FINAL PHASE 2 WORK PLAN AND SAMPLING PLAN

HUDSON RIVER PCB REASSESSMENT RI/FS

EPA WORK ASSIGNMENT NO. 013-2N84

SEPTEMBER 1992

Region II

ALTERNATIVE REMEDIAL CONTRACTING STRATEGY (ARCS)
FOR
HAZARDOUS WASTE REMEDIAL SERVICES

EPA Contract No. 68-S9-2001

TAMS Consultants, Inc.

and

Gradient Corporation

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II
JACOB K. JAVITS FEDERAL BUILDING
NEW YORK, NEW YORK 10278

SEP 30 1992

To All Interested Parties:

The U.S. Environmental Protection Agency (EPA) is pleased to release the Final Phase 2 Work Plan for the Reassessment Remedial Investigation and Feasibility Study for the Hudson River PCBs site.

On June 5, 1992, EPA released a review copy of the Phase 2 Work Plan for public comment. The public comment period was originally set to end on July 10, 1992, but it was extended to July 24, 1992 to allow the public to review the Phase 1 Responsiveness Summary which became available July 13, 1992. This Final Phase 2 Work Plan reflects changes made to the work plan based on comments received on the review copy.

The Phase 2 Work Plan describes the sampling efforts and data analyses which will be performed to supplement existing information, so that the fate and transport and the associated effects of the PCB-contaminated sediments can be better characterized. The Phase 2 Report, which documents the findings of the Phase 2 investigations, is expected to be released in August 1993. The detailed evaluation of remedial alternatives will be presented in the Phase 3 Report.

If you have any questions, or wish to participate in the Community Interaction Program established for this site, please contact Ms. Ann Rychlenski, of the External Programs Division at (212) 264-7214.

Sincerely yours,

Kathleen C. Callahan, Director
Emergency and Remedial Response Division

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FINAL PHASE 2 WORK PLAN
HUDSON RIVER PCB REASSESSMENT RI/FS

1. INTRODUCTION

1.1 Background

This document describes the work to be performed in Phase 2 of the Hudson River PCB Reassessment Remedial Investigation/Feasibility Study (RI/FS). The Hudson River PCB Superfund site extends from Hudson Falls in Warren County, New York to the Battery in New York City. USEPA's previous Feasibility Study (FS), the 1984 No-Action Record of Decision for contaminated river sediments and reasons for this Reassessment are described in the Introduction to the Phase 1 Report for this Reassessment. As was the case in the 1984 FS and ROD, the scope of potential remedial activities for this Reassessment is limited to the PCB-contaminated Hudson River sediments between Hudson Falls and Federal Dam at Troy.

In January 1991 USEPA issued a Phase 1 Work Plan describing the activities to be performed in that phase. In August 1991, USEPA issued a Phase 1 Report, entitled Interim Characterization and Evaluation, which described the results of Phase 1 studies. The findings presented in the Phase 1 Report are based on analysis of approximately 30,000 records of sediments, water, fish and other data, compiled from numerous sources. The purpose of the Phase 1 analysis was to:

- provide an interim evaluation, based on existing information concerning current levels of PCBs in various media of concern in the river, and changes in these levels;
- provide a preliminary or interim assessment of risks to human health and the environment posed by PCBs in the river; and
- provide the basis for assessing the needs for further sampling and analysis in Phase 2.

In September 1991, USEPA issued a Phase 2A Sampling Plan. The Phase 2A work began in December 1991 and is continuing. The complete Phase 2A effort is described in this document, as it is part of the Phase 2 work.

It is USEPA's continuing goal since this Reassessment commenced to solicit information and provide feedback to the public through a Community Interaction Program (CIP). CIP participants and committees have provided written and verbal comments on the Phase 1 Work Plan and Phase 1 Report, and the Scientific and Technical Committee discussed the Phase 2A Sampling Plan and Phase 2 Work Plan and Sampling Plan - Review Copy (June 1992). These comments are appreciated; they were reviewed and considered and in several cases were instrumental in developing this Final Phase 2 Work Plan.

1.2 Objective and Scope

The overall objective of Phase 2 is to complete the site characterization for the Reassessment RI/FS. This will be accomplished by obtaining information relating to the nature and extent of the PCB contamination in the river sediments as described below in Section 2, identifying sources of PCBs to the sediments and other media also to the extent described later in this Work Plan, and developing an understanding of the fate and transport of PCBs in the river system. This information will be utilized to prepare the baseline human-health risk assessment and the baseline ecological risk assessment. The results of Phase 2 activities will also be used in Phase 3 to define and evaluate remedial alternatives. The Phase 2 effort will culminate in a Phase 2 Report, similar in format to that of the Phase 1 Report.

The Reassessment requires knowledge of the source areas of PCBs and the future impact of PCBs in the Hudson River system under conditions of No Action and various remedial alternatives. In the Phase 1 Report it was determined that human-health risks from Hudson River PCBs are caused primarily by the consumption of contaminated fish. Therefore, two of the major questions that the Reassessment will address are: what is the reduction in PCB levels which is necessary to decrease fish-tissue concentrations in Study Areas B and C to levels that meet human-health criteria and; the ancillary question of which source areas in Study Area B, if any, may require remediation in order to achieve that reduction. In addition, due to the presence of endangered species and critical habitats in Study Areas B, C, and D, ecological risk will be evaluated during Phase 2. The effort in Phase 2 will focus on obtaining the information necessary to answer these questions among others, and perform the necessary evaluations. EPA will utilize this information in Phase 3 to select the most appropriate remedial alternative based upon this information, in light of the requirements of CERCLA and the National Contingency Plan (NCP).

1.3 Report Format

This document contains two Phase 2 plans: the Phase 2 **Work Plan** and the Phase 2 **Sampling Plan**. The Phase 2 **Work Plan** follows this Introduction as Sections 2 through 8. It describes field investigations and scientific/engineering analyses that will be conducted during Phase 2. The Sampling Plan, contained in Appendix A, describes with more specificity than the Work Plan itself, sampling techniques, locations, and number of samples proposed for Phase 2 field investigations.

The Phase 2 **Sampling Plan** (Appendix A) distinguishes between field studies for Phase 2A and those for Phase 2B whereas the Work Plan does not distinguish between phases. The description of Phase 2A in Appendix A incorporates modifications to the Phase 2A Sampling Plan. The description of Phase 2B sampling includes field and laboratory studies that will commence following approval of this document and related documents, *e.g.*, Health and Safety Plan, Sampling and Analysis Plan and Quality Assurance Project Plan.

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2. OVERVIEW OF DATA-COLLECTION PROGRAM FOR PHASE 2

This section presents an overview of Phase 2 data-collection tasks and a summary of these activities by geographic study areas. This section is intended for those readers interested in an overview of proposed Phase 2 efforts. Additional discussion of these tasks occurs in Section 3, Section 7 and in Appendix A.

The Hudson River PCB Superfund site extends from Hudson Falls, NY at River Mile (RM) 197 to the Battery at RM 0. Because of the site's size, three study areas have been defined, as well as one additional study area immediately north of the site. The four study areas, shown in Figures 2.1 and 2.2, are:

- Study Area A - The Hudson River from just above Fenimore Bridge (see Note 3 in Figure 2.1) in Hudson Falls, NY (RM 197) to upstream (RM 209) of Glens Falls, NY;
- Study Area B - The Hudson River from just above Fenimore Bridge in Hudson Falls, NY to the Federal Dam at Troy (RM 153);
- Study Area C - The northern, freshwater portion of the tidal Hudson River, extending from the Federal Dam (RM 153) to RM 55, the average northernmost extent of salt water; and
- Study Area D - The brackish portion of the tidal Hudson River, extending from the average northernmost extent of salt water (RM 55) to the Battery (RM 0).

The Phase 2 data-collection program includes many specialized tasks involving geophysical surveys, water sampling, sediment sampling, and ecological studies. Four main tasks comprise most of the Phase 2 data-collection activities. The first three tasks are largely related to the geochemical fate and transport of PCBs in the Hudson. The last task is designed to collect data to specifically examine the ecological impacts of PCBs in the Hudson. However, it is anticipated that data from all tasks will be utilized in all evaluations. The data-collection tasks are briefly described first in Section 2.1. Section 2.2 presents the specific data-collection tasks proposed for each Study Area.

Before beginning the discussion of the main data-collection tasks, it is important to note the PCB analytical procedures which will be utilized in all tasks. Analyses of PCBs in previous investigations have generally been reported on an Aroclor basis. Over time, a further understanding of PCB geochemistry has evolved with a recognition that Aroclor mixtures released to the environment do not remain there unaltered but are affected by many processes. In the Hudson, several studies have demonstrated that these processes have produced major changes in the original Aroclor mixtures released to the river. To estimate the effects of processes that alter Aroclor mixtures, *i.e.*, absorption, volatilization, oxidation and biodegradation, it will be necessary to perform congener-specific PCB analyses for all media sampled in Phase 2. This analytical procedure examines the PCB compounds in a sample on an individual or near-individual basis, rather than as mixtures of large numbers of compounds. The term *congener* refers to the 209 individual compounds classified as PCBs. Congener-specific analysis can be used to differentiate newly released Aroclor mixtures from older, altered mixtures. It can also be used to differentiate the process(es) responsible for the alteration. It is expected that a maximum of 70 to 80 congeners will be classified in the PCB analysis in this study, because of the limited number of calibration standards available.

2.1 Summary of the Four Main Data-Collection Tasks

2.1.1 Water-Column Sampling

Water-column sampling, to be performed in Study Areas A, B and C, entails collection of samples to identify sources of PCB loads in the water column. One sampling approach will involve the collection of water-column samples at 10 locations in Study Areas A and B. The other sampling approach for these same areas will involve the collection of flow-averaged water-column sample composites. Flow-averaged samples will be collected at a limited number of stations in the Upper Hudson to examine the mean PCB loading generated across several important reaches of the river. For Study Area C, water-column samples will be collected at 3 stations. All samples will be separated into suspended matter and dissolved-phase fractions for analysis. Other pertinent parameters will be measured as well. Samples will also be collected to study PCB suspended matter to dissolved phase equilibrium. Archived extracts of water-column samples taken during the period 1977 to 1986 from the Lamont-Doherty Geological Observatory and Rensselaer Polytechnic Institute will be reanalyzed to examine historic water-column PCB levels on the same basis as the current samples.

As a part of the water-column sampling program, a time-of-transit study will also be conducted. This study will examine the time required for a parcel of water to travel through Study Area B. Dye will be released above the northern boundary of Study Area B and tracked as it travels downstream. In this manner, the timing of the water-column transect sampling stations can be optimized to track a single parcel of water through the Upper Hudson.

2.1.2 High- and Low-Resolution Sediment Coring

High-resolution sediment coring involves the collection of sediment cores from depositional zones in all four study areas. These cores are divided into thin layers for subsequent PCB congener-specific analysis, radionuclide analysis and other analyses. Because sediments are first transported by the water column as suspended matter, analyses of the radionuclide-dated sediments at depositional locations can be used to examine historic, water-column PCB transport on suspended matter. By using data from water-column monitoring and from the literature, the total water-column loading can be examined over time as well. The sediments also record the congener mixture on the suspended matter. These data can be used to examine and fingerprint current and historic PCB sources to the river and their relative importance. Reanalysis of archived high-resolution sediment core extracts will be compared with current sediment samples to examine *in-situ* degradation.

Low-resolution sediment coring involves the collection of sediment cores in order to determine PCB concentrations in sediment. These cores will be divided into thick sections for subsequent PCB congener-specific analysis, radionuclide dating, and other analyses. Low-resolution sediment coring will be used to examine a limited number of areas in the Upper Hudson as well as to classify various sedimentological zones defined on the basis of the geophysical surveys. The samples will assist in defining the depth of PCB-bearing sediments in Study Area B. The basic intent of this sampling effort is two-fold: to expand the current database on the sediment PCB inventory in the Upper Hudson and to reexamine a limited number of historic sampling locations to evaluate current sediment PCB levels relative to the historic results. The final implementation of this sampling program is dependent upon a thorough review of the historic sediment records from NYSDEC, General Electric and others in conjunction with the results of the geophysical survey program (described below).

2.1.3 Geophysical Surveying and Confirmatory Sampling

Geophysical surveys will be made of the river bottom in portions of the Upper Hudson (Study Area B). These surveys will be made using sonar techniques to map river bathymetry, sediment morphology, sediment texture, and fine-grained sediment thicknesses. The sonar results will be calibrated or confirmed by sediment sampling in the survey areas (confirmatory sampling). Based on the survey results, maps of river depth and sediment characteristics will be created. These maps will be used in the selection of low-resolution coring sites, the estimation of sediment PCB inventories, the scourability assessment and the Feasibility Study.

2.1.4 Ecological Field Program

As part of the ecological investigation, a field investigation will examine sediment properties, including PCB levels, at a total of fifteen ecologically-sensitive locations in the four study areas. In addition, benthic samples will be collected from three of the ecologically-sensitive areas in Study Area B. These samples will provide needed data for the ecological exposure assessment, since they will be correlated by contemporaneous fish data. When possible, the results of the sediment coring efforts, described in Section 2.1.2 above, will be utilized in conjunction with these samples.

2.2 Data-Collection Program By Study Area

2.2.1 Study Area A: Fenimore Bridge to Upstream (RM 209) of Glens Falls

Study Area A is defined as the reach of the Hudson River from RM 209 (Sherman Island Dam) downstream to Fenimore Bridge at Hudson Falls, NY (see Figure 2.1). The purpose of delineating this study area is to identify baseline contaminant inputs to downstream Study Area B. This area also serves as a baseline for the ecological studies to be performed farther downstream. As indicated in the Phase 1 Report, some release of PCBs may have occurred in this reach; therefore, it cannot be assumed that river water flowing from Study Area A is free of contaminants.

The geochemical sampling program for Study Area A has been designed to determine current PCB loads entering Study Area B from Study Area A by sampling the water column in Area A and analyzing the samples for PCBs on a congener-specific basis. Both the water-column transects and the flow-averaged water sampling will collect samples from this study area. Historic water-column loads of PCBs from Study Area A to Study Area B will be estimated using data obtained from high-resolution sediment core samples also taken within this study area. Figures 2.3 and 2.4 show the water-column monitoring and high-resolution sediment coring locations, respectively.

In addition to examining the total water-column load, the congener composition of the PCB load in Study Area A will be determined. These data will be compared with downstream congener mixtures to evaluate the importance of PCB sources from Study Area A in downriver areas. Suspended matter/dissolved phase partitioning data obtained from the water-column sampling effort will be used in the interpretation of water-column samples and high-resolution sediment core samples. The literature investigation will continue in Phase 2 to provide additional data on known historic and current PCB sources, discharges and levels in Study Area A. These data will aid in the interpretation of Study Area A sample data with the goal of estimating current and future sources of PCBs from Study Area A to Study Area B.

The ecological field investigation for Study Area A involves two study locations. These locations will be used as a baseline to examine the potential ecological impacts in the more-highly contaminated locations found in Study Area B. Figure 2.5 shows the planned ecological investigation locations for Study Area A.

2.2.2 Study Area B: Federal Dam to Fenimore Bridge

Study Area B is defined as the 40 miles of the Upper Hudson beginning at Fenimore Bridge and terminating at the Federal Dam in Troy. There are several major Hudson tributaries in this reach, including the Mohawk, the Hoosic, and the Batten Kill. Although these tributaries are not considered part of the Hudson River site, they may be sources of contaminants to the Hudson River.

The principal objective of the geochemical data collection in Study Area B is to assess the current sources and loads to the area and to evaluate their impact within the area as well as on the Lower Hudson (Study Areas C and D). This investigation considers sources and loads under current conditions, as well as those potentially produced during high-flow events. A significant finding from the Phase 1 investigation is that a large portion of the water-column PCB load in Study Area B appears to enter the river upstream of Rogers Island. Therefore the data-collection program will examine portions of the river upstream of Rogers Island, as well as zones of known contamination, such as the Thompson Island Pool.

The ecological field effort is designed to examine a number of ecologically important locations characterized by high-sediment PCB levels. These locations are intended to represent areas subject to the maximum site-related ecological stresses. The data collected at these locations will also be used to evaluate the potential impacts of remedial activities, such as dredging. These locations are generally planned for zones of fine-grained material where local sediment PCB concentrations are likely to be relatively high.

2.2.2.1 Main Data-Collection Tasks

The investigation of Study Area B will include all tasks described in Section 2.1. The water-column sampling efforts will be conducted to examine conditions under high-flow and low-flow conditions. (Stations for Study Area B are shown in Figure 2.3.) The results of the water-column sampling combined with the flow-monitoring data obtained by the US Geological Survey (USGS) will permit the calculation of PCB water-column loads for Study Area B. Estimation of PCB loads passing each sampling location will be used to identify the river segments contributing most significantly to those loads. Thus to the extent that sediment-derived PCBs can be identified in water-column samples, the water-column studies will provide an independent confirmation of the relative contribution of the Upper Hudson sediments to water-column PCB loads. Congener-specific data will provide assistance in determining potential contaminant sources, since these data will be compared to the congener profile of potential sources. For example, it can be expected that in Study Area B only PCBs derived from sediment-related sources will have experienced *in-situ* degradation and, therefore, if these sources represent an important input to the water column, the water-column congener mixture will be dominated by less-chlorinated PCB congeners.

The water-column studies will also address questions related to temporal variability in PCB loads and factors that influence PCB transport. Both river flows and PCB loads exhibit strong seasonal variability. It has been postulated that PCB mass transport occurs largely during the spring high-flow season when the river's suspended load is high. As flow rates decrease from spring into summer, both suspended matter and total PCB load diminish. Data obtained from analysis of suspended and dissolved sample fractions are expected to permit the examination of temporal variability in water-column PCB loads. These data will consequently provide additional insight into the source of water-borne PCBs and the mechanisms influencing contaminant transport. It is important to note that under nearly all current conditions found in the Hudson, the water-column concentrations of PCBs are not limited by the solubility of the congeners but rather by PCB input and loss rates and by adsorption onto suspended sediments.

As a part of the water-column study in this area, a time-of-transit study will be conducted to aid in the collection of water-column transect samples. This study will track a parcel of water through the entire Study Area B portion of the river (Fenimore Bridge to Waterford). This study will be used to provide input for the timing of sample collections at the seven water-column transect stations located on the axis of the Hudson.

High-resolution sediment cores will be obtained at a number of Study Area B depositional locations using hand-coring techniques (see Figure 2.4). Sediment chronology at each coring location will be established using radionuclide-dating techniques, as described in Section 3. Because sediment deposited at a specific location can be assumed to reflect the composition of suspended matter transported past that point, interpretation of data from the high-resolution cores permits identification of different contaminant sources in recent sediment PCB mixtures. Thus, the high-resolution program will lend support to the results of the water-column studies previously described.

In addition to enabling a determination of recent water-column PCB congener concentrations and contributing sources, the high-resolution coring program will facilitate evaluation of historic PCB levels, loads and sources. These data will be compared to the historic Upper Hudson River water-column database to obtain a refined estimate of historic suspended-phase PCB loads passing the coring locations. Using PCB partitioning data from the literature and the Phase 2 data-collection program, an estimate will also be made of historic total water-column PCB load. Because *in-situ* PCB degradation may have affected high-resolution sediment core samples, particular care will be exercised in utilizing the data.

A number of archived sediment cores and sediment-core extracts collected by previous investigators will be reanalyzed and compared to data from high-resolution sediment samples taken during Phase 2 from the same locations. Figure 2.6 shows the sampling locations of existing, archived high-resolution cores. Archived and Phase 2 sediment-sample pairs will be used to determine *in-situ* degradation rates for PCBs by comparing sediment layers from the same time horizon in the paired samples. For example, the layer corresponding to 1963 from the archived core will be compared with the 1963 layer from the Phase 2 core. The change in congener composition and concentration divided by the time between core-collection events is expected to yield an estimate of the degradation rate.

Geophysical measurements, along with confirmatory sampling, will provide information on river-sediment textures, sediment thickness, and river topography, so that a plan view of river bottom conditions can be generated. Plate A.1 shows the proposed geophysical survey areas. The data on sediment physical properties will be combined with contamination data from other sampling efforts to examine the relationship between physical and chemical sediment properties. Ultimately, this data will be used to improve estimates of the sediment PCB mass and its spatial distribution.

Low-resolution sediment coring will be used to examine PCB contamination in a limited number of locations to augment and improve estimates of the spatial distribution of PCBs initially developed by kriging techniques (see Section 2.2.2.2). The low-resolution coring program will not be performed on the scale of NYSDEC'S 1984 effort but will, instead, be directed at maximizing the information that can be extracted from the geophysical surveys, the high-resolution coring study, the kriging analysis and other existing data. Figure 2.7 shows the portion of Study Area B where low-resolution coring is tentatively planned.

Some river reaches within Study Area B will be examined intensively in order to compare historic and current contaminant levels. Both PCB concentrations and congener distributions will be examined to determine changes in the sediment inventory over time. In other instances, samples will also be located so as to examine PCB levels in zones displaying particular geophysical patterns as determined from the geophysical investigation. In this manner, it may be possible to characterize sediment PCB levels extensively without having to sample intensively. Low-resolution coring may also be applied to the Bakers Falls Pool, the submerged Remnant Deposit 1 and the GE discharge area because these locations may represent sources of PCBs to the water column.

The ultimate use of the low-resolution data will be to improve estimates of PCB sediment mass for major zones of contamination. This information will be used in conjunction with kriging results (see Section 2.2.2.2 below), the scourability assessment (Section 5.3), and other site data to designate PCB-contaminated areas potentially subject to scour. Data collected and made available by GE will be included in the evaluation. If appropriate, the GE data will also be used to estimate which PCB-contaminated sediments represent likely sources of water-column PCBs under average-flow conditions.

The ecological field investigation for Study Area B will obtain data on sediment PCB levels in the biologically active portion of the sediments (approximately the upper 5 cm) from four locations (see Figure 2.5). Three of these locations will also be sampled to examine the benthic invertebrate community to evaluate the impact of PCBs on the local ecology as well as to provide data needed to evaluate the potential impacts of various remedial alternatives.

Taken together, the data on sediment physical properties derived from geophysical measurements and the data on contamination-distribution patterns derived from the sampling programs constitute much of the basic geochemical information needed in Phase 2. The ecological field investigation will provide additional data needed to assess the ecological impacts posed by PCB contamination. Although all Phase 2 sampling efforts involve all study areas, they are centered in Study Area B. In total, these data are needed to assess potential PCB sources to the water column, sediment mobility during storm events, operational difficulties likely to be associated with sediment removal, ecological impacts posed by PCB contamination and sediment removal, and requirements for establishing a long-term monitoring program.

2.2.2.2 Kriging of Sediment Data from the Thompson Island Pool

In addition to the main data-collection tasks described above, sediment-contaminant distribution and mass will be evaluated using geostatistical techniques. The 1984 NYSDEC database for the Thompson Island Pool provides the only basis for a relatively comprehensive assessment of PCB mass distribution in Study Area B at a particular point in time. Kriging methods, which attempt to find the minimum variance (most accurate), unbiased estimate of spatially-correlated data, will be applied to the 1984 data set with the refinements noted here.

Although previous attempts to apply geostatistical analysis to the analytical data obtained in the 1984 sediment survey have met with only limited success[1], available data appear not to have been utilized fully. Most samples collected in 1984 were first screened by a mass spectrometer; typically, those testing high for PCBs were sent for laboratory gas chromatographic (GC) analysis. Thus, the laboratory analyses represent only a fraction of the total data collected. The Phase 2 analysis will use the screening data as well as the GC results in the geostatistical analysis. Prior to submission of this Phase 2 Work Plan, a theoretical approach was developed by TAMS/*Gradient* to incorporate both data sets in the analysis. Preliminary tests of the method on PCB data for the southern part of the Thompson Island Pool revealed that the method has substantial potential to improve the accuracy of estimation. If warranted, the sample location coordinate system may be transformed from northing-easting coordinates to a grid aligned with the direction of river flow to improve further the spatial-correlation analysis.

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[1] Brown, M.P., M.B. Werner, C.R. Carnsone and M. Klein. 1988. "Distribution of PCBs in the Thompson Island Pool and the Hudson River: Final Report of the Hudson River PCB Reclamation Demonstration Project Sediment Survey." Division of Water, NYSDEC, Albany, NY.

Interpretation of estimates of sediment PCB contamination derived from kriging will depend upon how successfully the low-resolution cores reproduce the results of the 1984 sediment levels. To the extent that the levels agree, the estimates derived from kriging will be assumed to be good estimates of current conditions in locations where low-resolution coring is not performed. To the extent that they do not, then the estimates will not provide a direct indication of current sediment levels and additional low-resolution coring may be required if additional data on the sediment PCB inventory is needed; however, it is unlikely that additional data will be collected, and alternative approximation methods may be required.

2.2.2.3 Other Data-Collection Tasks

One other data-collection task is being considered for Study Area B. This task would involve sampling to assess scourability for contaminant-transport modeling. The basis for this task is discussed at length in Section 5 but will only be implemented if needed. The actual sampling and testing procedures for the scourability assessment are outlined in the Phase 2 Sampling Plan (Appendix A).

2.2.3 Study Area C: RM 55 to Federal Dam

Study Area C represents the northern, freshwater portion of the Hudson River estuary. The downstream boundary at River Mile 55 was selected because it is considered to be the average upstream limit of the salt front.

The main objective of the Phase 2 investigation in Study Area C is to evaluate the relative importance of the loading from Study Area B to the overall PCB load in Study Area C. An initial estimate of Upper Hudson PCB loading to the estuary was provided in the Phase 1 Report. A second objective of the investigation in this area is to assess the impact of PCB contamination on a number of ecologically important or sensitive sites.

The Phase 2 investigation in Study Area C involves four main data-collection tasks: high-resolution sediment coring, analysis of archived sediment cores, water-column sampling and an ecological field investigation. These tasks are designed to satisfy the objectives listed above. Data from the high-resolution sediment cores will be used to identify the Upper Hudson source in the PCB levels found in recent sediments and to estimate its importance relative to other sources in Study Area C. The reanalysis of archived sediment cores combined with recent high-resolution sediment core results will be used to assess PCB fate in the sediments of Study Area C. Data from the water-column samples collected on three separate occasions will provide an instantaneous measure of the relative importance of the Upper Hudson loading in Study Area C. The high-resolution core and water-column sample data will also be used in the ecological assessment in conjunction with the results of the ecological field investigation.

High-resolution cores to be obtained at several locations within Study Area C will be analyzed for congener-specific PCBs and a range of other parameters, which are necessary to adequately evaluate contaminant fate and transport. Figure 2.8 shows the high-resolution coring locations for Study Area C. As in Study Areas A and B, the high-resolution cores will be used to estimate historic PCB loads passing a particular sampling location. An assessment of possible sources of the sediment-borne PCBs will be derived from the congener-specific profiles of cores collected throughout the length of Study Area C. Since these cores will be radiometrically-dated, a comparison of congener profiles in sediments is expected to provide insight as to whether one upriver source is responsible for the contaminant load or whether multiple sources have contributed to the load. Archived sediment core sections are available for four historic coring locations in Area C (see Figure 2.9). These samples will be paired with their Phase 2 equivalents to assess *in-situ* degradation in the sediments of Study Area C.

Directly related to the issues concerning the high-resolution sediment coring task is the consideration of possible PCB loads from the Mohawk River. Available historic data poorly accounts for the contribution of the

Mohawk River to overall PCB releases to the estuary; during Phase 2, both water-column samples and high-resolution cores will be obtained within the Mohawk (see Figures 2.3 and 2.4). Data obtained from these samples will be used to estimate current- and historic-PCB loads contributed by the Mohawk to the Upper Hudson and, in turn, to the estuary.

The water-column sampling program in Study Area C is more limited than that for Study Area B due to the greater distance from the sources of concern in this investigation. Water-column samples will be collected from three stations in Study Area C on only three occasions (see Figure 2.10). These sampling events will roughly coincide with three water-column transects in Study Area B. However, no attempt will be made to try to follow a water parcel through Study Area C because of the complex nature of the tidal movements which are superimposed on the net freshwater flow through the study area. The water-column data will be used in conjunction with the high-resolution coring results, thereby providing a means to examine both the instantaneous and long-term PCB loading in Study Area C. The water-column results will also be used in the preparation of the ecological assessment for Study Area C.

The ecological field study in Study Area C will examine seven ecologically important locations in Study Area C (see Figure 2.11). These locations will be sampled for several parameters, including sediment PCB levels in order to provide needed data for the ecological assessment. Unlike Study Area B, no data will be collected on invertebrate communities although a habitat overview and general ecological evaluation will be performed for all locations.

In addition to Phase 2 sampling, the review of PCB discharge records begun in Phase 1 will be continued to further examine the likelihood of other significant releases to Study Area C. Data research will include discharge permit files (SPDES permits), NYSDEC and NYSDOH records of uncontrolled PCB releases, STORET system water-quality data base (for tributary-related contamination) and other information which may be available in local agency files.

2.2.4 Study Area D: Battery to RM 55

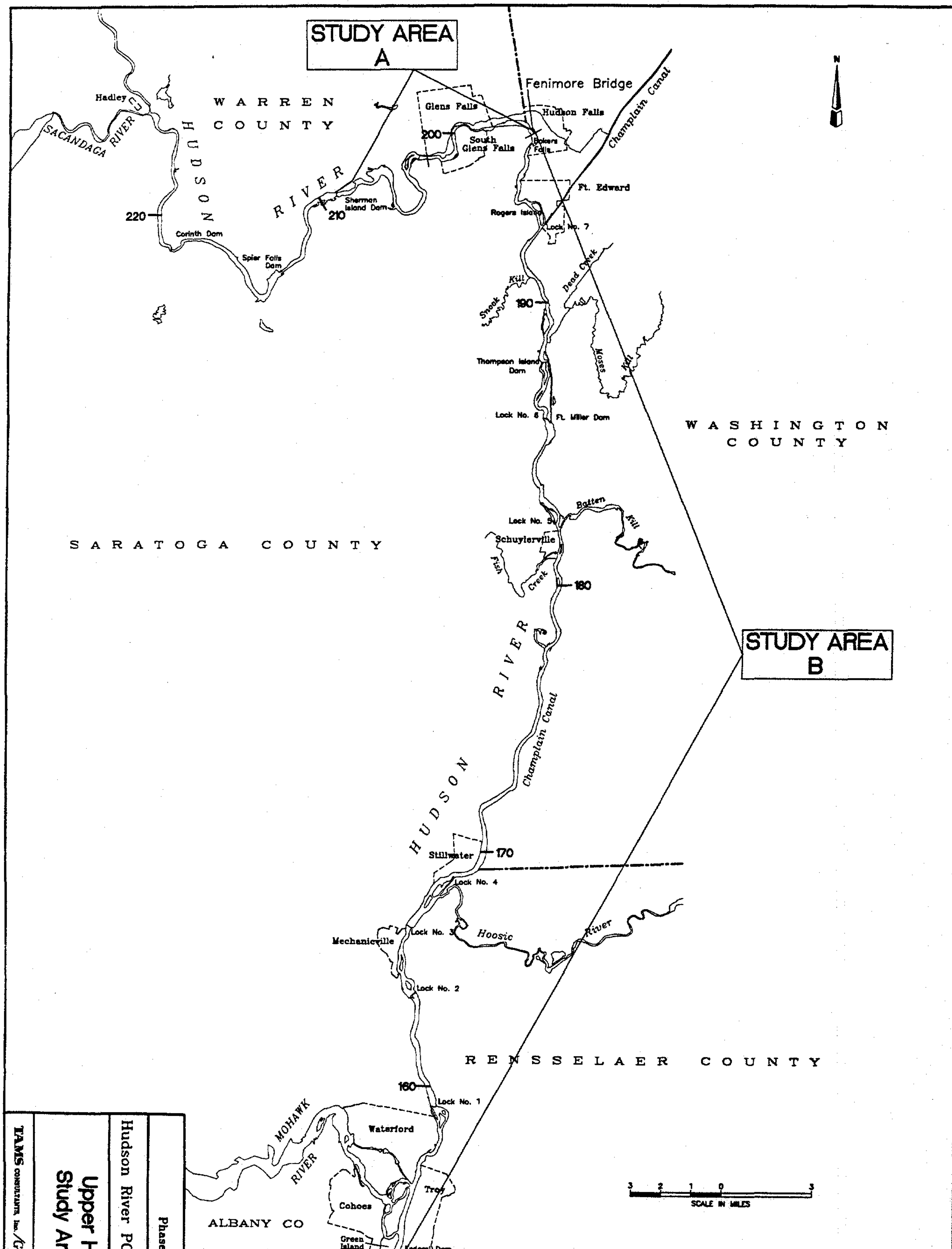
The Hudson River reach covered by Study Area D is the southern part of the estuary. It is defined as a separate study area, because its brackish water distinguishes it from the typically freshwater part of the estuary. Separating study areas of the estuary at River Mile 55 is also considered appropriate, because: 1) contaminant discharges from industries in the New York City Metropolitan Area are not expected to migrate upstream of the salt front;and 2) the ecosystem and sediment geochemical characteristics upstream of the salt front are different from those below the salt front.

