6. DATA DEVELOPMENT FOR MODEL APPLICATIONS

6.1 INTRODUCTION

The development and application of the HUDTOX PCB mass balance model relied on the extensive site data obtained from the database created to support this Reassessment RI/FS (USEPA, 1995) and other sources. This chapter presents the organization and analysis of the available data to specify required model forcing functions, initial conditions, rate coefficients, and state variable parameters. Additionally, observed spatial and temporal PCB concentration trends are presented to support model calibration, which is the topic of Chapter 7.

The following major sections are included in Chapter 6:

- 6.2 Available Data
- 6.3 Model Application Data Sets
- 6.4 Flow Balance
- 6.5 Mainstem and Tributary Solids Loads
- 6.6 Mainstem and Tributary PCB Loads
- 6.7 Sediment Initial Conditions
- 6.8 Water Temperature
- 6.9 Partitioning
- 6.10 Volatilization
- 6.11 Sediment Particle Mixing
- 6.12 Dechlorination
- 6.13 Sediment-Water Mass Transfer

Sections 6.4, 6.5 and 6.6 present development of the 21-year daily flow, solids and PCB inputs to the model. Section 6.7 presents development of beginning sediment PCB concentrations for the entire river from 1977 data for the historical calibration and 1991 data for the short-term hindcast applications. Sections 6.8 through 6.13 discuss the specification of various parameter values and other inputs to the model based on available data.

6.2 AVAILABLE DATA

The Hudson River is one of the most extensively monitored PCB contamination sites. The system has been studied extensively and monitored almost continuously over a period of more than 20 years. The various monitoring studies have provided numerous water column and sediment datasets useful to modeling PCB fate and transport in the system. Most of these data have been compiled by TAMS in the Hudson River Database, which was created to support this Reassessment.

The development and application of the HUDTOX model relied extensively on the Hudson River Database, in addition to data obtained from other sources. The Hudson River Database Report (USEPA, 1995) and accompanying CD-ROM database provides the validated data for the Phase 2 investigation. This Revised Baseline Modeling Report (RBMR) utilized Release 4.1b of the CD-ROM database, which was updated in fall 1998 (USEPA, 1998b). The Hudson River Database contains information from a large variety of different sources, including:

- New York State Department of Environmental Conservation (NYSDEC)
- New York State Department of Health (NYSDOH)
- New York State Department of Transportation (NYSDOT)
- General Electric Company (GE)
- Lamont-Doherty Earth Observatory (LDEO)
- Rensselaer Polytechnic Institute (RPI)
- U.S. Geological Survey (USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- U.S. Environmental Protection Agency (USEPA).

In addition to the Hudson River Database, site specific information was also obtained from a number of other sources, which are presented in the bulleted list below.

- An update to the GE database, dated 12 October 1998, was supplied by Kerry A. Thurston of O'Brien & Gere.
- To supplement the records available in Release 4.1b of the database, a portion of the 1997 USGS flow, suspended solids and PCB data were obtained directly from the USGS in Albany, New York (email to Penelope Moskus from Brian Wolorby on 8/12/98).
- Additional water column dissolved organic carbon data reported by J. Vaughn (1996), were used in addition to the measurements by GE and USEPA contained in the database.
- The 1998 GE Sediment sampling program data are not included in Release 4.1b although these data were also used. The poolwide average surface sediment PCB concentrations reported by QEA (1999) from these data were used as additional model calibration points for surficial sediment PCB concentrations in Thompson Island Pool (TIP) (Chapter 7).

- Atmospheric PCB concentration data from the Integrated Atmospheric Deposition Network (IADN) station at Point Petre, Ontario (Hoff, et al. 1996) were obtained to specify atmospheric PCB concentrations in the HUDTOX model.

Where necessary and appropriate, information from the scientific literature and various technical reports was also used to specify values for model process coefficients. These sources are cited in the report text.

The Data Evaluation and Interpretation Report (DEIR) (USEPA, 1997) and the Low Resolution Sediment Coring Report (LRC) (USEPA, 1998a) are companion reports to this Revised Baseline Modeling Report (RBMR). The DEIR contains a literature review of current and historical PCB water column data, and an evaluation of geochemical fate of PCBs in the sediments of the Upper Hudson River. The LRC contains an assessment of current and historical inventories of sediment PCBs in the Upper Hudson River. The reader is referred to these companion reports for additional details on the available datasets for this Reassessment.

6.3 MODEL APPLICATION DATASETS

The development and application of the HUDTOX model is based on the extensive sediment and water column monitoring datasets collected by primarily by the USEPA, USGS, NYSDEC, and the General Electric Company. A summary of the various data collection activities through 1994 is provided in the Hudson River Database Report (USEPA, 1995). In addition to the long-term record of PCB concentrations in water and sediment available from the combined datasets, a number of specific, focused studies were conducted by USEPA and GE. The data from these studies provide additional insight into processes affecting PCB fate and transport in the system, which supported parameterization of key processes in the HUDTOX model. This section provides an overview of the primary model application datasets and their use in the HUDTOX modeling effort.

6.3.1 Sediment Datasets

The primary sediment datasets used in this modeling effort are the sediment sampling surveys conducted by:

- NYSDEC in 1976-78 (Tofflemire and Quinn, 1979) and 1984 (Brown et al., 1988);
- GE in 1991 (O'Brien and Gere, 1993) and 1998 (O'Brien and Gere, 1999); and
- USEPA in 1992 and 1994 (DEIR and USEPA, 1998b).

The NYSDEC 1976-78, NYSDEC 1984, GE 1991 and the GE 1998 surveys are comprehensive assessments of PCB levels in the sediments. The NYSDEC 1976-78 and GE 1991 studies sampled the complete extent of the river from Fort Edward to Federal Dam, whereas, the NYSDEC 1984 survey was limited to Thompson Island Pool. The GE 1998 study extensively sampled Thompson Island Pool and included focused coring at a limited number of locations downstream as well. The USEPA 1994 studies were aimed at assessing PCB concentrations in a relatively small number of discrete areas in Thompson Island Pool and a few hotspot locations downstream.

Model initial conditions for sediment PCB concentrations for the 1977-1997 historical calibration were established from 1976-78 NYSDEC sediment PCB data, referred to as the 1977 NYSDEC data throughout this report (Section 6.7). The average surface sediment concentrations from the 1984, 1991, and 1998 datasets served as calibration targets for the historical calibration. The GE 1991 and 1998 data were considered primary calibration targets for surface sediments. The 1984 NYSDEC data and the 1994 USEPA low-resolution sediment core data were not primary calibration points for surface sediment PCBs because these data contain measurements of surface concentrations averaged over large depth intervals.

The sediment survey in Thompson Island Pool by GE in 1998 attempted to 'repeat' portions of the 1991 O'Brien and Gere, and 1994 USEPA sediment surveys (QEA 1999). Average concentrations for cohesive and non-cohesive sediments were computed for the 0-5 cm sediment layer and reported by QEA (1999). As the raw 1998 sediment data were obtained in a later phase of this project, the reported concentrations were used as additional model calibration targets for the Thompson Island Pool.

The "Low Resolution" sediment dataset collected by USEPA in 1994 provides assessments of sediment concentrations at approximately 20 locations in Thompson Island Pool (15 small zones and 4 near shore locations) and in 7 hotspots downstream of Thompson Island Pool. In addition, the USEPA data provide high-resolution core analyses at 28 selected locations in the Upper and Lower Hudson collected in 1992. The USEPA data are not extensive enough to serve as primary calibration information for the model. The main use of the 1994 USEPA sediment data was to assess changes in PCB levels relative to the 1984 measurements by NYSDEC at specific locations, which is a principal topic in the LRC (USEPA, 1998a). The high-resolution core data analyses included radionuclide dating, providing an estimate of sediment accumulation rates at specific locations (USEPA, 1997).

The sediment sampling effort conducted by USEPA included mapping of fine and coarse sediment grain size using side scan sonar images from Fort Edward to the Northumberland Dam (Flood, 1993). A qualitative sediment bed mapping survey was conducted by GE to characterize locations of fine and coarse sediment deposits between Northumberland Dam and Federal Dam (QEA, 1998a). The combined side scan sonar and qualitative bed mapping data were used to develop the model sediment segmentation (Section 5.3) and to classify some sediment samples for the purpose of determining fine and coarse sediment average PCB concentrations.

The GE 1991 and USEPA datasets included congener analysis in the water and sediments, which are available in the Hudson River Database, whereas the NYSDEC PCB analysis reported concentrations as Aroclors. The GE 1991 data were used to specify sediment initial conditions for modeling individual congeners and total PCBs over the period 1991 to 1997 (Section 6.7).

The GE 1991 data included measurement of porewater PCB and dissolved organic carbon data. These data were used to estimate in-situ sediment-water partition coefficients for individual congeners and the historical calibration state variable, Tri+. The development of the partition coefficients for Tri+ and congeners is presented in the DEIR (USEPA, 1997). The application of the partition coefficients estimated from these data is discussed in detail in Section 6.9.

A summary of the sediment datasets and their use in this modeling effort is summarized in Table 6-1.

6.3.2 Water Column Data

The principal water column datasets used for solids and PCBs in this modeling effort were the following:

- Long-term monitoring data collected at Fort Edward, Schuylerville, Stillwater and Waterford from 1977 to 1997 (collected by USGS, USEPA and GE)
- Thompson Island Dam data from 1991 to 1997 (collected by USEPA and GE)
- Mainstem and tributary solids data from the spring 1994 high flow survey (collected by USEPA)
- Mainstem data from the USEPA Phase 2 monitoring program in 1993
- High flow sampling data in 1997 (collected by GE)
- Thompson Island Pool float study data in 1996 and 1997 (collected by GE)
- Thompson Island Dam bias study data (collected by GE).

The long-term water column monitoring by USGS at Fort Edward, Schuylerville, Stillwater and Waterford, combined with the more recent sampling by GE and the USEPA at these and other locations, provides an extensive history of water column PCB and TSS concentrations in the Upper Hudson River. Monitoring of PCB and TSS concentrations by the USGS commenced in 1977 and continues to the present. The USGS data, combined with the more frequent data from the GE monitoring beginning in 1991, and the USEPA Phase 2 data collected in 1993 to 1994, allow specification of PCB and TSS loading at Fort Edward and the tributaries. In addition, these combined datasets permit development of in-river load estimates of PCB and TSS at Stillwater and Waterford over the entire historical calibration period. The long-term record of solids and PCB concentration measurements at Thompson Island Dam (1991 - 1997), Schuylerville (1977 - 1993), Stillwater (1977 - 1997) and Waterford (1977 - 1997) serve as principal calibration datasets for the HUDTOX modeling effort.

The GE water column monitoring data, which spans the period 1991 to the present, provides a high frequency monitoring dataset at Fort Edward and Thompson Island Dam, in addition to periodic data collected at downstream locations. GE also has conducted a number of specialized monitoring studies which provide insight into processes affecting PCB transport, localized sources of PCB loading and seasonal patterns in PCB fluxes.

The high flow event sampling in March and April of 1994 by USEPA represents the most extensive high flow solids monitoring dataset. Samples were collected during the only period over which tributary and mainstem TSS concentrations were measured simultaneously during a high flow event. While this dataset provides the most constrained assessment of solids dynamics over the course of a high flow event, PCBs were not simultaneously measured during this sampling event and a significant fraction of the total tributary flow was not measured for this period.

The USEPA also conducted a number of water column sampling surveys to assess PCB concentrations, sources, and transport in the system. Six of these surveys were down-river transects in which composite samples were collected over approximately two-week periods over six months spanning a range of seasonal conditions in the river. A series of seven sampling events occurring approximately monthly at 13 stations was also conducted in which sampling was timed to monitor the same parcel of water through the system. These USEPA Phase 2 data provide additional information about the spatial and seasonal patterns of PCB transport in the river and provide a determination of sediment-water partitioning behavior. Interpretation of the Phase 2 data and development of partitioning relationships from these data is presented in the DEIR (USEPA, 1997).

6.3.3 Conversion of PCB Data in Historical Calibration Datasets

Different sediment and water datasets used different analytical methods, which required various data adjustments in order to make the datasets comparable for use in the HUDTOX model calibration. The historical modeling state variable was the sum of tri and higher chlorinated congeners (denoted Tri+ in the remainder of this report). Individual congeners and total PCB could not be used for the historical calibration because neither congener analyses nor equivalent total PCB quantitations are available in the historical datasets. Individual Aroclors were also not consistently quantified between datasets. Additionally, Aroclors and total PCBs were considered unsuitable state variables for historical calibration because shifts in congener patterns due to weathering and/or dechlorination may result in variations in partitioning behavior. The Tri+ quantity could be determined in all datasets and was selected for the historical calibration. Tri+ was an attractive choice for a historical modeling state variable not only because it is consistently identified among datasets, but also because its composition is relatively less variable throughout the system than PCB forms including mono- and dichloro-biphenyls. Methods were previously developed (USEPA, 1998a, Butcher, 2000b) to convert the various PCB quantifications into estimates of the Tri+ concentration for each dataset. These methods are summarized for each dataset below.

6.3.3.1 USGS Water Column Data

The USGS water column data represent whole water analyses, with PCBs quantified using Aroclor standards. Packed column analysis was used until 1987, when data began to be analyzed with capillary columns. Approximately coincident with the USGS switch from packed column analysis to capillary column analysis beginning in 1987, a limited number of Aroclor standards were used relative to the earlier years.

Split sample analysis between USGS and Phase 2 data supported use of the USGS-reported total PCB concentration from the packed column analysis as a direct measure of the Tri+ sum. A regression relating USGS total PCB to the Tri+ sum gives a good linear fit with an intercept not significantly different from zero (USEPA, 1997). Thus, the USGS packed-column total PCB results were used directly as Tri+ through 1987.

Re-analysis of 60 USGS sample chromatograms by QEA (Rhea and Werth, 1999) supported use of the USGS reported Aroclor 1242 results or, when 1242 results are not available, use of Aroclor 1248 as the best representation of Tri+ concentration in the USGS data after 1987.

6.3.3.2 1976-1978 NYSDEC Sediment Data

Total PCBs were reported by O'Brien and Gere for the 1976-1978 sediment dataset. These were based on Aroclor analysis using a limited number of packed column peaks, which tended to miss the mono- and di-homologues. Based on reconstruction of the 1976-1978 total PCB results from USEPA Phase 2 sediment congener data, a regression between the Tri+ concentration and the 1977-1978 total PCB concentrations produced a zero-intercept model with which to estimate Tri+ concentrations from these data (Equation 6-1). Details of this analysis are presented in USEPA, 1998a and Butcher, 2000b.

$$\text{Tri+}\ (1977) = 1.131 \times [\text{Aroclor } 1016 + 1254] \qquad \textbf{(6-1)}$$

6.3.3.3 1984 NYSDEC Sediment Data

Total PCB concentrations reported for the 1984 sediment data were reported by NYSDEC as the sum of estimated concentrations of Aroclors 1242, 1254, and 1260. A constant conversion factor was determined to correct these data to a basis consistent with the Tri+ quantitation in the Phase 2 data (Equation 6-2). The analysis conducted to develop this conversion is presented in detail in USEPA, 1998a.

$$\text{Tri+}\ (1984) = 0.944 \times (1984 \text{ NYSDEC total PCBs}) \qquad \textbf{(6-2)}$$

6.3.3.4 GE Water Column and Sediment Data

The majority of GE water column results and all of the GE sediment data collected in 1991 include congener-specific analyses and homologue fractions. Tri+ concentrations were computed as the sum of tri-through deca-homologue concentrations.

6.3.3.5 USEPA Water Column and Sediment Data

All of the USEPA water column and sediment data include congener concentrations and calculated homologue concentrations. Tri+ concentrations were computed as the sum of tri- through deca-homologue concentrations

6.3.4 Data conversion for Total PCB and Congeners

While the primary calibration state variable in the long-term historical calibration is Tri+, short term hindcast applications over the period Jan. 1, 1991 through Sept. 30, 1997 were additionally conducted with individual congeners and total PCBs to test the Tri+ historical calibration.

Five congeners were selected for modeling based on physical and chemical properties and frequency of detection in all media types (sediment, water and biota). These five congeners are BZ#4 (a di-chlorobiphenyl), BZ#28 (tri-chlorobiphenyl), BZ#52 (tetra-chlorobiphenyl), BZ#101+90 (co-eluting penta-chlorobiphenyls) and BZ#138 (hexa-chlorobiphenyl).

In the GE congener quantitations, all five of the congener state variables co-elute with other congeners. BZ#28, 52 and 138 co-elute, respectively, with BZ#50, 73 and 163, all of which are minor congeners not quantitated by USEPA. The BZ#28, 52 and 138 concentrations in the GE data were used directly as measures of these congeners, ignoring the co-eluting, minor congeners. BZ#101 and BZ#90 co-elute in both the GE and the USEPA congener results and were not separated for modeling purposes. For the co-eluting BZ#4 and BZ#10 congeners, the average BZ#4/BZ#10 ratio determined in TIP water column and sediment samples presented by Hydroqual (1997) was used to compute BZ#4 concentrations in the GE water column and sediment data.

The GE database contains total PCB data analyzed by three different methods, which are referred to as the capillary column method (PCB_cap), the USGS method (PCB_usgs), and the Webb and McCall method (PCB_wm). The majority of the GE samples were analyzed using capillary columns, although a relatively small number of samples had only a USGS or Webb and McCall result reported. The method to be used was selected as follows: use PCB_cap result if available, or else use the PCB_usgs if available, and if neither PCB_cap or PCB_usgs are available, use PCB_wm.

6.4 FLOW BALANCE

6.4.1 Overview

The HUDTOX model is based on the principle of conservation of mass. Mass balances of flow, solids and PCBs are represented in the model. HUDTOX requires specification of all tributary and upstream flow inputs, in addition to external solids and PCB loads. The purpose of this section is to describe the development of daily flow inputs from upstream at Fort Edward and from tributaries and direct drainage flows for the calibration period (January 1, 1977 through September 30, 1997). Tributary inflows are specified for eight significant tributaries and four direct drainage inputs between Fort Edward and Federal Dam at Troy. Direct drainage flows were computed for drainage areas not included in the eight tributary watersheds and they are treated as additional tributary flows. The Fort Edward daily flow estimates were based on USGS flow gage data at Fort Edward. The Hoosic River and Mohawk River flow inputs were taken from continuous USGS records available for these tributaries. Ungaged tributary and direct drainage flows were estimated based on the Hoosic River flow records or other available USGS stream flow data in the Upper Hudson watershed.

Daily flow estimates for mainstem Hudson River locations downstream of Fort Edward were based on the sum of Fort Edward, tributary and direct drainage flow inputs. These synthesized flow time series were used for developing cumulative in-river solids and PCB load estimates to supplement the primary, long term sampling stations for use in model calibration (Sections 6.5 and 6.6).

6.4.2 Flow Data

Mainstem and tributary flow gages in operation during the study period are summarized in Table 6-2. The locations for these flow gages are shown in Figure 6-1. The Fort Edward gaging station (USGS # 01327750) was operational for the entire study period, whereas major gaps exist in daily flow records for the other mainstem stations. Reported USGS daily flow data for the Stillwater (USGS # 01331095) and Waterford (USGS # 01335754) stations are flagged by USGS as estimated values beginning in September 1992 at Stillwater and July 1992 at Waterford. This was due to construction activities that began in 1992 and continued through at least 1995 (USGS Water Resources Data 1993; and, Charles Fluelling, NYS Thruway, personal communication, February 27, 1997). The daily flows at Stillwater continued to be reported as estimates through the end of 1997 because this gage remained out of operation until that time. The only direct tributaries gaged for the entire study period are on the Hoosic (USGS # 01334500 at Eagle Bridge) and Mohawk Rivers (USGS # 01357500 at Cohoes, and # 01357499 at Crescent Dam). Stream flow data are available at two locations in the Fish Creek watershed: Kayaderosseras Creek (USGS # 01330500), and Glowegee Creek (USGS # 01330000). USGS flow monitoring at the Kayaderosseras Creek station was discontinued in 1995.

The ungaged tributary drainage area is a large percentage of the drainage area between Fort Edward and Waterford. The drainage area of tributaries feeding the Hudson River between Fort Edward and Waterford equals 1,794 mi^2. Only 33 percent of this area is gaged (Kayaderosseras Creek near West Milton (90 mi^2) and Hoosic River at Eagle Bridge (510 mi^2). Approximately 67 percent of the watershed area between Fort Edward and Waterford is ungaged. Flows draining ungaged watersheds were estimated as described in Section 6.4.

The Mohawk River is a large gaged tributary to the Hudson River (3,450 mi^2) which enters between Waterford and Federal Dam at Troy. The drainage area of tributaries feeding the Hudson River between Fort Edward and the Federal Dam at Troy equals 5,244 mi^2. Accounting for the gaged Mohawk River, Hoosic River and Kayaderosseras Creek drainages (3,450 + 510 + 90 = 4,050 mi^2), 77 percent of the tributary between Fort Edward and the Federal Dam at Troy (5,244 mi^2) is gaged.

Flood frequency analysis (Log Pearson Type III) was conducted based on 1930 to 1991 flows at Fort Edward by Butcher (2000a). As the period of record at Fort Edward commences in 1977, this analysis made use of flows estimated from the sum of flows measured upstream in the Hudson River at Hadley, NY (USGS gage # 01318500) and Sacandaga River (USGS gage # 01325000) for the period before 1977. The estimated 5, 50, and 100 year return frequency flows at Fort Edward based on this analysis are 30,126 cfs, 43,671 cfs and 47,330 cfs, respectively (Figure 6-2). The peak daily average flow at Fort Edward during the model calibration period occurred in 1983 (34,100 cfs), which has an estimated return frequency of approximately 11 years. In 1976, the year prior to the simulation period, a 37-year flow of approximately 42,000 cfs occurred, only 11 percent lower than the estimated 100 year flow.

6.4.3 Flow Estimation Methods

To specify daily upstream and tributary daily flow inputs to the HUDTOX model, daily average USGS flow records were used where possible and ungaged inflows estimated by relationship to these data. Upstream flow at Fort Edward was specified directly from the USGS data, without modification. Mohawk River flows (sum of daily flows at Cohoes and the Crescent Dam diversion), and the Hoosic River flows measured at Eagle Bridge were also used without modification. The USGS Fort Edward flow time series from 1977 to 1997 is shown in Figure 6-3.

Ungaged tributary flows were estimated using the drainage area ratio (DAR) method. This approach relates measured flows to unmeasured flows in similar watersheds by assuming equal flow yield per unit area of watershed. Based on gaged tributary flows, ungaged flows are computed using the ratio of watershed drainage areas (Equation 6-3).

$$Q_{ungaged\_tributary} = Q_{gaged\_tributary} \cdot \left(\frac{DA_{ungaged\_tributary}}{DA_{gaged\_tributary}} \right) \qquad \textbf{(6-3)}$$

where:

$Q_{ungaged\_tributary}$ = ungaged tributary flow

$Q_{gaged\_tributary}$ = gaged tributary flow

$DA_{ungaged\_tributary}$ = ungaged tributary drainage area

$DA_{gaged\_tributary}$ = gaged tributary drainage area.

The DAR approach was used to estimate all ungaged tributary and direct drainage flows based on USGS flow rate data from Kayaderosseras Creek, Glowegee Creek or the Hoosic River at Eagle Bridge. The ungaged area includes the Hoosic River watershed downstream of Eagle Bridge. Reference tributaries for each watershed in which flows were estimated were selected based on consideration of similarities in land use, topography, location and watershed size. Tributary watershed areas were estimated by digitizing the watershed boundaries from USGS topographical maps in a GIS (Table 6-3). All estimated tributary and direct drainage flows between Fort Edward and river mile 180 (just downstream of Schuylerville) were based on Kayaderosseras Creek or Glowegee Creek flow data, and those downstream of river mile 180 were based on Hoosic River at Eagle Bridge flow data (Table 6-3). The Kayaderosseras Creek gaging station is located in the upper portion of the watershed drained by Fish Creek (Figure 6-1). USGS flow monitoring at the Kayaderosseras Creek station was discontinued in 1995. Flow data collected on Glowegee Creek were used after 1995. The Glowegee Creek gage is located in the upper reaches of the same watershed as Kayaderosseras Creek and has a relatively small drainage area (26 mi^2).

Direct application of the DAR approach does not result in flows from individual tributaries that are mutually constrained in the sense that these estimates may not sum to observed flows at downstream locations in the Upper Hudson River. USGS flow estimates at Stillwater and Waterford were used to constrain estimated tributary flows in order to achieve a long-term seasonal average flow balance between Fort Edward and Waterford. Comparison of the estimated flows at Stillwater and Waterford for 1993 to the flow estimates presented in the DEIR (USEPA,

1997) showed the DEIR estimates to be substantially higher during low flow. Correlation of the DEIR summer average flow estimates with cumulative precipitation data revealed that the DEIR estimates were biased high (USEPA, 1999a). Consequently, the DEIR flow estimates were not used in any of the HUDTOX model applications and the USGS estimates at Stillwater and Waterford were used exclusively.

The seasons used in the seasonal flow balance were defined as follows:

- Spring: March, April, May
- Summer: June, July, and August
- Fall: September, October, and November
- Winter: December, January, and February

The seasonal mean flow computed by summing the Fort Edward and estimated tributary flows was compared to the seasonal mean flow from the USGS gages at Stillwater and Waterford over the period from March 1, 1977 to June 30, 1992 (Table 6-4). This period was used because all three gages (Fort Edward, Stillwater and Waterford) were operational. After September 1992, the gages at Stillwater Dam and Lock 1 at Waterford were influenced by dam construction activities and flows reported by USGS after this date are estimated.

The seasonal mean flows at Fort Edward, Stillwater and Waterford were computed from the USGS data over the period March 1, 1977 to June 30, 1992. Seasonal mean flow, increases in seasonal mean flow, and computed watershed flow yield between these locations are presented in Table 6-5. The ungaged tributary flows estimated by the DAR method were scaled using an adjustment factor, α, for season, j, in order to be achieve a long-term seasonal average flow balance between Fort Edward and Stillwater (Equation 6-4) and between Stillwater and Waterford (Equation 6-5). Equations 6-4 and 6-5 were solved for the adjustment factors (the α terms) for each season.

$$\left(\overline{Q}_{Still} - \overline{Q}_{FE}\right)_j = \left(a_{FE-Still}\right)_j \sum b_i \left(\overline{Q}_{reference}\right)_j \quad \textbf{(6-4)}$$

$$\left(\overline{Q}_{Watfd} - \overline{Q}_{Still}\right)_j = \left(a_{Watfd-Still}\right)_j \sum b_i \left(\overline{Q}_{reference}\right)_j \quad \textbf{(6-5)}$$

where:

$\alpha_{FE\text{-}Still}$ = seasonal adjustment factor for season *j* and for tributaries between Fort Edward and Stillwater

$\alpha_{Still\text{-}Watfd}$ = seasonal adjustment factor for season j and for tributaries between Stillwater and Waterford

$Q_{reference}$ = flow of gaged reference tributary

b_i = drainage area proration factor for tributary i

As discussed above, the drainage area proration factor for tributary i is the ratio of the ungaged to the gaged (or reference) tributary watershed areas (Equation 6-6).

$$b_i = DA_{ungaged\_tributary} / DA_{gaged\_tributary} \quad \textbf{(6-6)}$$

The mean seasonal flows, drainage area proration factors and seasonal adjustment factors are presented in Table 6-5.The seasonal flow adjustment resulted in average tributary flows that sum to the average flows at Stillwater and Waterford for the period considered in the flow balance.

The required adjustment for the ungaged tributary flow between Stillwater and Waterford was much less than 1.0 in the summer and fall (Table 6-5). This indicates that the extrapolation of the Hoosic River flows gaged at Eagle Bridge to ungaged tributaries using the DAR approach resulted in a significant overestimate of incremental flows during summer and fall in the reach from Stillwater to Waterford. It is possible that differences in watershed geology may cause different base flow behavior relative to higher flows in the Hoosic River compared to the smaller tributaries whose flow was estimated based on the Hoosic flow. Evaporative and other losses from the Hoosic River between Eagle Bridge and the Hudson may be significant during the summer and fall, which could result in an overestimate of the ungaged Hoosic River flows between Eagle Bridge and Hudson River for these periods.

To evaluate resulting tributary flows estimated in the manner described above, resulting flows at Stillwater and Waterford computed by summing the Fort Edward and tributary flows were plotted versus the USGS flow data (Figure 6-4). Generally, daily flow estimates were within 30 percent of the USGS estimates, however, during some high flow events, estimated flows differed by over 30 percent from the USGS flow. This was is not surprising, considering the DAR approach, which assumes that unit hydrograph responses seen at Eagle Bridge and Kayaderosserass Creek are instantly translated from the whole watershed to the Stillwater and Waterford gages. Thus the flow discrepancies are explained in part by relative timing of flood pulses.

To minimize error associated with estimating mainstem Hudson River flows during high flow events, an adjustment was applied for high flows differing by more than 30 percent from the USGS data. The USGS gage readings during the 1977 to 1992 period were assumed to be accurate within 30 percent during high flow events. Estimated tributary flows were adjusted to achieve agreement within 30 percent of the USGS flows when flow at Fort Edward was greater than 10,000 cfs. When the difference between estimated and USGS-reported flows was greater than 30 percent, the tributary flows were reduced according to their percent flow contribution at mean flow. This produced flow estimates within 30 percent of the USGS data for flows greater than 10,000 cfs at Fort Edward.

6.4.4 Results of Flow Balance

Analysis of the flow balance developed for the HUDTOX application period of January 1, 1977 to September 30, 1997 produces mean flows at Fort Edward, Schuylerville, Stillwater and Waterford of 5,248 cfs, 6,117 cfs, 6,603 cfs and 8,106 cfs, respectively. Mean Upper Hudson River flows increase 54 percent from Fort Edward to Waterford. The Fort Edward flow represents 79 percent and 65 percent of the average flow at Stillwater and Waterford, respectively. During this period, the estimated peak flows at Fort Edward, Schuylerville, Stillwater and Waterford are 34,100, 40,200, 46,800 and 70,500 cfs, respectively. Peak flows at Fort Edward and Schuylerville occurred in 1983, while at Stillwater and Waterford, peak flow occurred in 1977. The 1983 flow has an estimated return frequency at Fort Edward of approximately 11 years.

Figure 6-5 presents a summary of average daily flows for the study period, by tributary and mainstem station. The three largest tributaries in order of decreasing mean flow are the Mohawk River, Hoosic River and Batten Kill. Average flows increase by a factor of 1.2 and 1.5 from Fort Edward to Stillwater and Fort Edward to Waterford, respectively. Flows over Federal Dam, the downstream extent of the model are a factor of 2.5 larger than Fort Edward flows.

A plot of estimated flow contributions from each source along the river allows visualization of relative magnitude of the various tributary inputs (Figure 6-6). Approximately 35 percent of the flow volume at Waterford is due to tributary inputs entering between Fort Edward and Waterford. The Fort Edward flow represents about 65 percent of the flow past Waterford. The Hoosic River and Batten Kill are the largest sources, providing 16 percent and 7 percent of the flow at Waterford, respectively. At Federal Dam, approximately 62 percent of the total flow is from tributaries, with the Mohawk being the largest source, providing 41 percent of the total flow at Federal Dam. Only 38 percent of the flow at Federal Dam is from the Fort Edward flow during the 21-year study period.

6.4.4.1 Validation of the Flow Estimation Approach

While the above tributary and mainstem flow balance was determined for the period from March 1, 1977 to June 30, 1992, the adjustment factors in Table 6-5 were applied to the DAR-estimated tributary flows for the entire HUDTOX application period from January 1, 1977 to September 30, 1997. As a measure of accuracy, the estimated daily flows at Stillwater and Waterford were compared to the reported USGS daily flows and average annual flows. After 1992, the USGS flows are also estimated values at Stillwater and Waterford.

Estimated and USGS-reported flows were compared on a daily and average annual basis. The estimated and USGS-reported average annual flow passing Stillwater and Waterford was compared for each year of the calibration period (Table 6-6). Results indicate that mean annual flows are within 7 percent at Stillwater and 9 percent at Waterford. Percent differences for the 1993-1997 period, which is outside of the flow balance period, are consistent with the 1977 to 1992 flow balance period. The difference between estimated and USGS-reported average flow over the entire calibration period is about 1 percent at each location. Scatter plots of daily estimated versus USGS-reported flows at Stillwater and Waterford also show fairly good agreement for the 1993-1997 period, generally within about 30 percent (Figure 6-7). Inspection of the estimated and USGS-reported daily flow hydrograph also suggests that the flow estimation approach produced good results for this period (Figure 6-8). Based on the good agreement between the estimated and USGS-reported flows for the entire calibration period, the flow estimation method described above was considered to give good results that were acceptable for modeling purposes.

6.4.4.2 Application of Estimated Flows in Modeling

The USGS -reported flow at Fort Edward and the synthesized daily average flow time series for tributaries were input as discrete daily time functions in the HUDTOX model.

To compute in-river mass loads of solids and PCBs for comparison to model output, the estimated daily flow time series at TI Dam, Schuylerville, Stillwater and Waterford were used, instead of the USGS flow estimates, which are available at Stillwater and Waterford.

6.4.4.3 Summary of Flow Balance

Approximately 20 percent of the total tributary flow inputs to the HUDTOX model were estimated. Between Fort Edward and Waterford, approximately 60 percent of the tributary flows were estimated. Ungaged drainage areas between these stations accounts for 67 percent of the total tributary drainage area. Tributary flow estimates used the DAR approach, relating unmeasured flows to measured flows on Kayaderosseras Creek (substituting with Glowegee Creek after 1995), and the Hoosic River. Flow estimates were adjusted to achieve a seasonal water balance from 1977 to 1992 between Fort Edward and Stillwater and between Stillwater and Waterford. Based on comparison to USGS data, corrections were made to estimated flows during high flow periods to be within 30 percent of USGS flows. Estimated flows were compared to USGS-reported flows at Stillwater and Waterford, which are estimated by USGS, for the period 1992 to 1997 with good results. The estimated flows were used to specify flow inputs to the HUDTOX model and to develop in-river mass flux estimates for solids and PCBs, which is explained in the following sections.

Daily average flows over the study period increase by approximately a factor of 1.2 and 1.5 from Fort Edward to Stillwater and Fort Edward to Waterford, respectively. While the Fort Edward flow is the largest single flow input upstream of Waterford, the Mohawk River flow is larger than the Fort Edward flow and is the largest inflow between Fort Edward and Federal Dam.

6.5 MAINSTEM AND TRIBUTARY SOLIDS LOADS

6.5.1 Overview

The HUDTOX model requires specification of solids and PCB inputs, analogous to the specification of flow inputs from upstream and tributary sources. Daily average solids loading to the HUDTOX model from upstream at Fort Edward and from all tributary inputs was estimated for the entire calibration period: January 1, 1977 through September 30, 1997.

Total suspended solids (TSS) concentrations were not measured at all locations, or continuously throughout the calibration period, requiring estimation of a significant fraction of the total solids loading. Daily sampling frequency was approximately 11 percent at Fort Edward for the calibration period. Data was especially limited for tributaries, for which daily TSS monitoring frequency is less than 2 percent for those tributaries that were monitored. In addition, only 71 percent of the watershed area was monitored for TSS, requiring estimation of TSS loads from the other 29 percent of the watershed with no data.

As a consequence of the limited data available, resulting estimates of tributary loads are very uncertain. Initial estimates of tributary solids did not result in a solids balance for the mainstem Upper Hudson River. The sum of upstream and tributary loads were significantly lower than in-river estimates at Stillwater and Waterford. As a result, assumptions were required regarding in-river solids dynamics which led to adjustment of solids loads to achieve a long-term solids balance. Significantly more solids data are available at low and high flows for the main Thompson Island Pool tributaries (Snook Kill and Moses Kill), which allows estimation of solids loads to the Thompson Island Pool with more certainty than to downstream reaches. The significant uncertainty associated with the estimation of tributary solids loads downstream of Thompson Island Pool is addressed through model sensitivity analysis (Chapter 7).

Apparent decreases on solids loads over time at Fort Edward were observed during the calibration period. The solids loading was observed to be lower for given flows at Fort Edward after 1990, compared before 1990. In developing estimates of the Fort Edward solids loads, separate rating curves were developed for these periods based on this observation.

6.5.2 Solids Data

The available solids data for the mainstem and tributary stations are summarized in Tables 6-7 and 6-8, respectively. The locations of these solids sampling stations are shown in Figure 6-9. More frequent solids concentration data were available for mainstem stations than tributary stations, with no tributary solids data available prior to 1988. In addition, as illustrated in Figure 6-10, only 71 percent of the watershed area between Fort Edward and Waterford was monitored for solids, thus requiring estimation of solids loads from 29 percent of the total watershed area in the Upper Hudson River. Furthermore, for the 71 percent of the watershed area that was monitored, only very limited data are available for most of the tributaries. Generally, tributary samples were collected for only a short period of time during the 21-year study period. Solids samples were collected for mainstem and tributary stations on only 24 percent and 1 percent, respectively, of the total days in the 21-year simulation period.

An extensive record of suspended solids concentration data is available at Fort Edward, Stillwater and Waterford over the 21-year study period. Although numerous measurements are available, sampling frequency was sporadic during certain time periods.

Due to differences in sample collection methods between GE and USGS, there is uncertainty as to whether or not these datasets are comparable, especially at Fort Edward. The GE samples were collected by O’Brien & Gere by a number of methods. For the GE 1991 Thompson Island Pool Suspended Solids Study, a Manning automatic sampler was used to collect samples from an intake tube positioned at mid-depth (O’Brien & Gere, May 1993a). In the other GE studies, TSS samples were obtained using a 1.2-liter Kemmerer sampler to collect depth-composited samples either at 3-foot depth intervals throughout the water column (e.g. O’Brien & Gere, May 1993b), or at surface, mid-depth and deep sample depths (e.g. O’Brien & Gere 1998). The USGS TSS sampling method collected a continuous depth-integrated sample throughout the entire water column (personal communication 10/29/99, Ken Pearsall USGS, Albany New, York).

During periods when a strong vertical gradient in TSS concentrations existed, it is possible that the GE sampling approach may have resulted in a low bias in measured TSS concentration relative to TSS measurements obtained by the USGS sampling method. This potential is greatest during periods of high flow, due to possible occurrence of bed load. This may also affect estimates of PCB loading because the GE samples were analyzed for both TSS and PCB.

Relative differences in GE and USGS TSS concentrations were assessed several ways. First, daily average GE and USGS TSS concentrations between 5/10/91 and 4/9/97 were paired on the basis of date, resulting in 30 daily average data pairs. Scatter plots of the daily average pairs were developed for daily average flows above and below 10,000 cfs (Figure 6-11). Based on observation of the TSS/flow correlation and in-river PCB data, flow of approximately 10,000 to 11,000 cfs is considered to be an approximate threshold above which resuspension becomes significant in the river. Inspection of these scatter plots suggests that GE and USGS TSS measurements may be biased relative to each other, but in different directions at high and low flow. At low flow, GE TSS measurements appear to be significantly greater than USGS measurements. At high flow, the opposite may occur, at least for concentrations greater than 10 mg/L. These observations are not well supported due to the limited number of data pairs available and uncertainty as to exact times of collection. A second approach to investigating differences in USGS and GE data was to group the data by flow range and test for statistically significant differences in mean concentrations in each flow range. Two-sample and paired sample statistical tests were done at low flow (less than 10,000 cfs) and at high flow (greater than 10,000 cfs). The results of these tests tended to confirm what was observed in the above scatter plots: the GE measurements were higher at low flow, while the USGS measurements were higher at high flow.

The GE data represents a significant percentage of the total available daily average TSS measurements at Fort Edward (40 percent) for use in computing the upstream TSS loading. While comparison of USGS and GE data suggest that these data may have biases relative to each other, the limited data pairs available do not support discrimination between these datasets. The data were combined for use in computing Fort Edward TSS loads (Section 6.5).

6.5.3 Methods for Estimating Solids Loads

Solids loading estimates were based on sediment rating curves developed for the upstream load at Fort Edward, all tributary inputs and for long-term mainstem Hudson River TSS sampling stations. The mainstem Hudson River solids load estimates downstream of Fort Edward were used to develop a long-term solids balance for the river and for comparison to model output. The solids rating curves relate observed TSS concentrations to flow and thus describe solids loading as a function of flow. The general form of the rating curve is presented below (Equation 6.7)

$$TSS = aQ^b \qquad \textbf{(6-7)}$$

where:

Q = flow

a,b = fitting parameters

Using measured daily average TSS concentrations where available and concentrations estimated from rating curves for days on which no measurements were taken, daily average TSS loads were computed for the HUDTOX calibration period: January 1, 1977 through September 30, 1997. The daily solids load time series computed for Fort Edward and the tributaries were input directly into the HUDTOX model. The estimated in-river sediment loads passing Stillwater and Waterford were used as model calibration targets.

6.5.3.1 Mainstem Solids Loads

To develop suspended solids rating curves for the mainstem Hudson River sampling stations, daily average TSS concentrations were plotted versus daily average flow. Suspended solids concentrations are generally correlated with flow at Fort Edward, Stillwater and Waterford, with a stronger dependence of solids concentration on flow observed at higher flows (Figure 6-12). The relationship between solids concentration and flow is distinctly different at flows above approximately 1.0 to 1.5 times the average flow at each location. The flow at which the relationship between TSS and flow changes at each station is referred to as the flow cut-point. Regression equations were developed for each station that describe the relationship between TSS and flow above and below the flow cut-point.

A non-linear least squares regression approach was used to fit the data above and below the flow cut-point. An alternative approach considered was the Minimum Variance Unbiased Estimator (MVUE) method of Cohn et al. (1989). Comparison of results from these two methods shows that differences are small (Figure 6-13). The non-linear least squares regression approach has benefit of being applied using commonly available software rather than requiring special computer code.

The approach taken consisted of two phases. The first phase, using log-transformed data, simultaneously developed linear regression equations and refined the specification of the flow cut-point so as to obtain a continuous function relating TSS concentrations to flow over the entire flow range of interest. The second phase eliminated transformation bias by using non-linear least squares regression of the un-transformed data; retaining the first phase cut-point at the cost of a discontinuity in the TSS prediction at the cut-point. This process described above is presented below in more detail.

1. An initial cut-point was selected based on visual inspection of the TSS – flow plots.

2. The (log-transformed) data above and below the flow cut-point were fit with a linear least squares regression equation of the form $\ln(TSS) = A + B * \ln(Q)$, where A and B are the equation parameters.

3. The value of Q for which the low flow and high flow equations were equal at the cut-point was computed.

4. Step 2 was repeated with the value of Q computed in step 3.

5. Steps 2 through 4 were repeated until convergence was obtained.

6. The (un-transformed) data above and below the cut-point were fit with a non-linear

least squares regression equation of the form TSS = aQ^b, where a and b are the equation parameters. However, if the relationship between TSS and flow was not significant, the arithmetic average TSS was used.

The resulting rating curve equations for each station are presented below. The equations fit data below and above the cut-point, respectively.

Fort Edward Q_{cut} = 10,829 cfs

$$Q < Q_{cut} : \text{TSS} = 1.767 \times Q^{0.08624} \quad \textbf{(6-8a)}$$

$$Q \geq Q_{cut} : \text{TSS} = 1.431\text{E-}8 \times Q^{2.101} \quad \textbf{(6-8b)}$$

Schuylerville Q_{cut} = 3,866 cfs

$$Q < Q_{cut} : \text{TSS} = 3.79 \quad \textbf{(6-9a)}$$

$$Q \geq Q_{cut} : \text{TSS} = 0.0004238 \times Q^{1.13} \quad \textbf{(6-9b)}$$

Stillwater Q_{cut} = 7,555 cfs

$$Q < Q_{cut} : \text{TSS} = 0.0122 \times Q^{0.6937} \quad \textbf{(6-10a)}$$

$$Q \ ³ \ Q_{cut} : \text{TSS} = 4.555\text{E-}6 \times \text{Q } 1.595 \quad \textbf{(6-10b)}$$

Waterford Q_{cut} = 9,799 cfs

$$Q < Q_{cut} : \text{TSS} = 0.06739 \times Q^{0.5287} \quad \textbf{(6-11a)}$$

$$Q \geq Q_{cut} : \text{TSS} = 8.489\text{E-}9 \times Q^{2.213} \quad \textbf{(6-11b)}$$

Subsequent to development of rating curves based on all available data for the calibration period, investigation of possible changes over time in the solids load at Fort Edward was pursued. This was undertaken primarily in response to comments received from NOAA personal at the June 16 Science and Technical Committee Meeting, Albany, NY. Investigation of possible decreases in Fort Edward solids loading over the calibration period is prudent considering a number of possible factors, including: 1) washout and consolidation of former Fort Edward Dam impoundment sediments in the river; and 2) stabilization of the remnant deposit areas.

To initially assess whether the relationship between TSS and flow changed at Fort Edward over the calibration period, rating curves were developed as described above for the first five years (January 1, 1977 through December 31, 1982) and the last 5 years (January 1, 1993 through September 30, 1997) of the calibration period. Results indicated that there was a statistically significant reduction in TSS concentrations at both high and low flow between these two periods. This suggested it was necessary to account for the decrease in TSS loading in order to achieve the best estimate at Fort Edward over the calibration period. This required specification of time intervals over which to represent the change in solids loads.

Reductions in solids erosion over time from bedded sediments and the exposed remnant deposit areas were considered possible factors contributing to observed decreases over time in solids load at Fort Edward. A review of site information related to erosion of the former Fort Edward Dam sediments was used to estimate a reasonable time stratum. A number of sources document high erosion rates and solids loading to Thompson Island Pool following removal of the Fort Edward Dam. Various stabilization activities were conducted within the calibration period that were designed to reduce erosion of the former dam sediments.

Over the period July 1973 to April 1976, following removal of the Fort Edward Dam in 1973, approximately 1.0 million cubic yards of PCB laden sediments were washed downstream into Thompson Island Pool (NUS 1984). It is likely that significant erosion continued to occur after 1976. In 1978, areas of highly contaminated river-bank sediment that were exposed following the removal of the Fort Edward Dam were stabilized from a highly erodable state (Brown et al. 1988). The five discrete remnant sediment deposit areas upstream of Fort Edward identified by NUS (NUS 1984) were sources of sediment and PCBs until containment of the remnant deposit sediments in the fall of 1990. Following containment activities in 1990, PCB loading from the remnant deposit sediments appears to be small, if any (O'Brien & Gere 1996).

To account for changes in the TSS to flow relationship in specifying solids loads at Fort Edward, 1990 was considered a reasonable boundary for the two time strata. While decreases in solids loads also likely occurred before 1990, the stabilization activities completed by GE at the remnant deposit areas in the fall of 1990 provides a logical time stratum for investigating changes in solids loads.

The daily average TSS data at Fort Edward were grouped before and after Dec. 31, 1990 and tested for statistical difference at both high and low flow. Results indicate that there is a significant difference in the solids rating curves that were developed following the procedure presented above. Resulting Fort Edward rating curves for the pre and post 1990 periods are presented below and in Figure 6-14, for flows below and above the cut-points, respectively.

1977-1990 Q_{cut} = 10,100 cfs $Q < Q_{cut}$: TSS = $0.0674Q^{0.5024}$ **(6-12a)**

$Q \geq Q_{cut}$: TSS = $9.505E\text{-}7Q^{1.701}$ **(6-12b)**

1991-1997 Q_{cut} = 12,100 cfs $Q < Q_{cut}$: TSS = 3.23 **(6-13a)**

$Q \geq Q_{cut}$: TSS = $8.202E\text{-}11Q^{2.592}$ **(6-13b)**

These equations were used to compute cumulative suspended sediment loading at Fort Edward over the HUDTOX calibration period: January 1, 1977 to September 30, 1997. To illustrate the estimated change in loads before and after 1991, the average annual solids loading for each period were compared, showing 38% percent difference for the earlier and later periods, respectively. Part of this difference is attributable to differences in flow. The two largest flow events in the calibration period (1977 and 1983) occurred before 1991.

Because the time stratification approximately coincides with the time that TSS data became available from the GE studies, it is reasonable to consider the influence of data source on the observed decrease in solids loading. One way to assess the influence of data source is to investigate the justification for time stratification based the USGS data alone. It is not practical to attempt this with the GE data because GE data collection began in 1991.

Possible support for time stratification based only on the USGS data was investigated two ways. First, the USGS data at Fort Edward was time (before and after Dec. 31, 1990) and flow stratified (above and below 10,000 cfs) and the high and low flow data groups were compared for each period. This assesses whether there is a difference in mean concentrations at high and low flow between the two periods, although differences due to flow effects are not accounted for. Secondly, to account for the influence of flow on observed differences, TSS data from the two time periods were paired on the basis of flow. Typically, paired data had differences in flow of less than 1 percent. TSS data that could not be closely matched on the basis of flow were excluded from this paired comparison. The second approach addresses the question of whether the average difference in TSS concentrations between the two time periods is significantly different from zero while removing the obscuring influence of flow. The following statistical tests were done using Systat 8.0 (Systat 8.0 Statistics, 1998. SPSS, Inc.):

- Two-sample t-tests with logarithmically transformed data;
- Mann-Whitney U tests;
- Paired samples t-tests with logarithmically transformed data; and,
- Wilcoxon Signed Ranks tests.

For both low and high flows, all tests indicated that USGS TSS measurements for the later time period decreased relative to the earlier time period. The differences were found to be substantial, both in absolute terms and in terms of statistical significance (i.e. $p<0.05$ in all cases). These results show that the use of time stratification in computing the Fort Edward solids load is supported, at both high and low flows, regardless of whether or not the GE data are included. Inclusion of the GE data in developing the time stratified rating curves tends to increase computed TSS loads at low flow and decrease computed TSS loads at high flow. Use of the GE data was considered appropriate considering the large number of GE data available, uncertainty as to potential differences between the two datasets, and the observed changes in the USGS TSS/flow relationships independent of the GE data. In spite of observed differences between GE and USGS data, the use of time stratification in the rating curve is supported based on the finding that both the USGS dataset and the combined USGS-GE dataset show statistically significant decreases in concentration over time.

The time stratified rating curves developed based on all the available data (Equations 6-12 and 6-13) were used to compute TSS loads at Fort Edward for the model calibration. To develop the daily loading time series for the model calibration, measured daily average TSS concentrations were used where available, and TSS concentrations were computed using the rating curves for days upon which TSS was not measured.

In order to develop a long-term solids balance for the Upper Hudson River, cumulative solids loads at Stillwater and Waterford were computed in the same manner as described for Fort Edward. While decreases in TSS concentrations over time were also observed at Stillwater and Waterford at low flow, no statistically significant differences were observed at high flows. Based on this observation, the use of time-stratified ratings curves was not well supported at Stillwater and Waterford, and was not used in the calculation of solids loads at these locations. Estimates of in-river solids loads at Stillwater and Waterford were used in model calibration and in developing a long-term solids balance for the river (Section 6.5).

The solids rating curves at Fort Edward (Equations 6-8a and 6-8b), Stillwater (Equation 6-10a and 6-10b), and Waterford (Equation 6-11a and 6-11b) were used to estimate TSS concentration for days where measurements were not available. This allowed estimates of daily TSS loads at these locations for the entire calibration period (1977-1997).

6.5.3.2 Tributary Solids Loads

A major obstacle to estimating tributary solids loads was that available solids data were very limited. This factor, combined with uncertainty in estimated tributary flows (Section 6.4) resulted in poorly constrained estimates of tributary solids loading. There is significant uncertainty in the resulting tributary load estimates, especially downstream of Thompson Island Pool.

The general approach used for estimating tributary TSS loads was similar to that adopted for the Fort Edward load. TSS rating curves were developed to relate TSS concentrations to flow. Similar to the pattern observed at the mainstem stations, tributary solids concentrations were positively correlated with flow and the tributary rating curves generally exhibited a cut-point above which the slope of the relationship increases (Figure 6-15). The average flow of each tributary was observed to reasonably approximate the flow cut-point above which TSS concentrations increase significantly in each tributary. Below the average flow, TSS concentrations were generally not flow dependent or only weakly flow dependent, so average TSS concentrations were specified below average flow.

Many tributaries were not monitored for suspended solids concentration. Unmonitored tributaries represent 29 percent of the drainage area between Fort Edward and Waterford. For unmonitored tributaries, the TSS rating curves developed for the monitored tributaries were applied. Each unmonitored tributary was matched with a monitored tributary based on consideration of land use distribution, watershed size, topography and location (Table 6-9). The rating curve for Moses Kill was used to estimate solids loads for all unmonitored drainage areas between Fort Edward and Stillwater. The Hoosic River rating curve was applied for unmonitored drainages between Stillwater and Waterford. Loads for each of the unmonitored tributaries were scaled to account for differences in drainage area from the reference tributary.

In two cases, unmonitored drainage areas were reduced in the estimate of solids loading to account for sediment trapping. The unmonitored drainage area between Fort Edward and TI Dam includes the Champlain Canal, which is fed by Bond Creek and water diverted from the Hudson upstream of Fort Edward (Art Murphy, NYS Canal Corporation, personal communication). The canal is highly regulated and during high flow is allowed to overflow, delivering water to the Hudson via overland flow. This likely results in solids retention in the canal. The effective drainage area of the Champlain canal was assumed to be 8 mi^2, 26 percent of the canal's watershed area (31 mi^2). Fish Creek drains Saratoga Lake, which receives tributary runoff from the bulk of the Fish Creek watershed. It was assumed that 80 percent of the tributary solids load from Fish Creek watershed was retained in Saratoga Lake. Therefore, 90 mi^2 of the 245 mi^2 watershed was considered in computing tributary solids loads.

The flow-dependent rating curve coefficients developed for each tributary are presented in Table 6-10. As discussed above, constant concentrations were specified below the average flow.

Resulting tributary solids loads from application of the tributary TSS rating curves in the manner described above were evaluated in the context of a solids balance for the mainstem Upper Hudson River. The period chosen for the solids balance was Jan. 1, 1977 to Jun. 30, 1992 because all mainstem river flow gages were operational during this time. Limiting the mass balance to this period was intended to reduce error associated with flows reported as estimates by USGS after 1992.

A comparison of annual average mainstem solids yields for the drainage area at Stillwater and Waterford to tributary solids yield (Table 6-11) shows that mainstem yields are about a factor of two larger than the estimated tributary yields. Table 6-12 presents the mainstem solids load increments between Fort Edward, Stillwater and Waterford. Estimated solids loads passing Stillwater and Waterford are 1.7 and 2.0 times larger than the sum of Fort Edward and upstream tributary solids loads. Assuming the mainstem in-river solids load estimates are accurate, the observed increases in in-river solids loads must be explained by either:

- additional external loads, from tributary inputs or other sources;
- internal production of solids from primary production; or,
- net erosion of the sediment bed between Fort Edward and Waterford.

External sources other than tributary load inputs are assumed negligible and estimates of possible contributions of solids from primary production were insignificant. Therefore, if estimated tributary solids loads are assumed accurate, this implies that resuspension accounts for the observed increases and that the Upper Hudson River is on average net erosional between Fort Edward and Waterford.

Considering that the Upper Hudson is an impounded system with six dams over the 40 miles between Fort Edward and Waterford, it was considered unlikely that the river is net erosional over this reach. Typically, river impoundments experience net deposition. Required navigational dredging over the extent of the Upper Hudson also suggests that the river is depositional, however, erosion-derived sediment from other areas of the river could be responsible for required navigational dredging in the main channel. Based on the assumption that the river was net depositional on a reach basis, it was concluded that tributary loads were likely underestimated and required upward adjustment to achieve a long-term solids balance with observed loads passing Stillwater and Waterford.

6.5.3.3 Development of Long-term Solids Balance

Development of a long-term solids balance for the Upper Hudson is possible for reaches to which upstream and downstream in-river solids loads are known. For each reach, the sum of upstream loads, tributary loads and internal sources (resuspension or primary production) must equal the estimated in-river load. As discussed above, primary production contributions (from algal growth) and solids loads from external sources, excluding tributary inputs, (such as possible point source or other direct loads to the water column) were assumed insignificant in developing the solids balance. Thus, the solids balance required that upstream loads, tributary loads, and net solids loads from the sediment sum to the estimated in-river loads leaving each reach. Unless solids loads to the system being modeled are equal to solids transport out of the system, internal solids dynamics are unconstrained in the model. For example, if upstream and tributary loads are estimated without consideration of net solids exchange with the sediment bed, calibration of the model to observed in-river loads may result in unrealistic predictions of bed behavior.

In adjusting tributary solids loads to achieve a long-term solids balance, all impounded reaches of the Upper Hudson river from Fort Edward to Waterford were assumed to be net depositional over decadal time scales, even if there might be localized areas within reaches that are net erosional. Estimated solids loads passing Fort Edward, Stillwater and Waterford were assumed to be accurate.

Depositional loads to each reach were estimated and tributary TSS loads were increased between Thompson Island Dam and Waterford to equal the sum of observed loads at Waterford and the estimated depositional load. Tributary solids loads to Thompson Island Pool from Snook Kill, Moses Kill and direct drainage inputs were not adjusted. These tributary load estimates are based on sufficient TSS and flow data such that their solids loads are reasonably well known. The Mohawk River suspended solids loads were also not adjusted because insufficient data exist at Federal Dam to evaluate the solids balance between Waterford and Federal Dam.

A measure of the depositional load is the long-term average sediment burial velocity. Measurements of burial velocity were obtained by USEPA using radionuclide sediment core dating at 5 locations between Federal Dam and Fort Edward (USEPA, 1997). Two of these locations are in TIP. These measured burial velocities represent long-term average deposition at the core sites, however, these locations were generally positioned in low energy, highly depositional areas and are not considered representative of reach-wide average conditions. Therefore, estimation of sediment burial rates or reach-specific solids trapping efficiency was necessary. Solids trapping efficiency can be used to compute the average burial rate based on sediment density as shown later below.

Calculations of solids burial rates were available from a sediment transport model (SEDZL) developed for the Upper Hudson River by General Electric Company (GE) contractors (QEA, 1999). Flow and solids loading inputs to SEDZL were developed through discussion with the USEPA in the development of the HUDTOX model. As a result, the SEDZL inputs are nearly identical to the inputs described in this report. Initial sediment transport simulations conducted by GE were used to compute burial rates (and solids trapping efficiency) by reach for use in computing the tributary solids loads. Final results indicated that initial input assumptions were reasonable. The SEDZL simulation period was nearly the same as the HUDTOX 21-year historical calibration period. This sediment transport model was based on the same cohesive sediment resuspension formulations and site-specific data used to develop the Depth of Scour Model (DOSM) presented in Chapter 4. This model also used theoretical formulations for non-cohesive sediment armoring based in part on the non-cohesive sediment scour calculations in the DOSM. Earlier versions of SEDZL have been successfully applied on other similar river systems (e.g. Ziegler and Nisbet, 1994, Pawtuxet River, R.I.; Galiani et al. 1996, Buffalo River, N.Y.). Details of the SEDZL sediment transport model development and application to the Upper Hudson River are provided elsewhere (QEA, 1999).

Available SEDZL calibration results suggest the GE sediment transport model achieved reasonable agreement with estimated burial rates at the USEPA high-resolution sediment core sites (QEA, 1999). Results were within a factor of two with measured solids burial rates from all but one of the high resolution sediment cores. Agreement was within a factor of five for the remaining sediment core. The burial rate results from this sediment transport model contain uncertainty, however, due to large uncertainty in model inputs, especially tributary solids loads downstream of Thompson Island Pool. These uncertainties affect long-term solids burial rates in both cohesive and non-cohesive sediment areas. These limitations notwithstanding, burial rates from the SEDZL sediment transport model were considered reasonable estimates. Downstream of Thompson Island Pool, these estimates are affected by high uncertainty as would be any estimates that could be made, due to the limitations of the tributary flow and solids data.

Based on the above considerations, the reach-specific estimates of TSS trapping efficiency from the GE sediment transport model presented in Table 6-13 were used to develop the long-term solids balance for Jan. 1, 1977 through 1997. The trapping efficiency estimates by reach were area-weighted to determine trapping efficiencies for TI Dam to Stillwater (8.47 percent) and Stillwater to Waterford (3.66 percent) reaches. Solids depositional loads to the sediments in each reach were computed from the trapping efficiency and used to back-calculate total tributary loading to the each reach. The trapping efficiency is generally related to the depositional load as shown in Equation 6-14.

$$\text{Depositional load(kg/d)} = \begin{pmatrix} \text{upstream load} \\ + \text{tributary load} \end{pmatrix} \text{(kg/d)} \times \text{trapping efficiency (\%)} \qquad \textbf{(6-14)}$$

In order to determine depositional loads to each reach, calculation of tributary loads and upstream loads was done in succession for Thompson Island Pool, Thompson Island Dam to Stillwater, and Stillwater to Waterford. In Thompson Island Pool, the available data for tributaries (Snook Kill and Moses Kill) was sufficient to compute loads directly from data-based rating curves. A long-term data-based solids balance could not be conducted explicitly for Thompson Island Pool because Thompson Island Dam sampling began in 1991. Based on the successful calibration of the SEDZL model to available data at the dam (presented by QEA, 1999), the Thompson Island Pool trapping efficiency estimate is assumed reasonably accurate for use in computing the Thompson Island Dam solids load. This was estimated by multiplying the TIP trapping efficiency estimate (8.8 percent) and the sum of tributary and upstream loads (Equation 6-15). The incremental load computed for the Thompson Island Dam to Stillwater reach (Equation 6-16) was apportioned to each tributary based on the percent of total tributary watershed area, excluding watershed area draining to the upstream portion of river (Table 6-2), as shown below.

Thompson Island Dam to Stillwater solid balance:

$$L_{TID} = (1-.088) \times (L_{FE} + L_{Snook} + L_{Moses} + L_{DD}) \qquad \textbf{(6-15)}$$

$$\Delta L_{trib,TID\text{-}Still} = \frac{L_{Still}}{1\text{-}\%trap} - L_{TID} \qquad \textbf{(6-16)}$$

$$L_i = \Delta L_{trib,TID\text{-}Still} \times \left(\frac{DA_i}{DA_{TID-Still}} \right) \quad \textbf{(6-17)}$$

where:

L_{FE}, L_{TID}, L_{Still}	= TSS load at Fort Edward, TI Dam, Stillwater
L_{snook}, L_{Moses}, L_{DD}	= tributary TSS load from Snook, Moses, and direct drainage
$\Delta L_{trib,\ TID\text{-}Still}$	= incremental load from tributaries between TI Dam and Stillwater
L_i	= total load apportioned to tributary *i* in the solids balance
DA_i	= drainage area of tributary *i*
$DA_{TID\text{-}Still}$	= total incremental drainage area from TI Dam to Stillwater
%trap	= solids trapping efficiency

In order for rating curve tributary load estimates to equal the apportioned load to each tributary, an upward adjustment in the data based curves was required. The largest uncertainty in tributary TSS load estimates was assumed to be in the high-flow portion of the rating curve. Therefore, the tributary rating curve *b* coefficient (Equation 6-18) was adjusted iteratively until the resulting load equaled the specific value of L_i computed for each tributary. The constant low-flow concentrations were not adjusted.

$$\left\{ \begin{matrix} Q > \overline{Q},\ \text{TSS} = a \times Q^b \\ Q \le \overline{Q},\ \text{TSS} = c \end{matrix} \right\} = L_i \quad \textbf{(6-18)}$$

where:

c = constant low flow TSS concentration based on data average

Tributary loads between Stillwater and Waterford were adjusted in the same fashion. The resulting exponent in the rating curve equation, b, for each tributary ranged from 1.1497 for the Fish Creek to 2.236 for Deep Kill (Table 6-10).

