 4-8 hours. Using the guidance presented in U.S. EPA's (1991)Technical Support Document for Water Quality-Based Toxics Control, the lowest acute value would require a dilution factor of approximately 11:1 to be non-toxic (i.e., to yield 0.3 TUa); and the lowest chronic value would require a dilution factor of approximately 9.4:1. The benthic results would suggest that a dilution factor of 14.5 would result in no effect on organism growth. As discussed in Chapter 2, these dilution factors are easily obtained for Outfall 002, but outfall relocation would be required to achieve these values for the Georgetown Reservoir discharges from Outfall 003.

3.5 REFERENCES

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Zumwalt, D.C., F.J. Dwyer, I.E. Greer, and C.G. Ingersoll. 1994. *A water-renewal system that accurately delivers small volumes of water to exposure chamber*. Environmental Toxicology and Chemistry. 13:1311-1314.

Table 3-1 Summary of Sample Collection and Receipt Data for Samples from Washington Aqueduct

Sample Identification	EA Accession Number	Collection Time and Date	Receipt Time and Date	Sample Hardness (mg/L)
EFFLUENT:				
Dalecarlia Basin #2	AT9-1254	1352, 9 SEP 99	1805, 9 SEP 99	
Georgetown Basin #2	AT9-1637	1155, 1 DEC 99	1630, 1 DEC 00	
Georgetown Basin #2	AT0-386	1030, 3 MAY 00	1615 3 MAY 00	136
Dalecarlia Basin #3	AT0-436	0940, 25 MAY 00	1648, 25 MAY 00	144
Dalecarlia Basin #2	AT0-988	1220, 18 DEC 00	1605, 18 DEC 00	84
Dalecarlia Basin #2	AT1-162	1405, 12 APR 01	1645, 12 APR 01	
Dalecarlia Basin #2	AT1-224	1500, 14 MAY 01	1730, 14 MAY 01	
DILUTION WATER:				
Potomac River Water	AT9-1255	1510, 9 SEP 99	1805, 9 SEP 99	
Potomac River Water	AT9-1639	1155, 1 DEC 99	1630, 1DEC 99	
Potomac River Water	AT0-385	1410, 3 MAY 00	1615, 3 MAY 00	120
Potomac River Water	AT0-437	(a) 25 MAY 00	1648, 25 MAY 00	132
Potomac River Water	AT0-989	0830, 19 MAY 00	1045, 19 MAY 00	72
Potomac River Water	AT1-161	1305, 12 APR 01	1645, 12 APR 01	
Dalecarlia Basin #2 Water	AT1-225	1500, 14 MAY 01	1730, 14 MAY 01	
CONTROL SEDIMENT:				
Potomac River Sediment	AT9-1638	1155, 1 DEC 99	1630, 1 DEC 99	
Potomac River Sediment	AT0-389	1542, 8 MAY 00	0945, 9 MAY 00	
Magothy River Sediment	AT0-280	(a) 22 MAR 00	1225, 23 MAR 00	
Potomac River Sediment	AT0-990	0850, 19 DEC 00	1045, 19 DEC 00	

(a) Time of collection is not available.

Table 3-2 Summary of Acute Toxicity Test Results
Washington Aqueduct

Sample Location	Sample Date	Test Species	Testing Date	LC50	TUa
Preliminary testing:					
Dalecarlia #2	9 SEP 99	*D. magna*	10-12 SEP 99	>100	<1.0
Dalecarlia #2	9 SEP 99	*P. promelas*	10-12 SEP 99	>100	<1.0
Round #1:					
Georgetown #2	1 DEC 99	*D. magna*	7-9 DEC 99	>100	<1.0
Georgetown #2	1 DEC 99	*P. promelas*	7-11 DEC 99	29.3 (a)	3.4
Round #2:					
Georgetown #2	3 MAY 00	*D. magna*	4-6 MAY 00	>100	<1.0
Georgetown #2	3 MAY 00	*P. promelas*	4-8 MAY 00	>100	<1.0
Georgetown #2	3 MAY 00	*M. saxatilis*	11-15 MAY 00	>100 (a)	<1.0 (a)
Round #3:					
Dalecarlia #3	25 MAY 00	*D. magna*	30 MAY-1 JUN 00	>100	<1.0
Dalecarlia #3	25 MAY 00	*P. promelas*	30 MAY-1 JUN 00	>100	<1.0
Round #4:					
Dalecarlia #2	18 DEC 00	*D. magna*	20-22 DEC 00	>100	<1.0
Dalecarlia #2	18 DEC 00	*P. promelas*	20-24 DEC 00	>100	<1.0

(a) Unacceptable control mortality.

Table 3-3 Summary of Chronic Toxicity Test Results – Washington Aqueduct

Sample Location	Sample Date	Test Species	Testing Date	NOEC (Survival)	NOEC (Sub-lethal)	ChV
Round #1:						
Georgetown #2	1 DEC 99	*C. dubia*	7-13 DEC 99	100	100 (Reproduction)	>100
Georgetown #2	1 DEC 99	*P. promelas*	7-14 DEC 99	100	100 (Growth)	>100
Georgetown #2	1 DEC 99	*S. capricornutum*	23-27 DEC 99	N/A	100 (Cell Density)	>100
Round #2:						
Georgetown #2	3 MAY 00	*C. dubia*	4-10 MAY 00	100	25 (Reproduction)	35.4
Georgetown #2	3 MAY 00	*P. promelas*	4-11 MAY 00	100 [a]	100 (Growth) [a]	>100
Georgetown #2	3 MAY 00	*S. capricornutum*	4-8 MAY 00	N/A	12.5 (Cell Density)	17.7
Round #3:						
Dalecarlia #3	25 MAY 00	*C. dubia*	30 MAY-5 JUN 00	100	50 (Reproduction)	70.7
Dalecarlia #3	25 MAY 00	*P. promelas*	30 MAY-6 JUN 00	100 [a]	100 (Growth) [a]	>100
Dalecarlia #3	25 MAY 00	*S. capricornutum*	1-5 JUN 00	N/A	[a]	[a]
Round #4:						
Dalecarlia #2	18 DEC 00	*C. dubia*	27 DEC 00-3 JAN 01	100	100 (Reproduction)	>100
Dalecarlia #2	18 DEC 00	*P. promelas*	27 DEC 00-3 JAN 01	100	100 (Growth)	>100
Dalecarlia #2	18 DEC 00	*S. capricornutum*	4-8 JAN 01	N/A	100 (Cell Density)	>100

(a) River water (control/dilution water) was toxic to test organisms.

.

Table 3-4 Summary of Benthic Toxicity Test Results – Washington Aqueduct

Sample Location	Sample Date	Test Species	Testing Date	10-Day LC50	IC25 (Growth)
Round #1:					
Georgetown #2	1 DEC 99	*H. azteca*	29 DEC 99-8 JAN 00	>100	13.9
Round #2:					
Georgetown #2	3 MAY 00	*H. azteca*	12-22 MAY 00	>100	23.5
Round #3:					
Dalecarlia #3	25 MAY 00	*H. azteca*	13-23 JUN 00	>100	32.8
Round #4:					
Dalecarlia #2	18 DEC 00	*H. azteca*	29 DEC 00-8 JAN 01	>100	6.9

4. EFFLUENT CHEMICAL CHARACTERIZATION

The Study Plan indicated that existing effluent monitoring data (e.g., chemical parameters) collected at the basin discharge points would be obtained and evaluated to help compare concentrations at the edge of the acute and chronic mixing zones to the ambient water quality criteria. In addition, effluent samples used in the toxicity testing program would be analyzed for key parameters (e.g., total suspended solids, total and dissolved aluminum, total iron, total organic carbon, BOD, pH, alkalinity, and nitrogen and phosphorus compounds) using analytical methods which are U.S. EPA-approved (e.g., 40 CFR 136). This chapter also includes a brief discussion of the relationship between Potomac River flows and total suspended solids concentrations, as measured at Little Falls which is upstream of the Aqueduct discharges.

4.1 EXISTING AQUEDUCT EFFLUENT CHEMISTRY DATA

Aqueduct staff collect and chemically analyze effluent grab samples when basins are cleaned (and discharges to the Potomac are made). These samples are analyzed on-site by Aqueduct staff for the following water quality parameters: total aluminum, total iron, pH, total dissolved solids, total suspended solids and total solids. It should be understood that because of the way the basins and reservoirs are cleaned (fire hoses at Dalecarlia and front end loaders at Georgetown), grab sample data can be quite variable from minute to minute. Thus, mean effluent concentration data are probably the most reliable when evaluating the discharges. Summary data from the period 1997 through the first part of 2001 are presented in Tables 4-1a,b and 4-2a,b for discharges from the Dalecarlia and Georgetown facilities. More detailed data are available showing the exact times during each day that the grab samples were collected. Table 4-1 provides the mean, minimum and maximum values for each parameter for each discharge. Table 4-2 was provided to compare average effluent concentrations for each year by facility.

Overall mean total aluminum data for the four Dalecarlia Basins averaged 2,273 mg/L for the period 1997-2001. Similar total aluminum data for the Georgetown discharges yielded a mean concentration of 1,510 mg/L. The District of Columbia's Department of Health does not have a surface water quality standard for aluminum (Title 21, Chapter 11, §1104.6). U.S. EPA, however, presents a freshwater acute water quality criterion concentration of 0.750 mg/L, and a chronic criterion of 0.087 mg/L measured as total recoverable aluminum in the water column (63 Fed Reg 68360, 10 December 1998). Several important caveats to the Agency's 0.087 mg/L chronic criterion are also discussed in footnote "L" of EPA's Federal Register announcement, indicating that the value may not be applicable to all waterbodies. These cautions include:

- Total aluminum associated with clay particles might be less toxic that aluminum associated with aluminum hydroxide.

- The 0.087 mg/L chronic criterion value is based on toxicity tests using brook trout and striped bass in low pH water (6.5-6.6). This is lower than the pH of the Potomac River where organism exposure would occur.

- EPA is aware that many pristine high quality waters in the U.S. contain more than 0.087 mg/L aluminum when either total recoverable or dissolved aluminum is measured.

- As discussed in U.S. EPA's aluminum criteria document (EPA 1988, p. 22), if the chronic criterion would have been calculated using the normal criterion derivation approach (i.e., not lowered to protect the striped bass and brook trout under low pH conditions), the chronic criterion would have been 0.748 mg/L rather than the 0.087 mg/L value.

For the reasons bulleted above, if EPA's 0.87 mg/L chronic criterion is exceeded, the Agency suggests that a Water Effect Ratio might yield a more appropriate site-specific standard for aluminum.

Simple comparison of the mean effluent concentration for Dalecarlia versus the Agency's acute criterion indicates that a dilution factor of approximately 3,000 would be required to reduce concentrations to the criterion value (2,273 / 0.750). Three points need to made to clarify this comparison:

- Aluminum is the most abundant metallic element in the earth's crust with an average of 8.2 percent (Bodek et al. 1988). Shacklette and Borngen (1984) state that the geometric mean of aluminum in soils in the conterminous United States is 2.5 percent [=25,000 mg/kg].

- Actual field measurements made by EA during the dilution study (Chapter 2) indicated that total aluminum concentrations in the water column immediately downstream from Outfalls 002 and 003 are substantially lower. More specifically, total aluminum concentrations on the nearshore side at the first transect downstream from Outfall 002 (520 meters) averaged only 1.153 mg/L with the highest single value of 1.93 mg/L (see Table 2.1-4). Similarly, total aluminum concentrations at the nearshore side of the first transect downstream from Outfall 003 (70 meters) averaged 1.949 mg/L with the highest single value of 3.87 mg/L (see Table 2.1-3). Based on these data, it appears that a substantial amount of the total aluminum released to the water column is quickly lost to the sediments and is no longer directly available to water column species.

- Although simple comparisons between end-of-pipe total aluminum concentrations and EPA's ambient criterion would suggest that acute toxicity might be expected, the acute effluent toxicity testing (see Chapter 3) shows no acute toxicity to the three laboratory test species (i.e., LC50 values > 100 percent effluent).

Therefore, although effluent concentrations of aluminum are high, effluent toxicity testing does not suggest that the aluminum present in the samples is as bioavailable or toxic as the data used to determine EPA's aluminum criterion (which uses laboratory grade aluminum salts in clean water) would suggest.

4.2 EFFLUENT CHEMISTRY DATA GENERATED BY EA

As part of each of the effluent toxicity tests conducted as part of this program, samples were also analyzed for a variety of chemical parameters which are summarized in Table 4-3. Total aluminum concentrations measured in Dalecarlia and Georgetown samples are entirely consistent with the datasets produced by the Aqueduct (see Section 4.1). EA's dataset, however, also includes information on *dissolved* aluminum which shows that in each of the five effluent samples for which both total and dissolved aluminum data exist, the percentage of dissolved aluminum is considerably less than 1 percent of the total value. This is entirely consistent with the results obtained using U.S. EPA's geochemical speciation model MINTEQ. This result also helps explain why a given concentration of total aluminum in Aqueduct effluent samples is substantially less toxic than would be expected based upon simple comparisons to the results presented in U.S. EPA's (1988) aluminum criteria document (which requires the use of laboratory grade aluminum salts in clean water).

4.3 HISTORICAL POTOMAC RIVER FLOWS AND SUSPENDED SEDIMENT CONCENTRATIONS

To provide baseline information on the Potomac River for evaluations of the potential impacts of Washington Aqueduct discharges, historical river flow and suspended sediment data were obtained from the USGS.

4.3.1 Potomac River Flow Data

Daily Potomac River flows at Little Falls were obtained for the 20-year period, 1980 to 1999. A frequency distribution of these flow data by month is provided in Table 4-4. This table indicates that median (50-percentile) flows vary between 57.7 cms in October to 517.9 cms in March. The Washington Aqueduct's existing permit restricts discharges to times when river flows are above a 3.47-ft gage height, which corresponds to 153 cms (5,400 cfs). Table 4-4 indicates that flows greater than 153 cms occur less than 30 percent of the time during July, and less than 20 percent of the time during August to October. This makes it necessary for the Aqueduct to clean reservoirs and basins during the higher flow periods (e.g., springtime) in order to last until the next significant opportunity in the late fall.

4.3.2 Potomac River TSS Data

Suspended sediment concentrations were collected approximately once each month by the USGS at Chain Bridge during the 1980-1999 period. A frequency distribution of this suspended sediment data is provided in Table 4-5. On each day that a suspended sediment concentration was available, the value was multiplied by the Potomac River flow in order to determine a sediment load. A frequency distribution of the resulting sediment loads in the Potomac River is also provided in Table 4-5.

The suspended sediment concentrations have a median (50-percentle) value of 15 mg/L. During high flow conditions, suspended sediment concentrations increase rapidly above the 15-mg/L level. The relationship between suspended sediment and Potomac River flow is illustrated in Figure 4-1. At river flows less than 400 cms, the 15-mg/L value is typical of suspended sediment concentrations. However, at higher flows between 500 and 1,000 cms, suspended sediment concentrations increase to between 50 and 200 mg/L.

The frequency distribution of sediment load (Table 4-5) can be used to place in perspective the magnitude of solids being discharged from the Aqueduct's outfalls. The 25 May 2000 event at Dalecarlia Basin 3 discharged approximately 17,800 kg of solids. This solids mass is less than a 10-percentile value of daily Potomac River suspended sediment loads. Stated differently, 90 percent of the days each year, the daily mass of solids passing Little Falls exceeds the amount released from a discharge of Outfall 002. The 3 May 2000 event at Georgetown Reservoir discharged an estimated 153,600 kg of solids. This solids mass is between a 40- and 45-percentile value of daily Potomac River suspended sediment loads.

4.4 REFERENCES

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Shacklette, H.T and J.G. Boengen. 1984. *Element Concentrations in Soils and Other Surficial Materials in the Conterminous United States*. United States Geological Survey Professional Paper 1270.

U.S. EPA. 1988. *Ambient Water Quality Criteria for Aluminum- 1988*. U.S. EPA, Office of Water Regulations and Standards. Washington, D.C. NTIS # PB88-245998; EPA # 440/5-86-008..

Figure 4-1 Relationship Between Suspended Solids and Potomac River Flow, USGS Data at Chain Bridge, 1980-1999

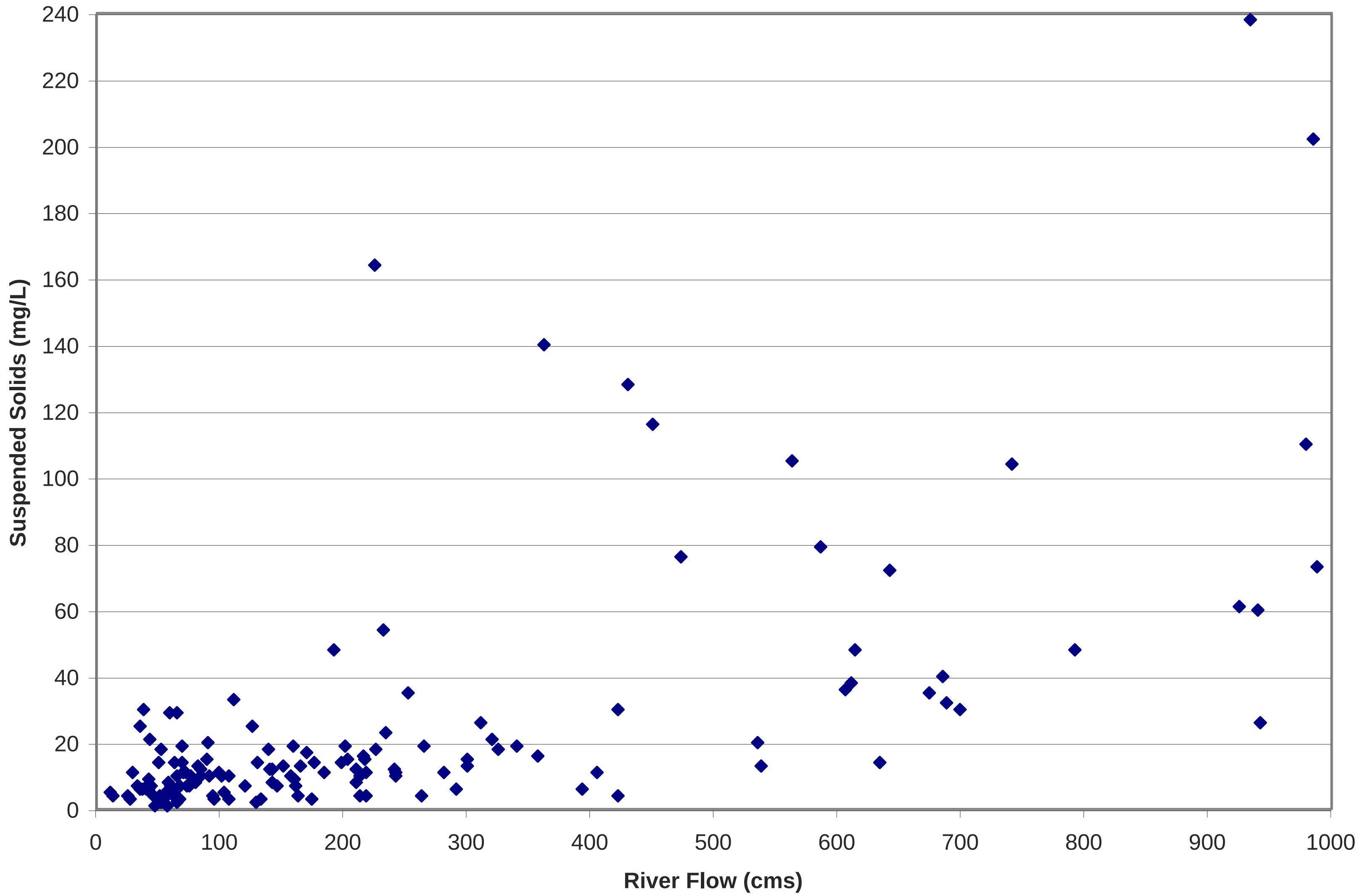

Table 4-1a Summary of chemistry monitoring data by analyte for each Dalecarlia Basin for the years 1997-2001

Dalecarlia Basin 1

Analyte	Units	n	Min	Mean	Max
Aluminum, total	mg/L	24	109	2,480	7,520
Dissolved Solids	mg/L	30	0	3,906	27,700
Iron, total	mg/L	24	27	552	2,710
pH	s.u.	186	6.50	7.11	7.97
Suspend Solids	mg/L	30	50	15,300	55,600
Total solids	mg/L	30	838	24,200	66,600

Dalecarlia Basin 2

Analyte	Units	n	Min	Mean	Max
Aluminum, total	mg/L	27	3	1,270	3,630
Dissolved Solids	mg/L	34	0	2,840	31,100
Iron, total	mg/L	27	4	217	744
pH	s.u.	240	6.17	7.16	7.72
Suspend Solids	mg/L	34	4	9,430	30,400
Total solids	mg/L	34	115	12,300	42,300

Dalecarlia Basin 3

Analyte	Units	n	Min	Mean	Max
Aluminum, total	mg/L	17	15.1	3,000	6,450
Dissolved Solids	mg/L	22	0	6,120	34,100
Iron, total	mg/L	17	4	560	1500
pH	s.u.	137	6.63	7.15	7.94
Suspend Solids	mg/L	23	72	20,800	38,300
Total solids	mg/L	22	303	26,900	47,000

Dalecarlia Basin 4

Analyte	Units	n	Min	Mean	Max
Aluminum, total	mg/L	14	1,250	2,350	4,200
Dissolved Solids	mg/L	19	337	1,550	6,710
Iron, total	mg/L	14	83	396	804
pH	s.u.	102	6.09	7.09	7.80
Suspend Solids	mg/L	19	3,940	18,000	38,700
Total solids	mg/L	20	6,150	19,900	44,500

Table 4-1b Summary of chemistry monitoring data by analyte for each Georgetown Basin for the years 1997-2001

Georgetown Basin 1

Analyte	Units	n	Min	Mean	Max
Aluminum, total	mg/L	8	104	2,508	8,803
Dissolved Solids	mg/L	10	3	491	1,605
Iron, total	mg/L	7	13	284	866
pH	s.u.	64	6.61		8.03
Suspend Solids	mg/L	10	904	20,337	69,220
Total solids	mg/L	10	1060	20,828	69,570

Georgetown Basin 2

MyName	Units	n	Min	Mean	Max
Aluminum, total	mg/L	7	0.348	511	2,276
Dissolved Solids	mg/L	10	79	522	2,134
Iron, total	mg/L	7	0.094	56	207
pH	s.u.	56	6.61		7.54
Suspend Solids	mg/L	10	5	2,954	12,400
Total solids	mg/L	10	23	3,476	14,214

Table 4-2a Average yearly concentrations measured during chemistry monitoring for each Dalecarlia Basin from 1997-2001

Analyte	Units	Year	n	Dalecarlia Basin 1	Dalecarlia Basin 2	Dalecarlia Basin 3	Dalecarlia Basin 4
Aluminum	mg/L	1997	15	3,210	1,490	2,770	2,210
Aluminum	mg/L	1998	13	2,220	1,270	2,820	1,760
Aluminum	mg/L	1999	24	3,060	1,170	4,180	2,490
Aluminum	mg/L	2000	20	2,410	1,430	1,830	2,020
Aluminum	mg/L	2001	10	651	800	3,500	2,970
Dissolved Solids	mg/L	1997	18	3,640	1,700	8,840	1,130
Dissolved Solids	mg/L	1998	17	3,640	1,640	2,760	771
Dissolved Solids	mg/L	1999	30	9,600	6,580	1,970	1,220
Dissolved Solids	mg/L	2000	26	1,350	504	12,600	589
Dissolved Solids	mg/L	2001	14	1,400	2,220	662	3,830
Iron	mg/L	1997	15	1,220	372	1,400	752
Iron	mg/L	1998	13	436	267	810	249
Iron	mg/L	1999	24	513	202	673	370
Iron	mg/L	2000	20	248	121	156	152
Iron	mg/L	2001	10	47.3	61.4	378	222
pH	s.u.	1997	135	7.11	7.04	7.09	6.81
pH	s.u.	1998	116	7.19	7.20	7.16	7.12
pH	s.u.	1999	162	7.06	7.16	7.30	7.35
pH	s.u.	2000	164	7.09	7.38	6.97	7.10
pH	s.u.	2001	88	**Average pH was not reported**			
Suspend Solids	mg/L	1997	18	27,500	12,700	38,200	29,500
Suspend Solids	mg/L	1998	17	16,900	7,520	19,200	10,000
Suspend Solids	mg/L	1999	30	10,600	6,820	26,500	13,500
Suspend Solids	mg/L	2000	27	11,100	13,900	8,810	16,600
Suspend Solids	mg/L	2001	14	3,620	3,300	31,500	12,900
Total solids	mg/L	1997	18	48,900	14,400	47,000	32,000
Total solids	mg/L	1998	17	20,500	9,150	22,000	10,800
Total solids	mg/L	1999	30	20,200	13,400	28,500	14,700
Total solids	mg/L	2000	27	14,900	14,400	21,500	17,100
Total solids	mg/L	2001	14	5,020	5,520	31,500	16,700

Table 4-2b Average yearly concentrations measured during chemistry monitoring for each Georgetown Basin from 1997-2001

MyName	Units	Year	n	Georgetown 1	Georgetown 2
Aluminum, total	mg/L	1997	2	3,329	2,276
Aluminum, total	mg/L	1998	2	109	198
Aluminum, total	mg/L	2000	4	427	
Aluminum, total	mg/L	2001	7	8,250	26
Dissolved Solids	mg/L	1997	4	804	1,906
Dissolved Solids	mg/L	1998	4	154	154
Dissolved Solids	mg/L	2000	4	475	
Dissolved Solids	mg/L	2001	8	547	183
Iron, total	mg/L	1997	2	866	207
Iron, total	mg/L	1998	2	27	60
Iron, total	mg/L	2000	3	62	
Iron, total	mg/L	2001	7	403	4
pH	s.u.	1997	22	**Average pH was not reported**	
pH	s.u.	1998	45	**Average pH was not reported**	
pH	s.u.	2000	27	**Average pH was not reported**	
pH	s.u.	2001	26	**Average pH was not reported**	
Suspend Solids	mg/L	1997	4	18810.00	12240.00
Suspend Solids	mg/L	1998	4	909.00	1948.00
Suspend Solids	mg/L	2000	4	6531.50	
Suspend Solids	mg/L	2001	8	68905.00	194.67
Total solids	mg/L	1997	4	19,614	14,146
Total solids	mg/L	1998	4	1,063	2,102
Total solids	mg/L	2000	4	7,006	
Total solids	mg/L	2001	8	69,452	377

Table 4-3 Analytical Chemistry Results Obtained from Effluent Toxicity Testing Program

	Location and Sample Collection Dates					
Analyte - units	Dalecarlia #2 09/09/99	Georgetown #2 12/01/99	Georgetown#2 05/03/00	Dalecarlia #3 05/25/00	Dalecarlia #2 12/18/00	Dalecarlia #2 04/18/01
Aluminum (Total) - mg/L	945	1,200	1,300	1,020	1,830	270
Aluminum (Diss.) - mg/L	0.093	0.593	0.016	<0.20 – U	--	<0.10 – U
Iron (Total) - mg/L	118	186	154	--	69	--
Alkalinity - mg/L	88.3	590	--	88.2	166	--
Hardness - mg/L	124	NV	136	144	84	104
Ammonia - mg/L	2.5	3.6	16.4	9.2	7.1	2.2
BOD 5-Day - mg/L	24.8	87.3	55.2	<40	92	78
pH- pH units	7.3	6.87	6.89	6.68		
TKN - mg/L	<0.50	52.0	48.3	36.5	<12.5	3.0
TOC - mg/L	240	259	129	86.1	80	120
Total Phosphorus - mg/L	10.5	44.7	19.9	14.7	1.93	5.7
TSS - mg/L	6,350	13,900	12,300	8,030	7,900	2,500
Nitrite - mg/L	<0.10 -U	<0.5 –U	2.2*	2.6*	0.1	0.027
Nitrate - mg/L	0.74	1.1	2.2*	2.6*	2.39	1.7
Phosphate - mg/L	<0.10 - U	<0.5 - U	<0.05 - U	7.2	--	--

U = Compound analyzed but not detected in the sample at the Reporting Limit concentration.
* = Concentration is for nitrate plus nitrite.
NV = No value.

Table 4-4 Frequency Distribution of Daily USGS Potomac River Flows at Little Falls, 1980-1999

Percent (%)	Flow (cms)											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	32.0	46.7	114.9	125.9	75.0	22.7	6.6	4.9	14.5	23.3	21.1	27.9
1	38.2	79.8	126.2	137.0	98.5	33.1	10.1	8.2	18.6	24.6	22.4	32.3
5	58.9	119.1	176.6	155.9	129.3	45.8	32.5	23.9	26.5	27.4	35.1	42.2
10	98.8	150.3	203.8	176.6	150.3	64.8	39.9	31.1	31.1	30.8	42.5	64.5
15	116.0	172.9	224.7	210.0	172.3	85.7	47.8	35.1	35.1	35.4	58.3	74.7
20	133.0	190.7	249.6	232.3	184.8	95.1	55.5	38.8	37.9	37.6	62.5	101.6
25	144.9	214.2	285.8	251.9	206.0	107.0	62.3	43.9	40.2	40.5	68.8	123.7
30	163.0	242.8	336.8	285.8	223.9	117.7	67.6	48.1	42.7	42.7	77.0	142.9
35	180.8	262.3	382.1	308.5	242.2	127.6	74.1	52.9	45.8	47.3	87.7	159.3
40	215.6	291.5	416.0	333.9	262.6	139.8	81.2	57.2	50.7	50.7	95.7	175.5
45	245.1	314.1	464.1	387.7	288.7	153.4	89.4	62.0	55.2	54.3	105.6	195.0
50	273.7	350.9	517.9	427.3	314.1	173.8	96.5	66.8	61.1	57.7	117.4	213.9
55	300.0	379.2	568.8	472.6	345.3	196.7	106.7	73.0	66.2	61.4	131.3	239.1
60	331.1	430.2	628.3	551.9	379.2	213.1	119.4	80.9	70.5	65.9	145.5	268.9
65	367.9	475.4	690.5	622.6	427.3	242.2	129.9	88.6	75.3	71.6	169.5	308.5
70	407.5	554.7	769.8	704.7	483.9	268.3	151.7	99.9	84.6	79.2	203.8	350.9
75	455.6	639.6	891.5	803.7	551.9	305.6	171.2	112.9	95.7	90.8	252.2	416.0
80	534.9	730.1	1024.5	942.4	650.9	342.4	192.4	135.8	111.5	110.4	302.8	486.8
85	633.9	891.5	1211.2	1129.2	817.9	399.0	227.0	167.3	140.7	191.3	365.1	571.7
90	959.4	1151.8	1528.2	1415.0	1064.1	489.6	294.3	249.0	207.2	328.3	503.7	733.0
95	1417.8	1533.9	2181.9	1842.3	1434.8	733.0	393.4	404.7	339.6	489.6	772.6	1010.3
99	2733.8	2943.2	3679.0	3254.5	2510.2	1307.5	699.0	1066.9	1432.0	1202.8	2300.8	2196.1
Mean	435.4	540.0	737.6	647.3	479.8	250.6	139.0	122.9	136.2	126.1	251.7	337.1
Max	9226	5915	5066	4330	3538	2623	1157	1899	7415	2372	8292	2711
Obs	620	565	620	600	620	600	620	620	600	589	570	589

Table 4-5 Frequency Distribution of Suspended Sediment Concentration and Load, (USGS Data at Chain Bridge, 1980-1999)

Percentile (%)	Suspended Sediment (mg/L)	Sediment Load (1,000 kg/day)
1	1	4.6
5	3	9.0
10	4	19.1
15	5	26.4
20	6	39.9
25	7	59.9
30	10	76.4
35	11	92.5
40	12	145
45	13	170
50	15	218
55	19	282
60	21	466
65	30	924
70	45	2,117
75	73	4,382
80	105	8,106
85	140	16,821
90	215	24,174
95	342	48,365
Mean	85	13,601
Obs	184	183

5. FISHERIES

To address concerns about potential impacts of the Aqueduct's discharge of solids on key anadromous and resident fish species, several lines of investigation were carried out. A list of species of concern was developed and discussed with key resource agencies. Life history data, particularly critical life stages and habitat requirements, were compiled for species of concern (Section 5.1). A qualitative evaluation was conducted by EA staff of potential fish habitat in the project area (Section 5.2), and potential impacts of sediment discharges to species of concern were evaluated (Section 5.3). Based on these studies, discharge management scenarios were developed that could minimize potential impacts to fisheries resources that may be at risk (Section 5.4).

5.1 LIFE HISTORY INFORMATION

Information in this section on life history and general distribution was compiled from major fisheries and Chesapeake Bay resources compendia including Lippson (1973), Lippson and Lippson (1984), U.S. Fish and Wildlife Service (1978), Lee et al. (1980), Funderburk et al. (1991), Cooper et al. (1994), and Jenkins and Burkhead (1994). References to recent occurrence and abundance are based on the District of Columbia Department of Health, Fish and Wildlife Division (DHFWD) file data.

The species discussed include those listed in the EPA-approved Study Plan dated 24 June 1999, which was negotiated with input from EPA Region III, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the D.C. Department of Health's Fish and Wildlife Division. In addition, the Federally endangered shortnose sturgeon (*Acipenser brevirostrum*) was included because of concerns regarding its possible occurrence in the project area.

5.1.1 Striped Bass (*Morone saxatilis*):

General

The striped bass is assigned to the family Percichthyidae, a loosely allied group of species that occur worldwide and are commonly referred to as the temperate basses. Striped bass grow to relatively large size. Sexual maturity of adults occurs at greater than 500 mm in length, and maximum sizes have been reported of 1,156 mm (males) and 1,829 mm (females). A maximum weight of 56.7 kg (125 lb.) was reported. Post-yolk sac larvae feed on zooplankton; juveniles feed on insects and other invertebrates and fish larvae; and adults consume primarily fish. The striped bass has historically been one of the most important commercial and recreation finfish species in Chesapeake Bay. A long-term decline in species abundance in the 1970s and 1980s was addressed with a fishing moratorium in the 1980s, and the species rebounded and again supports lucrative commercial and sport fishing interests.

Distribution

The striped bass is an anadromous species that naturally occurs from Canada south to northern Florida, and from Florida to Louisiana in the Gulf of Mexico. It has successfully been transplanted to the west coast. The Chesapeake Bay is the most important spawning and nursery ground on the Atlantic coast. Within the Bay there are 11 general spawning regions, including the tidal freshwater Potomac River. Adult and juvenile bass may be found anywhere in the Bay, and some, particularly juveniles, may stay in the Bay for several years before migrating to oceanic waters.

Habitat Requirements

Proper water temperatures are important to all life stages of striped bass. Temperatures $\leq$12 C are considered lethal to eggs and larvae. Historically, there have been a number of catastrophic mortalities of eggs and larvae in Bay rivers when cold snaps pushed water temperatures below 11 or 12 C. Larvae can tolerate temperatures of 12-23 C, but 18-21 C is optimum. Upper lethal limits for larvae have been reported as low as 28.9 C. Juveniles grow best at 24-26 C, and growth is greatly reduced at 30 C. The physiologically optimum temperature decreases as striped bass grow: 26 C for first year juveniles, 20-24 C for second year juveniles, and 20-22 C for adults. Based on several studies, dissolved oxygen (DO) concentrations of 5 mg/L or greater are considered necessary for protection of all life stages. Although striped bass spawn primarily in fresh water, salinities of 3-7 parts per thousand (ppt) were shown to enhance growth and survival of the young. Suspended solids concentrations of 500-1,000 mg/L can reduce hatching success and/or reduce survival of larvae. Striped bass larvae are very sensitive to acidic pH. Values as high as 6.5 have been reported to be lethal. Juveniles are a little more resistant. A pH range of 7.0-9.5 is recommended for striped bass culture.

Spawning

Striped bass spawn in tidal freshwater when water temperatures are between 14.4 and 21.2 C, with peak spawning between 17.8 and 20.0 C (Figure 5-1). The duration of spawning is variable, depending on environmental conditions. It can take place from five to nine weeks in the

Potomac River, generally from April into June, but in any given location the duration is likely shorter. Based on Potomac River temperature data for the last four years, the peak of spawning in the Potomac River was likely during the first half of May (Figure 5-1). Spawning takes place over bottoms of sand or mud, with some current. Eggs hatch in 48 hours at 17-20 C. The larval stage lasts approximately one month. Although Whitestone Point, approximately 20 miles downstream of the Washington Aqueduct study area, is reported to be the upstream-most limit of spawning in the Potomac River (Funderburk et al. 1991), spawning cannot be ruled out for the Aqueduct study area. Sampling by DHFWD from early April to late May 2000 upstream of Key Bridge yielded 149 striped bass including mature fish ranging in size up to 1,125 mm.

5.1.2 White Perch (*Morone americana*):

General

The white perch also belongs to the family Percichthyidae, or temperate basses. It is closely related to other *Morone* species such as the striped bass. Typical adult size range is 165-190 mm, but they can reach 300 mm and 0.5 kg. Food items range from zooplankton (larvae) to benthic invertebrates (juveniles) to fish for larger adults. The white perch is one of the most abundant species in Chesapeake Bay, and supports significant commercial and recreational fisheries.

Distribution

The white perch is found in brackish water along the eastern seaboard from Nova Scotia south to the Carolinas, and in coastal freshwater ponds and lakes. It is also present in Lake Ontario, which it may have reached through man-made canals. The white perch occurs throughout the upper Chesapeake Bay and tributaries, and in most lower Bay tributaries. This includes essentially the entire Potomac River for adults, and the area from Breton Bay upstream past Washington, including the Washington Aqueduct site, for spawning and nursery activities. They were among the most abundant species captured in the river by DHFWD in 2000, including over 900 individuals collected in Rock Creek.

Habitat Requirements

Adults exhibit schooling behavior and utilize a variety of habitats ranging from areas with substantial structure cover to areas with little or no cover. They may occupy depths up to 9 meters during daylight, but are near the surface (sometimes in schools) during the night. Larvae and juveniles inhabit shallow inshore waters over silt or mud bottoms, sometimes among vegetation, and in schools. Temperature tolerance varies with population, but Chesapeake Bay white perch typically prefer temperatures between 28 and 31 C. The species generally avoids DO levels less than about 6 mg/L. Egg, larval, and juvenile white perch occupy areas of low salinity, sometimes freshwater. Larvae and juveniles prefer salinities of 1.5 to 3.0 ppt, and adults typically are found in salinities of 5-18 ppt. Laboratory experiments showed that suspended sediment concentrations of 100 to 500 mg/L delayed egg hatching by up to 6 hours, and concentrations of 1,000 mg/L significantly reduced egg hatching success. Suspended sediment concentrations as low as 750 mg/L have been shown to be lethal to larvae. See Section 4.X for a discussion of natural Potomac River total suspended solids (TSS) concentrations. Deposition of sediment on white perch eggs is considered to be more important than suspended sediment. Little is known about the effects of pH on white perch, but some researchers have postulated that pH as low as 6.0 could be harmful.

Spawning

In the Chesapeake Bay, the white perch is semianadromous, moving from the more brackish reaches of the upper Bay and tributaries upstream to spawn in low salinity or freshwater (0-1.5 ppt optimal). Most spawning occurs over fine gravel or sand in less than 6 meters of water. Peak spawning occurs when the water temperature is between 10 and 16 C between mid-March and May (Figure 5-1). Eggs are demersal and attached, or can be pelagic. Hatching occurs between one and six days after fertilization, depending on temperature. The yolk sac larval stage lasts from 4 to 13 days. Based on published growth rates for Potomac River fish in 1987, a total duration of the larval stage was calculated as 41 days (with 19 mm beginning the juvenile stage). The Washington Aqueduct study area is reported to be within the natural spawning area of the species.

5.1.3 American Shad (*Alosa sapidissima*):

General

The American shad is a member of the herring family (Clupeidae), a primarily marine/estuarine group found throughout most of the world. Sexually mature adults may vary between 300 and 500 mm fork length, with a maximum length for the species reported as 760 mm. Young shad in freshwater feed on small crustaceans and insects, and switch to small shrimp after entering saltwater. Adults are planktivorous, feeding on both algae and zooplankton. The species is anadromous, living in the ocean and returning to freshwater solely for spawning. Historically, American shad supported important commercial and recreational fisheries. However, spawning-stream blockages (dams) and other perturbations in the late 19th and early 20th centuries greatly reduced their numbers. They are currently the subject of intensive restoration programs in the Chesapeake Bay and are under the protection of a 20-year fishing moratorium in Maryland.

Distribution

The American shad is native to the Atlantic coast from Labrador to Florida, and has been successfully introduced on the west coast of the U.S. The species historically spawned in most major tributaries of the Chesapeake Bay, including the Potomac River. Only 15 of 25 Maryland rivers currently have a spawning population of American shad, and most of those are under stress. The Potomac River population is said to be stable but threatened. The reach of the Potomac River from Cobb Island, Maryland upstream to Washington, including the Aqueduct study area, is potential spawning and nursery habitat for American shad.

Habitat Requirements

Owing to their anadromous life style, adult American shad enter the Chesapeake Bay only during the spring for spawning, then return to the ocean. Juveniles spawned in a given year leave the Bay for the ocean primarily from late October through November. Spawning and development of young takes place in relatively shallow, tidal freshwater reaches of tributary streams. Water temperatures between 13 and 26 C are required for development and survival of eggs. Temperatures above 30 C may be detrimental to all life stages. Various studies have demonstrated stress or more serious effects at DO levels below 4 or 5 mg/L. A concentration of 5 mg/L is generally considered a threshold for protection of all life stages. Due to their anadromous life style, American shad are tolerant of a wide range of salinities encountered naturally. Although adults appear to be tolerant of suspended solids, larvae may be sensitive, based on one study documenting reduced larval survival at a suspended solids concentration of 100 mg/L. See Section 4.X for a discussion of natural TSS concentrations in the Potomac River. Based on several laboratory studies, pH values of 6.0 or greater appear to be protective of eggs and larvae.

Spawning

Spawning may takes place anytime between mid-March and early June in Chesapeake Bay tributaries when water temperatures are between 12 and 21 C (Figure 5-1). At any one location, spawning may be of several weeks duration. Spawning takes place primarily in tidal or sometimes non-tidal freshwater in shallow areas with sandy or rocky substrate. Eggs are semidemersal to pelagic, and hatch in 2 to 17 days, depending on temperature. The yolk-sac larval stage is from 4 to 7 days duration and the post-yolk sac stage lasts 21-28 days. The Washington Aqueduct study area appears to have suitable spawning/nursery habitat for American shad. However, the Potomac River shad population is characterized as a "remnant" population with low abundance. The DHFWD collected only five individuals from the study area in 2000, two of which in excess of 400 mm in length may have been sexually mature.

5.1.4 Blueback Herring (*Alosa aestivalis*):

General

The blueback herring is also a member of the family Clupeidae. Mature adults are 250 mm in length or less, but the maximum recorded size was 380 mm. Apparently, both spawning adults and juveniles feed heavily on zooplankton, and adults may also utilize benthic invertebrates. Although less abundant than in past years, the species supports extensive commercial and recreational fisheries in Chesapeake Bay (harvested as "river herring" along with alewife). Blueback herring runs occur in 22 of 25 tributaries to the Chesapeake Bay, including the Potomac River. The Potomac River population is considered "stable."

Distribution

The blueback herring is distributed similar to the American shad, along the eastern seaboard from Nova Scotia to Florida. It is present in nearly every Chesapeake Bay tributary, and also utilizes extensive portions of the upper Bay proper as a nursery ground. It was historically common in the Potomac River from the Wicomico River upstream throughout the Washington, DC region, including the Washington Aqueduct region. While the Potomac River runs are currently considered "stable," certain tributary populations, e.g., Wicomico and Port Tobacco Rivers, are very low in abundance and considered remnant populations.

Habitat Requirements

Adult blueback herring spawn in fresh to slightly brackish water in the upper reaches of Chesapeake Bay tributaries. They tolerate a variety of physical habitats in their spawning reaches. The species is acclimated to the natural temperature regimes of the Bay, but there appears to be an upper limit of about 30 C for protection of young life stages. A DO concentration of at least 5.0 mg/L is considered necessary for protection of juveniles and adults. DO requirements of eggs is not known. All life stages are tolerant of a wide range of salinities.

Egg and larval blueback herring are rather sensitive to pH. Based on laboratory studies, pH values as high as 6.7 had some detrimental effects, depending on aluminum concentrations. Suspended solids concentrations of 1,000 mg/L did not impair egg hatching. Larvae may be more sensitive to suspended solids than eggs, but effects could not be separated from pH in available studies.

Spawning

Adult blueback herring migrate into the low salinity upper reaches of Chesapeake Bay tributaries to spawn. Spawning populations are thought to be discrete for each tributary stream, but some straying of spawning stock may occur. The optimum temperature range for spawning is 21.0 to 25.5 C which, in recent years, equates to the period mid-May into early June (Figure 5-1). Eggs are essentially pelagic, and hatch in 2 to 4 days depending on temperature. The yolk-sac larval stage lasts 2-3 days. The time from hatching to transition to the juvenile stage is unknown, but may be similar to that of the American shad, 25-35 days. The Washington Aqueduct area appears to meet spawning and nursery habitat requirements for blueback herring. In the Aqueduct vicinity, there is a stable remnant population in the Anacostia River. Reports of the species' probable extirpation from Rock Creek (Funderburk et al. 1991) appear inaccurate or dated since 203 individuals were collected from Rock Creek by DHFWD in 2000. An additional 276 individuals were collected from the river in the Aqueduct study area.

5.1.5 Alewife (*Alosa pseudoharengus*):

General

The alewife is also of the family Clupeidae (herrings), and is similar to the blueback herring, with which it is combined in commercial and recreational landings as "river herring." Adult alewives in the Chesapeake Bay average 230-250 mm in length, but can reach 380 mm. Larvae, juveniles, and adults are planktivorous, but adults also feed on benthic invertebrates. Although less abundant than in past years, the species supports extensive commercial and recreational fisheries in Chesapeake Bay (harvested as "river herring" along with blueback herring). The species occurs in 22 of 25 Chesapeake Bay tributary streams, including the Potomac River. The Potomac River runs are reported to be declining.

Distribution

Coastal populations exist from Newfoundland to South Carolina. Landlocked populations have become established in a number of locations including the Great Lakes. The species is common in the mid-Atlantic and Chesapeake Bay. The species distribution in the Bay is virtually identical to that of the blueback herring. The Potomac River contains suitable habitat from the Wicomico River upstream to Little Falls, including the Washington Aqueduct region. A number of discrete tributary populations in the Potomac have declined or disappeared. Near the Washington Aqueduct site, there appears to be a stable remnant population in Rock Creek. This is consistent with the collection of 785 individuals in Rock Creek by DHFWD in 2000.

Habitat Requirements

Alewife utilize the tidal freshwater reaches of Bay tributaries for spawning and development of young. Water temperature is important to all life stages. The majority of eggs in the upper Chesapeake Bay were collected at temperatures between 12 and 14 C. At incubation temperatures below 11 C, the majority of hatched larvae were deformed. Depending on acclimation temperature, upper temperatures as low as 28.4 C resulted in significant egg mortality. The upper temperature tolerance of yolk-sac larvae is about 31 C. Based on several studies, reported preferred and optimum temperatures for juveniles fell between 15 and 23 C. Reported upper lethal temperatures for juveniles and adults at summer acclimation temperatures ranged from 30 to 35 C. Limited data on dissolved oxygen requirements indicate that concentrations of 5 mg/L for eggs and larvae and 3.6 mg/L for juveniles and adults are protective. Mortalities have been observed in the laboratory at DO concentrations of 2.0-3.0 mg/L. Based on the documented locations of spawning and rearing, salinities of 5.0 ppt or less are required. Conversely, juveniles and adults are tolerant of a wide range of salinities. Although some laboratory data suggest no effect of pH 4.5 on young life stages, other tests, which included concentrations of available aluminum, reported mortality at pH 4.5. Based on limited information, it appears that pH $\geq$6.0 are protective. One available study on the effect of suspended solids indicated that concentrations of 50-1,000 mg/L had no effect on egg hatching success. Based on documented spawning sites, physical habitat is not important, except that sluggish flows are preferred.

Spawning

The species spawns in sluggish, tidal freshwater streams over a variety of substrates. They typically travel farther upstream to spawn than blueback herring. Most spawning takes place at water temperatures between 10 and 22 C. A range of 11.0-19.0 C has been reported for spawning in the Patuxent River. Based on recent Potomac River temperatures, spawning would have taken place between mid-March and early May (Figure 5-1). Eggs are semidemersal to pelagic, and take about 6 days to hatch at 15.6 C. The yolk-sac stage lasts 2-5 days, and the complete transition from hatching to juvenile stage may be similar to the American shad, 25-35 days. The portion of the Potomac River from the Wicomico River upstream to the District of Columbia (including the Washington Aqueduct area) provides suitable spawning and nursery habitat. However, as noted above, the Potomac River alewife runs are in decline. The closest reported for the Aqueduct area is a stable remnant population in Rock Creek. There may be other populations in the vicinity, however. In late March 2000, EA field personnel observed people netting "river herring" from Pimmit Run, a small stream entering the river on the right bank near Chain Bridge. River herring is a collective term for alewife and blueback herring, but, given the time of year, these fish were very likely alewives.

5.1.6 Yellow Perch (*Perca flavescens*):

General

The yellow perch is a member of the perch family (Percidae), which is primarily freshwater, and includes the pikeperches (e.g. walleye, sauger) and darters. The typical adult size range is 152-305 mm total length. Larval yellow perch feed on algae and plankton, and adults feed on a variety of invertebrates and fishes including, in Chesapeake Bay, anchovies, killifish, and silversides. Although much less abundant than in past years, the species continues to support modest commercial and sport fisheries in the Chesapeake Bay.

Distribution

The yellow perch is widely distributed throughout the upper Midwestern U.S. and Canada, and down the eastern seaboard to the Carolinas. Although freshwater, the species has become so acclimated to the brackish water in the Chesapeake Bay that they readily move back and forth between brackish and freshwater on spawning migrations. Most upper Bay rivers contain yellow perch, as do the upper reaches of some lower Bay rivers. The species has been reported in the Potomac River from Washington, D.C. downstream to Breton Bay in St. Mary’s County, MD. The species was reported from the project area—both in the river and in Rock Creek—during the year 2000 sampling program by DHFWD.

Habitat Requirements

Adults exhibit schooling behavior and typically inhabit slow-moving near-shore water with some cover, although they may be found at any depth in the Chesapeake Bay rivers. Larvae initially inhabit littoral zones, then migrate offshore into the water column, then back to the littoral zones as juveniles. Water temperatures up to about 30 C are tolerated, with preferred temperatures between 8 and 24 C, depending on life stage. Various levels of dissolved oxygen have been reported as lethal to yellow perch, but 5.0 mg/L is considered a minimum suitable concentration for the species. In the Chesapeake Bay, juvenile and adult yellow perch typically occur at salinities between 5 and 8 parts per thousand (ppt), with an upper limit of about 13 ppt. Spawning takes place in lower salinities, between 0 and 2 ppt. Sediment loading has been shown to affect survival of egg and larval yellow perch. In one study, egg hatching time was delayed 6-12 hours at concentrations up to 500 mg/L suspended sediment, and in another study, that same concentration significantly reduced larval survival after 96 hours. See Section 4.X for a discussion of natural TSS concentrations in the Potomac River. Normal pH levels in Chesapeake Bay are protective of yellow perch, but acid rain runoff in poorly buffered tributaries can be detrimental. A pH of 5.0 appears to be a threshold below which mortality of eggs and larvae is evident.

Spawning

In the Chesapeake Bay, adult yellow perch migrate from downstream tidal reaches into the upper reaches during late winter. Spawning takes place in tidal or non-tidal water with salinities from 0-2.5 ppt. A variety of bottom types is used, including aquatic vegetation. The general spawning temperature range is from 5.0 to 12.8 C, with peak spawning between 8.5 and 11.0 C (Figure 5-1). The peak range is typical of mid-March in most years. Eggs are laid in masses or ribbons on structure such as aquatic vegetation. At peak temperatures, hatching occurs in 20-27 days. The yolk-sac larval stage lasts 3-5 days; no duration was reported for the post yolk-sac larval stage. The Washington Aqueduct area appears to meet the species' requirements for a spawning and nursery area. However, the upstream-most spawning/nursery area has been reported to be downstream of the Aqueduct study area, downstream of the Anacostia River.

5.1.7 Smallmouth Bass (*Micropterus dolomieu*):

General

The smallmouth bass is a member of the sunfish family Centrarchidae. Mature fish may range from under 200 to greater than 400 mm in length. The maximum recorded length was 686 mm. The species is carnivorous throughout its life cycle, cycling from microcrustaceans and insects as fingerlings to crayfish and fish as adults. The smallmouth bass is a freshwater species, only occasionally entering tidal or brackish water.

Distribution

The smallmouth bass was native originally to the Mississippi and Great Lakes drainages in North America. The smallmouth bass, and many other family members have since been transplanted throughout the world, where they are esteemed as sport fish. The species was transplanted to the Atlantic drainages of Virginia, and presumably other mid-Atlantic states, starting in the late 1800s, and has since become widespread in freshwater portions of Chesapeake Bay tributaries. It is primarily an upland species however, and is only occasionally found in tidal freshwater. Sixty-two individuals were collected from the study area in 2000 by DHFWD, or less than one-fifth the number of largemouth bass collected (see below).

Habitat Requirements

The species prefers clear, cool water in streams with some current and riffles, or lakes. Gravel and rock substrates are preferred. Preferred temperatures are reported between 20 and 28 C, and 35 C is reported as an upper lethal temperature. Based on preferred habitat descriptions, the species would be expected to avoid water quality stresses attendant in low dissolved oxygen or pH, or high dissolved solids.

Spawning

The smallmouth bass is a nest-building species that prefers gravel substrate with some current. Silt, clay, and mud substrates are avoided. Spawning takes place in May or June at temperatures between 18 and 27 C (Figure 5-1). Eggs are demersal in the nest and hatch in 2-4 days. As noted above, the species is only an occasional inhabitant of tidal waters, and it is unlikely that any significant spawning activity would take place in the Washington Aqueduct study area.

5.1.8 Pumpkinseed (*Lepomis gibbosus*):

General

The pumpkinseed is another member of the sunfish family Centrarchidae. It is, with the other *Lepomis* species, the classic "sunfish." They may grow to 100-200 mm with a maximum length of 300 mm. Young fish feed on microcrustaceans and insects and progress with growth to snails, clams, and arthropods.

Distribution

This freshwater species was historically found throughout the eastern seaboard from Canada south to Georgia, the Great Lakes drainage, and the upper Mississippi drainage. It has been transplanted widely, particularly in the northwestern US. It is native to the Chesapeake Bay and is common in tidal and non-tidal freshwater and in brackish water. Based on published distribution records, the species is common in the tidal Potomac River at the District of Columbia and Washington Aqueduct study area. This is consistent with the collection of over 800 individuals from the Aqueduct study area during the DHFWD sampling in 2000.

Habitat Requirements

Pumpkinseed prefer calm water over soft or hard substrates, with cover available, particularly aquatic vegetation. Although technically a freshwater species, they are tolerant of brackish water, and often occur well downstream in tidal rivers at salinities up to 10 ppt, and have been recorded at salinities as high as 18.2 ppt. Pumpkinseed have been reported to tolerate pH levels as low as 4.1.

Spawning

The pumpkinseed builds nests and spawns over a range of temperatures from 13 to 28 C, with the optimum range being 21-24 C (Figure 5-1). Based on Potomac River water temperature data for the last four years, peak spawning occurred in the second half of May. Eggs hatch in 48 hours at temperatures of 19.0 to 25.0 C. Based on spawning habits and requirements, the Washington Aqueduct site likely supports spawning of pumpkinseed.

5.1.9 Bluegill (*Lemopis macrochirus*):

General

The bluegill is another sunfish (Centrarchidae) species, similar in body form and somewhat in coloration to the pumpkinseed. Adult size of the bluegill is quite variable, but is usually between 100 and 200 mm in length (VA populations), with a maximum recorded length of 381 mm. The young are planktivores and adults feed primarily on aquatic and terrestrial insects. The bluegill is common in tidal fresh and brackish waters of the Chesapeake Bay.

Distribution

The bluegill was originally native to the Great Lakes, Mississippi, Gulf of Mexico, and lower Atlantic drainages, but has since been transplanted throughout most of the US and many other countries. The species was transplanted into some Chesapeake Bay drainages, including the Potomac River, by the early 20^{th} century, and perhaps earlier. They are now common in many Bay rivers, and there are a number of collection records from the Potomac River near the District of Columbia. The DHFWD reported collecting 172 individuals from the Aqueduct study area in 2000.

Habitat Requirements

Adult bluegill school in clear, shallow water, often associated with aquatic vegetation. The species is tolerant of high temperatures up to 35 C. The species occupies brackish water in Bay tributaries, tolerating salinities up to 14 ppt. Juveniles school in the limnetic zone, and later move to inshore shallows. The species exhibits a moderate tolerance to low pH. Preferred substrates may be soft or hard.

Spawning

The bluegill builds nests in shallow water and spawns when water temperatures are between 17.0 and 27.0 C, primarily in May and June (Figure 5-1), but can spawn into August. Eggs hatch quickly, in 1.3 days at 22.2-23.3 C. The larval stage lasts 3 to 4 weeks. The habitat at the Washington Aqueduct study area, particularly the shallower, lower velocity areas outside of the channel, could support spawning and nursery activity of bluegill.

5.1.10 Channel Catfish (*Ictalurus punctatus*):

General

The channel catfish is a member of the family Ictaluridae, the freshwater, or bullhead, catfishes. Adults are 300-700 mm in length, with a maximum recorded length of 1,202 mm. Young feed on plankton and aquatic insects and juveniles and adults feed on aquatic invertebrates, fishes, other vertebrates, and some plant material. There is some commercial and recreational fishing for the species in Chesapeake Bay.

Distribution

The original distribution of channel catfish was from Canada to the Gulf of Mexico between the Rocky and Appalachian Mountains, and into Florida. The species has since been widely transplanted, including into Chesapeake Bay tributaries. Currently, the channel catfish exists only in the upper Bay from approximately Back River north, and in the Potomac River from approximately Douglas Point upstream beyond the District of Columbia. The species was rather uncommon in the catches of DHFWD in 2000; only 15 individuals were collected from the river and 24 from Rock Creek in the Aqueduct study area. However, the species may be more abundant than these data indicate because it is relatively difficult to collect with the electrofishing and seine gears used by DHFWD.

Habitat Requirements

The channel catfish prefers deeper water with some current, and tolerates clear to turbid water. The young have a strong schooling tendency, and inhabit shallower water. They are relatively tolerant of high water temperatures; adults prefer 33-34 C. The young are also temperature tolerant, with no developmental or lethal effects below about 35 C. They are tolerant of brackish water, have been found up to 21 ppt, but typically inhabit lower salinities (0-2 ppt). Lethal DO concentrations for juveniles are between 0.76 and 0.96 mg/L at 25-35 C. The species is apparently intolerant of low pH.

Spawning

The channel catfish builds nests in protected cover in waters of 0-2 ppt salinity. Spawning takes place between 21.0 and 29.0 C, with 27.0 C being the optimum, from May through July (Figure 5-1). Demersal eggs are laid in the nest in gelatinous masses and take 5 to 10 days to hatch. Spawning of channel catfish in the Potomac River at the Washington Aqueduct site is probably common.

5.1.11 Brown Bullhead (*Ameiurus nebulosus*):

General

The brown bullhead is in the family Ictaluridae with the channel catfish and other allied species. Adults are 140-340 mm standard length and the maximum length recorded was 508 mm. The omnivorous brown bullhead eats microcrustaceans as young, and various invertebrates, algae, and fish as adults.

Distribution

The brown bullhead is native to the Atlantic, Gulf, Mississippi, and Great Lakes drainages, and has been transplanted widely. The species is resident in freshwater and tidal brackish reaches of every Chesapeake Bay tributary, and is generally distributed in the upper Bay proper from Back River north. Potomac River records are numerous from Douglas Point upstream to beyond the District of Columbia. The DHFWD reported collecting 772 individuals from the Potomac and Anacostia Rivers at Washington, D.C., but only 26 of these were from the Aqueduct study area.

Habitat Requirements

The brown bullhead commonly inhabits shallow, muddy waters, and stays close to the bottom substrate. The species likes warm water and can survive temperatures up to 36 C with proper acclimation. It is tolerant of brackish water up to 8-10 ppt salinity. It may be relatively tolerant of low DO; one study reported a lower lethal level of 0.2 mg/L at low temperatures. Based on Virginia records, the species is somewhat tolerant of low pH.

Spawning

Nests are excavated, and spawning takes place between 21.0 and 25.0 C in the late spring in Maryland (Figure 5-1). Eggs hatch in 5 to 7 days. Parental protection is provided for the schooling young for some weeks before dispersal. Spawning is likely in the area of the Washington Aqueduct.

5.1.12 Shortnose Sturgeon (*Acipenser brevirostrum*):

General

The shortnose sturgeon belongs to the ancient family Acipenseridae. Although small for sturgeon, it is a relatively large fish that can grow to over four feet in length and 16.5 kg (36 lb), although most individuals encountered are not this large. It is a long-lived species, with one female reported to have lived 67 years. The species is adapted for benthic feeding and reportedly eats a variety of worms, mollusks, and crustaceans. The shortnose sturgeon is quite rare, and is a Federally-listed endangered species. It is the focus of intensive Federal and state search and monitoring efforts to determine its status in the Chesapeake Bay and tributaries.

Distribution

The historical distribution of the shortnose sturgeon was along the eastern seaboard from the St. Johns River in New Brunswick to the St. Johns River in Florida. Jenkins (1994) cited one valid record of the species in the Chesapeake Bay drainage prior to 1900 (Potomac River at Washington). The species was not again encountered in the Chesapeake Bay area until the 1970s. In 1996, the U.S. Fish and Wildlife Service initiated a Reward Program for reporting of incidental catches of shortnose sturgeon in commercial fishing gear. Approximately 30 specimens have been reported in that program, primarily north of the Bay Bridge. The species has not been documented in the Aqueduct project area. However, resource agency personnel have expressed concern that the shortnose sturgeon may overwinter in the deep channels in the project area (D.C. DHFWD 2001, personal communication).

Habitat Requirements

Little is known about the specific habitat requirements of the shortnose sturgeon. It is found most often in tidal rivers, but may occur from freshwater to the ocean. What is known of the species' life history suggests that deep, turbulent freshwater portions of tidal rivers may be required for spawning, and lower, more brackish reaches of tidal estuaries for overwintering. Juveniles typically inhabit deep river channels upstream of the salt wedge. Pollution, and consequent reduced dissolved oxygen concentrations, has been frequently cited as one possible reason for the disappearance of the species from many rivers. The species' requirements in terms of water quality may be similar to the other species discussed in this document.

Spawning

Shortnose sturgeon are slow to mature, and may take from two to 13 years depending on latitude. Age at first spawning may be anywhere from one to 16 years following maturation. Following initial spawning, they may not spawn again for one to 10 years. Spawning takes place from winter into summer, depending on latitude. A range of 9-12 C is cited as the spawning temperature, which would typically be in March in the Potomac River (Figure 5-1). Newly hatched larvae drift with the current until quiet areas are reached where the yolk sac is absorbed and feeding is initiated.

5.2 POTENTIAL FISH HABITAT IN THE PROJECT AREA

The area of the Potomac River from the Dalecarlia Reservoir Outfall 002 downstream to Theodore Roosevelt Island reflects a variety of aquatic habitats because it is a transition zone. In May 2000, EA scientists floated the entire Aqueduct study reach and recorded qualitative observations of available habitat. Particular note was made of substrate type, submerged and emergent aquatic vegetation, and current. Habitat data and photographs were superimposed on a USGS quad of the study area that was geo-referenced within Autocadd. The resulting Figure 5-2 is included at the end of this report.

At the very upper end of the project area near Outfall 002, the channel is very constricted with turbulent flow over boulder substrate (Figure 5-2). Going downstream, the river gradually widens and deepens, and flow velocities diminish. The widest areas are at the lower end of the project area, just upstream of Theodore Roosevelt Island (~1,000-1,500 ft.). Maximum depths in the project area vary from about 12-ft (MLW) just above Outfall 002 to nearly 60-ft in channel areas near the middle of the project area. Depths tend to be shallower in the lower portion of the project area, although there are a few small pockets of nearly 60-ft deep water. Silt and sand substrates are found in nearshore areas and embayments, particularly in the lower portion of the project area where currents are slower. Submerged aquatic vegetation (SAV) exists in some of the more sheltered nearshore and embayment areas, and is more prevalent in the downstream portion.

In an earlier study of the sediment discharges from the Dalecarlia and Georgetown Reservoirs, Dynamac Corporation (1992) concluded that *bottom sediments are apparently being continually redistributed* by storm-flow/scour events. This creates a very dynamic and generally poor environment for the benthic fauna.

Based on the habitat conditions in the project area, and inferences on the status of the food base from Dynamac Corporation (1992), portions of the area may not be considered high quality fish habitat. The turbulent flows in the upper portion of the project area would preclude use by some species, particularly the sunfishes that prefer quieter water. The dynamic and generally poor benthic fauna described by Dynamac Corporation (1992) would represent a poor food base for some adults and most young of the fish species of concern evaluated. Spawning and nursery activity is likely restricted to those nearshore and embayment areas with finer sediment and some cover such as SAV.

Although portions of the Aqueduct study area appears to represent marginal habitat to some degree, a more appropriate test of habitat value is the degree to which it is utilized by various fish species. Based on the fisheries collections made by the DHFWD in 2000, the area supports (at least during part of the year) a variety of fish species. Thirty-nine species were recorded during 2000, a number of which were common or abundant, including white perch, largemouth bass, alewife, blueback herring, yellow perch, and pumpkinseed. Thus, the available habitat is sufficient to support a relatively diverse and abundant fish community.

5.3 POTENTIAL FOR SEDIMENT-DISCHARGE IMPACTS TO FISH SPECIES OF CONCERN

Potential impacts would be primarily restricted to young life stages of some of the fish species of concern. Juvenile and adult fish are mobile, and would be expected to avoid the discharges if stressed. Larvae and, particularly eggs, would be unable to avoid the sediment plume in the discharge areas. Common species that may spawn in the river include white perch, largemouth bass, pumpkinseed, and, potentially, striped bass. River spawning by alewife, blueback herring, and yellow perch cannot be ruled out, but they are more likely to spawn in Rock Creek. American shad are reported in very low abundance in the river (Klauda et al. 1991), and this makes them particularly vulnerable because they could theoretically spawn in the project area.

The risks to young life stages of fish from the discharges are suspended solids—either in the water column or deposited on the substrate—and elevated aluminum concentrations. Based on literature observations of the effect of suspended solids on fish eggs and larvae (Section 5.1 above), exposure to 100 mg/L appears to be a threshold for effects on some species. This concentration was reported to delay egg hatching in white perch (Setzler-Hamilton 1991) and reduce larval survival in American shad (Klauda et al. 1991). Based on the modeled TSS concentrations during discharge events (Figures 2.3-2 to 2.3-4 and 2.3-7 to 2.3-9), suspended sediment concentrations in the water column exceed the 100 mg/L threshold only very near the discharges. The modeled discharge point concentration of 10,000 mg/L TSS is rapidly diluted such that TSS concentration at Dalecarlia Outfall 002 is below 100 mg/L virtually just beyond the discharge point (Figure 2.3-2). At the Georgetown Outfall 003, the 100 mg/L contour extends downstream about 300 meters (Figure 2.3-7). The elevated TSS concentrations are relatively short lived. Whereas the TSS plume configuration illustrated in Figure 2.3-7 reflects conditions during an approximate 3.5-hour discharge event, within two hours of discharge cessation, all river TSS concentrations are below 100 mg/L (Figure 2.3-8). The small areas of the river involved and short duration of the events should preclude significant impacts on fish or other aquatic organisms from suspended sediment.

Deposition of solids on the bottom may be more important than suspended sediment. The modeling results in Section 2. project some deposition of sediment in the river following the discharges. During spring discharges, incubating eggs that are covered by sediment may be subjected to reduced dissolved oxygen and potentially suffer mortality. The rapid decrease in TSS concentrations downstream of the discharges, evident in the above-referenced figures, is evidence of deposition. Consequently, it is concluded that the bulk of suspended solids fall to the substrate within a reasonably small area near the discharge. Fish eggs or larvae in this area would be at risk due to smothering and reduced dissolved oxygen. However, the area potentially affected represents a small portion of the Aqueduct study area.

Exposure of fish eggs and larvae to aluminum must be considered as a short-duration exposure, since the discharges are flushed through and out of the project area in no more than one-half day. The aluminum criteria document (U.S. EPA 1988) lists LC_{50} concentrations for several fish species ranging from 3,600 to 50,000 µg/L. During a typical 3.5-hour discharge event, such concentrations will exist in a small area for a short period of time. There are several important points to be made when making comparisons between field exposure and laboratory "effects values."

- The LC_{50} values for fish are based on 96 hour continuous exposure to a given concentration (e.g., 3,600 µg/L), whereas exposure to elevated concentrations in the river during a discharge event are expected to last for only a few hours.

- The laboratory experiments which generated these LC_{50} values used laboratory grade aluminum (i.e., dissolved aluminum), whereas the aluminum in the river is dominated by substantially less toxic forms of the metal measured as "total aluminum."

In Section 2., a strong correlation was established between TSS concentrations and total aluminum concentrations. Consequently, using the same TSS model relationships discussed above, and assuming a relatively conservative discharge concentration of total aluminum of 1,500,000 µg/L (Table 2.1-5), a reach of river of approximately 900 meters below the Georgetown Outfall 003 and a very small reach in the immediate vicinity of the Dalecarlia Outfall 003 will exceed the 3,600 µg/L LC_{50} concentration during discharge events. As with TSS concentrations, total aluminum concentrations will rapidly decrease with cessation of discharges. In addition, EPA (1999) has indicated that the dissolved form of metals is most appropriate for determining risk to aquatic organisms. Since dissolved aluminum concentrations measured in the project area were about 15 percent of total concentrations, it is very unlikely that any toxicity would be expressed beyond the immediate vicinity of the Dalecarlia Outfall 002 or beyond 300-400 meters below the Georgetown Outfall 003. Again, river concentrations will be quickly reduced to ambient, or background levels at the conclusion of the approximately 3.5-hour discharge event.

Another perspective on the potential toxicity of aluminum in the Aqueduct discharges is provided by the whole effluent toxicity testing program discussed in Section 3. of this report. Based on 48- and 96-hour testing using fathead minnows and water fleas (*Daphnia magna*), the Aqueduct effluents were not acutely toxic (LC_{50} values > 100 percent effluent).

In summary, there appears to be moderate risk to several fish species of concern from sediment discharges from the project reservoirs when young life stages are present. The primary risk is from deposition of suspended sediment on eggs and larvae, which could affect survival.

5.4 POTENTIAL DISCHARGE MANAGEMENT SCENARIOS TO MINIMIZE IMPACTS TO FISH SPECIES OF CONCERN

As described elsewhere in this report, discharges of sediment from the Dalecarlia and Georgetown Reservoirs are restricted by the NPDES permit to periods when the river flow is equal to or greater than 3.5 billion gallons per day (5,415 cubic feet per second [cfs]), or when the turbidity of the receiving water is equal to or greater than 100 NTU. Presumably, this restriction was incorporated to ensure that sediment discharges took place when the natural sediment load in the river was high, dispersion was quicker, and visual impacts least. On a practical basis, these restrictions have meant that discharges may take place in the spring when the flow/turbidity requirements are more likely. For example, the flow threshold is exceeded 90-95 percent of the time during March-May, but only 15-25 percent of the time during July-Oct.

Notwithstanding the greater probability of acceptable river flows during the spring months, recent operational history indicates that discharges take place primarily during non-spring months. During the calendar years 1996 and 1997, there were 29 discharge events among all of the Dalecarlia and Georgetown basins. Only nine of these (31 percent) took place during spring months (March-May).

There has been growing concern among resource agencies because spring discharges take place during the most biologically sensitive period when fish spawning takes place and young life stages are present. This is clearly illustrated in Figure 5-1, discussed earlier, which shows the spawning periods of species of concern covering the period March into June, or even July. Concern over the potential impacts of sediment discharges on fish and other aquatic resources was most recently discussed by a panel of resource agency personnel (Sutherland 1999). This panel recommended, among other things, that no sediment discharges be made between February 15 and June 15 to protect the important fish spawning period.

After thorough review of the biological issues, as well as the operational needs of the Washington Aqueduct facility, we provide the following recommendations for alterations to the discharge management protocols.

1. **Reduce the flow threshold (below which discharges cannot take place) by 20 percent.**

The new threshold flow would become 2.8 billion gallons per day (4,322 cfs). This would increase the probability of having flows acceptable for discharge by 5 to 10 percent in nearly all months. Such a change would ease the effect of other restrictions (see below) to provide protection during critical biological periods. This would require a revision to the current flow reduction in the NPDES permit.

2. **Eliminate discharges between 15 February and 15 June.**

This recognizes the importance of this period for critical spawning and nursery activity of fish species of concern in the tidal Potomac River in the vicinity of the Aqueduct.

3. **Discharge more slowly using more dilution water.**

Observations of Aqueduct cleaning and discharges suggest that the cleaning of each basin could occur more slowly (e.g., over 5 hours instead of 3 hours), and more water could be used during each cleaning such that discharge concentrations of TSS and aluminum might be substantially lower than the current condition (e.g., 3-10 times more dilute).

4. **Negotiate an agreement with the EPA and pertinent resource agencies to allow discharges during the spring on an emergency basis.**

With revisions to the discharge protocols as described in recommendations 1., 2., 3., and 4. above, the likelihood of a need to discharge during the spring period would be substantially reduced. However, there must be a mechanism whereby a discharge could take place during the spring period on an emergency need basis. This could be a repair situation, or anything that could threaten stable delivery of the potable water from the Washington Aqueduct.

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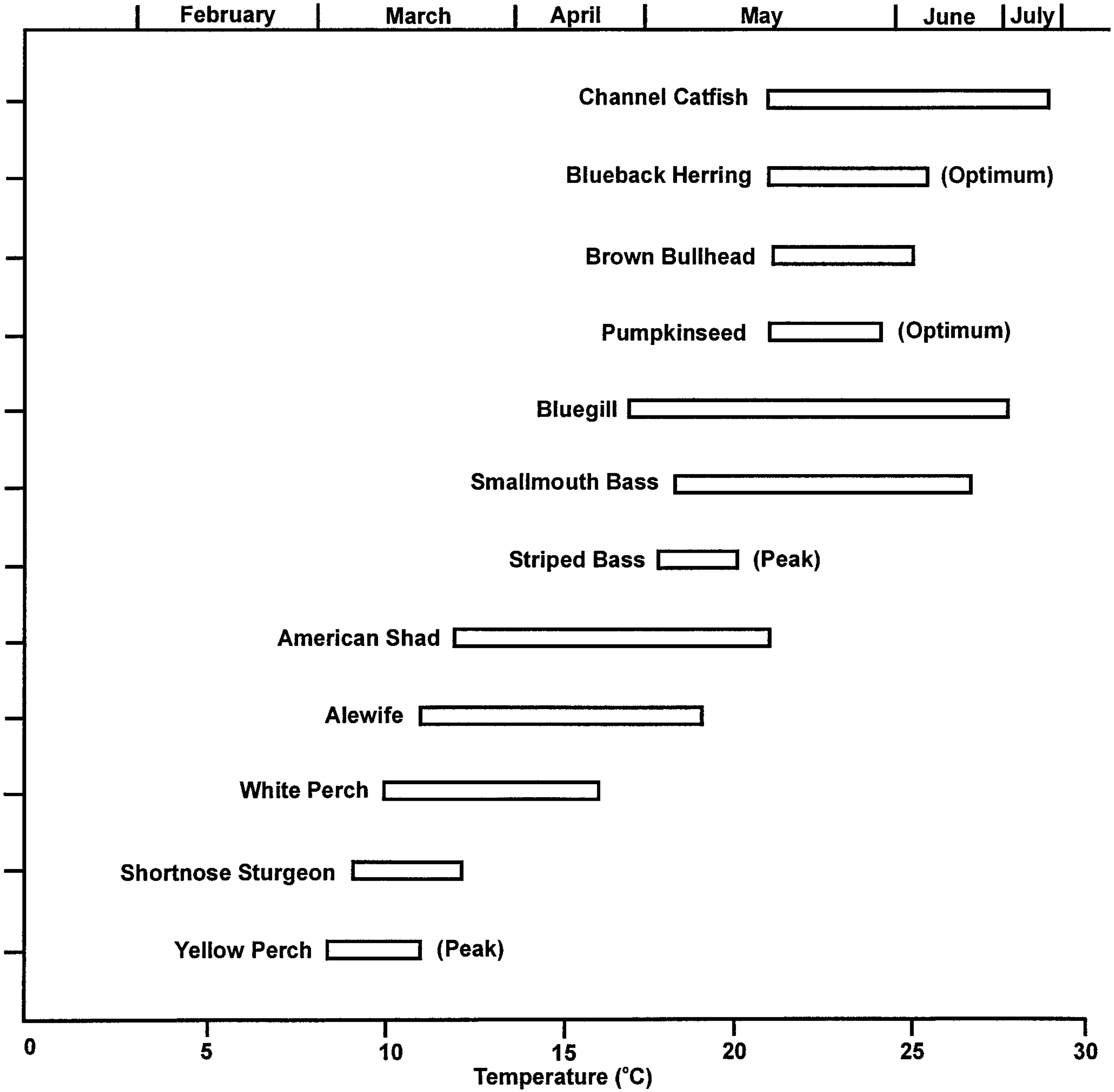

Figure 5-1. Spawning Periods for Fish Species of Concern
(Date-Temperature Relationship Based on Mean Potomac River Temperatures for the Period 1996-1999).