The focus of investigations in Study Area D will be to establish the significance of current PCB releases from the Upper Hudson (Study Area B) to the total contaminant burden found within Study Area D by determining the relative importance of various PCB inputs from the sediment records and other available release data to the estuary. Once an estimate of the relative burden contributed by various sources has been established, an assessment of the significance of remedial actions in Study Area B on Study Area D can be made. Additionally, the investigation in Study Area D will also include an ecological field study. The goals of the field study in Study Area D are similar to those of the other study areas, *i.e.*, to obtain the necessary data to perform an ecological assessment in a number of ecologically important areas. Two ecological field survey locations have been identified for Study Area D. These are shown in Figure 2.11.

Seven sediment cores will be collected within Study Area D for purposes of high-resolution analysis (see Figure 2.8). These cores will be analyzed in the same manner as high-resolution samples collected elsewhere in the Hudson and the resulting data will be evaluated similarly. Using the suspended PCB load estimates derived from the high-resolution core samples and literature data, total water-column PCB concentrations can be computed for current and historic conditions. Since high-resolution samples are to be analyzed for PCBs on a congener-specific basis, the historic PCB-congener profile will also provide significant additional insight about sources of the contaminant load. Figure 2.9 shows the historic high-resolution core locations for Study Area D.

The high-resolution core program for Study Area D must be considered in the context of the total effort described in this plan. Data derived from sediment cores collected in all four study areas will be needed to evaluate PCB sources and loads within Study Area D. For example, trends in congener patterns observed in Study Area C samples should continue into samples collected in Study Area D if no other PCB sources are present in the area. Therefore, shifts in congener patterns, for example, from an Aroclor 1242 pattern to one representative of a more heavily chlorinated Aroclor, are expected to be observable when an additional source of heavier congeners exists. The presence of discernible congener pattern changes from north to south may imply different sources.

A number of analysts have generated estimates of current PCB discharges to New York Harbor. The Phase 1 Report identified several such efforts and provided a tabulation of various PCB sources and their magnitudes. In addition, an independent estimate was generated, during Phase 1, of PCB loads currently released to the Hudson estuary (Study Area C) from the river above Federal Dam (Study Area B). During Phase 2, a projection of long-term PCB loading to the estuary will be formulated, using information derived from the water-column study and the high-resolution coring program described earlier in this plan. Also, USEPA's Water Management Division expects to sample combined sewer outfalls, POTW outfalls and river samples in Study Area D for PCB-congener analyses which will be evaluated in Phase 2.



Legend

180 River Mile

Note:

1. Study Area A: Sherman Island Dam to Fenimore Bridge
2. Study Area B: Fenimore Bridge to Federal Dam
3. Actual demarcation between Study Areas A and B is just north of Fenimore Bridge so that Study Area B includes the old Hudson Falls Treatment Plant outfall.

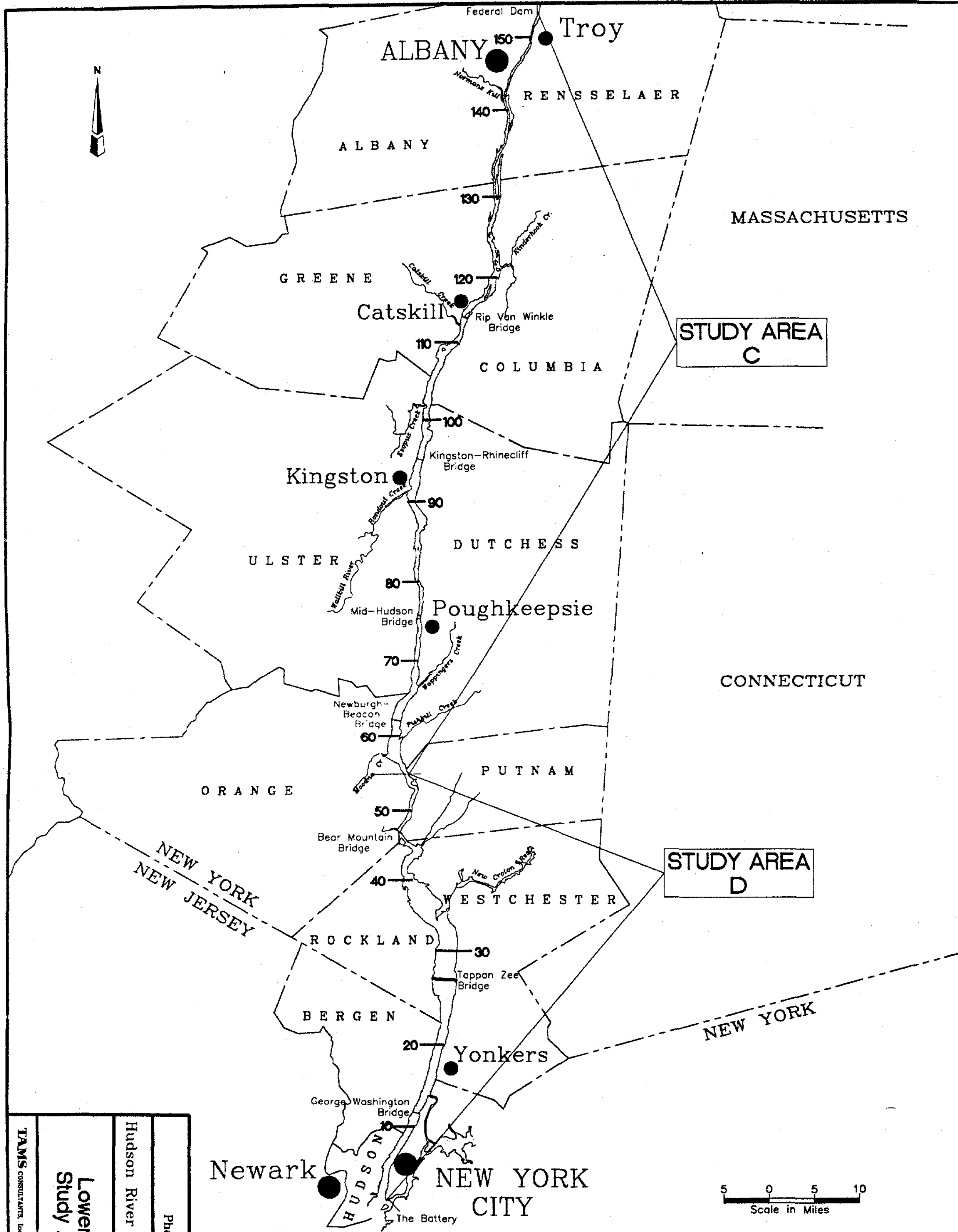
Phase 2 Work Plan

Hudson River PCB Reassessment RI/FS

Upper Hudson River
Study Areas A and B

TAMS Consultants, Inc./Gradient Corporation

Figure 2.1



Lower Hudson River
Study Areas C and D

Hudson River PCB Reassessment RI/FS

Phase 2 Work Plan

TAMS CONSULTANTS Inc./Gradient Corporation

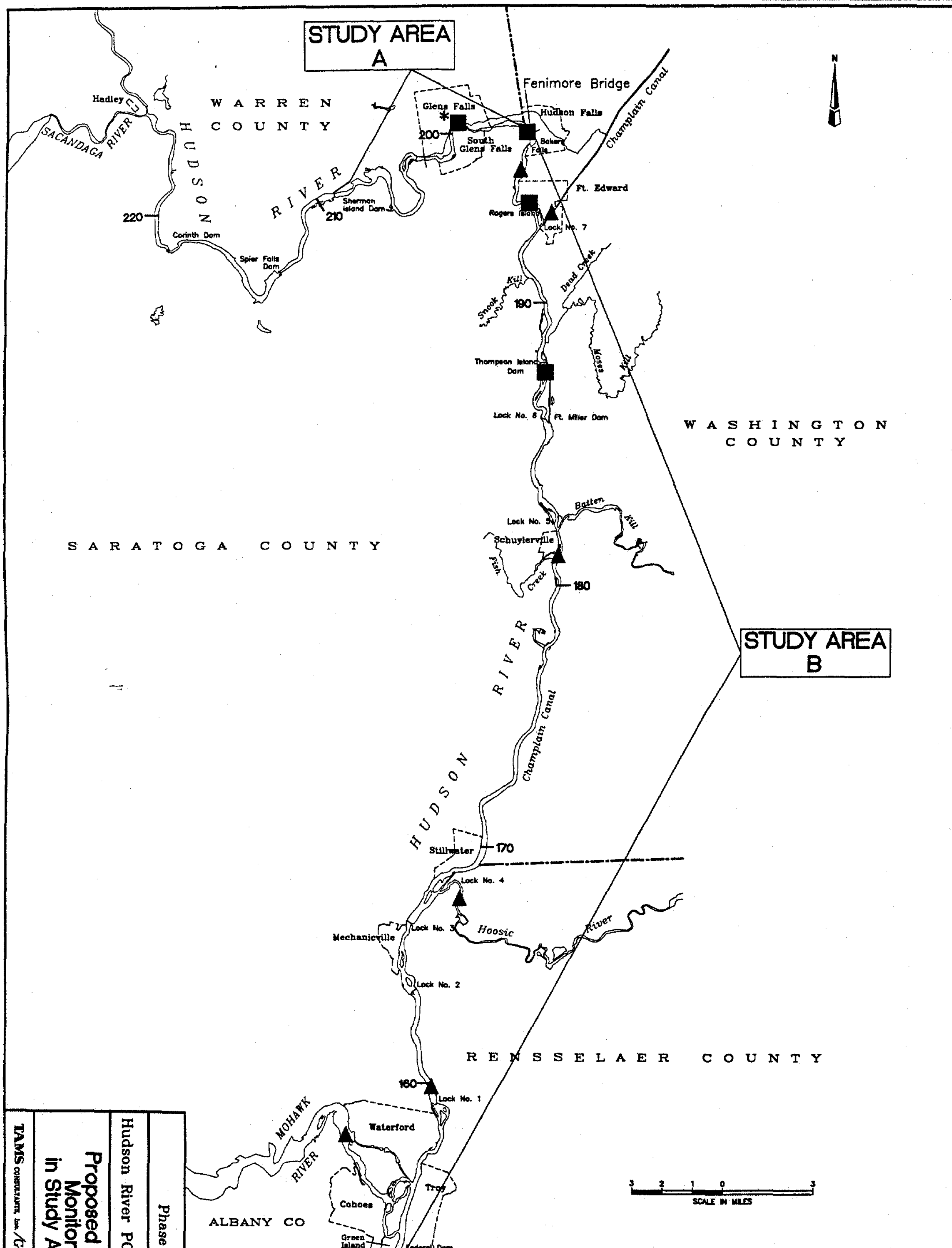
Figure 2.2

Legend

100 River Mile

Note:

1. Study Area C: Federal Dam to River Mile 55
2. Study Area D: River Mile 55 to The Battery



Legend

180 River Mile

▲ Proposed Water-Column Transect Sampling Station

■ Proposed Combined Water-Column Transect and Flow – Averaged Water-Column Sampling Stations

* A suitable location closer to the downstream limit of Study Area A will be used if available

Note:

1. Study Area A: Sherman Island Dam to Fenimore Bridge
2. Study Area B: Fenimore Bridge to Federal Dam
3. Actual demarcation between Study Areas A and B is just north of Fenimore Bridge so that Study Area B includes the old Hudson Falls Treatment Plant outfall.

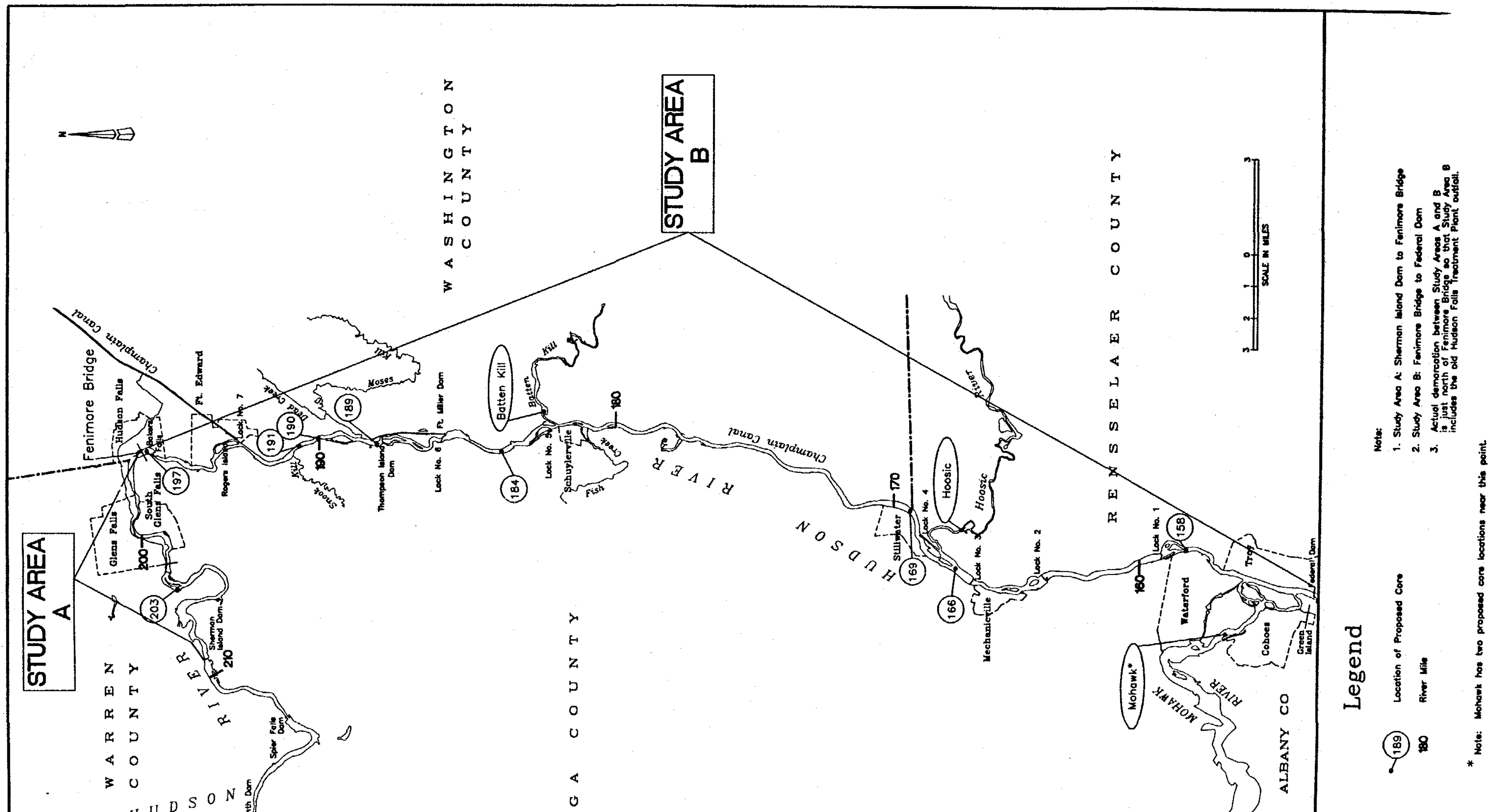
Phase 2 Work Plan

Hudson River PCB Reassessment RI/FS

Proposed Water-Column Monitoring Stations in Study Areas A and B

TAMS Consultants, Inc. / Gradient Corporation

Figure 2.3



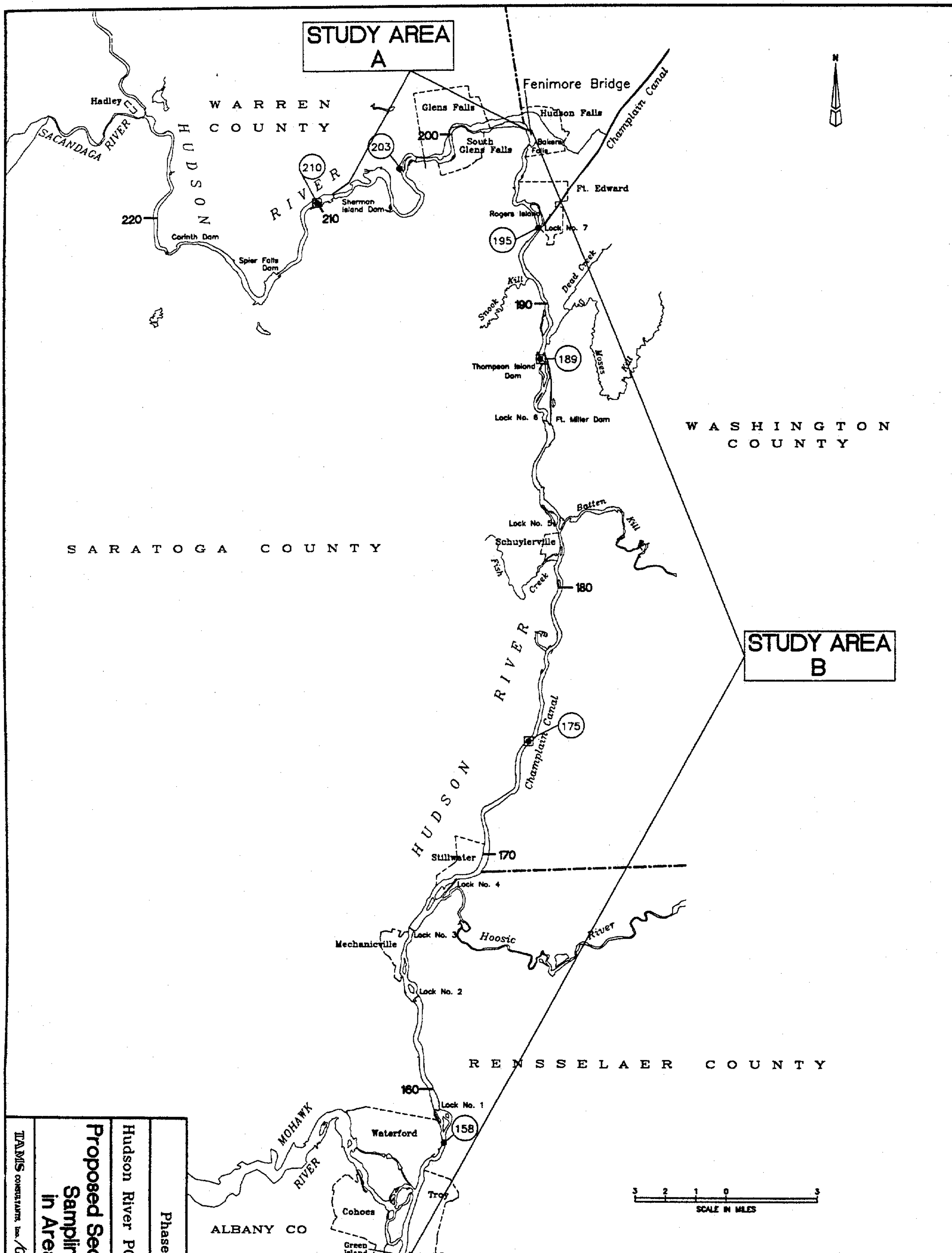
Phase 2 Work Plan

Hudson River PCB Reassessment RI/FS

Proposed High-Resolution Coring Locations in Study Areas A and B

TAMS Consultants, Inc./Gradient Corporation | Figure 2.4

312258



Legend

(189) Location of Proposed Sediment Sample

(210) Location of Proposed Combined Sediment and Benthic Sample

180 River Mile

Note:

1. Study Area A: Sherman Island Dam to Fenimore Bridge
2. Study Area B: Fenimore Bridge to Federal Dam
3. Actual demarcation between Study Areas A and B is just north of Fenimore Bridge so that Study Area B includes the old Hudson Falls Treatment Plant outfall.

Phase 2 Work Plan

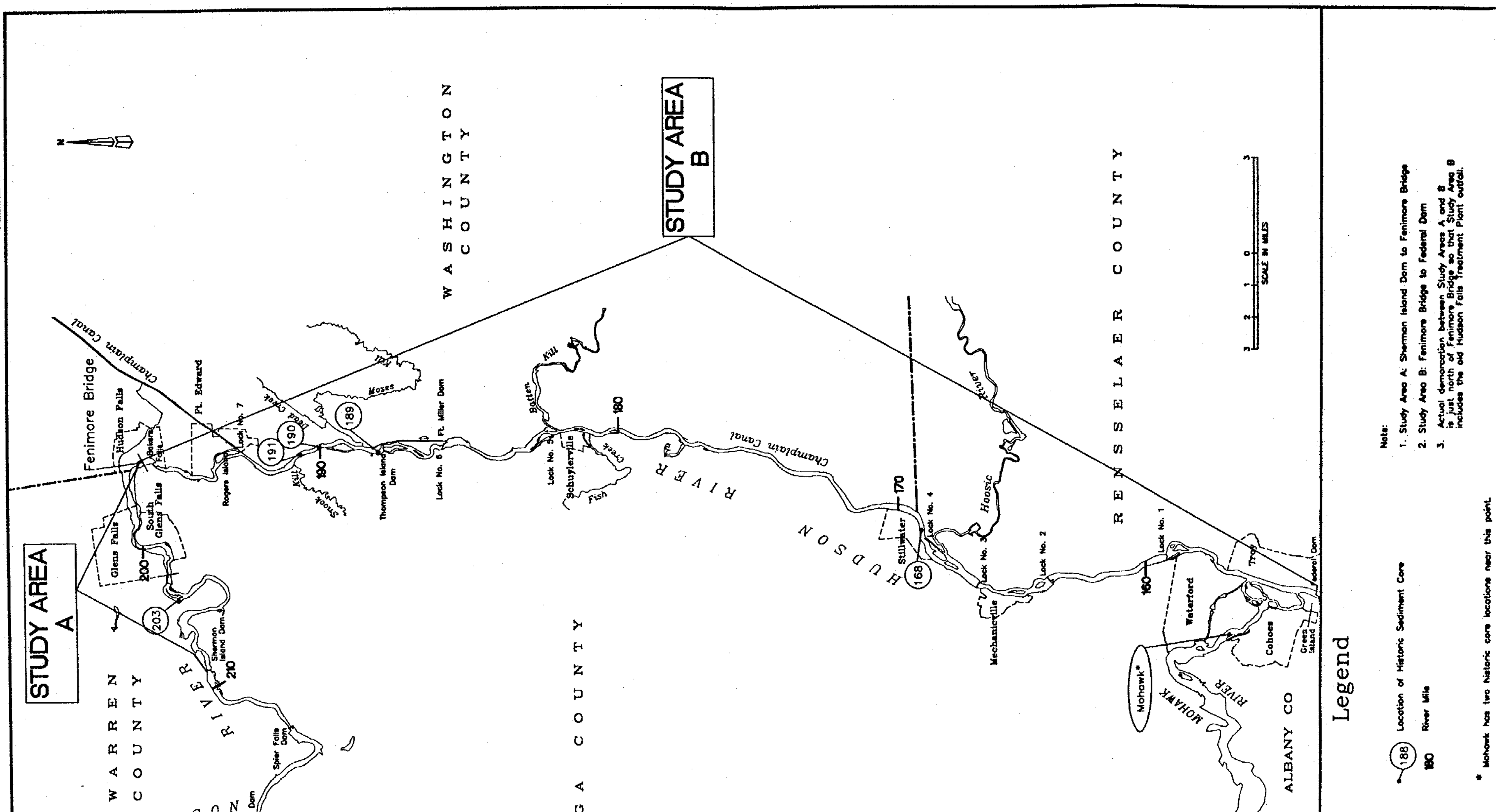
Hudson River PCB Reassessment RI/FS

Proposed Sediment and Benthic Sampling Locations in Areas A and B

TAMS Consultants, Inc. / Gradient Corporation

Figure 2.5

312259



Phase 2 Work Plan

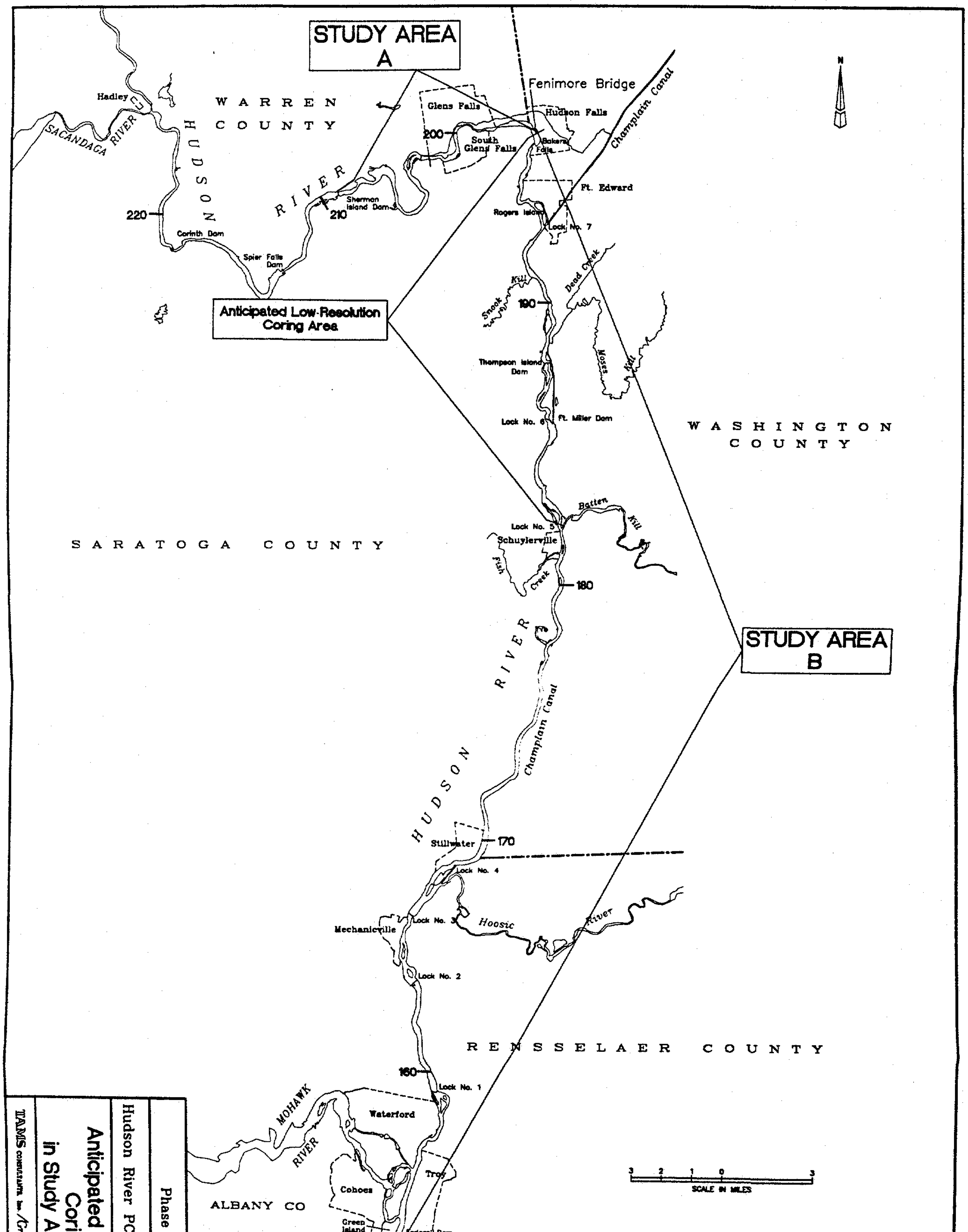
Hudson River PCB Reassessment RI/FS

Historic High-Resolution Coring Locations in Study Areas A and B

TAMS Consultants, Inc. / Gradient Corporation

Figure 2.6

312260



Legend

180 River Mile

Note:

1. Study Area A: Sherman Island Dam to Fenimore Bridge
2. Study Area B: Fenimore Bridge to Federal Dam
3. Actual demarcation between Study Areas A and B is just north of Fenimore Bridge so that Study Area B includes the old Hudson Falls Treatment Plant outfall.

