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General Electric Company
Albany, New York

Report

HUDSON RIVER
PCB DNAPL TRANSPORT STUDY

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1. INTRODUCTION

This report has been prepared by HydroQual on behalf of the General Electric Company (General Electric). It describes the results of the polychlorinated biphenyl (PCB) dense non-aqueous phase liquid (DNAPL) transport study conducted on the Hudson River in September 1996 (HydroQual, 1996). This study was designed to explore the hypotheses that PCB DNAPL transport from the Hudson Falls Plant site area provides unquantified PCB loadings into the Thompson Island Pool (TIP; Figure 1) that are, at least in part, responsible for the unaccounted-for water column load observed at the Thompson Island Dam (TID) monitoring station.

1.1 Background

DNAPL PCBs are present within fractured bedrock underlying the General Electric Hudson Falls Plant site (O'Brien & Gere, 1996). This material is believed to have migrated through bed rock fractures and accumulated in waterways within the 150 year old Allen Mill (Figure 2; O'Brien & Gere, 1994). Collapse of a wooden gate structure within the mill is believed to have resulted in the transport of PCB DNAPL into the Hudson River during September 1991 and until flow through the waterways was controlled in January 1993 (O'Brien & Gere, 1994). Although these sources have been controlled by remedial measures (O'Brien & Gere, 1996), PCB DNAPL from the plant site has continued to enter the river directly through fractures in the river bed. Such DNAPL activity was observed in 1994 following partial river bed dewatering conducted in association with the construction of a new dam near the Hudson Falls plant site (O'Brien & Gere, 1996) as well as during visual inspections of the dry river bed conducted during the summer of 1996. Moreover, an active DNAPL seep was discovered within the eastern bank of the Bakers Falls plunge pool by commercial divers contracted to perform a visual inspection of the pool in September 1996 (GE, 1996).

The PCB DNAPL loadings described above may be responsible, at least in part, for PCB loadings in the river that cannot be accounted for by known PCB fate and transport mechanisms (HydroQual, 1995; GE, 1997). Of particular interest is the increase in loadings observed at the TIP following the Allen Mill loading event of 1991 (HydroQual, 1995; Figure 3). The temporal correspondence of mill loadings and the increase in PCB loadings from the TIP suggest the mill loadings as the causative factor. For this hypothesis to be true, PCBs must have passed the Fort Edward sampling station (Figure 1) undetected and then been deposited within the pool. This could occur if PCBs enter the river between sampling events or are transported as part of the bed load passing under sampling devices.

Due to their density, PCB DNAPL from the Allen Mill or plant site area may be transported downstream along the sediment-water interface as part of the bed load. Such PCB bed loading may be more pronounced during periods of elevated river flow. Water column monitoring at the Fort Edward station does not include collection of water from the bottom one foot (estimated) of the water column and, therefore, does not include any bed load material. Within Thompson Island Pool, any unmeasured PCBs may subsequently become progressively mixed or dissolved in the water column, or incorporated into the surface sediments where they would be subjected to other fate-determining processes.

1.2 Objectives

The principal objective of the DNAPL transport study was to evaluate the likelihood that DNAPL loadings for the Hudson Falls Plant site environs are, at least partially, transported undetected into the TIP. Three specific questions were addressed:

- Is DNAPL sequestered in the region between Hudson Falls and the TIP?
- Does DNAPL that enters the TIP become trapped within the TIP?

- Is DNAPL preferentially transported along the river bottom as part of the bed load?

1.3 Approach

DNAPL transport was examined in two ways: 1) a conservative tracer with properties similar to PCB DNAPL was discharged into the river near Hudson Falls and tracked as it moved downstream; and 2) particulate phase PCB concentration and composition in suspended load and bed load were measured and contrasted at several stations. The study included:

- injection of 20 pounds of fluorescent particles possessing a density similar to that of Aroclor 1242 into the river from the Adirondack Hydro Development Corporation (AHDC) Hydroelectric Plant,
- collection of daily composites of water column and bed load particle samples at or near current water column monitoring stations for three days following fluorescent particle injection,
- analysis of water column and bed load particle samples for fluorescent resin particle concentration, PCB concentration, total solids, and total organic carbon (TOC), and
- development of fluorescent particle mass balances to evaluate their transport and by inference the transport of PCB DNAPL within the Hudson River.

2. METHODOLOGY

The materials and methods employed during the PCB DNAPL transport study generally followed the procedures contained in the work plan developed for the project (HydroQual, 1996).

2.1 Fluorescent Resin Particles

The fluorescent resin particles used for this study were manufactured by Day-Glo Color Corporation of Cleveland, Ohio (Day Glo). The particles are used as colorants for a variety of industrial and commercial applications and have a density similar to that of Aroclor 1242 (1.25 g/cm^3). The particles consist of a polyamide ester resin and a zinc-based fluorescent dye colorant. A material safety data sheet for the particles is contained in Appendix A.

The particles are produced by serial grinding of a block of fluorescent resin material to form a powder. A sample of the product of the first grinding was obtained from Day-Glo. This material was segregated into different size classes by dry sieving through a series of A.S.T.M. certified sieves. Particles passing a No. 60 sieve (nominal sieve aperture of 250 um) and retained on a No. 100 sieve (nominal sieve aperture of 150 um) were used in this study. The selection of this particle size range was based upon two lines of reasoning. First, the results of an empirical study involving the vigorous shaking of a small volume of PCB oil obtained from one of the wells at the Hudson Falls plant site in 1 liter of Hudson River water produced PCB oil droplets visually estimated to be between 100 and 200 um in diameter. Second, a spherical PCB oil droplet of 100 to 200 um in 1 L of water would produce a PCB concentration in the 1 to 2 ug/L range. This concentration is similar to that observed in the river during the Allen Mill PCB loading events of 1991 and 1992 (HydroQual, 1995). Although not conclusive evidence of the

DNAPL droplet size within the river, these observations provide a basis for selection of the fluorescent particle size range used in this study. A photo of the fluorescent particles under approximately 100x magnification through an epifluorescent microscope is presented in Figure 4.

The size distribution of fluorescent particles injected into the river deviated significantly from that expected based upon the sieves used to segregate the material; the distribution of particles was shifted toward the smaller particle sizes (Figure 5). This is likely due to electrostatic forces that promoted particle interactions and resulted in the retention of smaller particles along with larger particles on the sieves. Wet sieving would have significantly reduced this carryover of smaller particles, but hydration of the particles would have adversely affected material handling. Therefore, the dry sieved particles were injected into the river without additional processing. The selected sieve fraction provided greater than an order of magnitude range of particle sizes (19 - >380 um diameter) from which to assess the fate of PCB DNAPL.

One critical difference between the fluorescent particles and PCB DNAPL is that the DNAPL would be subject to dissolution during transport downstream from the Hudson Falls Plant site. While this would be difficult to simulate in a field study, the different particle sizes employed during this study may provide some insights into the effect of dissolution on PCB DNAPL transport by considering the smaller fluorescent particle size ranges as representative of smaller droplets formed upon DNAPL dissolution during transport.

2.2 Particle Injection

The particles were injected in slurry form into the fish bypass line of AHDC's hydroelectric plant (Figure 6a). Twenty pounds of fluorescent particles were slurried at

a 2 percent concentration using Hudson River water (Figure 6b and 6c). A surfactant (0.5% (wt./vol.) Triton 100) was added to the slurry to wet the particles and avoid particle agglomeration during injection. The fish bypass line discharges directly into the river within the turbine discharge zone. Introduction of the slurry at this location facilitated post-injection particle mixing. The particle slurry was pumped into the fish bypass line using a peristaltic pump over a two-hour injection period between 10:00 and 12:00 on September 17, 1996. River flow rate during the injection varied from approximately 950 to 1600 cfs (Figure 7) producing maximum water column particle concentrations ranging from 46 to 28 ug/l, respectively.

2.3 *In Situ* Particle Filtration

Natural water-borne particulates and fluorescent resin particles were collected by passive water column filtration devices deployed within the river downstream of the particle injection point (*in situ* filtration devices). Samples collected from these devices were used to evaluate the fate of injected particles.

2.3.1 Sample Locations

Water column particulate and fluorescent resin particle samples were collected from the Hudson River from three locations (Figure 8):

- approximately 300 feet upstream of the north end of Rogers Island (Rogers Island Station; HRM 194.9),
- beneath the Route 197 Bridge in Fort Edward (Fort Edward Station; HRM 194.2), and
- approximately 500 feet upstream of the Thompson Island Dam (Thompson Island Station; HRM 188.8).

Two *in situ* particle filtration devices (§2.3.2) were deployed at each of the sampling stations along the main channel flow path to facilitate the collection of representative samples. One sampler was deployed in the eastern and one in the western channel at the Fort Edward station (Figure 8).

2.3.2 Sample Collection Procedures

Water-borne particulate and fluorescent resin particle samples were collected from the river within 100 um mesh bags mounted on aluminum frames (Figures 9 and 10). Three sampling bags were fitted to each frame. One bag each was located at or near the air-water interface, at mid-channel depth, and at the sediment-water interface on each sampler. The mouths of the bags were formed by a 0.1 sq. ft. rectangular plastic support and oriented upstream to capture particles transported by the natural flow of the river. The samplers were anchored on the river bottom by concrete blocks. Once daily for the three days following fluorescent particle injection (September 18-20, 1996), the mesh bags and captured particles were collected and new bags were mounted on the samplers.

The bags and entrained particles were transferred to one quart plastic containers, labeled, and transported to HydroQual's facilities in Mahwah, N.J., where they were prepared for shipment to the laboratories for testing.

2.3.3 Sample Preparation

Once in the HydroQual laboratory, sediment samples were collected from the mesh bags. Mesh bags were cut open and laid onto clean aluminum foil. The entrained sediment and fluorescent particles were scraped from the bags using a stainless steel spatula and transferred to a clean pre-weighed glass petri dish. This transfer was conducted such that as many of the solids as possible were collected (quantitatively

transferred; Figure 11). The samples were then air dried for several days under a clean laboratory hood and weighed using an analytical balance.

Many of the samples dried into a flake-like solid that required breaking up prior to shipment to the laboratories. These samples were ground gently using a glass mortar and pestle. The dried sediment samples were transferred to plastic vials and shipped to the laboratories for testing. While grinding had the potential to alter the fluorescent particle size distribution, comparison of ground and unground samples illustrated insignificant differences in particle size distribution (Figure 12).

2.4 Sediment Traps

Settling particle samples were collected from various locations downstream of the particle injection point and analyzed for fluorescent particle and PCB concentrations. These data provided a means of qualitatively assessing the fate of particles passing upstream *in situ* particle filtration devices as suspended material.

2.4.1 Sampling Locations

Sediment traps were deployed within five quiescent regions downstream of the particle injection point (Figure 8):

- downstream of Fort Edward Dam Remnant Site 3 (1 sediment trap; HRM 196) and Remnant Site 4 (2 sediment traps; HRM 195.6),
- the southern tip of the unnamed island within the western channel of the river adjacent to Rogers Island (3 sediment traps; HRM 194.2),
- the southern tip of Rogers Island (3 sediment traps; HRM 193.7),

- a backwater region along the western shore immediately downstream of the H-7 site (3 sediment traps; HRM 193.1), and
- the southern tip of Griffin Island (3 sediment traps; HRM 189.5).

2.4.2 Sample Collection Procedures

The sediment traps were constructed from five-gallon plastic containers weighted with approximately 20 pounds of cured concrete (Figure 13). The pails were fitted with a plastic cover containing a four inch diameter opening in the center. The traps were deployed for one week beginning the day of particle injection. Upon retrieval, excess water from the traps was decanted into the river and the sediments were quantitatively transferred to labeled glass containers and transported to HydroQual's facilities in Mahwah, N.J.

2.4.3 Sample Preparation

Once received by HydroQual's laboratory, the sediment trap samples were evaporated in an oven at 105° C. The residual solids were quantitatively transferred to pre-weighed glass containers and weighed. The solids were then transferred to plastic vials and shipped to the laboratories for fluorescent particle and PCB analysis.

2.5 Particle Analysis Techniques

Particulate samples were analyzed for fluorescent particles, PCBs, and total organic carbon (TOC). Direct counts of fluorescent particles were conducted by SpectraScan, Inc., an optical consulting firm affiliated with the University of Southern California, Department of Biological Sciences. The analysis included the mounting of particle samples on specially treated glass slides and direct counting under an epifluorescent microscope.

The fluorescent particle analysis protocols are contained in Appendix B. Fluorescent particles were segregated into five discreet particle size fractions: 19-38 um, 39-114 um, 115 -190 um, 191-380 um, >380 um. Congener-specific PCB and TOC analyses were performed by Northeast Analytical, Inc. of Schenectady, N.Y. using methods NEA608CAP (O'Brien & Gere 1993) and EPA Method 415.1, respectively.

2.6 Mass Balance Calculations

The river flow, total solids, fluorescent particle, and PCB data collected during this study were used to develop mass balances to evaluate the fate of solids, fluorescent particles (and by inference PCB DNAPL), and particulate phase PCBs. These mass balances involved scaling up of the *in situ* filtration data to the entire river cross section at each of the sampling stations. The mass of river solids, fluorescent particles, and particulate phase PCBs passing sampling station i (Fort Edward, Rogers Island or Thompson Island) at location j (east or west channel) at water column depth k (air-water interface, mid-channel depth, or sediment-water interface) ($M_{i,j,k}$) was calculated as:

$$M_{i,j,k} = \frac{C_{i,j,k}\, S_{i,j,k}}{A_t}\, A_{i,j,k} \qquad (1)$$

where $C_{i,j,k}$ is the concentration (M/M) of particulate phase PCBs or fluorescent particles, and $S_{i,j,k}$ is the mass of solids (M) captured at sampling station i, sampling location j, and sampling depth k, A_t is the cross sectional area of the *in situ* filtration devices (L^2), and $A_{i,j,k}$ is the river cross sectional area (L^2) assigned to sampling station i, sampling location j, and sampling depth k. For river solids mass balance calculations $C_{i,j,k}$ was equal to 1.

The cross sectional areas assigned to each of the sampling locations and depths at each station ($A_{i,j,k}$) is graphically depicted in Figure 14. Results from sediment-water

interface samples were integrated over a four inch depth along one-half of the river cross section. The mid channel depth sample was integrated over one-half of the cross sectional area spanning the midpoint between the air-water interface and mid depth sampling locations to the sediment-water interface sampling area. The air-water interface sample was integrated over the remainder of the cross sectional area. Bathymetric data collected during the transect studies of 1995 and 1996 were used to develop the total river cross sectional areas at the different sampling stations (O'Brien & Gere, 1997). The total mass of materials passing each sampling station over a given sampling period (Mt_i) was calculated simply as the sum of the mass passing each cross sectional area as follows:

$$Mt_i = \sum_{j=1}^{2} \sum_{k=1}^{3} M_{i,j,k} \qquad (2)$$

These mass balances are presented in §3.4 (river solids), §4.3 (fluorescent particles) and §4.4 (particulate phase PCBs).

2.7 Quality Assurance/Quality Control

Quality Assurance/Quality Control (QA/QC) measures for the PCB DNAPL study generally followed the quality assurance project plan (QAPP) developed for the Hudson River Project (O'Brien & Gere, 1993). QA/QC sampling consisted of:

- the analysis of blind duplicates for PCBs, fluorescent particles, and TOC at a rate of approximately 15%, and
- the analysis of blind field blanks and matrix spikes at a rate of 30% for fluorescent particle analysis.

A summary of the samples collected during the study is contained in Tables 1 and 2.

3 RESULTS

3.1 River Hydrodynamics

River discharge measured at the Fort Edward gauging station varied considerably over the course of the PCB DNAPL transport study (Figure 7). During fluorescent particle injection (10:00 - 12:00 on September 17, 1996), river discharge averaged approximately 1000 cfs. River flows declined to less than 500 cfs by 16:00 on September 17 due to water retention in upstream impoundments and steadily increased to approximately 4000 cfs by 06:00 on September 18, 1996. Flows then increased to greater than 7000 cfs for a short period on September 18, 1996 due to releases from upstream impoundments. Flows remained relatively steady between 2000-3000 cfs for the remainder of the three day study. The extreme fluctuation in river flow during the first day of the study provides an opportunity to assess the impact of moderate flow events on PCB DNAPL loading in the river, as will be discussed in subsequent sections of this report.

3.2 *In Situ* Filtration

3.2.1 Total Filterable Solids

Total filterable solids[1] data were collected as part of the study to enable mass balance calculations of both fluorescent particles and PCBs, which were measured on a number per unit mass and mass per unit mass basis, respectively. Total solids collected in each of the particle filtration devices deployed at Fort Edward and Rogers Island generally varied between 1 and 5 grams per day (Table 1). The notable exceptions were the sediment-water interface samples collected from the Fort Edward station on

[1]Filterable solids are operationally defined in this report as solids retained within the *in situ* filtration devices.

September 18, 1996. On this day, east and west channel *in situ* filtration devices deployed at the sediment-water interface accumulated solids at rates of 25 and 67 grams/day, respectively. This five- to ten-fold increase in the total filterable solids captured occurred over a period in which river flow velocities fluctuated between less than 500 cfs and greater than 7000 cfs. These data suggest that flow event driven river bed loading may be an important process in the transport of solids from the remnant reach of the river to the TIP.

The *in situ* particle filtration devices deployed at the Thompson Island station accumulated 1.5 and 0.98 grams of filterable solids over the three day collection period. This is a factor of two to ten lower than that transported upstream. This difference indicates that during this study, the TIP was acting as a sink for solids transported from upstream.

3.2.2 Fluorescent Particles

3.2.2.1 Fluorescent Particle Mass Concentration Calculations

Fluorescent particle concentrations were reported as the number of particles in each of five size classes per gram of dried solids (Table 1). These number concentrations were converted to mass concentrations to facilitate the development of fluorescent particle mass calculations as follows:

$$C_i = n_i m_i \qquad (3)$$

where C_i is the concentration of particles represented by size class i (M/M), n is the number of particles detected in size class i per unit mass of sediment (#/M), and m_i is the mass of a single particle in size class i (M) which, assuming the particles are spherical, is calculated as:

$$m_i = \frac{4}{3} \pi r_i^3 \rho \quad (4)$$

where r_i is the radius of particles in size class i calculated as the volume averaged radius within a given size class, and ρ is the density of the fluorescent particles (1.25 g/cm^3). The mass of fluorescent particles within size class i retained (M_i) within the particle filtration devices and sediment traps can then be calculated as follows:

$$M_i = C_i S \quad (5)$$

where S is the total dry solids mass retained within the filtration devices of sediment traps. The remainder of this report will present fluorescent particle data in terms of mass concentrations (i.e., C_i in Equation 3).

3.2.2.2 Accuracy of Fluorescent Particle Enumeration

The accuracy of the fluorescent particle enumeration technique was assessed through the analysis of blind particle spiked samples. Dried sediment samples from the Hudson River were spiked with a known mass of fluorescent particles and sent to the laboratory for fluorescent particle enumeration. The spiked samples ranged in concentration from 0 mg/kg to 10,000 mg/kg and were prepared in triplicate. The lab reported the number of particles per gram of dried sediment in each of five different

particle size classes (Table 3). These were converted to fluorescent particle mass concentration in accordance with Equations 3 and 4. The total mass concentration of fluorescent particles was calculated as:

$$C_t = \sum_{i=1}^{5} c_i \qquad (6)$$

The results of the blank and spiked sample analyses are presented in Table 3 and Figure 15. The particle enumeration and mass calculation technique described above appears to overestimate the mass of fluorescent particles, particularly within the lower concentration ranges. This overestimation is likely the combined result of particle counting biases and limitations associated with the assumptions of spherical particles and mean particle diameter in the mass calculations.

The spiked sample results suggest that the accuracy of the fluorescent particle enumeration and mass calculations varies with concentration, from more than an order of magnitude at the lower end of the spiked concentration range to a factor of 4 to 5 at concentrations near 10,000 mg/kg. The calculated fluorescent particle concentrations detected in this study ranged between 1,000 and 72,000 mg/kg, with a geometric mean of 14,000 mg/kg (Figure 15). Because of the apparent bias at low particle concentrations, the interpretation of results focused more on the relative differences between fluorescent particle loadings at the different stations than on the absolute loading values. These biases are more fully explored in §4.1.

The presence of fine particles in three of the blank samples is likely the result of cross contamination during the preparation of the particle spikes and not background fluorescence as an additional blank collected from the Hudson River contained no fluorescent particles (Table 3).

3.2.2.3 Precision of Fluorescent Particle Enumeration

The precision of the particle sampling and enumeration techniques was assessed by the analysis of blind duplicate samples (Table 1). Duplicate samples were analyzed on 14 of the 52, or 27%, of the fluorescent particle samples. The relative range of the duplicate samples was calculated in accordance with the following equation:

$$RR_{1,2} = \frac{|n_1 - n_2|}{\frac{n_1 + n_2}{2}} 100 \qquad (7)$$

where $RR_{1,2}$ is the relative range between measured values n_1 and n_2, for samples 1 and 2. The RR is an estimate of measurement precision and was used to support the grouping of sample sets for subsequent data analyses. The average RR of all sample duplicates was approximately 75% (Figure 16). The RR of fluorescent particle samples collected simultaneously from the east and west channel of the river at the different sampling stations (calculated using a formula analogous to Equation 7) was within the average relative range of the sample duplicates (Figure 16). That is, there was no discernible difference between fluorescent particle concentrations in samples collected from the east and west channels. Therefore, west and east channel fluorescent particle data were grouped in subsequent data evaluations.

3.2.2.4 Spatial and Temporal Profiles in Fluorescent Particle Distribution

The size distribution of fluorescent particles captured within the *in situ* filtration devices appears in Figures 17, 18, and 19. Particles from the larger two size classes (190-380 um and >380 um) did not appear in any of the samples suggesting that these

particles were retained between the particle injection point and the first downstream sampling station (Fort Edward). Samples collected from the Fort Edward and Rogers Island stations did not illustrate any discernible relationship between particle size distribution and sample depth (Figures 17 and 18). However, fluorescent particles trapped at the Rogers Island station were notably smaller than those trapped at Fort Edward (Figures 17 and 18). In each of the Rogers Island air-water interface, mid-depth, and sediment-water interface samples, the smallest particle size class (19-38 um) represented the largest proportion of trapped particles. This difference in particle size distribution between the Fort Edward and Rogers Island stations suggests that the larger particles (39-114 um and 115-190 um) settled out between the two stations. This pattern continued downstream as particles appearing in the vertically integrated samples from the Thompson Island station consisted entirely of the smallest particle size class (19-38 um; Figure 19). Again, these data suggest that the larger particles (39-114 um and 115 - 190 um) passing the Rogers Island station settled within the river reach between the Rogers Island and Thompson Island stations.

Vertical profiles of fluorescent particle mass retained[2] in the Fort Edward and Rogers Island *in situ* filtration devices appear in Figure 20[3]. At the Fort Edward and Rogers Island stations there were no clear vertical gradients in fluorescent particle capture over the three day sampling period. Although mass retained in the filters decreased over time, patterns of vertical fluorescent particle distribution were not observed either spatially or temporally suggesting that the particle size classes measured within the river were uniformly distributed within the water column.

[2]Mass retained is defined here as the actual fluorescent particle mass captured within the sampling devices.

[3]Thompson Island samples were vertically composited due to low sediment particle loading and, therefore, do not appear in Figure 20.

A consistent spatial pattern in fluorescent particle loading was observed over the three day study (Figure 21).[4] On each day of sampling, the largest mass of fluorescent particles was retained at the Fort Edward station. On the first day following injection, the Fort Edward Station retained nearly 4.5 times the mass retained within the sampling devices deployed at Rogers Island. While this may be due, at least in part, to differences in the proportion of river cross sectional area sampled as a consequence of differences in bathymetric profiles between the two stations, it suggests that the reach between the two stations acted as a sink for fluorescent particles. This concept is further explored in Section 4 of this report.

This pattern of decreasing total retained particle mass continued downstream as the three-day vertically composited samples at the Thompson Island station contained only an estimated 10 mg of fluorescent particles. This compares to an approximate 2250 mg retained at the Fort Edward station and 700 mg retained at the Rogers Island station (Figure 21). As discussed above, these data suggest that TIP acted as a fluorescent particle sink during the study and will be explored more fully in Section 4.

The temporal pattern in total fluorescent particle mass captured at each of the stations was consistent with the pulse loading of a settlable substance into the river (Figure 22). The mass of particles trapped was highest on the day of particle injection and declined steadily over the three day study period at both the Fort Edward and Rogers Island stations. At the Fort Edward station, the mass of fluorescent particles retained within the sampling devices declined by a factor of approximately six between day 1 and day 2 of the study. An additional 16 percent decline in particle mass was observed between day 2 and 3. Similar patterns of reduced particle loading were observed at the

[4]As there were no clear vertical gradients at any of the stations the spatial profiles appearing in Figure 21 were developed by vertically integrating the fluorescent particle mass data for each of the stations.

Rogers Island Station, however, the total mass was significantly lower than at the Fort Edward station (Figure 22), as discussed above.

3.2.3 Total Organic Carbon

The total organic carbon content of the *in situ* filtration samples generally varied between 19 and 34 percent (Table 1). These data suggest that a large proportion of the natural solids retained within the devices was organic material, possibly plankton. This was supported by the visual observation of a green hued film that appeared on the surfaces of the particle filtration nets. This organic film appeared to reduce the effective mesh opening of the nylon bags, allowing the capture of particles with a diameter less than the original mesh openings (100 um).

Sediment-water interface samples collected from the Fort Edward station (Table 1 and Figure 23) contained TOC at levels considerably lower than samples collected from the other stations. TOC values for these samples ranged between 4 and 16 percent, with the lowest values associated with the samples collected on the first day of sampling. These samples contained a significant bed load which may have been driven by the rapid increase in flow that occurred over the first day of sampling (Figure 23). This bed load contained a large proportion of inorganic material including coarse sand and shale fragments. These inorganic bed loadings produced the vertical patterns in TOC appearing in Figure 23.

3.2.4 Particulate Phase PCBs

Solid samples collected from the *in situ* particle filtration devices were analyzed for PCBs by DB-1 capillary column techniques. The results of these analyses including total

PCB and PCB homolog distributions appear in Tables 1 and 2[5]. The precision of the PCB sampling and analysis techniques was assessed by the analysis of blind duplicate samples (Table 1). Six of the 37 *in situ* filtration samples were submitted blind to the laboratories for duplicate PCB analysis. The RR of these sample duplicates was calculated in accordance with Equation 7. These relative range calculations were used to support the grouping of sample sets for subsequent data analysis, as previously discussed.

The average relative range of duplicate PCB analyses of *in situ* particle filtration samples was approximately 50%, on an organic carbon normalization basis (Figure 24). The relative range of PCBs within trapped sediment samples collected simultaneously from the east and west channel of the river at the different sampling stations was within the average relative range of the sample duplicates (Figure 24). Since there were no discernible differences between organic carbon normalized PCB concentrations in samples collected from the east and west channels, these samples were grouped in subsequent data analyses.

Vertical profiles of total PCB concentration over the three day study at the Fort Edward and Rogers Island stations appear in Figure 25[6]. There was no consistent vertical pattern in PCB concentration over the course of the study. Total PCB concentrations generally ranged from 2 - 6 mg/kg. A notable exception is the air-water interface sample collected on September 19 at the Rogers Island station. This sample contained an average PCB concentration in excess of 10 mg/kg. This elevated mean concentration was forced by an 18.6 mg/kg concentration from the east channel station. This sample also

[5]PCB results have <u>not</u> been corrected for analytical biases and calibration errors associated with the Green Bay standardization of the DB-1 capillary column (HydroQual, 1997a).

[6] Samples collected from the Thompson Island Station were vertically composited, therefore, no discussion of vertical PCB profiles at this station is provided.

contained an organic carbon concentration that was on the higher end of the observed range (33%; Table 1).

Organic carbon normalization of the *in situ* particle filtration PCB results generally reduced the vertical variability in total PCB concentrations particularly in the air-water interface sample collected from Rogers Island on September 19 (Figure 26). However, organic carbon normalization increased the range in PCB concentrations observed at the Fort Edward station on September 18, 1996 (Figure 26). Organic carbon normalized PCB concentrations varied by a factor greater than three between the sediment-water interface and the other samples within the vertical profile. In contrast to the air-water interface sample at Rogers Island, this pattern in vertical PCB content was observed in samples collected from both the east and west channel at the Fort Edward station. These observations suggest that the nature of the PCB source to the sediment-water interface sample at Fort Edward differed from the source appearing in other samples within the vertical profile. This is further supported by differences in PCB composition, as will be discussed below.

On average, over the course of the three-day study there was little discernable difference in the PCB composition between the Fort Edward and Rogers Island Stations (Figure 27). Homolog distributions from these sites centered on tetrachlorinated biphenyls, with no detectable levels of monochlorinated biphenyls and less than seven percent dichlorinated biphenyls. In contrast, particulate samples collected from the Thompson Island station contained PCBs that were less chlorinated. Mono- and dichlorinated biphenyls constituted nearly 20 percent of the PCBs in these samples. These data are consistent with particulate phase PCB loading patterns documented for this reach of the river during the USEPA Phase II study (USEPA, 1997).

A notable exception to the consistency in PCB composition at Fort Edward and Rogers Island was the sediment-water interface samples collected on September 18. The PCB composition of these samples deviated from that of the other samples in the vertical profile. The air-water interface and mid channel depth samples contained PCBs characterized by a homolog distribution centered on the tetrachlorinated biphenyls (Figure 28), consistent with other PCB homolog distributions measured at this station. In contrast, the PCB composition of the sediment-water interface samples contained less chlorinated PCBs that closely resembled the unaltered Aroclor 1242 originating from the Hudson Falls plant site (Figure 28). These differences in PCB composition are also present in the PCB DB-1 capillary column peak data (Figure 29). These data suggest that the elevated flow event of September 18 may have transported PCB from the vicinity of the Hudson Falls Plant site as part of the sediment bed load.

3.3 Sediment Traps

Total solids, fluorescent particle, TOC, and PCB data for the sediment trap samples are contained in Tables 1 and 2. As these traps were designed and deployed as a qualitative measure of fluorescent particle and PCB fate, data interpretations will be limited to simple spatial and temporal profile analyses.

3.3.1 Total Solids

The total solids data collected from the sediment traps were used to calculate total fluorescent particle and PCB mass in accordance with Equation 5. Total solids accumulated within the sediment traps at rates varying from 0.8 to 6 grams over the seven day collection period (Table 1). The lowest solids accumulation rates were observed within traps placed downstream of the H-7 site (0.8 - 1.8 g; Table 1). Under the flow conditions observed during this study, the H-7 site was not as pronounced of a

depositional environment as the other sediment trap sites, which accumulated between 2.3 and 6.1 g over the sampling period.

3.3.2 Fluorescent Particles

Fluorescent particle data obtained from the sediment traps generally support observations made based on the *in situ* filtration data. The sediment traps were deployed as a qualitative measure of the fate of fluorescent particles not appearing within the particle filtration devices. As such, numerous traps were set in likely depositional areas between the particle filtration stations. Fluorescent particles were observed within all sediment traps deployed as part of this study. The mass of fluorescent particles retained in the sediment traps generally declined with distance from the particle injection point (Figure 30), possibly reflecting the reduction in fluorescent particle mass transport with river mile observed in the *in situ* filtration devices (Figure 21).