6. BENTHIC MACROINVERTEBRATE COMMUNITY

As presented in the 24 June 1999 Study Plan, the objective of the benthic study was to characterize the macroinvertebrate community before and after a discharge event to determine if effects were observed. In the previous benthic study by Dynamac (1992) a Ponar grab sampler was used to obtain benthic samples but it was determined to be inefficient due to the highly variable quantity of sediment that would be obtained over time from the study area. As noted by the Dynamac researchers,

> "*often…sediment could be collected from a particular location during one survey, and none would be collected during the next survey. The bottom sediments are apparently being continually redistributed, keeping the benthos in a constant state of disturbance*" (Dynamac 1992, p. 68).

Based on this observation, the sampling approach selected for the present study was to set Hester-Dendy artificial substrate samplers at upstream and downstream locations in the Potomac River. Typically, Hester-Dendy samplers are deployed in the euphotic zone (< 1 meter from the water surface) to allow periphyton growth, but to better address the potential impacts associated with the Aqueduct discharge, specifically the potential sedimentation and smothering effect of the benthos, the samplers were set on concrete blocks slightly above the bottom.

6.1 METHODS

The experimental design presented in the EPA-approved Study Plan included upstream versus downstream comparisons, as well as before versus after a solids discharge event from Outfall 003. To accomplish this, two sets of Hester-Dendy samplers with four replicates per set were deployed on 9 March 2000 at each of five locations: one reference site (UP1) located upstream of Outfall 003 and at four downstream locations (DS1, DS2, DS3 and DS4) (Figure 6-1). Upstream and downstream locations were selected to ensure reasonable comparability of key characteristics including river velocity and depth. Matching habitat characteristics at all stations as closely as possible is necessary to minimize benthic community differences due to habitat. A formal habitat assessment was conducted at each station location at the time of site selection and placement. Each Hester-Dendy sampler consists of eight 3 x 3 inch square masonite plates separated from each other by distances of 0.25 to 0.80 cm. These spaces are intended to allow different species of benthic macroinvertebrates to colonize the Hester-Dendy units over time. Two Hester Dendy samplers were attached to each concrete patio block so the plates were horizontal to the substrate and only a few inches above the sediment interface [Photo 6-1]. Each of the four blocks was tethered to a float at each station [Photo 6-2]. All samplers were set in 8 to 10 feet of water (below extreme low tide) with the blocks in close proximity to each other (approximately 5 feet apart). The first set (4 Hester-Dendy samplers) was retrieved on 27 April 2000, 5 days before the 3 May 2000 discharge event; and the second set was collected on 8 May 2000, 5 days after the event. During retrieval, observation of samplers and associated sediment were made for each block. A nylon mesh bag was placed over each sampler before it was removed from the water to prevent loss of organisms [Photo 6-3]. After each block was retrieved the Hester-Dendy samplers were removed from the blocks, each sampler enclosed in the mesh bag was placed in a labeled 1L polyethylene jar, preserved with 10 percent formalin, and transported to EA's Biology Lab for processing.

In the lab, each Hester-Dendy sampler was disassembled, placed in a 500 micron sieve, rinsed to remove the formalin, and gently scraped to remove the debris and organisms. The sieved material was then placed in a gridded dish and with the aid of a microscope all organisms were removed. The organisms were then placed in vials and preserved in 75 percent ethanol until identified by the taxonomist. The organisms were identified to the lowest practical taxon including the chironomid midges and oligochaete worms which were mounted on slides for microscopic viewing.

6.2 RESULTS

The benthic macroinvertebrate results are presented below. Section 6.2.1 presents the pre-discharge data and observations, and Section 6.2.2 presents the post-discharge data.

6.2.1 Pre-Discharge Data

The pre-discharge Hester-Dendy retrieval was conducted on 27 April 2000. During the 49 day colonization period, the Potomac River flows fluctuated between below average, typical high spring flow, and some days above the historical median daily streamflow (25,690 cfs, based on 70 years of U.S.G.S record) (Figure 6-2). The influence that the high river flow and sediment load had on sampler performance will be discussed below. One sampler block at Station DS3 was moved (vandalism or high flow related) approximately 100 feet towards mid-river so the data for replicates A and B are not valid for comparison. The habitat assessment conducted at all stations demonstrated that habitat characteristics were very similar at all locations.

The number of organisms collected at most stations was extremely low at both the upstream reference station (UP1), and the downstream stations.

- The upstream reference area (UP1) had the lowest abundance of any of the pre-discharge stations. Replicate values were 2, 4, 3, and1 with a mean of 2.5 organisms per Hester-Dendy unit.

- The highest abundance was at Station DS4 ranging from 35 to 65 organisms per replicate and the mean number for the four replicates was 49 (Table 6-1). Two of the replicates (on the same block) at DS1 were also high at 64 and 86 organisms but the mean was 43 organisms since the replicates on the other block only had 3 and 18 organisms.

- The other high organism numbers were from the block which was moved approximately 100 feet off-station at DS3, with 120 and 60 organisms, in contrast to the Station DS-3 replicates which were at the original station location which had 5 and 2 organisms.

The Station D53 block with the high organism numbers was moved towards the center of the river and was located behind a large exposed rock formation. Also, when it was retrieved, it was evident that it was resting on hard, probably rock bottom. There was a large number of snails, Gastropoda, on the moved DS3 replicates, which were also found in moderate abundance at Station DS4.

Observations made during retrieval help to explain the differences in abundance between sites and even replicates at the same site. During collection, every attempt was made to retrieve the samplers slowly to prevent the sediment and organisms from being dislodged from the Hester-Dendys as they were brought up from the bottom. As the nylon bags were being slipped over the samplers, (while they were still in the water) it was observed that different amounts of sediments covered the patio blocks and in some cases even the Hester-Dendy samplers. The sediment was very soft and unconsolidated so the amounts could only be estimated assuming that some material probably was sloughing off during retrieval. Some blocks were obviously totally covered with sediment since it took significant effort to break it free from the bottom initially [Photo 6-4]. The replicates with the higher abundance of organisms had approximately ½ inch of sediment on top of the block, which only contacted the bottom plates of the Hester-Dendy units. The DS3 block that was moved only had a thin film of sediment on its concrete surface and none on the sampler plates. The other samplers had 1 to 2 inches of sediment on some blocks and as much as 4 inches at some stations, which was observed covering the entire sampler when retrieved.

RIVER SEDIMENT AMOUNTS OBSERVED ON HESTER-DENDY BLOCKS DURING PRE- AND POST- DISCHARGE SAMPLER RETRIEVAL

	STATION				
DATE	UP1	DS1	DS2	DS3	DS4
27 April 2000	3-4”	0.5 –1”	3”	1-2”	0.5”
8 May 2000	3”	1”	2-3”	2”	0.5”

This sediment was deposited on the sampler at some time(s) during the colonization period, which compromised the sampling efficiency of the artificial substrate samplers and diminishes the value of the data for trend detection. What was clearly demonstrated by this study was that deposition of large amounts of sediment is probably a natural and regularly occurring process in this reach of the Potomac River. During the pre-discharge retrieval, the river was high, very turbid, and there was a notable amount of debris (e.g. logs, sticks) in the water indicating that sediment was probably continuing to be deposited. Even at the upstream reference, (which had up to 4 inches of sediment covering the block) and the stations downriver of Outfall 003, sediment deposition is periodically occurring at a high rate. This part of the river is wider than the area upstream of Fletchers Landing, slower velocity and shallower on the left bank, plus tidally influenced, which can result in deposition of larger amounts of sediment during high flow events.

6.2.2 Post-Discharge Data

Ten days later (five days after the 3 May 2000 discharge event) the second set of Hester-Dendys were retrieved. Station DS4 again had the highest abundance with a mean of 49 organisms, similar to the pre-discharge samples, followed by UP1 with a mean of 14 organisms (Table 6-2) which was somewhat higher than pre-discharge collection (mean of 3 organisms) but still far less than expected for spring time deployment of a Hester-Dendy sampler. Oligochaete worms, which are infaunal organisms adapted to living in sediment, were the dominant organisms at UP1. Station DS1 had considerably fewer organisms than pre-discharge (43 vs 0.3) but mean abundance at the other stations was almost identical (Table 6-1). Considering the close proximity of DS1 to Outfall 003, (40 m downstream) scouring of the substrate as a result of the discharge event *may* account for the lower abundance in the post-discharge sampler. Note that the amount of sediment covering the concrete blocks and Hester-Dendy samplers was very similar to the pre-discharge amounts with no visual evidence between pre and post discharge. There was slightly more sediment at DS1 but only about ½ inch more than in the pre-discharge survey.

RIVER SEDIMENT AMOUNTS OBSERVED ON HESTER-DENDY BLOCKS DURING PRE- AND POST- DISCHARGE SAMPLER RETRIEVAL

	STATION				
DATE	UP1	DS1	DS2	DS3	DS4
27 April 2000	3-4”	0.5 –1”	3”	1-2”	0.5”
8 May 2000	3”	1”	2-3”	2”	0.5”

The number of taxa in the pre- and post-discharge collections exhibited similar trends at most stations (Tables 6-3 and 6-4). Station DS4 had a mean of 13 taxa pre-discharge and 11 taxa post-discharge. In contrast, Station DS1 had a mean of 16 taxa pre-discharge due to the two high replicates and 0.3 taxa post discharge. Station UP1 had a mean number of taxa of 2 in pre-discharge samples and 6 taxa in post-discharge. At DS2 and DS3 the mean number of taxa was less than 4 taxa in the pre and post-discharge samples.

The number of “EPT taxa”, which are pollution sensitive taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), was very low at all stations in both the pre and post-discharge samples. The greatest number of EPT taxa was 2 in some replicates of DS4 during both surveys, and DS1 in one replicate in the pre-discharge survey. Many replicates at the other stations, including at UP1, the upstream reference, had zero EPT taxa in the pre and post-discharge surveys.

The dominant taxa at all stations had “tolerance values” that indicate that most taxa were generally pollution tolerant. Only one taxa, (the snail *Pleurocera* which was a dominant at DS4), was classified as sensitive. Tolerance values were available in the literature for 65 taxa that were collected during both surveys and only 8 of those taxa were considered somewhat sensitive.

6.3 SUMMARY AND CONCLUSIONS

The original intention of the study design was to compare downstream conditions against upstream (reference area) conditions; <u>and</u> to compare the after discharge data to the before discharge data. The observations and conclusions from this study are as follows:

The substrate in the study area consists of areas of sand, mud, boulders and bedrock. Large bedrock formations were evident along the shoreline and also out in mid-river where they were above the water surface during low tide. The softer sediments are in patches between or on these rock substrate areas. The sediment depth varies substantially as evidenced by the Dynamac

(1992) study which noted that at some locations it required several grabs with a Ponar sampler to fill a sample jar. They also noted that the amount of sediment present was highly variable from one sampling event to another as demonstrated by the inability to collect any substrate from a location where it was collected previously. This supports the concept that sediments are apparently being continually redistributed following medium to high flow events which was confirmed by our observations of sediment deposition during the Hester-Dendy study. Based on the pre- and post-discharge collections, a very large load of sediment naturally moves through this segment of the Potomac River during increased flows, and deposits in the wider, slower current velocity reach of the river. This was evident from the downstream stations as well as the upstream reference station (UP-1). These large sediment loads, which resulted before the Georgetown basin discharge event, compromised the resulting dataset that was collected using the Hester-Dendy sampling approach. So much sediment covered some of the Hester-Dendy units that organisms could not colonize the sampler resulting in lower than expected numbers of benthic organisms and taxa. These low numbers of organisms affect the ability to draw strong conclusions from the dataset both from upstream versus downstream and pre- versus post-discharge perspectives.

There was relatively high variability among the four replicates at some stations (e.g., Station DS1 Replicate A = 3 organisms; Replicate D = 86 organisms) which probably was due to the amount of sediment deposition on different samplers, which further complicated interpretation. It could be concluded that differences that did exist between upstream and downstream stations also were related to variable natural sediment deposition. Pre-discharge samples from UP1, which was covered with sediment, had a mean abundance of 2.5 compared to DS4 with 49 organisms, which had the least sediment deposition. DS4 is located in an area approximately 960 meters downstream of the Outfall 003 discharge, around a slight bend in the river where sediment deposition is not occurring at the same rate due to river hydrology characteristics which differ from the other stations.

The benthic community was very similar in the samples collected during the pre- and post-discharge surveys. Based on modeling and dye studies, the Hester-Dendy locations were expected to be in varying concentrations of the discharge plume. The only station where a difference was evident was at DS1 where pre-discharge mean abundance was 43 compared to post-discharge abundance of 0.3 organisms. This station had the highest between replicates variability (3 to 86 organisms) in the pre-discharge survey. DS1 is closest to Outfall 003 which may have resulted in scouring effects on the benthos reducing abundance in the post-discharge samplers, but this conclusion is only tentative considering the pre-discharge replicate variability.

The benthic community that was collected in the Hester-Dendy study (including replicates not covered by sediment) consisted of tolerant taxa which is a consequence of the rigorous naturally occurring environmental conditions they are exposed to on a periodic but regular basis. It is clear that a large sediment load goes through this area and the benthic community that is adapted to these conditions continues to exist. This can be placed into perspective using the information presented in Section 4.3.2 and Table 4-5 of this report. Based upon a 19 year historical dataset, the upper 10^{th} percentile daily sediment load value (24,174,000 kg/d) measured at the upstream end of the study area is approximately 157 times higher than the sediment load released from a typical discharge at Outfall 003 (24,174,000/153,600); and 1,358 times higher than the sediment load released from a typical discharge at Outfall 002 (24,174,000/17,800). Thus, the benthic community experiences a substantially larger sediment load from naturally occurring high-flow depositional events on a seasonal or periodic basis. Further, this tolerant community does not appear to differ based on the present study's upstream versus downstream station comparison. These results are generally consistent with the Dynamac (1992) study using a different sampling technique but also finding a tolerant benthic community. Based on our observations during this benthic study, interpretation of existing river and discharge sediment load data, and supporting information from past studies, intermittent Dalecarlia and Georgetown discharge events are not expected to have a substantial or cumulative impact on the tolerant benthic community present in this reach of the Potomac River.

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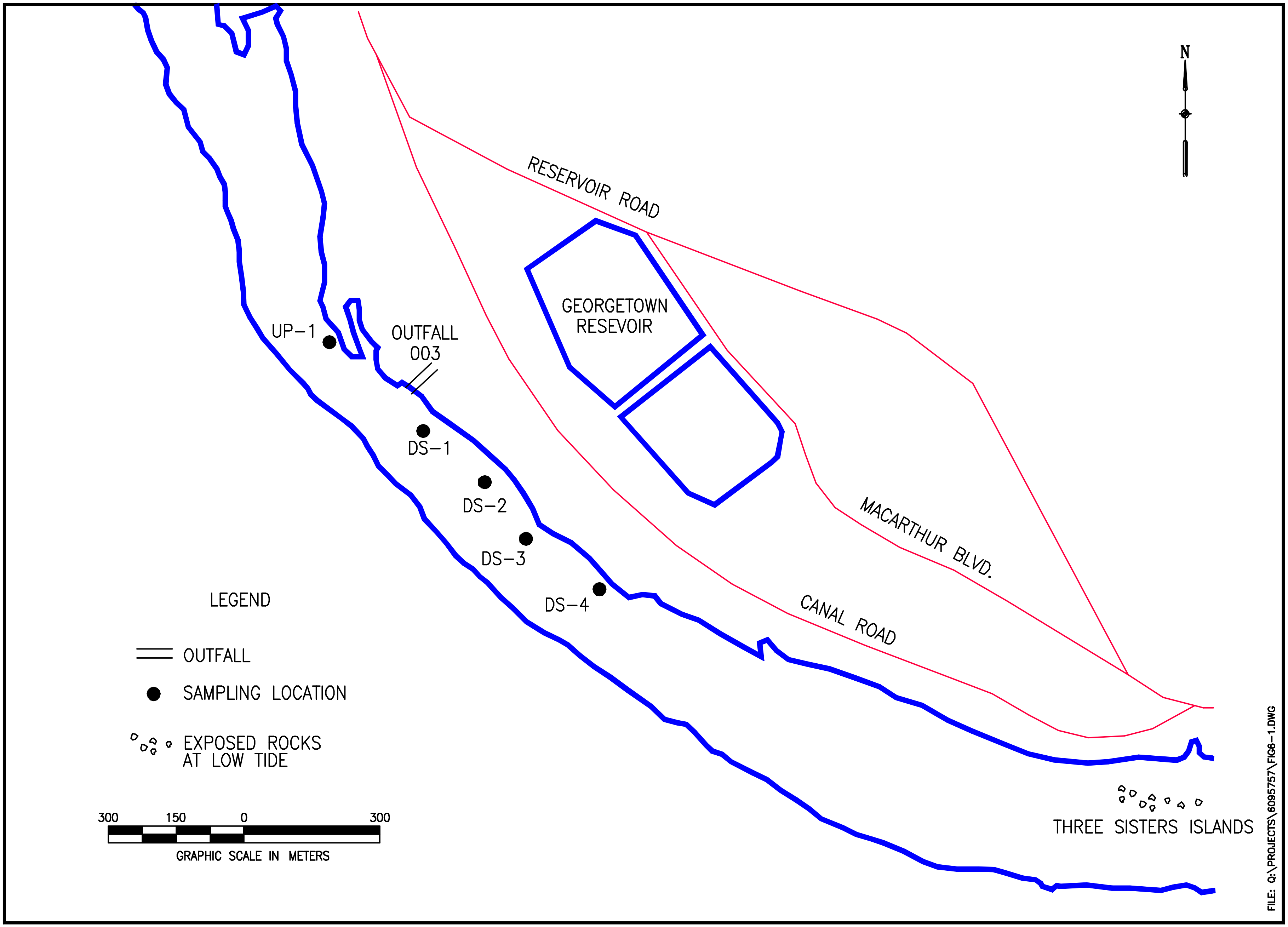


Figure 6-1. Locations of the Benthic Sampling Stations in the Vicinity of Outfall 003, April and May 2000

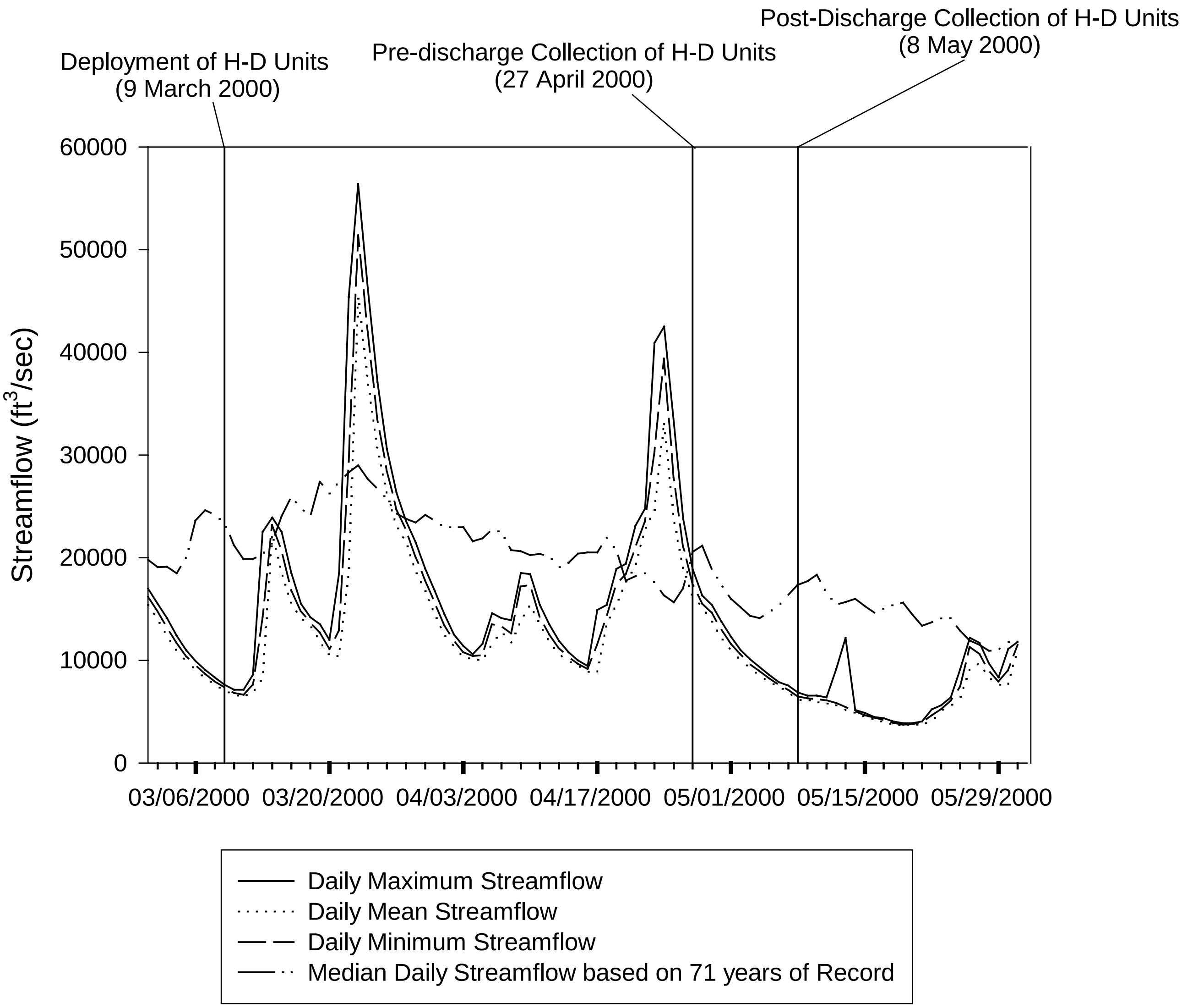


Figure 6-2. Potomac River flows (at Little Falls) for the benthic community study.

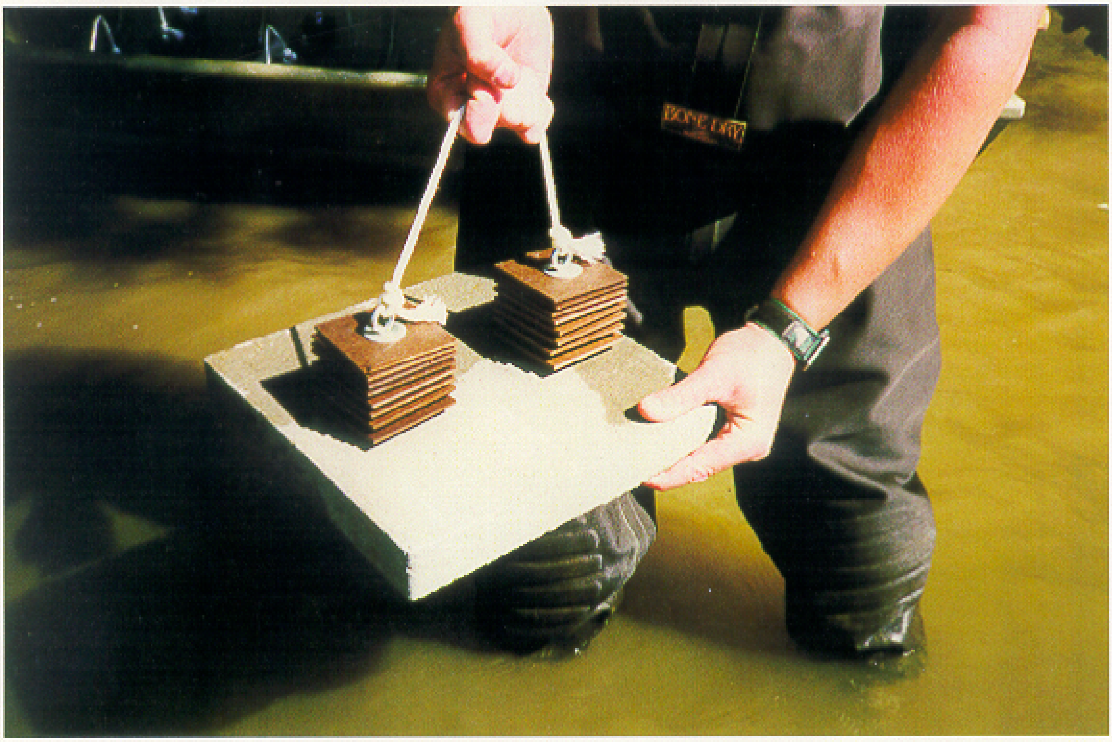


Photo 6-1. Hester-Dendy units on concrete block before placement.

Photo 6-2. Hester-Dendy marking at DS-2, (3-10-00).

Photo 6-3. Hester-Dendy upstream location, (5-8-00).

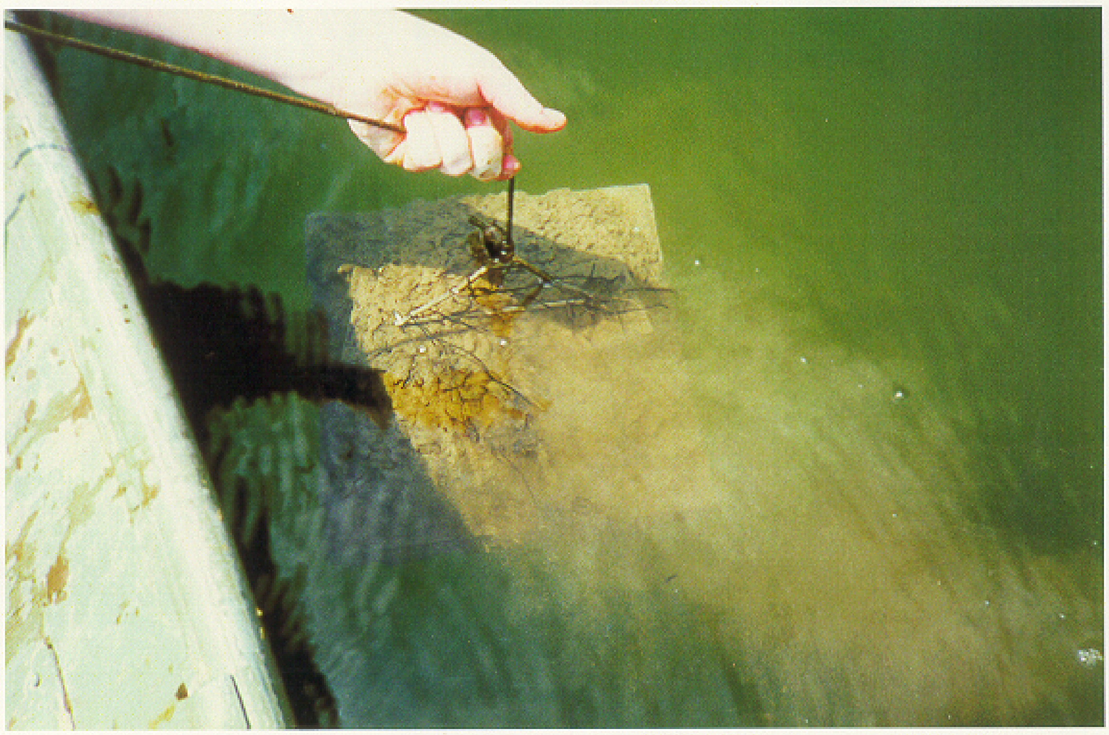


Photo 6-4. Gentle H-D removal at DS-3, (5-8-00).

TABLE 6-1 NUMBER OF BENTHIC MACROINVERTEBRATES COLLECTED ON 27 APRIL 2000 (PRE-DISCHARGE) CLASSIFIED BY MAJOR TAXONOMIC GROUP

	STATIONS																			
	UP1				DS1				DS2				DS3				DS4			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Nemertea	2	--	1	--	--	--	1	2					1	--	--	--	--	--	--	1
Oligochaeta	--	2	--	--	--	8	7	16	5	3	2	--	20	2	2	1	--	--	11	8
Hirudinea					1	1	1	--												
Gastropoda					--	2	2	4					40	43	--	--	11	21	11	9
Isopoda					--	2	4	4					3	--	--	--	--	1	--	1
Amphipoda					--	--	11	32					34	7	--	--	10	31	14	14
Hydrocarina	--	--	1	--	--	--	--	1	--	--	4	--								
Ephemeroptera					--	2	19	10					7	2	--	--	4	4	2	1
Odonata					--	--	3	1					1	1	--	--				
Trichoptera					--	--	--	1					2	--	--	--	--	1	--	--
Coleoptera					1	--	8	5					2	--	1	--				
Chironomidae	--	2	1	1	1	3	8	10	--	1	--	1	10	5	2	1	10	7	24	1
TOTAL	2	4	3	1	3	18	64	86	5	4	6	1	120[a]	60[a]	5	2	35	65	62	35
Mean	2.5				42.8				4.0				3.5				49.3			

(a) Data not valid for comparison because the samples were moved to a different location (mid-stream).

TABLE 6-2 NUMBER OF BENTHIC MACROINVERTEBRATES COLLECTED ON 8 MAY 2000 (POST-DISCHARGE) CLASSIFIED BY MAJOR TAXONOMIC GROUP

	STATION																			
	UP1				DS1				DS2				DS3				DS4			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Nemertea									1	--	--	--								
Oligochaeta	9	11	5	4					7	2	7	3	1	2	--	3	--	2	4	3
Hirudinea																				
Gastropoda	1	1	--	1									--	--	--	3	9	10	8	7
Isopoda	7	--	--	--																
Amphipoda	--	--	2	--													34	46	30	20
Hydrocarina									2	--	--	--								
Ephemeroptera	3	--	--	1									2	--	--	1	5	2	--	1
Odonata													--	--	--	1	1	--	--	1
Trichoptera																	--	1	--	--
Coleoptera	5	1	--	--													--	--	1	1
Chironomidae	1	2	--	2	--	1	--	--	--	1	--	--					1	2	6	2
TOTAL	26	15	7	8	0	1	0	0	10	3	7	3	3	2	0	8	50	63	49	35
Mean	14.0				0.3				5.8				3.3				49.3			

TABLE 6-3 NUMBER OF BENTHIC MACROINVERTEBRATES COLLECTED ON 27 APRIL 2000 (PRE-DISCHARGE)

	STATION																			
Taxa	UP1-A	UP1-B	UP1-C	UP1-D	DS1-A	DS1-B	DS1-C	DS1-D	DS2-A	DS2-B	DS2-C	DS2-D	DS3-A	DS3-B	DS3-C	DS3-D	DS4-A	DS4-B	DS4-C	DS4-D
	2		1																	
Prostoma sp.																				1
Eclipidrilus sp.							1	2					1							
Enchytraeidae							1													
Arcteonais lomondi		1																		
Chaetogaster limnaei																				7
Dero sp. (inc.)													1							
Nais communis						1		1					3						8	
Nais pardalis							1	2					1						1	
Nais variabilis										1			2						1	
Nais sp. (inc. spec.)								1												
Paranais litoralis															1					
Pristina leidyi								3												
Slavina appendiculata						7	2	4					6							
Specaria josinae								1												
Stylaria lacustris							1	2					4	2					1	1
Aulodrilus pigueti																				
Branchiura sowerbyi											1									
Ilyodrilus templetoni															1					
Quistadrilus multisetosus							1	1					2							
Limnodrilus hoffmeisteri		1							3							1				
Immature with hair chaetae									1				1							
Immature without hair chaetae							1	1	1	2	1									
Desserobdella phalera					1	1	1													
Laevapex fuscus																		2		
Laevapex diaphanus																	1			
Ferrissia sp.						1								1						
Physella sp.								1										1		1
Gyraulus deflectus?																				
Menetes dilatatus													1							
unid. planorbid (inc.)																				1
Bithynia tentaculata																	1	3	2	2
Amnicola limosa							1	1					2							
unid. hydrobiid (inc.)								1												
Pleurocera sp.						1	1	1					37	42			9	15	9	5
Caecidotea sp.						2	4	4					3					1		1
Gammarus fasciatus								2					3				4	16	2	2
Gammarus pseudolimnaeus																			2	
Gammarus sp. (imm.)							11	30					31	7			6	15	10	12
Koenikea sp.			1								4									
Unionicola sp.								1												
Caenis sp.						2	19	10					7	1					1	
Leucrocuta sp.																				
Stenacron interpunctatum														1			3	4	1	1
Stenonema sp.																	1			
Argia tibialis													1							

TABLE 6-3 NUMBER OF BENTHIC MACROINVERTEBRATES COLLECTED ON 27 APRIL 2000 (PRE-DISCHARGE)

	STATION																			
Taxa	UP1-A	UP1-B	UP1-C	UP1-D	DS1-A	DS1-B	DS1-C	DS1-D	DS2-A	DS2-B	DS2-C	DS2-D	DS3-A	DS3-B	DS3-C	DS3-D	DS4-A	DS4-B	DS4-C	DS4-D
Coenagrion/Enallagma sp.																				
Enallagma sp.							1	1												
unid. coenagrionid (early instar)							2													
Neurocordulia obsoleta														1						
Ceraclea sp.								1					1							
Neureclipsis sp.													1							
Polycentropus sp.																		1		
Dubiraphia sp.							1	1												
Macronychus glabratus													1							
Stenelmis sp.					1		5	4					1		1					
Berosus sp.							1													
Psephenus herricki							1													
Ablabesmyia sp.							1	1					3	1			1	3	1	
Brillia sp.																			1	
Cardiocladius sp.								1												
Chironomus sp.						1							1				1			
Cladotanytarsus mancus-gr.							1													
Clinotanypus sp.							1								1					
Corynoneura sp.																		1	2	
Cricotopus bicinctus																				
Cricotopus sp.				1																
Cryptochironomus sp.																				
Dicrotendipes sp.										1										
Endochironomus subtendens																	1	1		
Eukiefferiella sp.			1																	
Micropsectra																	1			
Nanocladius crassicornis																			3	
Nilotanypus sp.							1							1						
Parakiefferiella sp.																	2		7	
Paralauterborniella sp.								2												
Paratendipes albimanus-gr.						1		1												
Polypedilum		1					4	2					4	2	1		4	2	9	1
Procladius sp.								1					1			1				
Tanytarsus sp.		1			1			1					1							
Tanytarsus sp. (pupa)														1						
Unid. Chironomini - inc.								1												
Unid. Orthocladiinae - inc.												1								
Chironomidae - no head						1													1	
TOTAL BENTHOS	2	4	3	1	3	18	64	86	5	4	6	1	120	60	5	2	35	65	62	35
TOTAL TAXA	1	4	3	1	3	9	25	28	2	3	3	1	27[(a)]	11[(a)]	5	2	13	13	17	10
EPT TAXA	0	0	0	0	0	1	1	2	0	0	0	0	3[(a)]	2[(a)]	0	0	2	2	2	1

(a) Data not valid for comparison because the samplers were moved to a different location (mid-stream).

TABLE 6-4 NUMBER OF BENTHIC MACROINVERTEBRATES COLLECTED ON 8 MAY 2000 (POST-DISCHARGE)

	STATION																			
Taxa	UP1-A	UP1-B	UP1-C	UP1-D	DS1-A	DS1-B	DS1-C	DS1-D	DS2-A	DS2-B	DS2-C	DS2-D	DS3-A	DS3-B	DS3-C	DS3-D	DS4-A	DS4-B	DS4-C	DS4-D
									1											
Prostoma sp.																				
Eclipidrilus sp.																				
Enchytraeidae	1																			
Arcteonais lomondi		1																		
Chaetogaster limnaei																				
Dero sp. (inc.)																				
Nais communis																		1		
Nais pardalis																				
Nais variabilis																				
Nais sp. (inc. spec.)																			1	
Paranais litoralis																				
Pristina leidyi																				
Slavina appendiculata																				
Specaria josinae																				
Stylaria lacustris																		1	2	3
Aulodrilus pigueti		1																		
Branchiura sowerbyi																				
Ilyodrilus templetoni			1								1		1							
Quistadrilus multisetosus	1																			
Limnodrilus hoffmeisteri		1	2	2					5	2	3	2		2						
Immature with hair chaetae	2	1														1				
Immature without hair chaetae	5	7	2	2					2		3	1				2			1	
Desserobdella phalera																				
Laevapex fuscus																			1	
Laevapex diaphanus																				
Ferrissia sp.																				
Physella sp.	1																	1		1
Gyraulus deflectus?																		1		
Menetes dilatatus																				
unid. planorbid (inc.)																				
Bithynia tentaculata																		3		1
Amnicola limosa		1		1												2			1	2
unid. hydrobiid (inc.)																				
Pleurocera sp.																1	9	5	6	3
Caecidotea sp.	7																			
Gammarus fasciatus			2														14	17	16	11
Gammarus pseudolimnaeus																				
Gammarus sp. (imm.)																	20	29	14	9
Koenikea sp.									2											
Unionicola sp.																				
Caenis sp.	3			1									2			1				
Leucrocuta sp.																	2			
Stenacron interpunctatum																	3	2		1
Stenonema sp.																				
Argia tibialis																				

TABLE 6-4 NUMBER OF BENTHIC MACROINVERTEBRATES COLLECTED ON 8 MAY 2000 (POST-DISCHARGE)

	STATION																			
Taxa	UP1-A	UP1-B	UP1-C	UP1-D	DS1-A	DS1-B	DS1-C	DS1-D	DS2-A	DS2-B	DS2-C	DS2-D	DS3-A	DS3-B	DS3-C	DS3-D	DS4-A	DS4-B	DS4-C	DS4-D
Coenagrion/Enallagma sp.																1				
Enallagma sp.																	1			1
unid. coenagrionid (early instar)																				
Neurocordulia obsoleta																				
Ceraclea sp.																		1		
Neureclipsis sp.																				
Polycentropus sp.																				
Dubiraphia sp.	1	1																		
Macronychus glabratus																			1	1
Stenelmis sp.	4																			
Berosus sp.																				
Psephenus herricki																				
Ablabesmyia sp.																			1	
Brillia sp.																				
Cardiocladius sp.																				
Chironomus sp.	1																			
Cladotanytarsus mancus-gr.																				
Clinotanypus sp.																				
Corynoneura sp.																				
Cricotopus bicinctus				2		1												1		
Cricotopus sp.																				1
Cryptochironomus sp.										1										
Dicrotendipes sp.																				
Endochironomus subtendens																				
Eukiefferiella sp.																				
Micropsectra																				
Nanocladius crassicornis																				
Nilotanypus sp.																				
Parakiefferiella sp.																			1	
Paralauterborniella sp.																				
Paratendipes albimanus-gr.																				
Polypedilum																	1	1	1	1
Procladius sp.		2																	3	
Tanytarsus sp.																				
Tanytarsus sp. (pupa)																				
Unid. Chironomini - inc.																				
Unid. Orthocladiinae - inc.																				
Chironomidae - no head																				
TOTAL BENTHOS	26	15	7	8	0	1	0	0	10	3	7	3	3	2	0	8	50	63	49	35
TOTAL TAXA	9	6	3	4	0	1	0	0	3	2	2	1	2	1	0	6	7	12	13	12
EPT TAXA	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	2	2	0	1

7. SUMMARY AND CONCLUSIONS

The Washington Aqueduct produces drinking water for approximately one million citizens in the District of Columbia, Arlington County, VA, and the City of Falls Church, VA and its service area. Raw river water is obtained from the Great Falls Raw Water Intake or the Little Falls Pumping Station on the Potomac River. This water flows through the Dalecarlia Reservoir and is then diverted for settling to either the Dalecarlia plant or the Georgetown Reservoirs. As allowed in the Aqueduct's NPDES permit, residual solids from the Dalecarlia plant sedimentation basins are periodically discharged to the Potomac River through Outfall 002, which is located upstream of Chain Bridge. Residuals from Georgetown Reservoir Basins 1 and 2 and are periodically discharged to the Potomac River via Outfalls 003 and 004.

A water quality study was developed to be responsive to a series of specific technical issues raised by staff from U.S. EPA and the District of Columbia's Department of Health. A formal Aqueduct study plan (dated 24 June 1999) was developed and approved by U.S. EPA. This report presents the results from those studies and includes discussions of: effluent dilution and fate modeling, effluent toxicity testing and chemical characterizations, discussions of fisheries issues, and the results of a field program to evaluate the benthic macroinvertebrate community. The findings from these efforts are summarized below.

7.1 EFFLUENT FATE AND TRANSPORT MODELING

A key part of the program was to determine acute and chronic dilution factors for the Aqueduct discharges, and to examine the fate of released solids as they travel downstream. Modeling studies used the Surfacewater Modeling System (SMS), which includes the U.S. Army COE – supported models RMA2, RMA4, and SED2D. The model extended 8.0 km from Outfall 002 (upstream of Chain Bridge), downstream to below Roosevelt Island, and contained a total of 2,021 elements and 6,281 nodes.

Plume mapping studies were conducted at Outfall 002 (Dalecarlia Basin) and Outfall 003 (Georgetown Reservoir). At each outfall, a Rhodamine WT dye-tracer study was performed on the day the reservoir was being drawn down, and a turbidity study was performed the following day during a solids clean-out event.

- At Outfall 002, 22 percent of the total mass discharged passed beyond the downstream end of the model during a 24-hr run. The resulting depositional footprint estimated using the SED2D model was 1-mm thick in the vicinity of the Outfall 002 and decreased to approximately 0.02 mm downstream in the vicinity of Roosevelt Island.

- At Outfall 003, 13 percent of the total mass discharged passed beyond the downstream end of the model during a 24-hr run. SED2D indicated that the resulting depositional footprint typically exceeded 1 mm in the first 350 m, exceeded 0.2 mm for approximately 2,500 m along the shallow near-shore region downstream, and decreased to approximately 0.05 mm in the vicinity of Roosevelt Island.

- To put the Aqueduct releases into perspective, daily Potomac River flows and total suspended solids (TSS) loads measured at Little Falls (upstream) were obtained for the 20-year period, 1980 to 1999. The median (natural) suspended load in the Potomac River for this period was 218,000 kg/day. The 25 May 2000 discharge event from Dalecarlia Basin 3 released approximately 17,800 kg of solids, a value which is exceeded on 90 percent of the days each year by the daily mass of solids in the Potomac River passing Little Falls. The 3 May 2000 discharge event from Georgetown Reservoir released an estimated 153,600 kg of solids. This solids loading from Georgetown Reservoir is exceeded on 55 to 60 percent of the days each year by the daily mass of solids passing Little Falls.

- Based on current regulatory guidance, a chronic mixing zone at Outfall 002 (at the permitted river flow of 153 cms) is limited by the 10 percent cross-section criterion at a dilution factor of 51. Using U.S. EPA’s (1991) 1-hr float time approach, the acute dilution factor is calculated to be 169 in this turbulent and rapidly moving portion of the Potomac River. The complete mix dilution factor for Outfall 002 would be a factor of 1,160.

- At Outfall 003 (Georgetown Reservoir) the chronic mixing zone is limited by the 10 percent cross-section criterion resulting in a dilution factor of 4.3. The 1-hr average exposure associated with acute criterion results in a dilution factor of approximately 2.3. The complete mix dilution factor would be a factor of 136.

- At Outfall 003, acute and chronic dilution factors increase when calculated using TSS rather than a conservative dye tracer. The resulting chronic mixing zone dilution factor was 31.6 and the acute dilution factor (1-hour average exposure) was 8.1.

- Relocation of Outfall 003 to a distance 200-m offshore resulted in an acute (1-hour average exposure) dilution factor of 8.4 and a chronic (10 percent cross-section) dilution factor of 18.6 (conservative dye tracer).

7.2 TOXICITY TESTING

Acute and chronic toxicity tests were performed on effluents collected from the Dalecarlia and Georgetown facilities during normal periodic cleaning operations. As described in the Study Plan, toxicity tests were conducted on three different fractions of the Aqueduct effluent: whole effluent samples (using acute toxicity tests); supernatant from the settled whole effluent (using chronic toxicity tests); and the settled solids portion of the whole effluent (using benthic tests).

- The acute test results indicate that (with one exception) the whole effluent samples collected for the preliminary testing and for Rounds #1 through #4, were <u>not</u> acutely toxic to the test organisms. The 48- and 96-hour LC50 values were >100 percent effluent (TUa <1.0) for *D. magna*, *P. promelas* and *M. saxatilis*. One fathead minnow test showed some level of dose-related acute toxicity, which resulted in a 96-hour LC50 value of 29.3 percent effluent

- The chronic toxicity test results showed that in two of the four rounds, the effluent was not chronically toxic. In the other two rounds, the lowest 7-day chronic value (ChV) for a fish or invertebrate was 35.4 percent effluent. It is noteworthy that 7-day chronic effluent toxicity tests were conducted and reported in the Dynamac (1992) study which showed "*that the effluent released from the sampled sedimentation basins had no effect on either mortality or growth of fathead minnows.*"

- For the benthic testing, the 10-day LC50 values (based on survival) from the four rounds of testing were >100 percent sample, but the effluent concentration causing a reduction in growth (the IC25 value) ranged from 6.9 to 32.8 percent effluent.

Interpretation of these effluent toxicity test results is complicated by the fact that these tests continuously expose the test organisms in the laboratory to a series of effluent concentrations for 2 to 10 days (depending upon the test). In contrast, exposure to the Aqueduct plume is a transient phenomenon which lasts for perhaps 4-8 hours. Using the guidance presented in U.S. EPA's (1991)Technical Support Document for Water Quality-Based Toxics Control, the lowest acute value would require a dilution factor of approximately 11:1 to be non-toxic (i.e., to yield 0.3 TUa); and the lowest chronic value would require a dilution factor of approximately 9.4:1.

The benthic results would suggest that a dilution factor of 14.5 would result in no effect on organism growth. As discussed in Chapter 2, these dilution factors are easily obtained for Outfall 002, but outfall modification or relocation would be required to achieve these dilution factors for the Georgetown Reservoir discharges from Outfall 003.

7.3 EFFLUENT CHEMICAL CHARACTERIZATION

The study summarized the recent chemistry data collected and analyzed by the Aqueduct, and generated additional effluent chemistry data as part of the toxicity testing program. Overall mean total aluminum concentrations for the Dalecarlia and Georgetown basins averaged 2,273 and 1,510 mg/L, respectively, for the period 1997-2001. EA Engineering's data included both total and dissolved aluminum, and indicated that the percentage of *dissolved* aluminum is considerably less than one percent of the total aluminum value in the effluent samples. Although total aluminum concentrations are high, effluent toxicity testing does not suggest that the aluminum in the effluent samples is as bioavailable or toxic as the data used to determine EPA's aluminum criterion would suggest (which requires the use of reagent grade aluminum salts in clean laboratory water).

7.4 FISHERIES ISSUES

Life history information for each of the key species in the Study Plan was assembled and presented in the report, followed by discussions of the potential effects of Aqueduct discharges on the fish community. The report concludes that *potential* impacts to the fishery would be primarily restricted to young life stages of some of the fish species of concern. Juvenile and adult fish are mobile, and would be expected to avoid the discharges if stressed. Larvae, and particularly eggs, however, would be less able to avoid the sediment plume in the discharge areas.

Risks to young life stages of fish from the discharges are from suspended solids (either in the water column or deposited on the substrate) and elevated aluminum concentrations. Studies from this water quality program indicate that a substantial quantity of solids falls to the substrate within a reasonably small area near the discharge (primarily from Outfall 003), and there could be moderate risk to several fish species of concern from sediment discharges when young life stages are present. The primary risk is from deposition of suspended solids onto eggs and larvae (causing smothering and reduced oxygen levels), which could affect survival. However, the area potentially affected represents a small portion of the Aqueduct study area.

Management options to minimize potential impacts on fishery resources are also discussed in the report. These include:

- Eliminating discharges between 15 February and 15 June of each year to avoid spawning and nursery periods (which would require a revision to the existing river flow restriction in the NPDES permit).

- Reducing the river flow threshold (below which Aqueduct discharges cannot take place) by 20 percent

- Cleaning and discharging solids more slowly using more dilution water to reduce effluent concentrations and maximize the assimilative capacity into the River

- Negotiating an agreement with the EPA and pertinent resource agencies to allow discharges during the spring on an emergency basis

7.5 BENTHIC MACROINVERTEBRATE STUDIES

The study design used Hester-Dendy artificial substrate units to allow comparisons between upstream (reference) and downstream benthic organism communities; and to compare the post-discharge benthic data to the before discharge data. The observations and conclusions from this study are as follows:

- The substrate in the study area consists of areas of sand, mud, boulders and bedrock. Large bedrock formations were evident along the shoreline and also out in mid-river where they were above the water surface during low tide. The softer sediments are in patches between or on these rock substrate areas. Sediments are being continually redistributed following medium to high flow events which was confirmed by our observations of sediment deposition during the Hester-Dendy study.

- Based on the pre- and post-discharge collections, a very large load of sediment naturally moves through this segment of the Potomac River during times of increased flows, and deposits in the wider, slower current velocity reach of the river. This was evident at the downstream stations *as well as* the upstream reference station (UP-1). These large sediment loads, which resulted before the Georgetown basin discharge event, compromised the resulting dataset that was collected using the Hester-Dendy sampling approach. So much sediment covered some of the Hester-Dendy units that organisms could not colonize the samplers resulting in lower than expected numbers of benthic organisms and taxa. These low numbers of organisms affect the ability to draw strong conclusions from the dataset both from upstream versus downstream and pre- versus post-discharge perspectives.

- The benthic community was very similar in the samples collected during the pre- and post-discharge surveys. Based on modeling and dye studies, the Hester-Dendy locations were expected to be in varying concentrations of the discharge plume. The only station where a difference was evident was at the first downstream station (DS1) where pre-discharge mean abundance averaged 43 compared to post-discharge abundance of 0.3 organisms. DS1 is closest to Outfall 003, which may have resulted in scouring effects on the benthos reducing abundance in the post-discharge samplers, but this conclusion is only tentative considering the pre-discharge replicate variability.

- The benthic community that was collected in the Hester-Dendy study (including replicates not covered by sediment) consisted of tolerant taxa, which is a consequence of the rigorous naturally occurring environmental conditions they are exposed to on a periodic but regular basis. It is clear that a large natural sediment load is transported through this area and the benthic community that is adapted to these conditions continues to exist. As an example, based upon a 19 year historical dataset, the <u>upper</u> 10th percentile daily sediment load value measured at the upstream end of the study area is approximately 157 times higher than the sediment load released from a typical discharge at Outfall 003, and 1,358 times higher than the sediment load released from a typical discharge at Outfall 002.

- This tolerant community does not appear to differ based on the present study's upstream versus downstream station comparison. Based on our observations during this benthic study, interpretation of existing river and discharge sediment load data, and supporting information from past studies, intermittent Dalecarlia and Georgetown discharge events are not expected to have a substantial or cumulative impact on the tolerant benthic community present in this reach of the Potomac River. These results are generally consistent with the Dynamac (1992) study using a different sampling technique but also finding a tolerant benthic community.

Appendix A

Dye Concentration and Turbidity Data at Transects During the 2, 3, 24, and 25 May 2000 Plume Mapping Surveys