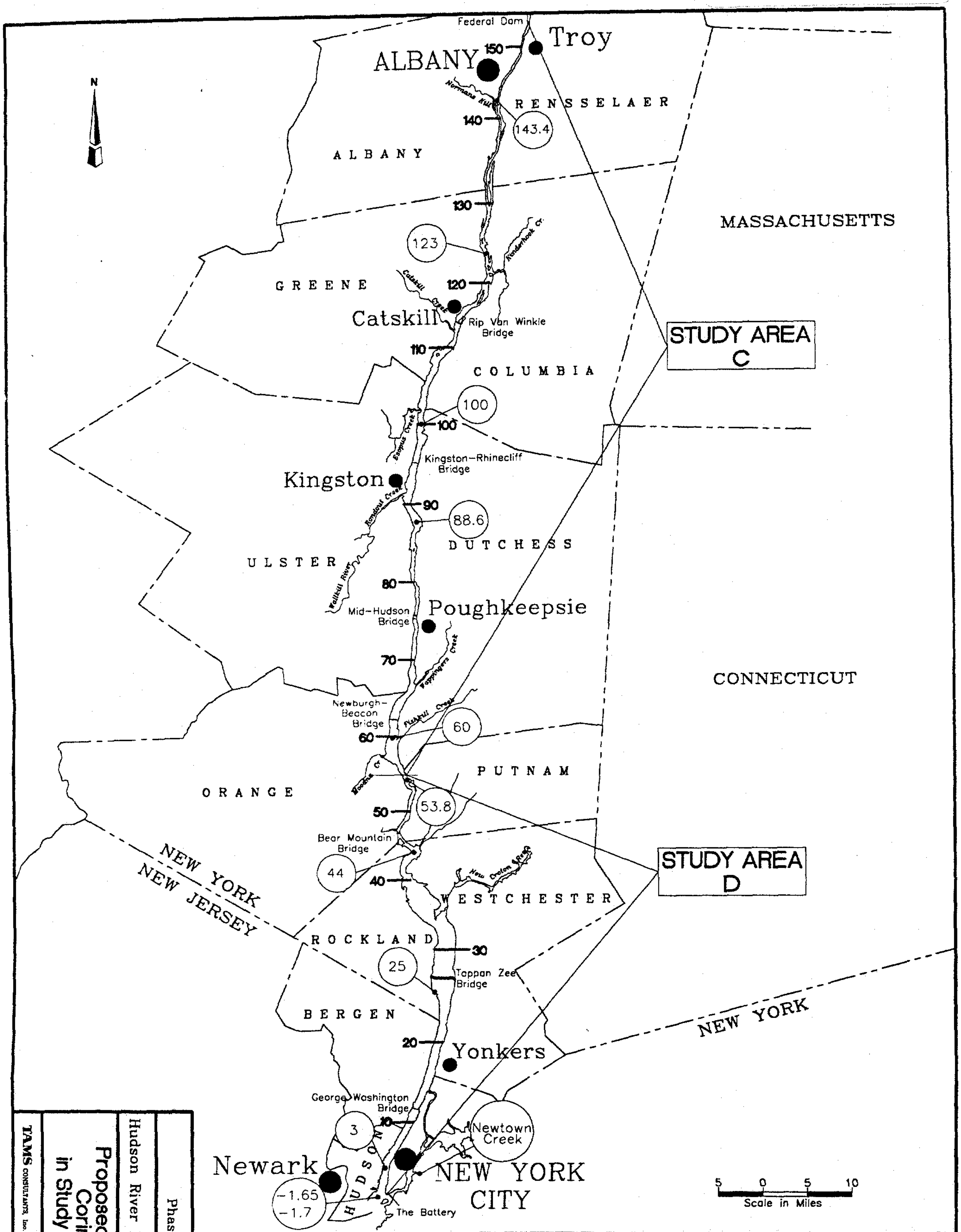
Phase 2 Work Plan

Hudson River PCB Reassessment RI/FS

Anticipated Low-Resolution Coring Area in Study Areas A and B

TAMS Consultants Inc./Gradient Corporation

Figure 2.7



Phase 2 Work Plan

Hudson River PCB Reassessment RI/FS

Proposed High-Resolution Coring Locations in Study Areas C and D

TAMS Consultants, Inc./Gradient Corporation

Figure 2.8

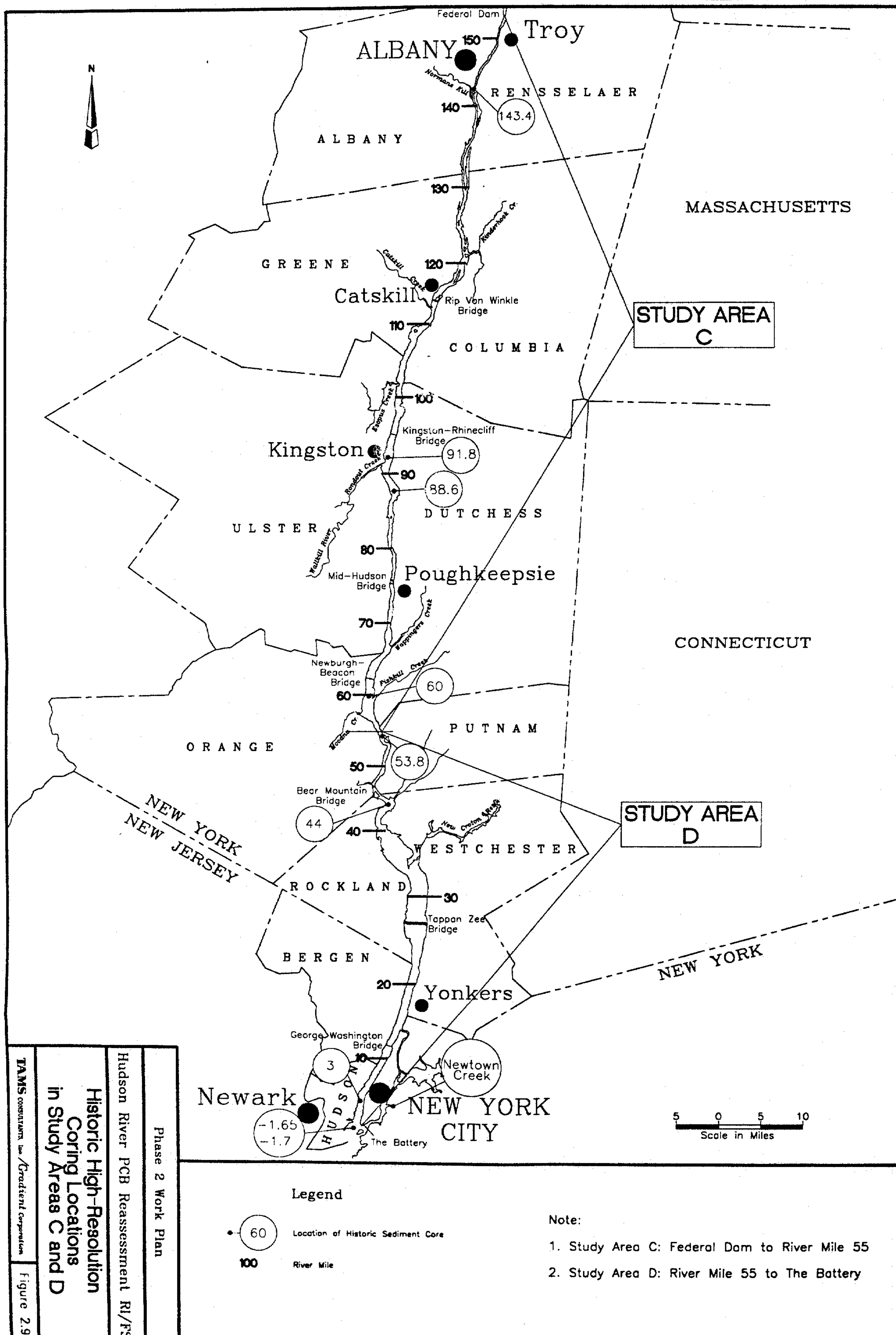
Legend

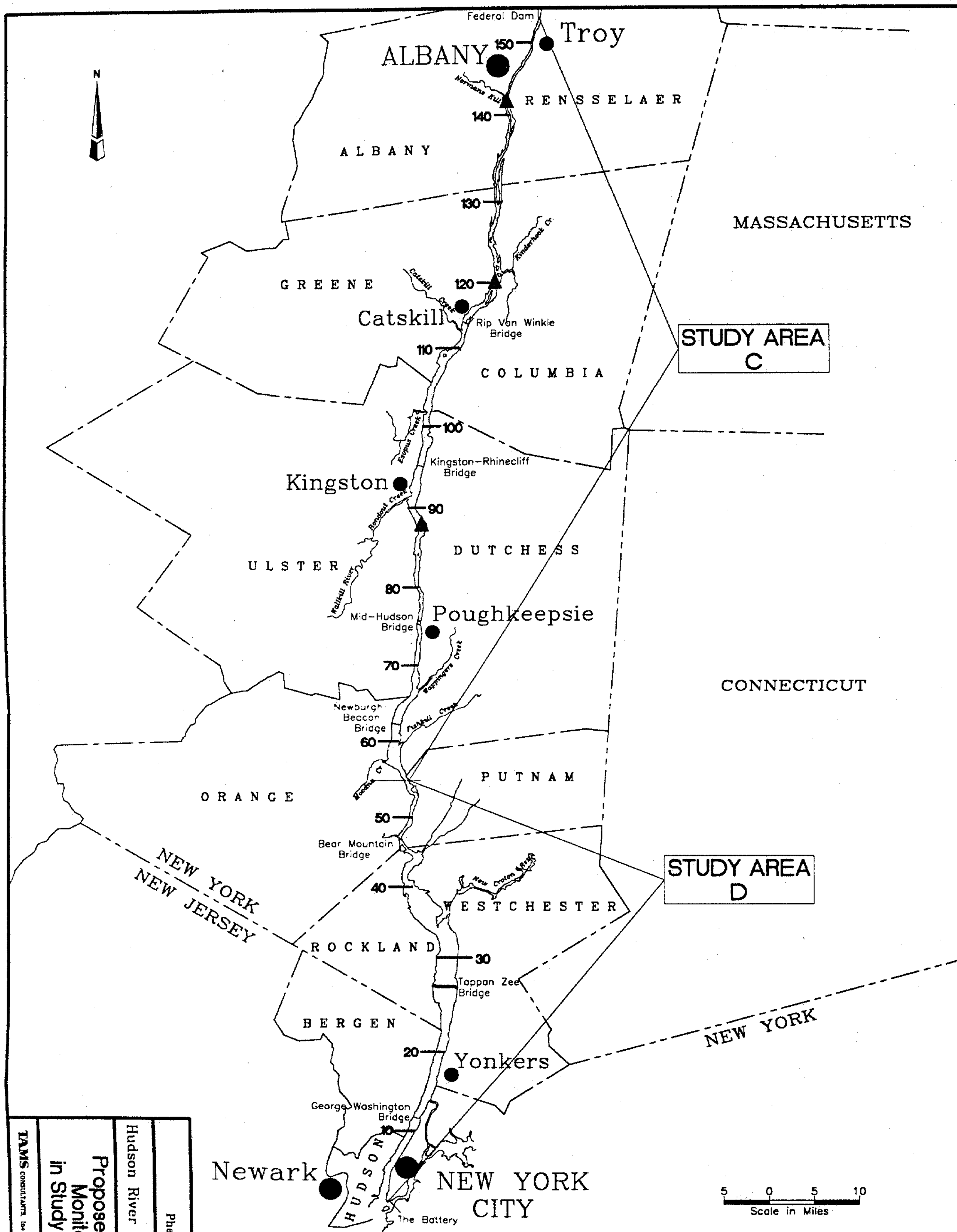
(60) Location of Proposed Core

100 River Mile

Note:

1. Study Area C: Federal Dam to River Mile 55
2. Study Area D: River Mile 55 to The Battery


Federal Dam
Troy
ALBANY
150
140
143.4
Normans Kill
RENSSELAER
ALBANY
N
130
MASSACHUSETTS
Kinderhook Cr.
GREENE
Catskill Creek
120
Catskill
Rip Van Winkle
Bridge
STUDY AREA
C
110
COLUMBIA
100
Esopus Creek
Kingston-Rhinecliff
Bridge
Kingston
91.8
Rondout Creek
90
88.6
DUTCHESS
ULSTER
Wallkill River
80
Mid-Hudson
Bridge
Poughkeepsie
70
Wappingers Creek
CONNECTICUT
Newburgh-
Beacon
Bridge
Fishkill Creek
60
60
Moodna Cr.
PUTNAM
ORANGE
50
53.8
Bear Mountain
Bridge
STUDY AREA
D
New Croton Res.
44
40
NEW YORK
NEW JERSEY
WESTCHESTER
ROCKLAND
30
Tappan Zee
Bridge
BERGEN
NEW YORK
20
Yonkers
George Washington
Bridge
3
10
Newtown
Creek
Newark
HUDSON
NEW YORK
CITY
-1.65
-1.7
The Battery
5 0 5 10
Scale in Miles
Legend
60 Location of Historic Sediment Core
100 River Mile
Note:
1. Study Area C: Federal Dam to River Mile 55
2. Study Area D: River Mile 55 to The Battery
Phase 2 Work Plan
Hudson River PCB Reassessment RI/FS
Historic High-Resolution
Coring Locations
in Study Areas C and D
TAMS Consultants, Inc. / Gradient Corporation
Figure 2.9



Legend

100 River Mile

▲ Proposed Water-Column Transect Sampling Station

Note:

1. Study Area C: Federal Dam to River Mile 55
2. Study Area D: River Mile 55 to The Battery

Phase 2 Work Plan

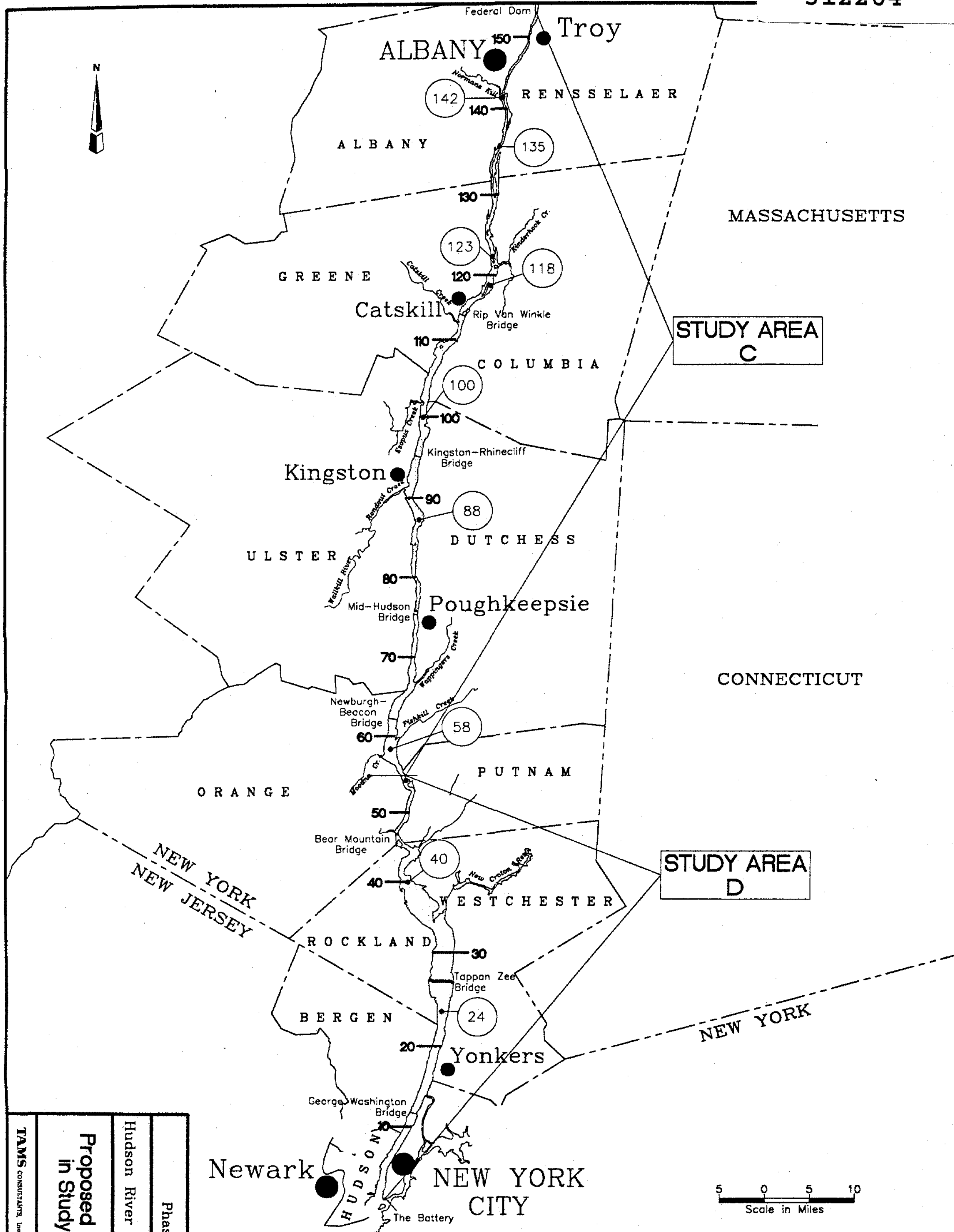
Hudson River PCB Reassessment RI/FS

Proposed Water-Column Monitoring Stations in Study Areas C and D

TAMS Consultants, Inc / Gradient Corporation

Figure 2.10

312264



Legend

88 Location of Proposed Sediment Samples

100 River Mile

Note:

1. Study Area C: Federal Dam to River Mile 55

2. Study Area D: River Mile 55 to The Battery

Phase 2 Work Plan

Hudson River PCB Reassessment RI/FS

Proposed Sediment Sampling in Study Areas C and D

TAMS Consultants, Inc / Gradient Corporation

Figure 2.11

3. MAIN GEOCHEMICAL DATA-COLLECTION TASKS

This section presents a detailed discussion of the main geochemical data-collection tasks, *i.e.*, water-column sampling, sediment sampling and geophysical surveys plus a discussion on the need for congener-specific PCB analysis, in order to explain how the data derived from these tasks will be specifically utilized in Phase 2. (Section 2 provides an overview of these tasks for the general reader and summarizes data-collection activities by study area.)

3.1 Congener-Specific Analysis of PCBs

As noted in the Phase 1 Report and elsewhere, the nature of PCB compounds is relatively complex. There are ten homolog groups, varying from one to ten in the number of chlorine atoms attached to the biphenyl molecule. Within each homolog group there exists a range of isomers, which vary based on the positioning of the chlorine atoms around the molecule. The number of isomers per homolog group varies from one for decachlorobiphenyl to forty-six for pentachlorobiphenyl. Collectively, the isomers are called congeners and refer to the 209 individual compounds classified as polychlorinated biphenyls.

The importance of this distinction in PCB classes arises from the means by which PCBs were produced and eventually released to the environment. PCBs were produced for industrial use as commercial mixtures called Aroclors, which typically contained several homolog groups, each containing many congeners. Analyses of PCBs in the environment have been reported historically on an Aroclor basis. This analytical approach became questionable, when it became generally known that Aroclor mixtures released to the environment did not remain there unaltered. Instead the mixtures undergo various processes, such as adsorption, volatilization, oxidation and degradation, which alter the original Aroclor mixture released to the environment.

In order to assess the impact of these processes, which vary in degree throughout the Hudson, PCB analyses will be necessary on a congener-specific basis. For example, in some cases the variation in congeners within a single homolog group may be used to define a specific geochemical process. Congener-specific analysis can also be used to differentiate newly released Aroclor mixtures from relatively older, altered congener mixtures.

Congener-specific analyses are proposed for all PCB analyses in Phase 2, because of their ability to differentiate fresh Aroclor mixtures from each other, to separate altered from unaltered mixtures and to differentiate the net effects of the various geochemical and biodegradation processes. Figure 3.1 illustrates the differences among several standard Aroclor mixtures on a homolog basis. Even with these limited 10 basic divisions, differences among the mixtures are clear. When congener analyses are applied to environmental samples, these distinct Aroclor signatures plus the alterations as a result of various processes become evident.

In this study, congener-specific analysis refers to the separation of the sample PCB mixtures by gas chromatography into a maximum of about 120 to 130 peaks (two to three congeners are occasionally represented by a one peak). Nevertheless, the level of separation to be achieved is sufficient for the necessary resolution of data. Of the congeners represented by these peaks, roughly 70 to 80 have reference standards to which their analyses can be referenced. The concentrations represented by the remaining peaks will be estimated based on their analytical response factors as published in the literature.

3.2 Water-Column Sampling and Analysis

As part of the investigation in Phase 2, a set of water-column samples will be collected from the Upper and Lower Hudson (Study Areas A, B and C). These samples will be analyzed for a number of parameters and used to examine both current PCB loads and geochemical processes affecting those loads. These data will also be used in the ecological evaluation to examine the PCB exposure to the biota via the water column.

The data-collection program for the water column consists of five separate subtasks:

- Water-Column Transects Sampling;
- Time-Of-Transit Study;
- Water-Column PCB-Equilibrium Study;
- Flow-Averaged Water-Column Sampling; and
- Analysis of Historic Water-Column Samples.

These subtasks are described in Sections 3.2.1, 3.2.2, 3.2.3, 3.2.4 and 3.2.5, respectively.

3.2.1 Transect Sampling

This subtask will involve sampling in Study Areas A, B and C. In the Upper Hudson, this subtask is designed to measure a series of instantaneous analytical water-column parameters (*i.e.*, "snapshots" of water-column conditions), as a parcel of water travels through Study Areas A and B. The Upper Hudson transect is defined as a longitudinal series of water-column sampling stations in the direction of flow between Glens Falls and Waterford. As a parcel of water travels through these areas, its PCB load may change. Changes in the PCB loading will be used to understand where in the Upper Hudson the PCB load is derived and, once in the water column, how this load is altered or transferred to the Lower Hudson (Study Areas C and D).

In the Lower Hudson (Study Area C), the complexity of the flow regime is such that following a water parcel in this area is quite difficult since the tidal fluctuations are substantially greater than the net freshwater flow. In this area, water-column samples will be collected subsequent to the Upper River transect but without the strict adherence to a time-of-transit schedule. The purpose of the water-column sampling in this region is two-fold: first to provide an indication of water-column PCB levels for the purposes of the ecological assessment and, second to examine the instantaneous loadings of PCBs from the Upper Hudson and other sources to this area. These data will be used in conjunction with the high-resolution sediment coring results to compare long-term and short-term PCB transport.

To accomplish the purpose of this subtask, a series of sampling stations will be established to collect samples for the following parameters:

- Dissolved phase PCB-congener concentrations;
- Suspended matter PCB-congener concentrations;
- Total suspended solids (total suspended matter);
- Total organic carbon on suspended solids;
- Dissolved organic carbon (DOC);
- Chlorophyll-a;
- Total water-column PCBs;
- General water-quality parameters, *e.g.*, pH, temperature, conductivity, dissolved oxygen.

For Study Areas A and B, the individual sampling events will be performed so as to follow in a general fashion the same parcel of water as it travels through the Upper Hudson. The time for a parcel of water to travel through the Upper Hudson will be established as part of the time-of-travel study which is discussed in Section 3.2.2. For the purposes of geochemical water-column sampling, a water parcel is considered to be relatively large, of the scale of one quarter mile in length. This scale is the result of the actual time required to collect a sample during which the river continues to flow beneath the sampler. By sampling the same parcel of water at each sampling station, changes in the parameters for the parcel of water as it travels between two successive stations can be measured. Ignoring for the moment any geochemical processes which may affect the loading, increases in the water-column PCB concentration across a pair of monitoring stations would be interpreted as the result of an additional PCB load originating in the intervening river section. Decreases in concentration would be interpreted as the result of dilution by tributary additions or by loss from the water column. Comparison of the differences in congener mixtures at the two stations would yield information on the nature of the source or the geochemical processes in the intervening river section.

The use of congener-specific data, using preliminary data collected by General Electric in 1991, is shown in Figure 3.2, which illustrates changes in the water-column homolog mixture between two monitoring points in the Upper Hudson on two separate dates. The monitoring points represented are the Route

197 Bridge at Fort Edward and the Thompson Island Dam, *i.e.*, the input point and the output point of the Thompson Island Pool, respectively. The mixture of PCBs in the water column shifts toward lighter homologs as a result of passage through the pool. It is interesting to note the effect is more pronounced in May than in April 1991. On the same dates, water-column concentrations increased from Fort Edward to the Thompson Island Dam from 16 to 43 ng/L (April 5) and from 12 to 75 ng/L (May 3). A preliminary interpretation of these data suggests that a significant portion of the PCB load on these days was derived from the Thompson Island Pool and that the source from the Pool has a significant proportion of mono- and dichlorobiphenyls, unlike any of the known historic releases to the area. The mixture found at Fort Edward appears to be similar to that of Aroclor 1242, as shown in Figure 3.3. It could also be a blend of Aroclor 1242 (80 percent) and Aroclor 1254 (20 percent) also shown in Figure 3.3.

The use of congener-specific data can also show the variation of local source loadings with time. Figure 3.4, based on GE data, shows variability in the congener mixture over time at the Thompson Island Dam, specifically gradual increase in importance of the mono- and dichlorobiphenyls in the load leaving the pool. Given the occurrence of *in-situ* degradation and dechlorination in the PCBs of the Thompson Island Pool, the data could be interpreted to suggest that the change in homolog mixture results from diffusion of the altered, partially dechlorinated PCBs out of the sediments and into the water column. This would be consistent with the more pronounced shift toward lighter congeners in May versus April when lower flows and warmer temperatures would increase the relative contribution from the sediments to the water column.

Through collection of information on dissolved and suspended matter, it will be possible to distinguish better among PCB sources. For example, if the Thompson Island Pool source of mono- and dichlorobiphenyls is a diffusive one, *i.e.* PCBs enter the water column in dissolved form, then the distribution of these congener concentrations would raise the dissolved phase levels relative to the dissolved-suspended phase equilibrium. Conversely, if these PCBs enter the pool via scour or resuspension of sediments, then the suspended-phase levels would be increased relative to equilibrium. No data are currently available to permit this type of analysis.

The collection of transect samples will permit identification of those regions of the river where PCB sources exist and provide information as to the type or nature of the source. Transect samples also effectively fingerprint the source by identifying the congener pattern derived from the source, which can then be traced in downstream reaches.

The measurement of total suspended solids is needed to determine the total PCB flux past any monitoring point. This flux can be computed as follows:

$$Flux = Q * (PCB_{Diss} + TSS * PCB_{SS} * 1 \text{ kg} / 10^6 \text{ mg})$$

where:

Flux	=	PCB Flux in ng/s
Q	=	Water flow in L/s
PCB_{Diss}	=	Dissolved phase total PCB concentration in ng/L
TSS	=	Total suspended solids in mg/L
PCB_{SS}	=	Suspended solids total PCB concentration in ng/kg

Measurements of total organic carbon on suspended solids, dissolved organic carbon and chlorophyll-a are needed to interpret dissolved-suspended phase PCB partitioning, because each of these parameters affects equilibrium partitioning of PCBs in the water column. One or more of these parameters is expected to correlate with variations in measured dissolved-suspended phase PCB distributions. Specifically, increases of total organic carbon on suspended matter or chlorophyll-a permit a greater fraction of the water-column PCB load to be carried by suspended matter, since these properties are expected to correlate with the fraction of PCBs adsorbed to particulate matter. Conversely, increases in dissolved organic carbon should permit a greater fraction of PCBs to exist in the dissolved phase, since the presence of additional dissolved organic carbon would hold additional PCBs in solution bound to dissolved organic carbon (DOC). (Herein, the term dissolved phase refers to both dissolved PCBs and PCBs bound to DOC.)

Total water-column PCB analysis will be done in accordance with NYSDEC analytical procedures to provide a tie between the other PCB analyses and standard NYSDEC results.

The remaining parameters (pH, temperature, conductivity and dissolved oxygen) are standard water-quality parameters. These parameters will be monitored in the field across water sample locations and within a single sampling cross-section.

3.2.2 Time-of-Travel Study

This subtask is intended to examine the time-of-travel for a water parcel to travel the length of the Hudson in Study Areas A and B. These data are needed to assist in the collection of water-column transect samples in these study areas. As explained above the water-column transects are intended to examine how the water-column inventory of PCBs varies as the river travels through the Upper Hudson. The time-of-travel study is intended to determine the timing of the sampling points located throughout the Upper Hudson so as best to monitor a given parcel of water during its transit.

The time-of-travel study will be accomplished by injecting a fluorescent dye into the river above the first water-column transect monitoring station and monitoring its initial arrival or the occurrence of its maximum concentration at each of the subsequent downstream stations. The time of initial arrival and the time of maximum concentration relative to the initial release can be thought of as measures of the front and the center of the water parcel. In this manner the timing for the collection of water-column transect samples at each Upper Hudson location can be arranged so as to monitor a single parcel of water.

The need to accomplish this type of water-column monitoring is based on the historic water-column monitoring record which shows substantial temporal variation in water-column PCB levels. In order to avoid the natural variability in water-column levels and examine local PCB inputs in the Upper Hudson, it is important to minimize the temporal variation in a given water-column transect.

3.2.3 PCB-Equilibrium Study

This subtask will involve the collection of duplicate water-column transect samples, which will be held for approximately four days prior to filtration and analysis. The purpose of this subtask is to examine whether PCB-congener concentrations in dissolved and suspended matter phases are at equilibrium in the water column. If substantive changes are noted between the original and the duplicate water-column samples, these changes would suggest that an effective equilibrium did not exist in the water column at the time of sampling. The basic premise of this study is that PCB equilibration between these phases is not instantaneous in the water column. The samples for this study will be held sufficiently long before filtering to permit the system to reach an effective equilibrium. By comparing these results to samples that are filtered shortly after collection, it will be possible to evaluate the ambient congener distribution relative to the "equilibrium" distribution. The definition of "equilibrium" for this system is not necessarily a true thermodynamic one. It is the point at which little change takes place in the dissolved and suspended matter PCB-congener concentrations, *i.e.*, a steady-state end point. In general, this end point appears to be fairly well-defined, based on the relatively consistent observed partition coefficients reported in the literature.

The differences in the PCB-congener distributions at various points relative to equilibrium will be used to define the type of PCB source to the river and aid in the actual identification. For example, if a sample yields a congener distribution that shows dissolved phase dominance relative to equilibrium, the conclusion would be that the PCB source in the upriver reach was predominantly a dissolved-phase input. Such sources would include PCB diffusion from the sediments or a groundwater input. The measured distribution could not be obtained by sediment scour or a suspended-matter input.

Evidence for this lack of equilibrium can be seen in the data collected on Upper Hudson water-column suspended matter in 1983 by Bopp *et al.* (1985).[1] Their data were derived from eleven sample pairs of large-volume water samples. One of the samples in each pair was filtered using a glass-fiber filter (GFF) several days after collection; the other sample in the pair was a large-volume filter (LVF) sample, which was collected *in-situ* by placing a filtering apparatus directly into the river. The results of one such pair of samples taken at Mechanicville, NY are shown in Figure 3.5, showing the packed-column peak data for the samples. Packed-column peak analysis separates the congeners into approximately 22 peaks with several congeners represented by each peak. In general, the resolution between congeners decreases with increasing peak number. In Figure 3.5, the main peaks represent tri- and tetrachlorobiphenyls, which are the main components of Aroclor 1242. A clear difference in congener distribution occurs between the *in-situ* sample (LVF) and the sample held for several days (GFF). This difference in congener pattern was also accompanied by an increase in the total PCB concentration for the peaks shown in the suspended matter on the GFF sample (6.6 mg/kg) relative to the LVF sample (1.25 mg/kg). These results plus those of the other sample pairs suggest that PCB inputs upstream of Mechanicville (located between Waterford and Stillwater) in 1983 contained a significant dissolved-phase source and that given sufficient time, the dissolved PCB would sorb to the suspended matter.

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[1]Bopp, R.F., H.J. Simpson, and B.L. Deck. 1985. "Release of Polychlorinated Biphenyls from Contaminated Hudson River Sediments." Final Report NYS C00708 to NYSDEC, Albany, NY. Lamont Doherty Geological Observatory of Columbia University, Palisades, NY.