Resulting increases in tributary solids loads to achieve the long-term solids balance were significant. Tributary loads between Thompson Island Dam and Stillwater were increased by a factor of 2.46. Between Stillwater and Waterford, tributary loads were increased by a factor of 1.91. The adjusted rating curves required to achieve the solids balance are shown with the data and data-based rating curves to demonstrate the required adjustments at high flow (Figure 6-15). While the adjusted Hoosic River rating curve looks reasonable, the adjustment of the Batten Kill rating curve does not agree well with the limited available data. However, considering the limited data available and the fact that the Batten Kill flow is estimated based on a much smaller tributary, there is considerable uncertainty in the TSS versus flow relationship observed for Batten Kill. Flow phasing errors (timing of peak flows) based on relating Batten Kill flow to Kayaderosseras Creek flow may have significantly affected the Batten Kill rating curve.

6.5.4 Results

A long-term solids balance was developed for the period Jan. 1, 1977 through September 30, 1997. The Fort Edward solids rating curve and the tributary rating curves adjusted to achieve the solids balance were applied to develop daily time series inputs to the HUDTOX model for the calibration period. Annual average mainstem and tributary solids loads for the calibration period are presented in Figure 6-16.

Results show that annual average sediment load increases by a factor of 2.8 between Fort Edward and Stillwater and by a factor of 5.7 between Fort Edward and Waterford over the calibration period. In comparison, average flow increases by a factor of only 1.2 and 1.5 percent between these locations, respectively. Watershed TSS yield increases by a factor of 2.1 and 3.5 moving downstream from Fort Edward (10.7 MT/yr-mi^2) to Stillwater (22.2 MT/yr-mi^2) and Waterford (37.4 MT/yr-mi^2), respectively.

To illustrate relative sediment load contributions, percent of annual average solids loads for low and high flow periods, "non-event" and "event", respectively, are plotted in sequence from upstream to downstream (Figure 6-17). This plot shows that high and low flow tributary solids contributions are about the same and also illustrates the importance of tributary loads downstream of Thompson Island Dam. The Batten Kill load is about the same magnitude as the Fort Edward load and the Hoosic River load is approximately twice as large as the Fort Edward load. Without accounting for depositional losses, at Stillwater and Waterford, only 36 and 17 percent, respectively, of the external solids load entering the river is attributed to Ft. Edward. Only 5 percent of the suspended solids load at Federal Dam enters the system at Fort Edward, due to the large contribution from the Mohawk River.

The distribution of mainstem solids loads over the range of observed flows was analyzed to understand the relative importance of high and low flow solids transport (Figure 6-18). At Fort Edward, Stillwater and Waterford approximately 55, 50, and 70 percent of the TSS transport occurs below two times the average flow ($Q/Q_{avg} = 2.0$). At Fort Edward, two times the average flow, 10,496 cfs, is approximately equal to the high/low flow strata used to specify the TSS rating curves, 10,000 cfs.

6.5.5 Summary of Solids Load Estimates

Mainstem solids load estimates were developed for Fort Edward, Stillwater and Waterford using rating curves developed using non-linear least squares fitting. At Fort Edward, time stratification in the load estimates was based on observed changes in the TSS to flow relationship between the 1977-1990 and 1991-1997 periods. Annual average sediment loads for the 1991-1997 period are 40% percent lower than the loads for the 1977-1990 period at Fort Edward. The time-stratified solids rating curves for the 1991-1997 period are considered the best estimates of future TSS loading at Fort Edward (Chapter 8).

Tributary loads were initially computed using rating curves based on the limited available tributary data. These results required adjustment for tributaries between Stillwater and Waterford to achieve a long-term solids balance from 1977 to 1992 consistent with the assumed depositional character of the Upper Hudson River. Estimates of solids trapping efficiency by reach developed by QEA (1999) using the SEDZL sediment transport model were used to compute tributary loads between these locations. The data based tributary rating curves were scaled up at high flow to achieve the necessary TSS loading increase. Results produced tributary solids yields in reasonable agreement with literature ranges (Table 6-14), although the adjusted rating curves did not agree with the limited data in all cases (Figure 6-15). Final tributary load estimates between Thompson Island Pool and Waterford are considered very uncertain.

The solids balance achieved for the 1977-1992 period gave good results for the entire calibration period when compared to estimated solids fluxes passing Stillwater and Waterford. Results show that mainstem solids loads increase by a factor of 5.7 from Fort Edward to Waterford. This illustrates the significance of tributary loads, which are very uncertain due to limited tributary solids and flow data. The large degree of uncertainty in these estimates imparts significant uncertainty to the model calibration below Thompson Island Dam (Chapter 7).

6.6 MAINSTEM AND TRIBUTARY PCB LOADS

6.6.1 Overview

Application of the HUDTOX model requires specification of all external flow inputs, solids loads and PCB loads. Just as flow (Section 6.4) and solids loading (Section 6.5) time series were developed for the calibration period, upstream and tributary loading time series were developed for the seven PCB state variables: total PCB, Tri+, BZ#4, BZ#28, BZ#52, BZ#90&101, and BZ#138. Tri+ load estimates were developed for the long-term historical calibration period, January 1, 1977 through September 30, 1997. Load estimates for total PCB and the five congener state variables were estimated for the short-term hindcast period: April 1, 1991 through September 30, 1997. To aid in model calibration, estimates of in-river fluxes were also developed for Tri+ at Schuylerville, from 1977-1992; Stillwater and Waterford from 1977 to 1997; and, for Tri+ and Total PCB at Thompson Island Dam from 1991-1997. In developing the Thompson Island Dam PCB load estimates, a correction was applied to measurements taken at the west shore station to correct for observed biases in these data (QEA, 1998b). The in-river load estimates were calculated solely for comparison to model output and do not represent additional loads to the model.

6.6.2 PCB Data

6.6.2.1 Data Availability for Estimating PCB Loads

Mainstem Upper Hudson River PCB data were available from the USGS (1977-present), GE (1991-present) and from the USEPA 1993 Phase 2 investigation (1993). While the USGS dataset represents an extensive historical record of PCB concentrations, due to analytical and sampling limitations these data can only be used to develop approximate estimates of water column PCB load (USEPA, 1997). As discussed in Section 6.3.3.2, there is uncertainty associated with the USGS PCB quantitation and the translation of these quantitations to estimates of the long-term calibration state variable, Tri+.

The most extensively sampled mainstem stations in the model domain are Fort Edward, Thompson Island Dam, Schuylerville, Stillwater and Waterford. Exact sample collection locations varied at these stations, especially at Fort Edward. Samples collected in the vicinity of Fort Edward by the various USGS, GE and USEPA Phase 2 data collection efforts were grouped to represent Fort Edward concentrations. The same was done for the other stations.

The data available from each source at the primary mainstem sampling stations are summarized for Tri+ by year in Table 6-15 and for total PCB and congeners in Table 6-17. Significantly fewer data are available for tributaries, with only Batten Kill, Hoosic River and the Mohawk River actually being sampled for PCB (Table 6-16). Additionally, no tributary PCB data are available prior to 1991. Figure 6-19 presents the location of the long-term PCB monitoring stations on the mainstem Upper Hudson River and the tributary sampling stations within the study area.

The long-term combined dataset from USGS, GE and USEPA represents good coverage of the high and low flow regimes. Figure 6-20 shows the distribution of data over the range of sampled flows.

The USGS PCB data are reported as Aroclor quantitations or the sum of Aroclor quantitations and neither individual congener nor complete unbiased total PCB concentrations are available from these data. Thus the total PCB and congener data are limited to the GE and USEPA data collection periods, which began in 1991. Congener data are available for all five congener state variables, however, at Fort Edward BZ#4 and 138 were quantified in only about half of the samples in which total PCB was quantified. BZ#28, 52, and 101+90 were quantified in nearly all of the samples in which total PCB was quantified.

While continuous sampling was conducted at Fort Edward and Thompson Island Dam from 1991 through 1997, GE and USEPA conducted little or no sampling at stations downstream of Thompson Island Dam from 1993 to 1997. As a result, a continuous record of PCB concentrations over the calibration period (1977-1997) is only available for Tri+ at Fort Edward, Stillwater, and Waterford. Sampling at Schuylerville by USGS ended in 1992.

6.6.2.2 Thompson Island Dam West Shore Station Bias Correction

As summarized in QEA (1998b), an apparent sampling bias was discovered in fall of 1997 in PCB measurements from the routine monitoring station located on the west shore of Thompson Island Dam. A significant fraction of the GE and USEPA data at Thompson Island Dam were collected from stations on the west shore. The samples collected at this station are not always representative of the average PCB concentration leaving the pool, hence the term “bias”, and must be corrected for use in mass balance analysis.

The bias appears to be related to contribution of PCB from nearshore contaminated sediments under conditions of incomplete lateral mixing. The magnitude of the bias, in terms of percent difference between the west shore and center channel locations, is related to flow conditions and upstream PCB concentration. During high flow periods sufficient lateral mixing occurs to prevent any significant lateral gradients at the dam. During periods of high PCB loading at Fort Edward, the relative contribution of the nearshore hotspots is smaller.

After discovery of the west shore station bias, GE modified its monitoring program to better quantify the magnitude of the bias (O’Brien & Gere, 1998). The modified program included collection of samples further upstream and downstream of Thompson Island Dam, in the center channel of the river, and on lateral transects. These data allowed assessment of the relative degree of bias over different flow and upstream loading conditions. An analysis conducted by USEPA, (USEPA, 1999b) indicated that the ratio of west shore to center channel Tri+ concentrations approached unity for concentrations and flows at Fort Edward greater than 15 ng/L and 4,000 cfs, respectively. For flows less than 4,000 cfs and concentrations less than 15 ng/L at Fort Edward, a significant high bias exists for the west shore concentrations relative to the center channel. Segregating the observed ratios by these criteria produces the results in Table 6-18, which also presents results for total PCB based on an identical analysis. These values were used to "bias-correct" the west shore observations to better represent mean concentrations leaving Thompson Island Pool, based on Fort Edward concentration and flow conditions. The bias-corrected west shore concentrations were used when center channel observations were not available to compute PCB loads at Thompson Island Dam and for comparison to model output.

6.6.2.3 Data Development for Computing PCB Loads

The combined USGS, GE, and USEPA water column PCB datasets were reduced to daily average values for estimating daily average PCB loads. On numerous occasions, multiple samples were collected at these locations on the same day, especially at Fort Edward and Thompson Island Dam. Daily average concentrations were computed for days on which multiple measurements were reported. In computing daily average concentrations, the Phase 2 flow-average concentrations (which are from 15-day composite samples) were only used if no discrete measurements were available from GE or USGS.

Exact sample collection points at the mainstem sampling stations varied between and within agencies. Data from the various sample collection points at the primary sampling stations were combined to provide a record of concentrations at each location. At Fort Edward, samples were collected from the east and west channel of Rogers Island. Where same day measurements were taken in each channel, these were averaged. Otherwise, data from east or west channel, included with data from various other studies in the direct vicinity of the northern tip of Rogers Island were included in estimating PCB loads at Fort Edward.

PCB concentrations reported as non-detect were assigned a value of one-half the detection limit concentration. Detection limits vary among datasets. Although the USGS laboratory reports a theoretical quantitation limit of 0.01 µg/L through 1983, the practical quantitation limit was often considered to be 0.1 µg/L because of the small size of the water samples (Bopp et al., 1985). With water year 1984, the practical quantitation limit was lowered to 0.01 µg/L, however, the data were often reported as if they adhere to the previous quantitation limit through 1984 and 1985. In 1986, the quantitation limit began to be consistently reported as 0.01 µg/L. For the purposes of this project, USGS data in the printed Water Resources Data, New York and the USGS/Albany NWIS database were cross-checked to recover original quantitations at the 0.01 µg/L theoretical quantitation limit where possible. For the majority of the GE data, the detection limit was reported as 11 ng/L. The Phase 2 results include reported detection limits for non-detect values and an adjusted value for non-detects based on a treatment procedure (USEPA, 1989) for non-detect values put forth by EPA.

6.6.2.4 Overview

Calibration of the HUDTOX model to daily average PCB concentrations required specification of daily average PCB loads at Fort Edward and from tributaries. Thus, it was necessary to develop estimates of daily average loads at Fort Edward and for the tributaries for input to HUDTOX over the 21-year historical calibration period. While estimates of daily average PCB load passing the downstream stations were used for comparison to model output, these were developed on a daily basis for consistency with the Fort Edward load estimation and to develop estimates for the entire 21-year period. Estimates of annual PCB load at the long-term sampling stations are presented in the DEIR for part of the historical calibration period (USEPA, 1997). The annual load results computed from the sum of estimated daily loads (Section 6.6.3) are compared to the DEIR estimates.

In order to develop loads for Tri+, it was necessary to estimate concentrations for long periods of time between 1977 and 1991 that contained very few measurements. The estimated loads for these periods have high uncertainty. Sampling frequency was sufficiently high from 1991-1997 at Fort Edward and Thompson Island Dam that load estimates for the period 1991-1997 are considered more accurate than estimates for 1977-1991, with the exception of the period following the collapse of the Allen Mill gate structure at the Hudson Falls plant site. This event led to episodic elevated PCB loading in late 1991 and early 1992 that was probably not fully captured by routine sampling.

Loads of total PCB and the five congener state variables were also determined at Fort Edward for the short-term hindcast period (Jan. 1, 1991 to Sept. 30, 1997). In cases where congeners were not quantified while total PCB was quantified, congener concentrations were estimated based on their average observed mass percent in total PCB measurements.

This section presents the development of the mainstem Upper Hudson River load estimates for Tri+ over the period January, 1 1977 to September 30, 1997 and for total PCB and congeners BZ#4, BZ#28, BZ#52, BZ#90&101 and BZ#138 over the period January 1, 1991 to September 30, 1997.

6.6.2.5 Mainstem Tri+ Loads 1977-1997

In-river PCB loads were estimated at the primary long-term USGS monitoring locations, most importantly, at Fort Edward, the upstream boundary of the HUDTOX model. Specification of PCB loading at Fort Edward was done on a daily average basis, consistent with the input frequency of flows and solids loading.

Estimates of annual historical PCB loads at Fort Edward, Schuylerville, Stillwater and Waterford based on the USGS data are presented in the DEIR (USEPA, 1997). These estimates were based on application of two methods: the ratio estimator by Cochran (1977), and the averaging estimator presented by Dolan et al. (1981). An overview of these and other methods is presented by Preston et al. (1991). While these methods are suitable for estimating annual loads, estimates of daily average PCB load were sought for simulating PCB dynamics in HUDTOX on daily time scales. The HUDTOX calibration includes comparison to daily average PCB concentration measurements. To develop a method for estimating daily average PCB loads, flow-dependent regression relationships were explored, as was linear interpolation of measured concentrations and use of seasonal average concentrations by year.

Regression methods were eliminated because no significant relationships were observed among PCB concentration, flow and suspended solids concentration. Relationships between these parameters at Fort Edward were explored for 2-year intervals to reduce confounding effects of long-term reductions in concentrations (e.g. Figures 6-21 and 6-22). Elevated PCB loads do appear to be partially correlated with flow and TSS concentrations, however, significant variability in the correlations is observed at high and low-flow conditions. These observations did not support use of flow-based regression methods.

Based on exclusion of regression methods, a combination of linear interpolation of measured concentrations between sampling dates and use of seasonal average concentrations by year was selected. The appropriateness of either of these individual methods depends on data availability. During periods of low data frequency, linear interpolation has a significant potential for bias due to the presence of high or low measurements that have biases relative to mean concentrations. During high sampling frequency, linear interpolation may more accurately describe daily loads when concentrations are changing as a result of seasonal effects or upstream source activity. Prior to 1991, a combination of seasonal average concentrations by year and linear interpolation was used to estimate daily PCB concentrations at Fort Edward. Beginning in 1991, GE began regular monitoring of PCBs at Fort Edward and data availability over the period 1991 to 1997 was considered sufficient to support linear interpolation of measured concentrations over time for all PCB forms modeled.

During the earlier historical period, large data gaps exist and data collection was sparse, especially from 1977 to 1984. Due to the limited amount of data available during various times in the calibration period, seasonal average concentrations were used in lieu of the linear interpolation approach. Seasonal average concentrations were computed during each year and applied in the respective individual years. Periods of application of each approach were specified based on inspection of the PCB concentration time series at Fort Edward. Figure 6-23 presents the daily average measured and estimated PCB concentrations at Fort Edward. Inspection of this figure reveals the time periods selected for application of each method. The black line on this figure shows estimated concentrations based on the data, shown as symbols.

One complication in the use of linear interpolation is the apparent occurrence of random "pulse" loading events of PCBs at Fort Edward, identified through inspection of the Ft. Edward daily average concentrations. These pulses occasionally occur in conjunction with high flow events. Two such examples are presented in Figure 6-24. On May 9, 1994 a concentration of 130 ng/L was observed at Fort Edward and concentrations measured 3 days before and 3 days after this measurement both showed concentrations less than 15 ng/L. On April 25, 1983 a concentration of 900 ng/L was observed three days following and two days preceding measurements less than 20 ng/L.

The occurrence of these pulse load events appears only partially correlated with flow. Due to very high concentrations, however, these events can contribute large mass loading of PCBs to Thompson Island Pool. The use of linear interpolation during periods of infrequent sampling sometimes exaggerated the apparent contribution of pulse loads that were characterized by only a single or very few data points. Interpolation in these situations caused estimated loads to be strongly affected by individual high concentration measurements for long periods of time prior to and following the measurements. This was considered unreasonable based on inspection of the high frequency data collected by GE beginning in 1991. These data suggest that these pulse load events are of short duration, on the order of days rather than weeks. Based on these observations, the pulse loading events were assigned a duration of 6 days, assuming that the measured value captured the peak concentration. Seasonal average values were then applied for the periods before and after these events to the preceding and following measurements.

Considering the low sampling frequency, it is very likely that many pulse load events were missed, which introduces large uncertainty into the PCB load estimates, considering the large magnitude of observed pulse loads. It is noteworthy that a single measured pulse load in 1992 was responsible for 19 percent of the estimated total PCB load in that year alone. The uncertainty due to pulse loads is further exacerbated in the early historical period by the fact that sampling frequency was lowest during the period when PCB loads were at their highest levels.

Estimates of daily average in-river Tri+ loads at Thompson Island Dam, Schuylerville, Stillwater and Waterford were computed using the same approach as that implemented for Fort Edward. These loads were estimated for comparison to model output. Periods over which interpolation was used varied among stations due to variations in sampling frequency among stations.

6.6.2.6 Tributary Tri+ Loads 1977-1997

Due to extremely limited data, tributary PCB loads were estimated in a different manner from mainstem loads. For the monitored tributaries, Batten Kill, Hoosic River and Mohawk River, the average PCB concentration was calculated and the assumption was made that this concentration remained constant for the entire study period (Table 6-19). Measured concentrations were substituted when available. Because the three monitored tributaries were also the only tributaries with known PCB dischargers, it was assumed that these tributaries would have higher PCB concentrations than the other tributaries in the study area. The Tri+ concentrations in the unmonitored tributaries were assumed to equal the lowest recorded Tri+ concentration from the three monitored tributaries, 0.17 ng/l.

These values were assumed to represent background concentrations for the unmonitored tributaries. It is possible that historical tributary PCB concentrations were higher, however, the relative contribution of tributary PCB loads compared to the upstream PCB load at Fort Edward is small (less than 5 percent) and has negligible impact on the HUDTOX model predictions.

6.6.2.7 Tri+ Load Results 1977-1997

To evaluate results, total annual Tri+ loads estimated for each mainstem station are compared to annual loads presented in the DEIR by USEPA (1997) (Table 6-20, Figure 6-25). The DEIR annual load estimates are based on application of a flow-stratified version of the ratio estimator developed by Cochran (1977). This comparison recognizes that comparison to the DEIR estimates is affected for some periods by use of different Tri+ concentration and flow data. Nonetheless, the DEIR load estimates provide a reasonableness check against the estimates developed as describe above because the DEIR estimates were based on a different method.

The DEIR estimates used Tri+ concentrations estimated from the USGS data that do not reflect the more recent approach developed by Rhea and Werth (1998) to account for analytical bias in these data. Therefore, based on the average effect of the bias correction, the DEIR estimates are estimated to contain a high bias of approximately 14 to 16 percent relative to the estimates presented here. Comparison of the DEIR estimates at the mainstem stations to those developed herein for the period 1977-1990 shows that on a cumulative loading basis, the DEIR values are on average 18 to 26 percent larger on an annual basis, consistent with the approximate magnitude of the analytical bias correction. This comparison suggests that the loads estimated here are consistent with the DEIR estimates, after accounting for the analytical bias.

Several important observations can be made from inspection of the estimated annual Tri+ loads over the simulation period. It is clear that a significant declining trend in Tri+ loads past all of the mainstem stations occurred over the period 1977 to 1997 (Figure 6-26). While, the overall trend is clearly declining, estimated loads show large year to year variability (some years' loads are greater than previous years). Of particular note is the large increase in Tri+ loads in 1983-84 and 1991-92. The large temporary increase in PCB load in 1991-92 is associated with the failure of the Allen Mill gate structure in September 1991 (USEPA, 1997). The 1983 load increase reflects high spring floods occurring in that year.

Average daily loads at Fort Edward over the period 1980-1984 were approximately 1.21 kg/d compared to an average of 0.45 kg/d for 1985-1990. Following an increase in loads in 1991-1992 due to the Allen Mill event, loads continued to decline. Average loading at Fort Edward for the period 1994-1997 was 0.24 kg/d. The 1997 Fort Edward daily average load was about 0.8 kg/d.

A conspicuous result is that the estimated Tri+ load passing Fort Edward is much lower than estimated PCB loads passing Schuylerville, Stillwater and Waterford in 1977, 1978, and 1979, relative to the remainder of the simulation period (Figure 6-26). This suggests that either large unmeasured external loads were entering the river upstream of Schuylerville, or that the sediment contribution of Tri+ between Fort Edward and Schuylerville was very large during this period. It is possible that additional sources were active during this period, perhaps from land-disposed PCB laden sediments near the river. The low sampling frequency at Fort Edward may also have missed significant high concentration events, resulting in an underestimate of the Fort Edward load. The most likely explanation, however, is that large amounts of unstable contaminated sediment deposits, released by the 1973 dam removal at Fort Edward, were available for mobilization within the Thompson Island Pool in this period. It should be noted, however, that the period of highest upstream loading, from 1977 to 1983, contains only 22 percent of the 801 daily average measurements at Fort Edward. In 1977, when loads were the second highest of any year in the calibration, only 3 samples were collected. Due to the high uncertainty in Fort Edward loads in the late 1970's and early 1980's, comparison of model results to downstream data was discounted during this period (Chapter 7).

An important understanding gained from interpreting the estimated loads is that the majority of PCB transport occurs during non-flood flow periods. The term "low flow" is used throughout this report to refer to non-flood flows less than 10,000 cfs at Fort Edward, which is approximately twice the average flow. Low flow periods are characterized by relatively low sediment scour, although approximately 50% of the total solids transport occurs at low flow. By comparison, between 65 and 70% of PCB transport in the Upper Hudson River occurs at low flow (Figure 6-27).

Analysis of Tri+ PCB load gain across Thompson Island Pool also shows the significance of sediment-water exchanges at low flow (Figure 6-28). For the period 1993-1997, between 60 and

70 percent of the Tri+ load gain across Thompson Island Pool occurs during the summer months, June through August, when flows are typically very low. This observation does not diminish the significance of high flow events in mobilizing PCBs due to flow-dependent resuspension, however, it does suggest that flow-dependent resuspension is not the dominant process controlling sediment-water PCB mass fluxes in the Upper Hudson River. This focuses attention on the importance of low flow sediment to water PCB mass transfer processes, which is discussed in Section 6.12.

A plot of relative contributions of tributaries to the cumulative Tri+ load over the calibration period is presented in Figure 6-29. Tributary loads are insignificant relative to upstream loads.

6.6.2.8 Mainstem and Tributary Total PCB and Congener Loads 1991-1997

Specification of daily upstream and tributary PCB loads was also required for the hindcast application period, Jan.1, 1991 to Sept. 30, 1997. Sampling frequency was approximately biweekly at Fort Edward and Thompson Island Dam for ice-free conditions during this period. In winter months, sampling frequency was approximately monthly. At Stillwater and Waterford, sampling by GE and USEPA provided total PCB and congener measurements through 1993. Daily average loads of total PCB and the five congener state variables (BZ#4, BZ#28, BZ#52, BZ#90+101, and BZ#138) were estimated by linear interpolation of daily average values at Fort Edward over this period. For total PCB daily average loads were also estimated by interpolation at Thompson Island Dam for comparison to model output (Chapter 7). As discussed in Section 6.3, a correction was developed for the Thompson Island Dam data to account for the observed bias in the west shore sampling station measurements. Because sampling frequency was lower and the sampling period much shorter at Stillwater and Waterford, daily average loads were not estimated for total PCB and congeners at these locations.

The estimated loads of congeners BZ#28, BZ#52, and BZ#90+101 are considered known to within the certainty of the estimated total PCB load because the number of data points used was nearly the same as for total PCB. BZ#4 and BZ#138, however, have reported quantitations greater than zero for only 42 and 34 percent of the total PCB results, respectively in Release 4.1b of the Hudson River Database. Zero, or non-detects were frequent for BZ#4 and BZ#138 when other congeners were measured in fairly high concentrations. Concentrations of BZ#4 and BZ#138 were estimated based on observed ratios to total PCB. Evaluation of these ratios at Fort Edward showed a seasonal pattern, with BZ#4 mass fraction highest in the summer months and BZ#138 showing the opposite behavior. This probably reflects enhanced sediment-water release of BZ#4 during summer months from contaminated sediment deposits upstream of Fort Edward. This may also reflect enhanced mobilization of heavier congeners during resuspension events upstream of Fort Edward, based on an observed negative correlation of the BZ#4 mass fraction with flow.

An additional observation was that in 1991 and 1992, average BZ#4 fractions (0.035) were approximate to that in Aroclor 1242 (0.0313), which is the primary source material of the Fort Edward PCB load. In the other years where congener data are available (1993, 1996, and 1997) BZ#4 mass fractions were significantly higher, on average about 0.09 (Figure 6-30). Some measurements showed BZ#4 fractions greater than 0.25. These observations probably reflect the release of fresh Aroclor 1242 material during the Allen Mill event. In light of these observations, the monthly average ratios to total PCB for the period 1991-1992 and 1993-1998 were used to estimate BZ#4 and BZ#138 concentrations when total PCB was quantified but the congener results reported as zero.

The same approach as used in developing tributary loads for Tri+ was used for specifying tributary loads for Total PCB. The average measured concentrations was used for monitored tributaries, while the minimum measured concentration (0.51 ng/l) in the monitored tributaries was assigned to the unmonitored tributaries (Table 6-19). Tributary loads for individual congeners were assumed insignificant and specified as zero.

6.6.3 Total PCB and Congener Load Results 1991-1997

Annual average total PCB and congener loads computed at Fort Edward are presented in Table 6-21. Consistent with the long-term declining trend in Tri+ loads observed at all mainstem stations, the total PCB and congener loads at Fort Edward are also observed to decline over the period 1992-1997 following the increase in load associated with the Allen Mill gate structure event in the fall of 1991 (Figure 6-31).

Comparison of total PCB loads at Fort Edward and Thompson Island Dam shows that annual average total PCB load gain across Thompson Island Pool is approximately a factor of two larger than the load gain of Tri+. The difference is primarily due to the release of BZ#4 from Thompson Island Pool sediments, which is not reflected in the Tri+ load gain.

6.6.4 Summary of PCB Load Estimates

Daily average estimates of PCB loads at Fort Edward, TI Dam, Stillwater and Waterford were developed for use in the long term historical calibration and short-term hindcast applications. Tri+ loads were developed for the long-term calibration, from January 1, 1977 to September 30, 1997, using a combination of linear interpolation and seasonal averages of measured concentrations by year. Seasonal average values were specified during periods where data sampling frequency was too low to support linear interpolation. Total PCB and congener load estimates were developed for the short-term hindcast period, January 1, 1991 to September 30, 1997, using linear interpolation. Total PCB loads for this period were estimated at Fort Edward and at Thompson Island Dam. Congener loads were only estimated at Fort Edward. The Thompson Island Dam total PCB loads were developed for comparison to model output. Monitored tributaries were assigned the average measured concentrations. For unmonitored tributaries, loads were specified for total PCB and Tri+ based on the minimum measured concentrations from monitored tributaries. During the historical calibration period, tributary PCB loads represent less than 3 percent of the total loading of PCB between Fort Edward and Waterford.

The resulting daily average PCB loads estimated as described above were used to develop input time series of PCB loads for the HUDTOX model at Fort Edward and all 12 tributaries. Estimated loads at Thompson Island Dam, Stillwater and Waterford were used for comparison to model output.

PCB load estimates at Fort Edward are very uncertain in the first few years of the historical calibration period and again in the fall of 1991 due to low sampling frequency during periods of high, fluctuating loads. Based on observation of high concentrations at Schuylerville, the Fort Edward load may have been under-estimated or other sources may have been active from 1977 to about 1984. An additional source of uncertainty in the Fort Edward load arises from the apparent occurrence of random pulse loading events, which are suspected to be only partially captured by available data.

Load results show overall, a strong declining trend in upstream PCB loads from the late 70s to the late 90s, with a noticeable temporary interruption in 1991 due to the Allen Mill event. Currently, Fort Edward loads and load gain through the system are comparable to loads observed approximately 10 years ago in the late 1980s.

Analysis of PCB loads estimated at Fort Edward and Thompson Island Dam shows that approximately 60 percent to 70 percent PCB loading at Fort Edward, and PCB load gain across Thompson Island Pool, occurs at flows less than 10,000 cfs at Fort Edward.

6.7 SEDIMENT INITIAL CONDITIONS

6.7.1 Overview

The HUDTOX model requires specification of initial PCB concentrations, in addition to sediment specific weight (mass of dry solids per unit volume), sediment particulate organic carbon content (f_{OC}) and sediment dissolved organic carbon concentrations (DOC). This section presents specification of initial PCB concentrations in 1977 and specific weight. Specification of sediment f_{OC} and DOC concentrations is presented in Section 6.9, which also includes specification of partition coefficients.

Sediment initial conditions for Tri+ are developed from the 1977 NYSDEC sediment dataset. Average concentrations were determined on a dry weight concentration basis for specific sediment layer intervals over discrete areas of the river corresponding to individual segments, or groups of segments in areas of limited data. Concentrations were averaged over 2 cm intervals in the sediment bed to develop concentrations for each HUDTOX sediment layer, down to 26 cm. Sediment specific weight was established based on the USEPA Phase 2 low resolution coring data. Average values were determined for cohesive and non-cohesive sediment for the entire river.

6.7.2 Sediment Specific Weight

Specific weight is defined as the mass of dry solids per unit volume of wet sediment, or the sediment solids concentration. The HUDTOX model requires specification of sediment specific weight as an initial condition, which is held constant through the simulation (See Chapter 5).

Sediment specific weight values for the HUDTOX sediment layers have been determined using a subset of the USEPA Phase 2 low resolution sediment core data for which specific weight was estimated as wet bulk density times percent solids. Some of the reported data were excluded due to anomalous values for bulk density, percent solids or both. A total of 535 specific weight measurements from 169 sediment cores were used (there are values for multiple core slices at most locations).

An attempt was made to incorporate the following three criteria used by Zeigler and Nisbet (1994) to identify cohesive sediments:

1. $d_{50} < 250$ µm;
2. percent clay and silt > 15%; and,
3. percent moisture > 75% .

The percent moisture values were deemed unsuitable for this purpose, therefore, samples were classified as cohesive or non-cohesive based on criteria #1 and #2, using the ASTM sediment classifications provided in the Hudson River Database. The sediment classifications (up to 3 classes are identified based on visual description or grain size) are associated with a descriptor (either abundant, some, trace, or few) indicating relative abundance of the associated material. The descriptors provided for each sample were used to infer grain size and the percent clay and silt.

Samples classified as fine sand, silt, clay, or organics were assumed to meet the criteria of $d_{50} <$ 250 µm, except those containing "some" coarse sand and/or gravel. Fine sand samples having "some" or "abundant" silt, clay, or organics were assumed to meet criterion #2 and were considered cohesive. A total of 30 fine sand samples having "few", "trace" or no silt, clay, or organics were classified as non-cohesive. All other samples were classified as non-cohesive. This resulted in a total of 366 samples classified as cohesive and 169 samples classified as non-cohesive.

Specific weight values were grouped by sediment type (cohesive and non-cohesive) for top core sections, which have an average depth of 10 inches. Mean specific weights for cohesive (0.84 g/cc) and non-cohesive (1.38 g/cc) sediments were selected to represent the sediment specific weight in HUDTOX.

The cohesive sediment average specific weight (0.84 g/cc) is 37 percent lower than the average specific weight for non-cohesive sediment (1.38 g/cc). The difference in specific weights of the cohesive and non-cohesive sediments determined from the TAMS low resolution sediment cores is mainly due to differences in porosity (average porosity is 0.59 for cohesive and 0.37 for non-cohesive), which accounts for approximately 93 percent of the difference in specific weights. The difference in particle density (average particle density is 2.16 for cohesive and 2.22 for non-cohesive) contributes approximately 5 percent of the difference in specific weight.

6.7.3 1977 Tri+ Initial Conditions

6.7.3.1 1977 NYSDEC Sediment Data

Initial conditions were developed from the 1977 NYSDEC data. These data were collected from a sediment coring and grab sampling program spanning the Upper Hudson River from the Bakers Falls area to Troy. The most extensive sampling occurred in Thompson Island Pool. Approximately 30 samples were collected north of Fort Edward, and 24 samples downstream of

Federal Dam at Troy, falling outside of the HUDTOX model domain. Approximately 40 other samples lacked location data (river mile or northing/easting coordinates) and were not usable for developing sediment initial conditions. A total of 961 sample locations, consisting of 623 grab samples and 338 core samples were available within the HUDTOX domain.

A number of the 1977 samples were excluded from use in specifying initial conditions due to anomalies in the data. A group of grab samples all reported to be located at river mile 189.2 and having very high PCB concentrations were considered suspect and dropped, as was a group of grab samples reported to have been collected at river mile 156.5 on December 27, 1977. No documentation could be found supporting this December sampling event (QEA, 1999). One additional sample was excluded, ID number 30291, which had a very high PCB concentration and was surrounded in close proximity by samples with much lower concentrations.

The 1977 NYSDEC data core sample depths varied widely. Surficial layer sectioning ranged from 1.5 cm to 56 cm, with an average of 7.5 cm. Grab samples were taken by a Shipek sampler and usually obtained a 0-5 inch depth composite (Tofflemire and Quin, 1979). The average surface sample depth of core and grab samples combined is 10.9 cm.

The 1977 NYSDEC samples were not analyzed for solids specific weight. Measurement of principal fraction-phi, %gravel, %sand, %silt, %clay, %total solids, % volatile solids and texture is reported for many samples, however numerous samples do not have results for one or more of these parameters.

6.7.3.2 Methods

HUDTOX requires specification of initial conditions as bulk concentrations (mass of PCB per unit bulk volume of sediment). Average dry weight Tri+ concentrations (mass of PCB per mass of dry solids) were computed from the 1977 NYSDEC sediment data. In order to specify sediment initial conditions on a bulk concentration basis, average dry weight PCB concentrations were computed for cohesive and non-cohesive sediment from these data and multiplied by the sediment specific weight values (Section 6.7.2).

Samples were classified as cohesive or non-cohesive following hierarchy of methods, dependent on the parameters reported for each sample (Table 6-22). After classification of the individual core sections according to the criteria in Table 6-22, all core sections in each core were assigned the cohesive/non-cohesive classification of the top-most section. The samples classified as cohesive or non-cohesive were mapped to the HUDTOX water column segments based on location information.

To specify sediment Tri+ initial conditions, the NYSDEC 1977 data were averaged horizontally and vertically for cohesive and non-cohesive sediment types in each HUDTOX layer. The vertical segmentation scheme employs 2 cm layers throughout the modeled portion of the sediment bed (0-26 cm).

The core section and grab sample data were mapped onto the HUDTOX vertical sediment layer segmentation using a length-weighted-average calculation for each sample:

$$C_j = \frac{\sum_{i=1}^{n} C_i l_i}{\sum_{i=1}^{n} l_i} \quad \textbf{(6-19)}$$

where:

C_j = concentration of layer j (mg/L)
C_i = concentration of sample i in layer j (mg/Kg)
l = length of section i in layer j (cm)
n = number of sections extending into layer j

Once each sample was mapped onto the vertical segmentation intervals, using equation 6-19, average Tri+ concentrations were computed for specific intervals of the river based on data availability. For some portions of the river, data falling in multiple adjacent water column segments were grouped and averaged together, by sediment layer interval and sediment type. Average concentrations were computed for each group. The Thompson Island Pool water column segments were divided into 7 averaging groups, and the segments downstream of Thompson Island Pool were divided into 10 averaging groups (Table 6-23).

6.7.3.3 1977 Initial Condition Results

The 1977 initial condition surficial sediment Tri+ concentrations for cohesive and non-cohesive segments are shown in Figure 6-32. Maximum concentrations of both cohesive sediment, 290 mg/kg, and non-cohesive sediment, 44 mg/kg, occurs in Thompson Island Pool (Figure 6-33). Minimum concentrations are 7.2 mg/kg for cohesive sediment and 3.3 mg/kg for non-cohesive sediment, occurring just below Stillwater Dam and below the Lock 1 Dam, respectively. The vertical profiles computed for each segment are shown in Figure 6-34 with plus and minus two standard errors. Inspection of the vertical profiles shows that peak concentrations typically occur at depths less than 12 cm. The vertical profiles do not show a significant gradient with depth, which is attributed to the variable surface core section thickness used in the sampling, ranging from 1.4 to 46 cm. The average surface sediment sample thickness is 7.5 cm with a standard deviation of 6.3 cm.

6.7.4 1991 Initial conditions and model calibration targets

Sediment initial conditions for total PCB, Tri+ and the congener state variables were computed from the 1991 GE composite sediment sampling data for use in the short term hindcast application conducted from Jan. 1, 1991 to Sept. 30, 1997. Tri+ concentrations were also used as model calibration targets.

6.7.4.1 Data

In the GE 1991 composite sampling survey, approximately 520 individual samples were collected in Thompson Island Pool and approximately 480 from Thompson Island Dam to Federal Dam. The Thompson Island Pool was divided into 6 sub-reaches, in which 5 to 12 composites samples were collected. The composites generally contain on the order of 10 to 20 individual samples collected over a range of ¼ mile or more. Thus, the 1991 data do not represent individual cohesive or non-cohesive sediment deposits. Individual sediment core samples were grouped as fine or coarse sediments in the laboratory after determination of sediment type based on texture and bulk density. After sectioning into 0-5, 5-10, and 10-15 cm layers, the individual layer sections were composited in each group and analyzed for PCB. As discussed in Section 6.3, sediment BZ#4 concentrations were estimated from the co-eluting BZ#4&BZ#10 sum.

6.7.4.2 Methods

The calculation of 1991 concentrations involved vertically mapping concentrations on the 2 cm model sediment layer intervals as conducted for the 1977 NYSDEC data using equation 6-19. The constant core sectioning employed in the 1991 survey resulted in interpolation at only two depths, 5 cm and 10 cm. Grab samples were assumed to represent 10 cm.

Each sample in the composite was assigned the composite concentration for each sediment layer. The composite samples were classified as cohesive or non-cohesive based on the fine/coarse designation assigned to the composite samples during collection. Similar to the approach employed for the 1977 NYSDEC data, samples in adjacent water column segments were grouped by sediment type based on data availability (Table 6-24).

6.7.4.3 1991 Initial Condition Results

The longitudinal (down-river) surface sediment concentration profiles computed for each PCB state variable from the GE 1991 data are presented with the data in Figures 6-35 through 6-38. Down-river trends show that PCB concentrations in Thompson Island Pool and between Thompson Island Dam and Schuylerville are very elevated relative to concentrations observed downstream of Stillwater. This trend has persisted from 1977, where a similar pattern is observed in Tri+ concentrations (Figure 6-32). Examination of congener concentrations shows that BZ#4 concentrations exhibit a larger decrease relative to the heavier congeners. Congener concentrations normalized to BZ#52 concentrations show that the ratio of BZ#4/BZ#52 drops markedly at Schuylerville (Figure 6-39), while ratios of the heavier congeners increase. This is attributed to in-place dechlorination of sediment PCBs between Fort Edward and Schuylerville. Decreased BZ#4 concentrations downstream of Schuylerville may be related to weathering processes, whereby heavier congeners are preferentially delivered to downstream sediments via deposition and loss of the lighter more mobile congeners via volatilization or export over Federal Dam.

Poolwide average surface sediment concentrations in TIP are shown for each state variable in Table 6-25.

6.7.5 Summary

Sediment initial conditions were computed in 1977 from the NYSDEC data for the historical calibration period for Tri+ and in 1991 from the GE composite sampling data for the short-term hindcast period. Sediment conditions were computed for all seven PCB state variables in 1991 (total PCB, Tri+, BZ#4, BZ#28, BZ#52, BZ#90+101, and BZ#138). The Tri+ concentrations were used as model calibration targets for the long-term historical calibration, while the other

PCB forms were used as initial conditions for shorter-term 1991-1997 simulations. Concentrations were mapped onto sediment segment layers according to Equation 6-19. Average concentrations for cohesive and non-cohesive sediment concentrations were computed for specific intervals of the river, based on data availability. Due to the averaging approach taken, the specified initial conditions do not represent discrete PCB hotspots in many areas.

Based on the specified initial conditions for the congeners, BZ#4 represents the largest fraction of the total PCB mass in Thompson Island Pool and between Thompson Island Dam and Schuylerville, approximately 25 percent. Below Lock 5 at Schuylerville the concentration of BZ#4 declines significantly and at Waterford, the BZ#4 mass fraction is on the order of 5 percent.

6.8 WATER AND AIR TEMPERATURES

A number of processes represented in the HUDTOX model are temperature dependent. These include: partitioning, volatilization and porewater diffusion rates. A large number of in-situ water temperature data are available from the USEPA and GE datasets. No in-situ temperature data were available for sediments. The sediment bed temperatures were assumed to follow the water column temperature. Sediment temperatures are likely to be damped relative to surface water temperatures by heat exchange with groundwater and underlying bedrock, however, no data exist with which to evaluate this.

Monthly-average water column temperatures were computed for the primary Upper Hudson River sampling locations for application in HUDTOX. Some smoothing of the monthly average curves at each station was required (Figure 6-40). The annual time series represented by the monthly average was used to describe the HUDTOX calibration and forecast application periods. The monthly time series specified at each station was applied to segments between station midpoints. For example, the Thompson Island Dam temperature series applies to the downstream half of Thompson Island Pool and half the distance to the Schuylerville sampling station.

Year to year variations in mean monthly water temperatures are fairly small. The largest year to year variability appears to occur during April and May for which the standard deviation of observations is approximately 30 to 50 percent (in degrees Celsius), depending on location. Peak monthly average temperature occurs in July. During non-winter months, water temperature generally exhibits a continual increase from Ft. Edward downstream to Waterford. In July, at peak temperature, the mean water column temperature increases 3.6 °C, from Ft. Edward (24.2 °C) to Waterford (27.8 °C) as shown in Figure 6-41. During the winter months, the entire river is about the same temperature. Minimum mean monthly temperature is 1.1 °C in January.

Temperature gradients between near shore and center channel may exist due to a number of factors, which may result in positive or negative gradients. Shallow, near shore areas of the river can experience more solar heating due to slower velocities and depth, which may serve to increase temperatures relative to the center channel. Groundwater inflows may serve to decrease near shore temperatures relative to the center channel and likely cause sediment temperatures to lag water column temperatures.

Very little data exist with which to evaluate possible temperature gradients between center channel and shallow near shore areas. In HUDTOX, no lateral temperature gradients are represented.

Monthly average air temperature data were obtained from the NOAA-NCDC daily summaries for Glens Falls/Warren County, New York.

6.9 PARTITIONING

6.9.1 Overview

In natural systems the fate and transport of PCBs and other hydrophobic chemicals is largely controlled by their degree of partitioning to sediment particles and dissolved organic matter (DOC-bound). While sorption and desorption are complex processes, often the dissolved phase and particle phase concentrations are assumed to be in equilibrium. This assumption is reasonable when sorption kinetics are rapid relative to other processes affecting concentrations. Two-phase and three-phase models of equilibrium partitioning assume that measured concentrations in one phase can be used to predict concentration in the other phase(s).

The equilibrium partitioning assumption was evaluated by USEPA (1997) and found to be valid for the Upper Hudson River. TAMS computed particulate concentrations predicted from measured dissolved concentrations using two-phase partition coefficients and compared results to observed values throughout the Upper Hudson River over a range of environmental conditions. The predictions were unbiased for the majority of samples and average difference between the predictions and observations was 45 percent, and only 33 percent for stations downstream of Thompson Island Dam. Results for data collected near Fort Edward suggest non-equilibrium conditions at this station. These predictions represent a high degree of accuracy relative to similar reported studies and suggest it is possible to predict the phase distribution of PCB congeners to within about 33 percent for the freshwater Hudson below Thompson Island Dam. Equilibrium assumptions were proposed to be adequate to represent fate and transport of PCBs in the Hudson (USEPA,1997).

Development of two-phase and three-phase equilibrium partition coefficients for 64 congeners are presented in the DEIR. Three-phase partition coefficients were estimated using numerical optimization from USEPA Phase 2 water column data and 1991 GE sediment composite data, both of which report particulate and apparent dissolved (truly dissolved plus DOC-sorbed) concentrations. The reader is referred to the DEIR for details of those analyses. Partition coefficients computed from water column data are considered to be more accurate than partition coefficients computed between sediment and porewater due to differences in analytical and sample collection methods. There is, however, considerable uncertainty in the determination of three-phase partition coefficients in both media. Results show that for the lightest congeners, the DOC-bound fraction may comprise up to 50 percent of the total PCB concentration in the water column, but is generally less than 10 percent for congeners constituting Tri+. In the sediments, results suggest that a significant fraction of the porewater concentration is associated with DOC for all congeners. The mono- and di-chlorinated congeners exhibit different partitioning behavior than the other congeners in that their K_{poc} and K_{doc} (see Equations 5-10 and 5-11) values are of approximately the same order of magnitude. Further, because of their lower partition coefficients, porewater concentrations of mono- and di-chlorinated congeners are enhanced relative to the heavier congeners, which may facilitate greater sediment-water transfer of these congeners via porewater. Enhanced flux of these congeners relative to the heavier congeners may also occur due to the presence of elevated DOC, considering the differences in ratios of K_{poc} to K_{doc} for the heavy and light congeners (USEPA, 1997).

Three-phase equilibrium partitioning was adopted for HUDTOX based on two considerations. First, because of the importance of the DOC phase in affecting the phase distributions of the lighter congeners, it is necessary to use three-phase partitioning to properly account for the ratios between sediment-water transfer of congeners in porewater. A sensitivity analysis presented in the DEIR (USEPA, 1997) suggests that dissolved and DOC-bound concentrations are likely to be of the same order of magnitude. Second, truly dissolved chemicals are thought to be more readily bioavailable than those sorbed to DOC and accounting for the DOC fraction may provide a better estimate of exposure to biota.

The HUDTOX model applies three-phase equilibrium partitioning equations presented in Section 5.2 (Equations 5-10 and 5-11). In these equations, the K_{poc} and K_{doc} values for congeners and Tri+ are temperature corrected according to the temperature correction slope factor (Equation 5-12) recommended for all congeners in the DEIR (USEPA, 1997). The temperature correction is log-linear and a 10-degree C change in temperature reduces partition coefficients by 28 percent.

In addition to the three-phase partition coefficients presented for congeners in the DEIR, three-phase coefficients were also developed by USEPA, 2000 for Tri+, following the same approach. To compute total PCB partition coefficients, mass-weighted values from Tri+ and the mono- and di-chlorinated congeners were used. The mass weighting used average congener and Tri+ mass fractions in the USEPA and GE water column data. Details of this analysis are presented below.

Application of the three-phase partitioning model requires specification of the fraction of organic carbon (f_{OC}) in suspended and bedded sediment particles, as well as concentrations of DOC in the water column and sediment porewater. For bedded sediments, average f_{OC} values were computed from the GE 1991 composite sediment data based on sediment type and location. For the water column f_{OC} was found to be correlated with flow. A function relating water column f_{OC} to flow was applied in HUDTOX. Average sediment DOC concentrations were also computed from the GE data based on sediment type and location. Water column DOC concentrations were observed to be relatively invariant in the Upper Hudson throughout the year and exhibit small differences between locations. Average DOC concentrations were computed from the GE, Phase 2, and J. Vaughn (1996) data. The development of the f_{OC} and DOC concentrations for sediment and water are presented in detail below.

Based on the specified parameters influencing partitioning of PCB, typical phase distributions of PCB in the Upper Hudson River are presented for winter and summer low and high flow conditions.

6.9.2 Partition Coefficients

The three-phase partition coefficients developed based on the UPEPA Phase 2 water column for Tri+ and congeners BZ#4, BZ#28, BZ#52, BZ#90&101, and BZ#138 are used in HUDTOX (Table 6-26). These partition coefficients are temperature corrected in the HUDTOX model according to the temperature correction slope factor developed for all congeners in the DEIR (Equation 5-12).

Consistent with the equilibrium assumption employed in the HUDTOX model, a single partition coefficient was applied for the whole Upper Hudson River. Non-equilibrium conditions appear to occur in some of the Phase 2 data, particularly at Fort Edward, resulting in higher apparent partition coefficient estimates than downstream. Partition coefficient estimates were corrected for the possible presence of non-equilibrium samples by use of the median of individual estimates to describe the central tendency of observations. Partitioning at Thompson Island Dam and downstream locations appears to be generally at equilibrium conditions for tri- and higher-chlorinated congeners, however, for mono-, di-, and tri-chlorinated congeners, there appears to be some local non-equilibrium at Thompson Island Dam (possibly associated with sediment-water transfer of predominately the dissolved phase for these congeners).

Generally, the Phase 2 data do not indicate a clear distinction between partitioning behavior among stations and differences among stations are likely attributable to variations in organic carbon concentration and water temperature (USEPA, 1997).

In addition to Tri+ and the five congeners, total PCB is an additional HUDTOX state variable. Partition coefficients were not developed for total PCB as part of the DEIR or LRC investigations. To estimate K_{POC} and K_{DOC} for total PCB, a mass weighting approach was adopted using values determined for Tri+ and the mono- and di-chlorinated congeners. The average mass fraction of total PCB represented by Tri+, BZ#1, BZ#4, and BZ#8 were computed at Fort Edward, Thompson Island Dam, Schuylerville, Stillwater and Waterford from the USEPA Phase 2 data and the GE data (Table 6-27). Because these mass fractions do not sum to unity due to exclusion of other mono- and dichlorobiphenyls for which partition coefficients were not calculated, the mass fractions were normalized by the total mass represented by these congeners and multiplied by their respective partition coefficients to compute a mass-weighted value for total PCB as described by Equation 6-20.

$$K_{poc} = \frac{\left(K_{poc}X\right)_{BZ\#1} + \left(K_{poc}X\right)_{BZ\#4} + \left(K_{poc}X\right)_{BZ\#8} + \left(K_{poc}X\right)_{Tri+}}{X_{BZ\#1} + X_{BZ\#4} + X_{BZ\#8} + X_{Tri+}} \quad \textbf{(6-20)}$$

where:

X = mass fraction for each PCB form
K_{poc} = particulate organic carbon partition coefficient (l/kg)

This procedure was repeated for K_{DOC}, resulting in K_{POC} and K_{DOC} estimates for each of the five stations listed above (Table 6-28, Figure 6-42). The shift in the congener distribution toward the mono- and di- fraction due to gain of these constituents across Thompson Island Pool and loss downstream of Thompson Island Dam is evident in the pattern of results. While partition coefficients for individual congeners and Tri+ exhibit some spatially variability (probably related to differences in dissolved organic carbon and temperature, as discussed above), the changing composition of total PCB is an additional factor contributing to spatial variability and uncertainty in the total PCB partition coefficient. This was a consideration in deciding not to calibrate to total PCB concentrations, but rather to focus the calibration on Tri+ and use additional congener calibrations to strengthen the Tri+ calibration. This is discussed in Chapter 7.

To determine a single value of K_{POC} and K_{DOC} for total PCB for application in HUDTOX, the station values were distance-weighted using the distance between midpoints of each location divided by the total distance between upstream and downstream locations. The Waterford value was assumed to represent the reach from Waterford to Federal Dam in the distance weighting (Table 6-29). While the Fort Edward value may be affected by non-equilibrium conditions (see above), it receives a fairly small distance weighting factor and does not significantly affect the result. The log K_{poc} and log K_{doc} values determined by this method for total PCB are 5.64 and 4.22, respectively.

Sediment three-phase partition coefficients were also estimated by USEPA (1997) from the 1991 GE composite sediment sampling data. These estimates were subsequently updated to account for corrections to analytical biases in the GE data (Table 6-26). While the GE data allowed estimates of sediment partition coefficients, a number of important factors in the sampling and analysis procedures affect the quality of these estimates. Samples were frozen prior to analysis, which may alter all phases of the matrix (USEPA, 1997), and field blank contamination affected 87 percent of the PCB analyses. These limitations suggest that the accuracy of the GE estimates are low compared to the values estimated from the USEPA Phase 2 water column data. Therefore, the Phase 2 water column estimates were chosen to describe both sediment and water column partitioning behavior in HUDTOX. Application of the water column estimates may have contributed to difficulty in calibrating the model to individual congeners, which is discussed in Chapter 7.

6.9.2.1 Water Column Organic Carbon Concentrations

The HUDTOX model employs three-phase equilibrium partitioning formulations (Equations 5-13 through 5-16), which compute PCB distribution among particulate organic matter, dissolved organic carbon (DOC) and water (Section 5.2). In these equations, the concentration of particulate organic material is computed as the sediment solids concentration times the fraction of organic carbon in the sediment particles, f_{OC}. Values for f_{OC} and DOC are specified separately for the water column and sediments. Values for both of these parameters were determined from site-specific data and specified as model inputs. The determination of water column f_{OC} and DOC values considered spatial and temporal patterns in data. This section presents the development of these parameters for the water column. The next section presents development of the sediment f_{OC} and DOC values.

6.9.2.2 Water Column DOC

In addition to the USEPA Phase 2 data and the GE monitoring data, water column DOC measurements were also available from investigative studies conducted at Rensselaer Polytechnic Institute (Vaughn 1996). The GE water column organic carbon data required extensive filtering due to numerous inconsistencies among reported TSS, TOC and DOC concentrations in the dataset. Measurements were only used for samples meeting the following criteria: [TOC] < [TSS] and, [TOC] ≥ [DOC]. This resulted in use of 17 percent of the 421 samples for which TSS, TOC and DOC concentrations are reported in the Release 4.1b of the Hudson River Database. Table 6-30 summarizes the number of data used from each source by mainstem Hudson River location, along with a statistical summary of the data at each location.

Dependencies of DOC concentration on flow, season, and location were investigated with the combined USEPA, GE and J. Vaughn datasets. Consistent with the findings in the DEIR based on the USEPA Phase 2 data, DOC was observed to be slightly negatively correlated with flow, and only weakly correlated with temperature (and season). The observed decrease in mean concentrations in the spring is explained by the dependence on flow. The lowest DOC concentrations tend to occur coincident with the highest flows and lowest temperatures during the snowmelt runoff period (Figure 6-43). A plot of the DOC versus river mile suggests some dependence of DOC concentration on location, which is also evident in the mean values (Figure 6-44). Differences between locations are generally small. Mean values at the primary mainstem locations (Ft. Edward, Thompson Island Dam, Schuylerville, Stillwater and Waterford) differ by a maximum of 14 percent.

Even considering the slight negative correlation of DOC on flow and temperature, DOC concentrations are relatively invariant in the Upper Hudson River. Maximum deviations from mean concentration at each location is less than 30 percent (excluding a possible outlier of 0.94 mg/L at Stillwater from USEPA Transect 4). Specification of mean values by reach was judged to give adequate representation of DOC concentrations in the model. The DOC data were grouped into the four reaches presented below for the purpose of specifying mean DOC concentrations (Table 6-31).

6.9.2.3 Water Column f_{OC}

Water column f_{OC} values were specified based on estimates available from the USEPA Phase 2 data and the GE data. As discussed above, filtering of the GE dataset was required in order to identify samples with reported TSS, total organic carbon (TOC), and DOC concentrations consistent with each other. This resulted in use of only 17 percent of the 421 samples for which TSS, TOC and DOC concentrations are reported in the Release 4.1b of the Hudson River Database. The GE data reports concentrations for TSS, TOC and filterable TOC (labeled TOC_f in the database). For each sample, particulate organic carbon (POC) concentration was computed as TOC – TOC_f. Subsequently, f_{OC} was computed as POC /TSS.

In the USEPA Phase 2 studies, POC was not measured directly in the water column. However, weight-loss-on-ignition (WLOI) data were reported and can be used to estimate POC (USEPA, 1997). The Phase 2 data contain WLOI data at two temperatures, 375 °C and 450 °C (for Transect 1 only), however a conversion factor was developed so that all WLOI data could be converted to a common temperature. Based on zero-intercept regression analysis using sediment data, $WLOI_{375}$ can be converted to organic carbon weight fraction as (USEPA, 1997):

$$f_{OC} = 0.611 * WLOI_{375} \quad \textbf{(6-21)}$$

$$WLOI_{375} = WLOI_{450} * 0.864 \quad \textbf{(6-22)}$$

The combination of f_{OC} estimates obtained from the USEPA and GE data resulted in 24 to 296 measurements at the primary mainstem sampling locations.

Results in the DEIR (from analysis of the Phase 2 data) show that f_{OC} is significantly correlated to flow but not to location at a 95 percent confidence level. Based on this observation the dependence of f_{OC} on flow was analyzed to develop a functional relationship for the HUDTOX model. The data were plotted versus flow normalized by mean flow at each location (Figure 6-45). While f_{OC} is clearly negatively correlated with flow, there is significant variability in f_{OC} across the range of flows sampled, with the greatest variability observed at low flow. A power function regression analysis was used to fit the data as a function of normalized flow. This produces a model which generally describes f_{OC} well at high flows, but has limited predictive ability at low flow due to significant variability in the observations. This function was applied in the HUDTOX model to compute f_{OC} as a function of flow (Equation 6-23).

$$f_{OC} = 0.175 \times \left(\frac{Q}{\overline{Q}} \right)^{-0.3687} \tag{6-23}$$

For application in HUDTOX, the average flow of each model segment was computed for segment below TIP by using segment specific flow, Q, and the average flow of total flow estimated upstream flow inputs, $\overline{Q}$.

Evaluating the behavior of this equation over the range of flows modeled shows that at the lowest flow conditions, f_{OC} is approximately 0.22 and 0.08 at the low and high end of the flow range, respectively. At the average flow, f_{OC} is 0.175.

6.9.2.4 Sediment Organic Carbon Concentrations

Average sediment fraction of organic carbon (f_{OC}) values and porewater dissolved organic carbon (DOC) concentrations were developed from GE and USEPA Phase 2 data. The HUDTOX model requires specification of these input values, which determine PCB phase partitioning in the three-phase partitioning calculations. The data were segregated by sediment type (cohesive or non-cohesive) and location in the River and average concentrations were determined for each sediment type over intervals of the River that were dependent on data availability and apparent spatial trends in these values. The specification of (f_{OC}) and DOC values is described below.

6.9.2.5 Porewater DOC

The sediment DOC measurements available from the GE 1991 Sediment Sampling and Analysis Program (O'Brien and Gere, 1993) were used to specify DOC concentrations by reach in the HUDTOX model. The Phase 2 sediment studies did not measure porewater DOC concentrations. The GE DOC data are measurements of filterable TOC obtained from sediment core composites. A total of 86 sediment DOC measurements are available from Fort Edward to Federal Dam.

Spatial differences along the river and between fine and coarse sediment areas were investigated. When plotted versus river mile, the data show a trend of increasing porewater DOC concentrations with distance downstream from Fort Edward (Figure 6-46). The GE samples were composited by sediment type and composites are identified as being from coarse or fine sediments. The available DOC data are biased toward fine sediment composites, with only a small percentage of the DOC measurements being from coarse sediment. Based on the distinction of coarse and fine sediments in the GE composites, and the limited number of coarse sediment DOC data available, no distinction between fine and coarse sediment DOC concentrations is supported.

Considering that fine and coarse sediments were observed to have different organic carbon content, correlation between sediment f_{OC} and DOC was investigated as an alternate approach to investigating differences in porewater DOC concentration between fine and coarse sediment. A scatter plot of sediment DOC versus f_{OC} shows no correlation between these two parameters. Thus, DOC was specified on river mile intervals, with no distinction between fine and coarse sediment, as shown in Figure 6-46.

6.9.2.6 Sediment f_{OC}

Sediment f_{OC} values were specified using data from the GE 1991 Sediment Sampling and Analysis Program (O'Brien and Gere, 1993). While measurements of sediment f_{OC} concentrations are also available from the USEPA Phase 2 data, the GE 1991 data are extensive enough to provide a good estimate of mean f_{OC} values throughout the Upper Hudson River. The GE composites consisted of fine and coarse sediment collected over intervals of about 2 miles downstream of Thompson Island Pool and about 1 mile in Thompson Island Pool. The composite data were assigned river mile location corresponding to the approximate midpoint of the sampling interval and plotted versus river mile to investigate changes in f_{OC} along the river (Figure 6-47). Sediment organic carbon content was observed to decline with distance downstream from Ft. Edward. Measured values ranged from 6.9 to 0.3 percent for fine (cohesive) sediment and 4.6 percent to 0.2 percent for coarse (non-cohesive) sediments with the highest values being measured in Thompson Island Pool.