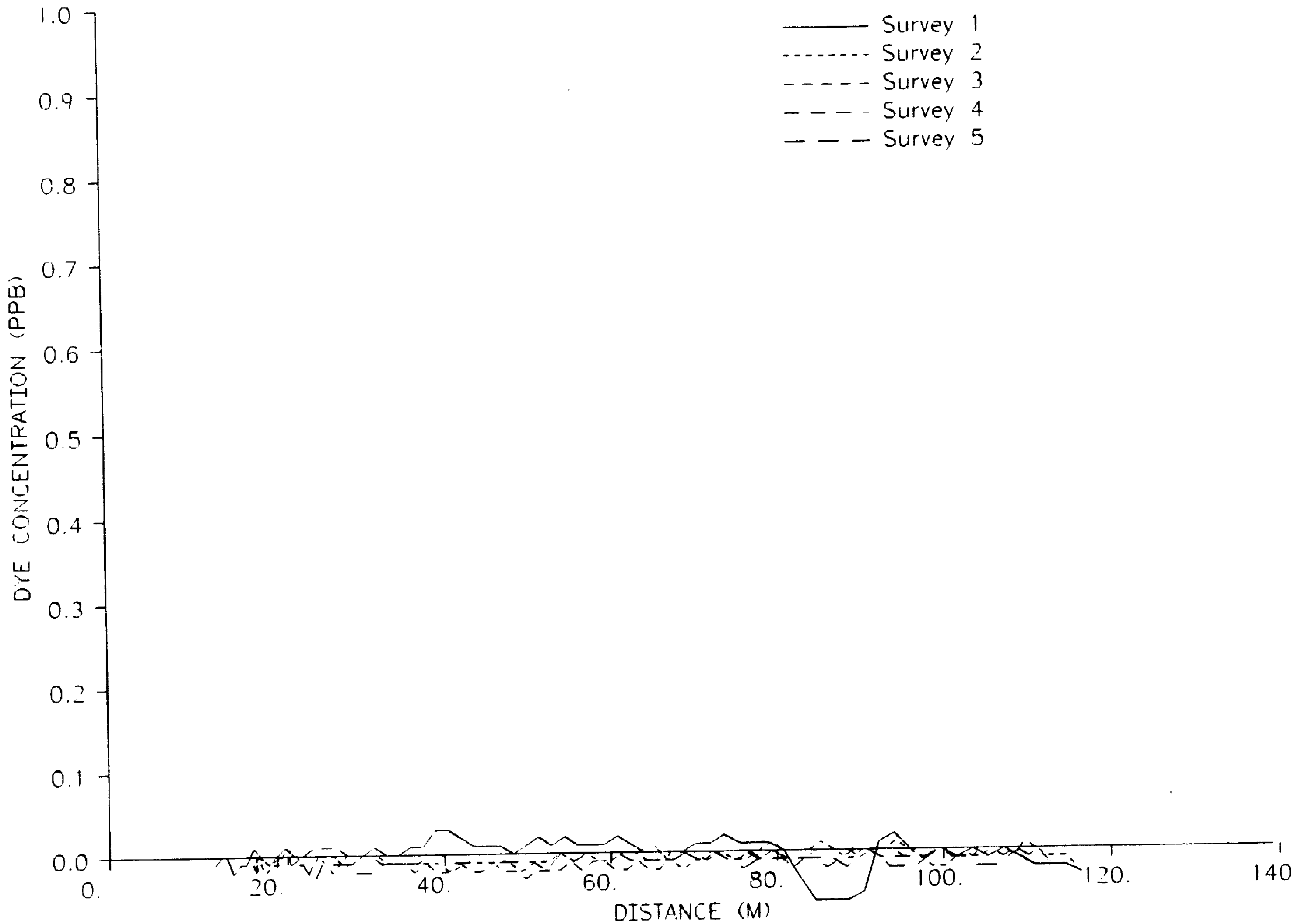


FIGURE A.1-1 OBSERVED DYE CONCENTRATION AT TRANSECT 7 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

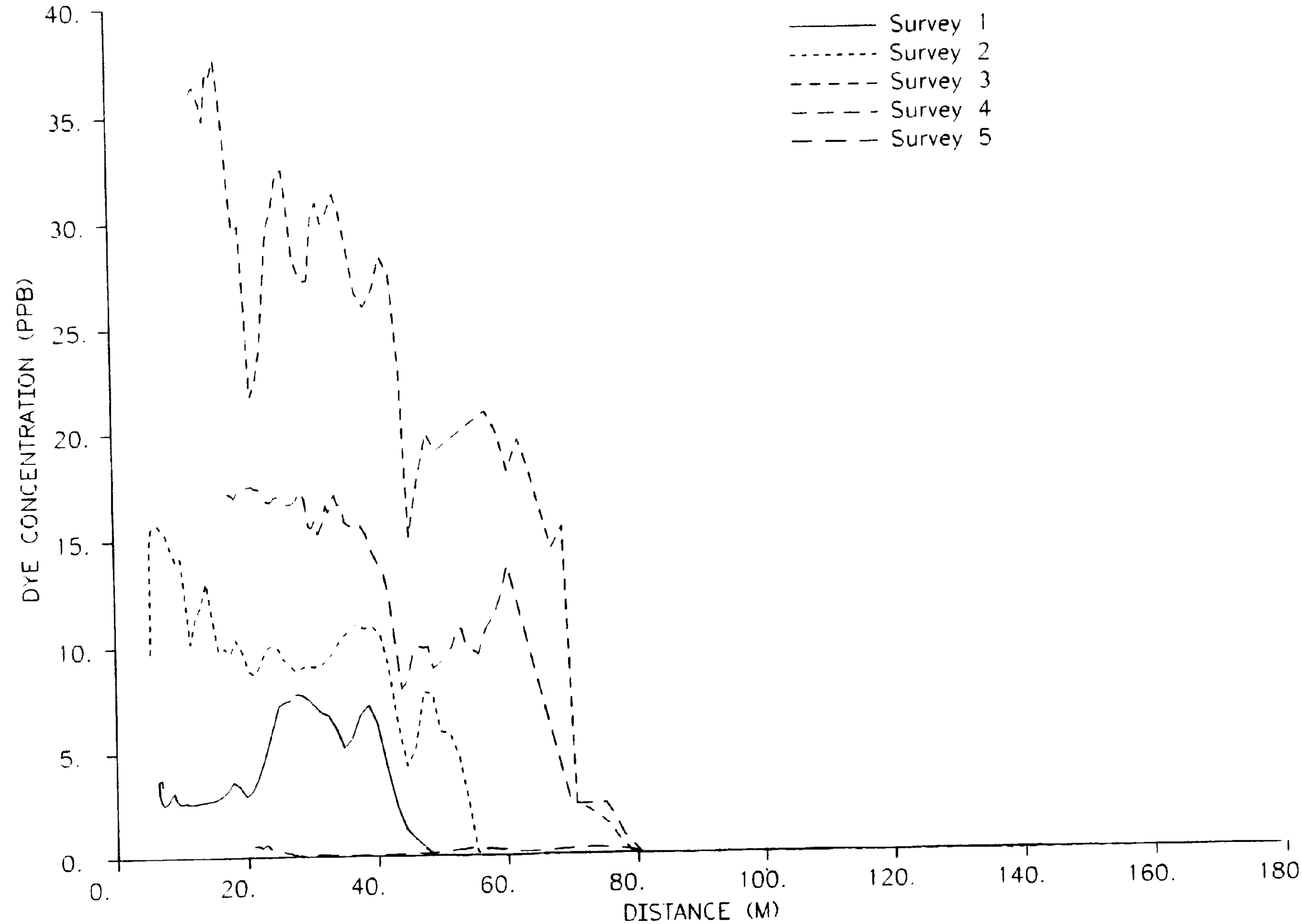


FIGURE A.1-2 OBSERVED DYE CONCENTRATION AT TRANSECT 8 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

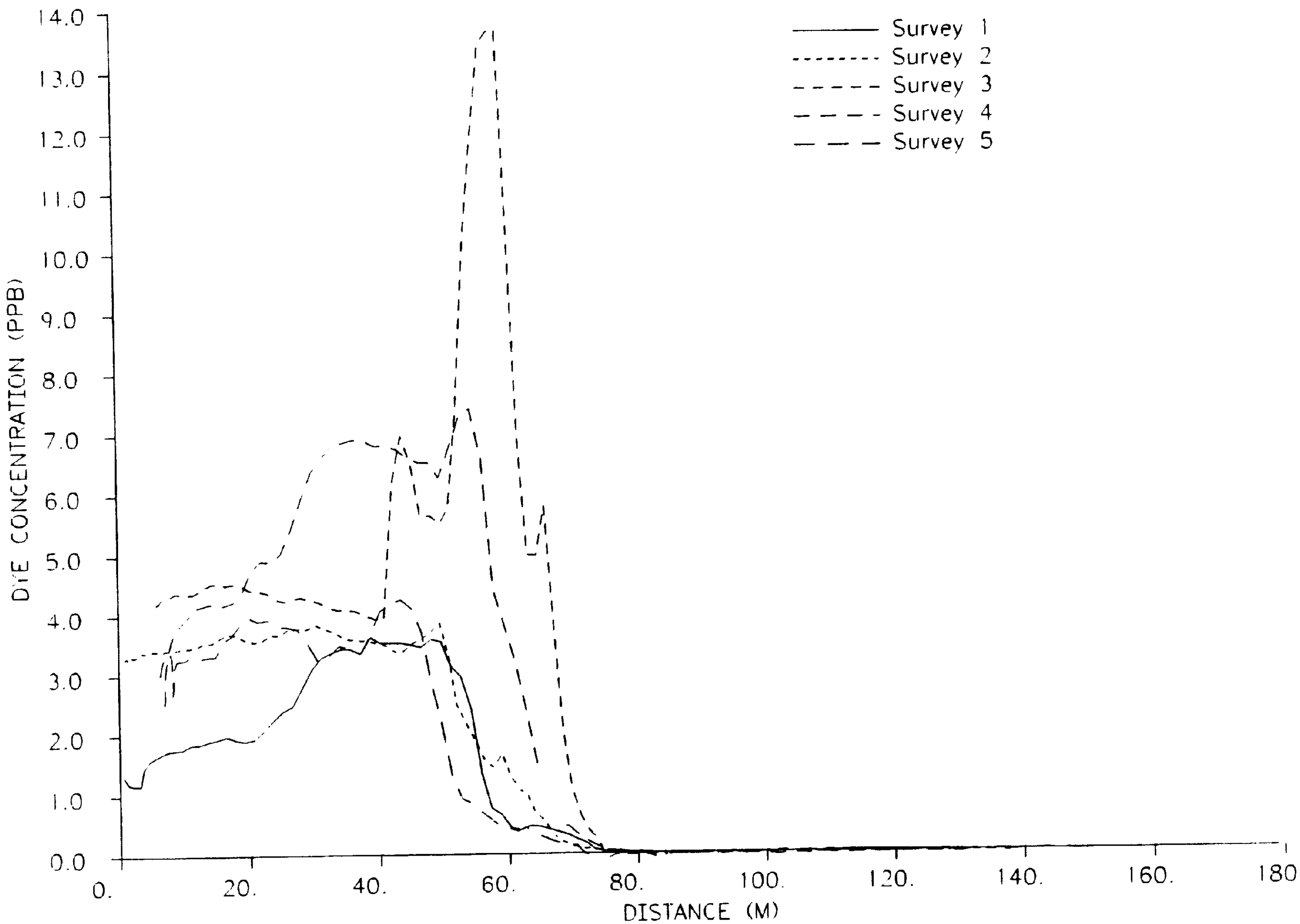


FIGURE A.1-3 OBSERVED DYE CONCENTRATION AT TRANSECT 9 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

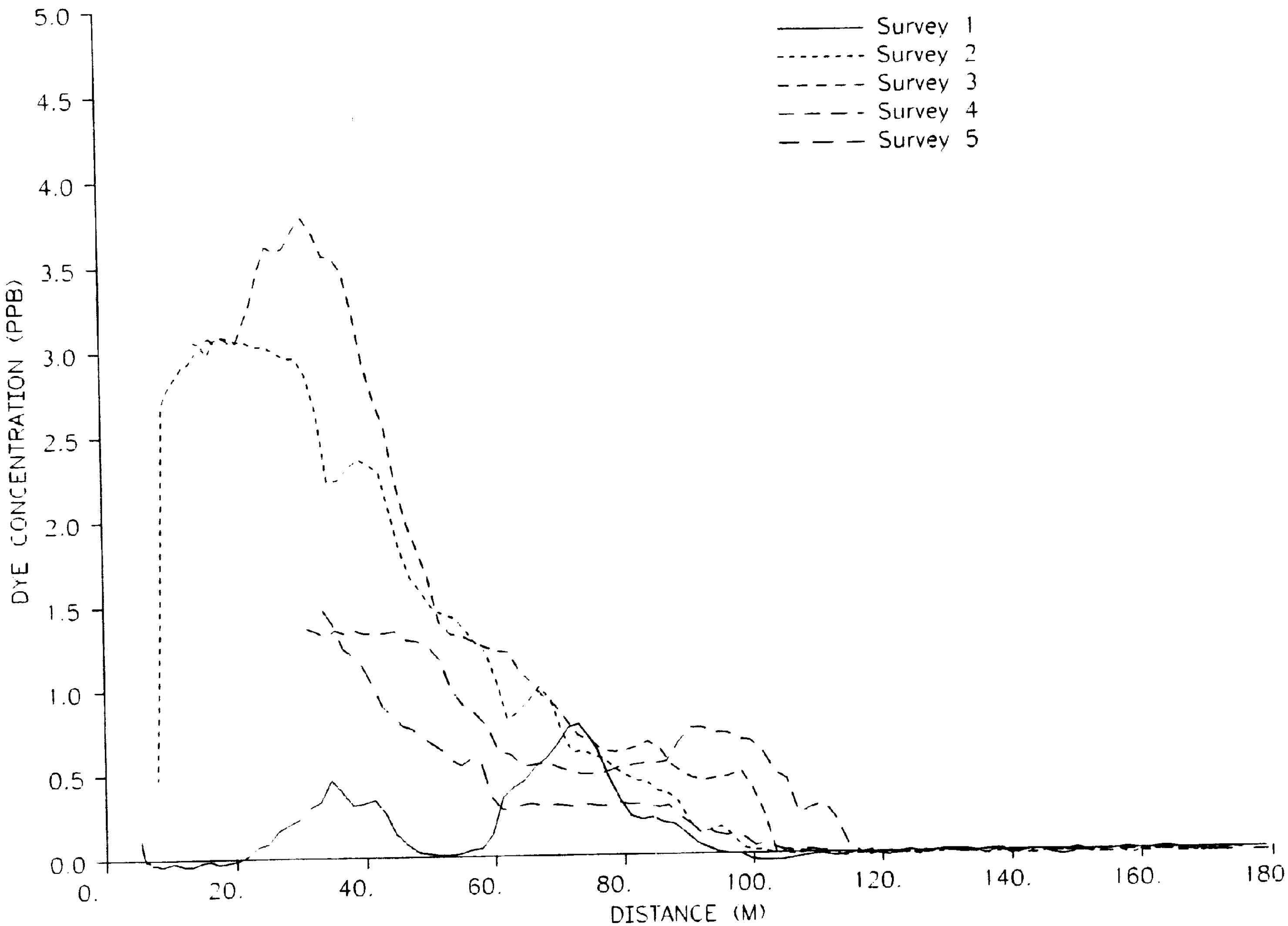


FIGURE A.1-4 OBSERVED DYE CONCENTRATION AT TRANSECT 10 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

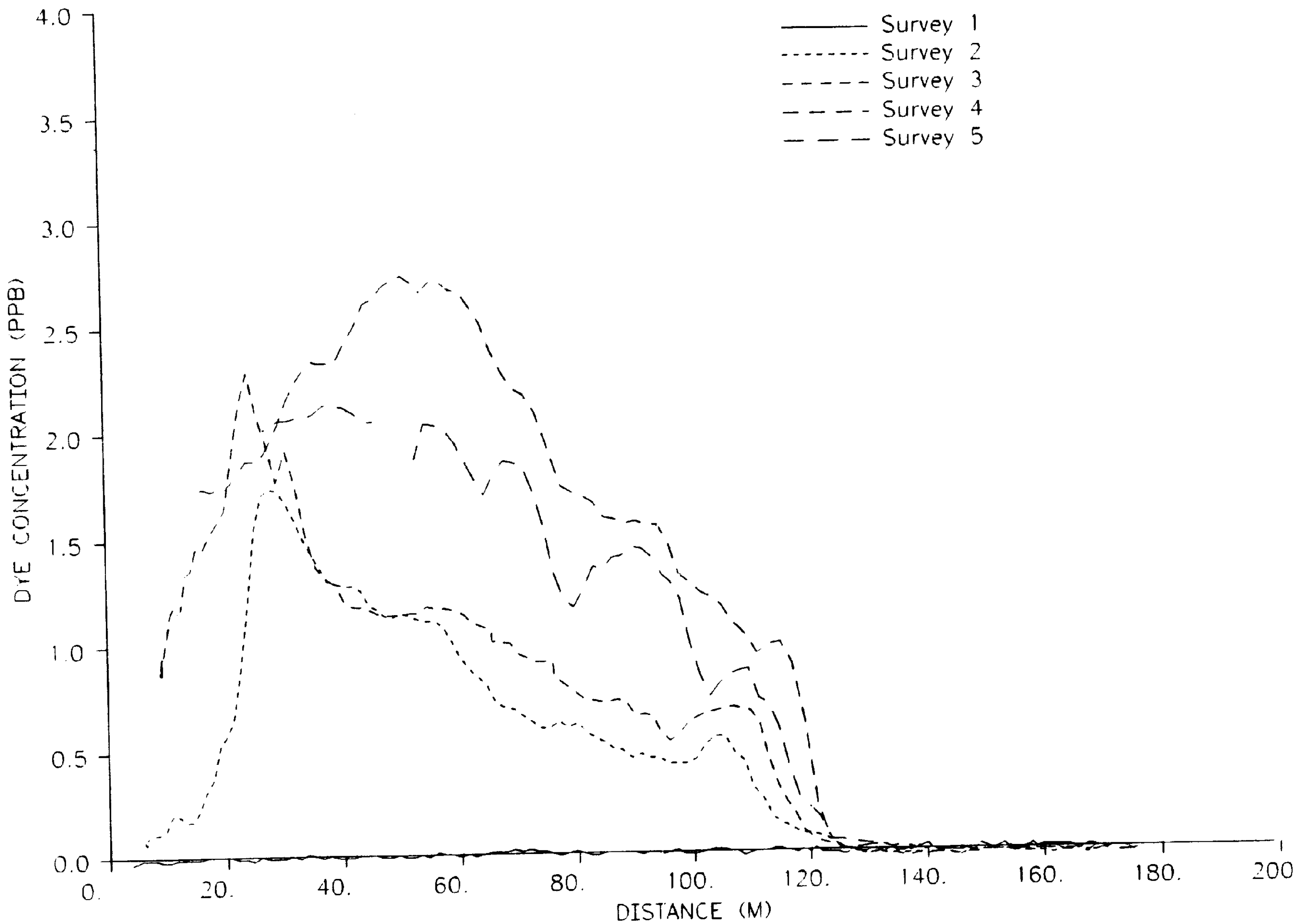


FIGURE A.1-5 OBSERVED DYE CONCENTRATION AT TRANSECT 11 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

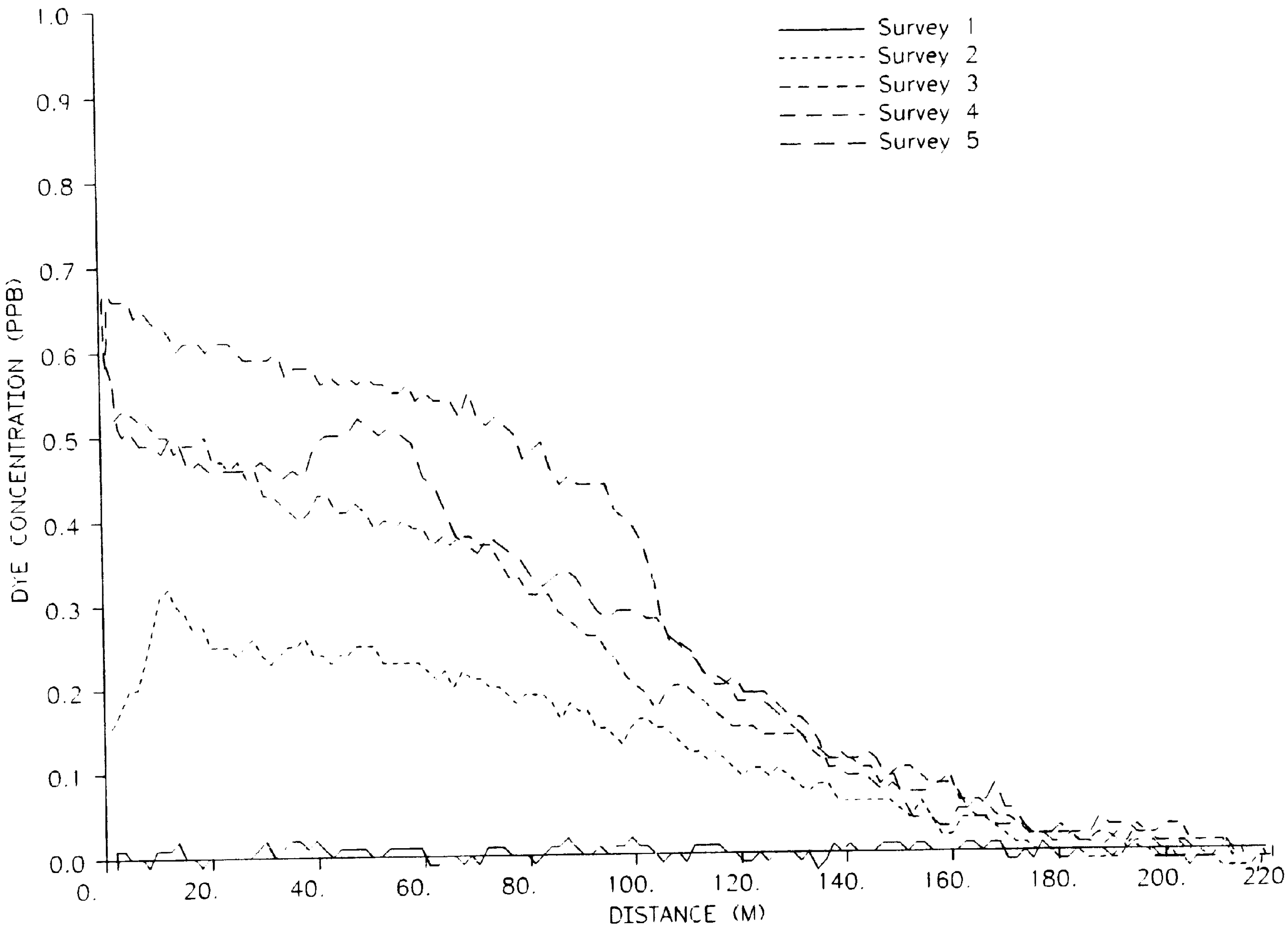


FIGURE A.1-6 OBSERVED DYE CONCENTRATION AT TRANSECT 12 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

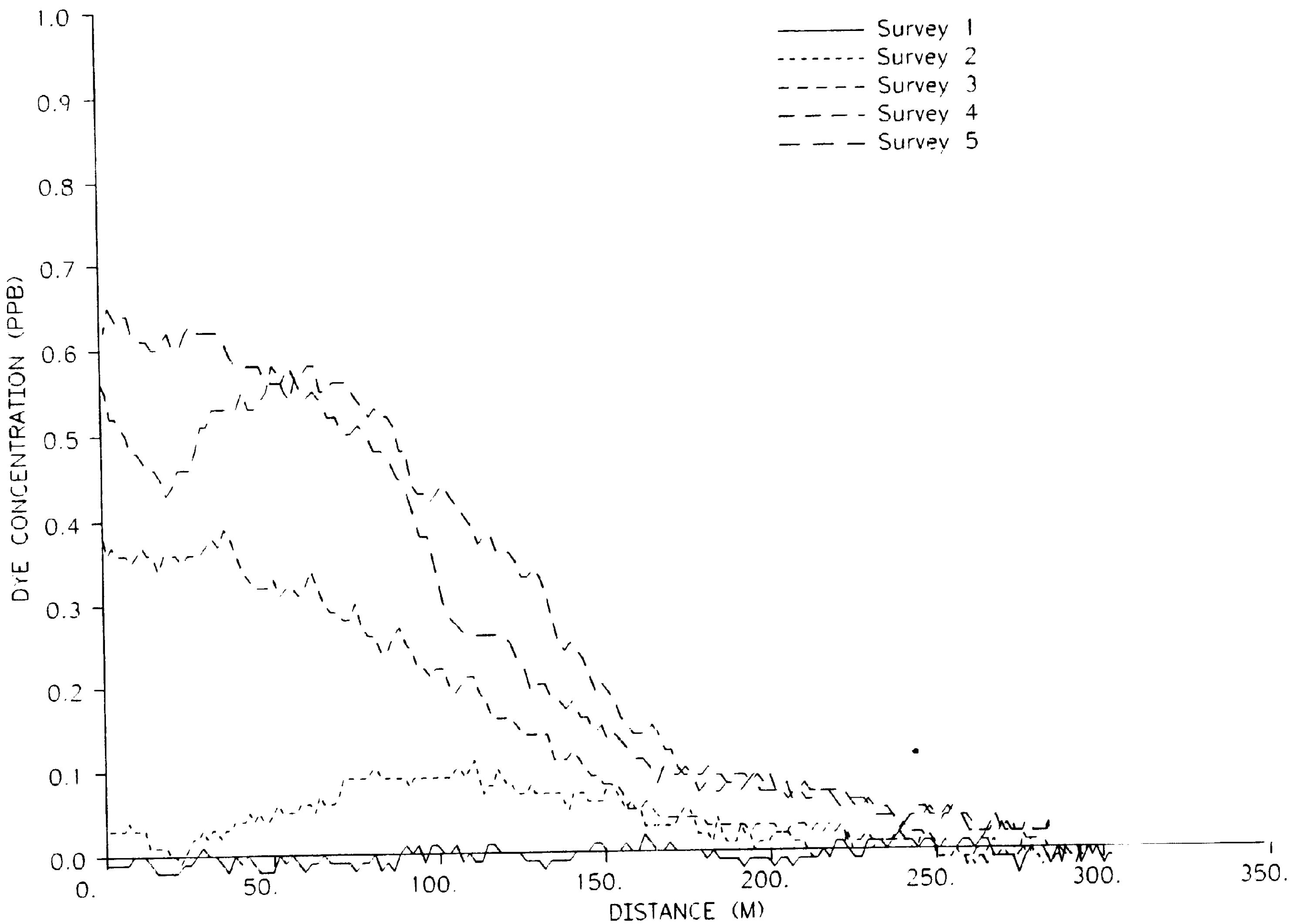


FIGURE A.1-7 OBSERVED DYE CONCENTRATION AT TRANSECT 13 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

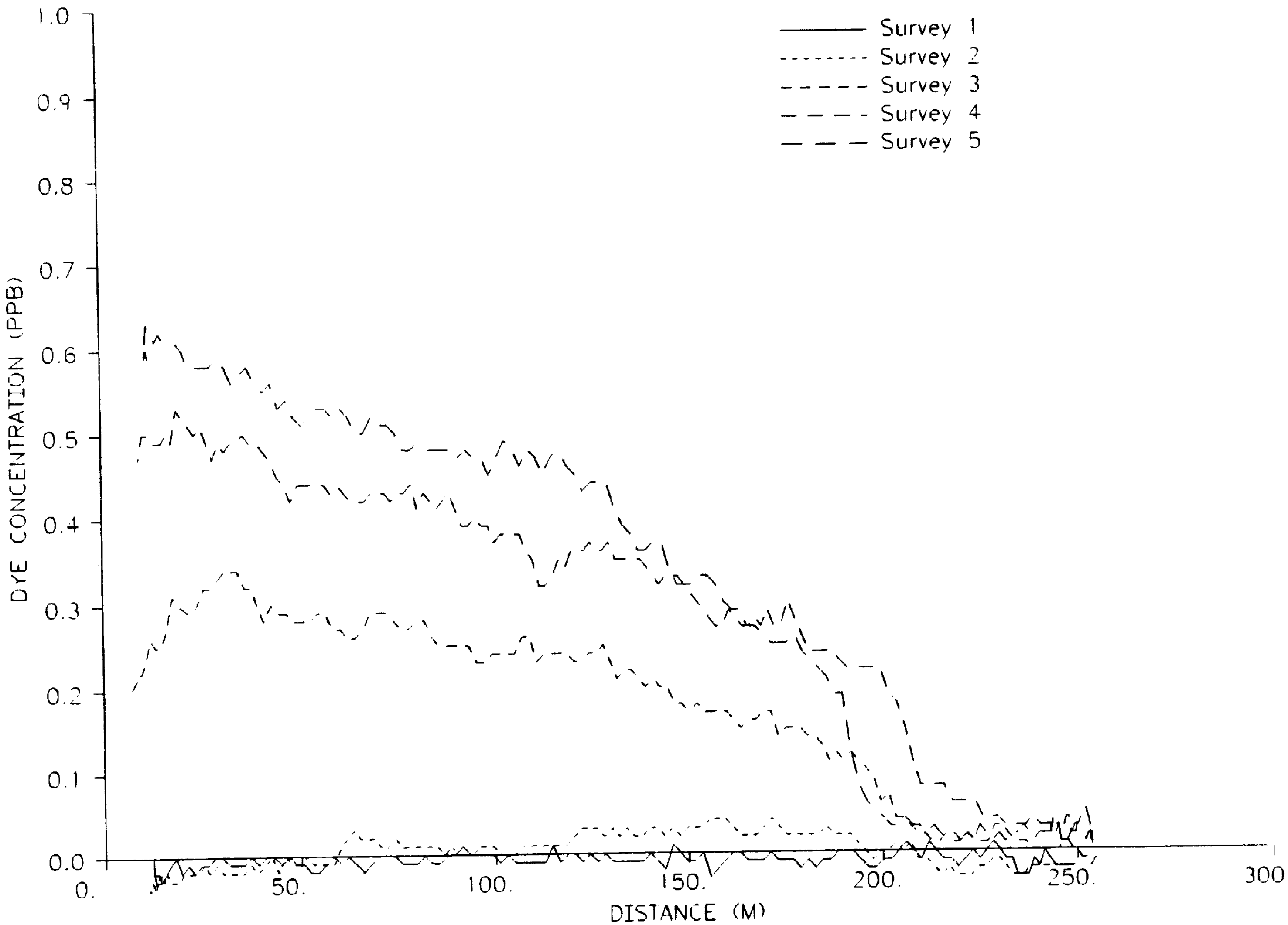


FIGURE A.1-8 OBSERVED DYE CONCENTRATION AT TRANSECT 14 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

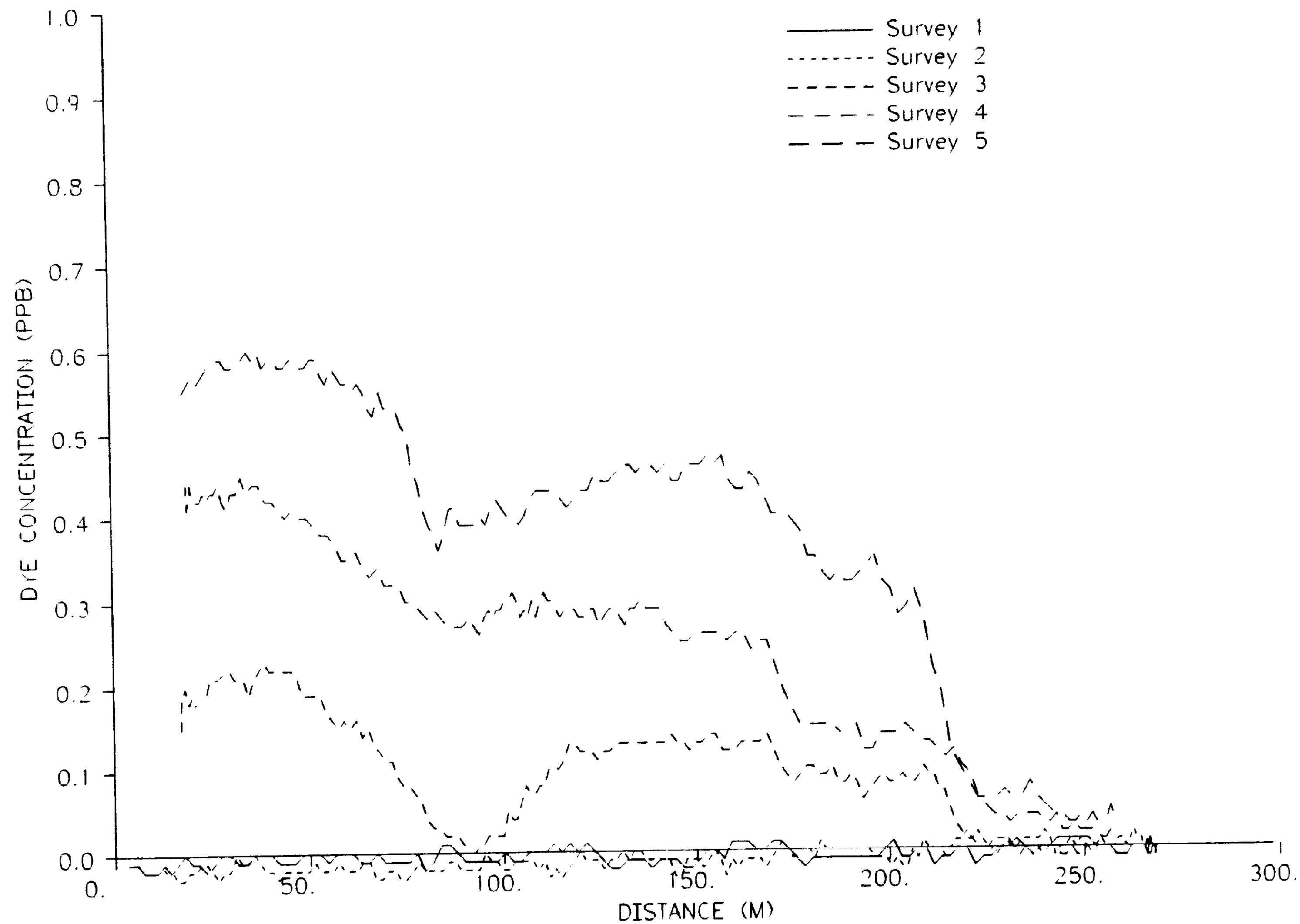


FIGURE A.1-9 OBSERVED DYE CONCENTRATION AT TRANSECT 15 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

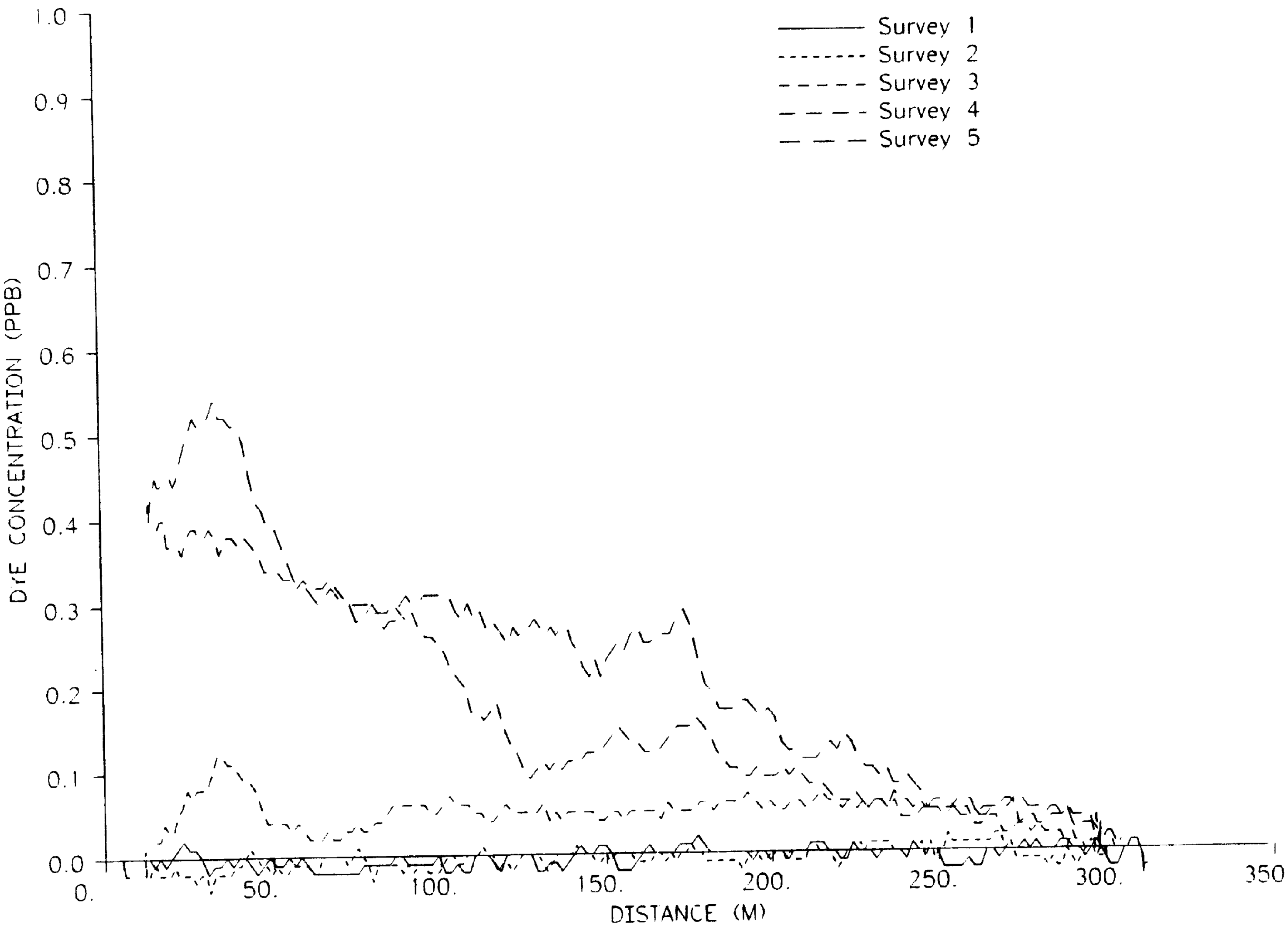


FIGURE A.1-10 OBSERVED DYE CONCENTRATION AT TRANSECT 16 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

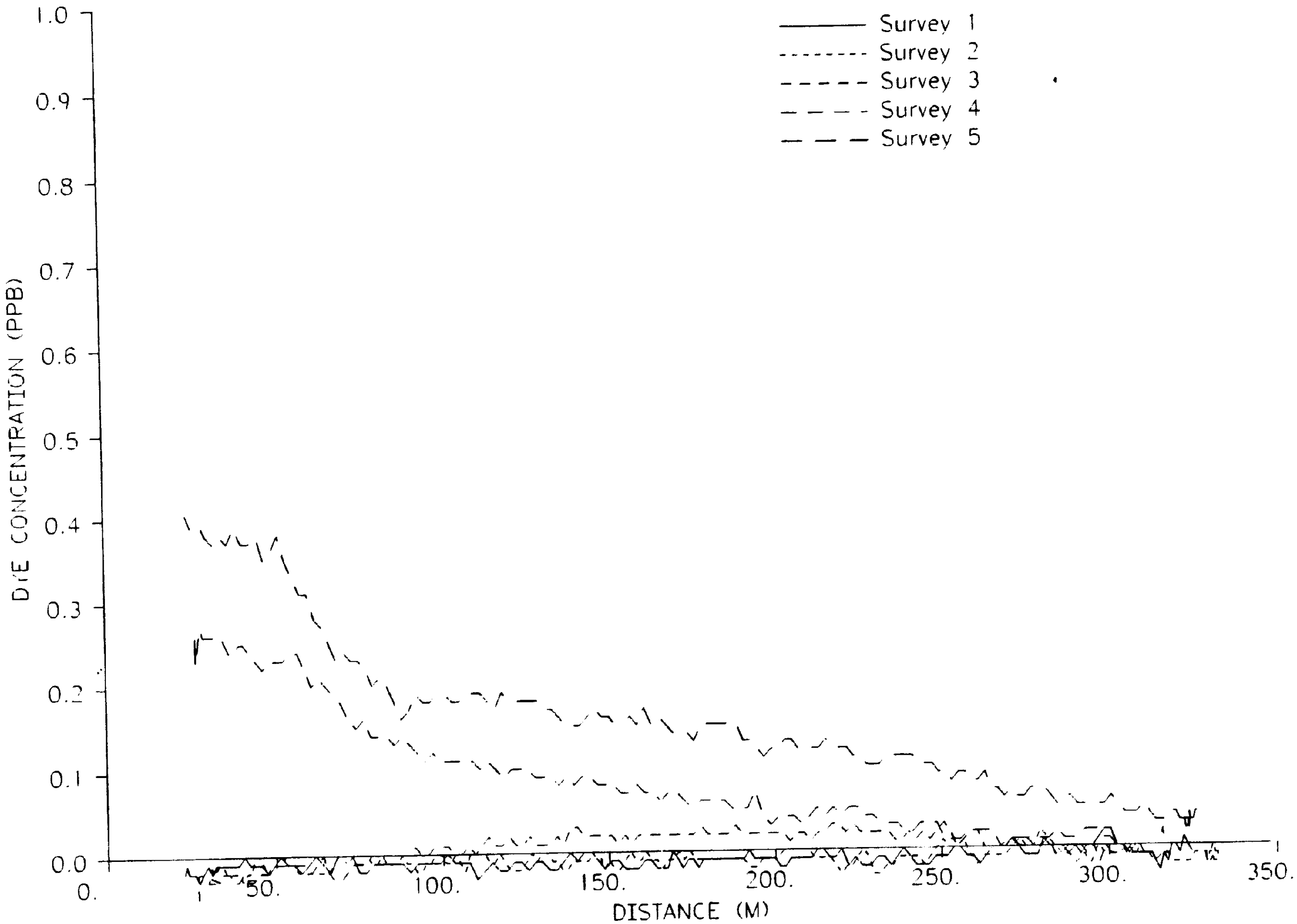


FIGURE A.1-11 OBSERVED DYE CONCENTRATION AT TRANSECT 17 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

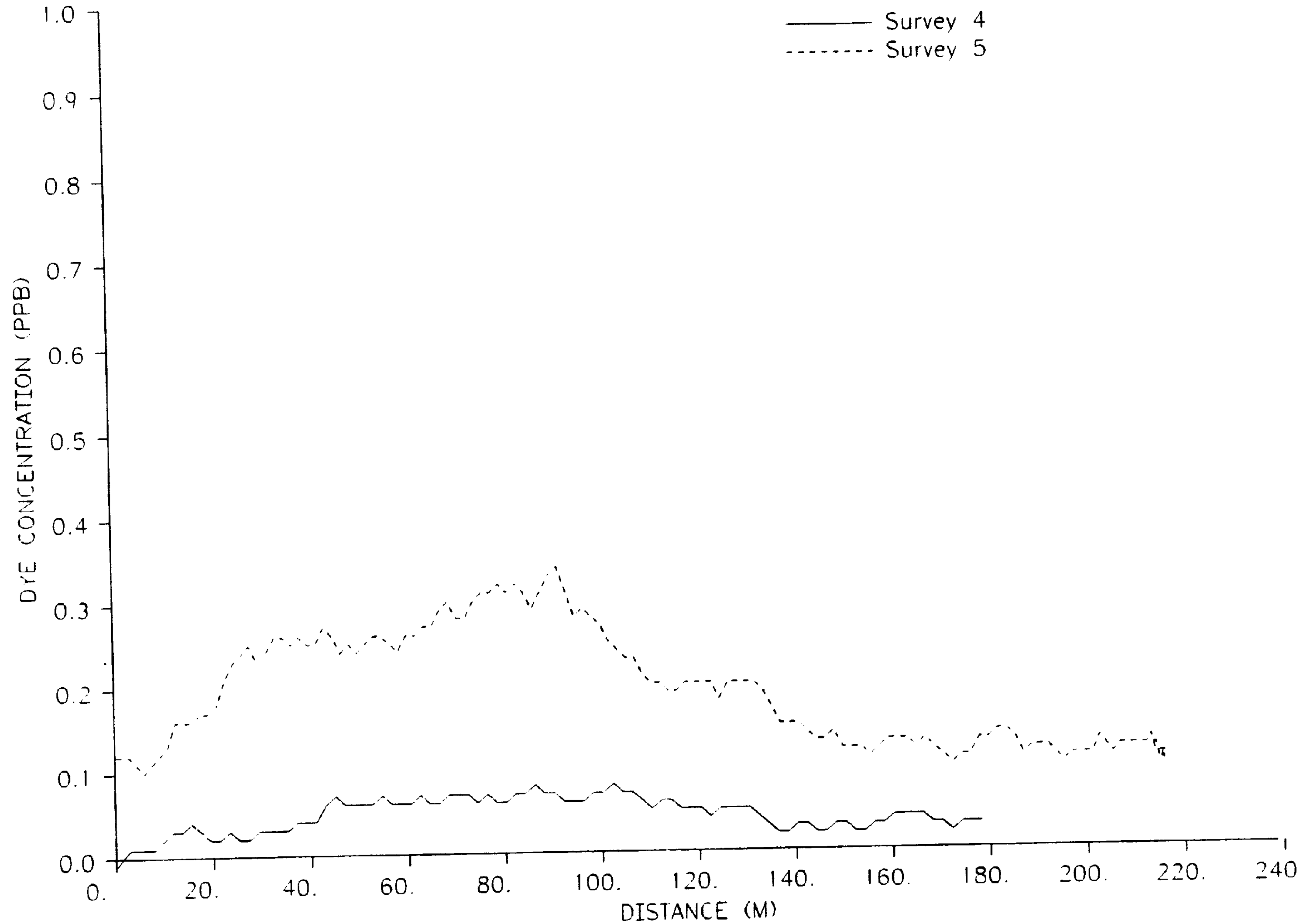


FIGURE A.1-12 OBSERVED DYE CONCENTRATION AT TRANSECT 18 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

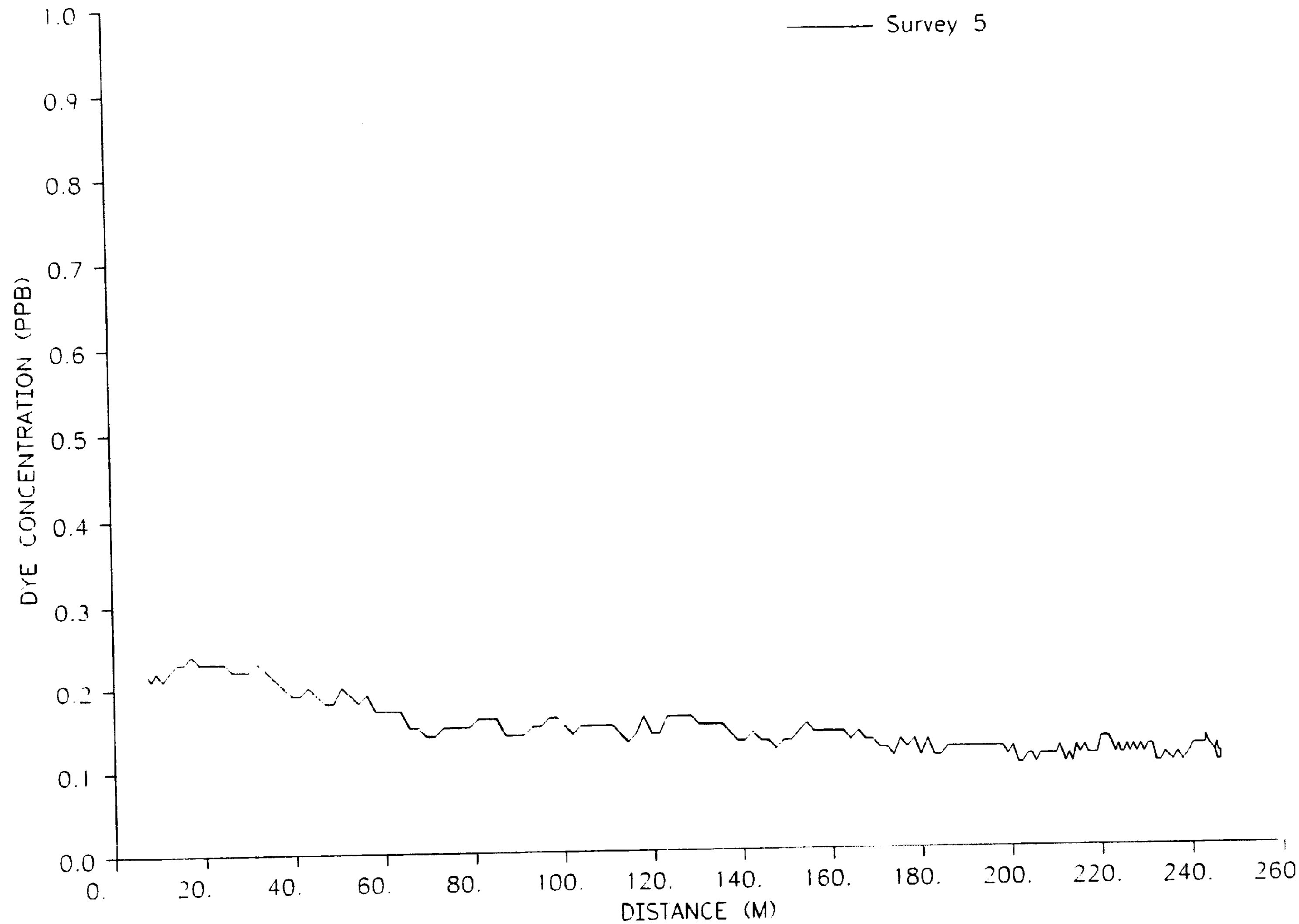


FIGURE A.1-13 OBSERVED DYE CONCENTRATION AT TRANSECT 19 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

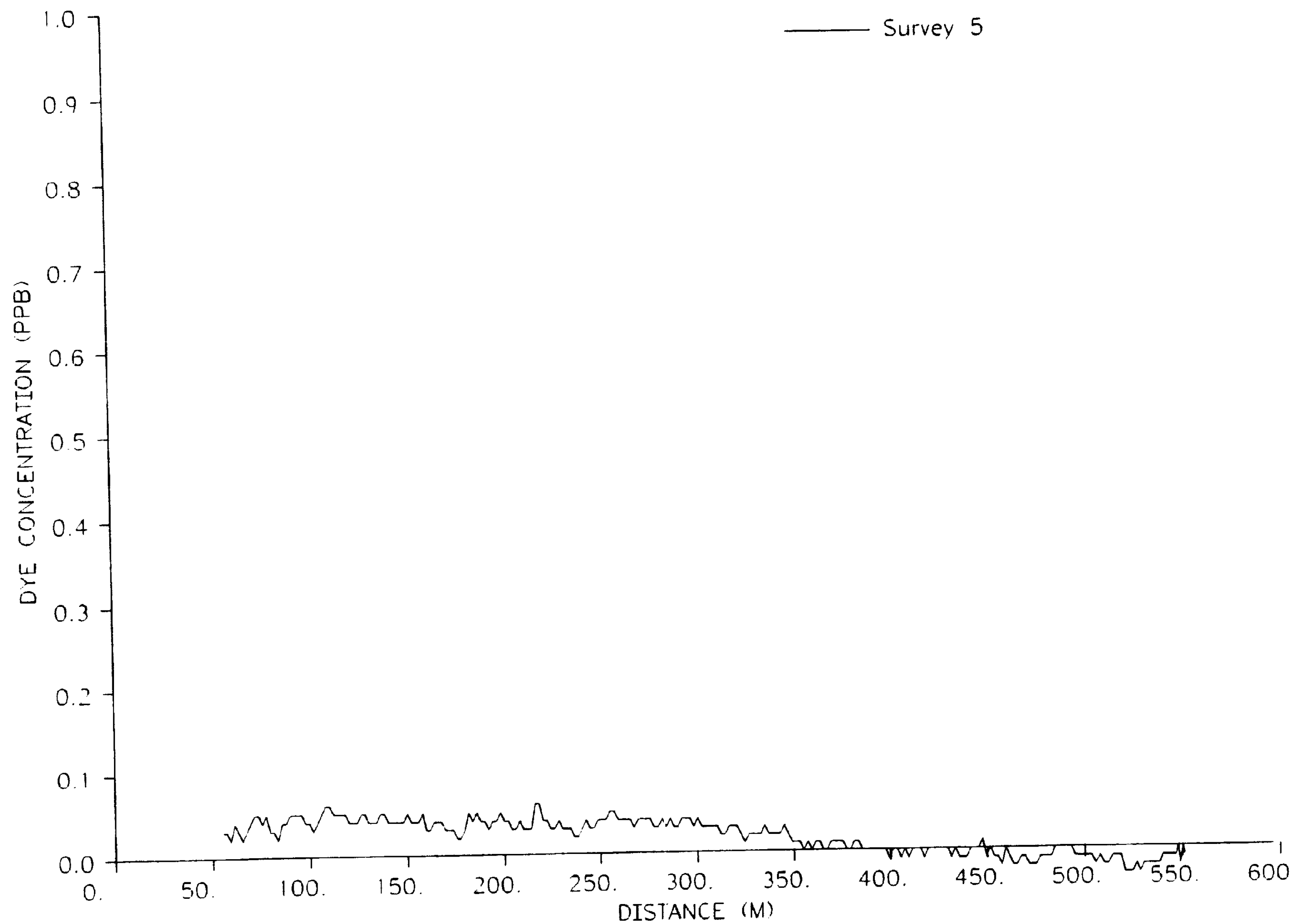


FIGURE A.1-14 OBSERVED DYE CONCENTRATION AT TRANSECT 20 DURING THE 2 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

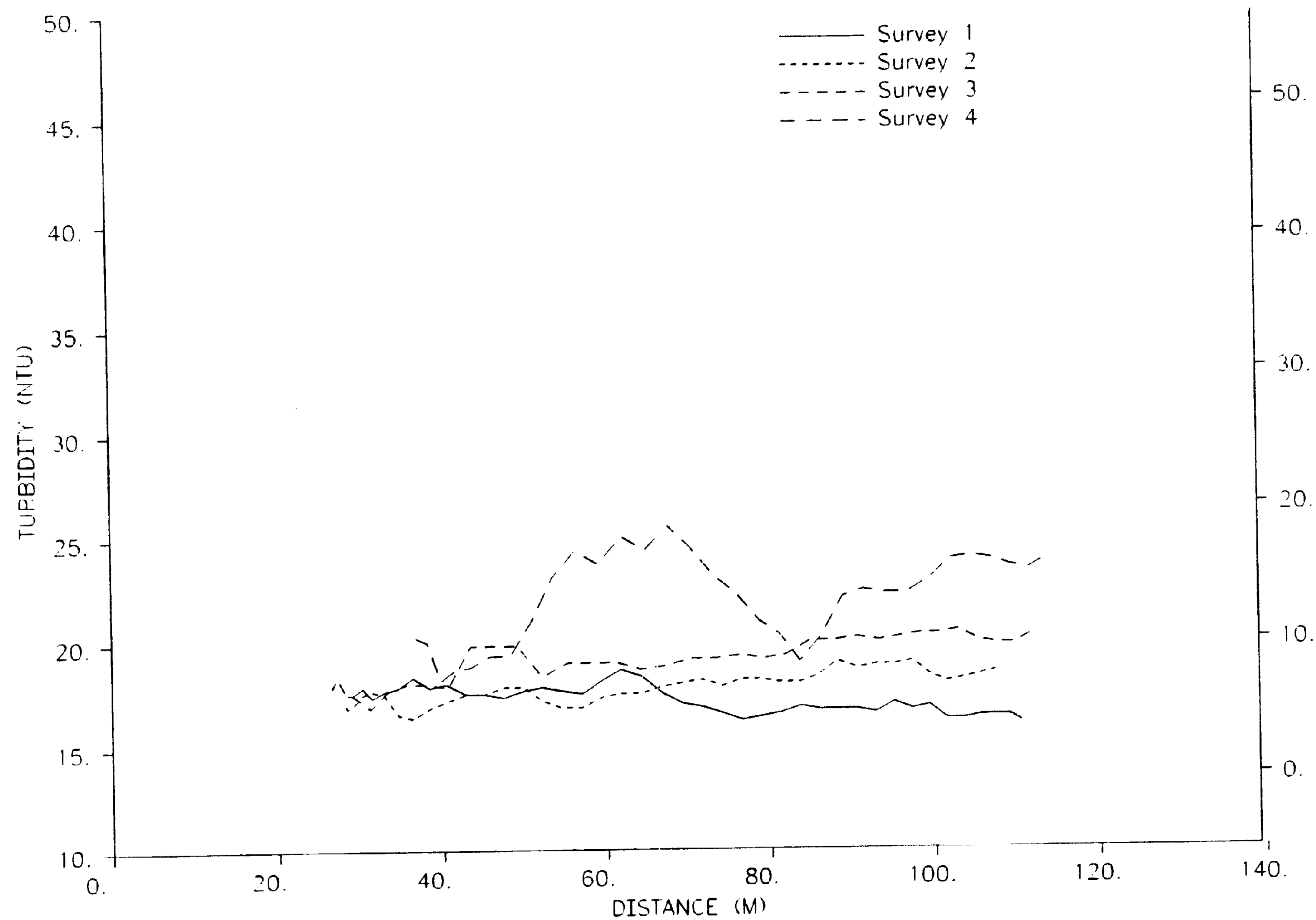


FIGURE A.2-1 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 7 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

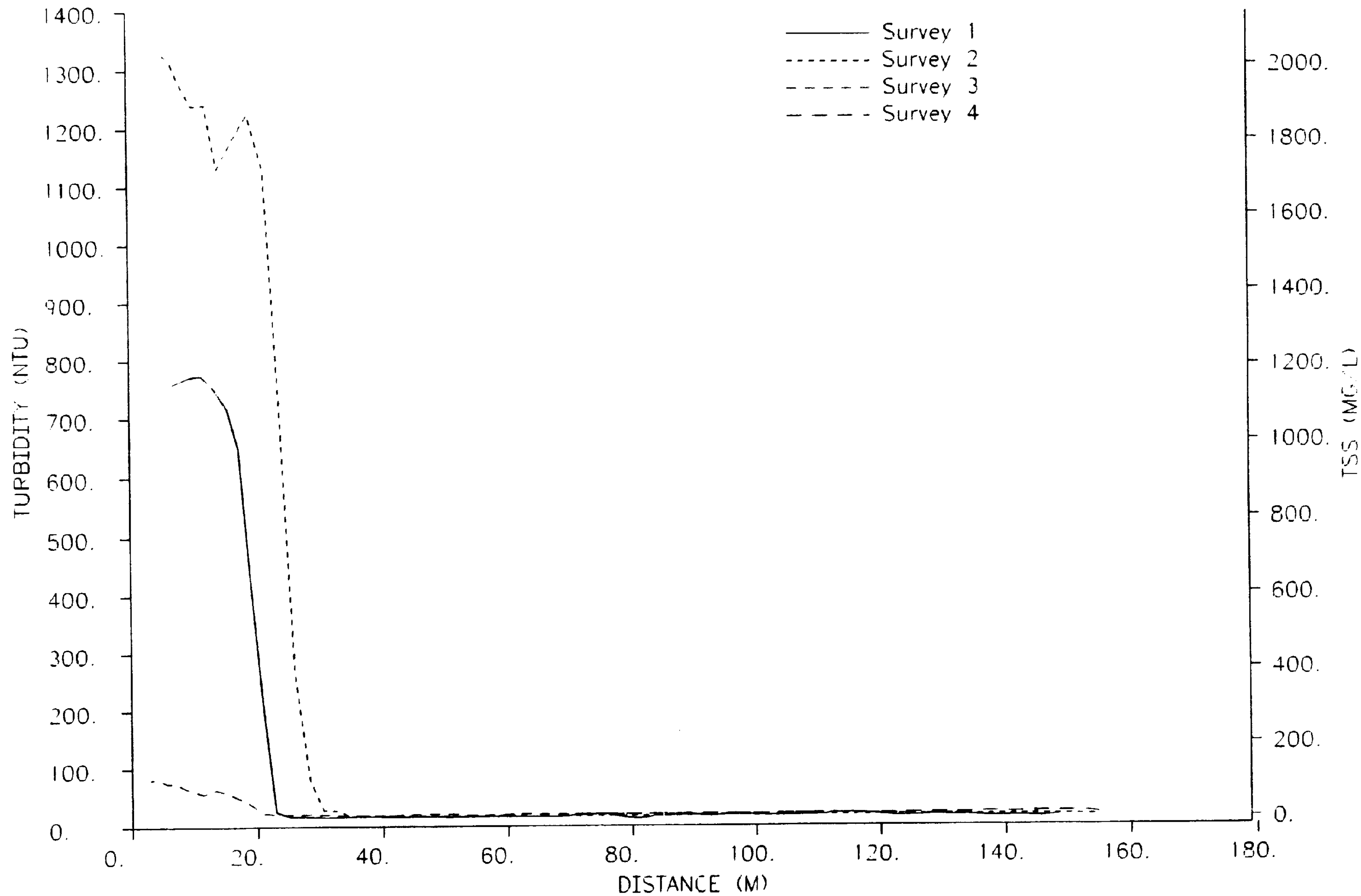


FIGURE A.2-2 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 8 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

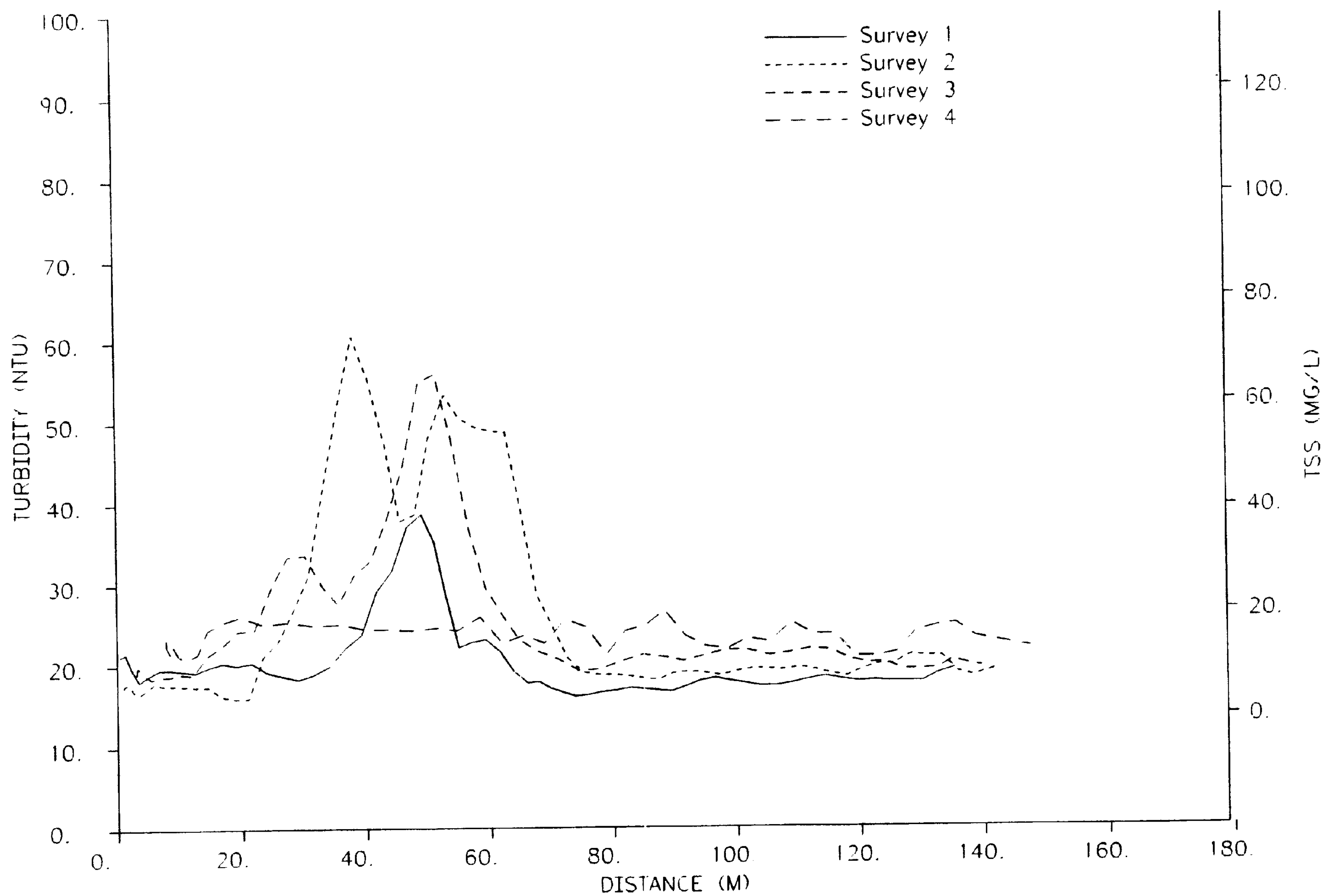


FIGURE A.2-3 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 9 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

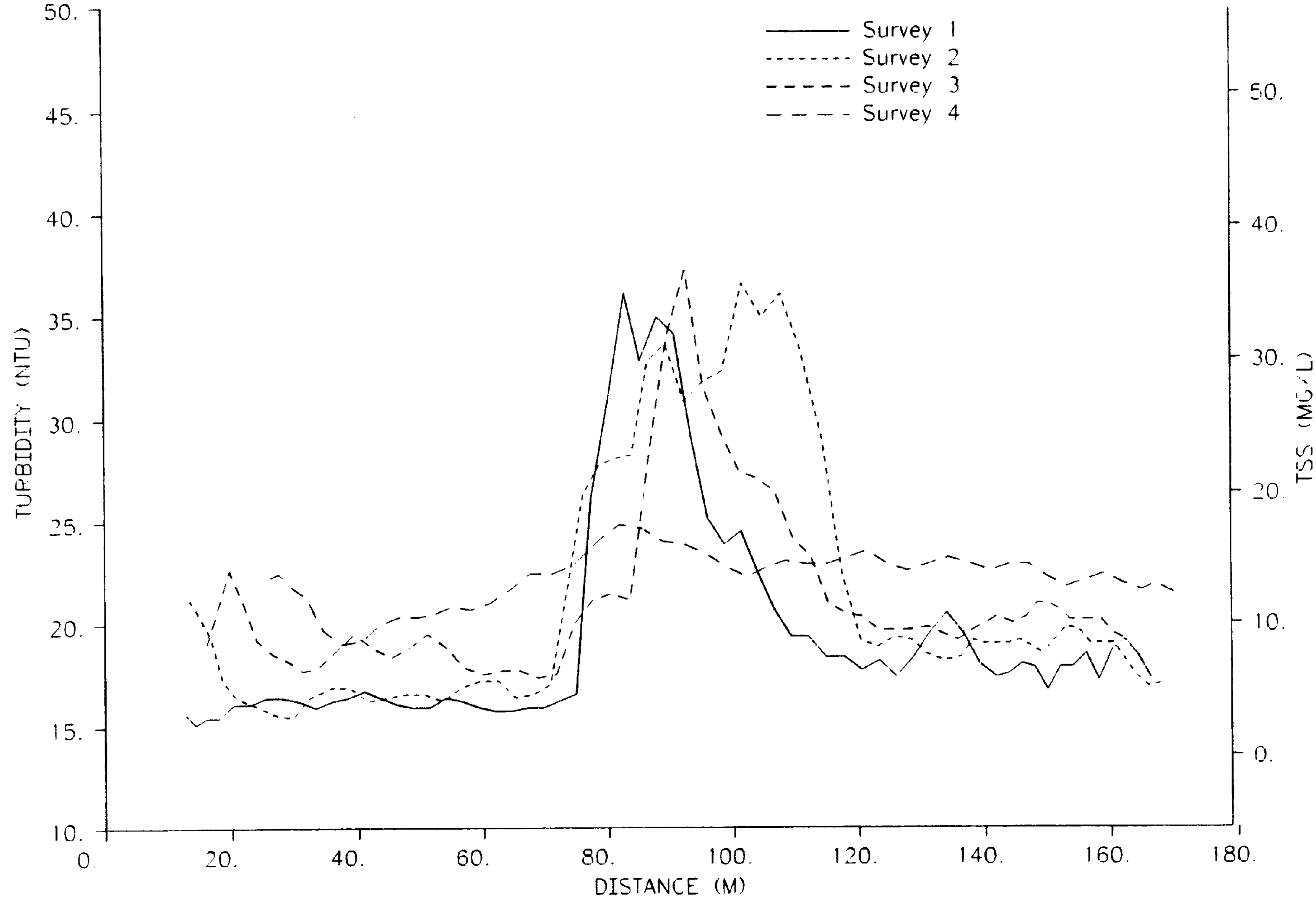


FIGURE A.2-4 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 10 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

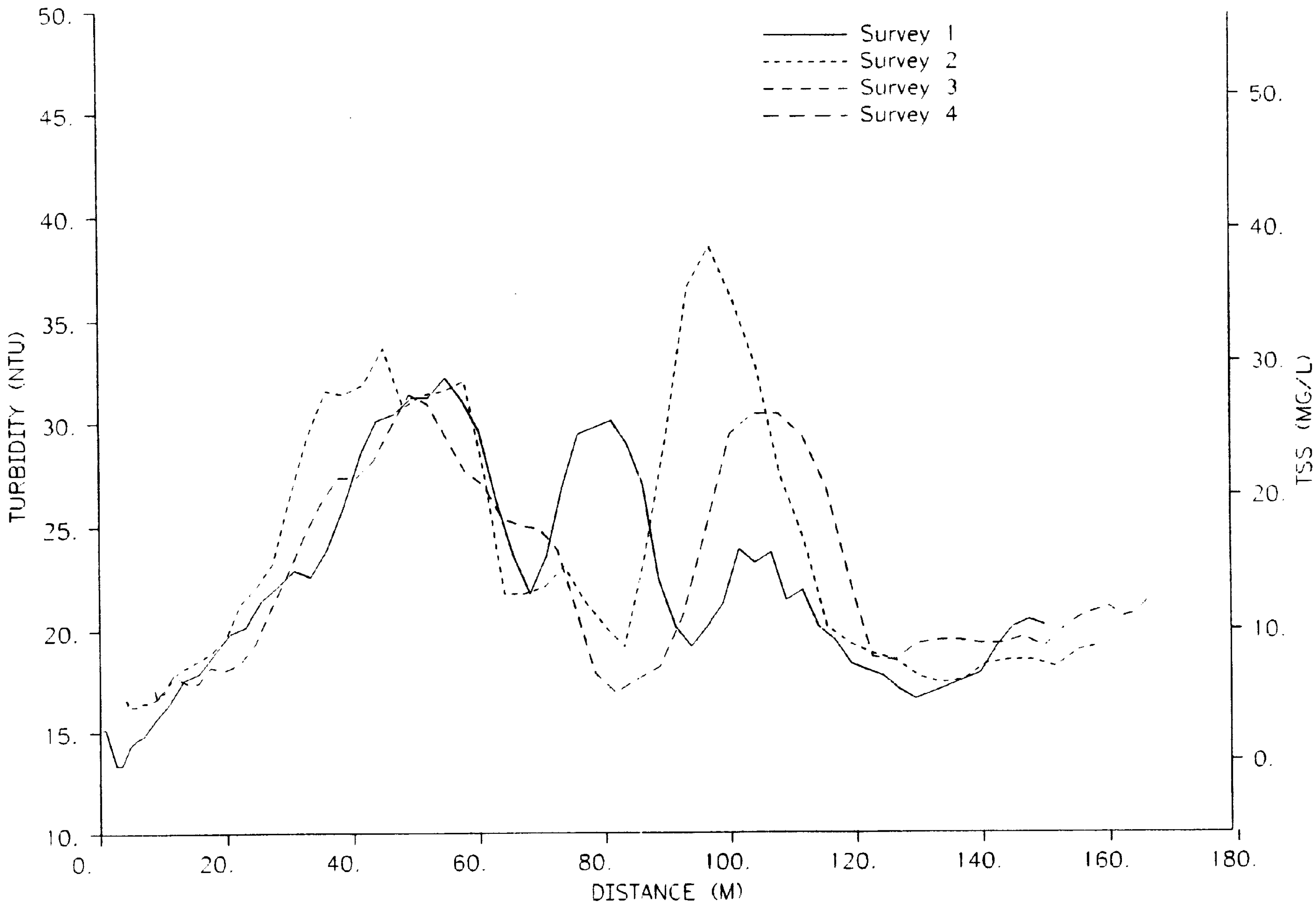


FIGURE A.2-5 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 11 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

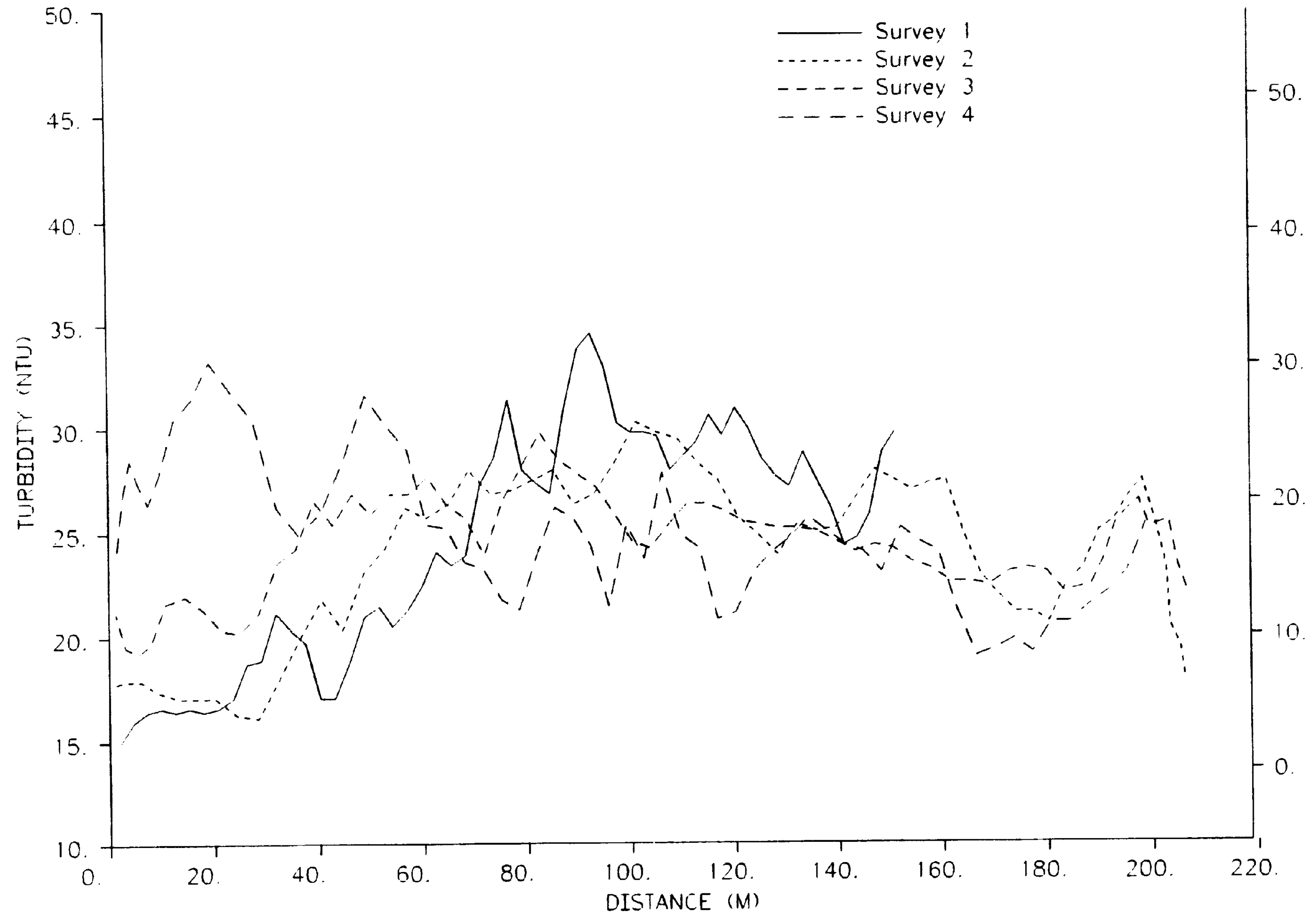


FIGURE A.2-6 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 12 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

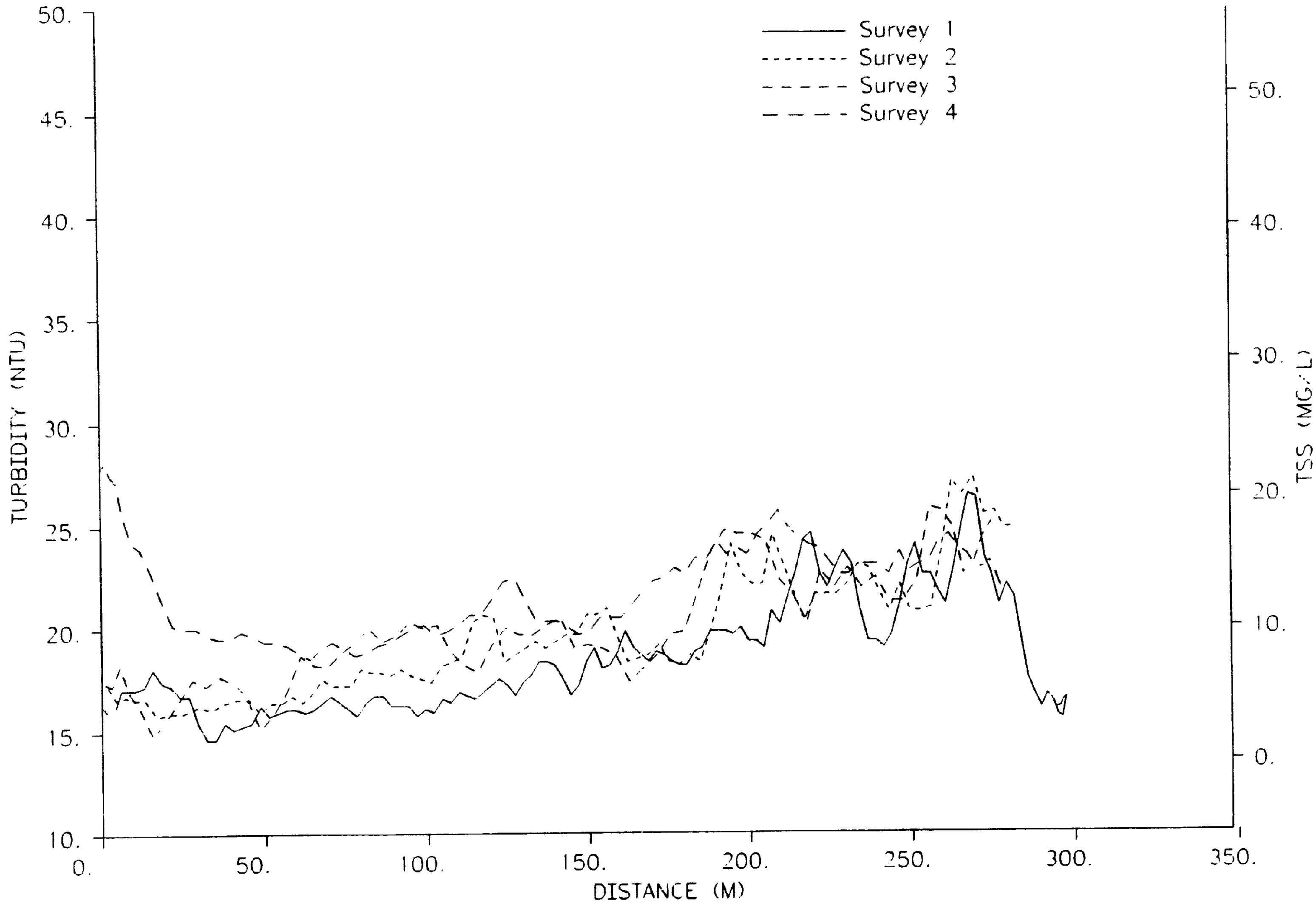


FIGURE A.2-7 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 13 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

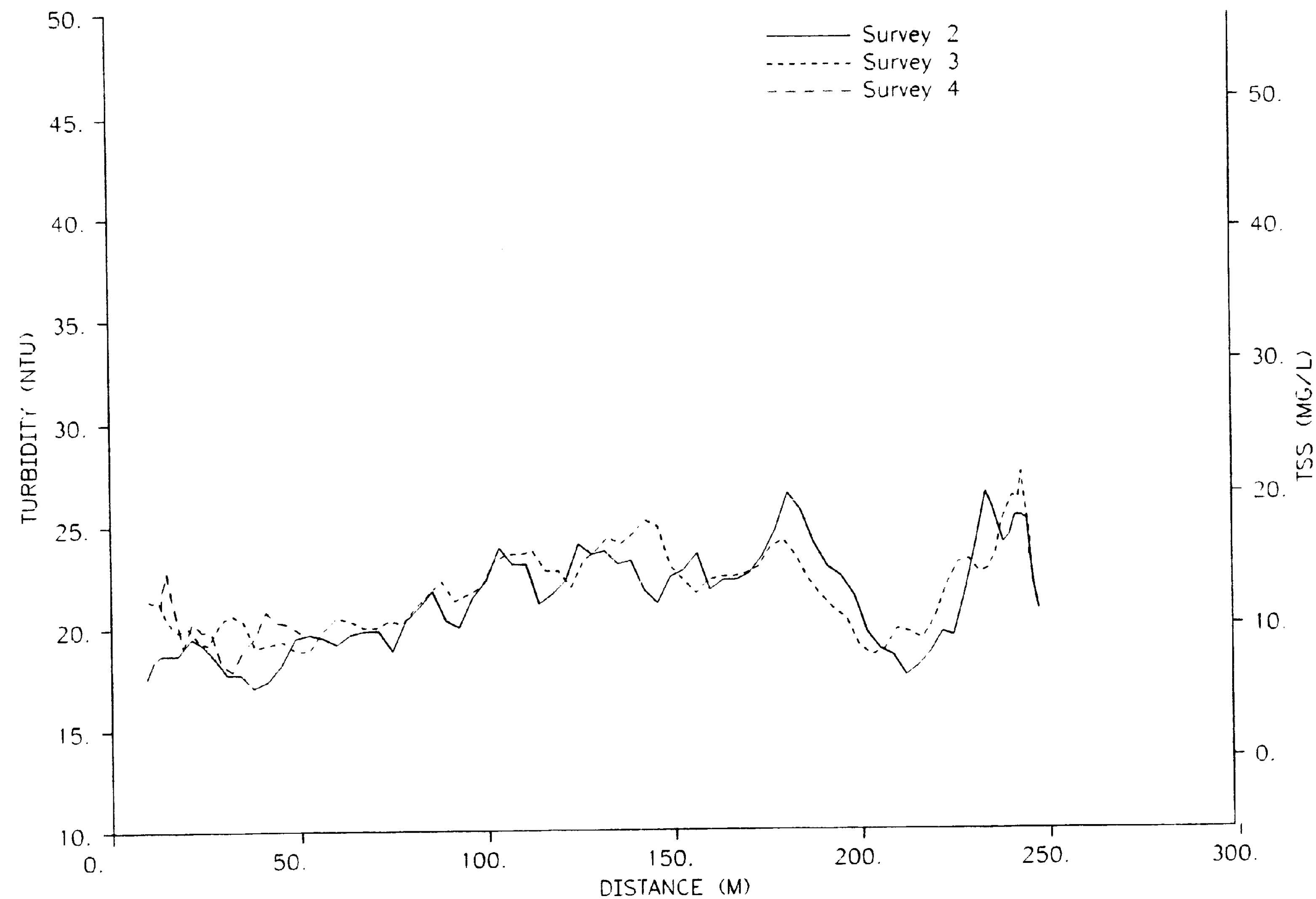


FIGURE A.2-8 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 14 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

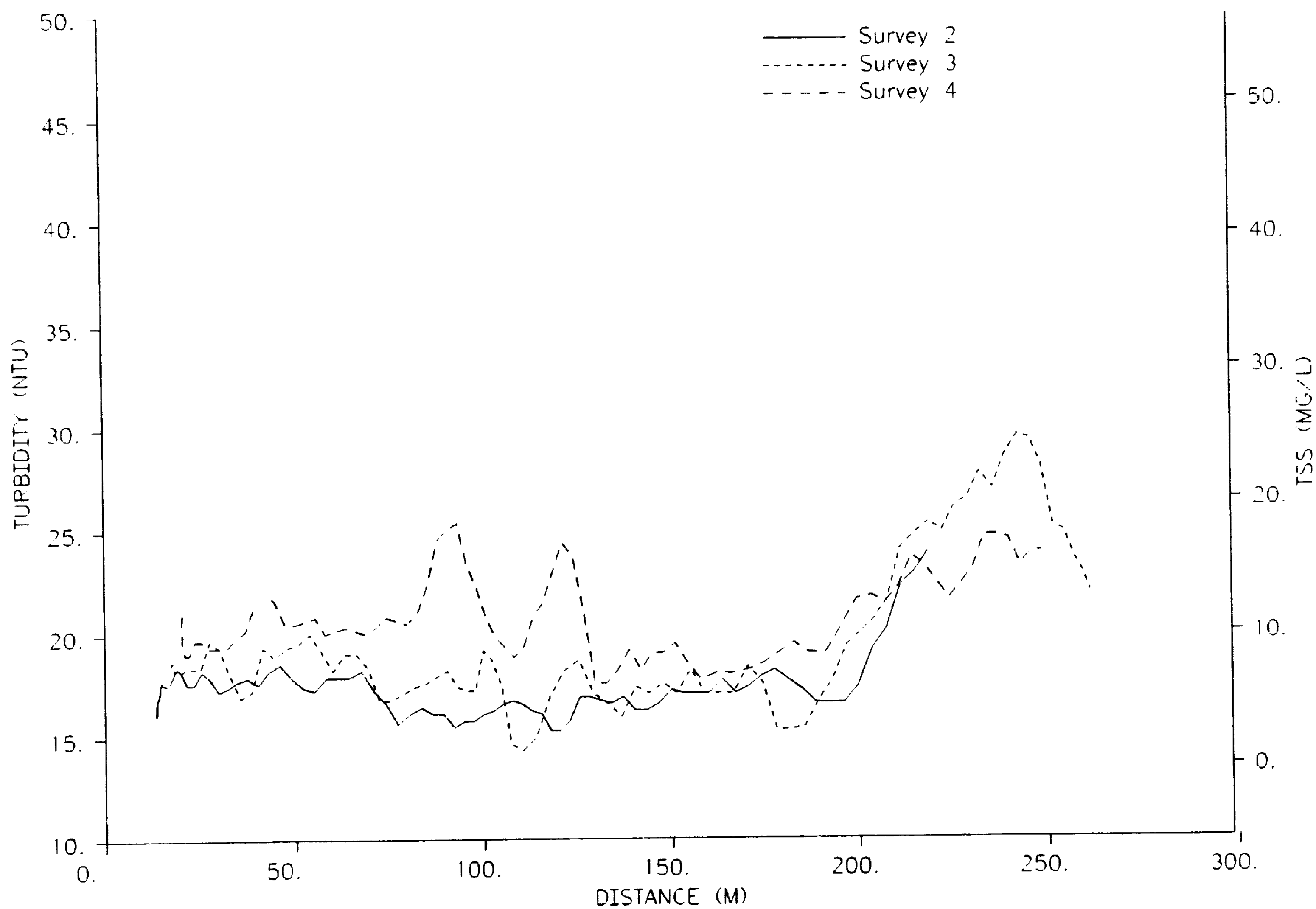


FIGURE A.2-9 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 15 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

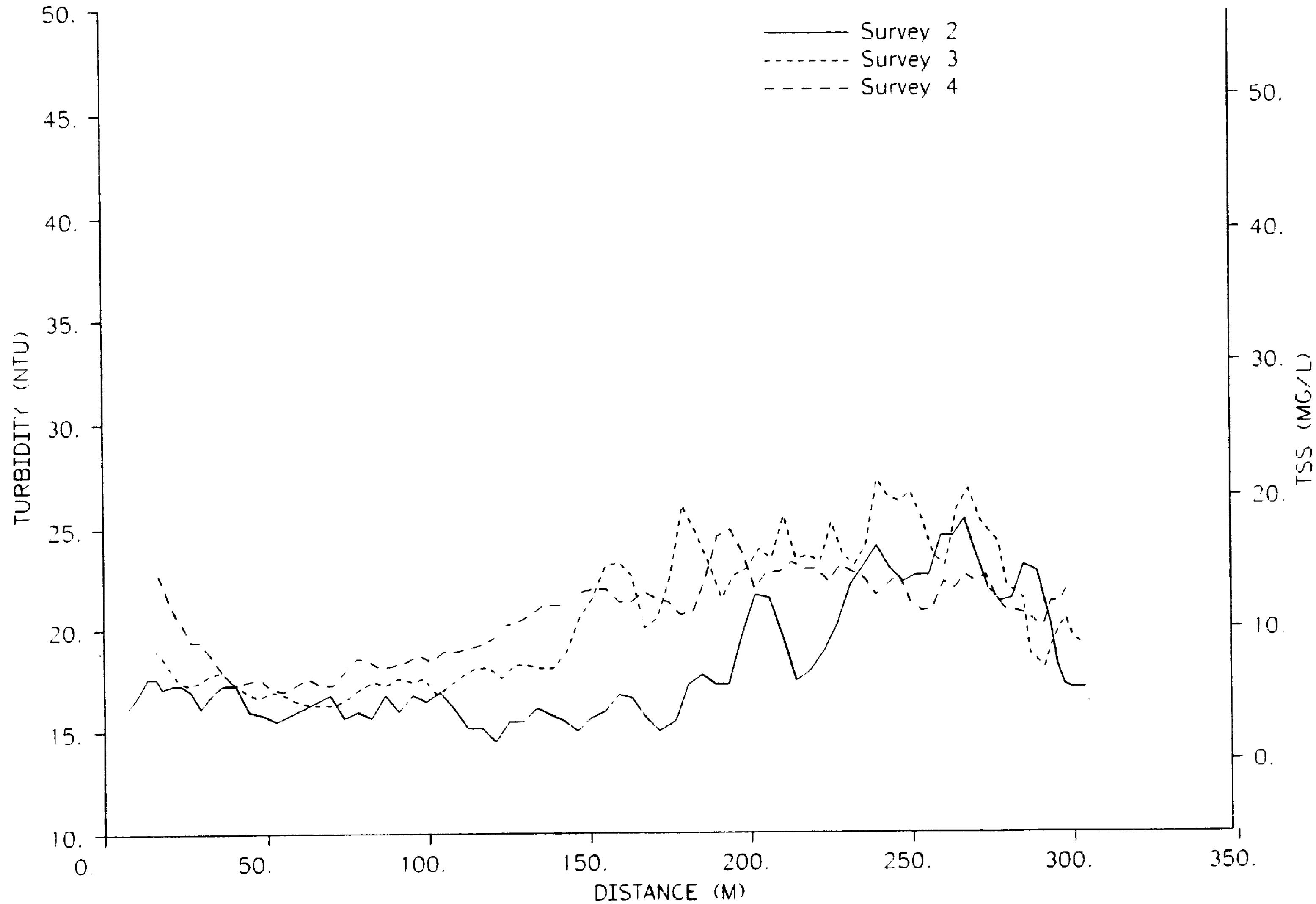


FIGURE A.2-10 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 16 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

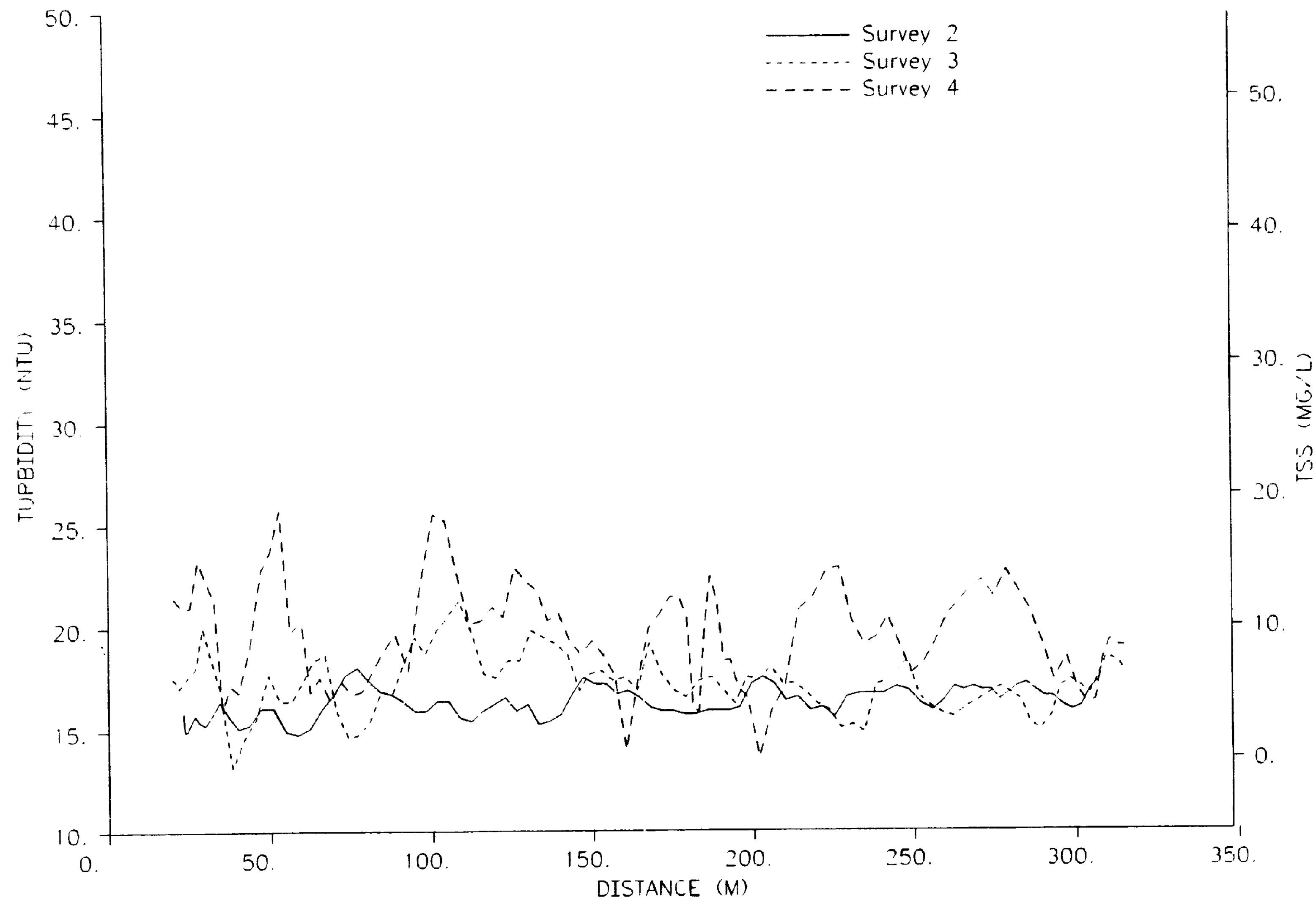


FIGURE A.2-11 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 17 DURING THE 3 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 003, GEORGETOWN RESERVOIR