Direct quantitative analysis of the sediment trap data is not possible due to the spatially variable nature of particle deposition expected within the river. Deposition is a complex phenomenon dependant on numerous system and particle properties including localized river flow velocities, water depth, sediment bed type, and particle size and density. Moreover, the sediment traps were designed to maximize particle capture. Hence, the sediment trap data cannot be used to quantitatively evaluate fluorescent particle deposition. Nonetheless, the sediment trap data qualitatively support the *in situ* particle filtration results suggesting that particles are lost due to settling between the different stations.

3.3.3 Total Organic Carbon

The total organic carbon content of sediment trap samples varied from 10 to 18 percent (Table 1). This is approximately half that observed in the *in situ* particle filtration samples, suggesting that more inorganic material was captured in the sediment traps than in the filtration devices. There appeared to be no discernible spatial pattern in the organic carbon content of the sediment trap samples.

3.3.4 Particulate Phase PCBs

The total PCB concentration of sediment trap samples varied over an order of magnitude from approximately 3 to 30 mg/kg (Table 1 and Figure 31). The highest concentrations were observed within the upstream extreme of the TIP, in traps deployed downstream of the unnamed island within the western channel of Rogers Island. Disregarding the sediment traps in the remnant area, which may not represent a depositional environment similar to that of the other sampling stations, a spatial pattern in sediment trap PCB concentrations is apparent. Sediment traps closest to the headwaters of the TIP accumulated solids with higher PCB concentrations than those at the downstream stations. This spatial pattern suggests that PCBs transported downstream of the Hudson Falls Plant site are deposited within the upstream portion of the TIP.

As with the *in situ* particle filtration samples, PCBs in sediment traps deployed within the TIP (RM 193.2 and 189.5) were less chlorinated than samples collected upstream (Figure 31). Again, these observations are consistent with particulate phase PCB compositions reported by the EPA in 1993 (EPA, 1997).

3.4 River Solids Mass Balance

River solids loading estimates for the different stations calculated in accordance with Equations 1 and 2 and integrated over the three day study period indicate that an estimated 290 kg of solids were transported from upstream of Fort Edward and into the TIP over the course of the three-day study (97 kg/day; Figure 32). This is considerably lower than the 5500 kg/day of solids transport estimated from total suspended solids and river flow data collected over the same period (O'Brien & Gere, 1997). The differences between these two estimates of solids transport are likely attributable to a number of factors including: 1) low trapping efficiency of the natural suspended solids on the 100 um mesh of the *in situ* particle filtration devices, 2) reduced water flow through the filters as solids accumulated on the mesh, and 3) a possible overestimation of the solids transport from the TSS and flow data since TSS concentrations during the study were at or near the method detection limit. Nonetheless, this discrepancy adds uncertainty to the mass balance calculations performed for fluorescent particles and particulate phase PCBs, which is discussed in detail in §4.1.

4. DISCUSSION

The fluorescent particle and PCB data presented in Section 3 provide insights into the transport of PCB DNAPL in the Hudson River system. However, mass balances for these materials (§2.7) provide a more quantitative perspective on the study. Prior to developing the particulate phase PCB and fluorescent particle mass balances, the inherent uncertainties of the study design and methods were explored to provide an interpretive context for the evaluation of mass balance calculation results.

4.1 Assessment of Study Uncertainties

4.1.1 Fluorescent Particle Quantification

The accuracy and precision of the fluorescent particle quantification were assessed by enumerating particles in each of five size classes and calculating particle mass concentrations (Equations 3-5) for triplicate sediment samples spiked with known concentrations of fluorescent particles (Table 3; Figure 15) and through the enumeration and mass concentration calculation of duplicate samples collected from the river (Tables 1 and 2; Figure 16). Based upon the spiked sample results, this method appears to over quantify fluorescent particle concentrations by nearly an order of magnitude at the concentrations observed during this study (Figure 15). The accuracy improves slightly at the higher concentration ranges, however, spiked and calculated concentrations still deviate by at least a factor of five. The precision of the analysis also appears to improve at higher concentrations as sample replicates produce more consistent calculated concentrations at the higher concentration range (Figure 15). This is consistent with the analysis of duplicate samples collected from the river which possessed a geometric mean concentration of 14,000 mg/kg and produced an average relative range of approximately 75% (Figure 15). These data indicate that the particle enumeration and mass calculation

method produces a high bias in the fluorescent particle mass concentrations likely attributable to the assumptions used in calculating particle mass.

The particle size distributions reported by the laboratory originate from a direct count of the fluorescent particles. Therefore, these data should be unaffected by the high bias in particle mass calculations described above. The particle size distribution patterns observed in samples collected from the river are consistent with patterns of particle sorting observed in natural systems. The larger particles appeared to have settled out of the water column upstream near the particle injection site, and progressively smaller particles appear to have settled as the particles advanced downstream (Figures 17-19). These particle size distribution changes provide an unbiased interpretive framework within which to assess the more quantitative mass balance calculation results.

4.1.2 *In situ* Particle Trapping

The river solids mass balance (§3.4) underestimates the river solids loading calculated from river flow and TSS data collected at the time of the study. These data indicate that the *in situ* filtration devices are inefficient traps for river solids as approximately 1-5% of the estimated river solids transported in the system during the study were accounted for in the *in situ* filtration devices. These data suggest that mass balance calculations using these solids transport estimates will be biased low. This is particularly true for the particulate phase PCB mass balance calculations as PCBs will be sorbed to river solids. However, the fluorescent particles injected into the system are independent of river solids. Therefore, the trapping efficiency of river solids may not necessarily reflect that of the fluorescent particles, especially considering the expected differences in particle size distribution and density. This would impact the trapping efficiency of fluorescent particles in the *in situ* filtration devices. Nonetheless, the

differences in river solids loading estimates adds uncertainty to the particulate phase PCB and fluorescent particle mass balance calculations.

4.1.3 Implications for Data Analysis

The uncertainties inherent in the fluorescent particle enumeration and mass concentration calculations and in the river solids mass balance have implications for the evaluation of fluorescent particle and particulate phase PCB data..

4.1.3.1 Fluorescent Particles

The uncertainties described above place limitations on the interpretation of fluorescent particle mass balance data. Since the particle size distribution data are relatively independent of the biases in the mass calculations, fluorescent particle data analyses focused on these data. Moreover, with the uncertainties in the absolute fluorescent particle mass balance numbers, evaluations centered on the relative changes in mass transport between the different sampling stations. These relative changes were evaluated within the context of the observed changes in particle size distribution, which are unaffected by the mass calculation biases. These analyses assumed that biases in particle trapping and enumeration and mass calculation were the same for each sampling station, location, and depth.

4.1.3.2 Particulate Phase PCBs

The low trapping efficiency of river solids observed in the *in situ* particle filtration devices produces a low bias in the particulate phase PCB mass balances. Therefore, interpretation of the results presented in Section 3 focused on relative changes in total particulate phase PCB mass transported at the different stations. These data were also

compared to the patterns in particulate phase PCB transport measured by the EPA (EPA, 1997).

4.1.4 Implications for Assessment of DNAPL Transport

The uncertainties in the sampling and analytical methods discussed above provide limits within which the results of the PCB DNAPL transport study data can be evaluated. Specifically, the apparent biases in the fluorescent particle enumeration and mass calculation technique focuses the evaluation of mass balance calculations on relative changes in transport between the different sampling stations and comparison to the unbiased particle size distribution results. Additionally, the low trapping efficiency of river solids by the *in situ* particle filtration devices limits evaluation of particulate phase PCB loadings to relative changes between the different sampling stations and comparison to similar measurements performed by the EPA. Due to differences between fluorescent particles used in this study and river solids, the implications of the low trapping efficiency on fluorescent particle mass balances is less clear. However, the fluorescent particle trapping efficiency is still likely to be low.

4.2 River Solids Loading

The three-day river solids loading estimate appears in Figure 32. An estimated 13 percent of the filterable solids passing Fort Edward appear to be retained within the river between the Fort Edward and Rogers Island sampling stations. An additional 63 percent of the filterable solids passing Fort Edward are retained between Rogers Island and the Thompson Island sampling stations. These data indicate that the TIP is a sink for filterable solids transported from upstream. While there is some uncertainty regarding these mass balances (§4.1), these observations are consistent with independent solids loading

estimates, which characterize the TIP as a depositional environment under the low to moderate flows observed during this study (HydroQual, 1997c).

Flow event driven loading of filterable solids appears to be an important process transporting solids from upstream into the TIP. An extreme fluctuation in river flow velocity occurred during the first day of sampling (September 18, 1997; Figure 7) and appeared to increase the quantity of solids transported from upstream of the TIP. This was particularly evident in the sediment-water interface samples collected from the Fort Edward station. In these samples, total solids retained in the filters were an order of magnitude higher than that retained on subsequent days and at different sampling stations (Table 1). These data suggest that event driven sediment bed loading may be an important mechanism by which solids and their associated contaminants are transported within the system. This process is driven by flow velocities at the sediment-water interface that produce shear stresses in excess of the critical shear stress for solids mobilization. Since this is a threshold phenomenon, sediment bed loading likely occurs over a relatively short period as river flow velocities reach the critical shear velocities and would, therefore, be difficult to characterize using conventional methodologies. This will be further discussed below.

4.3 Fate of PCB DNAPL Loadings to the River

Three-day total fluorescent particle mass balance calculations were performed for each of the three sampling stations using Equations 1 and 2 as described in §2.6. Separate calculations were performed for each of the particle size ranges. These were then summed to produce a total fluorescent particle balance. The mean particle size within a size class was calculated as the volume-weighted particle diameter, as discussed in §3.2.

Although there was uncertainty associated with the mass balance calculations (§4.1), the fluorescent particle mass balance appeared to close. That is, the particle size distribution differences between what was injected and what was measured downstream accounted for the majority of the mass loss observed. This may be due to offsetting biases. The fluorescent particle enumeration and mass calculation technique appeared to be biased high, while the river solids (and possibly the fluorescent particle) trapping efficiency of the *in situ* filtration devices was biased low. Nonetheless, this pattern in particle size distribution is consistent with particle sorting in natural systems. The consistency between particle size distribution observations and mass balance calculations provides support for the mass balance numbers.

The results of the fluorescent particle mass balances appear in Figures 33 and 34. Of the 100% (9.1 kg) of particles injected into the river near the Hudson Falls Plant site (HRM 196.9), an estimated 72% (6.6 kg) were transported downstream to the Fort Edward station (HRM 194.4). These calculations suggest that an estimated 28% (2.5 kg) of the fluorescent particle mass released into the river was retained between the particle injection point and the Fort Edward station. This pattern of particle retention continued as only an estimated 55% (5.0 kg) passed the Rogers Island station, indicating that approximately 18% of that injected (1.6 kg) was retained within the river between the Fort Edward and Rogers Island sampling stations. Over the three-day study, only an estimated 1% (0.1 kg) was transported downstream of the Thompson Island station (Figure 33). These data indicate that 99% of the particles injected in the river near the Hudson Falls plant site were retained in the river upstream of the Thomson Island Station. This particle balance is qualitatively supported by the results of the sediment trap study (Figure 30). Fluorescent particles were observed in each of the sediment traps indicating that particles settled between the different *in situ* filtration sampling stations.

Fluorescent particles retained upstream of the Fort Edward station consisted predominantly of the smallest particle size class (19-38 um) and the two larger size classes greater than 190 um (Figure 35c). This distribution was calculated as the difference between the mass of particles injected (Figure 35a) and the mass of particles passing the Fort Edward station (Figure 35b), on a size class basis. The retention of the smaller particles between the injection point and the Fort Edward station may be the combined result of: 1) smaller particles passing through the 100 um mesh of the *in situ* filtering devices and, 2) loss of particles near the injection point. There was visual evidence of the latter as during injection particles were observed floating along the shoreline. The smaller particles may have been entrained in bubbles produced as water, surfactant, and particles passed through the AHDC fish bypass line and subsequently washed up on shore. The larger particles retained upstream of the Fort Edward station likely settled within the river near the injection point as they were never detected downstream and were unlikely to have been entrained in bubbles during the injection due to their mass.

Several inferences with regard to the transport and fate of PCB DNAPL within the Hudson River may be drawn from the fluorescent particle data. First, PCB DNAPL droplets in excess of 190 um will likely be sequestered near the discharge point, where they would be subject to dissolution. Mobilization of these droplets downstream may be limited at the flows observed during this study (less than the 7000 cfs), but may be mobilized under higher flow events. Such temporary storage is demonstrated by the presence of fluorescent particles in sediment bed load samples collected during the spring high flow event of April 1997 (HydroQual, 1997b). These particles varied in size, but were represented predominantly by the smaller size class (19-38 um). Second, PCB DNAPL existing in the river over the particle size range tested (19-380 um) would be deposited upstream of the Thompson Island Dam. That is, little, if any DNAPL would be transported downstream of the TIP. Once within these sediments, DNAPL would be subject to other

fate determining processes such as dissolution, diffusion, advection, and partitioning onto sediment solids.

4.4 Particulate Phase PCB Loading into Thompson Island Pool

Particulate phase PCB loading estimates were calculated in accordance with Equations 1 and 2 and provided a means of assessing the spatial patterns of particulate phase PCB loading in the system. Since the solids balance calculations suggest a low bias in the solids capture efficiency of the devices, results of PCB mass balance calculations were evaluated qualitatively by examining spatial patterns in particulate phase PCB loadings.

4.4.1 Particulate Phase PCB Loading Estimates

Three day total particulate phase PCB mass transport estimates derived from the *in situ* filtration devices are presented in Figure 36. These mass transport estimates generally followed the spatial patterns in solids loading, as particulate phase PCB concentrations did not vary appreciably between the different stations. Similar to the fluorescent particle mass transport results, solid phase PCB loading was highest at the Fort Edward station and declined with distance downstream. These data are consistent with EPA observations of particulate phase loadings during the 1993 Phase II study (USEPA, 1997) and indicate that particulate phase PCBs entering the TIP from upstream are deposited in the pool. Once there, they are subject to other fate determining processes including burial, resuspension, partitioning between dissolved and aqueous phases, dissolved phase diffusion from sediment pore water to the water column, dechlorination, and advection as the result of ground water movement.

The composition of PCBs collected in the *in situ* filtration devices and sediment traps generally agreed with particulate phase data collected by the EPA in 1993 (Figure 37). Although total PCB levels were considerably lower, the total chlorines per biphenyl generally fell within the range of 3.4 to 3.8. This is higher than the chlorination level of Aroclor 1242 and may reflect partitioning of dissolved phase PCB with the organic carbon observed within the samples. The organic carbon content of the *in situ* filtration and sediment trap samples was relatively high, ranging from 20 - 30 percent, and may reflect the accumulation of suspended algae within the traps.

4.4.2 Particulate Phase PCB Bed Loading

PCB loading at the Fort Edward station integrated over a period during which the river flow fluctuated from approximately 300 cfs to 7000 cfs (Figure 7) depicted clear vertical patterns (Figure 38). PCB bed loading[7] (Figure 14) at this station was three to five times the loading occurring within the air-water interface and mid channel depth compartments. Moreover, this bed loading differed in composition from that of the other samples within the profile and more closely resembled unaltered PCBs consistent with that found on the Hudson Falls Plant site (Figure 28). These data indicate that bed loading during elevated flow events may be transporting PCB from the Hudson Falls Plant site area downstream into the TIP. Such loading would escape detection under the current monitoring program, which does not include sampling near the sediment-water interface and does not sample at a frequency sufficient to capture short term loading events such as that observed during this study (O'Brien & Gere, 1992). These data suggest that a portion of the loading from the Hudson Falls Plant site area into the TIP may be missed under the current monitoring program.

[7]PCB bed loading was operationally defined as loading occurring within four inches of the sediment-water interface.

5 CONCEPTUAL MODEL OF PCB DNAPL TRANSPORT IN THE UPPER HUDSON RIVER

The behavior of PCB DNAPL within natural aquatic systems is not well understood. However, the results of the PCB DNAPL transport study provide a basis upon which to develop a conceptual model of PCB DNAPL transport within the upper Hudson River (Figure 39).

5.1 PCB DNAPL Loadings

Direct PCB DNAPL discharges have been observed in the Hudson River adjacent to the Hudson Falls Plant site (Figure 39). The collapse of a gate structure within the 150 year old Allen Mill in September 1991 is believed to have caused the release of a substantial quantity of PCB DNAPL into the Hudson River. This event represented the largest PCB loading to the system since the cessation of plant discharges in the late 1970s. Additionally, PCB DNAPL oils are being transported through bed rock fractures and released directly into the Hudson River from river bed seeps adjacent to the Hudson Falls Plant site. These seeps represent an additional source of PCB DNAPL to the system. Oil collection efforts from one seep alone (Seep 13) have yielded an estimated 16 liters (48 lbs) of PCB DNAPL oils (GE, 1996).

5.2 PCB DNAPL Accumulation/Dissolution

Once in the river, PCB DNAPL may accumulate near the source location as the larger fluorescent particles appeared to do. Theoretically, DNAPL oil discharges or droplets emanating from the bed rock fractures will behave in a manner similar to the fluorescent particles possessing the same diameter. That is, droplets in excess of 190 um

will likely settle from the water column and associate with the river bed during periods of non-scouring flows.

5.3 Mobilization of PCB DNAPL During Periods of Elevated Flow Velocities

As flow velocities along the sediment-water interface increase during periods of elevated flow, the DNAPL droplets accumulated in the river may become resuspended in the water column and be subject to downstream transport (Figure 39). Such a process may have transported the fluorescent particles observed in the bed load samples during the spring high flow event of 1997 (seven months after the particles were discharged into the river). Such resuspension occurs almost instantaneously at the point when critical shear velocities are reached at the sediment bed surface and would be difficult to capture using conventional sampling and analysis techniques.

5.4 Retention of PCB DNAPL in TIP

Once mobilized, PCB DNAPL is subject to advection downstream. Upon reaching the TIP, river flow velocities decrease and the droplets settle and accumulate in the surface sediments (Figure 39). The fluorescent particle data suggested that the majority of PCB DNAPL being transported downstream from Hudson Falls is retained within the TIP during periods of relatively low river flow. Once within the TIP sediments, PCB DNAPL is subject to various sediment exchange mechanisms including dissolution, partitioning onto sediment solids, and diffusive or advective flux from the sediment to the water column (Figure 39; Inset). These processes may be responsible, at least in part, for the unaccounted-for load observed from the TIP during summer low flow periods (GE, 1997; HydroQual, 1995).

6. CONCLUSIONS

The PCB DNAPL transport study provides a unique data set from which to infer the behavior of PCB DNAPL within the Hudson River system. The fluorescent particles employed during this study possessed a density similar to that of PCB DNAPL oils found on the Hudson Falls Plant site and a particle size distribution believed to be representative of DNAPL oil droplets within the river. As such, the behavior of these particles was considered to represent PCB DNAPL behavior in the system. Several conclusions regarding PCB DNAPL may be drawn from the results of this study:

- PCB DNAPL with droplet sizes greater that approximately 200 um entering the river under low river flow conditions will be sequestered near the point of entry into the system,
- PCB DNAPL sequestered near the point of entry into the river may be mobilized during high flow events, possibly as part of the sediment bed load, and
- PCB DNAPL transported downstream to the TIP will be deposited within the TIP during low flow conditions.

The results of this study suggest that oil phase PCB loadings from regions of the river adjacent to the Hudson Falls plant site may be episodic in nature and may be transported as part of the sediment bed load. Based on the results of this study, these loadings would be deposited in the TIP. The sampling methods currently employed for monitoring the PCB dynamics of the system do not capture such loadings. To the extent that these loadings are occurring, they may be contributing to the water column PCB loadings observed across the TIP.

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Table 1.
Raw Fluorescent Particle, PCB, Total Solids, and TOC Data.

SAMPLE #	SAMPLING SITE	SAMPLE LOCATION	SAMPLE DEPTH	SAMPLE TYPE	SAMPLE DATE	Mass Solids Collected (g)	PCB Conc. (mg/kg)	TOC Conc. (mg/kg)	Fluorescent Particle Concentration (#/g)			
									19-38 um	39-114 um	115-190um	Total
1	Fort Edward	West	A/W Int.	Particle Trap	09/18/96	3.83	2.50	190000	1.271E+06	5.180E+04	7.580E+03	1.330E+06
2	Fort Edward	West	Mid Depth	Particle Trap	09/18/96	3.99	3.46	200000	1.220E+06	1.828E+04	9.143E+03	1.247E+06
3	Fort Edward	West	S/W Int.	Particle Trap	09/18/96	67.16	2.16	40000	1.040E+05	4.573E+03	1.524E+02	1.087E+05
4	Fort Edward	East	A/W Int.	Particle Trap	09/18/96	7.27	4.49	270000	2.774E+05	3.630E+04	1.426E+04	3.280E+05
5	Fort Edward	East	S/W Int.	Particle Trap	09/18/96	25.00	6.05	87000	3.909E+04	7.566E+03	3.783E+03	5.044E+04
6	Fort Edward	West	A/W Int.	Particle Trap	09/19/96	3.67	2.83	340000	2.954E+05	2.016E+04	4.745E+03	3.203E+05
7	Fort Edward	West	Mid Depth	Particle Trap	09/19/96	2.10	5.34	310000	3.686E+05	9.997E+03	1.249E+03	3.798E+05
8	Fort Edward	West	S/W Int.	Particle Trap	09/19/96	7.92	2.55	92000	1.010E+05	4.316E+03	1.285E+03	1.066E+05
9	Fort Edward	East	A/W Int.	Particle Trap	09/19/96	3.54	8.68	310000	3.162E+05	1.028E+04	0.000E+00	3.265E+05
10	Fort Edward	East	Mid Depth	Particle Trap	09/19/96	2.80	6.58	250000	1.008E+06	4.460E+03	4.460E+03	1.017E+06
11	Fort Edward	East	S/W Int.	Particle Trap	09/19/96	4.70	2.85	160000	1.636E+05	2.242E+03	1.120E+03	1.670E+05
12	Fort Edward	West	A/W Int.	Particle Trap	09/20/96	2.97	3.22	290000	3.794E+05	2.581E+03	1.290E+03	3.833E+05
13	Fort Edward	West	Mid Depth	Particle Trap	09/20/96	3.85	3.38	230000	3.112E+05	5.895E+03	0.000E+00	3.171E+05
14	Fort Edward	West	S/W Int.	Particle Trap	09/20/96	5.28	1.77	160000	1.529E+05	7.542E+03	0.000E+00	1.604E+05
15	Fort Edward	East	A/W Int.	Particle Trap	09/20/96	4.23	4.25	270000	5.457E+05	6.063E+03	2.425E+03	5.542E+05
16	Fort Edward	East	Mid Depth	Particle Trap	09/20/96	2.90	3.74	270000	3.791E+05	6.174E+03	0.000E+00	3.853E+05
17	Fort Edward	East	S/W Int.	Particle Trap	09/20/96	2.85	4.89	230000	5.248E+05	1.414E+04	3.859E+03	5.428E+05
18	Rogers Is.	West	A/W Int.	Particle Trap	09/18/96	1.33	2.67	220000	1.882E+06	1.398E+04	0.000E+00	1.896E+06
19	Rogers Is.	West	Mid Depth	Particle Trap	09/18/96	2.77	5.04	200000	1.211E+06	1.278E+04	0.000E+00	1.224E+06
20	Rogers Is.	West	S/W Int.	Particle Trap	09/18/96	4.48	3.19	190000	1.018E+06	1.173E+04	3.912E+03	1.034E+06
21	Rogers Is.	East	A/W Int.	Particle Trap	09/18/96	2.38	2.71	300000	1.646E+06	1.304E+03	0.000E+00	1.647E+06
22	Rogers Is.	East	Mid Depth	Particle Trap	09/18/96	2.42	4.48	240000	9.869E+05	1.121E+04	3.738E+03	1.002E+06
23	Rogers Is.	East	S/W Int.	Particle Trap	09/18/96	2.98	5.15	210000	1.131E+06	3.823E+03	0.000E+00	1.135E+06
24	Rogers Is.	West	A/W Int.	Particle Trap	09/19/96	2.17	2.96	320000	3.363E+05	7.852E+03	1.308E+03	3.455E+05
25	Rogers Is.	West	Mid Depth	Particle Trap	09/19/96	1.68	3.54	290000	5.520E+05	1.210E+04	0.000E+00	5.641E+05
26	Rogers Is.	West	S/W Int.	Particle Trap	09/19/96	0.75	4.70	240000	8.580E+05	2.055E+04	0.000E+00	8.786E+05
27	Rogers Is.	East	A/W Int.	Particle Trap	09/19/96	1.07	18.60	330000	4.164E+05	4.626E+03	0.000E+00	4.210E+05
28	Rogers Is.	East	Mid Depth	Particle Trap	09/19/96	1.47	4.72	240000	3.666E+05	0.000E+00	0.000E+00	3.666E+05
29	Rogers Is.	East	S/W Int.	Particle Trap	09/19/96	2.10	4.46	250000	1.302E+05	6.203E+03	3.100E+03	1.395E+05
30	Rogers Is.	West	A/W Int.	Particle Trap	09/20/96	2.55	2.44	260000	2.424E+05	7.820E+03	0.000E+00	2.502E+05
31	Rogers Is.	West	Mid Depth	Particle Trap	09/20/96	1.60	2.30	260000	3.682E+05	4.328E+03	0.000E+00	3.725E+05
32	Rogers Is.	West	S/W Int.	Particle Trap	09/20/96	1.47	2.37	200000	5.678E+05	7.672E+03	0.000E+00	5.755E+05
33	Rogers Is.	East	A/W Int.	Particle Trap	09/20/96	3.15	2.56	330000	1.443E+05	9.626E+03	0.000E+00	1.539E+05
34	Rogers Is.	East	Mid Depth	Particle Trap	09/20/96	0.52	2.87	280000	1.734E+05	0.000E+00	0.000E+00	1.734E+05
35	Rogers Is.	East	S/W Int.	Particle Trap	09/20/96	2.56	7.40	330000	9.450E+04	0.000E+00	0.000E+00	9.450E+04

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Raw Fluorescent Particle, PCB, Total Solids, and TOC Data.

SAMPLE #	SAMPLING SITE	SAMPLE LOCATION	SAMPLE DEPTH	SAMPLE TYPE	SAMPLE DATE	Mass Solids Collected (g)	PCB Conc. (mg/kg)	TOC Conc. (mg/kg)	Fluorescent Particle Concentration (#/g)			
									19-38 um	39-114 um	115-190um	Total
36	Thompson Is.	West	Depth Comp.	Particle Trap	09/20/96	0.98	5.47	-NA-	5.604E+04	0.000E+00	0.000E+00	5.604E+04
37	Thompson Is.	East	Depth Comp.	Particle Trap	09/20/96	1.47	5.14	-NA-	1.321E+05	0.000E+00	0.000E+00	1.321E+05
38	A-1	Remnant 3	-NA-	Sediment Trap	09/23/96	4.51	6.44	130000	3.928E+06	2.329E+04	0.000E+00	3.951E+06
39	B-2	Remnant 4	-NA-	Sediment Trap	09/23/96	6.12	2.35	150000	3.089E+05	4.231E+03	0.000E+00	3.131E+05
40	B-3	Remnant 5	-NA-	Sediment Trap	09/23/96	3.99	2.41	160000	7.138E+04	3.244E+03	0.000E+00	7.462E+04
41	U-4	Unnamed Is.	-NA-	Sediment Trap	09/23/96	4.04	31.90	140000	2.431E+04	0.000E+00	0.000E+00	2.431E+04
42	U-5	Unnamed Is.	-NA-	Sediment Trap	09/23/96	3.93	27.10	150000	8.619E+04	3.192E+03	0.000E+00	8.938E+04
43	U-6	Unnamed Is.	-NA-	Sediment Trap	09/23/96	2.32	12.60	180000	9.729E+04	1.081E+04	0.000E+00	1.081E+05
44	R-7	Rogers Is.	-NA-	Sediment Trap	09/23/96	4.49	6.89	150000	1.471E+05	7.006E+03	3.503E+03	1.576E+05
45	R-8	Rogers Is.	-NA-	Sediment Trap	09/23/96	4.64	8.72	170000	8.815E+04	0.000E+00	0.000E+00	8.815E+04
46	R-9	Rogers Is.	-NA-	Sediment Trap	09/23/96	5.37	6.07	160000	2.237E+05	4.387E+03	0.000E+00	2.281E+05
47	H-10	H-7	-NA-	Sediment Trap	09/23/96	1.78	2.80	150000	6.565E+04	0.000E+00	0.000E+00	6.565E+04
48	H-11	H-7	-NA-	Sediment Trap	09/23/96	1.44	3.79	120000	5.944E+04	0.000E+00	0.000E+00	5.944E+04
49	H-12	H-7	-NA-	Sediment Trap	09/23/96	0.84	-NA-	-NA-	2.508E+04	0.000E+00	0.000E+00	2.508E+04
50	G-13	Griffin Is.	-NA-	Sediment Trap	09/23/96	3.79	5.74	120000	1.070E+06	5.015E+03	0.000E+00	1.075E+06
51	G-14	Griffin Is.	-NA-	Sediment Trap	09/23/96	5.02	5.97	120000	2.645E+04	0.000E+00	0.000E+00	2.645E+04
52	G-15	Griffin Is.	-NA-	Sediment Trap	09/23/96	4.75	5.73	100000	2.095E+04	0.000E+00	0.000E+00	2.095E+04
DUPLICATES:												
53	Fort Edward	West	S/W Int.	Particle Trap	09/18/96	-NA-	3.06	26000	-NA-	-NA-	-NA-	-NA-
54	Fort Edward	East	S/W Int.	Particle Trap	09/18/96	-NA-	2.98	84000	-NA-	-NA-	-NA-	-NA-
55	Fort Edward	West	S/W Int.	Particle Trap	09/19/96	-NA-	1.37	140000	-NA-	-NA-	-NA-	-NA-
56	Fort Edward	West	Mid Depth	Particle Trap	09/20/96	-NA-	2.81	270000	-NA-	-NA-	-NA-	-NA-
57	Rogers Is.	West	S/W Int.	Particle Trap	09/18/96	-NA-	2.58	230000	-NA-	-NA-	-NA-	-NA-
58	Rogers Is.	East	S/W Int.	Particle Trap	09/20/96	-NA-	6.95	290000	-NA-	-NA-	-NA-	-NA-
59	B-2	Remnant 4	-NA-	Sediment Trap	09/23/96	-NA-	2.42	130000	-NA-	-NA-	-NA-	-NA-
60	G-14	Griffin Is.	-NA-	Sediment Trap	09/23/96	-NA-	5.84	110000	-NA-	-NA-	-NA-	-NA-
61	Fort Edward	West	S/W Int.	Particle Trap	09/18/96	-NA-	-NA-	-NA-	7.128E+04	2.970E+03	0.000E+00	7.425E+04
62	Fort Edward	East	A/W Int.	Particle Trap	09/18/96	-NA-	-NA-	-NA-	4.495E+06	1.345E+05	1.551E+04	4.645E+06
63	Fort Edward	East	S/W Int.	Particle Trap	09/18/96	-NA-	-NA-	-NA-	2.900E+06	1.318E+04	0.000E+00	2.913E+06
64	Fort Edward	West	S/W Int.	Particle Trap	09/19/96	-NA-	-NA-	-NA-	5.327E+04	2.536E+03	0.000E+00	5.581E+04
65	Fort Edward	East	S/W Int.	Particle Trap	09/19/96	-NA-	-NA-	-NA-	1.645E+05	1.028E+04	0.000E+00	1.748E+05
66	Rogers Is.	West	S/W Int.	Particle Trap	09/18/96	-NA-	-NA-	-NA-	2.191E+06	1.558E+04	0.000E+00	2.207E+06
67	Rogers Is.	West	A/W Int.	Particle Trap	09/19/96	-NA-	-NA-	-NA-	6.043E+05	1.108E+04	0.000E+00	6.154E+05
68	Rogers Is.	West	A/W Int.	Particle Trap	09/20/96	-NA-	-NA-	-NA-	2.780E+05	0.000E+00	0.000E+00	2.780E+05
69	Rogers Is.	East	A/W Int.	Particle Trap	09/20/96	-NA-	-NA-	-NA-	2.683E+04	2.063E+03	0.000E+00	2.889E+04

Table 1. (3/3)
Raw Fluorescent Particle, PCB, Total Solids, and TOC Data.