The data were grouped by river mile interval to compute average fine and coarse sediment concentrations for specification in HUDTOX (Table 6-32). The f_{OC} values specified in HUDTOX range from 3.7 percent to 1.6 percent for fine sediment and from 1.3 percent to 0.7 percent for coarse sediment.

6.9.2.7 Distribution of PCBs in sediment and water

Based on the specified parameters influencing the partitioning calculations in the HUDTOX model, typical phase distributions of PCBs in sediment and water are presented below for all PCB state variables, along with the approximate range of distributions that may result in the model. Parameters controlling the three-phase partitioning include: K_{POCc}, K_{DOC}, f_{OC}, DOC, and temperature.

Waterford was chosen to illustrate the typical summer and winter, high and low-flow ranges of water column partitioning behavior because it experiences the largest changes in temperature (1.1 °C to 27.8 °C), and the largest range of observed suspended solids concentration. Typical low and high-flow TSS concentrations of 5 and 100 mg/L were chosen for this illustration. Similarly, typical high and low flow f_{OC} values specified are 22 and 8 percent, respectively. Water column DOC was specified as 4.01 mg/L.

The range of partitioning behavior due to the range of parameter values specified for this illustration is presented for each state variable, using water column and sediment 3-phase partitioning coefficients (Table 6-33). Note that results are independent of the actual PCB concentration. Results are displayed as percent of PCB in each phase: truly dissolved, DOC-bound and sorbed to particulate organic carbon. The apparent dissolved phase includes truly dissolved and DOC-bound PCBs.

6.9.2.8 Partitioning Summary

Partitioning behavior of PCB to particulate matter and colloids is represented in HUDTOX through the application of equilibrium three-phase partitioning equations that compute distribution of PCB among water, dissolved organic carbon and particulate organic carbon. The equilibrium assumption was evaluated by USEPA (1997) and found to be reasonable for the Upper Hudson River, although evidence of non-equilibrium conditions was observed. This primarily affected Fort Edward and TI Dam concentrations. Three-phase partition coefficients for Tri+ and congeners estimated from USEPA Phase 2 water column data were specified for HUDTOX. Partition coefficients were not varied spatially. Results suggest that with accurate representation of temperature, f_{oc} and DOC it is possible to predict phase distributions of individual congeners to within 45 percent for the Upper Hudson River upstream of Thompson Island Dam and to within 33 percent below Thompson Island Dam.

Because estimates of partition coefficients for total PCB were not available from previous investigations, these were estimated based on mass weighting of values determined for Tri+ and mono and di-chlorinated congeners. Estimates were computed for the primary sampling stations between Fort Edward and Waterford. A spatial pattern in results was observed, consistent with the relative changes in congener distributions through the system. These results were distance weighted to obtain an estimate for total PCB for the entire system. Considering that total PCB is used only for estimating total PCB transport and is was not used for primary calibration of the HUDTOX model, uncertainty in total PCB partitioning behavior does not affect the calibration.

6.10 VOLATILIZATION

6.10.1 Overview

Air-water exchange by volatilization is a transport pathway for water-borne PCBs in the Upper Hudson that is explicitly represented in the HUDTOX model. Whereas Chapter 5 presents the empirical model formulations used in the computation of air-water exchange, this section presents specification of chemical-specific and hydrodynamic parameters affecting the rate of volatilization. An assessment of volatilization losses at dam cascades is also presented, with the conclusion that this process is not large enough to warrant explicit representation in the HUDTOX model.

6.10.2 Volatilization Mass Transfer

Volatilization affects PCB transport in the Upper Hudson by serving as a net loss pathway for water column borne PCB in the truly dissolved phase. Air-water exchange of truly dissolved PCB occurs across the air-water interface of the entire river and is enhanced by induction of air in cascades such as falls over dams.

The rate of volatilization tends to be chemical specific and is determined by Henry's Constant. Volatilization is enhanced by hydrodynamically-induced and wind-driven shear stresses at the water surface. Due to temperature dependencies, volatilization is also seasonally dependent, exhibiting higher rates during warm temperature periods. Liquid phase and air-phase resistances control the rate of volatilization, which are dependent on the concentration and diffusivity of PCB in each phase.

Volatilization rates are computed in HUDTOX according to the O'Connor Dobbins formulation presented in Chapter 5. This equation computes volatilization mass transfer coefficients across the air-water interface based on water column depth and velocity, temperature, and chemical specific properties, including atmospheric concentrations, molecular weight and Henry's constant. Enhanced volatilization due to cascades at dams is not represented in the model based on a determination that this processes is of small importance in affecting PCB transport in the system. This determination is summarized below.

Also presented in this section are estimates of Henry's constant and molecular weight obtained from literature sources and site-specific data.

6.10.2.1 Henry's Constant and Molecular Weight

Chemical-specific properties, Henry's Constant (H) and molecular weight (MW) were estimated for each PCB state variable. Values for H and MW are presented for a wide range of PCB congeners. For Tri+ and total PCB, estimates of these parameters were developed for specific locations by mass weighting congener results based on the average mass fraction of each congener.

Henry's coefficients were obtained for individual congeners from Brunner et al. (1990). The H values in units of (atm-m^3/mol) are presented in Table 6-34 and Figure 6-48. Average congener mass fractions for the primary Upper Hudson sampling stations were computed from the GE and USEPA data (Tables 6-35 and 6-36). Based on these results, individual congener H values were mass-weighted to arrive at a value for each location specific to the GE and USEPA datasets (Table 6-37 and Figure 6-49). A weighted average of these values for each location was computed based on the number of samples in each dataset used to determine average congener mass fractions. Results reveal a down-river pattern in H that reflects the shift in congener distributions through the system. H values are highest at Thompson Island Dam, reflecting the gain in mono- and di-homologues across Thompson Island Pool. The final values for each location were then distance weighted by the distance between sampling midpoints to arrive at a final value of H for total PCB (1.85e-4) and Tri+ (1.69e-4) for application to the entire Upper Hudson (Table 6-38).

MW is constant for each congener in a given homologue group and is a fixed quantity. MW values are presented in the DEIR (Table 4-8) for each homologue group. MW was computed for total PCB and Tri+ by mass-weighting congener values in an identical manner as done to estimate H. Results of this calculation are presented in Tables 6-39 and 6-40, and illustrated in Figure 6-50.

A summary of the H and MW values specified for each state variable is presented in Table 6-41.

6.10.2.2 Film Transfer Coefficients

As described in Chapter 5 (Section 5.2.3), air-water chemical exchange (or volatilization) rates in HUDTOX are determined through application of the stagnant layer "two-film" theory. As a result, overall volatilization rates (K_V) are controlled by liquid-phase (K_L) and gas-phase (K_G) exchange coefficients acting in series (see Equation 5-18). Since these coefficients function in a series fashion (with K_G being adjusted by a chemical- and temperature-dependent Henry's Law Constant), the smallest of these two factors may be considered to be "controlling" (or limiting) the overall volatilization rate. However, even the non-limiting factor may still have a substantial effect on the volatilization rate under conditions when both are of similar magnitudes.

In the Upper Hudson River, flow and environmental conditions largely determine whether the liquid-phase or gas-phase coefficient has a more limiting effect on volatilization. The gas-phase tends to be limiting during cooler conditions (because K_G decreases with temperature) as well as during higher flow conditions (because K_L generally increases with flow). Conversely, the liquid-phase tends to more limiting on volatilization during lower flow (average and below) periods and especially as water temperatures warm up (e.g., summer low flow conditions). Differences in chemical-specific diffusivity (D_w) across the range of PCB congeners evaluated in this modeling study can change the limiting phase between liquid and gas.

Determination of the liquid-phase transfer coefficient (K_L) for a specific river cross-section using the O'Connor-Dobbins reaeration formulation (Equation 5-20) requires both depth and velocity. Table 6-42 provides the Leopold and Maddox (1953) coefficients that were specified for each HUDTOX river cross-section to estimate velocity and depth as a function of flow. Note that depths were estimated for average flow conditions and assumed to be constant due to the mitigating effects of dams on water level variations as flow changes.

6.10.2.3 Atmospheric PCB Concentrations

Given the air-water mass transfer rates, air-water flux depends on the gradient between the dissolved water phases and the atmospheric gas phase; therefore, computation of this flux requires specification of the atmospheric gas phase boundary condition. For this boundary condition an annual average value was estimated for Tri+ from 1977-1997 and for total PCBs and the two congeners from 1991-1997. The procedure for setting this boundary condition involved establishing a recent reference concentration based on measurement of total PCBs in the atmosphere and back projecting from that reference value to obtain estimates of historical levels. The nearest and most recent reference value was the 1992 annual average atmospheric gas phase total PCB value of 170 ± 86 pg/m^3 determined by Hoff *et al.* (1996) at the Integrated Atmospheric Deposition Network (IADN) station at Point Petre, Ontario. Historical concentrations were determined by scaling this value to a curve developed using PCB profiles collected in dated (1940-1981), ombrotrophic peat bogs (Rapaport and Eisenreich, 1988) and observed water column PCB load decay rates for rivers draining Lake Michigan watersheds from 1981-present (Marti and Armstrong, 1990). This scaling process produced a curve which reflects the synthesized time series of atmospheric total PCB concentration from 1977-1997 (Figure 6-51). Also included in Figure 6-51 as a check on this approach, are seasonal data reported by NYSDEC (undated) and data from Buckley and Tofflemire (1983), both of which represent air sampled in the vicinity of the Upper Hudson River. Additionally, the line representing historical atmospheric PCB concentrations estimated by Mackay (1989) in conducting a modeling analysis for Lake Ontario is included.

Ideally, the estimate of historical atmospheric concentrations for congeners or the Tri+ mixture would be made by applying measured ratios of these constituents to the hindcast total PCBs. This was possible for estimating BZ#4 and BZ#52 levels by using ratios reported by Hornbuckle (personal communication, 11/18/98) for samples collected over Lake Michigan. For Tri+, a ratio was determined by assuming the atmospheric gas phase concentrations for both Tri+ and total PCBs in 1992 were in equilibrium with the dissolved phase in the water column and computing a gas phase Tri+/total PCB ratio for 1992 on that basis. Then Tri+ was hindcast using the same scaling curve as was used for total PCBs in Figure 6-51. The resulting HUDTOX boundary condition values used for these PCB state variables are presented in tabular form on Figure 6-51.

6.10.3 Gas Exchange at Dams

A method of estimating gas exchange at river cascades presented by Cirpka et al. (1993) was overviewed in the DEIR (USEPA, 1997) and air-water transfer of Tri+ based on this equation was assessed by QEA (1999). For chemicals with small Henry's constants this model can be expressed as (QEA 1999):

$$c_d = \left(\frac{1}{1 + \frac{GH}{Q}} \right) c_u + \left(\frac{\frac{GH}{Q}}{1 + \frac{GH}{Q}} \right) \frac{c_{air}}{H} \qquad \textbf{(6-24)}$$

where:

G/Q = ratio of entrained air flow rate to river flow rate
c_d = concentration downstream of cascade
c_u = concentration upstream of cascade

The air flow to river flow ratio is can be estimated from the cross-section dimensions of the fall and the river flow rate (c.f. McLachlan et al. 1990). For the two river cascades (shown as a series of small drops) studied in Cirpka et al. (1990) these ratios were about 0.03 to 0.07 for cascades of approximately 1 to 2 meters. The falls over dam weirs on the Upper Hudson are approximate to these heights, varying from about 2 to 6 m, although the nature of the falls are somewhat different from the cascades in Cirpka et al. (1990), equation 6-24 is assumed to provide a reasonable estimate of air-water mass transfer for the dams on the Upper Hudson River. Based on this equation, QEA (1999) estimated maximum concentration reductions due to loss at dams to be less than 3% for Tri+.

Because volatilization at dams is estimated to have a small impact on water column concentrations, it was not included in the HUDTOX model.

6.11 SEDIMENT PARTICLE MIXING

Vertical mixing of sediment particles and associated porewater in the sediment bed arises from bioturbation and other physical processes. The activities of infaunal organisms inhabiting the surface sediments, called bioturbation, include: burrow and tube excavation and their ultimate collapse or infilling, ingestion and excretion of sediment, plowing through the surface sediment, and building of mounds and digging of craters (Boudreau, 1997). As discussed in Chapter 5, particle mixing is represented as a diffusional process in HUDTOX. The model requires as input, specification of a depth over which mixing occurs, and an associated mixing rate, or particle diffusion rate.

No direct evidence is available for particle mixing rates in the Upper Hudson River, however, Olsen et al. (1981) determined surface particle diffusion rates of approximately 1 cm^2/yr in Foundry Cove and Lents Cove in the Lower Hudson River. This is a relatively low rate compared to the ranges typically observed, which is about from 1 to 100 cm^2/yr (e.g. Boudreau 1997, Matisoff 1982). More specifically, Aller (1982) estimated bioturbation-induced particle mixing rates in Narragansett Bay to range from 5 to 32 cm^2/yr, Brownawell (1986) estimated a biodiffusion coefficient of 9.4 cm^2/yr in Buzzards Bay, and Thibodeaux et al. (1990) estimated biodiffusion coefficients of 9-13 cm^2/yr. These authors suggest that bioturbation-induced particle mixing can occur to a depth of 6-10 cm and that benthic organism density and associated mixing generally decreases with depth from the sediment surface.

Particle mixing depths are often estimated by inspection of vertical concentration profiles of tracer material, often radionuclides such as ^{210}Pb, ^{137}Cs, or ^{7}Be. Observation of contaminant profiles can also provide an indication of mixed depth. Finely section sediment cores collected by USEPA in 1992 and by GE in 1998 (QEA 1999) provide a means to qualitatively assess mixed depths. Inspection of ^{137}Cs and PCB profiles at five high-resolution core sites in the Upper Hudson River, shown in Figure 3-53 in the DEIR (USEPA, 1997), suggests mixed depths may be greater than 20 cm in some locations.

Figures 6-52a-c, presented by QEA (1999), show PCB concentration profiles for 27 sediment cores collected in 1998. Mixed depths appear to vary widely, with a number of cores showing little or no gradient to 10 cm or more. Non-cohesive sediments are likely less mixed due to lower bulk density, larger grain sizes, and reduced sediment deposition relative to cohesive sediments. Due to the variability in mixed depths and particle mixing rates, there is large uncertainty associated with the parameterization of particle mixing in the model.

Considering the uncertainty in sediment mixing depth, this parameter was considered a calibration parameter and was varied spatially to achieve reasonable fits to long-term sediment trajectories (Chapter 7).

6.12 DECHLORINATION

Anaerobic and aerobic dechlorination processes have the potential to alter PCB congener distribution in the water column and sediments. These processes are of particular concern for the historical calibration as the state variable, Tri+, is subject to potential mass loss due to dechlorination in the sediments. The influence of dechlorination on the sediment inventory of PCBs has been extensively assessed as presented in the DEIR (USEPA, 1997). This assessment compared congener patterns in the sediment to known source material (primarily Aroclor 1242 at Fort Edward) and found little evidence for extensive dechlorination. Results showed minimal aerobic dechlorination and suggested that anaerobic dechlorination of Hudson River sediments is limited to meta- and para- chlorines, which limits its ability to reduce sediment PCB mass. The DEIR concluded that dechlorination mass losses are theoretically limited to 26 percent in Hudson

River sediment. Dechlorination losses of more than 10 percent were limited to concentrations greater than 30 mg/kg and below this level, dechlorination losses were frequently observed to be zero, compared to the original Aroclor 1242 source material. Sediments as old as 35 years were found with little or no dechlorination. No sediments were found with dechlorination mass loss greater than 25 percent, based on change in molecular weight, and the median mass loss was 7 percent since the time of PCB deposition. The mean mass loss was 8 percent.

Based on the interpretations provided by USEPA (1997) in the DEIR, which are partially summarized above, the overall impact of dechlorination on the historical and future fate of sediment PCB reservoirs in the Upper Hudson is small. Therefore, the HUDTOX model does not include representation of dechlorination processes.

6.13 SEDIMENT-WATER MASS TRANSFER

6.13.1 Overview

Sediment to water PCB mass transfer in the HUDTOX model occurs due to either porewater diffusion, particulate phase mass transfer, or by sediment resuspension, as discussed in Chapter 5. During high flow periods, sediment resuspension can be the dominant sediment-water transfer mechanism, however, under low flow conditions resuspension contributions can be small relative to other mechanisms giving rise to transfer of PCB from sediment to water. These include numerous processes that act on particulate and dissolved phase PCBs. Possible transfer mechanisms for the dissolved phase include:

- molecular diffusion of dissolved phase PCB in porewater;
- diffusion of colloid-bound PCBs in porewater;
- groundwater advection up through the sediment bed;
- hydrodynamically induced advective pumping; and,
- biologically enhanced porewater transport.

Non flow dependent transfer mechanisms may act on particulate phase PCBs, resulting in subsequent desorption to the water column at the sediment-water interface. These processes may include:

- bioturbation by benthic organisms;
- emergence and uprooting of macrophytes;
- physical disturbance from wind waves or fish activity; as well as,
- direct desorption from surface sediments to the water column.

The magnitude of these various processes can vary seasonally as a function of temperature and climatological conditions. Biologically enhanced sediment-water transfer of PCBs is temperature dependent due to increased biological activity during warm temperatures. Groundwater advection transfer will vary with the groundwater hydraulic gradient. Measurements of groundwater seepage in the Upper Hudson River indicated large spatial and temporal variability, ranging from negative (river losses) to positive groundwater inflows. The highest groundwater inflow rates were measured in late May and early June (HSI Geotrans 1997). In the absence of any physical disturbance of the upper sediment layer (*e.g.*, bioturbation, advection or dispersion), exchange of PCBs between the sediments and water takes place by molecular diffusion (for dissolved material) or Brownian diffusion (for colloidal bound material). Valasaraj et al. (1997), using a water diffusivity of 5.6 x 10^{-6} cm^2/sec, estimated that mass transfer rates due to molecular diffusion applied to the dissolved phase of a chemical in sediment porewater would be on the order of 0.02 cm/day. Application of this mass transfer rate to porewater concentrations of PCBs results in a relatively small mass flux from sediments to water.

Direct desorption of particulate phase PCBs and subsequent transfer to the water column can be enhanced by bioturbation of surface sediments via the following sequence of processes: first, particles can be transported by mixing processes from depth to the sediment-water interface; second, while residing briefly at this interface, particles can desorb a fraction of the sorbed PCB before being mixed back into deeper sediments; and finally, desorbed PCB can move through the benthic boundary layer into the overlying water column (Portielje and Lijklema, 1999; Thibodeaux, 1996). Several authors have shown these processes can increase effective chemical mass fluxes across the sediment-water interface by a factors of 10-1000 (*e.g.,* Thibodeaux, 1996; Nadal, 1998; Thoms et al., 1995; Reible et al., 1991). Horn et al. (1979) suggested that this non-flow-dependent sediment-water exchange process is important for PCBs in the Hudson River. They further suggested that approximately half of PCB transport in the Hudson River occurs at low to moderate flows and is not the result of solids scour from the sediment bed. In comparison to their calculation of molecular diffusion mass transfer of 0.02 cm/day, Valasaraj et al. (1997) estimated that a biodiffusion (bioturbation-induced mass transfer of porewater chemical) mass transfer rate would be approximately 12 cm/day.

Analysis of low flow PCB load gain of across TIP reveals that sediment-water transfer mechanisms are occurring at rates much greater than those typically associated with molecular diffusion. This indicates that transfer mechanisms other than molecular diffusion are operative at high rates under low flow conditions. While individual sediment-water transfer processes (such as those listed above) have been extensively studied and measured in other systems (*e.g.*, Thibodeaux, 1996), direct measurement of these processes has not been conducted for the Upper Hudson River. Due to a lack of site-specific information, development of a process-level model to describe low-flow sediment to water mass transfer was not supported. Therefore, an empirical modeling approach was adopted to describe effective sediment-water mass transfer of PCB under low flow conditions.

A seasonally-variable mass transfer rate coefficient operating on porewater PCBs was derived from observations of PCB load gain across Thompson Island Pool under low flow. This effective mass transfer coefficient (k_f) represents the combined effect of all the various processes contributing to low-flow sediment-water transfer of PCBs. The k_f time series derived from observations describes the average low-flow mass transfer occurring during specific intervals over which average values were computed. This approach provides a reasonable estimate of mean behavior and was used successfully in the historical calibration to Tri+.

In attempting to apply the calibrated Tri+ model to individual congeners, it was found that a single porewater PCB mass transfer coefficient could not be used to simultaneously model multiple PCB congeners. Differences in sediment-water partitioning behavior apparently cause differences in observed effective sediment water mass transfer coefficients for individual congeners. Calibration to individual congeners could have been achieved by deriving congener-specific mass transfer coefficients, however, this would have essentially resulted in multiple calibrations that are not mutually consistent. In order to maximize use of the congener simulations in evaluating the historical calibration to Tri+, a modeling approach was sought that could simultaneously describe sediment-water mass transfer for the range of congener partitioning behavior represented by the five congeners chosen for modeling.

Analysis of congener patterns in sediment porewater, on sediment particles and in the Thompson Island Pool load gain suggested that the low flow load gain is dominated by particle-based processes. This analysis also suggested that separation of the porewater and particulate phase mass transfer processes may provide a model capable of describing a range of PCB congeners simultaneously, with varying only congener-specific chemical properties in model inputs. Separate mass transfer coefficients for the particulate and dissolved phases were therefore derived such that the combined contribution to overall sediment-water mass transfer resulted in the same amount. This was done by picking a ratio between these processes that optimized agreement with the observed congener distribution in the water column at Thompson Island Dam.

This approach, while subject to a number of large uncertainties, permitted a reasonable simulation of all five congener state variables, in addition to the principal state variable, Tri+. The historical Tri+ calibration was run with the separate particulate and porewater mass transfer coefficients and compared to the calibration achieved with the single k_f function. Results are presented in Chapter 7.

Because results for simulations with the computed porewater and particulate mass transfer coefficients showed good performance for BZ#28 and BZ#52, the two congeners most like Tri+, the historical calibration to Tri+ based on the k_f series was accepted as the model calibration (Chapter 7) and used for model forecasting (Chapter 8).

The analysis of sediment-water mass transfer rates is summarized below.

- To describe low-flow sediment-water transfer of Tri+ for the historical calibration, an empirical modeling approach was used due to a lack of site-specific information on individual processes.

- A seasonally-variable mass transfer rate coefficient was computed from observations of low flow load gain across Thompson Island Pool, which was used in the historical calibration to Tri+.

- The application of the model to individual congeners provided insights as to the relative importance of dissolved phase versus particulate phase mass transfer processes.

- While representation of these processes provided better agreement to individual congener data, results for Tri+ tended to confirm the historical calibration based on the effective porewater mass transfer coefficient.

This section presents the development of the effective mass transfer function, k_f, and subsequent investigation of sediment-water transfer of congeners. Sensitivity analysis are presented in Chapter 7 that explore the significance of implementing separate particulate and porewater mass transfer processes to describe congener load gain.

6.13.2 Calculation of k_f for Tri+

6.13.2.1 Data

The seasonally-variable low flow effective mass transfer coefficient, k_f, was derived from observations of Tri+ load gain across Thompson Island Pool under non-resuspending conditions. Observations of low flow load gain, determined from paired (same day) daily average PCB concentrations at Fort Edward and Thompson Island Dam, were segregated by flow and TSS concentrations. Based on the observed knee in the TSS-flow correlation at approximately 10,000 (Figure 6-12), sediment resuspension is considered significant at flows above 10,000 cfs. Below 10,000 cfs, PCB load gain observations coincident with TSS less than or equal to 10 mg/L were assumed to minimally affected by sediment resuspension. To evaluate this assumption, the relationship between same-day TSS concentrations at Thompson Island Dam and Fort Edward was examined (Figure 6-53). The correlation exhibits high variability, with approximately equal distribution about the 1:1 line, suggesting that on average, TSS transport may be considered conservative in Thompson Island Pool at flows less than 10,000 cfs and TSS less than 10 mg/L. A regression of these data suggest that at very low concentrations, TSS is slightly higher at Thompson Island Dam, however, at concentrations above about 3 mg/L, concentrations at Thompson Island Dam are lower than at Ft. Edward. The apparent lack of significant resuspension contributions in these data suggests that use of data under these conditions for computing low-flow sediment-water mass transfer coefficients is reasonable. Due to the elevated loading of PCBs observed at Fort Edward beginning in September, 1991 from the Allen Mill gate failure, none of the 1991-92 data were used in any of the evaluations of mass transfer rates. The large pulse loading of PCBs influenced PCB loads at Fort Edward for the later part of 1991 and early 1992. The effect of this load on surface sediment concentrations in Thompson Island Pool is unknown, imparting additional uncertainty to calculations of load gain across Thompson Island Pool for this period, therefore the mass transfer analysis was limited to observations collected from 1993 through 1997. Observations of load gain across the Thompson Island Pool for this period were based on daily average PCB concentrations at Fort Edward and Thompson Island Dam. At Thompson Island Dam, the bias-corrected concentrations were used, as described in Section 6.3.

The effective sediment-water mass transfer coefficient relates observations of low flow load gain to surficial sediment concentrations. In order to make use of the 1993 –1997 observations of load gain, estimation of corresponding sediment concentrations was required. The surficial sediment concentration for Tri+ was estimated for each year by applying a first order rate of decline computed from observed poolwide average surficial sediment concentrations from 1991 to 1998 (k = $^-0.076$ yr^{-1}). The 1991 average concentrations were computed from the 0-5 cm layer concentrations in GE 1991 composite sediment data, which were collected before the Allen Mill

Event occurred in the fall of 1991. This event increased surface sediment concentrations by an unknown amount and produced a noticeable increase on observed PCB load gain across Thompson Island Pool . The average Poolwide 1998 sediment surface sediment concentrations reported by QEA for cohesive and non-cohesive sediment (1999) were used. The unknown perturbation of sediment concentrations from the Allen Mill Event in 1991 imparts uncertainty to the estimated rate of sediment concentration declines from 1991 to 1998. Estimated poolwide sediment and porewater concentrations for all modeled PCB groups using this approach are shown in Table 6-43 and 6-44.

6.13.2.2 Approach

To compute the effective mass transfer coefficient for Tri+, Thompson Island Pool was represented as a single control volume and the following mass balance equation for the water column was employed to relate observed load gain to sediment concentrations (Equation 6-25).

$$k_f = \frac{1}{A_s}\left(\frac{(QC)_{TID} - (QC)_{FE}}{C_{PW}}\right) \cdot 244.659 \qquad \textbf{(6-25)}$$

where:

k_f = effective mass transfer rate (cm/day)
QC_{TID} = product of flow and concentration at TI Dam, (cfs · mg/L)
QC_{FE} = product of flow and concentration at Fort Edward, (cfs · mg/L)
C_{pw} = Apparent porewater Tri+ concentration (mg/L)
A_s = Surficial sediment area (m^2)
244.659 = Conversion factor to cm/day

Application of this simplistic mass balance calculation implies the following assumptions.

1. The time of travel between upstream and downstream locations is less than one day and therefore samples collected at Fort Edward and TI Dam on the same day can be reasonably assumed to represent the same parcel of water.

2. Volatilization losses across TIP do not significantly affect the observations of low flow load gain.

3. The gradient of porewater to water column concentrations can be approximated with the porewater concentration. Because porewater concentrations are typically at least 1 to 2 orders of magnitude greater than water column concentrations, this assumption is valid.

For consistency between the calculation of k_f values and implementation in HUDTOX, sediment surface area was calculated based on the model segmentation. The percentage of cohesive and non-cohesive sediment area were used to determine area weighted average values for sediment properties, such as: bulk density, porosity, f_{OC}, and DOC concentration (Table 6-45). To compute the porewater PCB concentration, the 3-phase partitioning equations presented in Chapter 5 were employed with the input values in Table 6-43 and the Phase 2 water column partition coefficients.

Partition coefficients were temperature-adjusted according to the water column temperature time series in the model (Section 6.8).

Equation 6-25 was solved for each individual observation of paired (same day) concentrations at Fort Edward and Thompson Island Dam, censored as described in the above section. The k_f values for Tri+ ranged from -1.0 to 65 cm/d. Negative results occurred for days where lower concentrations were observed at Thompson Island Dam than at Fort Edward. This affected 7 percent of the observations and these results were excluded in developing the effective mass transfer function. (Figure 6-54)

6.13.2.3 k_f Results

Individual values of k_f were plotted versus Julian day to discern the average seasonal pattern in low flow load gain for the 1993-1997 period. The k_f values were distinctly higher in summer months relative to most of the year (Figure 6-54). Observed high values in March and April (Julian days ~60-120) maybe a result of resuspension activity during the spring runoff period, either preceding these data, or not represented by the associated TSS measurements. The average mass transfer rate in specific time intervals was used to develop a variable k_f annual time series, which was incorporated into the HUDTOX model. The approximate mean value (10.2 cm/d) of the low temperature period, September through April, was applied for these months. The resulting k_f series shows that from early May to mid June, k_f increases from about 10 to 25 cm/d and declines to about 10 cm/d at the end of August (Table 6-46, Figure 6-55). The seasonal dependence on the low-flow mass transfer rate is clearly evident, with the peak mass transfer occurring in mid June. The causal factors leading to the peak rate occurring in mid June are poorly understood. Peak water column temperature is observed in July (Figure 6-41). It is notable that the timing of the peak mass transfer rates are generally coincident with the timing of the highest measured groundwater influx rates (HSI Geotrans, 1997).

6.13.2.4 Implementation in HUDTOX

The sediment-water transfer of porewater PCBs is computed in HUDTOX by Equation 5-22. To correctly implement the k_f time series in HUDTOX, Equation 5-22 was rearranged to achieve the same form of expression of the mass transfer coefficient as in Equation 6-26. This shows that k_f is equal to the following terms.

$$kf = \frac{E \cdot n_{ij}}{L_{\mathrm{ij}} \cdot n_j} \qquad \textbf{(6-26)}$$

The HUDTOX model input describing the transfer rate is the dispersion coefficient, E. Therefore, Equation 6-26 was solved for E for each value of k_f in the annual time series and the resulting series for E was input to HUDTOX. The mixing length, L_{ij}, was specified as 0.02 m. The average porosity between sediments and water (n_{ij}) computed based on the average sediment porosity of 0.527 and water column porosity of ~1.0 is 0.7635.

6.13.3 Analysis of congener and total PCB mass transfer coefficients

The k_f series developed as presented above for Tri+ was used in the historical 1977-1997 calibration. Following the historical calibration to Tri+, the HUDTOX model was tested through short-term hindcast applications to total PCB and five congeners (BZ#4, BZ#28, BZ#52, BZ#90+101, and BZ#138) for 1991 to1997. BZ#4 exhibits the largest deviation in environmental behavior relative to Tri+ and BZ#4 is not a component of Tri+. All of the other congeners are included in Tri+. BZ#4 is the least hydrophobic of these congeners and also has the highest volatility.

Initial investigations revealed that the porewater mass transfer coefficient, k_f, developed for Tri+ was not applicable to all congeners. This is apparent through comparison of observed effective sediment-water mass transfer rates for total PCB and the five congeners. These rates were estimated following the same approach as for Tri+ explained in the previous section (Figure 6-56) and plotted versus the k_f values for total PCB. Sediment concentrations used in calculation of k_f for congeners were computed as described above (Table 6-43 and 6-44). Results for BZ#4 show significantly lower k_f values relative to the other results. BZ#28 results were in best agreement with total PCB results, although still noticeably higher. Tri+, BZ#52, 101+90 and 138 show higher values relative to total PCB. Thus, the k_f for total PCB over-predicts BZ#4 load gain, while under-predicting load gain for Tri+, BZ#28, 52, 90+101, and 138. The differences in apparent k_f values among congeners is also shown through comparison of results for 14 selected days on which quantitations were available for all five congeners at Fort Edward and Thompson Island Dam (Figure 6-57).

An objective of modeling congeners was to evaluate the Tri+ calibration for PCBs exhibiting different environmental behavior. While congener-specific mass transfer coefficients could have been developed for the short-term hindcast applications, this would have somewhat diminished the use of the model for this purpose because in effect individual calibrations would be developed for each congener. Therefore, the sediment-water mass transfer processes were investigated through use of the congener data with the goal of representing sediment-water mass transfer processes in a consistent manner across all PCB groups modeled (i.e. Tri+, Total PCB and individual congeners). This would allow simultaneous application of the Tri+ calibration to all congeners, varying only congener-specific chemical properties.

Differences in partitioning behavior among congeners was considered in order to explain differences in effective mass transfer rates. The water column partition coefficients estimated from the USEPA Phase 2 water column data are compared to the estimates from the GE 1991 sediment data in Figure 6-58. The estimates of effective k_f values for individual congeners used pore water congener concentrations estimated through application of the sediment partition coefficients from the GE 1991 sediment data. Large differences in estimated sediment-water partitioning coefficients exist for the lighter congeners, while the heavier congeners show approximately the same values in the water and sediment. While initially congener-specific estimates of k_f used sediment partition coefficients, use of the water column values to compute effective mass transfer values did not result in convergence of these values among congeners. This suggests that there are factors other than influences of sediment-water partitioning on pore water PCB concentrations controlling the relative flux of congeners out of the sediments.

Observation of the relative distributions of PCBs in pore water, surface sediments, and in the water column at Thompson Island Dam suggest that a pore water source alone cannot account for the observed congener patterns in the water column. This is illustrated through comparison of the expected pore water distribution in sediment pore water, the measured distribution on particulate sediments, and measured distribution in the Thompson Island Pool PCB load gain for 15 congeners (Figure 6-60). These congeners are those for which 3-phase partition coefficients were estimated from the Phase 2 water column data and the GE 1991 sediment data (USEPA 1997). Inspection of the congener distribution in these three compartments suggests that a combination of dissolved phase and particulate phase pathways is required to match the observed congener pattern at Thompson Island Dam.

Using pore water transfer only (represented by k_f) means that relative sediment-water flux of the congeners under non-resuspending conditions is fixed by their relative concentrations and sediment-water partitioning, which does not appear to be the case. By implementation of a particulate transfer mechanism in the description of sediment-water mass transfer, the relative flux of congeners from the sediments is determined not only by concentrations and partition coefficients, but also by the relative ratio of the particulate and pore water transfer mechanisms.

The mechanisms contributing to enhanced sediment-water transfer of PCBs are due to physical perturbations of the surficial sediments (see list of possible mechanisms above), and are largely independent of chemical properties (assuming dynamic desorption effects are small). The effect of these processes, however, varies by congener due to differences in partitioning behavior. Therefore, modeling the relative sediment-water flux ratios of the congeners may be possible by representing the relative contribution of dissolved and particulate phase PCBs and congener-specific partition behavior. It was postulated that the mechanisms affecting sediment particles at the sediment-water interface was resulting in desorption of PCBs from the sediment to the water column. The relative degrees of desorption among congeners was assumed to occur in ratios determined by equilibrium phase partitioning on suspended solids in the water column.

6.13.4 Estimation of Particulate and Pore water Mass Transfer Rates

As discussed above, in estimating separate mass transfer rates for particulate and pore water pathways, the sediment partition coefficients derived from the GE 1991 sediment data were used. Differences in mass transfer among PCB congeners were assumed to be due only to chemical specific properties. That is, the resulting rates reflect differences among congeners resulting directly from differences in their partitioning behavior.

Similar to the development of k_f for pore water mass transfer, separation of pore water and particulate transfer processes was also represented by simple mass transfer coefficients, which combine to produce the total sediment-water flux for Tri+ computed by k_f.

The load gain represented by the effective mass transfer (k_f) can be assumed to represent the sum of the load gain of particulate pathway processes and the load gain of pore water pathway processes as in the equation below:

$$\Delta L_p + \Delta L_d = \Delta L_{kf} \qquad \textbf{(6-27)}$$

where:

ΔL_p = load gain from particulate pathway
ΔL_d = load gain from pore water pathway
ΔL_{kf} = total load gain produced by the effective mass transfer rate

The individual load terms in this equation can be expressed in terms of their respective mass transfer rates (Equation 6-28).

$$(k_p \cdot A_s \cdot C_p \cdot r \cdot d_f) + (k_d \cdot A_s \cdot C_d) = (k_f \cdot A_s \cdot C_d) \qquad \textbf{(6-28)}$$

where:

k_p = particulate mass transfer rate (cm/day)
k_d = pore water mass transfer rate (cm/day)
k_f = effective mass transfer rate (cm/day)
A = surficial area (m^2)
Cp = particulate PCB concentration in the sediment (mg_{PCB}/Kg_{solid})
r = sediment dry bulk density (Kg_{solid}/L_{bulk})
C_d = apparent dissolved PCB concentration ($mg_{PCB}/L_{porewater}$)
d_f = fraction dissolved in the water column

This equation assumes the water component of the concentration gradients are negligible. The d_f term reflects the assumption that desorption occurs from sediment particles according to equilibrium partitioning in the water column (based on partition coefficients estimated from the Phase 2 water column data). The k_d and k_p terms can be solved for through specification of R. This produces two equations and two unknowns, from which values of k_p and k_d can be determined (Equation 6-29, 6-30).

$$k_p = \frac{k_f \cdot C_d}{C_p \cdot r + R \cdot C_d} \qquad \textbf{(6-29)}$$

$$R = \frac{k_d}{k_p} \qquad \textbf{(6-30)}$$

The value of R was determined through congener pattern matching. An initial value of R was specified and k_d and k_p were solved for using equation 6-29 and 6-30. Then, the relative percent load gain (RP_I) for each of the 15 congeners) for which water column and sediment partition coefficients were estimated (Table 6-47) was computed according to Equation 6-31.

$$RP_i = \frac{\left[(k_p \cdot A_s \cdot C_p \cdot r \cdot d_f) + (k_d \cdot A_s \cdot C_d)\right]_i}{\sum_{i=1}^{15}\left[(k_p \cdot A_s \cdot C_p \cdot r \cdot d_f) + (k_d \cdot A_s \cdot C_d)\right]_i} \qquad \textbf{(6-31)}$$

The RP values were plotted for each congener, representing the computed congener distribution in the TIP load gain, which was matched to the observed distribution. R was optimized to minimize cumulative squared error between computed and observed RP for each of the 15 congeners as shown in Figure 6-60 for summer and non-summer periods.

The value of R was 710 for summer conditions (June through August) and 725 for non-summer conditions (September through May). The resulting mass-transfer coefficients for each modeled congener are shown in Table 6-47. These rates were used in short-term hindcast applications presented in Chapter 7. Results showed that this approach gave reasonable results, however, did not completely explain differences in sediment-water mass transfer between congeners.

Table 6-1. Sediment Data Sets Used in Development and Application of the HUDTOX Model.

Year	Agency	Program description	Purpose of study	Parameters*	Use in HUDTOX
1977	NYSDEC	Sediment core and grab sampling between Fort Edward and Federal Dam	Extensive mapping and sediment sampling to asses extent of PCB pollution in the UHR	PCB Aroclors, visual texture, grain size, %sand/silt/clay	Specification of sediment Tri+ PCB initial conditions for the 1977-1997 calibration.
1984	NYSDEC	Sediment core and grab sampling	Confirm locations of PCB hotspots in TIP	PCB Aroclors, visual texture, bulk density	Specification of sediment Tri+ PCB calibration targets.
1991	General Electric	Composite sediment sampling	Provide sufficient data to calculate mean PCB concentrations over 1 to 2 mile intervals of the UHR	PCB congeners, porewater PCB congeners, TOC, DOC, bulk density, texture, grain size	Specification of Total PCB, BZ#4, BZ#52, and Tri+ initial conditions for 1991-1997 calibration. Specification of sediment Tri+ PCB calibration targets. Specification of sediment DOC levels.
1994	USEPA	High resolution core sampling	Investigation of long-term trends in PCB transport, release and degradation via the sediment record	PCB congeners, porewater PCB congeners, TOC, DOC, bulk density, texture, grain size, radionuclides	Assesment of model-computed sediment burial rates in calibration.
1994	USEPA	Low resolution sediment core sampling	Investigation of PCB levels in selected hotspots of the UHR	PCB congeners, bulk density, texture, grain size, organic carbon	Specification of sediment Tri+ and Total PCB calibration parameters and determination. Specification of sediment organic carbon levels.
1994	USEPA	Confirmatory sediment sampling	Calibration of the side scan sonar signal to sediment properties	Texture, grain size, bulk density	Specification of mean cohesive and noncohesive bulk density values.
1994	USEPA	Sediment type mapping between Fort Edward and Northumberland Dam	Side scan sonar survey of bottom sediments	Areal distribution of fine and coares sediment	Establishing cohesive and noncohesive sediment segmentation, classification of PCB samples as cohesive or noncohesive in setting initial conditions.
1997	General Electric	Sediment type mapping between Northumberland Dam and Federal Dam at 77 transects	Qualitative sediment type determinations based on visual inspection of grab samples or by probing	Qualitative sediment type determination at specific points	Establishing cohesive and noncohesive sediment segmentation.
1998	General Electric	Extensive sediment sampling in TIP and limited numer of locations between TI Dam and Federal Dam		PCB congeners, bulk density, radionuclides	HUDTOX surface sediment Tri+ concentrations for model calibration.

*The list of parameters is not comprehensive and only presents those of interest to the development and calibration of HUDTOX.

Table 6-2. USGS Gage Information for Gages used in Flow Estimation.

USGS gaging station	USGS Station No.	Drainage Area (mi^2)	Period of Operation
Hudson River at Fort Edward, NY	01327750	2817	1/1/77 - 9/30/97
Hudson River at Stillwater, NY	01331095	3773	1/1/77 - 9/30/97[1]
Hudson River above Lock 1 near Waterford, NY	01335754	4611	3/1/77 - 9/30/97[1]
Glowegee Creek at West Milton, NY	01330000	26	10/1/90 - 9/30/97
Kayaderosseras Creek near West Milton, NY	01330500	90	1/1/77 - 9/30/96
Hoosic River near Eagle Bridge, NY	01334500	510	1/1/77 - 9/30/97
Mohawk River at Cohoes, NY	01357500	3450	1/1/77 - 9/30/97
Mohawk River Diversion at Crescent Dam, NY	01357499	N/A	1/1/77 - 9/30/97

Source: USGS

[1] Due to construction, many of the flows recorded after 6/30/92 were rated as "poor" by the USGS. "Poor" means that "about 95 percent of the daily discharges have less than "fair" accuracy. "Fair" means that about 95 percent of the daily discharges are within 15 percent.

Table 6-3. Drainage Areas and Reference Tributaries Used to Estimate Daily Tributary Flows.

Tributary	Drainage Area (mi^2)	Gaged Reference Tributary
Snook Kill	75	DAR to Kayaderosseras Creek for the period 1/1/77 – 9/30/96. DAR to Glowegee Creek for the period 9/30/96 – 9/30/97. (Note: Kayaderosseras Creek flow data are unavailable after 6/30/96 so Glowegee Creek was used.)
Moses Kill	55	
Thompson Island Pool direct runoff	31	
Batten Kill	431	
Fish Creek	245	
Flatey Brook	8	DAR to Hoosic River at Eagle Bridge, NY
Schuylerville-Stillwater direct runoff	80	
Hoosic River	720	
Anthony Kill	63	
Deep Kill	16	
Stillwater-Waterford direct runoff	39	
Mohawk River[1]	3,450	USGS gage at Cohoes + Diversion at Crescent Dam

Source: LTI GIS

[1]The Mohawk River stations are near the Mohawk-Hudson confluence so no drainage area adjustment was required.

Table 6-4. Mean Seasonal USGS Flows For Select Flow Gauges in the Study Area for the Period 3/1/77 to 6/30/92.

Season	Fort Edward	Stillwater	Waterford	Glowegee Creek	Kay. Creek @ West Milton	Hoosic River @ Eagle Bridge
Winter	5274.1	6582.5	8283.7	36.1	133.6	1042.9
Spring	7773.6	10052.9	12866.1	56.0	254.3	1770.4
Summer	3267.2	4000.1	4579.9	16.5	80.2	545.1
Fall	4489.8	5582.4	6579.0	31.5	106.1	743.5

Source: TAMS/Gradient Database/Release 4.1b

Table 6-5. Seasonal Tributary Flow Adjustment Factors applied to Tributaries between Fort Edward and Stillwater, and between Stillwater and Waterford.

Season	Fort Edward Yield (cfs/mi^2)	Fort Edward - Stillwater			Stillwater - Waterford		
		$\Delta\ \bar{Q}_{FE\text{-}Still}$ (cfs)	α_{FS}	Incremental Yield (cfs/mi^2)	$\Delta\ \bar{Q}_{\text{Still-Watfd}}$ (cfs)	α_{SW}	Incremental Yield (cfs/mi^2)
Winter	1.872	1175	0.88	0.311	658	0.98	0.143
Spring	2.760	2025	0.81	0.537	1043	0.92	0.226
Summer	1.160	653	0.83	0.173	35	0.10	0.0076
Fall	1.594	986	0.94	0.261	253	0.53	0.055

Table 6-6. Hudson River Flows Yearly Averages Estimated and USGS Gage Data.

Year	Stillwater		RPD[1]
	Estimated (cfs)	USGS (cfs)	
1977	8618	8731	-1%
1978	6415	6235	3%
1979	7612	7749	-2%
1980	4515	4327	4%
1981	5724	5626	2%
1982	6203	6107	2%
1983	7677	7486	3%
1984	7450	7360	1%
1985	5170	5140	1%
1986	7542	7291	3%
1987	6548	6296	4%
1988	5000	5030	-1%
1989	6330	6568	-4%
1990	9111	9303	-2%
1991	5500	5926	-7%
1992	6084	6374	-5%
1993	6252	6377	-2%
1994	6593	6862	-4%
1995	5093	5081	0%
1996	8694	8940	-3%
1997	7297	7469	-2%
Overall	6616	6654	-1%

[1]RPD = Relative Percent Difference

Year	Waterford		RPD
	Estimated (cfs)	USGS (cfs)	
1977	10154	10538	-4%
1978	7879	7672	3%
1979	9652	9672	0%
1980	5405	5239	3%
1981	6902	6635	4%
1982	7460	7440	0%
1983	9455	9358	1%
1984	9259	9153	1%
1985	6172	5868	5%
1986	9134	8968	2%
1987	7865	7648	3%
1988	6238	6062	3%
1989	7783	7902	-2%
1990	11141	11755	-5%
1991	6823	7503	-9%
1992	7168	7601	-6%
1993	7758	8068	-4%
1994	8130	8475	-4%
1995	6187	6255	-1%
1996	11111	11483	-3%
1997	8691	9039	-4%
Overall	8106	8196	-1%

Table 6-7. Summary of Available Solids Data for Mainstem Stations; Number of Samples and Source of Suspended Solids Sample Data by Station.

Year	Ft. Edward			TID		Stillwater			Waterford		
	USGS	**Phase 2**	**GE**	**Phase 2**	**GE**	**USGS**	**Phase 2**	**GE**	**USGS**	**Phase 2**	**GE**
1977	1					33			47		
1978	30					30			31		
1979	52					34			32		
1980	55					27			37		
1981	55					29			24		
1982	49					43			32		
1983	40					126			134		
1984	34					209			247		
1985	17					82			129		
1986	27					306			295		
1987	15					49			85		
1988	38					68			101		
1989	23					157			334		
1990	3					275			242		
1991	19		65			373		60	251		120
1992	21		67			390		28	390		34
1993	27	58	56	78		387	2		410	288	1
1994	30	47	31	40		386	35		405	89	
1995	68		68			303			299		
1996	27		71		4	30			66		
1997	19		155		190	19			25		

Source: USGS Gaging Records; Butcher, 1993; Bopp, 1994.

Table 6-8. Summary of Available Solids Data for Tributaries; Number of Samples and Source of Suspended Solids Sample Data by Station.

Year	Batten Kill			Hoosic River			Mohawk River		Moses Kill		Snook Kill	
	USGS	Phase 2	GE	USGS	Phase 2	GE	USGS	Phase 2	Phase 2	GE	Phase 2	GE
1988	6			2								
1989				4			2					
1990				1			10					
1991			25	4		24	5					
1992			28			28	2					
1993		5	1	9	6	1	9	6				
1994		32		12	32		18	31	32		31	
1995				3			25					
1996							10					
1997										115		117

Source: TAMS/Gradient Database/Release 4.1b

Table 6-9. Reference Tributaries for Unmonitored Tributaries

Reference Tributary	Unmonitored Tributaries
Moses Kill	TIP Direct Drainage Area, Flately Brook, TID-Schuylerville Direct Drainage Area, Schuylerville-Stillwater Direct Drainage Area
Batten Kill	Fish Creek
Hoosic River	Anthony Kill, Deep Kill, Stillwater- Waterford Direct Drainage Area

Table 6-10. Tributary Solids Rating Curve Equations for Data-Based Rating Curves and Adjusted Rating Curves for the Long-Term Solids Balance.

Tributary[1]	Flow cut-point (cfs)[2]	Unadjusted		Adjusted		10/1/77-9/30/97 Unadjusted Average Load MT/Year	10/1/77-9/30/97 Adjusted Average Load MT/Year
		A	B	A	B		
Snook Kill	105	0.0070	1.5618	0.0070	1.5618	4,222.4	4,222.4
Moses Kill	77	0.0437	1.2943	0.0437	1.2943	2,619.4	2,619.4
Ungaged/Direct drainage to TIP	43	0.0437	1.2943	0.0437	1.2943	197.9	197.9
Batten Kill	602	0.0110	0.9933	0.0110	1.2190	7,797.0	37,754.6
Ungaged TID - Schuylerville (Moses Kill)	42	0.0437	1.2943	0.0437	1.5910	691.2	2,716.0
Fish Creek (Batten Kill)	357	0.0010	0.9933	0.0110	1.1490	3,035.8	7,884.0
Flately Brook (Moses Kill)	12	0.0437	1.2943	0.0437	1.8500	78.2	701.1
Ungaged Schuylerville - Stillwater (Moses Kill)	117	0.0437	1.2943	0.0437	1.2190	11,411.1	7,008.0
Hoosic River	1,328	0.0015	1.2270	0.0015	1.2870	45,736.3	73,985.0
Deep Kill (Hoosic River)	24	0.0015	1.2270	0.0015	2.2360	47.1	1,643.9
Anthony Kill (Hoosic River)	94	0.0015	1.2270	0.0015	1.7880	313.3	6,473.7
Ungaged Stillwater - Waterford (Hoosic River)	58	0.0015	1.2270	0.0015	1.9250	150.6	4,008.2
Mohawk River	5,661	0.0002	1.2800	0.0002	1.2800	246,673.7	246,673.7

[1] Tributaries in parentheses are the reference tributaries.

[2] Flow cut-points are specified as the average flow.

Table 6-11. Cumulative Mainstem Solids (SS) Loads and Yields

Station	Cumulative SS Load (MT) (1/1/77 - 9/30/97)	Cumulative SS Load (MT) (10/1/77 - 9/30/97)	Drainage Area (mi^2)	Yield (MT/mi^2*yr) (10/1/77 – 9/30/97)
Fort Edward	622,518	587,550	2,817	10.43
Stillwater	1,737,328	1,640,581	3,773	21.74
Waterford	3,574,041	3,239,717	4,611	35.13

Data Source: Hudson River Database Release 4.1b.

Table 6-12. Cumulative Solids Loads and Corresponding Yields by Reach (10/1/77 - 9/30/97)

Reach	Cumulative Solids Load (MT)		Average Annual Yield by Reach (MT/mi^2*yr)	
	Load increment between mainstem stations	Sum of tributary Solids loads	Yield increment between mainstem stations	Yield delivered by tributaries using rating curve
Fort Edward - Stillwater	1,053,031	601,061	55.1	31.4
Stillwater - Waterford	1,599,136	924,948	95.4	55.2

Table 6-13. Solids (TSS) Trapping Efficiencies by Reach Estimated by QEA Using SEDZL and Applied to Estimate Tributary TSS Loads in HUDTOX.

Reach	Trap%[1] computed by SEDZL[2]	Area-weighted reach average Trap% applied to compute tributary TSS loads
Fort Edward to TI Dam	8.8	8.8
TI Dam to Lock 6	0.8	
Lock 6 to Northumberland Dam	2.3	
Northumberland Dam to Stillwater Dam	11	8.47
Stillwater Dam to Lock 3	10	
Lock 3 to Lock 2	1.8	
Lock 2 to Lock 1	<0.1	3.66
Lock 1 to Federal Dam	<0.1	0

[1] Trap% = TSS trapping efficiency, or percent of upstream and tributary solids load retained.

[2] From QEA, 1999.

Table 6-14. Comparison of LTI and Literature-Based Annual Average Sediment Yield Estimates by Watershed.

Tributary	SCS Report - p. 34, 48, 49				SCS rpt. p. 103	Load/area Calc. Using LTI land use dist (GIS) and SCS soil loss/year by land use *DR=0.08		**Summary Yields (MT/mi2-yr)**		
	Tons	Square Miles	Tons/square mile-yr (no DR)	**Tons/mi2-yr (8% DR)**		w cropland adequately treated	w cropland needing treatment	**Minimum**	**Maximum**	**LTI Estimate**
Snook Kill	72,751	122	595	**47.6**		32.2	32.2	32.2	47.6	56.3
Moses Kill	69,306	69	1,003	**80.2**		47.9	47.9	47.9	80.2	47.6
Batten Kill	70,877	176	402	**32.1**		33.2	33.2	32.1	33.2	87.6
Fish Creek	109,154	256	427	**34.2**		36.5	36.5	34.2	36.5	32.2
Flately Brook	75,759	85	887	**71**		42.8	42.9	42.8	71	87.6
Hoosic River	106,021	236	448	**35.9**		39.4	39.4	35.9	39.4	102.8
Deep Kill	38,547	68	570	**45.6**		46.4	46.4	45.6	46.4	102.8
Anthony Kill	29,617	66	445	**35.6**	**33.6**	53.4	53.5	33.6	53.5	102.8
TIP Direct						53.3	53.3	53.3	53.3	6.4
TI Dam-Schuylerville Direct						45.2	45.2	45.2	45.2	87.6
Schuylerville-Stillwater Direct						44.2	44.2	44.2	44.2	87.6
Stillwater-Waterford Direct						54.8	54.8	54.8	54.8	102.8

Reference: USDA, Soil Conservation Service. 1974. Erosion and Sediment Inventory: New York.

Table 6-15. Number of Tri+ PCB Data Available by Source and Year at Each Hudson River Mainstem Sampling Station.

Year	Fort Edward			Thompson Island Dam			Schuylerville			Stillwater			Waterford		
	GE	P2	USGS	GE	P2	USGS	GE	P2	USGS	GE	P2	USGS	GE	P2	USGS
1977			3						33			35			52
1978			35						12			31			31
1979			53						15			36			37
1980			55						14			28			42
1981			58						34			33			25
1982			49						34			44			33
1983			44						41			49			51
1984			34						29			35			39
1985			17						18			18			67
1986			28						25			25			24
1987			15						10			8			24
1988			38						20			23			21
1989			23						20			19			26
1990			26						5			15			18
1991	38		19	32			35			36		16	36		17
1992	79		21	54			22			27		24	27		25
1993	60	99	27	51	99		1	6			3	22	1	91	30
1994	37		30	35								19			30
1995	73		71	67								21			22
1996	107		26	93								21			26
1997	97		19	185			17					19			20
1998	38			50			35								
Total	529	99	691	567	99		110	6	310	63	3	541	64	91	660

Source: Hudson River Database Release 4.1b

Table 6-16. Number of Days With Available PCB Data for Monitored Tributaries (Batten Kill, Hoosic River, Mohawk River).

Year	Batten Kill							Hoosic River							Mohawk River						
	Tri+	Total	BZ#4	BZ#28	BZ #52	BZ#90 +101	BZ#138	Tri+	Total	BZ#4	BZ#28	BZ #52	BZ#90 +101	BZ#138	Tri+	Total	BZ#4	BZ#28	BZ #52	BZ#90 +101	BZ#138
1991		18	18	18	18	18	18		17	17	17	17	17	17							
1992		26	26	26	26	26	26		25	25	25	25	25	25							
1993	5	6	6	6	6	6	6	6	8	8	8	8	8	8	6	7	7	7	7	7	7
Total	5	50	50	50	50	50	50	6	50	50	50	50	50	50	6	7	7	7	7	7	7

Table 6-17. Number of PCB Data Available for Each Congener and Total PCB by Source and Year at Each Hudson River Mainstem Sampling Station[1].

Year	Fort Edward		Thompson Island Dam		Schuylerville		Stillwater		Waterford	
	GE	Phase2	GE	Phase2	GE	Phase2	GE	Phase2	GE	Phase2
1991	30		30		30		31		31	
1992	73		51		20		26		24	
1993	60	12	51	12	1	6		2	1	13
1994	32		35							
1995	55		50							
1996	85		75							
1997	78		147		16					
1998	32		41		29					
Total	445	12	480	12	96	6	57	2	56	13

[1] The numbers in this table apply to each PCB type individually.

Source: Hudson River Database Release 4.1b

Table 6-18. Criteria and Factors Used in Adjustment of Thompson Island Dam West Shore PCB Data Bias.

Fort Edward Condition	Criteria	Total PCBs	Tri+ PCBs
Low Flow, Low Upstream Concentration	Q < 4000 cfs C < 17 ng/L (Total) or ≤ 15 ng/L (Tri+)	0.64	0.69
Low Flow, High Upstream Concentration	Q < 4000 cfs C ≥ 17 ng/L (Total) or > 15 ng/L (Tri+)	0.80	0.88
High Flow, Low Upstream Concentration	Q ≥ 4000 cfs C < 17 ng/L (Total) or ≤ 15 ng/L (Tri+)	0.78	1.00
High Flow, High Upstream Concentration	Q ≥ 4000 cfs C ≥ 17 ng/L (Total) or > 15 ng/L (Tri+)	1.00	1.00

Table 6-19. Tri+ and Total PCB Concentration Statistics for Monitored Tributaries.

Tributary	PCB Form	Count	Average Concentration (ug/L)	Std. Dev.	Maximum Concentration (ug/L)	Minimum Concentration (ug/L)
Batten Kill	Tri+	5	0.00149	0.00276	0.00710	0.00000
	Total	50	0.00606	0.01052	0.04764	0.00000
Hoosic River	Tri+	6	0.00205	0.00120	0.00437	0.00108
	Total	50	0.01132	0.01282	0.05131	0.00000
Mohawk River	Tri+	6	0.00084	0.00054	0.00146	0.00017
	Total	7	0.01162	0.01568	0.03967	0.00115

Source: Hudson River Database Release 4.1b

Table 6-20. Comparison of Annual Tri+ PCB Load Estimates at Hudson River Mainstem Station Presented in the DEIR[1] and by LTI[2] in this Report.

Year	Fort Edward		Schuylerville		Stillwater		Waterford	
	DEIR	LTI	DEIR	LTI	DEIR	LTI	DEIR	LTI
1977	1,414	673	2,519	2,215	2,926	2,545	2,439	2,394
1978	544	351	2,747	1,821	2,138	1,680	2,260	2,047
1979	1,272	978	4,635	3,987	3,008	3,081	2,963	3,355
1980	439	430	760	772	899	851	1,007	785
1981	354	291	962	1,207	922	946	1,299	1,188
1982	374	325	528	490	635	717	818	774
1983	657	551	997	967	1,612	1,486	1,191	1,133
1984	477	617	830	478	826	678	702	501
1985	294	186	324	157	299	186	432	179
1986	423	191	320	180	358	130	366	153
1987	197	220	213	157	235	157	300	241
1988	119	65	83	59	105	73	100	73
1989	445	103	195	136	200	159	151	124
1990	398	224		363	220	336	115	404
1991	185	259		465	208	257	212	271
1992	825	604		655	411	491	317	438
1993	310	234		283	420	445	229	268
1994	90	155		240		126		128
1995		108		157		92		83
1996		59		219		154		168
1997		29		130		80		139

[1] Data Evaluation and Interpretation Report (TAMS, 1997), Table 3-23 Ratio Method.

[2] Limno-Tech, Inc.

Table 6-21. Estimated Average Annual Load at Fort Edward by PCB Type from 1991-1997.

Year	Tri+ (kg/day)	Total (kg/day)	BZ#4 (kg/day)	BZ#28 (kg/day)	BZ#52 (kg/day)	BZ#90+101 (kg/day)	BZ#138 (kg/day)
1991	0.7108	1.1784	0.0415	0.0901	0.0638	0.0189	0.0140
1992	1.6496	1.8622	0.0571	0.1169	0.0930	0.0304	0.0188
1993	0.6417	0.9880	0.0738	0.0931	0.0865	0.0238	0.0098
1994	0.4246	0.4813	0.0404	0.0483	0.0437	0.0217	0.0102
1995	0.2949	0.3462	0.0192	0.0335	0.0216	0.0116	0.0080
1996	0.1618	0.2223	0.0153	0.0164	0.0155	0.0073	0.0040
1997	0.1063	0.1258	0.0120	0.0068	0.0072	0.0043	0.0015

Table 6-22. Cohesive/non-cohesive Sample Classification Criteria Applied to 1977 NYSDEC Data to Compute HUDTOX Sediment Tri+ Initial Conditions.

Classification	Classification Criteria Reach	Side Scan Sonar Region	Texture Class*	Principal Fraction**	Other
Cohesive	Fort Edward to Lock 5	Fine	-	-	
Non-cohesive	Fort Edward to Lock 5	Coarse	n.appl.	-	
Non-cohesive	Fort Edward to Lock 5	Fine	8,9	-	
Cohesive	Fort Edward to Lock 5	Coarse	-	<= 200	
Cohesive	downstream of Lock 5	NA	-	<= 200	
Non-cohesive	downstream of Lock 5	NA	-	>= 400	
Cohesive	downstream of Lock 5	NA	-	300	%clay + %silt ≥ 25
Non-cohesive	downstream of Lock 5	NA	-	300	%clay + %silt < 25
Cohesive	downstream of Lock 5	NA	< 4	NA	
Non-cohesive	downstream of Lock 5	NA	≥4, ≤10	NA	
Cohesive	downstream of Lock 5	NA	>10 or NA	NA	Tri+ ≥ 50 ppm
Non-cohesive	downstream of Lock 5	NA	>10 or NA	NA	Tri+ < 50 ppm
Cohesive	all	either	-	-	$f_{OC} \geq 0.10$

NA=not available, shaded dash cells indicate not applicable

*Modified from Tofflemire and Quinn, 1979

Texture No. (txtno)	Sediment type description
txtno<1	clay
1 ≤ txtno < 2	silt
2 ≤ txtno < 4	muck, muck&wood chips
4 ≤ txtno < 6	fine sand, fine sand & wood chips
6 ≤ txtno < 8	sand, sand & wood chips
8 ≤ txtno < 10	coarse sand, course sand & wood chips
txtno > 10*	considered unclassified - no matching class in Tofflemire and Quinn, 1979

** From USEPA Hudson River Database Release v4.1b

Principal fraction	Type
100	clay
200	silit
300	fine sand
400	medium sand
500	coarse sand
600	gravel

Table 6-23. Sample Count and Averaging Groups for Specifying 1977 Sediment Initial Conditions for HUDTOX from the NYSDEC Data.