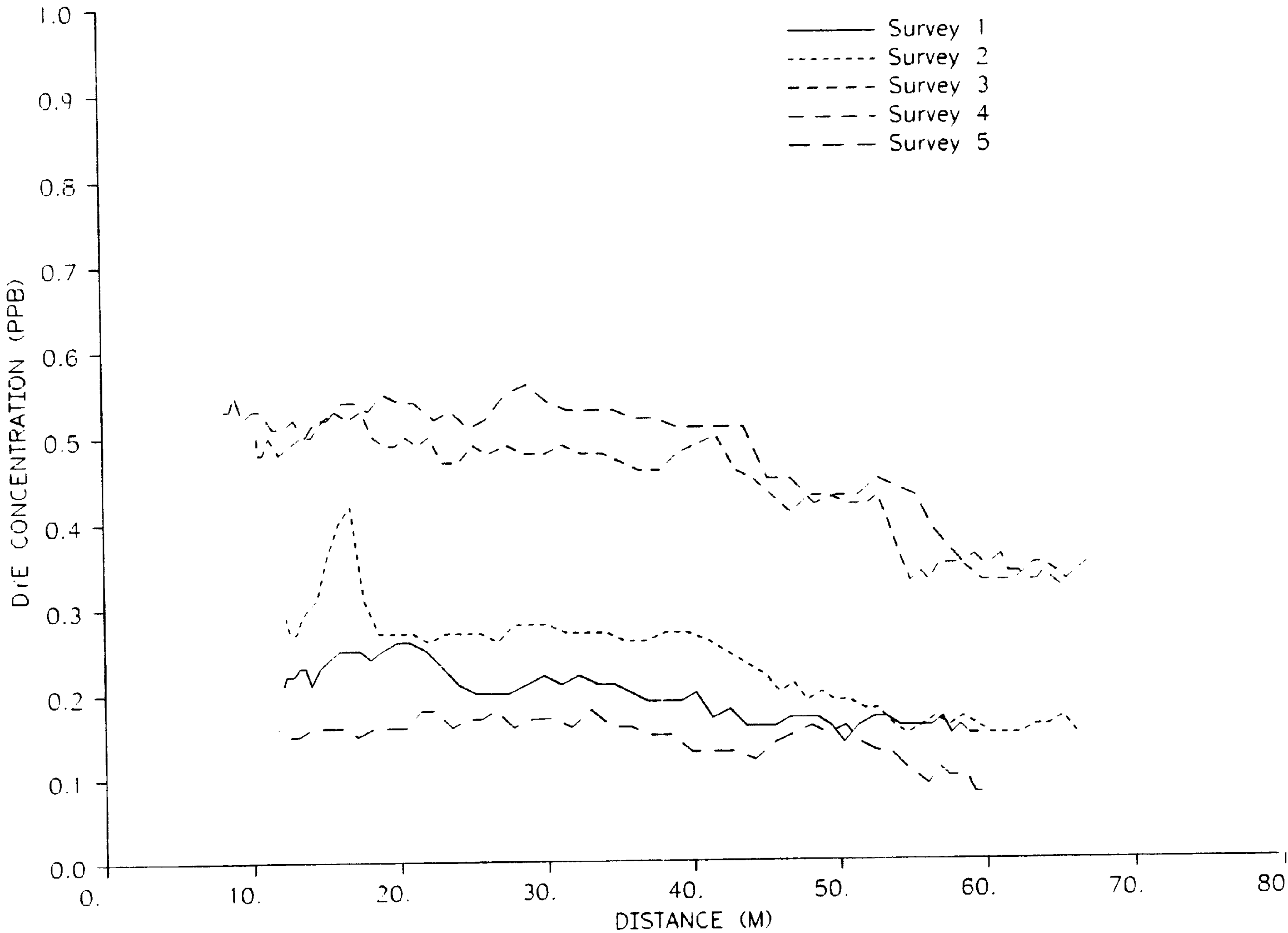


FIGURE A.3-1 OBSERVED DYE CONCENTRATION AT TRANSECT 1 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

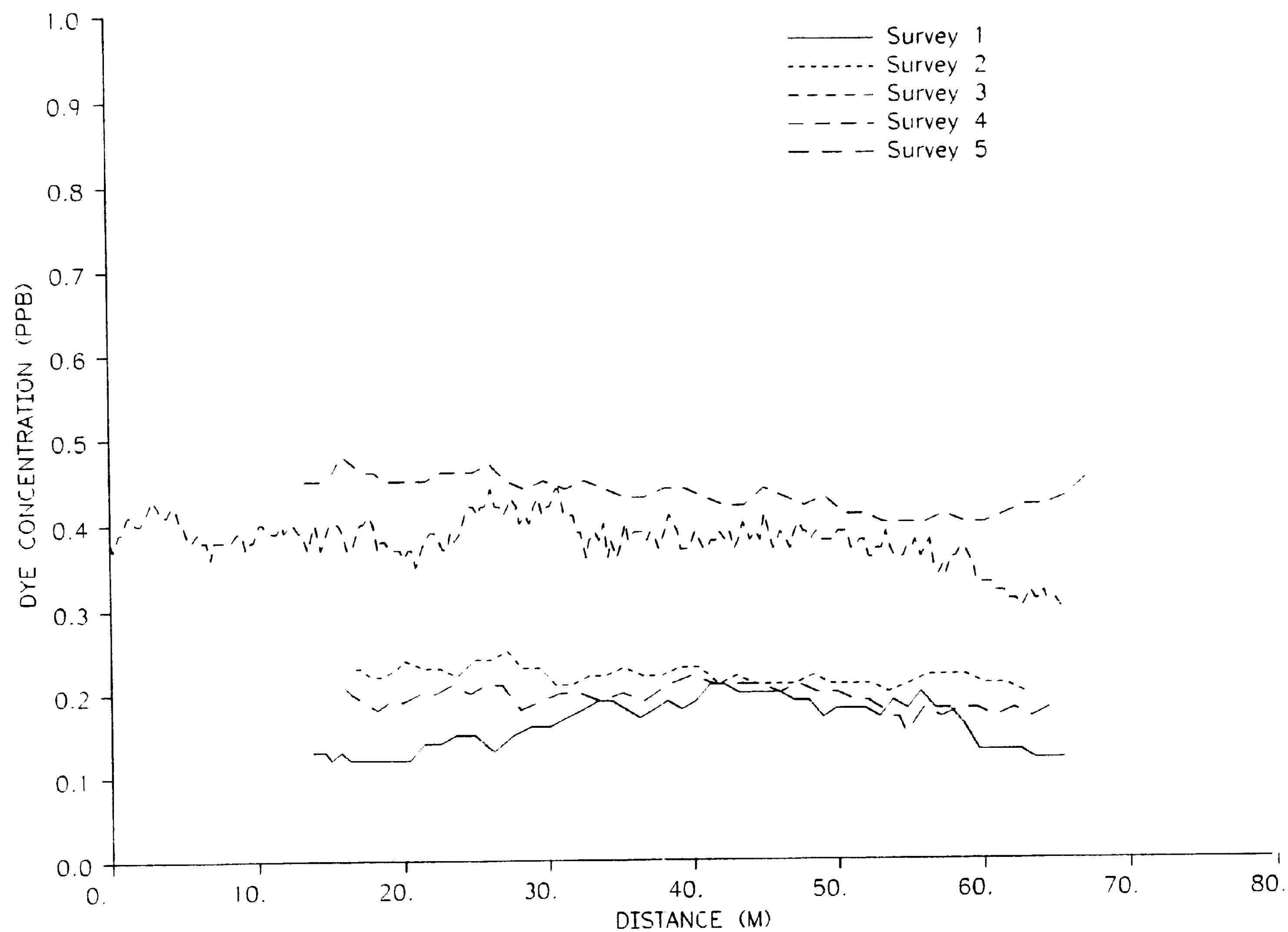


FIGURE A.3-2 OBSERVED DYE CONCENTRATION AT TRANSECT 2 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

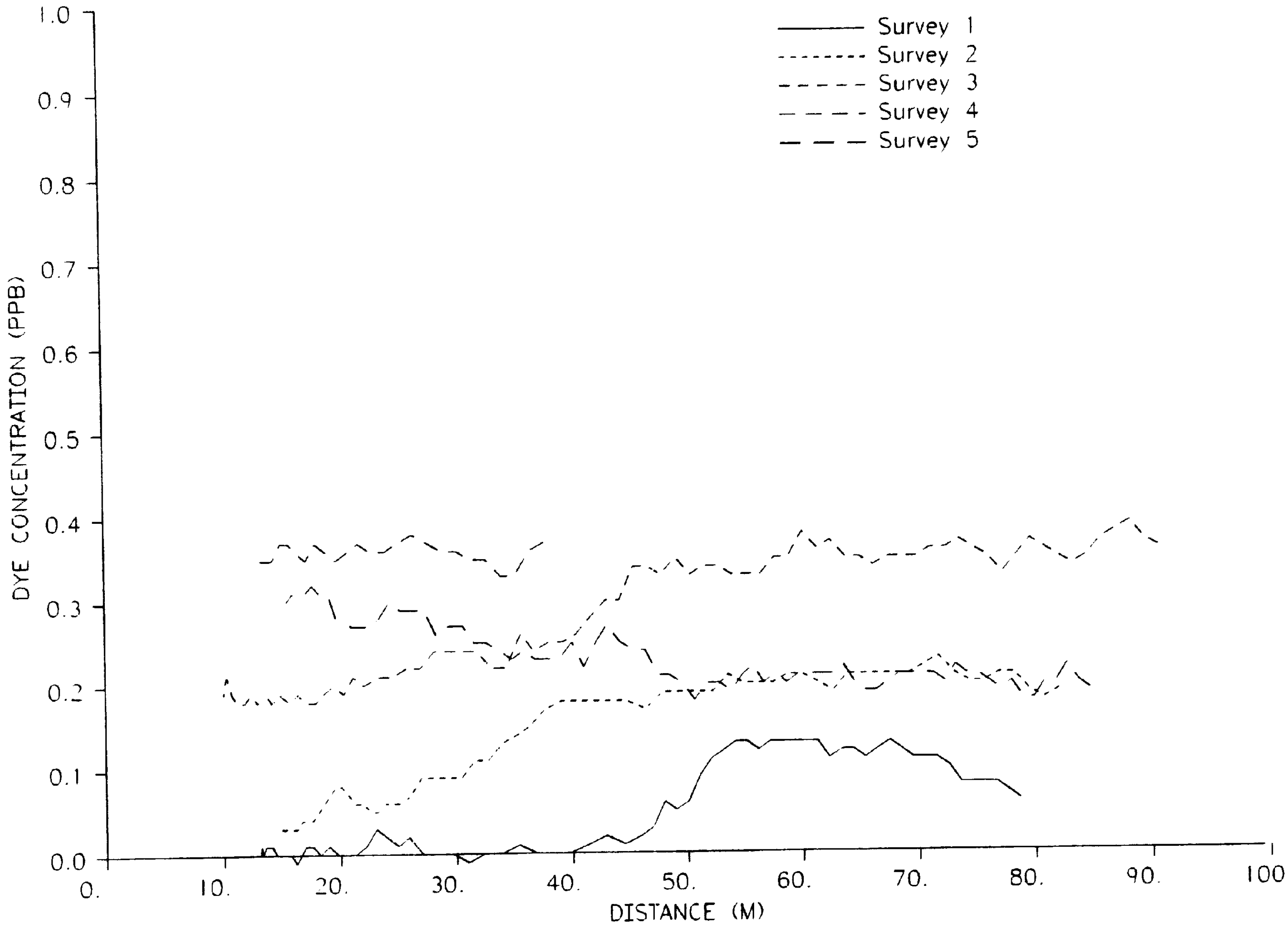


FIGURE A.3-3 OBSERVED DYE CONCENTRATION AT TRANSECT 3 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

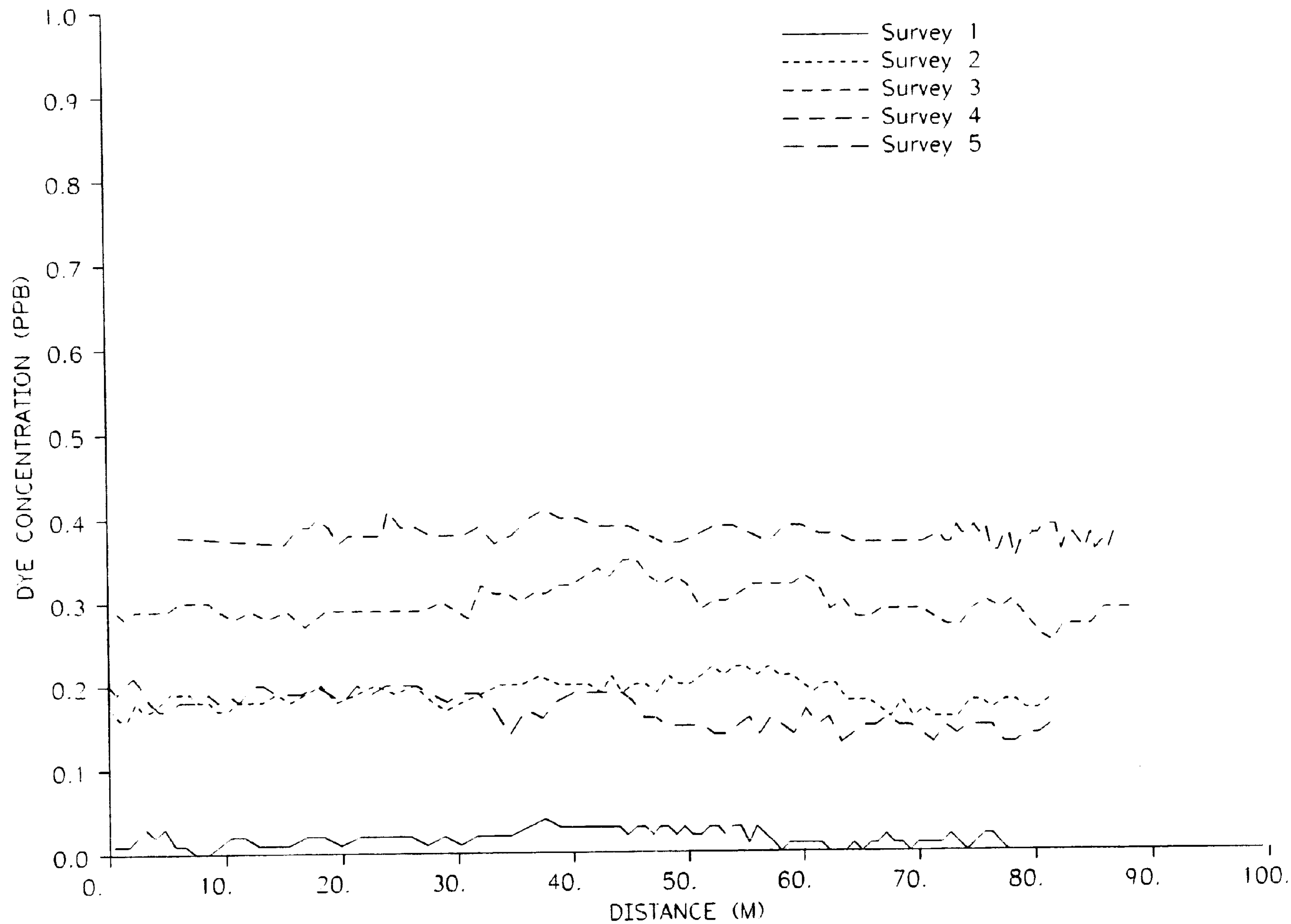


FIGURE A.3-4 OBSERVED DYE CONCENTRATION AT TRANSECT 4 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

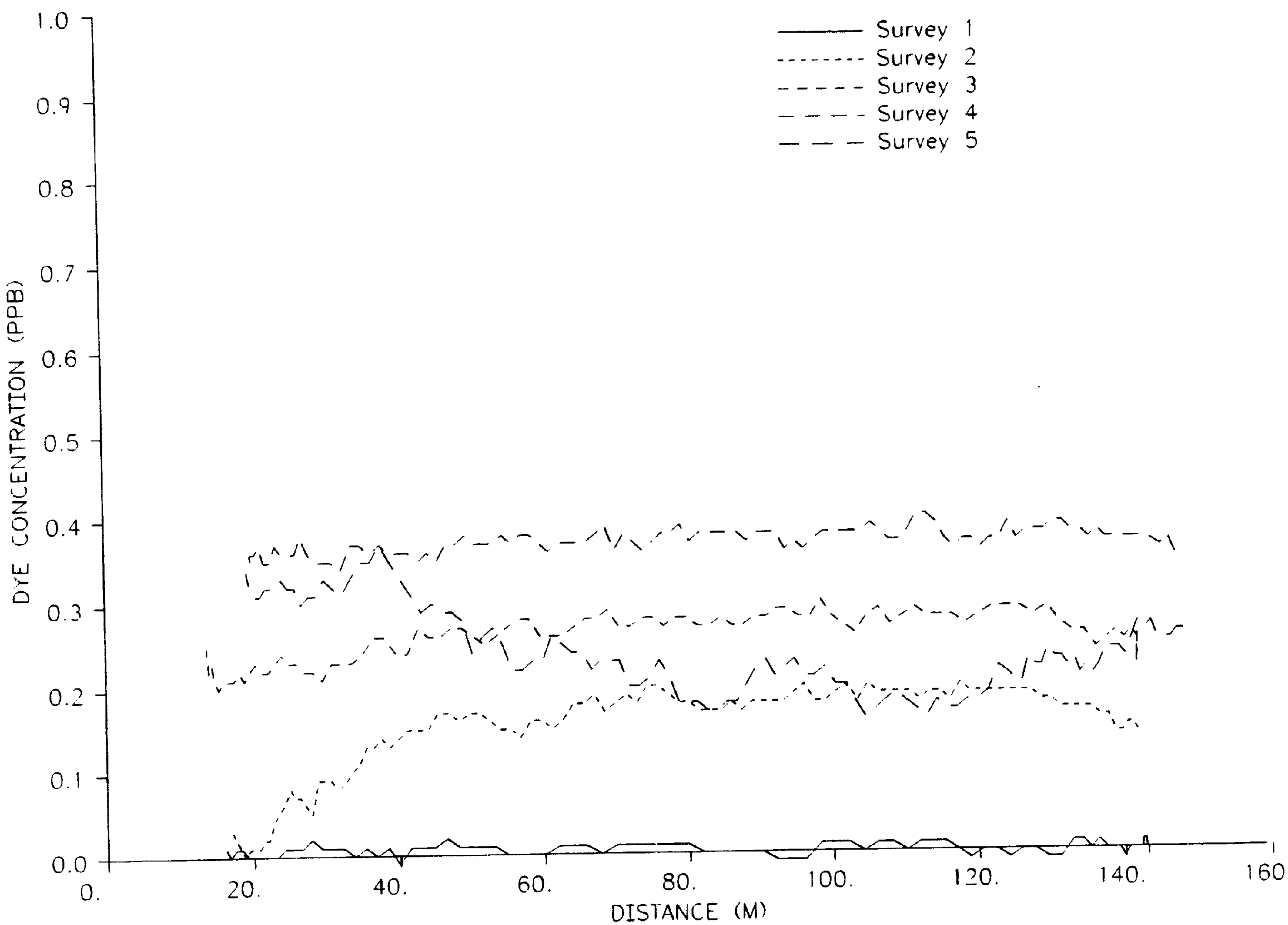


FIGURE A.3-5 OBSERVED DYE CONCENTRATION AT TRANSECT 5 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

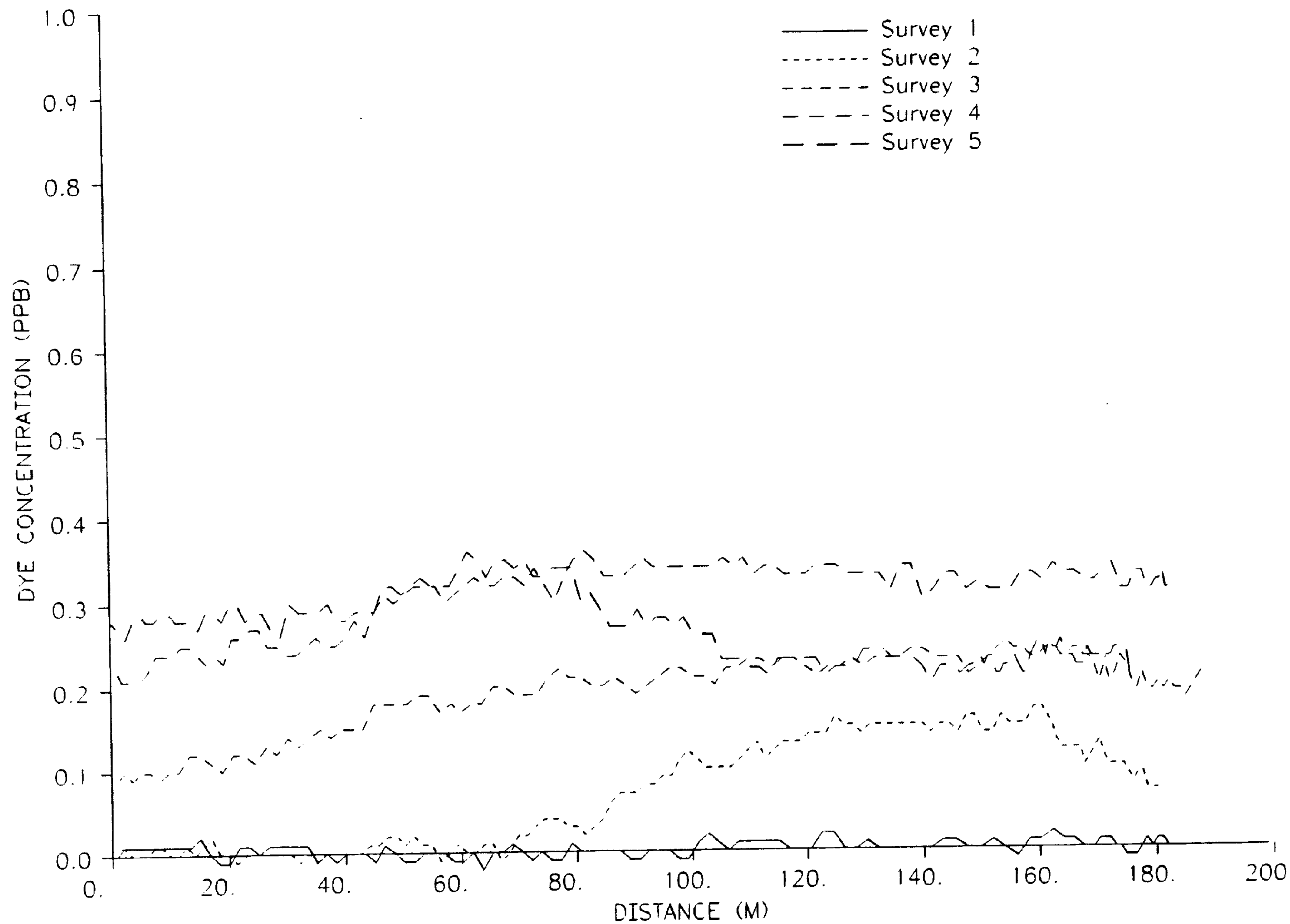


FIGURE A.3-6 OBSERVED DYE CONCENTRATION AT TRANSECT 6 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

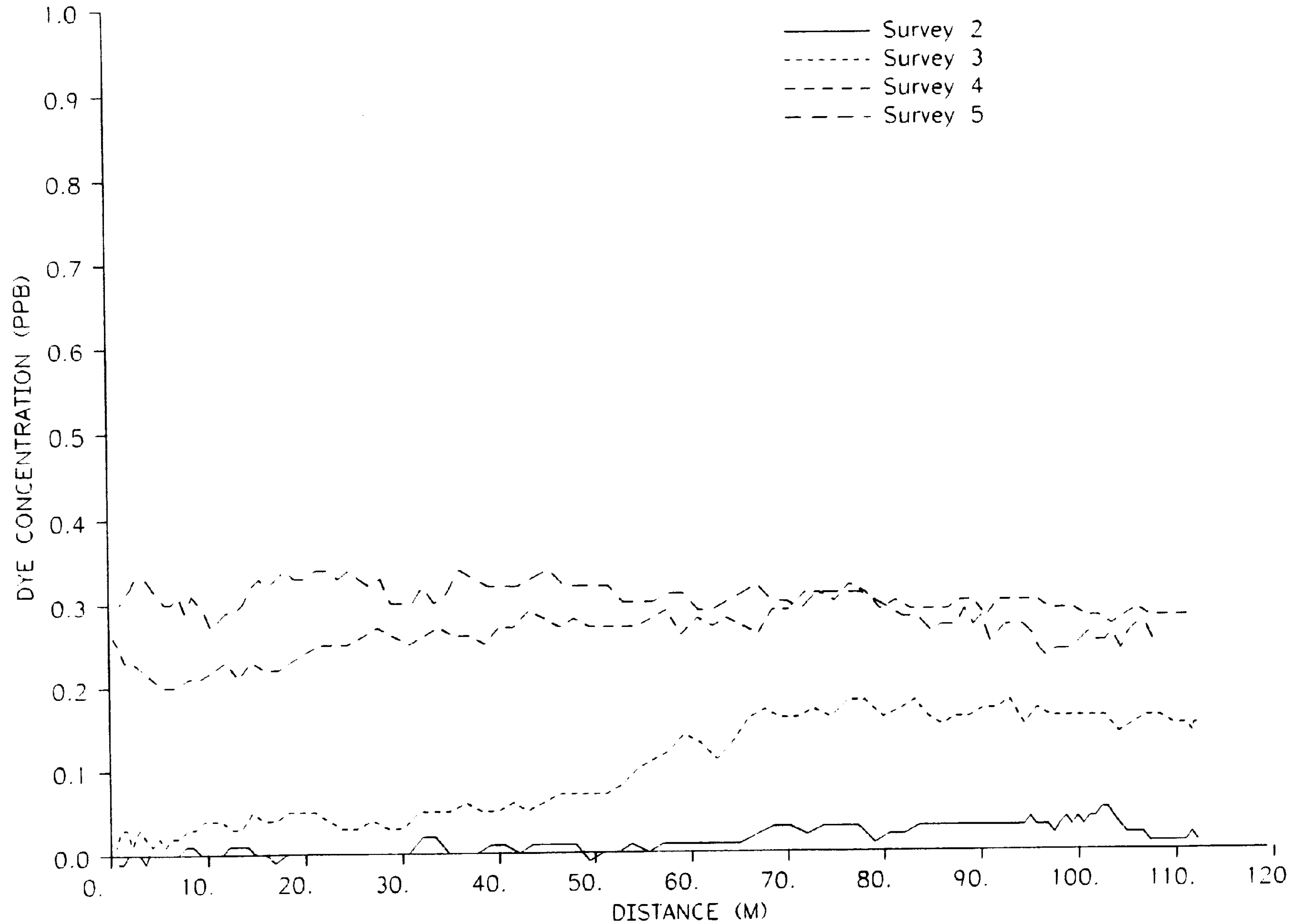


FIGURE A.3-7 OBSERVED DYE CONCENTRATION AT TRANSECT 7 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

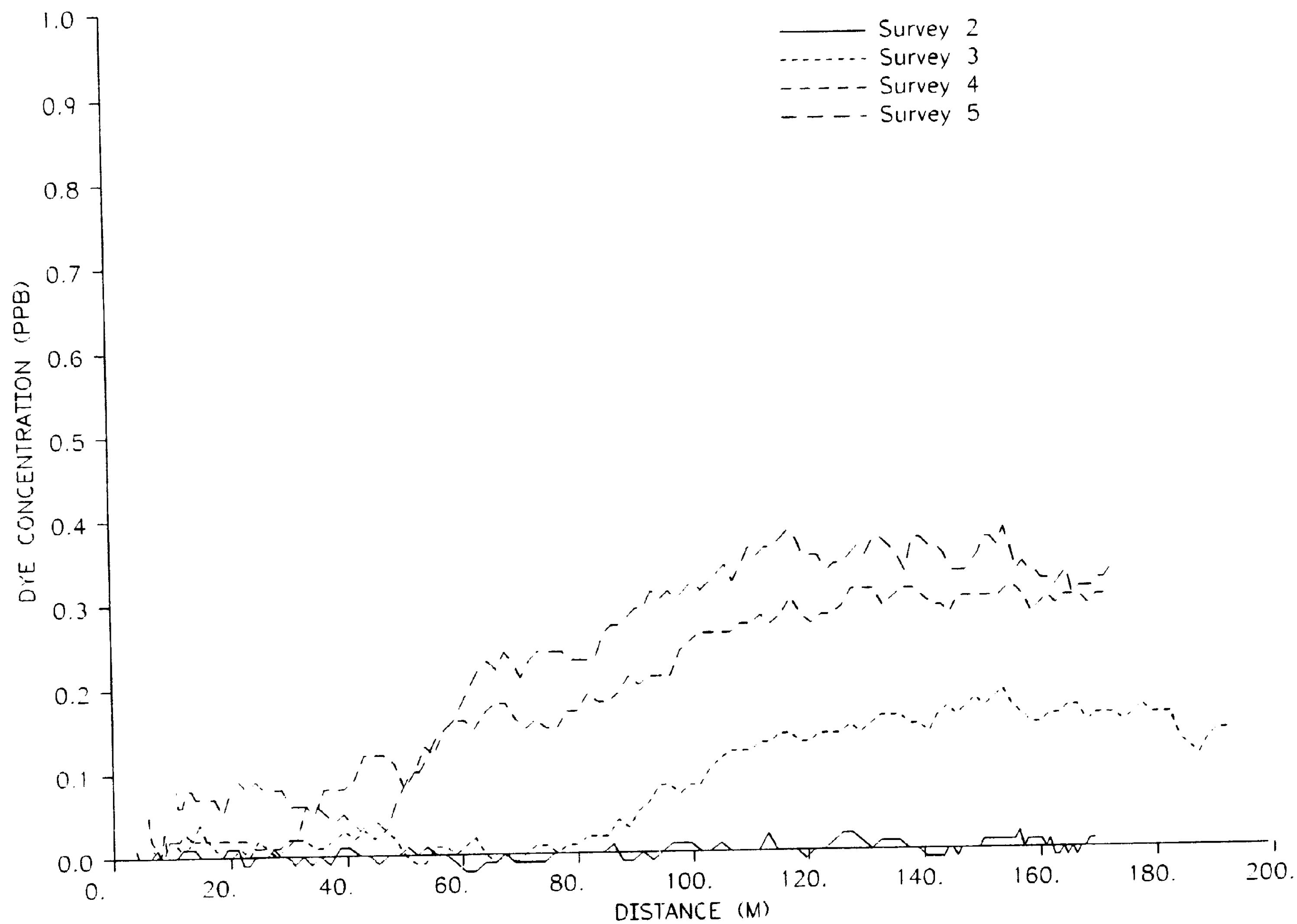


FIGURE A.3-8 OBSERVED DYE CONCENTRATION AT TRANSECT 10 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

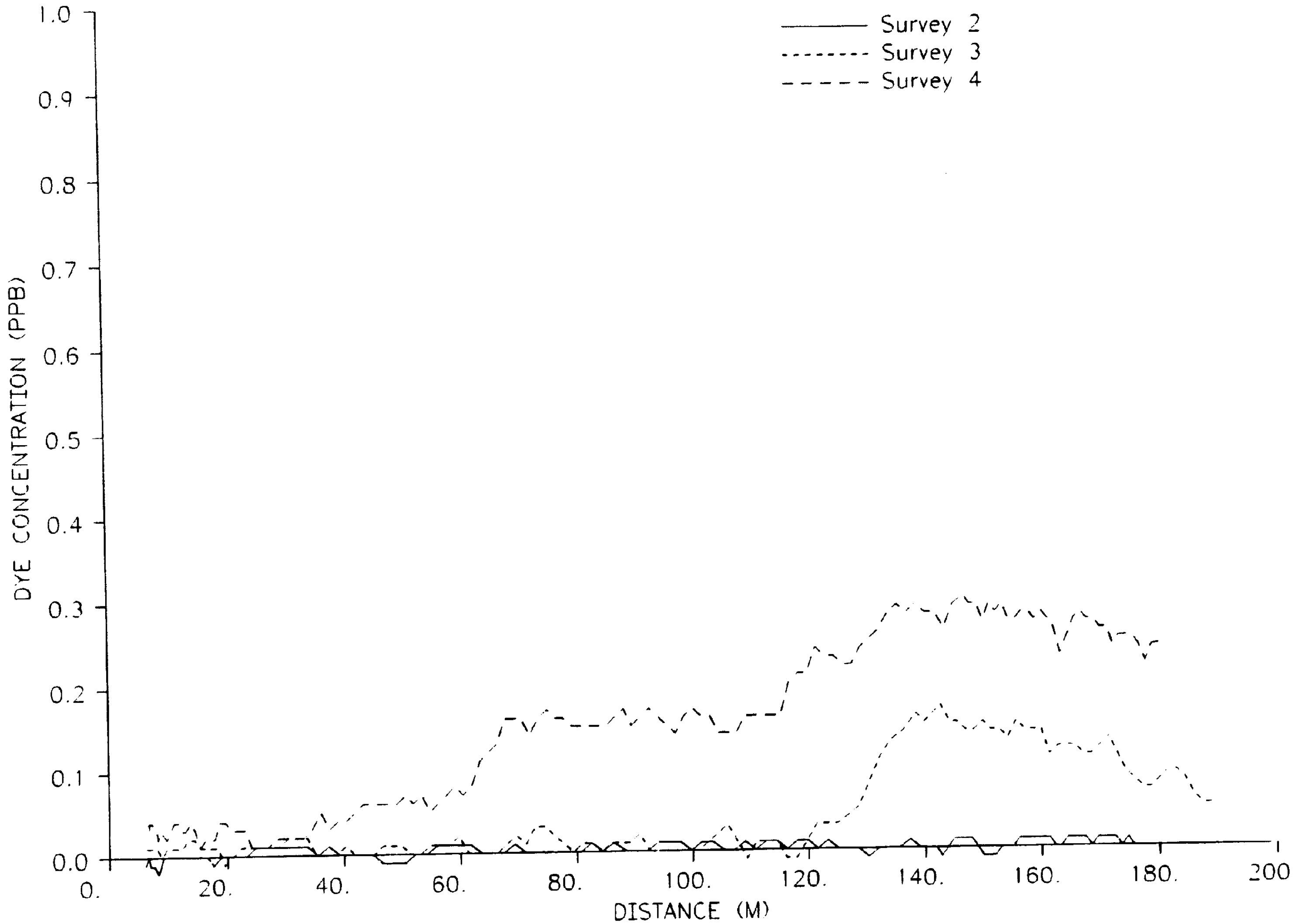


FIGURE A.3-9 OBSERVED DYE CONCENTRATION AT TRANSECT 11 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

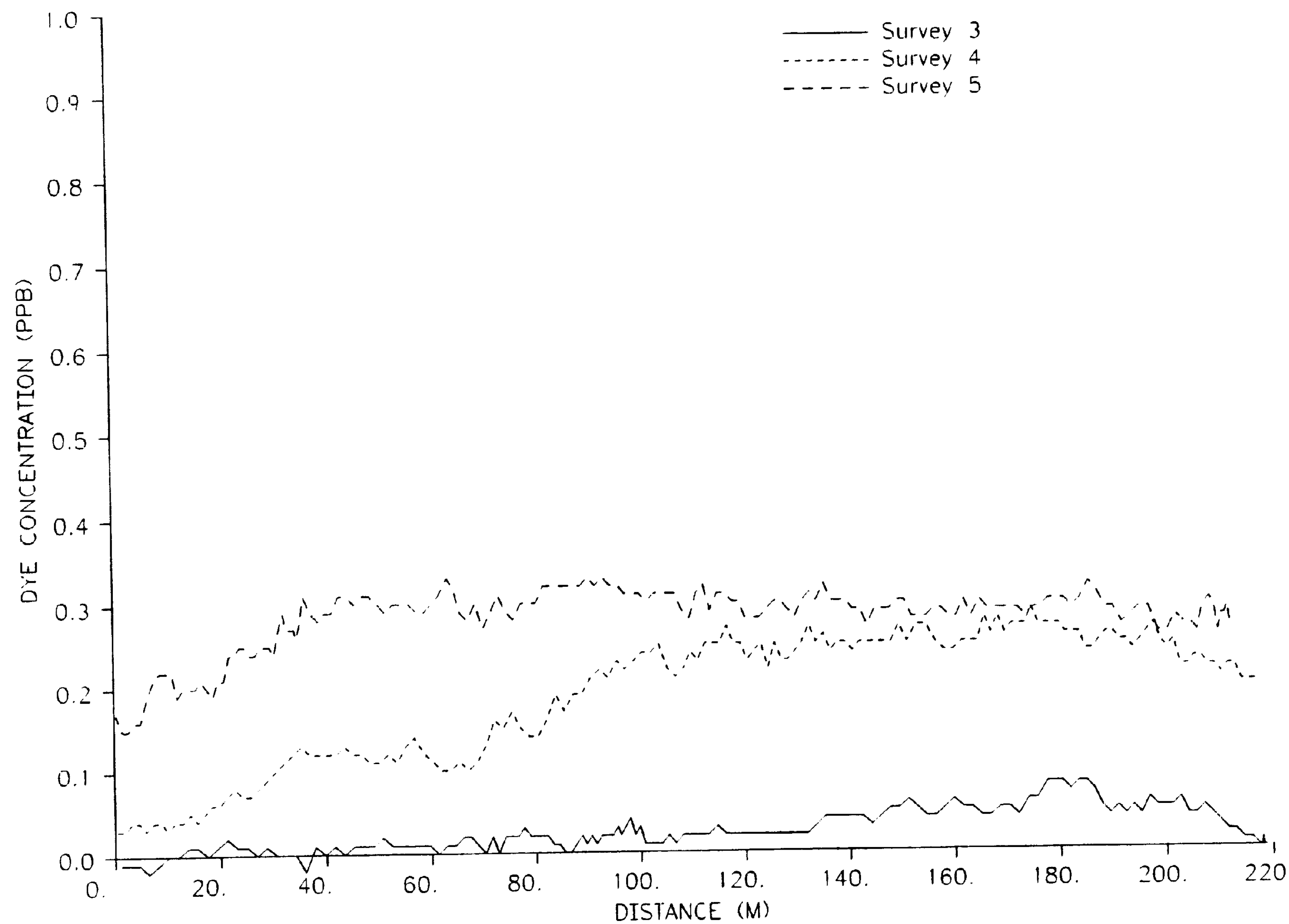


FIGURE A.3-10 OBSERVED DYE CONCENTRATION AT TRANSECT 12 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

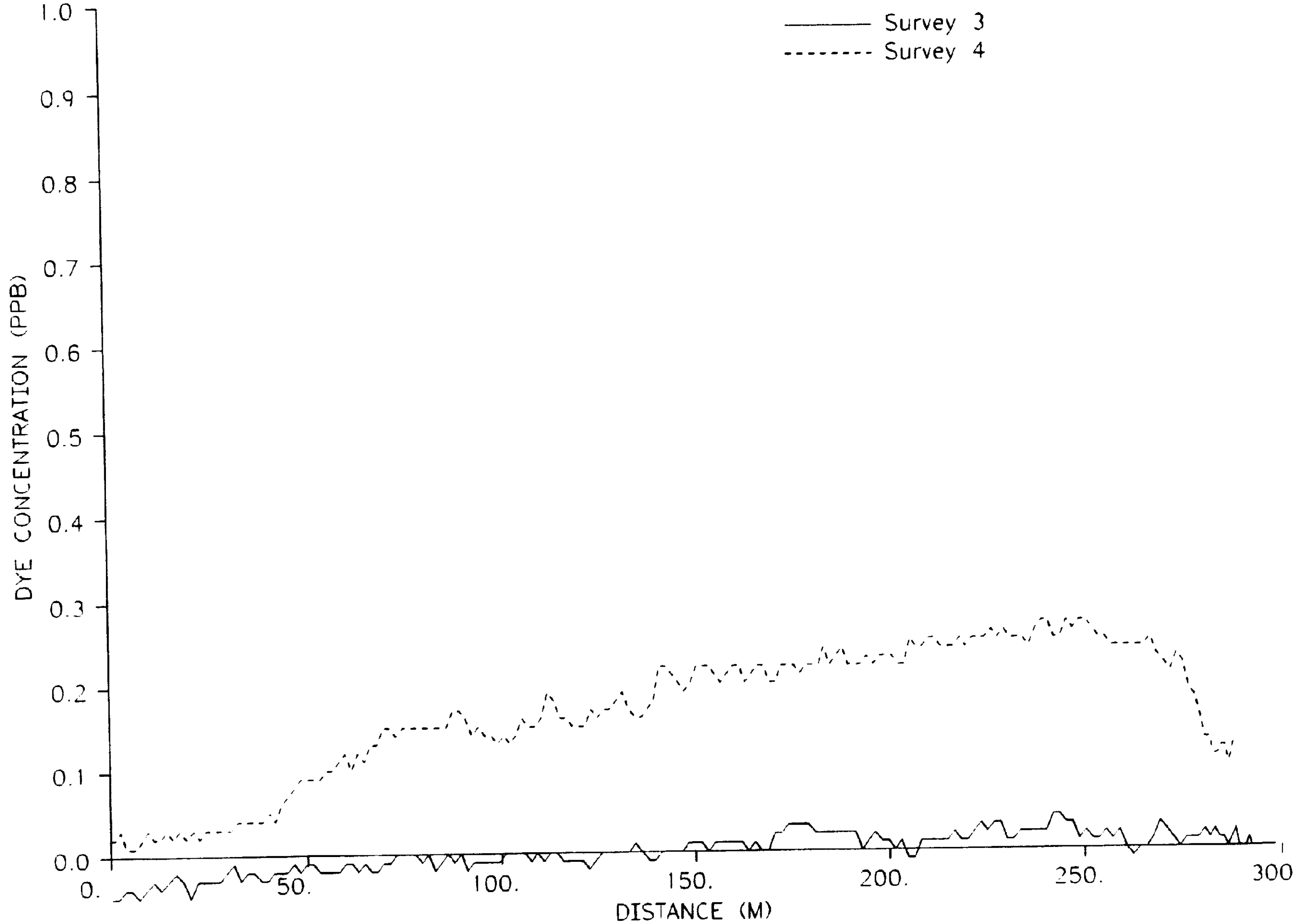


FIGURE A.3-11 OBSERVED DYE CONCENTRATION AT TRANSECT 13 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

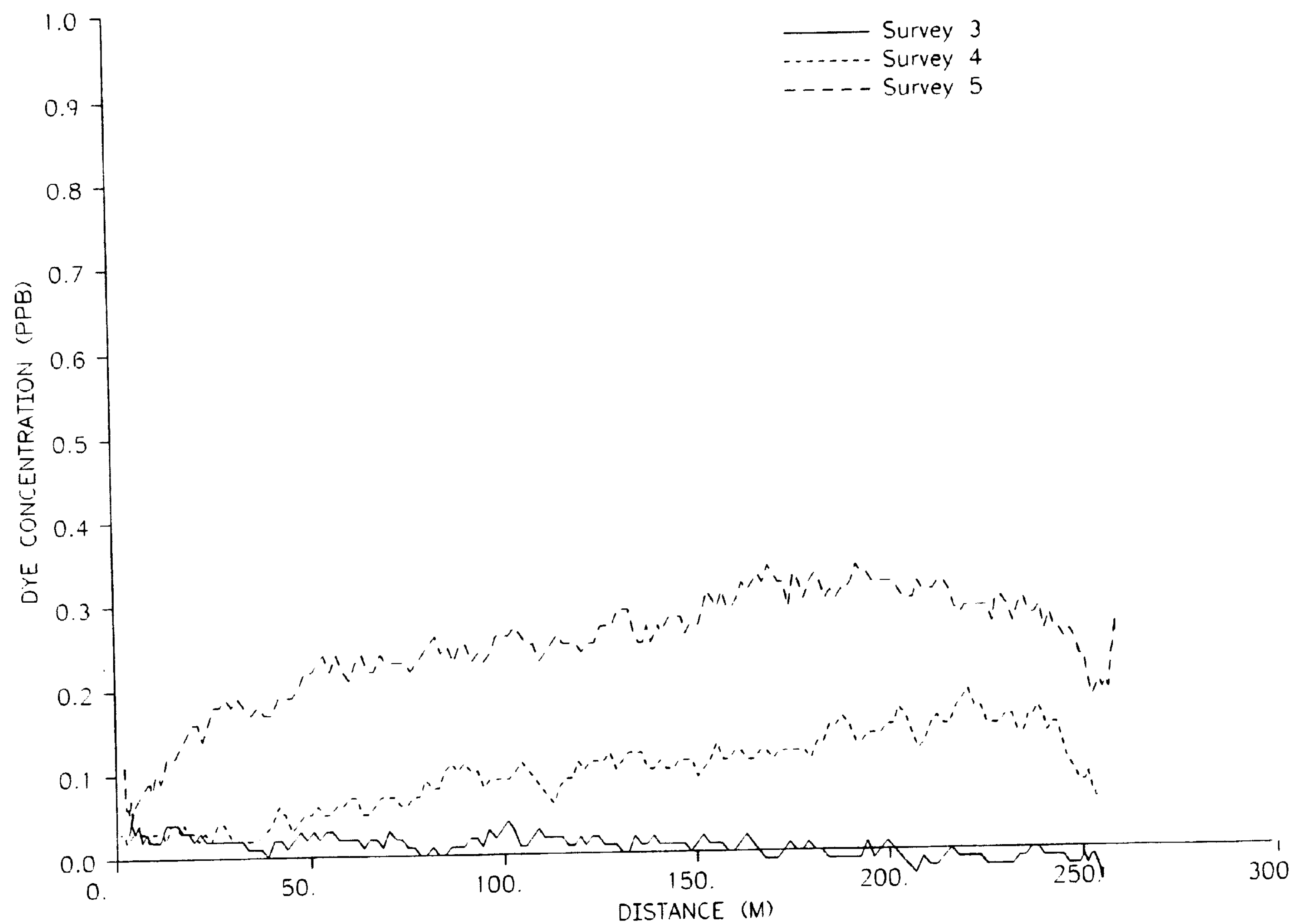


FIGURE A.3-12 OBSERVED DYE CONCENTRATION AT TRANSECT 14 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

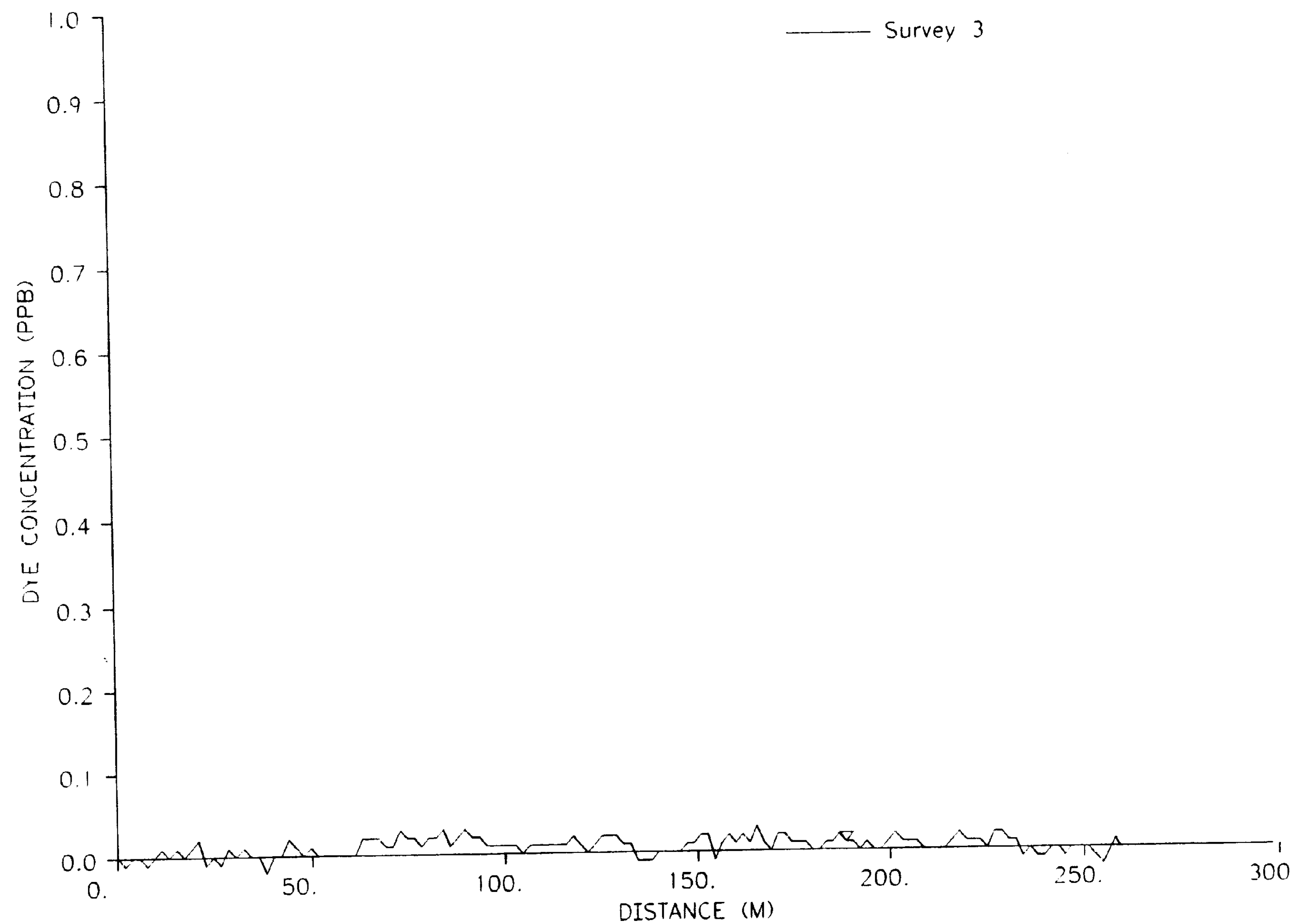


FIGURE A.3-13 OBSERVED DYE CONCENTRATION AT TRANSECT 15 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

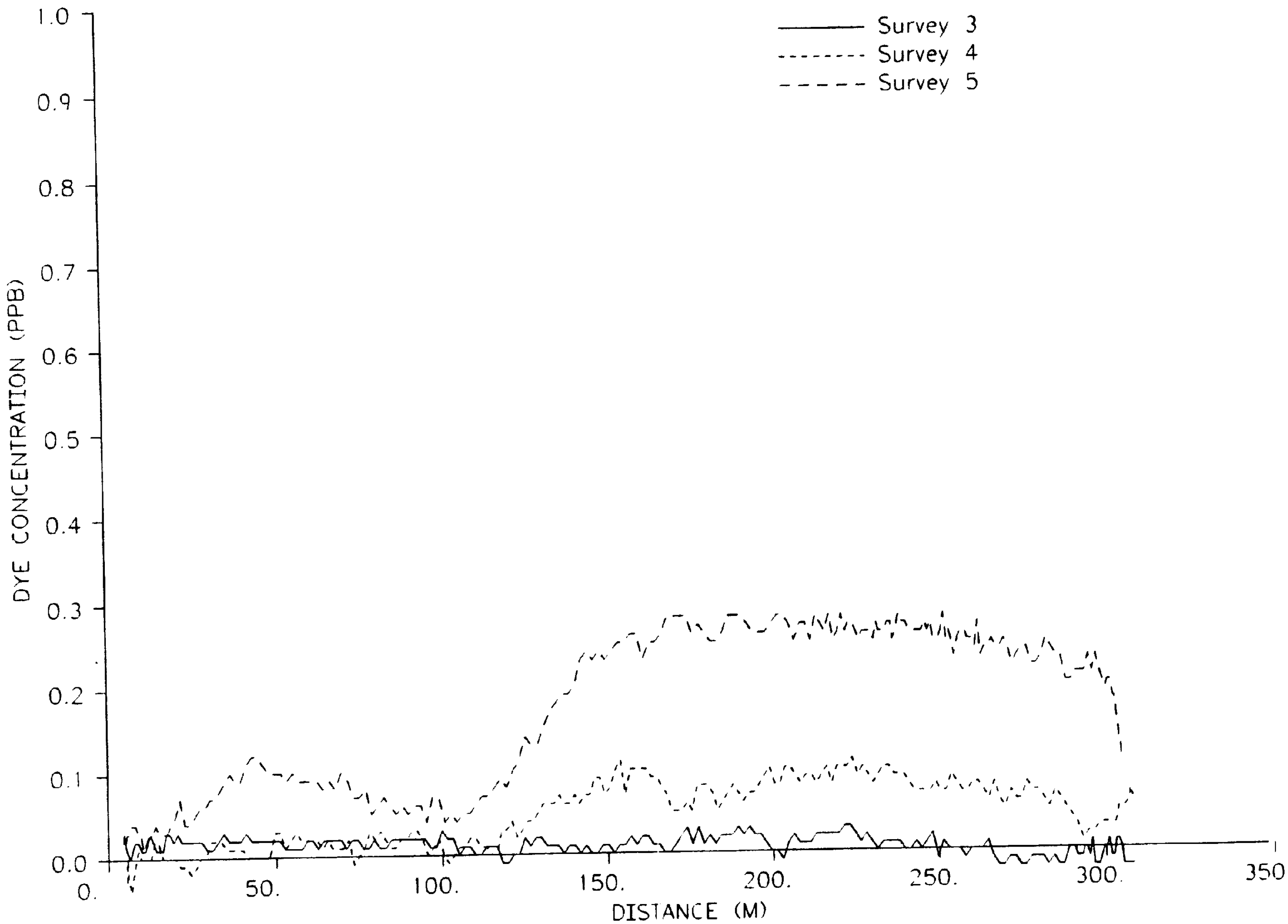


FIGURE A.3-14 OBSERVED DYE CONCENTRATION AT TRANSECT 16 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

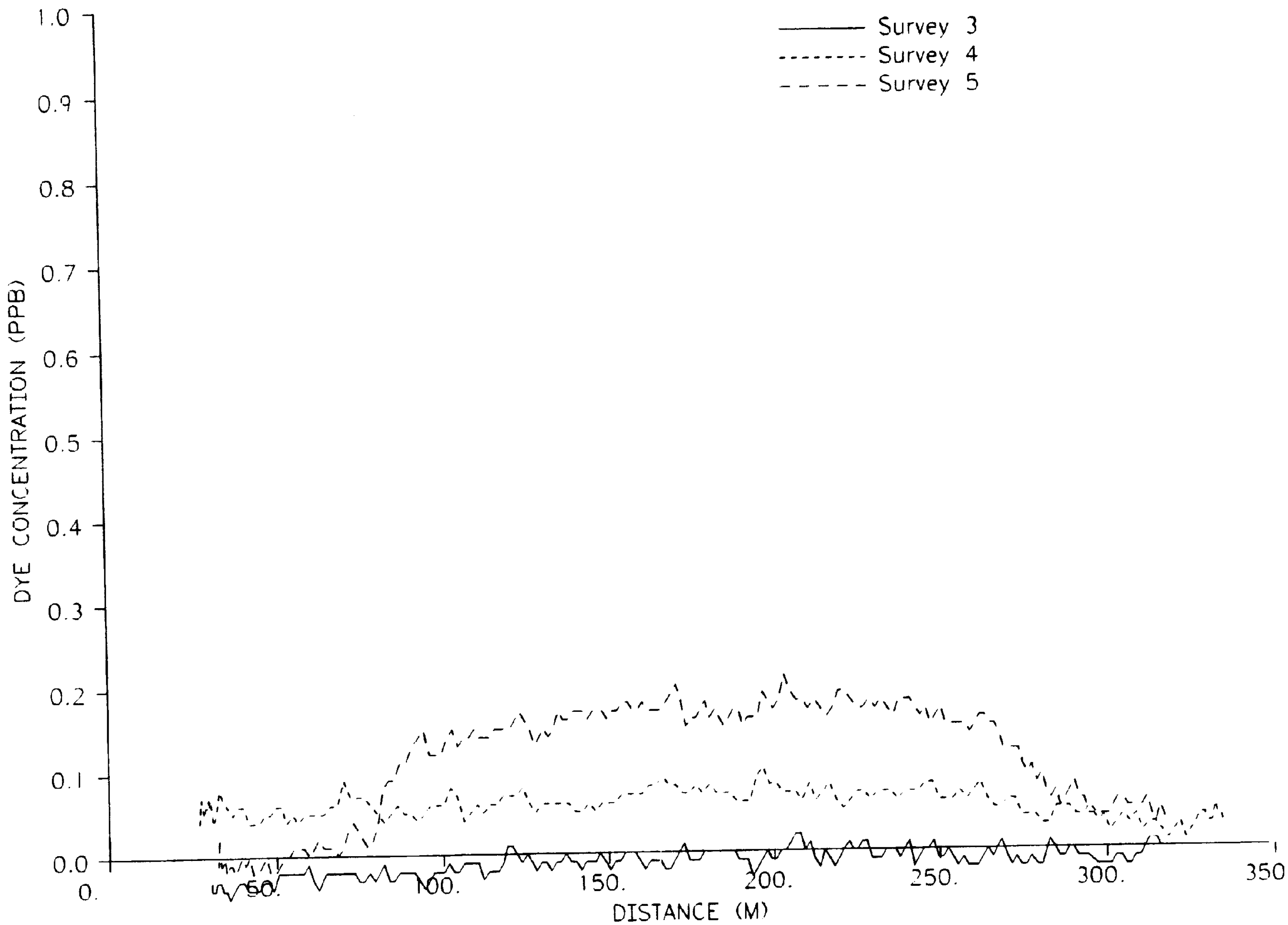


FIGURE A.3-15 OBSERVED DYE CONCENTRATION AT TRANSECT 17 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

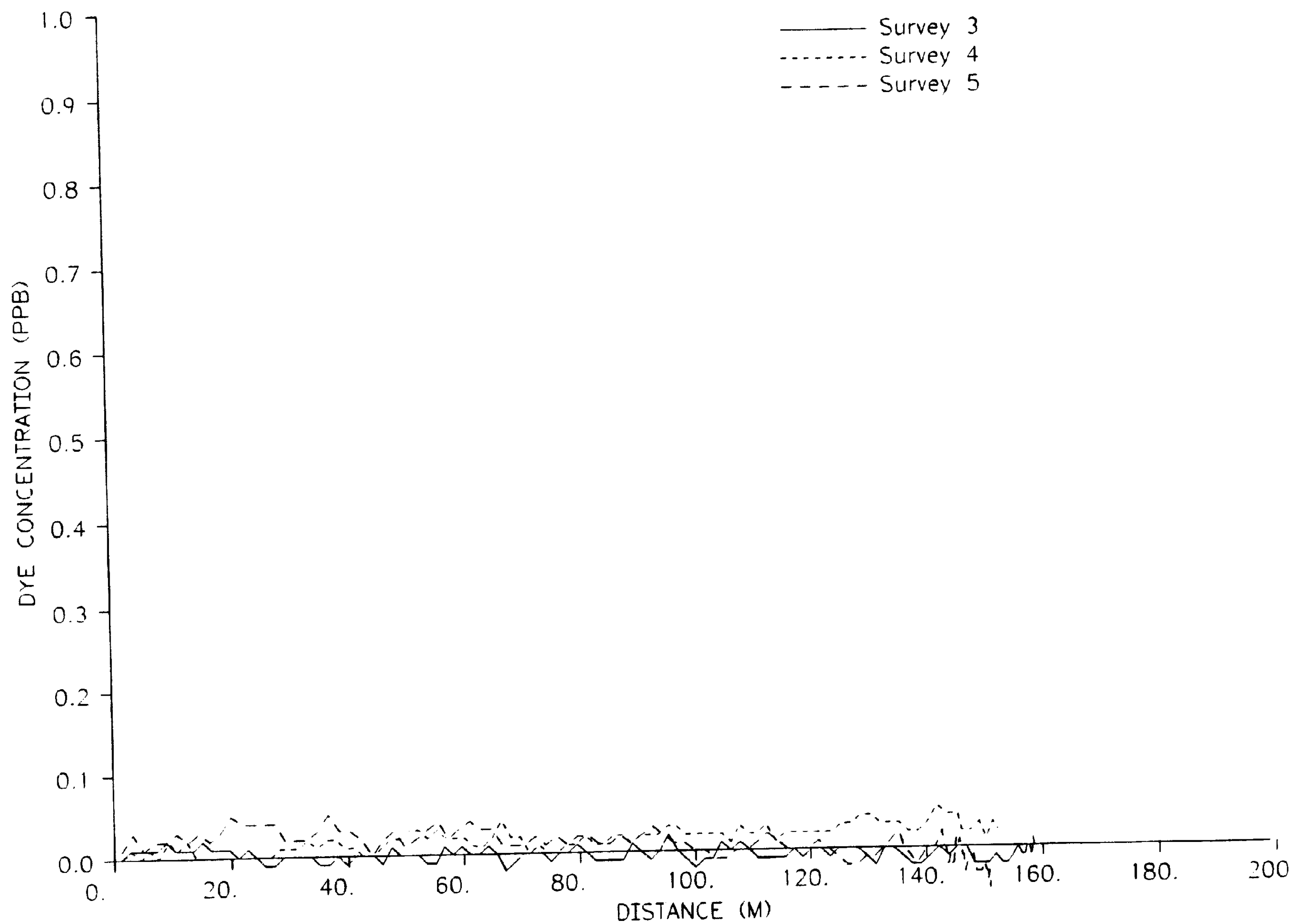


FIGURE A.3-16 OBSERVED DYE CONCENTRATION AT TRANSECT 18 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

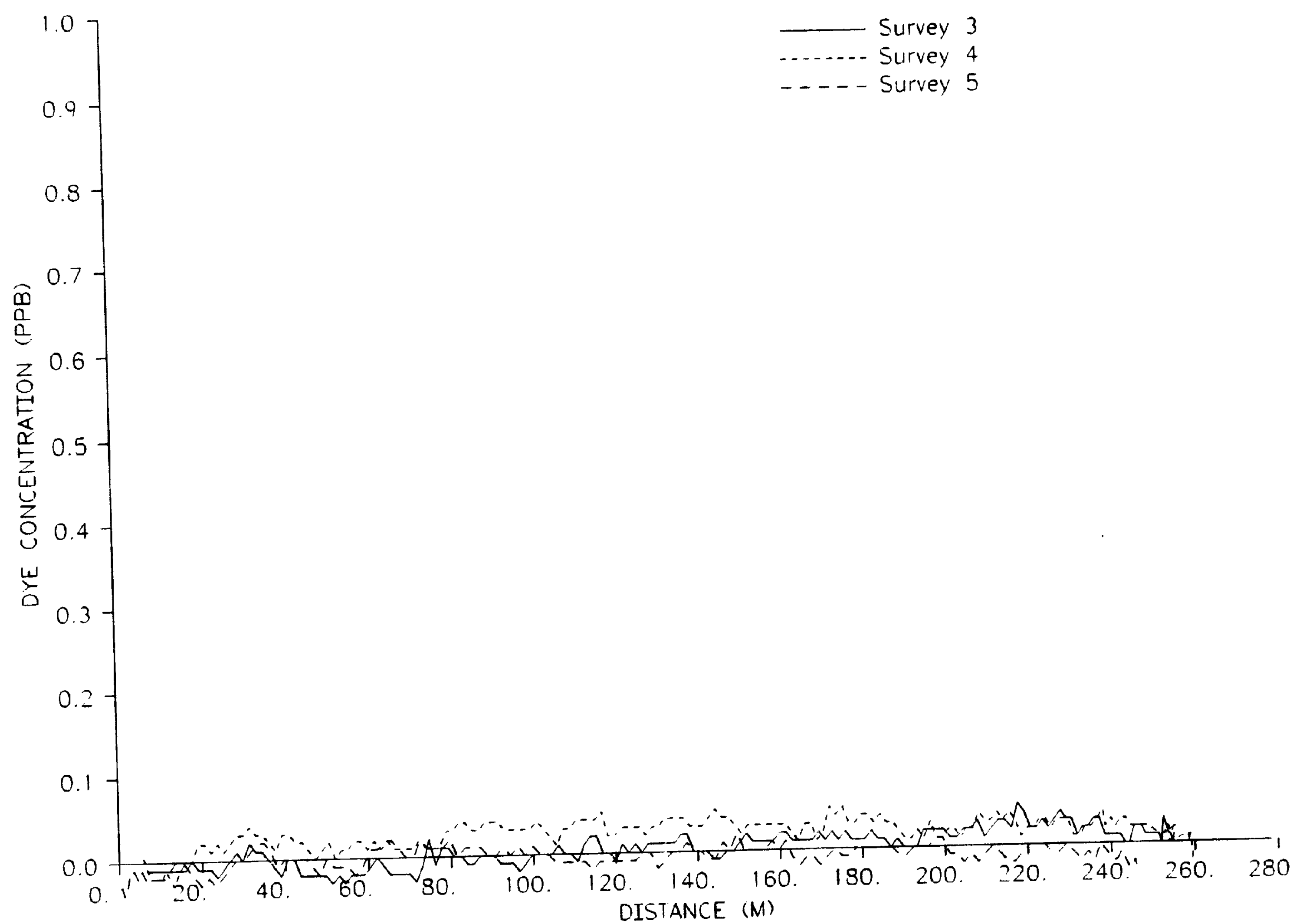


FIGURE A.3-17 OBSERVED DYE CONCENTRATION AT TRANSECT 19 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

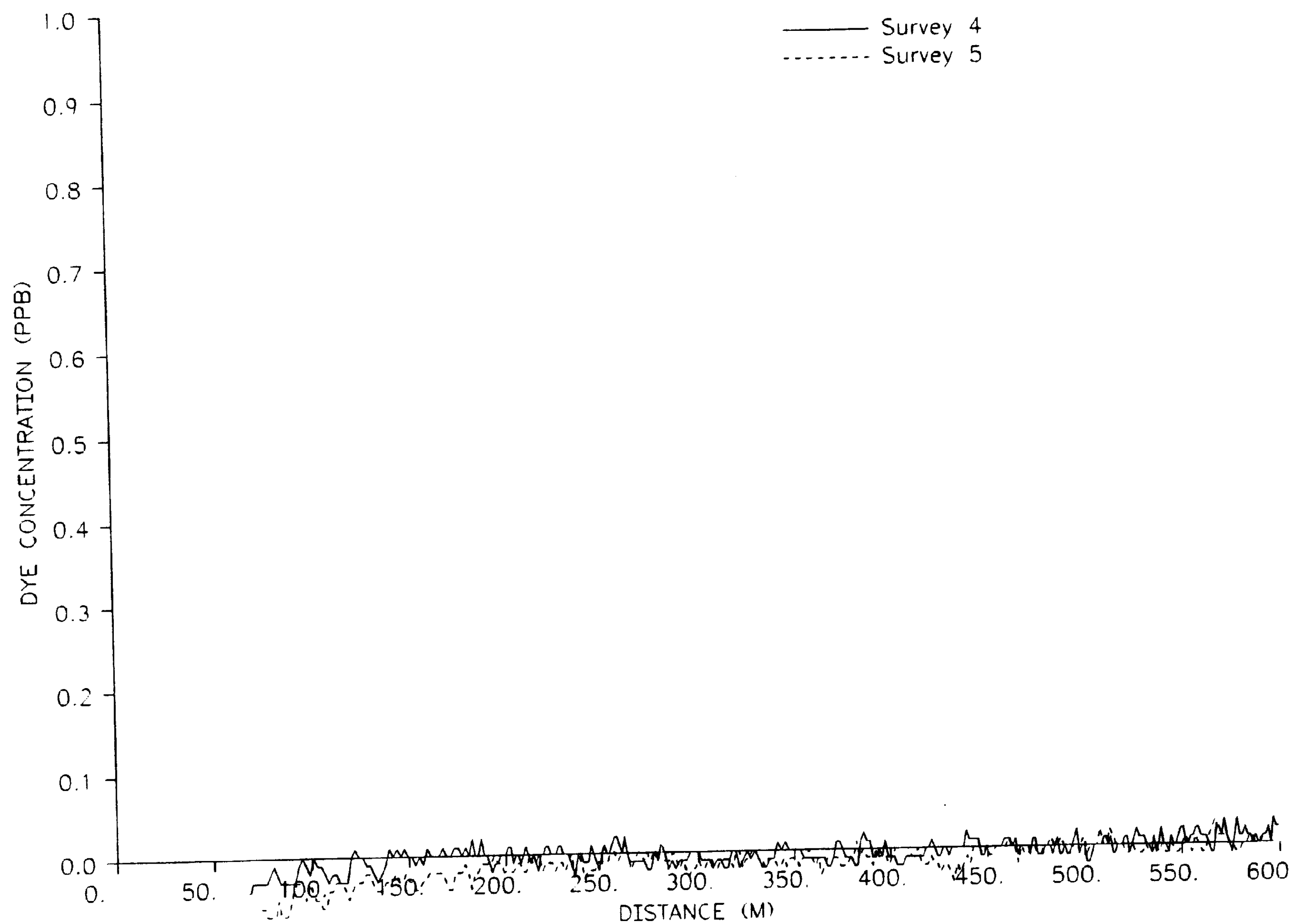


FIGURE A.3-18 OBSERVED DYE CONCENTRATION AT TRANSECT 20 DURING THE 24 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

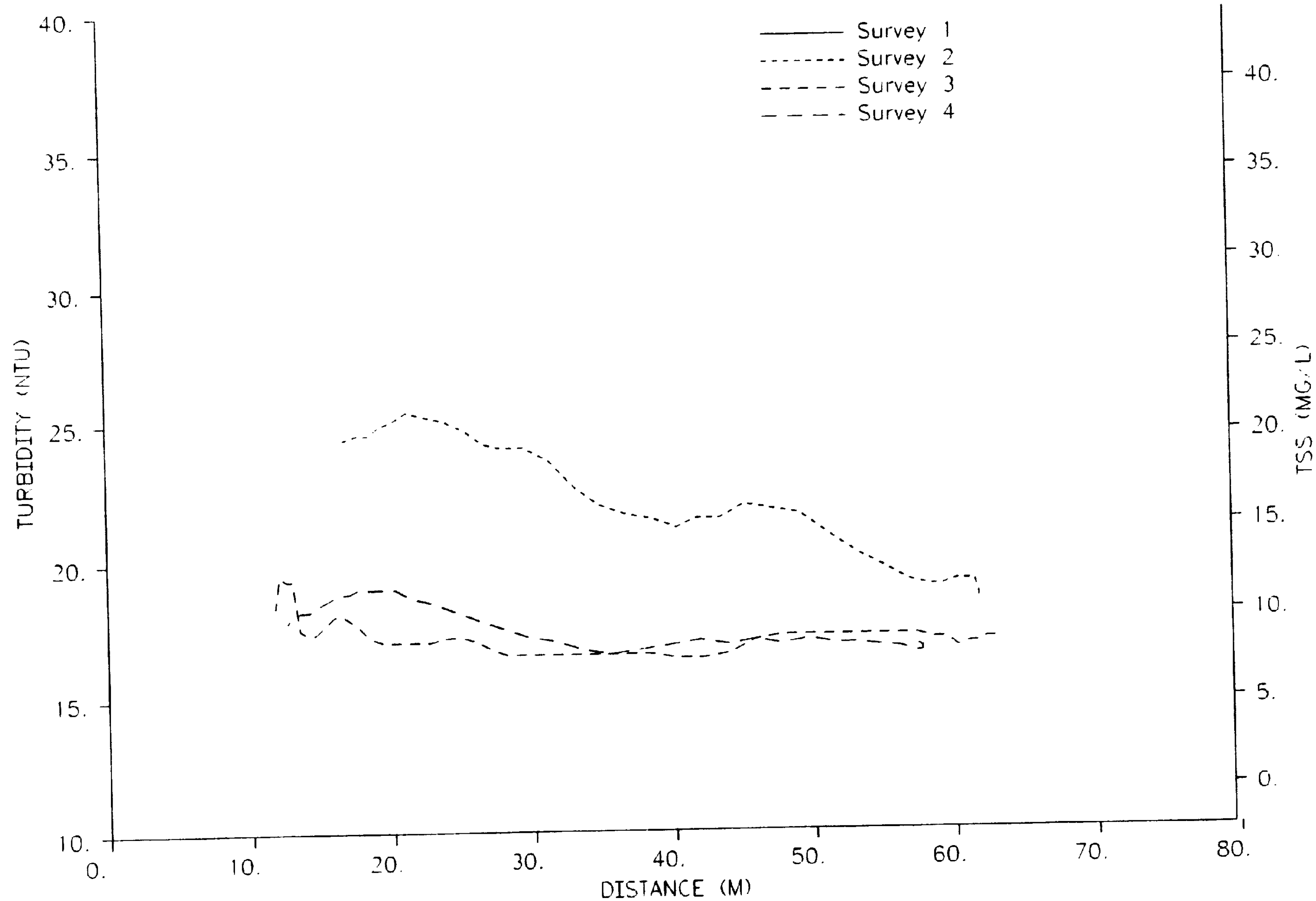


FIGURE A.4-1 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 1 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

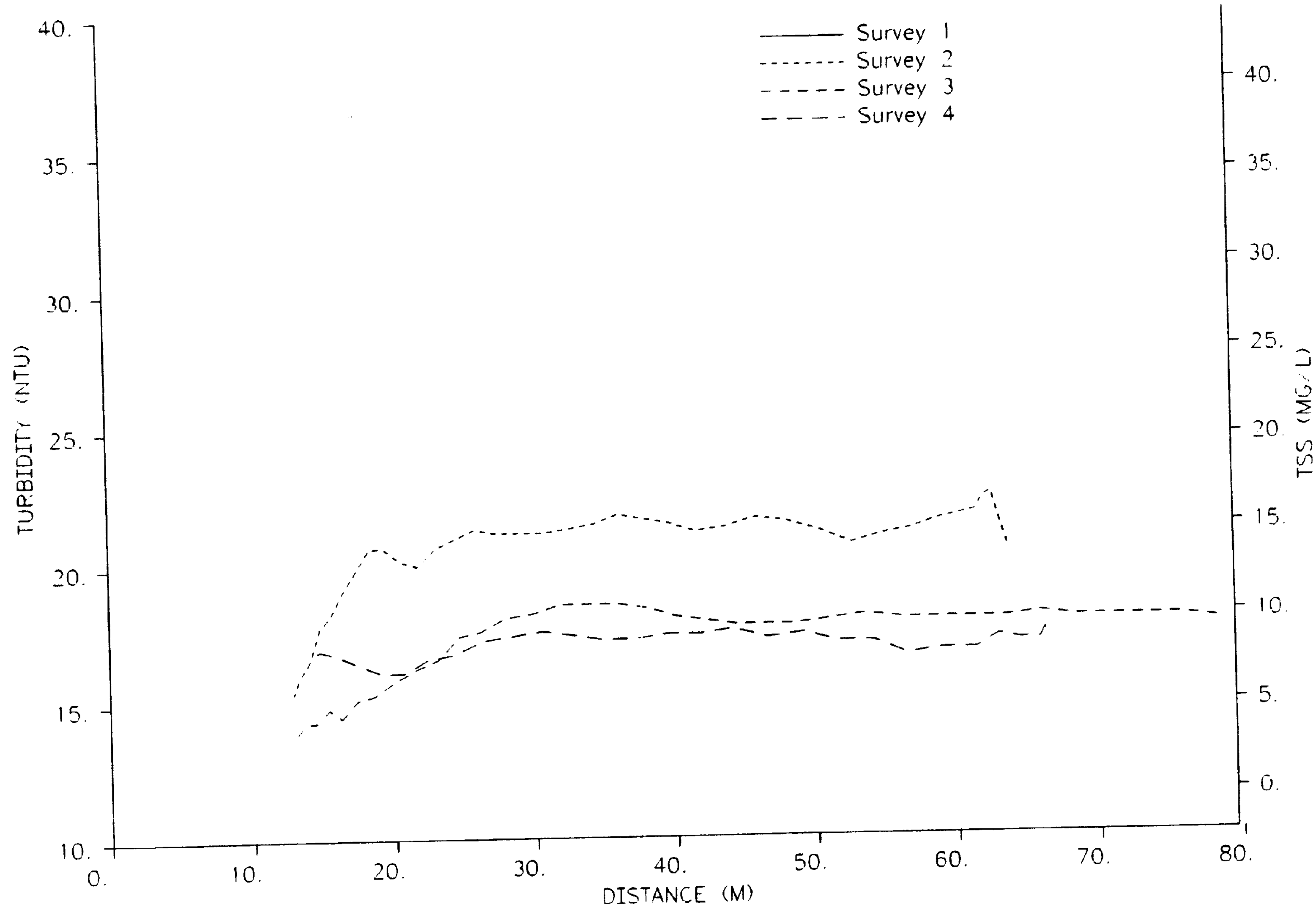


FIGURE A.4-2 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 2 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

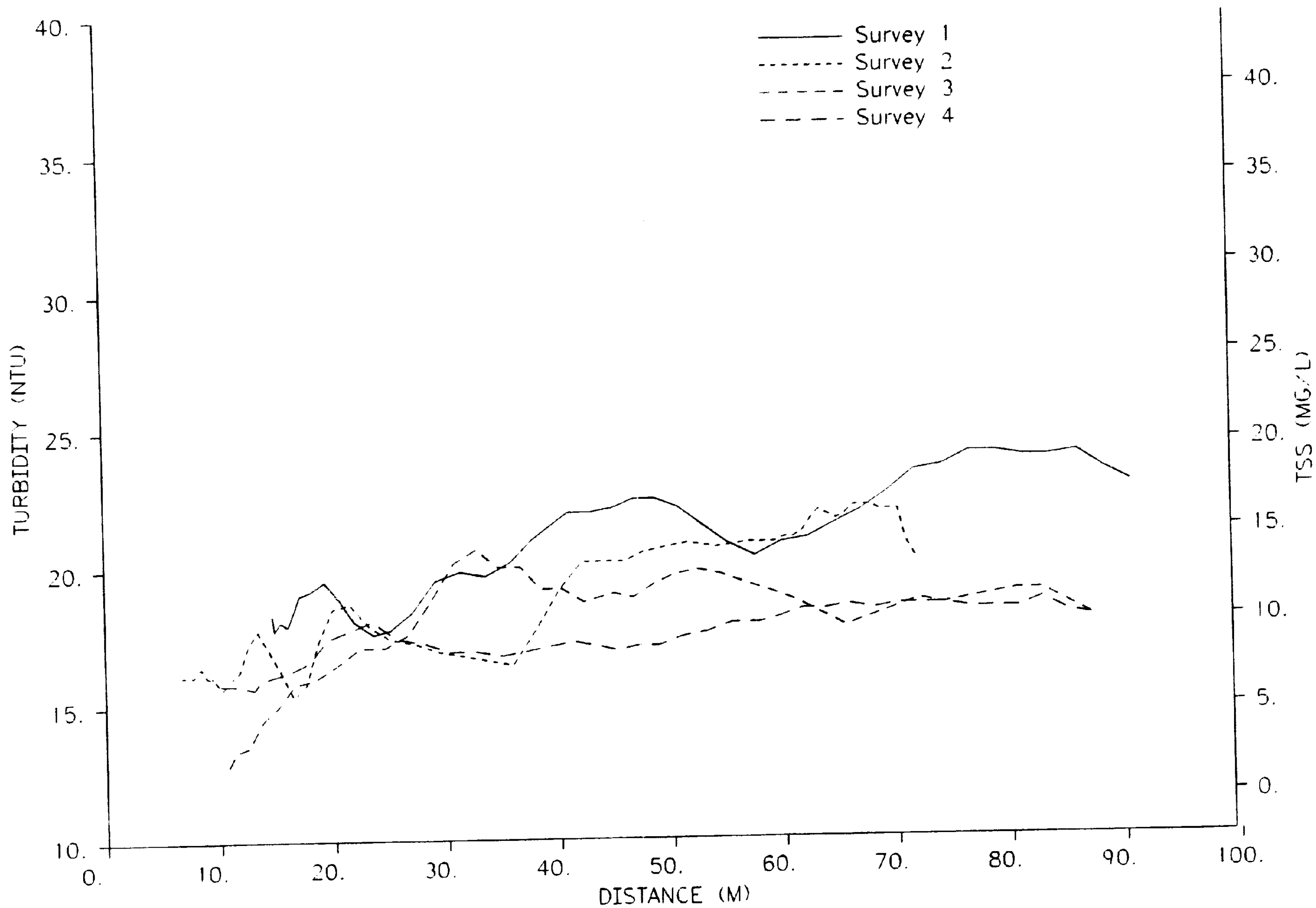


FIGURE A.4-3 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 3 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