SAMPLE #	SAMPLING SITE	SAMPLE LOCATION	SAMPLE DEPTH	SAMPLE TYPE	SAMPLE DATE	Mass Solids Collected (g)	PCB Conc. (mg/kg)	TOC Conc. (mg/kg)	Fluorescent Particle Concentration (#/g)			
									19-38 um	39-114 um	115-190um	Total
70	B-2	Remnant 4	-NA-	Sediment Trap	09/23/96	-NA-	-NA-	-NA-	3.039E+05	0.000E+00	0.000E+00	3.039E+05
71	U-4	Unnamed Is.	-NA-	Sediment Trap	09/23/96	-NA-	-NA-	-NA-	1.221E+04	0.000E+00	0.000E+00	1.221E+04
72	R-8	Rogers Is.	-NA-	Sediment Trap	09/23/96	-NA-	-NA-	-NA-	2.393E+05	0.000E+00	0.000E+00	2.393E+05
73	R-9	Rogers Is.	-NA-	Sediment Trap	09/23/96	-NA-	-NA-	-NA-	8.220E+04	5.137E+03	0.000E+00	8.734E+04
74	G-15	Griffin Is.	-NA-	Sediment Trap	09/23/96	-NA-	-NA-	-NA-	4.485E+04	0.000E+00	0.000E+00	4.485E+04

Notes

1) NA - not applicable or not analyzed
2) A/W Int. = air / water interface
3) S/W Int. = sediment water interface
4) Depth Comp. = composite of all 3 sample depths
5) PCB Data are not corrected for analytical biases

Table 2.
In Situ Particle Filtration and Sediment Trap
Total PCB and PCB Homolog Distributions.

(1/2)

321472

SAMPLE #	SAMPLING SITE	SAMPLE LOCATION	SAMPLE DEPTH	PCBs (mg/kg)	PCB Homolog Distribution in Weight Percent									
					MONO	DI	TRI	TETRA	PENTA	HEXA	HEPTA	OCTA	NONA	DECA
1	Fort Edward	West	A/W Int.	2.50	0.00	8.79	35.09	37.11	11.35	5.77	1.76	0.12	0.00	0.00
2	Fort Edward	West	Mid Depth	3.46	0.00	8.57	37.12	40.30	9.59	3.38	0.95	0.08	0.00	0.00
3	Fort Edward	West	S/W Int.	2.16	0.00	10.08	40.82	38.94	7.69	2.12	0.35	0.00	0.00	0.00
4	Fort Edward	East	A/W Int.	4.49	0.00	6.42	34.72	40.97	11.12	5.13	1.50	0.14	0.00	0.00
5	Fort Edward	East	S/W Int.	6.05	0.00	17.48	43.36	30.58	5.84	2.08	0.61	0.06	0.00	0.00
6	Fort Edward	West	A/W Int.	2.83	0.00	5.41	26.88	43.78	13.77	7.20	2.67	0.28	0.00	0.00
7	Fort Edward	West	Mid Depth	5.34	0.00	4.07	31.91	45.18	11.96	5.04	1.68	0.15	0.00	0.00
8	Fort Edward	West	S/W Int.	2.55	0.00	10.71	41.16	35.75	8.02	3.17	1.08	0.10	0.00	0.00
9	Fort Edward	East	A/W Int.	8.68	0.00	6.62	36.27	40.65	10.03	4.40	1.70	0.34	0.00	0.00
10	Fort Edward	East	Mid Depth	6.58	0.00	4.75	33.74	43.62	11.00	4.65	1.73	0.52	0.00	0.00
11	Fort Edward	East	S/W Int.	2.85	0.00	7.18	34.41	39.76	11.21	5.18	2.08	0.19	0.00	0.00
12	Fort Edward	West	A/W Int.	3.22	0.00	6.17	36.41	41.06	10.19	4.16	1.82	0.19	0.00	0.00
13	Fort Edward	West	Mid Depth	3.38	0.00	7.46	33.14	41.47	11.22	4.80	1.76	0.15	0.00	0.00
14	Fort Edward	West	S/W Int.	1.77	0.00	8.07	34.04	39.55	10.57	5.33	2.24	0.21	0.00	0.00
15	Fort Edward	East	A/W Int.	4.25	0.00	4.78	30.83	43.89	12.41	6.04	1.89	0.16	0.00	0.00
16	Fort Edward	East	Mid Depth	3.74	0.00	4.98	27.81	44.71	12.93	7.02	2.30	0.24	0.00	0.00
17	Fort Edward	East	S/W Int.	4.89	0.00	5.40	29.77	45.39	12.06	5.62	1.56	0.19	0.00	0.00
18	Rogers Is.	West	A/W Int.	2.67	0.00	6.70	33.16	41.11	11.13	5.76	2.04	0.10	0.00	0.00
19	Rogers Is.	West	Mid Depth	5.04	0.00	6.79	34.47	43.92	9.71	3.97	1.09	0.05	0.00	0.00
20	Rogers Is.	West	S/W Int.	3.19	0.00	7.44	36.12	41.69	9.61	4.08	0.96	0.10	0.00	0.00
21	Rogers Is.	East	A/W Int.	2.71	0.00	5.47	27.83	41.83	13.62	7.95	3.05	0.26	0.00	0.00
22	Rogers Is.	East	Mid Depth	4.48	0.00	5.39	31.29	43.65	12.23	5.88	1.43	0.13	0.00	0.00
23	Rogers Is.	East	S/W Int.	5.15	0.00	5.61	31.12	44.72	11.62	5.35	1.48	0.11	0.00	0.00
24	Rogers Is.	West	A/W Int.	2.96	0.00	4.79	25.72	46.04	13.88	6.83	2.42	0.32	0.00	0.00
25	Rogers Is.	West	Mid Depth	3.54	0.00	5.13	30.82	45.46	12.03	5.25	1.18	0.14	0.00	0.00
26	Rogers Is.	West	S/W Int.	4.70	0.00	4.97	34.73	44.39	10.53	4.37	0.94	0.07	0.00	0.00
27	Rogers Is.	East	A/W Int.	18.60	0.00	1.29	31.64	56.72	7.49	2.33	0.49	0.03	0.00	0.00
28	Rogers Is.	East	Mid Depth	4.72	0.00	3.98	25.95	45.34	15.13	7.56	1.83	0.21	0.00	0.00
29	Rogers Is.	East	S/W Int.	4.46	0.00	5.91	33.58	42.31	11.16	5.27	1.61	0.16	0.00	0.00
30	Rogers Is.	West	A/W Int.	2.44	0.00	6.34	30.87	42.68	12.34	5.88	1.69	0.20	0.00	0.00
31	Rogers Is.	West	Mid Depth	2.30	0.00	7.14	32.18	41.58	11.63	5.78	1.53	0.16	0.00	0.00
32	Rogers Is.	West	S/W Int.	2.37	0.00	8.52	33.69	39.70	11.03	5.54	1.38	0.13	0.00	0.00
33	Rogers Is.	East	A/W Int.	2.56	0.00	5.55	26.77	42.21	13.34	8.22	3.82	0.09	0.00	0.00
34	Rogers Is.	East	Mid Depth	2.87	0.00	5.56	28.90	42.66	12.22	7.98	2.55	0.14	0.00	0.00
35	Rogers Is.	East	S/W Int.	7.40	0.00	5.39	31.81	41.72	12.29	6.54	2.01	0.24	0.00	0.00
36	Thompson Is.	West	Depth Comp.	5.47	8.42	12.86	30.02	29.84	10.58	5.38	2.12	0.59	0.09	0.10
37	Thompson Is.	East	Depth Comp.	5.14	9.05	12.66	29.56	30.47	10.41	5.39	1.87	0.38	0.10	0.11
38	A-1	Remnant 3	-NA-	6.44	0.17	4.58	27.14	44.78	13.22	7.60	2.12	0.34	0.05	0.00

Table 2. (2/2)

In Situ Particle Filtration and Sediment Trap
Total PCB and PCB Homolog Distributions.

321473

SAMPLE #	SAMPLING SITE	SAMPLE LOCATION	SAMPLE DEPTH	PCBs (mg/kg)	PCB Homolog Distribution in Weight Percent									
					MONO	DI	TRI	TETRA	PENTA	HEXA	HEPTA	OCTA	NONA	DECA
39	B-2	Remnant 4	-NA-	2.35	1.29	11.67	34.10	34.70	11.09	5.34	1.46	0.29	0.06	0.00
40	B-3	Remnant 5	-NA-	2.41	0.78	10.98	33.74	35.04	12.15	5.56	1.44	0.26	0.04	0.00
41	U-4	Unnamed Is.	-NA-	31.90	2.27	9.06	31.86	36.49	12.42	5.44	1.72	0.53	0.20	0.00
42	U-5	Unnamed Is.	-NA-	27.10	2.62	8.97	30.72	35.63	12.95	6.23	2.06	0.65	0.19	0.00
43	U-6	Unnamed Is.	-NA-	12.60	2.55	9.36	30.81	35.44	12.42	6.13	2.32	0.74	0.24	0.00
44	R-7	Rogers Is.	-NA-	6.89	1.64	7.39	30.76	38.95	12.34	6.47	2.02	0.36	0.06	0.00
45	R-8	Rogers Is.	-NA-	8.72	1.84	8.16	33.19	38.65	10.94	5.38	1.51	0.29	0.05	0.00
46	R-9	Rogers Is.	-NA-	6.07	1.82	7.79	31.01	38.34	12.22	6.47	1.96	0.32	0.06	0.00
47	H-10	H-7	-NA-	2.80	2.98	14.77	32.79	32.81	9.71	5.11	1.59	0.21	0.04	0.00
48	H-11	H-7	-NA-	3.79	3.38	17.55	32.39	29.86	9.76	4.92	1.76	0.33	0.05	0.00
49	H-12	H-7	-NA-	-NA-	-NA-	-NA-	-NA-	-NA-	-NA-	-NA-	-NA	-NA-	-NA-	-NA-
50	G-13	Griffin Is.	-NA-	5.74	7.28	14.53	32.12	30.33	9.35	4.40	1.55	0.39	0.07	0.00
51	G-14	Griffin Is.	-NA-	5.97	5.94	13.74	33.36	31.02	9.43	4.53	1.54	0.35	0.08	0.00
52	G-15	Griffin Is.	-NA-	5.73	6.21	13.77	33.31	30.88	9.33	4.47	1.60	0.37	0.07	0.00
DUPLICATES														
53	Fort Edward	West	S/W Int.	3.06	0.71	10.21	39.98	39.09	7.32	2.34	0.32	0.03	0.00	0.00
54	Fort Edward	East	S/W Int.	2.98	0.15	7.94	34.07	35.78	11.59	7.80	2.29	0.32	0.05	0.00
55	Fort Edward	West	S/W Int.	1.37	0.57	7.81	35.47	39.54	10.68	4.68	1.14	0.11	0.00	0.00
56	Fort Edward	West	Mid Depth	2.81	0.00	7.57	36.07	39.53	10.50	4.93	1.19	0.19	0.01	0.00
57	Rogers Is.	West	S/W Int.	2.58	0.00	8.11	35.90	41.33	9.72	3.87	0.90	0.17	0.00	0.00
58	Rogers Is.	East	S/W Int.	6.95	0.19	6.48	37.56	40.21	9.83	4.34	1.25	0.14	0.00	0.00
59	B-2	Remnant 4	-NA-	2.42	1.17	11.72	34.14	35.03	11.05	5.14	1.39	0.29	0.06	0.00
60	G-14	Griffin Is.	-NA-	5.84	6.22	13.62	33.01	31.16	9.57	4.49	1.50	0.37	0.07	0.00

Notes

1) NA - not applicable or not analyzed
2) A/W Int. = air / water interface
3) S/W Int. = sediment water interface
4) Depth Comp. = composite of all 3 sample depths
5) PCB Data are not corrected for analytical biases

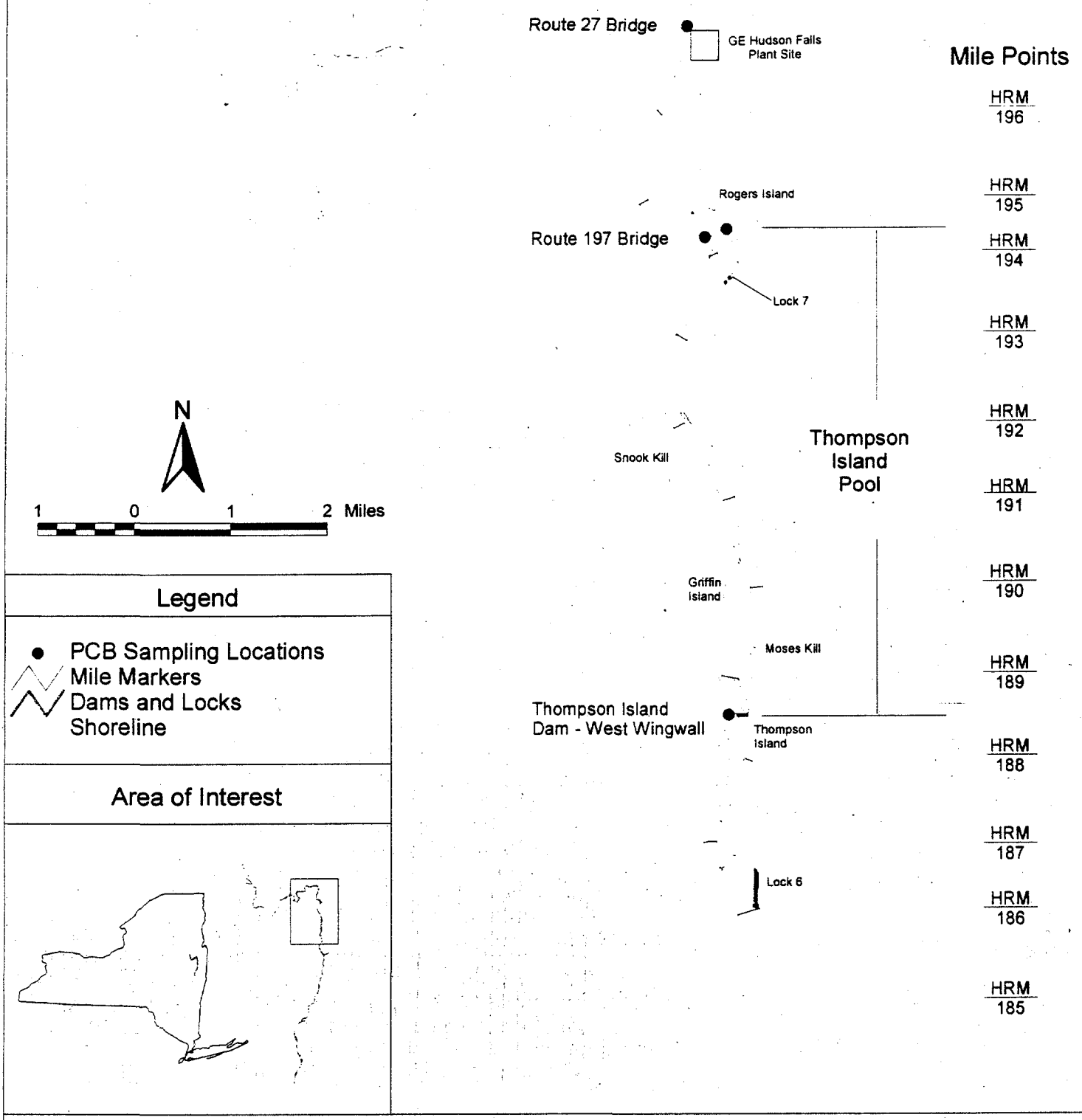
Table 3.
Fluorescent Particle Blank and Spiked Sample Results.

Spiked Sample ID	Spiked Conc. (mg/Kg)	Fluorescent Particle Number Concentration (#/g)				
		19-38 um	38-114 um	114-190 um	190-380 um	>380 um
A	0	589	0	0	0	0
B	10	3420	316	52	0	0
C	100	592000	12200	2760	99	49
D	1000	270000	1520	865	359	45
E	10000	630000	14900	4810	778	0
F	0	743	0	0	0	0
G	10	18700	99	197	0	0
H	100	15500	359	247	98	0
I	1000	-NA-	-NA-	-NA-	-NA-	-NA-
J	10000	572000	17900	7200	927	48
K	0	480	17	0	0	0
L	10	1140	52	0	0	0
M	100	41800	437	430	0	0
N	1000	320000	4110	1480	396	0
O	10000	625000	13800	4070	97	0
BLANK*	0	0	0	0	0	0

**Blank sample prepared separate from other spiked samples to test for natural sediment epifluorescence. Small number of fine fluorescent particles in other 0 mg/Kg spiked samples likely due to cross contamination from balance during laboratory preparation.*

FIGURES

Figure 1



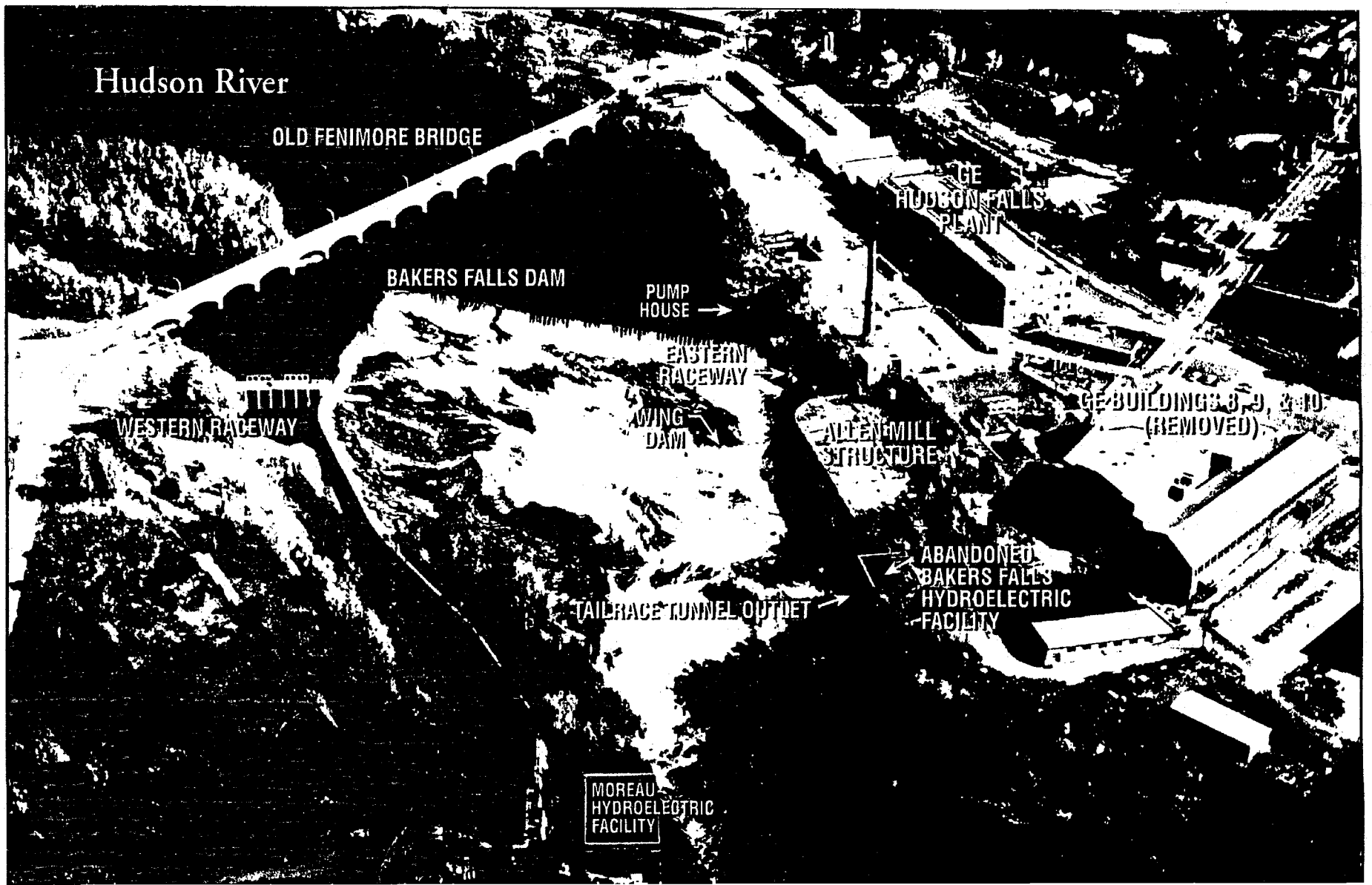
GENERAL ELECTRIC COMPANY - HUDSON RIVER PROJECT
Thompson Island Pool and Routine Water Column Monitoring Locations

HydroQual, Inc.

June, 1997

321476

Figure 2.
Areal Photo of Hudson Falls Plant Site and Allen Mill Structure.



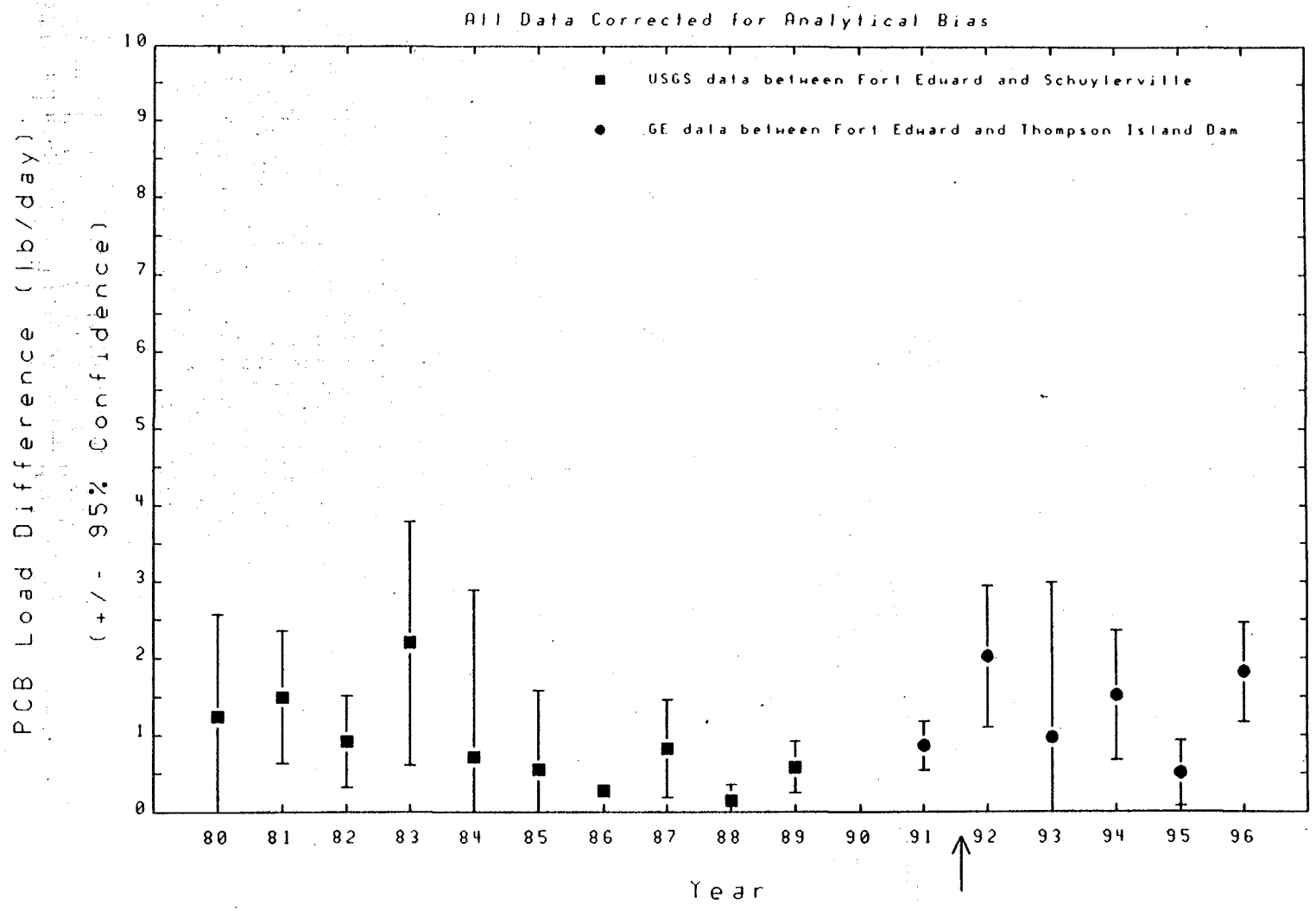


Figure 3.
Average Annual Low Flow TIP Loading.
Note: Fort Edward flow < 10,000 cfs; high loads from 9/91 to 12/91 excluded.

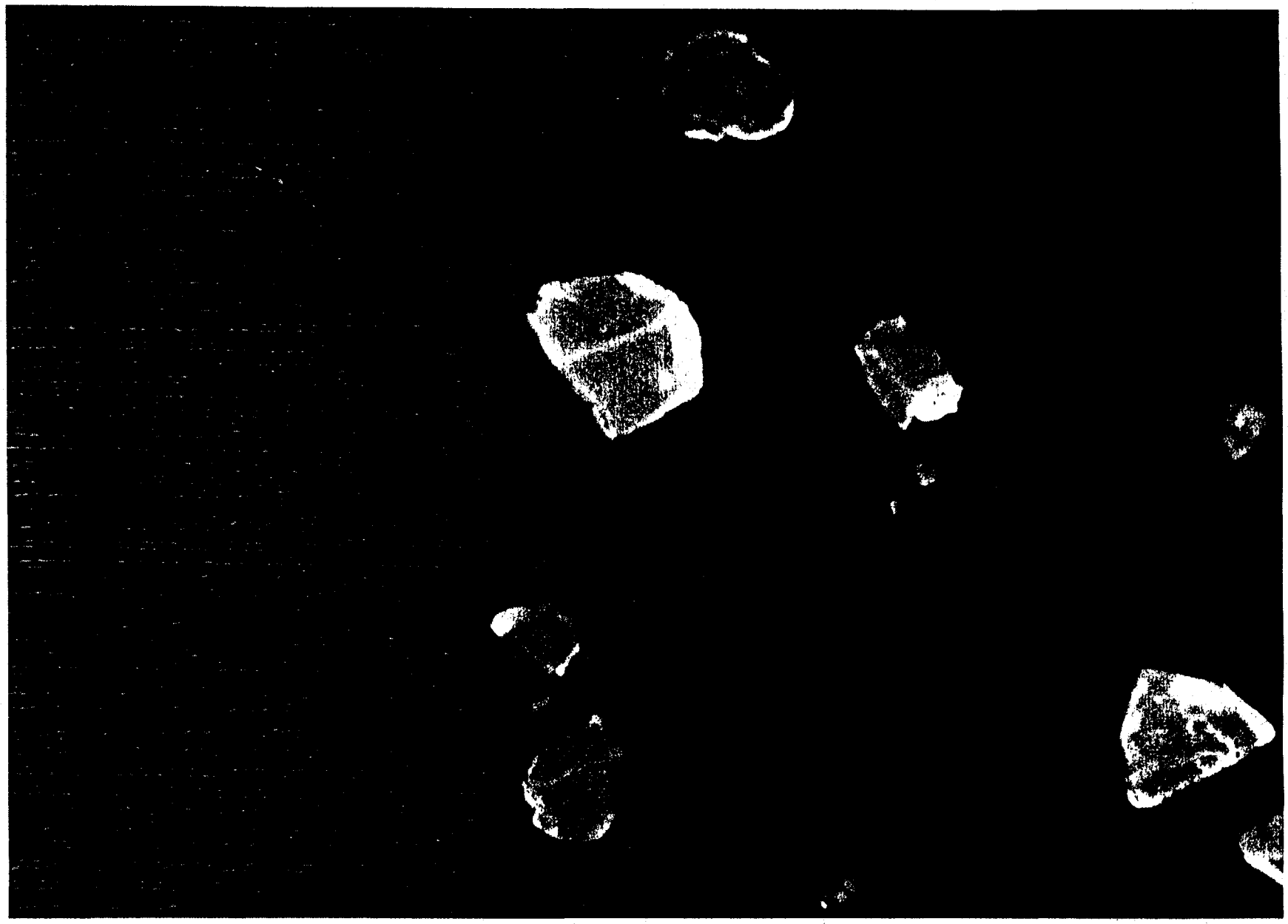


Figure 4.
Epifluorescent Photograph of Fluorescent Particles Within Natural Sediment at Approximately 100x Magnification