Bopp *et al*. (1985) note that part of the difference between the samples may stem from differences in the filters used. The large change in the total PCB concentration and the congener pattern, however, would suggest that a real change occurred during sample storage.

Samples for this PCB-Equilibrium Study will be collected at 10 transect sampling locations in Study Areas A and B, during both a high-flow condition and a low-flow condition. These samples should provide equilibrium data for the range of conditions expected in Study Areas A and B.

Dissolved organic carbon will also be measured to evaluate whether measured changes in the PCB distribution are related to changes in this parameter.

3.2.4 Flow-Averaged Sampling

Unlike water-column transects, which are designed to obtain snapshots, this subtask is designed to determine relatively long-term averages of water-column conditions. The need for this type of sampling stems from the inherent variability found in water-column samples. Figure 3.6 presents preliminary GE monitoring data from Study Area B for the period April 1 to June 24, 1991. Data were collected three times per week at each sampling station. The measured variability, as shown by the vertical lines in Figure 3.6, is substantial. This variability can be attributed to variations in suspended matter load, flow, sediment scour, etc. Flow-averaged sampling avoids those variations by compositing samples. (The water-column transect study will be subject to these variables, but effects will be minimized by monitoring appropriate parameters, separating dissolved from suspended matter PCBs, and by sampling the same parcel of water through Study Areas A and B.)

Figure 3.6 also shows the means in water-column PCB concentrations in Study Area B using spring 1991 data. The sampling effort to achieve these results was substantial, *i.e.*, 28 points per station for a total of 168 measurements. The flow-averaged sampling program is intended to obtain a similar mean trend without an extensive analytical program. For the time period shown in Figure 3.6, the flow-averaged sampling would have produced three samples for analysis per station instead of twenty eight.

The flow-averaged water-column sampling program entails the collection of water-column samples on a regular basis, essentially every other day. The volume of water collected on a given day is proportional to the flow measured that day by the USGS hydrologic monitoring stations in the Upper Hudson, using a scale developed prior to the onset of sampling. After the required number of samples have been collected and the period of sampling is over, these samples are combined to yield one large sample for PCB analysis. The concentration in the combined sample is then a flow-weighted average of the water-column concentrations.

A single combined sample will be generated for monitoring stations at Glens Falls, Fenimore Bridge at Bakers Falls, Route 197 Bridge at Fort Edward and Thompson Island Dam, for a minimum of three separate sampling periods. These samples will permit the construction of a plot similar to that shown in Figure 3.6. The set of sampling stations is limited to four, based on the trend in water-column loading developed in the Phase 1 Report and supported by the data from General Electric, which indicate that PCB loading originates in the reaches among these four monitoring stations.

The following analyses will be performed on the flow-averaged water-column samples:

- Dissolved phase PCB congeners;
- Suspended-matter phase PCB congeners;
- Dissolved organic carbon;
- Total suspended matter; and
- Standard water-quality parameters - pH, temperature, conductivity, dissolved oxygen.

The dissolved and suspended-matter phase PCB congener analyses are required to describe the flow-averaged total PCB concentration. The information will not be equivalent to the water-column transect sampling, since the flow-averaged samples will be held for as many as several weeks before filtration, allowing the PCB distribution to equilibrate and losing the information on potential source type. Thus, the two sampling methods complement each other. The water-column transect sampling gives instantaneous congener-related conditions, which can be used to locate contaminant sources and examine the effects of biogeochemical processes while generating an instantaneous PCB loading. The flow-averaged samples describe the mean total PCB loading, but potentially the congener distribution needed to identify specific sources and biogeochemical processes is altered.

The dissolved organic carbon and total suspended solids analyses will also be performed on a flow-weighted basis. These parameters are needed for the same reasons as for the water-column transects.

The standard water-quality parameters, pH, temperature, conductivity and dissolved oxygen, will be recorded at the time of sample collection. These data will be used qualitatively in support of the other parameters.

3.2.5 Analysis of Historic Samples

Scientists of the Lamont-Doherty Geological Observatory, between 1977 and 1986, have collected water-column samples for PCB analysis. These samples were separated into dissolved and suspended-matter fractions, analyzed using packed-column gas chromatography and archived. These samples are available for reanalysis on a congener-specific basis for the Phase 2 investigation and will provide information on the types of PCB congener mixtures historically carried by the Hudson River. The data will be compared with current congener mixtures to establish how the mixture has changed over time.

These archived-sample-analysis data complement other data sources available to the Reassessment, including the USGS monitoring records and the high-resolution sediment coring effort. The large USGS data set is limited in both its detection limit and its resolution of PCB congeners. This data set provides many limited resolution snapshots of the water-column PCB concentration. The high-resolution sediment core data provides information on PCB congener concentrations of historic suspended matter, with a two to three-year level of resolution. Historic water-column samples have the PCB congener resolution of the high-resolution cores and the instantaneous nature of the USGS data and will be a useful tool in examining historic trends and extrapolating future trends.

The analysis of historic samples will provide the historic, dissolved-phase PCB congener concentrations, a data set not available from any other source. These data will be used to assess the accuracy of using literature partition coefficient data to predict total water-column PCB concentrations, based on suspended matter or high-resolution sediment-core PCB concentrations.

The analysis of the archived water-column extracts will be essentially the same as the analysis of all other PCB samples for the Phase 2 investigation.

3.3 Sediment Coring and Analysis

The sediment investigations represent a major portion of the Phase 2 investigation, because of the considerable mass of PCBs contained in the sediments and the unique ability of sediments to record historic riverine conditions. The sediment investigations consist of four subtasks:

- High-resolution sediment coring;
- Analysis of archived sediment extracts;
- Low-resolution sediment coring; and
- Confirmatory sediment sampling.

These subtasks are described in Sections 3.3.1, 3.3.2, 3.3.3 and 3.3.4.

3.3.1 High-Resolution Coring

The goal of this sampling subtask is to collect and analyze sediment cores from locations in all four study areas. These cores will be obtained from river areas known or believed to accumulate sediments at a rapid rate, typically 1 cm/yr or more. Because these areas rapidly accumulate sediments on a more-or-less continuous basis, they effectively preserve each year's sediment deposits. Since the river itself is responsible for continuously delivering the sediments to these locations as it transports sediments downstream and out to the Atlantic Ocean, the sediment deposits at each location represent an average of the water-column suspended-matter properties. By separating the deposits in annual or biannual layers, it is possible to examine the historic trend in water-column suspended-matter properties.

The term *high-resolution* sediment coring refers to the method by which sediment cores are collected and separated. After collection, a sediment core is gently extruded from the coring tube and sliced into thin layers of 2 to 4 cm in thickness. These layers, which approximate annual or biannual deposit thickness, permit the analysis of one to two years of sediment accumulation per slice. This technique produces a highly resolved sediment-deposition chronology.

Although the process of slicing a sediment core into thin layers is not sufficient to establish the history of sediment deposition at a given location, natural and anthropogenic time markers are incorporated into the suspended matter before it is deposited at a given location. These time markers are the radionuclides Beryllium-7 (Be-7), Cesium-137 (Cs-137) and Cobalt-60 (Co-60). Use of these radionuclides as time markers is based on their known rate of input to the Hudson Basin.

Geochemical application of these radionuclides is diverse and well documented. These radionuclides are utilized in lakes, rivers, oceans and estuaries as time markers or clocks for establishing sediment-deposition rates. The power of the techniques arises, in part, from the simplicity of measurement. Radionuclides in sediments are analyzed by simply drying the sediment and placing it in a gamma spectrometer where the gamma radiation given off by the radionuclide can be measured and recorded. The sample is left in the counter for a period of hours to days in order to accumulate sufficient counting statistics. Once counted, the sample can then be used for other chemical analyses as needed. The sensitivity of the measurement is quite high. Typical detection limits are 200 picocurie per kilogram (pCi/kg) for Be-7 to 25 pCi/kg for Cs-137. (A picocurie is a measure of radioactivity. One picocurie represents 2.2 disintegrations per minute.)

Radionuclides in the sediments are used in two ways, as a clock in the case of Be-7 and as an event marker in the case of Cs-137. Be-7 is a naturally occurring radionuclide produced in the upper atmosphere by cosmic radiation. Its rate of fallout is fairly constant with time. The fallout rate at Albany has been measured at 0.018 pCi/cm^2·day (Olsen, *et al.* 1984).[2] Because its input is relatively constant with time, Be-7 is suitable for use as a sediment clock. For Be-7 the clock is started at the time of sediment deposition. Because Be-7 exhibits an exponential decay with a half life of 53.3 days, it will be detectable in sediments for only six months to a year; after one year virtually all of the Be-7 will be decayed. Thus, the Be-7 clock is limited to the uppermost sediment layers, typically 2 to 4 cm in depth.

Cs-137, on the other hand, is an anthropogenic radionuclide, produced in atomic-weapons testing and nuclear-power reactors. Most of its release to the environment has resulted historically from atmospheric weapons testing. The historic input of Cs-137 to the New York area has been summarized

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[2]Olsen, C.R., I.L. Larson, R.H. Brewster, N.H. Cutshall, R.F. Bopp and H.J. Simpson. 1984. "A Geochemical Assessment of Sedimentation and Contaminant Distribution in the Hudson-Raritan Estuary." NOAA Technical Report NOS OMS 2, U.S. Dept. of Commerce.

by Bopp *et al.*(1982)[3]. Figure 3.7 shows the history of atmospheric fallout and nuclear-reactor releases to the Hudson Valley. The three main event markers are: 1) appearance of Cs-137 in 1954, as a consequence of the onset of atmospheric atomic-weapons testing; 2) a Cs-137 maximum in 1963 corresponding to an extensive amount of atmospheric weapons testing just prior to the implementation of the atmospheric test ban treaty; and 3) the 1971 Cs-137 release directly to the Lower Hudson by the Indian Point nuclear-power facility. The Cs-137 peak in 1971 can be distinguished from the 1963 peak by the presence of Co-60 in the sediments associated with 1971. Co-60 was released along with Cs-137 by the Indian Point facility. The impact of the reactor release of Cs-137 to the Lower Hudson is limited to the brackish portion of the estuary (Study Area D). Thus, for Study Areas A, B and C, there are three time constraints or horizons: Be-7 in surface sediments, Cs-137 maximum in 1963 and Cs-137 appearance in 1954; Study Area D has one more, corresponding to the 1971 reactor release.

Because of its geochemistry, the Cs-137 record in the sediments is not as simple as the history shown in Figure 3.7. Cesium is a particle-reactive element, which quickly binds to soil and sediment. As a result, a large inventory in soil was generated as a result of pre-1966 atmospheric fallout. Although the maximum atmospheric input to the Hudson watershed occurred in 1963 and has since tapered off greatly, soils in the watershed continue to release Cs-137 to the Hudson River via soil erosion and dissolution. This release is such that any post-1954 sediment deposited in the Hudson contains Cs-137. The net result yields a Cs-137 maximum in 1963 to 1964 sediments, which gradually decreases to the present.

Figure 3.8 illustrates the Cs-137 record in a Lamont-Doherty core collected in 1986 at RM 88.6 near Kingston in Study Area C. The profile closely fits the known Cs-137 input function, yielding an annual deposition

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[3] Bopp, R.F., H.J. Simpson, C.R. Olsen, R.M. Trier and N. Kostyk. 1982. Chlorinated hydrocarbons and radionuclide chronologies in sediments in the Hudson River and estuary. *Environmental Science and Technology*, 16: 666-672.

rate of 1.5 to 1.8 cm/yr. Be-7 was detected only in the top sediment layer (0-2 cm) with a deposition rate of less than 2 cm/yr, consistent with the Cs-137 deposition rate. This type of core chronology can be readily converted to a year-of-deposition relationship. The total PCB concentration for the core layers is plotted in Figure 3.8. The conversion is shown in Figure 3.9. The approximate uncertainty in the sediments' ages are shown by the vertical line on the total PCB curve. Like all of the interpretable high-resolution cores collected by Lamont-Doherty in the Lower Hudson, this core shows a PCB maximum in the early 1970s.

The application of radionuclide analysis to sediment cores permits an estimation of the year of deposition for individual sediment layers. Knowing the approximate year of deposition and assuming that the sediments deposited that year directly reflected water-column conditions, it is then possible to estimate historic water-column trends.

Taken alone, the sediment record can be used to evaluate qualitatively long-term transport trends. Because data on water-column flow and suspended-matter levels are available for the Hudson in some coring locations, it is possible to quantitate in these instances historic PCB transport at these locations. Literature data and data from the Phase 2 water-column studies will be used to predict the total water-column PCB concentrations based on the sediment record. In addition to recording the total PCB transport, sediments also record the PCB-congener mixture on the suspended matter. Thus, dated sediment samples can be used to determine the historic mean congener mixtures. To the extent that a specific congener mixture or fingerprint can be tied to a source or source area, the sediment record can then be used to monitor the importance of the source over time.

Most of the previous high-resolution sediment core work was done in the 1970s and early 1980s. The core collection sites for the Phase 2 high-resolution sediment core program were selected with the intention of updating data for these previous core locations and examining the most recent sediment and, therefore water-column trends. By coring at these previously studied locations, it is also possible to examine the fate of PCBs within the sediments, as discussed below.

Additional parameters to be analyzed as part of the high-resolution core program are designed to augment the interpretation of the radionuclide and PCB data. Grain-size distribution analysis will reveal any changes in the depositional environment at the coring location. Total carbon and total inorganic carbon analyses will be used to examine total organic carbon content variations through a core. The total inorganic carbon analysis is expected to represent a small correction to the total carbon analysis, so that only a limited number of total inorganic carbon analyses will be required. The total nitrogen and total organic nitrogen analyses are used in a similar way, except that organic nitrogen is measured directly. The differences between total nitrogen and total organic nitrogen measurements are expected to be small, therefore only a limited number of total organic nitrogen analyses will be performed as a check. The need for the total organic carbon and total organic nitrogen data is two-fold. First, sediment PCB concentration is expected to correlate with total organic carbon levels. Second, the organic carbon to nitrogen ratio is an excellent indicator of wood cellulose. Wood-waste materials constitute much of the original deposits found behind the Fort Edward Dam. When the dam was removed, these woody materials were deposited with the sediments downstream of Fort Edward for many miles. Wood cellulose is characterized by very high C/N ratios relative to typical soil or sediment organic material. Thus, the C/N ratio will be a good indicator of materials deposited following removal of the dam.

The last parameter to be measured for the high-resolution sediment coring program is reduction-oxidation potential (redox). Reducing sediments have been shown to correlate with anaerobic biodegradation in Study Area B by scientists at NYSDOH. The redox measurements should assist in the interpretation of PCB-congener distributions in the sediments, since reducing conditions presumably should correlate with zones of obvious PCB degradation.

3.3.2 Analysis of Archived Sediment Extracts

This subtask is an extension of the high-resolution sediment coring program. The goal is to reanalyze archived sediment core extracts for comparison with Phase 2 sediment-core results. Because it is possible to date the sediment layers from a core, it is also possible to compare sediment layers of the same time horizon among cores. This subtask will involve the comparison of Phase 2 high-resolution sediment core layers with their dated counterparts in archived sediment cores. The archived core layers require reanalysis, because they were originally analyzed by packed-column gas chromatography. The Phase 2 sediment cores, like all Phase 2 analyses will be analyzed for PCBs on a congener-specific basis. Thus, the reanalysis of the archived cores will permit direct comparison of the two data sets. For example, the core layer corresponding to 1973 in a Phase 2 core collected in 1992 could be directly compared with the core layer corresponding to 1973 collected in a core from the same general location in 1977. This comparison would permit the study of *in-situ* degradation rates over the intervening period, in this case 15 years. Thus, by selecting several layer pairs corresponding to various time intervals, it will be possible to examine the effects of *in-situ* processes on potential PCB degradation at the coring location. The rate of degradation is an important parameter in estimating future river conditions, since *in-situ* degradation affects the PCB inventory available for interactions with other site media. Thus, in areas where *in-situ* degradation is substantial, future PCB levels and inventories may be reduced. Conversely, in areas where little degradation occurs, PCB sediment concentrations are likely to remain relatively constant.

In-situ degradation is already known to have occurred in the sediments of the Upper Hudson although estimates of the rate of degradation are limited. In the Lower Hudson, evidence suggests, by comparison, that *in-situ* degradation is slow or absent. By comparing archived and Phase 2 sediment core pairs for Study Areas A, B, C and D, it will be possible to estimate *in-situ* degradation rates within each area.

The selection of archived sediment-core layers for reanalysis will be based on the strength of dating constraints for the layer. The sediment layers most tightly constrained are those corresponding to the 1954 appearance of Cs-137, the Cs-137 maximum, the 1971 Cs-137/Co-60 maximum (Study Area D only), the early 1970s PCB maximum and the date of collection of the archived core.

3.3.3 Low-Resolution Coring

The analytical program for low-resolution coring is similar to that for high-resolution coring. The difference between the two programs arises from the selection of coring sites and the subdivision of cores. The high-resolution coring effort requires that particularly close attention be given to the selection of coring sites on the basis of the sediment-deposition rate. The low-resolution coring does not. While high-resolution coring attempts to study water-column trends, low-resolution coring is intended to obtain estimates of sediment-PCB mass. Thus, the high-resolution cores are separated by long distances (typically 10 miles or more), while the low-resolution coring locations will be limited to Study Area B, mostly in areas of known or suspected sediment contamination.

The term *low-resolution coring* arises from the subdivision of these cores. In general, low-resolution cores will be separated into 5 inch layers (13 cm) as compared to the 2 to 4 cm thick layers used in high-resolution core separation. The relatively thick nature of the core sections in low-resolution coring will permit only the approximate determination of the total depth of recent PCBs and Cs-137 bearing sediment. The purpose of this analysis is to determine the volume of contaminated sediment in a given area.

The selection of areas to be studied by low-resolution coring will be based on the geophysical-survey results and the results of the analysis of historical sediment PCB studies by NYSDEC (see discussion of kriging in Section 2), the USEPA, General Electric and other organizations. The purpose of sampling in a given area will be based on one of two possible reasons; in areas where previous studies have occurred, the sampling will attempt to reconfirm the levels of PCBs previously found, or in cases where little or no sampling has occurred, the sampling will attempt to examine the current PCB levels in order to establish the area's relative importance to the total sediment PCB inventory. In the latter cases some of the data will be used in conjunction with the geophysical surveys in order to classify the type of sediment contamination associated with a given sedimentological zone. Whenever possible, the interpretation of the coring data will be closely tied to the geophysical survey results. The final selection of low-resolution coring sites will be made upon the completion of the geophysical survey analysis and the analysis of the historic sediment data.

3.3.4 Confirmatory Sediment Sampling

This subtask is intended to provide confirmatory data on the texture of sediments located throughout the geophysical-survey area. Sediment textures depicted by the geophysical-survey instruments represent relative changes in sediment topography, reflectivity and density. The confirmatory sediment samples provide an absolute measure of these sediment properties, which in effect are used to calibrate the geophysical-survey data. The confirmatory sediment samples will be analyzed for only two parameters, grain-size distribution and a measure of organic carbon. In addition, some sediment cores will be X-rayed to examine sediment-density variations. These variations should correspond with those seen by the geophysical surveying equipment. These parameters are sufficient to describe the sediments for geophysical-survey purposes. The sediment parameters will also be used in the interpretation of other data collected in Phase 2 and will be particularly useful in the assessment of scourability presented in Section 5.

3.4 Geophysical Surveying

The goal of the geophysical surveying data-collection task is to produce a set of maps detailing bathymetry, sediment morphology, sediment texture, and fine-grained sediment thicknesses at specific locations within

Study Area B only. These maps will be produced from the analysis of sonar data, which will be collected as a part of the geophysical surveys. The sonar results will be calibrated against the confirmatory sample results discussed above.

The basic principal of the geophysical-surveying techniques is the use of sound as a replacement for light in generating a picture-like mosaic of the river bottom. The surveying equipment generates sonic signals, which pass through the water and are reflected by the bottom materials. The equipment uses several frequencies to scan the bottom of the river. As the equipment is pulled through the water by a survey vessel, various transponders scan the river bottom by generating and recording sonic signals. The survey vessel follows previously defined survey lines to ensure complete coverage of the river bottom.

Three transponder systems, a depth transponder, a subbottom profiler and a side-scan-sonar system, are used. The depth transponder determines river depth or bathymetry. The subbottom profiler is capable of penetrating fine-grain sediments on the river bottom to determine their thickness. The depth of fine-grain sediments is the difference between the river depth measured by the depth transponder and the depth of the reflection horizon measured by the subbottom profiler. The side scan sonar is the most sophisticated of the three transponder systems. This system uses two frequencies of sound to scan the river bottom. Each of the two frequencies generates its own reflectivity pattern for the river bottom. Unlike the other two measurement systems, the side-scan sonar is able to measure in two dimensions, creating a picture-like image of the river bottom as the transponder is pulled through the water. The term side-scan sonar comes from the ability of this measurement system to look to the side as well as straight down. This ability to look to the side is achieved by a sophisticated data-processing scheme that handles the returning sonic signals. The swath of the river bottom covered by the side-scan sonar is dependent upon the resolution required. For the Phase 2 survey work, the swath will be fairly small, about 75 meters (255 ft) wide in order to resolve the bottom features to a resolution of about 15 cm (6 in). At this resolution, bottom features such as boulders, logs, and bedrock outcrops are readily discerned. More importantly, areas of gravel, sand, and fine-grained material can be discerned as well. The side-scan sonar record will form the main data set for maps of the river's sediment morphology and texture.

The geophysical data are compiled, reviewed and linked to ship-positioning data collected simultaneously with the geophysical data. Bathymetry will be used to generate maps of river-bottom depth. The side-scan sonar tracks are merged together to create mosaic pictures of the river bottom. These mosaics are then used to produce maps of sediment morphology by interpreting the reflectivity patterns in conjunction with the confirmatory sample results discussed in Section 3.3.4. The sub-bottom profile data will be used with these maps to provide a third-dimension measurement and permit the estimation of fine-grained sediment volumes in areas of concern.

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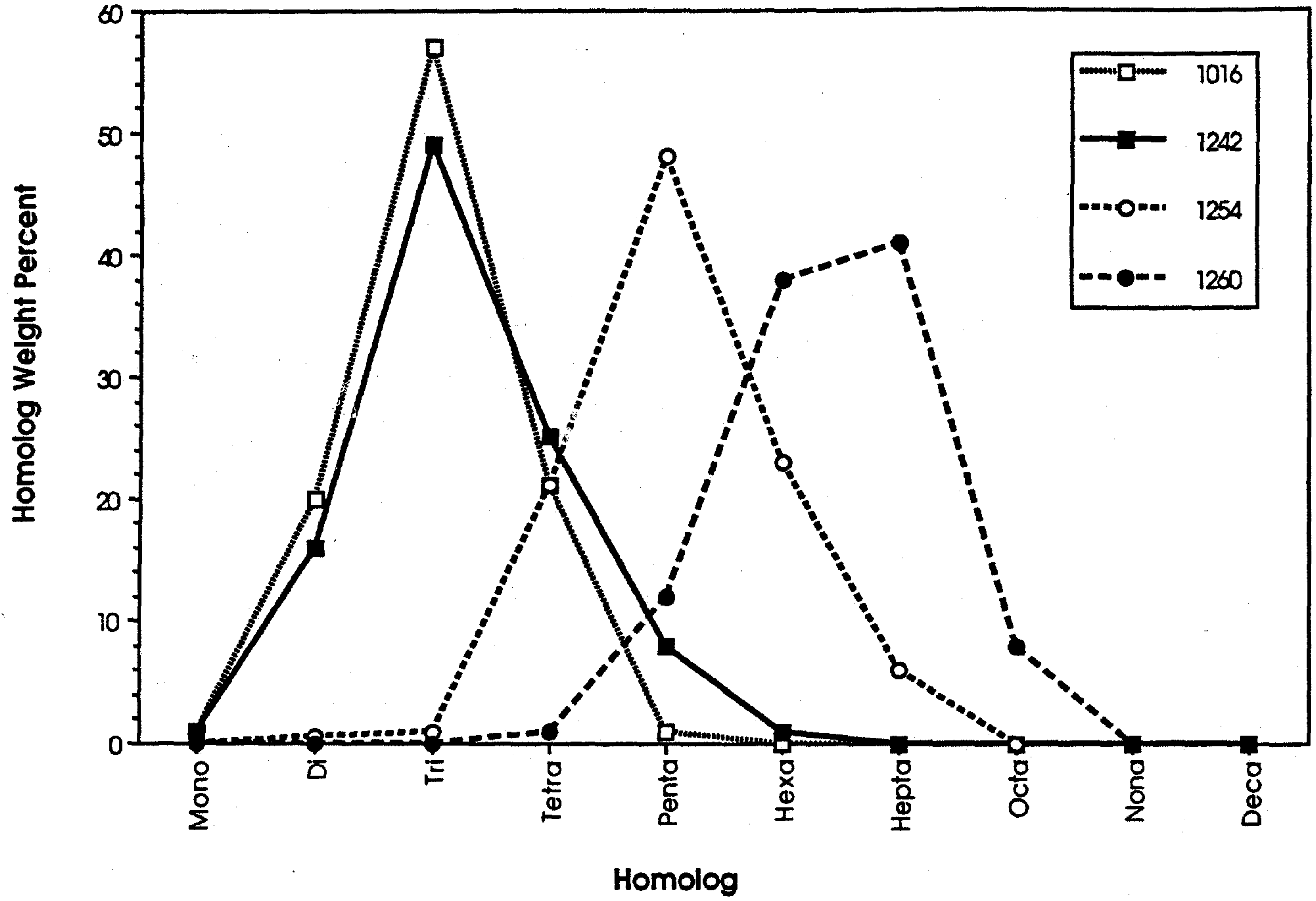
Figure 3.1

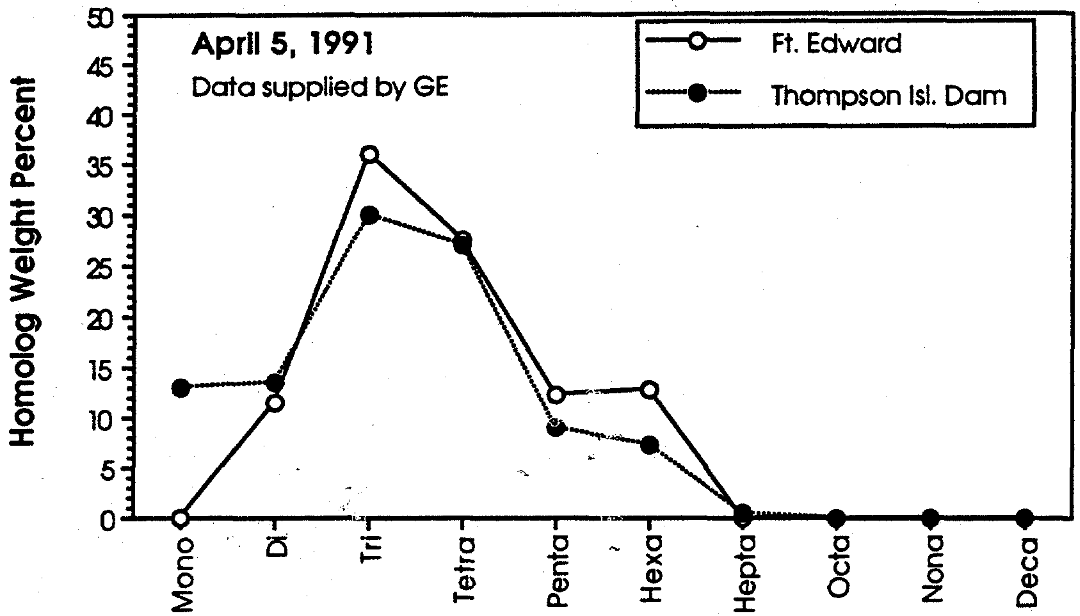
Homolog Content of Some Standard Aroclors

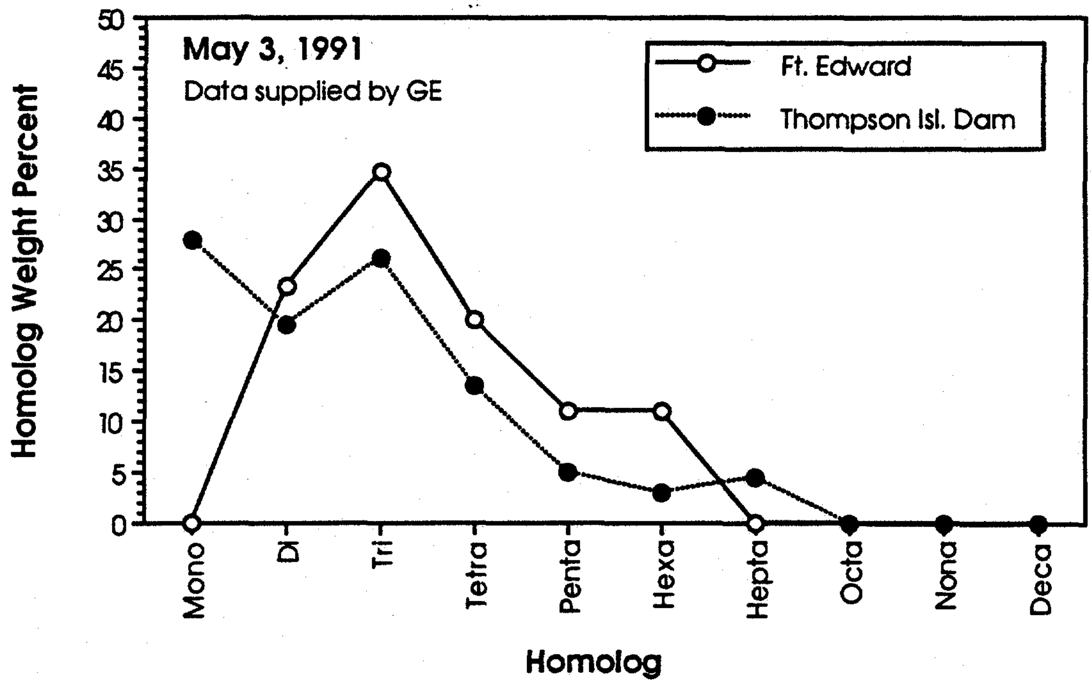


Note: The symbols indicate the mass percentage represented by the PCB homolog group on the horizontal axis. The lines connecting the symbols are intended to highlight the homolog group patterns and do not represent additional data.