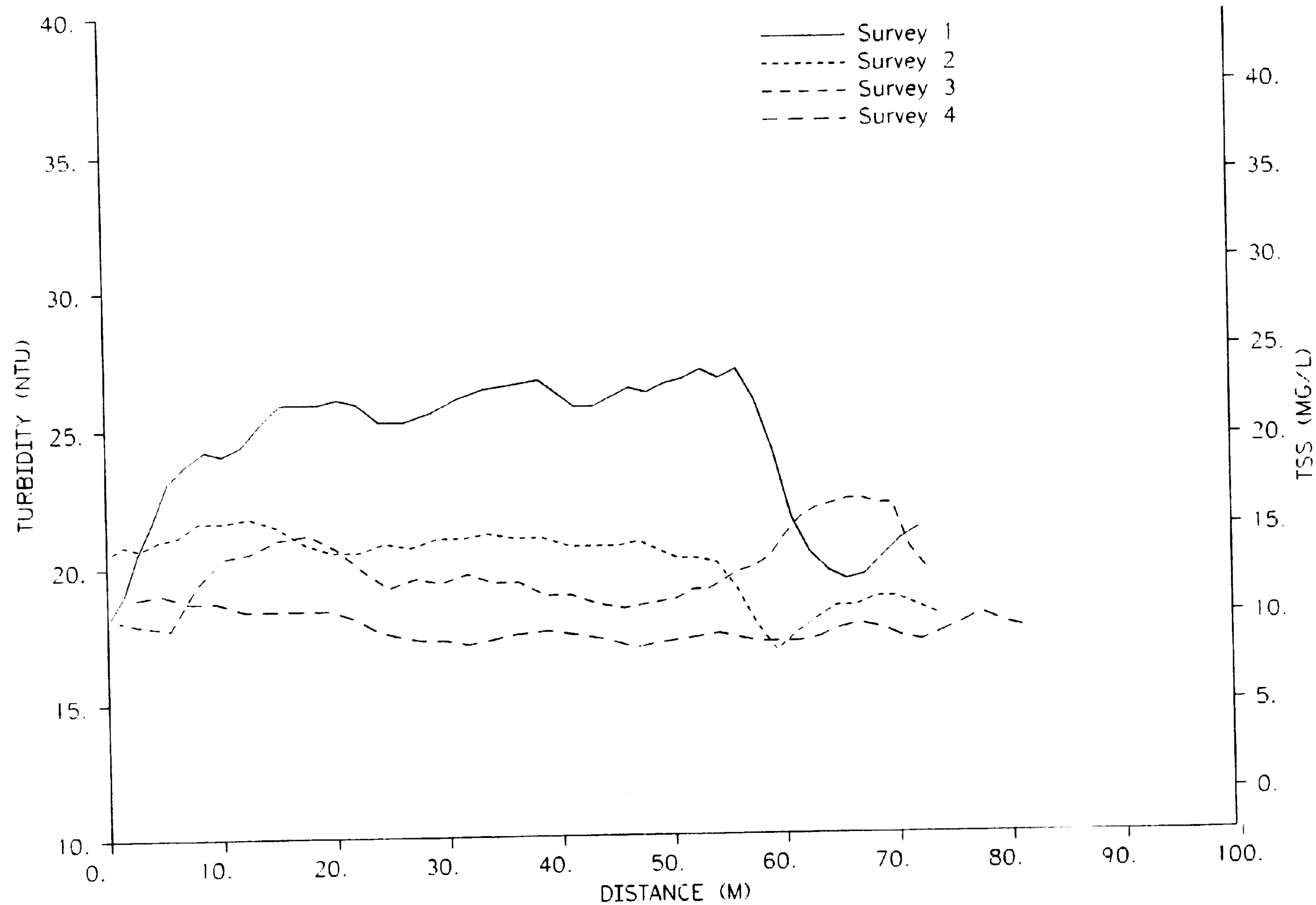


FIGURE A.4-4 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 4 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

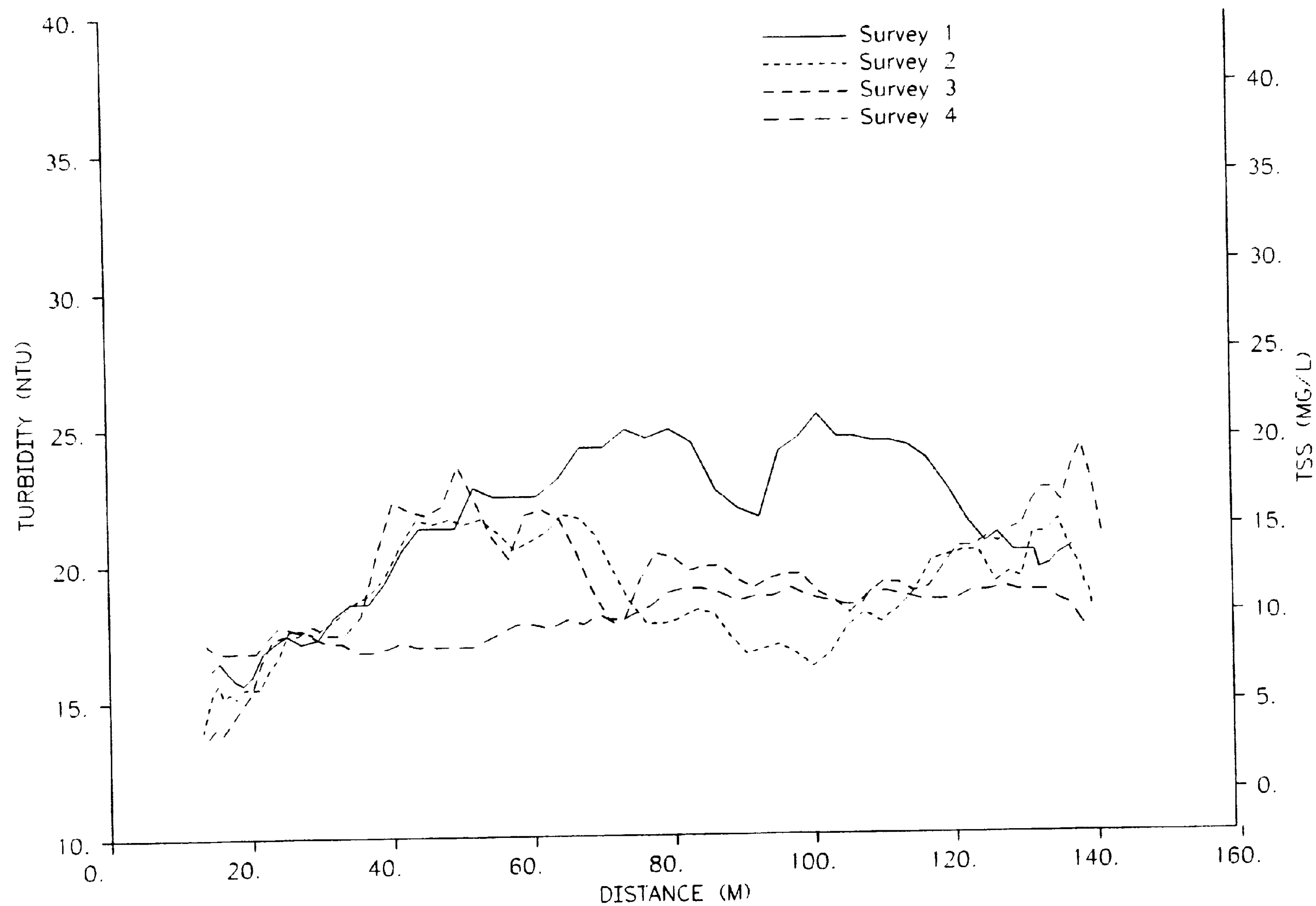


FIGURE A.4-5 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 5 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

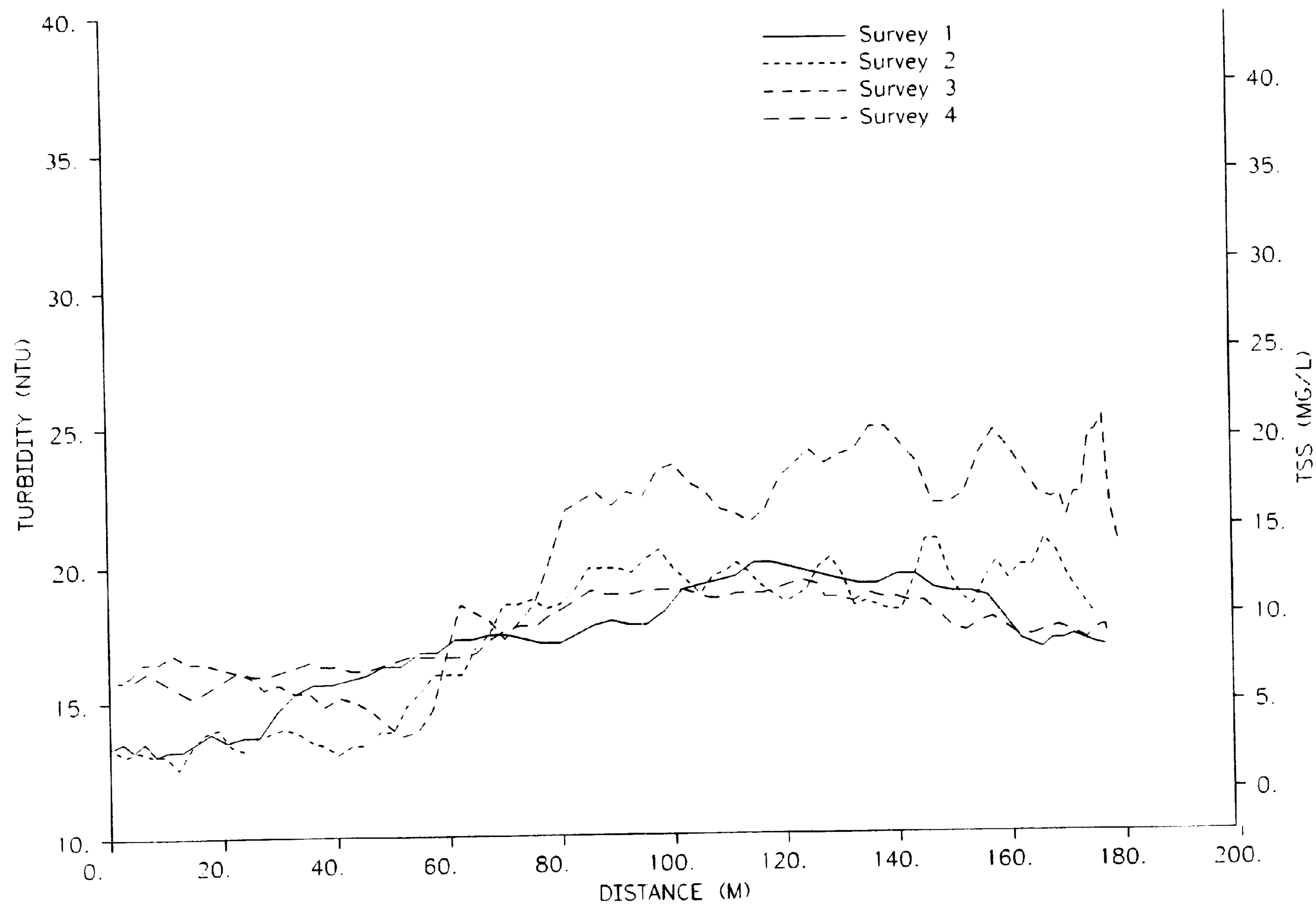


FIGURE A.4-6 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 6 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

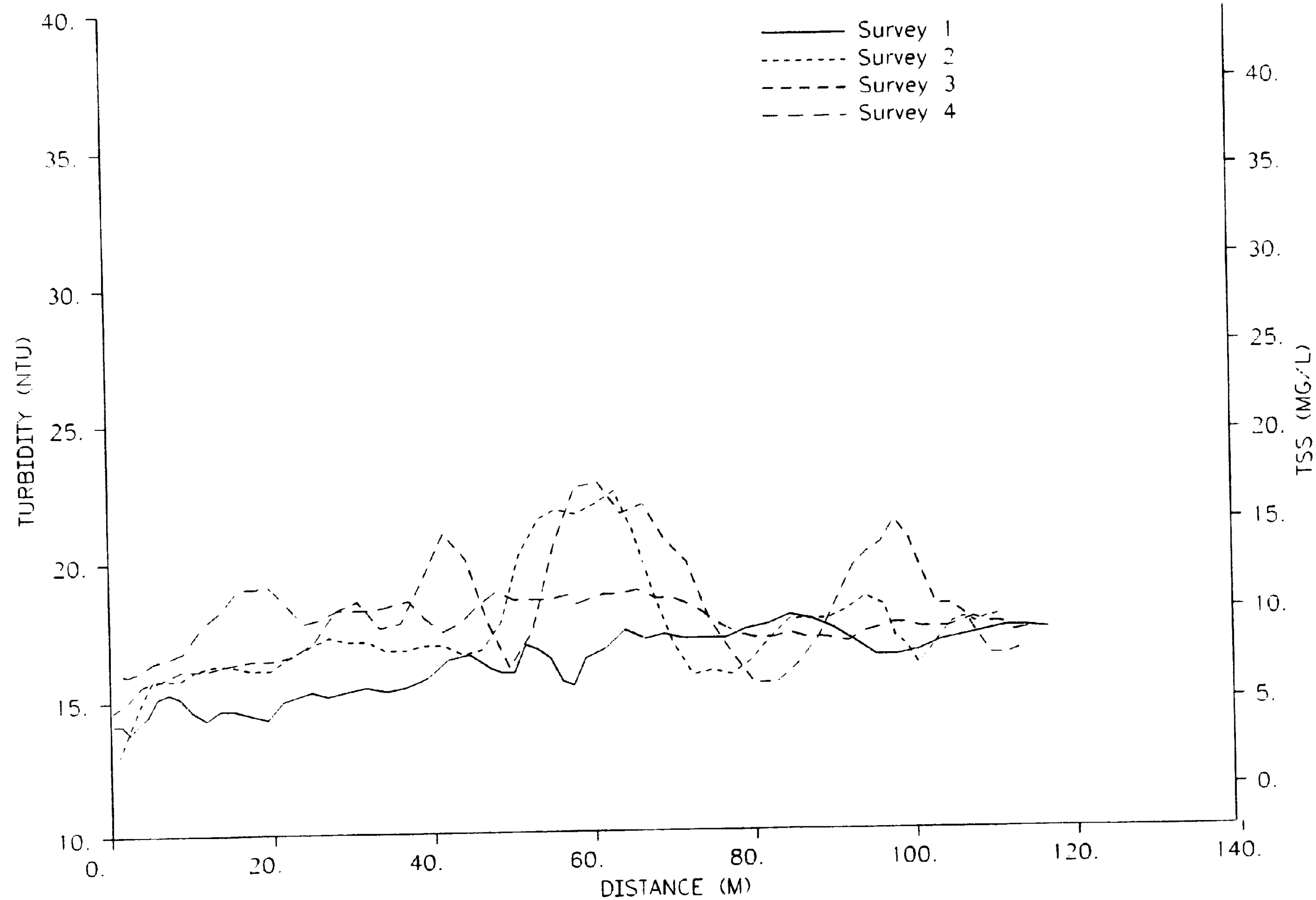


FIGURE A.4-7 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 7 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

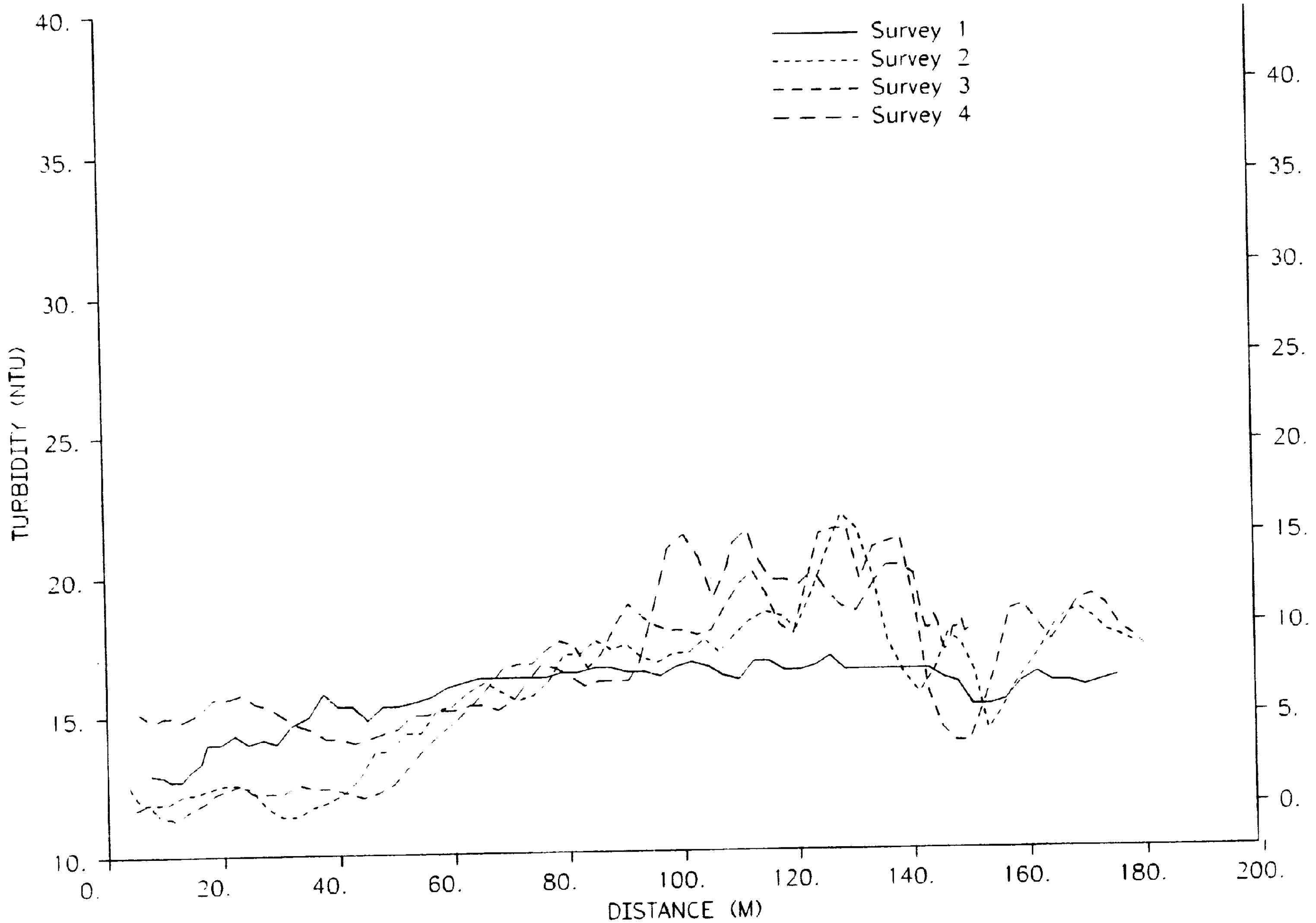


FIGURE A.4-8 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 10 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

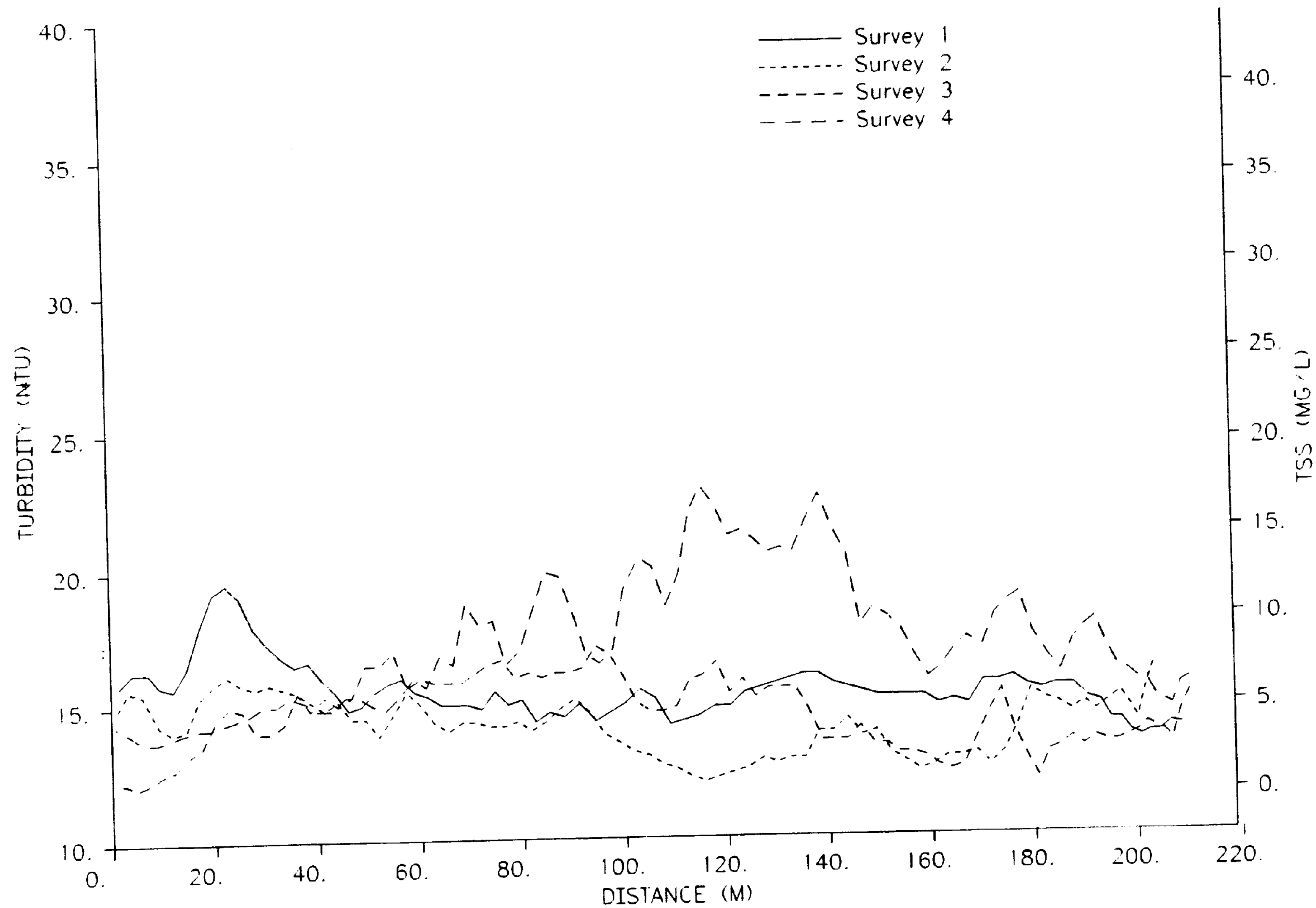


FIGURE A.4-9 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 12 DURING THE 25 MAY 2000 PLUME MAPPING STUDY AT OUTFALL 002, DALECARLIA BASIN 3

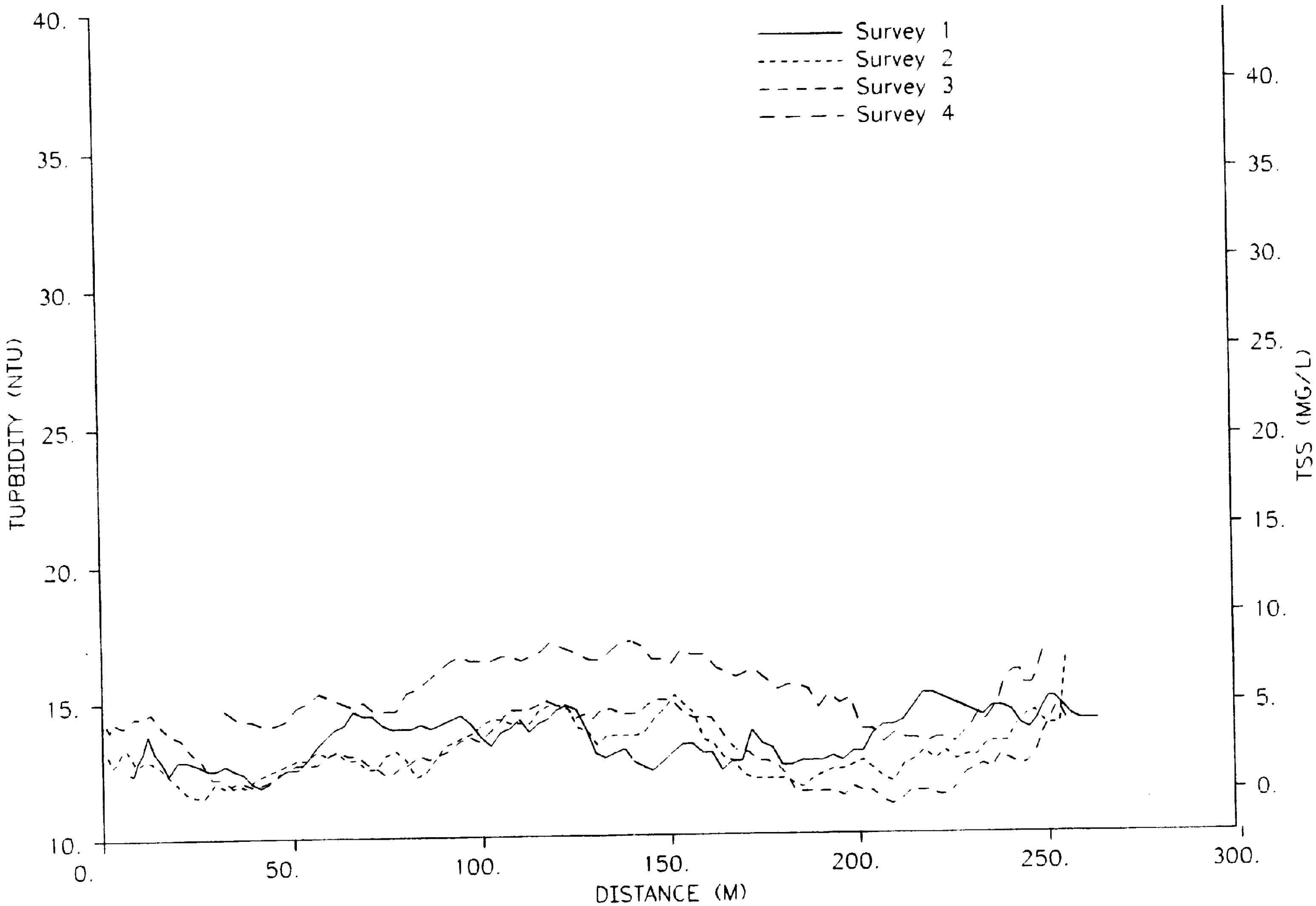


FIGURE A.4-10 OBSERVED TURBIDITY CONCENTRATION AT TRANSECT 14 DURING THE 25 MAY 2000 PLUME MAPPING SURVEY AT OUTFALL 002, DALECARLIA BASIN 3

Appendix B

Effluent Fate and Transport Modeling

APPENDIX B
EFFLUENT FATE AND TRANSPORT MODELING

A hydrodynamic model of the Potomac River was developed to simulate both river flow and the suspended solids discharge plume from the Washington Aqueduct outfalls. The primary objective of the modeling was to determine acute and chronic dilution factors as a function of effluent loading and river flow. A secondary goal was to model the fate of the released solids as they are transported downstream. The modeling used the Surfacewater Modeling System (SMS), which includes the U.S. Army COE – supported models RMA2, RMA4, and SED2D (see Section B.2). To provide the necessary data for model development and calibration, field studies were performed including:

- A bathymetry survey of this river segment to provide cross-sectional geometry for model development

- Dye-tracer and turbidity plume mapping surveys during solids discharge events at Dalecarlia (Outfall 002) and Georgetown Reservoir (Outfall 003) to provide data sets for model calibration

The results of the field surveys are presented and Section B.1 and the development of the Potomac River model is addressed in Section B.2, and modeling runs addressing the fate of the released solids and mixing zone issues are provided in Section B.3.

B.1 FIELD STUDIES

The bathymetry survey of the Potomac River area included in the model was performed on 6-7 April 2000. During the same two days, cross-sectional velocity measurements were collected along two transects. At Outfall 003 from Georgetown Reservoir, a dye-tracer plume mapping survey was performed on 2 May 2000 and a turbidity mapping survey was performed on 3 May 2000 in conjunction with a suspended solids discharge event. At Outfall 002 from Dalecarlia Basin, a dye-tracer plume mapping survey was performed on 24 May 2000 and a turbidity mapping survey was performed on 25 May 2000 in conjunction with a suspended solids discharge event from Dalecarlia Basin 3. Each of these field studies is addressed below.

B.1.1 Bathymetry Survey

A bathymetry survey of the Potomac River was conducted during 6-7 April 2000 extending for a 7.5-km distance from Memorial Bridge, upstream to Chain Bridge. During these two days, depth data were measured along a total of 46 transects, which are illustrated in Figure B.1-1. In the upstream reach approaching Chain Bridge, the higher river velocities made it difficult to perform individual transects. Therefore, one sinuous transect was performed along the centerline.

The bathymetry measurements were made using an Innerspace Model 448TDSR Depth Sounder. Positioning for the bathymetry survey was performed using an Innerspace Model 610 Mobile hydrographic differential positioning system (HDGPS). The system includes a Starlink Radiobeacon Receiver that provides real-time differential corrections. The positioning and depth data were recorded at a 1-second interval to a laptop computer used onboard the survey boat as a data logger. Water elevations during the survey were recorded using an ENDECO 1029 water level recorder. The water level recorder was deployed at a location on the opposite bank from Outfall 003 were water depths increase quickly near shore. The observed water elevations were used to adjust the depth measurements recorded during the surveys to mean low water (MLW). The tide datum was established by correlating the observed tide record from the ENDECO recorder with tide elevations reported by NOAA at Washington DC. Bathymetric cross-sections of the Potomac River are displayed in Figure B.1-2 at six representative locations along the study area. These locations are indicated in Figure B.1-1 as Transects B1 to B6.

The Surfacewater Modeling System (SMS) used for the Potomac River model has the capability to import bathymetry data and extrapolate this data to individual model nodes. To provide an improved data set for SMS extrapolation, additional cross-sectional depth transects were interpolated at a uniform 100-m spacing along the river centerline. This was accomplished by interpolating between the observed cross-sections in a direction parallel to the river centerline.

The bathymetry data used in the model was augmented with hydrographic survey data collected by the National Ocean Service (NOS). The NOS data are available from NOAA on a CD. In 1976 and 1977, NOS conducted surveys H9478 and H9488, which covered portions of the area included in the Potomac River model. In general, the bathymetry data interpolated to the 100-m transect spacing provided adequate representation of the site. The NOS data were used to augment the survey data in the vicinity of Roosevelt Island and the downstream section of the model between Roosevelt Island and Memorial Bridge.

B.1.2 Cross-Sectional Velocity Survey

On 6 and 7 April 2000, cross-sectional velocities were measured using a Marsh McBirney Model 201 flow meter. The flow meter was mounted on a rigid 4.5-m (15-ft) rod. The velocity data were measured along Transects B3 and B4, which are indicated in Figure B.1-1. Transect B3 was located approximately 400-m downstream of Outfall 003 and Transect B4 was located approximately 1,700-m downstream in a broader section of the river. The velocity surveys on both 6 and 7 April 2000 took place during an ebb tide. On 6 April 2000 the survey was performed 3.5 hrs to 5 hrs after high water, and on 7 April 2000 the survey was performed 1.5 hrs to 3 hrs after high water. Potomac River conditions during the velocity surveys are summarized in the following table.

Survey	Tide Height (m)	River Flow (cms)
6 April 2000	0.41 – 0.19	399
7 April 2000	0.74 – 0.43	372

At Transect B3, measurements were made at five stations spaced evenly across the river. At Transect B4, 6-7 stations were used. At each station, velocity readings were made at 0.6-m (2-ft) intervals down to a 3.7-m (12-ft) depth. The boat was anchored at each station. Usually the boat rode at its anchor due to the ebb current and provided a stable platform. Occasionally, the windage of the boat slackened the anchor line and the resulting movement of the boat would effect the measurements. At these times the survey crew would wait several minutes for conditions to stabilize.

The velocity data collected during 6-7 April 2000 are provided in Table B.1-1. The velocity survey was performed to provide data to use when adjusting the model's channel friction coefficients, which determine the lateral flow distribution. Since the model is vertically averaged, a vertical averaged velocity was calculated at each station and included in Table B.1-1. The velocity data will be displayed in figures as part of model calibration in Section B.2. At Transect B3, vertical average velocities were typically 10-20 cm/sec off-channel towards the left bank (stations V1 and V2). Maximum vertical average velocities of 42-59 cm/sec were in the channel at station V4.

At Transect B4, the velocity distribution was more uniform across the river and was typically 20-30 cm/sec away from the near-shore stations (stations V1 and V6). The lower 8.8 cm/sec and 11.2 cm/sec vertical average velocities at transect stations V3 and V4 on 6 April 2000 resulted from wind effects and were not used during model comparisons.

B.1.3 Plume Survey Methodology

Basin/reservoir cleanings are typically a two-step process. The overlying water is released to the river on the first day (usually a 6-14 hour period), and then the solids are hosed or pushed out on the morning of the second day (usually a 3-4 hour period). Plume mapping surveys were performed at Outfalls 002 and 003 in conjunction with suspended solids discharge events. On the day preceding the reservoir clean-out, the overlying water in the reservoir is discharged to the river to provide access. The dye-tracer studies were performed during this 6-12 hour drawdown period. The dye study can only be performed during the reservoir drawdown when relatively clean water is being discharged because the suspended sediment masks the fluorometer reading at high TSS values and provides a false positive at lower TSS levels. During the dye study, Rhodamine WT dye was injected into the discharge flow for an approximately 6-hour period. The discharge flow present on the day of the reservoir drawdown was typically several times higher than the flow used during the actual solids clean-out event. The release of dye for a several hour period allows the resulting dye distribution in the Potomac River to simulate both the build-up and subsequent dispersion of the suspended solids release, which typically lasts for approximately 3-4 hours. During the surveys, the plume mapping transects were repeated approximately every 1.5 to 2 hours. In addition, during each dye and turbidity study, at least one full mapping survey was performed after the discharge was turned off.

The transects used during the plume mapping surveys are listed in Table B.1-2 and illustrated in Figure B.1-4. Table B.1-2 includes the distance of each transect downstream from Outfalls 002 and 003. During the 2-3 May 2000 surveys at Outfall 003 (Georgetown Reservoir), Transects 7 to 20 were used. Transect 7 was the upstream background transect, and Transect 8 was located at Outfall 003. During the 24-25 May 2000 surveys at Outfall 002 (Dalecarlia Basin), Transects 1 to 20 were used, excluding Transects 8 and 9, which were closely spaced specifically for the previous Outfall 003 survey.

During the dye surveys, a 20-percent solution of rhodamine WT dye was injected into the reservoir outflow using a precision metering pump. The dye container rested on an electronic scale and the dye weight was periodically recorded and used to calculate the dye injection rate. During the dye study, effluent dye samples were collected from the reservoir outflow. At Outfall 003 (Georgetown Reservoir), the effluent sampling point was at the large concrete outfall structure near the river. At Outfall 002 (Dalecarlia Basin), the effluent sampling point was at a manhole approximately 110-m downstream of the dye injection location. The reservoir discharge flows during the dye studies were calculated from the dye injection rate and the measured effluent concentrations.

The dye plume mapping surveys were performed using a boat equipped with a Turner Designs Model 10 fluorometer set up in the flow-through mode. A 0.5-in. polyethylene sampling hose was mounted to a strut on the side of the boat at a fixed 0.3-m depth and the other end was connected to the fluorometer flow cell. An in-line pump was placed after the fluorometer to reduce the risk of air bubbles, which can cause false positive readings. A temperature probe was mounted in the flow path to provide data used to correct for the temperature dependence of dye fluorescence. The fluorometer and temperature readings were recorded at 1-second intervals with a Campbell CR10 data logger as the boat moved continuously along the survey transects.

The survey boat was also equipped with a Tremble ProXRS GPS system that also recorded continuously at a 1-second interval. Field notes were maintained on the few second offset between the system clocks on the two data loggers so that the files could be properly merged during subsequent data processing.

The fluorometer was calibrated at the end of the survey day using site water for the calibration dilutions. The site water was collected earlier in the day prior to the initiation of dye injection. The fluorometer readings and temperature data were converted to dye concentrations in parts per billion (ppb) using the relationship:

$$C(\text{ppb}) = S\,(R-R_b)\,e^{0.027\,(T-20)}$$

Where
- C = dye concentration (ppb)
- R = field fluorometer reading
- R_b = background fluorescence
- T = field temperature (°C)
- S = slope from the calibration for appropriate scale

The exponential term in the above equation corrects the fluorometer reading for the temperature dependence of fluorescence to a standard 20 C value.

The turbidity plume mapping surveys were performed in a similar manner as the dye survey by continuously recording data as the boat moved along survey transects. A Coastal MacroLite with an OBS-3 turbidity sensor was mounted on a fixed strut at a 0.3-m depth. The turbidity sensor measures the back scatter of light emitted from a source contained in the probe. The turbidity values were recorded continuously at 2-second intervals to a lap-top computer that was used as a data logger. The survey boat also contained a Trimble GPS system that recorded at 1-second intervals.

An ENDECO 1029 water level recorder was deployed at a location on the opposite bank of the river from Outfall 003 for the duration of the dye and turbidity plume mapping studies.

B.1.4 Physical Conditions During the Plume Mapping Surveys

2-3 May 2000 (Outfall 003) – Georgetown Reservoir

The tide heights during the dye and turbidity plume mapping surveys on 2 and 3 May 2000 are provided in Figures B.1-5 and B.1-6. In addition to the tide curve, these figures indicate the duration of the discharge event and the times of each survey. Both the dye and turbidity studies started during an early ebb tide and the last survey was performed near or just following low slack water. On 2 May 2000, the ebb tide water elevations decreased from 1.09 m to 0.09 m, and on 3 May 2000 the ebb tide decreased from 0.93 m to -.05 m. Potomac River flows at the USGS gage at Little Falls are displayed in Figure B.1-7 for the 2-3 May 2000 period. During the 2 May 2000 dye study, river flow decreased from approximately 305 cms to 300 cms, and during the 3 May 2000 turbidity study, river flow decreased from 272 cms to 266 cms.

24-25 May 2000 (Outfall 002) – Dalecarlia Basin 3

The tide heights during the dye and turbidity plume mapping surveys on 24 and 25 May 2000 are provided in Figures B.1-8 and B.1-9. In addition to the tide curve, these figures indicate the duration of the discharge event and the times of each survey. Both the dye and turbidity studies started during an early flood tide and the last survey was performed during the following ebb tide. It should be noted that at the Potomac River flow conditions associated with these studies, the river current does not reverse direction during a flood tide, but only slows up. On 24 May 2000, the flood tide water elevations during the surveys increased from 0.53 m to 1.24 m, and on 25 May 2000 the flood tide increased from 0.32 m to 1.08 m. Potomac River flows at the USGS gage at Little Falls are displayed in Figure B.1-10 for the 24-25 May 2000 period. River flows during the 24-25 May 2000 period were significantly lower than during 2-3 May 2000. During the 24 May 2000 dye study, river flow increased from approximately 160 cms to 170 cms, and during the 25 May 2000 turbidity study, river flow increased from 190 cms to 215 cms.

B.1.5 Water Chemistry Data

River Water Chemistry Data

Surface water samples were collected as part of the turbidity plume mapping surveys on 3 May 2000 at Outfall 003, and 25 May 2000 at Outfall 002. These samples were analyzed for total suspended solids (TSS), dissolved aluminum, and total aluminum. In addition, a turbidity reading was made onboard the boat at the time of sample collection. The turbidity readings were made using a Hach model 2100 turbidity meter, which was calibrated each day using standard solutions. The water samples for total-aluminum were preserved with acid and all samples were placed on ice.

The water chemistry samples were collected along the same transects used for the turbidity mapping surveys (Figure B.1-4). However, because of the time required to collect and process each sample, only approximately every-other transect was employed. On 3 May 2000 (Outfall 003), Transects 7, 9, 11, 12, 13, 14, and 16 were used. On 25 May 2000 (Outfall 002), Transects 1, 4, 6, 9, 12, and 14 were used. A left and right sample was collected at the upstream Transects 1, 4, and 7 where the river is narrower, and a left, middle, and right sample was collected downstream where the river is wider. At each outfall, three sets of water chemistry samples were collected during the period that the four turbidity plume mapping surveys were performed. A total of 43 water samples were collected at river stations during the 3 May 2000 survey, and a total of 42 water sample were collected during the 25 May 2000 survey.

The water chemistry results from the 3 May 2000 turbidity study at Outfall 003 (Georgetown Reservoir) are provided in Table B.1-3 and the results for the 25 May 2000 study at Outfall 002 (Dalecarlia Basin 3) are provided in Table B.1-4. These tables provide concentrations for dissolved and total aluminum, TSS, and turbidity arranged by survey and transect. The tables also provide the times of the water chemistry surveys. The data from the Outfall 002 and 003 studies indicate similar relationships between the parameters, thus allowing the combined data sets to be graphically displayed. The relationship between dissolved and total aluminum is provided in Figure B.1-11. The figure indicates that dissolved Al in the surface waters sampled has a value of approximately 100-150 μg/L, which does not noticeably increase as the total Al concentrations increase from approximately 500 μg/L to 3,000 μg/L. At total Al concentrations of less than 500 μg/L, dissolved Al decreases below the 150-μg/L level.

The relationship between total Al and TSS is displayed in Figure B.1-12. The majority of the data from both the Outfall 002 and Outfall 003 studies display a linear relationship between total

Al and TSS. Figure B.1-12 indicates that as total Al increases from approximately zero to 2.5 mg/L (2,500 μg/L), TSS increases from approximately zero to 30 mg/L.

Relationship Between TSS and Turbidity

The relationship between TSS and turbidity was examined to provide a method to convert the readings from the probe used on the survey boat during the turbidity plume mapping surveys to TSS concentrations. The relationship between TSS and turbidity displayed by the 85 water chemistry samples collected during the 3 and 25 May 2000 surveys was evaluated. Figure B.1-13 indicates that a linear relationship exists with the following regression equation ($R^2 = 0.76$):

$$\text{TSS (mg/L)} = 1.541\ \text{Turbidity(NTU)} - 2.40$$

The above equation relates turbidity as measured by the Hach turbidity meter on the water chemistry sampling boat to TSS. An additional data set was examined to relate values obtained from the turbidity probe used on the plume mapping boat to the Hach meter measurements. During the turbidity surveys, 13 grab samples were collected next to the turbidity probe on the plume mapping boat. Following the survey, these samples were processed with the Hach turbidity meter. Based on these samples, the relationship between turbidity as measured by the turbidity probe and the Hach meter is provided in Figure B.1-14. Excluding 2 outliers (indicated on the figure), the data indicate a linear relationship between the two sensors. Assuming that both probes were properly calibrated to a "NTU" scale, one would expect a regression slope of 1.0 with an intercept indicating a uniform offset. Taking into account the scatter of the turbidity data, a relationship with a slope of 1.0 reasonably fits the plotted points. Following a conversation with technical staff at Coastal Leasing, the provider of the turbidity probe, a relationship with a slope of 1.0 was selected. The regression line shown in Figure B.1-14 was forced to have a slope of 1.0 and the resulting R^2 value of 0.76 was only slightly less than the 0.84 value obtained for an unconstrained regression. The relationship between the two turbidity sensors was combined with the relationship between turbidity and TSS to provide an equation to convert the survey turbidity data to TSS. An examination of the turbidity data during the two surveys indicated a slight shift in the intercept for NTU resulting in the following expressions:

$$\text{TSS (mg/L)} = 1.541\ \text{Turbidity} - 20.9 \quad \text{3 May 2000 (Outfall 003)}$$
$$\text{TSS (mg/L)} = 1.541\ \text{Turbidity} - 17.8 \quad \text{25 May 2000 (Outfall 002)}$$

In the above equations, turbidity is the value measure by the turbidity probe on the plume survey boat.

Effluent Water Chemistry Data

Effluent water chemistry samples were collected periodically from the reservoir discharge during the 2-3 May and 24-25 May 2000 studies. Similar to the river water chemistry samples, the effluent samples were analyzed for TSS and total and dissolved aluminum. The results of effluent water chemistry samples collected during the reservoir drawdown and during the suspended solids discharge on the following day are provided in Table B.1-5. At Outfall 003 (Georgetown Reservoir), TSS values were <2.5 mg/L during the drawdown phase and total aluminum concentrations ranged from 187 to 233 μg/L. During the solids discharge on the following day, TSS values ranged from 4,700 mg/L to 12,300 mg/L, with two additional values of less than 1,000 mg/L that most probably are associated with temporary lulls in the clean out. Lower TSS values could also possibly result from sampling the upper layer of a potentially stratified out flow. During the solids release on 3 May 2000, total aluminum concentrations ranged from 26 to 1,300 mg/L.

At Outfall 002 (Dalcarlia Basin), TSS concentrations were low during most of the drawdown (<5 mg/L), although TSS increased near the end as the basin elevation reached bottom. During the solids discharge on the following day, TSS concentrations ranged from 4,600 to 16,500 mg/L before dropping off to 235 mg/L at the end of the discharge event. Total aluminum concentrations during the discharge event ranged from 1,020 to 1,810 mg/L and decreased to 28.1 mg/L at the end.

B.1.6 Particle Size Distribution

The size of the particles in the effluent is an important factor in the modeling of solid's transport and deposition in the Potomac River. As discussed below, particle size distributions were determined using several methods to address the characteristics of the floc that is produced in the water treatment process.

Standard ASTM Particle Distribution

During the suspended solids discharge events, sediment samples were collected from the bottom of each reservoir. On 3 May 2000, a sediment sample was collected from Georgetown Reservoir, and on 25 May 2000, two samples were collected from Dalecarlia Basin 3. Each sample was a composite of material collected from two locations. A particle size analysis was performed on each sample and the results are provided in Table B.1-6. The two Dalecarlia samples were very similar and an average distribution is also provided in the table. Based on particle size, the Georgetown sample was 50.2 % sand, 31.6% silt, and 18.2% clay. The averaged Dalecarlia sample contained more sand and less clay and silt than the Georgetown sample. The Dalecarlia fractions were 81.3% sand, 12.4 % silt, and 6.3% clay. Since the water for both reservoirs is drawn from the same location in the Potomac River, there is no apparent reason for the particle size fractions to differ except possibly for natural seasonal variation over the period of time since the previous clean out. The Georgetown and averaged Dalecarlia data were combined to provide a composite particle size distribution that is considered to be representative of typical conditions. The composite sample was 65.7 % sand, 22.0 % silt, and 12.3 % clay (Table B.1-6).

The specific gravity of the sediment and the sediment concentrations (by weight) of the material collected from the bottom of the reservoirs are provided in the following table:

Reservoir	Specific Gravity	Concentration (gm/kg)
Georgetown	2.5	44.8
Dalecarlia	2.41	63.5

Particle Characteristics of Floc

The composite particle size distribution based on sediment samples from the Georgetown and Dalecarlia Reservoirs indicated that the material was 65.7% sand, 22.0% silt, and 12.3 % clay (Table B.1-6). However, this particle distribution does not reflect the presence of the floc resulting from the addition of alum in the treatment process. The ASTM hydrometer and sieve methodology for determining particle size uses sodium hexametaphosphate as a de-floccing agent. The resulting size distribution, therefore, reflects the underlying particles, but not the aggregated particles forming the floc. On 5 March 2001, an additional sediment sample was obtained from the bottom of a Dalecarlia basin during a clean-out event. This sample was subject to a hydrometer test without the use of a de-floccing agent. Normally for a hydrometer test, an approximately 50-gm sample of equivalent dry weight is added to a 1-liter cylinder. However, since the sediment concentrations of the gelatinous samples obtained directly from the floor of the reservoir are approximately 50 gm/kg, an equivalent 50-gm dry weight sample almost fills the cylinder, and particle settling does not occur.

In order to perform a hydrometer test, a 5-gm equivalent dry weight sample was used, which reduces the test resolution. During the hydrometer test, the settling of the floc appeared to entrain any fine particles present resulting in a fairly clear liquid above a distinct liquid/sediment interface. Starting with a mixed solution, the liquid/sediment interface was at 60 % of the cylinder height after 5 minutes, 42% of the height after 10 minutes, and 25 % of the height after 1 hour. The hydrometer responded to the rapid removal of suspended material in the upper half of the cylinder and indicated no additional change in specific gravity after approximately 15 minutes. The results of the hydrometer test are provided in Table B.1-7. The constant hydrometer readings between 15 minutes and 20 hours indicates that fine material was not present in the sample. However, the hydrometer's zero point was adjusted to take into account the reading accuracy, which resulted in 2.7 percent of the material remaining in suspension (Table B.1-7). Based upon the ASTM hydrometer test methodology, the particle settling velocity associated with the 2.7 percent of material remaining in suspension after 15 minutes is less than 0.018 cm/sec.

In a standard hydrometer test, the particle velocity is related to a particle diameter according to Stokes' law and assuming a spherical particle with a density associated with the dry sample. However, a floc is composed of a collection of particles and the floc also has a very high moisture content. The dry weight density of samples obtained from Georgetown and Dalecarlia reservoirs was approximately 2.5 gm/cm^3 (typical for soil), but the density of the original gelatinous substance was closer to 1.03 gm/cm^3 (yielding approximately 50 gm of dry weight per liter of sample). Tambo and Watanabe (1979) presented a paper on the physical characteristics of flocs including results from experimental studies with aluminum flocs. The settling velocity equation for a non-spherical floc particle was given as:

$$W \text{ (cm/sec)} = 2882 (rho_f - rho_w) D_f^2$$

Where: W = settling velocity (cm/sec)
rho_f = floc density (gm/cm^3)
rho_w = water density (gm/cm^3)
D_f = floc diameter (mm)

This paper also presented a relationship for floc density as a function of floc diameter:

$$rho_f - rho_w = 0.0005/D_f^{1.23}$$

Combining these two equations to eliminate density provides the following relationship for settling velocity as a function of floc diameter:

$$W = 0.2447\ D_f^{\ 0.77}$$

Using the above equation, floc diameters associated with the settling velocities resulting from the hydrometer test are provided in Table B.1-7. For comparison purposes, Table B.1-7 also includes particle diameters for a spherical particle. The range of settling velocities in Table B.1-7 correspond to a range of floc diameters of approximately 0.03 to 0.4 mm. A spherical sand or silt particle would require a diameter 4-10 times smaller in order to posses a similar settling velocity.

B.1.7 Plume Surveys at Outfall 003 (Georgetown Reservoir)

A dye-tracer plume mapping study was performed at Outfall 003 on 2 May 2000 while the Georgetown Reservoir was being drawn down. The following day (3 May), a turbidity plume mapping study was performed during and for several hours after a suspended solids discharge event. As discussed in Section B.1.4, both studies took place primarily during an ebb tide.

Dye Plume Mapping Surveys (2 May 2000)

On 2 May 2000, a 20-percent solution of Rhodamine WT dye was injected into the reservoir outflow starting at 0749 hours and continued until 1406 hours. Several hours into the study, the dye injection rate was increased because a higher discharge concentration would provide better resolution in the plume map. Between approximately 1240 and 1310 hours, there was a lull in dye injection because the liquid level in the dye container had fallen below the intake tube. During the period of dye injection, three effluent samples were collected at the concrete outfall structure near the river at approximately 1-hour intervals and analyzed for dye concentration. The dye injection rate as determined from the scale readings and the measured effluent concentrations are provided in Table B.1-8. The discharge flow can be calculated from the dye injection rate and the observed effluent concentrations. The calculated discharge flows are also provided in Table B.1-8. The average discharge flow based on the three samples was 3.46 cms (79 mgd).

The transects used during the dye survey were listed in Table B.1-2 and illustrated in Figure B.1-4. Outfall 003 is located at Transect 8 and Transect 7 (150-m upstream of Outfall 003) was used for background. The times of the five dye plume mapping surveys are summarized in the following table.

2 May 2000 – Outfall 003

Survey	Time (hrs)
Dye Injection	0749 - 1406
Survey 1	0820 – 0915
Survey 2	1009 – 1117
Survey 3	1134 – 1235
Survey 4	1338 – 1448
Survey 5	1509 - 1631

The dye concentration data recorded along each transect are provided in Appendix Figures A.1-1 to A.1-14 for Transects 7 to 20. The minimum, maximum, and mean dye concentrations along each transect are summarized in Table B.1-9. An examination of Table B.1-9 indicates that the leading edge of the dye plume arrived downstream at Transects 10, 13, and 16 respectively during the first three surveys. By survey 5, dye had just arrived at Transect 20 (5.05 km downstream from Outfall 003), 8.5 hours after the initiation of dye injection.

The plume buildup downstream from Outfall 003 is illustrated in the appendix figures. Background dye variation at Transect 7 (150-m upstream of the outfall) was typically within 0.02 ppb of zero (Figure A.1-1). At Transect 8 (Figure A.1-2), dye concentrations exceeded 10 ppb as the survey boat approached the discharge. During the surveys, a back eddy was observed in the shallow near shore region just downstream of Outfall 003. Higher dye concentrations were present along the offshore edge of the eddy. This is observable at Transect 9 (Figure A.1-3, 70-m downstream), which displays offshore concentrations exceeding 6 ppb during surveys 3 and 4, and with lower concentrations in the near shore region. Transects 12 and 13 (Figures A.1-6 and A.1-7), display the build up of the dye plume with increasing concentrations during surveys 1 to 4, and with a decrease in dye concentration during survey 5, approximately 1-hour after dye injection ended. Maximum dye concentrations decreased from 2.7 ppb at Transect 11 to less than 0.7 ppb at Transects 12 and 13. Transect 14 (Figure A.1-8) was far enough downstream that it did not immediately respond to the end of dye injection and dye concentrations continued to increase between surveys 4 and 5. Transects 10 to 17 (Figures A.1-4 to A.1-11) display the gradual mixing of the plume form the discharge (left) to far (right) bank.

Dye concentrations at the far bank remained at background levels upstream of Transect 16, and exceeded background at Transect 17 only during survey 5.

A plume map displaying dilution contours was constructed from the dye survey data for the 500-m region downstream from Outfall 003 (Transects 8-11). The dilution contours were based on the average dye concentrations during surveys 2 and 3, since at Transect 10, dye concentrations were already decreasing during surveys 4 and 5. The discharge dye concentration during this period was 20.7 ppb based on an average of survey values in the vicinity of the discharge. The resulting dilution contour map (Figure B.1-15) indicates that the contour for a dilution factor of 5 extended 120 m, slightly pass Transect 9, and a dilution factor of 10 extended approximately 380 m. The arc of the factor of 5-dilution contour delineates the approximate offshore extent of the eddy that was located downstream of the outfall. A dilution factor of 20 extended beyond Transect 11, which was 480-m downstream.

Turbidity Plume Mapping Surveys (3 May 2000)

On 3 May 2000, the suspended solids discharge event lasted for 3.5 hours, from approximately 1000 hours to 1330 hours. The effluent samples collected and analyzed for aluminum and TSS were previously presented in Table B.1-5. Three of the effluent samples had TSS concentrations that varied between 4,500 mg/L and 12,300 mg/L. Between 1120 and 1250 hours there appeared to be a lull in the clean-out and TSS values were temporarily less than 1,000 mg/L.

The transects used during the turbidity surveys were listed in Table B.1-2 and illustrated in Figure B.1-4. The times of the four turbidity mapping surveys are summarized in the following table.

3 May 2000 – Outfall 003

Survey	Time (hour)
Clean out	1000 - 1330
Survey 1	1018 - 1050
Survey 2	1118 - 1222
Survey 3	1301 - 1352
Survey 4	1527 - 1622

Outfall 003 is located at Transect 8 and Transect 7, 150-m upstream of Outfall 003, was used for background. During the first survey, transects were performed downstream only as far as Transect 13, because it was apparent that the survey was ahead of the turbidity plume and all readings were approaching background levels. During the remaining surveys, transects were performed through Transect 17, just upstream of Key Bridge. The turbidity data recorded along each transect are provided in Appendix Figures A.2-1 to A.1-11 at Transects 7 to 17. The relationship between turbidity and TSS developed in Section B.1.5 was used to transform the turbidity survey data into TSS. The TSS values are presented in the appendix figures by the addition of a second axis. The resulting minimum, maximum, and mean TSS concentrations along each transect are summarized in Table B.1-10.

Examination of Table B.1-10 and Figure A.2-1 indicates that mean background TSS levels at Transect 7 were typically 6-8 mg/L during the 4 surveys. At the outfall (Transect 8), a maximum value of 2,164 mg/L was measured during survey 2. The lower maximum value of 142 mg/L measured at the outfall transect during survey 3 was recorded just following the 1120-1250 hour lull in the effluent TSS concentrations. At Transects 8-10, maximum TSS concentrations were present during surveys 1-3 and values decreased by survey 4, which was started approximately 2-hours after the clean-out was completed. At Transect 9, 70-m downstream of Outfall 003, the maximum TSS was 78-86 mg/L during surveys 2 and 3, decreasing to 28 mg/L during survey 4 (Figure A.2-3). At Transect 10, 200-m downstream of Outfall 003, the maximum TSS value was 43 mg/L during survey 3, decreasing to 19 mg/L during survey 4 (Figure A.2-4).

Downstream of Transect 12 (Figures A.2-6 to A.2-11), there were no clearly evident TSS plume features. This contrasts with the previous day’s dye survey when a plume was present with maximum concentrations along the near shore, extending both laterally and in a downstream direction. At Transect 16 (Figure A.2-10), slightly elevated TSS concentrations were present in the channel during survey 2. This location is farther downstream than the suspended solids plume would have been expected to reach in the 1.5 hours since the beginning of the discharge event. These slightly elevated TSS concentrations are therefore attributed to natural conditions. At Transect 17 (Figure A.2-11), the data is more irregular during survey 4 and the spikes are considered to be associated with the probe being exposed to air as the boat passes over waves.

A contoured map of TSS values is provided in Figure B.1-16 for the 450-m reach from Outfall 003 to Transect 11. The data set used for the figure is a composite of the highest turbidity values along each of these four transects during the four surveys (Figures A.2-2 to A.2-5). The turbidity values were converted to TSS using the relationship developed in Section B.1-5. The resulting TSS values were 2,000 mg/L at the outfall, decreasing to maximum values of 85 mg/L at Transect 9, 48 mg/L at Transect 10, and 43 mg/L at Transect 11. The 48-mg/L TSS value at Transect 10 corresponds to a dilution factor of at least 40:1. The high suspended loads discharged from Outfall 003 are being dissipated in the river at a higher rate than would be indicated by the dye study. In Figure B.1-16, the maximum dye concentration at Transect 10 corresponded to a dilution factor of 10:1, a factor of four smaller than that determined using the TSS plume data. The increased dilution observed in the turbidity survey may result in part from settling and stratification of TSS in the water column. The turbidity probe used for the plume mapping surveys was mounted in the upper portion of the water column. It is likely that higher TSS concentrations were present in the lower portion of the water column.

B.1.8 Plume Surveys at Outfall 002 (Dalecarlia Basin)

A dye tracer plume mapping survey was performed at Outfall 002 on 24 May 2000 while the Dalecarlia Basin was being drawn down. The following day, 25 May 2000, a turbidity plume mapping survey was performed during and for several hours after a suspended solids discharge event associated with the basin clean out. As discussed in Section B.1.4, both studies primarily took place during a flood and early ebb tide.

Dye Plume Mapping Surveys (24 May 2000)

On 24 May 2000, a 20-percent solution of Rhodamine WT dye was injected into the outflow from Dalecarlia Basin 3 starting at 0809 hours and continuing to 1415 hours. Several hours into the study the dye injection rate was increased. This was done to provide better resolution in the plume map. During the period of dye injection, 11 effluent samples were collected at a manhole several hundred meters from the injection point at approximately 30-minute intervals. The dye injection rate determined from the scale readings and the measured effluent concentrations are provided in Table B.1-11. The discharge flow can be calculated from the dye injection rate and the observed effluent concentrations. The calculated discharge flows are provided in Table B.1-11 and the average discharge flow from the 11 samples was 1.75 cms.

The discharge flow from Dalecarlia was also calculated based on the observed drawdown of Basin 3. Between 0805 hours and 1340 hours, the basin's elevation decreased 5.92 m (19.42 ft). This level change, coupled with the basin area of 5,888 m^2 yields an average discharge flow of 1.73 cms (39.6 mgd). This discharge flow is in excellent agreement with the 1.75-cms value calculated from the dye injection rate and the 1.73-cms flow value was used in subsequent analysis.

The transects used during the dye surveys were listed in Table B.1-2 and illustrated in Figure B.1-4. The times of the five dye plume mapping surveys are summarized in the following table.

24 May 2000 – Outfall 002

Survey	Time (hrs)
Dye Injection	0809 – 1415
Survey 1	0842 – 0902
Survey 2	0950 – 1029
Survey 3	1107 – 1249
Survey 4	1338 – 1509
Survey 5	1555 – 1728

Outfall 002 is located approximately 520-m upstream from Transect 1 in a relatively narrow and high velocity portion of the river. Transect 1, just below Chain Bridge was considered to be the farthest upstream location that was safe for performing lateral plume mapping surveys. During the first survey, transects were performed downstream only as far as Transect 6, because it was apparent that the survey was ahead of the dye plume and all readings were at background levels. Surveys 2 and 3 went progressively farther downstream and surveys 4 and 5 were performed to Transect 20 at Memorial Bridge. The dye concentration data recorded along each transect are provided in Appendix Figures A.3-1 to A.3-18 at Transects 1 to 20. The minimum, maximum, and mean dye concentration along each transect is summarized in Table B.1-12.

The mean transect concentrations in Table B.1-12 indicate that the downstream leading edge of the dye plume reached Transects 4, 7, and 12 respectively during the first 3 surveys. By survey 5 the dye arrived at Transect 17 (Key Bridge, 5.7 km downstream of Outfall 002), 9-hrs after the beginning of dye injection. Figure A.3-1 displays the dye build up at Transect 1 during the survey period. At this first transect, 520-m downstream of Outfall 002, the dye was already well mixed with a small concentration gradient increasing from left to right bank. The mean transect concentration increased from 0.20 - 0.24 ppb during surveys 1 and 2, to 0.44 - 0.47 ppb during surveys 3 and 4 after the dye injection rate was increased at 0953-hrs. Survey 5 started approximately 1.5 hours after the end of dye injection, and the average Transect 1 concentration had already decreased to 0.14 ppb.

At Transect 3 (Figure A.3-3), the dye plume arrived during survey 1 along the deeper right bank (higher downstream velocity), and the dye distribution built up to a more even distribution during surveys 3 and 4. At Transect 4 (Figure A.3-4), the dye was fully mixed laterally during all 5 surveys and the figure clearly shows the buildup of dye during surveys 1 to 4 and the decreased concentration during survey 5. Figure A.2-6 shows the arrival of the dye plume at Transect 6 (2,280-m downstream) during survey 2 on the right bank (main channel) and the subsequent buildup of dye on the shallower left side of the river during surveys 3 and 4. Transect 10 (Figure A.3-8) is located approximately 300-m downstream of where the river has started to widen out. Figure A.3-8 shows the arrival of the plume by survey 3 and the gradual buildup of dye concentrations along the shallow left bank area during surveys 4 and 5. The dye plume continued to mix into the left bank region at Transects 11-17 during surveys 4 and 5 (Figures A.3-11 to A.3-17). Dye was not observed at Transects 18-20 (Figures A.3-18 to A.3-20).

Between surveys 3 and 4 during the 24 May 2000 dye study at Outfall 002, the survey boat was able to travel upstream of Transect 1 and perform several mapping transects in the vicinity of the discharge. The time interval between surveys 3 and 4 was near high water and the river currents upstream of Transect 1 were less than at other times during the study. The resulting dilution contour map is presented in Figure B.1-17. During this survey (1322-1339-hrs) the discharge dye concentration was 34.2 ppb. Figure B.1-17 indicates that the 10, 30, and 40 fold dilution contours were approximately 85-m, 135-m, and 190-m downstream of Outfall 002 along the discharge (left) bank. Downstream of the outfall, there was a very sharp lateral gradient as the dye mixed from the quieter back eddy formed in the lee of the shoreline protrusion at the discharge into the high velocity and turbulent flow coming from Little Falls. Within the 200-m region included in the dilution contour map, the plume gradually mixed across the remaining width of the river.

Turbidity Plume Mapping Surveys (25 May 2000)

On 25 May 2000, the suspended solids discharge event lasted for 3.5 hours, from approximately 0830 hours to 1200 hours. The effluent samples collected and analyzed for aluminum and TSS were previously presented in Table B.1-5. Four of the five effluent samples had TSS concentrations that varied between 4,600 mg/L and 16,500 mg/L.

The transects used during the turbidity survey were listed in Table B.1-2 and illustrated in Figure B.1-4. The times of the 4 turbidity mapping surveys are summarized in the following table.

25 May 2000 – Outfall 002

Survey	Time (hour)
Clean out	0830 – 1200
Survey 1	0907 – 1006
Survey 2	1101 – 1148
Survey 3	1259 – 1345
Survey 4	1445 – 1532

During all 4 surveys, transects were performed downstream to Transect 14, while downstream of Transect 7 only every other transect was used. Although it was not possible to perform an upstream background transect, turbidity values at the downstream transects, ahead of the turbidity plume indicate background levels. The turbidity data recorded along each transect are provided in Appendix Figures A.4-1 to A.4-10 at Transects 1 to 14. The relationship between turbidity and TSS developed in Section B.1.5 was used to create a second axis on these figures to display TSS. The minimum, maximum, and mean TSS concentrations along each transect are summarized in Table B.1-13. Turbidity data were not recorded at Transects 1 and 2 during survey 1 because of an instrumentation problem.

Examination of Table B.1-13 indicates that TSS levels of 3-6 mg/L at Transects 12 and 14 during surveys 1 and 2 were most likely representative of background levels. During surveys 1 and 2, which were performed while the clean-out was in progress, the highest TSS concentration along Transects 1 to 4 was 25.1 mg/L, and transect average concentrations varied between 11.4 and 18.5 mg/L. During survey 4, several hours after the completion of the clean-out, transect average turbidities along Transects 1-4 varied between 8.5 and 9.6 mg/L. The higher TSS concentrations during surveys 1 and 2 at Transects 1 to 4 are evident in Figures A.4-1 to A.4-4. Transect 6 (Figure A.4-6) displays a built up in TSS with the mean transect value increasing from 7.7 mg/L to 12.1 mg/L during surveys 1 to 3, before decreasing to 9.0 mg/L during survey 4. At Transect 12 (Figure A.4-9), survey 4 shows an increase in TSS to 21 mg/L in mid-river, while values during the other three surveys ranged up to 13.8 mg/L, but are not noticeably distinguishable from background variation. At Transect 14 (Figure A.4-10), TSS concentrations during survey 4 were also slightly elevated in comparison to surveys 1 to 3.

Vertical TSS Data

Following each 25 May 2000 turbidity plume mapping survey, a vertical turbidity profile was performed at Transects 1, 4, 6, and 7. These vertical data are presented in Table B.1-14 after being converted to TSS. The measurements were taken mid-channel at a 1.5-m interval down to a 9-m depth, except at Transect 6, which had a shallower 4.6-m depth. At Transects 1 and 4, the vertical TSS concentrations did not vary significantly with depth, although values did vary slightly between surveys. Surveys 1 and 2, performed while the clean out was under way, had higher TSS values (10.7-16.4 mg/L) than surveys 3 and 4 (7.6-13.8 mg/L), which were performed 1.5 to 3.5 hrs after the clean-out was completed. This effect was most noticeable at the vertical station on Transect 4, which decreased from 16.9-21.2 mg/L during survey 2 to 7.9-9.0 mg/L during survey 3. At the station on Transect 7, TSS values at a 9-m depth increased during surveys 1 to 3 from 10.6 to 28.7 mg/L, then decreased back to 13.2 mg/L at survey 4, 3.5 hrs after the solids release finished.