HUDTOX Segment	Number of samples		Averaging Group	Count of samples in averaging group		
	Cohesive	Non-cohesive		Cohesive	Non-cohesive	Total
1	1	3	1	8	25	33
2		2				
3	5	2				
4		4				
5	2	3				
6		10				
7		1				
8	12	8	2	29	62	91
9	4	16				
10	1	5				
11	5	8				
12	1	16				
13	6	9				
14	6	3	3	15	18	33
15	1	9				
16	8	6				
17	8	4	4	11	30	41
18	1	16				
19	2	10				
20	5	3	5	19	12	31
21	2	8				
22	12	1				
23	5	6	6	13	15	28
24	2	6				
25	6	3				
26	4	22	7	40	50	90
27	23	21				
28	13	7				
29	29	50	8	29	50	79
30	42	22	9	42	22	64
31	56	15	10	56	15	71
32	2	1	11	22	14	36
33	5	1				
34	15	12				
35	8	5	12	56	26	82
36	25	9				
37	23	12				
38	19	5	13	27	8	45
39	8	3				
40	17	9	14	29	20	49
41	12	11				
42	4	2	15	12	8	20
43	8	6				
44	3	5	16	11	10	21
45	8	5				
46	53	6	17	55	8	63
47	2	2				

Table 6-24. Averaging Groups for Specifying Sediment Initial Conditions from the 1991 GE Composite Sampling Data.

HUDTOX water column segment	Number of samples		Total number of samples	Averaging Group	Count of samples		
	Cohesive	Non-cohesive			Cohesive	Non-cohesive	Total
1		5	5	1	8	70	78
2		5	5				
3		7	7				
4		10	10				
5	8	19	27				
6		5	5				
7		19	19				
8	46	5	51	2	47	36	83
9		11	11				
10	1	20	21				
11	15	9	24	3	29	30	59
12		7	7				
13	14	14	28				
14	19	9	28	4	19	9	28
15	1	10	11	5	1	10	11
16	22	13	35	6	22	13	35
17	17	12	29	7	17	12	29
18		13	13	8	0	13	13
19	10	10	20	9	10	10	20
20		23	23	10	0	23	23
21	3	5	8	11	3	5	8
22	26		26	12	26	0	26
23	18	8	26	13	27	9	36
24		1	1				
25	9		9				
26		17	17	14	18	33	51
27		13	13				
28	18	3	21				
29	10	29	39	15	10	29	39
30	7	18	25	16	7	18	25
31	16	6	22	17	16	6	22
32		7	7	18	17	31	48
33		16	16				
34	17	8	25				
35	16	11	27	19	77	58	135
36	33	16	49				
37	28	31	59				
38	9	10	19	20	18	15	33
39	9	5	14				
40		17	17	21	6	19	25
41	6	2	8				
42	8	14	22	22	15	16	31
43	7	2	9				
44	1	36	37	23	1	48	49
45		12	12				
46		43	43	24	0	71	71
47		28	28				
		Grand Total:	978		394	584	978

Table 6-25. Pool-Wide Thompson Island Pool Average Surficial Sediment Concentrations for Each PCB State Variable.

	Concentrations in mg/L bulk		
PCB Type	**Cohesive**	**Non-Cohesive**	**Area-Weighted Average**
Total	40.44	28.28	31.08
Tri+	18.01	14.51	15.31
BZ#4	9.30	5.16	6.11
BZ#28	0.74	0.95	0.90
BZ#52	1.14	0.79	0.87
BZ#90+101	0.18	0.13	0.14
BZ#138	0.11	0.07	0.08

Source: Hudson River Database Release 4.1b

Table 6-26. 3-Phase Partition Coefficients Estimated from Phase 2 Water Column Data (TAMS, et. al, 1997) and GE Sediment Data (updated by Butcher, 1998)

	Phase 2 Water Column		GE Sediment Data	
Parameter	**log k_{POC}**	**log k_{DOC}**	**log k_{POC}**	**log k_{DOC}**
Tri+	5.845	3.96	N/A	N/A
BZ#4	5.19	5.43	4.73	3.60
BZ#28	5.84	4.16	6.49	4.36
BZ#52	5.82	4.28	5.98	4.32
BZ#101+90	6.18	4.54	5.98	4.68
BZ#138	6.43	4.86	6.31	5.12

N/A = None Available

Table 6-27. Mass Fraction of Total PCB Represented by Tri+, BZ#1, BZ#4, and BZ#8 at Mainstem Hudson River Stations Determined from GE and USEPA Phase 2 (P2) Data.

	Total PCB		Tri+ PCB		BZ#1		BZ#4		BZ#8	
Location	**GE**	**P2**	**GE**	**P2**	**GE**	**P2**	**GE**[1]	**P2**	**GE**[2]	**P2**
Fort Edward	98.13%	89.70%	90.59%	74.76%	0.08%	4.26%	3.60%	8.28%	3.86%	2.40%
Thompson Island Dam	98.80%	93.74%	60.25%	49.79%	10.83%	16.79%	24.38%	24.86%	3.33%	2.29%
Schuylerville	98.69%	94.97%	66.86%	62.95%	8.55%	11.45%	20.02%	18.61%	3.25%	1.96%
Stillwater	98.64%	95.94%	81.65%	72.61%	4.32%	12.04%	9.53%	9.27%	3.14%	2.02%
Waterford	98.41%	94.07%	82.25%	71.56%	2.87%	5.20%	10.04%	15.60%	3.25%	1.70%

[1] GE reports BZ#4 and BZ#10 together as one result.

[2] GE reports BZ#8 and BZ#5 together as one result.

Source: Hudson River Database Release 4.1b

Table 6-28. Estimated Partition Coefficients (K_{POC}, K_{DOC}) for Total PCB by Source and Agency at Mainstem Hudson River Stations.

LTI ID	Log K_{POC} (L/Kg)		Log K_{DOC} (L/Kg)		Number of GE Data	Number of P2 Data
	GE	P2	GE	P2		
Fort Edward	6.23	5.20	4.46	3.61	348	12
Thompson Island Dam	5.25	4.16	4.13	3.06	475	12
Schuylerville	5.46	4.60	4.20	3.30	94	6
Stillwater	5.90	5.19	4.34	3.70	55	3
Waterford	5.98	4.84	4.39	3.38	53	13

Table 6-29. Estimated Partition Coefficients (K_{POC}, K_{DOC}) for Total PCB at Mainstem Hudson River Stations and Averaged Over Study Reach.

LTI ID	Average Log K_{POC}[1] (L/kg)	Average Log K_{DOC}[1] (L/kg)	Distance Used in Weighting (m)
Fort Edward	6.19	4.43	4,828
TI Dam	5.22	4.11	10,541
Schuylerville	5.41	4.15	16,335
Stillwater	5.87	4.30	20,036
Waterford	5.75	4.19	9,415
Final Estimate[2]	5.64	4.22	

[1] Average was determined by weighting each source's value with the number of data points presented in Table 6-28.

[2] Final estimate was determined by weighting the station specific average value with the distance associated with each station in the last column of this table.

Table 6-30. Statistical Summary of Dissolved Organic Carbon (DOC) Water Column Data.

Location	River Mile	Count of DOC Concentrations	Average DOC Concentration (mg/L)	Maximum DOC Concentration (mg/L)	Minimum DOC Concentration (mg/L)	Std. Dev.
Above Fort Edward	199.5	13	5.75	9.69	3.97	1.77
Above Fort Edward	197.6	29	4.82	5.94	4.01	0.51
Above Fort Edward	197	6	3.58	5.00	2.00	1.28
Above Fort Edward	195.5	14	4.65	5.28	3.75	0.51
Fort Edward	194.6	25	5.03	6.30	4.15	0.62
Fort Edward	194.4	8	4.41	7.00	2.00	1.70
Thompson Island Pool	193.7	2	3.44	3.92	2.96	0.68
Thompson Island Pool	189	11	4.43	7.00	1.00	1.44
Thompson Island Dam	188.5	28	5.00	5.53	4.11	0.39
Between TI Dam and Schuylerville	182.3	6	3.60	5.34	1.93	1.56
Schuylerville	181.4	17	4.25	7.00	2.00	1.36
Schuylerville	181.3	8	5.30	6.57	4.46	0.76
Stillwater	168.3	29	4.35	8.00	0.94	1.29
Waterford	156.5	50	4.01	6.00	1.00	1.01
Below Federal Dam	151.7	3	4.34	4.63	4.16	0.26
Below Federal Dam	125	2	4.04	4.39	3.69	0.50
Below Federal Dam	110	1	3.80	3.80	3.80	
Below Federal Dam	77	2	3.55	3.83	3.26	0.40

Table 6-31. Mean DOC Concentrations by Reach in Upper Hudson River.

Reach	River Miles	DOC Concentration (mg/L)
FE-TID	194.5-188.5	4.32
TID-Schuylerville	188.5-181.4	4.28
Schuylerville-Stillwater	181.4-168.2	4.63
Stillwater-Waterford	168.2-156.5	4.01

Table 6-32. Mean Sediment f_{OC} Values Specified from GE 1991 Composite Data for River Mile intervals in HUDTOX.

Downstream-Upstream River Mile	Mean f_{OC}	
	Fine (Assigned to Cohesive)	Coarse (Assigned to Non-cohesive)
193.5-194.5	0.037	0.013
192.5-193.5	0.017	0.008
191.5-192.5	0.022	0.011
190.5-191.5	0.022	0.013
189.5-190.5	0.023	0.008
188.5-189.5	0.027	0.008
188.5-183	0.028	0.008
183 -180	0.016	0.013
180 -175	0.016	0.01
175 -170	0.017	0.007
170 -155	0.021	0.008

Source: Hudson River Database Release 4.1b

Table 6-33.
Illustration of Typical Low and High Flow Partitioning Behavior During Cold Weather and Warm Weather Periods.

PCB state variable	Summer						Winter					
	low flow			high flow			low flow			high flow		
	f_{diss}	f_{doc}	f_p	f_{diss}	f_{doc}	f_p	f_{diss}	f_{doc}	f_p	f_{diss}	f_{doc}	f_p
Total	0.70	0.04	0.26	0.26	0.01	0.72	0.49	0.06	0.45	0.13	0.02	0.86
Tri+	0.61	0.02	0.37	0.18	0.01	0.81	0.39	0.03	0.58	0.09	0.01	0.91
BZ#4	0.51	0.43	0.07	0.35	0.30	0.34	0.30	0.61	0.10	0.18	0.38	0.44
BZ#28	0.61	0.04	0.35	0.19	0.01	0.80	0.39	0.06	0.55	0.09	0.01	0.90
BZ#52	0.61	0.03	0.36	0.19	0.01	0.81	0.39	0.04	0.57	0.09	0.01	0.90
BZ#90+101	0.41	0.05	0.54	0.09	0.01	0.90	0.23	0.06	0.72	0.04	0.01	0.95
BZ#138	0.28	0.06	0.65	0.06	0.01	0.93	0.14	0.08	0.78	0.02	0.01	0.96

Input Conditions

parameters	winter low flow	winter high flow	summer low flow	summer high flow
m_s	5	100	5	100
θ_s	1	1	1	1
foc-s	0.22	0.08	0.22	0.08
DOCs	4.01	4.01	4.01	4.01
Temp	1.13	1.13	27.8	27.8

Table 6-34. Henry's Law Constants Developed Expirementally by Brunner, et. al. (1990) for Selected Congeners.

BZ #	Brunner's HLC[1] (atm-m3/mol)
4	0.000230
5	0.000230
6	0.000250
7	0.000280
8	0.000230
9	0.000280
10	0.000230
12	0.000140
16	0.000200
18	0.000250
19	0.000230
20	0.000160
22	0.000140
24	0.000220
26	0.000200
28	0.000200
29	0.000200
31	0.000190
32	0.000200
33	0.000160
34	0.000200
36	0.000170
37	0.000100
40	0.000100
41	0.000140
42	0.000140
44	0.000140
47	0.000190
49	0.000210
51	0.000140
52	0.000200
54	0.000200
62	0.000210

BZ #	Brunner's HLC[1] (atm-m3/mol)
64	0.000140
66	0.000120
67	0.000100
69	0.000210
70	0.000100
74	0.000100
79	0.000090
85	0.000066
87	0.000074
91	0.000120
95	0.000120
97	0.000074
99	0.000078
101	0.000090
102	0.000090
119	0.000074
120	0.000056
128	0.000013
129	0.000029
130	0.000037
131	0.000039
132	0.000044
134	0.000049
135	0.000056
136	0.000088
138	0.000021
141	0.000023
143	0.000039
146	0.000025
147	0.000051
151	0.000059
153	0.000023
159	0.000020

BZ #	Brunner's HLC[1] (atm-m3/mol)
160	0.000020
163	0.000015
165	0.000029
170	0.000009
172	0.000013
173	0.000014
174	0.000014
178	0.000023
179	0.000024
180	0.000010
185	0.000016
194	0.000010
195	0.000011
196	0.000010
198	0.000014
199	0.000010
201	0.000017
202	0.000018

[1] Source: Brunner, S., et.al. "Henry's Law Constants for Polychlorinated Biphenyls: Experimental Determination and Structure-Property Relationships." Environ. Sci. Tech., Vol. 24, No. 11, 1990.

Table 6-35. Congener Distribution of Total PCB by Mass Fraction at Mainstem Hudson River Stations Using 1993 USEPA Phase 2 Data (Number of observations).

Congener Number	Fort Edward (12)	Thompson Island Dam (12)	Schuylerville (6)	Stillwater (3)	Waterford (13)	Upper Hudson Average
BZ#1	4.258%	16.793%	11.449%	12.040%	5.201%	9.240%
BZ#2	0.000%	0.000%	0.000%	0.000%	0.109%	0.031%
BZ#3	0.151%	0.138%	0.000%	0.000%	0.181%	0.126%
BZ#4	8.283%	24.865%	18.613%	9.273%	15.605%	16.090%
BZ#5	0.005%	0.007%	0.000%	0.009%	0.000%	0.004%
BZ#6	0.575%	0.603%	0.454%	0.515%	0.513%	0.545%
BZ#7	0.061%	0.026%	0.022%	0.000%	0.013%	0.029%
BZ#8	2.397%	2.292%	1.963%	2.021%	1.705%	2.093%
BZ#9	0.196%	0.222%	0.101%	0.106%	0.068%	0.148%
BZ#10	1.681%	4.261%	2.854%	1.552%	3.225%	2.935%
BZ#12	0.060%	0.086%	0.055%	0.114%	0.140%	0.092%
BZ#15	7.739%	1.019%	1.613%	1.763%	1.820%	3.125%
BZ#16	0.990%	0.573%	0.658%	0.520%	0.712%	0.729%
BZ#17	0.837%	0.613%	0.393%	0.000%	0.932%	0.693%
BZ#17NT	1.471%	1.151%	1.687%	2.421%	1.722%	1.549%
BZ#18	4.029%	3.121%	4.088%	5.016%	4.162%	3.902%
BZ#19	3.257%	4.531%	3.508%	1.863%	4.620%	3.917%
BZ#20	0.187%	0.093%	0.030%	0.000%	0.081%	0.100%
BZ#20 (as BZ#52)NT	0.514%	0.518%	0.890%	0.882%	0.652%	0.627%
BZ#22	1.886%	1.152%	1.571%	1.994%	1.197%	1.466%
BZ#23NT	0.168%	0.062%	0.172%	0.206%	0.144%	0.137%
BZ#24NT	0.106%	0.078%	0.149%	0.245%	0.123%	0.118%
BZ#25	0.380%	0.308%	0.355%	0.537%	0.524%	0.409%
BZ#26	1.363%	1.657%	1.737%	2.332%	2.140%	1.771%
BZ#27	1.002%	1.364%	1.589%	2.042%	1.264%	1.315%
BZ#27 & BZ#_24_	0.763%	1.009%	0.508%	0.000%	1.005%	0.812%
BZ#28	6.012%	3.522%	5.456%	7.195%	5.390%	5.191%
BZ#29	0.075%	0.057%	0.061%	0.058%	0.096%	0.074%
BZ#31	4.289%	3.458%	4.430%	5.689%	5.096%	4.410%
BZ#32NT	3.389%	2.201%	2.636%	3.063%	2.962%	2.839%
BZ#33	0.429%	0.179%	0.100%	0.000%	0.106%	0.202%
BZ#33NT	0.259%	0.125%	0.223%	0.303%	0.211%	0.208%
BZ#34NT	0.378%	0.200%	0.164%	0.161%	0.237%	0.250%
BZ#37	3.331%	1.918%	2.847%	4.048%	2.626%	2.747%
BZ#40	0.739%	0.384%	0.401%	0.423%	0.611%	0.546%
BZ#41	1.025%	0.454%	0.495%	0.337%	0.645%	0.655%
BZ#42	0.476%	0.200%	0.138%	0.000%	0.309%	0.282%
BZ#42NT	0.294%	0.200%	0.468%	0.653%	0.454%	0.361%
BZ#44	3.340%	1.805%	2.501%	2.922%	2.548%	2.579%
BZ#45	0.351%	0.227%	0.104%	0.000%	0.321%	0.255%
BZ#45NT	0.561%	0.378%	0.596%	0.842%	0.566%	0.538%
BZ#47	1.762%	1.104%	1.234%	1.153%	1.657%	1.452%
BZ#48NT	0.900%	0.417%	0.600%	0.750%	0.706%	0.670%
BZ#49	2.650%	1.642%	1.567%	1.512%	2.517%	2.134%
BZ#51NT	0.429%	0.255%	0.320%	0.381%	0.399%	0.358%
BZ#52	3.689%	2.596%	3.287%	3.937%	3.455%	3.301%
BZ#53	1.202%	1.004%	1.115%	0.682%	1.231%	1.113%
BZ#56	2.530%	0.507%	0.565%	0.494%	0.876%	1.146%
BZ#58NT	0.083%	0.059%	0.127%	0.212%	0.125%	0.103%
BZ#59	0.160%	0.086%	0.056%	0.000%	0.116%	0.104%
BZ#60NT	0.996%	0.498%	0.697%	0.856%	0.976%	0.812%

Table 6-35. Congener Distribution of Total PCB by Mass Fraction at Mainstem Hudson River Stations Using 1993 USEPA Phase 2 Data (Number of observations).

Congener Number	Fort Edward (12)	Thompson Island Dam (12)	Schuylerville (6)	Stillwater (3)	Waterford (13)	Upper Hudson Average
BZ#63NT	0.140%	0.051%	0.032%	0.041%	0.076%	0.078%
BZ#64NT	1.845%	1.228%	1.560%	1.884%	1.976%	1.687%
BZ#66	2.445%	1.211%	1.715%	2.265%	1.876%	1.855%
BZ#67NT	0.070%	0.033%	0.089%	0.096%	0.083%	0.069%
BZ#69NT	0.008%	0.006%	0.010%	0.031%	0.013%	0.011%
BZ#70	3.086%	1.637%	2.430%	3.148%	2.585%	2.485%
BZ#72	0.000%	0.012%	0.009%	0.000%	0.016%	0.009%
BZ#74	0.669%	0.261%	0.180%	0.000%	0.418%	0.384%
BZ#74NT	1.481%	0.810%	1.392%	2.112%	1.428%	1.321%
BZ#75	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#77	0.378%	0.129%	0.114%	0.161%	0.306%	0.244%
BZ#82	0.186%	0.102%	0.168%	0.183%	0.194%	0.164%
BZ#83	0.074%	0.050%	0.082%	0.091%	0.075%	0.070%
BZ#84	0.331%	0.203%	0.324%	0.215%	0.315%	0.284%
BZ#85	0.268%	0.140%	0.216%	0.219%	0.252%	0.220%
BZ#87	0.519%	0.274%	0.449%	0.450%	0.558%	0.452%
BZ#91	0.171%	0.133%	0.181%	0.136%	0.254%	0.183%
BZ#92	0.174%	0.097%	0.237%	0.073%	0.250%	0.177%
BZ#95	0.643%	0.494%	1.092%	1.444%	0.676%	0.724%
BZ#96NT	0.014%	0.015%	0.016%	0.029%	0.015%	0.016%
BZ#97	0.411%	0.177%	0.295%	0.348%	0.336%	0.309%
BZ#99	0.522%	0.247%	0.438%	0.419%	0.538%	0.437%
BZ#101 with BZ#_90_	0.831%	0.563%	0.845%	0.928%	1.060%	0.834%
BZ#105	0.234%	0.141%	0.258%	0.293%	0.319%	0.241%
BZ#105 & BZ#_168_	0.055%	0.038%	0.000%	0.000%	0.045%	0.037%
BZ#107	0.059%	0.031%	0.038%	0.034%	0.073%	0.051%
BZ#110	0.459%	0.193%	0.156%	0.000%	0.362%	0.292%
BZ#110NT	1.123%	0.719%	1.212%	1.662%	1.485%	1.167%
BZ#114NT	0.000%	0.001%	0.002%	0.000%	0.004%	0.002%
BZ#115	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#118	0.673%	0.304%	0.523%	0.472%	0.624%	0.530%
BZ#119	0.021%	0.009%	0.011%	0.012%	0.021%	0.016%
BZ#122	0.011%	0.002%	0.004%	0.000%	0.003%	0.005%
BZ#123	0.002%	0.000%	0.000%	0.000%	0.001%	0.001%
BZ#126	0.005%	0.000%	0.000%	0.002%	0.001%	0.002%
BZ#128	0.040%	0.025%	0.043%	0.029%	0.045%	0.037%
BZ#129	0.013%	0.003%	0.000%	0.000%	0.010%	0.007%
BZ#135	0.007%	0.010%	0.004%	0.000%	0.012%	0.009%
BZ#135 (as BZ#52)NT	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#136	0.023%	0.024%	0.040%	0.049%	0.055%	0.036%
BZ#137	0.024%	0.010%	0.028%	0.044%	0.028%	0.024%
BZ#138	0.265%	0.176%	0.414%	0.408%	0.478%	0.331%
BZ#140NT	0.004%	0.002%	0.000%	0.000%	0.001%	0.002%
BZ#141	0.020%	0.019%	0.029%	0.038%	0.028%	0.024%
BZ#143	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#143NT	0.021%	0.008%	0.018%	0.048%	0.015%	0.017%
BZ#144NT	0.005%	0.003%	0.006%	0.012%	0.008%	0.006%
BZ#146NT	0.015%	0.024%	0.005%	0.000%	0.020%	0.016%
BZ#149	0.152%	0.073%	0.103%	0.089%	0.252%	0.149%
BZ#151	0.058%	0.037%	0.044%	0.026%	0.077%	0.054%
BZ#153	0.177%	0.140%	0.231%	0.242%	0.307%	0.215%

Table 6-35. Congener Distribution of Total PCB by Mass Fraction at Mainstem Hudson River Stations Using 1993 USEPA Phase 2 Data (Number of observations).

Congener Number	Fort Edward (12)	Thompson Island Dam (12)	Schuylerville (6)	Stillwater (3)	Waterford (13)	Upper Hudson Average
BZ#156	0.003%	0.003%	0.005%	0.000%	0.007%	0.004%
BZ#156NT	0.018%	0.006%	0.003%	0.011%	0.024%	0.014%
BZ#157	0.014%	0.003%	0.012%	0.026%	0.002%	0.008%
BZ#158	0.010%	0.005%	0.000%	0.000%	0.010%	0.007%
BZ#165	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#167	0.003%	0.003%	0.000%	0.000%	0.002%	0.002%
BZ#169NT	0.387%	0.083%	0.160%	0.831%	0.055%	0.213%
BZ#170	0.017%	0.008%	0.016%	0.019%	0.028%	0.018%
BZ#171	0.005%	0.004%	0.003%	0.006%	0.010%	0.006%
BZ#172NT	0.002%	0.001%	0.004%	0.011%	0.006%	0.004%
BZ#174	0.001%	0.004%	0.002%	0.000%	0.002%	0.002%
BZ#174NT	0.020%	0.006%	0.014%	0.022%	0.023%	0.017%
BZ#175NT	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#176	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#177	0.020%	0.012%	0.010%	0.012%	0.027%	0.018%
BZ#178	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#178 (as BZ#52)NT	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
BZ#179	0.000%	0.002%	0.000%	0.000%	0.000%	0.001%
BZ#180	0.041%	0.010%	0.026%	0.038%	0.066%	0.038%
BZ#183	0.006%	0.003%	0.005%	0.007%	0.015%	0.008%
BZ#184NT	0.004%	0.005%	0.014%	0.000%	0.008%	0.007%
BZ#185	0.000%	0.000%	0.001%	0.002%	0.001%	0.000%
BZ#187	0.043%	0.022%	0.038%	0.022%	0.066%	0.042%
BZ#189	0.013%	0.000%	0.000%	0.000%	0.000%	0.003%
BZ#190	0.010%	0.001%	0.000%	0.000%	0.004%	0.004%
BZ#191	0.002%	0.000%	0.001%	0.002%	0.001%	0.001%
BZ#192 (as BZ#52)NT	0.009%	0.003%	0.004%	0.003%	0.009%	0.006%
BZ#193	0.000%	0.001%	0.000%	0.000%	0.001%	0.000%
BZ#194	0.011%	0.001%	0.003%	0.018%	0.009%	0.007%
BZ#195	0.001%	0.001%	0.002%	0.000%	0.002%	0.001%
BZ#196	0.010%	0.004%	0.003%	0.000%	0.009%	0.006%
BZ#197NT	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#198	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#199	0.001%	0.000%	0.000%	0.000%	0.002%	0.001%
BZ#200	0.002%	0.000%	0.003%	0.010%	0.000%	0.002%
BZ#201	0.043%	0.011%	0.016%	0.045%	0.033%	0.029%
BZ#202	0.007%	0.003%	0.007%	0.029%	0.008%	0.008%
BZ#203NT	0.018%	0.014%	0.012%	0.008%	0.024%	0.017%
BZ#205	0.000%	0.000%	0.005%	0.000%	0.000%	0.001%
BZ#206	0.000%	0.001%	0.000%	0.015%	0.007%	0.003%
BZ#207	0.001%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#208	0.002%	0.000%	0.000%	0.007%	0.005%	0.002%

Source: Hudson River Database Release 4.1.

Table 6-36. Congener Distribution of Total PCB by Mass Fraction at Mainstem Hudson River Stations Using 1991-1998 GE Data (Number of observations).

Congener Number	Fort Edward (350)	Thompson Island Dam (475)	Schuylerville (94)	Stillwater (55)	Waterford (53)	Upper Hudson Average
BZ#1	0.085%	10.830%	8.553%	4.319%	2.867%	6.200%
BZ#2	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#3	0.001%	0.029%	0.150%	0.151%	0.379%	0.055%
BZ#4 & BZ#10	3.599%	24.383%	20.025%	9.528%	10.041%	15.366%
BZ#5 & BZ#8	3.856%	3.333%	3.247%	3.140%	3.249%	3.489%
BZ#6	0.868%	0.798%	0.772%	0.844%	0.849%	0.825%
BZ#7 & BZ#9	0.421%	0.352%	0.309%	0.335%	0.363%	0.371%
BZ#11	0.000%	0.000%	0.001%	0.000%	0.000%	0.000%
BZ#12 & BZ#13	0.001%	0.009%	0.027%	0.030%	0.003%	0.009%
BZ#14	0.003%	0.014%	0.055%	0.000%	0.000%	0.012%
BZ#16 & BZ#32NT	6.530%	4.500%	4.937%	6.081%	6.234%	5.406%
BZ#17	5.385%	3.845%	4.374%	5.694%	5.659%	4.611%
BZ#18 & BZ#15	6.554%	4.033%	4.541%	5.945%	5.979%	5.141%
BZ#19	0.557%	3.074%	2.651%	2.129%	2.025%	2.073%
BZ#20 & BZ#33 & BZ#53	3.712%	2.222%	2.442%	3.007%	2.862%	2.825%
BZ#22 & BZ#51NT	4.127%	2.223%	2.474%	3.235%	3.005%	2.989%
BZ#23NT	0.000%	0.020%	0.000%	0.000%	0.000%	0.009%
BZ#24NT & BZ#27	0.541%	1.815%	1.572%	1.459%	1.493%	1.323%
BZ#25	0.683%	0.815%	0.814%	0.989%	1.025%	0.790%
BZ#26	0.847%	1.103%	1.127%	1.545%	1.707%	1.073%
BZ#28 & BZ#50	5.922%	3.135%	3.807%	5.212%	5.051%	4.357%
BZ#29	0.050%	0.059%	0.041%	0.062%	0.056%	0.055%
BZ#30	0.001%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#31	4.526%	3.230%	3.541%	4.422%	4.589%	3.834%
BZ#34NT& BZ#54	0.029%	0.069%	0.075%	0.040%	0.028%	0.052%
BZ#35NT	0.003%	0.001%	0.002%	0.000%	0.000%	0.002%
BZ#36	0.008%	0.007%	0.000%	0.007%	0.005%	0.007%
BZ#37 & BZ#42 & BZ#59	2.583%	1.555%	1.697%	1.959%	2.002%	1.963%
BZ#39NT	0.000%	0.000%	0.001%	0.001%	0.012%	0.001%
BZ#40	0.725%	0.397%	0.435%	0.612%	0.528%	0.531%
BZ#45	0.624%	0.515%	0.605%	0.673%	0.636%	0.575%
BZ#46NT	0.308%	0.224%	0.248%	0.255%	0.281%	0.260%
BZ#47	0.494%	0.416%	0.381%	0.659%	0.594%	0.461%
BZ#48NT & BZ#75	0.636%	0.385%	0.496%	0.408%	0.402%	0.483%
BZ#49	2.382%	1.708%	1.760%	2.223%	2.289%	2.000%
BZ#52 & BZ#73	5.202%	3.866%	3.934%	4.604%	4.689%	4.410%
BZ#55 & BZ#64NT & BZ#71	3.618%	2.183%	2.049%	2.812%	2.752%	2.722%
BZ#56 & BZ#60	2.704%	1.327%	1.666%	2.305%	2.458%	1.938%
BZ#58NT & BZ#63	0.129%	0.119%	0.096%	0.161%	0.156%	0.125%
BZ#62 & BZ#65	0.010%	0.005%	0.000%	0.000%	0.000%	0.006%
BZ#66 & BZ#93 & BZ#95	6.132%	3.341%	4.024%	4.703%	4.720%	4.499%
BZ#68	0.000%	0.015%	0.014%	0.000%	0.000%	0.008%
BZ#70 & BZ#76 & BZ#61	2.233%	1.120%	1.427%	1.924%	1.886%	1.610%
BZ#74 & BZ#94	1.199%	0.621%	0.720%	0.986%	0.894%	0.861%

Table 6-36. Congener Distribution of Total PCB by Mass Fraction at Mainstem Hudson River Stations Using 1991-1998 GE Data (Number of observations).

Congener Number	Fort Edward (350)	Thompson Island Dam (475)	Schuylerville (94)	Stillwater (55)	Waterford (53)	Upper Hudson Average
BZ#77 & BZ#110	2.145%	1.194%	1.342%	1.515%	1.570%	1.569%
BZ#82	0.215%	0.106%	0.125%	0.191%	0.172%	0.153%
BZ#83 & BZ#109	0.130%	0.104%	0.101%	0.180%	0.250%	0.124%
BZ#85 & BZ#116	0.571%	0.304%	0.346%	0.351%	0.392%	0.406%
BZ#87 & BZ#111 & BZ#119	0.966%	0.477%	0.544%	0.665%	0.717%	0.672%
BZ#89	0.030%	0.030%	0.045%	0.069%	0.045%	0.034%
BZ#91 & BZ#98 & BZ#55	0.355%	0.262%	0.225%	0.285%	0.282%	0.293%
BZ#96NT	0.560%	0.559%	0.508%	0.417%	0.388%	0.538%
BZ#99	0.727%	0.395%	0.429%	0.449%	0.479%	0.518%
BZ#100NT & BZ#67	0.042%	0.034%	0.032%	0.046%	0.033%	0.037%
BZ#101 & BZ#90NT	2.609%	1.328%	1.563%	1.625%	1.810%	1.827%
BZ#103 & BZ#57	0.037%	0.049%	0.020%	0.029%	0.015%	0.039%
BZ#104NT & BZ#44	4.088%	2.142%	2.530%	3.262%	3.307%	2.961%
BZ#107 &BZ#108 & BZ#147	0.021%	0.021%	0.008%	0.017%	0.029%	0.020%
BZ#122 & BZ#131 & BZ#133	0.001%	0.001%	0.001%	0.008%	0.002%	0.001%
BZ#123	0.019%	0.005%	0.007%	0.002%	0.002%	0.009%
BZ#128	0.003%	0.001%	0.005%	0.004%	0.004%	0.002%
BZ#129	0.000%	0.000%	0.001%	0.000%	0.000%	0.000%
BZ#130NT	0.003%	0.001%	0.004%	0.000%	0.000%	0.002%
BZ#132NT & BZ#105	0.335%	0.188%	0.436%	0.744%	0.782%	0.321%
BZ#134 & BZ#143 & BZ#114	0.004%	0.003%	0.006%	0.011%	0.005%	0.004%
BZ#135 & BZ#124	0.057%	0.056%	0.058%	0.121%	0.119%	0.063%
BZ#136	0.640%	0.314%	0.386%	0.488%	0.558%	0.454%
BZ#137	0.002%	0.002%	0.004%	0.011%	0.000%	0.003%
BZ#138 & BZ#163	0.400%	0.253%	0.509%	0.910%	0.879%	0.394%
BZ#139 & BZ#140	0.002%	0.000%	0.000%	0.000%	0.000%	0.001%
BZ#141	0.039%	0.017%	0.067%	0.019%	0.011%	0.029%
BZ#144NT	0.079%	0.076%	0.093%	0.184%	0.193%	0.090%
BZ#146NT & BZ#161	0.030%	0.013%	0.041%	0.058%	0.047%	0.026%
BZ#149 & BZ#118 & BZ#106	3.824%	1.942%	2.277%	2.200%	2.410%	2.652%
BZ#150 & BZ#112 & BZ#115	0.018%	0.013%	0.013%	0.018%	0.021%	0.015%
BZ#151	1.561%	0.786%	0.868%	0.810%	0.985%	1.069%
BZ#152 & BZ#86 & BZ#97	0.330%	0.177%	0.228%	0.344%	0.327%	0.251%
BZ#153	0.119%	0.056%	0.261%	0.347%	0.280%	0.123%
BZ#154	0.005%	0.001%	0.000%	0.011%	0.000%	0.003%
BZ#155 & BZ#84 & BZ#92	1.980%	1.281%	1.480%	1.639%	1.875%	1.587%
BZ#157	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#158	0.005%	0.002%	0.004%	0.011%	0.004%	0.004%
BZ#166	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#167	0.001%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#168	0.000%	0.008%	0.000%	0.000%	0.000%	0.004%
BZ#170	0.002%	0.000%	0.000%	0.000%	0.000%	0.001%
BZ#171 & BZ#156	0.007%	0.004%	0.009%	0.022%	0.004%	0.006%
BZ#172NT & BZ#192	0.001%	0.000%	0.000%	0.010%	0.000%	0.001%

Table 6-36. Congener Distribution of Total PCB by Mass Fraction at Mainstem Hudson River Stations Using 1991-1998 GE Data (Number of observations).

Congener Number	Fort Edward (350)	Thompson Island Dam (475)	Schuylerville (94)	Stillwater (55)	Waterford (53)	Upper Hudson Average
BZ#173NT	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#174 & BZ#181	0.025%	0.012%	0.051%	0.072%	0.013%	0.023%
BZ#175NT	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#176	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#177	0.010%	0.006%	0.017%	0.048%	0.016%	0.011%
BZ#178	0.010%	0.003%	0.005%	0.001%	0.002%	0.005%
BZ#179	0.038%	0.024%	0.093%	0.011%	0.000%	0.033%
BZ#183	0.013%	0.005%	0.016%	0.033%	0.002%	0.010%
BZ#185	0.000%	0.001%	0.003%	0.006%	0.004%	0.001%
BZ#187 & BZ#182	0.049%	0.021%	0.071%	0.123%	0.075%	0.044%
BZ#189	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#190	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#191	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#193	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#194	0.001%	0.001%	0.000%	0.000%	0.000%	0.001%
BZ#195	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#196 & BZ#203	0.002%	0.002%	0.000%	0.024%	0.024%	0.004%
BZ#197NT	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#198	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#199	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#200 & BZ#204	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#201	0.003%	0.002%	0.000%	0.028%	0.023%	0.004%
BZ#202	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#205	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#206	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#207	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#208	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
BZ#209	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

Source: Hudson River Database Release 4.1.

Table 6-37. Estimated Henry's Law Constants (HLC) for Total and Tri+ PCB by Source and Agency at Mainstem Hudson River Stations.

LTI ID	Tri+ HLC (atm-m^3/mol)		Total HLC (atm-m^3/mol)		Number of GE Data	Number of Phase 2 Data
	GE	Phase 2	GE	Phase 2		
Fort Edward	1.62E-04	1.67E-04	1.71E-04	1.79E-04	348	12
Thompson Island Dam	1.75E-04	1.75E-04	1.97E-04	2.00E-04	475	12
Schuylerville	1.70E-04	1.70E-04	1.90E-04	1.88E-04	94	6
Stillwater	1.68E-04	1.66E-04	1.80E-04	1.78E-04	55	3
Waterford	1.68E-04	1.70E-04	1.80E-04	1.85E-04	53	13

Table 6-38. Estimated Henry's Law Constants (HLC) for Total PCB at Mainstem Hudson River Stations and Averaged Over Study Reach.

LTI ID	Average Tri+ PCB HLC[1] (atm-m^3/mol)	Average Total PCB HLC[1] (atm-m^3/mol)	Distance Used in Weighting (m)
Fort Edward	1.62E-04	1.71E-04	4,828
TI Dam	1.75E-04	1.97E-04	10,541
Schuylerville	1.70E-04	1.89E-04	16,335
Stillwater	1.68E-04	1.80E-04	20,036
Waterford	1.68E-04	1.81E-04	9,415
Final Estimate[2]	1.69E-04	1.85E-04	

[1] Average was determined by weighting each source's value with the number of data points presented in Table 6-37.
[2] Final estimate was determined by weighting the station specific average value with the distance associated with each station in the last column of this table.

Table 6-39. Estimated Molecular Weight for Total and Tri+ PCB by Source and Agency at Mainstem Hudson River Stations.

LTI ID	Tri+ Mol. Wt. (g/mol)		Total Mol. Wt. (g/mol)		Number of GE Data	Number of Phase 2 Data
	GE	Phase 2	GE	Phase 2		
Fort Edward	288.6	281.1	282.8	264.9	348	12
Thompson Island Dam	283.9	276.5	256.4	244.2	475	12
Schuylerville	286.0	278.4	262.5	254.5	94	6
Stillwater	285.7	279.2	272.9	259.7	55	3
Waterford	286.0	279.6	274.0	262.4	53	13

Table 6-40. Estimated Molecular Weight for Total PCB at Mainstem Hudson River Stations and Averaged Over Study Reach.

LTI ID	Average Tri+ PCB Mol. Wt.[1] (g/mol)	Average Total PCB Mol. Wt.[1] (g/mol)	Distance Used in Weighting (m)
Fort Edward	288.4	282.2	4,828
TI Dam	283.8	256.1	10,541
Schuylerville	285.5	262.0	16,335
Stillwater	285.4	272.2	20,036
Waterford	284.8	271.7	9,415
Final Estimate[2]	285.3	267.4	

[1] Average was determined by weighting each source's value with the number of data points presented in Table 6-39.
[2] Final estimate was determined by weighting the station specific average value with the distance associated with each station in the last column of this table.

Table 6-41. Estimated Henry's Law Constants and Molecular Weight by PCB Type.

PCB Type	Henry's Law Constant ($atm\text{-}m^3/mol$)	Henry's Law Constant @ 20°C (unitless)	Molecular Weight (gm/mol)
BZ#4	2.30E-04	0.009561068	223.1
BZ#28	2.00E-04	0.008313973	257.5
Total PCB	1.85E-04	0.007690425	267.4
Tri+ PCB	1.69E-04	0.007025307	285.3
BZ#52	2.00E-04	0.008313973	292.0
BZ#90+101	9.00E-05	0.003741288	326.0
BZ#138	2.10E-05	0.000872967	361.0

Table 6-42. Coefficients Used to Estimate Depth and Velocity as a Function of Cross-Section Average Flow in HUDTOX for Calculation of Liquid-Phase (K_L) Air-Water Transfer Rates.

Segments Forming Cross-section	a [1]	b [1]	c [2]	d [2]
1, 2,	0.002064	1.0	1.483	0.0
3, 4,	0.001631	1.0	1.851	0.0
5, 6, 7	0.001683	1.0	2.604	0.0
8, 9, 10	0.001707	1.0	2.183	0.0
11, 12, 13	0.001424	1.0	2.032	0.0
14, 15, 16	0.001404	1.0	2.699	0.0
17, 18, 19	0.001495	1.0	2.874	0.0
20, 21, 22	0.001345	1.0	2.695	0.0
23, 24, 25	0.001477	1.0	3.182	0.0
26, 27, 28	0.001207	1.0	2.343	0.0
29	0.002300	1.0	1.951	0.0
30	0.001120	1.0	3.494	0.0
31	0.001260	1.0	3.862	0.0
32	0.000960	1.0	3.917	0.0
33	0.002020	1.0	3.120	0.0
34	0.001660	1.0	2.843	0.0
35	0.001410	1.0	3.755	0.0
36	0.001210	1.0	4.201	0.0
37	0.001130	1.0	4.242	0.0
38	0.000930	1.0	3.693	0.0
39	0.002100	1.0	2.993	0.0
40	0.001340	1.0	1.926	0.0
41	0.000620	1.0	4.179	0.0
42	0.001370	1.0	3.178	0.0
43	0.000940	1.0	2.467	0.0
44	0.001340	1.0	2.886	0.0
45	0.000840	1.0	4.150	0.0
46	0.000820	1.0	4.561	0.0
47	0.000550	1.0	5.772	0.0

[1] *Average cross-section velocity,* $u = a \cdot Q^{b}$

[2] *Average cross-section depth,* $D = c \cdot Q^{d}$ *(assumed constant)*

Table 6-43. Annual Average Bulk Sediment Concentrations by PCB Type.

Year	PCB Type						
	Tri+ (mg/L)	Total (mg/L)	BZ#4 (mg/L)	BZ#28 (mg/L)	BZ#52 (mg/L)	BZ#90+101 (mg/L)	BZ#138 (mg/L)
1991	18.435	32.870	5.170	0.650	0.670	0.120	0.065
1992	17.085	30.462	4.791	0.602	0.621	0.111	0.060
1993	15.834	28.231	4.440	0.558	0.575	0.103	0.056
1994	14.674	26.164	4.115	0.517	0.533	0.096	0.051
1995	13.599	24.247	3.814	0.479	0.494	0.089	0.048
1996	12.603	22.471	3.534	0.444	0.458	0.082	0.044
1997	11.680	20.825	3.276	0.412	0.424	0.076	0.041
1998	10.825	19.300	3.036	0.382	0.393	0.070	0.038

Table 6-44. Annual Average Pore Water Concentrations by PCB Type.

Year	PCB Type						
	Tri+ (mg/L)	Total (mg/L)	BZ#4 (mg/L)	BZ#28 (mg/L)	BZ#52 (mg/L)	BZ#90+101 (mg/L)	BZ#138 (mg/L)
1991	0.00198	0.00760	0.03225	0.000108	0.000091	0.000013	0.000007
1992	0.00184	0.00704	0.02989	0.000100	0.000084	0.000012	0.000007
1993	0.00170	0.00653	0.02770	0.000092	0.000078	0.000011	0.000006
1994	0.00158	0.00605	0.02567	0.000086	0.000072	0.000010	0.000006
1995	0.00146	0.00561	0.02379	0.000079	0.000067	0.000010	0.000005
1996	0.00136	0.00520	0.02205	0.000074	0.000062	0.000009	0.000005
1997	0.00126	0.00482	0.02043	0.000068	0.000057	0.000008	0.000004
1998	0.00116	0.00446	0.01893	0.000063	0.000053	0.000008	0.000004

Table 6-45. Estimated Sediment Properties in Thompson Island Pool Based on Area Weighting by Sediment Type.

Parameter	Symbol	Fort Edward - TI Dam	Units
Surface Area	A	1,826,220	m^2
% cohesive	A_c	23.28	%
% noncohesive	A_n	76.72	%
Bulk Density	ρ_b	1.254	g_{solid}/cm_{total}^3
Solids Concentration	m_s	1,254,300	mg_{solid}/L_{total}
Porosity	θ_s	0.527	L_{water}/L_{total}
Fraction Organic Carbon	$foc_{(s)}$	0.0182	gm_{carbon}/gm_{solid}
DOC Concentration	DOC_s	41.25	$mg_{carbon}/L_{bulksed}$

Table 6-46. Annual Time Series of Sediment-Water Mass Transfer Rate for Tri+ PCBs.

Date	Day of Year	k_f (cm/day)	k_f (m^2/sec)
1/1	1	10.17	4.039E-08
1/16	15	10.17	4.039E-08
1/31	31	10.17	4.039E-08
2/15	46	10.17	4.039E-08
3/1	61	10.17	4.039E-08
3/16	76	10.17	4.039E-08
3/31	92	10.17	4.039E-08
4/15	107	10.17	4.039E-08
5/1	122	10.17	4.039E-08
5/16	137	10.17	4.039E-08
5/31	153	19.39	7.702E-08
6/15	168	23.51	9.341E-08
7/1	183	21.49	8.539E-08
7/16	198	12.16	4.831E-08
7/31	214	10.99	4.368E-08
8/15	229	10.17	4.039E-08
8/31	244	10.17	4.039E-08
9/15	259	10.17	4.039E-08
9/30	275	10.17	4.039E-08
10/15	290	10.17	4.039E-08
11/1	305	10.17	4.039E-08
11/15	320	10.17	4.039E-08
12/1	336	10.17	4.039E-08
12/15	351	10.17	4.039E-08
12/31	365	10.17	4.039E-08

Table 6-47. Congener Sediment and Water Partitioning Coefficients.

Congener	$H_2O\ K_{POC}$[1]	$H_2O\ K_{DOC}$[1]	Sed. K_{POC}[2]	Sed. K_{DOC}[2]
BZ#1	5.65	5.12	4.46	3.63
BZ#4 + BZ#10	5.19	5.43	4.73	3.60
BZ#5 + BZ#8	5.67	5.56	5.78	4.03
BZ#15 + BZ#18	5.40	4.66	5.95	4.23
BZ#28	5.84	4.16	6.23	4.36
BZ#31	5.80	4.40	6.17	4.33
BZ#44	5.85	4.16	5.87	4.24
BZ#52	5.82	4.28	5.98	4.32
BZ#66 + BZ#95	6.27	4.89	6.09	4.53
BZ#70	6.15	4.65	5.91	4.18
BZ#101+BZ#90	6.18	4.54	5.98	4.68
BZ#118+BZ#149	6.41		6.10	4.91
BZ#138	6.43	4.86	6.31	5.12
BZ#153	6.38	5.00	6.28	5.25
Total	5.64	4.22	5.417	3.876

[1] Derived from USEPA Phase 2 Water Column Data

[2] Derived from GE Sediment and Pore Water Data

Source: DEIR (TAMS, 1998)

Table 6-48. Annual Time Series of Pore Water and Particulate Mass Transfer Coefficients by PCB Type.

Julian	k_d (cm/day)	$k_{p'}$ (cm/day)[1]						
Day	All PCB Types	BZ#4 + BZ#10	BZ#28	BZ#52	BZ#[90+101]	BZ#138	Total	Tri+
0	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
15	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
31	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
46	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
61	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
76	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
92	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
107	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
122	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
137	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
153	1.36603	0.001740	0.001055	0.001086	0.000731	0.000549	0.001264	0.001039
168	1.65661	0.002110	0.001280	0.001317	0.000887	0.000666	0.001533	0.001260
183	1.51450	0.001929	0.001170	0.001204	0.000811	0.000609	0.001401	0.001152
198	0.85687	0.001092	0.000662	0.000681	0.000459	0.000344	0.000793	0.000652
214	0.77472	0.000987	0.000599	0.000616	0.000415	0.000311	0.000717	0.000589
229	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
244	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
259	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
275	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
290	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
305	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
320	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
336	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
351	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424
365	0.68610	0.000879	0.000436	0.000454	0.000289	0.000220	0.000550	0.000424

[1] $k_p' = k_p * d_f$ where d_f = apparent dissolved fraction in the water column

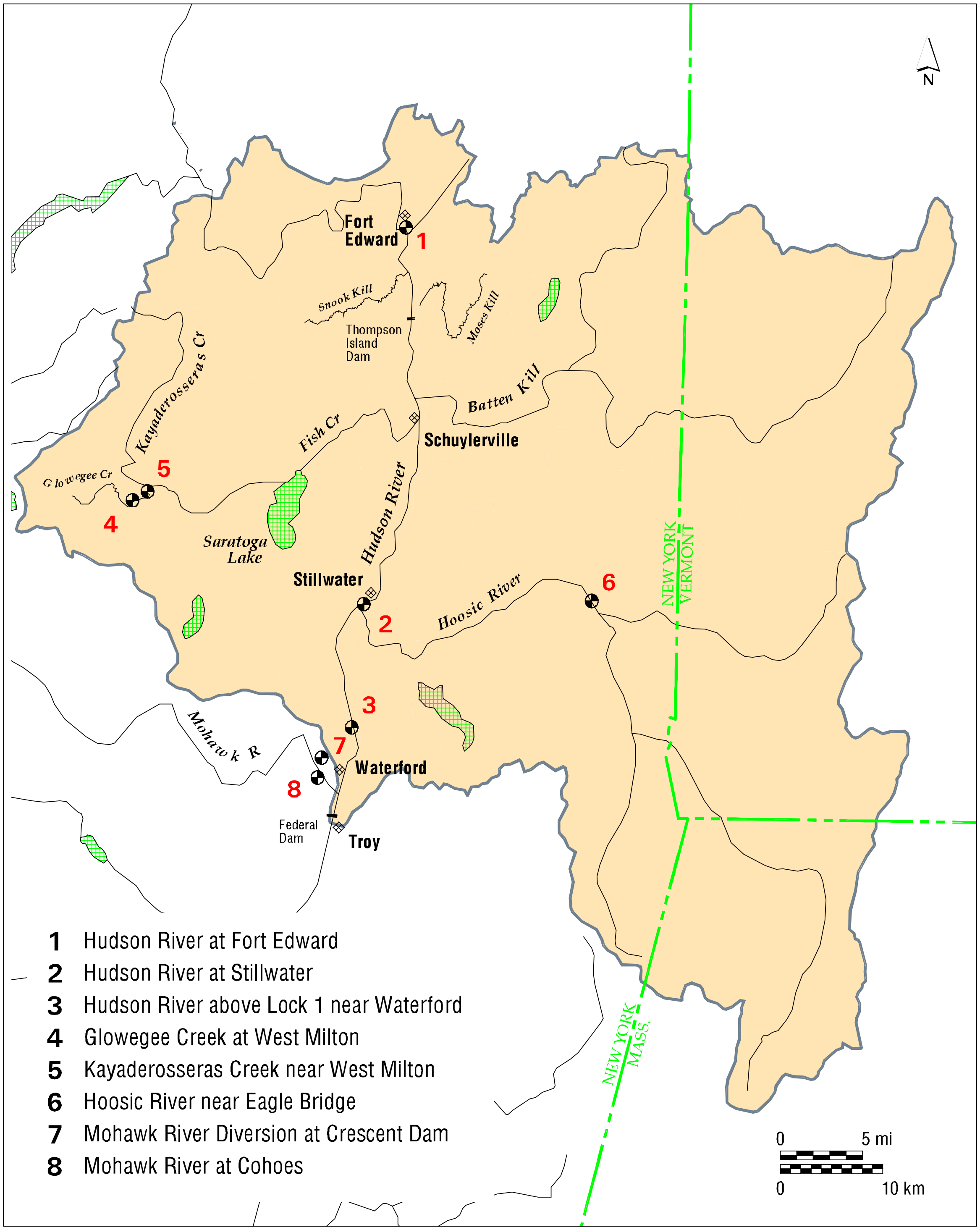
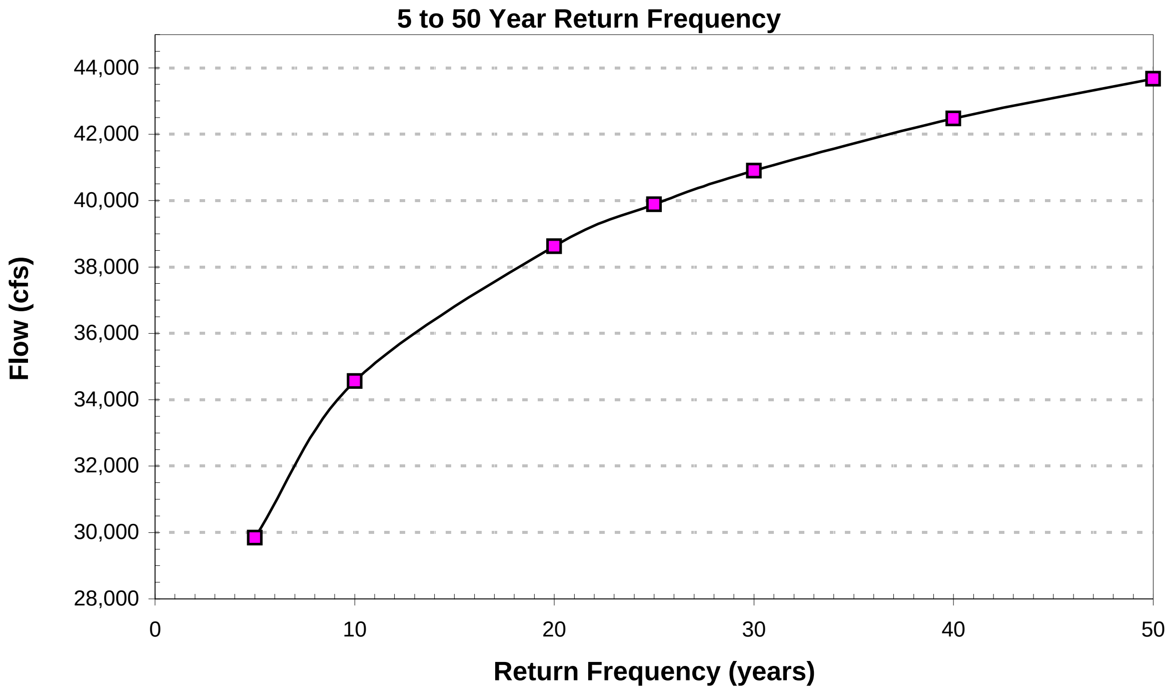


Figure 6-1. Upper Hudson River Basin USGS Flow Gage Stations Used in HUDTOX Modeling.



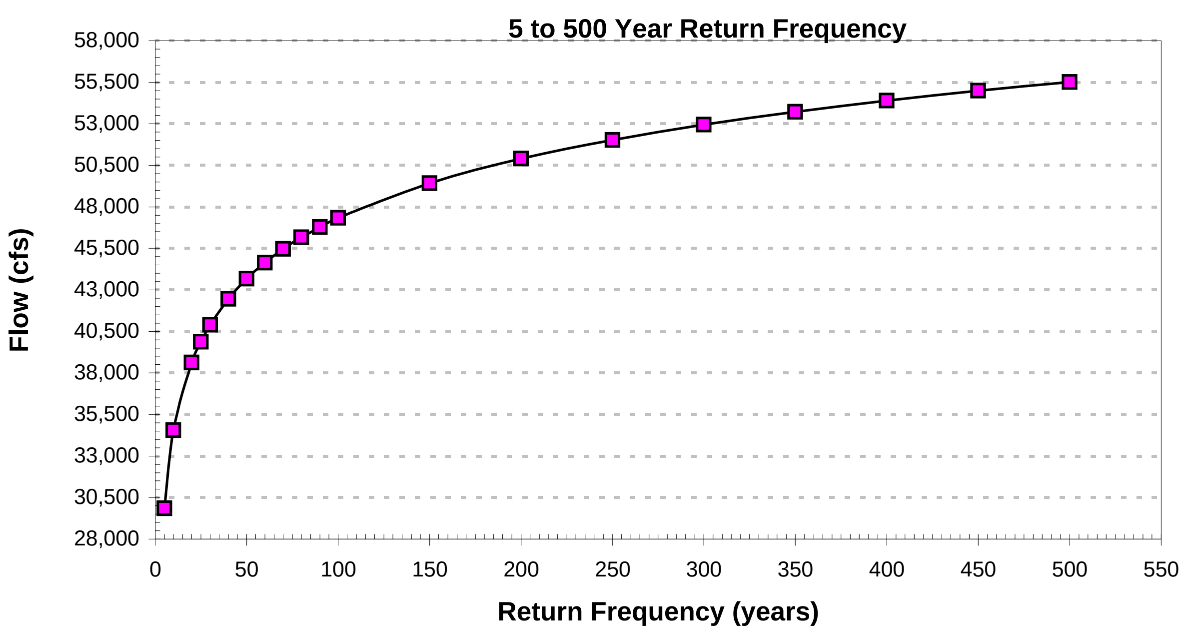


Figure 6-2. Log Pearson Flood Frequency Analysis for Fort Edward gage, Hudson River, NY Analysis (Butcher, 1993).

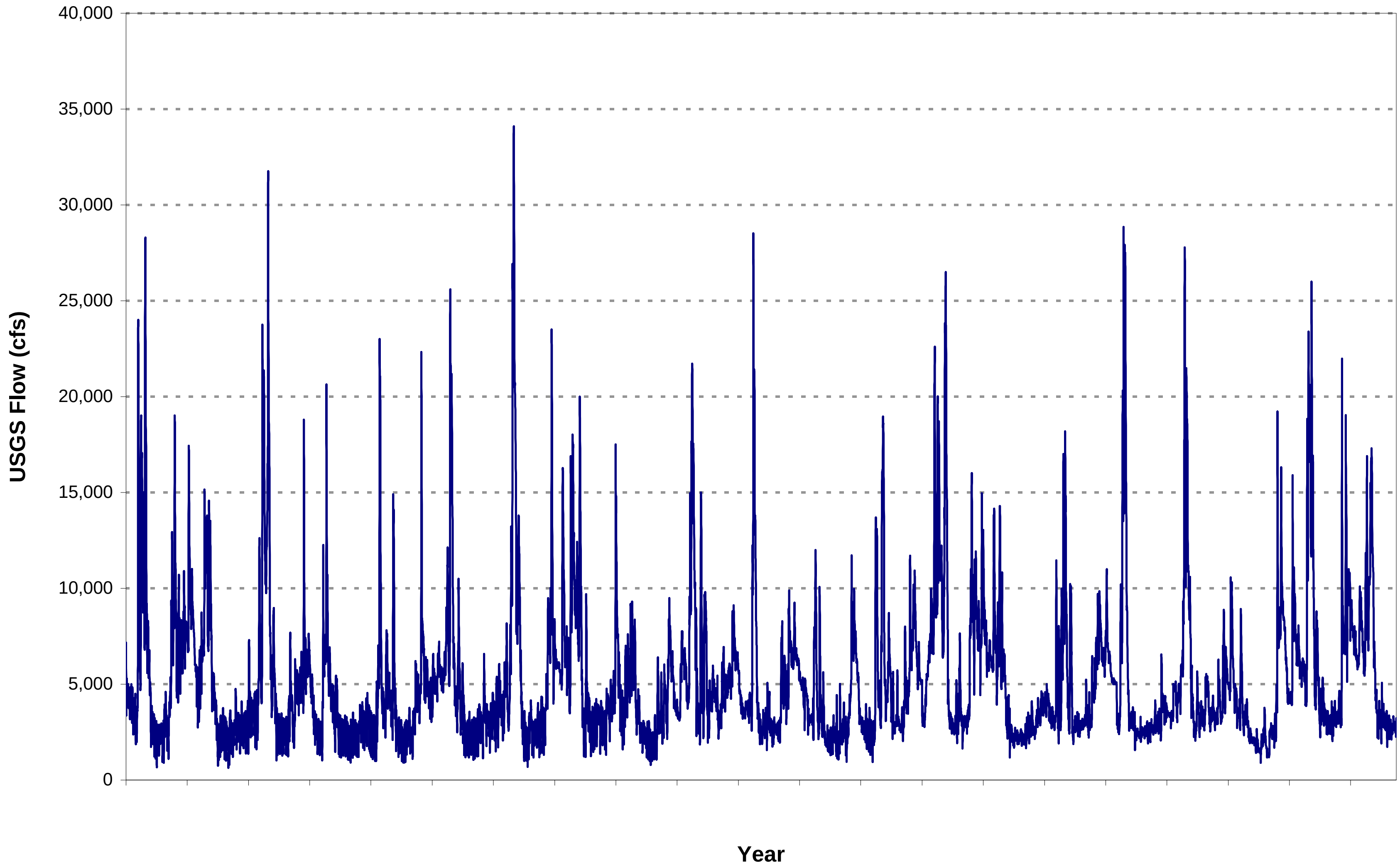


Figure 6-3. USGS Flow Time Series at Fort Edward from 1/1/77 - 9/30/97.