Figure 3.2

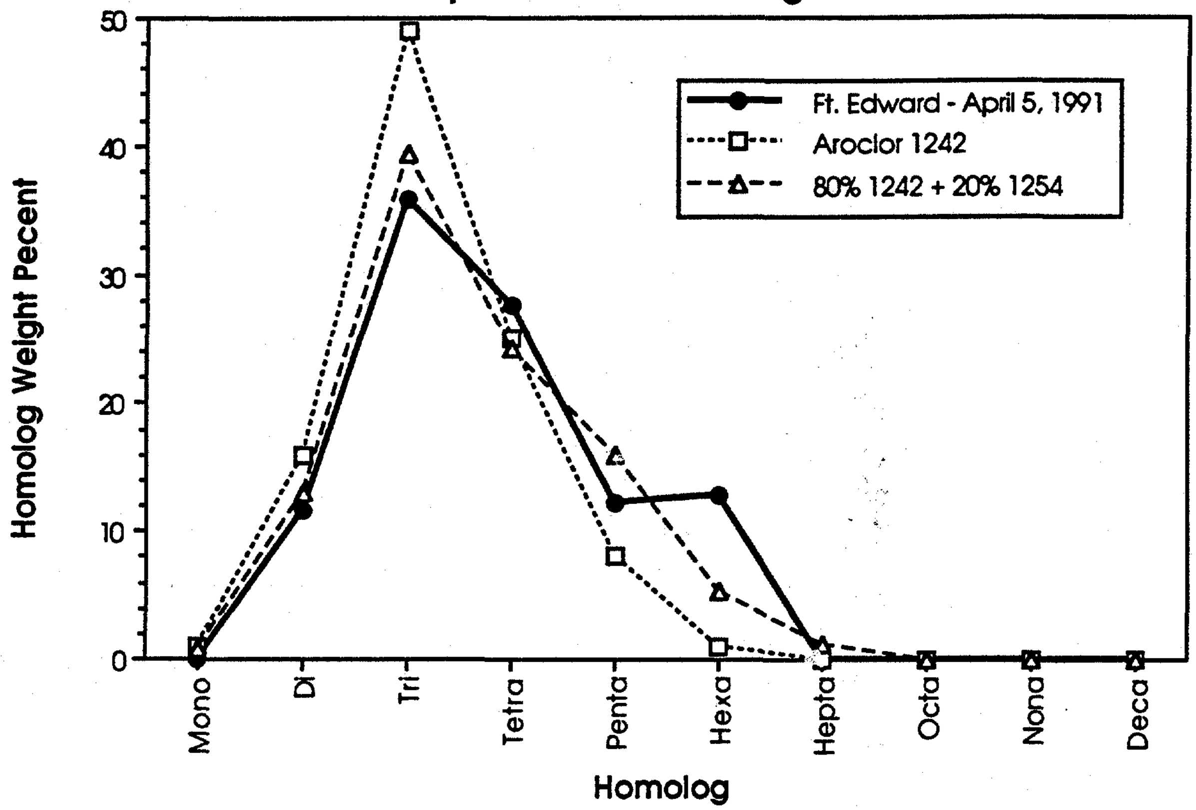
A Comparison of the Homolog Ratios in Total PCBs Across The Thompson Island Pool





Note: The symbols indicate the mass percentage represented by the PCB homolog group on the horizontal axis. The lines connecting the symbols are intended to highlight the homolog group patterns and do not represent additional data.

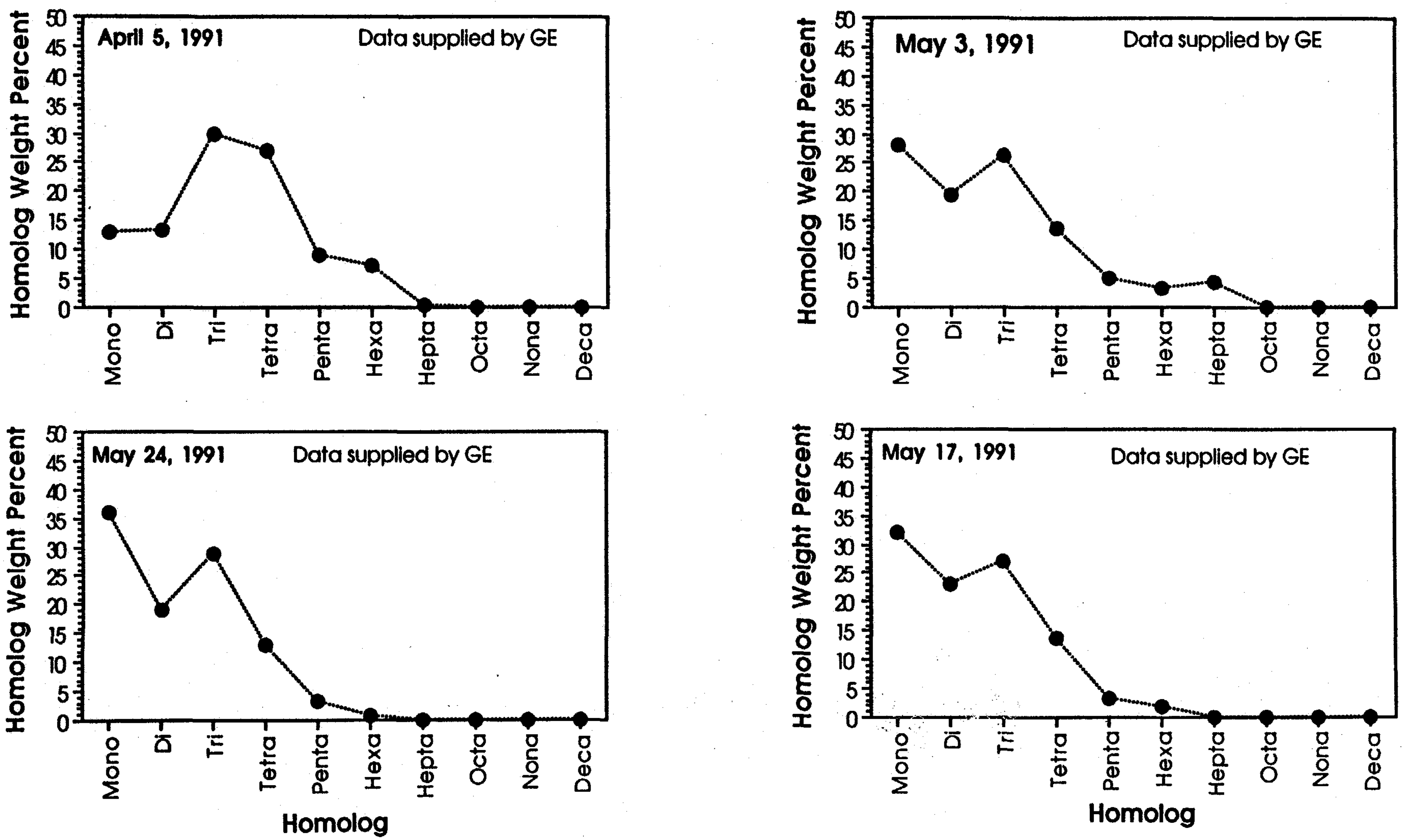
Figure 3.3
A Comparison of Homolog Mixtures



Note: The symbols indicate the mass percentage represented by the PCB homolog group on the horizontal axis. The lines connecting the symbols are intended to highlight the homolog group patterns and do not represent additional data.

Figure 3-4

Variation in the Homolog Distribution at the Thompson Island Dam with Time



Note: The symbols indicate the mass percentage represented by the PCB homolog group on the horizontal axis. The lines connecting the symbols are intended to highlight the homolog group patterns and do not represent additional data.

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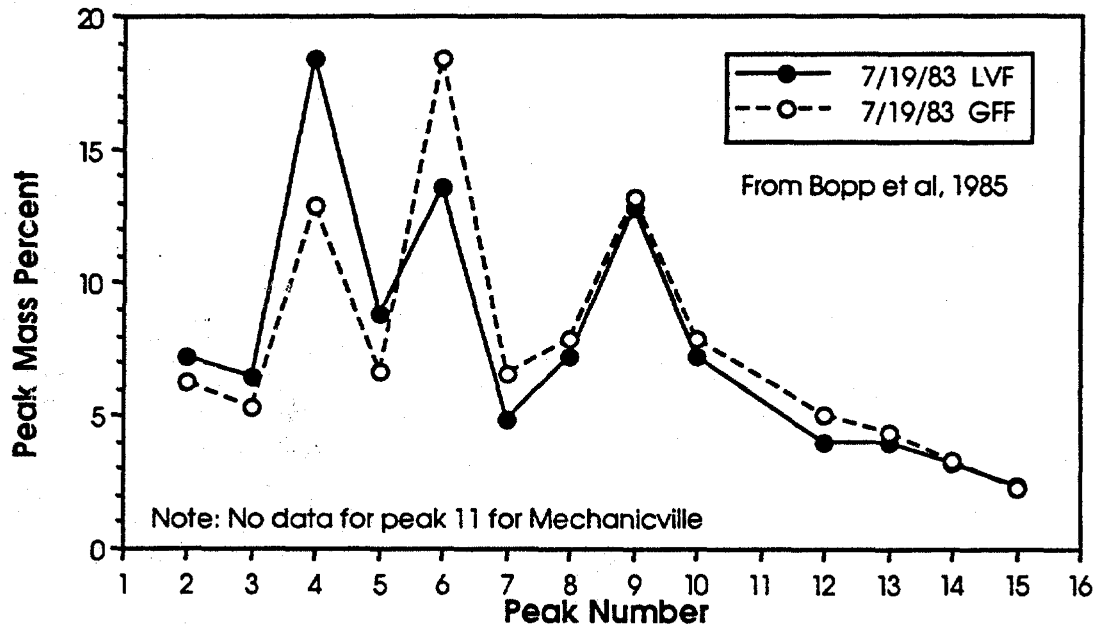
Figure 3.5

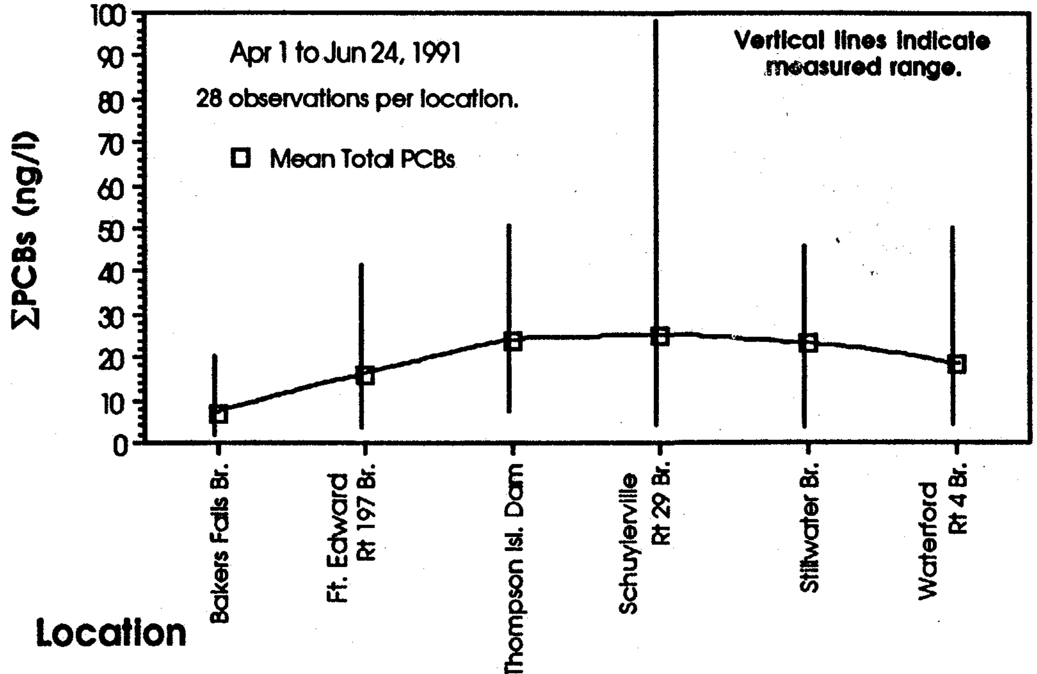
Comparison of Suspended Matter Packed Column Peak Results From Mechanicville, N.Y



Note: The symbols indicate the mass percentage represented by the PCB homolog group on the horizontal axis. The lines connecting the symbols are intended to highlight the homolog group patterns and do not represent additional data.

Figure 3.6

Total PCB Levels in the Hudson River



Data provided by General Electric

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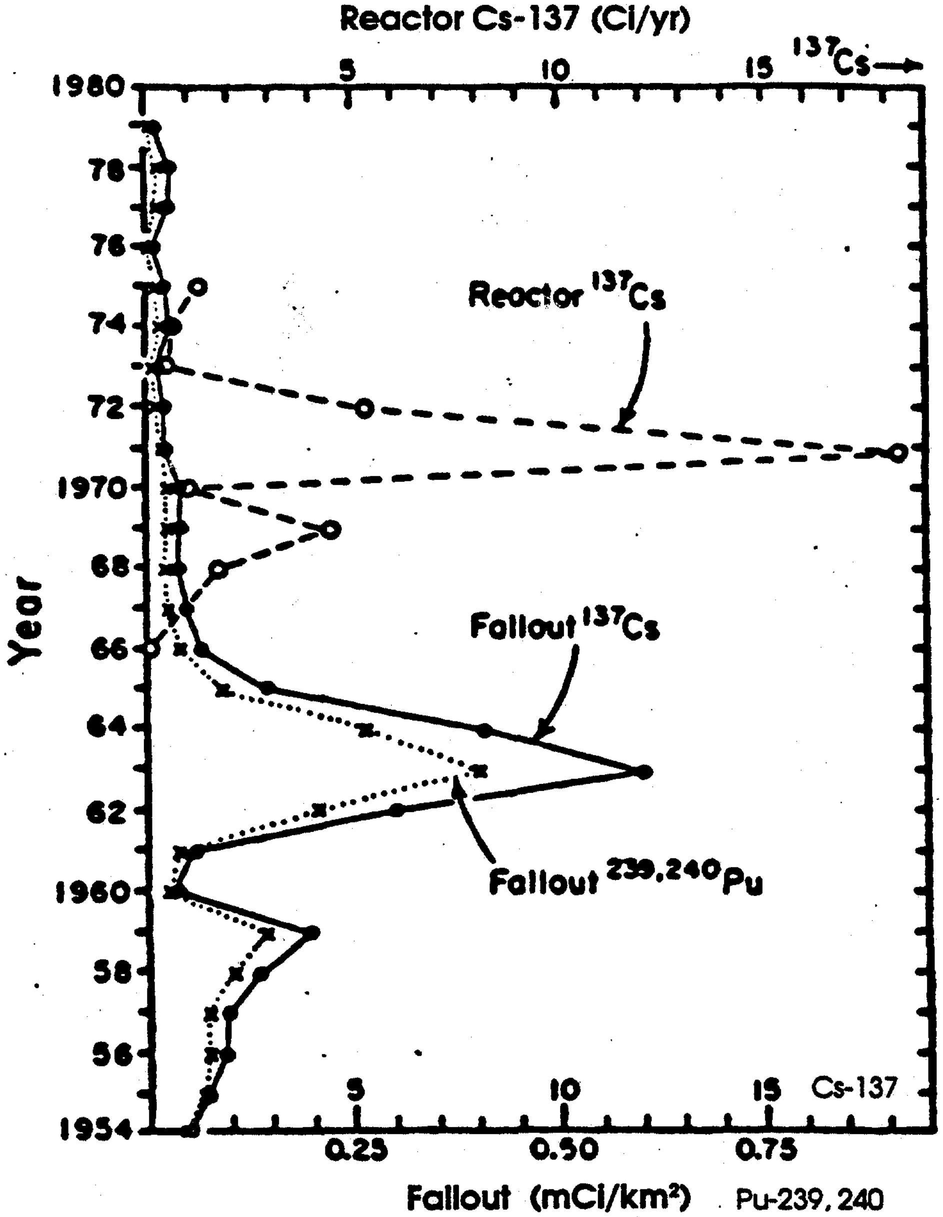
Figure 3-7
Radionuclide Input to the Hudson Basin



Time history of fallout radionuclides delivered at New York and reactor releases from the Indian Point facility, decay corrected to 1980.

From Bopp et al, 1982

Figure 3.8

Cesium-137 and Total PCBs in a Core from RM 88.6 by Depth

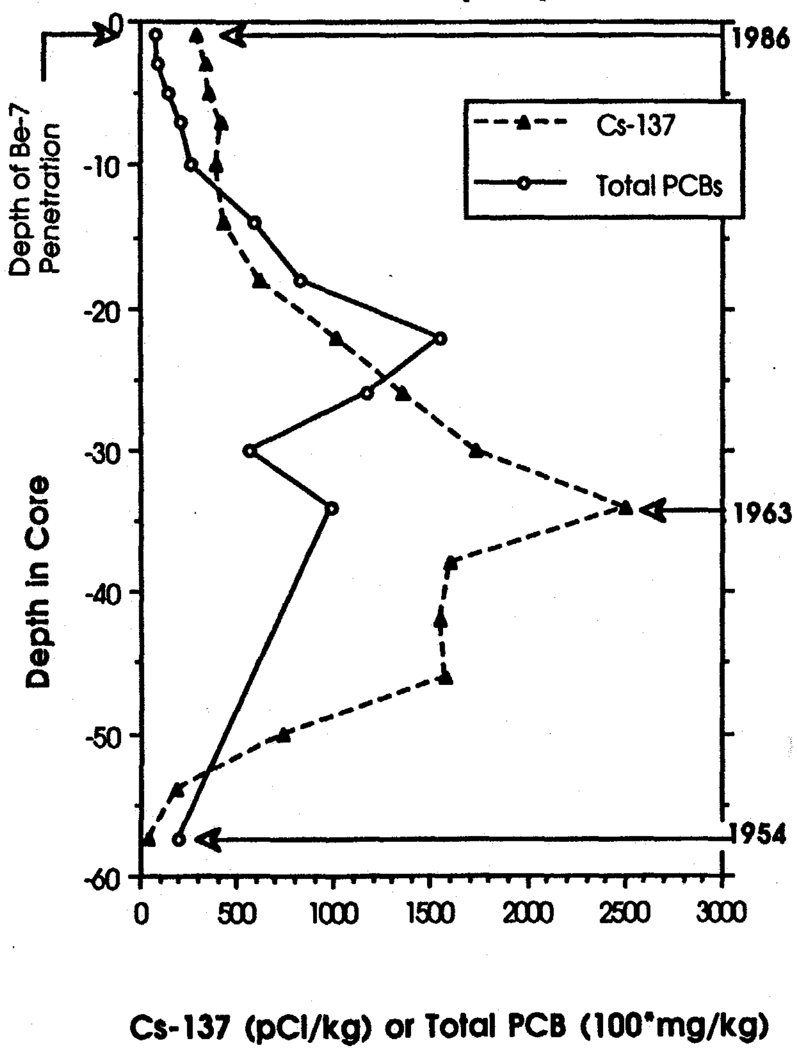
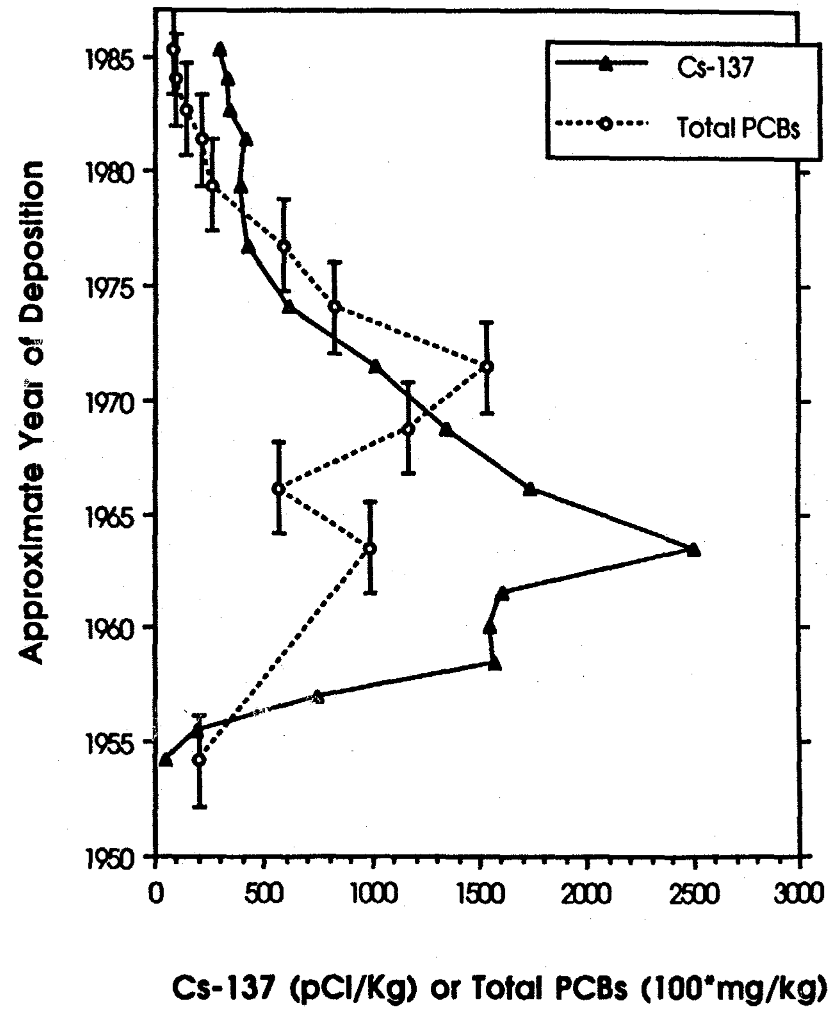


Figure 3.9

Cesium-137 and Total PCBs in a Core from RM 88.6 by Approximate Year of Deposition



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4. UPDATE OF TAMS/GRADIENT DATABASE

4.1 Computer Database

Phase 1 included the acquisition and analysis of available data on PCBs in the Hudson River. These data were assembled into a computerized database. Some minor omissions were noted in the Phase 1 Report, and others were noted in public comments on that report. In Phase 2, the TAMS/Gradient database will be updated for all four study areas to include:

- Data inadvertently omitted in Phase 1;
- Data collected by others which have, or will, become available, since Phase 1; and
- Data from Phase 2 sampling and analysis.

All additions to the database will be summarized and identified. When significant additions are made, analyses and findings of the Phase 1 Report will be checked, updated and utilized. As was the case in Phase 1, all data will be validated prior to being entered in the database during Phase 2. In addition to the sampling and analysis data generated in Phase 2, additional data for upgrading the TAMS/Gradient database will include, but not be limited to, the items described in subsequent sections.

4.1.1 Historic Data in STORET Database

STORET includes many scattered and miscellaneous records of measurements of PCBs in water, sediment and fish in the Hudson and its tributaries in addition to those used in Phase 1. A complete listing of STORET PCB records for the State of New York will be examined for additional pertinent data. An important facet of this work for Study Area B will be accession of PCB measurements from the Hoosic and Mohawk Rivers.

4.1.2 GE Monitoring Data and HRRS Data

As part of the remedial activities associated with the remnant deposits, GE is conducting an environmental-baseline Remnant-Deposit Monitoring Program. This program includes monitoring of PCBs in sediment, water, aquatic biota and air. Ten aquatic sampling stations were established: two above the remnant deposits, six within the remnant-deposit area, and two downstream. Sampling commenced in 1989. GE also began a Temporal Water-Column Monitoring Program in 1991. The latter program includes biweekly water-column analyses at six stations, with weekly congener-specific analyses at an 11 ppt (parts per trillion or ng/L) detection limit. The extensive sampling from these monitoring programs will provide important input to the database. The recent congener-specific sampling will complement data to be collected in Phase 2.

The GE Hudson River Research Study (HRRS) was conducted between August and October, 1991 following completion of the Phase 1 Report; the data generated have not been integrated into the database, and will be in Phase 2. The HRRS was designed to (1) demonstrate that aerobic PCB biodegradation could occur under actual field conditions, based on prior laboratory investigations; (2) identify the key variables that influence the rate and extent of PCB biodegradation in Hudson River sediments; and (3) investigate the potential for natural aerobic degradation to occur in these sediments via indigenous PCB-degrading microorganisms.

4.1.3 USGS Water-Column Monitoring

In Phase 1, USGS flow data were obtained through the end of Water Year 1990; PCB and other water-quality data were obtained through the end of Water Year 1989. During Phase 2, attempts will be made to obtain the 1991 flow data as well as the 1990 and 1991 PCB and water-quality data. The availability of PCB data will depend on the extent of analysis delays currently being experienced by USGS.

4.1.4 NYSDEC Fish Data

The Phase 1 Report utilized NYSDEC fish sampling through 1988. Data for 1990 and 1991 will be incorporated into the database in Phase 2, once the final data are available from NYSDEC.

4.2 Other Data Sources

4.2.1 Point-Source Data

There are additional data to be collected on point sources of PCBs to the Hudson system. Table B.2-1 of the Phase 1 Report identified currently permitted PCB discharges into the Upper Hudson River drainage basin from the State of New York. In addition, another known source is permitted to discharge PCBs into the Hoosic River by the Commonwealth of Massachusetts. During Phase 1, only current (1991) SPDES Permits and Discharge Monitoring Reports were examined; examination of older SPDES files for these and other facilities may provide additional relevant information.

4.2.2 Other Current RI/FS Investigations

Currently, RI/FS investigations are being performed at the old GE Capacitor Manufacturing facility in Hudson Falls. According to NYSDEC, approximately 100 cubic yards of PCB-contaminated soils and oils were removed in January 1990 from an air plenum underneath the plant building. The data obtained from the NYSDEC study will be assessed.

The results of another RI/FS study being performed at the Ciba-Geigy facility upstream of the GE facility will also be reviewed.

4.2.3 Dredge-Spoil Disposal Sites

In Table B.2-2 of the Phase 1 Report, the PCB-contaminated dredge-spoil disposal sites located near the Upper Hudson River (Study Area B) were identified. These include, among others, Old Moreau Dredge-Spoil Area, Special Area 13 and Moreau Dredge-Spoil Disposal Site. These sites are subject to ongoing monitoring by NYSDOT and NYSDEC. All pertinent records will be obtained and evaluated in Phase 2.

5. CONTAMINANT FATE AND TRANSPORT ANALYSIS

The Reassessment requires estimation of the future impact of PCBs in the Hudson River system under conditions of No Action and various remedial alternatives. USEPA believes that an exhaustive investigation of all aspects of the physical/biological river system is not necessary for a Reassessment. Rather, the effort in Phase 2 should be specifically focused on providing information relevant to an informed decision among alternative remedial actions.

The information germane to the Reassessment includes expected risks under different remedial options. Evaluation of future risks includes consideration of both human health and ecological risks. In the Phase 1 Report it was determined that human health risks from Hudson River PCBs are presented primarily by the consumption of contaminated fish. Therefore, the impacts of remedial alternatives on bioaccumulation of PCBs by the fish populations must be considered. Analysis of ecological risks also requires an understanding of bioaccumulation in fish, as well as exposure concentrations which may affect other species. To provide this information in Phase 2, it is necessary to develop a quantitative understanding of (1) future trends in environmental concentrations of PCBs, and (2) pathways for the accumulation of PCBs from the environment into the fish population.

The choice among remedial alternatives will require the answers to several specific questions relating to the future status of PCBs in Hudson River fish populations, including the following:

1. When will the PCB levels in the fish population recover to levels meeting human health and ecological risk criteria under continued No Action?

2. Can remedies other than No Action significantly shorten the time required to achieve acceptable risk levels, or, conversely, could it make the current conditions worse?

3. Are there contaminated sediments now buried and effectively sequestered from the food chain which are likely to become "reactivated" following a major flood, resulting in an increase in contamination of the fish population?

These questions reflect two different time scales, and a range of spatial scales. Possibilities of catastrophic flood scour, or sediment disequilibration following dredging, are events on a temporal scale of hours, days or weeks, occurring in specific physical locations. On the other hand, the question of the general recovery of the fish population, particularly under conditions of No Action, appears to be measured on the scale of years. Assessing long-term impacts also has a broad spatial scale, which will be measured over whole reaches of the river.

Obtaining answers to these questions requires an estimate of future PCB status in the Hudson. However, it does not necessarily require the use of a highly detailed, dynamic transport model which attempts to describe all aspects of the system. For instance, modeling the short-term transport of PCBs in riparian systems can be attempted utilizing computer codes which account for the time-dependent behavior of flocculating, compressible organic sediments. Such state-of-the-art models, while difficult to parameterize and calibrate, are useful tools toward *understanding* the dynamic, micro-scale processes of PCB cycling in rivers. Fairly successful results have been reported for simulating sediment-bound PCB transport individual events, using a time step of seconds.[1] However, the spatial and temporal scales used in these models are not particularly relevant to the questions we need to answer for the Reassessment, and thus the expense of implementing such a model cannot be justified when other alternatives are available.

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[1] Gailani, J., C.K. Ziegler and W. Lick. 1991. The Transport of Suspended Solids in the Fox River. (Draft). Dept. of Mechanical and Environmental Engineering, University of California, Santa Barbara.

An apt analogy for the issue of appropriate model scale is provided by attempts to model weather and climate. That is, very detailed models of meteorological processes have been developed, yet it is still not feasible to obtain accurate estimates of the exact weather conditions for a given location two weeks hence. On the other hand, by viewing the problem from a lumped, temporally averaged perspective, fairly reliable predictions can be made of *average* climate conditions for the state of New York in the month of August next year and one certainly doesn't try to get a prediction of these averages by running a daily weather model one year into the future. For the Hudson River PCBs Reassessment predicting the future "climate" (*i.e.*, the average conditions in a given reach in a given future season), and not the "weather" (*i.e.*, the exact conditions at a particular river mile on a particular date in the future) is of interest.

The answers to the questions can be determined using a three-component approach, focused to the Reassessment as follows:

1. **Long-term analysis of impacts using PCB mass-balance approach.** This will involve analysis and prediction aimed at a seasonal time scale and a reach-based spatial scale (regardless of the internal time step that may be required by a computer model).

2. **Bioaccumulation analysis to predict average response of fish populations to environmental PCB levels.** This involves predicting future bioaccumulation from predicted environmental concentrations of PCBs in water *and* sediment.

3. **Erodibility analysis of contaminated sediment areas.** This involves analysis of specific local response to prospective flood events. Potential scour and entrainment of sediment must be assessed in detail, but not necessarily the exact details of flood transport.

These components are discussed in the following sections.

5.1 Component 1 - PCB Mass-Balance Analysis

The objective of this component is to predict the PCB levels in water and sediment on a year-by-year and reach-by-reach average basis. It will be used to analyze the potential impacts of various remedial and source-control schemes, and will provide the input to Component 2, from which impacts on the fish population will be estimated. The mass-balance analysis will utilize USEPA's modeling package - WASP5[2].

5.1.1 General Concept and Level of Detail

Analysis of the current and future PCB mass-balance in the Hudson River will be an essential component of the Reassessment. As noted above, we will address long-term, average transport processes separately from the potential for catastrophic flood scour. The long-term modeling is designed to assess impacts over a planning horizon of decades, and at a spatial scale of 3 to 5 mile reaches - a scale appropriate to estimation of average effects in fish populations. The analysis will concentrate on Study Areas B and C, *i.e.* from Hudson Falls, upstream of Fort Edward, to the approximate location of the salt front at River Mile 55. Detailed mass-balance analysis will not be attempted for Study Area D (the saline part of the estuary) due to the difficulty of quantifying PCB sources in the New York metropolitan area.