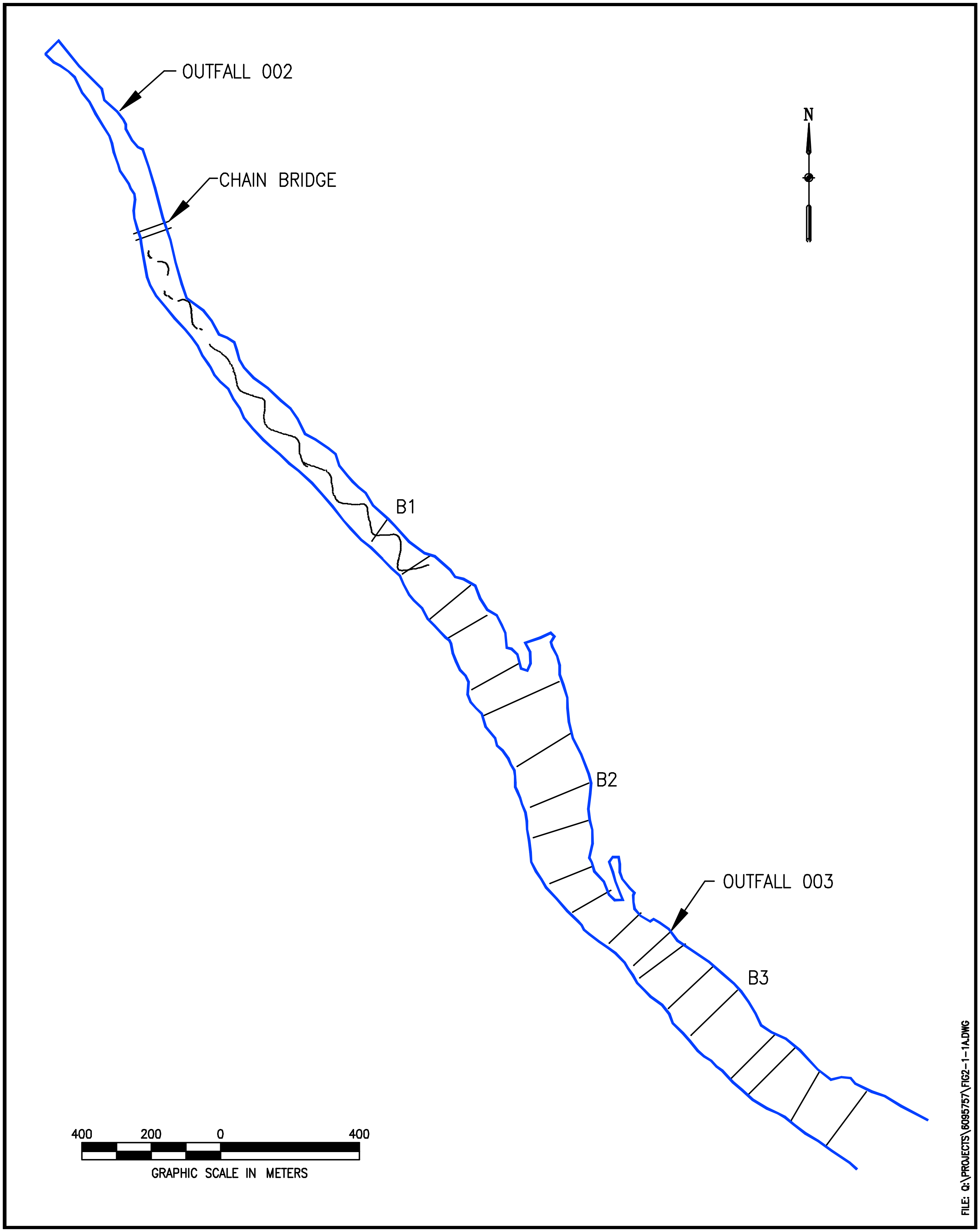


Figure B.1-1A. Transects Used During the Bathymetry Study

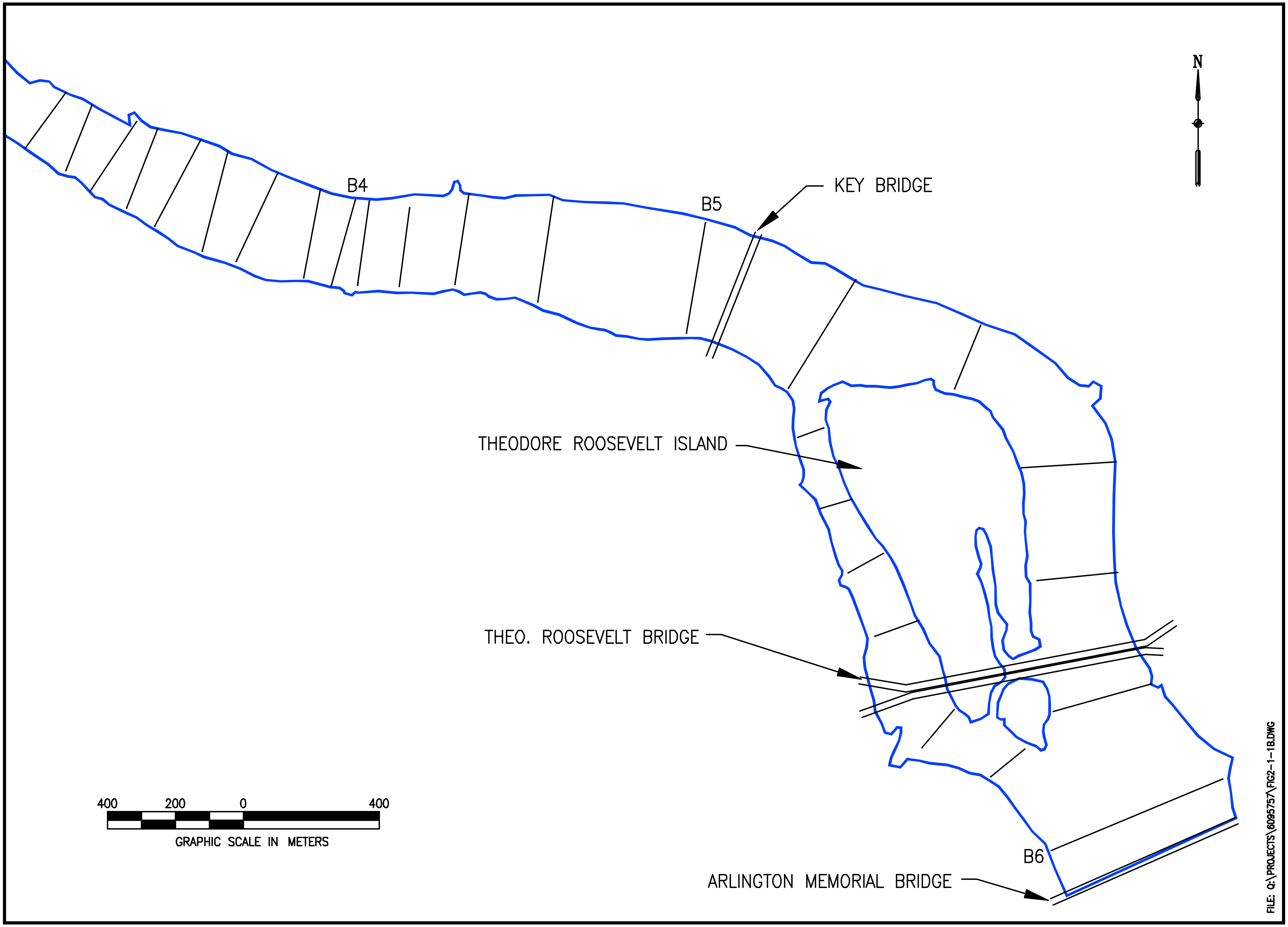
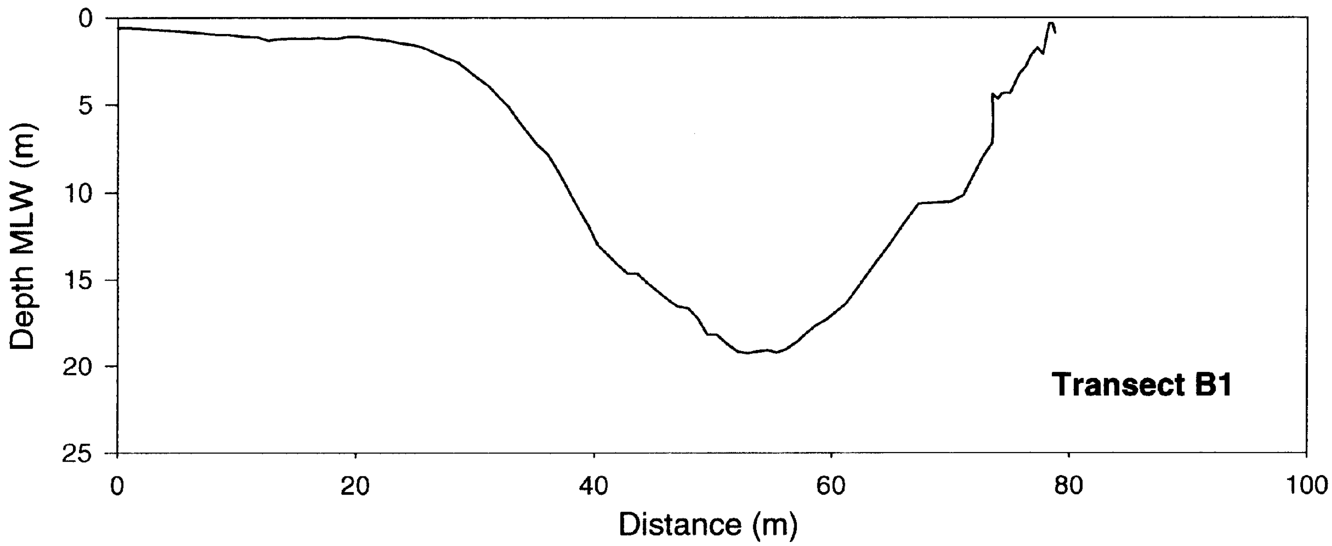
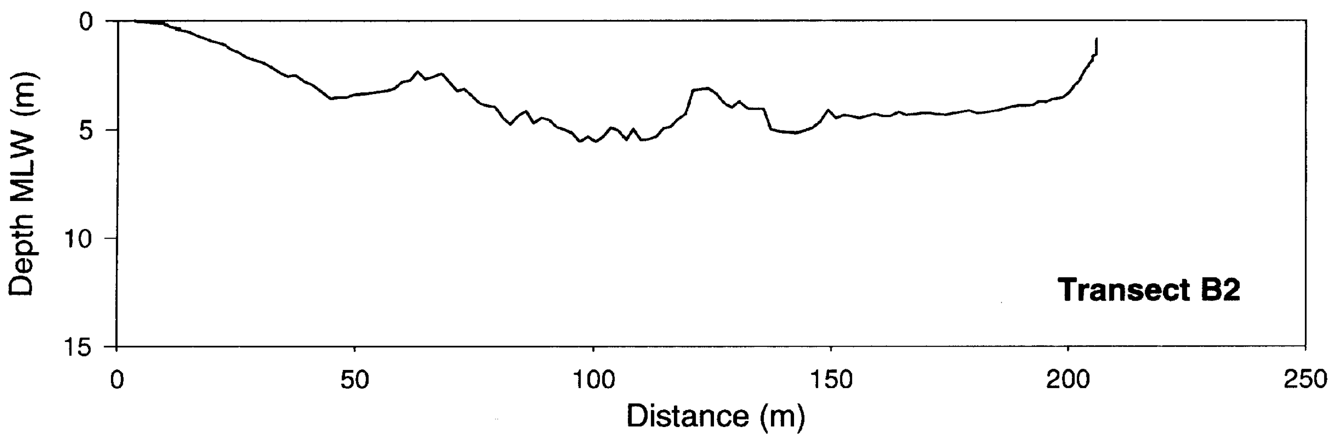


Figure B.1–1B. Transects Used During the Bathymetry Study





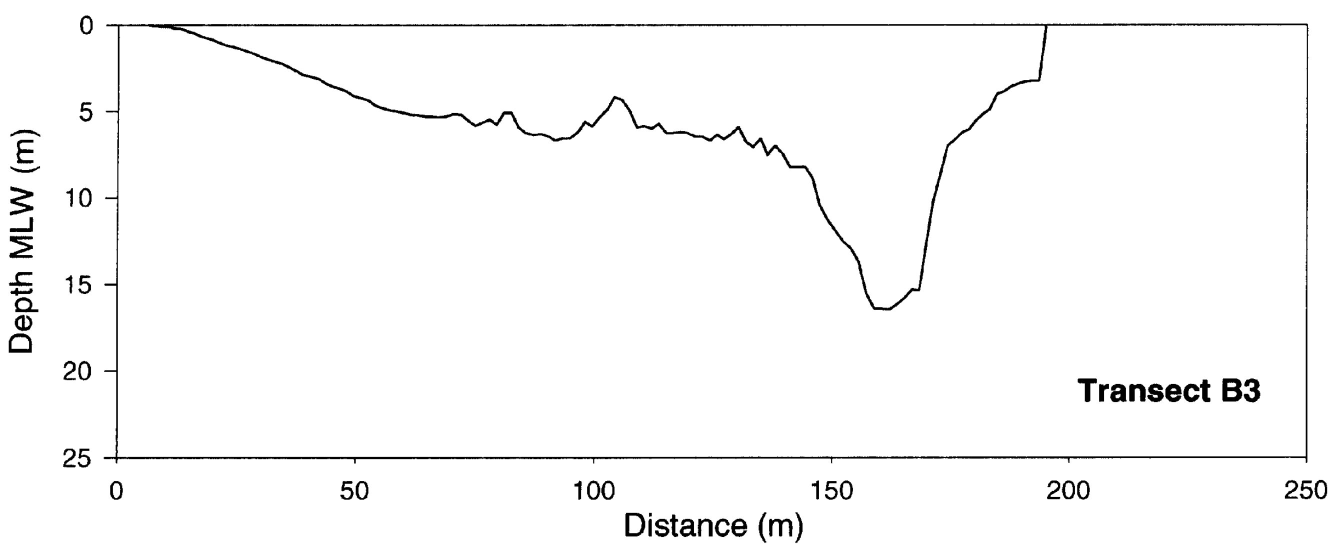


Figure B.1-2 Cross-Sectional Depth Profile at Transects B1, B2, and B3
During the 6-7 April 2000 Bathymetry Survey

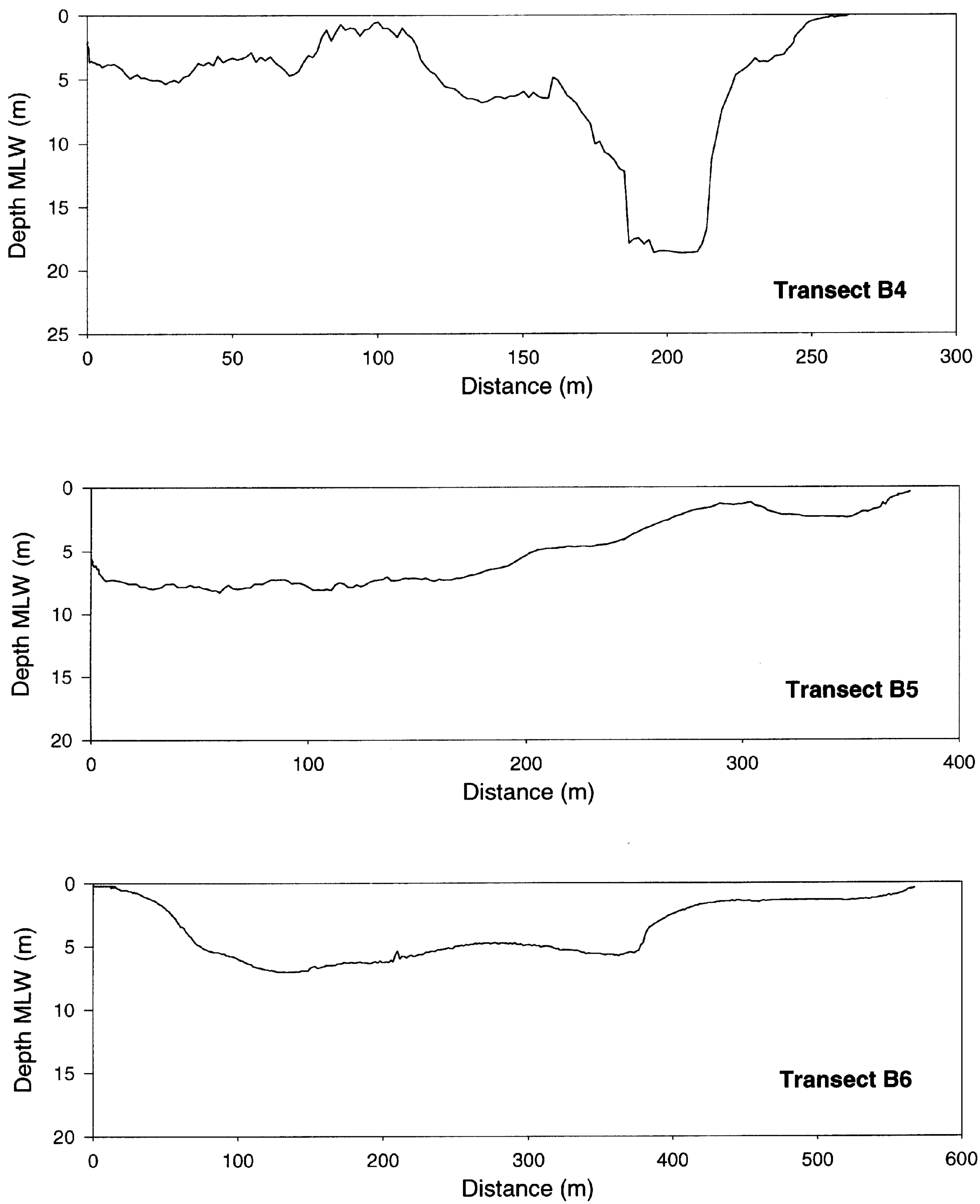


Figure B.1-3 Cross-Sectional Depth Profile at Transects B4, B5, and B6
During the 6-7 April 2000 Bathymetry Survey

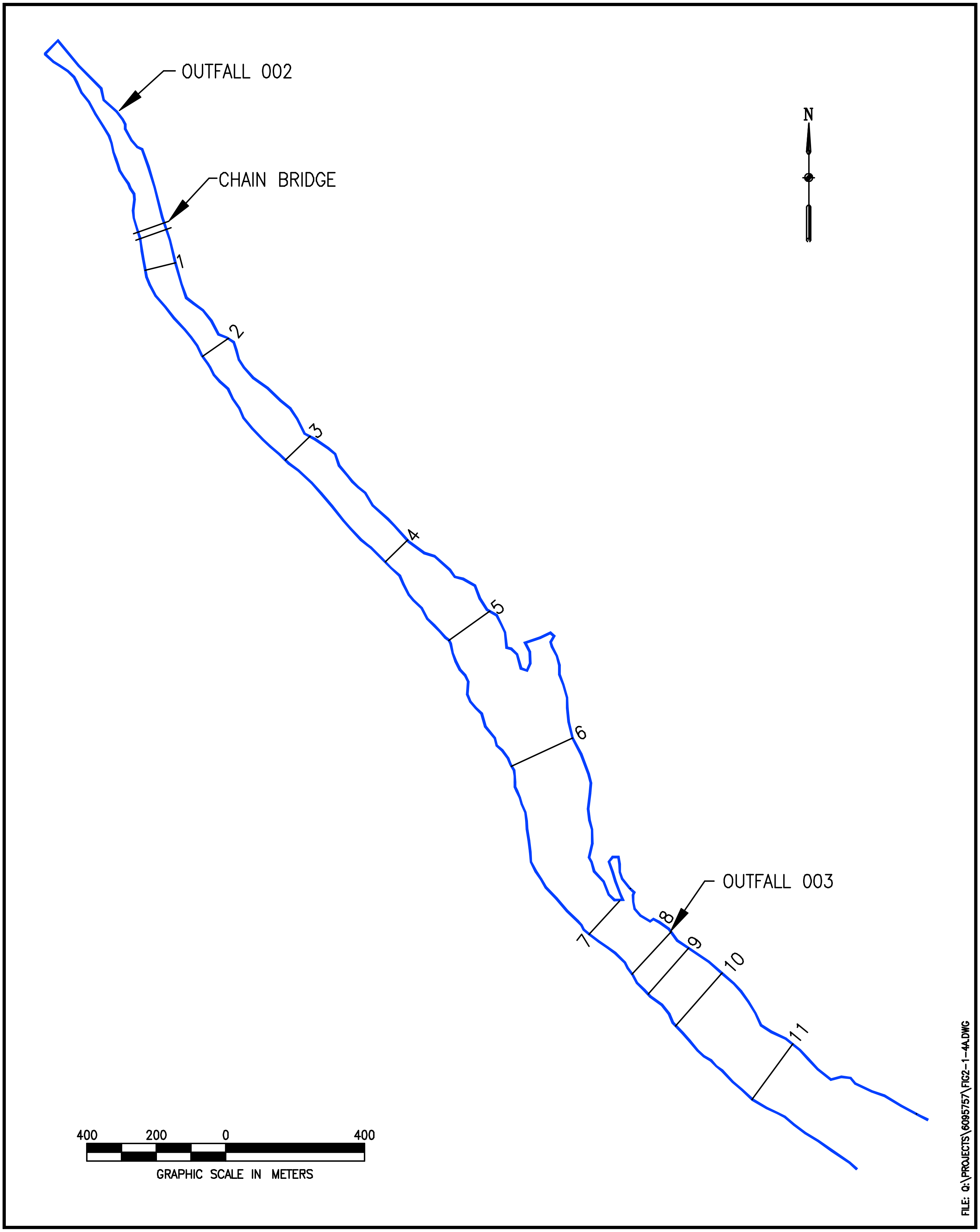


Figure B.1-4A. Transects Used During the Dye and Turbidity Plume Mapping Surveys

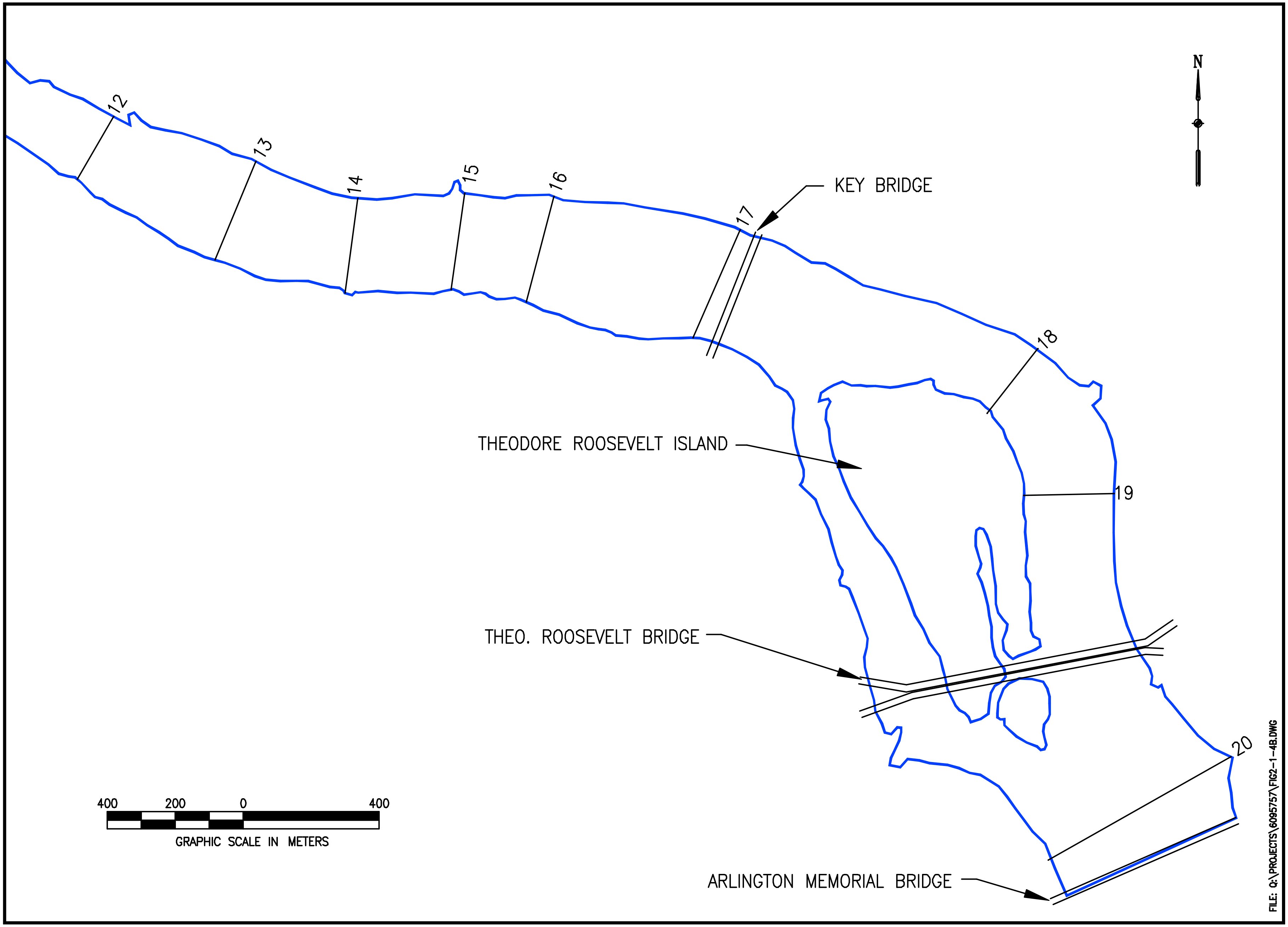


Figure B.1-4B. Transects Used During the Dye and Turbidity Plume Mapping Surveys

Figure B.1-5 Tide Height During the 2 May 2000 Dye Survey at Outfall 003, Georgetown Reservoir

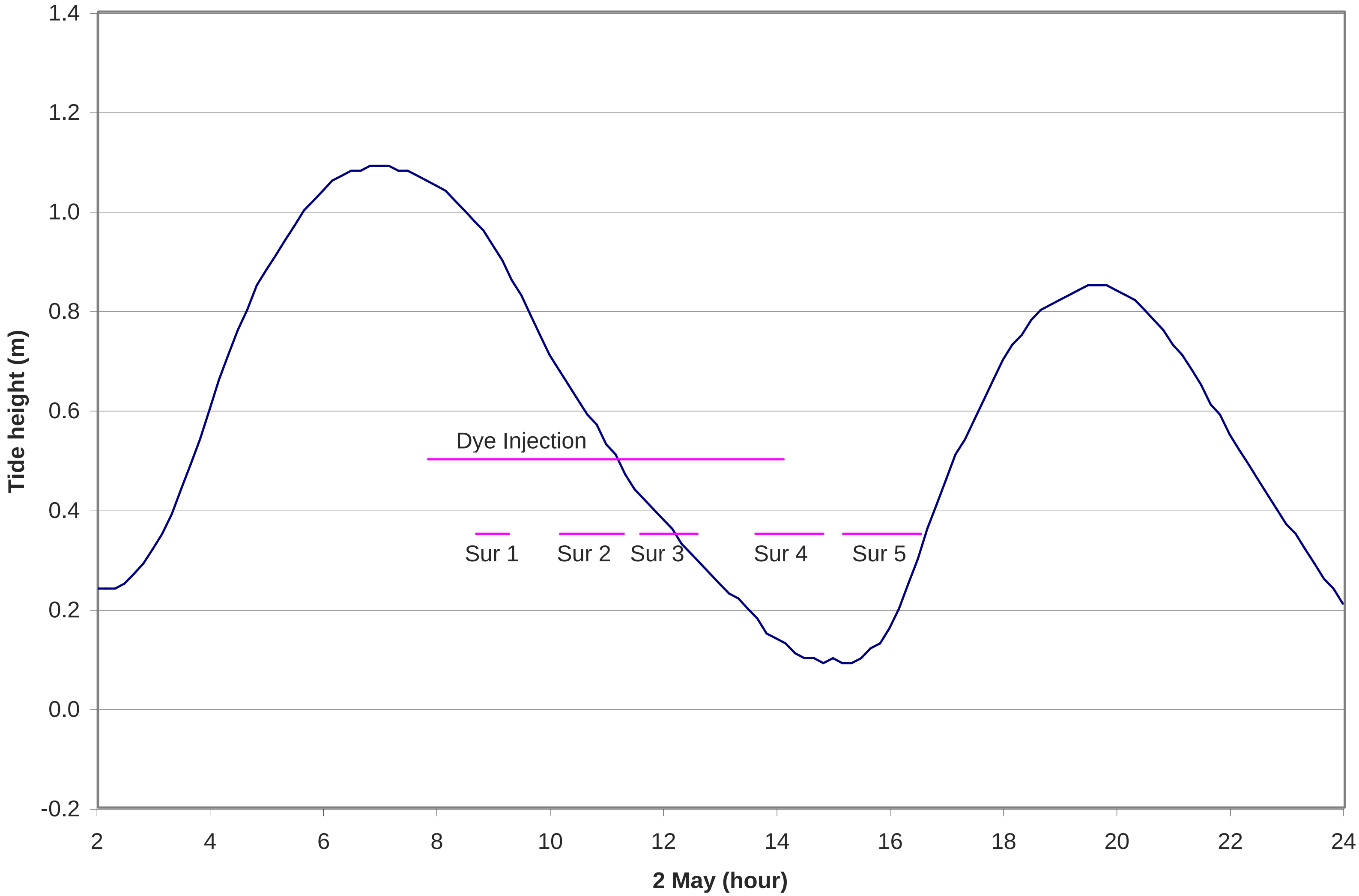


Figure B.1-6 Tide Height During the 3 May 2000 Turbidity Survey at Outfall 003, Georgetown Reservoir

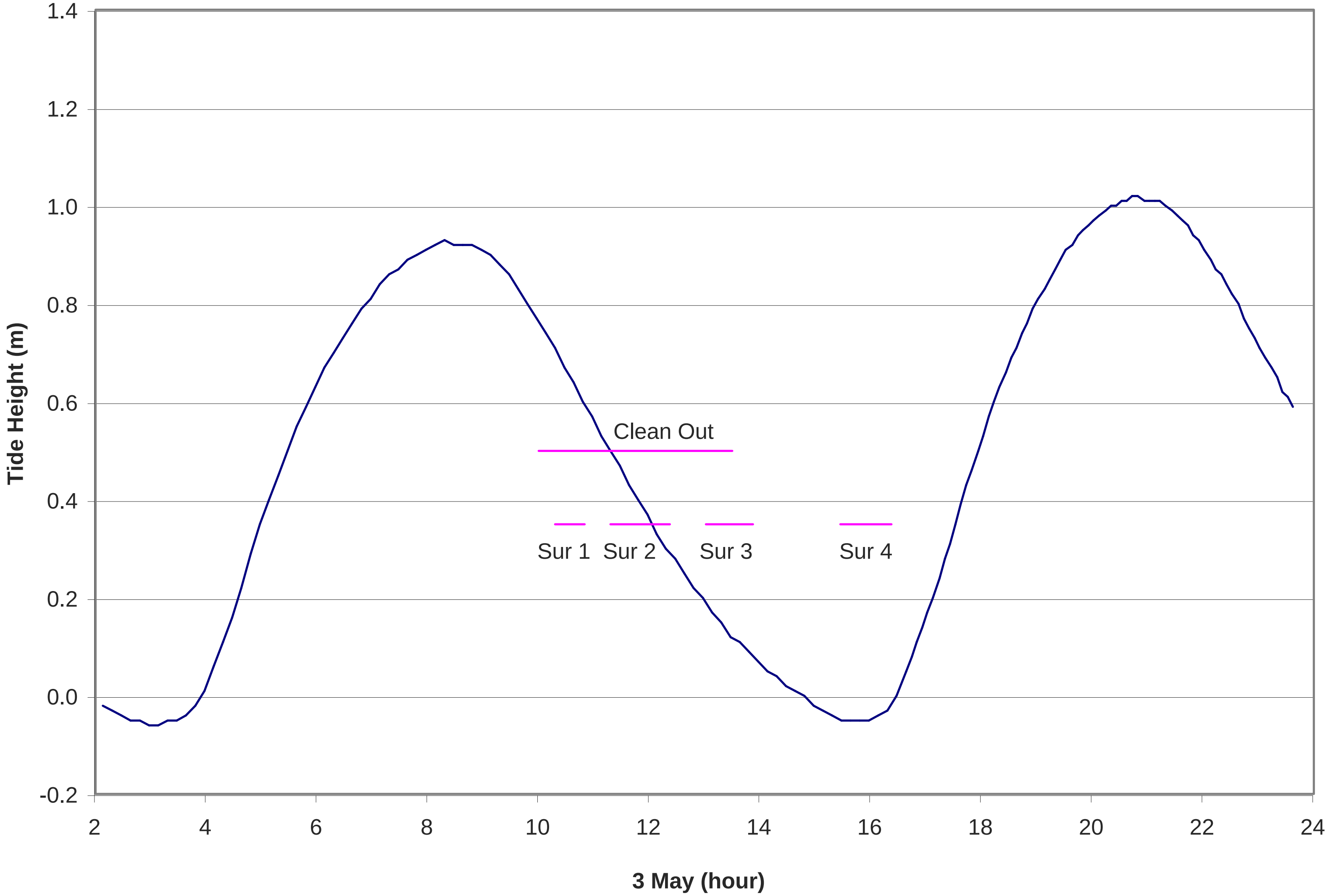


Figure B.1-7 Potomac River Flow During the 2-3 May 2000 Surveys at Outfall 003, Georgetown Reservoir

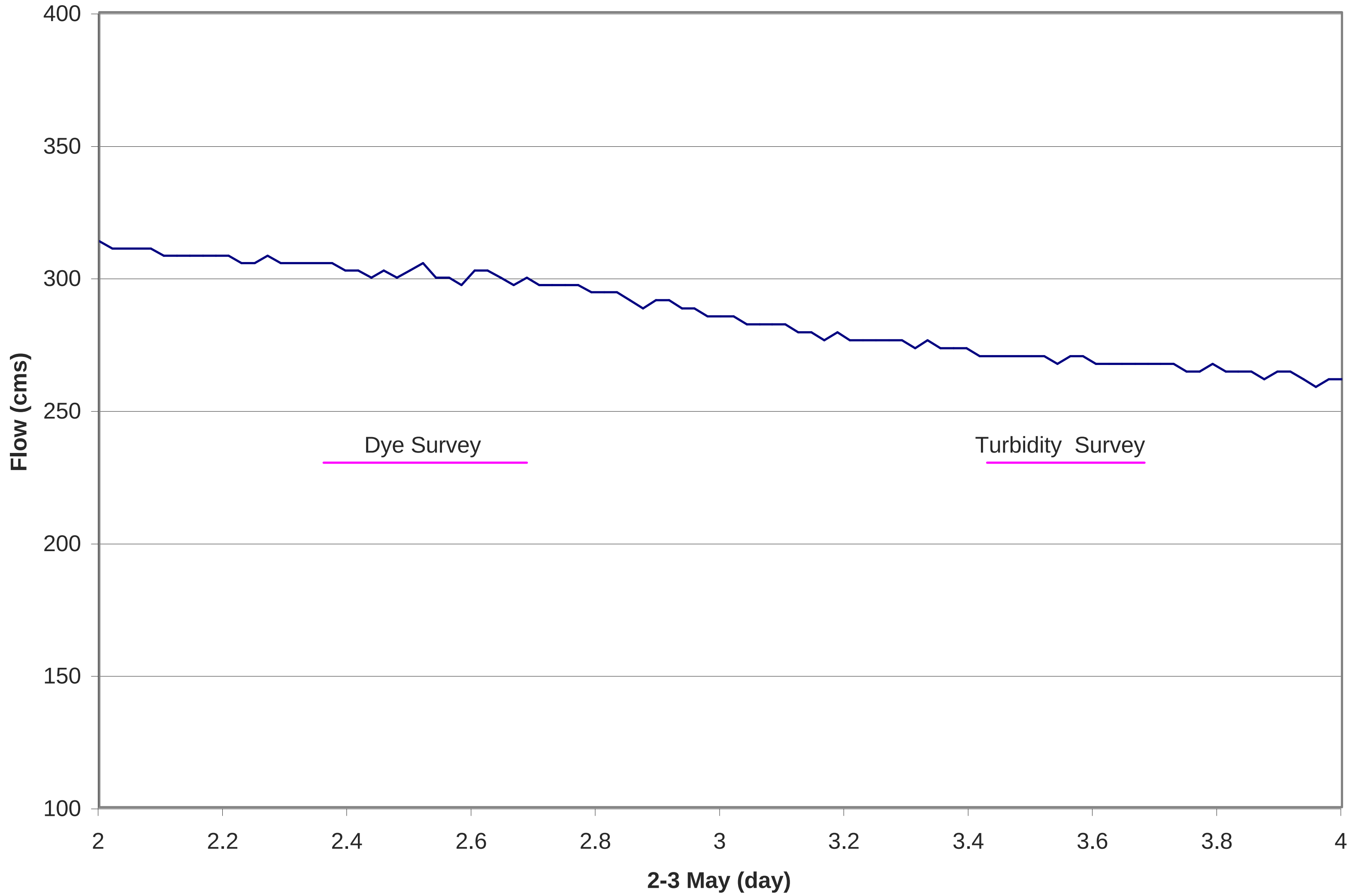


Figure B.1-8 Tide Height During the 24 May 2000 Dye Survey at Outfall 002, Dalecarlia Basin

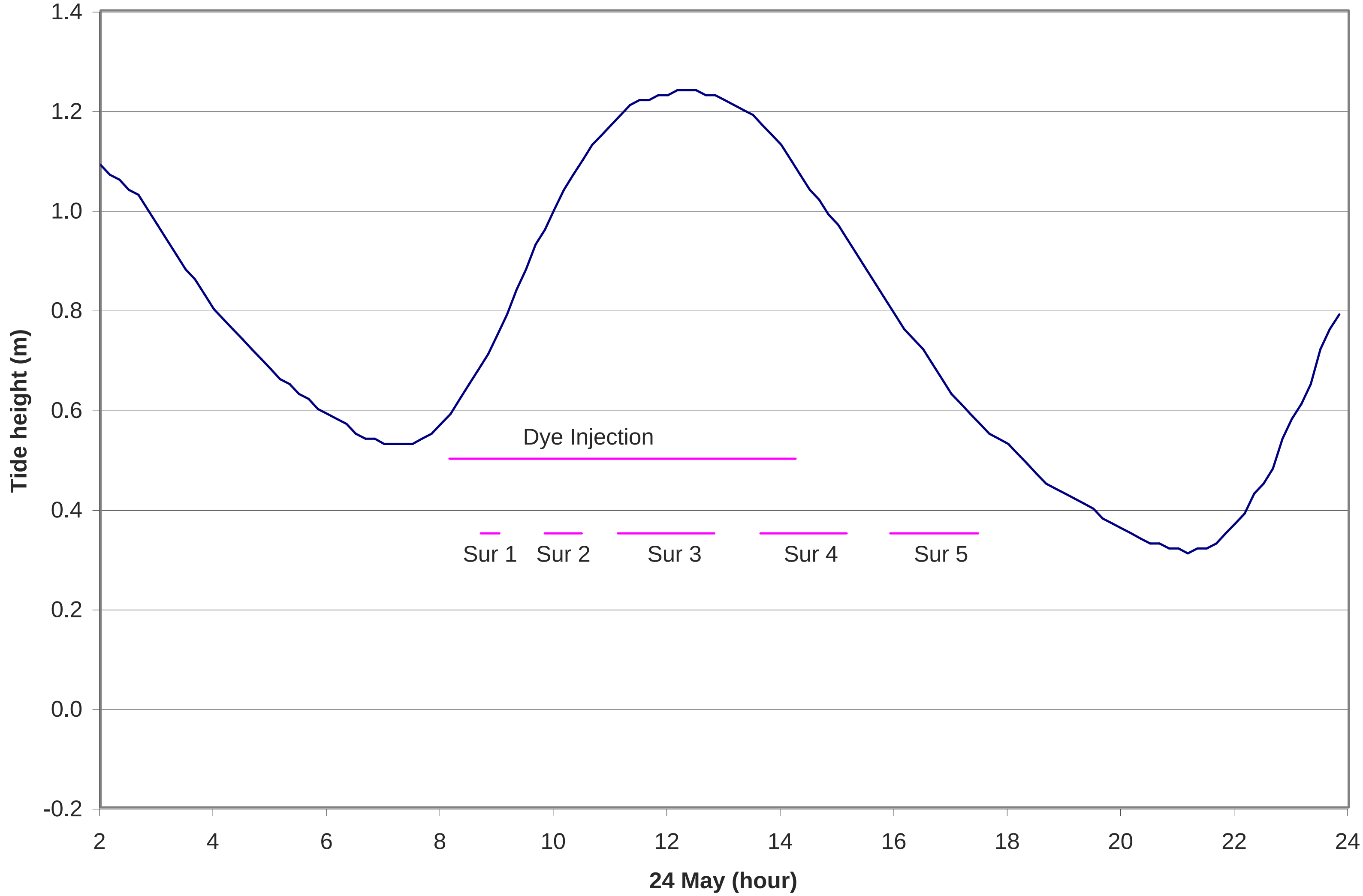


Figure B.1-9 Tide Height During the 25 May 2000 Turbidity Plume Survey at Outfall 002, Dalecarlia Basin

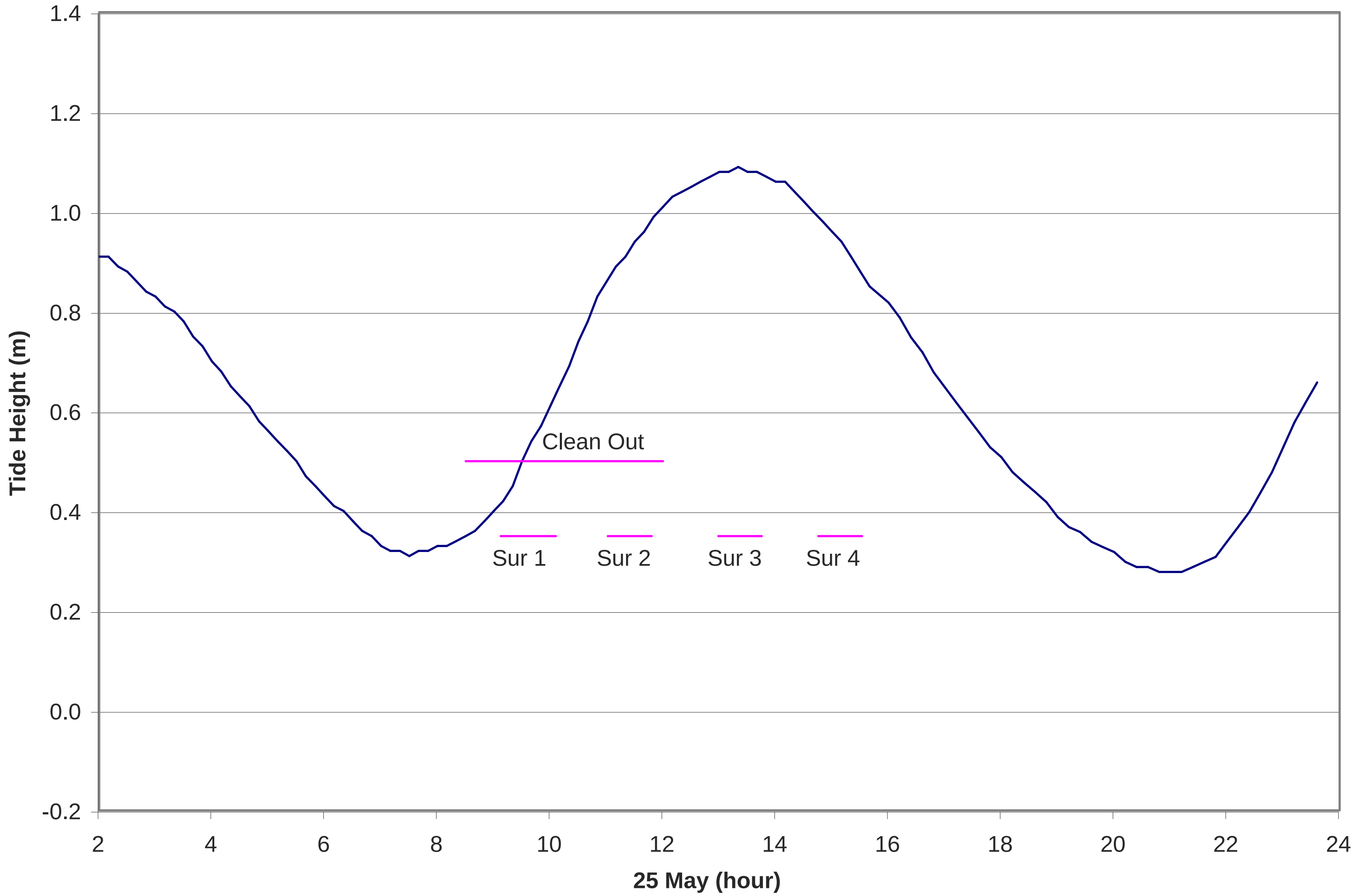


Figure B.1-10 Potomac River Flow During the 24-25 May 2000 Surveys at Outfall 002, Dalecarlia Basin

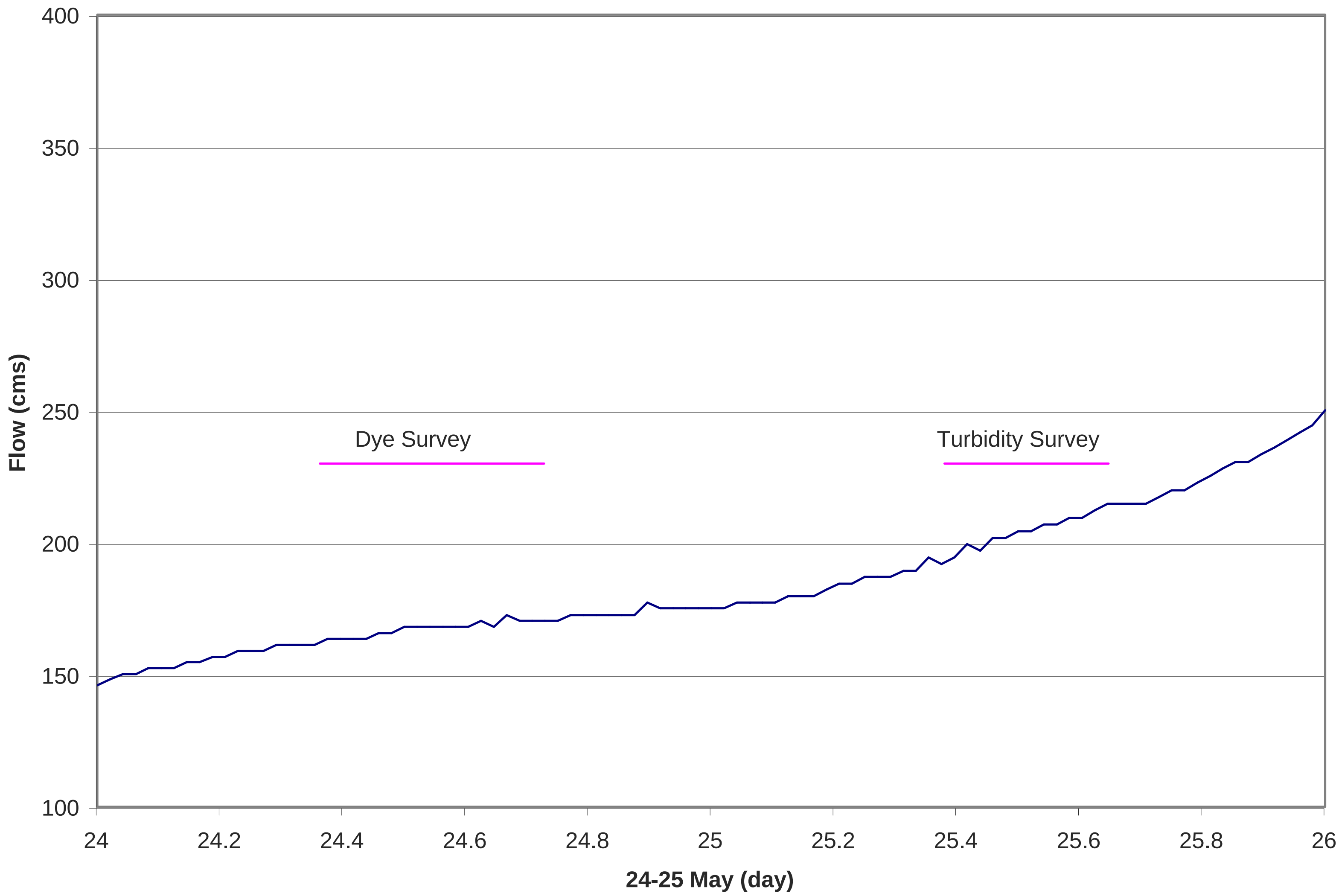


Figure B.1-11 Relationship Between Total and Dissovled Aluminum in Water Samples Collected During the Turbidity Surveys at Outfalls 002 and 003

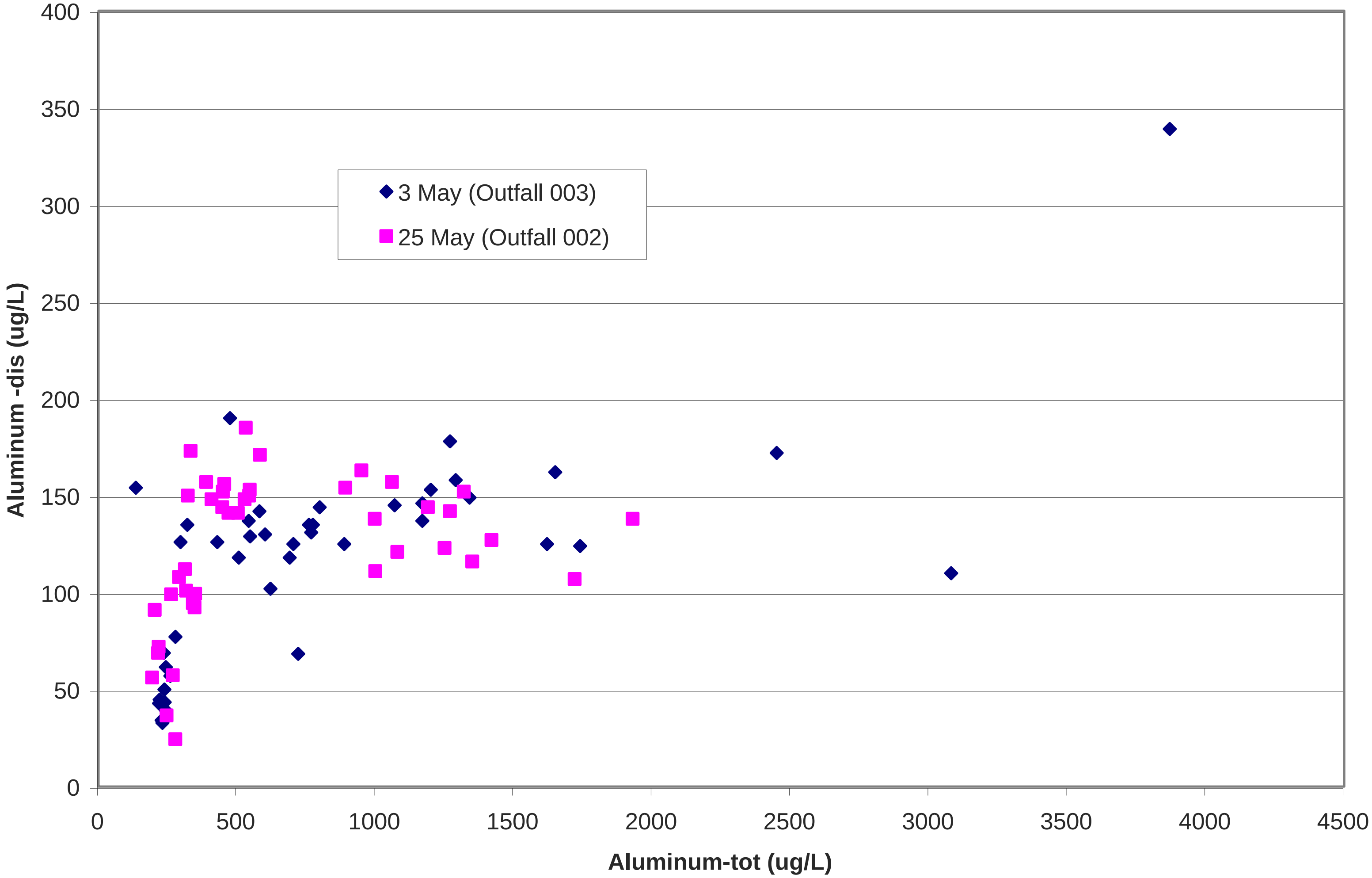


Figure B.1-12 Relationship Between Total Aluminum and TSS in Water Samples Collected During the Turbidity Surveys at Outfalls 002 and 003

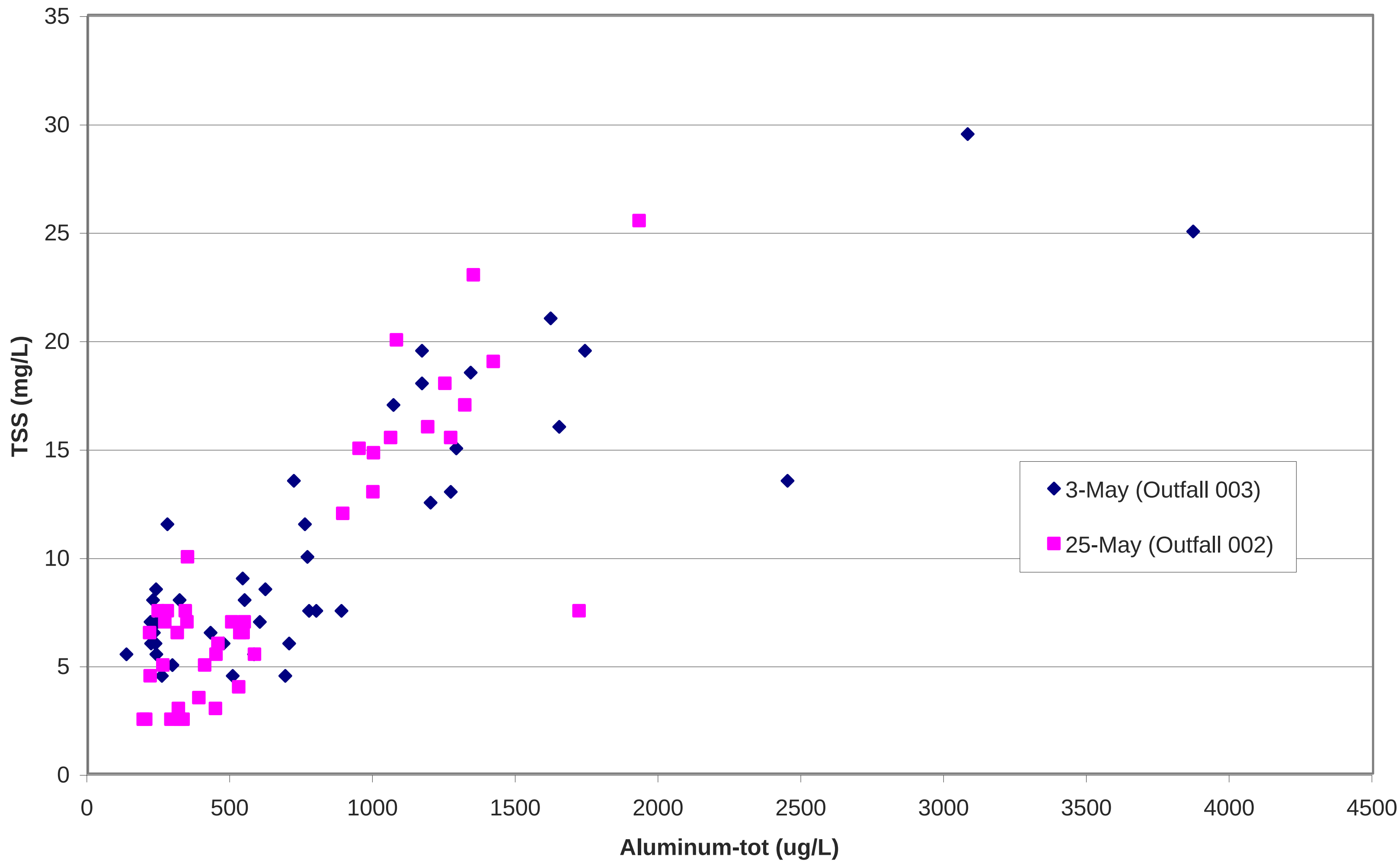
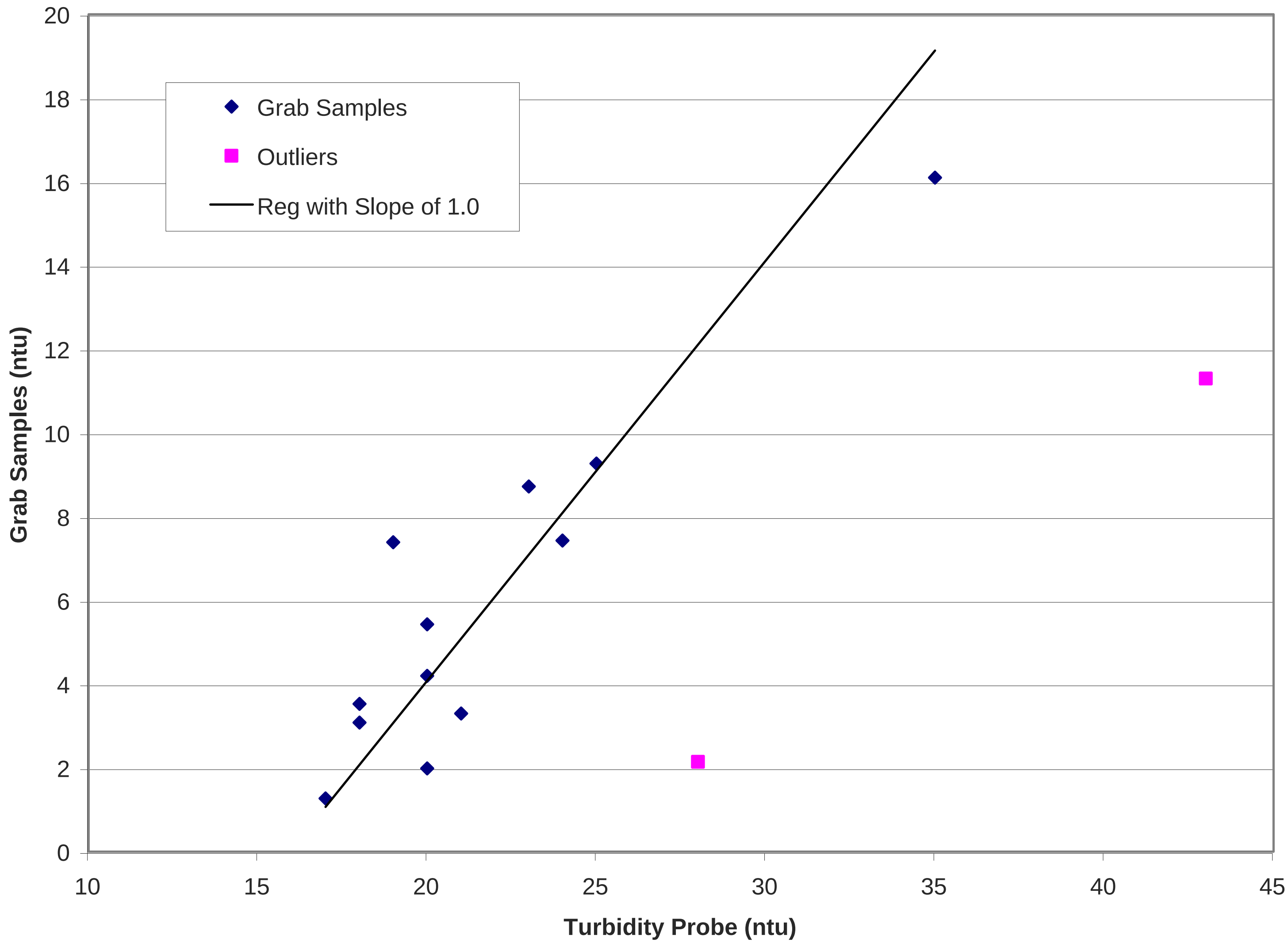


Table B.1-13 Minimum, Maximum, and Mean TSS Concentrations at Transects During the 25 May 2000 Turbidity Survey at Outfall 002, Dalecarlia Basin

Transect		TSS (mg/L) during Survey			
		1	2	3	4
1	Min		10.1	7.0	7.8
	Max		21.3	16.8	11.5
	Mean		16.2	8.9	9.5
2	Min		5.5	3.3	6.3
	Max		17.6	10.8	10.1
	Mean		13.8	8.6	8.5
3	Min	7.8	4.8	1.0	5.5
	Max	19.8	16.8	15.3	11.5
	Mean	14.5	11.4	9.6	9.1
4	Min	8.5	3.3	4.8	7.8
	Max	25.1	16.1	16.8	12.3
	Mean	18.5	11.8	11.3	9.6
5	Min	5.5	3.3	2.5	7.8
	Max	22.8	16.8	23.6	13.1
	Mean	14.5	10.7	12.2	9.8
6	Min	1.0	1.0	2.5	4.8
	Max	13.1	15.3	23.6	12.3
	Mean	7.7	8.5	12.1	9.0
7	Min	3.3	1.8	4.0	6.3
	Max	10.1	17.6	20.6	13.1
	Mean	6.8	8.2	9.8	9.5
10	Min	1.8	-1.3	-1.3	3.3
	Max	9.3	19.8	18.3	17.6
	Mean	6.2	6.3	6.9	8.5
12	Min	2.5	0.3	-0.5	2.5
	Max	13.8	10.1	11.5	21.3
	Mean	5.9	3.8	4.0	8.3
14	Min	-0.5	-0.5	-1.3	2.5
	Max	6.3	10.1	6.3	9.3
	Mean	3.1	2.5	2.5	5.9

Clean out: 0830 - 1200 hrs
Survey 1: 0907 - 1006 hrs
Survey 2: 1101 - 1148 hrs
Survey 3: 1259 - 1345 hrs
Survey 4: 1445 - 1532 hrs

Figure B.1-14 Relationship Between Turbidity Probe on Survey Boat and Grab Samples Processed with Hach Turbidity Meter



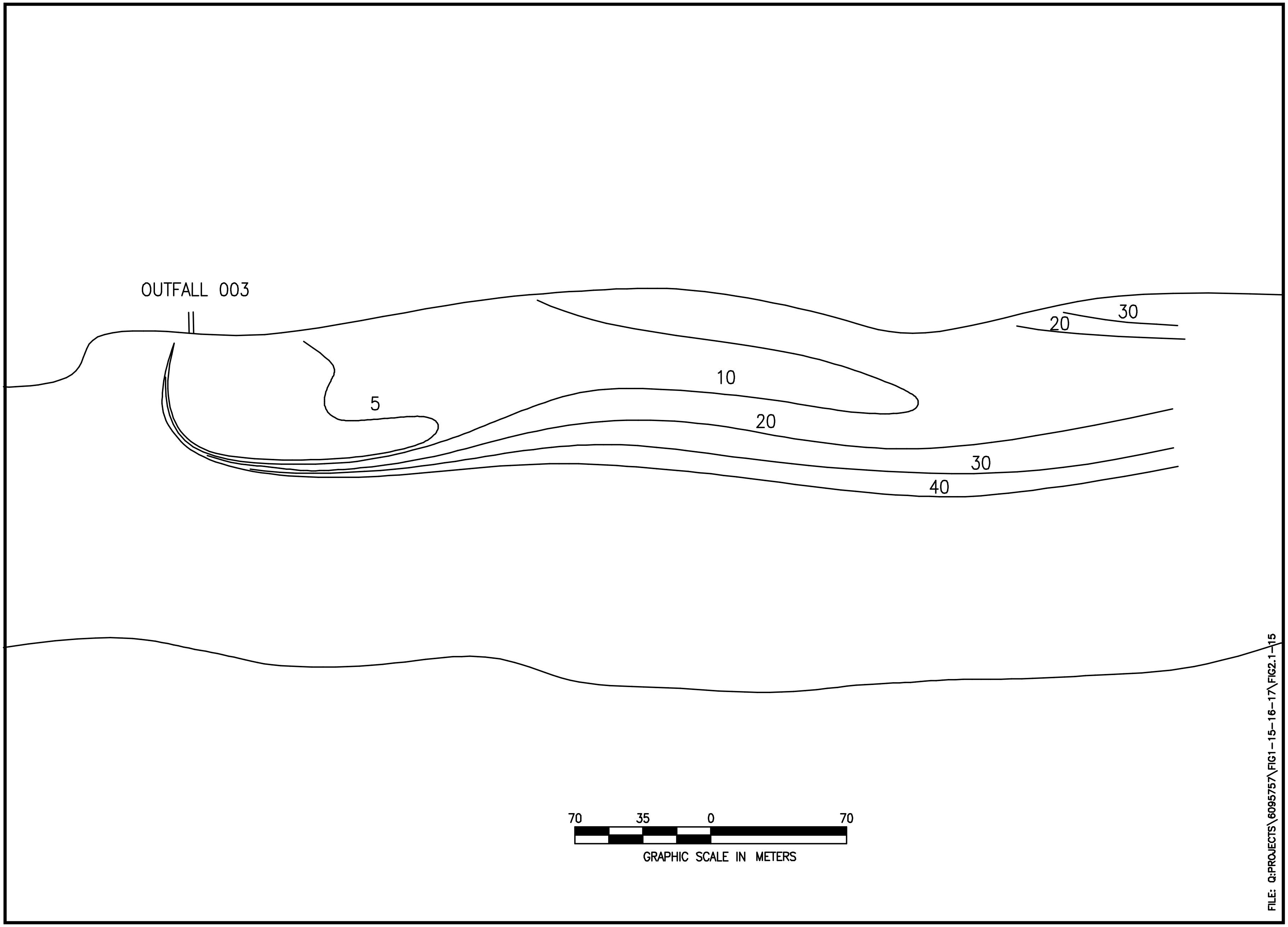


Figure B.1–15. Average Dye Dilution Contours During Surveys 2 and 3
of the Outfall 003 Plume Mapping Survey, 2 May 2000

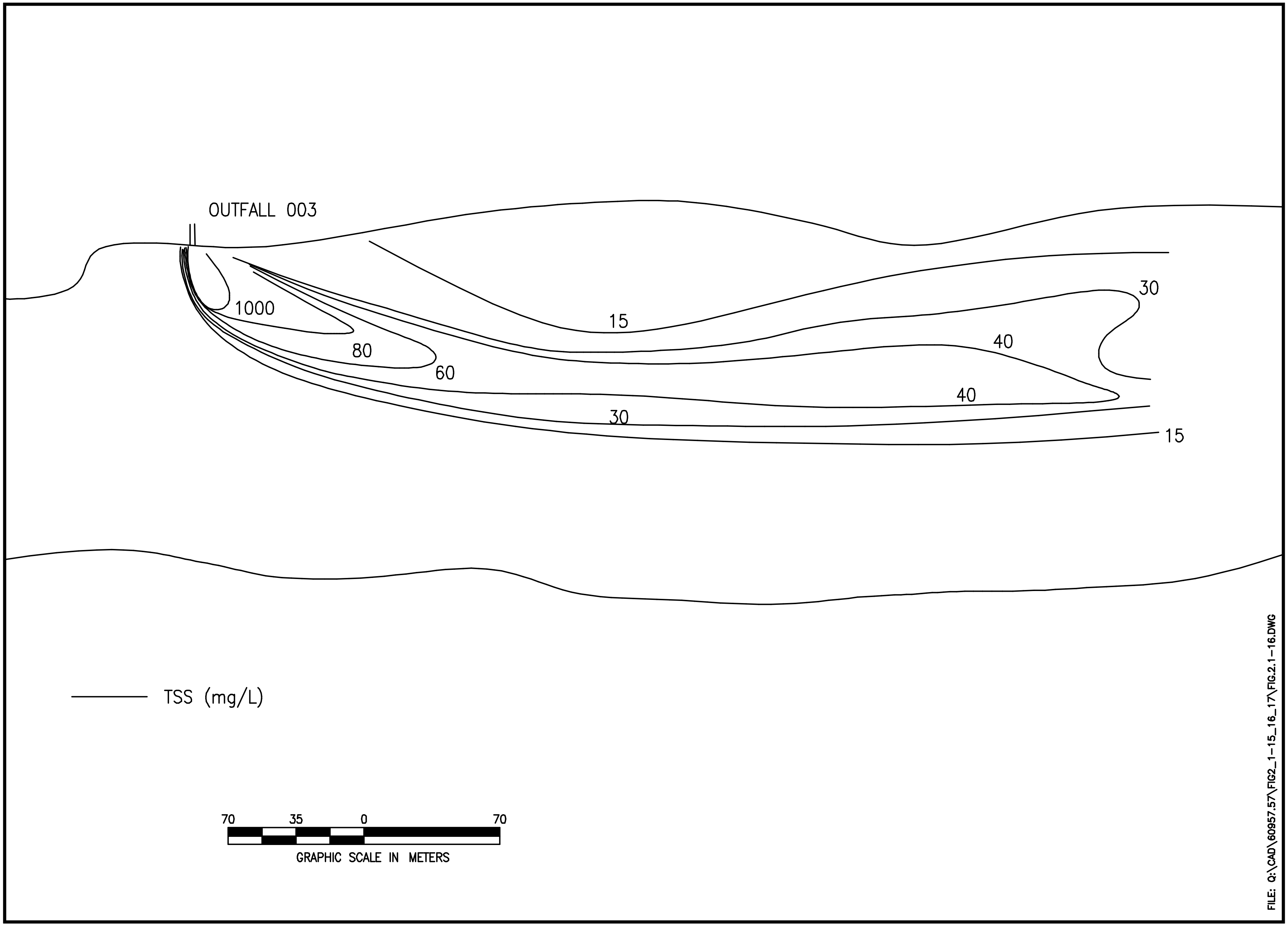


Figure B.1-16. Maximum TSS Concentrations During the Turbidity Plume Mapping Surveys at Outfall 003, 3 May 2000

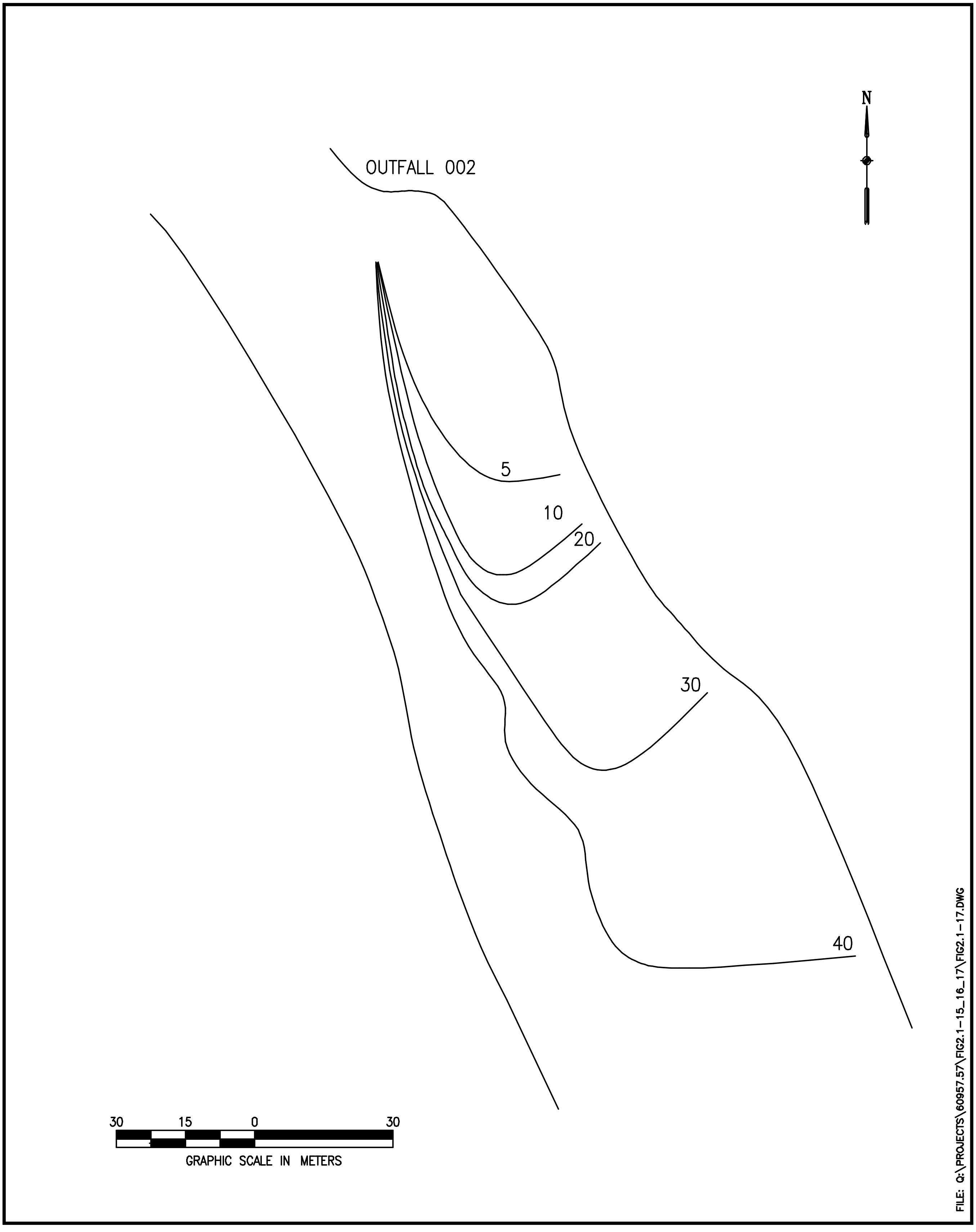


Figure B.1-17. Dye Dilution Contours During the Outfall 002 Plume Mapping Survey, 24 May 2000(1320-1340 hrs.)

Table B.1-1 Cross-Sectional Velocity Measurements at Two Potomac River Transects, 6-7 April 2000

Transect B3 - 6 April (1401-1438 hr)

Depth (m)	Velocity (cm/sec) at Station				
	V1	V2	V3	V4	V5
0.6	5.5	14.6	33.8	56.7	43.9
1.2	7.3	13.4	32.3	55.5	47.5
1.8	6.7	15.8	40.8	58.5	39.6
2.4	8.5	14.6	36.6	63.4	39.0
3.0	9.1	14.6	37.8	62.2	39.6
3.7		13.7	34.7	57.9	37.8
Mean	7.4	14.5	36.0	59.0	41.2

Transect B4 - 6 April (1456-1525 hr)

Depth (m)	Velocity (cm/sec) at Station						
	V1	V2	V3	V4	V5	V6	V7
0.6	17.1	15.2	9.1	6.1	27.4	45.7	19.8
1.2	20.4	18.3	7.9	4.6	15.2	36.6	6.1
1.8	23.8	17.1	8.5	18.3	19.8	39.0	
2.4	28.7	13.4	9.1	9.1	24.4	33.5	
3.0	25.0	6.1	13.4	16.8	21.3	29.0	
3.7	18.3		4.6	12.2	15.2	29.0	
Mean	22.2	14.0	8.8(a)	11.2(a)	20.6	35.5	13.0

a) Values not used in analysis.

Transect B3 - 7 April (1234-1316 hr)

Depth (m)	Velocity (cm/sec) at Station				
	V1	V2	V3	V4	V5
0.6	13.7	19.8	27.4	45.7	30.5
1.2	13.7	21.3	27.4	51.8	33.5
1.8	15.2	21.3	18.3	39.6	39.6
2.4	18.3	13.7	19.8	44.2	29.0
3.0		15.2	18.3	33.5	27.4
3.7		15.2	21.3	39.6	25.9
Mean	15.2	17.8	22.1	42.4	31.0

Transect B4 - 7 April (1324-1403 hr)

Depth (m)	Velocity (cm/sec) at Station					
	V1	V2	V3	V4	V5	V6
0.6	21.3	33.5	33.5	24.4	33.5	21.3
1.2	24.4	33.5	25.9	24.4	36.6	12.2
1.8	19.8	18.3	24.4	22.9	24.4	12.2
2.4	16.8		45.7	18.3	27.4	12.2
3.0	15.2		25.9	21.3	21.3	9.1
3.7	10.7		10.7	12.2	12.2	
Mean	18.0	28.4	27.7	20.6	25.9	13.4

Table B.1-2 Transects Used During the Dye and Turbidity Plume Mapping Surveys at Outfalls 002 and 003

Transect	Distance from 002 (m)	Distance from 003 (m)	Georgetown (003)		Dalecarlia (002)	
			Dye 2-May	Turbidity 3-May	Dye 24-May	Turbidity 25-May
1	520				x	x
2	790				x	x
3	1,150				x	x
4	1,560				x	x
5	1,880				x	x
6	2,280				x	x
7	2,780	-150	x	x	x	x
8	2,930	0	x	x		
9	3,000	70	x	x		
10	3,130	200	x	x	x	x
11	3,410	480	x	x	x	
12	3,830	900	x	x	x	x
13	4,320	1,390	x	x	x	
14	4,630	1,700	x	x	x	x
15	4,950	2,020	x	x	x	
16	5,190	2,260	x	x	x	
17	5,710	2,780	x	x	x	
18	6,640	3,710	x		x	
19	7,020	4,090	x		x	
20	7,980	5,050	x		x	

Table B.1-3 Water Chemistry Data Collected During the 3 May 2000 Turbidity Study at Outfall 003, Georgetown Reservoir

Aluminum-dis (ug/L)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
7	34.2		32.8	43.4		61.6			
9	50.1	44.8	178	68.8	190	339	42.9	57.0	125
11	145	131	129	77.1	110	135	39.2	135	102
12	172	125	118	137	146	124			
13				149	137	142	126	126	118
14				162	158	144			
16				125	153	135	130	68.4	154

Aluminum-tot (ug/L)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
7	228		231	239		243			
9	238	221	1270	236	475	3870	219	259	704
11	1070	768	548	278	3080	760	243	774	621
12	2450	1620	691	1170	1170	1740			
13				1340	542	581	429	296	507
14				1650	1290	799			
16				888	1200	321	602	721	135

TSS (mg/L)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
7	8.0		6.5	5.5		7.0			
9	8.5	6.0	13.0	6.0	6.0	25.0	7.0	4.5	6.0
11	17.0	10.0	8.0	11.5	29.5	11.5	7.0	7.5	8.5
12	13.5	21.0	4.5	18.0	19.5	19.5			
13				18.5	9.0	5.5	6.5	5.0	4.5
14				16.0	15.0	7.5			
16				7.5	12.5	8.0	7.0	13.5	5.5

Turbidity (ntu)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
7	6.3		8.1	7.3		6.7			
9	7.0	8.2	11.8	6.8	7.8	21.4	6.5	5.7	6.8
11	8.4	8.1	6.9	7.1	17.6	6.8	6.4	7.5	6.2
12	16.1	12.1	6.8	10.7	10.3	11.7			
13				10.9	5.8	5.6	8.2	4.5	5.2
14				11.8	10.1	6.7			
16				7.6	9.2	3.8	7.0	7.9	3.7

Note: R = right, M = middle, and L = left when facing downstream.

Survey 1: 1033 - 1119 hrs
Survey 2: 1238 - 1353 hrs
Survey 3: 1455 - 1614 hrs

Table B.1-4 Water Chemistry Data Collected During the 25 May 2000 Turbidity Study at Outfall 002, Dalecarlia Reservoir (Basin 3)

Aluminum-dis (ug/L)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
1	111		123	142		138	36.6		24.3
4	116		127	121		152	57.4		94.6
6	138	144	112	157	154	141	107	144	148
10	99.4		101	148		152	150		171
12	56.1	68.9	92.4	153	157	156	185	163	173
14		72		91	108	99	150		141

Aluminum-tot (ug/L)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
1	1000		1250	1270		1930	246		278
4	1350		1420	1080		1320	269		341
6	998	1190	313	1060	892	504	1720	447	528
10	349		317	409		449	544		583
12	194	216	347	547	389	455	532	950	333
14		218		203	291	263	323		470

TSS (mg/L)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
1	14.8		18.0	15.5		25.5	7.5		7.5
4	23.0		19.0	20.0		17.0	7.0		7.5
6	13.0	16.0	6.5	15.5	12.0	7.0	7.5	3.0	4.0
10	10.0		3.0	5.0		5.5	6.5		5.5
12	2.5	6.5	7.0	7.0	3.5	6.0	6.5	15.0	2.5
14		4.5		2.5	2.5	5.0	2.5		sample?

Turbidity (ntu)

Transect	Survey 1			Survey 2			Survey 3		
	R	M	L	R	M	L	R	M	L
1	8.6		12.1	12.8		17.8	7.7		7.6
4	10.6		12.5	11.7		11.9	6.3		7.3
6	12.3	12.6	6.7	11.6	11.8	5.8	7.6	5.9	6.6
10	6.3		7.0	5.2		4.4	5.9		5.6
12	5.0	5.6	6.3	5.4	3.7	4.2	5.4	8.6	3.1
14		4.8		3.9	4.1	4.3	3.7		4.2

Note: R = right, M = middle, and L = left when facing downstream.

Survey 1: 0915 - 1034 hrs
Survey 2: 1126 - 1245 hrs
Survey 3: 1349 - 1514 hrs

Table B.1-5 Effluent Water Chemistry Data Collected During the 2-3 May 2000 Georgetown Reservoir and 24-25 May 2000 Dalecarlia Basin Studies

Georgetown Reservoir (Outfall 003)

Time (hour)	Al-dis (ug/L)	Al-tot (ug/L)	TSS (mg/L)
2 May - Drawdown			
1013	65.7	215	<2.5
1111	52.0	233	<2.5
1225	58.4	187	<2.5
1410	59.4	192	<2.5
1544	46.1	196	<2.5
3 May - Clean Out			
1005	16	1,300,000	12,300
1035	62,400(a)	761,000	4,700
1120	730	25,900	166
1205	256	32,900	
1250	1,360	256,000	958
1320	45,700(a)	661,000	4,720

Dalecarlia Basin 3 (Outfall 002)

Time (hour)	Al-dis (ug/L)	Al-tot (ug/L)	TSS (mg/L)
24 May - Drawdown			
0906	62.7	537	5
0930	61.9	271	2.5
1030	66.8	274	3.5
1305	17.7	9,080	303
1430	34.9	468,000	3,160
25 May - Clean Out			
0850	80.9		4,610
0940	<200	1,020,000	8,030
1025	107		5,550
1040		1,810,000	
1055	17.7	1,580,000	16,500
1145	108	28,100	235

a) MINTEQ, a thermodynamic equilibrium model, indicates that the dissolved fraction should be less than 1-percent of the total for these elevated total aluminum samples. These values were not used in the dissolved analysis.

Table B.1-6 Particle Size Distribution of Sediment Samples Collected in the Reservoirs during the 3 and 25 May 2000 Solids Discharge Events.

Particle Diameter (mm)	Cumulative Particle Distribution (%)				
	George-town	Dalecarlia			Composite(a)
		Sample-1	Sample-2	Average	
9.50	100	100	100	100	100
4.75	100	100	100	100	100
2.00	98.9	100	99.8	99.9	99.4
0.850	82.3	82.5	63.9	73.2	77.8
0.425	71.0	55.7	41.6	48.7	59.8
0.250	64.5	40.3	30.9	35.6	50.1
0.150	59.4	29.7	24.4	27.1	43.2
0.0750	54.1	21.9	19.4	20.7	37.4
0.0322	44.0	17.8	16.3	17.1	30.5
0.0210	36.8	16.2	15.8	16.0	26.4
0.0122	35.0	13.0	14.8	13.9	24.5
0.0087	33.2	12.2	13.7	13.0	23.1
0.0062	29.6	9.7	12.1	10.9	20.3
0.0032	22.4	8.1	9.5	8.8	15.6
0.0012	13.5	4.1	5.3	4.7	9.1
Sand	50.2	80.4	82.2	81.3	65.7
Silt	31.6	14.0	10.8	12.4	22.0
Clay	18.2	5.5	6.9	6.3	12.3

a) Composite was constructed using the Georgetown and the average Darcarlia sample.