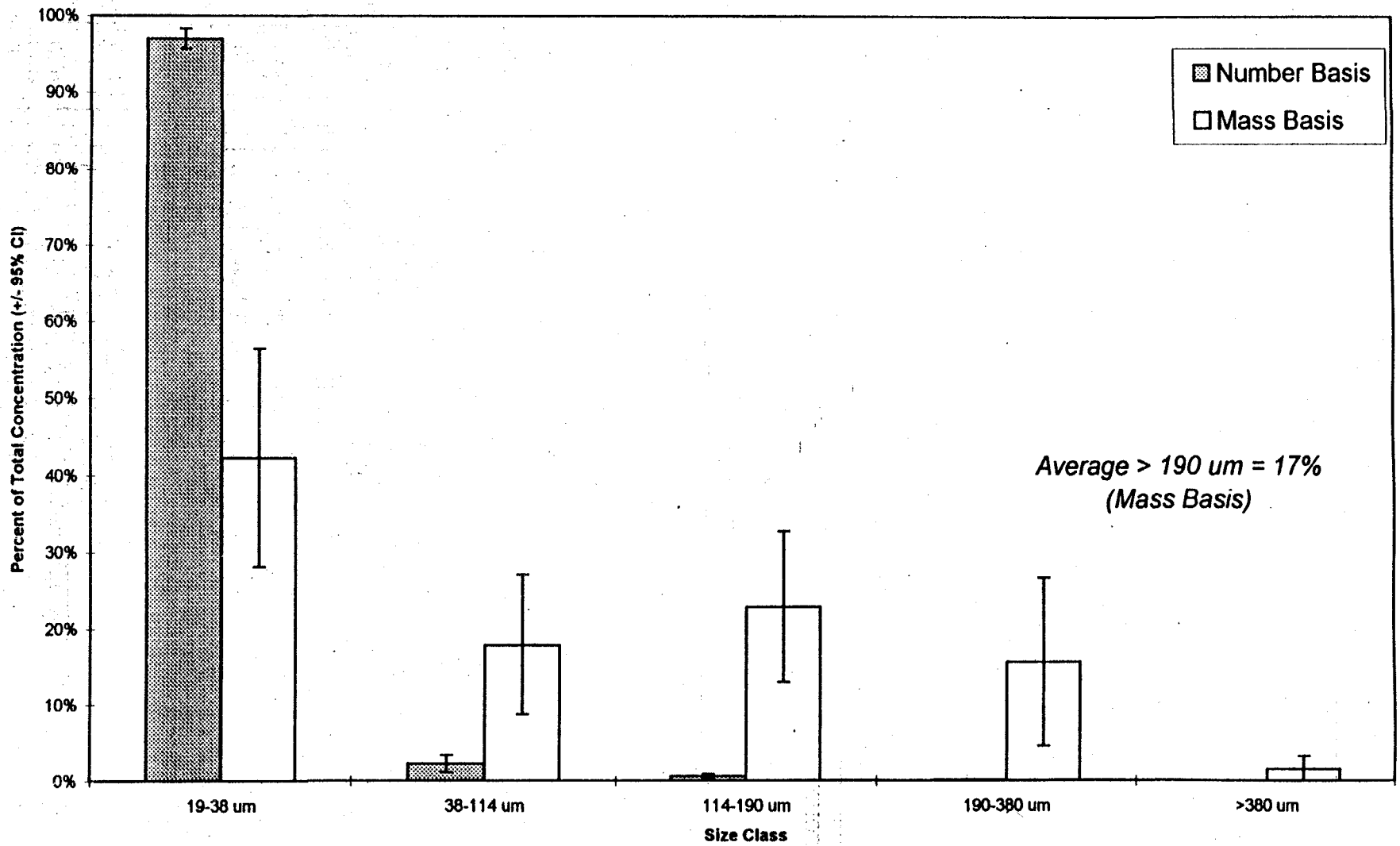
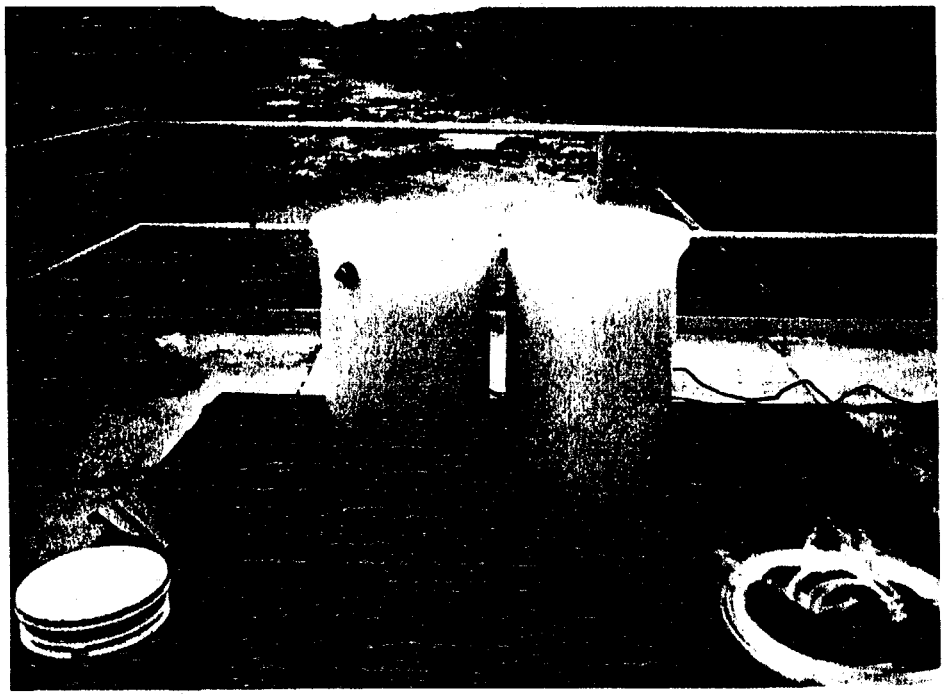
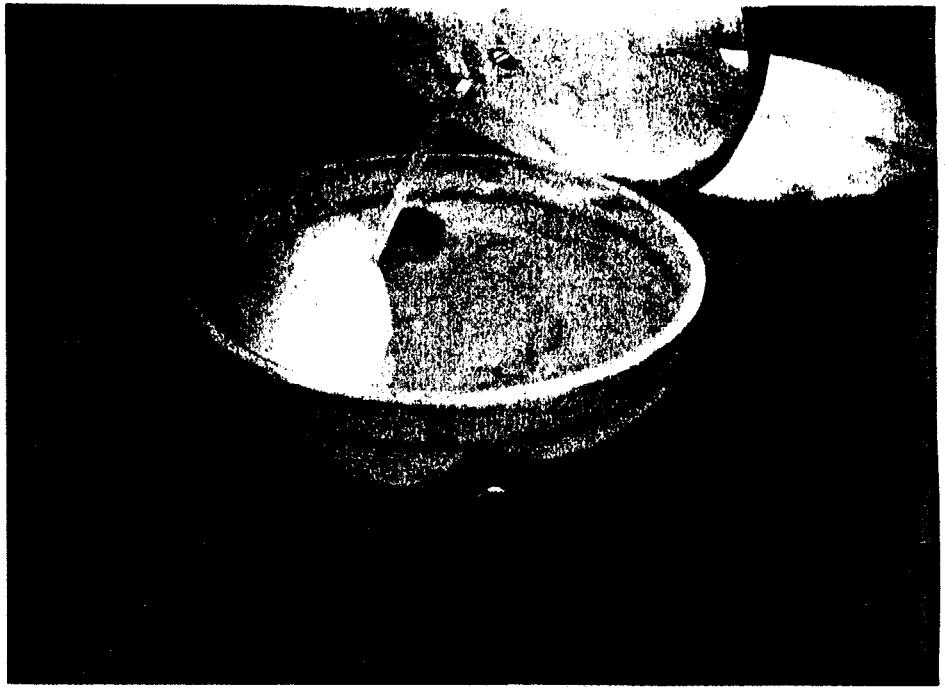


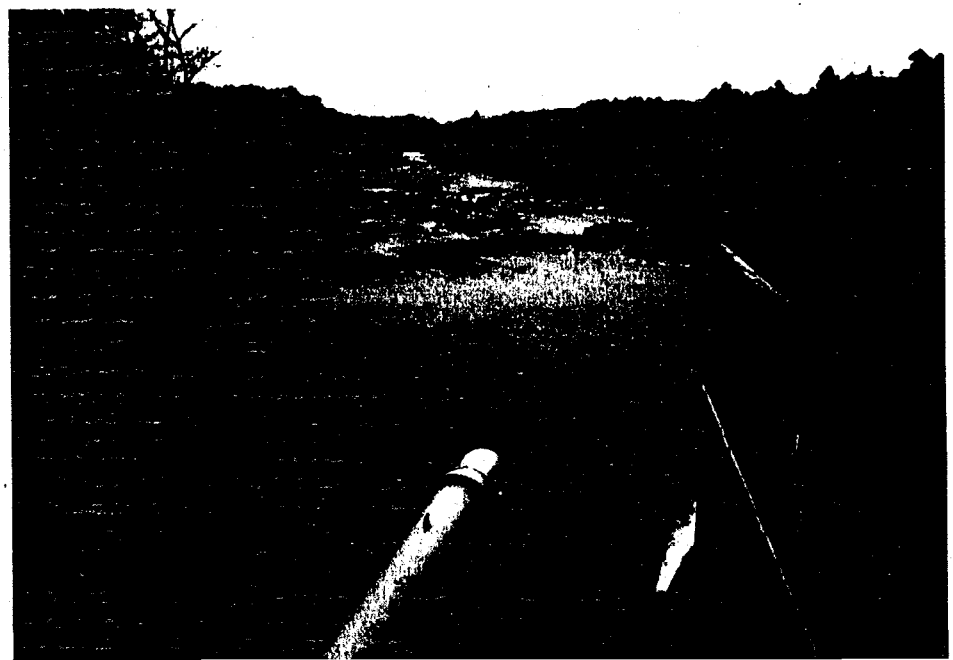
Figure 5.
Mean Particle Size Distribution of Fluorescent Particles Injected Into Hudson River.

(a)



(b)





(c)

Figure 6.
Photographs of a and b) Fluorescent Particle Slurry and c) Fish Bypass Line at Adirondack Hydro Development Corporation's Hydroelectric Station in Hudson Falls, New York into which slurry was injected.

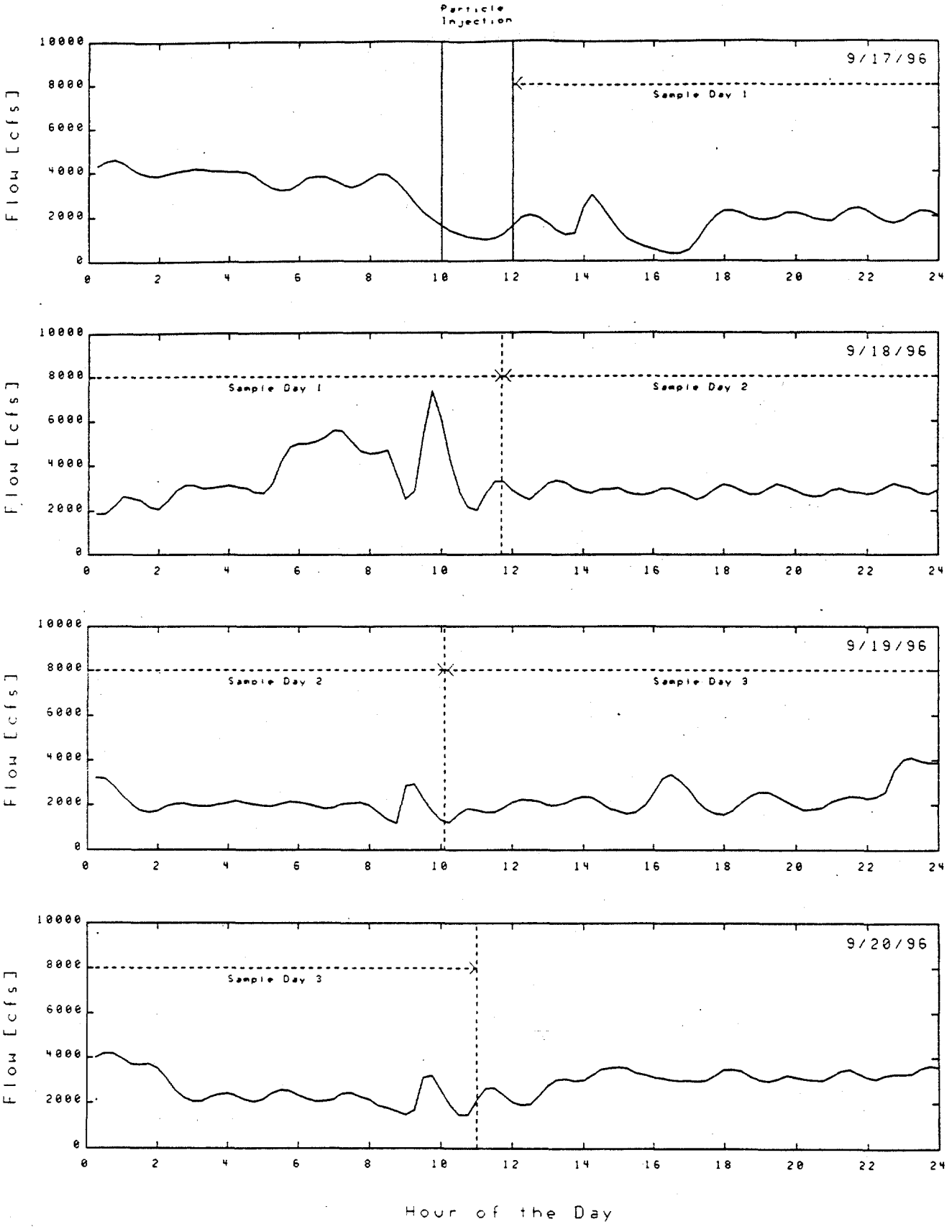


Figure 7.
Hudson River Flows at Fort Edward During the DNAPL Transport Study.
Note: Data are 15 minute flows from USGS station at Fort Edward, NY (Gage #01327750); filtration device sampling times are averages for all stations.

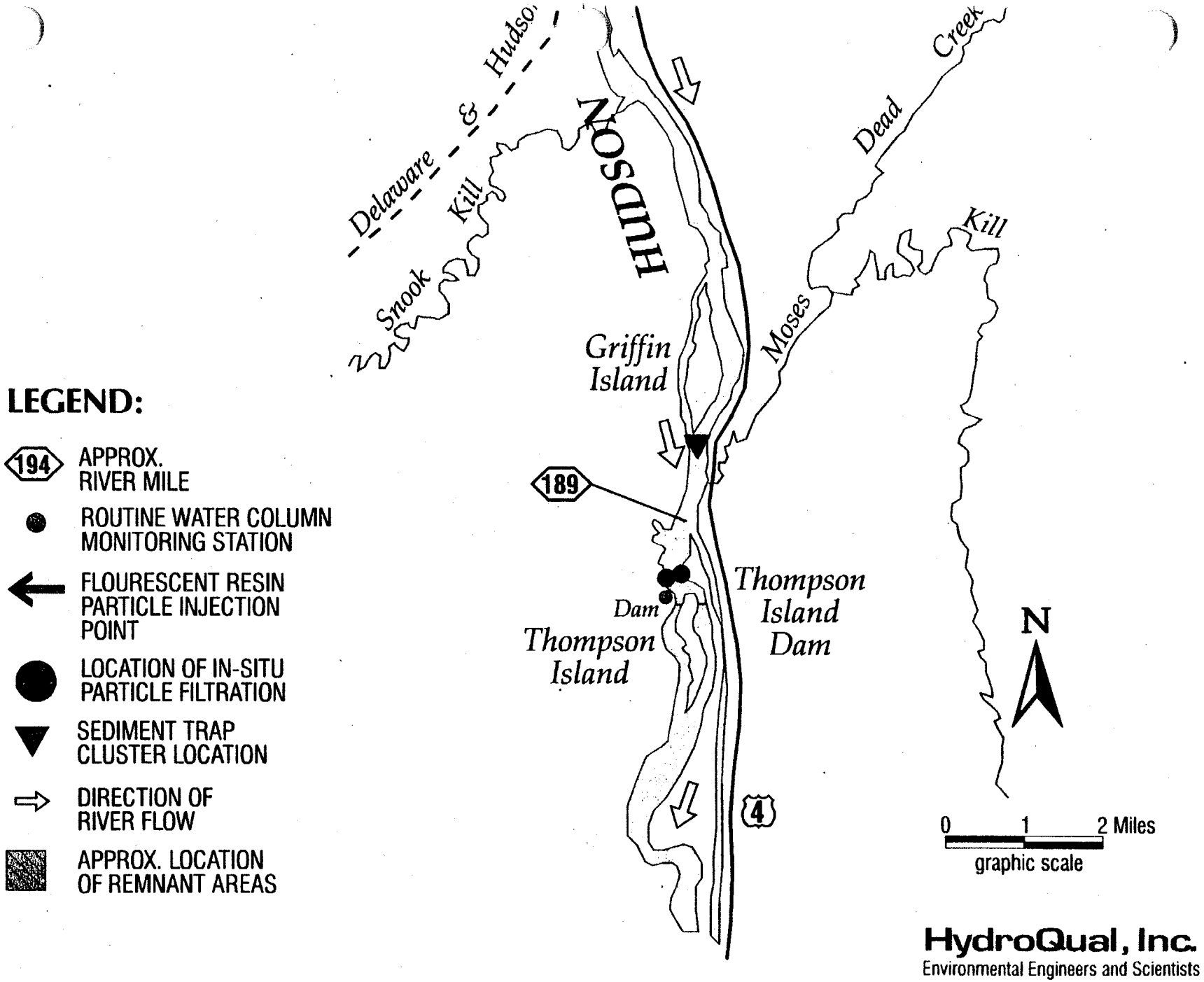
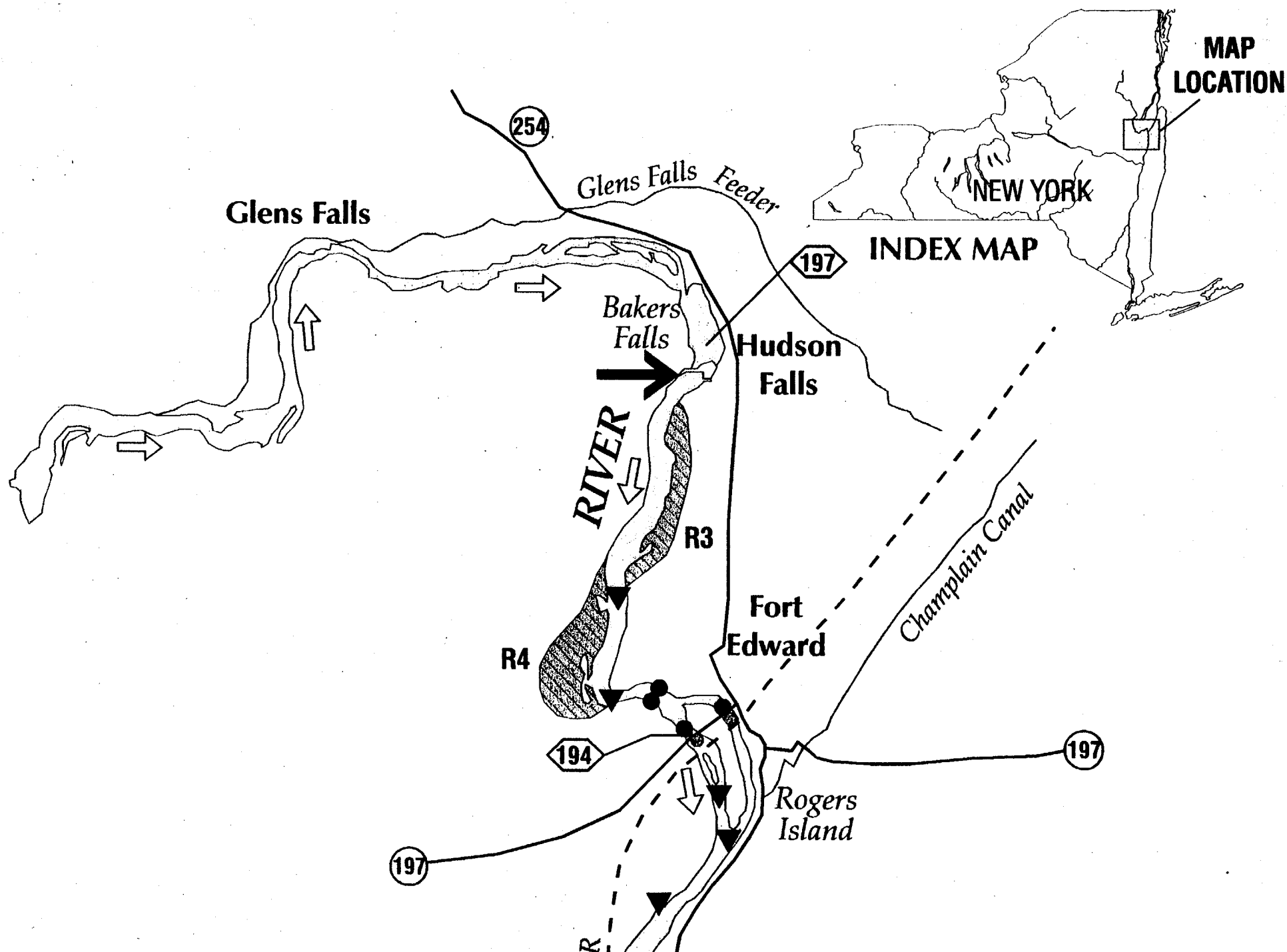


FIGURE 8. FLOURESCENT RESIN PARTICLE INJECTION AND SAMPLING LOCATIONS

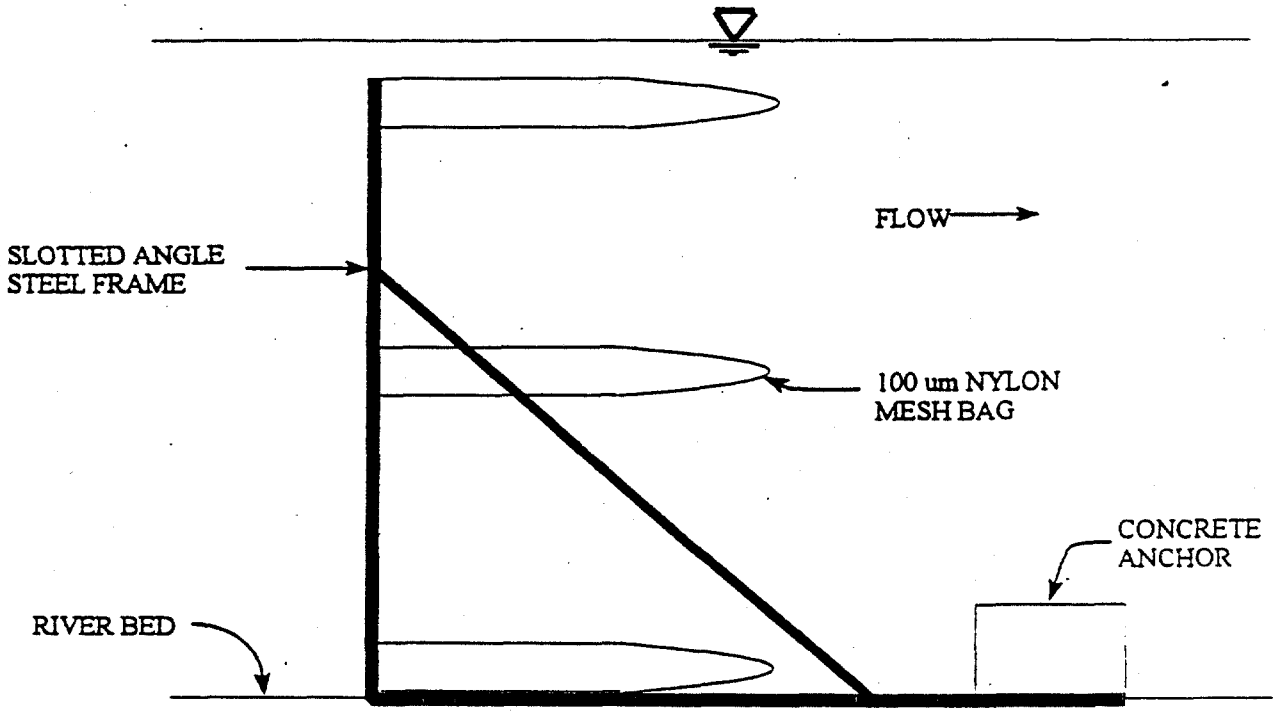
321483


MAP LOCATION
NEW YORK
INDEX MAP
254
Glens Falls Feeder
Glens Falls
197
Bakers Falls
Hudson Falls
RIVER
R3
R4
Fort Edward
Champlain Canal
194
197
197
Rogers Island

321484

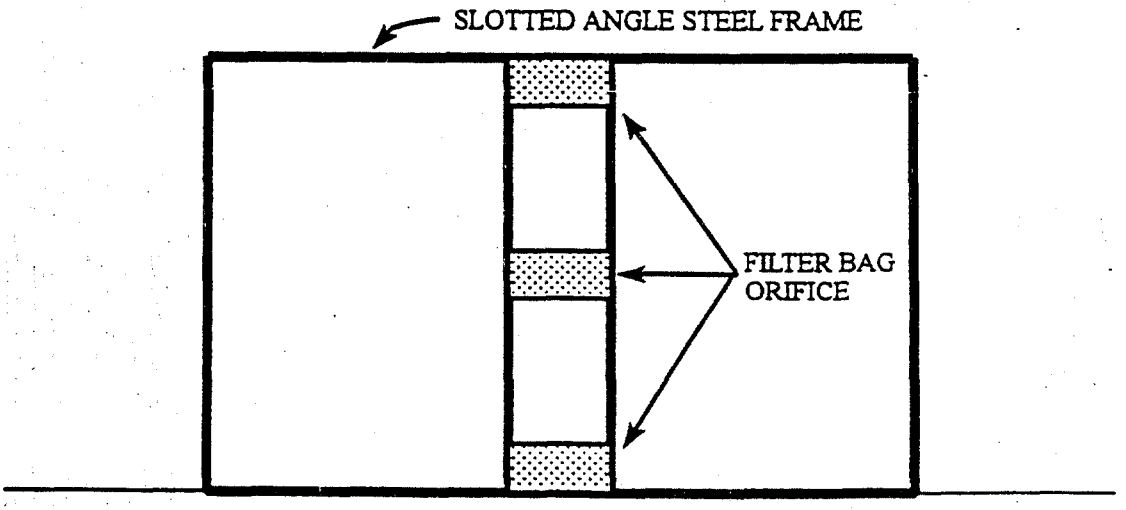
Figure 9.

GENERAL ELECTRIC COMPANY
HUDSON RIVER PCB DNAPL TRANSPORT
SCHEMATIC OF IN-SITU FILTERING APPARATUS



SIDE ELEVATION VIEW

NOT TO SCALE



FRONT ELEVATION VIEW

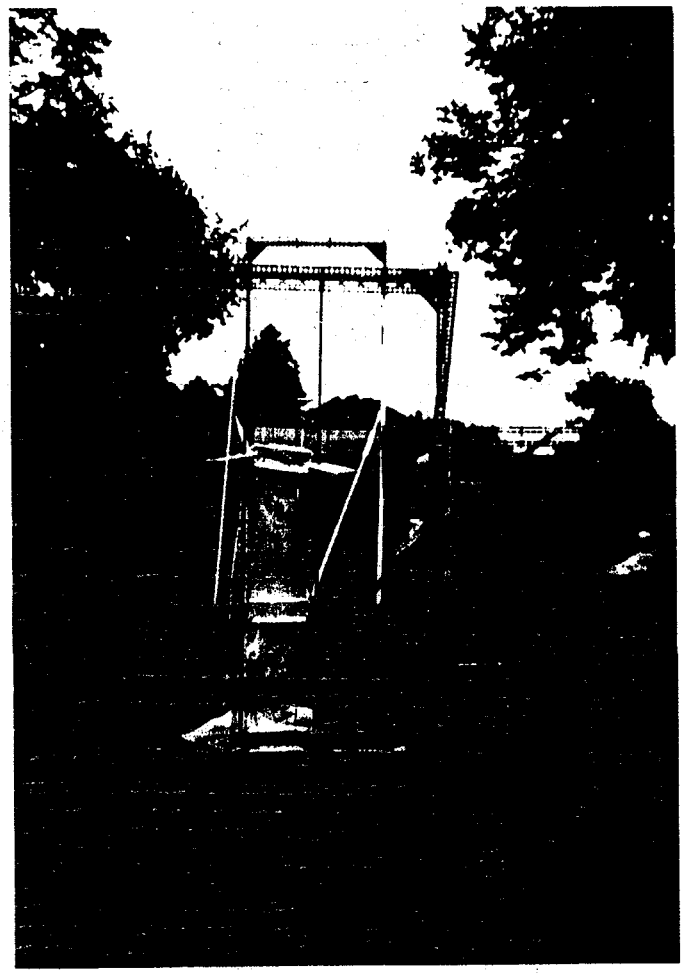
NOT TO SCALE

I:\DIV52\PROJECTS\612205\DWG\PARTRAP.FIG

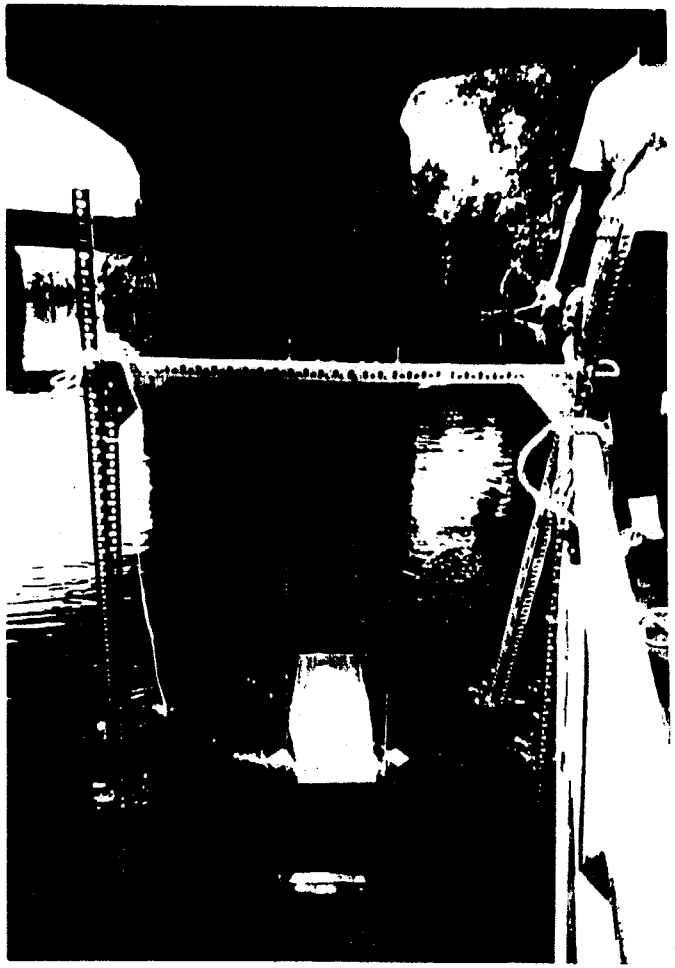
DATE: AUGUST 6, 1996

FILE NO. 0612.205-01F

O'BRIEN & GERE ENGINEERS INC.