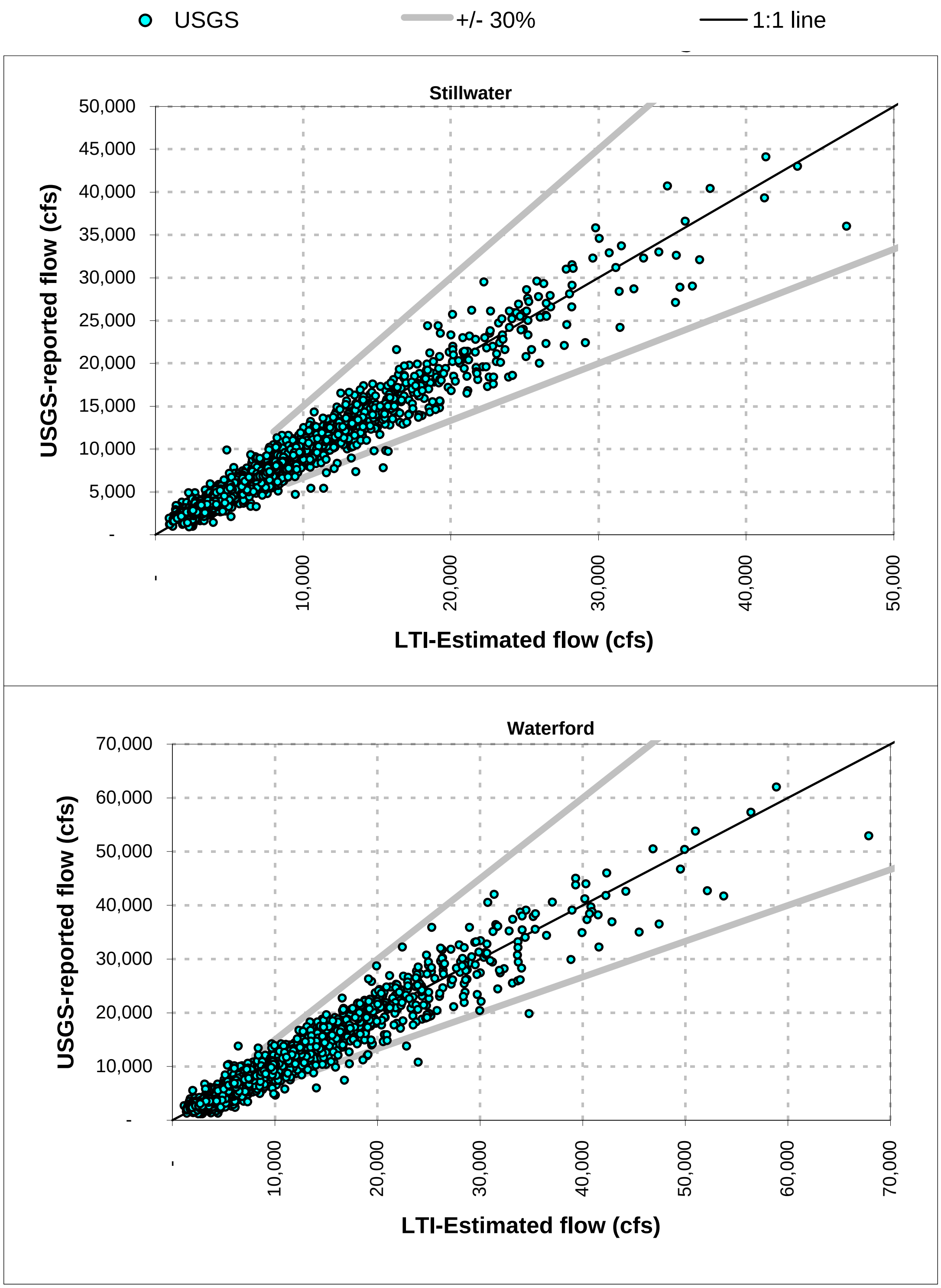


Figure 6-4. Comparison of LTI-Estimated Flow (DAR-based, seasonally & high-flow adjusted) and the USGS-Reported Flow.

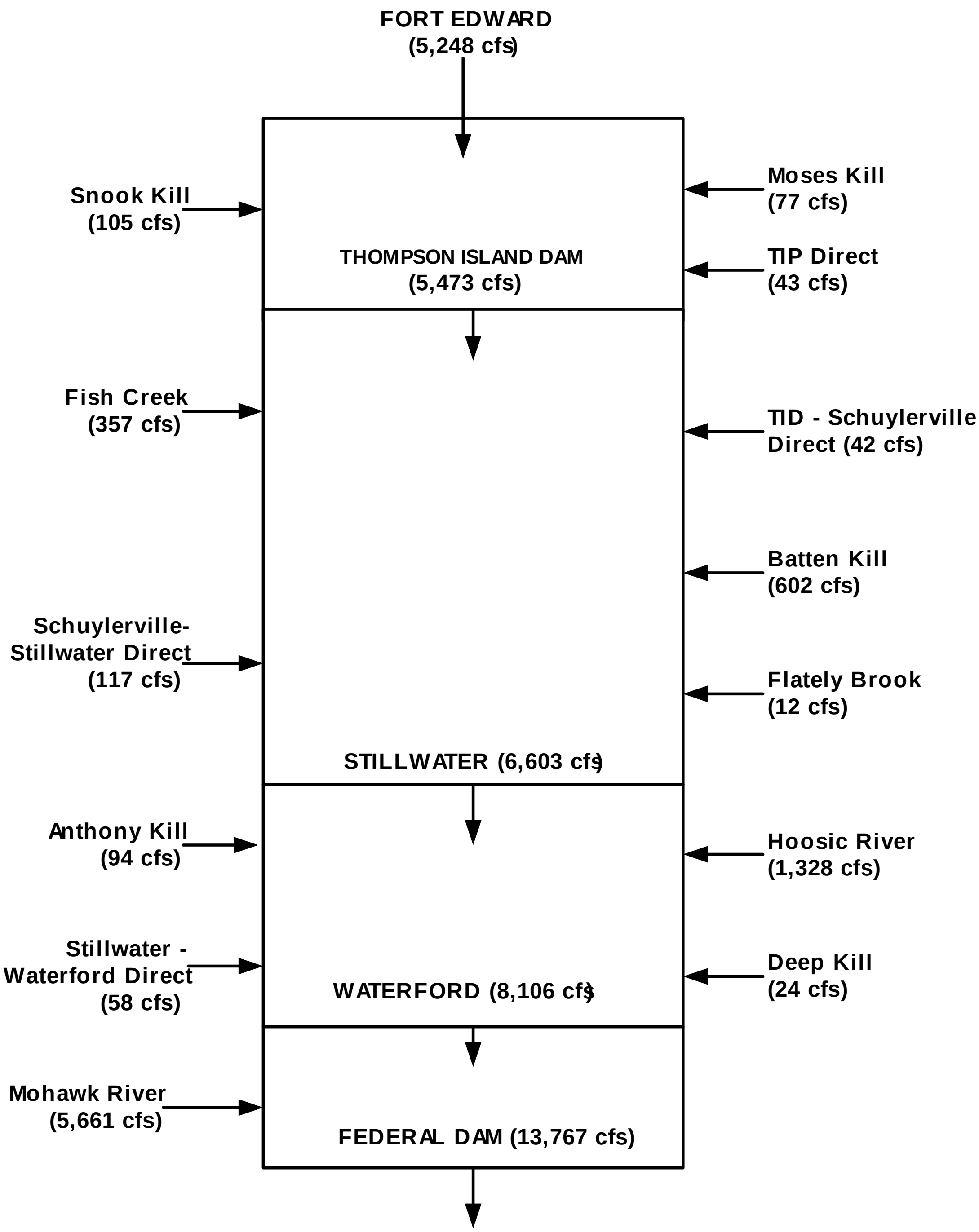


Figure 6-5. Estimated Daily Average Mainstem and Tributary Flows for the Upper Hudson River between Fort Edward and Federal Dam. (1/1/77 - 9/30/97)

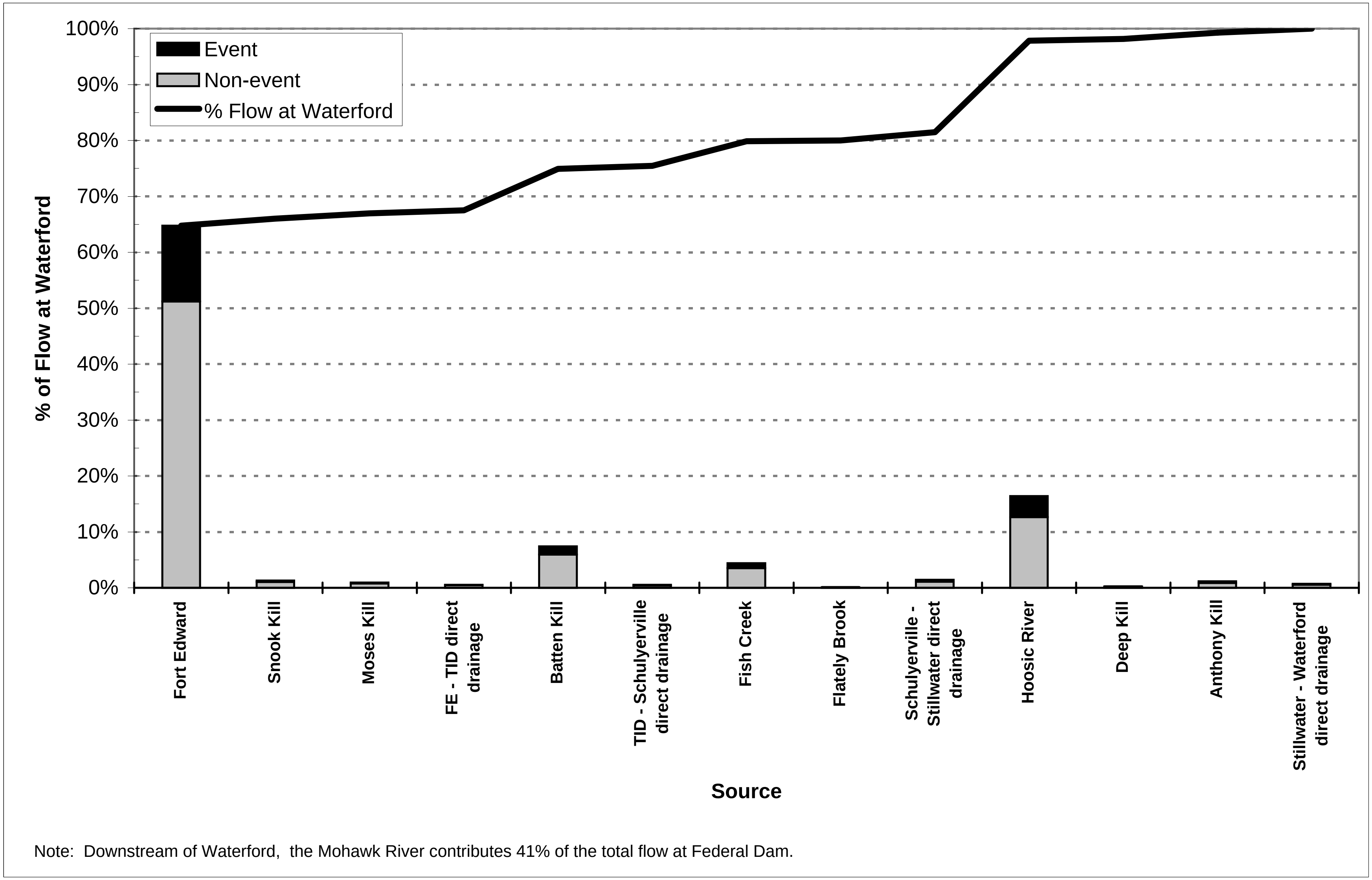
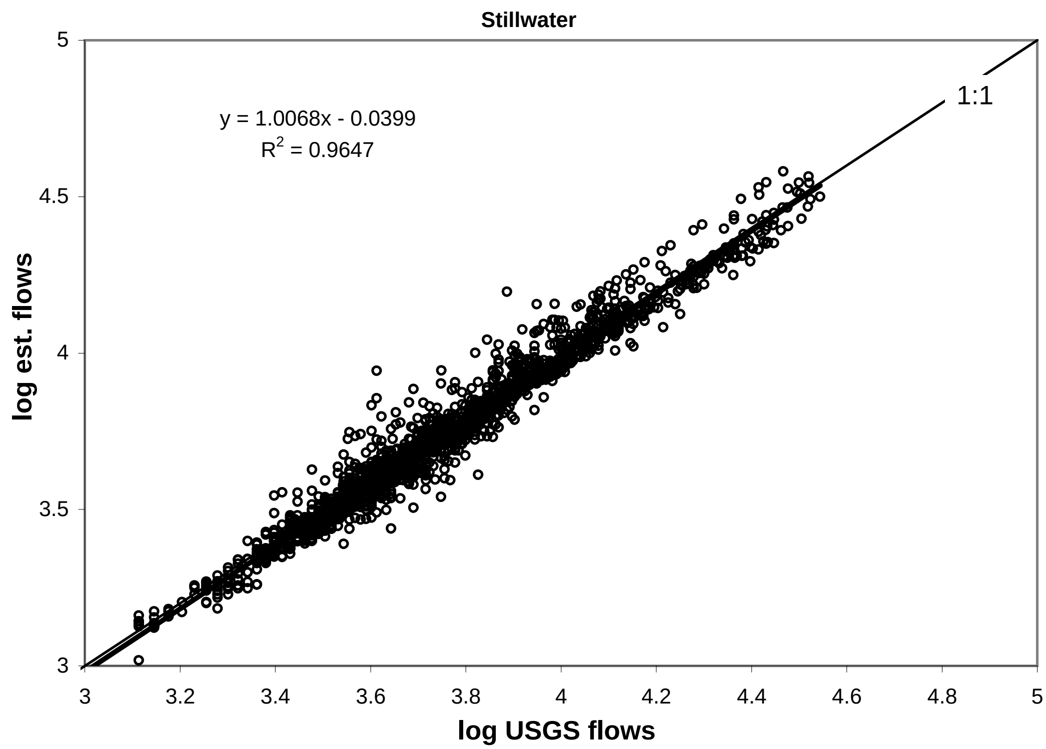


Figure 6-6. Relative Percent Flow Contribution from Fort Edward and Tributaries between Fort Edward and Waterford.



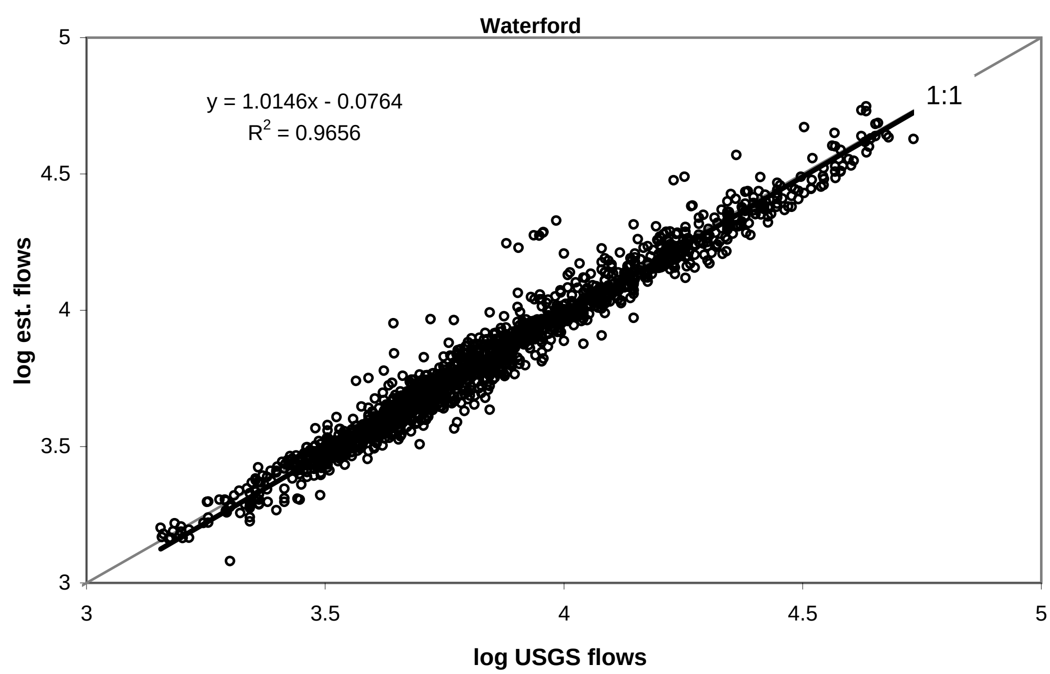


Figure 6-7. 1993 - 1997 Estimated versus USGS-Reported Daily Average Flow at Stillwater and Waterford.

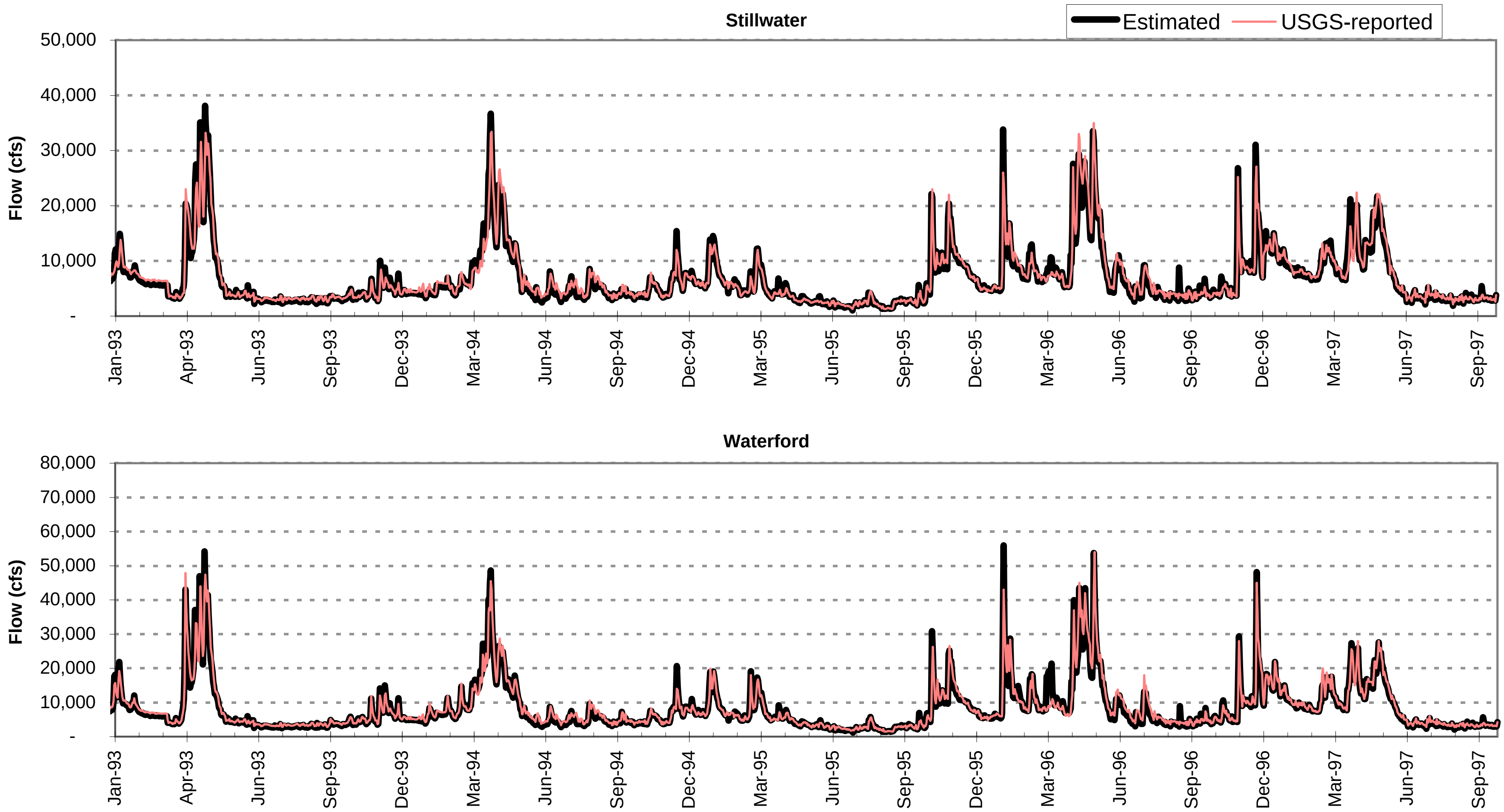


Figure 6-8. 1993 - 1997 Estimated versus USGS-Reported Daily Average Flow Time Series at Stillwater and Waterford.

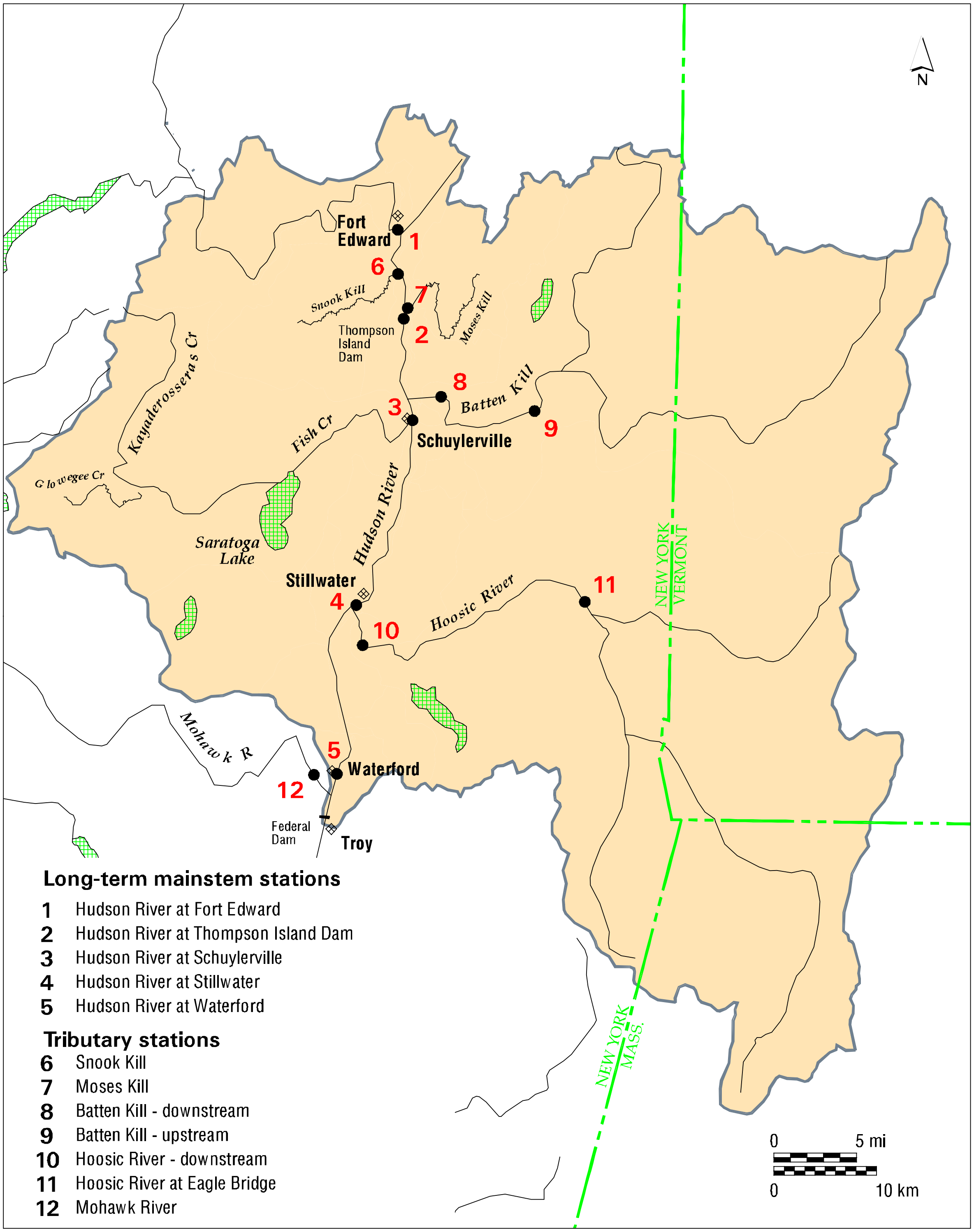


Figure 6-9. Upper Hudson River Basin Primary Mainstem and Tributary Sampling Locations for Solids Used in HUDTOX Modeling.

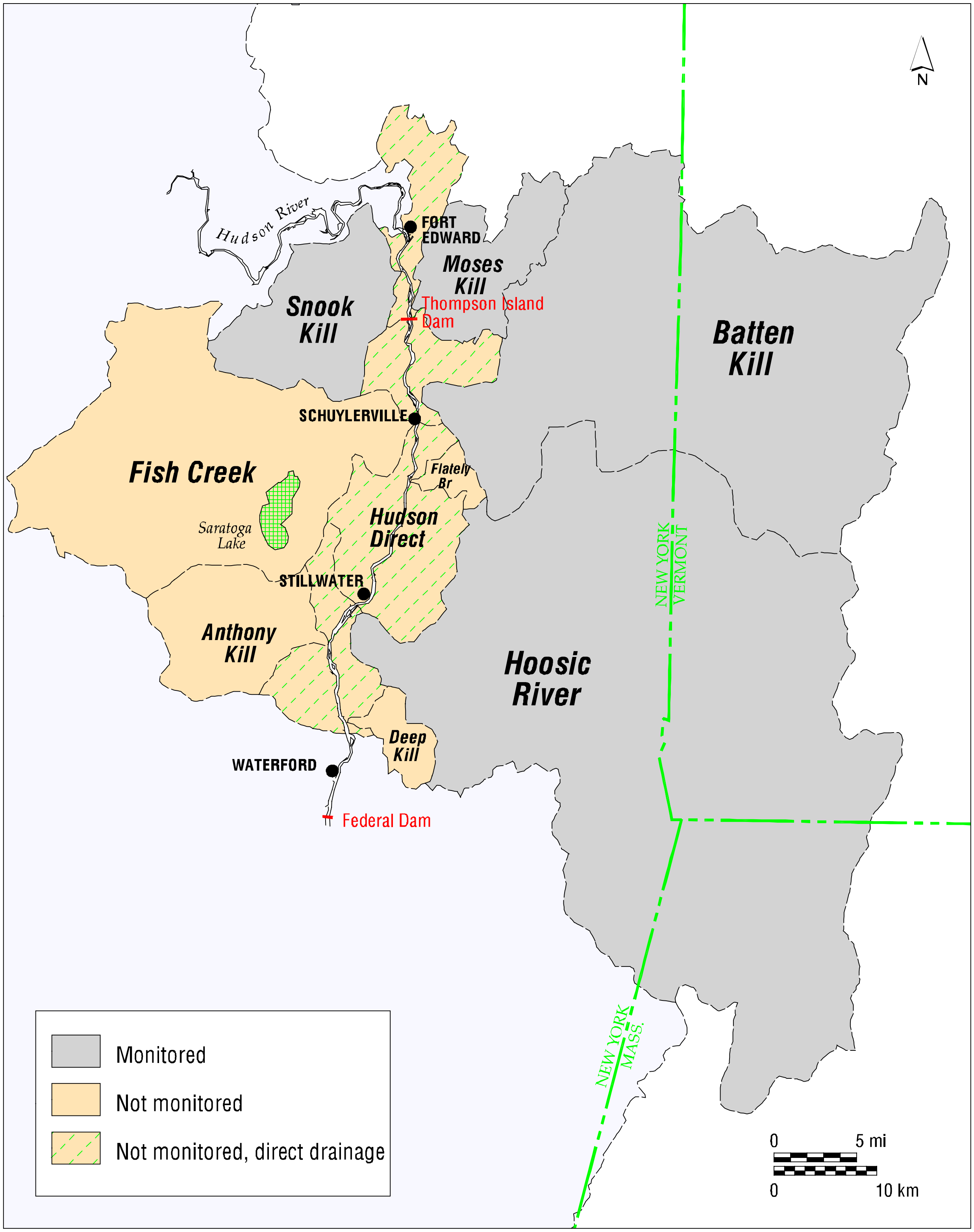


Figure 6-10. Monitored and Unmonitored Subwatersheds for Solids Between Fort Edward and Waterford.

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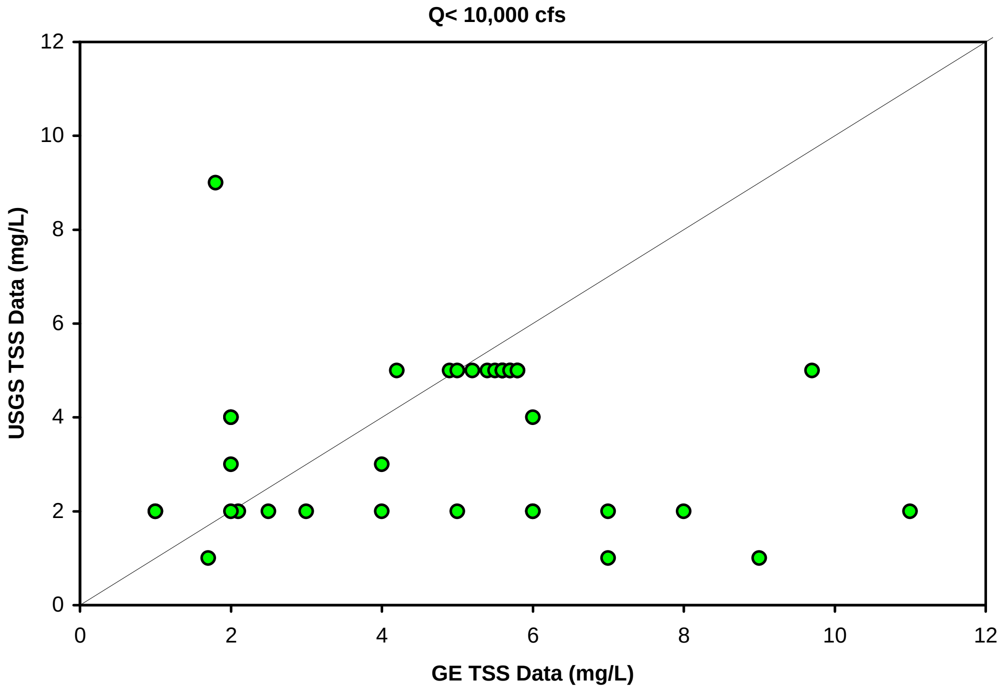


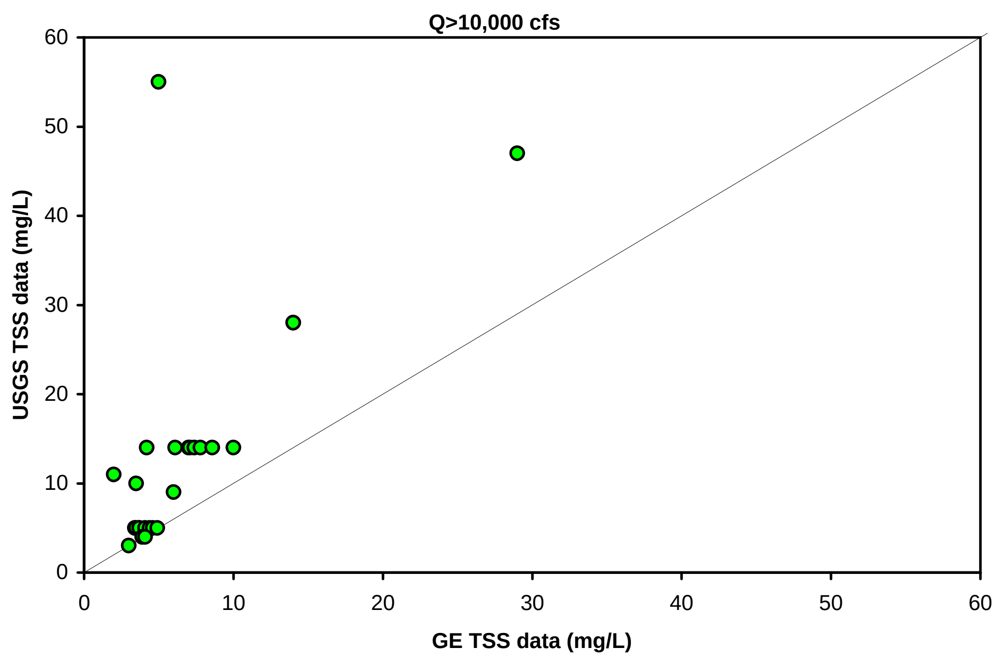


Figure 6-11. GE versus USGS TSS Data at Fort Edward for High and Low Flow Data Pairs from 4/1/91 to 9/15/97.

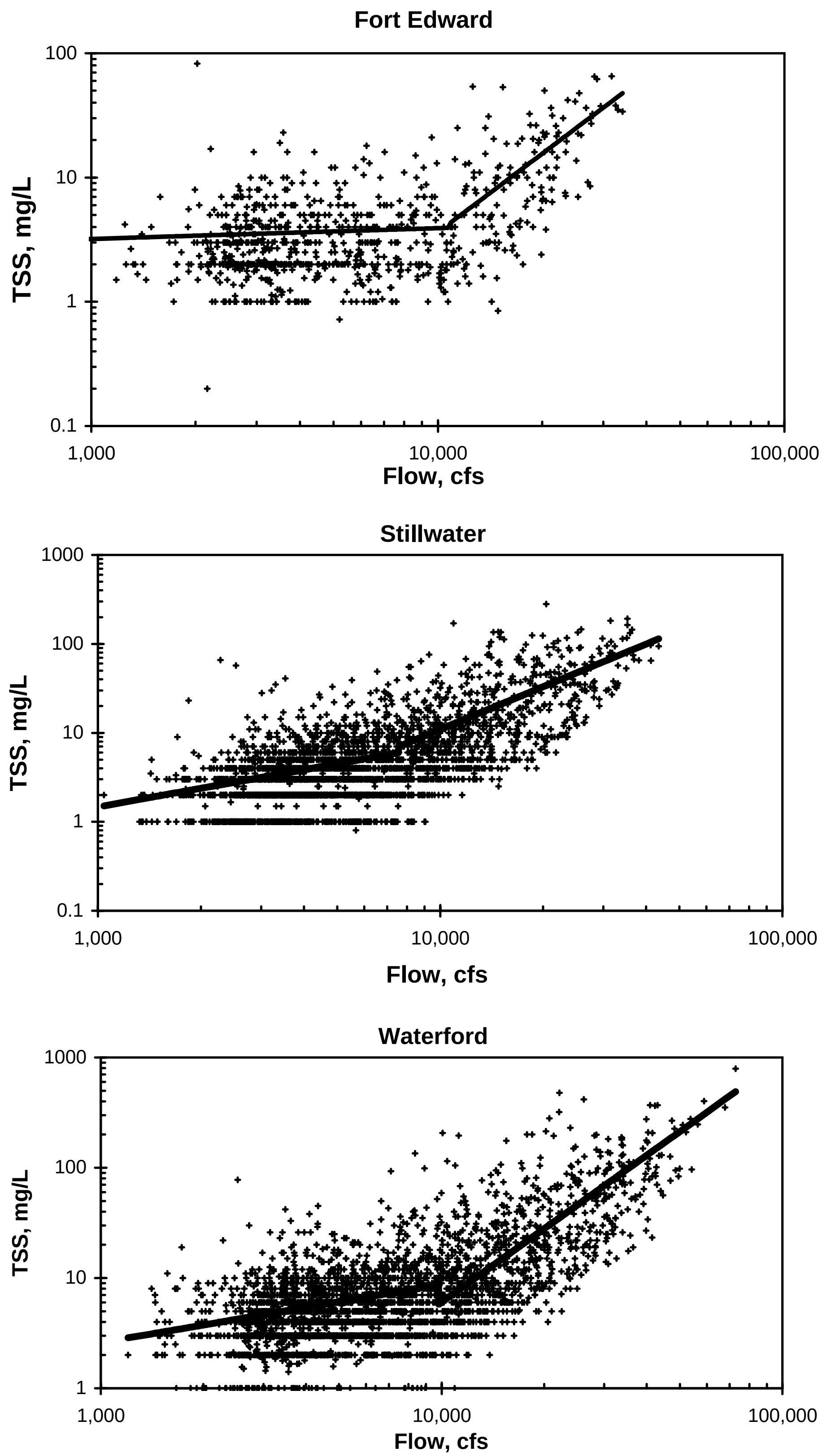


Figure 6-12. Observed Total Suspended Solids (TSS) versus Flow, 1977-1997 and TSS Rating Curves for this Period at Fort Edward, Stillwater and Waterford.

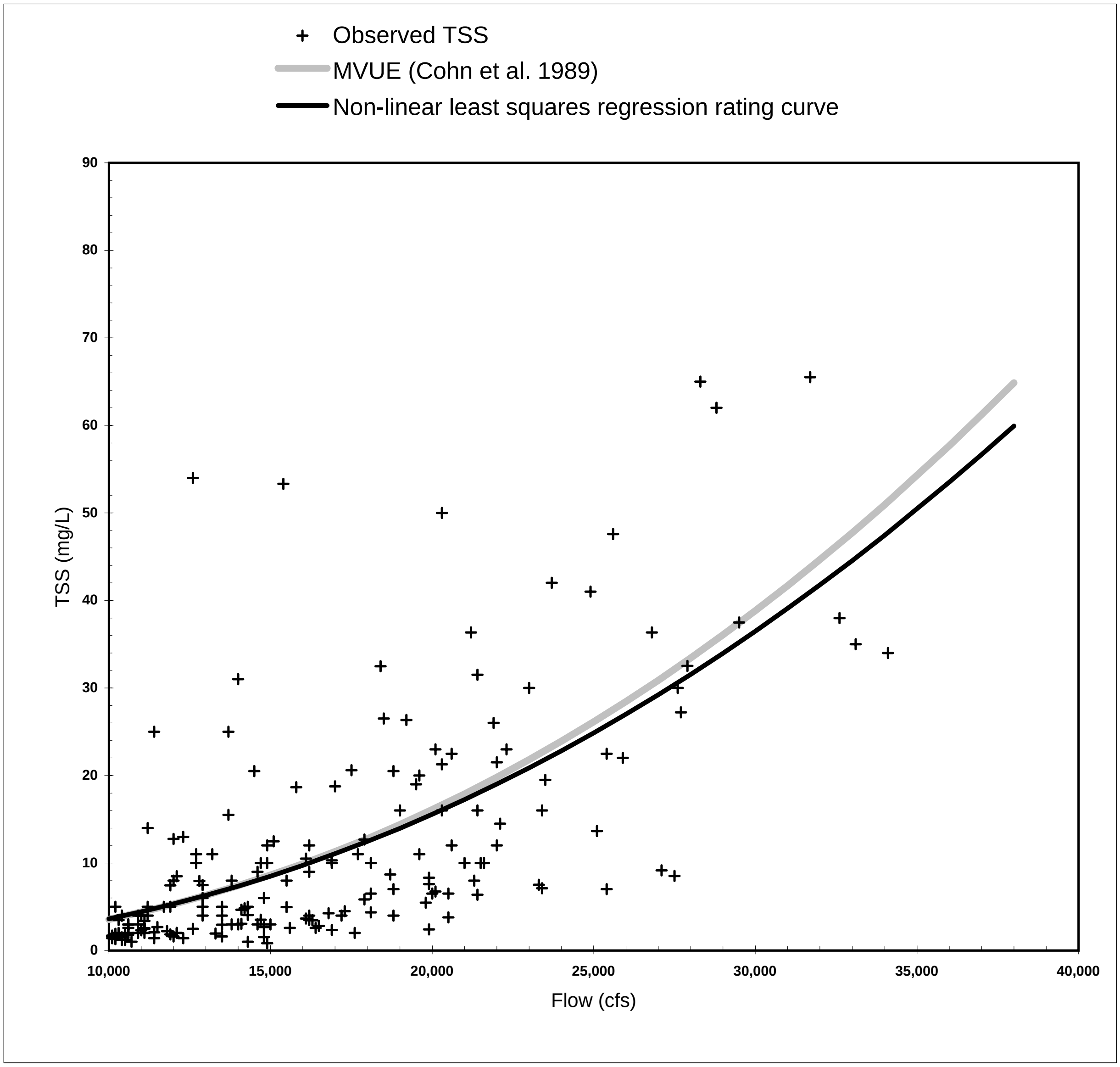


Figure 6-13. Comparison of Total Suspended Solids (TSS) High-Flow Rating Curves for Fort Edward, 1977-1997, Using MVUE (Cohn et al. 1989) and Non-linear Regression Analysis.

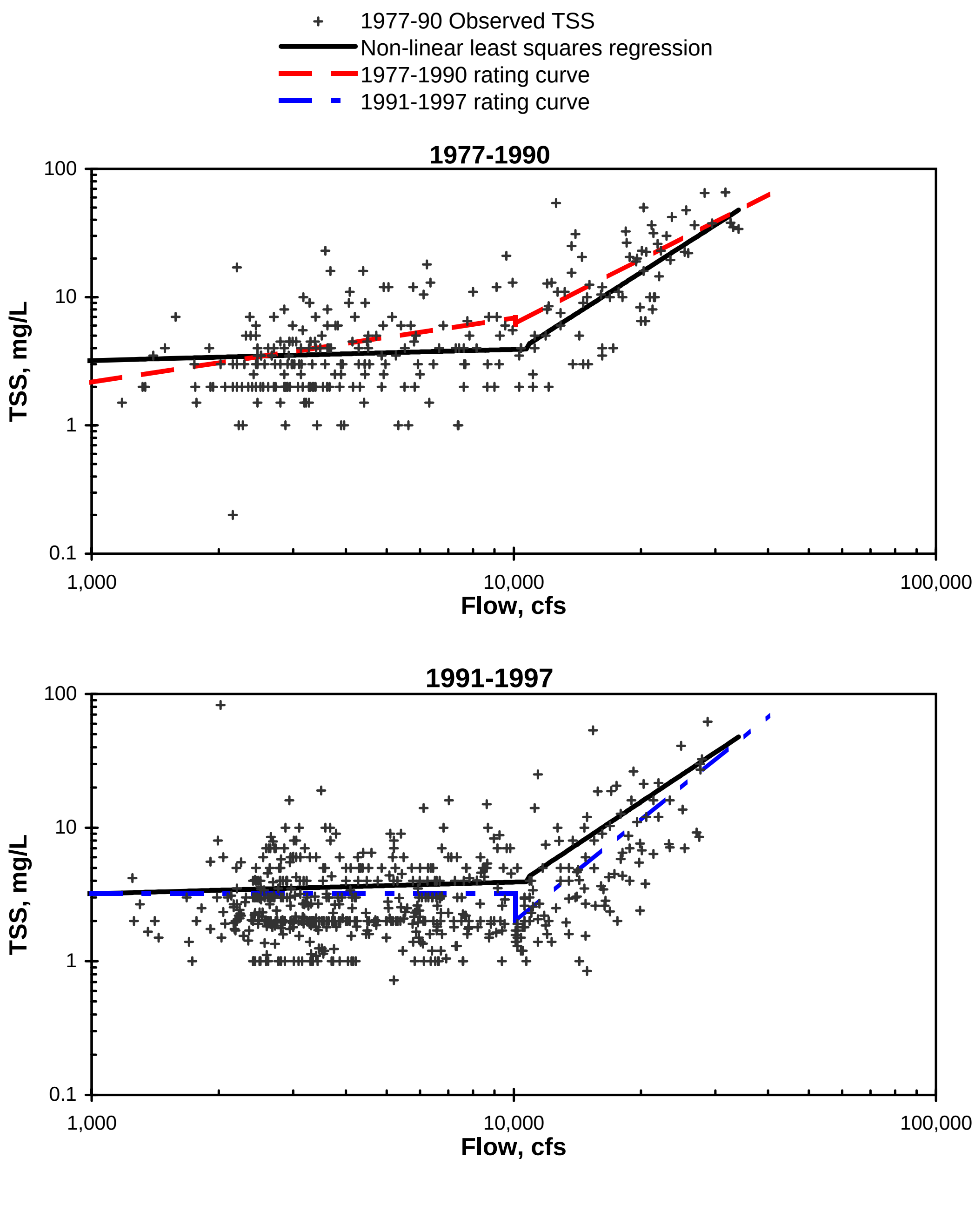


Figure 6-14. Comparison of 1977-1990 and 1991-1997 Total Suspended Solids (TSS) Rating Curves at Fort Edward versus the 1977-1997 Rating Curve.

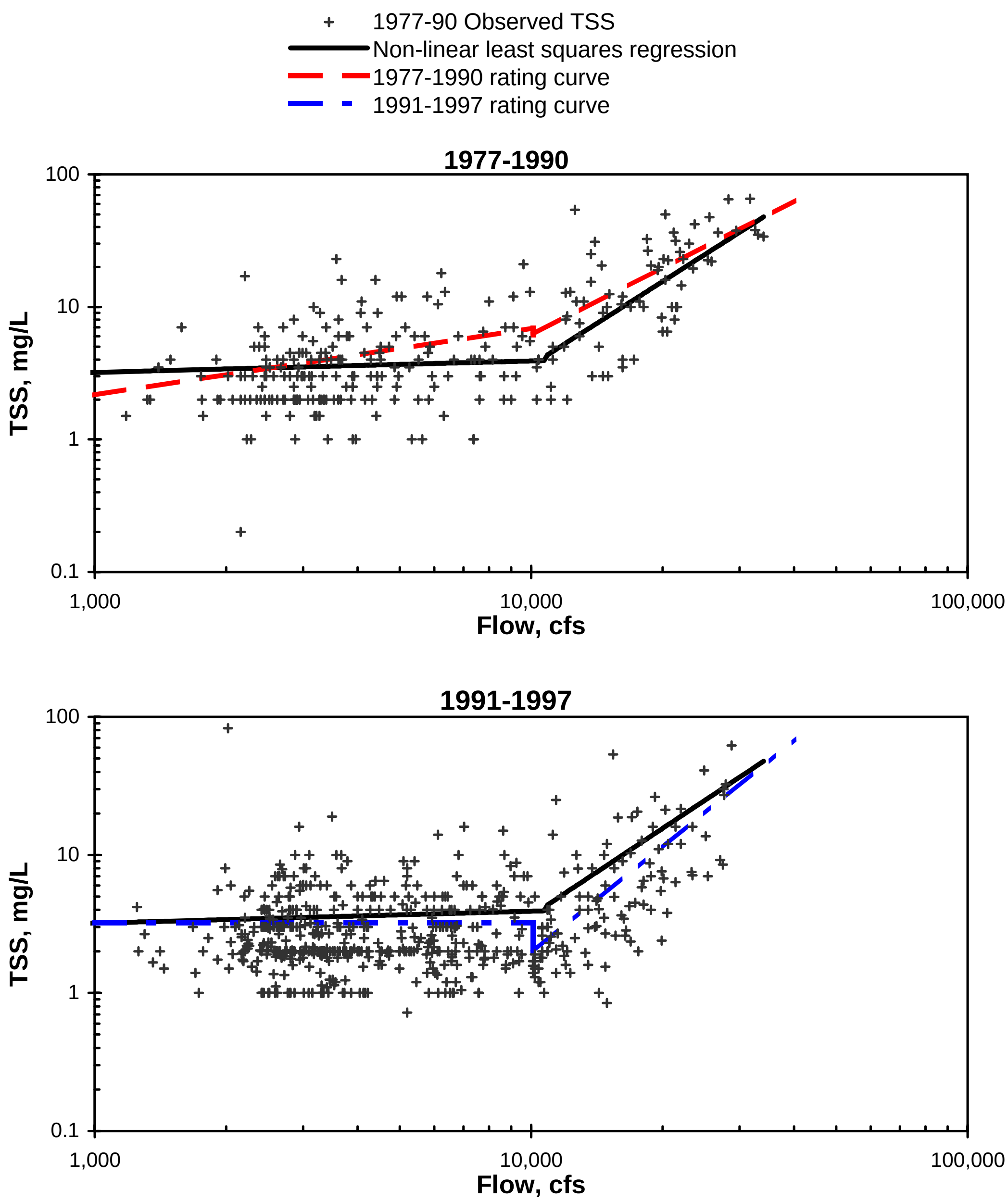


Figure 6-14. Comparison of 1977-1990 and 1991-1997 Total Suspended Solids (TSS) Rating Curves at Fort Edward versus the 1977-1997 Rating Curve.

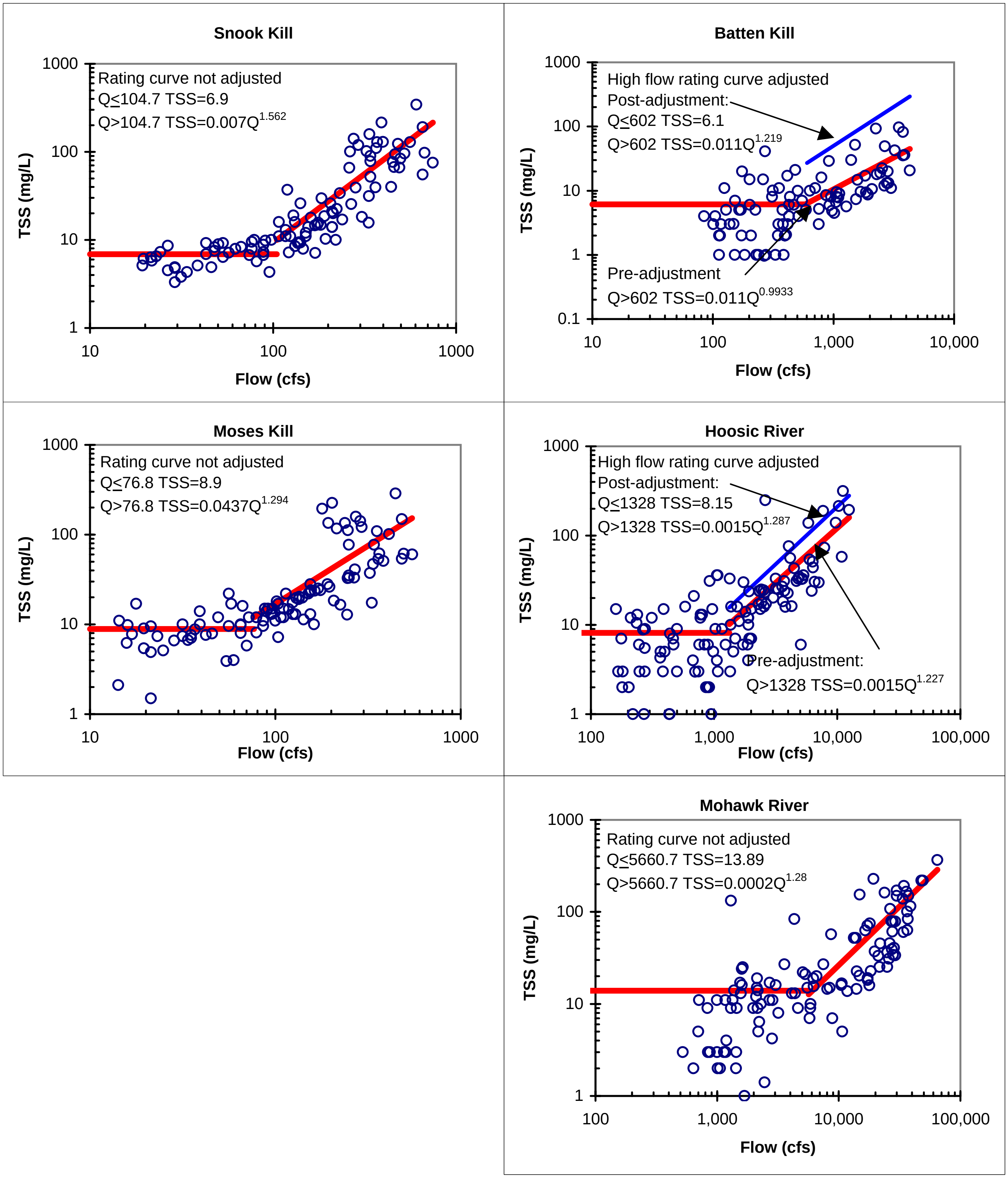
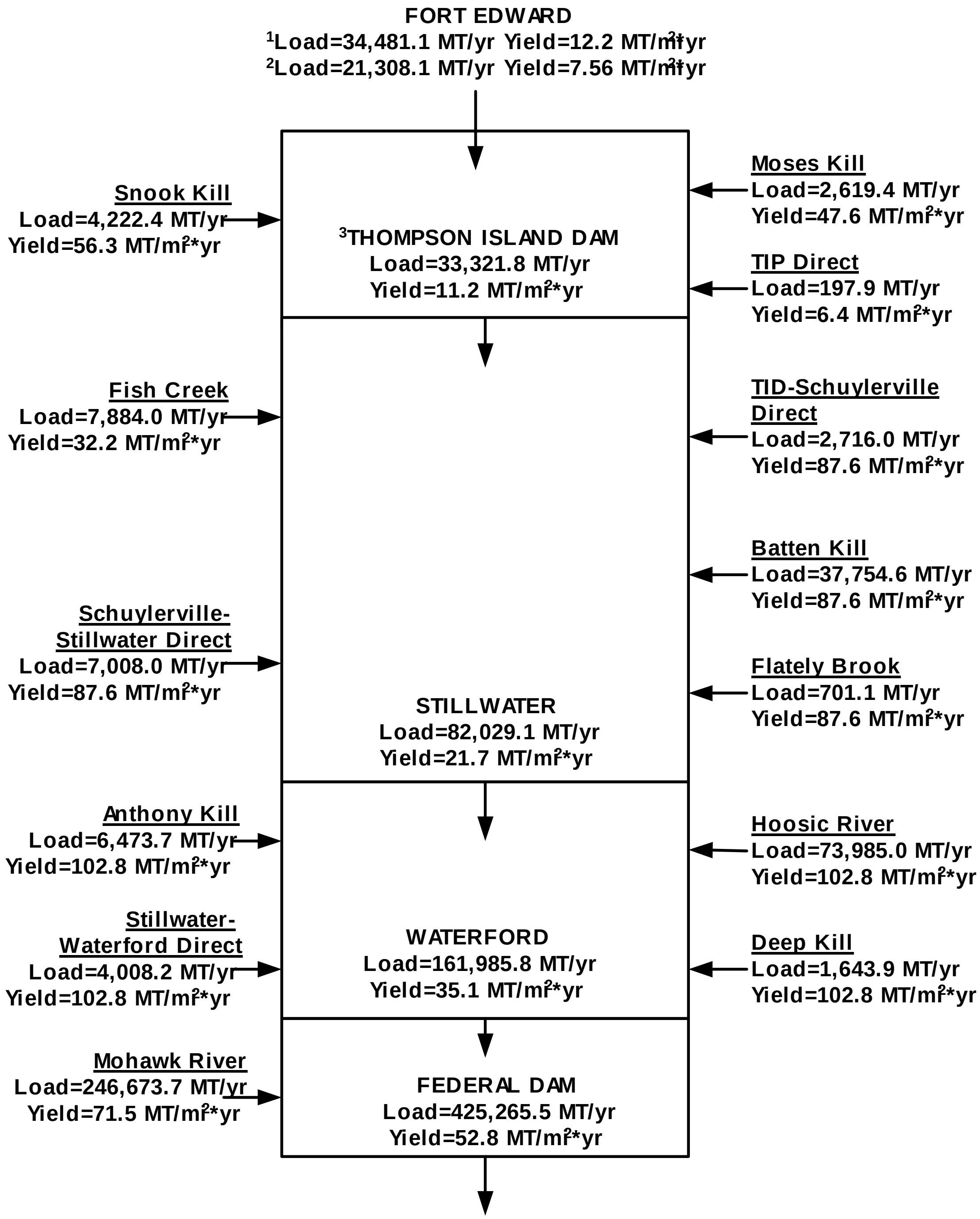


Figure 6-15. Tributary TSS Rating Curves: Based on Data and Adjusted to Achieve Solids Balance.



[1] 1/1/77 - 12/31/90
[2] 1/1/91 - 12/31/96
[3] TID loads are the sum of FE, Snook, Moses and TIP direct drainage loads, accounting for an 8.5% trapping efficiency in TIP

Figure 6-16. Mainstem and Tributary Suspended Solids Watershed Loads and Yields based on HUDTOX Suspended Solids Loading Estimates (10/1/77-9/30/97).

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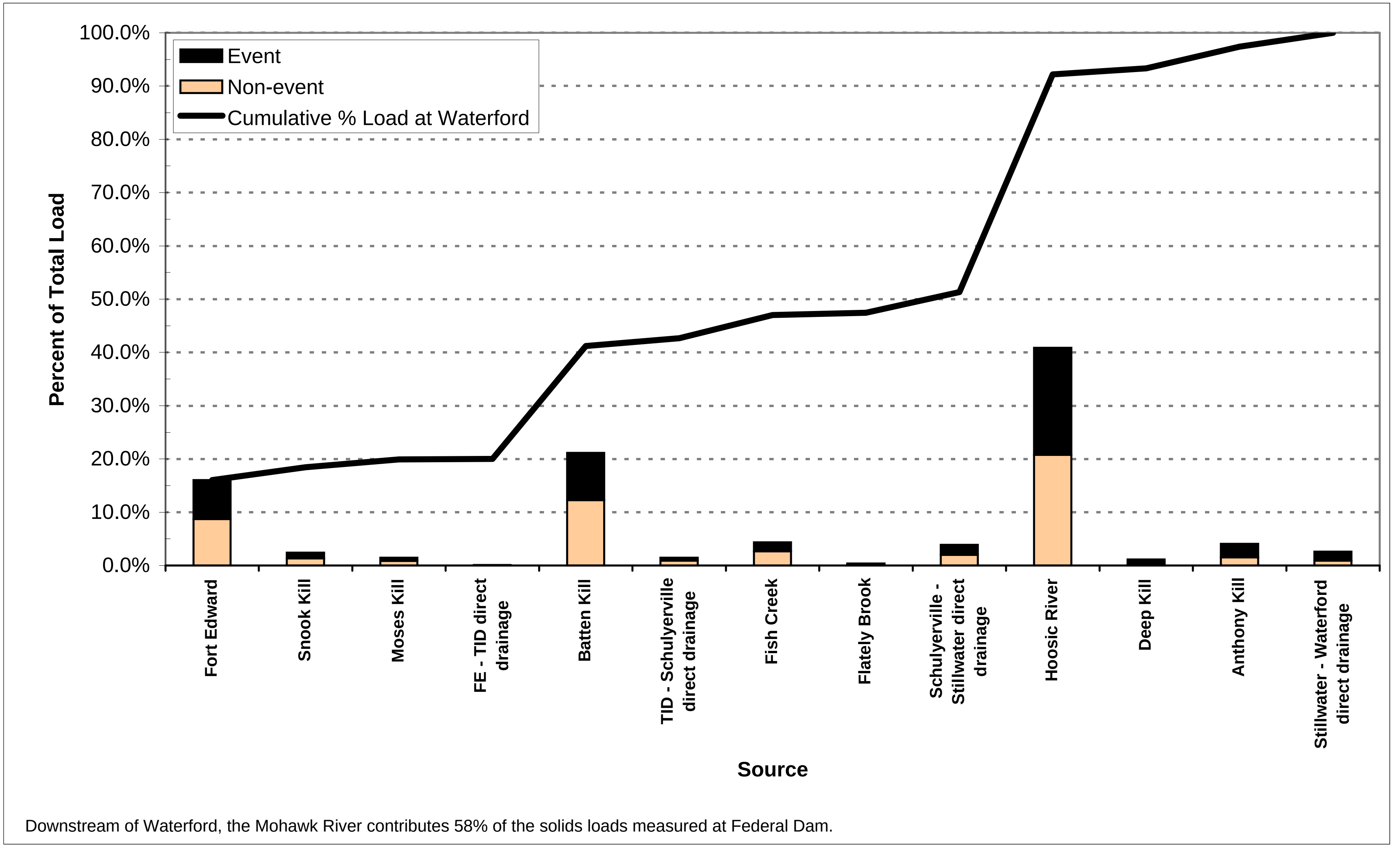


Figure 6-17. Relative Percent Solids Contribution from Fort Edward and Tributaries between Fort Edward and Waterford.

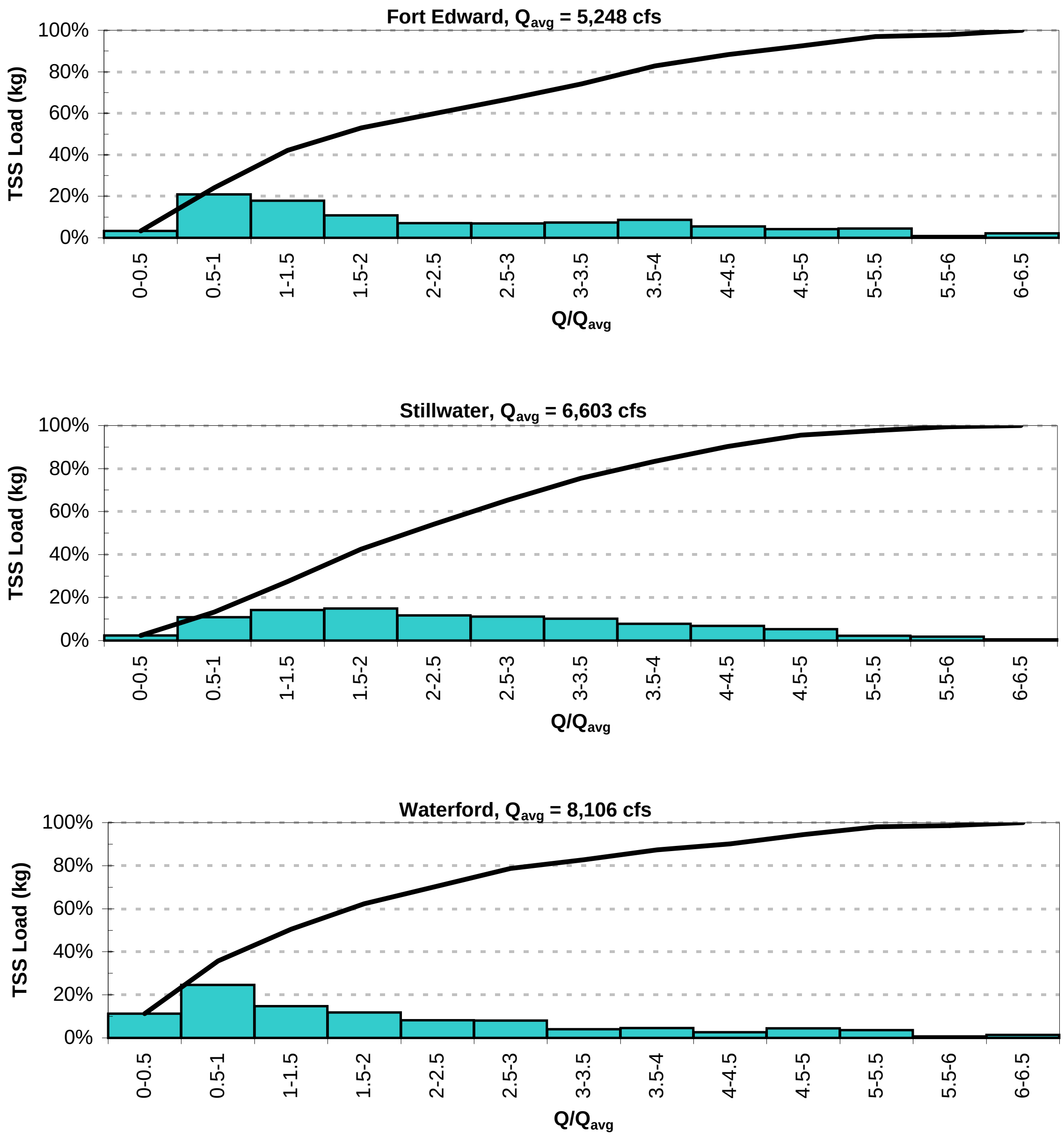


Figure 6-18. Distribution of TSS Load Over Flow Range at Fort Edward, Stillwater, and Waterford from 1977 - 1997.