Georgetown Reservoir - 3 May 2000

Dalecarlia Basin - 25 May 2000

Size Classification

Sand > 0.05 mm

Silt 0.002 < < 0.05 mm

Clay < 0.002 mm

Table B.1-7 Results of Hydrometer Test Performed on Sediment Sample Without the Use of a De-Floccing Agent

Minutes	Settling Velocity (cm/sec)	Diameter (mm)		Distribution (%)
		Spherical (a)	Floc (b)	
1	0.256	0.056	1.058	99.1
2	0.128	0.039	0.429	102.7
3	0.085	0.032	0.253	102.7
4	0.064	0.028	0.177	84.55
5	0.052	0.025	0.134	70.00
6	0.043	0.023	0.106	66.36
7	0.038	0.021	0.088	51.82
8	0.033	0.020	0.074	39.09
9	0.029	0.019	0.064	35.45
10	0.027	0.018	0.057	15.45
11	0.024	0.017	0.050	11.82
12	0.023	0.017	0.045	2.73
14	0.019	0.015	0.037	2.73
15	0.018	0.015	0.034	2.73

a) Diameter assuming a spherical particle.
b) Diameter assuming an alum floc (Tambo and Watanabe, 1979).

Table B.1-8 Dye Injection Rates, Discharge Dye Concentrations, and Calculated Discharge Flow During the 2 May 2000 Dye Study at Outfall 003 (Georgetown Reservoir)

Dye Injection Rate

Time	Dye Injection Rate (gm/min)	Calculated Concentration(a) (ppb)
0749-0924	14.7	14.2
0924-1030	17.0	16.4
1030-1240	22.0	21.2
1240-1310	dye off	
1310-1406	20.0	19.3

a) Calculated discharge concentration assuming a 3.46 cms flow.

Discharge Dye Concentration and Flow

Time (hr)	Discharge Concentration (ppb)	Calculated Discharge Flow (cms)
1013	14.8	3.83
1111	18.4	3.08
1225	21.2	3.46
	Average Flow	3.46

Table B.1-9 Minimum, Maximum, and Mean Dye Concentrations at Transects During the 2 May 2000 Dye Survey at Outfall 003, Georgetown Reservoir

Transect		Dye Concentration (ppb) during Survey				
		1	2	3	4	5
7	Min	-0.06	-0.02	-0.03	-0.03	-0.02
	Max	0.03	0.01	0.01	0.00	0.01
	Mean	0.00	-0.01	-0.01	-0.01	-0.01
8	Min	-0.04	-0.05	-0.02	-0.02	-0.01
	Max	7.80	15.71	37.71	17.52	0.58
	Mean	1.79	4.34	13.02	7.18	0.12
9	Min	-0.01	-0.02	-0.10	-0.04	-0.02
	Max	3.62	3.85	13.68	7.41	4.25
	Mean	0.99	1.52	2.86	2.70	1.92
10	Min	-0.04	-0.17	-0.02	-0.03	-0.02
	Max	0.78	3.08	3.79	1.40	1.53
	Mean	0.10	0.85	1.08	0.41	0.24
11	Min	-0.03	-0.04	-0.03	-0.02	-0.02
	Max	0.02	1.74	2.29	2.74	2.13
	Mean	0.00	0.46	0.75	1.21	0.80
12	Min	-0.02	-0.03	-0.01	-0.01	0.00
	Max	0.02	0.32	0.53	0.67	0.60
	Mean	0.00	0.12	0.21	0.34	0.26
13	Min	-0.03	-0.02	-0.02	0.00	0.01
	Max	0.02	0.11	0.40	0.58	0.65
	Mean	0.00	0.04	0.15	0.29	0.24
14	Min	-0.03	-0.04	-0.02	0.02	0.00
	Max	0.01	0.04	0.34	0.53	0.63
	Mean	-0.01	0.00	0.17	0.30	0.27
15	Min	-0.02	-0.03	-0.01	0.01	0.03
	Max	0.01	0.02	0.23	0.45	0.60
	Mean	0.00	-0.01	0.10	0.26	0.39
16	Min	-0.03	-0.04	-0.01	0.00	0.00
	Max	0.02	0.02	0.12	0.40	0.54
	Mean	0.00	-0.01	0.04	0.15	0.24
17	Min	-0.03	-0.03	-0.05	-0.01	0.02
	Max	0.02	0.02	0.03	0.27	0.41
	Mean	-0.01	-0.01	0.00	0.10	0.14
18	Min				-0.02	0.02
	Max				0.08	0.28
	Mean				0.04	0.12
19	Min					0.04
	Max					0.18
	Mean					0.08
20	Min					-0.03
	Max					0.06
	Mean					0.02

Dye injection : 0749 - 1406 hrs
Survey 1: 0820 - 0915 hrs
Survey 2: 1009 - 1117 hrs
Survey 3: 1134 - 1235 hrs
Survey 4: 1338 - 1448 hrs
Survey 5: 1509 - 1631 hrs

Table B.1-10 Minimum, Maximum, and Mean TSS Concentrations at Transects During the 3 May 2000 Turbidity Survey at Outfall 003, Georgetown Reservoir

Transect		TSS (mg/L) during Survey 1	2	3	4
7	Min	3.9	3.9	3.9	1.7
	Max	9.2	9.2	15.2	19.7
	Mean	5.6	6.6	8.6	13.2
8	Min	-8.1	3.9	6.2	10.0
	Max	1174.7	2164.2	142.4	16.0
	Mean	129.1	273.9	24.0	12.8
9	Min	0.9	1.7	5.4	0.9
	Max	43.1	86.0	78.4	28.0
	Mean	9.5	18.9	17.6	15.3
10	Min	0.9	2.4	1.7	7.0
	Max	48.3	38.5	43.1	19.0
	Mean	9.0	11.7	11.7	13.3
11	Min	-2.1	3.9	3.9	
	Max	30.3	43.1	29.5	
	Mean	12.3	14.8	13.0	
12	Min	0.9	0.9	7.0	2.4
	Max	38.5	28.0	28.0	33.3
	Mean	16.7	15.4	16.5	17.2
13	Min	-0.6	2.4	0.2	7.0
	Max	25.0	28.0	32.5	25.0
	Mean	7.4	8.8	10.0	13.0
14	Min		3.9	5.4	5.4
	Max		22.0	25.8	14.5
	Mean		12.1	13.2	10.4
15	Min		0.2	-0.6	3.9
	Max		40.1	28.0	22.0
	Mean		9.0	9.2	11.2
16	Min		-0.6	3.9	3.9
	Max		29.5	28.8	20.5
	Mean		7.4	10.9	10.9
17	Min		-0.6	-3.6	-8.1
	Max		8.4	16.0	40.7
	Mean		4.3	5.7	9.6

Clean out: 1000 - 1330 hrs
Survey 1: 1018 - 1050 hrs
Survey 2: 1118 - 1222 hrs
Survey 3: 1301 - 1352 hrs
Survey 4: 1527 - 1622 hrs

Table B.1-11 Dye Injection Rates, Discharge Dye Concentrations, and Calculated Discharge Flow During the 24 May 2000 Dye Study at Outfall 002 (Dalecarlia Basin)

Dye Injection Rate

Time	Dye Injection Rate (gm/min)	Calculated Concentration(a) (ppb)
0809-0953	9.4	18.1
0953-1040	15.8	30.4
1040-1255	16.9	32.5
1255-1415	17.8	34.2

a) Calculated discharge concentration assuming a 1.73-cms flow.

Discharge Dye Concentration and Flow

Time (hr)	Discharge Concentration (ppb)	Calculated Discharge Flow (cms)
906	12.60	2.49
930	16.23	1.93
1002	33.08	1.59
1030	40.67	1.29
1100	38.46	1.46
1129	46.11	1.22
1158	36.01	1.56
1230	24.64	2.29
1305	39.80	1.49
1330	25.90	2.29
1400	37.27	1.59
	Average Flow	1.75

Table B.1-12 Minimum, Maximum, and Mean Dye Concentrations at Transects During the 24 May 2000 Dye Survey at Outfall 002, Dalecarlia Basin

Transect		Dye Concentration (ppb) during Survey				
		1	2	3	4	5
1	Min	0.14	0.15	0.33	0.32	0.08
	Max	0.26	0.42	0.53	0.56	0.18
	Mean	0.20	0.24	0.44	0.47	0.14
2	Min	0.12	0.20	0.30	0.40	0.15
	Max	0.21	0.25	0.44	0.48	0.22
	Mean	0.16	0.22	0.38	0.44	0.19
3	Min	-0.01	0.03	0.18	0.33	0.18
	Max	0.13	0.23	0.39	0.38	0.32
	Mean	0.05	0.13	0.28	0.36	0.23
4	Min	0.00	0.15	0.25	0.35	0.13
	Max	0.04	0.22	0.35	0.41	0.24
	Mean	0.02	0.18	0.30	0.38	0.17
5	Min	-0.01	0.00	0.20	0.34	0.16
	Max	0.02	0.20	0.30	0.40	0.37
	Mean	0.00	0.14	0.26	0.37	0.24
6	Min	-0.02	-0.01	0.08	0.19	0.20
	Max	0.02	0.17	0.25	0.36	0.36
	Mean	0.00	0.07	0.18	0.29	0.26
7	Min		-0.01	0.01	0.20	0.23
	Max		0.05	0.18	0.32	0.34
	Mean		0.01	0.09	0.27	0.30
10	Min		-0.02	-0.01	0.00	0.03
	Max		0.02	0.19	0.31	0.38
	Mean		0.00	0.08	0.18	0.24
11	Min		-0.02	-0.01	0.01	
	Max		0.01	0.17	0.30	
	Mean		0.00	0.04	0.15	
12	Min			-0.02	0.02	0.04
	Max			0.08	0.29	0.33
	Mean			0.02	0.18	0.26
13	Min			-0.08	-0.02	
	Max			0.04	0.27	
	Mean			-0.01	0.15	
14	Min			-0.04	0.02	0.04
	Max			0.04	0.19	0.90
	Mean			0.01	0.09	0.25
15	Min			-0.02	0.00	
	Max			0.03	0.00	
	Mean			0.01	0.00	
16	Min			-0.02	-0.04	0.01
	Max			0.03	0.11	0.28
	Mean			0.01	0.04	0.18

Table B.1-13 Minimum, Maximum, and Mean TSS Concentrations at Transects During the 25 May 2000 Turbidity Survey at Outfall 002, Dalecarlia Basin

Transect		TSS (mg/L) during Survey			
		1	2	3	4
1	Min		10.1	7.0	7.8
	Max		21.3	16.8	11.5
	Mean		16.2	8.9	9.5
2	Min		5.5	3.3	6.3
	Max		17.6	10.8	10.1
	Mean		13.8	8.6	8.5
3	Min	7.8	4.8	1.0	5.5
	Max	19.8	16.8	15.3	11.5
	Mean	14.5	11.4	9.6	9.1
4	Min	8.5	3.3	4.8	7.8
	Max	25.1	16.1	16.8	12.3
	Mean	18.5	11.8	11.3	9.6
5	Min	5.5	3.3	2.5	7.8
	Max	22.8	16.8	23.6	13.1
	Mean	14.5	10.7	12.2	9.8
6	Min	1.0	1.0	2.5	4.8
	Max	13.1	15.3	23.6	12.3
	Mean	7.7	8.5	12.1	9.0
7	Min	3.3	1.8	4.0	6.3
	Max	10.1	17.6	20.6	13.1
	Mean	6.8	8.2	9.8	9.5
10	Min	1.8	-1.3	-1.3	3.3
	Max	9.3	19.8	18.3	17.6
	Mean	6.2	6.3	6.9	8.5
12	Min	2.5	0.3	-0.5	2.5
	Max	13.8	10.1	11.5	21.3
	Mean	5.9	3.8	4.0	8.3
14	Min	-0.5	-0.5	-1.3	2.5
	Max	6.3	10.1	6.3	9.3
	Mean	3.1	2.5	2.5	5.9

Clean out: 0830 - 1200 hrs
Survey 1: 0907 - 1006 hrs
Survey 2: 1101 - 1148 hrs
Survey 3: 1259 - 1345 hrs
Survey 4: 1445 - 1532 hrs

Table B.1-14 Vertical TSS Profiles Measured During the 25 May 2000 Turbidity Survey at Outfall 002, Dalecarlia Basin

Transect	Depth (m)	TSS (mg/L) during Survey			
		1	2	3	4
1	0.3	14.7	10.7	7.6	13.0
	1.5	15.6	13.2	8.6	12.6
	3.0	13.9	15.9	9.2	11.3
	4.6	14.6	14.9	8.2	10.6
	6.1	16.4	11.5	9.0	10.4
	7.6	16.4	12.2	8.4	13.9
	9.1	13.2	13.6	7.9	12.9
4	0.3	11.6	16.9	8.1	11.0
	1.5	13.0	18.6	7.9	12.7
	3.0	13.9	20.6	9.0	11.5
	4.6	13.3	21.2	8.2	10.4
	6.1	12.6	19.2	8.7	12.7
	7.6	14.6	20.9	9.0	13.3
	9.1	14.3	20.6	8.1	11.2
6	0.3	18.3	13.2	9.8	10.4
	1.5	13.6	15.3	12.4	12.4
	3.0	14.4	17.6	9.8	11.5
	4.6	18.7	16.9	13.5	13.5
7	0.3	8.2	2.8	12.6	8.7
	1.5	5.6	5.9	11.8	12.1
	3.0	7.6	10.6	11.8	11.8
	4.6	10.1	9.0	15.3	10.4
	6.1	11.3	9.6	21.8	10.2
	7.6	9.2	16.4	18.4	13.0
	9.1	10.6	16.6	28.7	13.2

Notes: Vertical profiles were performed following horizontal plume mapping.
Field turbidity values were converted to TSS.
Survey 1: 1018-1049 hrs
Survey 2: 1155-1227 hrs
Survey 3: 1352-1421 hrs
Survey 4: 1543-1617 hrs

B.2 MODEL CALIBRATION

The model used to evaluate Aqueduct discharges to the Potomac River was the Surfacewater Modeling System (SMS), developed by BOSS International and Brigham Young University. SMS is a pre- and post-processor for surface water modeling and analysis. It includes interfaces with several numerical models including the U.S. Army Corps of Engineers, Waterways Experiment Station (WES) supported models RMA2, RMA4, and SED2D.

- RMA2 is a two-dimensional depth averaged finite-element hydrodynamic numerical model. It computes water surface elevations and horizontal components for free-surface flow in two-dimensional flow fields. RMA2 was used to provide a hydrodynamic solution for the modeled portion of the Potomac River. For the Aqueduct model, time-variable river flows were applied at the upstream model boundary, and time-variable tidal elevations were applied at the downstream model boundary. The resulting output file provides a flow velocity and a water surface elevation at each model node for each solution time step.

- RMA4 is a two-dimensional finite-element water quality model. The model simulates the advection-diffusion processes and treats pollutants either as conservative or nonconservative using first order decay. RMA4 uses the hydrodynamic solution file from RMA2 as an input file along with additional information on pollutant loadings and diffusion coefficients. As part of the Aqueduct model, RMA4 was used to simulate the discharge plumes resulting from the dye studies, while treating dye as a conservative tracer. The calibration of the Aqueduct model to the observed instream dye distribution was used to establish appropriate lateral and longitudinal diffusion coefficients.

- SED2D is a two-dimensional finite-element model for vertically averaged sediment transport in open channel flow. The model simulates both deposition and erosion and treats two sediment categories: 1) “noncohesive”, which is usually referred to as sand; and 2) “cohesive”, which is referred to as clay. SED2D also uses the hydrodynamic solution file from RMA2 as an input file along with additional information including sediment loads, particle settling velocities, and shear stress for deposition and erosion. As part of the Aqueduct model, SED2D was used to model the suspended solids load during a reservoir clean-out event, and to simulate the resulting water column concentrations and the depositional patterns.

B.2.1 Model Grid

The model domain was selected to extend from a location approximately 180-m upstream of Outfall 002, downstream past Roosevelt Island to Memorial Bridge. The total length of the model along the Potomac River was 8.0 km. The finite-element nature of RMA2 allows a variable model cell size to be used. Thus, a smaller element can be used in the vicinity of the outfalls where greater resolution is desired. The dynamic nature of the discharge flow entering transverse to the river flow and the accompanying large concentration gradients makes a smaller element size in the vicinity of the outfalls necessary for improved numerical stability. During the initial model development a typical element size was approximately 100 meters long and 30-40 meters wide in the river away from the immediate vicinity of an outfall. In the final version of the model contained in this report, each of these far-field cells was subdivided into four elements with a typical element size of 50-m long and 15 to 20-m wide. A much smaller element size was used in the vicinity of Outfalls 002 and 003. The model places nodes at the corner of each element and also mid-way along each side. The Aqueduct model contains a total of 2021 elements and 6281 nodes. For each model time step, the model solution files contains x and y velocity components, water surface elevations, and concentrations at each node. In general, the model was approximately 6 elements wide upstream in the vicinity of Outfall 002, increasing to 12 elements wide by Outfall 003. Between Outfall 003 and Roosevelt Island, the model maintained 12 elements across the river, although the element width varied with the river width resulting in curve-linear coordinates. The original 100-m elements were maintained below Roosevelt Island approaching the downstream tidal boundary.

Outfalls 002 and 003 were modeled as an inset box on the shoreline. The discharge at Outfall 003 was very turbulent with high velocities that would be unstable in a numerical model. The width and depth of the element representing Outfall 003 was set at the smallest value for which numerical stability could be maintained in the model. At Outfall 002, the actual discharge is sub-surface and a surface boil was observed during the dye study located in the lower velocity region in the lee of the shoreline protrusion at the outfall. Because of this orientation, the size of the inset box on the shoreline used to represent Outfall 002 was not considered to be important for representation of downstream plume characteristics.

The finer model grid in the vicinity of Outfalls 002 and 003 are displayed in Figure B.2-1. The smaller elements at Outfall 002 are approximately 5x5 m and the smaller elements at Outfall 003 are 5x7 m. The model grid used in the Potomac River beyond the vicinity of the outfalls is displayed in Figure B.2-2, which extends from below Outfall 003 to the downstream end of the model at Arlington Memorial Bridge.

B.2.2 RMA2 Model Development

Model Boundaries

The RMA2 model was set-up using real-time data at the upstream and downstream boundaries. At the upstream boundary, the 15-minute USGS flow data was obtained at the Little Falls gage on days that field surveys were performed (Figures B.1-7 and B.1-10). At the downstream boundary the 5-min tide data obtained from the water level recorder deployed during each field survey was used. The correction of this data to a MLW datum was discussed in Section B.1.1, and the tide curves on the days of the dye and turbidity plume mapping surveys were displayed in Figures B.1-5, B.1-6, B.1-8, and B.1-9.

When modeling individual days on which the dye and turbidity surveys were performed, the Aqueduct model was typically started several hours before the initiation of dye injection or solids discharge, near the preceding high or low slack water.

Eddy Viscosity

The principal calibration parameters in RMA2 are eddy viscosity and channel roughness. Eddy viscosity (E) controls the fluid momentum transfer between water masses moving at different speeds. The eddy viscosity in the Aqueduct model was assigned by allowing the model to automatically adjust E after each iteration based upon a Peclet number. The Peclet number defines the relationship between velocity, elemental length, fluid density, and eddy viscosity. The Peclet number (P) is recommended to be between 15 and 40, and the formula that relates P to eddy viscosity is given as:

$$P = rho\ U\ dx\ /E$$

Where rho = fluid density (kg/m^3)
U = average elemental velocity (m/sec)
dx = element length (m)
E = eddy viscosity (Pascal-sec)

As the Peclet number is increased, the eddy viscosity decreases. A Peclet number of 20 was determined to provide numerical stability in the RMA2 model over a range of flow and tidal conditions.

Cross-Sectional River Velocity

The Manning's coefficient option was selected for determining channel roughness in the RMA2 model. The user has the choice of entering a uniform Manning's coefficient or providing a relationship where the Manning's coefficient varies as a function of water depth. Providing a higher Manning's coefficient for the shallower off-channel area, and a lower Manning's coefficient in the deeper channel, increases the velocity difference between these two regions. This velocity variation as a function of depth was most noticeable during the 6-7 April 2000 cross-sectional velocity surveys (Section B.1-2, Table B.1-1) at Transect B3. The RMA2 model was executed for 6 and 7 April 2000 and the resulting velocities along Transects B3 and B4 were compared to observations. This comparison is illustrated in Figure B.2-3 for Transect B3 and Figure B.2-4 for Transect B4. The Manning's distribution selected for use in the model has the following form.

River Depth (m)	Manning's Coefficient
.5	0.047
2	0.035
4	0.030
6	0.027
10	0.024
14	0.023
16	0.021

At depths greater than 6 meters, the Manning's coefficients in the above table are similar to those contained in RMA2 as a default setting based on San Francisco Bay.

B.2.3 Calibration of Diffusion to the Dye Survey Data (RMA4)

Longitudinal and lateral diffusion were calibrated by fitting RMA2/RMA4 to the dye plume mapping data obtained on 2 May 2000 at Outfall 003 (Georgetown Reservoir) and 24 May 2000 at Outfall 002 (Dalecarlia Basin).

On 2 May 2000 (Outfall 003, Georgetown Reservoir), the model was started at 0600 hour (near high slack) approximately 2.0 hours before Outfall 003 was turned on and the initiation of dye injection. As discussed in Section B.1.6 (Table B.1-8), the average discharge flow during the reservoir drawdown was 3.46 cms. The dye concentrations used in the model are provided in the upper portion of Table B.1-8. During the 6-hour dye release, discharge dye concentrations varied between 14.2 ppb and 21.2 ppb. Because of the travel time between the reservoir outflow and the river, the times for the changes in effluent concentration were lagged slightly in the model. Due to the uncertainty associated with the approximately one-half hour period when there was no dye injection (1240-1310 hrs, Table B.1-8), a low 5-ppb concentration was used during this interval.

On 24 May 2000 (Outfall 002, Dalecarlia Basin), the model was started at 0600 hour (near low slack) approximately 2.0 hours before Outfall 002 was turned on and the initiation of dye injection. As discussed in Section B.1.6 (Table B.1-10), the average discharge flow during the reservoir drawdown was 1.73 cms. The dye concentrations used in the model are provided in the upper portion of Table B.1-10. During the 6-hour dye release, discharge dye concentrations varied between 18.1 ppb and 34.2 ppb. Because of the travel time between the reservoir outflow and the river, the times for the changes in effluent concentration were lagged slightly in the model.

Diffusion coefficients were selected using a model option that automatically generates a value at every time step for each element based on the element size and average current velocity. The x-direction current velocity is set along the direction of the average flow in the element. The calculated diffusion value is scaled by a factor input by the user. For the Aqueduct model, a x-direction scale factor of 0.2 was used, which was within the recommended range. The y-direction diffusion coefficient is set as a fraction of the x-direction coefficient. The process of fitting the RMA4 model to the dye plume mapping data showed that the selection of the y-direction diffusion scale factor was important for reproducing the observed dye distribution. Beyond the immediate vicinity of Outfall 003, a y-direction scale factor of 0.15 was used throughout the model. This means that the y-direction diffusion coefficient was equal to 15-percent of the x-direction coefficient, a value within the recommended range. Downstream of Outfall 003, the predicted dye plume traveled along the shallow near-shore region with higher near shore concentrations than observed in the field. It was necessary to increase the y-direction scale factor along this near shore region in order to decrease concentrations and achieve agreement with measured observations. The y-direction scale factor was increased in two regions associated with Outfall 003; the first being a 40x40-m region directly in front of Outfall 003, and the second region extended 620-m downstream and approximately 80-m offshore along the shallow near shore zone. In the region directly in front of Outfall 003, a y-direction scale factor of 0.4 was used to achieve agreement with the observed initial dilution. Within the second near shore region, a y-direction scale factor of 0.25 was used (25 percent of the x-direction diffusion coefficient). This shallower near shore region contains lower velocities and subsequently the x-direction diffusion coefficients selected by the model are smaller than values further out in the river.

For the 24 May 2000 dye simulation, the x-direction diffusion scale factor was maintained at 0.2 throughout the model domain and the y-direction scale factor was maintained at 0.15 beyond the vicinity of the outfalls. Downstream of Outfall 002 the y-direction scale factor had to be increased to 0.7 for a 420-m reach in order to obtain the lateral nearly mixed condition observed at Transect 1 (Figure A.3-1). The 0.4 and 0.25 y-direction scale factors that were used in the near shore region downstream of Outfall 003 were not necessary for the Outfall 002 simulation. The model parameters used in the resulting four regions of the model are summarized in the following table.

Region	**Peclet**	**x-Dir Scaling**	**y-Direction Scaling**	
			002 Simulation	**003 Simulation**
1) Main Model	20	0.20	0.15	0.15
2) Downstream 002	20	0.20	0.70	0.70
3) Adjacent 003	20	0.20	0.15	0.40
4) Downstream 003	20	0.20	0.15	0.25

A comparison of predicted and observed dye concentrations at the survey transects for the 2 May 2000 Outfall 003 study (Georgetown Reservoir) are provided in Figures B.2-5 and B.2-6. A comparison of predicted and observed dye concentrations for the 24 May 2000 Outfall 002 study (Dalecarlia Basin) are provided in Figures B.2-7 to B.2-9. At each transect the figures illustrate the dye distribution from let to right bank when facing downstream.

Outfall 003 (Georgetown Reservoir)

Figure B.2-5 illustrates the agreement between observations and model predictions at Transect 9, 70-m downstream of Outfall 003, and Transect 12, 900-m downstream. At Transect 9, the build-up of the dye plume is illustrated between surveys 1 and 3. During survey 3, the model correctly predicted higher concentrations along the offshore edge of the eddy with lower concentrations towards shore. Farther downstream at Transect 12 (Figure B.2-5) the dye distribution is much smoother and there is very good agreement between predicted and observed values both at the shoreline and in the lateral distribution.

Figure B.2-6 illustrates the agreement between observation model predictions at Transects 14 and 16 during survey 3 and 5. At both transects the model provides very good agreement with observations for both the near shore concentrations and the lateral dye distribution across the river. At Transect 16 during survey 3, dye is just beginning to arrive, and by survey 5, concentrations have increased, particularly along the discharge (left) bank. A comparison of Transects 12, 14, and 16 illustrates the mixing of the plume towards the far (right) bank with increasing downstream distance.

Outfall 002 (Dalecarlia Basin)

A comparison of predicted and observed dye concentrations illustrating the calibration of the RMA4 model at Outfall 002 is provided in Figures B.2-7 to B.2-9. Figure B.2-7 illustrates the agreement between observation model predictions at Transects 1 and 3. By Transect 3, both the model and observations are fully mixed laterally and there is very good agreement on the amount of dye build-up between surveys. The higher observed dye concentrations at Transect 1 during survey 3 may indicate that the river is not yet fully mixed vertically at this upstream location.

Figure B.2-8 displays dye results at Transects 6 and 10 during surveys 2, 3, and 4. During survey 2 at Transect 6 and survey 3 at Transect 10, the dye arrived slightly faster than indicated by the model. However, model predictions during subsequent surveys at Transects 6 and 10 were in very good agreement with observations. Transects 6 and 10 are both downstream from a location were the river increases in width and the resulting dye distributions illustrate the lateral mixing from higher values in the main channel (right bank) towards the shallower region (left bank). Figure B.2-9 displays predicted and observed dye distributions at Transects 12 and 14, and similarly illustrates the build-up of dye between surveys and the decreasing concentrations toward the shallower left bank.

Transect Averaged Dye Distribution

An additional way for comparing differences between observations and model predictions is provided by examining the lateral average dye concentrations at each transect. The lateral average dye concentrations during the plume surveys were summarized in Table B.1-9 at Outfall 003 and Table B.1-12 at Outfall 002. The corresponding lateral average dye concentrations were calculated from the model output and are displayed in Figure B.2-10 at Outfall 003 and Figure B.2-11 at Outfall 002 for surveys 2 to 5. The Outfall 002 dye survey (Figure B.2-10) shows excellent agreement between observed and predicted values as the leading edge of the dye distribution traveled downstream from survey to survey.

At Outfall 002 (Figure B.2-11), the longitudinal dye distribution was in good agreement during surveys 2 and 3 while the dye traveled 4,000 meters downstream. During surveys 4 and 5, at downstream distances of approximately 4,500 to 6,500 meters, the modeled dye lagged observations by several hundred meters. This region 4,500 to 6,500 m downstream of Outfall 002 corresponds to a region downstream of Outfall 003 where the lateral average dye concentrations were in good agreement. The Outfall 002 dye plume was primarily moving along the main channel, while the Outfall 003 dye plume was in the shallower off-channel region. This may indicate that the model slightly under estimates main channel velocities in this downstream region.

B.2.4 Modeling the Suspended Solids Plume (SED2D)

The suspended solids discharge from the Georgetown Reservoir (Outfall 003, 3 May 2000) and Dalecarlia Basin (Outfall 002, 25 May2000) were modeled with SED2D. SED2D requires the RMA2 hydrodynamic output file, diffusion coefficients, and the particle characteristics of the material being discharged.

SED2D Diffusion

The characterization of diffusion in SED2D varied from RMA4. While RMA4 used a scaling factor, SED2D used a Peclet number similar to the way eddy viscosity was treated in RMA2. The intent during model development was to use diffusion as calibrated with the dye surveys for both RMA4 and SED2D. SED2D diffusion similar to that used in RMA4 was determined by executing SED2D for a range of Peclet numbers. These SED2D scenarios used a very fine particle with a very low fall velocity that essentially behaved as a conservative tracer similar to the conservative dye in RMA4. A Peclet number of 10 was determined to match the RMA4 dye results at Outfall 002 and 003. The Peclet number is used to determine the x-direction diffusion. The y-direction diffusion is calculated as a fraction of x-value, similar to RMA4. The same y-direction scaling factors were used in SED2D as in RMA4 including 0.25 and 0.4 in the vicinity of Outfall 003, 0.7 downstream of Outfall 002, and 0.15 throughout the remainder of the model.

Particle Characteristics

The composite particle size distribution based on sediment samples collected during this project from the Georgetown and Dalecarlia Reservoirs indicated that the material was 65.7 % sand, 22.0 % silt, and 12.3 % clay (Table B.1-6). However, this particle distribution does not reflect the presence of the floc resulting from the addition of alum in the water treatment process. An analysis of particle size without using a de-floccing agent (which is typically used in particle size determinations) yielded a much narrower range of particle size with an absence of the finer clays (Table B.1-7).

Modeling the discharged material as a single particle classification (floc) was not considered to be realistic because considerations of all the available data indicated that a coarser and finer material were also likely to be present. Even though the results in Table B.1-7 for a spherical particle did not indicate the presence of sand (> 0.05 mm), coarser sand was observed in the bottom of the settling column during the test on the floc. Based on this observation, an assumption that 25 % of the discharged material existed as sand was considered to be reasonable. The remaining 40.7 % of the 65.7 % sand fraction in Table B.1-6 would be associated with the floc.

During the settling test on the floc, it is also believed that any finer particles present were entrained earlier in the test, and therefore were not observable at the longer settling times normally associated with finer silt and clay. To provide for a finer particle classification, it was assumed that 10 % of the discharged material was present as silt. The remaining 24.3 % of the 34.3 percent silt/clay fraction in Table B.1-6 would be associated with the floc.

The particle size distribution from the settling tests and the particle scenario selected for the model are summarized in the following table.

ASTM Test Results				**Model Scenario**		
Material	**Dia (mm)**	**ASTM (%)**	**Floc (%)**	**Material**	**Dia (mm)**	**Percent**
Sand	> 0.05	65.7	88.2	Sand	> 0.05	25
Silt	0.002-0.05	22.0	11.8	Floc	> 0.05	65
Clay	< 0.002	12.3	0	Silt	< 0.05	10

SED2D provides different mechanisms for the simulation of noncohesive particles (sand) and cohesive particles (silt and clay). The floc was modeled using the cohesive particle mechanism. For sand, the model requires the particle diameter, settling velocity, and material density. For a cohesive particle, the model requires settling velocity and shear stresses for deposition and erosion. SED2D calculates a bottom shear stress as a function of velocity and channel friction at each location in the model. The bottom shear stress must be below the depositional shear stress for a particle to be deposited. If the bottom shear stress increases above the erosional shear stress, a particle will be resuspended.

The relationship between particle size, shear stress, and other physical site conditions effecting sediment transport is under active investigation by the U.S. Army Engineer Waterways Experiment Station (WES) and other investigators.   WES has indicated that provided a sufficiently wide initial particle size distribution, fine-grained sediment is sorted by particle size during deposition. Both settling velocities and critical shear stresses for deposition vary sharply between silt and clay fraction. Particle size has not been well correlated to the readability of cohesive fine-grained sediments. On tests performed on sediments from New Bedford Harbor (UASCE 1993) the critical shear stress for deposition was found to be 0.043 n/m^2 (newton/m^2) for particles < 0.014 mm, and 0.33 n/m^2 for particles between 0.014-0.028 mm. The critical shear stress for erosion was slightly higher: 0.06 n/m^2 for particles < 0.014 mm and 0.38 n/m^2 for particles 0.014-0.028 mm. At larger particle sizes the critical shear stress for deposition increased more slowly, to 0.42 n/m^2 for particles 0.028-0.074 mm.

A paper on tidal resuspension of sediments in the Chesapeake Bay (Sanford et al, 1991), reported that the majority of tidally eroded material was redeposited locally during slack tide. Thus tidal erosion probably accounted for a relatively small part of the observed net sediment loss. The paper concluded that a more likely cause of massive erosion is the combination of tidal and wind driven current with wave-induced velocities and pressure fluctuations during storms.   Sanford (1991) also indicated that critical shear stresses for erosion on the order of 0.1 n/m^2 are commonly reported in the literature. Sanford (personal communication) recommended that a critical shear stress of 0.1 n/m^2 be used for both deposition and erosion.

Based upon a review of the particle data, the following particle attributes were used in the model.

Particle Characteristics

Parameter	**Sand**		**Parameter**	**Floc**	**Silt**
Diameter (mm)	0.05		Diameter (mm)	.05	.002
Settling Vel.(m/sec)	0.00208		Settling Vel. (m/sec)	2.4E-4	8.2E-5
Density (gm/cm^3)	2.5		Shear Stress (newton/m^2)	0.1	0.1

SED2D Model Execution

SED2D was executed three time for each of the two outfalls to provide model simulations for the sand, floc, and silt particle classes. The water column TSS concentrations for the three particle classes were summed at each model node to provide composite TSS concentrations. In general, the TSS discharge concentration was modeled as being 10,000 mg/L using a 0.132-cms flow at Dalecarlia Basin and a 1.138-cms flow at Georgetown Reservoir. A 3.5-hour suspended solids discharge event was modeled at both outfalls.

There was an alteration to the 10,000 mg/L for 3.5-hour discharge scenario at each outfall. On 3 May 2000 at Outfall 003, the discharge was temporarily turned on between 0915 hrs and 0938 hrs, before the main clean-out event started at 1004 hrs. This pre-release was included for two 15-minute model time steps. On 25 May 2000 during survey 2 of the Outfall 002 study, the observed TSS concentrations at the upstream transects were underestimated by the model. The clean-out of solids from a reservoir is not a continuous process and the 10,000-mg/L TSS discharge concentration assumed at Outfall 002 was based on individual measurements varying between 4,600 mg/L and 16,500 mg/L. In keeping with this expected variability, the TSS discharge concentration was temporarily increased prior to survey 2. A summary of the total mass discharged at each outfall, including the alterations from a uniform scenario, is provided in the following table.

Mass of Discharged Solids (kg)

Material	Outfall 002 (Dalecarlia)	Outfall 003 (Georgetown)
Sand	4,455	38,407
Floc	11,583	99,860
Silt	1,782	15,363
Total	17,820	153,630

The surface area of Georgetown Reservoir (66,425 m^2) is approximately 11 times greater than the surface area of Dalecarlia Basin 3 (5,897 m^2). The increase in mass of solids discharged at Outfall 003 is approximately proportional to the increase in reservoir size.

A frequency distribution of suspended load at Chain Bridge, based on historical USGS data, is presented in Chapter 4 (Section 4.3.2, Table 4-5). The 17,820-kg discharged solids mass at Outfall 002 is less than a lower 10-percentile value of the daily Potomac River suspended load. The 153,630-kg discharged solids mass at Outfall 003 is between a 40- and 45-percentile of daily Potomac River suspended load.

A comparison between observed surface and predicted TSS values is provided in Figures B.2-12 and B.2-13 for Outfall 002 from Dalecarlia Basin, and in Figures B.2-14 and B.2-15 for Outfall 003 from Georgetown Reservoir. The SED2D model output only contained the TSS loadings from the outfalls and did not include the natural background concentrations in the Potomac River. This was done to allow the model to illustrate the incremental increase in TSS concentration directly associated with operations at the reservoirs. However, to make comparisons to the observed survey data, a background TSS concentration was added to the model predictions when generating the figures. The background concentrations were selected based upon examination of the survey data. For the 3 May 2000 survey at Outfall 003, a background TSS concentration of 8 mg/L was used at Transects 10 to 14, decreasing to 6 mg/L at Transect 16. For the 25 May 2000 survey at Outfall 002, a background TSS concentration of 8 mg/L was used at Transects 1 to 8, decreasing to 6 mg/L at Transect 10, and 3 mg/L at Transect 12. The observed TSS data in Figures B.2-12 to B.2-15 was smoothed using a 3-point rolling average.

When comparing observed and predicted TSS concentrations in Figures B.2-12 to B.2-15 several considerations need to be kept in mind.

- In areas where there is a shallow near-shore zone, such as downstream of Outfall 003, background TSS was observed to decrease between the main-channel (right bank) and the shallower (lower velocity) left bank. In the following figures, the uniform background concentrations added to the model predictions was representative of the higher main channel TSS values. As a result, in the near-shore region observed TSS values decrease below this background level. In these areas, greater attention should be given to the relative difference between scenarios than their absolute values.

- The TSS discharge had a density greater than the receiving water and could be expected to create a sinking plume with a stronger influence in the lower portion of the water column. As a result, the near surface observations may underestimate the water column averaged SED2D predictions. This effect was particularly noticeable at the near-field transects in the vicinity of Outfall 003.

- The turbidity probe, mounted on a fixed strut on the survey boat, was effected by surrounding turbulence that resulted from changes in boat speed and wave action. The downstream transects (> Transect 12) were in a wider, more open portion of the Potomac

River with larger waves and the survey boat may have been operated at a slightly higher speed. These site conditions may have contributed to TSS variability at some transects.

Outfall 002, Dalecarlia Basin

As previously discussed, the solids discharge event at Outfall 002 on 25 May 2000 lasted for approximately 3.5 hours. The event was modeled assuming a 10,000-mg/L TSS concentration and a 0.132-cms discharge flow. A total solids mass of 17,820 kg was discharged. The model results for sand (25%), floc (65%) and silt (10%) were combined to determine a total TSS concentration. A comparison between observed and predicted TSS concentrations are provided in Figures B.2-12 and B.2-13.

Figure B.2-12 displays good agreement between predicted and observed TSS concentrations at Transects 1 and 4 during surveys 2, 3, and 4. Surveys 3 and 4 were performed after the solids clean-out event had ended. At Transect 1, the modeled TSS concentration quickly decreased to background levels during surveys 3 and 4. At Transect 4, TSS concentrations during survey 3 had decreased approximately two-thirds of the way from survey 2 to survey 4 levels. At Transect 4, the relative difference in predicted concentrations between each survey shows good agreement with observations.

Figure B.2-13 displays the TSS build-up at Transect 8 during surveys 1, 2, and 3 and Transect 14 during surveys 2,3, and 4. Transects 8 is located where the river had widened out, providing a lower velocity region near the left bank. The observed data indicates that there is a natural lateral TSS gradient with values decreasing to below 5 mg/L in the quieter waters. This lateral gradient was not incorporated into the 8-mg/L background concentration that was added to the model. At Transect 8, the model correctly indicated that the TSS plume arrived following survey 1, and the TSS increase between surveys 1 and 3 was in good agreement between the model and observations. At Transect 8, the decrease in the survey 1 to survey 3 TSS build-up between the main channel and the left bank has also well represented by the model. At Transect 14, the model correctly indicated that the plume arrived between surveys 3 and 4, and the predicted increase between these two surveys was in very good agreement with the relative difference between observations along the transect.

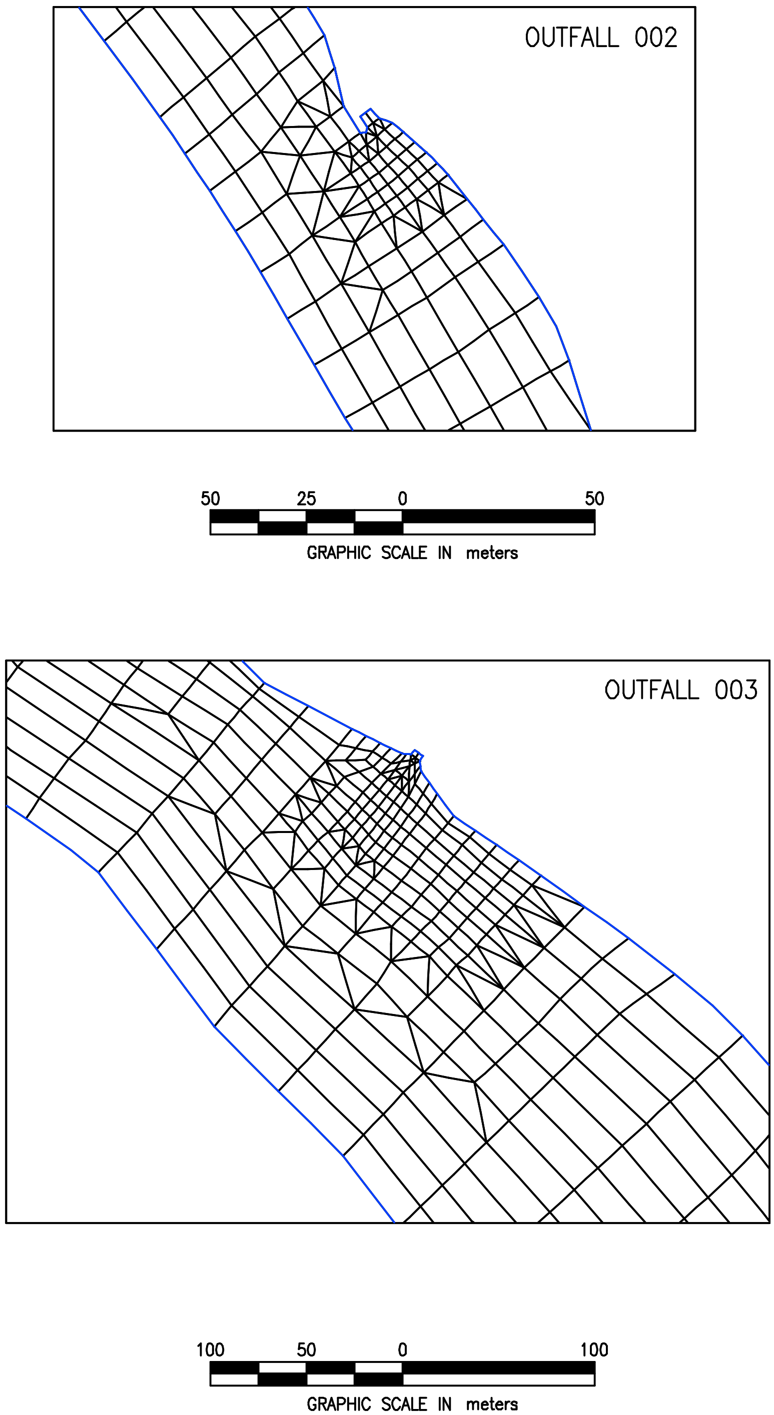
Outfall 003, Georgetown Reservoir

As previously discussed, the solids discharge event at Outfall 003 on 3 May 2000 lasted for approximately 3.5 hours. The event was modeled assuming a 10,000-mg/L TSS concentration and a 1.138-cms discharge flow resulting in a total solids mass of 153,630 kg. The model results for sand (25%), floc (65%) and silt (10%) were combined to determine a total TSS concentration. A comparison between observed and predicted TSS concentrations are provided in Figures B.2-14 and B.2-15.

Figure B.2-14 provides results at Transect 11 (480-m downstream from Outfall 003) and Transect 12 (900-m downstream). At Transect 11, the decrease in TSS concentrations near the left bank and the sharp delineation of the plume width at approximately one-half the river width were well represented by the model. The lower near-shore concentrations and a higher off-shore plume centerline were features associated with a back-eddy. The lower observed concentrations during survey 3, the time of maximum plume build-up, were attributed to water column stratification. Before coming well mixed, the higher density suspended solids plume would result in higher water column average TSS concentrations than would be observed with a near surface probe.

At Transect 12 (Figure B.2-14), maximum plume build-up was reached during survey 3 with the highest TSS concentrations located near shore. The relative concentration increase at the shoreline between surveys 1 and 3 was in good agreement between the model and observations. Off-shore, observed and predicted concentrations were similar, however, the variation in the field data masked the survey-to-survey differences.

Model results at Transect 14 (1700-m downstream), and Transect 16 (2,260-m downstream) are provided in Figure B.2-15. At Transect 14, observed TSS concentrations of 10-15 mg/L during surveys 2 and 3 were in good agreement with the model beyond the near shore region, where agreement is masked by background variation. At Transect 16, observed TSS concentrations were higher on the right side of the river, even during survey 2, which occurred early than the expected arrival time of the plume. It is believed that these higher observed values resulted from a combination of both natural and probe induced background conditions. The downstream transects were in more open water with more wave action. In Figure B.2-15, the relative differences in the middle portion of the river between observed TSS values during surveys 2, 3, and 4 were similar to changes predicted by the model.



FILE: Q:\PROJECTS\6095757\JYOST\FIG2-2-1.DWG

Figure B.2-1. Near-Field Model Grid Used at Outfalls 002 and 003

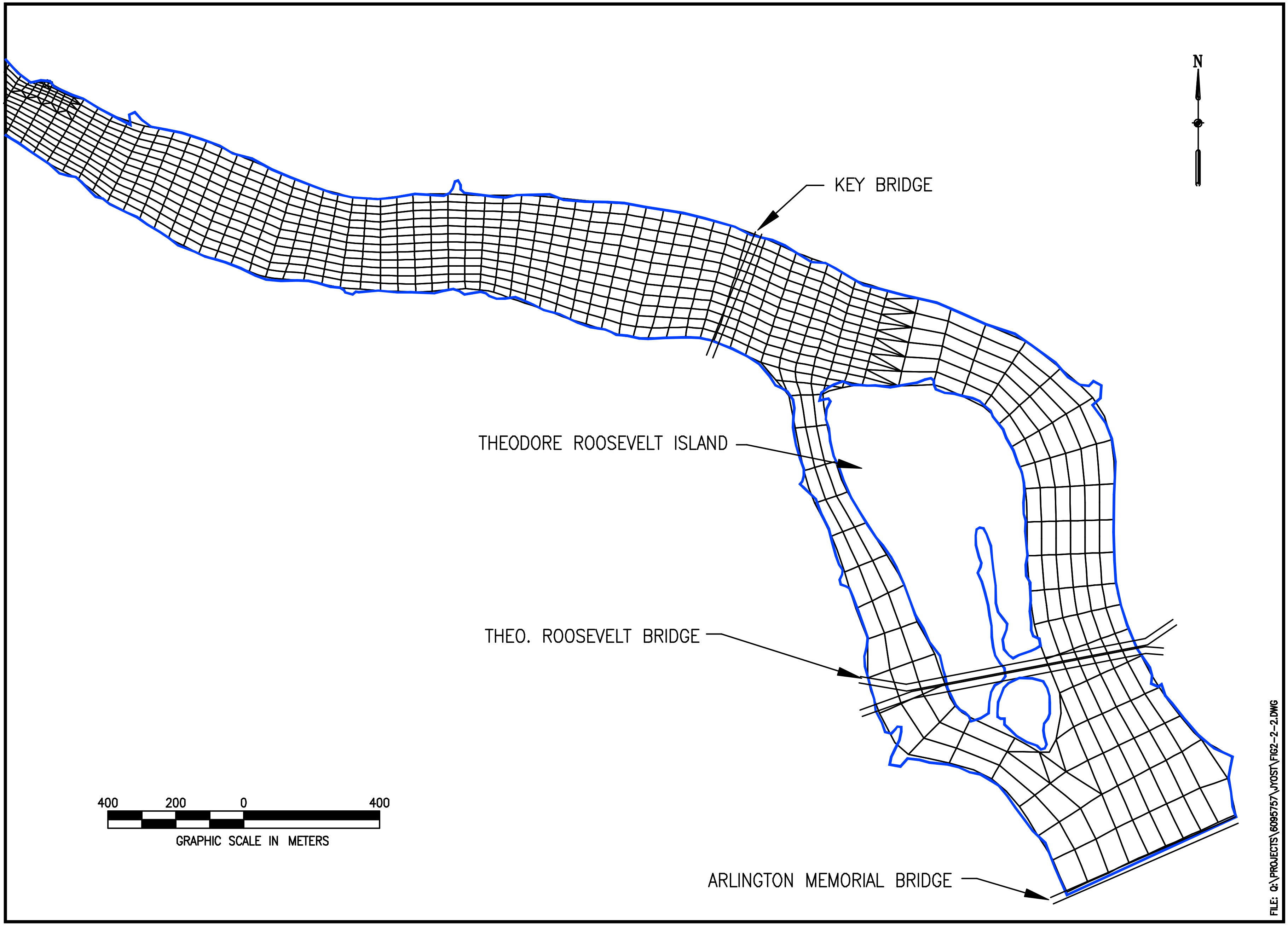


Figure B.2–2. Model Grid Used in the Downstream Portion of the Potomac River Model

Figure B.2-3 Observed and Predicted Potomac River Velocity Along Transect B3, 6-7 April 2000

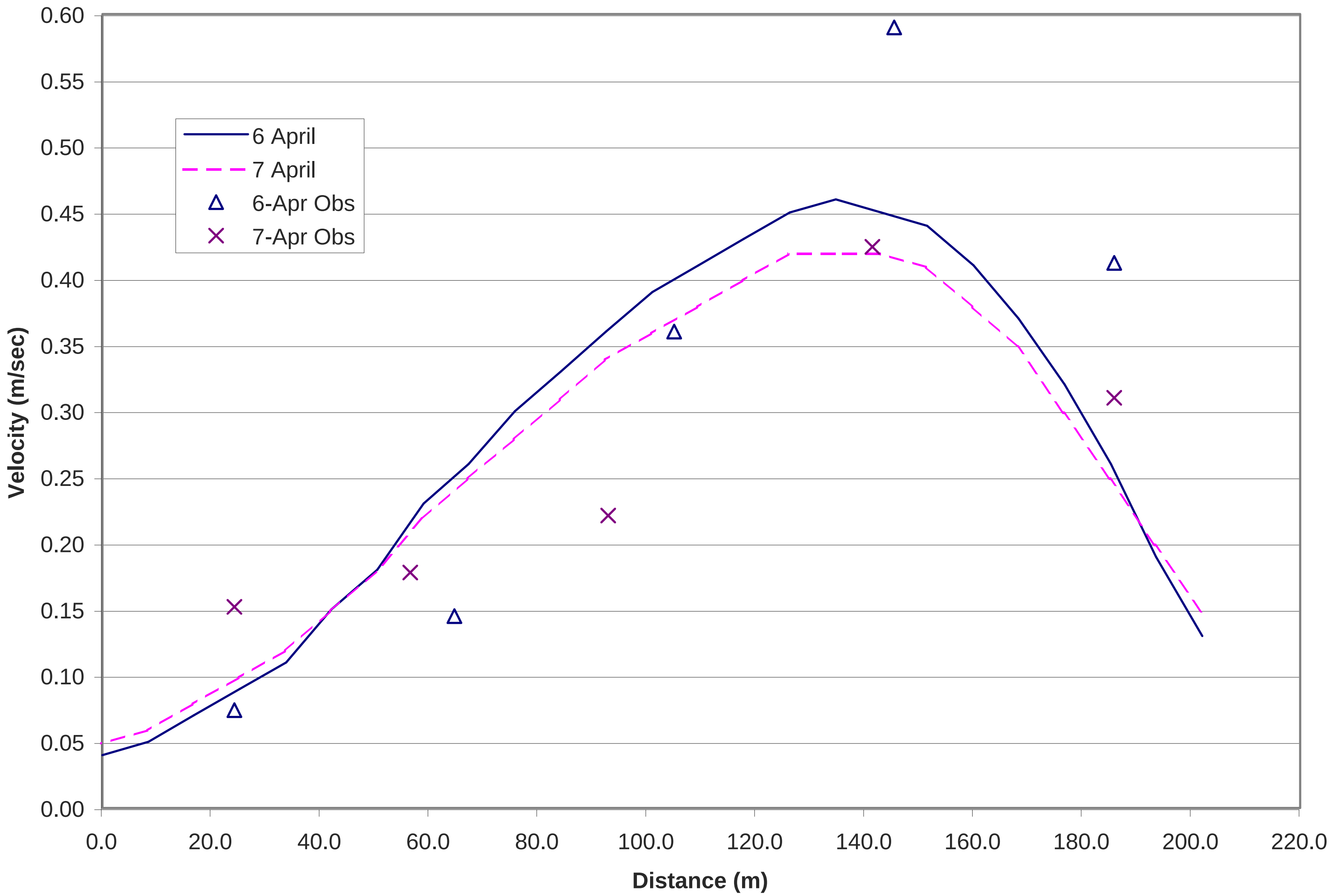
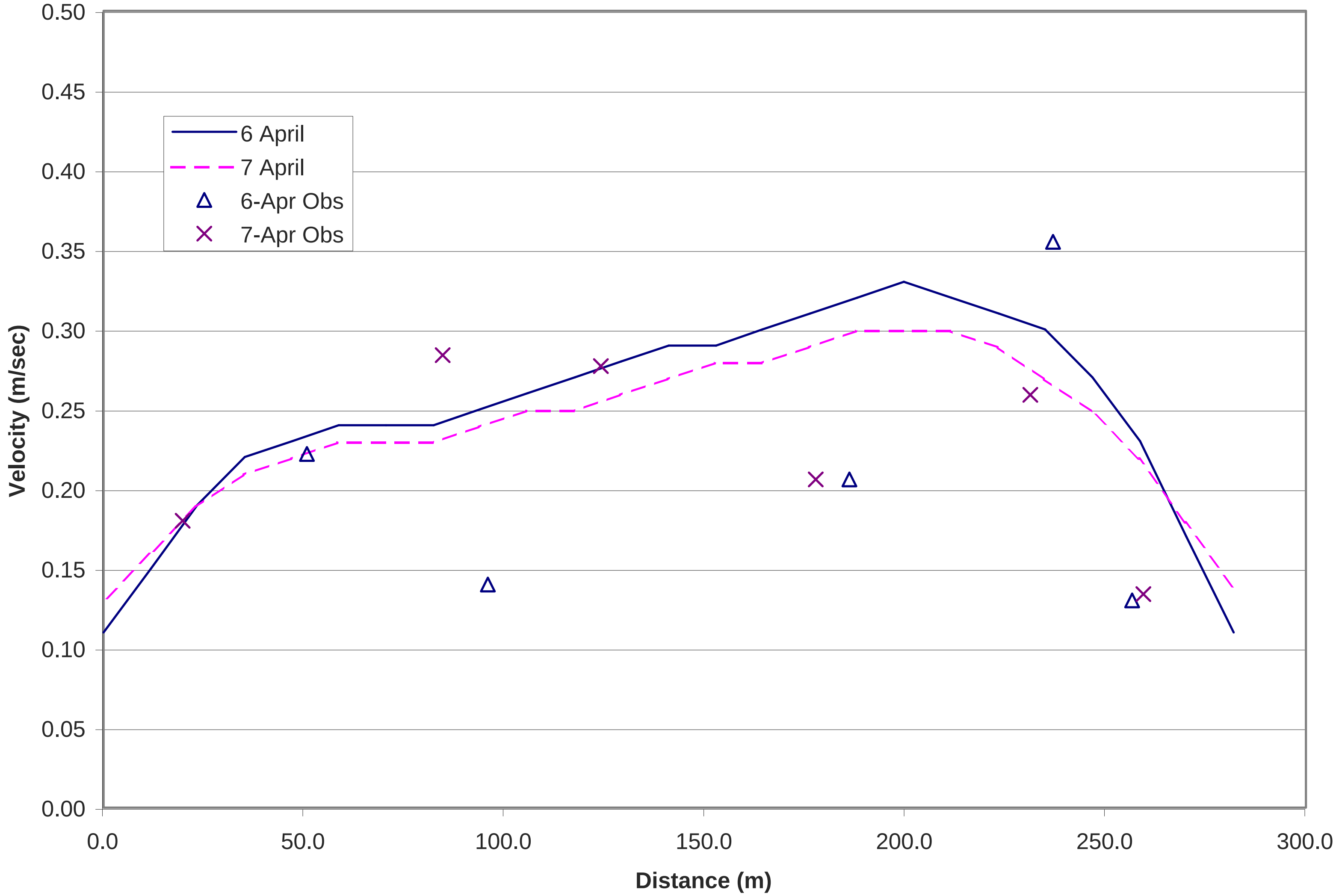


Figure B.2-4 Observed and Predicted Potomac River Velocity Along Transect B4, 6-7 April 2000



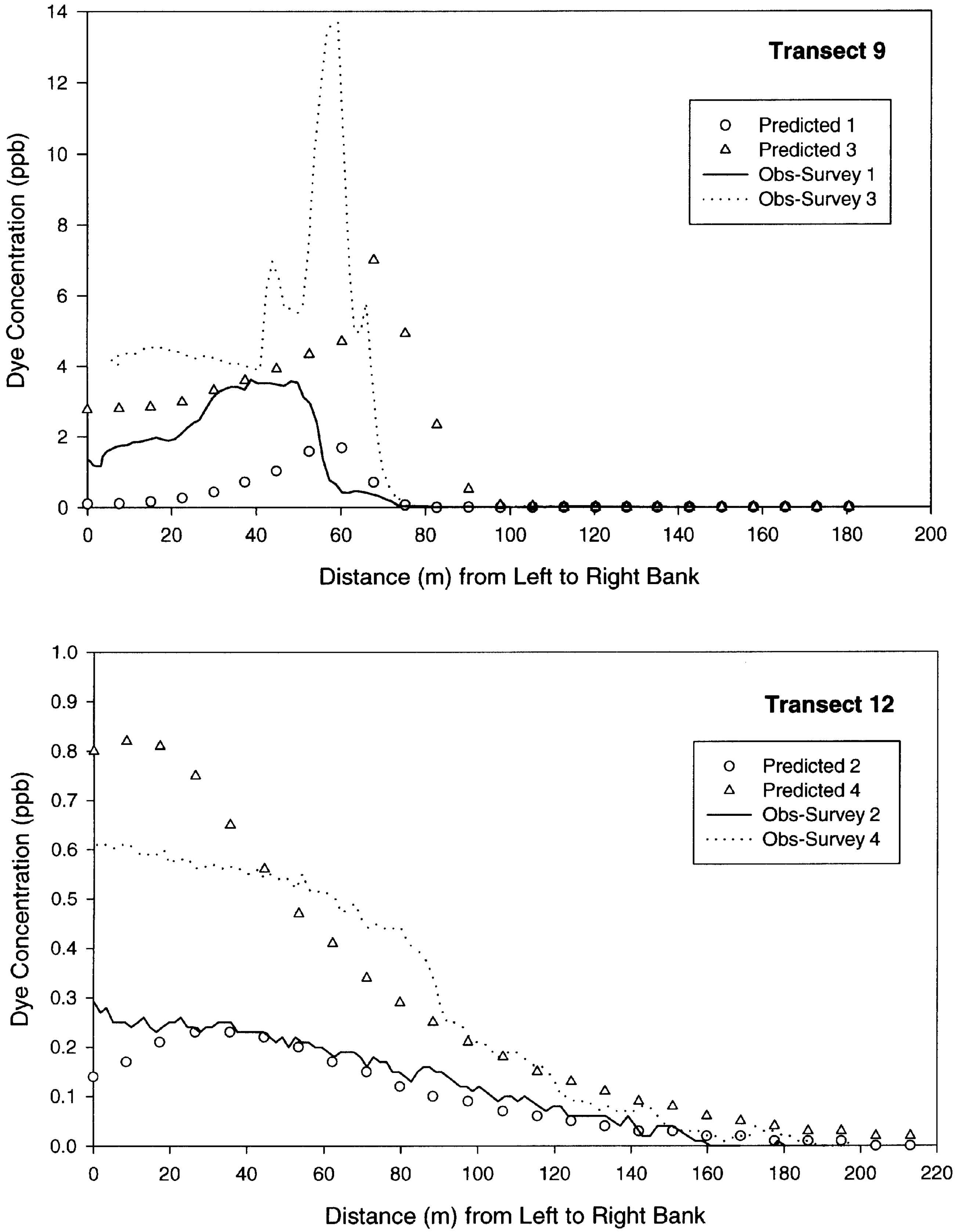
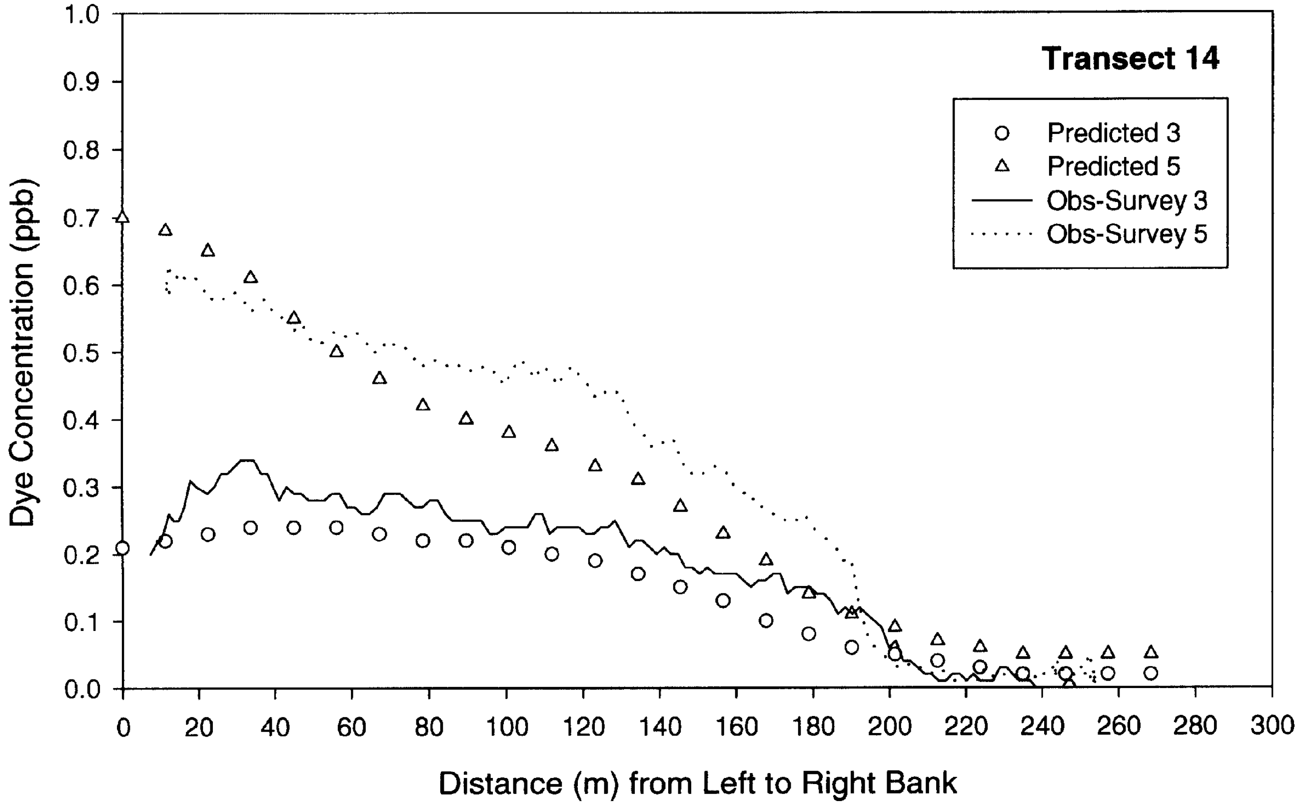


Figure B.2-5 Comparison of Observed and Model-Predicted Dye Concentrations at Transects 9 and 12, Outfall 003, 2 May 2000.



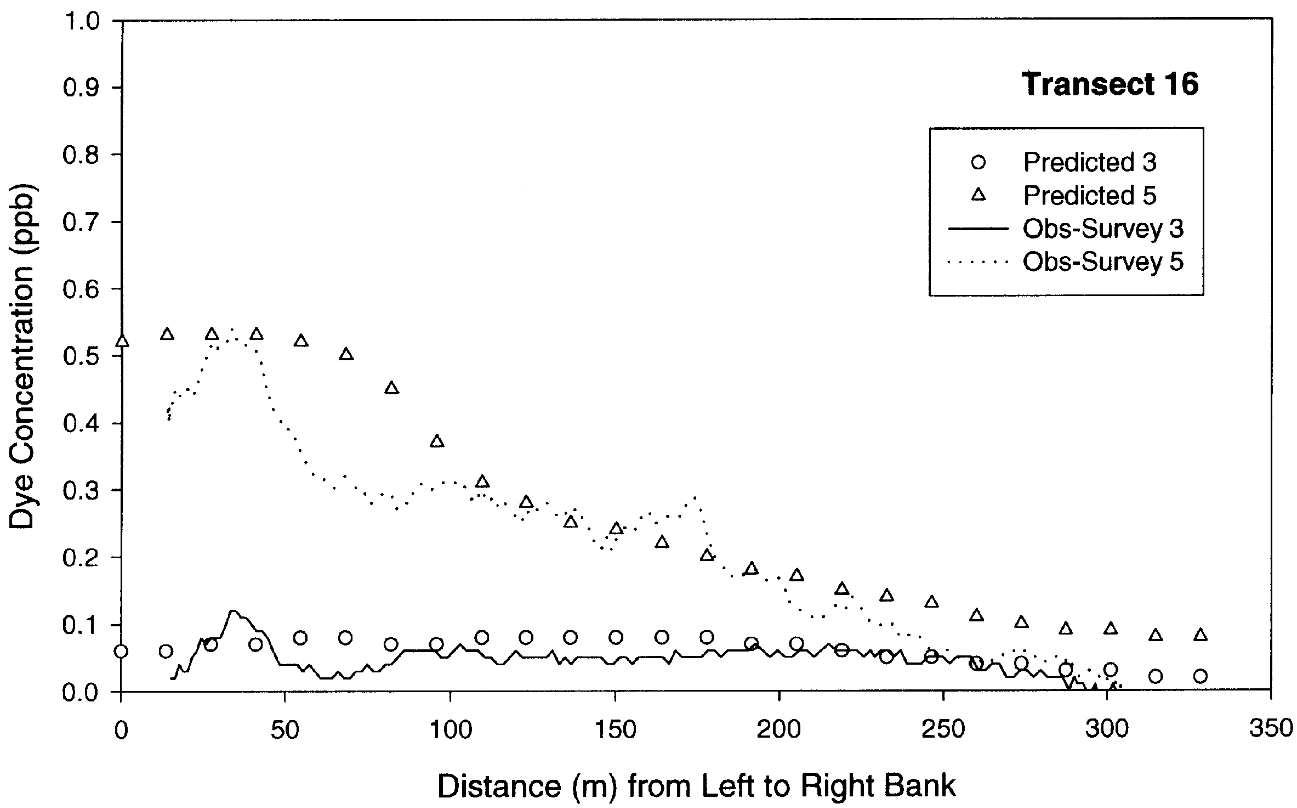
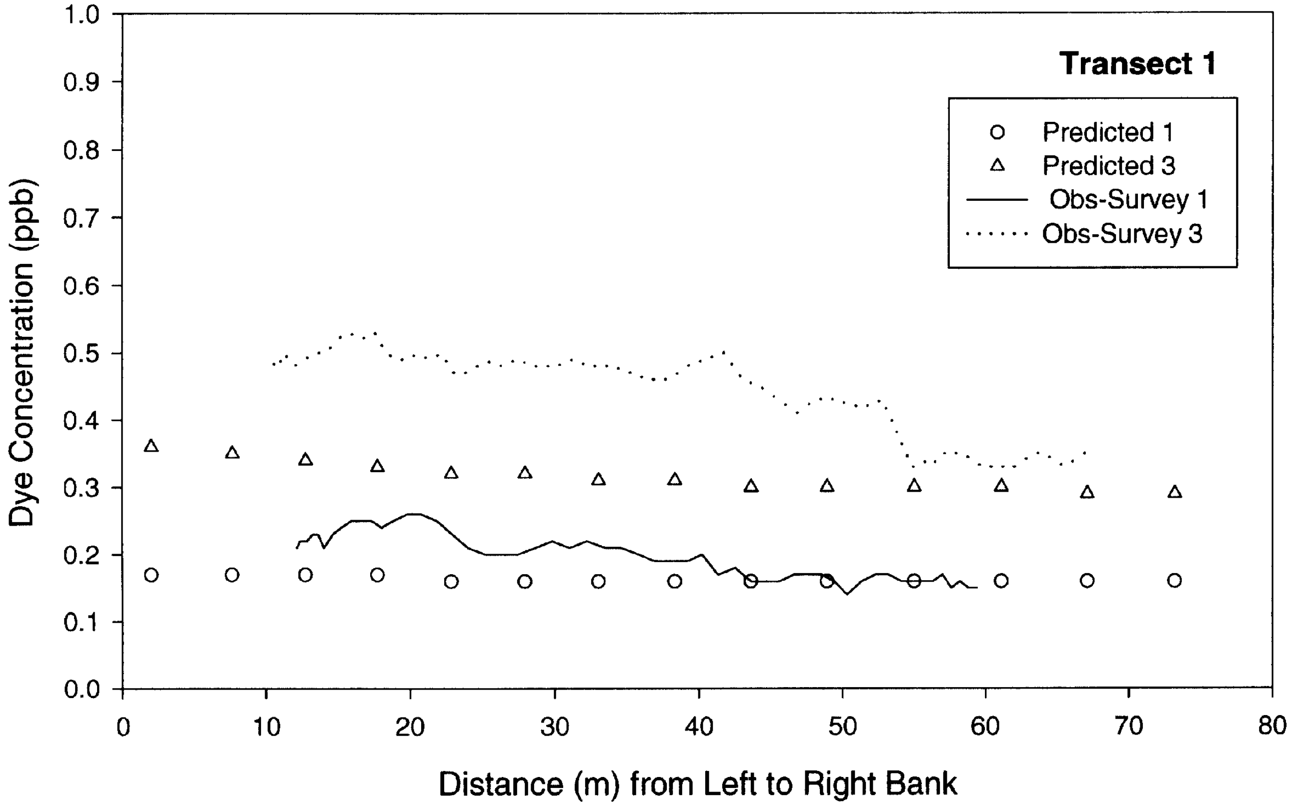


Figure B.2-6 Comparison of Observed and Model-Predicted Dye Concentrations at Transects 14 and 16, Outfall 003, 2 May 2000.



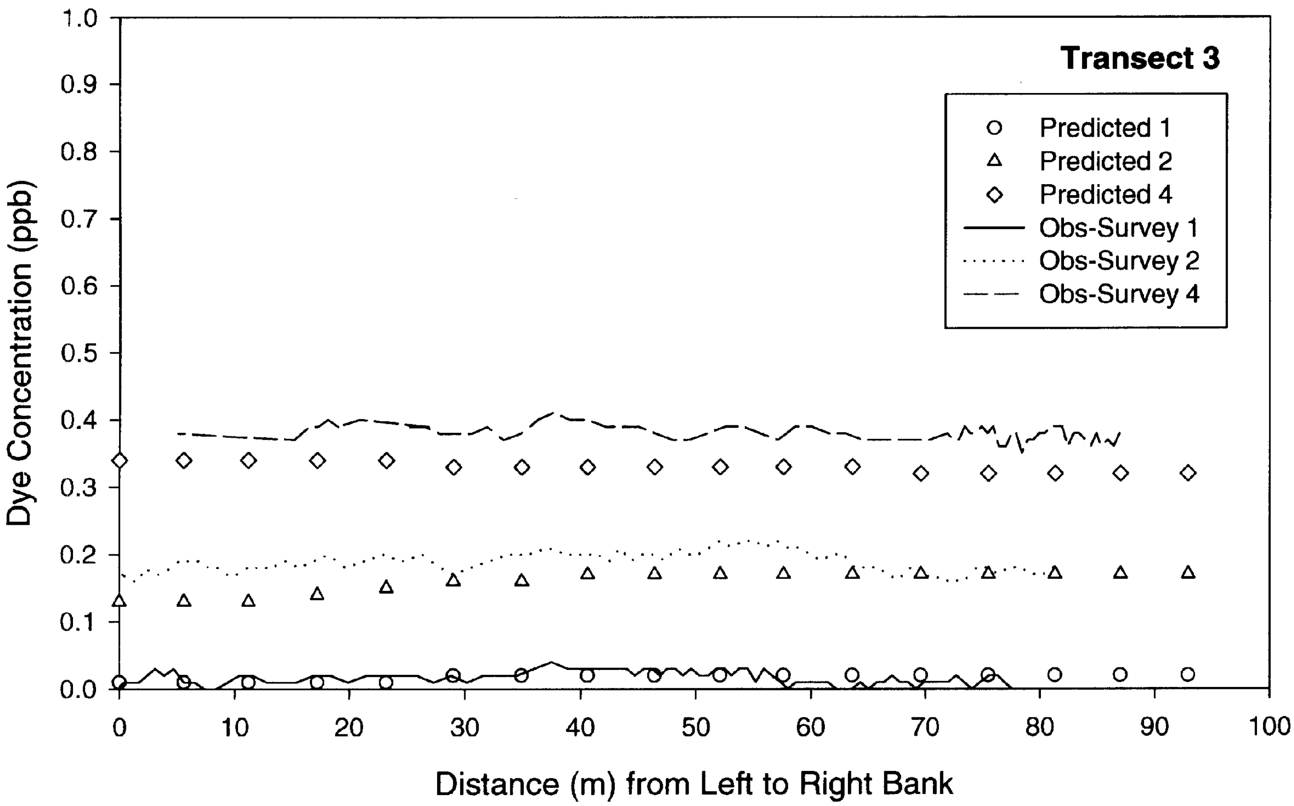
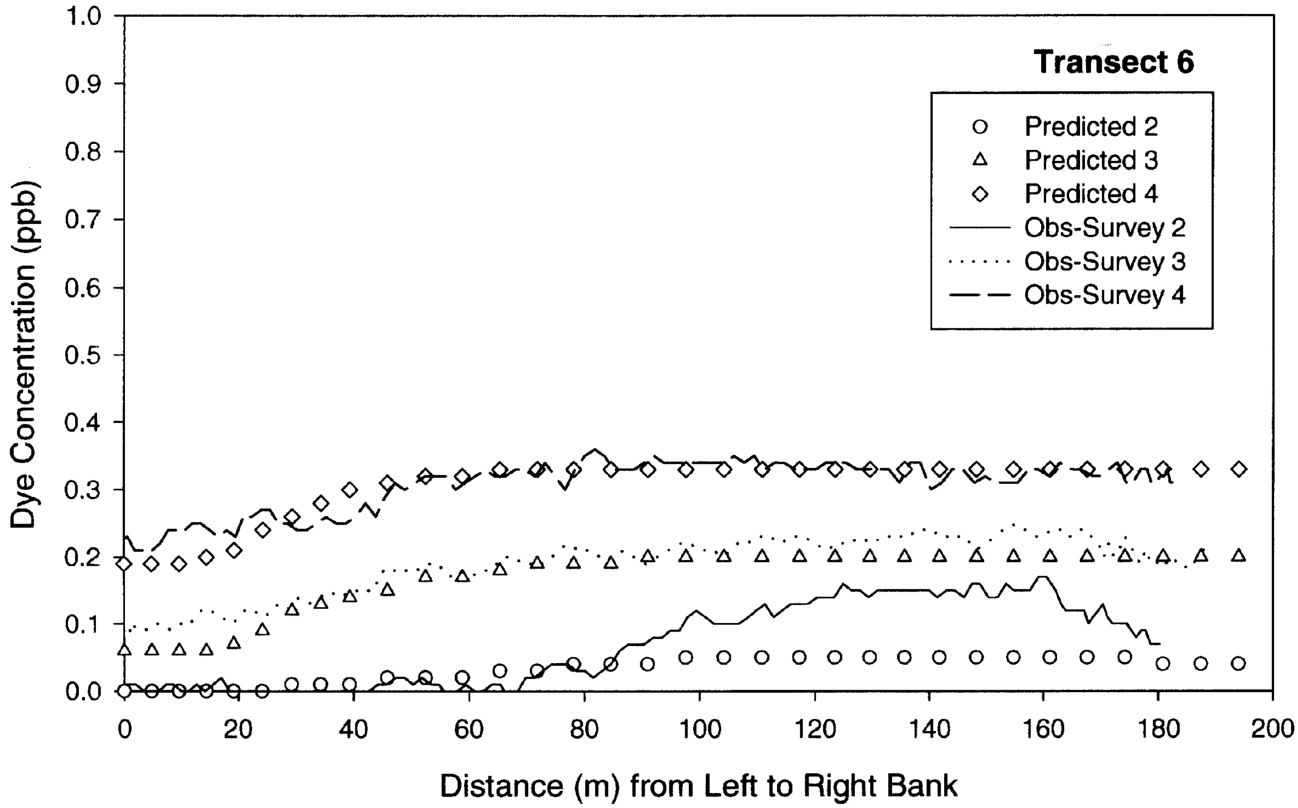


Figure B.2-7 Comparison of Observed and Model-Predicted Dye Concentrations at Transects 1 and 3, Outfall 002, 24 May 2000.