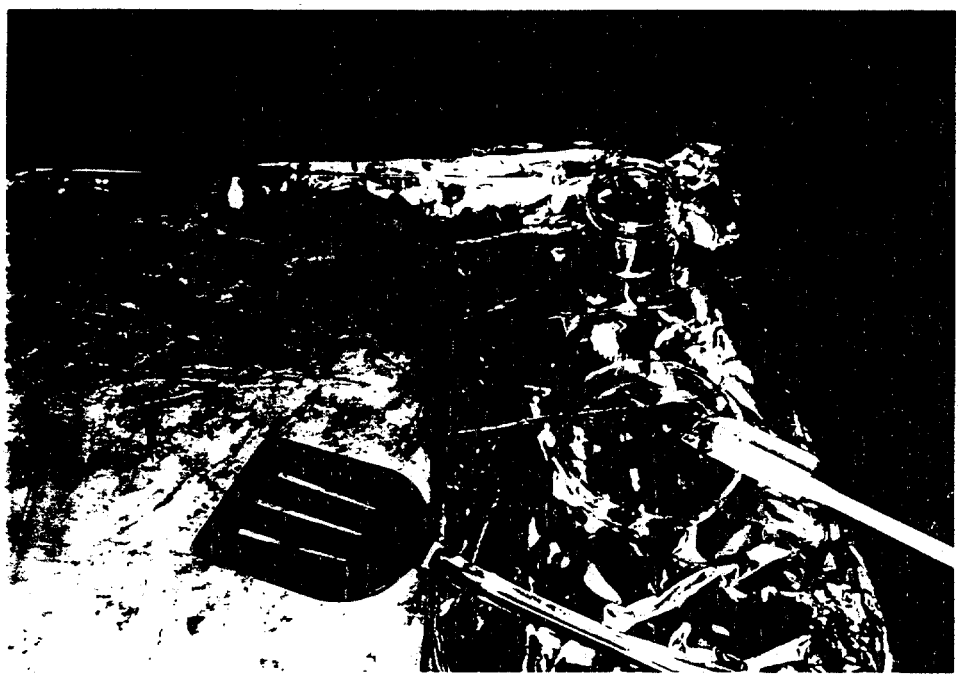
(a)



(b)

Figure 10.
Photographs of *In Situ* Filtration Device a) Assembled on Shore and b) Deployed Within River at Rogers Island East Channel Location.

(a)



(b)

Figure 11.
Photographs of Laboratory Processing of *In Situ* Filtration Samples a) Mesh Nylon Bag Laying Open on Clean Aluminum Foil Awaiting Processing and b) Scraped Solids Sample after Transfer from Mesh Bags into Glass Petri Dish for Drying.

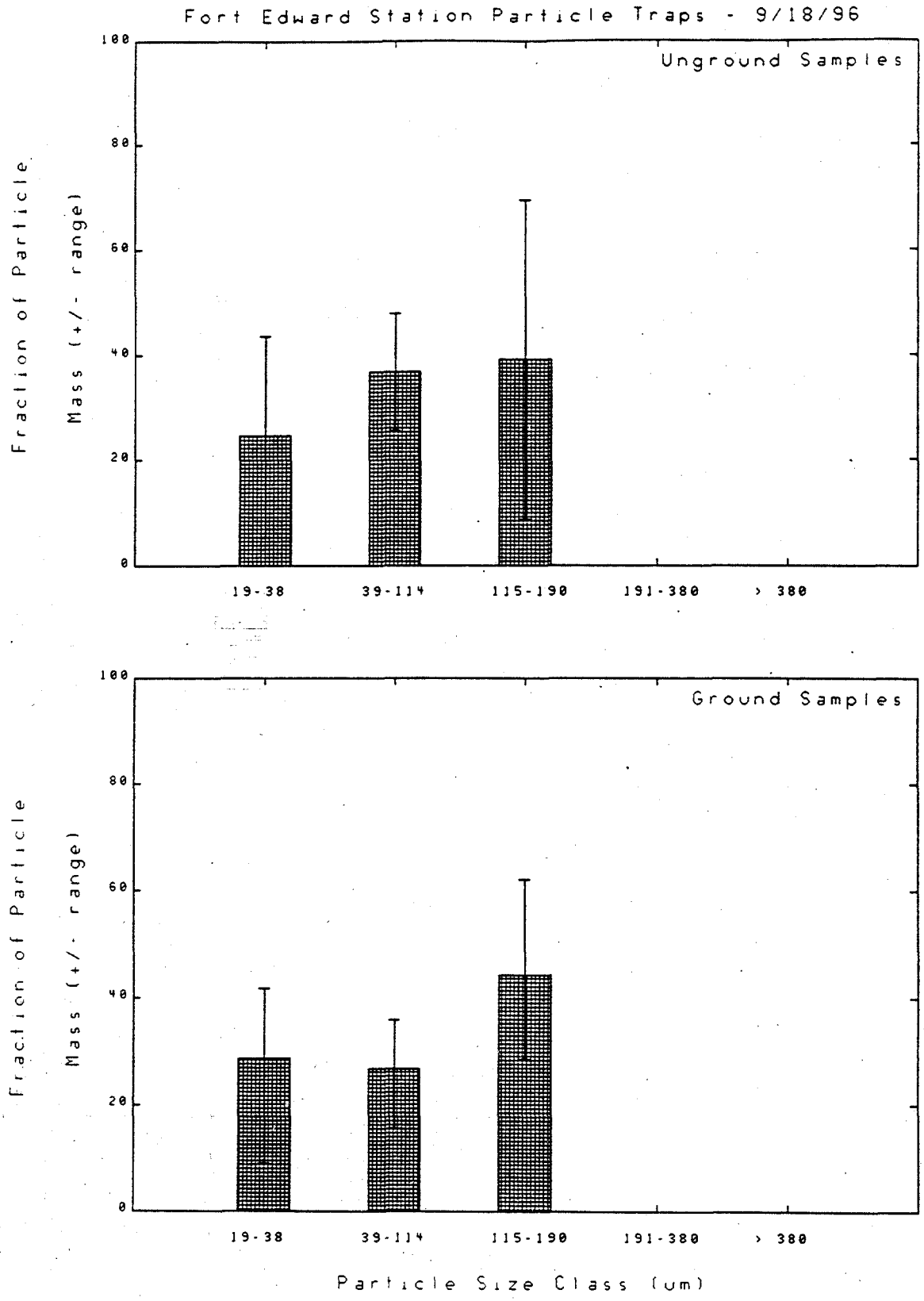


Figure 12.
Fluorescent Particle Size Distribution of Ground and Unground *In Situ* Filtration Samples.

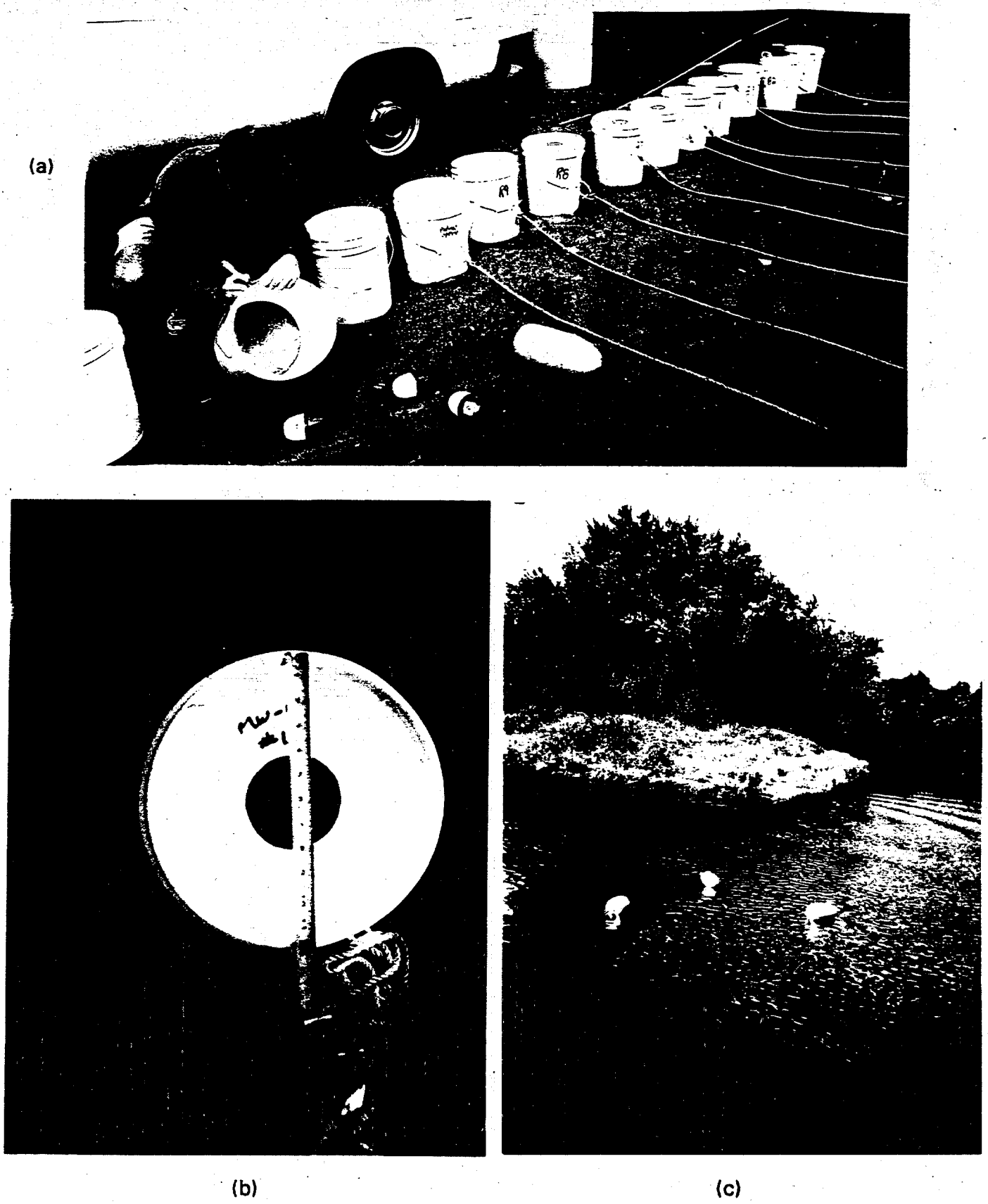


Figure 13.
Photographs of Sediment Traps a) Assembled on Shore Prior to Deployment, b) Top View and c) Deployed Downstream of Unnamed Island in Western Channel of Rogers Island.

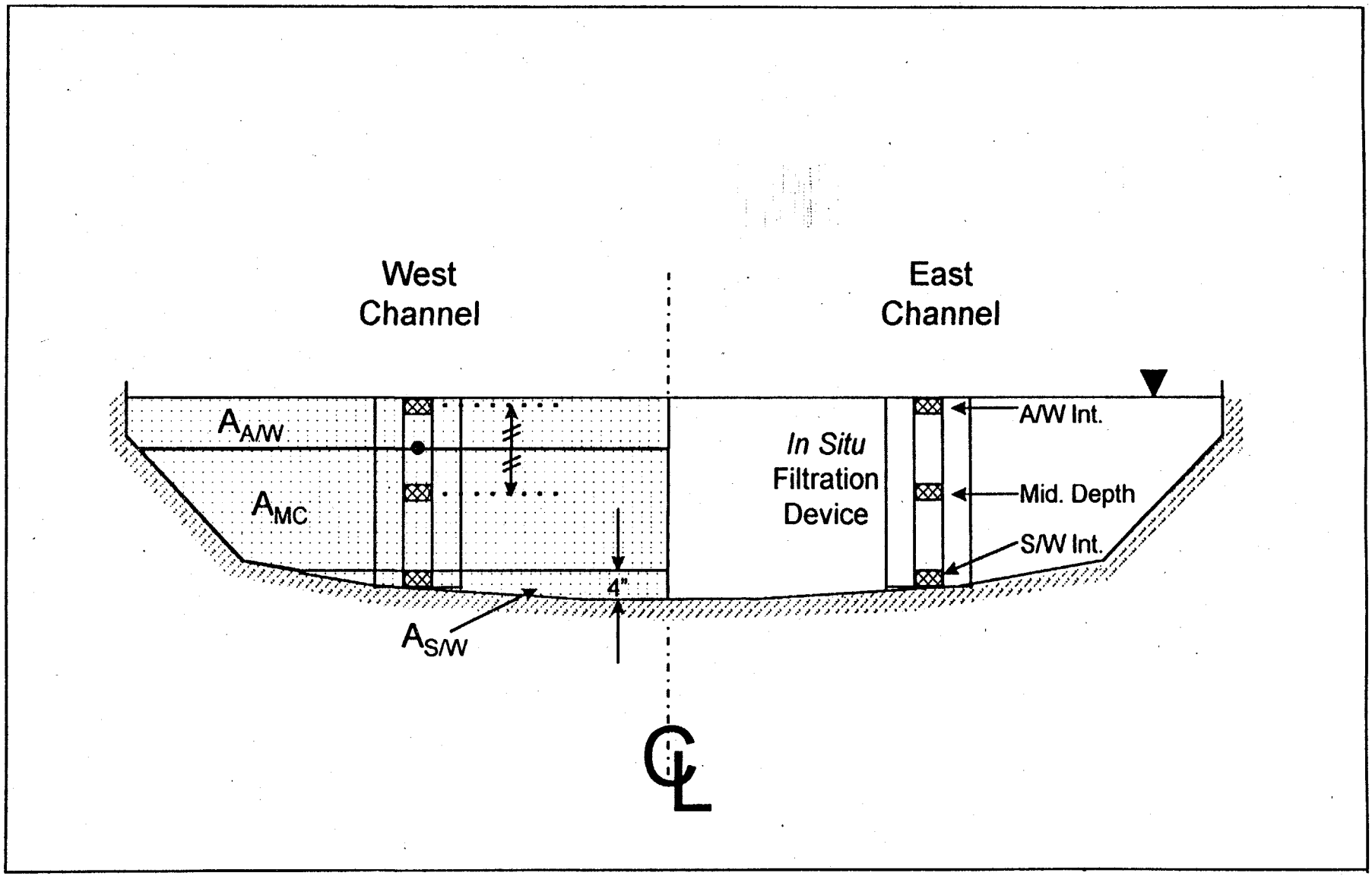


Figure 14.
Schematic of Assigned Cross Sectional Areas for *In Situ* Filtration Mass Balance Calculations.

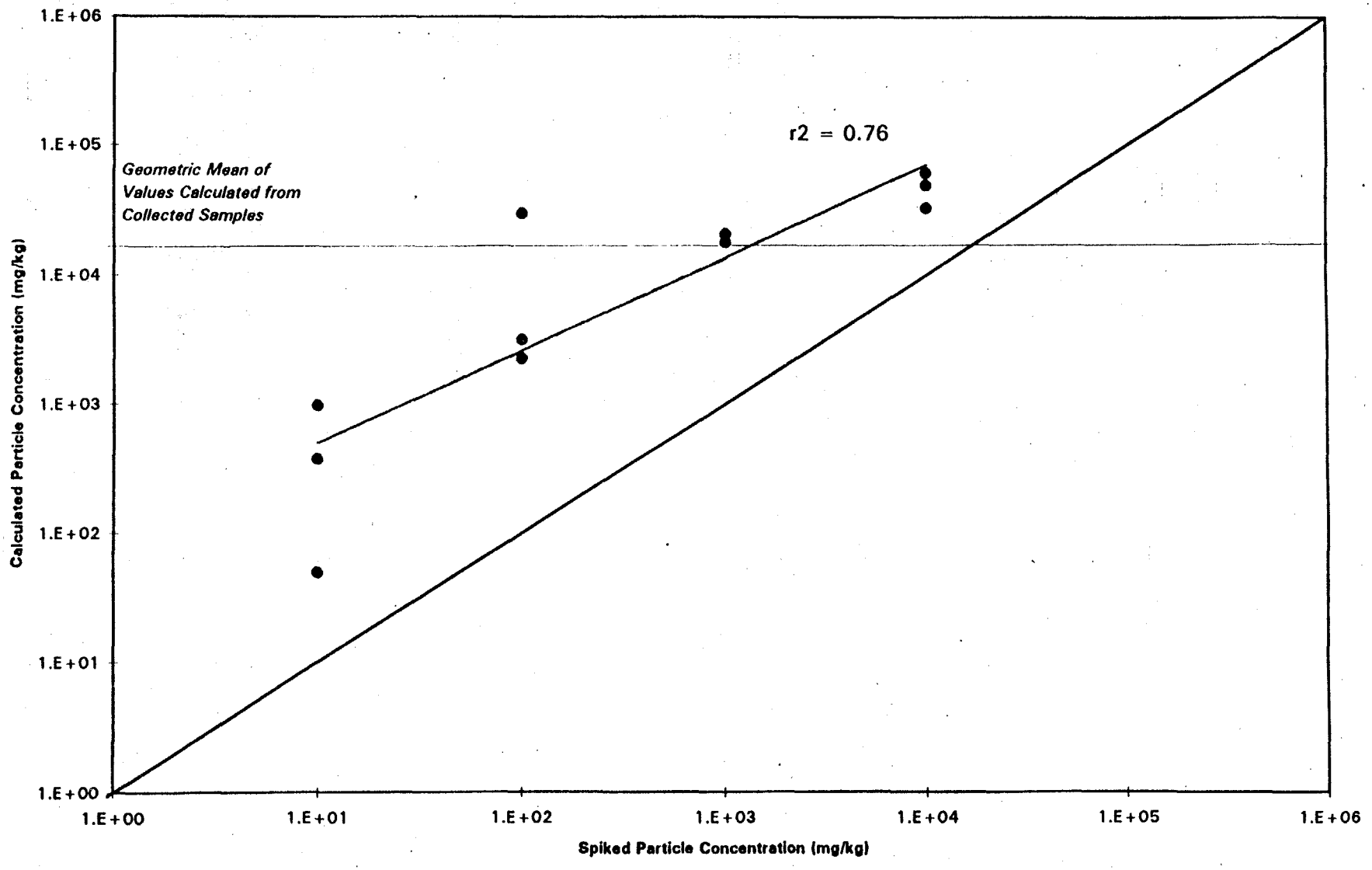


Figure 15.
Blank and Spiked Sediment Fluorescent Particle Analysis Results.

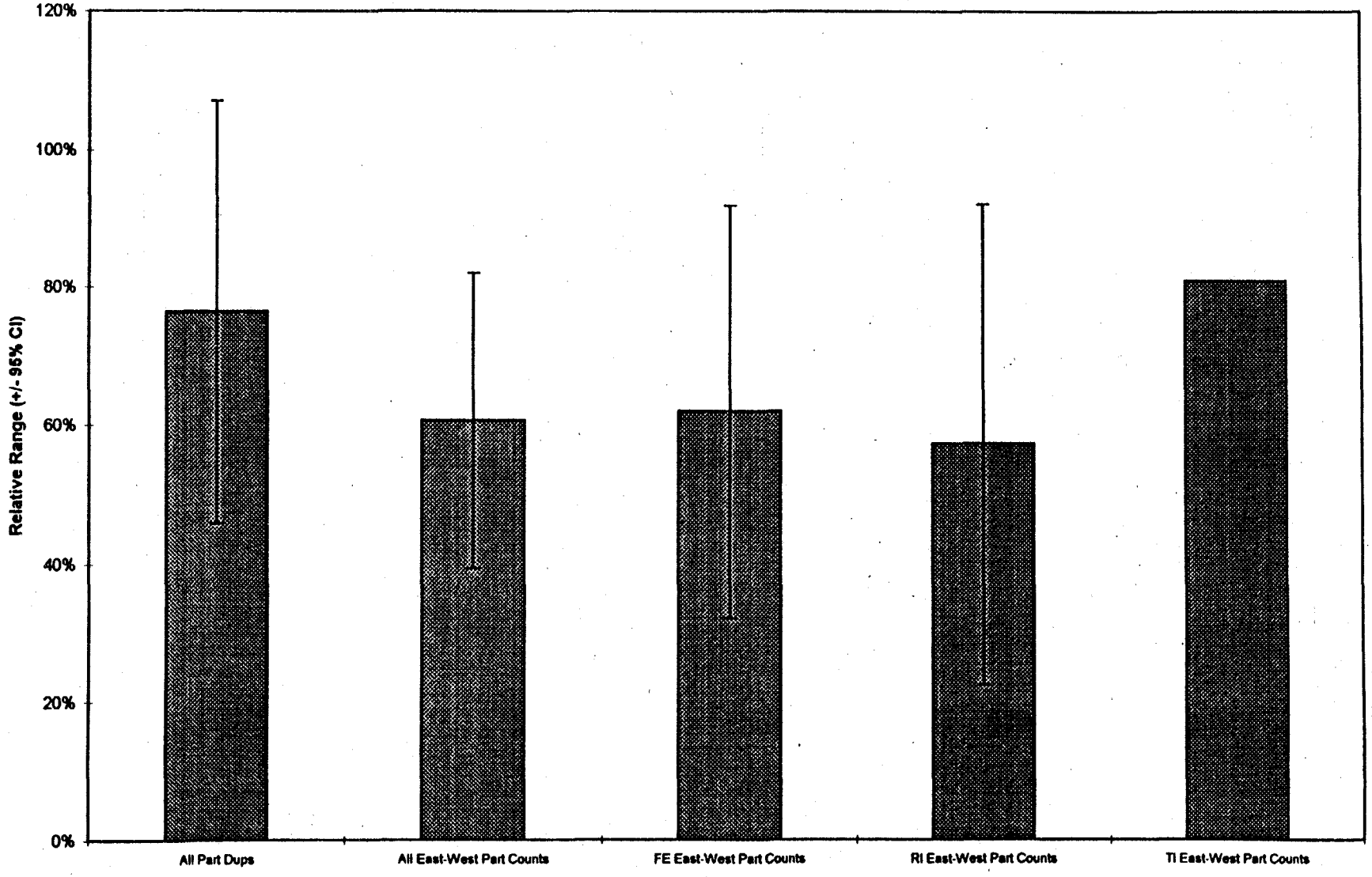


Figure 16.
Mean ± 95% Confidence Intervals of the Relative Range of Fluorescent Particle Counts for Various Sample Groupings.

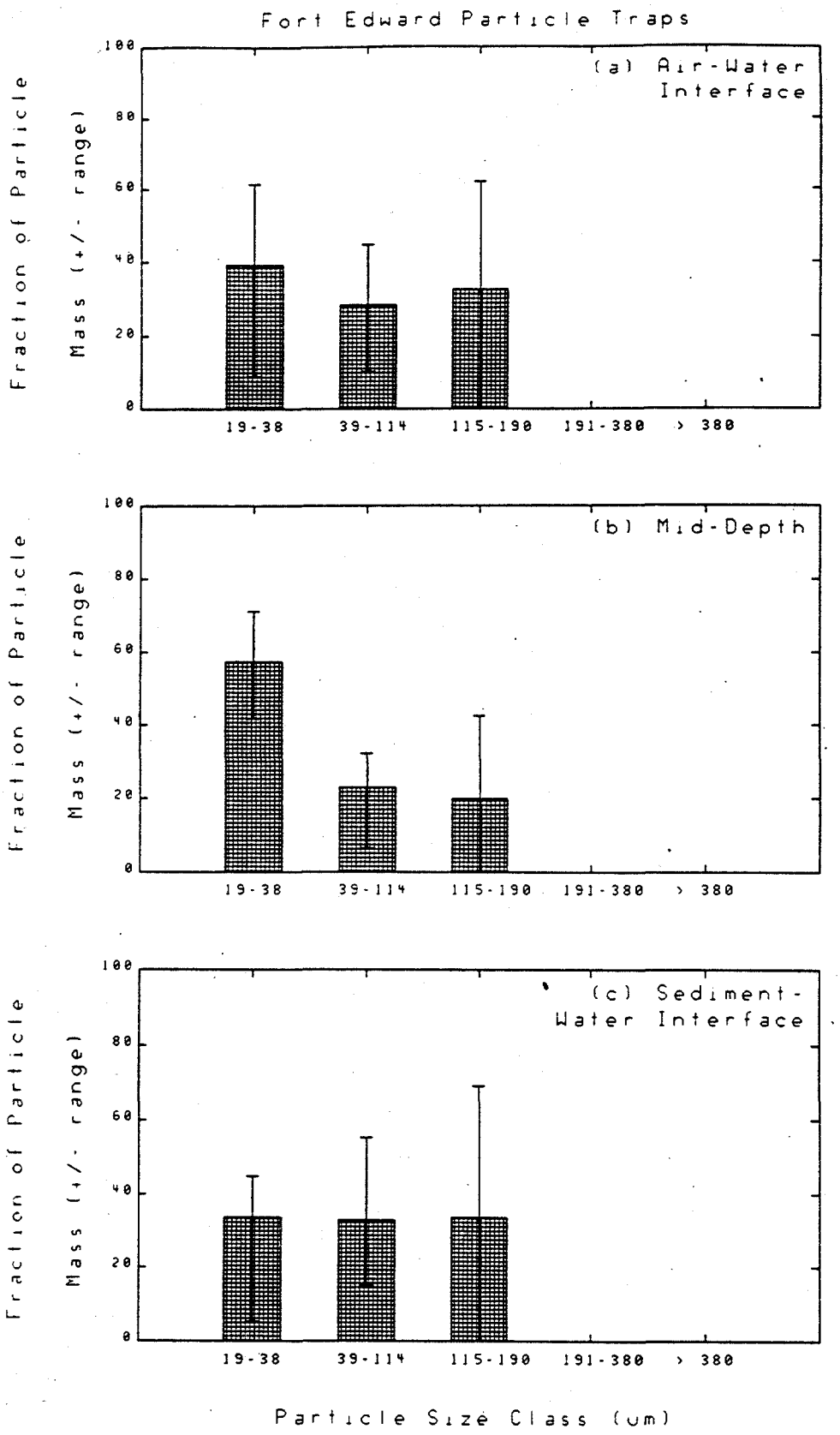


Figure 17.
Mass Fraction of Particles Within Five Particle Size Classes Captured Within Fort Edward *In Situ* Filtration Devices deployed at the a) Air-water Interface, b) Mid Channel Depth, and c) Sediment-Water Interface.

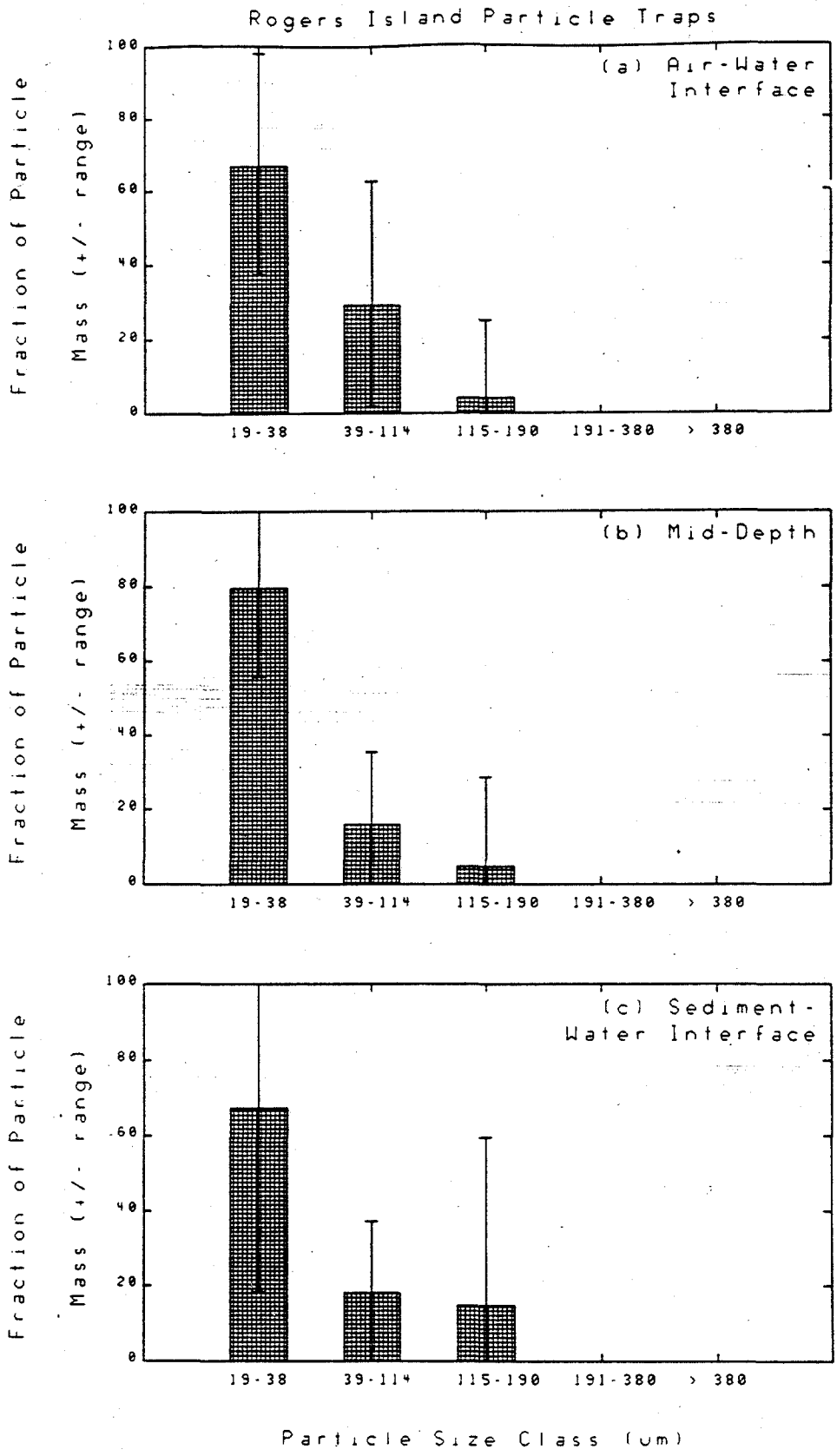


Figure 18.
Mass Fraction of Particles Within Five Particle Size Classes Captured Within Rogers Island *In Situ* Filtration Devices deployed at the a) Air-water Interface, b) Mid Channel Depth, and c) Sediment-Water Interface.

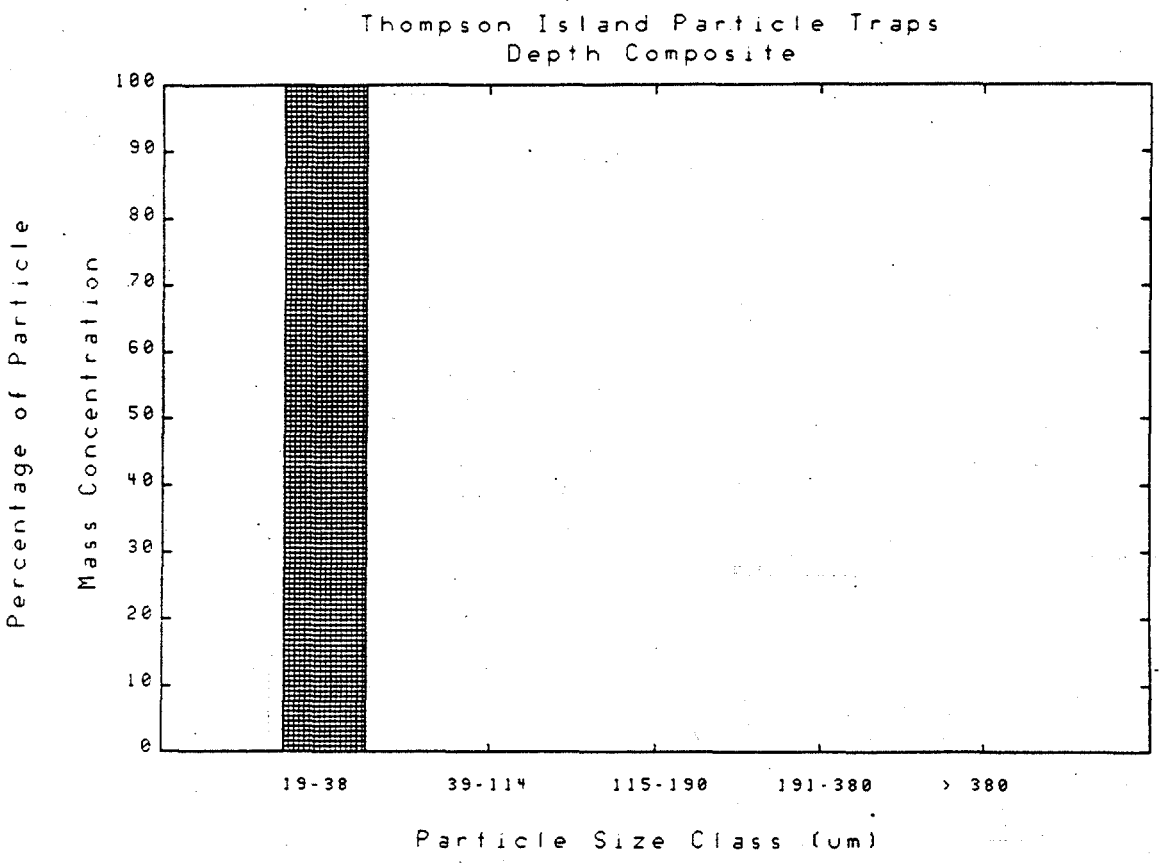


Figure 19.
Mass Fraction of Particles Within Five Particle Size Classes Captured Within Thompson Island Pool *In Situ* Filtration Devices.