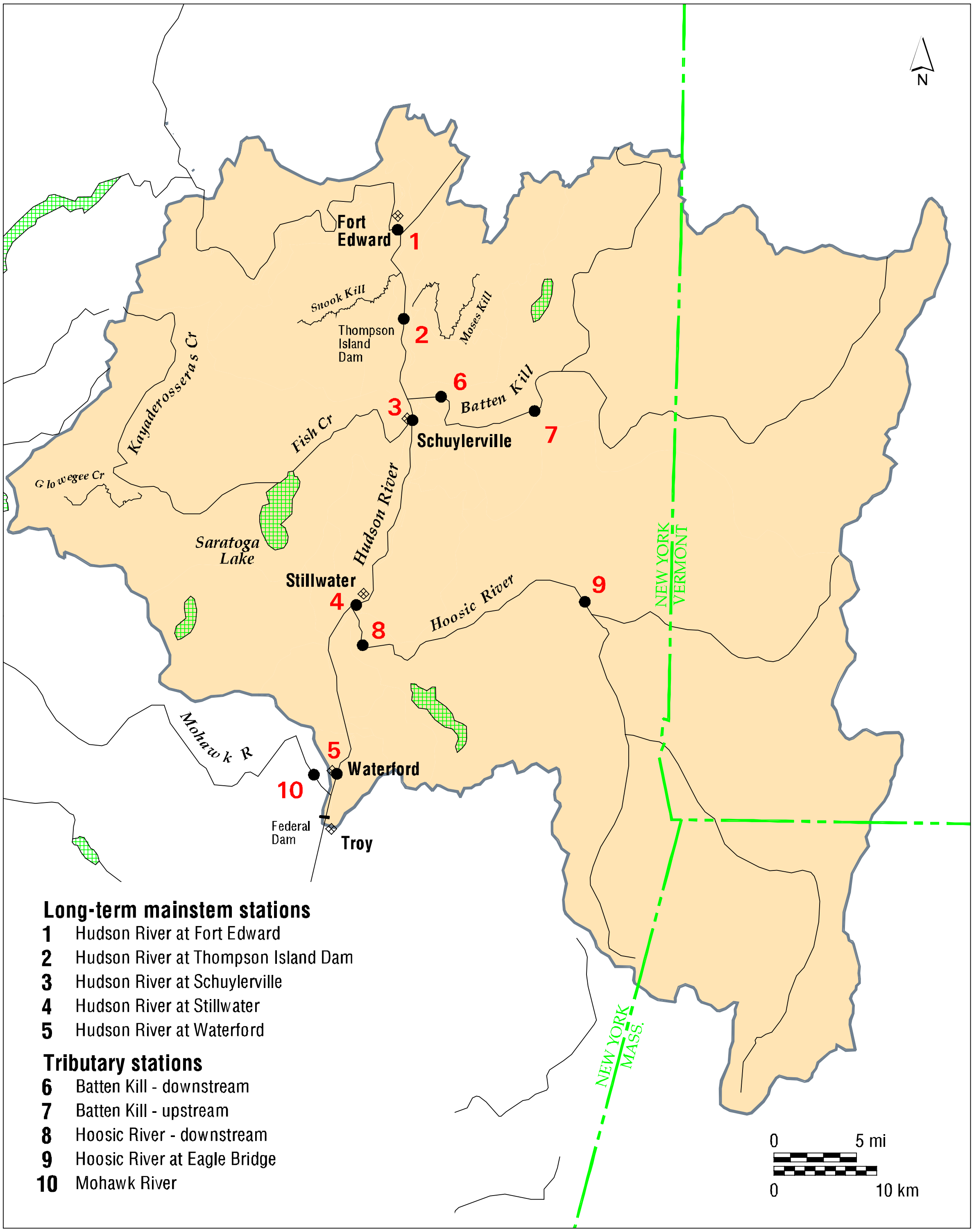


Figure 6-19. Upper Hudson River Basin Primary Mainstem and Tributary Sampling Locations for PCB Data Used in HUDTOX Modeling.

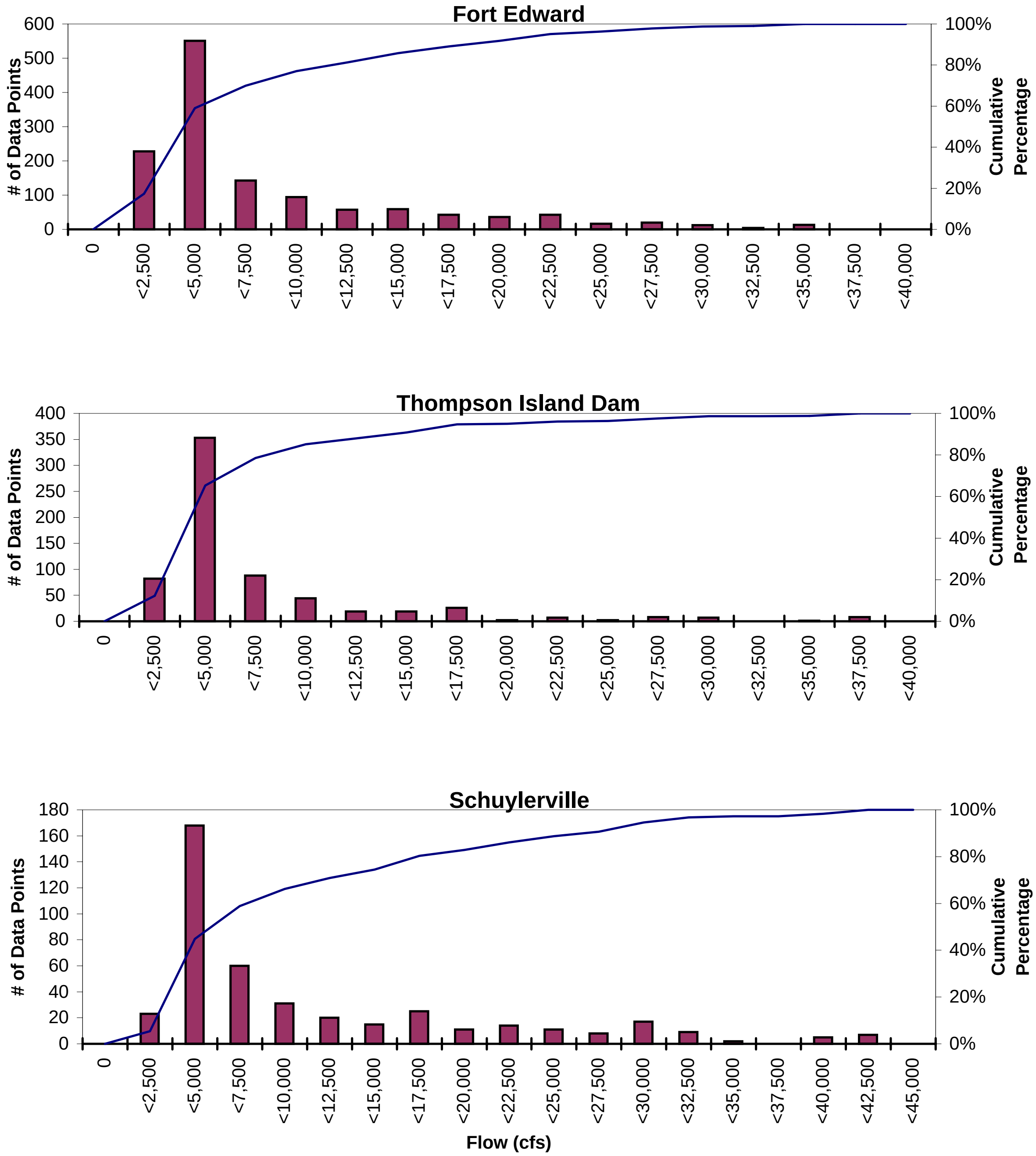
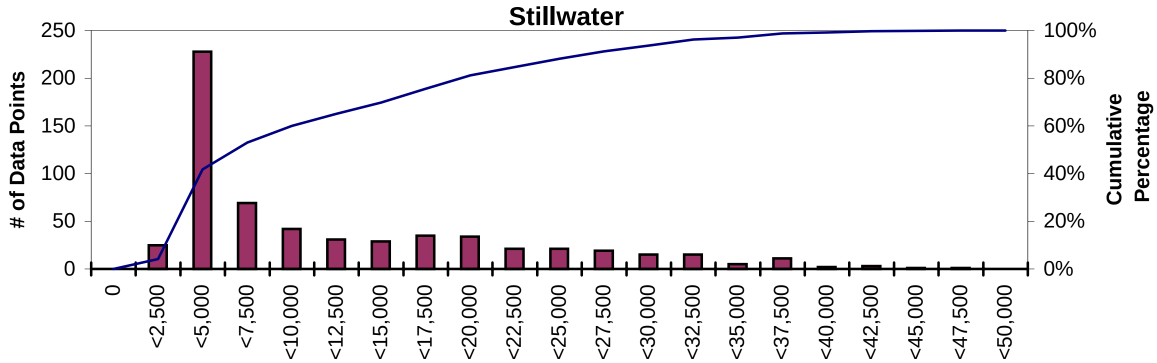


Figure 6-20a. Distribution of Available Tri+ PCBs Concentration Data by Flow Intervals for Mainstem Hudson River Sampling Stations (January 1977 - May 1998).



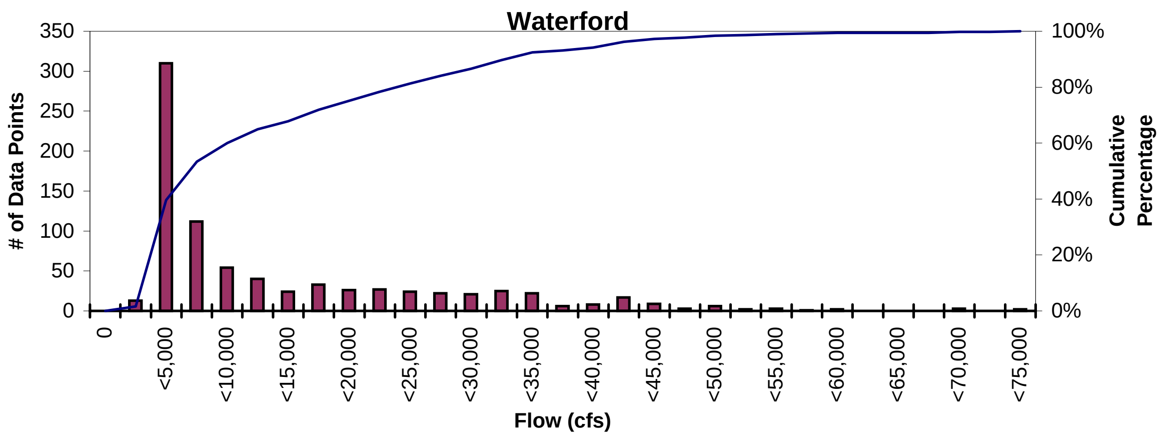


Figure 6-20b. Distribution of Available Tri+ PCBs Concentration Data by Flow Intervals for Mainstem Hudson River Sampling Stations (January 1977 - May 1998).

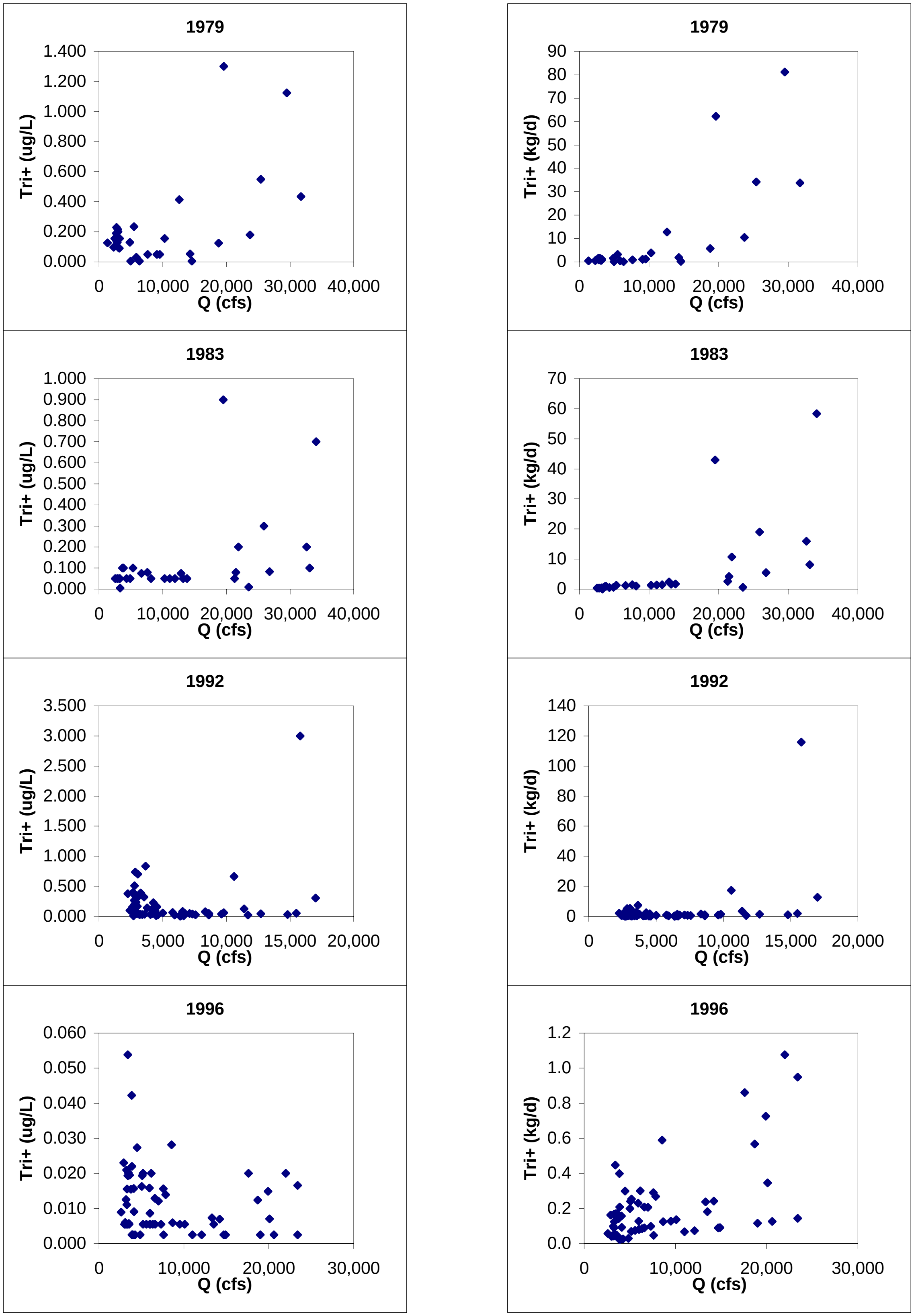


Figure 6-21. Tri+ PCB Concentrations and Load versus Flow at Fort Edward for Selected Years.

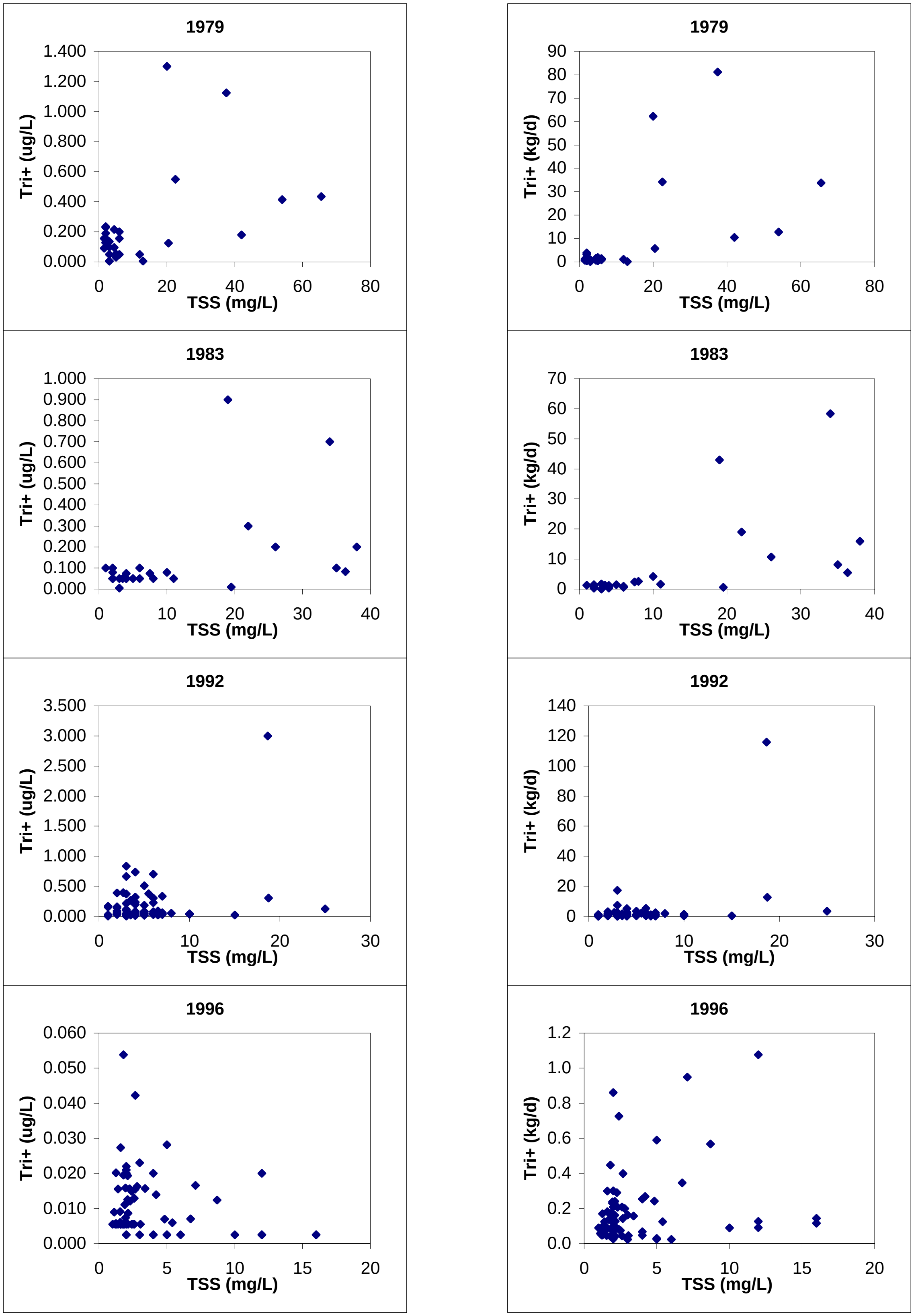


Figure 6-22. Tri+ PCB Concentrations and Loads versus Total Suspended Solids (TSS) Concentration at Fort Edward for Selected Years.

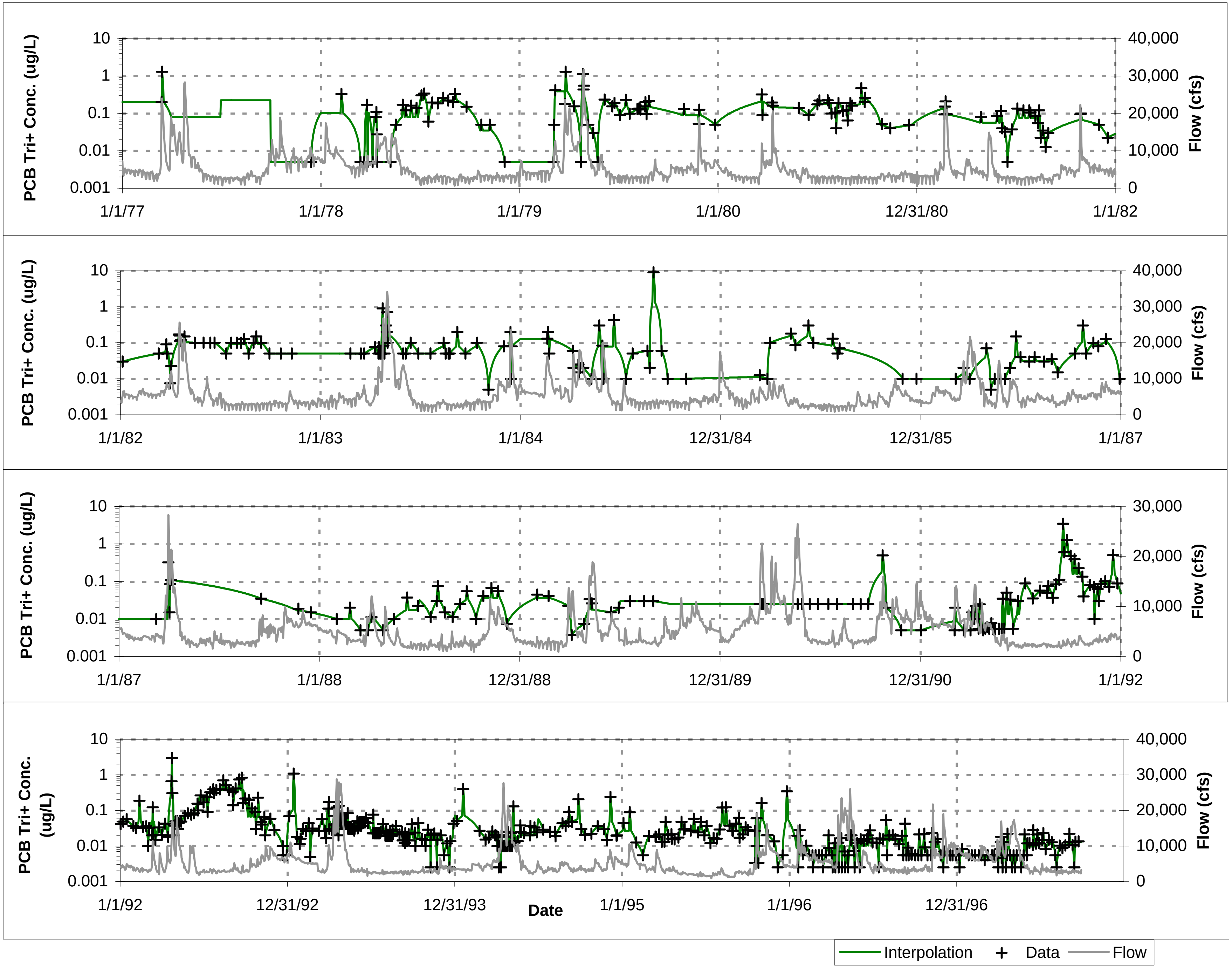


Figure 6-23. Interpolated Daily Tri+ PCB Concentration and Flow at Fort Edward, 1977-1997.

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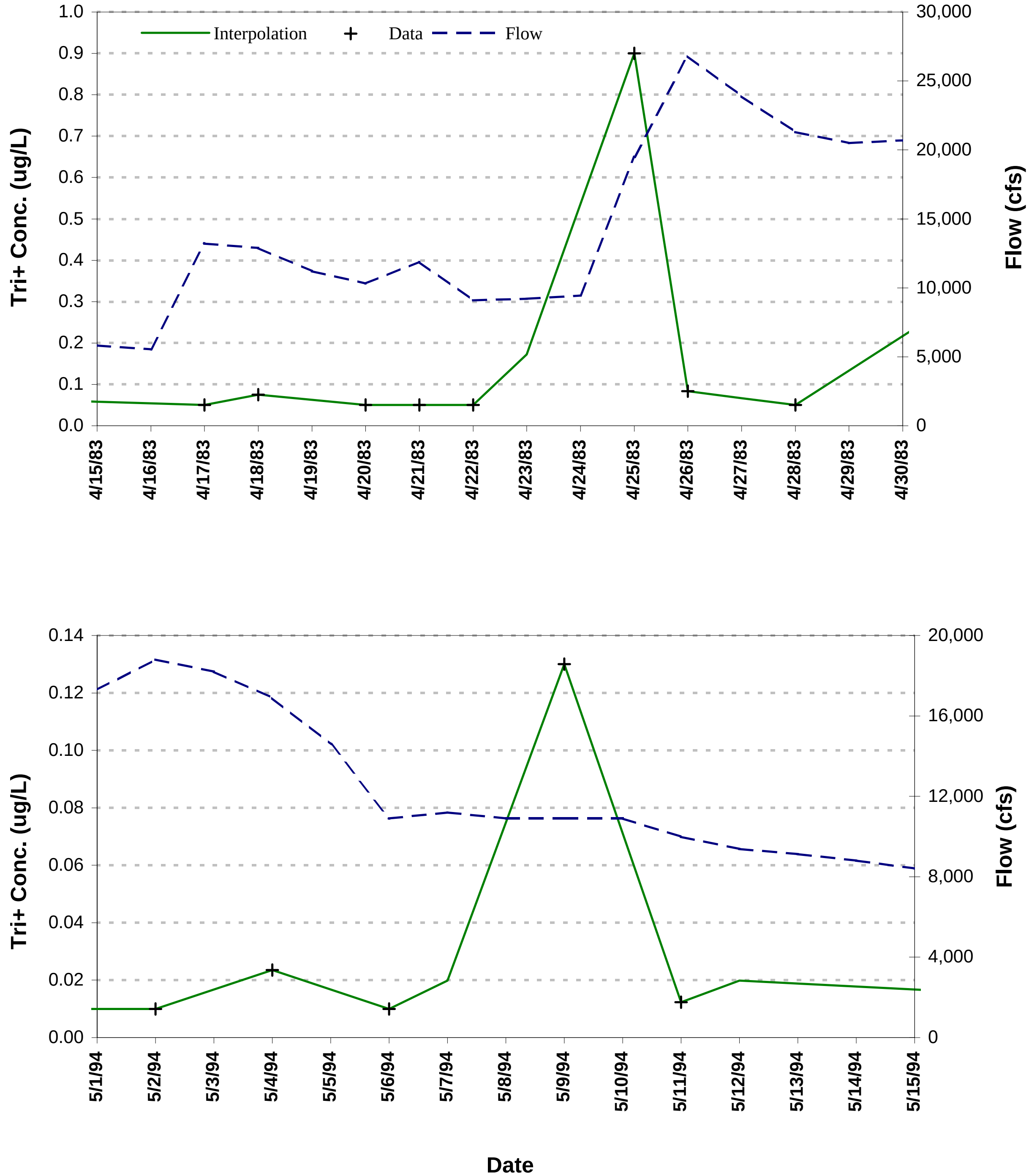


Figure 6-24. Examples of Apparent Tri+ Pulse Loading Events at Fort Edward in 1983 and 1994.

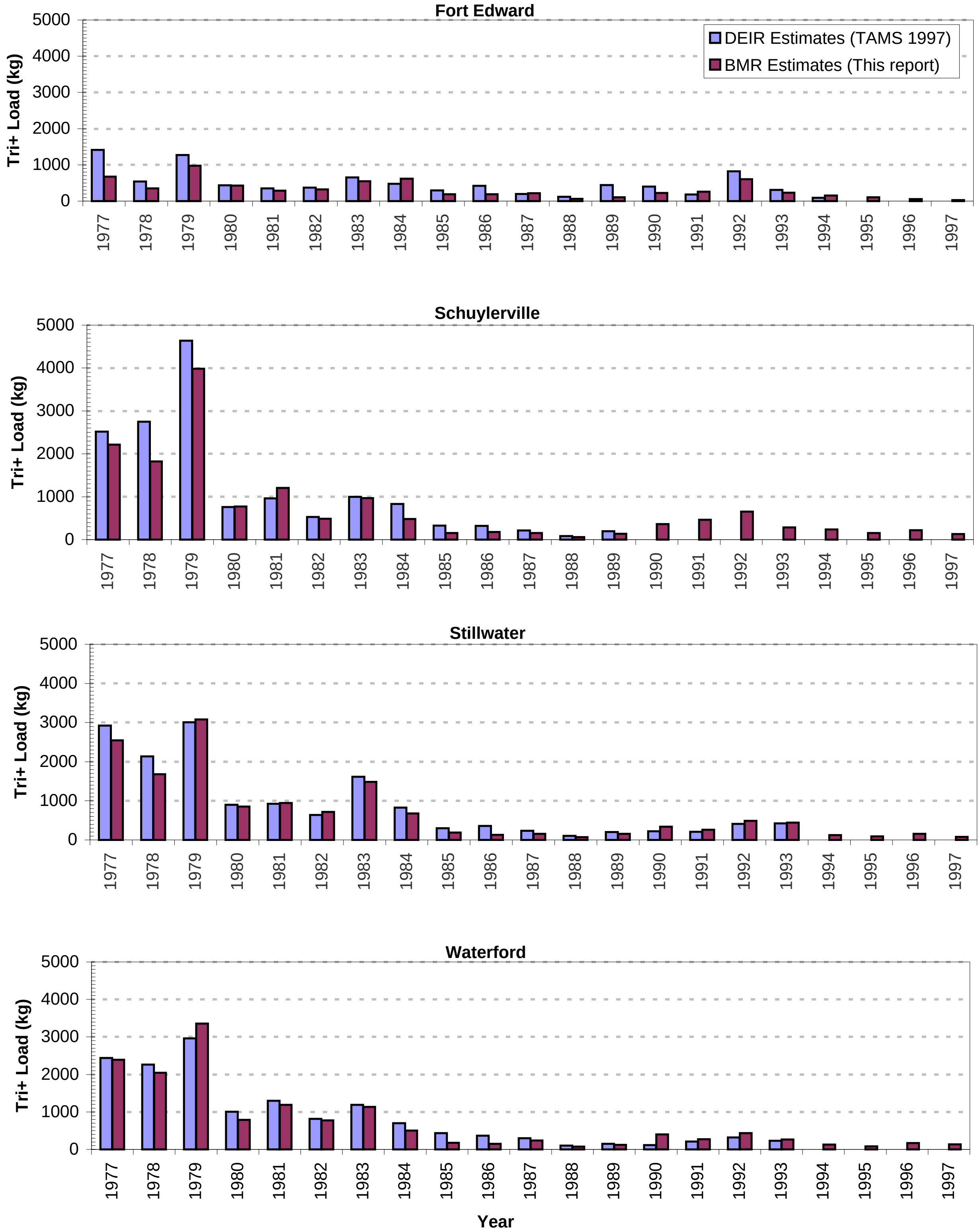


Figure 6-25. Estimated Annual Tri+ Load at Mainstem Hudson River Sampling Stations Compared to DEIR Estimates.

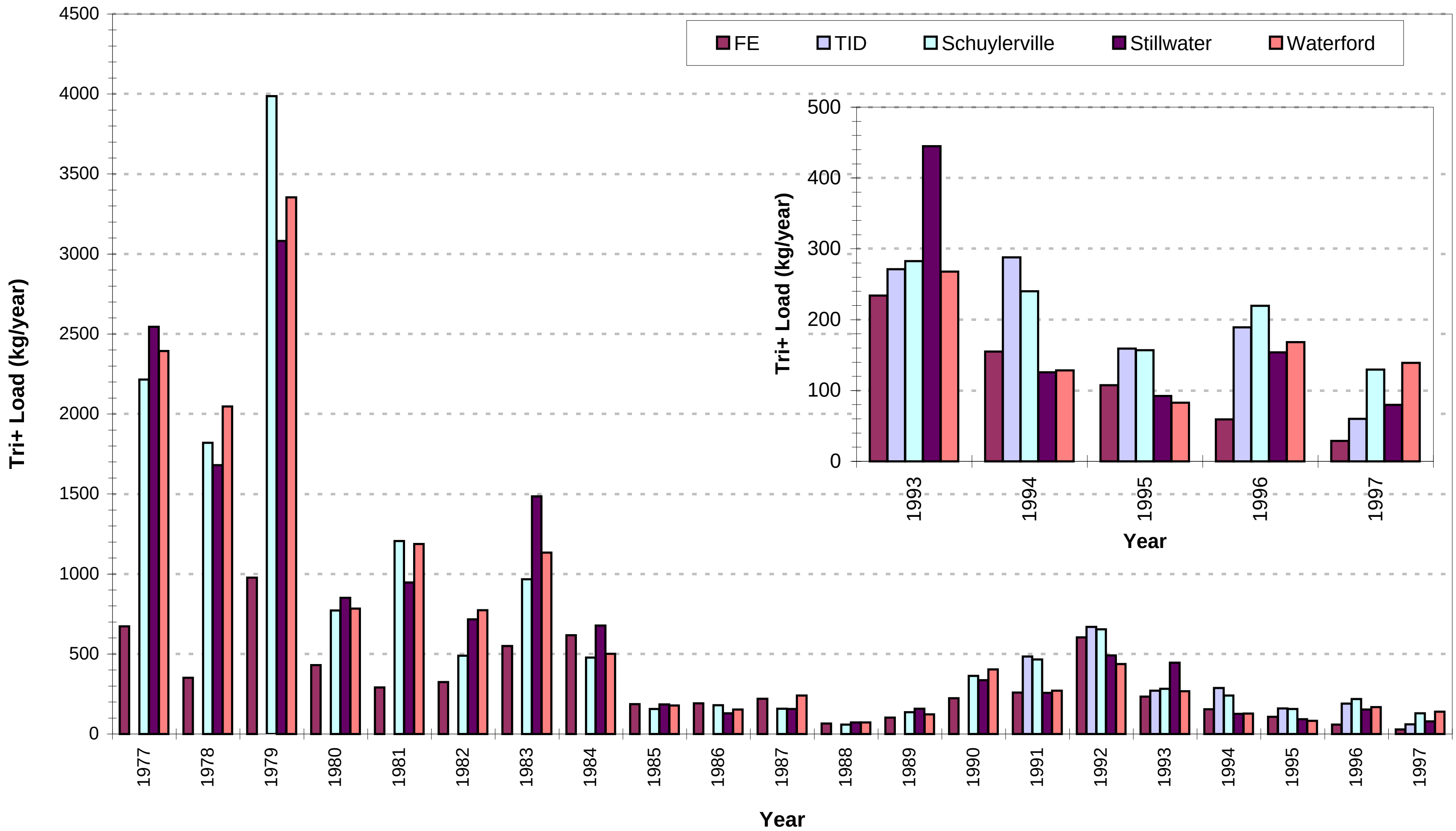


Figure 6-26. Estimated Annual Tri+ Load at Hudson River Mainstem Sampling Stations.

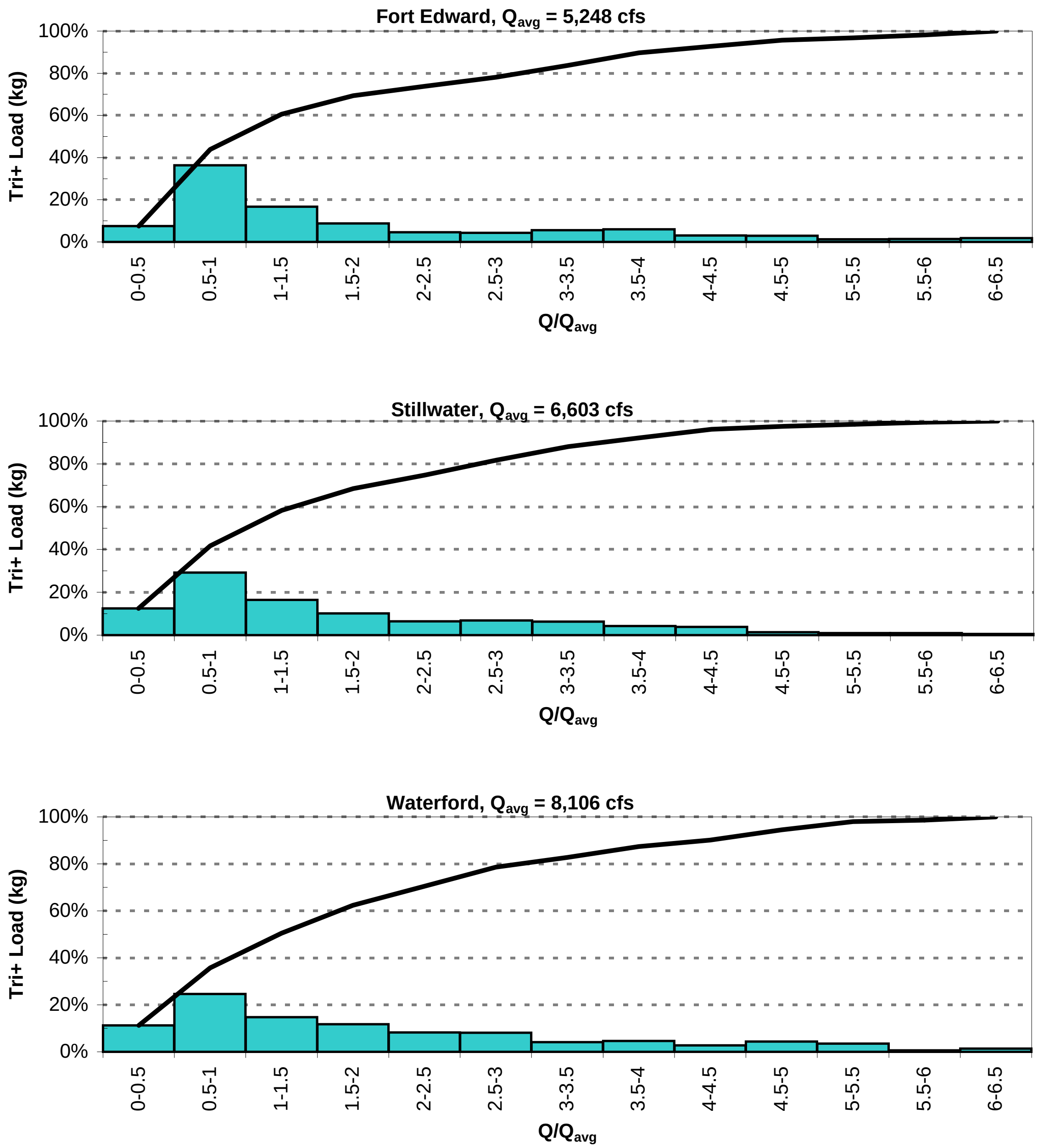


Figure 6-27. Distribution of Tri+ Load Over Flow Range at Fort Edward, Stillwater, and Waterford from 1977 - 1997.

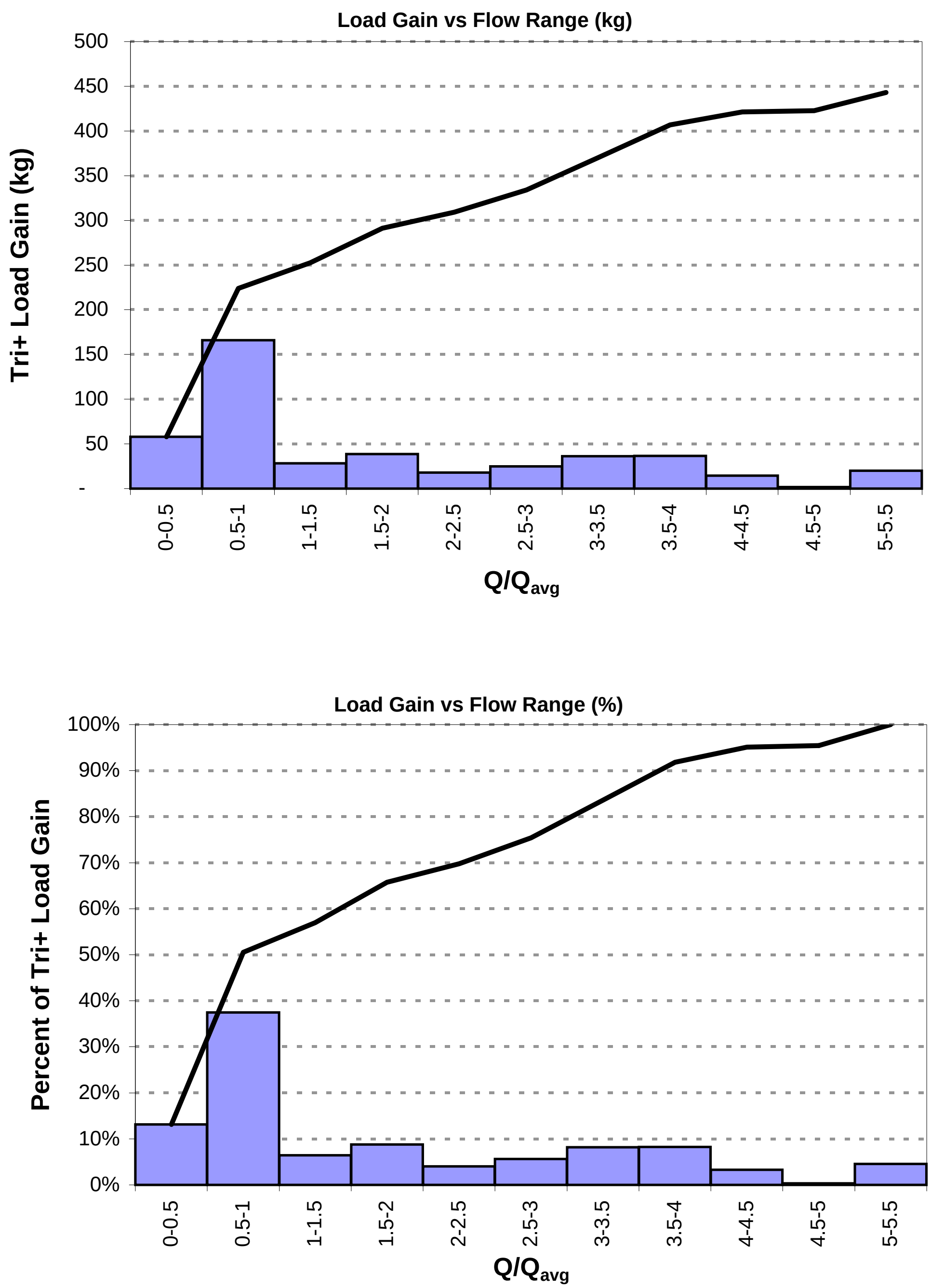


Figure 6-28. Distribution of Tri+ Load Gain Across Thompson Island Pool (TIP) Over Flow Range for 1993-1997.

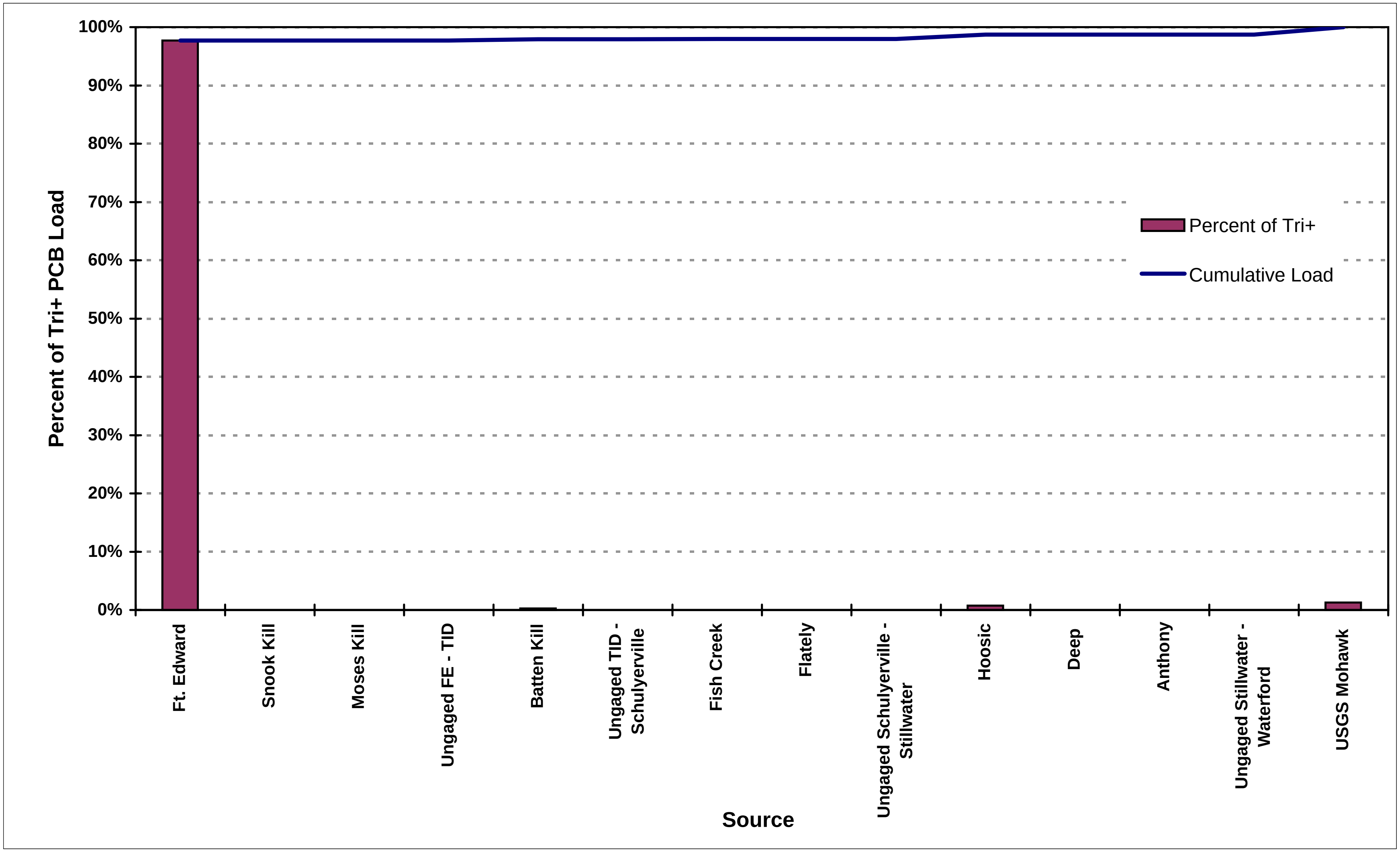


Figure 6-29. Relative Contribution of Estimated External Tri+ PCB Loads to the Upper Hudson River by Source, 1977-1997.

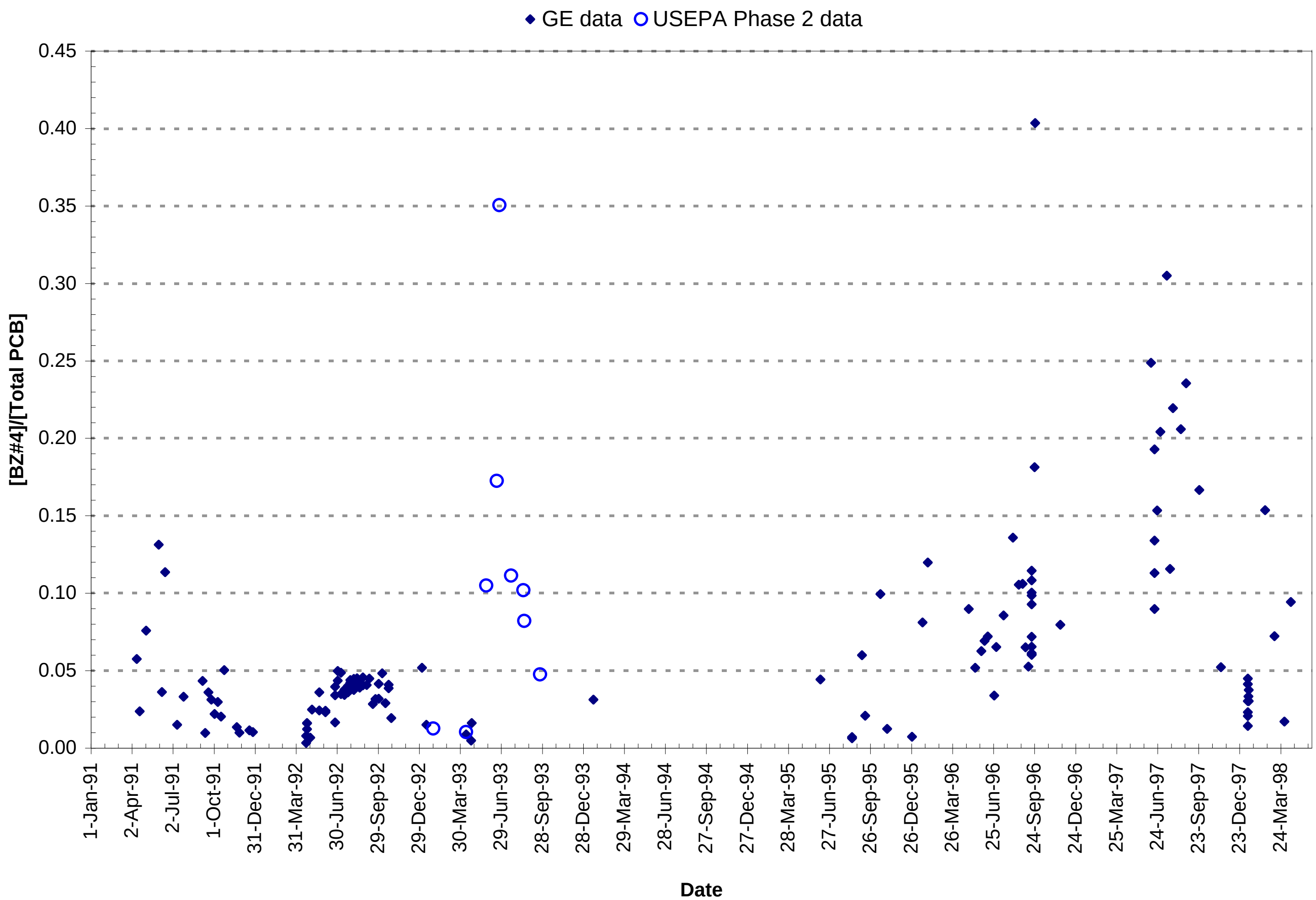


Figure 6-30. Ratio of Congener BZ#4 to Total PCBs at Fort Edward, 1991-1997, GE and USEPA Phase 2 Data.

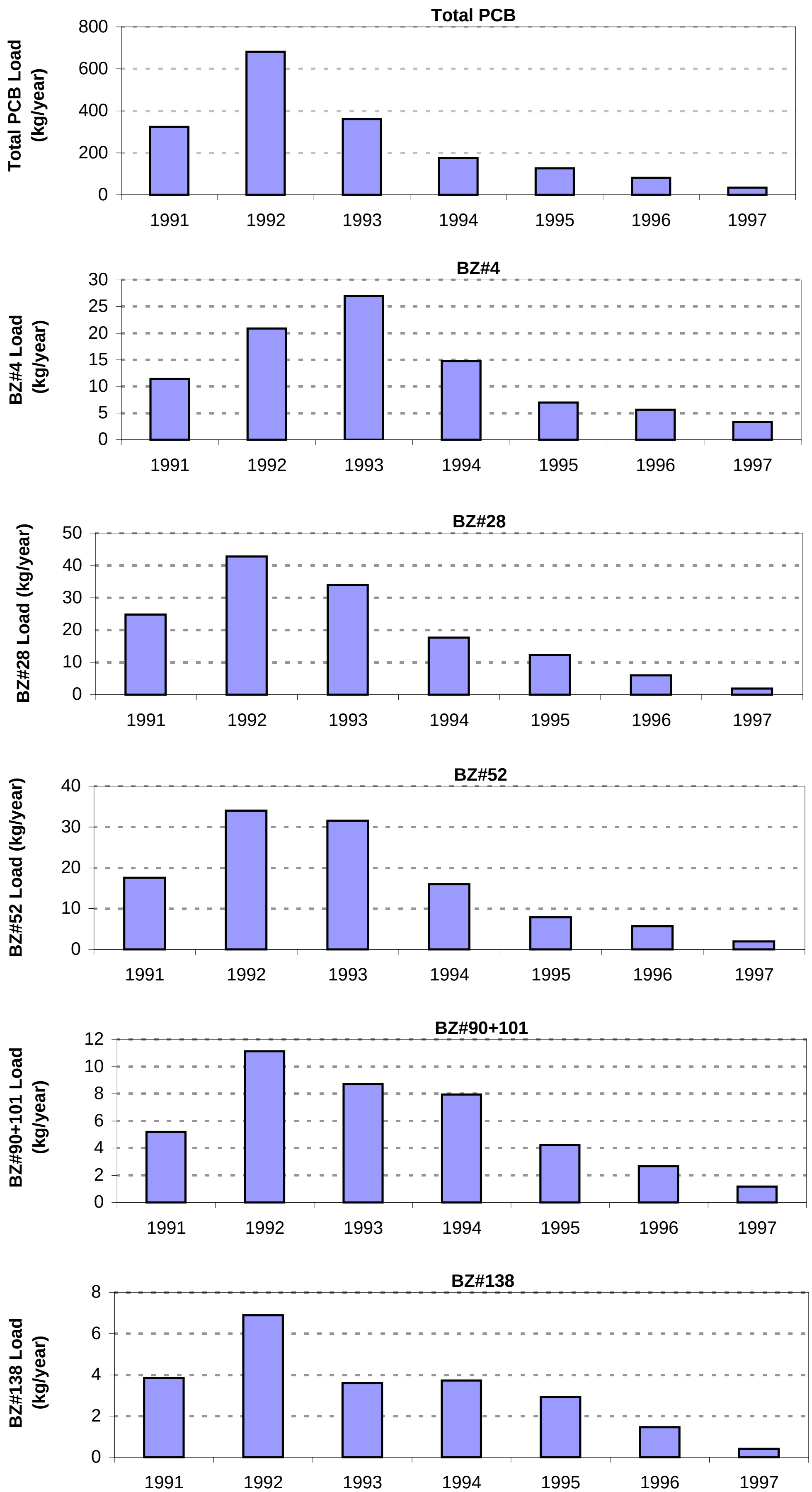
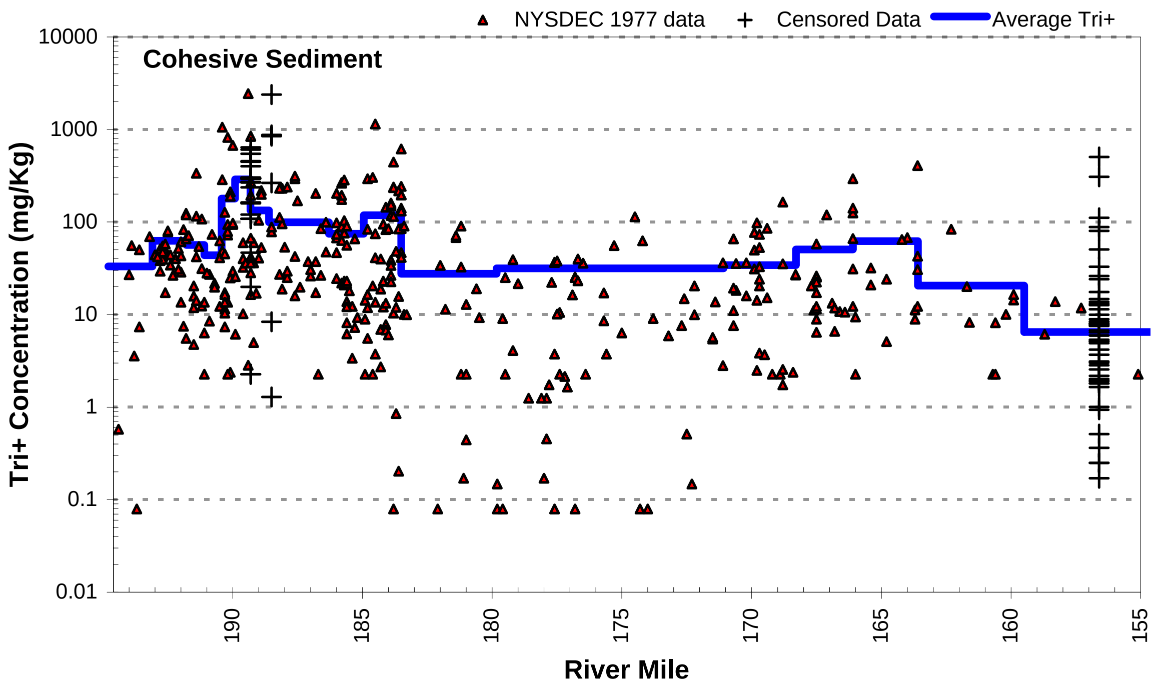


Figure 6-31. Estimated Annual Total and Congener PCB Loads at Fort Edward.



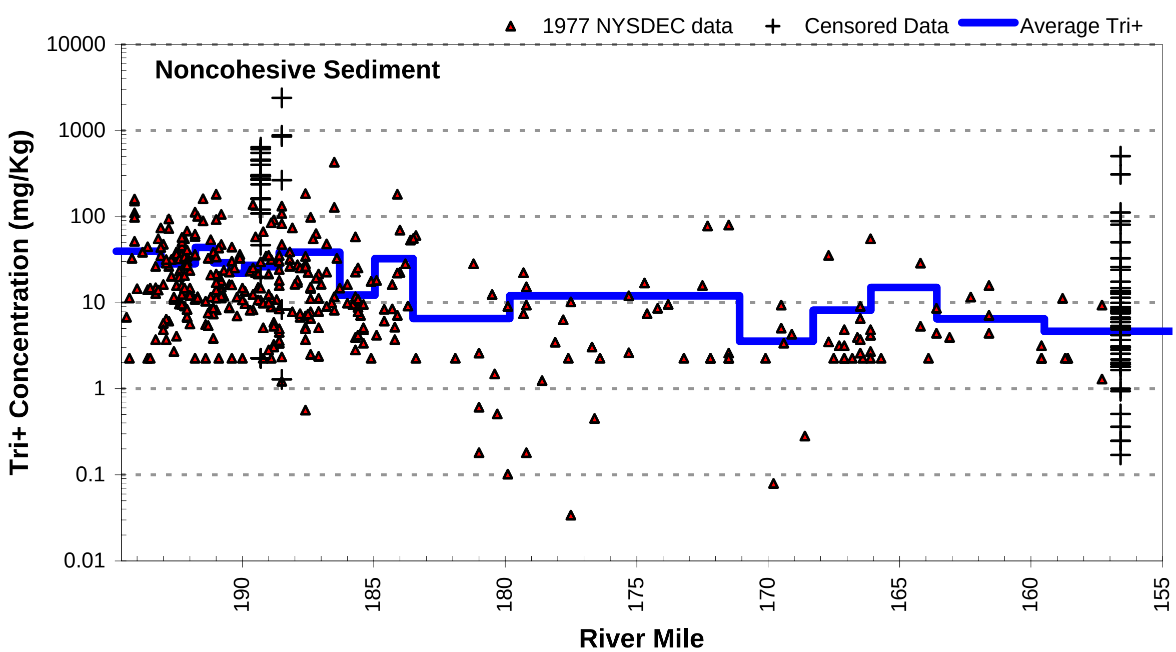
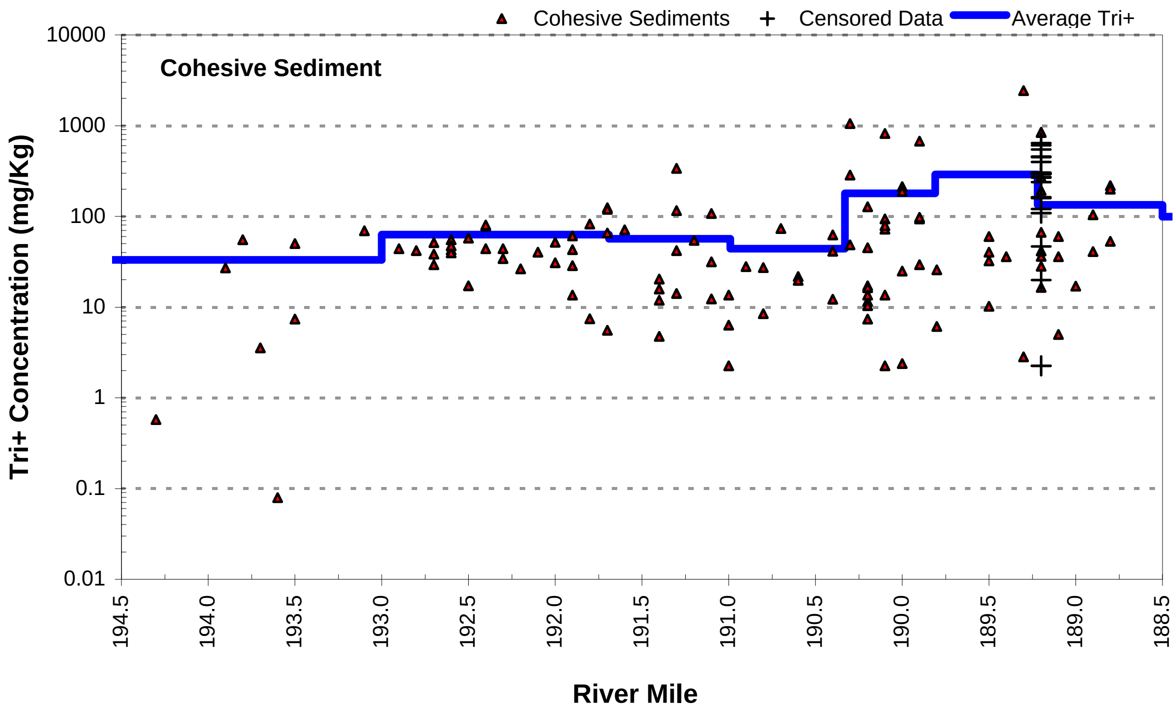


Figure 6-32. 1977 Sediment Tri+ PCB Initial Conditions Computed from the NYSDEC Data, Fort Edward to Federal Dam.