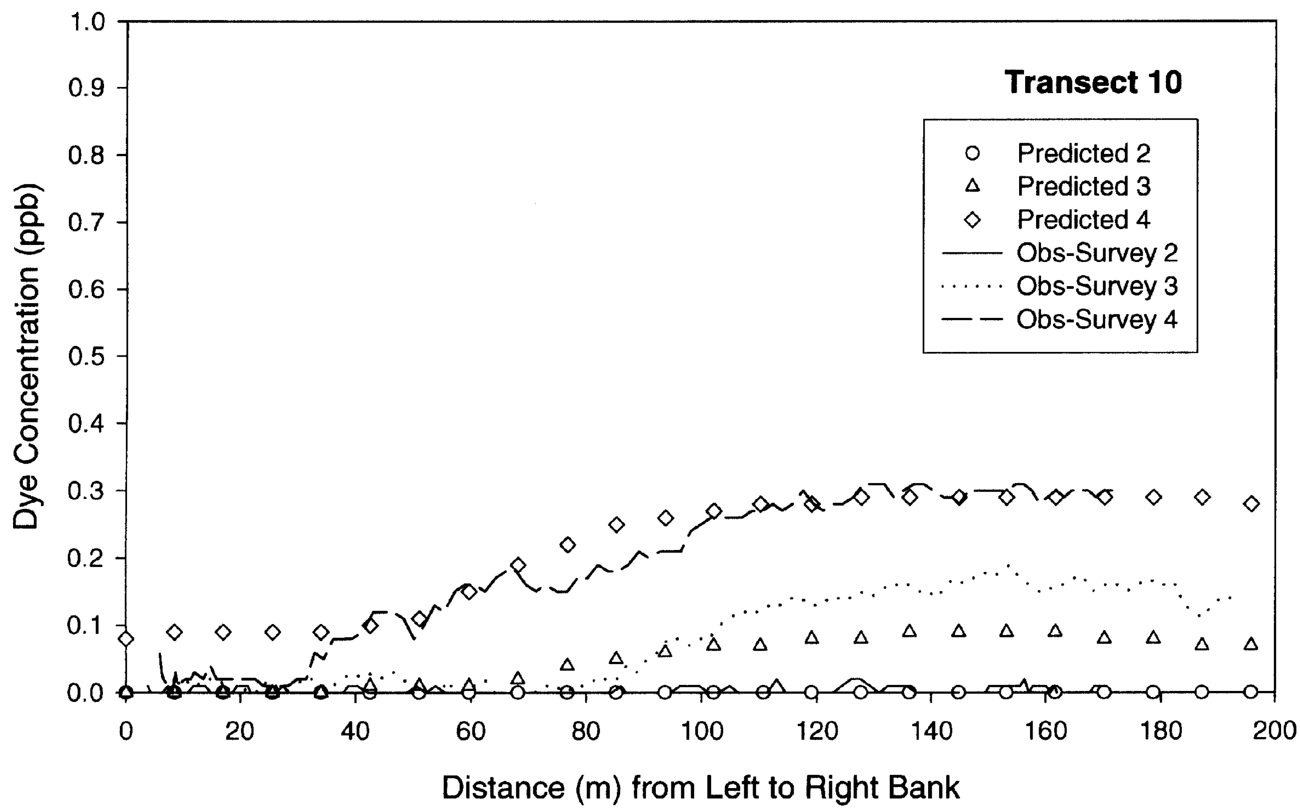
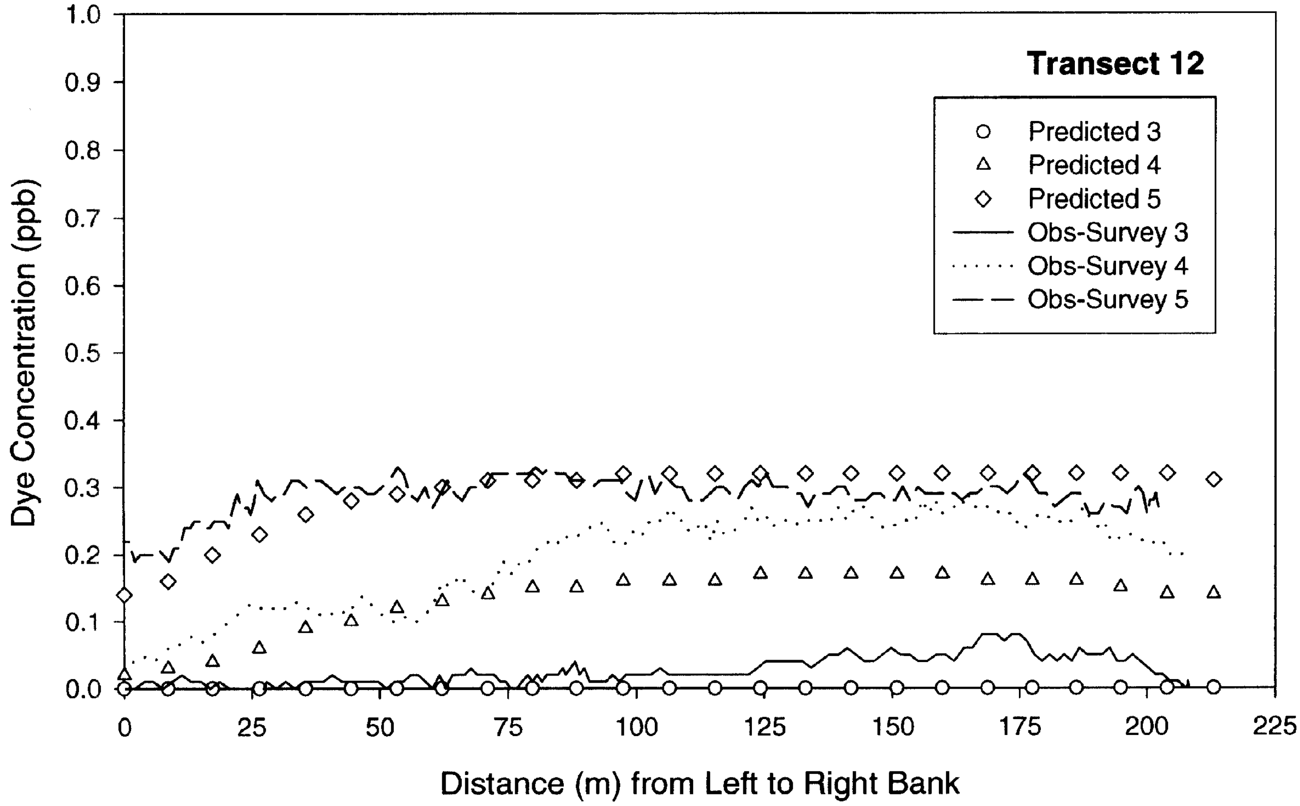


Figure B.2-8 Comparison of Observed and Model-Predicted Dye Concentrations at Transects 6 and 10, Outfall 002, 24 May 2000.



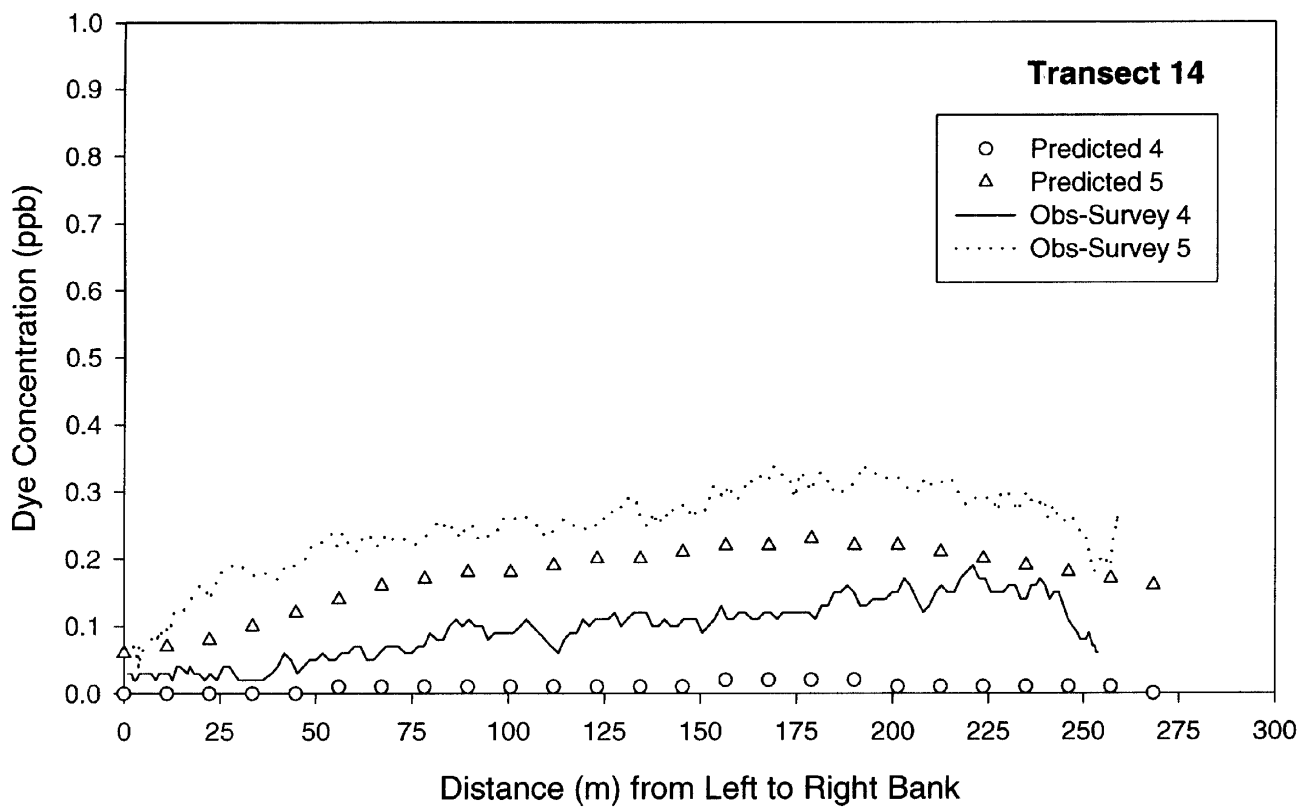


Figure B.2-9 Comparison of Observed and Model-Predicted Dye Concentrations at Transects 12 and 14, Outfall 002, 24 May 2000.

Figure B.2-10 Comparison of Predicted and Observed Transect Average Dye Concentrations, Outfall 003 Survey, 2 May 2000

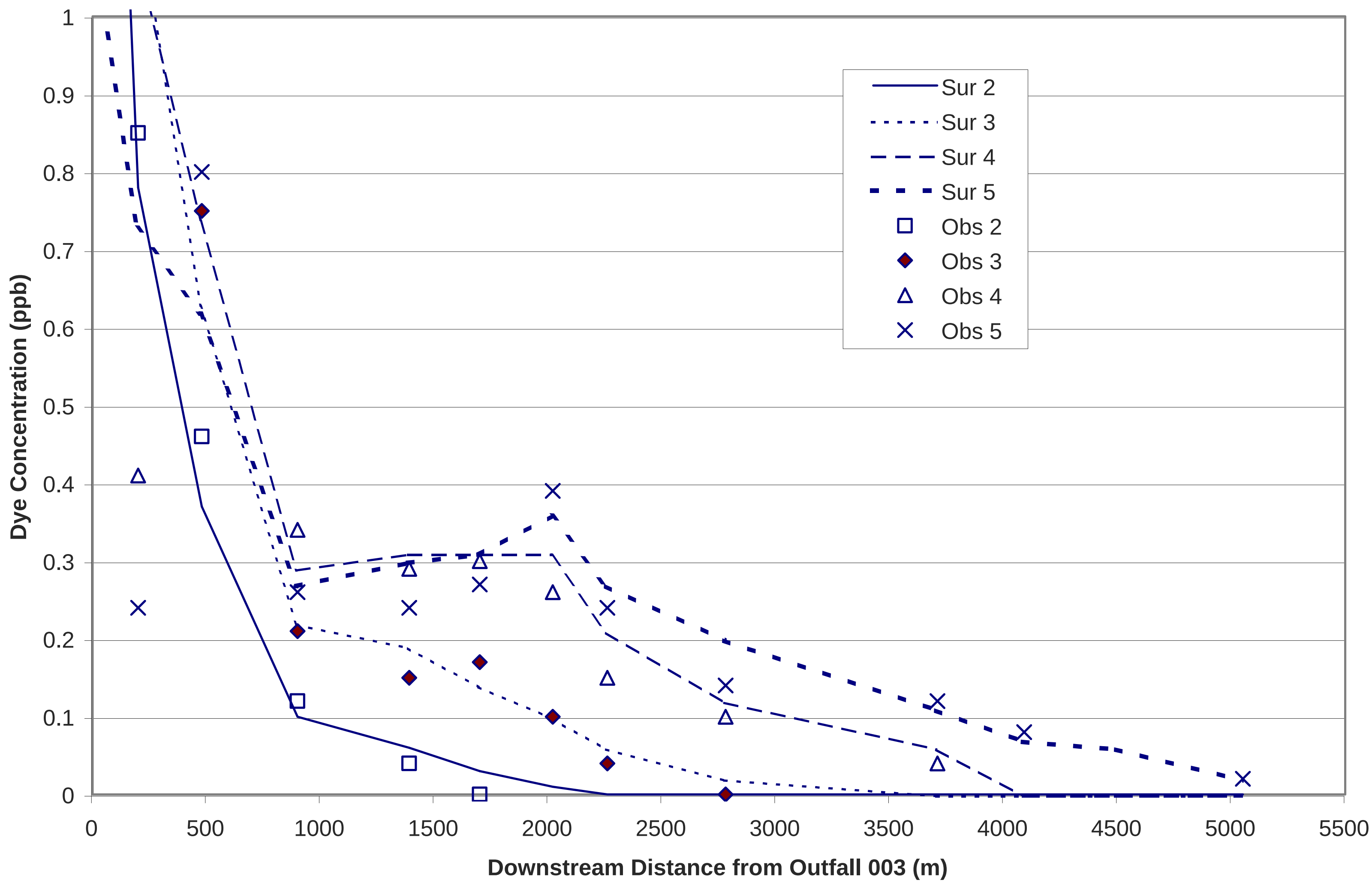
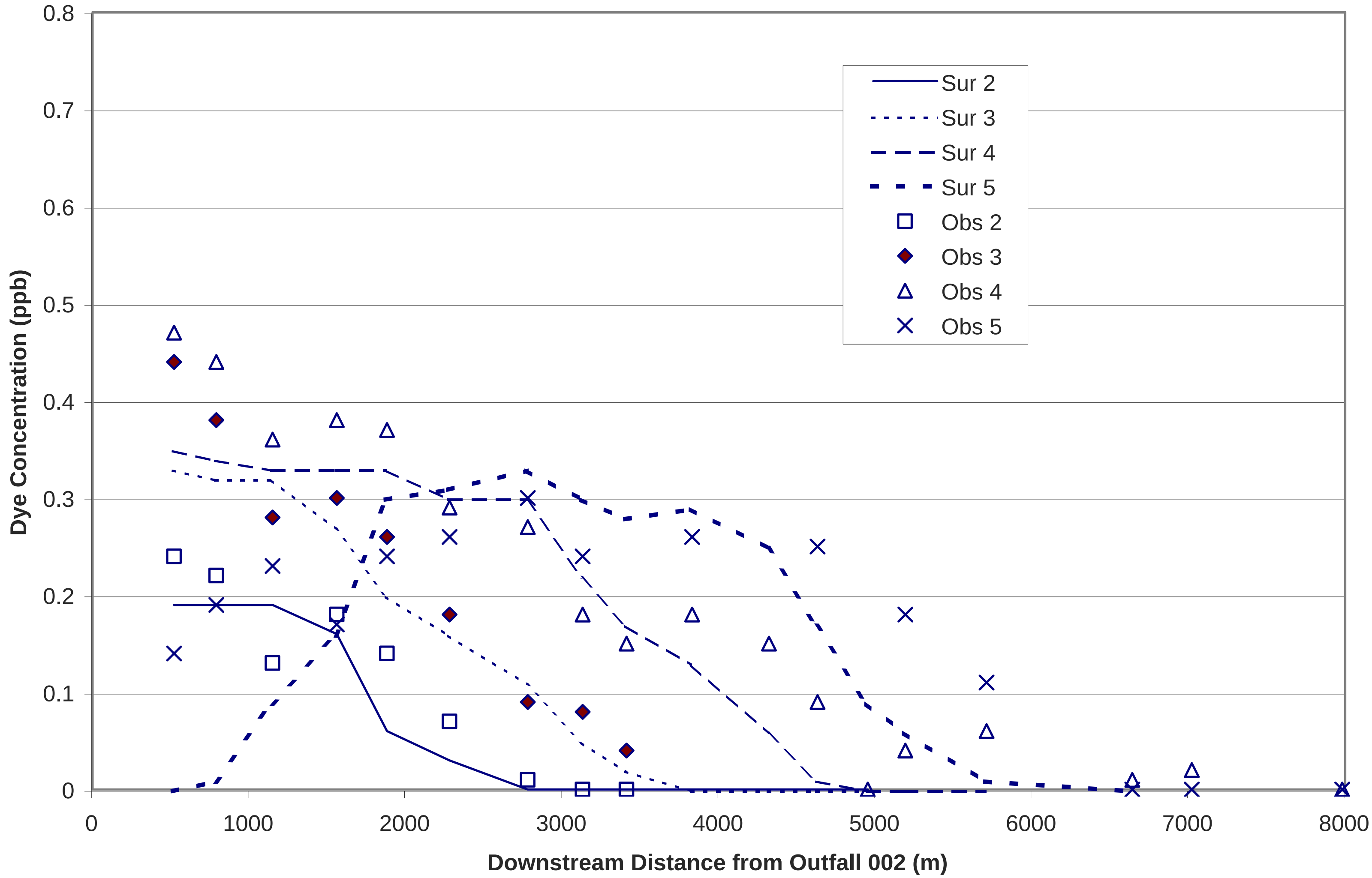
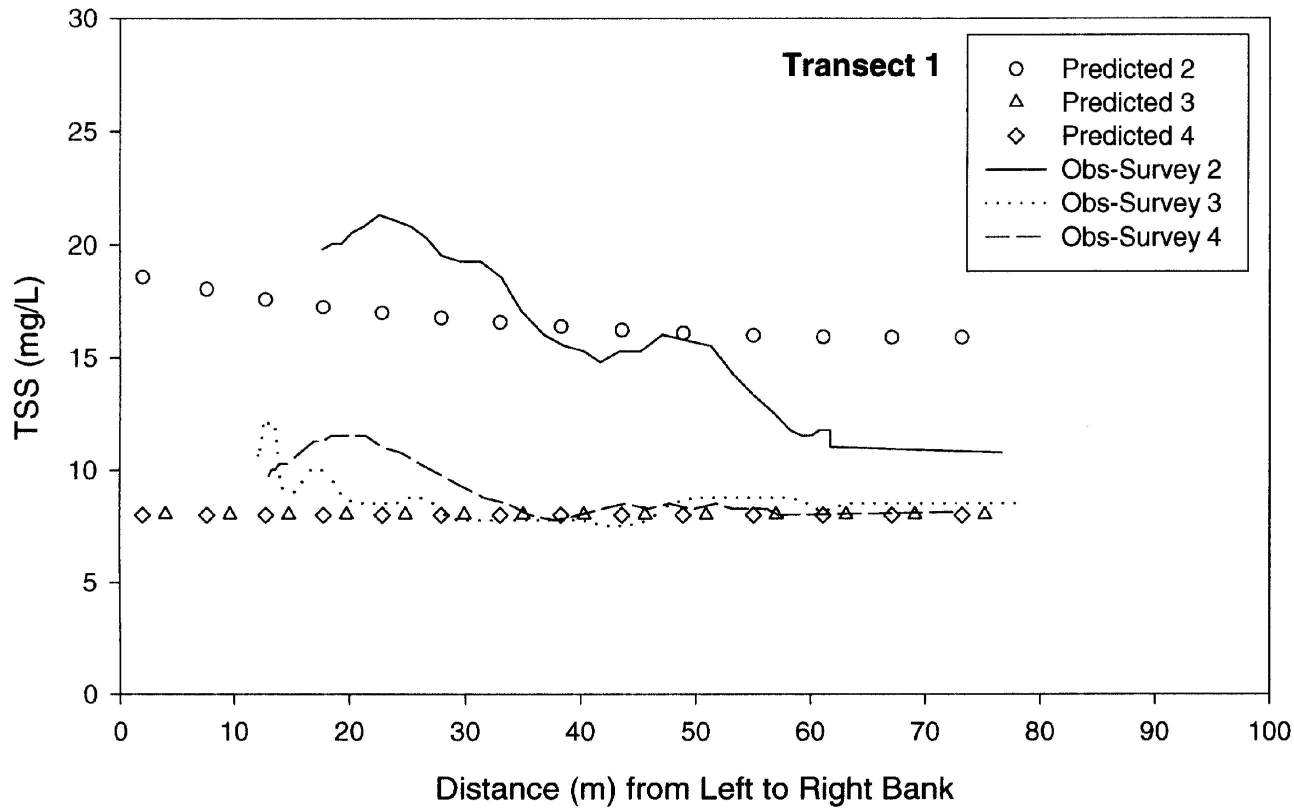


Figure B.2-11 Comparison of Predicted and Observed Transect Average Dye Concentrations, Outfall 002 Survey, 24 May 2000





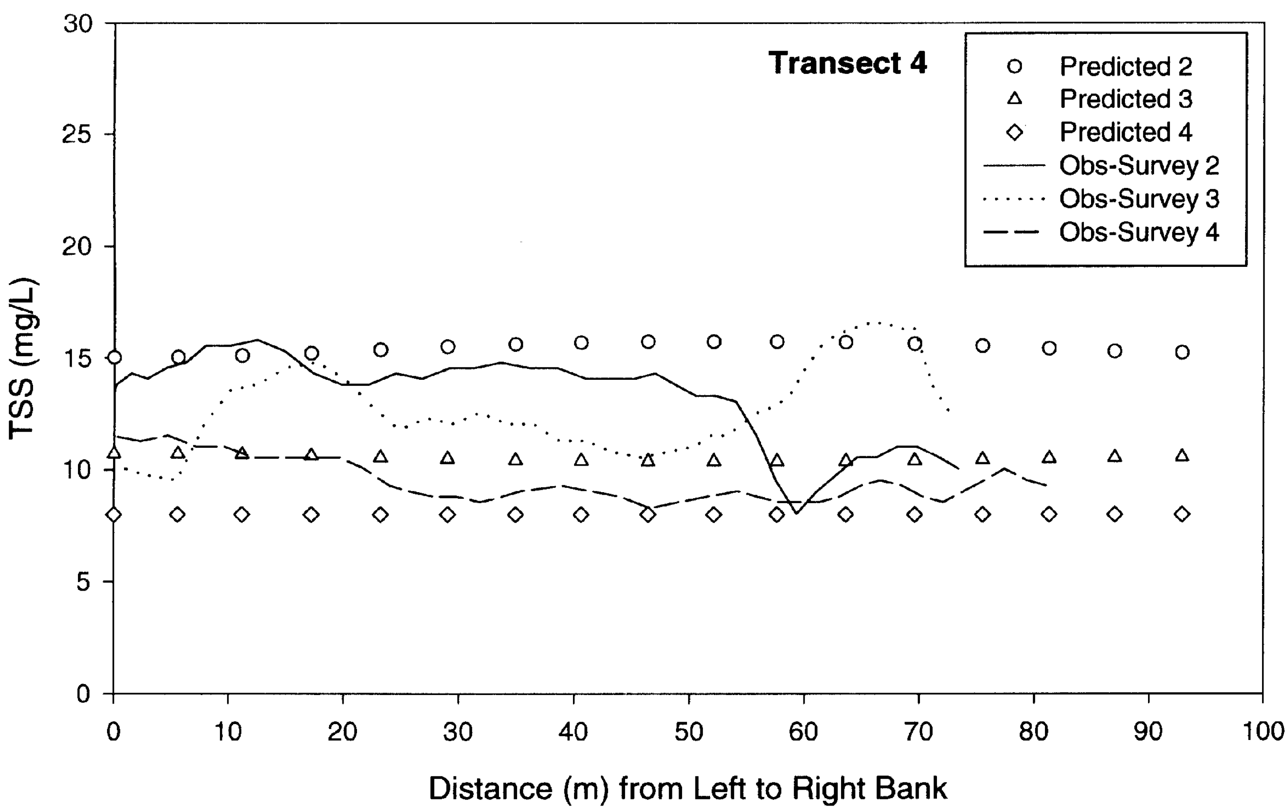
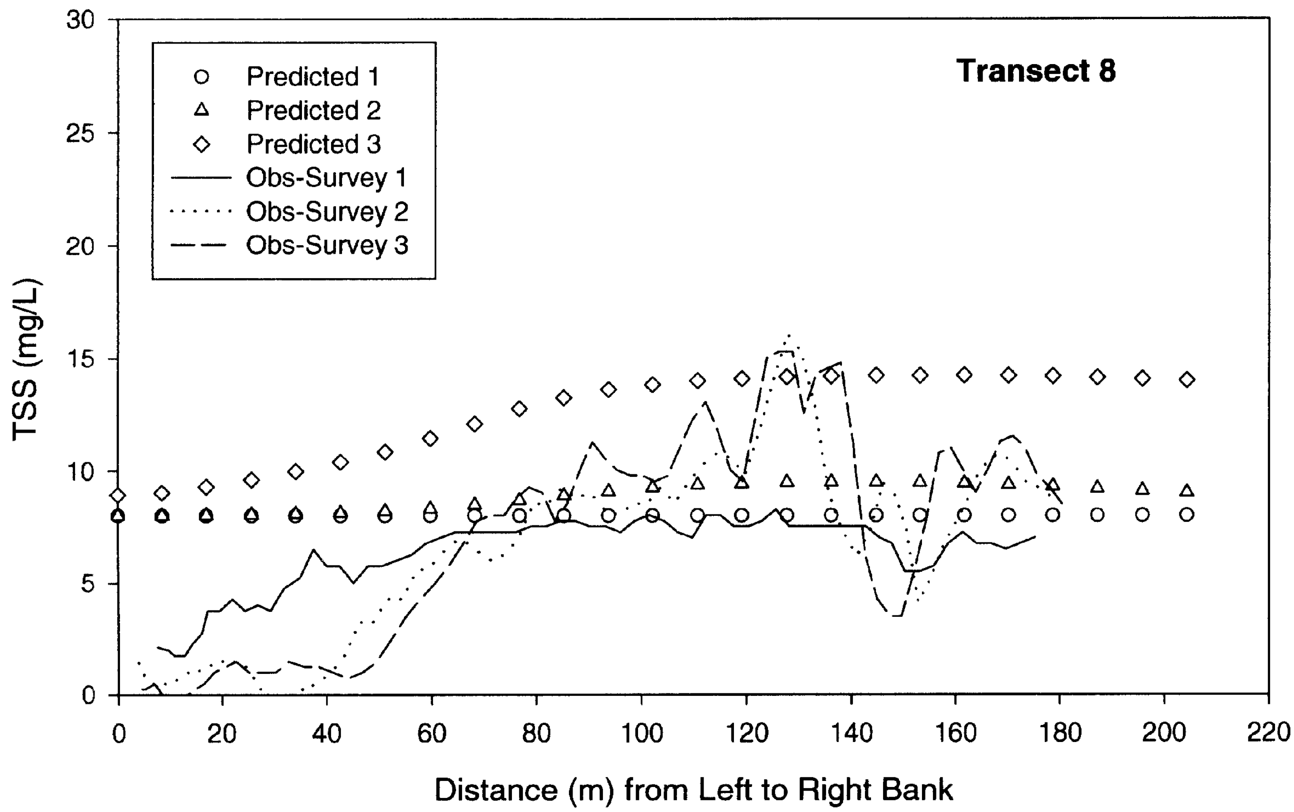


Figure B.2-12 Comparison of Observed and Model-Predicted TSS Concentrations at Transects 1 and 4, Outfall 002, 25 May 2000



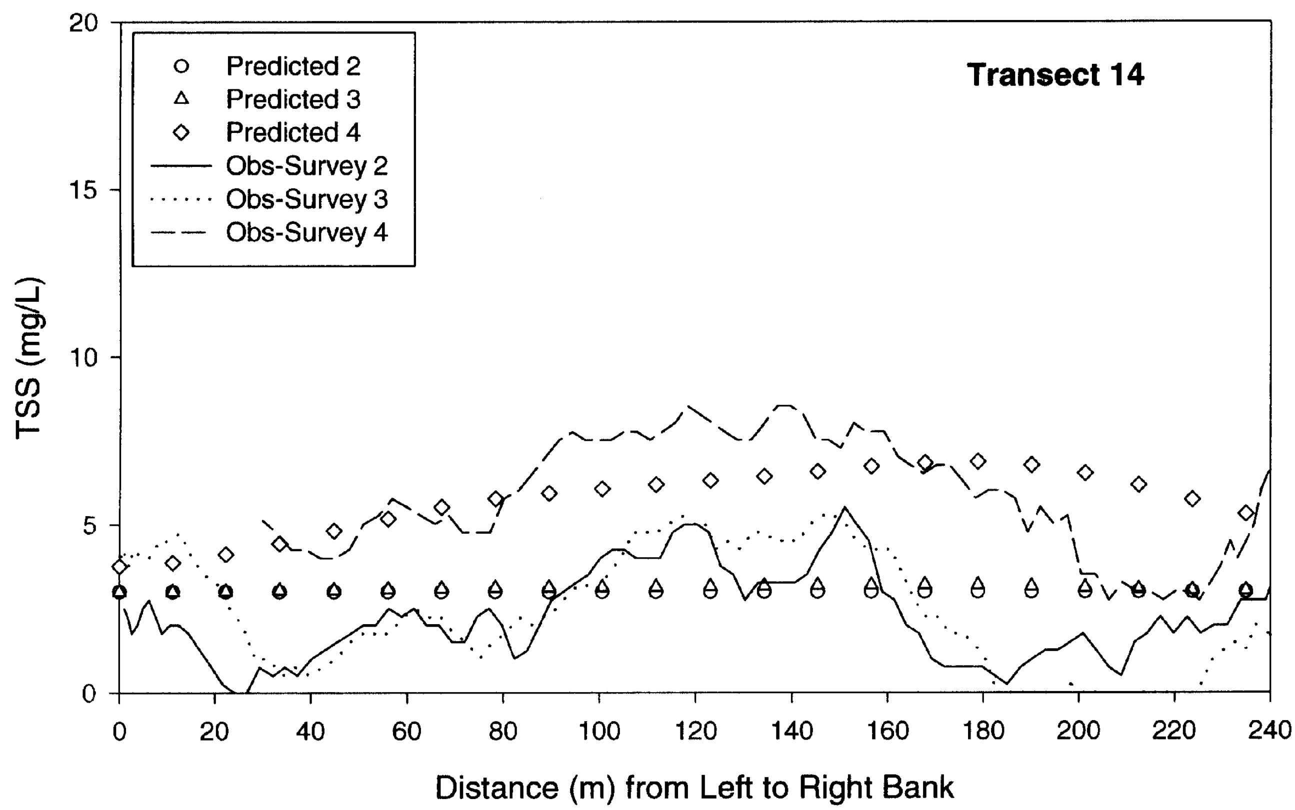
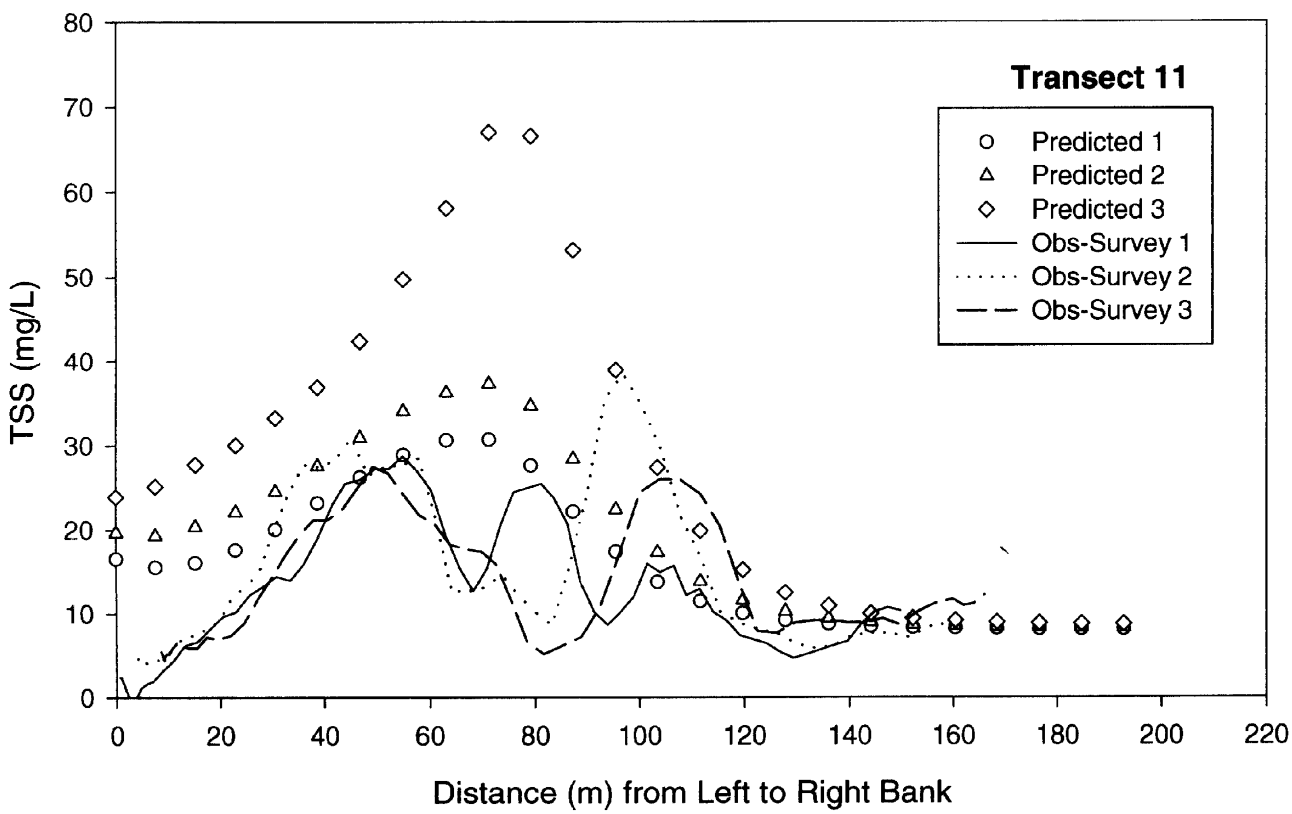


Figure B.2-13 Comparison of Observed and Model-Predicted TSS Concentrations at Transects 8 and 14, Outfall 002, 25 May 2000



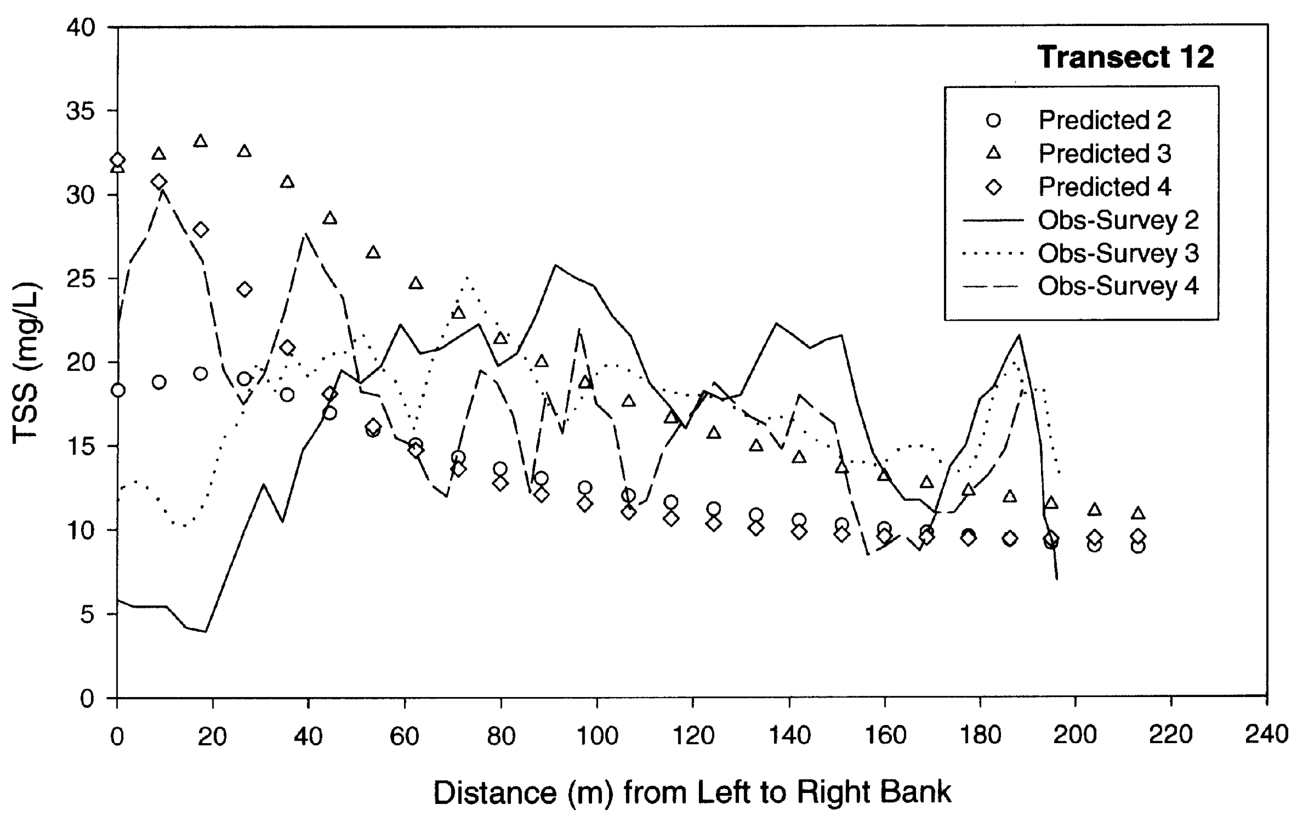


Figure B.2-14 Comparison of Observed and Model-Predicted TSS Concentrations at Transects 11 and 12, Outfall 003, 3 May 2000

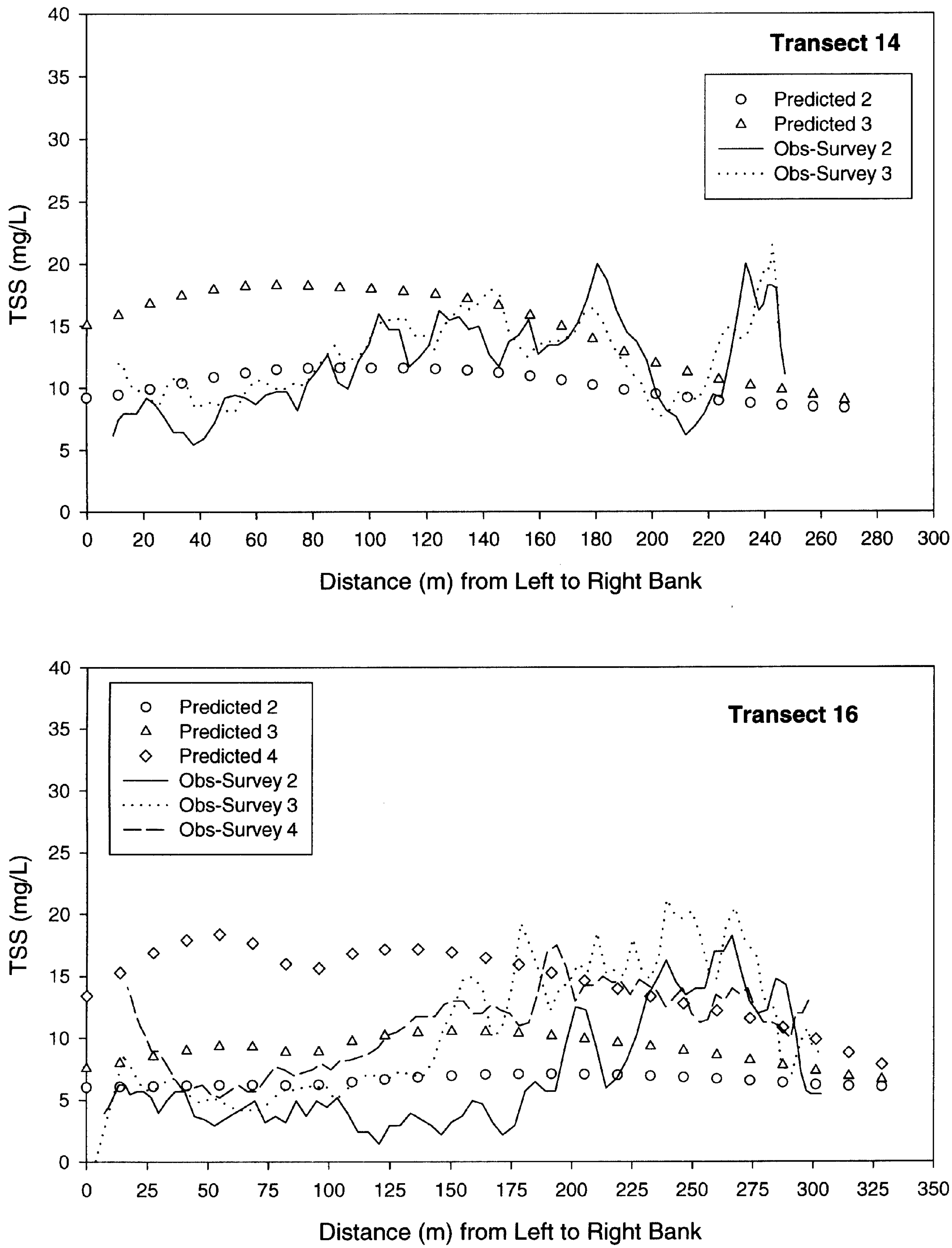


Figure B.2-15 Comparison of Observed and Model-Predicted TSS Concentrations at Transects 14 and 16, Outfall 003, 3 May 2000

Appendix C

Study Plan for Washington Aqueduct Water Quality Studies (24 June 1999)

Prepared by EA Engineering for the Metropolitan Washington Council of Governments

Study Plan for Washington Aqueduct Water Quality Studies

Prepared for:
Metropolitan Washington Council of Governments
777 North Capitol Street, N.E. Suite 300
Washington, D.C. 20002-4226

Prepared by:
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15 Loveton Circle
Sparks, MD 21152
(410) 771-4950

61129.02

24 June 1999
Approved by U.S. EPA Region III

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

JUN 24 1999

Mr. Thomas P. Jacobus, Chief
Washington Aqueduct
Department of the Army
Baltimore District, US Army Corps of Engineers
Washington Aqueduct Division
5099 MacArthur Boulevard, NW
Washington, DC 20315-0220

RE: Washington Aqueduct Water Quality Study

Dear Mr. Jacobus:

By this letter, EPA approves the June 21, 1999 revised "Study Plan for the Washington Aqueduct Water Quality Studies" and the clarifying language received by facsimile on June 24, 1999. As you know, since its inception this project has presented a myriad of complicated technical and policy issues upon which the US EPA Regional and National offices, the DC Department of Health and the US Fish and Wildlife have consulted.

I would like to acknowledge the contribution of the staff at EA Engineering, Science and Technology, Inc., and in particular Mr. William Rue, who have worked through the various issues with patience and insight.

I would also like to thank you and the Aqueduct staff for the many hours you have spent explaining how raw water is removed from the Potomac, made into drinking water and distributed to the millions of customers. We greatly appreciate the care you have expressed and the several guided tours of the Aqueduct you have provided.

As we commence the next phase, which is the actual gathering of data, we look forward to continuing the work in the spirit of scientific discovery and cooperation in which we have begun.

Mary Letzkus is the staff person assigned to this project. If you have any questions or need clarification, please do not hesitate to call her at 215-814-2087.

Sincerely,

Pat M Gleason

Patricia M. Gleason, Chief
DC/MD Branch

cc: cc: William Rue, EA Engineering
Rebecca Hanmer, EPA Region III DC Liaison
Beth McGee, US FWS
Jon Siemien, DC Fisheries
James Collier, DC DOH
Mary Letzkus, EPA

24 June 1999 Revision

Study Plan for Washington Aqueduct
Water Quality Studies

Introduction

The U.S. Army Corps of Engineers owns and operates the Dalecarlia and McMillan water treatment plants which supply water to the District of Columbia, Arlington, and Falls Church. Raw water is obtained for both plants from the Great Falls Raw Water Intake or the Little Falls Pumping Station on the Potomac River. The water flows through the Dalecarlia Reservoir and is then diverted for settling to either the Dalecarlia plant or the Georgetown Reservoirs.

Residual solids from the Dalecarlia plant sedimentation basins are periodically discharged to the Potomac River through Outfall 002. Residuals from the McMillan plant are generated in the Georgetown Reservoir Basins 1 and 2. Those residuals are periodically discharged into the Potomac River via Outfalls 003 and 004. These discharges are allowed in the Aqueduct s NPDES permit.

The timing of these residual discharges is dictated by a number of factors. If permit conditions are satisfied (e.g., acceptably high river level and/or ambient turbidity condition), then a sedimentation basin is usually discharged based on a general frequency (e.g., 3 or 4 times a year at Dalecarlia and twice a year at Georgetown), or the observation of excess solids buildup.

This water quality study plan was developed to be responsive to the specific technical issues raised by U.S. EPA staff in discussion documents and conference calls on 3 October and 13 November 97, written comments dated March 1998, and follow-up negotiations from January-March 1999. The proposed studies are also influenced by the November 97 site visit to observe the cleaning of the Georgetown Reservoir basin and the discharges from Outfalls 003. Section 1 of this study plan addresses effluent dilution and fate issues, which are critical to interpreting all of the subsequent information using U.S. EPA s (1991) water quality-based approach. Section 2 discusses the laboratory testing to quantify the toxicity of whole effluent, effluent supernatant, and solid phases of the effluent, and Section 3 addresses chemical testing. Fishery studies are described in Section 4 and an approach for determining a site-specific aluminum criterion is presented in Section 5. An artificial substrate approach for evaluating potential effects to the benthic invertebrate community is presented in Section 6.

1. Potomac River Modeling for Effluent Dilution and Fate

1.1 Modeling Goals

The proposed numerical model of the Potomac River will simulate both river flow and the suspended solids plume from the Washington Aqueduct discharges. The primary objective of the modeling is to determine acute and chronic dilution factors as a function of effluent loading and river flow. The determination of both water column dilution factors and the spatial distribution of particle deposition will allow potential areas of concern to be identified. The proposed model domain will extend from slightly upstream of Outfall 002 to the downstream end of Roosevelt Island.

1.2 Model Selection

A detailed and finely calibrated hydrodynamic model is difficult to develop for hydrologically complex sites such as the Potomac River. Sedimentation may occur at many locations including back eddies and other irregular channel features, some of which exceed a model s capability to represent. However, the capabilities of a hydrodynamic model to serve as a tool to examine mixing zone issues can be maximized by proper model selection and the collection of appropriate field data.

The model will be selected based upon key site characteristics. The relatively shallow nature of the Potomac River in relation to its width makes a 2-dimensional (vertically mixed) hydrodynamic model appropriate. In addition to hydrodynamic flow routines, the model should have the capability to simulate suspended solids and sedimentation processes. A temporally dynamic model (rather than steady state) will allow the simulation of the several hour discharge period for solids and the resultant plume build-up and dissipation. Sedimentation rates vary both laterally and longitudinally in response to river velocity caused by changes in cross-section and by reduced velocity areas beyond the main channel. The sedimentation routine should have the capability to respond to cell-by-cell variability in river velocity rather than employing global values. A finite-element model has the capability to use a varying model cell size which would allow a finer model grid to be used in the near-field area of concern (i.e., the acute mixing zone).

Two models with potential applicability are U.S. EPA s WASP5 model and the TABS-2 model which is supported by the U.S. Army Corps of Engineers.

- WASP5 has more limited suspended solids routines, and the occurrence of sedimentation is not directly linked within the WASP5 model to the cell-by-cell velocity field. As a result the model does not internally vary the sedimentation rate between low and high velocity regions, but this rate is left as a parameter for the user to control in the input file.

- The TABS-2 modeling system includes a 2-dimensional hydrodynamic model, and sedimentation is carried out in the companion model STUDH. The TABS-2 model employs shear stresses at the bed-water column interface to determine deposition or erosion spatially over the 2-dimensional velocity field.

Both models can use a variable cell size to provide higher spatial resolution in areas of potential concern and can perform time varying simulations. The more detailed hydrological and suspended solids processes in a model such as TABS-2 makes it a better choice for this water quality program than the more widely known WASP5 model. The D.C. Department of Health has developed a WASP/TAM [Tidal Anacostia Model] model which is based on U.S. EPA's WASP5 model. It is anticipated that the model used for the Aqueduct project will perform more detailed hydrodynamic calculations within the study area than the TAM model developed for Total Maximum Daily Load calculations for the Anacostia River watershed. However, the District's WASP/TAM model will be examined and appropriate attributes including boundary conditions and model grid will be incorporated or used as a basis for additional model refinement.

A mixing zone model such as U.S. EPA s CORMIX has limited applicability to represent the Washington Aqueduct discharges. At many sites, a model such as CORMIX is suitable for performing mixing zone analyses -- particularly in the near-field region associated with the *acute* mixing zone. However, at spatial scales expected to be associated with a *chronic* mixing zone for the Potomac River, a hydrodynamic model (as discussed in the previous paragraph) is more appropriate. The CORMIX model may be suitable for acute mixing analysis at Outfall 002 where the discharge is located adjacent to a deeper cross-section. However, at Outfall 003 and 004 the existing shallow shoreline discharge may be incompatible with the CORMIX model and acute mixing will most likely need to be determined using a hydrodynamic model.

1.3 Data Requirements and Model Calibration

The field work required to provide data for model parameterization and calibration will include the following tasks:

- Bathymetric Survey
- TSS plume mapping during one discharge event at both Outfalls 002 and 003
- Particle size distribution and settling velocity data for effluent samples
- Dye study to determine near- and far-field dispersion coefficients

The primary data requirements to develop the hydrodynamic model are (1) channel geometry data and (2) plume mapping data under known effluent and river flow conditions for establishing longitudinal and lateral dispersion.

A bathymetric survey will be performed by measuring depths along transects within the proposed model domain (which extends from above Outfall 002 to the downstream end of Roosevelt

Island). The measured transects will include the proposed transects for the TSS plume mapping surveys and additional transects, as necessary, including the channels on both sides of Roosevelt Island, to provide adequate channel geometry data for the hydrodynamic model. Instream velocities will be measured along one transect representative of the deep channel and the wide shallow shoreline areas downstream of Outfall 003. The cross sectional velocity data will be used for model verification of the partitioning of the total flow along the transect. A water level recorder will be installed within the study area during each field survey. The water level data will allow the tidally influenced elevations measured during the bathymetric survey to be related to a common datum, and provide assistance in establishing the water-level boundary condition used at the downstream end of the model.

Sampling transects for the TSS plume mapping survey will be selected at locations downstream of Outfalls 002 and 003. Near field sampling at Outfall 002 is unsafe and will not be attempted. The discharge event will be monitored at transects further downstream as the river broadens and slows down. The number of transects will be dependent on the length of the discharge event. The transect grid at Outfall 003 will extend downstream beyond Outfall 004. River characteristics are similar at Outfalls 003 and 004 and the Outfall 003 plume survey will provide model calibration for both reaches. A transect will also be sampled upstream of the surveyed outfall to provide ambient (background) TSS data. The TSS plume mapping surveys will consist of both continuous transects performed from a boat, and grab samples. On the boat a turbidity sensor will be mounted at a fixed 1-ft depth. Turbidity readings will be continuously recorded at a 2-second sampling interval as the boat moves along the transect grid. The boat will be equipped with a global positioning system (GPS) and the location information will also be continuously recorded. During the Outfall 003 survey, a second field crew will collect grab samples in the shore zone which can not be reached by the boat. At select locations, grab samples will also be obtained along the boat transects. The grab samples will be analyzed for TSS, turbidity, and aluminum.

During a discharge event and associated TSS plume mapping, effluent flow will be estimated by a composite of several methods. Effluent velocity measurements will be made at an available access point such as the open sluice before entering the closed pipeline or at a manhole. The Aqueduct will also provide an estimate of the flow used during the basin cleaning (e.g., metering the fire hoses used to push out the solids). These TSS and flow data will allow an estimate of the relative contribution of solids to be calculated (Aqueduct versus river).

The water released during a discharge event can be mapped using Rhodamine WT[1] dye tracing

1 Rhodamine WT is a fluorescent dye developed for water tracing and poses no known environmental or health hazards. The dye is detectable to 10 parts per trillion (ppt) using a fluorometer. The National Sanitation Foundation International has certified Rhodamine WT at a concentraiton not to exceed 100 ppt in drinking water.

techniques. A dye study performed independently of a solids discharge event[2] will provide additional field data to calibrate the lateral dispersion coefficients in the model. If properly scheduled, the opportunity exists to perform a dye study on the day prior to the residual solids discharge event as the reservoir is being drawn down. During the period of reservoir draw down, a representative flow is present at the outfalls which, except for an initial flush, does not contain a high TSS loading. A dye study performed during the period of reservoir drawdown should allow a longer sampling period for the collection of data along the river transects than the residual solids discharge event. The dye study should also provide for a more uniform discharge loading and higher precision in the plume measurements which will allow for better dilution contours from the field data. The availability of both TSS and dye mapping data at each outfall, most likely under different discharge flow conditions, will provide useful plume mixing and dispersion information to the model during the calibration process.

During the dye mapping survey, Rhodamine WT dye will be continuously injected at a manhole or wet well between the reservoir and the river outfall. The mapping survey will be performed along the same transect grid as established for the TSS plume mapping. Similarly to the TSS plume mapping, dye data will be continuously collected along transects with a fluorometer intake set at a fixed near-surface depth on the survey boat. Grab samples for dye measurements will also be collected in the near-shore zone at Outfall 003 where the boat cannot reach. Effluent samples for the analysis of TSS will be collected during the drawdown period to characterize the solids loading.

A 2-dimensional cell grid will be developed for the hydrodynamic model based upon the channel geometry data from the bathymetric survey. The use of a finite-element model will allow the selection of a finer grid in the near-field region of concern for the acute dilution factor. With a defined cross-sectional area, channel slope, and appropriate channel friction coefficients, a hydrodynamic model will predict water elevation for a given flow. Since the study area is tidally influenced, a downstream elevation boundary condition will be required in the model to properly represent the time varying river cross-section and corresponding velocities. Longitudinal and lateral dispersion in the model will be adjusted based upon the turbidity and dye data collected along lateral transects during the plume mapping surveys. Particle size distribution and settling velocity data for several effluent samples will be used to parameterize the sedimentation procedures. These additional data will supplement the particle size data available in the Dynamac (1992) report.

[2] A dye study performed during an actual residual solids discharge event will result in inaccurate results (false positive) due to scattering of light by suspended particles (i.e., the wavelength shift associated with the scattering of light by suspended solids in the fluorometer sample chamber will cause an increase in the detected signal at the wavelength associated with the dye fluorescence).

1.4 Model Scenarios

The calibrated model will be used to determine acute and chronic dilution factors at each of the three outfalls.   Water quality regulations for the District of Columbia state that a chronic mixing zone shall not exceed 10 percent of the cross-sectional area and shall not occupy more than one-third of the width of the waterway. The dilution present at the downstream location where the plume width meets the spatial dimension of the allowed mixing zone will be determined from the model output. Allowed dimensions for an acute mixing zone are not addressed in the District of Columbia s water quality regulations. Guidance for determining an acute mixing zone will therefore be based upon the U.S. EPA s (1991) Technical Support Document for Water Quality-Based Toxics Control. Application of the TSD guidance for determining an acute mixing zone is difficult at existing outfall locations because several of the outfalls structures are set back from the shoreline (Outfalls 003 and 004). However, one method in the TSD for determining an acute mixing zone is based upon a 1-hour float time. With this method, an acute dilution factor is calculated from the one-hour time-weighted average exposure concentration which would be experienced by a drifting organism. One-hour average exposure concentrations can be determined by performing particle tracking within the hydrodynamic model.

Acute and chronic dilution factors will be determined for a range of river flows and discharge mass loadings. Model scenarios will include river flows both above and below the existing 3.5 bgd release condition. The dilution factors will allow instream concentrations at the edge of the mixing zones to be compared to appropriate water quality standards for determining under what discharge and river flow conditions, if any, the discharge may not be in compliance. The model will allow scenarios such as increasing the duration of the discharge period to be examined (e.g., 8-10 hr discharge period rather than a 3-4 hr period). A model scenario simulating releases while the reservoir is being drawn down prior to the discharge of the residual solids will be included. Alternative discharge locations (such as an offshore diffuser) can also be examined.

The model s capability to predict the suspension/sedimentation of discharged material as a function of particle size and river flow will address environmental concerns which may extend beyond the mixing zones.   The transport and settling of the solids loading during a discharge event will be characterized to the downstream end of Roosevelt Island. The availability of the predicted plume distribution (dilution) in the water column, and the associated spatial distribution of sedimentation will provide for the identification of potential impact areas.

2. Effluent Toxicity Testing

2.1 Toxicity Testing Goals

The toxicity of the discharges to freshwater test species will be quantified to determine whether the effluents have a reasonable potential to be toxic at the edge of mixing zones. Acute toxicity testing will be conducted on whole effluent samples, and chronic toxicity testing will be conducted on the supernatant from settled whole effluent. Benthic sediment toxicity testing will be conducted on the settled solids portion of the whole effluent. Results from the initial toxicity testing will be shared with U.S. EPA so that any modifications in test design/methodology can be implemented early in the process.

2.2 Whole Effluent Acute Toxicity Testing

The acute toxicity testing will consist of four separate events during 1 year, using dilutions of whole effluent samples. Recognizing that discharges only occur on an as needed basis during high receiving water flows, an attempt will be made, (to the extent possible) to incorporate seasonal variability into the sampling and testing schedule. Additionally, when the whole effluent samples are collected, the sample will include representative worst case solids discharge conditions in the composite sample (e.g., second day hosing down operations). The acute toxicity testing will be conducted in accordance with EA s Standard Operating Procedures (EA 1996) which are consistent with U.S. EPA s (EPA 1993) *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*, Fourth Edition. Whole effluent toxicity (WET) testing will be conducted using two standard freshwater test species (a fish and an invertebrate)

- Fathead minnows, *Pimephales promelas* (96 hr static acute tests)
- Water flea, *Daphnia magna* (48 hr static acute tests)

This results in eight WET acute tests (4 discharge events X 2 species).

For each testing event, static acute toxicity tests will be performed with *D. magna* (48 hour) and *P. promelas* (96 hour). The use of *Daphnia magna* for acute WET testing in the NPDES program is common, and the neonates are *somewhat* larger than the alternate invertebrate test species[3]. A sample of upstream Potomac River water will serve as the dilution water for the acute toxicity tests. We propose that the tests will consist of five whole effluent concentrations: for example 100, 50, 25, 12.5, 6.25 percent effluent, an upstream Potomac River control, and a laboratory water control (moderately hard synthetic water). This dilution series could be modified based on the results of the dilution modeling discussed above. At test initiation, the *D. magna* will be $\leq$ 24-hour old neonates, while the *P. promelas* test organisms will be 1-14 days in age. The test organisms will not be fed during the exposure period. The test chambers (effluent treatments and control) will be gently aerated at a rate of approximately 100 bubbles per minute during the tests to achieve some mixing of the effluent.

[3] The reason for the selection of *D. magna* in this program is the larger size of the neonates (less than 24-hour old young) that are used to initiate the tests. The neonates of the alternative invertebrate test species for acute toxicity testing (*Ceriodaphnia dubia*) are approximately one-tenth the size of a *D. magna* neonate, and would be impossible to locate in the whole effluent tests. It will still be difficult to locate the *D. magna* neonates at 24-hour intervals for headcounts in the whole effluent (with its associated fine particulates). Thus *C. dubia* was considered infeasible for the planned whole effluent acute toxicity study.

In addition to the *D. magna* and *P. promelas* testing, striped bass (*Morone saxatilis*) will be evaluated during the whole effluent acute toxicity testing portion of this study. Testing will be initiated with *M. saxatilis* prolarvae (2-9 days posthatch). Because *M. saxatilis* embryos and larvae are only available during a very limited portion of the year, the *M. saxatilis* testing may not be possible during all four sampling events. As ASTM Standard Guide E 1241-92 observes, striped bass embryos and larvae are difficult to work with the proposed aeration/mixing of the test solutions may not be an acceptable practice for the proposed striped bass prolarvae testing, and the results will need to be interpreted with caution.

2.3 Particulate Phase (Supernatant) Chronic Testing

Chronic toxicity of the discharge will be evaluated four separate times during a 1 year period using dilutions of a supernatant prepared from settled effluent samples. Testing methodologies will be in accordance with U.S. EPA s (1994a) *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to Freshwater Organisms* (EPA/600/4-91/002). The chronic toxicity testing will be performed using three species (fish, invertebrate, plant)

- Fathead minnow, *P. promelas* 7-day larval survival and growth test
- (EPA Method 1000.0)
- Water flea, *Ceriodaphnia dubia* survival and reproduction test (EPA Method 1002.0)
- Green algae, *Selenastrum capricornutum* 96-hour growth test (EPA Method 1003.0)

This results in 12 chronic tests (4 discharge samples X 3 species).

The suspended particulate phase preparation procedure will be a modification of the elutriate preparation described in EPA/COE s (1998) Inland Testing Manual. The modification will be that the effluent sample will <u>not</u> be diluted 4:1 with upstream dilution water prior to mixing and settling. The suspended particulate phase will be prepared by stirring the effluent sample for 30 minutes, allowing the sample to settle for one hour, and then using the resulting effluent supernatant as the 100 percent suspended particulate phase sample. Particulate material will not be kept in suspension during the chronic testing. The *S. capricornutum* algal growth test requires that the sample be filtered through a 0.45 μm filter prior to testing. Effluent dilutions for testing (e.g., 100, 50, 25, 12.5, 6.25 percent) will be prepared by diluting the 100 percent supernatant sample with upstream Potomac River water. The control treatments will consist of an upstream Potomac River water control, and a laboratory freshwater control. The laboratory control water (per EPA (1994a) guidelines for *P. promelas* and *C. dubia)* will be moderately hard synthetic water, and algal media will be utilized for the *S. capricornutum* testing.

2.4 Benthic Testing

The benthic testing portion of the toxicity characterization study will consist of four test events during a 1 year period to address the suspended solids in the effluent samples [4 acute tests = 4 discharge events X 1 species]. Ten day acute toxicity tests (survival and growth endpoints) will be performed using the amphipod, *Hyalella azteca*. Methods will follow U.S. EPA s (1994b) freshwater sediment toxicity testing protocol manual to the extent possible, since the sample is an effluent, not a sediment. Testing will employ two overlying water renewals per day.

Natural Potomac River surficial sediment samples will be layered in the test chambers (300 ml lipless beakers), and the effluent samples will be allowed to settle onto these sediments. To obtain dose-response data for the benthic testing, the 100 percent effluent samples will be diluted using upstream Potomac River water such that the data can be compared to controls, and interpreted relative to effluent/particulate dilutions at the edge of appropriate mixing zones (e.g., 50, 25, 12.5 percent effluent samples settled onto river sediment). These exposure concentrations may be adjusted based on the results of the modeling program discussed in Section 1 above. Control treatments
will be natural Potomac River surficial sediment, and a separate artificial laboratory sediment with similar grain size distribution layered over the base Potomac River sediment layer.

All toxicity test results will be interpreted relative to dilutions at the edge of acute and chronic mixing zones. Initially, effluent samples from Outfall 003 will be tested, assuming that this represents the worst case (more solids and less dilution). However with a goal of collecting samples representing four seasonal conditions, evaluation of samples from Outfalls 002 and 004 may be necessary.

3. Effluent Chemical Characterization

3.1 Goal

Use existing effluent data on concentrations of solids and key chemical constituents in the discharges to calculate preliminary projections of receiving water concentrations in comparison to ambient water quality criteria.

3.2 Approach

Existing effluent monitoring data (flow, chemical parameters) collected at the basin discharge points will be obtained and evaluated to help compare concentrations at the edge of the acute and chronic mixing zones to the ambient water quality criteria. Reasonable potential procedures (as outlined in EPA's (1991) Technical Support Document) that statistically project an effluent concentration by accounting for effluent variability and the uncertaintly associated with small data sets will not be used for this preliminary screening. Rather the existing effluent data will be adjusted using only the acute and chronic dilutions factors and the adjusted concentrations will be compared to water quality criteria. In addition, effluent samples used in the toxicity testing program will be analyzed for key parameters (e.g., total suspended solids, total and dissolved aluminum, total iron, total organic carbon, BOD, pH, alkalinity, and nitrogen and phosphorus compounds). All analytical methods used will be U.S. EPA-approved (e.g., 40 CFR 136). As additional data are collected and the variability of effluent concentrations analyzed, the Technical Support Document's reasonable potential procedures may be used to further evaluate the need for effluent controls on key parameters.

4. Fisheries Issues

4.1 Goals

U.S. EPA Region III expressed concern that key anadromous and resident fish species might potentially be affected by the Aqueduct discharges based upon general life history data. Four specific goals have been identified for study: (1) identify the critical life stages and habitat requirements of the fish *species of concern* in the vicinity of the Aqueduct outfalls, (2) assess the amount of potential fish habitat that may be influenced by the discharge plumes, (3) assess the overall potential for impacts to *species of concern* from the discharge, and (4) identify Aqueduct discharge management scenarios that may minimize potential impacts to fisheries resources that may be at risk.

4.2 Approach

A literature review will be conducted to identify the critical life stages and habitat requirements of fish *species of concern* in the vicinity of the Aqueduct outfalls. Fish species identified in U.S. EPA Region III s Conceptual SOW and other species of importance to local resource professionals will be the potential species evaluated in this study. Resource agencies including USFWS, NMFS, DC Fish and Wildlife, MDNR and the Maryland Heritage Program will be consulted to derive the list of locally important species. This list (at a minimum) will include both anadromous and resident species of commercial and recreational importance that are known to utilize the Potomac River in the general vicinity of Washington, D.C. for at least part of their life cycle. For example:

Anadromous species	Resident Species
Striped bass (*Morone saxatilis*)	Yellow perch (*Perca flavescens*)
White perch (*Morone americana*)	Smallmouth bass (*Micropterus dolomieu*)
American shad (*Alosa sapidissima*)	Sunfish species (*Lepomis* spp.)
Blueback herring (*Alosa aestivalis*)	Channel catfish (*Ictalurus punctatus*)
Alewife (*Alosa pseudoharengus*)	Brown bullhead (*Ictalurus nebulosus*)

For each *species of concern*, life history, distribution, and optimal habitat requirements for the Potomac drainage populations will be gathered from contemporary and historical literature. Information will be tabulated to derive a range of optimum river temperatures at which the sensitive life stages (e.g., spawning, egg, larval development) of the species occur and the approximate duration of the spawning/rearing period. Historical Potomac River water temperature information will be retrieved from the USGS database and compared to the optimum spawning/rearing temperatures of sensitive life stages to identify the months during which Aqueduct discharges could potentially affect species of concern. In addition, the length of spawning and rearing periods for each species of concern will be compared to the typical Aqueduct discharge duration to assess the potential that a discharge event could disrupt the development of an entire cohort of a species within the Potomac River.

The habitat assessment proposed for the Washington aqueduct will examine macrohabitat features within the vicinity of the Aqueduct outfalls both inside and outside of the area of plume influence. The assessment will be focused on documenting the availability of various habitat features and not specifically on habitat quality. The macrohabitat features in the reach from 100-200 meters upstream of Outfall 002 down to Roosevelt Island will be mapped during a float trip of the area.

Once the area of potential plume influence is understood (from plume mapping), transects will be assessed within, upstream of, and downstream from the area of solids influence. A minimum of one transect will be assessed upstream of Outfall 002. Five or 6 transects will be assessed within the plume area and at least 2 others will be assessed outside of the influence of the plume (preferably downstream). The extent of various macrohabitat features present along each transect will be documented. This will include: substrate; embeddedness; extent of riffle, run, pool habitat; depth of riffles, runs, pools; and extent of instream cover features.

The preferred habitats of the species of concern will be derived for existing life history information. The extent of preferred habitat inside and outside of the area of plume influence will be evaluated based upon the habitat mapping and transect data. The potential for impacts of the plume to key habitats of the species of concern will be evaluated on this basis.

Sediment suspension and deposition modeling (Section 1) will help identify the appropriate areal extent of potential fish habitat influenced by each outfall. To assess potential disturbances to reproductive success, the available habitat affected by the discharge (based on the modeling) will be compared to optimum spawning habitats or known spawning areas for the *species of concern* in this reach of the Potomac. The proportion of spawning/rearing habitat affected by the discharge will be compared to the availability of comparable spawning/rearing habitat in the immediate vicinity outside the discharge area.

The spawning and habitat evaluations will help to define the risk that the discharge may have on *species of concern*. Based on the results of the fisheries literature search, in combination with the U.S. Fish and Wildlife Service s (2 March 99) recommendations, Aqueduct discharge management scenarios will be suggested (if warranted) to minimize potential impacts to fisheries resources in the areas identified as potentially at risk.

5. Aluminum Criteria Modification

5.1 Goals

If aluminum is determined to exceed applicable ambient water quality standards (see EPA s note in 63 Fed Reg 68361; 10 Dec 98) at the edge of mixing zones, it may be desirable to quantify the bioavailability of the aluminum in the effluent so that the ambient standard can be appropriately adjusted (e.g., if the same concentration of total aluminum is half as toxic in Outfall 003 effluent than total aluminum salts are in pure lab water, EPA guidance would allow the standard to be multiplied by a factor of 2.0).

5.2 Study Approach

EPA comments suggested using the Agency s (1994) Water Effect Ratio (WER) procedure for aluminum. However EPA s (1994c) WER document was not written to address this type of situation, where alum is added, solids are settled, and there is a long period of time before the water is released to the river. As a result, a modification of the WER approach is more appropriate because of the nature of the effluent matrix. More specifically, the aluminum in Aqueduct effluents is expected to be less bioavailable because of its chemical form and binding to particulates which has occurred over an extended period of time (Hall and Hall 1989). U.S. EPA s (1994c) WER procedure does not allow for long periods for binding, and the introduction of laboratory grade aluminum salts to an effluent mixture will not yield results which reflect what happens in normal Washington Aqueduct operations, or in the Potomac River after release.

Recognize that EPA s WER procedure introduces laboratory-grade soluble metal salts to the effluent sample and lab water sample and then allows a 1-hour binding period before initiating the side-by-side toxicity tests. A slightly modified WER procedure is therefore proposed, where the toxicological responses to a given concentration series[4] of aluminum in Aqueduct effluent samples is compared to the response from concentrations of laboratory grade aluminum salts (e.g., aluminum chloride) in lab water. Using this approach, the WER would be based on the form(s) of aluminum actually present in the effluent sample, rather than a different form of aluminum that is *added* to the sample in the laboratory. This approach more accurately reflects the chemical forms of aluminum that actually occur in the sample and are introduced into the river (and is compared to the lab water/aluminum salts mixture that serves as the basis of U.S. EPA s aluminum criterion)-- which is the precise goal of the Agency s WER guidance. U.S. EPA researchers noted that "the proposed modification to the WER is acceptable provided that the ratio of effluent to upstream water to simulate downstream water does not exceed the ratio that will occur in the actual downstream water under comparable flow conditions". A more detailed study plan will be developed if this study is required.

Consistent with EPA s (1994) guidance for freshwater WERs, the primary test species will be *Daphnia magna* (or *Ceriodaphnia dubia* if possible). The proposed secondary species will be the fathead minnow (*Pimephales promelas*).

6. Macroinvertebrate Community Studies

6.1 Goals
Use U.S. EPA s artificial substrate approach to characterize the macroinvertebrate community prior to and after a discharge event to determine if effects are observed.

6.2 Study Approach

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4 Aluminum salts would not be <u>added</u> to the effluent samples. Instead, the effluent would be diluted from its initial concentration using Potomac River water to generate a concentration series for toxicity testing.

Artificial substrate samplers (i.e., modified Hester Dendy) will be used to obtain qualitative and quantitative samples of macroinvertebrates at upstream and downstream locations in the Potomac River. As discussed in U.S. EPA s (1990) Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters, there are several clear advantages for this type of approach: multiplate samplers are excellent for water quality monitoring; it offers a uniform substrate for colonization; it provides habitats of known area for quantification; samples can be collected for a known period of time at known depths, and a negligible amount of debris is collected making enumeration more efficient. Limitations in a waterbody such as the Potomac River are that the units may be subject to vandalism, and the colonization units can be washed away under high flows.

Macroinvertebrate studies will focus on Outfall 003, assuming it to be the area most heavily influenced by Aqueduct discharges as a result of substantially slower river velocities (versus Outfall 002). Based on a reconnaissance of the study area, and a formal habitat assessment, sampling locations will be selected near the Outfall 003 discharge and at several locations downstream to describe a possible gradient of effect. As appropriate, one (or more) reference location(s) will also be selected and sampled upstream of Outfall 003. Upstream and downstream locations will be selected to ensure comparability of key characteristics including river velocity and depth. The reference locations will be selected to match habitat characteristics as closely as possible to the stations downstream of Outfall 003 to minimize benthic community differences due to habitat.

Two sets of artificial substrates (with 3 replicates/set) will be deployed at upstream and downstream locations in the river approximately six to eight weeks before a discharge event, to allow for colonization. Substrates will be placed a few inches above the sediment interface and oriented so that the plates are horizontal. One set will be collected before a discharge event, and the second set will be retrieved approximately 2-3 days after the event. This will allow for upstream and downstream comparisons, both before and after a solids discharge event.

7. Proposed Sequence of Events

A specific schedule for this study is not possible because of the unpredictable / receiving stream-dependent nature of the Aqueduct discharges which dictate when many of the study components occur. As requested by EPA, the following table presents a *generalized* plan for the order that

the various components might be conducted. This is not a formal schedule and the markings are only intended to indicate the general period of time that a task might be worked on.

Generalized Sequence of Events for Water Quality Studies

Study Plan Tasks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**

Modeling												
Model set-up	XX	XX	XX									
Bathymetry		XX										
Field survey #1			XX									
Field survey #2					XX							
Model calibration				XX		XX	XX	XX				
Model runs								XX	XX	XX	XX	XX
Toxicity testing			XX		XX		XX		XX			XX
Chemical evaluations	XX	XX		XX		XX		XX		XX		XX
Fishery investigations		XX		XX		XX			XX			XX
WER study						XX	XX	XX	XX	XX	XX	XX
Benthic study						XX	XX	XX				

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