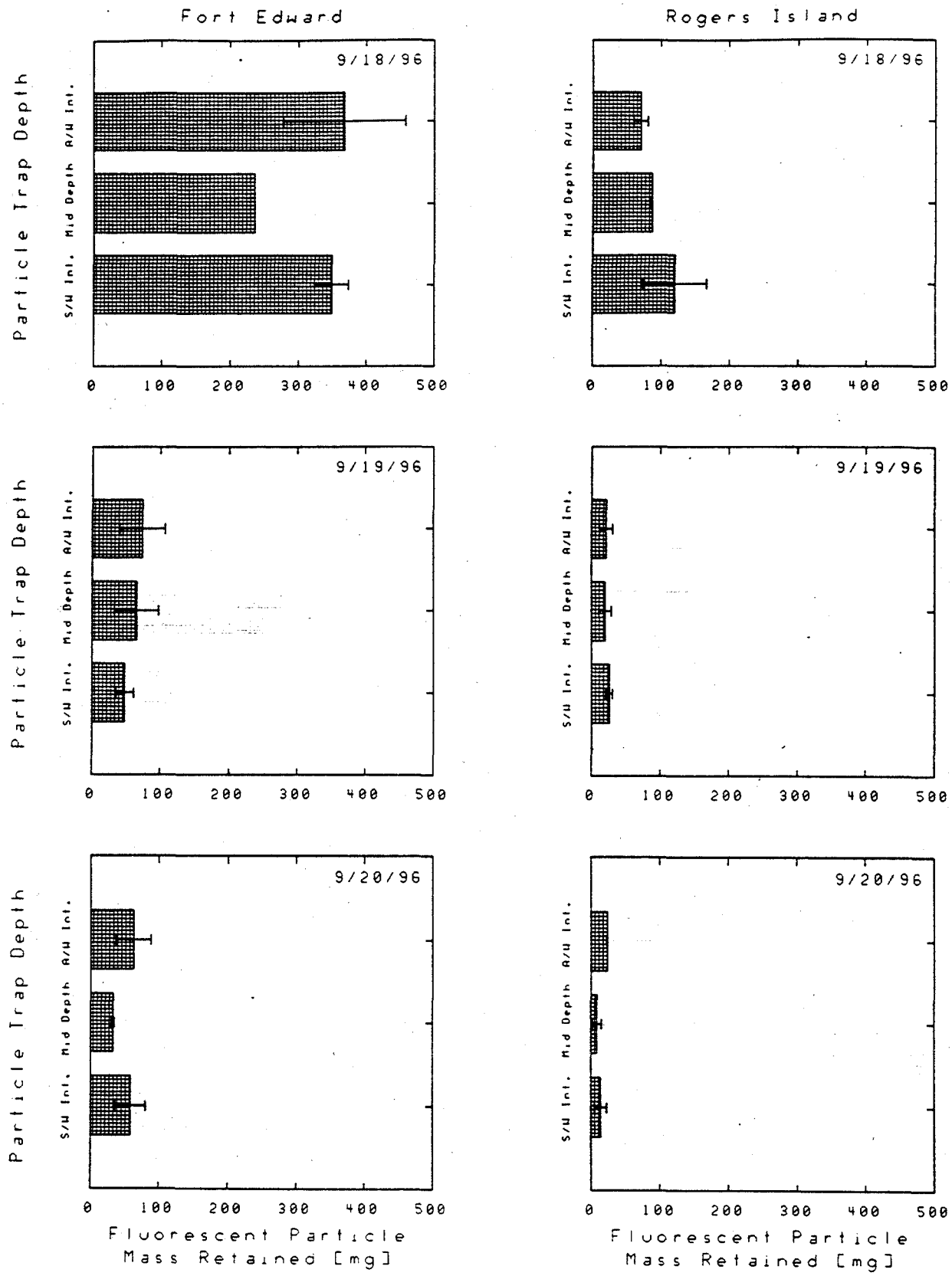


Figure 20.
Fluorescent Particle Mass Retained on Fort Edward and Rogers Island *In Situ* Filtration Devices at Different Deployment Depths over the Three Day Study.
Note: plots are mean ± range for east and west channel data combined.

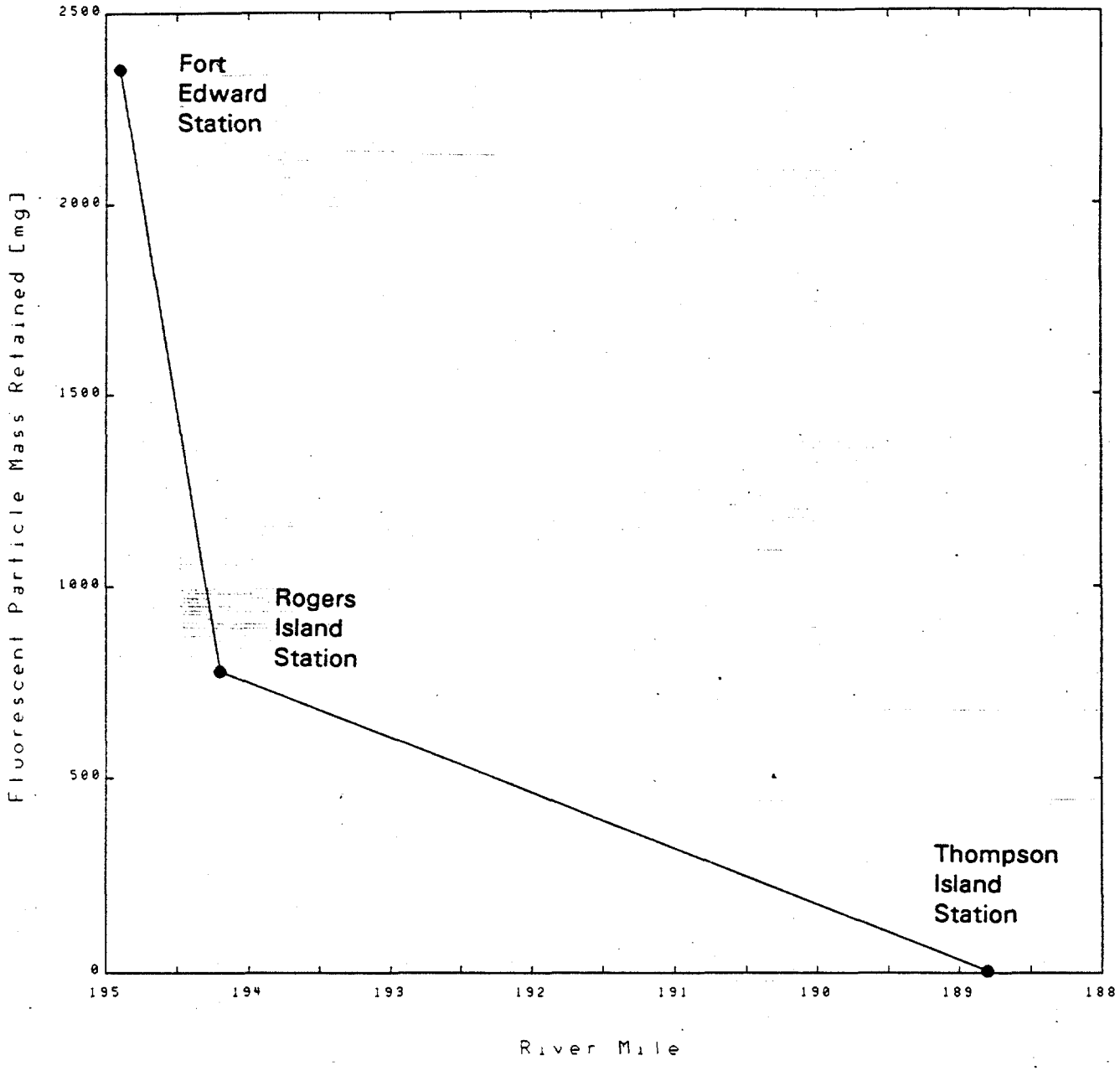


Figure 21.
Spatial Profile of Total Fluorescent Particle Mass Retained Within the *In Situ* Filtration Devices over the Three Day Study.

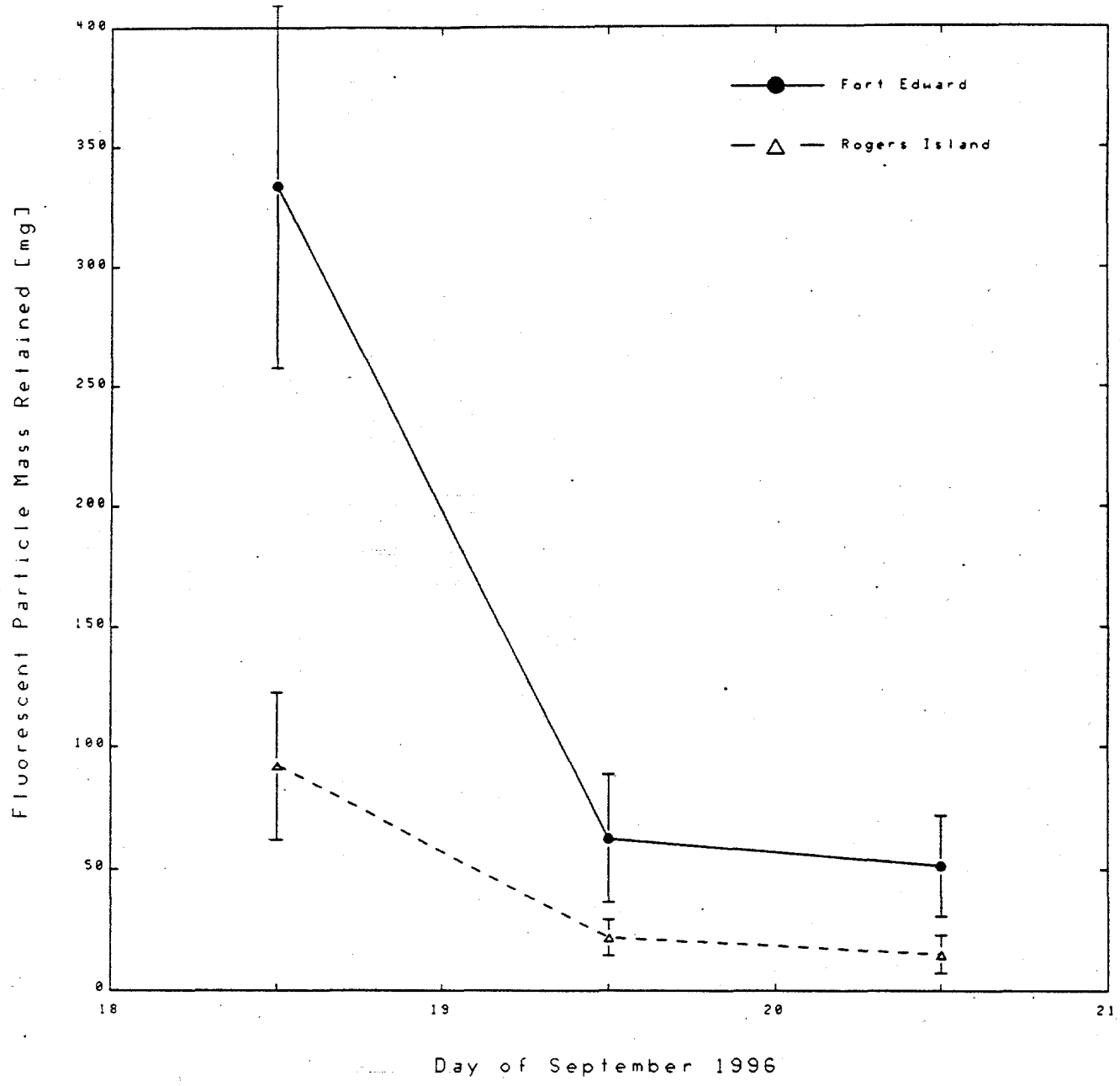


Figure 22.
Temporal Profile of Total Mass of Fluorescent Particles Retained Within the *In Situ* Filtration Devices Deployed at Fort Edward and Rogers Island Stations.

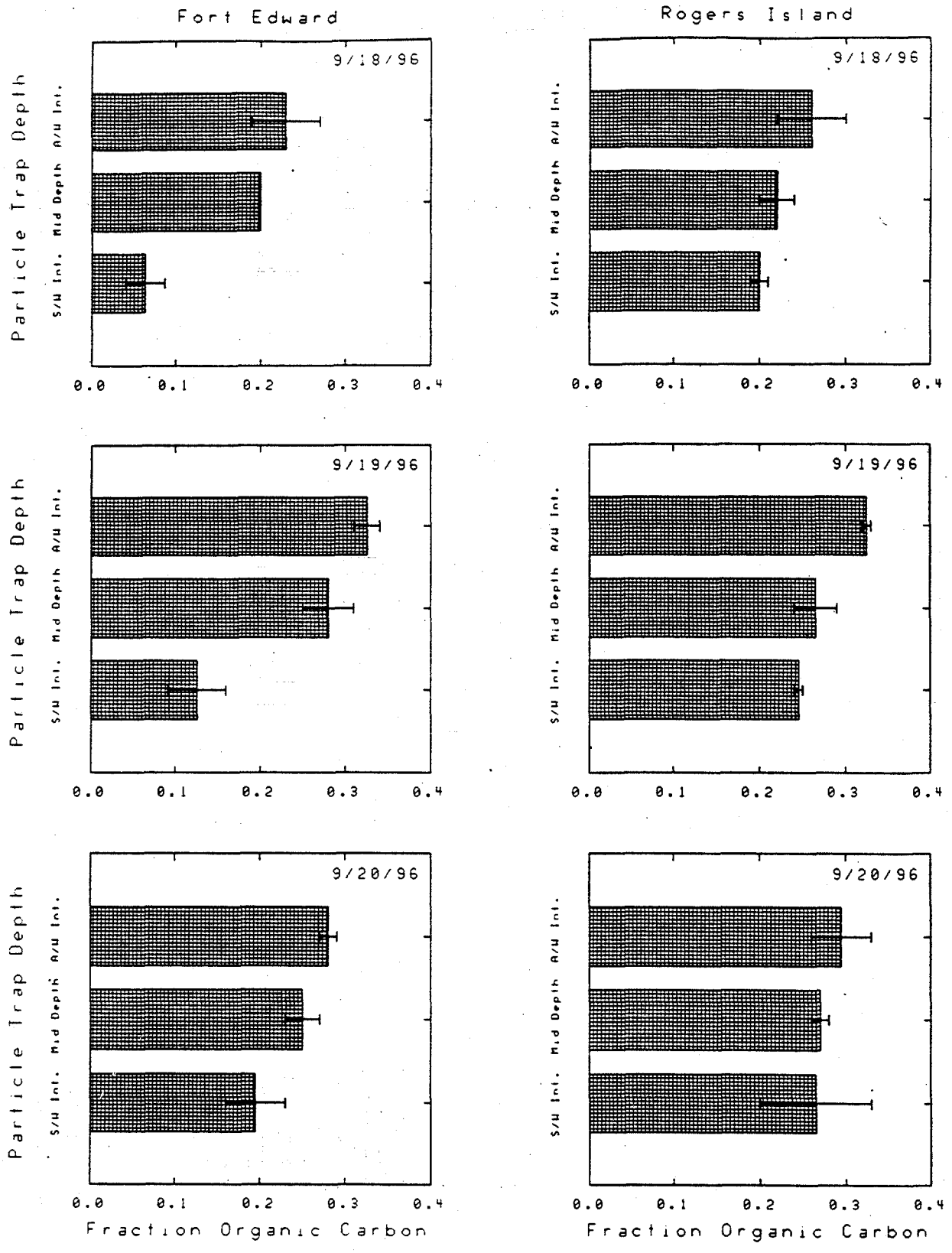


Figure 23.
Fraction Organic Carbon of Solids Retained Within Fort Edward and Rogers Island *In Situ* Filtration Devices at Different Deployment Depths over the Three Day Study.
Note: plots are mean ± range for east and west channel data combined.

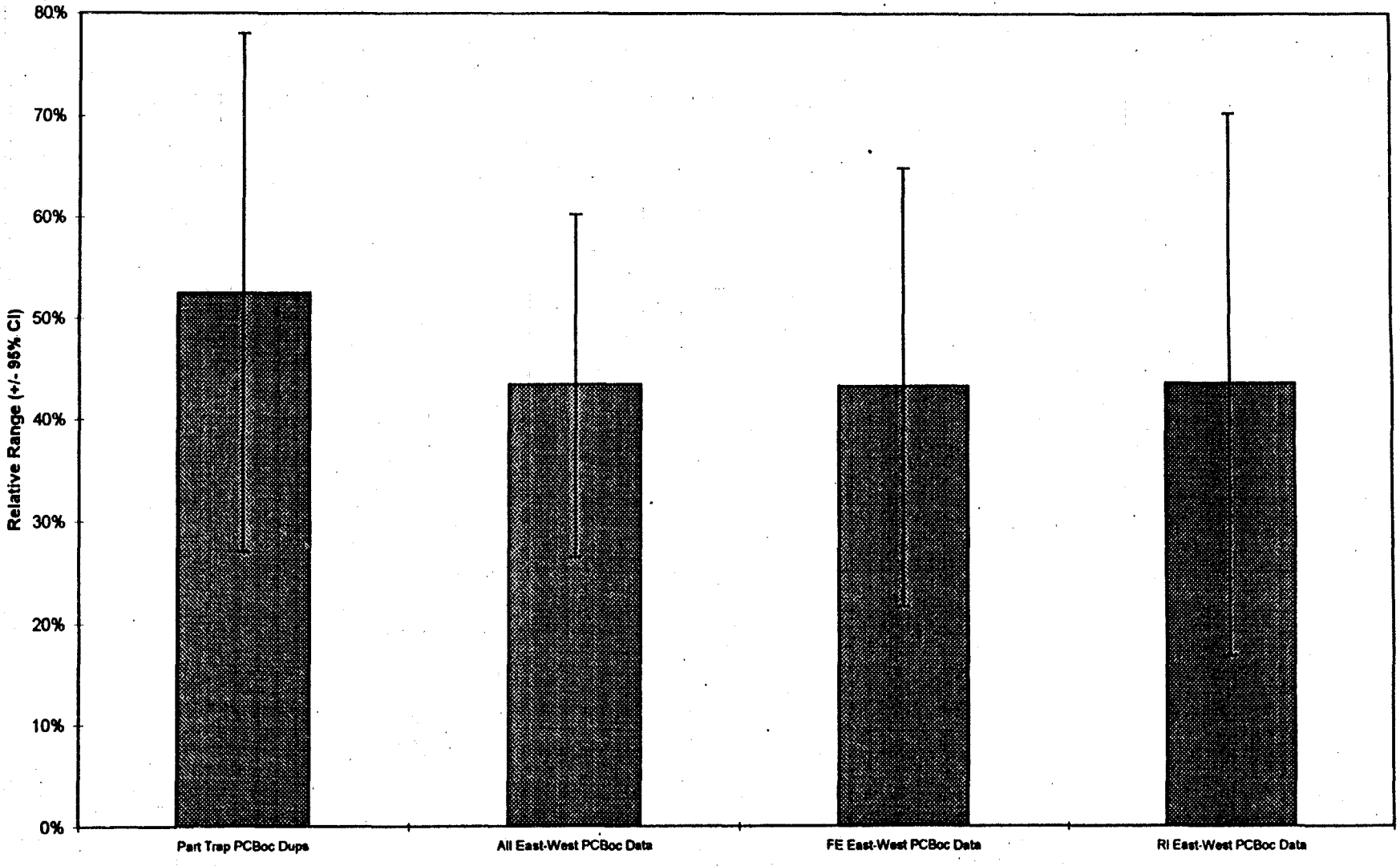


Figure 24.
Mean ± 95% Confidence Intervals of the Relative Range of Organic Carbon Normalized PCB Concentrations of *In Situ* Filtration Samples for Various Sample Groupings.

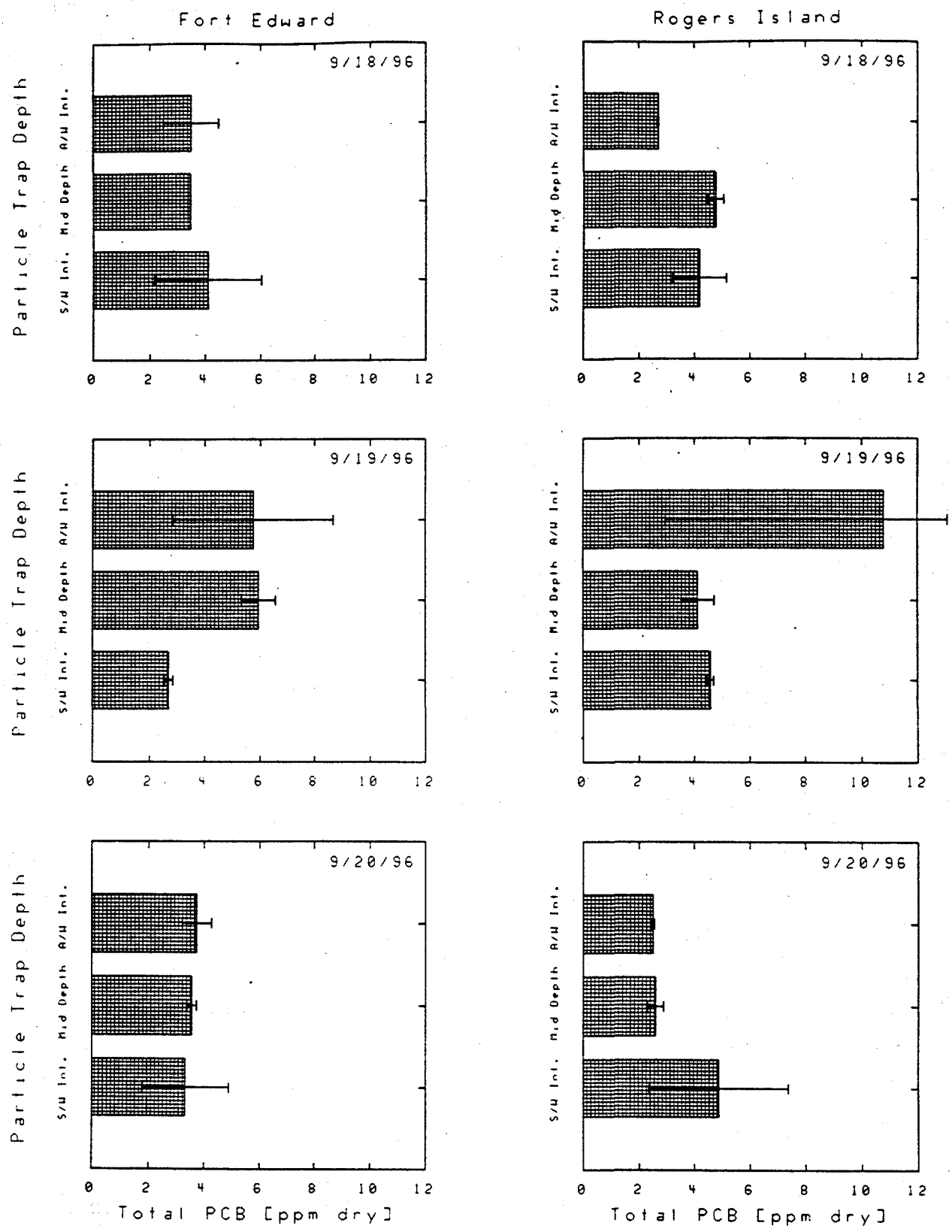


Figure 25.
Total PCB Concentrations of Sediments Retained on Fort Edward and Rogers Island *In Situ* Filtration Devices at Different Deployment Depths over the Three Day Study.
Note: plots are mean ± range for east and west channel data combined; PCB data not corrected for analytical biases.

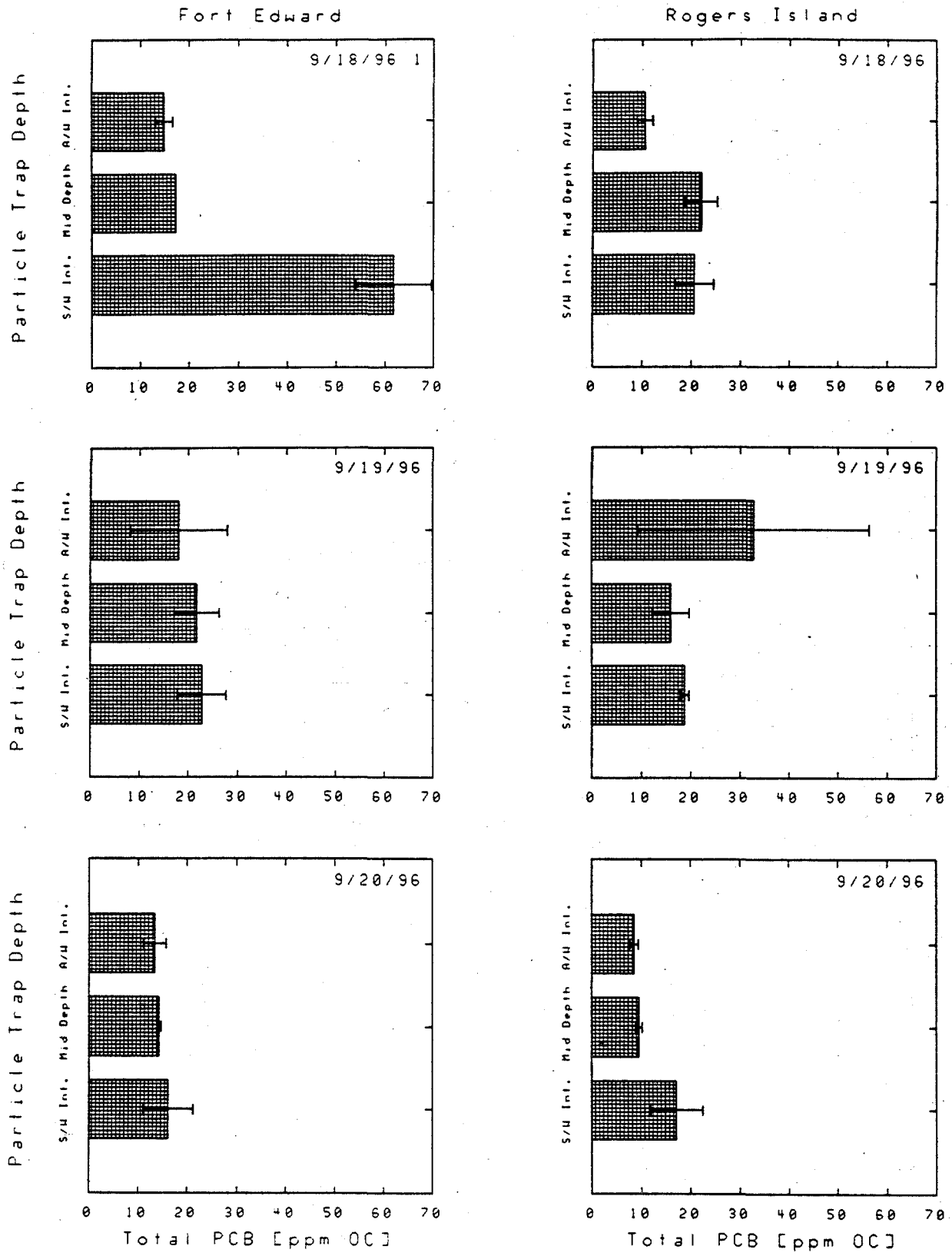


Figure 26.
Organic Carbon Normalized PCB Concentrations of Sediments Retained on Fort Edward and Rogers Island *In Situ* Filtration Devices at Different Deployment Depths over the Three Day Study.
Note: plots are mean ± range for east and west channel data combined; PCB data not corrected for analytical biases.

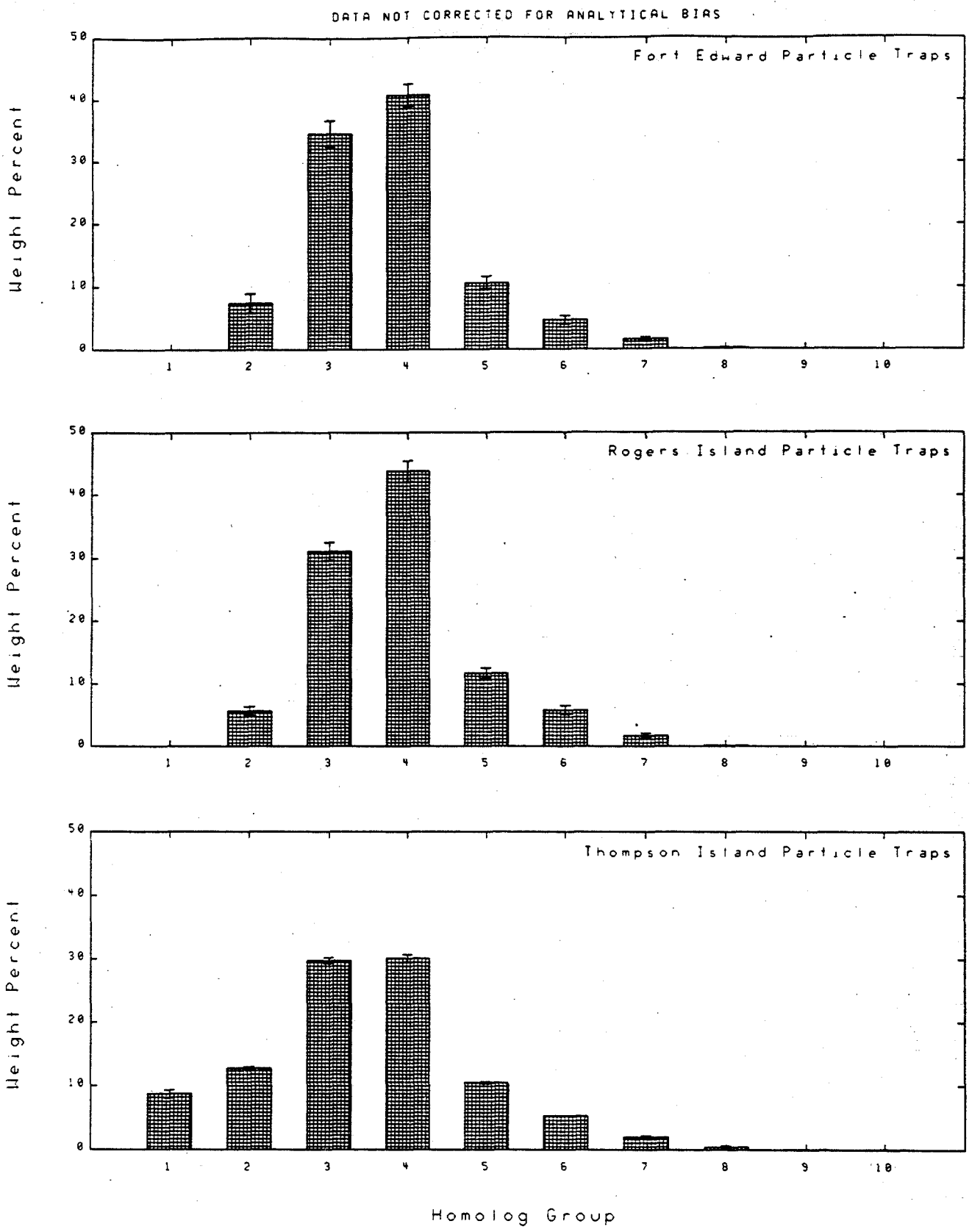


Figure 27.
Mean ± 95% Confidence Interval of PCB Homolog Distribution of Sediment Samples Collected from *In Situ* Filtration Devices.