In general, the mass-balance analysis involves the characterization of PCB stores and fluxes in the river. The dominant store is sediment-bound PCBs in the river, while fluxes include rates of transport from one medium to another, advective transport by the river, as well as any continued loading into the system. The mass-balance analysis can be implemented in a form suitable for predicting future conditions by using the computer modeling package WASP5. The transport portion of WASP5 is essentially a mass-balance accounting by segment,

[2] Ambrose, R.B., T.A. Wool, J.L. Martin, J.P. Connolly and R.W. Schanz. 1992. WASP5.x, A Hydrodynamic and Water Quality Model - Model Theory, User's Manual, and Programmers Guide. U.S. EPA Environmental Research Laboratory, Athens, GA

providing a framework for assessing the mass-balance of PCBs under No Action and remedial alternatives.

WASP5 is well-suited to the task of macroscale analysis due to its link-node formulation. It allows incorporation of all the stores and fluxes most important to long-term PCB status: sediment storage, multi-phase transport in water, transport to and from sediments, volatilization, and degradation. The chemical-transport module, TOXIWASP, allows detailed consideration of chemical reactions, and the model can simultaneously simulate a number of constituents. In this case we can simulate representative PCB congeners. The general partitioning/transport aspects of the model are summarized in Figure 5.1.

In order to implement WASP5, several flux parameters must be identified. Important fluxes include loadings to the river, transport from sediment to the water column, from the water column to air, and advective transport through each reach. Loss or transformation of PCBs by degradation will also be considered. The planned approach to some of the important aspects are discussed below.

5.1.2 Advective Transport

The mass-balance modeling will, first of all, include an advective transport component. This addresses the movement with river flow of all phases of PCBs. WASP5 handles advective and dispersive transport based on input from a hydrodynamic model. It is likely that realistic long-term average modeling results, appropriate for mass-balance modeling, can be obtained by simulation with flows represented by seasonal average conditions, rather than modeling actual day-to-day variability. However, the transport model will be driven by measured USGS daily flows routed through the system with a hydrodynamic model. This will 1) allow us to test the appropriateness of the averaged model; 2) examine the effect of actual day-to-day variability on transport/concentration predictions; and 3) potentially improve model calibration by closer representation of actual hydrodynamics corresponding to the PCB concentration observations.

For reach-by-reach hydrodynamic routing a one-dimensional representation of the water column will be adequate to address spatially-averaged transport phenomena. TAMS' proprietary model LATIS[3] will be used for hydrodynamic simulation. This model is a link-node solution for gradually varied, unsteady flow, and will be adapted to provide input to the transport component of WASP. LATIS is similar in theory, physical representation of the river, and explicit solution method to the hydrodynamic model from the WASP package, DYNHYD5, which was employed in Phase 1 of this project. LATIS offers advantages over DYNHYD5 in providing a more sophisticated representation of river cross sections (profile defined by up to 30 points, versus DYNHYD's simple trapezoidal approximation) and includes routines to handle dams and other structures in the river (provisions which are absent from DYNHYD). However, DYNHYD5 (suitably modified for run-of-the-river dams) may be used as a check on the results obtained with LATIS.

5.1.3 Flux from Sediments

One of the crucial aspects of the analysis is evaluation of PCB transport from in-place sediments to the water column. This consists of two separate issues: catastrophic mass erosion of contaminated sediments under extreme flood conditions, and transport from sediments to the water column under "typical" non-catastrophic conditions. The first aspect cannot be handled entirely in the context of macroscale, mass-balance modeling, but will be evaluated through erodibility analysis, including hydrodynamic modeling, to be described below. However, the long-term impacts of extreme floods can be evaluated in the mass-balance context once the potential loading has been estimated.

The macroscale, mass-balance model is most applicable to quasi-steady conditions, in which the sediments and bed configuration change only gradually with time and are not subject to massive disequilibration. This does not mean that no scour occurs, only that the bed configuration is nearly stable over time.

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[3]Balloffet, A., E. Cole and A.F. Balloffet. 1974. Dam collapse wave in a river. *Journal of the Hydraulics Division*, ASCE, 100 (HY5): 645-665.

The mass-balance approach thus handles the quasi-steady case in which deposition and resuspension are both present, but nearly in balance with one another over a reasonably large area and time. This is considered appropriate for the Upper Hudson, where dam structures have a strong influence on sediment deposition, for the time period *since* the disturbance introduced by removal of the Fort Edward Dam in 1973. Analysis of the data in Phase 1 suggests this assumption is appropriate post 1983. The assumptions are also appropriate for the lower, estuarine Hudson where sedimentation velocities appear to be relatively steady on a year-to-year basis.

Transport of PCBs from the sediments under "typical" (quasi-steady) conditions involves several processes:

1. Diffusion through, and out of the sediments of the dissolved PCB fraction and fraction sorbed to dissolved organic matter.
2. Advection through, and out of the sediments in baseflow seepage, of both dissolved and sorbed components.
3. Sediment entrainment/exchange, involving exchange of sediment with the water column from an active mixing zone of the sediment bed.

Phase 2 sampling is designed to identify this portion of the problem in several ways. First, congener-specific PCB levels will be obtained at a number of water-column and sediment-sampling locations (see Appendix), allowing direct estimation of fluxes. In addition to these point estimates, the flow-averaged water-column sampling will provide information on concentration gain/loss between stations, indirectly identifying average flux from the sediments. Finally, if high-resolution cores are obtained which do not exhibit substantial PCB degradation, then the data can be used for the fitting of diagenetic models to describe sediment deposition and contaminant fluxes.[4] For instance, it has already been demonstrated that radionuclide profiles can be used

[4]Berner, R.A. 1980. "Early Diagenesis, A Theoretical Approach". Princeton University Press, Princeton, NJ

to obtain accurate estimates of diffusion coefficients in Hudson River sediments.[5]

5.1.4 Suspended Sediment/DOC/Water Partitioning

Even though PCB-phase partitioning in the water column is not instantaneous and reversible, it can be assumed so for the long time horizons of the mass-balance model. Also linear partitioning will be assumed, which is generally appropriate when sorption sites are plentiful. WASP5 also provides the option of making the sorption coefficient dependent on solids concentration, as proposed by DiToro.[6]

Analysis of multi-phase partitioning will be required in the modeling. Much of the transport of PCBs is expected to take place sorbed to fine sediments. However, it has also been observed that Hudson River PCB concentrations obtained by filtering water samples at 0.7 microns may be approximately a factor of 2 greater than concentrations obtained by instream large-volume filtration at 1.2 microns.[7] The reasons for this discrepancy are not clear at present, but are being investigated in Phase 2. In general, for strongly hydrophobic chemicals such as PCBs a significant role for facilitated transport involving binding of PCBs to dissolved organic compounds (DOC) or, more generally, to non-settling non-filterable organic matter (NSOM) can be expected. Chin *et al.* note that "the amount of polymeric organic matter commonly found in natural aqueous systems is apparently enough to effect the partitioning of very

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[5] Olsen, C.R., H.J. Simpson, T.-H. Peng, R.F. Bopp and R.M. Trier. 1981. Sediment mixing and accumulation rate effects on radionuclide depth profiles in Hudson estuary sediments. *Journal of Geophysical Research* 86(C11): 11020-11028.

[6] DiToro, D.M. 1985. A particle interaction model of reversible chemical sorption. *Chemosphere* 14(10):1503-1538.

[7] Bopp, R.F., H.J. Simpson and B.L. Deck. 1985. Release of Polychlorinated Biphenyls from Contaminated Hudson River Sediments. Final Report NYS C00708 to NYSDEC. Lamont Doherty Geological Observatory, Palisades, NY.

hydrophobic...contaminants such as PCBS..." making the observed partition coefficients "highly dependent" on the organic-carbon concentration.[8]

WASP5 provides the opportunity to simulate several sediment classes, including DOC. At least two classes would be needed for PCB modeling besides DOC, generally representing fine silt particles which are filterable but do not settle out in the upper Hudson, and heavier settleable particles.

At present, data are rather limited on levels of non-filterable organic matter in the Hudson. Data on water-column partitioning in the Hudson will be collected during the PCB-Equilibrium Study (Section 3).

5.1.5 Evaluation of Degradation and Volatilization Rates

Degradation and volatilization rates may vary considerably among PCB congeners. It will not be feasible to model all the PCB congeners present in the Hudson system. However, it is planned to model the behavior of a representative selection of congeners typical of Aroclor 1242, Aroclor 1254 and their breakdown products.

Mass rates of natural degradation of PCBs in the sediments of the Hudson have been the subject of considerable debate. In the Thompson Island Pool sediments, at least, it is clear that anaerobic dechlorination of various congeners is taking place. This may be an important source for the loading of mono- and dichlorobiphenyls into the water column. However, it is not yet clear if, or to what degree, these processes represent a significant reduction in the total mass of PCBs present in the sediments. Many cores from the Lower Hudson appear to show little or no degradation.

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[8]Chin, Y.-P., W.J. Weber and B.J. Eadie. 1990. Estimating the effects of dispersed organic polymers on the sorption of contaminants by natural solids. 2. Sorption in the presence of humic and other natural macromolecules. *Environ. Sci. Technol.* 24(6): 837-842.

A significant amount of laboratory-scale work has been conducted on the degradation of PCBs, and GE has recently reported field-scale investigations. However, extrapolation of these results to *in-situ* sediment conditions is questionable. Therefore, attempts to ascertain degradation rates from field data will be made. The primary source of information for this will be congener analysis of sediment cores. Shifts in congener patterns resulting from dechlorination have been reported by previous authors.[9] While there is no doubt that some reductive dechlorination does take place in the sediments, the average rate is difficult to determine over the whole area of contaminated sediments; if certain areas have changed significantly and other areas very little, then one cannot *a priori* assume that biodegradation will proceed at a predictable rate throughout the contaminated area. Further, the process may largely involve the reduction of more-reactive congeners and accumulation of more- recalcitrant congeners, and it is not clear whether this process results in a significant net molar loss of total PCBs (via mineralization, or enhanced volatilization or dissolution) from the system. However, anaerobic dechlorination clearly does play a role in altering the congener composition, which may in turn alter bioaccumulation potential and toxicity.

In investigating this problem, the work of examining congener patterns in the hot-spot sediments will be continued. If possible, this will be done in both low-resolution sampling and in intact, dateable high-resolution cores, which would yield an approximate time scale for the reduction process. Sediment cores will be obtained from the same locations of earlier analyzed and archived cores. This should enable direct comparison of the status of PCBs in similar locations in space, at two different points in time.

Aerobic degradation takes place in the oxygenated sediments and in the water column. Rates in the sediment are again difficult to determine, and may be difficult to distinguish from differential desorption of lighter

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[9] Bopp, R.F., H.J. Simpson and B.L. Deck. 1985. "Release of Polychlorinated Biphenyls from Contaminated Hudson River Sediments." Final Report NYS C00708 to NYSDEC, Albany, NY. Lamont Doherty Geological Observatory of Columbia University, Palisades, NY ; Brown, J.F., R.E. Wagner, and D.L. Bedard. 1988. PCB dechlorination in Hudson River sediment. *Science* 240: 1675-1676.

chlorinated congeners. However, the net effect of these processes can be observed in the sediments. For degradation in the water column, the initial approach will be to investigate literature evidence on aerobic-degradation rates in order to determine if this phenomenon is significant in terms of the PCB mass-balance. Additional work to quantify degradation will be needed only to the degree that model results are sensitive to this rate.

Volatilization is known to play a significant role in the depletion of PCBs in the water column. Photolysis may also be an important loss mechanism. The present plan is to rely on published and theoretically derived values of these parameters. As with the aerobic-degradation rates, model results would be subjected to an uncertainty analysis, which might suggest the need for further research on these parameters, if results are particularly sensitive to them.

5.1.6 Model Calibration and Uncertainty Analysis

For a model to be useful as a predictive tool, three things must be accomplished: 1) the model must be calibrated to observations; 2) the ability of the model to predict beyond the calibration data set must be verified; and 3) an estimate must be formed of the uncertainty associated with model predictions. In Phase 2, the mass-balance modeling will employ sequential calibration and validation, in which the observational data are split into two sets, the first data subset is used to calibrate the model, and the second is used to verify the calibration. The performance of the model will also be assessed in terms of its ability to reproduce historical trends, as far as these are known. Finally, we will provide an evaluation of the reliability of predictions from the modeling, using techniques such as those recently promulgated by IAEA[10].

The primary data available for model calibration in Phase 2 will be the congener-specific measurements of PCBs, in all phases, in the water column. These will include the Phase 2 water-column-transect monitoring and the flow-

[10]International Atomic Energy Agency. 1989. Evaluating the Reliability of Predictions Made Using Environmental Transfer Models. Safety Series No. 100. IAEA, Vienna.

averaged water-column sampling. The data obtained will be supplemented by the extensive congener-specific data obtained by GE's contractors for the Temporal Water-Column Monitoring Program and the Remnant-Deposit Monitoring Program.

The performance of the calibrated model can also be examined through comparison to historic and secondary data. The most important historic data are the USGS monitoring of total PCBs in the water column, from which estimates of annual mass transport were developed in Phase 1. Additionally, the possibility that dateable high-resolution cores can be used to provide an indicator of long-run trends in water-column transport will be investigated. This may provide further information useful in testing the modeling. The high-resolution cores are also expected to provide valuable information for model parameter identification. For instance, it has already been demonstrated that radionuclide profiles can be used to obtain accurate estimates of diffusion coefficients in Hudson River sediments.[11] To the extent that high-resolution cores are obtained from sites without substantial degradation, they can be used for fitting of diagenetic models to describe sediment deposition and contaminant fluxes.[12]

An important part of the mass-balance modeling effort will be the assessment of model-prediction uncertainties. Confidence bounds will be developed for each significant store and flux in the mass-balance. The cumulative impact of uncertainties will be assessed through implementing the mass-balance model in a Monte Carlo simulation mode.

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[11]Olsen, C.R., H.J. Simpson, T.-H. Peng, R.F. Bopp and R.M. Trier. 1981. Sediment mixing and accumulation rate effects on radionuclide depth profiles in Hudson estuary sediments. *Journal of Geophysical Research* 86(C11): 11020-11028.

[12]Berner, R.A. 1980. "Early Diagenesis, A Theoretical Approach". Princeton University Press, Princeton, NJ

5.2 Component 2 - Biotic Effects/Bioaccumulation Analysis

The previous section covered methods to estimate the long-term, steady-state environmental distribution of PCBs in the Hudson. This in itself does not yield decision criteria for the Reassessment: such criteria depend on analysis of risks. Human-health risks are presented primarily through PCB levels in the fish population, and the PCB burden in fish constitutes a direct ecological risk. Thus, the Reassessment requires estimation of future concentrations in the fish population. To accomplish this the use of a simplified functional representation of a steady-state food-web model is proposed, which relates observed fish PCB burden simultaneously to concentrations in both water and sediment.[13] This approach is intended to reflect the basic dynamics of food-chain bioaccumulation in the Hudson, while keeping data-collection requirements at a feasible level.

Relationships to predict PCB levels in fish will be developed for selected species in Study Areas B and C. Calibrated models will be developed for those species for which there is a sufficient database. Sufficient data will not be available for some species which are of interest either because they represent a significant focus of angler effort or are of ecological significance. For such species it will be necessary to extrapolate from the monitored species.

5.2.1 Limitations of Established Approaches to Bioaccumulation

There are two types of strategies which have commonly been used for the prediction of bioaccumulation from preferentially sediment-bound contaminants. These range from the very complex to the very simple, and each approach has its own strengths and limitations. At one end of the spectrum, one can attempt to build a detailed food-web model, which describes the flux of the contaminant from sediment and water and through all the compartments of the food

[13]This section describes the methods to be used to estimate and predict bioaccumulation in any specific fish population. Choice of which fish populations to include in the calculation of human health risk is an exposure assessment issue, addressed in Section 6.

chain. Such an approach has previously been attempted for the striped bass population in the Lower Hudson[14]. The food-web approach is theoretically satisfying. However, it requires large amounts of data, not only on PCB levels in various trophic compartments, but also on population dynamics and feeding preferences. This approach was feasible for striped bass only because of the large body of population data which had been developed over time in the course of studies for power plant cooling water intakes. Similar databases are not available for Upper Hudson river fish, nor are there many data on concentrations in lower trophic levels. Further, a complete food-web model requires the measurement or calibration of numerous parameters, which essentially describe the rate of flux between each of the compartments in the model. Such models are chronically plagued by the problem of over parameterization, in which the data are not sufficient to establish a unique set of parameter values. This in turn reduces the predictive ability of the model. A full food-web-model approach for all species in the Upper Hudson was not deemed feasible or appropriate within the time constraints of the Reassessment.

At the other extreme, various methods have been proposed to predict bioaccumulation directly from concentrations in sediment. Among these are the Thermodynamic Bioaccumulation Potential (TBP) approach of the U.S. Army Engineers and EPA[15] and the Equilibrium Partitioning (EqP) approach recently proposed for establishing sediment-quality criteria from water-quality criteria[16]. These methods have the advantage of moderate data requirements and ease of use. However, they are limited in their ability to accurately reflect true conditions in rivers, such as the Hudson. Essentially, the TBP and EqP methods both make

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[14] Thomann, R.V., J.A. Mueller, R.P. Winfield and C.-R. Huang. 1989. "Mathematical Model of the Long-Term Behavior of PCBs in the Hudson River Estuary." Report prepared for The Hudson River Foundation, June 1989. Grant Nos. 007/87A/030 and 011/88A/030.

[15] U.S. Environmental Protection Agency Office of Water and Department of the Army Corps of Engineers. 1991. Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual. EPA-503/8-91-001, February 1991.

[16] U.S. Environmental Protection Agency Office of Water. 1991. "Proposed Technical Basis for Establishing Sediment Quality Criteria for Non-ionic Organic Chemicals Using Equilibrium Partitioning. August 1991, Office of Science and Technology, Health and Ecological Criteria Division, Washington, DC

the assumption that all pathways of bioaccumulation, whether initiated in the sediment or in the water column, can be assessed by measuring concentrations in the sediment - *i.e.*, that concentrations in the sediment, water column, and aquatic biota (including food sources) are in equilibrium. This simplification becomes crucial when there is a possibility of significant uptake into the food chain from dissolved water-column concentrations (and food components) separately from sediment pathways. While the equilibrium assumptions may provide an adequate description for a small pond, disequilibrium is likely in a large flowing river. Indeed, the data reviewed in Phase 1 indicate that water-column concentrations of PCBs (adjusted for dilution) tend to remain relatively constant between Fort Edward and Waterford, while the local sediment concentrations vary by orders of magnitude. Thus, water-column concentrations at certain points are responding to sediment concentrations miles upstream, and local sediment concentration is not necessarily a good predictor of local water-column concentration. In turn the local sediment concentration alone would be an inadequate predictor of PCB concentrations in fish in the reach.

5.2.2 Proposed Approach

The proposed approach to predicting PCB dynamics in the fish population draws upon recent work of Thomann *et al.*[17] However, the model presented there is reduced and simplified to reflect the data availability in the present study. Thomann *et al.*'s work provides a detailed study of organic-chemical accumulation in an amphipod-sculpin food web in Lake Ontario. The model was developed in steady-state form, reducing the need to study population dynamics. It involves five interactive biological compartments, and was developed with the intention of providing a generic modeling framework for the accumulation of chemicals in aquatic systems. The compartments include a benthic-invertebrate component, and the relative impact of the benthic component (given equilibrium partitioning) is shown to be directly related to the sediment/overlying water-partition coefficient.

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[17]Thomann, R.V., J.P. Connolly and T.F. Parkerton. 1992. An equilibrium model of organic chemical accumulation in aquatic food webs with sediment interaction. *Env. Tox. and Chem.*, 11: 615-629.

If the structure of the generic model proposed by Thomann *et al.* as applied to a particular fish species is analyzed, it can be seen that it consists of one output variable (concentration in the target species), a number of internal rate constants (controlling transfer between different biotic compartments), and two input or forcing functions (the chemical concentration in water column and sediment). In the Lake Ontario case, Thomann *et al.* were able to calibrate transfer rates between all compartments of the model, due to extensive data collection on all trophic levels by previous researchers. However, in essence the model consists of predicting an output concentration from two input functions, the chemical concentration in water and sediment. Therefore, the model can be represented in its simplest form as a bivariate regression relationship or bivariate bioaccumulation factor (BAF), which is appropriate when water column and local sediment are not in equilibrium. The internal rate constants have then been subsumed into the overall equilibrium coefficients, thus representing a black-box approach. This is the appropriate approach to take when data are lacking on bioconcentrations for the lower trophic levels. Such an approach, once calibrated, will not result in any loss of predictive power for an individual species. The main drawback resulting from lack of information on the inner workings of the model is a reduction in our ability to predict accumulation in species for which calibration data are not available.

Analysis of the historical database in Phase 1 provides support for the idea that PCB concentrations in the fish population, on a lipid-adjusted basis, can be reasonably predicted directly from environmental concentrations without explicit modeling of population dynamics. The empirical evidence is summarized in Figures B.4-25 (reproduced here as Figure 5.2) through B.4-29 of the Phase 1 Report, as well as earlier work of Brown *et al.*[18] These show a strong linear relationship between summer average PCB concentration in water and lipid-adjusted PCB burden in fish. This suggests that summer average (*i.e.*, non-

[18]Brown, M.P., M.B. Werner, R.J. Sloan and K.W. Simpson. 1985. Polychlorinated biphenyls in the Hudson River, recent trends in the distribution of PCBs in water, sediment and fish. *Environmental Science and Technology* 19(8): 656-661.

scouring) water concentrations provide a reasonable predictor of PCB concentrations in fish, via a BAF. However, the observations presented in Phase 1 address only the correlation between PCB concentrations in water and fish PCB burden. Direct sediment/benthic pathways will also be important. Phase 1 developed a correlation between fish PCB burden and PCB concentrations in sediment, because of a lack of an adequate database; the direct sediment measurement for Phase 1 are primarily at two points in time (1978 and 1984) and, except for limited data in 1978, confined to a location (the Thompson Island Pool) where a contemporaneous database for fish concentrations does not exist. This deficiency will be corrected in Phase 2.

The proposed approach is more sophisticated than simple equilibrium approaches, as it recognizes the possible disequilibrium between sediment and water column. However, substantial insight on the approach can be gained from recent work on equilibrium-partitioning concepts. For a system in which sediment and water are in equilibrium there is a strong theoretical basis for the BAF approach. Indeed, for true equilibrium conditions, a BAF approach should be as effective a prediction tool as any identifiable food-web model.[19] The basic argument can be introduced by considering the case of a closed system, constituting a well-mixed body of water with no influx or efflux. In this closed system, PCB concentrations in all compartments would be in equilibrium, with the concentration in any one compartment derivable from observations in any other compartment. Then, a univariate BAF can be established from measurements in any single medium.

In a flowing river, the usual case is that the upper sediment layer and the water column are *not* in equilibrium with each other. Further, the upper, bioactive sediment zone is typically not in equilibrium with deeper, buried sediments. However, the sediment-sorbed PCB concentrations and pore-water PCB concentrations within the bioactive zone should be very close to equilibrium,

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[19]DiToro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomas and P.R. Paquin. 1991. Technical basis for establishing sediment quality criteria for non-ionic organic chemicals using equilibrium partitioning. *Environmental Toxicology and Chemistry* 10(12): 1541-1583.

while in the water column the dissolved and suspended sediment-bound PCB fractions should also be close to equilibrium (except during transient events) although their measurement may be hindered due to a DOC phase. The fact that the water and sediment compartments are not in equilibrium with each other, but are approximately internally equilibrated, suggests that the optimal predictors of concentrations in biota should be bivariate BAFs, relating body burden to *both* sediment and water-column chemical concentrations. Correlating to both removes the difficulty of the water and sediment not being in equilibrium (which is equivalent to saying that the water concentration cannot be predicted solely from the local sediment concentration). It further accounts for bioaccumulation pathways from both water and sediment.

Under our assumptions, equilibrium partitioning is not valid between sediment and flowing water, but is valid within the sediment and within the water column. The work of DiToro *et al*. thus provides some important insights into the optimal parameterization of the model. As noted above, for hydrophobic contaminants such as PCBs, it is necessary to describe a three-phase system, in which PCBs in both sediments and water column are found in dissolved form, sorbed to particulate matter, and complexed with dissolved organic compounds (DOC). Fish may accumulate PCBs through partitioning from the water column, through ingestion of sediment, or through the food chain, while organisms at lower trophic levels may also accumulate PCBs from both water column and sediments. For a fully equilibrated system, sediment-pore-water PCB dissolved concentrations might provide a good index of bioavailability, but it is typically a very difficult task to separate the dissolved and DOC fractions. Fortunately, for lipophilic compounds in sediments at normal organic carbon contents, the partition coefficients are such that the mass present in dissolved and DOC-complexed forms is relatively small compared to the total particulate-sorbed mass. This implies that the dissolved portion can be quite well predicted from the sediment-water partition coefficient, regardless of DOC levels. (DOC complexed mass is, however, important in predicting total flux out of the sediments.) On the other hand, pore-water concentrations will vary significantly in response to the organic-carbon content in sediment, *i.e.*, the fraction of organic carbon in the sediments on a weight basis (foc). Therefore, sediment concentration normalized to foc is the best, readily available predictor of dissolved concentrations in an equilibrium system.

PCBs may enter the food chain both through the dissolved phase and through ingestion of particulate matter. As DiToro *et al*. state, "biological effects appear to correlate to the interstitial water concentration. This has been interpreted to mean that exposure is primarily via pore water. However, the data correlate equally well with the organic carbon-normalized sediment concentration... This suggests that the sediment organic carbon is the route of exposure. In fact, neither of these conclusions necessarily follow from these data."

The reason for this surprising conclusion is contained in fugacity,[20] or chemical potential theory.[21] This holds that the biological activity of a contaminant is controlled by its chemical potential. As discussed by DiToro *et al*., if pore water and organic carbon are in equilibrium then the chemical potentials exhibited by the two phases are equal. "Hence, so long as the sediment is in equilibrium with the pore water, the route of exposure is immaterial. Equilibrium experiments cannot distinguish between different routes of exposure." Thus, in the simplified equilibrium case, it is only necessary to estimate the chemical potential in one phase. The question then becomes one of which phase is easiest to measure. Where DOC complexing occurs it is clear that sediment PCB concentration normalized to organic carbon is the most directly measurable index of chemical potential.

The equilibrium partitioning/fugacity arguments thus inform us that the best readily measurable index of chemical potential should be the sediment-sorbed fraction normalized to foc, which removes the problem of estimating the magnitude of the DOC fraction. This should apply to both sediments and water

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[20]Fugacity is a measure of the escaping tendency of a chemical from one phase to another.

[21]Mackay, D. 1979. Finding fugacity feasible. *Environ. Sci. Technol.* 13:1218.

column. These should be compared to the lipid-normalized burden in the organism.[22] The correlation analysis will thus be used to predict fish PCB burdens from future environmental concentrations through species-specific relationships of the following form:

$$\frac{Cf_i}{fl_i} = Bw_i \cdot \frac{Cs_w}{foc_w} + Bs_i \cdot \frac{Cs_s}{foc_s}$$

in which, for species i:

Cf	=	PCB concentration in fish (wet weight)
fl	=	lipid fraction in fish
Bw	=	Partial BAF relating fish concentration to water-column concentration
Cs_w	=	PCB concentrations on suspended solids
foc_w	=	organic carbon fraction of suspended solids
Bs	=	Partial BAF relating fish concentration to upper zone sediment concentration
Cs_s	=	PCB concentration in upper zone sediments (dry weight basis)
foc_s	=	organic carbon fraction of the sediments

Phase 2 data gathering is designed to allow the examination and testing of the suitability of this proposed method for predicting future PCB burdens in fish from environmental PCB concentrations. If the method proves feasible it will be used to assess the likely impact of the various remedial options under consideration, as well as the recovery time under No Action. In addition, for the one population (striped bass) for which there is a sufficient

[22] Chiou, C.T. 1985. Partition coefficients of organic compounds in lipid-water systems and correlations with fish bioconcentration. *Environ. Sci. Technol.* 19: 57-62.

database to construct a detailed food-web model, we may attempt a refinement of the food-web modeling previously undertaken by Thomann *et al*.

5.2.3 Extrapolation to Unmonitored Species

The methods discussed in the previous section are directly applicable only to species for which there is a sufficient database to determine the correlation parameters. While extensive monitoring data are available on certain fish species, other fish species of importance to anglers (*e.g.*, pike) or of particular ecological interest as endangered (*e.g.*, shortnose sturgeon) have not been regularly monitored. In the absence of monitoring, BAFs cannot be calibrated for these species. However, certain inferences can be drawn on expected levels from data in other species, based on differences in portion of life cycle spent in the Hudson, feeding behavior, growth rate, and lipid content. We will investigate using techniques such as the EPA supported model FGETS[23] to relate predictions in monitored species to levels in unmonitored species.

5.3 Component 3 - Erodibility Analysis

Sediments constitute the major store of PCBs in the Hudson. The Thompson Island Pool is of particular concern, as large quantities of PCB contaminated sediments were deposited in this reach following the removal of the Fort Edward Dam in 1973. PCBs are also stored in depositional areas throughout the Hudson below the Thompson Island Dam. However, much of the contaminated sediment is currently buried at depth, and not in ready contact with the water column or biota. Stored PCBs in buried sediments affect water-column PCB concentrations only through slow diffusive flux.

The mass-balance approach to the analysis (Component 1) addresses current and future PCB dynamics in the Hudson given a quasi-steady-state situation for contaminated sediments. This refers to a situation in which a

[23]Suarez, L.A. and M.C. Barber. 1987. FGETS, A Simulation Model for Predicting Bioaccumulation of Non-Polar Organic Pollutants by Fish. EPA/600/3-87/038.

sudden change in PCB flux due to extensive scour of currently buried contaminated sediments does not occur. This appears to fit the observed data on PCB load, where we have noted that the load appears to have stabilized over the years. Furthermore, a significant gain in load, which could be attributed to scour of contaminated sediments, has not been observed between the upstream and downstream ends of the Thompson Island Pool (see Figure 5.3).

The quasi-steady-state approach assumes that introduction of PCBs into the water column by flood scour is currently a process of relatively minor significance which occurs at an approximately constant annual rate. Although this appears to represent the situation observed in recent years, it is not sufficient to assume, without further investigation, that no change in the system will occur in response to future major flood events. Therefore, a third component must be added to the analysis. This is an assessment of the potential for flood scour of buried, contaminated sediments. This includes the possibility that a major flood might reintroduce quantities of now-sequestered PCBs into the water column and surface-sediment layers available to the water column and biota.

Hence, the objective of Component 3 is to evaluate the probability of flood erosion of contaminated hot-spot sediments during realistic future extreme flood events. One result of the analysis will include a map of erosion probability which can be superimposed on the map of PCB sediment distribution. This will serve to identify the relative risk posed by different PCB-source areas, as well as yielding the overall likelihood of significant remobilization of buried PCBs. Such a map will also be a guide to planning remediation of sediments, if necessary. To accomplish this analysis laboratory experiments, field studies, mathematical modeling, and statistical analyses will be necessary. The map will incorporate statistical techniques to show upper and lower bounds in the critical regions of erosion. The work is divided into two studies, hydraulic and sediment transport/erodibility studies.

5.3.1 Hydraulic Studies

The first requirement is the determination of the maximum hydraulic energy available for erosion. Phase 1 included analysis to determine the 50-year, 100-year, 200-year and 500-year recurrence floods, defined through an extreme-value distribution. These (and other) flows can be routed through the study areas and the local water velocities and elevations determined. Local water velocities will determine the shear and sediment-transport capacity during high flows, thus yielding a recurrence model for shear at any specific location.