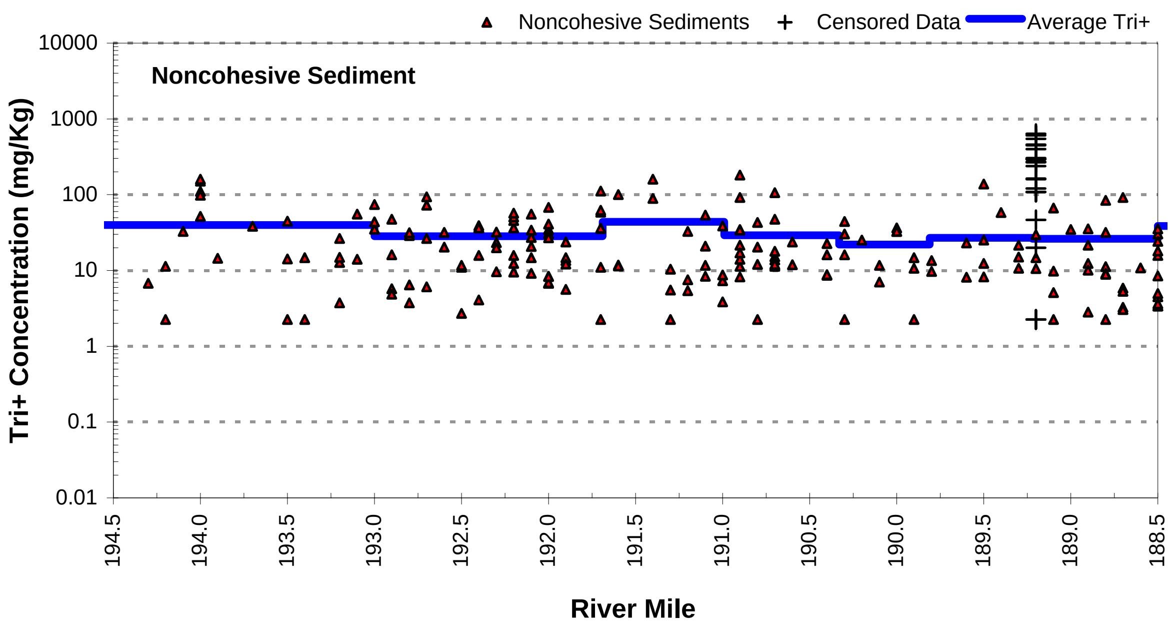
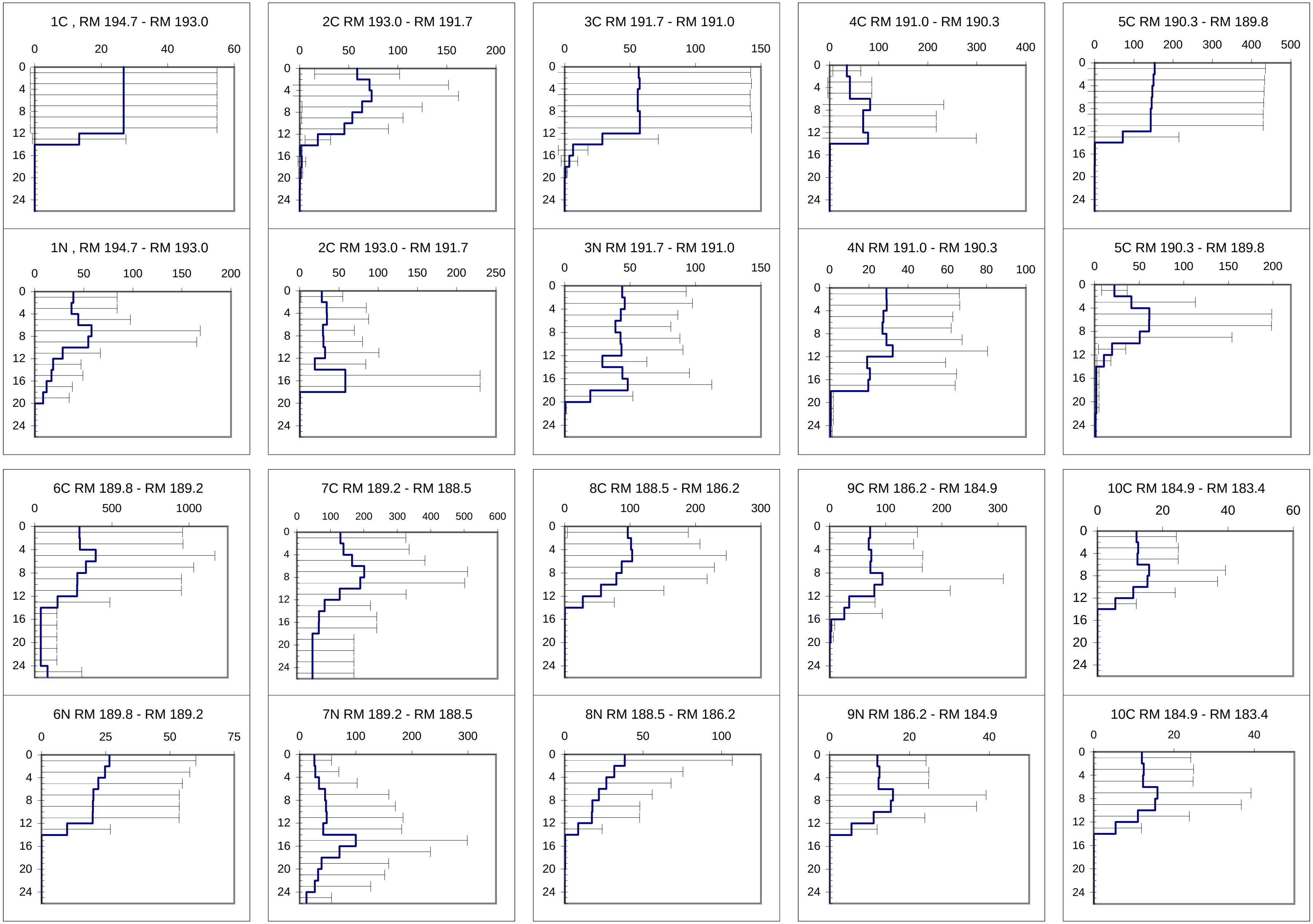


Figure 6-33. 1977 Sediment Tri+ PCB Initial Conditions Computed from the NYSDEC Data, Thompson Island Pool.



Vertical axis is depth in centimeters, horizontal axis is Tri+ concentration in mg PCB/ Kg dry weight. Group descriptions (e.g. 1C, 1N) are described in Table 6-23.
Average concentrations are plotted by layer with +/- 2 standard errors.

Figure 6-34a. 1977 Sediment Tri+ Initial Conditions Computed from 1977 NYSDEC Data: Vertical Profiles.

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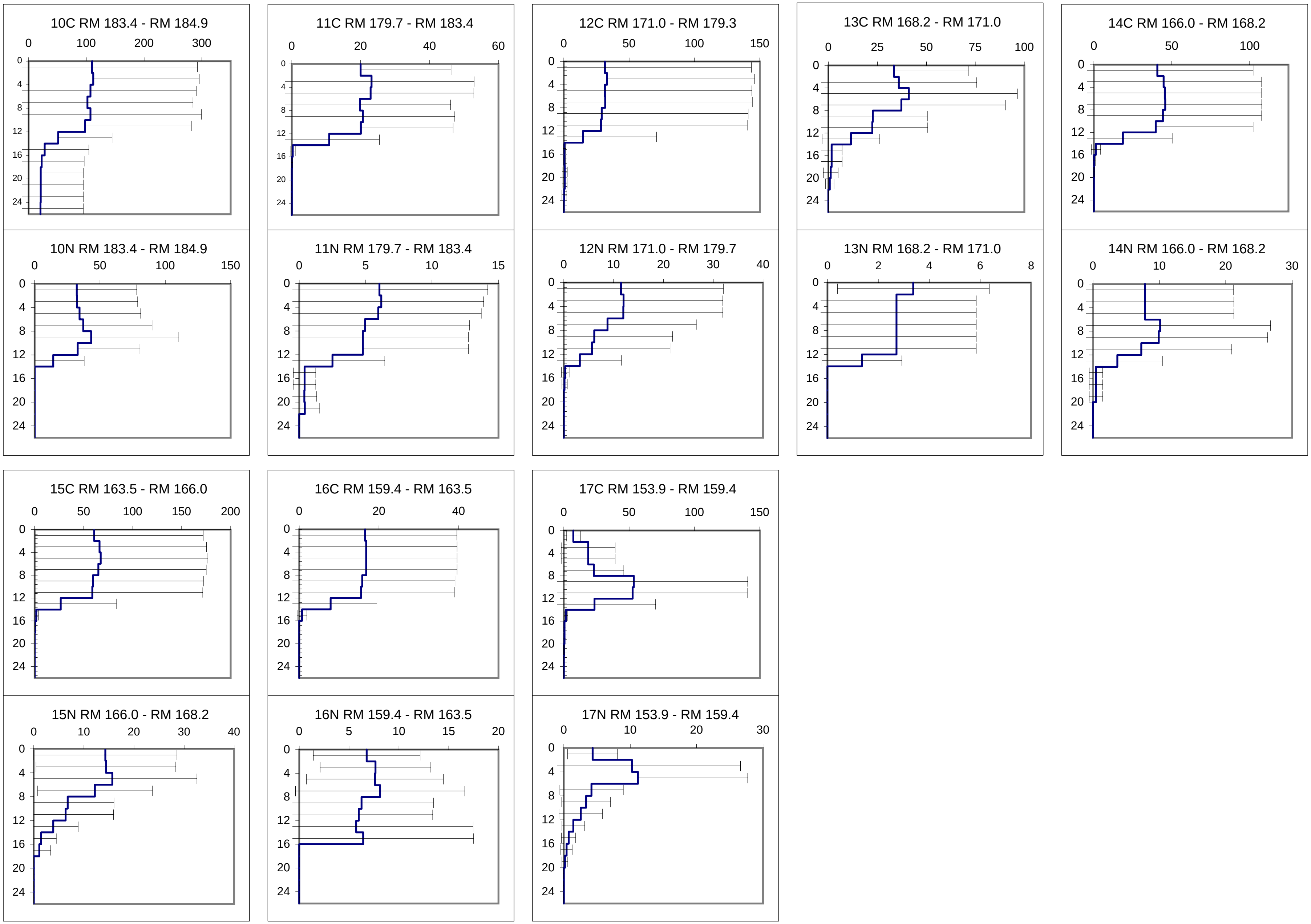


Vertical axis is depth in centimeters, horizontal axis is Tri+ concentration in mg PCB/ Kg dry weight. Group descriptions (e.g. 1C, 1N) are described in Table 6-23.
Average concentrations are plotted by layer with +/- 2 standard errors.

Figure 6-34b. 1977 Sediment Tri+ Initial Conditions Computed from 1977 NYSDEC Data: Vertical Profiles.

Limno-Tech, Inc.

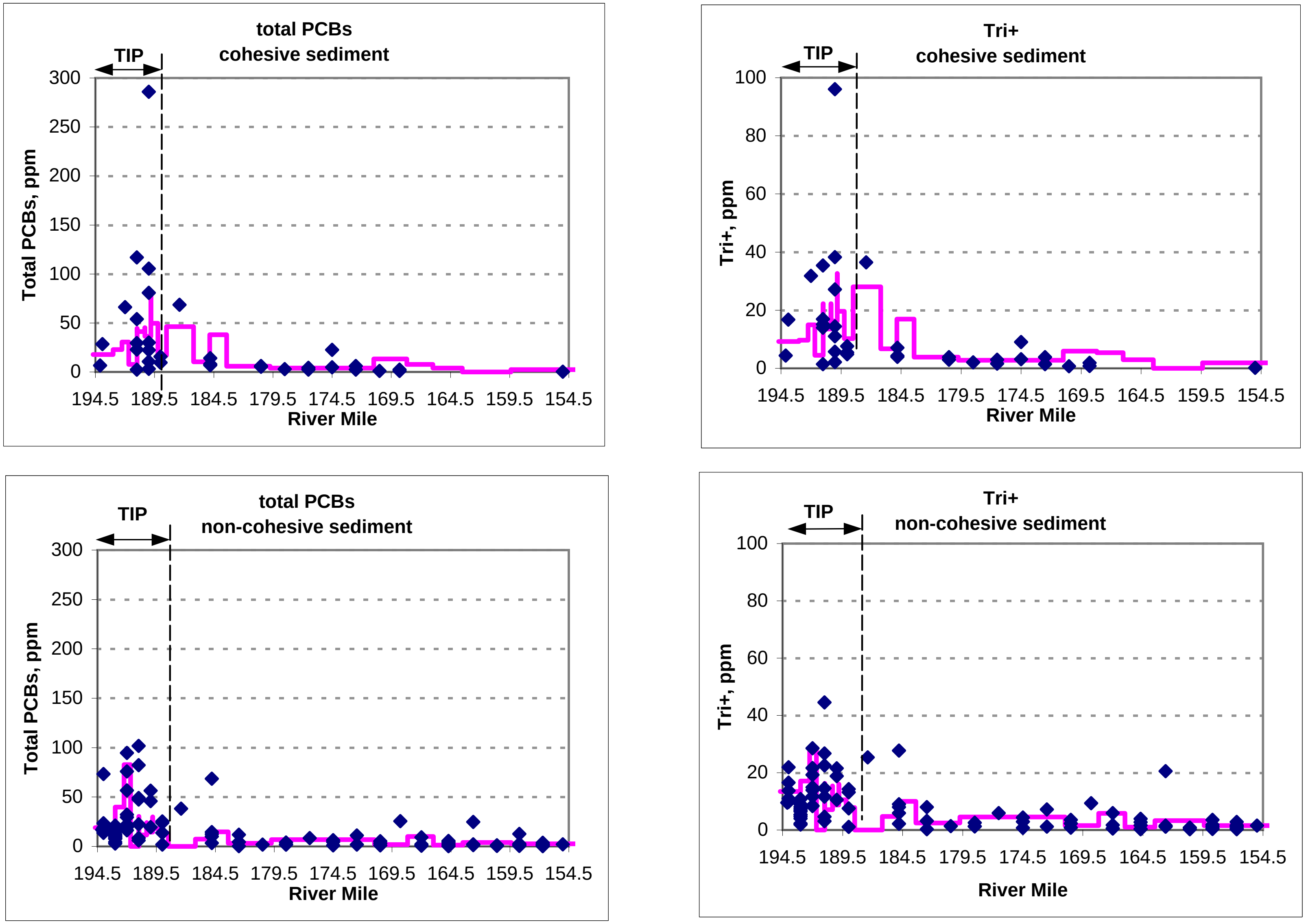


Figure 6-35. Comparison of Measures Total PCB & Tri+ PCB Data to 1991 Model Initial Conditions in the Top Layer (0-5 cm) of Cohesive and Non-cohesive Sediment

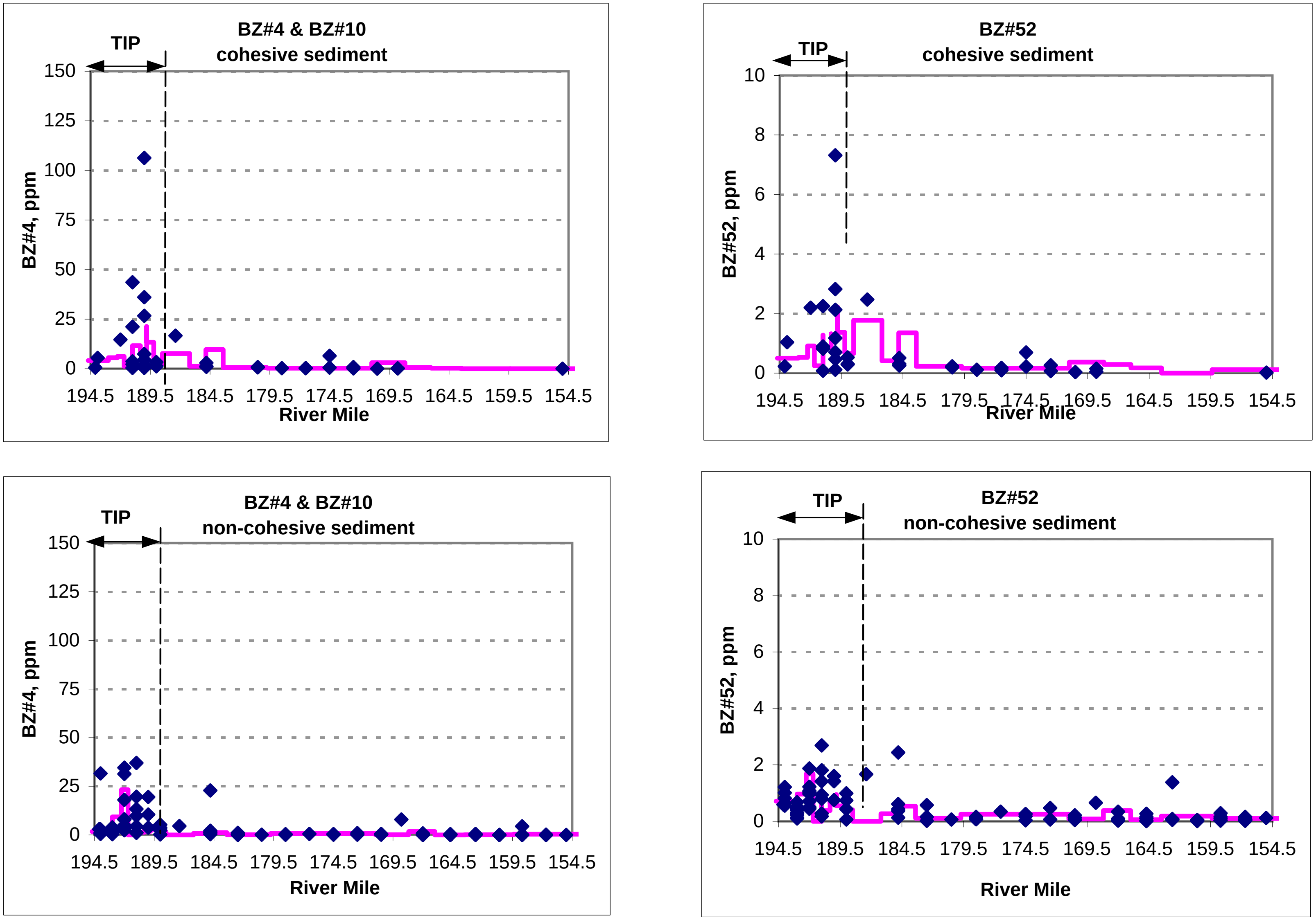


Figure 6-36. Comparison of Measured BZ#4 (& #10) & BZ#52 Data to 1991 Model Initial Conditions in the Top Layer (0 to 5 cm) of Cohesive and Non-cohesive Sediments.

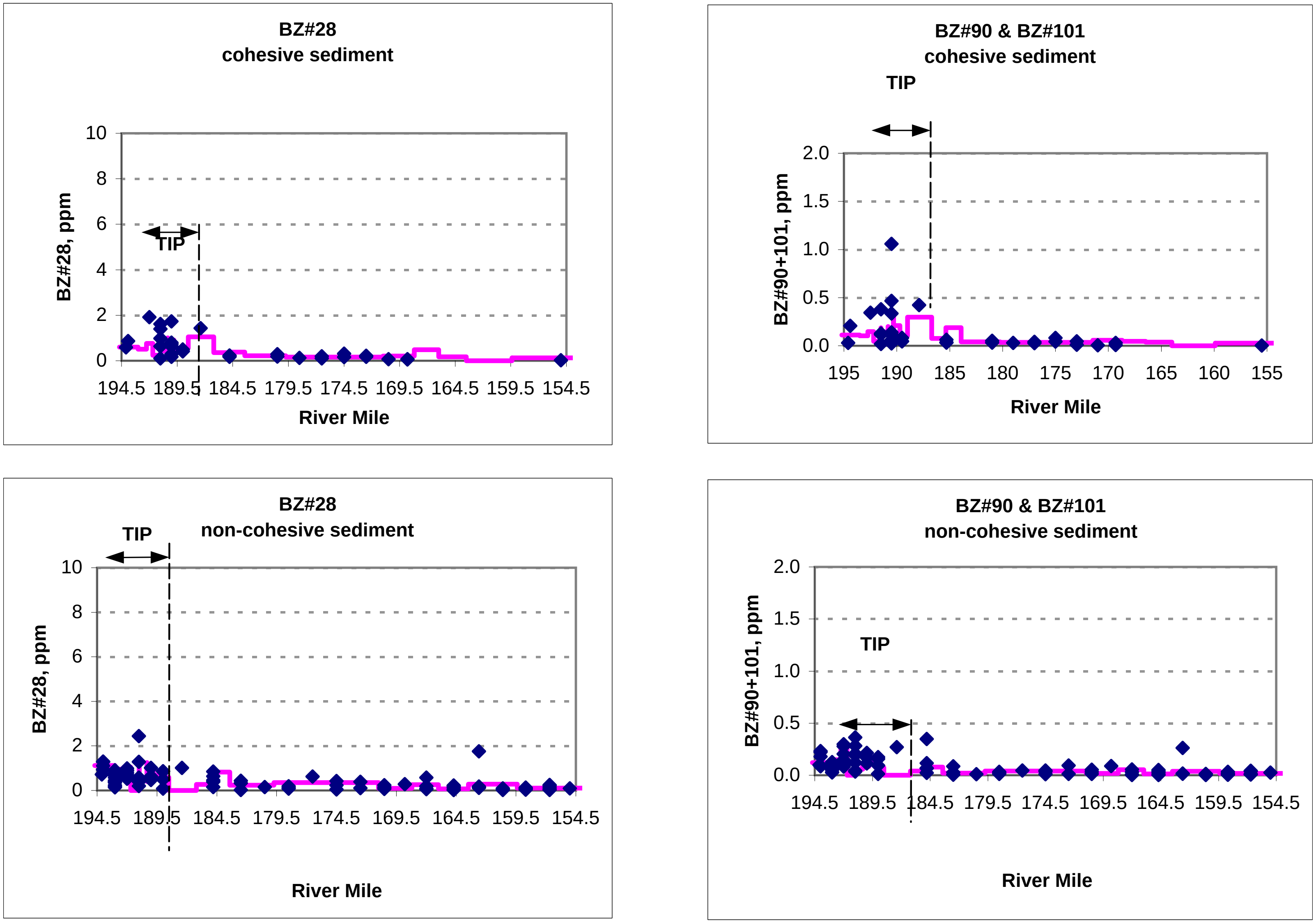
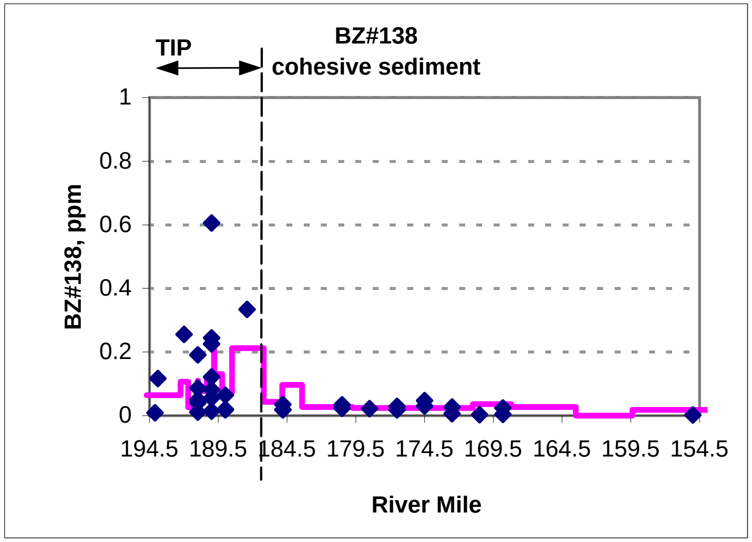


Figure 6-37. Comparison of Measured BZ#28 and BZ#90+101 Data to Model Initial Conditions in the Top Layer (0 to 5 cm) of Cohesive and Non-cohesive Sediments.



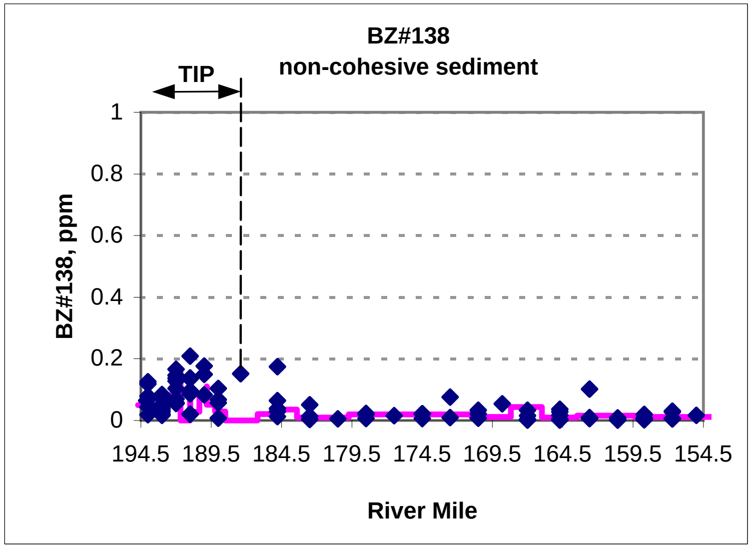


Figure 6-38. Comparison of Measured BZ#138 Data to Model Initial Conditions in the Top Layer (0 to 5 cm) of Cohesive and Non-cohesive Sediments.

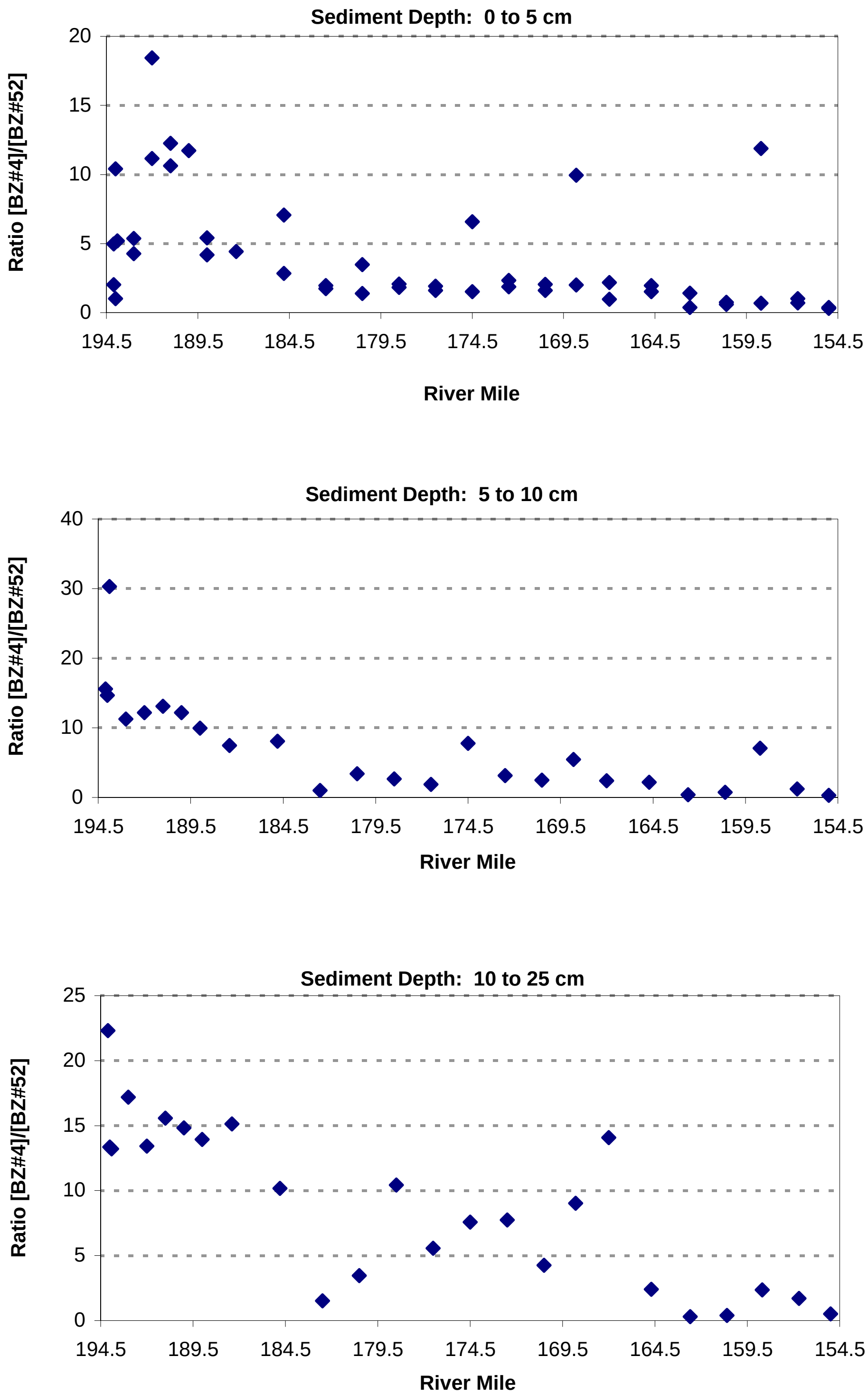


Figure 6-39. Ratio of Average BZ#4 1991 Concentrations to Average BZ#52 1991 Concentrations by Sediment Depth.

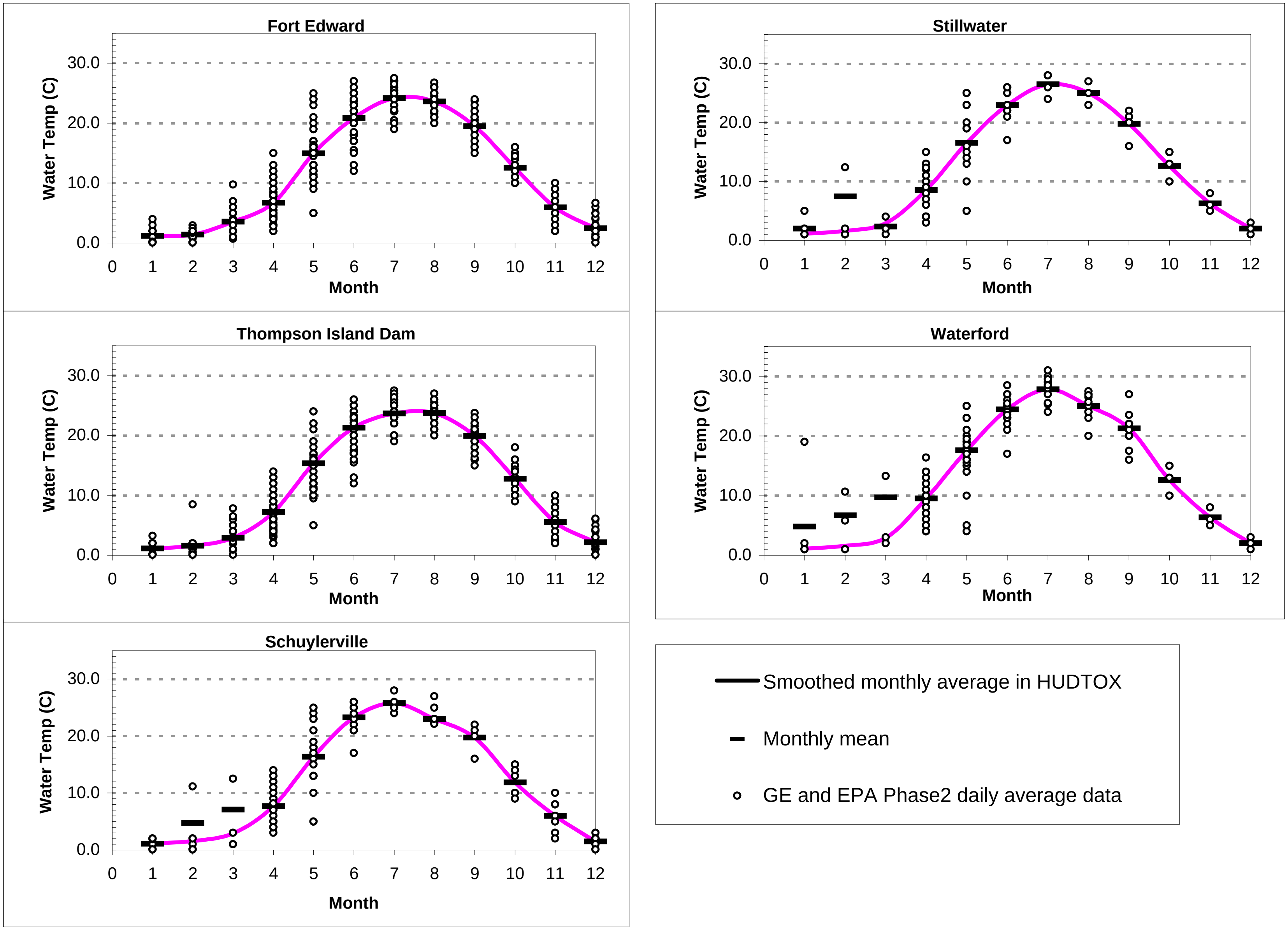


Figure 6-40. Monthly Average Water Temperature Functions Applied in HUDTOX and Observed Water Temperatures.

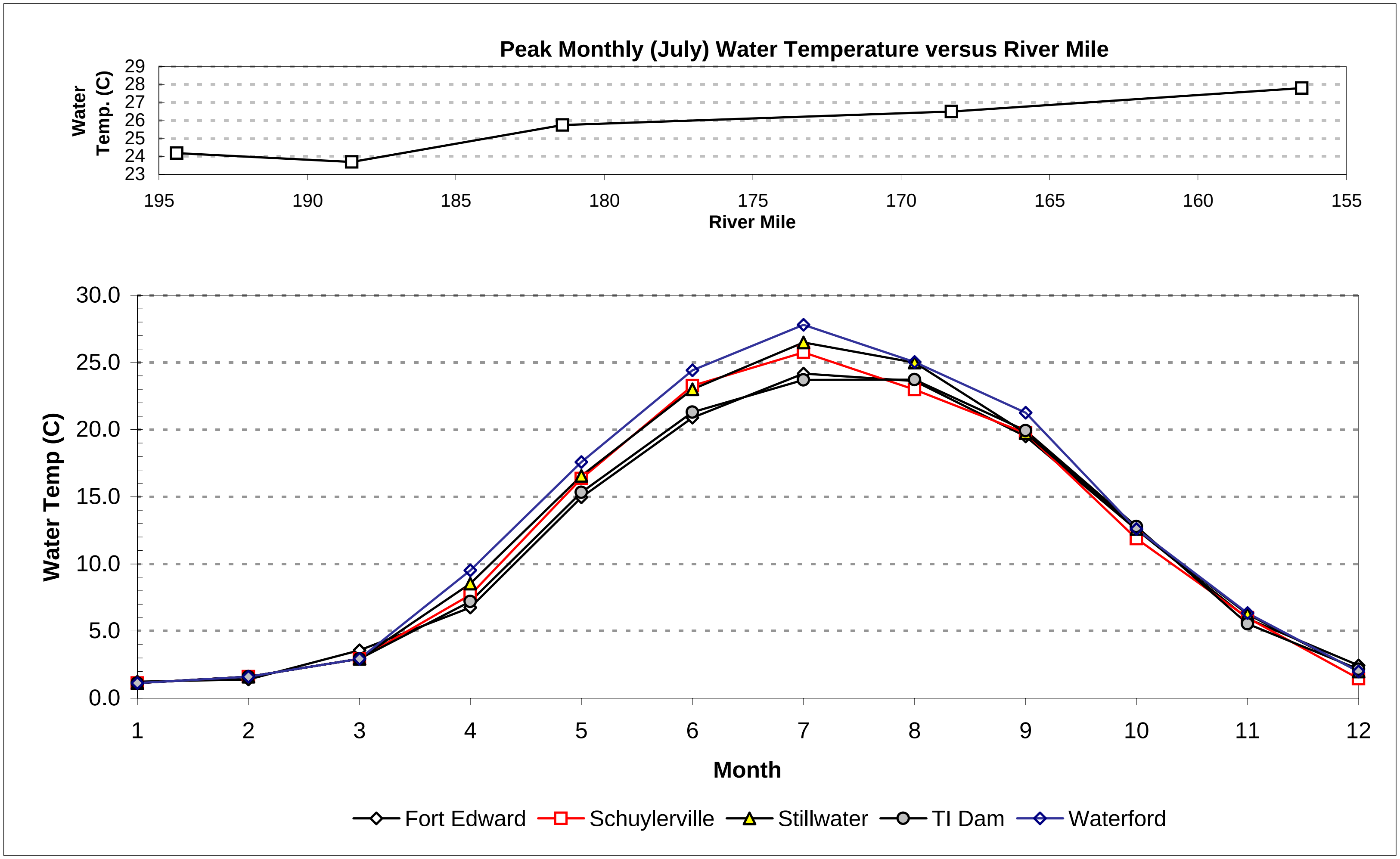
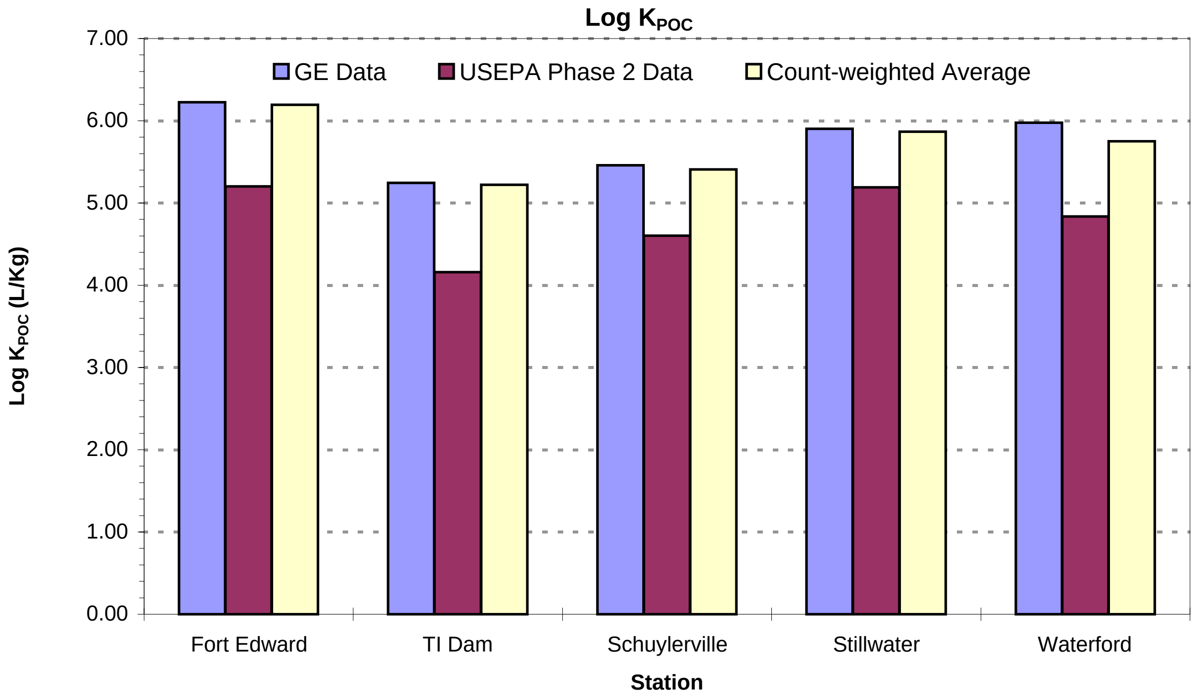


Figure 6-41. Comparison of Monthly Mean Temperatures at Mainstem Upper Hudson River Stations.



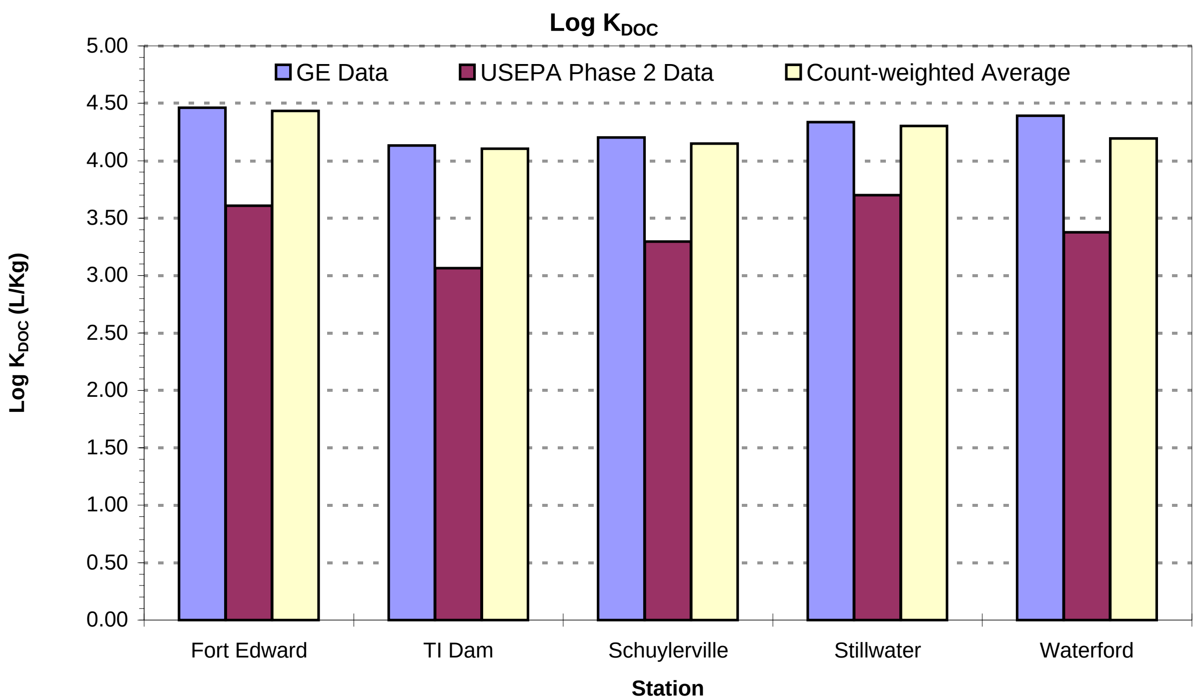


Figure 6-42. Estimated Partition Coefficients for Total PCB by Station and by Source.

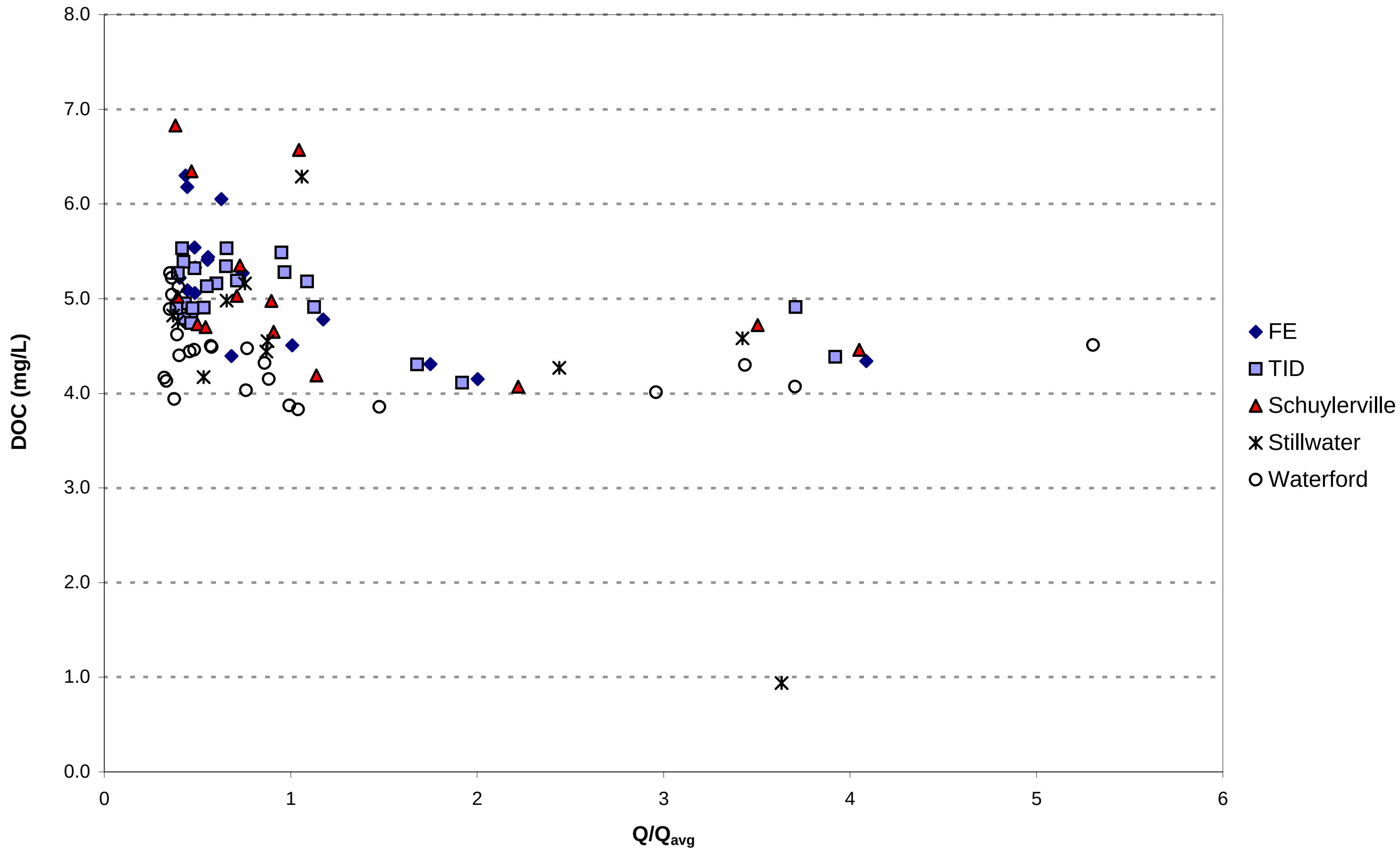


Figure 6-43. Observed Dissolved Organic Carbon (DOC) Concentrations versus Normalized Flow between Fort Edward and Federal Dam.

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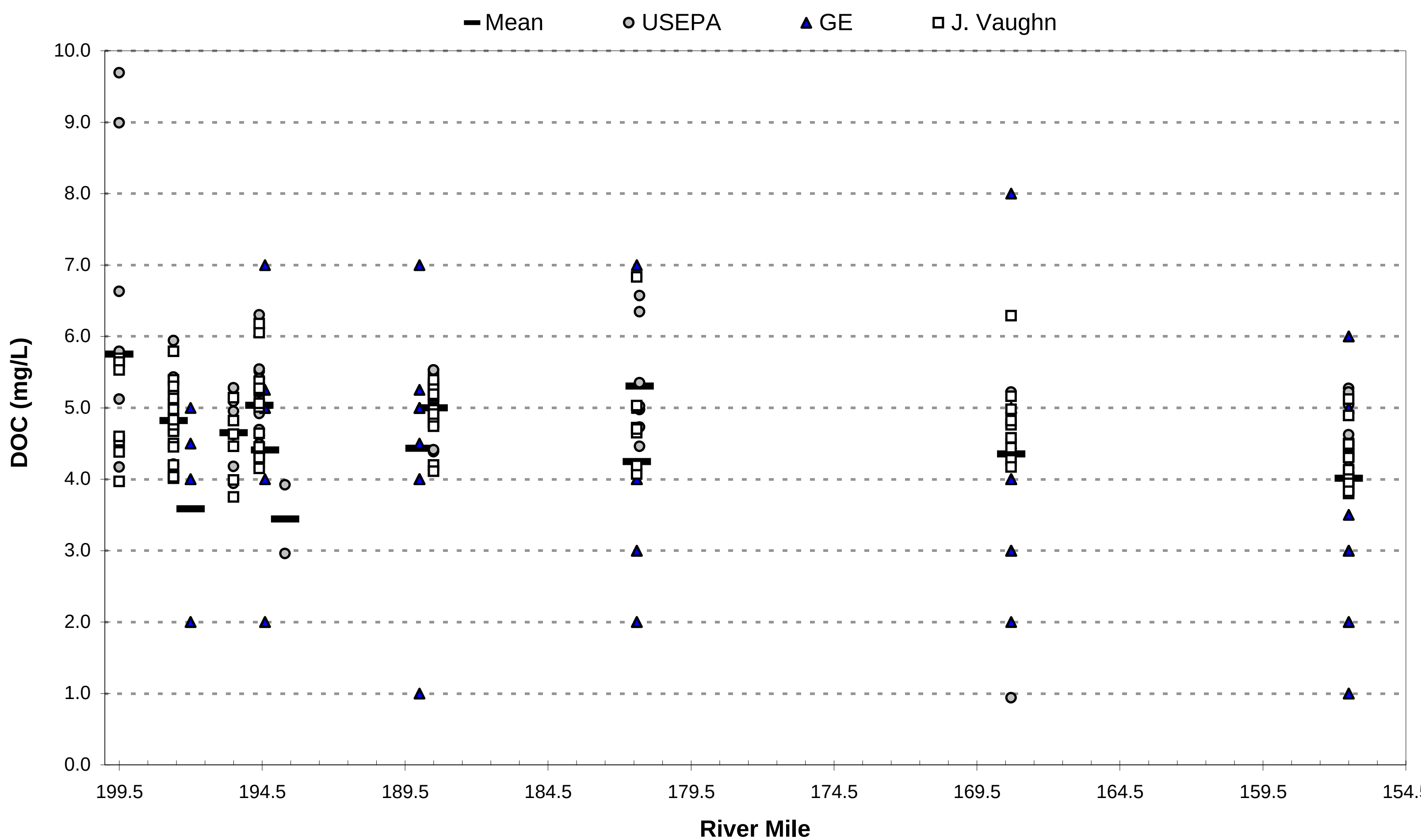


Figure 6-44. Observed Dissolved Organic Carbon (DOC) Data versus River Mile between Fort Edward and Federal Dam.

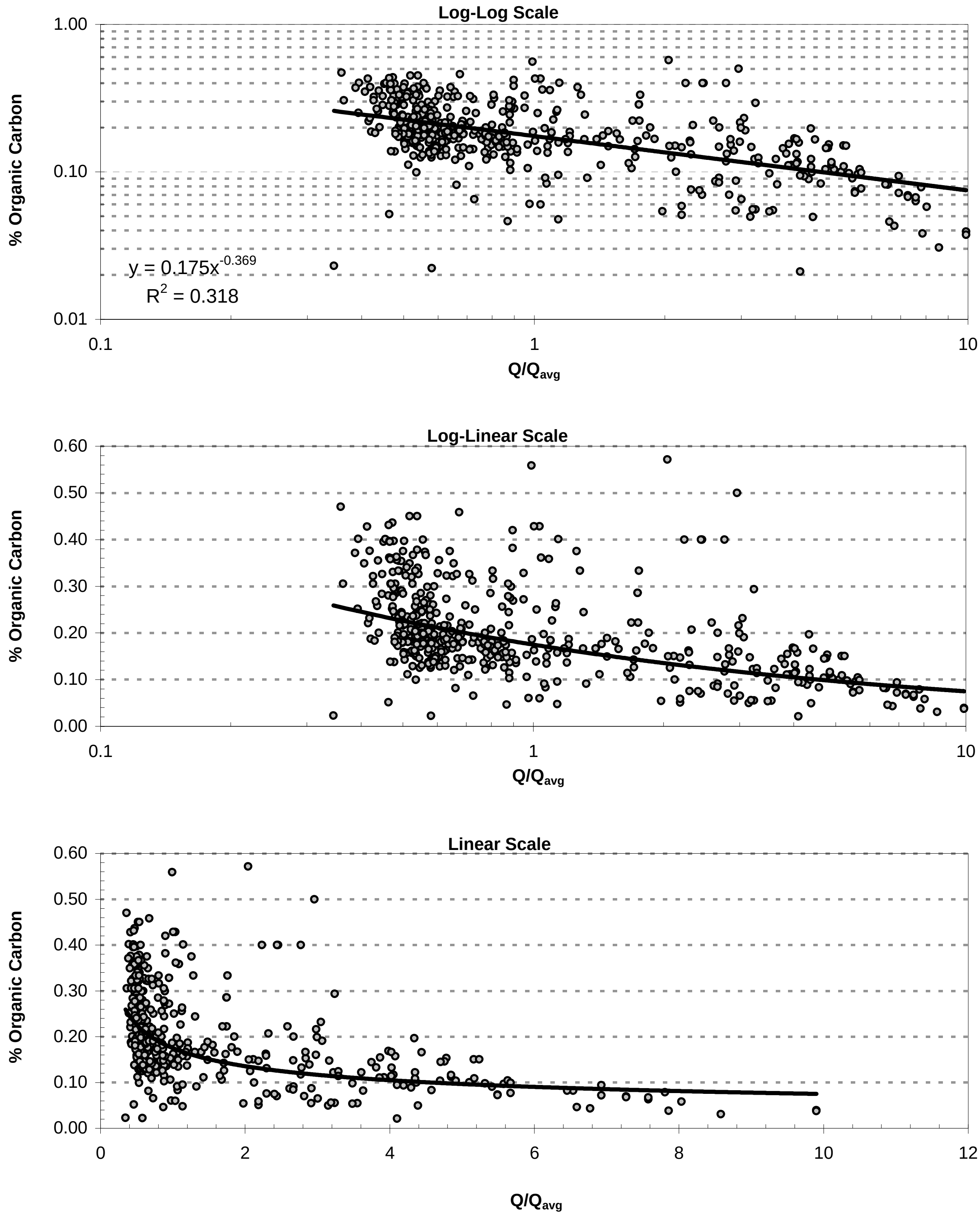


Figure 6-45. River-wide Fraction Organic Carbon (f_{OC}) Function Based on a Power Function Fit to f_{OC} Data for Mainstem Hudson River Stations.

Reach	Average	Max	Min	Stdev	Count
TIP	31.51	81	10	16.70	49
TI Dam to Stillwater	49.38	92	12	23.48	21
Stillwater to Waterford	61.53	117	21	30.56	13
All data	40.73	117	10	23.94	83

Note: 3 apparent outliers were excluded from averages. These values were 178, 212, and 169 mg/L

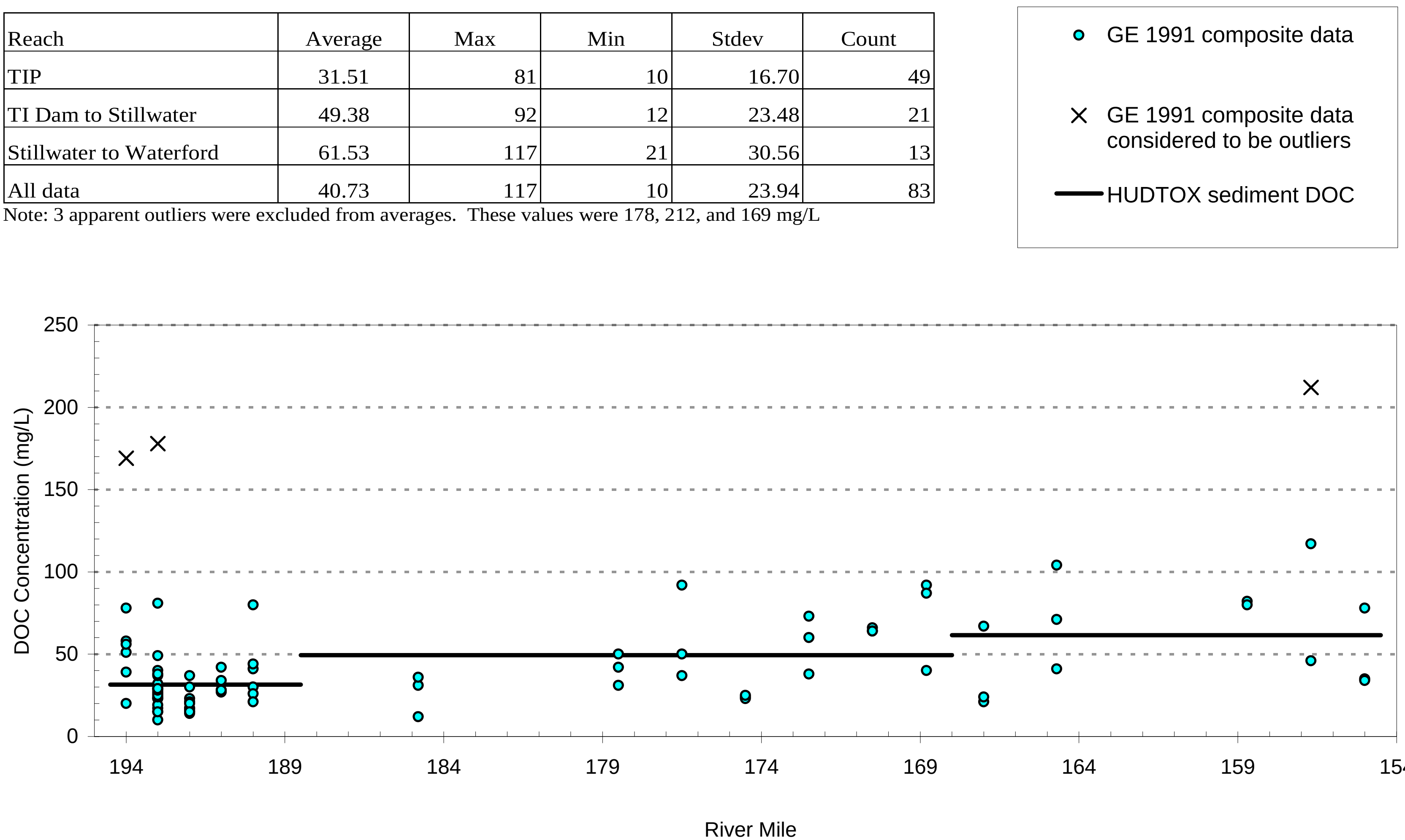


Figure 6-46. Specified Sediment Dissolved Organic Carbon (DOC) Concentrations in HUDTOX.

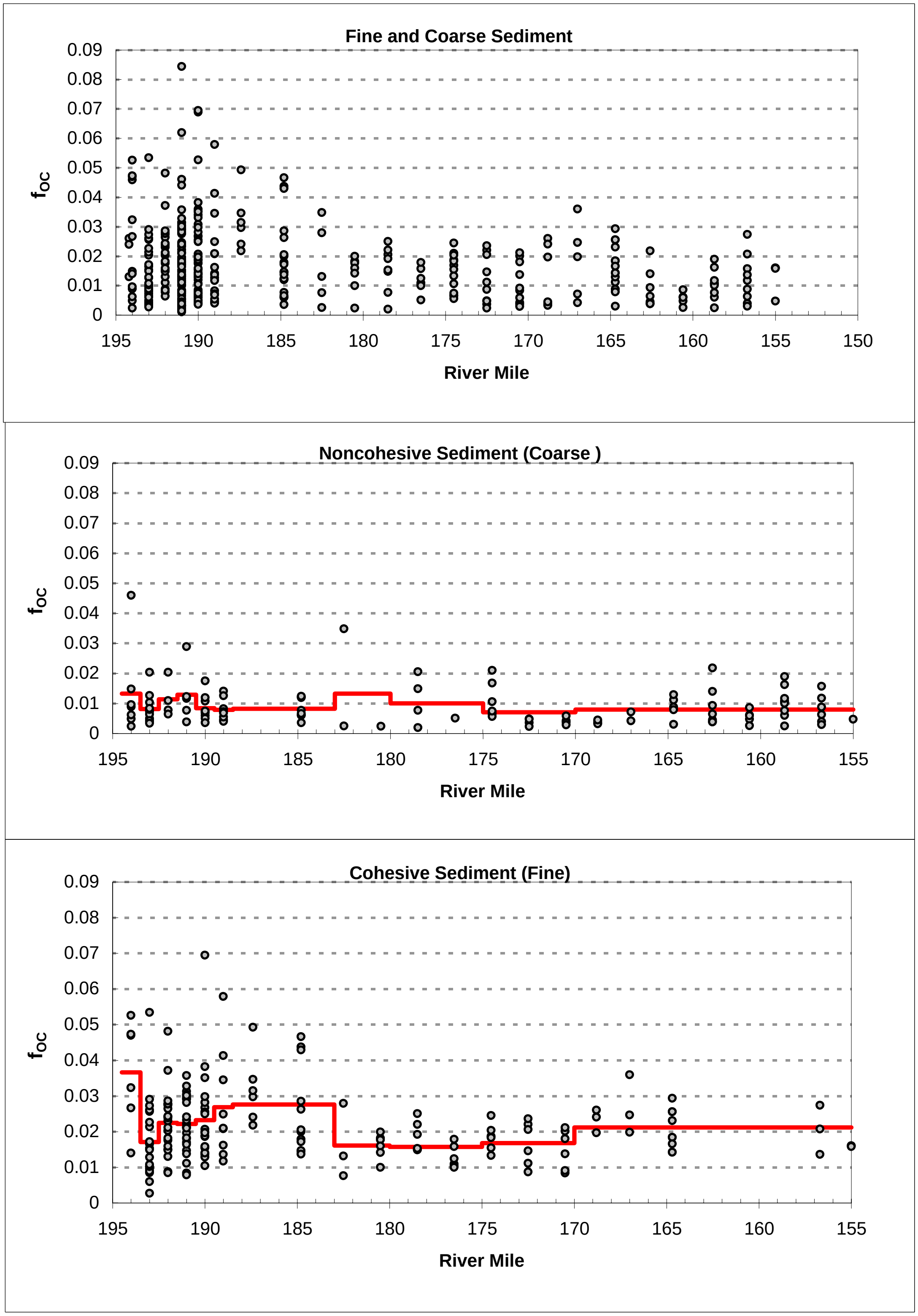


Figure 6-47. f_{OC} versus River Mile from the 1991 GE Composite Sampling and Values Specified for Cohesive and Non-cohesive Sediment in HUDTOX.