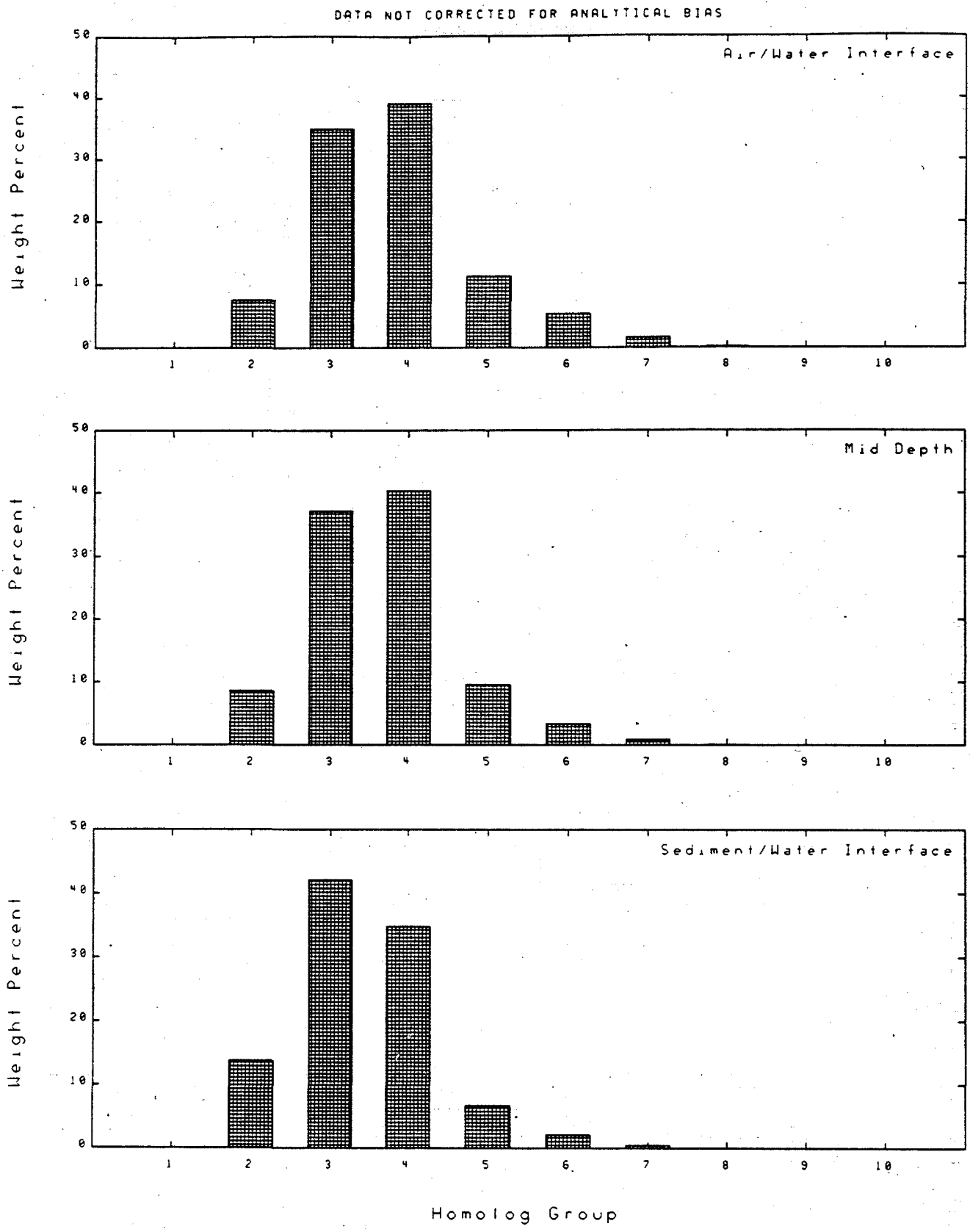


Figure 28.
PCB Homolog Distributions of Samples Collected from Fort Edward *In Situ* Filtration Devices at Different Deployment Depths on September 18, 1996.

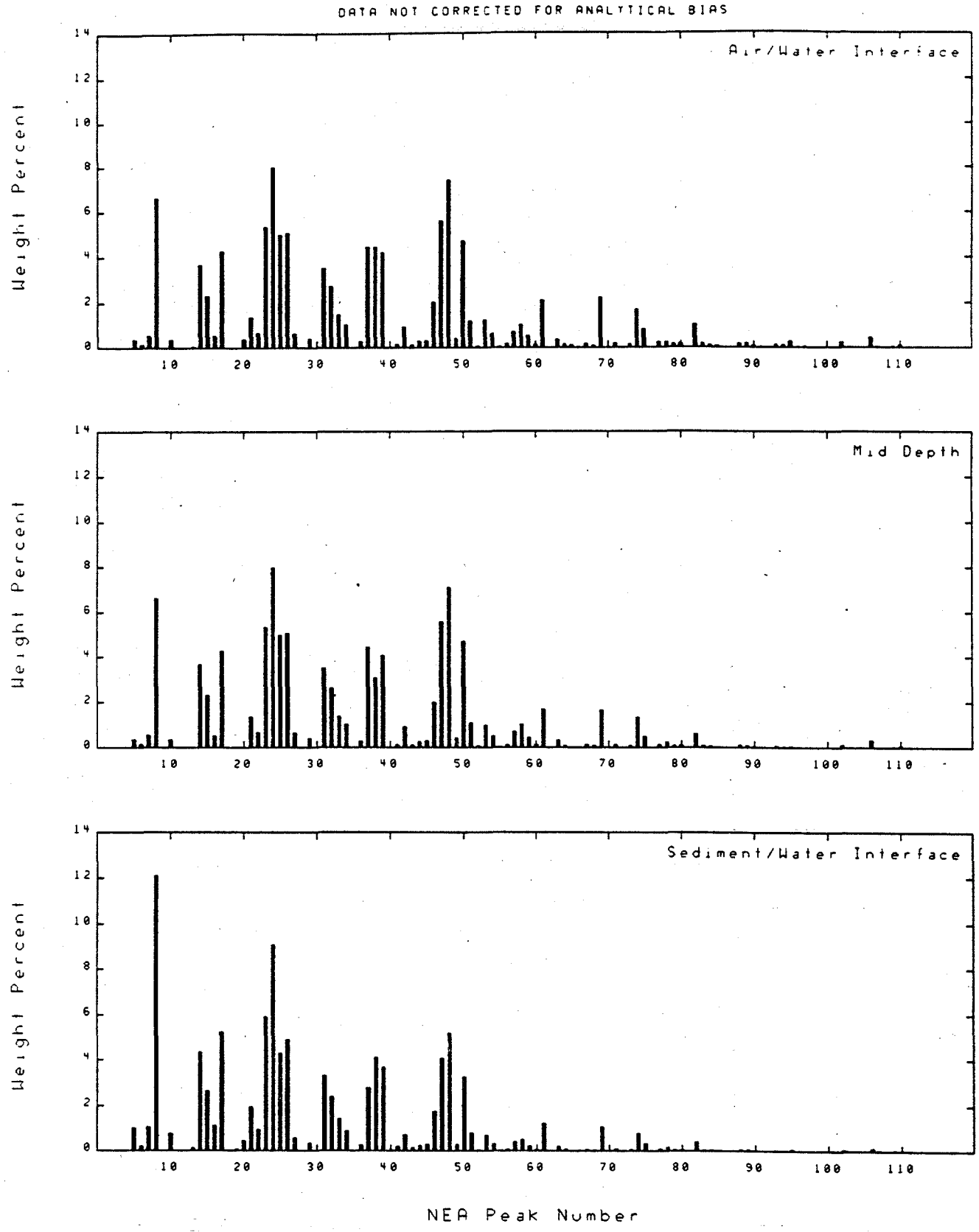


Figure 29.
PCB Congener Distributions of Samples Collected from Fort Edward *In Situ* Filtration Devices at Different Deployment Depths on September 18, 1996.

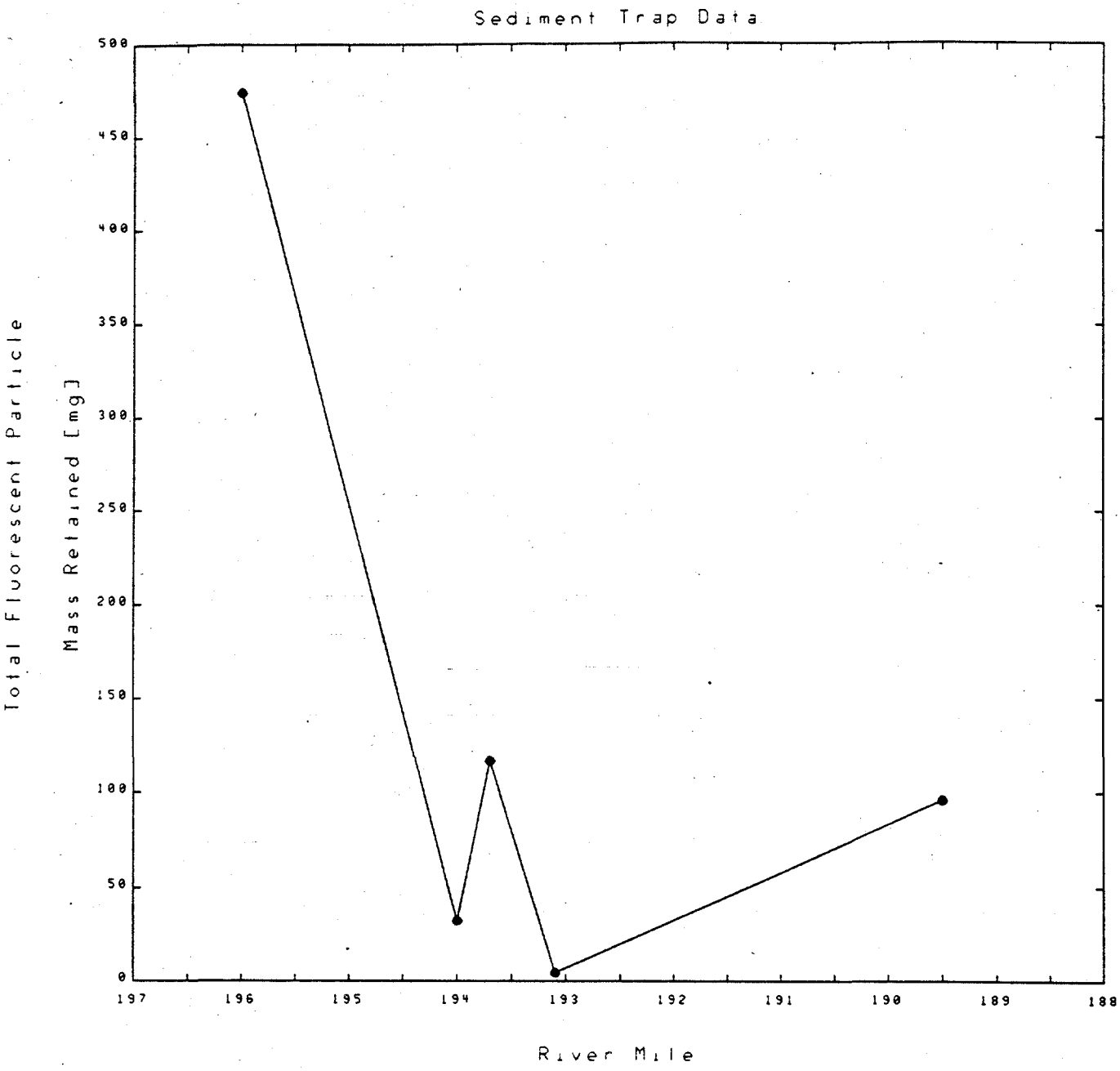


Figure 30.
Spatial Profile of Total Mass of Fluorescent Particles Captured Within Sediment Traps.

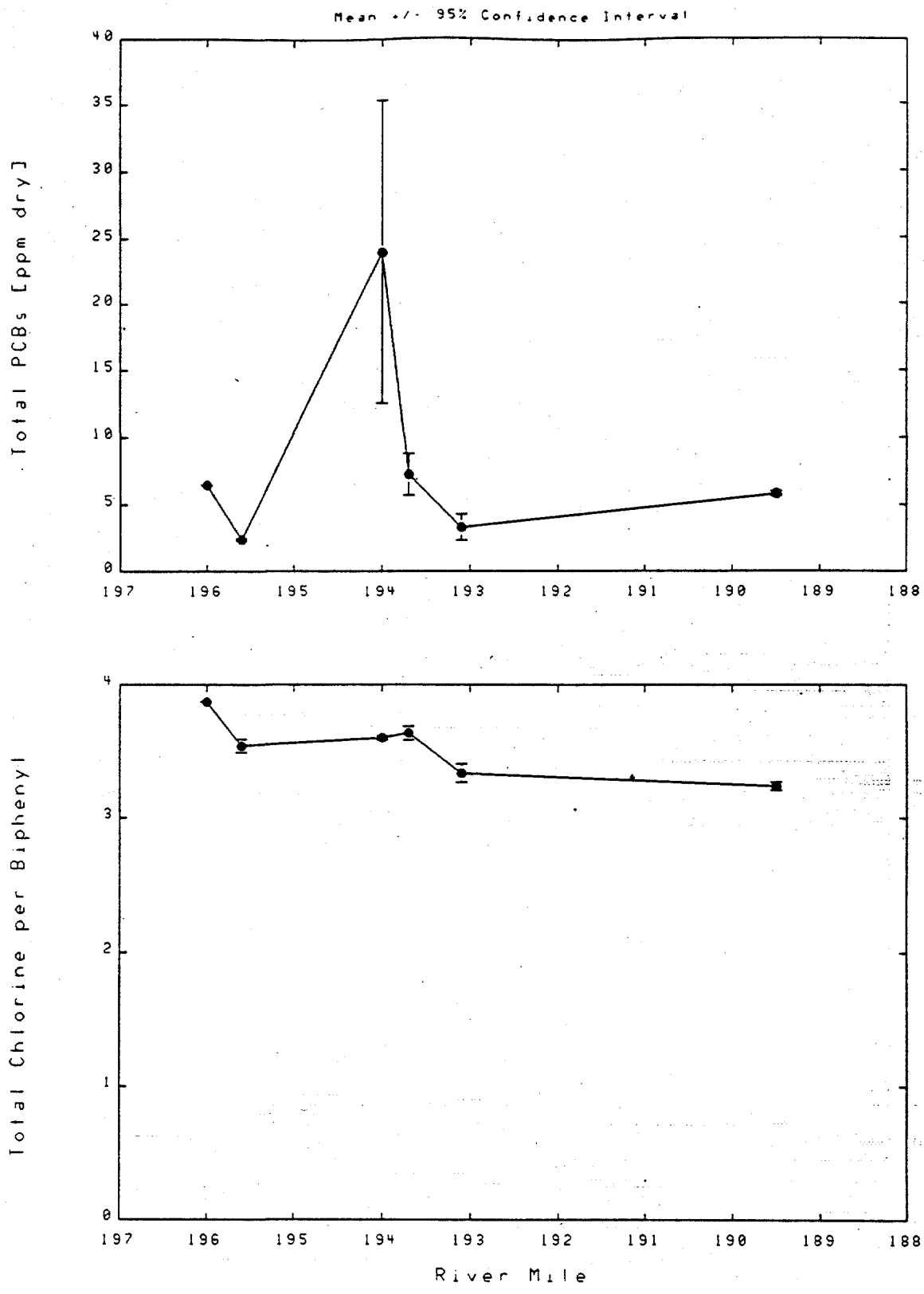
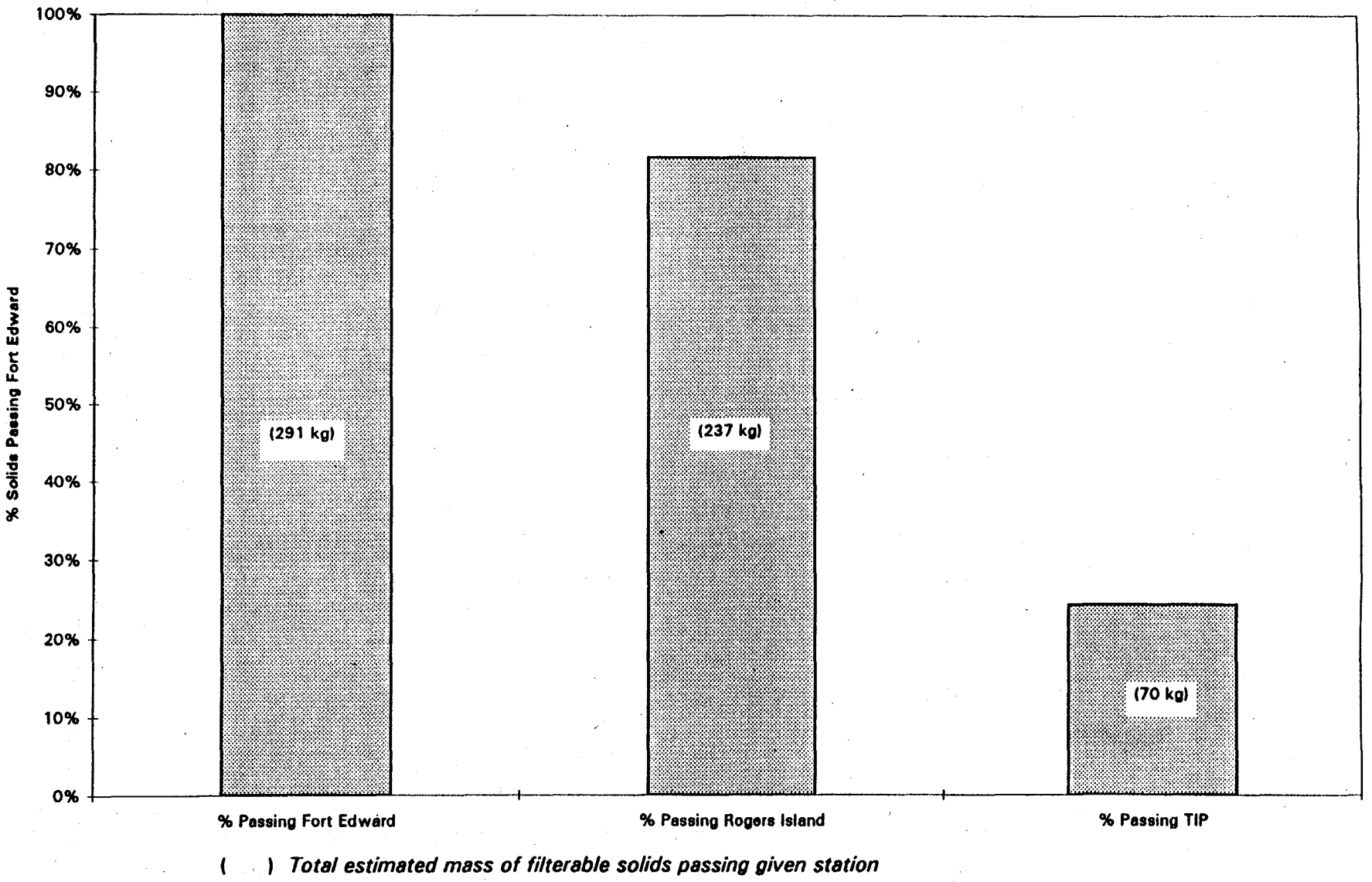


Figure 31.
Spatial Profiles of Sediment Trap Total PCBs and Total Chlorine/Biphenyl.



( ) *Total estimated mass of filterable solids passing given station*

Figure 32.
Three Day River Solids Mass Transport Estimates for Fort Edward, Rogers Island, and Thompson Island *In Situ* Filtration Stations.

Summary of Fluorescent Particle Loading Totals (in kilograms)

Fort Edward					Rogers Island					Thompson Island*				
	Day1	Day2	Day3	TOTAL		Day1	Day2	Day3	TOTAL		Day1	Day2	Day3	TOTAL
A/W Int	1.3	0.3	0.2	1.8	A/W Int	0.6	0.2	0.2	1.1	A/W Int				0.0
Mid Dpth	2.6	0.7	0.4	3.7	Mid Dpth	2.5	0.7	0.3	3.5	Mid Dpth			0.1	0.1
S/W Int	0.8	0.1	0.1	1.1	S/W Int	0.3	0.1	0.0	0.4	S/W Int				0.0
TOTAL	4.8	1.1	0.7	**6.6**	TOTAL	3.4	1.0	0.6	**5.0**	TOTAL	0.0	0.0	0.1	**0.1**

* note Thompson Island data is a 3-day composite from A/W Int, Mid Dpth, and S/W Int particle traps

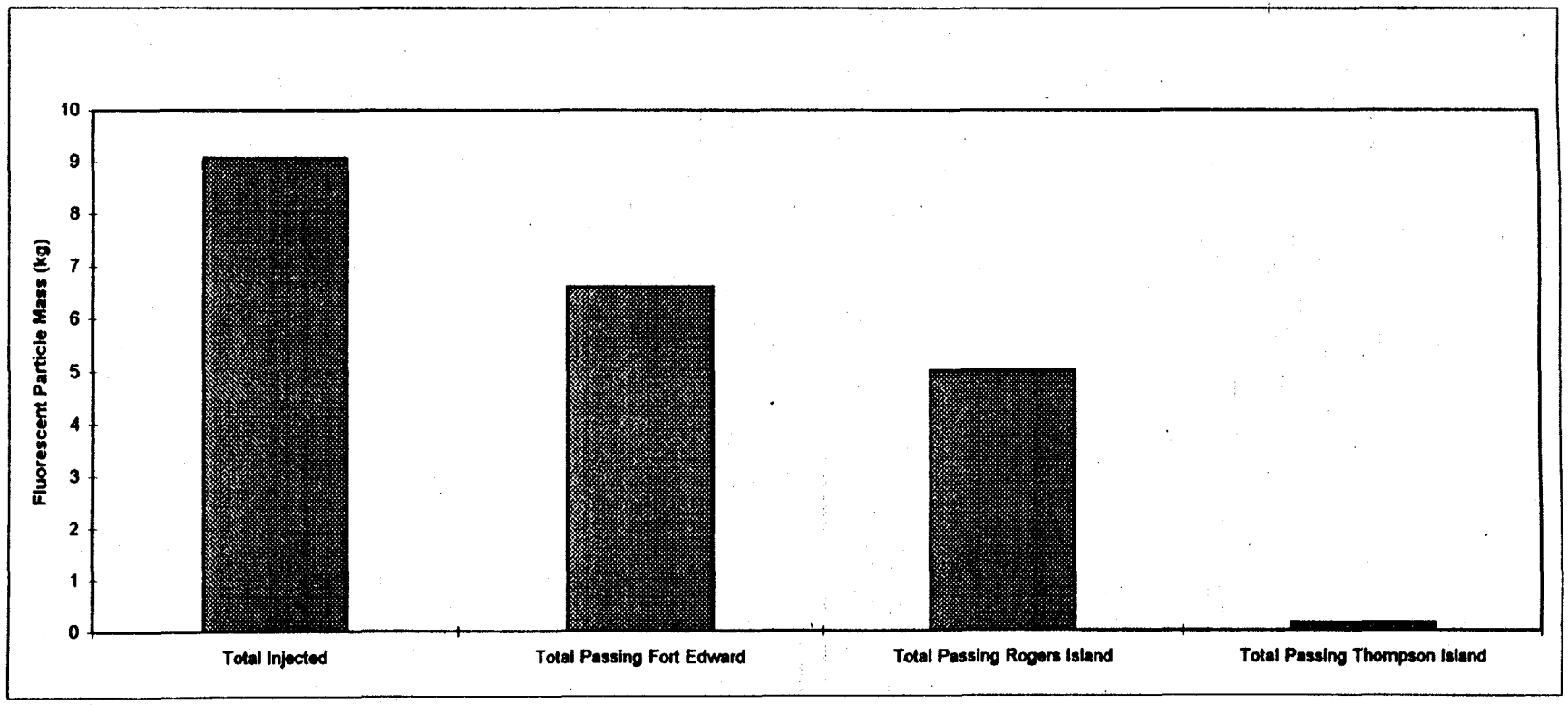
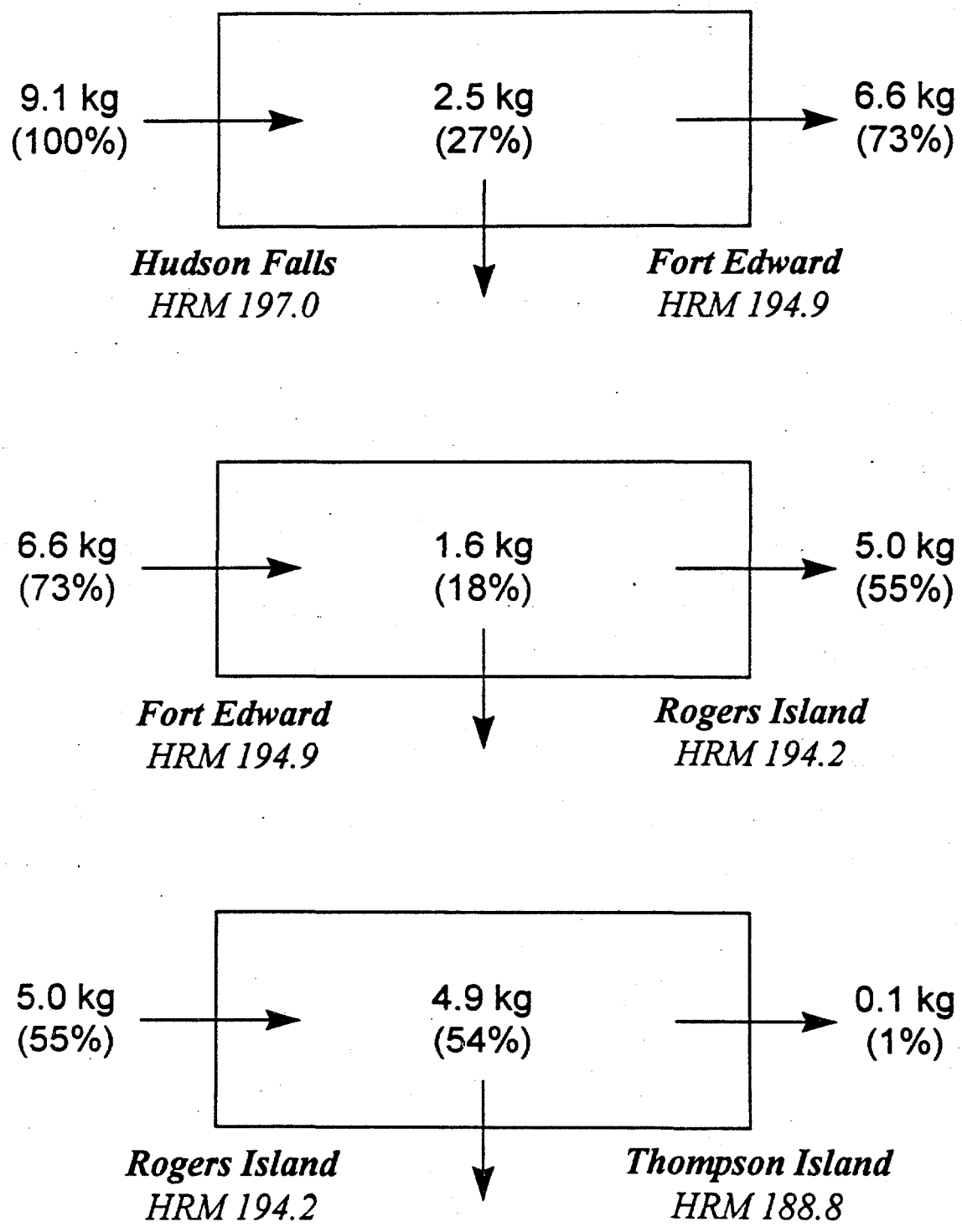
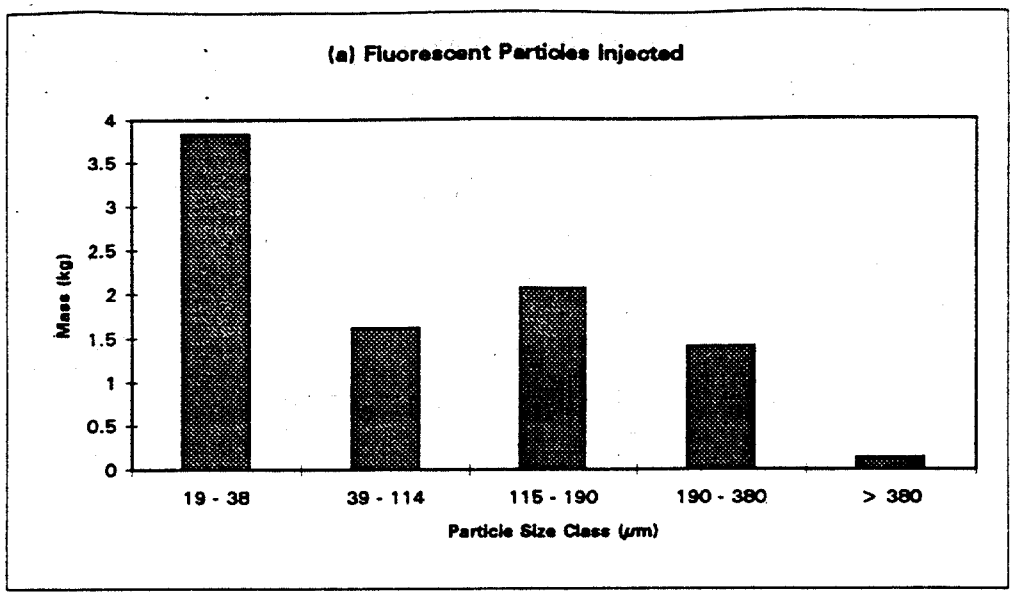
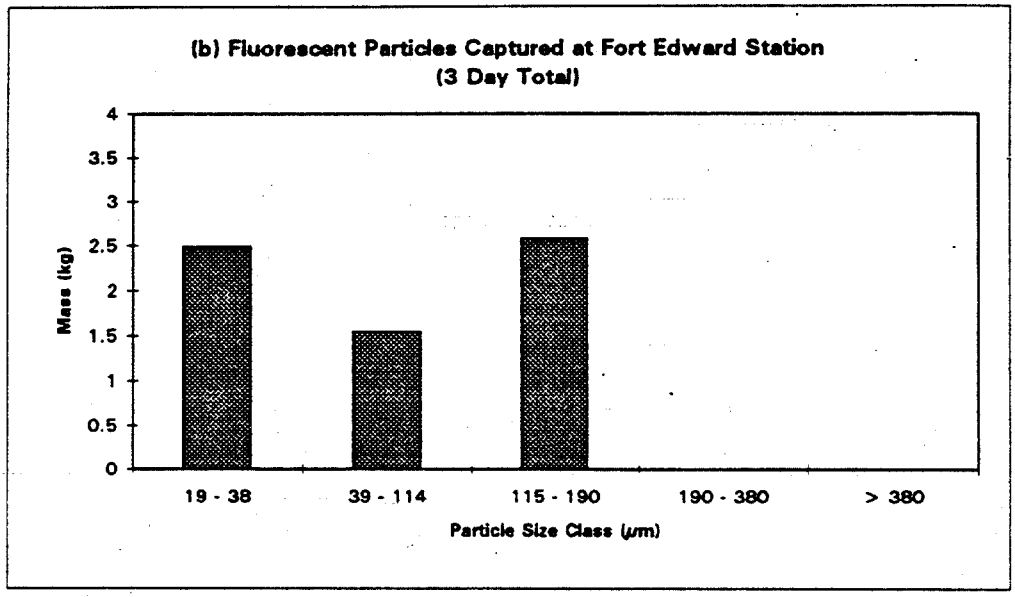


Figure 33.
Three Day Fluorescent Particle Mass Transport Estimates for Fort Edward, Rogers Island, and Thompson Island *In Situ* Filtration Stations.