Phase 1 included preliminary efforts at modeling flows in the Thompson Island Pool using one- and two-dimensional applications of a link-node model, WASP5. For the purposes of assessing erodibility it has been determined that one-dimensional flow routing will be sufficient, and is the appropriate level of detail in light of both available calibration data and uncertainties inherent in modeling sediment properties. While it would be of technical interest to utilize a computer code written to solve a two- or three-dimensional representation of flow, this effort would not necessarily result in any improvement in accuracy of the predictions. This is because model results are dependent on representation of the physical process, numerical-solution procedure, initial and boundary conditions, and calibration of parameter values, all of which introduce errors. Therefore, the model results are also subject to uncertainty, and this uncertainty will increase if, for instance, the calibration data are inadequate to the discretization detail of the model. A detailed review of uncertainty in models is given by Beck.[24]

A classic application of an appropriate type of model for a large river system, the Rhine-Meuse estuary, is described by Roelfzema *et al.*[25] These researchers have used a one-dimensional model to represent areas where the

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[24]Beck, M.B. 1987. Water quality modeling: a review of the analysis of uncertainty. *Water Resources Research* 23(8): 1393-1442.

[25]Roelfzema, A., M. Karelese, A.J. Strujik and M. Adriaanse. 1984. "Water Quantity and Water Quality Research for the Rhine-Meuse Estuary". Publication No. 325. Delft Hydraulics Laboratory

width/depth ratio is less than 100. For an area whose width is extremely large they used a two-dimensional depth-averaged model. In regions where stratified salinity distribution is observed, a two-dimensional laterally-averaged model was utilized. A three-dimensional model was employed to represent the sea-area at the mouth of the estuary.

The width-depth ratio of the Hudson within Study Area B is less than 100. Therefore, a one-dimensional approach is appropriate to both hydraulic and sediment-transport modeling.

5.3.2 Sediment Erodibility

In addition to hydraulic stresses, the potential for erosion on the river bed will depend on characteristics of the sediment. The general hypothesis is that the hydraulic shear stress must exceed a critical bed shear stress, τ^*_c, for erosion/resuspension to take place. The mechanisms causing bed erosion are different for cohesive and non-cohesive sediments. Therefore, to study erodibility of the river bed, the study area must be demarcated according to the cohesiveness of the bed material. A literature review was carried out to obtain background information to define, quantitatively, the term cohesive material. Some considered sediments having more than 10% clay-size particles (4 μm), by weight, to be cohesive.[26] Other researchers working on estuarine sediment transport treated sediments of particle size 60 μm as cohesive.[27] Still others, working on the design of canals conveying water, found that soils characterized by a mean diameter of less than 100 μm exhibit cohesiveness.[28] As there is no consistent agreement on the definition of cohesive material, we have defined cohesive bed material as having more than 10% clay-size particles (<4 μm) and/or

[26] Raudkivi, A.J. 1990. "Loose Boundary Hydraulics" (3rd edition), p.300. Pergamon Press.

[27] Parchure, T.M. & A.J. Mehta, 1985. Erosion of cohesive sediment deposits. ASCE Journal of Hydraulic Engineering 111 (HY10): 1308-1326.

[28] Vanoni, V.A., 1977. "Sedimentation Engineering." ASCE Manuals and Reports No: 4, pg. 107.

having a mean diameter (d_{50}) of less than 100 µm (d_{50} ≤100 µm). This definition will be used in the erodibility studies, and bed material containing a d_{50} greater than 100 µm will be considered cohesionless.

No laboratory experiments will be conducted to determine critical shear stress for cohesionless material. As there are numerous formulae available to determine critical shear stress for cohesionless sediment, they have not been summarized in a table. Formulae available in the literature will be used to determine the values. However, studies will be conducted to determine the composition of cohesionless material on the bed to choose the appropriate formula.

The course to be pursued in estimating erodibility in Phase 2 will depend on the importance of cohesive sediments in the area of contamination. That is, if cohesive sediments occupy only a small fraction of the bed in the contaminated area, it will be appropriate to address scour potential of these areas through approximation methods. However, if cohesive sediments represent a significant portion of the area, a more accurate determination of erosion rates and critical shear stress would be required.

The critical shear stress for cohesive material cannot be estimated from simple, universal formulae. The common approach is to conduct laboratory experiments for specific sediments and develop formulae relating the observed erosion rates and critical shear stress to other variables that can be measured in the field. Some of the formulae proposed for cohesive sediments, relating erosion rate, critical shear stress, vane shear strength, and other variables, are tabulated in Table 5.1. These are not directly applicable to our study, as the relationships are material- and site-specific. Therefore, for significant areas of cohesive bed material encountered in Study Area B, critical shear stress and erosion rates would need to be determined experimentally.

Over the last three decades, several laboratory techniques have been used to study material properties of cohesive sediments. The choice of a particular technique depended on the research problem that was investigated, availability of equipment, *etc.* The different techniques are tabulated in Table 5.2, and their advantages and disadvantages are summarized. As the major objective in the Reassessment is estimating erosion potential of inplace sediments during floods, the technique used by Schünemann and Kühl[29] will be adapted and described in more detail in the Phase 2B Sampling and Analysis/Quality Assurance Project Plan. As shown in Table 5.2, the technique of Schünemann & Kühl offers a number of advantages:

- A relatively undisturbed sediment core is used.
- Erosion rates for various turbulent conditions (flow regimes) can be obtained.
- Erosion rates can be related to the density of the bed.
- A continuous measurement of sediment concentration in the water column is possible.
- The entire depth of water column in the field can be simulated.

Specific issues relating to use of the apparatus shown in Appendix A are described below:

(1) Determination of the relationship between shear stress and RPM: The Phase 2B Sampling and Analysis/Quality Assurance Project Plan will explain the methodology in more detail and will show how the relationship of shear stress τ vs. RPM is obtained during the calibration stage of the experiment.

(2) Effect of fluid shear: Fluid shear, or the velocity gradient, is an important parameter in the design of clarifiers and flocculators because it controls the formation and break up of flocs. It would be an important factor if we were studying the *settling* properties of cohesive sediment. However, as we are studying solely the erosion characteristics of the sediment bed, the parameter is not significant.

[29] Schünemann, M. & H. Kühl, 1991, "A Device for Erosion Measurements of Naturally Formed, Muddy Sediments: The EROMES System." GKSS 91/E/18, GKSS Research Centre, Germany.

(3) Scaling from experiment to the field: The total volume of water contained in the sample tube and the large vessel is equivalent to the volume occupied by a hypothetical 4 inch diameter cylinder occupying the entire water depth. Thus the suspended sediment concentration in the system would represent the actual concentration of the eroded sediment that would exist in the field. Therefore, we feel that the system represents the field.

(4) Laminar vs. turbulent-flow regimes: In a river, the bed configuration is the result of the interaction of the fluid and sediment particles. The presence of bed forms, sediment motion, and the interaction of the fluid on particles create a complex flow pattern. For all purposes, it is reasonable to assume that the flow at the sediment-water interface is turbulent. The laboratory system also simulates a turbulent regime.

(5) Effect of spatial distribution of shear on the sample: The presence of baffles in the small tube (see Appendix A) creates a complex type of flow pattern within the sample tube and produces an approximately uniform distribution of shear stress at the water-sediment interface.

(6) Method of determination of effective stress: A gamma density probe will be utilized to measure the density of the sample at specified depth intervals. This in turn will be used to determine the effective stress.

The experimental apparatus can be used to measure depths of erosion and critical shear stress at different threshold levels of erosion.[30] It is intended to fit a statistical distribution for the critical bed shear stress and use this as an input for the determination of erodibility. The concept of a probability distribution for critical stress has been used by Einstein as quoted by Vanoni[31] and Partheniades.[32] It is felt that the distribution will vary depending on the type of material leading to different distributions being used at different locations.

To summarize, Component 3 encompasses:

(a) Determination of the probability distribution of extreme flood events, and hydraulic modeling of the resultant flows;

(b) Determination of the physical properties of the sediment, and the distribution of different sediment types throughout the Thompson Island Pool;

(c) Evaluation of the statistical distribution of the critical shear stress, using laboratory experiments for cohesive sediment, if required;

(d) Use of the statistical distribution of critical shear stress, recurrence probability of extreme flood events, and hydraulic modeling of resultant available shear stress, to develop the spatial probability distribution of erosion potential; and

(e) Combination of the results of (d) and measurements of PCB concentrations in sediment to evaluate and map the risk of erosion of contaminated sediments.

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[30]Lavalle, J.W. and H. O. Mofjeld. 1987. Do critical stresses for incipient motion and erosion really exist? *ASCE Journal of Hydraulic Engineering* 113(JHY 3)(3): 370-385.

[31]Vanoni, V.A. 1977. "Sedimentation Engineering". ASCE Manuals and Reports No. 54, pg. 94.

[32]Partheniades, E. 1965. Erosion and deposition of cohesive soils. *ASCE Journal of Hydraulic Engineering* 104(HY2): 279-283.

Table 5.1
Summary of Critical Stress Formulae for Cohesive Sediment

Reference	Expression
Ariathurai, R. and K. Arulanandan. 1978. Erosion rates of cohesive soils. ASCE Journal of Hydraulic Engineering 104(HY2): 279-283.	$\varepsilon=\alpha\left(\frac{\tau_b-\tau_c}{\tau_c}\right)$
Raudkivi, A.J. 1982. "Grundlagen des Sediment-transports", pp.90-91.	$\varepsilon=K\left(\frac{u_*^2}{u_{*c}^2}-1\right)$
Parchure, T.M. and A.J. Mehta. 1985. Erosion of cohesive sediment deposits. ASCE Journal of Hydraulic Engineering 111(HY10): 1308-1326.	$\varepsilon=\varepsilon_f e^{\alpha_2(\tau_b-\tau_c)^{1/2}}$
Dunn, quoted by E. Partheniades and R.E. Paswell. 1970. Erodibility of channels with cohesive boundary. ASCE Journal of Hydraulic Engineering 96(HY3): 755-771.	$\tau_c \propto S_v$
Nother, B. 1989. "Untersuchungen zum Resuspensionsverhalten von Astuarschwebstoff". GKSS 89/E/38. GKSS Research Centre, Germany.	$\varepsilon=1.18(\tau-\tau_{*c})$ $\varepsilon=0.84(\tau-\tau_{*c})$
Smerdon and Beasley, quoted by Partheniades and Paswell 1970. Erodibility of channels with cohesive boundary. ASCE Journal of Hydraulic Engineering 96(HY3): 755-771.	$\tau_c=0.0034(P.I.)^{0.84}$
Teisson, C. 1991. Cohesive suspended sediment transport: feasibility and limitations of numerical modeling. Journal of Hydraulic Research 29(6): 755-770.	$u_{*c}=3.2\times10^{-5}C_s^{1.175}$ $u_{*c}=5.06\times10^{-8}C_s^{2.35}$

Table 5.1 Continued

Definition of Terms for Critical Stress Formulae

e	Erosion Rate
τ, τ_b	Bed Shear Stress
τ_{*c}, τ_c	Critical Shear Stress
α, K	Constants
u_*	Shear Velocity
u_{*c}	Critical Shear Velocity
C_s	Suspended Sediment Concentration
S_v	Vane Shear Strength
P.I.	Plasticity Index
e_f	Floc Erosion Rate

TABLE 5.2

COMPARISON OF LABORATORY TECHNIQUES TO MEASURE CONSTITUTIVE PROPERTIES OF COHESIVE SEDIMENTS

N°	Names of Researchers	Year*	Method	Advantages	Disadvantages
1	Graham, D.I. *et al.*[33]	1992	• Annular carousel/flume, rectangular X Section 0.35 m deep and 0.40 m wide - Outer radius 3.0m • Field sediment	• No pumps to break flocculated sediment • Hydrodynamics of carousel predetermined	• Secondary currents • Curvature and wall effects • Mixed sediment poured into flume
2	Schünemann, M. & H. Kühl	1991	• 10 cm dia cylindrical cores • Estuarine sediment	• Undisturbed sample • Erosion rate can be measured • Continuous monitoring of sediment concentration in water column • Entire water column in the field represented	• Small size of sediment core • Logistical problems in transporting sample to the laboratory
3	Parchure, T. M. & A.J. Mehta	1985	• Annular flume, 0.20 m wide 0.46 m deep, mean dir 1.5 m • Lake mud, commercial. Kaolinite, (d_{50} = 1 μm)	• No pumps to break flocculated sediment • Controlled laboratory study	• Rotation induced secondary currents • Completely distributed sample • Deposited beds over a short period of time, 1.7 days • Curvature • Entire field conditions not represented
4	Partheniades E.	1965	• Rectangular flume 0.30 m wide, 0.45 m deep, and 18 m long • San Francisco Bay mud. Clay (< 2 μm) 60% Silt (2 μm - 50 μm) 40%, Sand • Velocity of flow; 0.38 - 2.34 ft/sec	• Easy technique • Experience exists	• Completely disturbed sample • Artificially formed bed, 0.1 ft thick, or • Bed formed by pouring a suspension • Entire field conditions not represented
5	Krone R.B.[34]	1963	• Rheological properties • Capillary viscometer • Rotating cylinder viscometer. • Estuarine muds	• Determination of specific properties under controlled conditions	• Completely disturbed sample • Secondary currents • Small scale • Entire field conditions not represented

* Refers to the date of publication of either the report or the article.

[33] Graham, D.I., P.W. James, T.E.R. Jones, J.M. Davies, and E.A. Delo, 1992. "Measurement and Prediction of Surface Shear Stress in Annular Flume," ASCE Journal of Hydraulic Engineering 118 (HY9) 1270-1286.

[34] Krone, R.B., 1963, "A Study of Rheologic Properties of Estuarial Sediments, Technical Bulletin No. 7, Committee on Tidal Hydraulics, US Army Corps of Engineers.

Figure 5.1

Schematic PCB Mass Balance Model

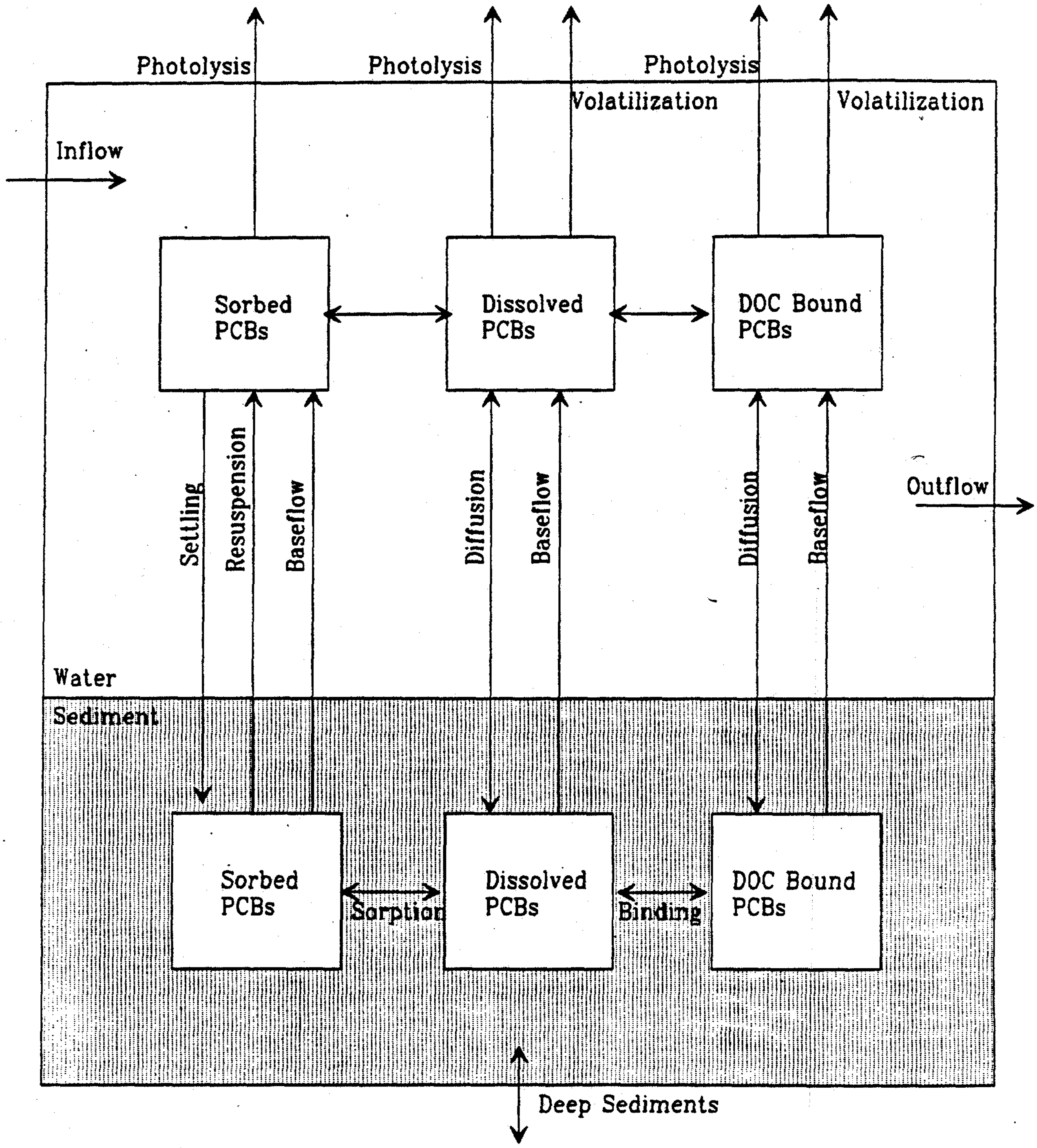


Figure 5.2

Total PCBs Yearling Pumpkinseed

vs. Summer Concentrations in Water at Stillwater

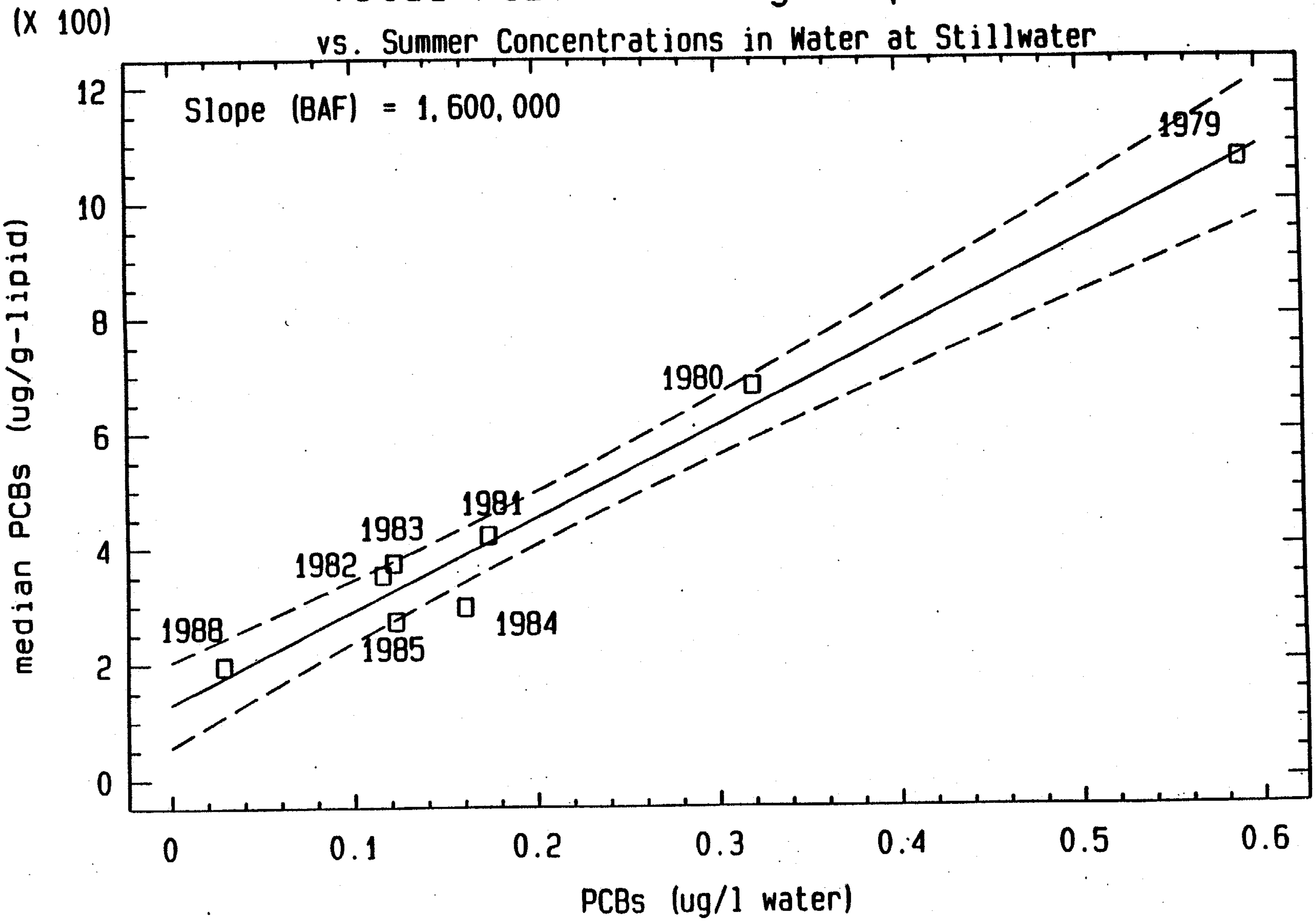
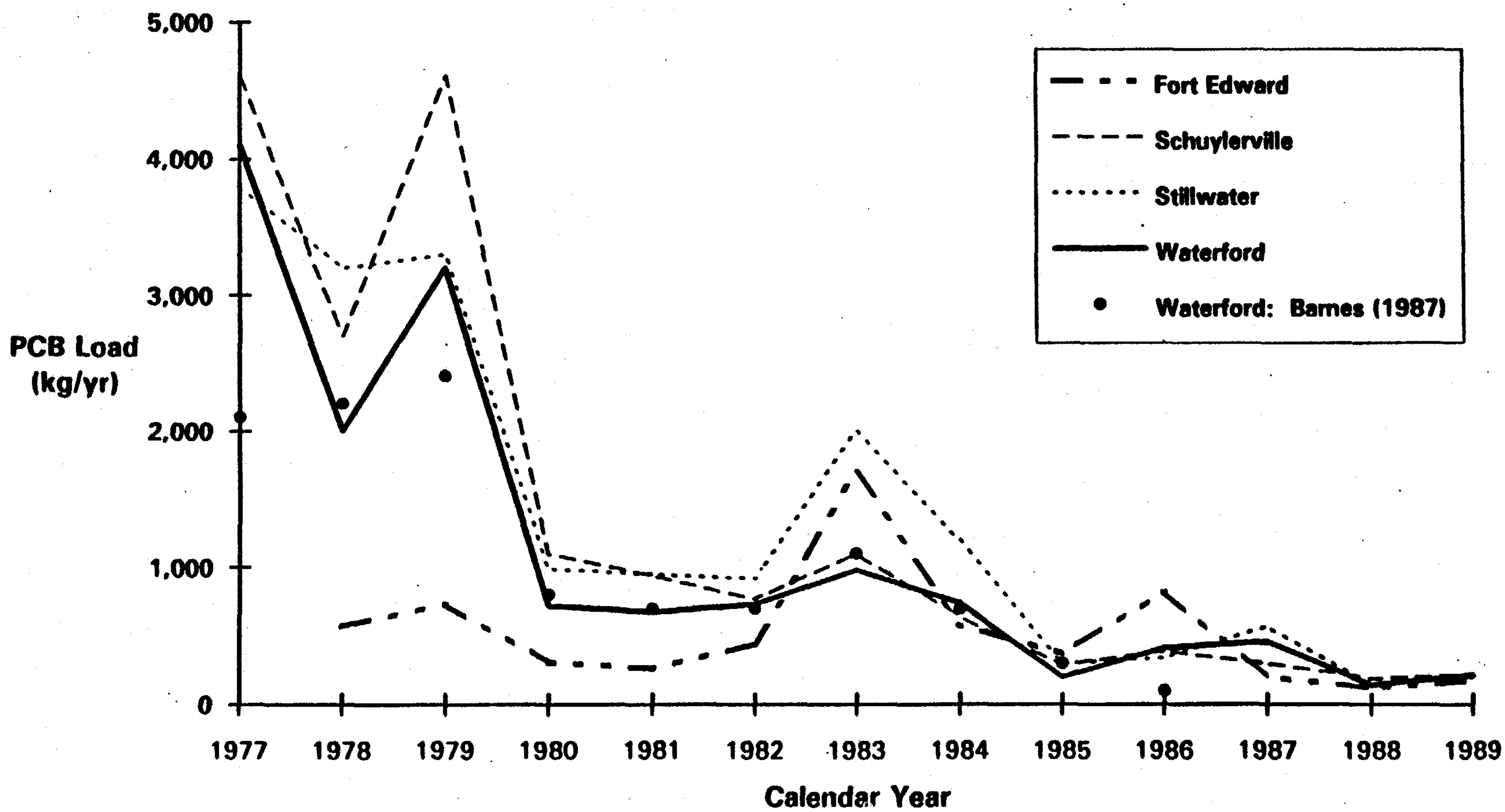


Figure 5.3

PCB Mass Transport: Corrected Mean Method Estimates



6. BASELINE HUMAN HEALTH RISK ASSESSMENT

The Phase 1 Report provided a preliminary baseline human health risk assessment and indicated that there was an unacceptable human health risk associated with eating fish from the Upper Hudson River. To perform a final baseline risk assessment in Phase 2, additional data will be utilized, *e.g.*, 1990 and 1991 fish data, sediment and water-column data collected in Phase 2, and relevant new information on PCB health risks, if any.

6.1 Study Area B

The preliminary human health risk assessment for the Upper Hudson was presented in the Phase 1 Report. Where updated site-specific information can be obtained, it will be incorporated into the final risk assessment. This information falls into two categories: exposure assessment and toxicity information, as described below.

6.1.1 Exposure Assessment

Estimates of risks will be calculated for the central tendency and high-end individual risks in accordance with current EPA guidance[1]. This guidance also indicates that given sufficient information on particular exposure factors, Monte Carlo techniques can be used to estimate the central tendency and high-end risks. Consequently, Monte Carlo methods will be used in the exposure assessment to the extent data are available to define input parameters.

6.1.1.1 Fish Consumption

The Phase 1 preliminary human health risk assessment adopted the average recreational fish-consumption value of 30 g/day that is suggested by the USEPA for the fish-consumption pathway. The Phase 2 baseline assessment will evaluate whether there are adequate data to justify a different, site-specific

[1] USEPA. 1992. Memorandum to Assistant Administrators, Regional Administrators from F. Henry Habicht II, Deputy Administrator, USEPA, Washington, D.C. February 26.

or region-specific, *e.g.*, northeast, value for fish consumption that would apply in the Hudson River area in the absence of a fishing ban. Additionally, the Phase 2 human health risk baseline assessment will provide a discussion of potentially sensitive subgroups, such as recreational or subsistence anglers.

6.1.1.2 Exposure-Point Concentrations in Fish

The Phase 1 preliminary human health risk assessment relied on fish data collected through 1988. NYSDEC fish sampling data for 1990 will be available for Phase 2. These data, along with any data available for 1991 and 1992, will be used to refine the estimates of current and projected, future PCB concentrations in fish.

During Phase 1 exposure point concentrations for PCBs in Upper Hudson fish were calculated without differentiating among species. During Phase 2, the possibility of refining the estimates of exposure point PCB concentration in fish to reflect inter-species variability will be evaluated. This evaluation will include the possibility of establishing an exposure point concentration specific to individual fish species caught by Upper Hudson fishermen and the relative frequency with which these particular species are consumed.

Human uptake of PCBs from fish may also be affected by handling of fish following capture from the river. Specifically, as discussed in the Phase 1 Report, cooking practices may affect the final concentrations of PCBs in fish flesh prior to its consumption. The Phase 2 assessment will determine whether there are new and adequate data available to determine confidently an appropriate adjustment factor to account for the effects of cooking.

6.1.1.3 Uncertainty Analysis

In Phase 2, a quantitative uncertainty analysis using Monte Carlo simulation techniques will be conducted. This analysis will provide an indication of appropriate upper-bound exposures to PCBs from the consumption of Hudson River fish and take into account components of uncertainty such as fish species, fishing preference, location within the river, fish consumption, future PCB levels in fish and other exposure factors. In addition, current risk assessment techniques will be used to discuss uncertainties (USEPA, 1992).

6.1.2 Toxicity Assessment

6.1.2.1 Carcinogenic Toxicity

The Phase 1 preliminary human health risk assessment used a Carcinogenic Slope Factor (CSF) of 7.7 $(mg/kg\text{-}d)^{-1}$ to estimate the cancer risk associated with exposures to PCBs from the Hudson. This value was applied to total PCB exposure. Toxicity studies upon which this Slope Factor is based were recently reevaluated by the Institute for Evaluating Health Risks (IEHR). The results of the IEHR Reassessment may affect the estimated CSF for PCBs. The Office of Research and Development (ORD) of USEPA is considering the new information provided by the IEHR Reassessment to determine its impact on the CSF. Should the ORD determine that an adjustment of the CSF is appropriate in light of the new information, the new CSF will be incorporated into the Phase 2 human health risk assessment. If USEPA establishes separate CSF values for distinct Aroclor mixtures or to account for degree of chlorination, this approach will be adopted to determine cancer risks from PCB exposures.

6.1.2.2 Non-Cancer Toxicity

The Phase 1 preliminary human health risk assessment evaluated potential risks from non-cancer toxicities of PCBs by using an interim Reference Dose (RfD) value that had been reviewed by USEPA, but was not promulgated. The Environmental Criteria Assessment Office (ECAO) of USEPA is currently evaluating available non-cancer toxicity data on PCBs to determine whether the data support promulgation of an RfD. This evaluation should be completed prior to the completion of the Phase 2 human health risk assessment. The new RfD or non-cancer toxicity endpoints will be incorporated into the assessment, pending ECAO release.

6.2 Study Area C

A complete human health risk assessment for the Lower Hudson (Study Areas C and D), incorporating identification of all PCB sources and exposure pathways, is complicated by the large geographic area and sources of PCBs other than the Upper Hudson (Study Area B) that contribute to PCB levels found in sediment and fish. Efforts will be limited to Area C where the effects of sources other than those from the Upper Hudson are less extensive than in Area D.

Efforts in Study Area C during Phase 2 will be directed to characterizing better the relative magnitude of the Upper Hudson PCB source compared to other sources in the Lower Hudson. Potential exposures and concomitant risks, as a result of river-borne PCBs in this section of the river will be evaluated with a focus on fish and water consumption (Poughkeepsie water supply).

7. BASELINE ECOLOGICAL RISK ASSESSMENT

The Phase 2 baseline ecological risk assessment will follow the most recent USEPA Superfund guidance for ecological risk assessment (USEPA 1989[1], 1991[2], 1992a[3] 1992b[4], 1992c[5]). Phase 2 efforts will build upon the Phase 1 interim assessment and quantify, where possible, ecological risks and impacts associated with the presence of PCBs in the Hudson River.