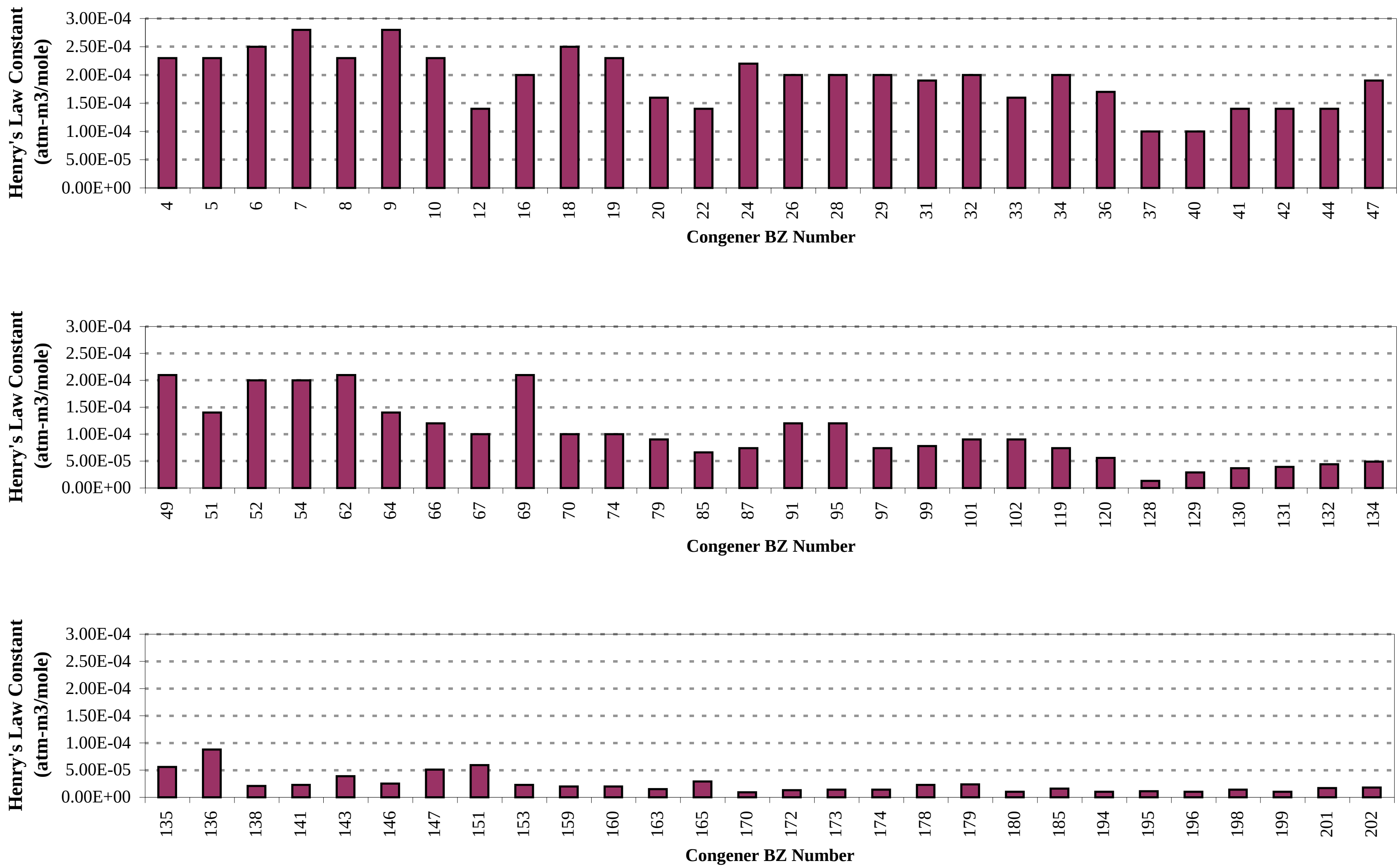
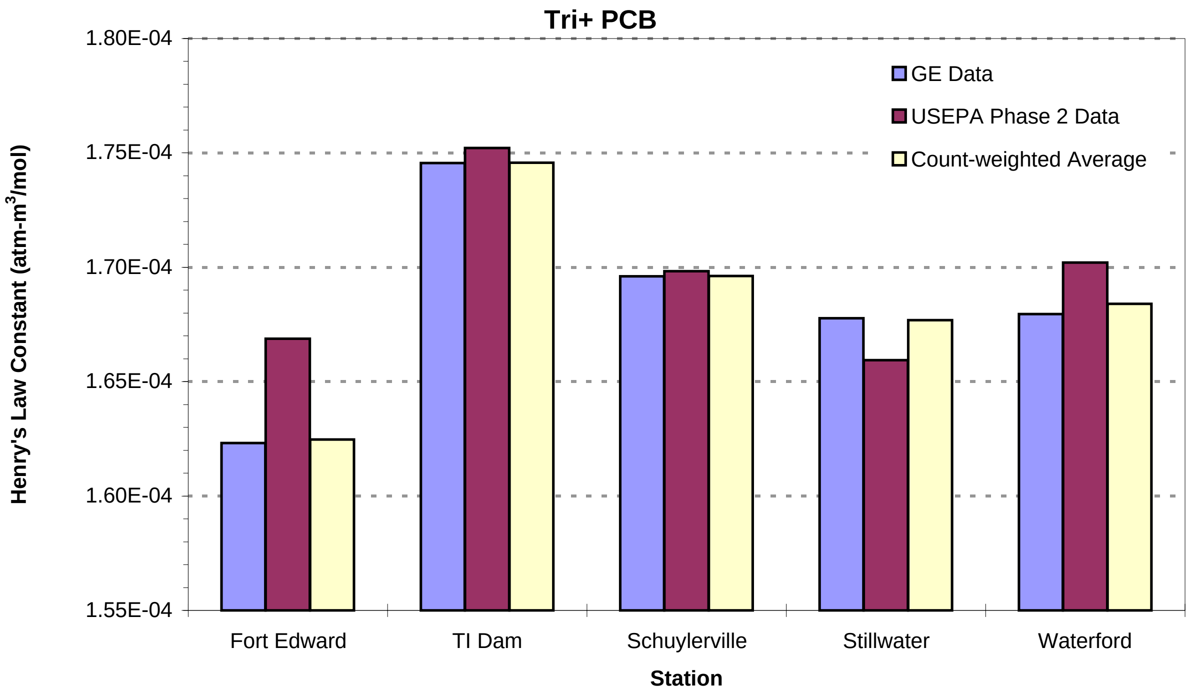


Figure 6-48. Estimated Henry's Law Constant for Selected Congeners Determined Experimentally by Brunner, et. al (1990).



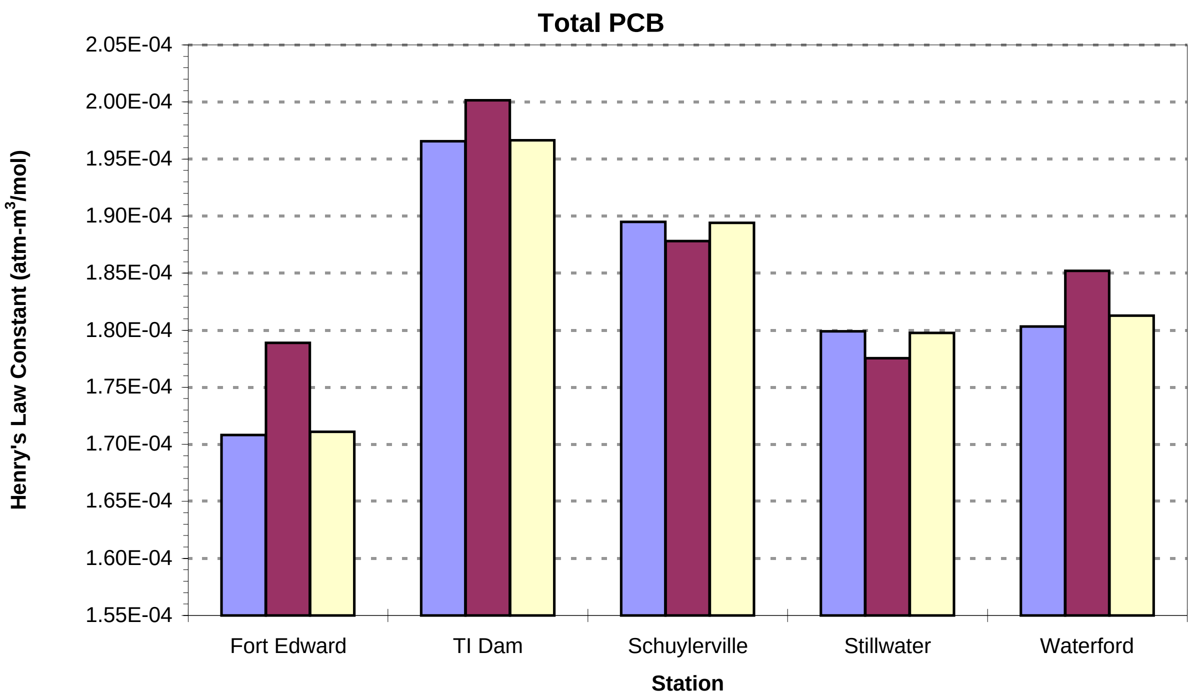


Figure 6-49. Estimated Henry's Law Constants for Tri+ and Total PCB by Station and Data Source.

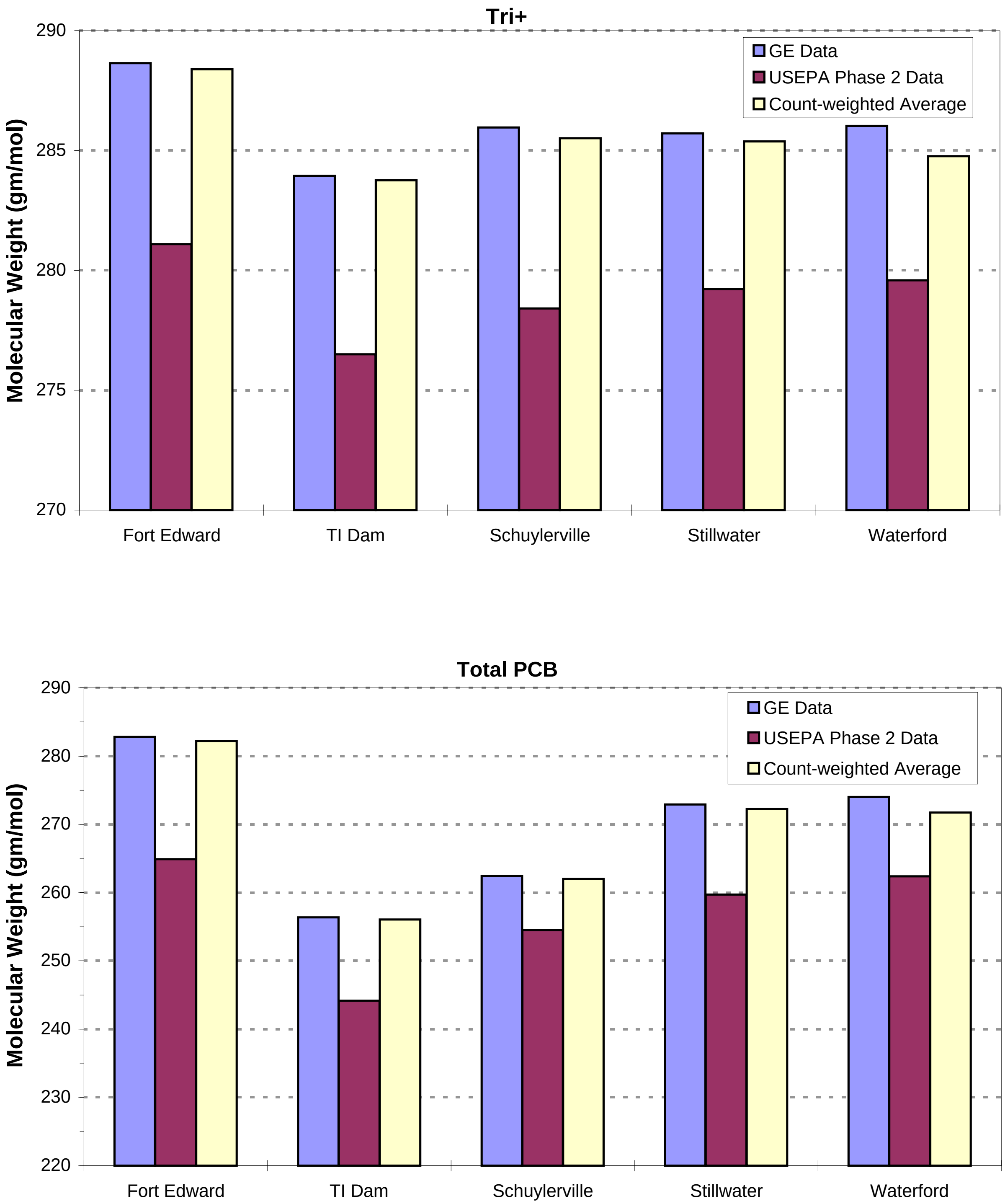
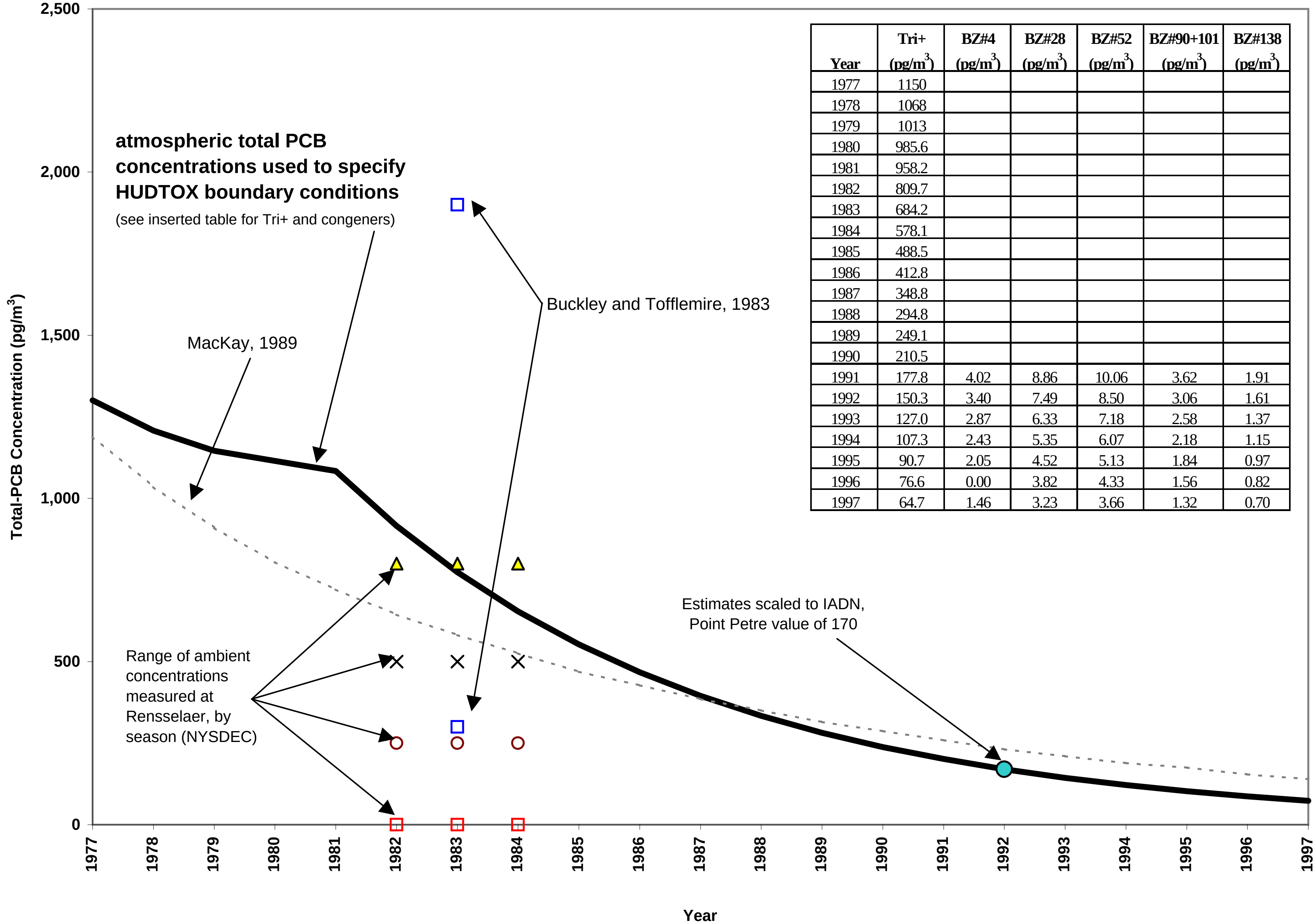
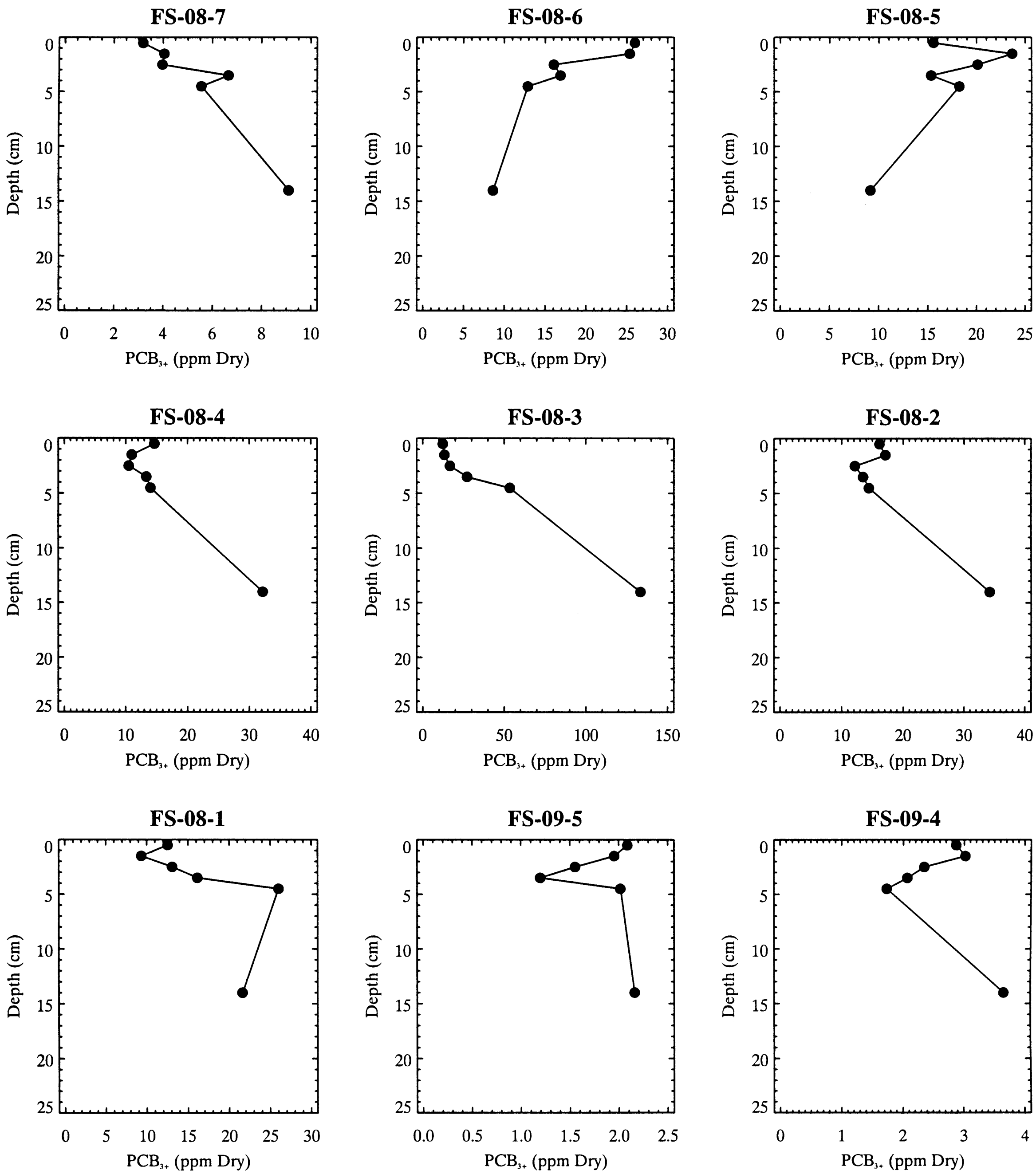


Figure 6-50. Estimated Molecular Weight for Tri+ and Total PCB by Station and Data Source.



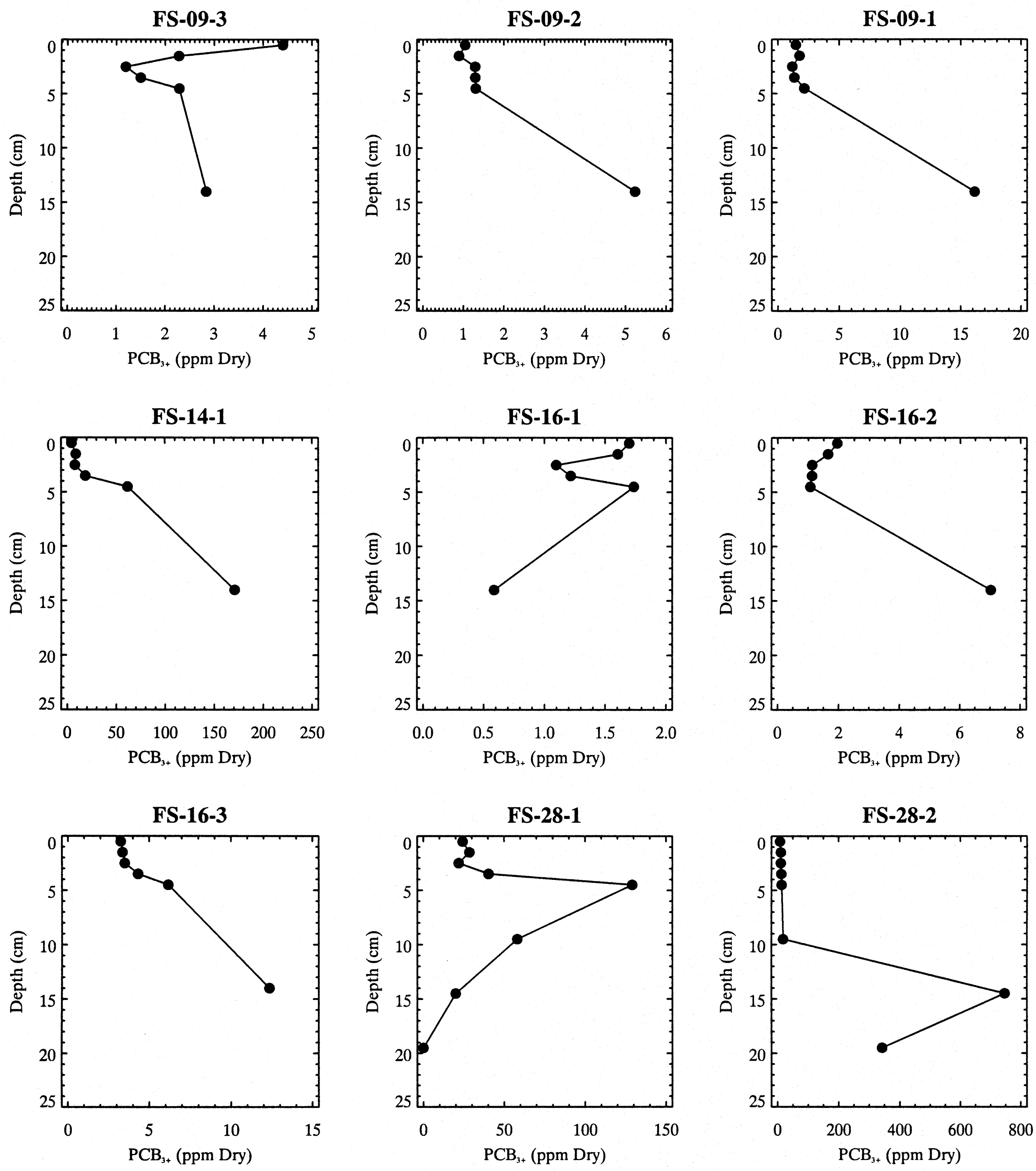
Year	Tri+ (pg/m³)	BZ#4 (pg/m³)	BZ#28 (pg/m³)	BZ#52 (pg/m³)	BZ#90+101 (pg/m³)	BZ#138 (pg/m³)
1977	1150					
1978	1068					
1979	1013					
1980	985.6					
1981	958.2					
1982	809.7					
1983	684.2					
1984	578.1					
1985	488.5					
1986	412.8					
1987	348.8					
1988	294.8					
1989	249.1					
1990	210.5					
1991	177.8	4.02	8.86	10.06	3.62	1.91
1992	150.3	3.40	7.49	8.50	3.06	1.61
1993	127.0	2.87	6.33	7.18	2.58	1.37
1994	107.3	2.43	5.35	6.07	2.18	1.15
1995	90.7	2.05	4.52	5.13	1.84	0.97
1996	76.6	0.00	3.82	4.33	1.56	0.82
1997	64.7	1.46	3.23	3.66	1.32	0.70

Figure 6-51. Specification of Historical Atmospheric Gas-Phase PCB Boundary Concentrations for the 1977-1997 HUDTOX Calibration Period.



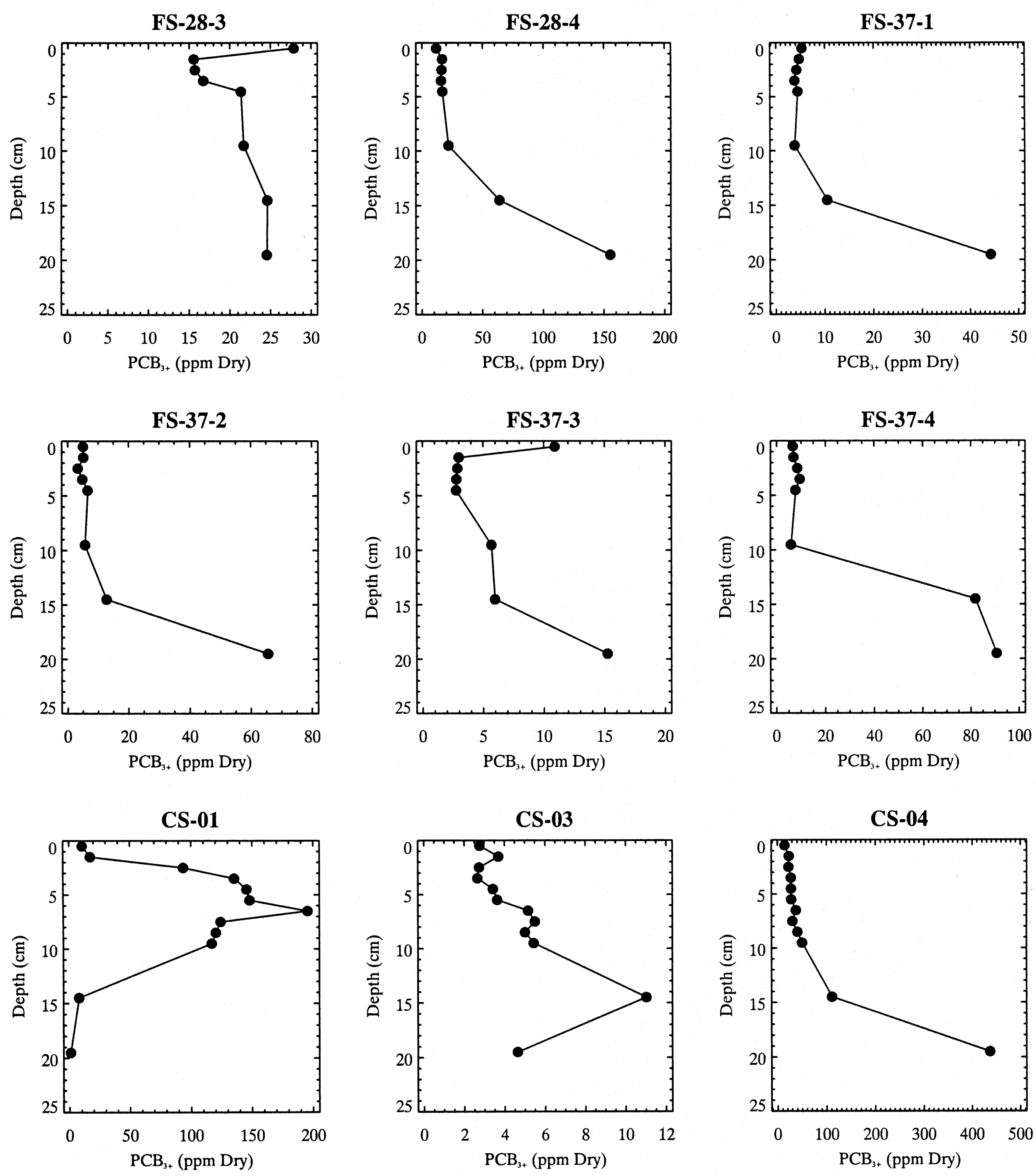
Note: Core sections shown are the top 23 cm of each core, plotted at segment midpoint.

Figure 6-52a. Vertical Profiles of PCB_{3+} within Finely Segmented Sediment Cores Collected from the Upper Hudson River (from QEA, 1999).



Note: Core sections shown are the top 23 cm of each core, plotted at segment midpoint.

Figure 6-52b. Vertical Profiles of PCB_{3+} within Finely Segmented Sediment Cores Collected from the Upper Hudson River (from QEA, 1999).



Note: Core sections shown are the top 23 cm of each core, plotted at segment midpoint.

Figure 6-52c. Vertical Profiles of PCB_{3+} within Finely Segmented Sediment Cores Collected from the Upper Hudson River (from QEA, 1999).

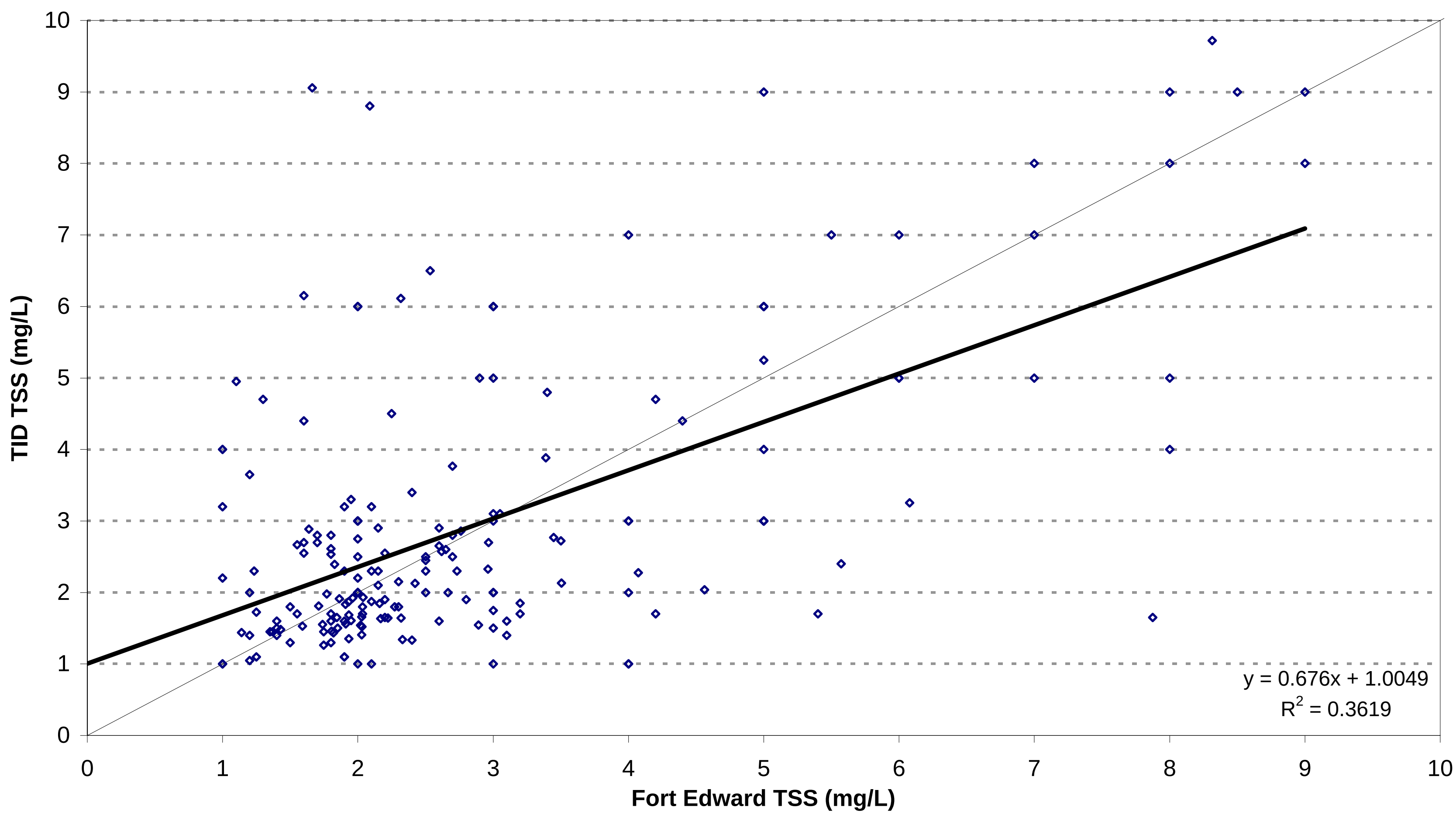


Figure 6-53. Comparison of Same-Day Suspended Solids (TSS) Concentration Data at Fort Edward and Thompson Island Dam when TSS Concentration Is Less Than 10 mg/L and Fort Edward Flow Is Less Than 10,000 cfs (1993-1997).

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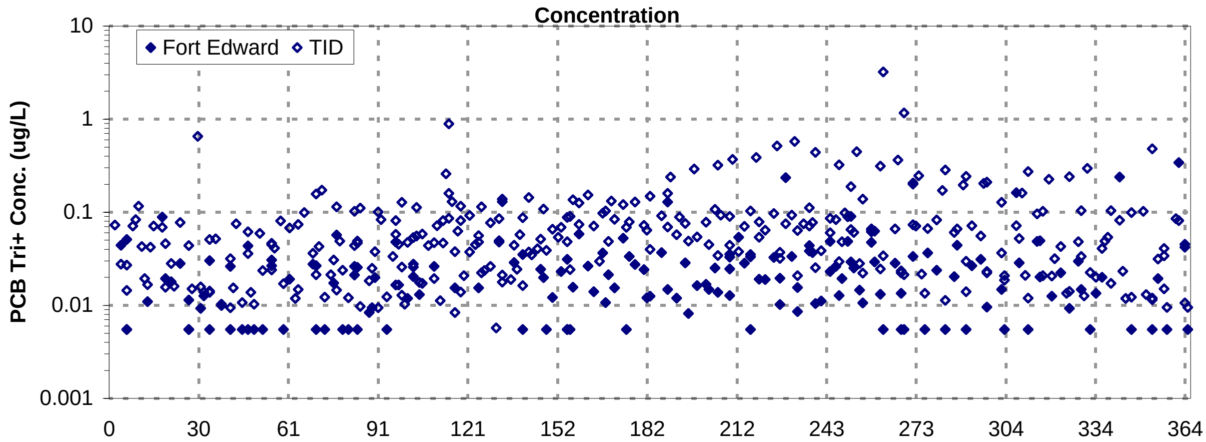
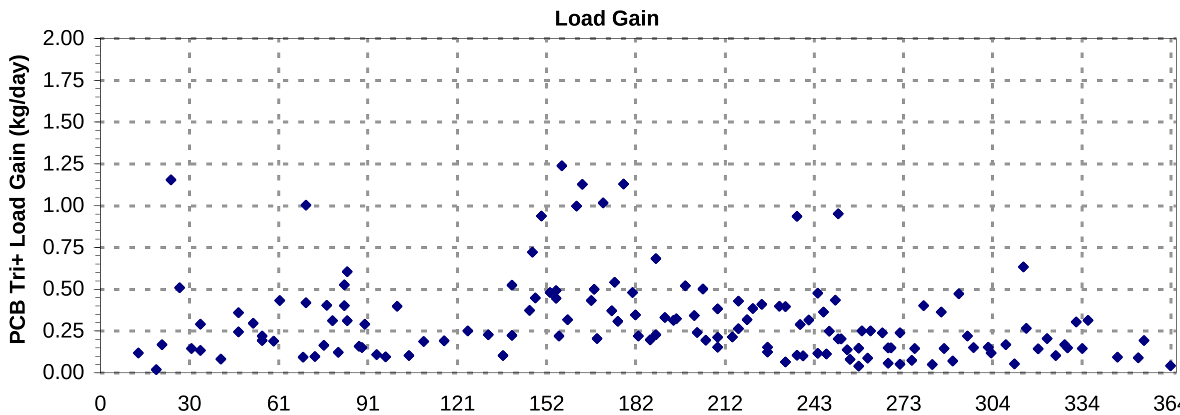
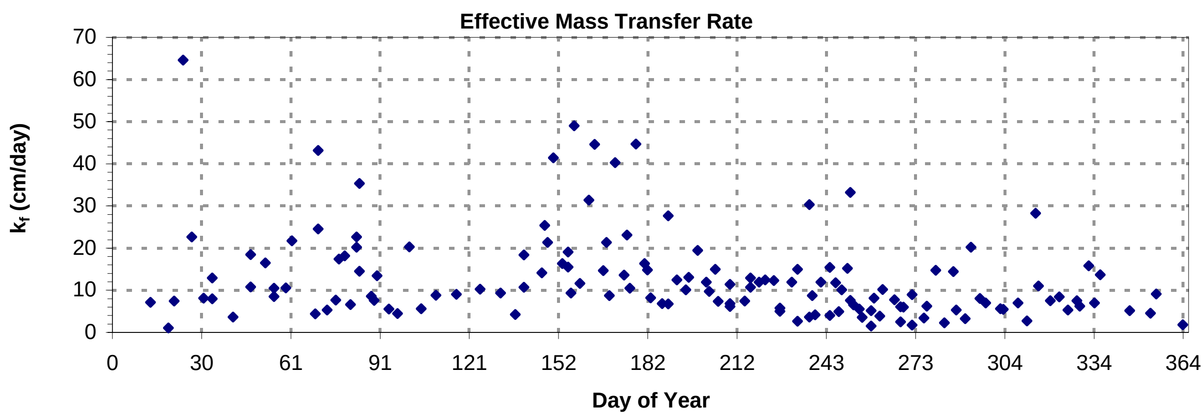


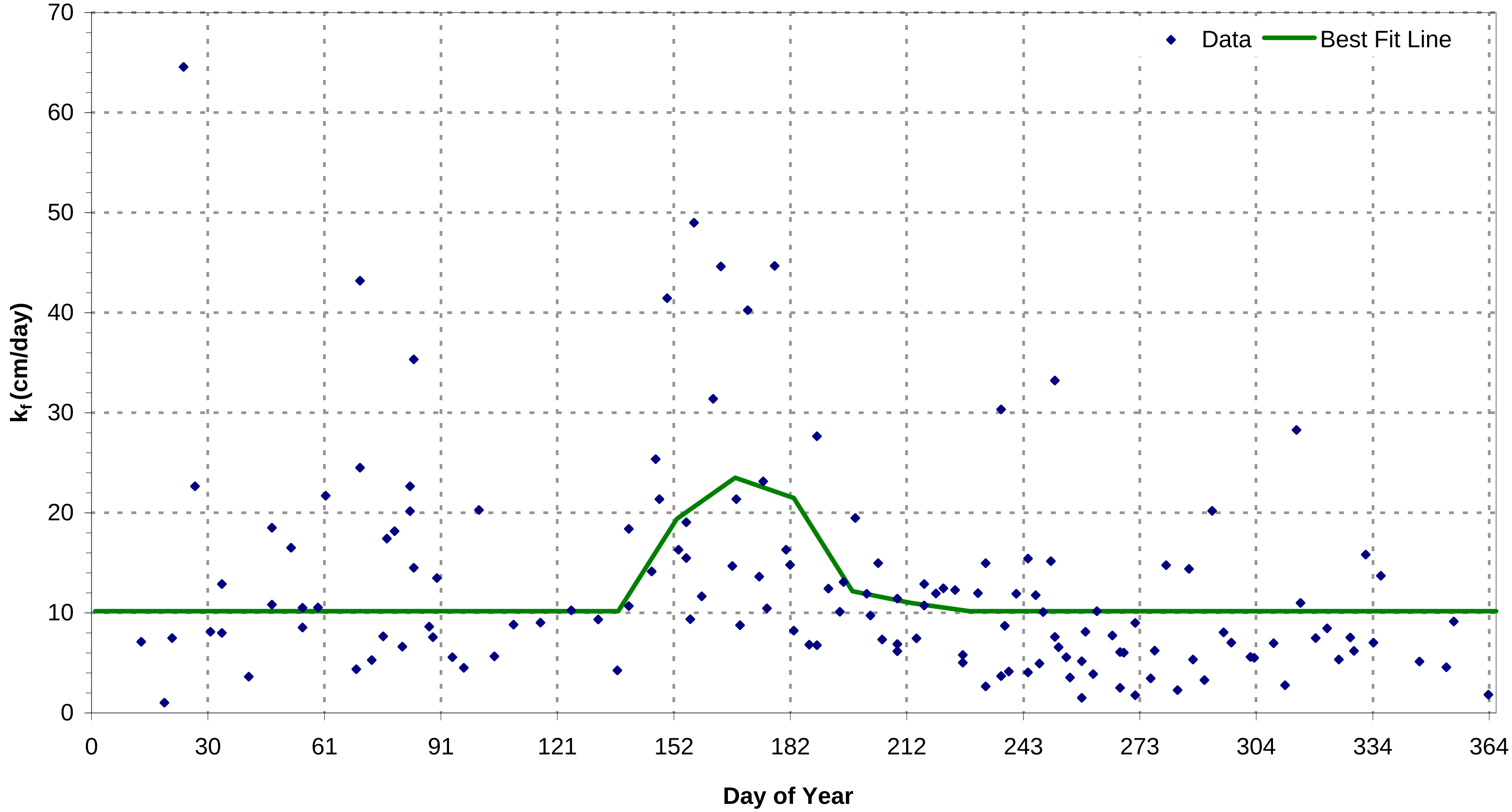


Note: Days when FE Q > 10,000 cfs or TSS at FE or TID > 10 mg/L were not used. 1991 and 1992 data were not used. Load gains < 0 were not included.



Note: Days when FE Q > 10,000 cfs or TSS at FE or TID > 10 mg/L were not used. 1991 and 1992 data were not used. Values of kf < 0 were not used.

Figure 6-54. Temporal Patterns in Water Column Tri+ PCB Concentration at Fort Edward and Thompson Island Dam, Tri+ PCB Loading Increase Across Thompson Island Pool, and Calculated Effective Sediment-Water Mass Transfer Rates Across Thompson Island Pool.



Note: Days when FE Q > 10,000 cfs or TSS at FE or TID > 10 mg/L were not used. 1991 and 1992 data were not used. Values of kf < 0 were not used.

Figure 6-55. Computed Effective Mass Transfer Rate for Tri+ PCBs in Thompson Island Pool, 1993-1997.

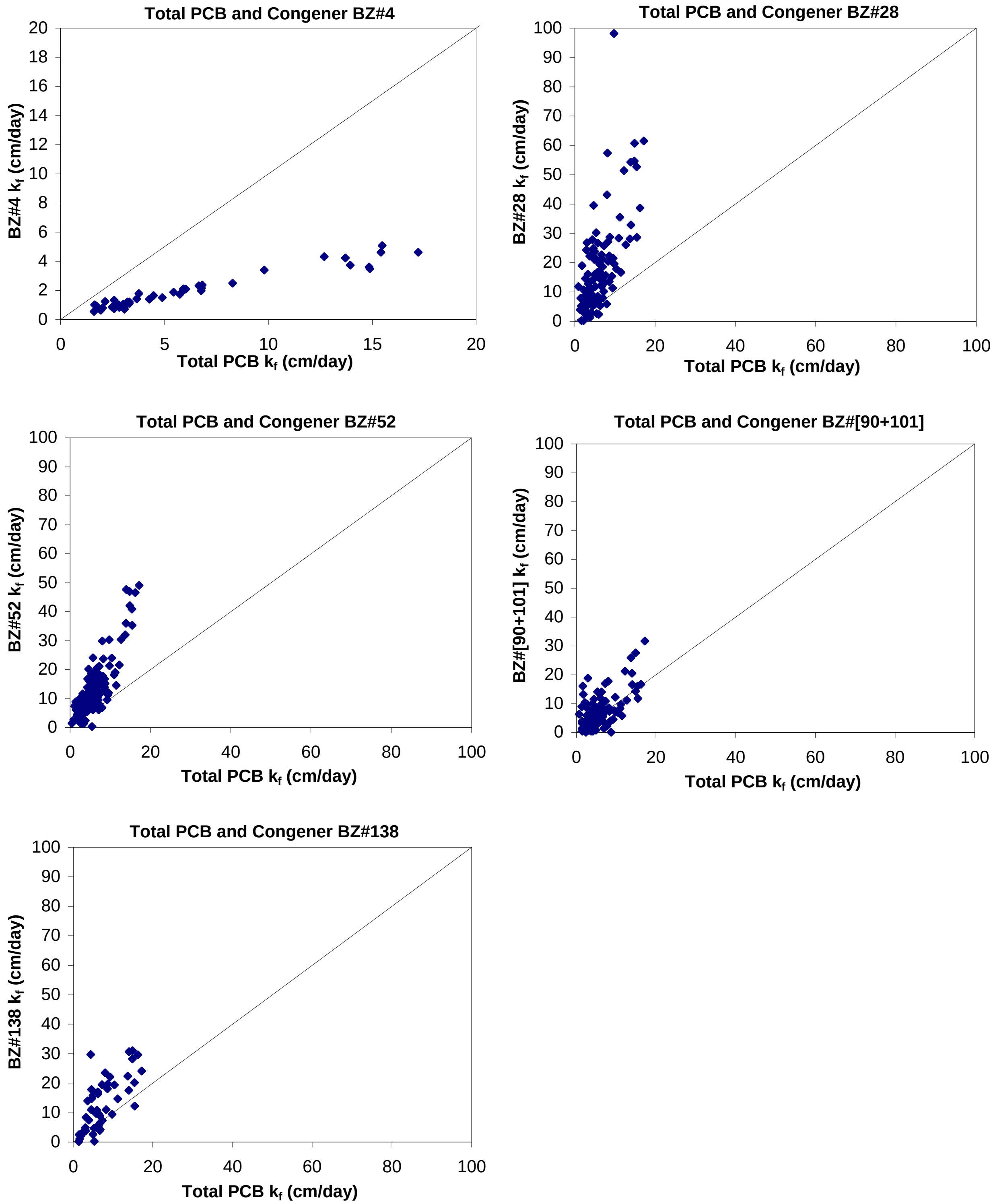
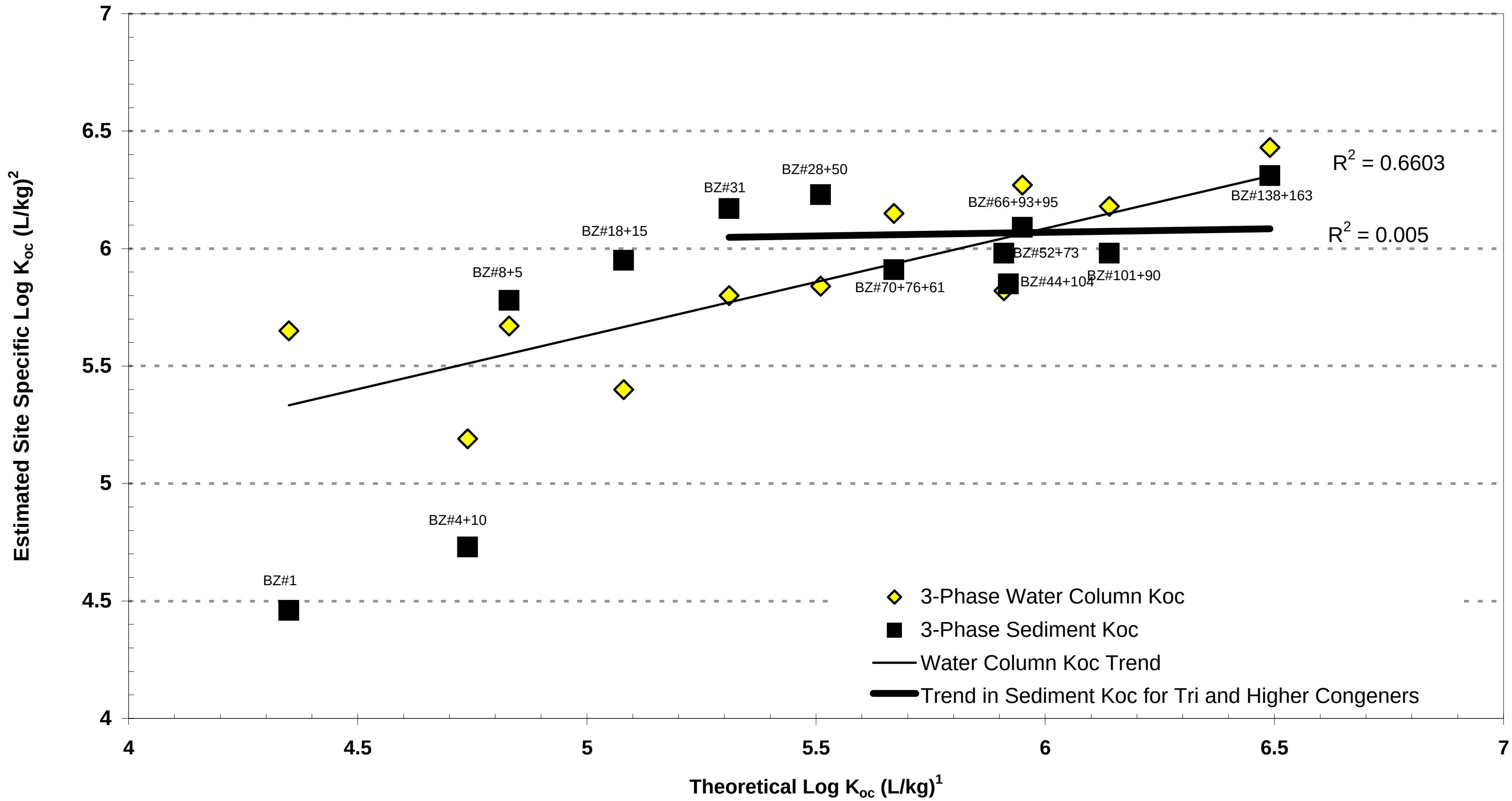


Figure 6-56. Scatter Plots of Estimated Sediment-Water Mass Transfer Rate: Congeners versus Total PCB.



[1] Source: DEIR Table 3-9 (from Burkhard (1984) as cited in Mackay et al. (1992)) (TAMS, 1997)

[2] Source: DEIR Table 3-8, 3-10a (TAMS, 1997), Memorandum from J. B. Butcher, "Sediment Partition Coefficients and GE Data Revision", 5/18/98.

Figure 6-57. Comparison of Estimated Site-Specific Water Column and Sediment Koc Values for Congeners as Determined in the DEIR.

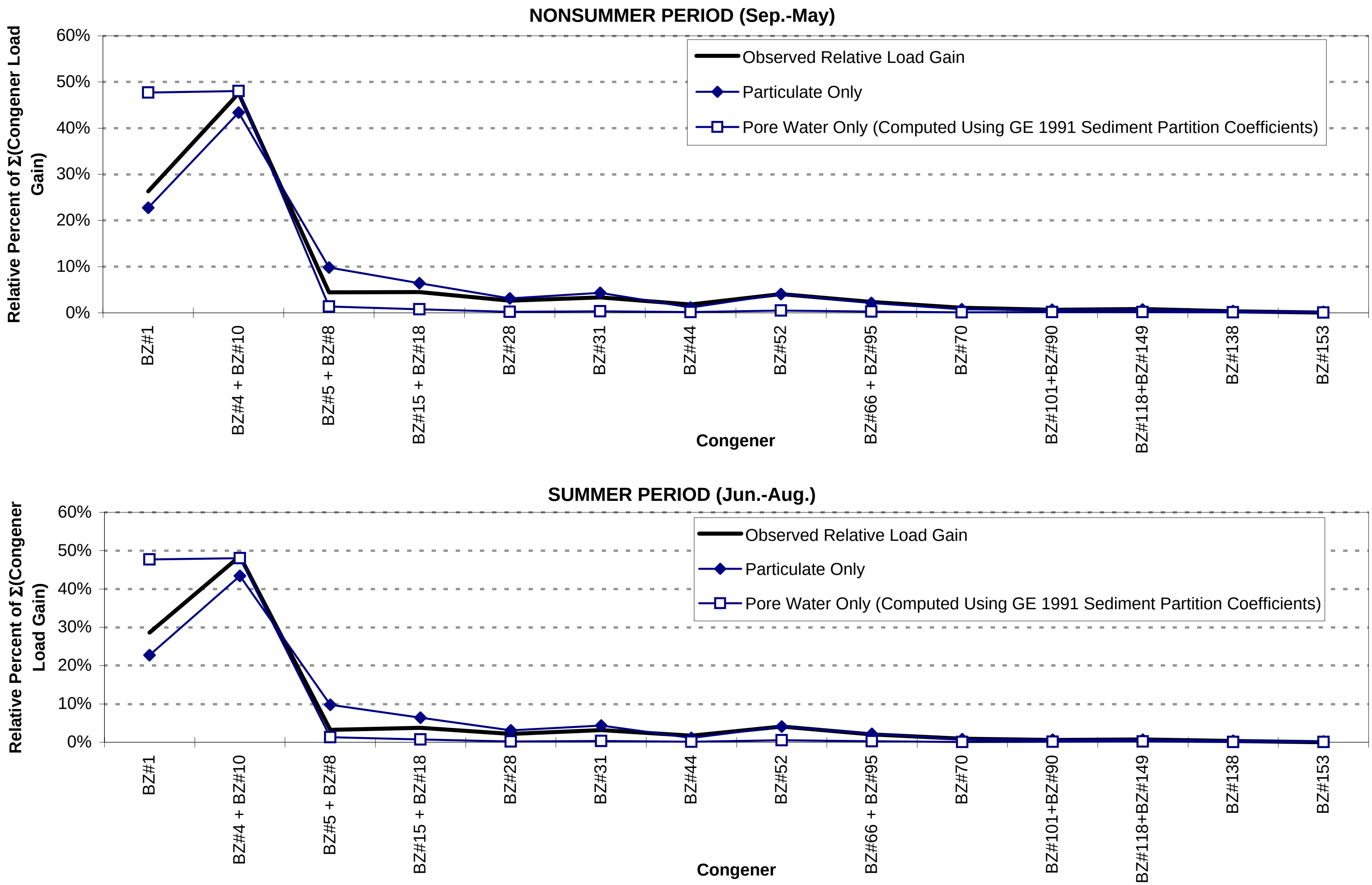


Figure 6-58. Average Observed versus Porewater and Particulate Predicted Relative Load Gain at Thompson Island Dam by Season, 1991-1997.

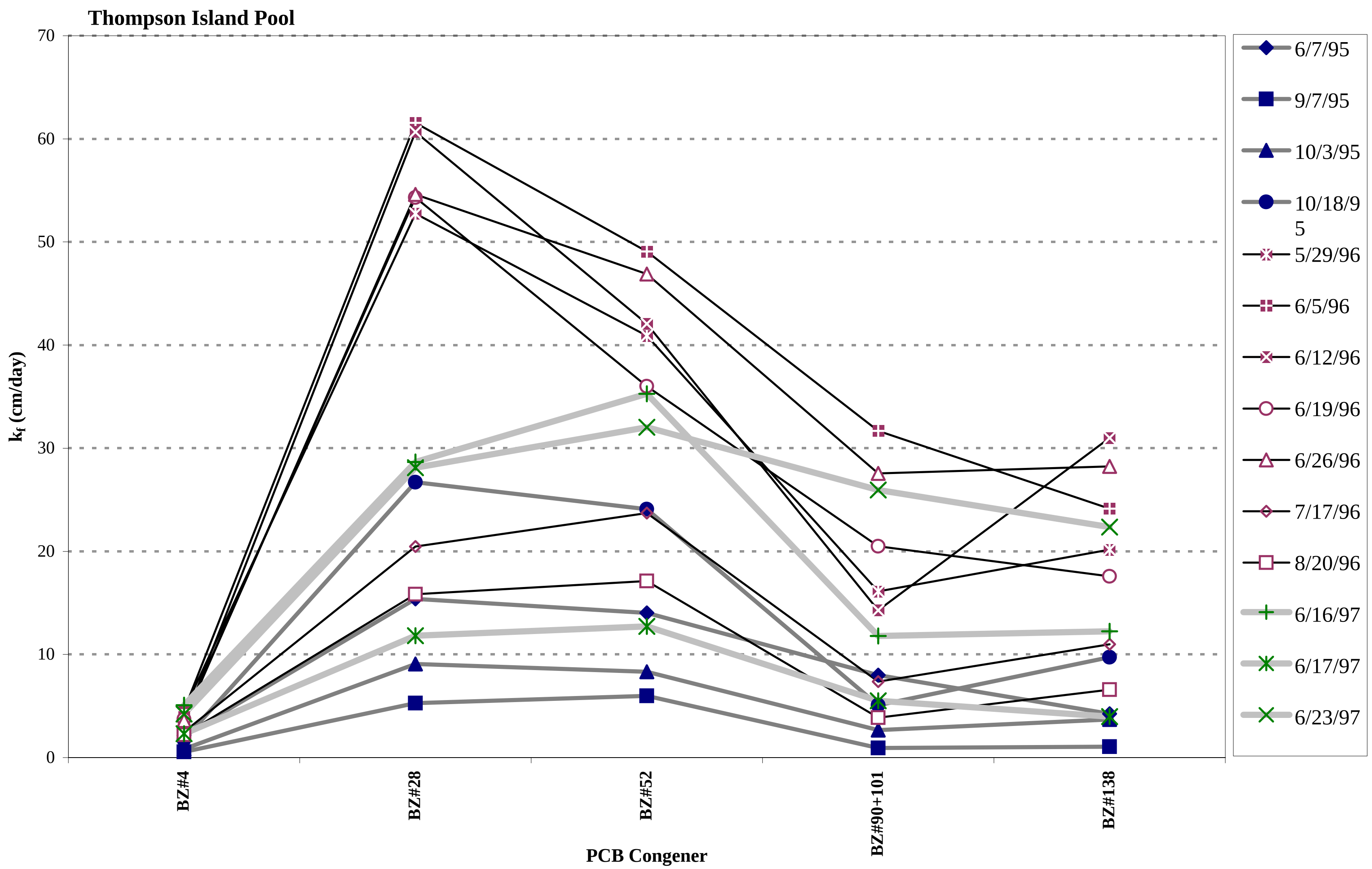
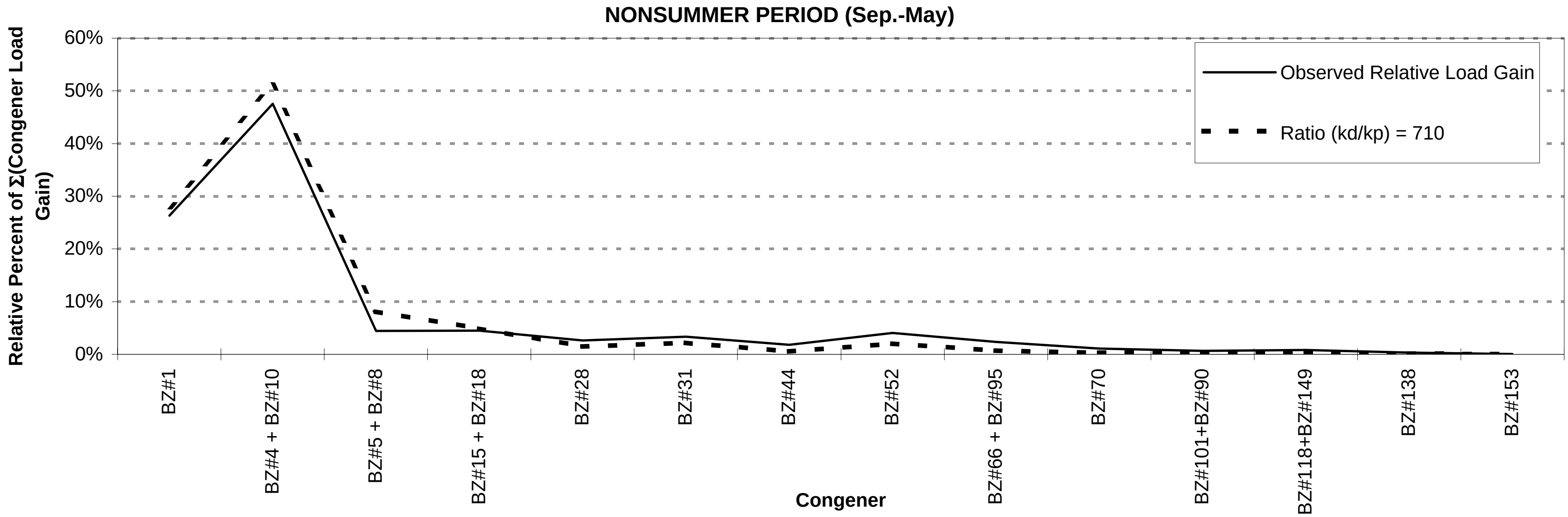


Figure 6-59. Comparison of Congener Specific Apparent Sediment-Water Mass Transfer Rates by Date.



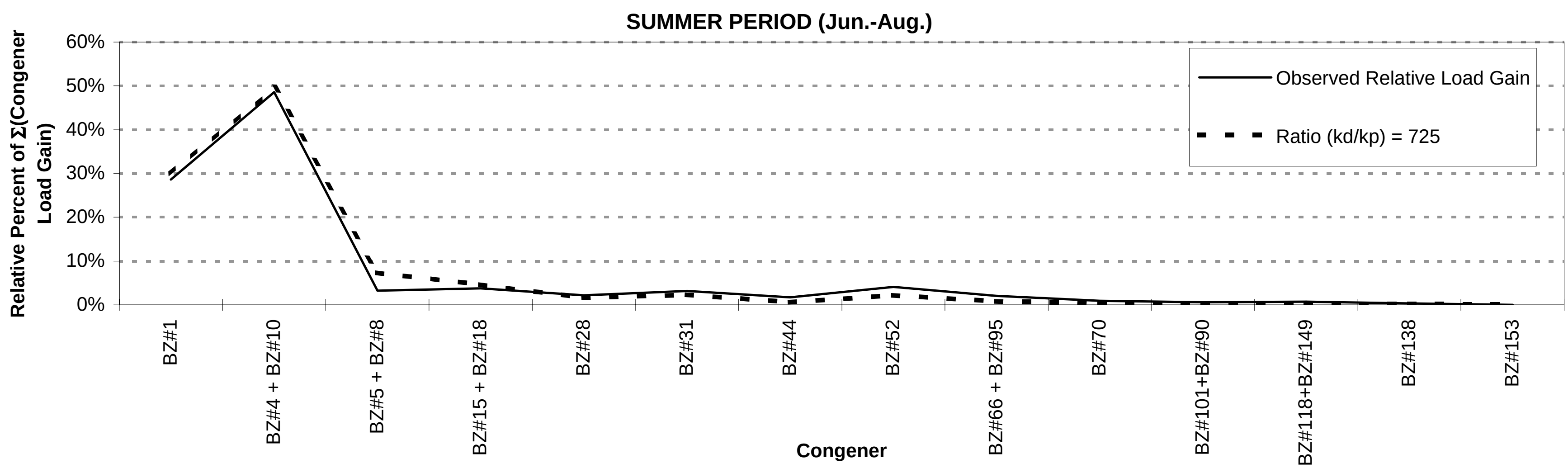


Figure 6-60. Comparison of Fit Using Ratio of Pore Water to Particulate Mass Transfer Coefficients to Average Observed Predicted Relative Load Gain at Thompson Island Dam by Season, 1991-1997.