Figure 34.
Summary of Three Day Fluorescent Particle Mass Balance.







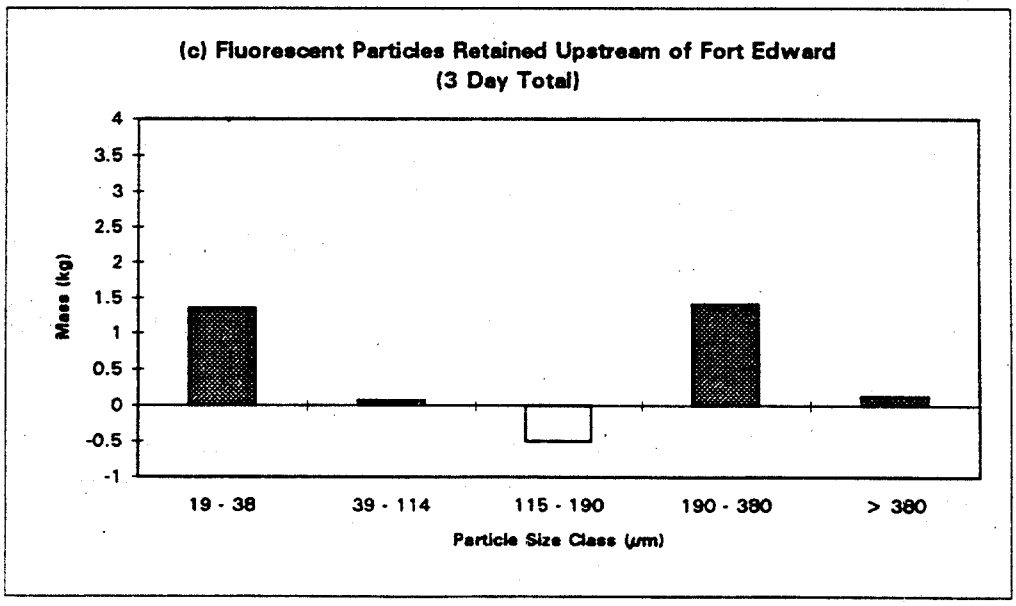


Figure 35.
Fluorescent Particle Size Distribution of a) Injected Particles, b) Particle Captured at the Fort Edward Station, and c) Particles Retained Upstream of Fort Edward.

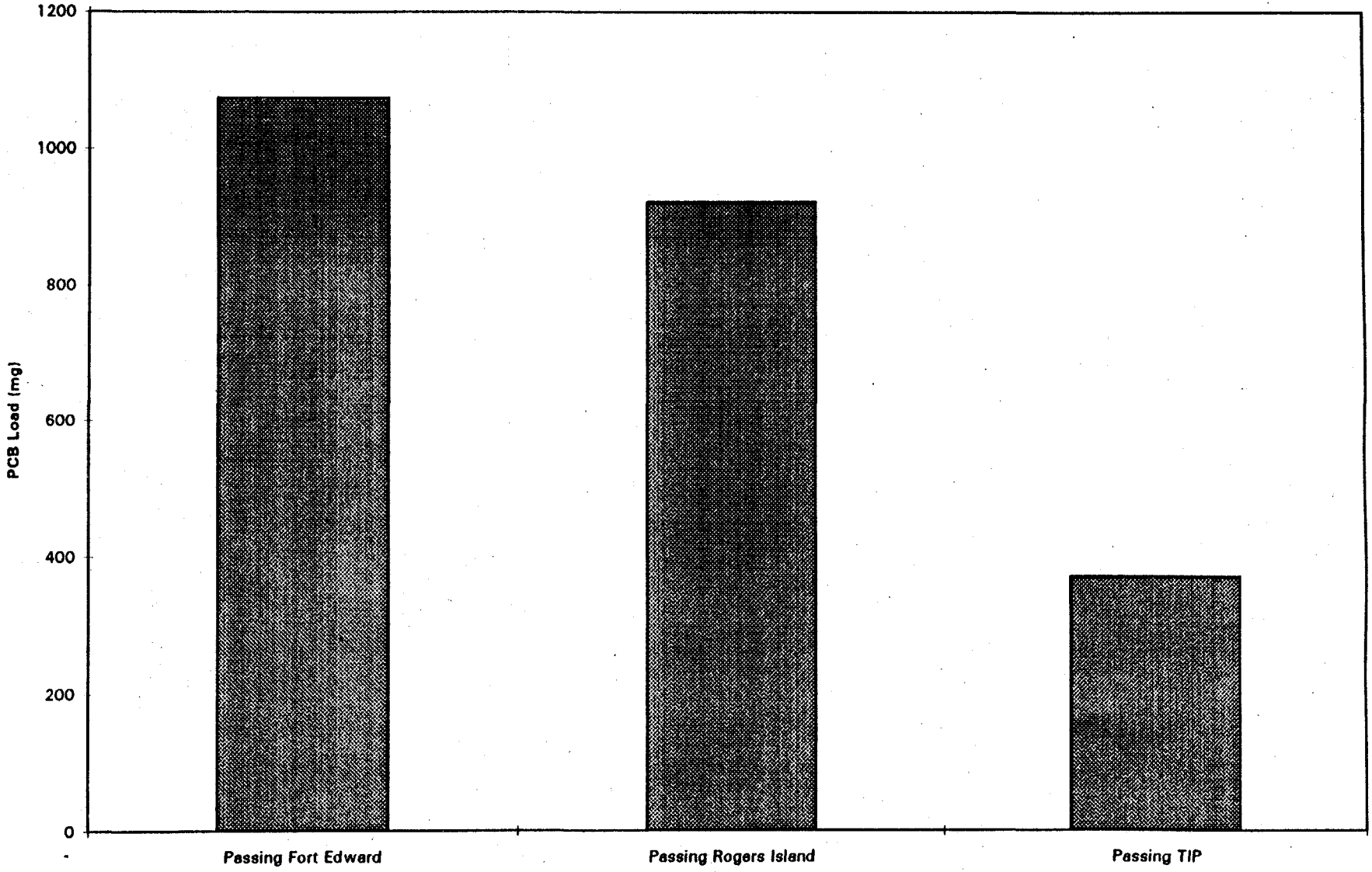


Figure 36.
Three Day PCB Mass Transport Estimates for Fort Edward, Rogers Island, and Thompson Island *In Situ* Filtration Stations.

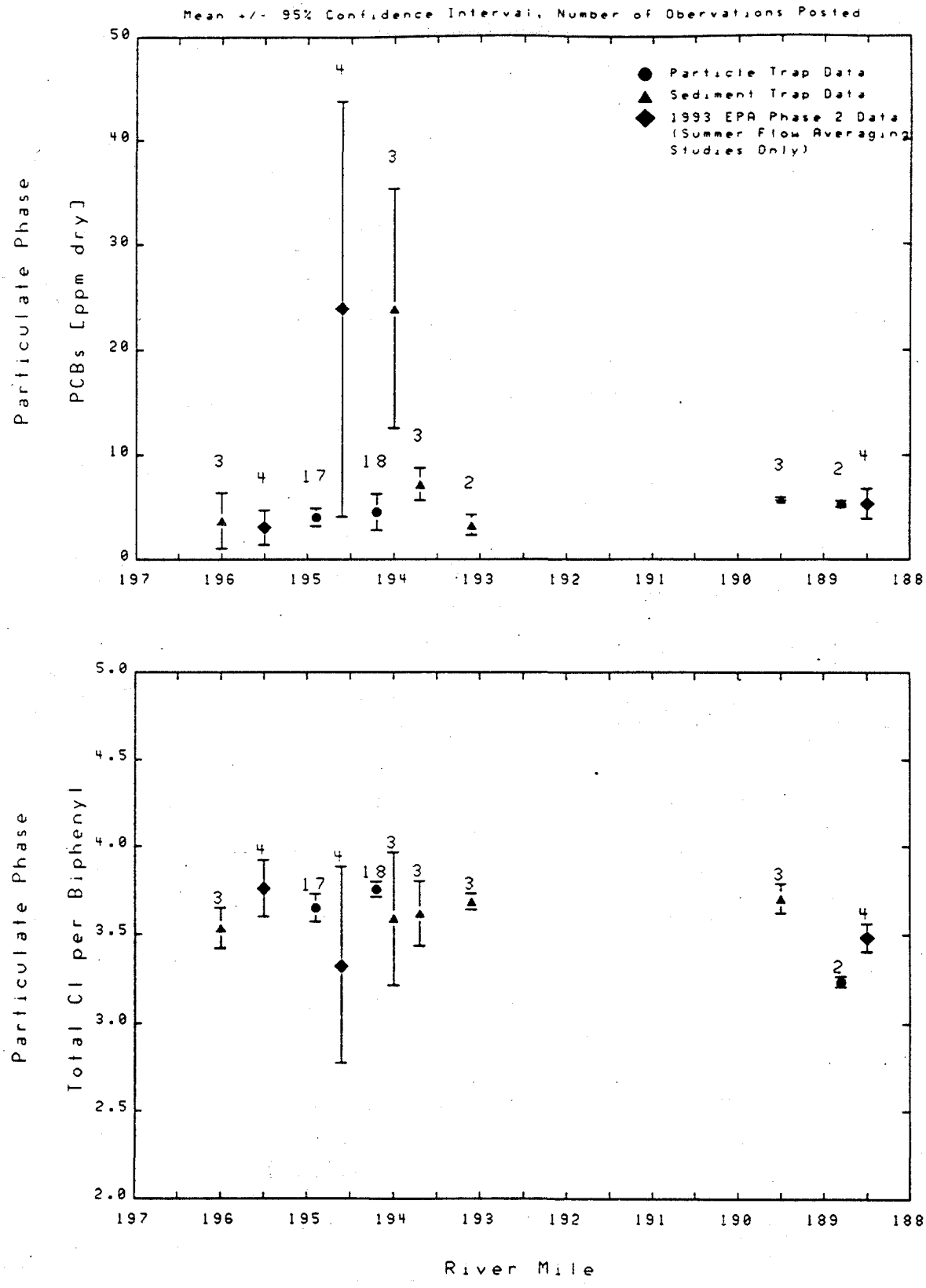


Figure 37.
Comparison of Total PCB and PCB Composition Between USEPA Particulate Phase PCB Data Collected in 1993 and *In Situ* Filtration and Sediment Trap Samples.

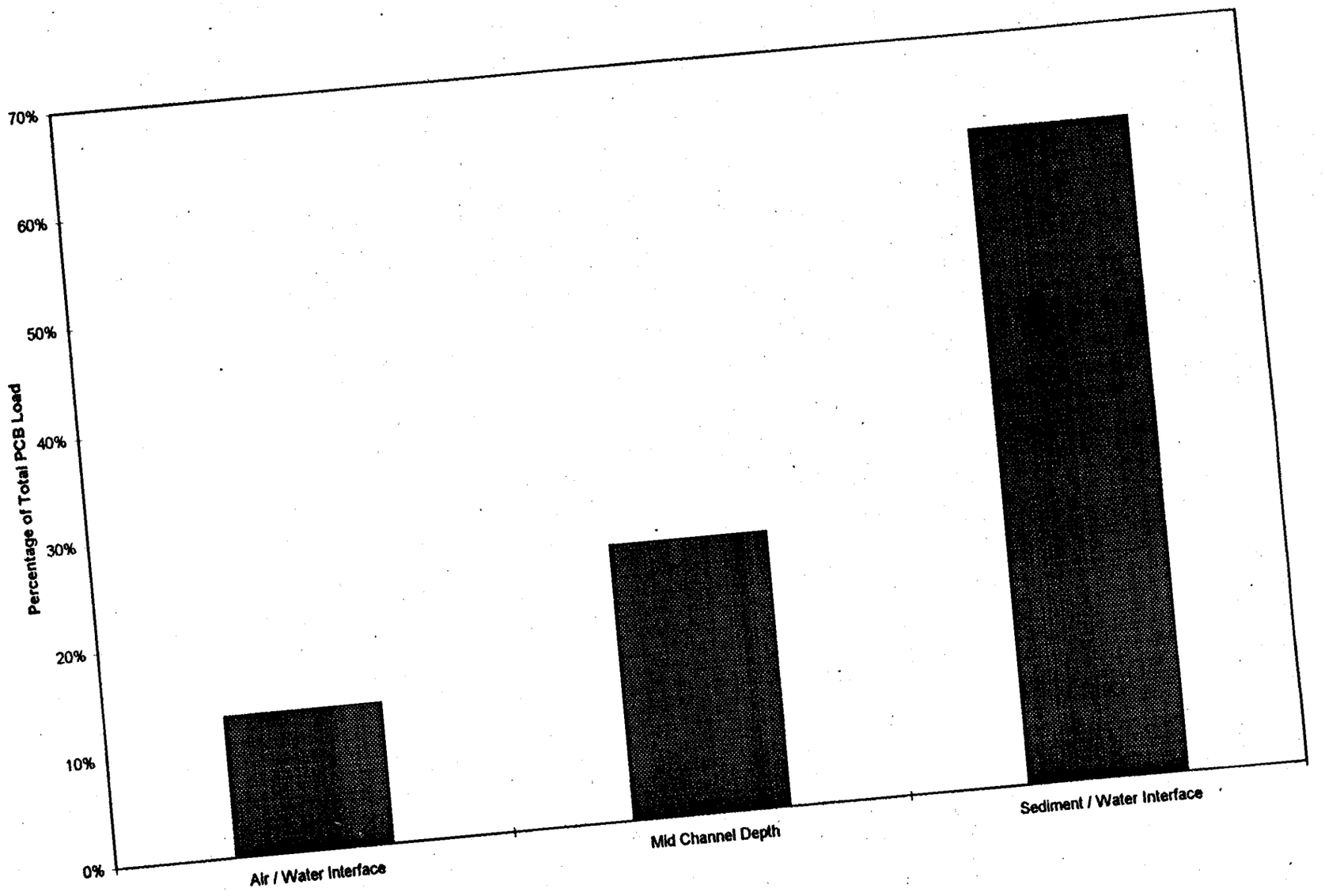
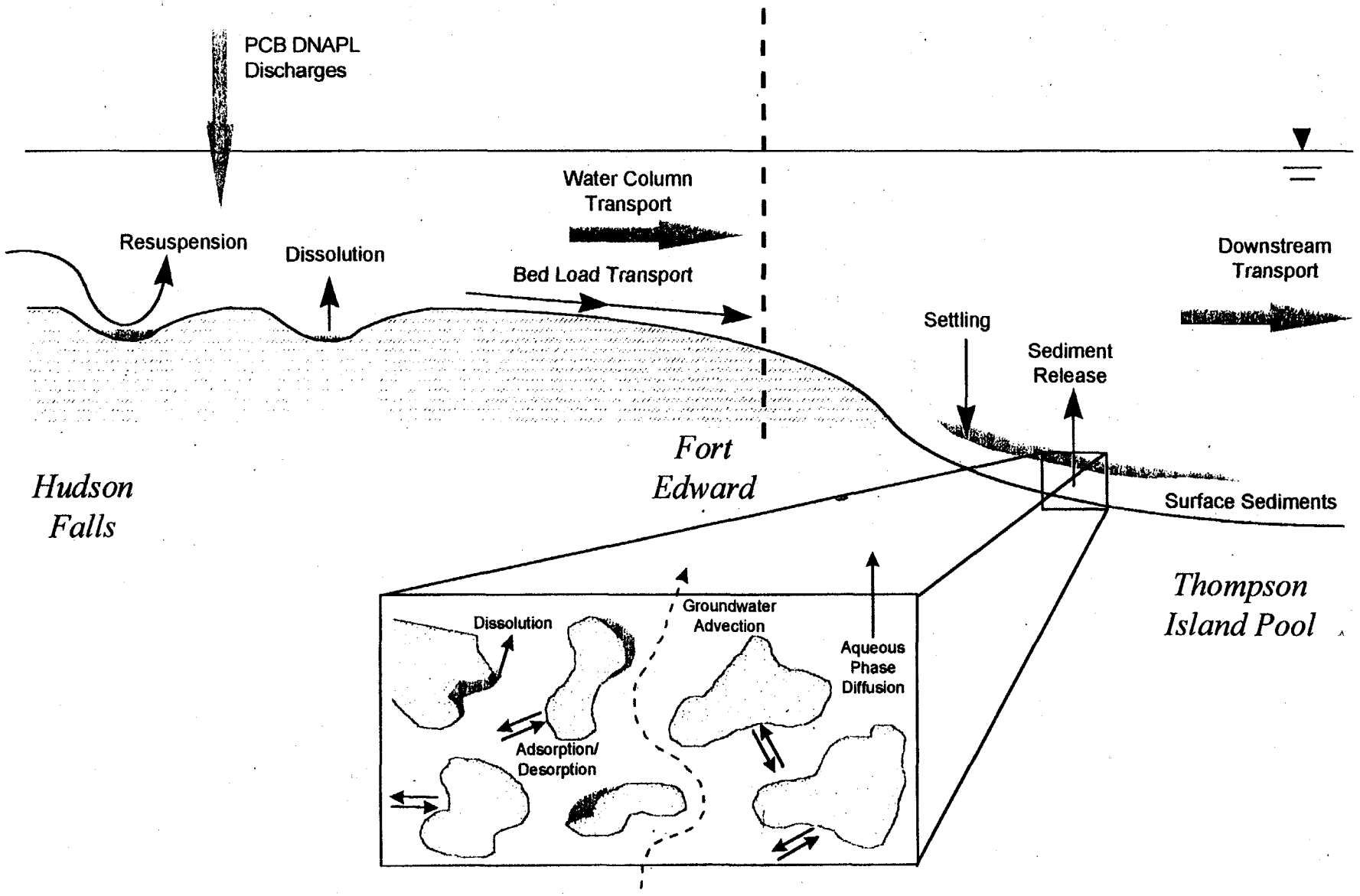


Figure 38.
Vertical Profile of Relative Particle Phase PCB Loading at the Fort Edward Station on September 18, 1996.

FIGURE 39. Conceptual Model of PCB DNAPL Dynamics.



MATERIAL SAFETY DATA SHEET

Printed : 02/20/95

Revised : 02/20/95

SECTION I - PRODUCT IDENTIFICATION

Manufacturer: DAY-GLO COLOR CORP
ENVIRONMENTAL HEALTH & SAFETY
4515 ST CLAIR AVENUE
CLEVELAND OH 44103

Information Phone: 216-391-7070
Emergency Phone: 800-424-9300

Product Class: SYNTHETIC ORGANIC COLORANT
Trade Name : SATURN YELLOW ZQ PIGMENT
Product Code : ZQ-17N
C.A.S. Number: MIXTURE
Prepared By : SCOTT A. FLEMING
Title : REGULATORY CHEMIST

Hazard Ratings: Health - 1
none -> extreme Fire - 1
0 ---> 4 Reactivity - 0

SECTION II - HAZARDOUS INGREDIENTS

Ingredients	CAS #	Weight %	Exposure Limits ACGIH/TLV	Exposure Limits OSHA/PEL	VP mm HG

(No hazardous ingredients known at this time.)

SECTION III - PHYSICAL DATA

Boiling Range: None
Evap. Rate: Non Volatile
Volatiles vol % 00.00 Wgt% 00.00
Appearance: Colored powder
V.O.C.: See Section IX

Vapor Density: Non Volatile
Liquid Density: Heavier than Water.
Wgt per gallon: 10.00 Pounds.

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flammability Class: NA Flash Point: None F LEL: None UEL: None

-EXTINGUISHING MEDIA:

Based on the NFPA quide, use dry chemical, water or other extinguising agent suitable for Class A fires. For large fires, use water spray or fog, thoroughly drenching the burning material.

-SPECIAL FIREFIGHTING PROCEDURES:

Clear area of personnel. Approach upwind. Wear self-contained breathing apparatus.

-UNUSUAL FIRE & EXPLOSION HAZARDS:

Improper handling may lead to dust cloud formation which, as with any organic compound, may be an explosion hazard.

SECTION V - HEALTH HAZARD AND PERSONAL PROTECTION INFORMATION

-FIRST AID:

EYES: Flush with water for at least 15 min. while holding eyelids open.

SKIN: Practice good industrial hygiene, wash with soap and water.

INGESTION: Give water, do not induce vomiting. Call a physician.

INHALATION: Remove to fresh air. Treat symptoms. Call a physician.

-TOXICOLOGY INFORMATION:

No toxicity studies have been conducted on this product.

-PRIMARY ROUTE(S) OF EXPOSURE:

EYE CONTACT: May cause slight irritation

SKIN CONTACT: May cause slight irritation

INHALATION: Treat as a nuisance dust. Avoid breathing.

-SYMPTOMS OF EXPOSURE:

A review of available data does not identify any symptoms from exposure.

-CHRONIC:

CARCINOGENICITY: NTP? (N) IARC MONOGRAPHS? (N) OSHA REGULATED? (N)

Long term exposure may result in dermatitis for sensitive individuals.

-AGGRAVATION OF EXISTING CONDITIONS:

Respiratory allergies and diseases may be aggravated in extreme exposures.

-RESPIRATORY PROTECTION:

A dust mask or NIOSH approved respirator with a dust filter.

-VENTILATION:

General ventilation for comfort conditioning is usually enough to maintain the dust within the nuisance limit of 5 mg/cu.m.

-PROTECTIVE EQUIPMENT:

GLOVES: Required only for sensitive individuals.

EYE PROTECTION: Glasses or goggles are recommended.

RESPIRATORY PROTECTION: Use a NIOSH approved dust respirator.

SECTION VI - REACTIVITY DATA

STABLITY: [ ] Unstable [x] Stable

HAZARDOUS POLYMERIZATION: [ ] May occur [x] Will not occur

-INCOMPATABILITY:

Avoid contact with strong oxidizers (eg. chlorine, peroxides, chromate, nitirc acid, perchlorates, concentrated oxygen, permanganates) which can generate heat, fires, explosions and the release of toxic fumes.

SECTION VI - REACTIVITY DATA (cont.)

-CONDITIONS TO AVOID:
Avoid excessive dust in vicinity of electrical or other spark generating equipment. Avoid extreme heat.

-HAZARDOUS DECOMPOSTION PRODUCTS:
The fumes and smoke released contain oxides of carbon and nitrogen which are highly toxic. Do not breath smoke or fumes. Wear suitable protective equipment.

SECTION VII - SPILL OR LEAK PROCEDURES

-SPILL CONTAINMENT AND RECOVERY:
This product is not defined as a hazardous waste under EPA 40 CFR 261. Sweep up & dispose of as any dust or dirt.

-DISPOSAL:
Same as above.

SECTION VIII - REGULATORY INFORMATION

-FEDERAL REGULATIONS:
OSHA HAZARD COMMUNICATION RULE, 29 CFR 1910.1200: See Section II for hazardous ingredients as defined.

-CERCLA/SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT (TITLE III)
This is not a regulated material under 40 CFR 117, 302. Notification of spills not required.

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-SECTIONS 311 AND 312 - MATERIAL SAFETY DATA SHEET REQUIREMENTS:
Our hazard evaluation has found this product to be non-hazardous.

-SECTION 313 - LIST OF TOXIC CHEMICALS (40 CFR 372):
See Section X.

-TOXIC SUBSTANCES CONTROL ACT (TSCA):
All components in this product are listed, or are excluded from listing, on the U.S. Toxic Substances Control Act (TSCA) 8(b) Inventory.

-FEDERAL WATER POLLUTION CONTROL ACT,CLEAN WATER ACT,40CFR401.15:
This product contains no ingredients regulated by this Act.

-CLEAN AIR ACT, 40 CFR 60, SECTION 111, 40 CFR 61, SECTION 112:
This product contains no ingredients regulated by this Act.

-STATE REGULATIONS:
MICHIGAN CRITICAL MATERIALS: This product does not contain ingredients listed on the Michigan Critical Register.

-CONEG-COALITION OF NORTHEAST GOVERNORS:
This product is in compliance with the CONEG (Conference of Northeast Governors) requirements thru 1/1/1994 (ie total cadmium, chromium, lead and mercury less than 100 ppm). The detection limits of the test method used (in ppm) indicated by < and also the analytical test results for the pigment are as follows:

ANTIMONY	(Sb) <4	ARSENIC	(As) <4
BARIUM	(Ba) <0.50	CADMIUM	(Cd) <0.25
CHROMIUM	(Cr) <0.50	COPPER	(Cu) 1.3
LEAD	(Pb) <1.0	MERCURY	(Hg) <0.05

(cont.)

SECTION VIII - REGULATORY INFORMATION (cont.)

-CONEG-COALITION OF NORTHEAST GOVERNORS: (cont.)

NICKEL	(Ni) <0.75	SELENIUM	(Se) <4
SILVER	(Ag) <0.50	ZINC	(Zn) 38,500

In other words Zinc and Copper were the only element found in our pigments.

-TRANSPORTATION-49 CFR 172-101:
This product is not regulated by DOT.

-FDA-21 CFR:
DAY-GLO Color Corp.'s products are not listed by the FDA for use under 21 CFR, since potential applications are so numerous that specific applications must be submitted to the FDA for inclusion in the 21 CFR FDA listing.

-CLEAN AIR ACT AMMENDMENTS OF 1990
No DAY-GLO product contains an ozone depleting substance (ODS) nor are any of our products manufactured with them.

SECTION IX - PRECAUTIONARY & LABEL INFORMATION

-HMIS LABEL STATEMENT:

ZQ-17N SATURN YELLOW PIGMENT
HEALTH - 1 FLAMMABILITY - 1 REACTIVITY - 0

PRECAUTIONS: Can cause respiratory irritation. Avoid breathing dust. Use & store with adequate ventilation. Dust explosion hazard with ignition source.
FIRST AID: EYES: Flush with water for 15 minutes. SKIN: Wash with soap and water. INGESTION: Give water, do not induce vomiting. Call a physician.
FIRE FIGHTING USE: Water spray, dry chemical, foam or CO2 (Toxic fumes emitted on burning).
SPILL CONTROL: Sweep up & dispose according to local, state and federal regulations.

CONTAINS:	CAS NO. OR NJ TSRN:
RESIN	80100023-5027-P
ALBERTA YELLOW	80100023-5004-P
C>14 ALCOHOL	71750-71-5

TARGET ORGANS: NO ORGANS AFFECTED.

COATING V.O.C. : NONE
MATERIAL V.O.C.: NONE

-OTHER PRECAUTIONS:
None

SECTION X - ADDITIONAL REGULATORY INFORMATION

-SARA TITLE III SECTION 313:
This product contains the following toxic chemicals subject to the reporting requirements of section 313 of the Emergency Planning and Community Right To Know Act of 1986 and of 40 CFR 372:

CAS#	Chemical Name	Percent by Weight
	None	

-PROP 65 (CARCINOGEN):
WARNING: This product contains a chemical known to the state of California to cause cancer.

CAS#	Chemical Name
	None

-PROP 65 (TERATOGENIC):
WARNING: This product contains a chemical known to the state of California to cause birth defects or other reproductive harm.

CAS#	Chemical Name
	None

-PROP 65 (BOTH CARCINOGEN AND TERATOGENIC):
WARNING: This product may contain a chemical known to the state of California to cause cancer or birth defects or other reproductive harm

CAS#	Chemical Name
	None

SECTION X - ADDITIONAL REGULATORY INFORMATION (cont.)

-DISCLAIMER:

The information contained herein is believed to be accurate, but is not warranted. Nothing contained herein constitutes a specification nor is it intended to warrant suitability for the intended use.

SpectraScan
Environmental and Optical Consulting

HUDSON RIVER PCB DNAPL TRANSPORT STUDY

FLUORESCENT PARTICLE COUNTING PROTOCOL

A quantitative assessment of fluorescent particles in sediment samples is performed as follows:

Particle Mounting

1) A known amount of dry sediment (M) is added to 100 ml of particle free water (V_t),

2) the suspension is thoroughly mixed with a vortex mixer,

3) a subsample (V_f) of the sediment suspension is placed on a 4.8 cm Millipore filtration funnel which is then filled with particle free water containing a dilute detergent solution to prevent particle aggregation,

4) the dilute sediment suspension is then filtered through a Whatman GF/C glass fiber filter,

5) the filter is then placed on a small glass plate containing a gelatin-glycerol based optical embedding medium to fix the particles to the filter, and

6) a thin glass coverslip is placed over the filter.

Particle Counting:

1) The mounted filter is scanned at low magnification (e.g., x 2.6) using a Zeiss epiflurescence microscope equipped with UV and visible excitation lamps[1],

2) fluorescent particles are manually counted on a calibrated grid of known area at 20-30 different locations on the filter to estimate an average number of particles per grid area,

[1]Optimal excitation for the particles is 490 nm, the emission at that excitation wavelength is 575 nm (yellowish color) which can be differentiated from natural sediment minerals and organic particulates. No significant background from natural sediments was observed in test Hudson sediment samples.

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3) the total number of particles filtered (N_t) is calculated as the average number of particles (N_g) per unit grid area (A_g) times the total filter area, (A_f):

$$N_t = \frac{N_g}{A_g} * A_f$$

4) the number of particles per mass of sediment (C) is calculated as:

$$C = \frac{N_t}{\frac{M}{V_t} * V_f}$$