An ecological assessment will be performed for the Hudson River using information from selected sites sampled during the investigation. This range includes fresh, brackish, and salt water habitats. The highest concentrations of PCBs have been detected in Study Area B, and therefore much of the focus of the ecological risk assessment will be directed there. In addition, the scope of potential remedial activities for this Reassessment is limited to the PCB-contaminated sediments in Study Area B. Selected sites in Study Areas C and D will be evaluated owing to the presence of many significant fish and wildlife habitats in these regions. Although PCB concentrations generally decrease along the Hudson, many unique natural areas (important habitats for sensitive species) occur in the Lower Hudson, and therefore potential ecological impacts will be evaluated to determine whether sensitive species may suffer adverse effects from PCB exposure. Study Area A is considered to be a background area, and data collected there will be used to evaluate baseline conditions upstream of Study Area B.

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[1] USEPA. 1989. "Risk Assessment Guidance for Superfund. Volume II: Environmental Evaluation Manual." Office of Emergency and Remedial Response, USEPA: Washington, DC. Interim Final, March 1989.

[2] USEPA. 1991. Ecological assessment of Superfund sites: an overview. ECO Update 1(2). Office of Solid Waste and Emergency Response, USEPA: Washington, DC.

[3]USEPA. 1992a. Report on the Ecological Risk Assessment Guidelines Strategic Planning Workshop. USEPA, Risk Assessment Forum, Washington, DC. EPA/630/R-92/002.

[4]USEPA. 1992b. Peer Review Workshop Report on a Framework for Ecological Risk Assessment. USEPA, Risk Assessment Forum, Washington, DC. EPA/625/391/022.

[5]USEPA. 1992c. Framework for Ecological Risk Assessment. USEPA, Risk Assessment Forum, Washington, DC. EPA 630/R-92/001.

The principal tasks of the Phase 2 ecological risk assessment are summarized below.

- Problem Formulation. Specific objectives and the scope of the ecological assessment will be described and potential exposure pathways, ecological receptors and endpoints of concern will be identified.

- Site Description and Characterization. An overview of the site will be provided and site characteristics relative to potential exposure pathways will be discussed.

- Characterization of Stress. Exposure pathways, the routes by which ecological receptors may be exposed to PCBs, will be examined and exposure point concentrations will be quantified. Sediment sampling will play a major role in quantifying exposure point concentrations.

- Characterization of Ecological Effects. Ecological assessment endpoints will be defined and toxicity data describing the measured effects of PCBs will be reviewed and evaluated. The Phase 1 interim assessment examined toxicity endpoints such as reproduction, growth, survival, etc. and reviewed literature describing adverse effects on selected species. The toxicity information gathered in Phase 1 will be expanded and updated.

- Risk Characterization. This component requires combining the exposure and toxicity data and quantifying, where possible, risks to selected ecological receptors. This includes a evaluation of uncertainties, which involves assessing the uncertainties of contaminant concentrations, toxicity data, exposure assumptions, and discusses limitations of the methods utilized to assess ecological risk.

The ecological risk assessment will rely upon a weight-of-evidence approach, supported by literature reviews, sediment sampling, a benthic invertebrate study, and an evaluation of chemical analytical data relative to environmental benchmarks. The ecological risk assessment process is dynamic and incorporates a multidirectional flow of information among its five components. For example, the problem formulation, characterization of stress and characterization of ecological effects all share common elements, such as receptors. The entire ecological assessment process set forth by the USEPA recognizes the necessity of evaluating many factors in order to interpret and characterize ecological risk.

7.1 Problem Formulation

The problem formulation will provide the foundation for proceeding with the subsequent portions of the ecological risk assessment. It describes the specific objectives, the scope of the ecological assessment and the rationale for the study site. It will identify potential exposure pathways, ecological receptors, endpoints of concern, and known ecological effects.

Potential exposure pathways (*i.e.*, links between the sources of contamination and the receptors exposed) will be identified by considering the source locations, the media through which contaminants may be transported, the potential for bioaccumulation and characteristics of the receptors.

A list of potential ecological receptors will be developed and will reflect the input from agencies regarding "species of concern". The list will include those species which are likely to occur at the site or (in the absence of toxicological data on such species) are phylogenetically or trophically similar to species likely to occur. Consideration will be given to the inclusion of species or groups that represent different trophic levels, a variety of feeding types, and several habitats (aquatic, wetland, shoreline).

The identification of known ecological effects of PCBs will also be included in this component by investigating various databases and publications. Information will be obtained from USEPA's Ambient Water Quality Criteria (AWQC) documents and Aquatic Toxicity Information Retrieval (AQUIRE) in order to identify known effects of PCBs. Additional information such as fish or wildlife consumption advisories issued by the New York State Department of Health (DOH) will augment the above information.

7.2 Site Description and Characterization

This task will provide a brief background and overview of the site and update and expand the information contained in the Phase 1 Report. It will describe site characteristics relative to ecological components (receptors) and review physical and chemical conditions including PCB concentrations detected in sediment, water, and biotic samples. Aquatic and terrestrial habitats will be examined at sites selected for evaluation. Potential sites include the four Hudson River Estuarine Sanctuaries and areas considered by NYSDEC, USFWS, DOI and NOAA to be "unique, unusual, or necessary for continued propagation of key species" (USEPA, 1989).

The site characterization will build upon the receptors identified in the problem formulation component. An update of the literature review initiated during Phase 1 and data gathered from various agencies will provide information on the species expected to occur at various locations in the Hudson River. The primary receptors of concern in this assessment are expected to be resident and migratory fish species. Fish occupy relatively high trophic positions, and consequently are likely to accumulate high levels of PCBs, if present. Appropriate species of fish will be selected to quantitatively determine potential PCB body burdens. Additional receptors that may be evaluated qualitatively include benthic invertebrates, fish species, shoreline birds and mammals and sensitive species of concern.

7.3 Characterization of Stress

The characterization of stress component will further define receptors, exposure pathways, and estimate exposure point concentrations. The results of the site characterization and problem formulation will guide this effort.

PCBs are considered to be the prime stressor of concern in this Reassessment. Therefore, the characterization of stress is limited to PCBs. Concentrations of contaminant levels in affected media will be used to estimate

PCB concentrations (body burdens) of exposed organisms. Sediment, water column, fish and invertebrate PCB data available from Phase 1 and proposed Phase 2 sediment sampling will be used to estimate general contaminant levels.

The characterization will include information on feeding habits, life histories, habitat preferences, trophic status, migratory habits, reproductive strategies and other attributes which could influence their exposure or sensitivity to contaminants. USEPA guidance indicates that the ecological risk assessment must focus on a limited number of receptors in order to develop a "reasonable and practical evaluation" (USEPA, 1991). Characterization of receptors for the site will be derived from literature reviews, reviews of existing studies and will be supplemented by the results of the proposed sediment sampling and benthic surveys.

Estimates of exposure point concentrations will utilize both measured data and fate and transport models (see Section 5). A sediment sampling program at fifteen sites along the Hudson River is proposed in order to obtain representative exposure concentrations at a range of habitats and locations (See Figures 2.5 and 2.11). A more detailed description of the sediment sampling program is presented in the Phase 2 Sampling Plan (See Appendix A).

7.4 Characterization of Ecological Effects

This section will develop information on the toxicity of PCBs to ecological receptors utilizing literature reviews and previous studies. It will select levels at which adverse effects on selected receptors are observed. This section principally depends on evaluating previous toxicity studies, owing to the difficulties of obtaining site- and species-specific data.

As recommended in current USEPA guidance (1992b), a field effort will be included as part of the ecological effects component. A benthic invertebrate community assessment will be conducted at two test sites of known PCB concentrations and one reference area in the Upper Hudson River. This study will examine community diversity, species abundance and potential effects of PCBs on the benthic community. Potential nonchemical stressors, such as temperature and dissolved oxygen, will also be measured. This survey will provide an assessment of the current impacts of PCBs on benthic invertebrate communities and assist in the evaluation of potential impacts of various remedial alternatives on the biota. A detailed description of the ecological survey is presented in the Phase 2 Sampling Plan (See Appendix A).

7.5 Risk Characterization

This component will compare and interpret the results of the characterization of stress component to the toxicity assessment. A variety of techniques will be used to present both qualitative or quantitative risk characterizations. This section will also discuss the uncertainties present in all components of the risk assessment and evaluate the ecological significance of the results.

A "weight-of-evidence" approach will be used in characterizing ecological effects , combining information generated from literature reviews, site-specific field sampling, and toxicity benchmarks in order to evaluate ecological risks.

A Toxicity Quotient (TQ) or, if data are available, an Analysis of Extrapolation Error (AEE), will be calculated for receptor species. The TQ method involves comparing an exposure point concentration to a benchmark, such as a toxicity endpoint. Values of TQ exceeding one are considered to indicate the potential for adverse effects. This method assumes that the toxicity benchmark adequately reflects the assessment endpoint. This assumption is most reliable when toxicity tests have been performed for site-specific species or when scientific literature values closely reflect site conditions and species. The AEE method calculates the probability that an exposure point concentration will exceed the toxicity endpoint rather than comparing them arithmetically as in the TQ (Barnthouse *et al.*, 1986)[6].

Uncertainty analyses of the exposure point concentrations, toxicity endpoints, and exposure pathways will be performed. Quantification of uncertainty is directly incorporated into the AEE[3], but is not directly addressed in the TQ.

The ecological significance of the observed or predicted effects will include a summary of the associated ecological risks and uncertainties within the context of a "weight-of-evidence" approach. This final phase of the risk assessment will offer professional interpretations and judgments concerning the magnitude of the overall ecological effects of PCBs at selected areas within the Hudson River.

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[6] Barnthouse, L.W., G. W. Suter II, S. M. Bartell, J. J. Beauchamp, R. H. Gardner, E. Linder, R. V. O'Neil and A. E. Rosen. 1986. "User's Manual for Ecological Risk Assessment." Oak Ridge Nat. Lab., Oak Ridge, TN, Env. Sci. Div. Public No. 2679.

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8. FEASIBILITY STUDY ANALYSES

The Phase 1 Report presented general response actions and potential clean-up technologies and process options for PCB-contaminated sediments in Study Area B. Engineering analyses will be performed in Phase 2 for utilization in the Phase 3 Feasibility Study.

8.1 Sediment Volumes and Areas

During Phase 2 the areas and volume of sediments within Study Area B subject to possible remedial action will be identified. Geophysical-survey and confirmatory sampling data from Phase 2 will be used to identify likely depositional areas within the various reaches of the river and will, in turn, enable computation of the contaminated sediment volume. Together with the historical and recent or planned PCB analyses of the sediments, identification of approximate areas of sediment subject to possible treatment, *i.e.* sediment with PCBs exceeding preliminary remedial-action criteria, will be made. The volume of sediment requiring treatment will also be analyzed in terms of PCB concentrations and current and future availability to the water column and biota. A map of potential remediation areas and sediment volumes will be prepared to aid in the evaluation of remedial alternatives.

8.2 Technology and Process Option Screening

During Phase 1, several established and innovative technologies within several response action categories were identified. These and potentially other technologies will be examined for their implementability. Those technologies that are infeasible to implement will be eliminated from further evaluation.

The criterion for elimination of a particular technology or process option during Phase 2 will be technical feasibility. Technologies or process options will be determined to be technically infeasible based on study area-specific factors. Conditions, such as a sediment matrix being incompatible with a technology or process, restricted access of the process equipment to the possible remediation areas, and other such factors will be grounds to evaluate technically infeasible processes. All technologies or processes that are removed from further consideration will be documented in the Phase 2 Report.

8.3 Identification and Evaluation of Technology Process Options

Those technologies and processes carried forward for more detailed consideration will be evaluated based on three criteria:

- effectiveness;
- implementability; and
- relative cost.

This screening step will evaluate each process option within the same technology type to determine which are most effective. The process option determined to be most effective will be carried forward in the screening evaluation for further development. Typically, process effectiveness depends on such factors as: 1) ability to handle the range of sediment volumes that could require remediation; 2) the ability to meet a range of remediation goals; 3) potential impacts to human health or the environment during construction and implementation; and 4) whether the process or technology is proven and reliable for site-specific contaminants and conditions.

Implementability is evaluated based on both the technical and administrative ability to implement a technology process. Technologies that are technically infeasible would not be considered implementable, so this screening step typically focuses on administrative factors. Administrative considerations include any permits, availability of treatment or storage and disposal services within the vicinity and the availability of technology vendors.

Relative capital and operation and maintenance (O&M) costs, rather than detailed estimates, are used for this evaluation. An evaluation is made of high, moderate, and low cost process technologies at this stage.

8.4 Treatability Study Literature Assessment

During Phase 1, numerous technologies were evaluated to assess their suitability for remediating the Upper Hudson's contaminated sediments. Technologies considered during Phase 1 included those associated with response actions not requiring sediment removal as well as technologies that would be components of actions involving sediment removal and treatment. Part of the program to be accomplished during Phase 2 will be to evaluate experiences at other Superfund sites where contaminated sediments are either being remediated or are about to undergo remediation. In addition, considerable developmental activity has been occurring within the private sector and by federal agencies on systems and technologies that treat contaminated soils; these developments were reviewed during Phase 1 and that review will be updated during Phase 2. Finally, several comments were received on the Phase 1 Report related to treatment technologies and these also will be further evaluated.

8.4.1 In-Situ Remediation

Technologies in this category include engineered approaches to stabilize or cap sediments so that sediment-bound contaminants are not scoured and released to the water column. The geophysical program described earlier in this work plan will generate significant new data describing the distribution and physical characteristics of contaminated sediments. That information will provide the basis for further evaluation of *in-situ* engineered solutions; no specific treatability studies are envisioned with regard to *in-situ* remedial response actions, such as capping and/or stabilization of sediments.

Alternatively, *in-situ* treatment of contaminants may be accomplished through bioremediation whereby natural biodegradation processes are enhanced by manipulation of environmental conditions conducive to microbial activity. Bioremediation was discussed in the Phase 1 Report and it was reported that, as of that time, no full scale *in-situ* programs had been conducted using those techniques. It is expected that the General Electric Hudson River Research Study (HRRS) will provide the most relevant data on the viability of *in-situ* treatment.

Consequently, its results will be reflected in the Phase 2 Report and the final Feasibility Study. In addition, analysis of historic and recent sediment cores will be useful in assessing rates of natural biodegradation. No further treatability studies directed at bioremediation are planned during Phase 2.

8.5 Sediment-Disturbance Impact Assessment

Before any of the physical/chemical/thermal treatment technologies can be applied, it will be necessary to remove or disturb the contaminated sediments. Dredging or actions within the river for a bioremediation program may disrupt the river's ecosystem by both resuspension of bottom materials and disturbance or removal of aquatic habitat, wetlands, etc. Response actions involving dredging of sediments have been studied for the Hudson River and widely applied at other Superfund sites. The ramifications of the processes will be evaluated in Phase 2 and will continue to be evaluated in Phase 3. Data for the assessment will be obtained from the geophysical program. In particular, the contaminant/sediment distribution maps generated by that program are expected to provide a relatively complete characterization of the material that would have to be removed to achieve various remedial objectives.

Among the outputs of the geophysical program will be maps of sediment-distribution patterns illustrating various classes of bottom materials. Using both the maps and laboratory data, an engineering assessment will be performed of sediment-disturbance impacts. Factors that will be considered include presence of obstructions such as boulders and cobbles, the continuity of contaminated sediment formations composed of removable materials, the extent to which contaminants adhere to homogeneous formations of suspendable sandy/silty materials, and the problem of access for equipment. Estimates of sediment resuspension particularly during dredging will be made using published data for various dredging systems, assuming they would operate on the same type of materials that would be removed from the Hudson as part of a remedial action.

APPENDIX A

PHASE 2 SAMPLING PLAN

APPENDIX A
PHASE 2 SAMPLING PLAN

A.1 Introduction

In accordance with the Scope of Work for the Reassessment, a Phase 2 investigation will be performed to characterize and analyze further site conditions. The Phase 2 program is based on the review and synthesis of the information collected and reported in the Phase 1 Report entitled "Interim Characterization and Evaluation" (August 1991) and on the input of the Hudson River Oversight Committee and the participants in the Community Interaction Plan. The various data needs and the major data-collection tasks have been discussed in the Phase 2 Work Plan to which this sampling plan is attached.

The Phase 2 sampling effort consists of two parts, Phase 2A, which began in December 1991 and Phase 2B, which will begin upon approval of the Phase 2 Work Plan. For each phase, a Sampling and Analysis Plan/Quality Assurance Project Plan is required and is reviewed by USEPA-Region II. The Phase 2A SAP/QAPP has already been approved by USEPA; the Phase 2B SAP/QAPP, describing in detail the protocols for the sampling program presented here, will be submitted upon approval of this document.

The description of the Phase 2A sampling tasks was the subject of the Phase 2A Sampling Plan (September 1991). Because the scope of some tasks has been subsequently adjusted and refined, these changes are described here. This Sampling Plan also describes the Phase 2B sampling tasks. A summary of the work to be performed for all tasks in Phases 2A and 2B is presented in Tables A.1.1 and A.1.2.

A.2 Phase 2A Sampling

A.2.1 Establishment of Control Points for Precision Navigation

The success of the Phase 2 program is dependent upon precise navigation in the Hudson River. The ability to compare results among the various sampling tasks is contingent upon knowing precisely all sampling locations in the Hudson. For this reason, a system of shoreline points will be established to enable precision navigation, nominally accurate to one meter. To the extent that shoreline control points still exist from previous investigations, these will be utilized. It is anticipated that for the geophysical survey of Upper Hudson, between the Bakers Falls Pool and the Lock 4 Dam about 20 shoreline points will need to be established, either from existing points from prior investigations, or from appropriate surveying techniques, with about one control point every one and one-half miles.

For the high-resolution coring locations that do not fall within the geophysical survey area, additional shoreline control points will need to be established. Because of the distance between the individual coring locations, one control point will be established for each coring location. For the Lower Hudson, 12 control points will be required. For the Upper Hudson, four to five additional control points will be required.

All shoreline points will be referenced to the N.Y.S. Plane Coordinate System, North American Datum (NAD27), the historic reference system for most previous surveys. Vertical data will be referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929).

A.2.2 Geophysical Surveys from the Bakers Falls Pool to the Lock 4 Dam

This task, using geophysical measurement techniques, will involve the study of river bottom sediment textures, bathymetry, topography and sediment thickness in the most PCB-laden region of the Hudson. These data will be used to construct a computer-generated map of the river bottom conditions, effectively providing an aerial photograph type perspective of the river-bottom conditions. The information will be calibrated and confirmed by sample collection as described in Section A.2.3. The many important potential uses of this information are to: provide a basis for the selection of additional coring locations in Phase 2B, identify areas of river sediment susceptible to scour, and estimate volumes of mobile sediments, among others.

The geophysical surveys proposed here include side-scan sonar, bathymetry and single frequency sub-bottom profiling. Plate A.1 is a map of the Upper Hudson, showing the areas to be surveyed as a part of this effort. About three quarters of the survey will cover areas believed to contain PCB hot spots or remnant deposits. The remaining survey effort, more exploratory in nature, will examine areas that would appear to represent depositional conditions similar to those found at the hot spots, but not delineated as hot spot areas. The data collection effort began in December 1991, was paused during the winter months and was completed in June, 1992. Currently, the data are undergoing analysis in order to produce the final maps and interpretations. Following are brief descriptions of the individual sub-tasks to be completed as a part of the geophysical survey effort.

A.2.2.1 Bakers Falls Pool to River Mile 182

1. A side-scan sonar survey of all accessible areas in this region of the river will be conducted using 100 and 500 kHz sonar. Data on the river bottom will be collected at relatively high-resolution, covering a swath roughly 75 m across. The swath width may be adjusted in the field to allow for variations in the width of the river at the discretion of the field scientists. The survey lines will generally run parallel to the direction of river flow. Each survey line will be roughly one to two miles long, depending on navigational constraints. Each of these lines will be separated by about 40 m, yielding bottom coverage for the river of about 150 percent. This method will ensure that the

edges of each swath overlap and that the bottom of the river will be completely surveyed. Figure A.2.1 is a schematic showing the approximate layout of the survey grid. The survey of the Thompson Island Pool will cover the entire navigable area between the former dam site at Fort Edward and the Thompson Island Dam. This survey will cover 20 of the 40 previously defined hot spots. The survey of the Bakers Falls Pool will cover the area behind the Bakers Falls Dam to roughly one quarter-mile upstream. The survey between the Thompson Island Dam and River Mile 182 will cover all accessible areas in this region and an additional 15 of the 40 previously defined hot spots. The survey coverage of the river bottom in the last region may be somewhat limited because of the unknown and potentially shallow water depths in some areas of this region. In addition to the areas described above, the survey may also cover depending on water depth or other limiting conditions, the river area between Bakers Falls and the former dam site at Fort Edward. This last survey area represents an addition to the areas originally listed in the Phase 2A Sampling Plan.

- Navigation will be nominally accurate to 1 m and referenced to the N.Y.S. Plane Coordinate System, North American Datum (NAD27).
- Vertical data will be referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929).
- Data from the bathymetry and sub-bottom profiling equipment will be collected concurrently with the side-scan sonar data, except where limited water depths require the use of a smaller boat. In these cases, data will be collected on separate survey runs.

2. A bathymetric survey will be conducted for the areas defined for the side-scan sonar survey. The survey will consist of survey lines about 150 m apart perpendicular to the direction

of flow. These data will be used in conjunction with the bathymetry data obtained during the side-scan-sonar survey, effectively generating a wire net of coverage of the river bottom.

- Navigational and vertical data will be of the same quality as that for the side-scan sonar survey.

3. A single frequency sub-bottom profile survey will be conducted for all surveyed areas.

   - Navigational and vertical data will be of the same quality as that for the side-scan sonar survey.
   - Data will be collected concurrently with the bathymetry and side-scan sonar surveys except as noted above.

A.2.2.2 Upper Hudson River from River Mile 182 to the Lock 4 Dam

1. This area was originally proposed in the Phase 2A Sampling Plan. However, the addition of the area between the Baker Falls dam and the former dam site at Fort Edward precludes the coverage of this area. This change in the geophysical survey plan will yield essentially continuous coverage from the Bakers Falls pool to RM 182.

A.2.3 Confirmatory Sampling for Calibration of Geophysical Surveys

To ensure proper interpretation of the geophysical data to be collected, confirmatory sediment samples will be collected following the completion of the geophysical surveys. Sediments from an anticipated 200 locations will be collected by hand coring or by grab sampling at the geophysical survey areas. The confirmatory sampling locations will be selected, based on the geophysical results, and placed using the same navigational controls and precision as that for the geophysical surveys so that the two sets of data can be directly correlated and mapped. All samples will be visually examined and classified. Based on the field classifications, a large fraction of the sediment samples will be analyzed for grain-size distribution and total organic carbon content. Additional activities are noted below.

- Sediment samples will be visually examined for sediment texture and stratification for calibration of both the side-scan sonar and the sub-bottom profiling survey data.
- Cores will be photographed to record visible sedimentological structures.
- Some cores will be X-rayed to detect *in-situ* density variations before extrusion of the core.
- Core samples will be extruded in the field for visual and manual examination.
- Surficial sediments (0 to 2 inches) will be analyzed for grain-size distribution, for total carbon/total nitrogen content and for total inorganic carbon content. (Total organic carbon content is obtained as the difference between the total carbon and total inorganic carbon analyses.)

A.2.4 High-Resolution Coring

This task will involve the collection of sediment cores from locations in Study Areas A, B, C and D (see Section 2 for definitions). These cores will be analyzed for radionuclides on a two to four cm layer basis in order to establish the year of deposition of a given sediment layer. These same layers will be analyzed for PCB concentration on a congener-specific basis as well as other parameters. A total of 25 core locations have been chosen.

The Phase 2A effort will begin with core collection from Study Areas C and D. This effort, as outlined below, contains two more core locations than the original Phase 2A Sampling Plan, In addition, several of the coring locations have been refined or moved as follows:

1. Cores will be collected from twelve locations in Study Areas C and D. Their locations are shown in Figure A.2.2.

- Cores will be collected from the following, previously sampled approximate locations: RM -1.7, -1.65, 3, 44, 53.8, 60, 88.6, 143.4 and Newtown Creek. The location at 91.8 has been dropped since it would most likely duplicate the data at RM 88.6.

- Cores will be collected from approximate RM locations 24, 100 and 123 to expand the core database. The locations at 100 and 123 are essentially refinements of the core locations originally planned for RM 115 and 130. The RM 24 location is intended to provide additional data on the transitional portion of the estuary, between the harbor and the freshwater regimes.

2. Cores will be collected from thirteen locations in Study Areas A and B. Their locations are shown in Figure A.2.3.

- Cores will be collected from the following, previously sampled approximate locations: RM 189, 190, 191, and 203. A core will be collected at RM 169 in place of the original coring location at RM 168 based on recent field data showing this to be a better coring location.

- Cores will be collected from the following new locations to expand the core database: RM 158, 166, 184 and 197. The core locations at RM 158 and 184 represents additions to the Phase 2A effort. The core at RM 158 will be used in conjunction with the extensive fish flesh PCB data collected from that general location by the NYSDEC. The coring location at RM 195 has been dropped based on the initial geophysical survey results which indicate the general absence of fine-grained sediments in this area. Similarly, the core scheduled for RM 197 may be dropped or assigned to another location based on the initial results of the geophysical survey which suggest the absence of fine-grained sediments in this area as well.

- Cores will be collected from the Batten Kill, the Hoosic River and the Mohawk Rivers (two cores) near their confluence with the Upper Hudson to evaluate the relative historical contribution of PCBs from each river. The Batten Kill represents an addition to the Phase 2A program.

3. All cores will be collected using a hand-coring technique whenever possible.

- Cores will be transported in a vertical position as collected to a field laboratory location or to the Lamont-Doherty Geological Observatory for subsequent sample preparation.

- Cores will be sectioned into approximately 2 cm layers for the uppermost eight centimeters. The remainder of the core will be sectioned into 4 cm layers. These sections will be subsampled by removing representative portions of each section for the various analysis whenever possible. When a core section cannot be subsampled in this fashion, the core section will be homogenized while wet and subsequently subsampled. Portions will be reserved for PCB, total organic nitrogen, and grain-size distribution analyses. The remaining portion of each layer will be dried under a PCB-free atmosphere and analyzed for radionuclides (Cs-137, Be-7 and Co-60), total carbon/total nitrogen, and total inorganic carbon concentrations. Subsequently, this portion of the sample (typically about half of a given layer) will be archived in a sealed aluminum can.

- To the extent that a core does not yield an interpretable radionuclide chronology, one additional core may be collected from the original location to replace the first core. If the second attempt does not yield an interpretable core chronology, the location will be abandoned.

A.2.5 Water-Column Transect Sampling

Water-column sampling tasks are designed to determine current waterborne PCB levels and congener mixtures in both dissolved and suspended matter fractions in the river. Data obtained from this effort will be used to investigate the approximate location of the current PCB sources with emphasis on those in Study Area B and the effect, if any, of recent remedial efforts on the water-column levels. The effort is also designed to examine the correlation of PCB loads with water flow. Finally, the results will be used to examine the partitioning of PCB congeners between the dissolved and suspended matter phases. This task is expected to extend over several months, with sampling events separated by four to six weeks. The task efforts are described below. The water-column transects will be performed in Study Areas A, B, and C. The stations in Study Area C represent additions to the original Phase 2A program.

A.2.5.1 Monitoring from Glens Falls to Waterford

1. Water monitoring stations will be sampled on approximately seven separate occasions at 9 locations from Glens Falls to Waterford plus a location on the Mohawk River. The locations are shown in Figure A.2.4.

   - Seven locations (constituting one transect in the direction of flow) will be sampled along the main river axis in order to delimit the area of the Upper Hudson where the current base load originates, as follows: Glens Falls, Bakers Falls, upper remnant deposit pool, Rogers Island at Fort Edward, Thompson Island Dam, Schuylerville, and Waterford. Based on an evaluation of recent data, the stations at Stillwater and the lower remnant deposit pool have been dropped from the Phase 2A program. Additional samples will be obtained from the Hoosic and Mohawk Rivers just upstream of their confluences with the Upper Hudson and on the Champlain Canal just above Lock 7. These stations are additions to the Phase 2A Sampling Plan.

   - A sample will be collected during each transect sampling round from an off-site location to serve as a sampling blank.

   - At each station, data will be collected on water-column conductivity, temperature, dissolved oxygen, and pH.

   - Water will be collected at each station for PCB analysis (in a 20-liter aliquot), dissolved organic carbon analysis, total suspended matter analysis, total organic carbon analysis on suspended matter, and chlorophyll-a analysis. A small subset of samples will be analyzed for PCBs using one liter samples. The total organic carbon analysis on suspended matter represents an addition to the Phase 2A Sampling Plan.

   - Each 20-liter sample collected for PCB analysis at each station will be separated by filtration into a dissolved fraction and a particulate fraction. The samples will be filtered in the field as soon as possible after collection but no more than four hours after collection. Each fraction will be analyzed on a congener-specific basis.

- Four separate sampling events along the transect will attempt to coincide with low flow (less than 8,000 cfs at Fort Edward) to typify current low flow PCB transport conditions.

- Three separate sampling events along the transect will attempt to coincide with higher flow events to examine current high flow PCB transport conditions. When possible, these events will coincide with sustained high flow for at least one to two days prior to sampling.

- Samples will be collected from north to south (upstream to downstream) while monitoring the flow at the USGS hydrographic stations in the Upper Hudson so as to generally follow the same parcel of water through the Upper Hudson River. Additional data on the time between sampling stations will be obtained from the time-of-travel study (see Section A.3.8).

- During one low-flow and one high-flow event, two 20-liter samples will be collected at each station along the transects, one to be field-filtered, and one to be laboratory-filtered. The laboratory sample will be held a minimum of four days before filtering to ensure that an effective equilibrium between dissolved and particulate phases is reached. These samples will provide the basis for the examination of equilibrium between suspended matter and dissolved phase PCBs.

- When feasible, samples will be collected at several points across the river and mixed together to account for cross-section heterogeneity in the PCB levels. At locations where this is not possible (*e.g.*, the station at the Thompson Island Dam), a sample will be collected by the most representative means possible.

A.2.5.2 Monitoring in the Lower Hudson

1. Water monitoring stations will be sampled on approximately three separate occasions at three locations from Albany to the Kingston Area. The monitoring stations will be at approximately RM 142, 123 and 88 as shown in Figure A.2.5.

These sampling events will be held just subsequent to the water-column transects in the Upper Hudson so as to maximize the comparability between the data sets.

- Two events will coincide with low-flow transects in the Upper Hudson. The third will coincide with a high-flow event.
- If possible, samples will be collected from a single point in the center of the channel so as to represent the mean conditions of the water column at the sampling location.
- Where or when such sampling is not practical, shoreline sampling points will be sought out where local influences should be minimal. In this manner the sample should again be representative of the mean water-column conditions. (The homogeneity of the water column in the Lower Hudson has been well demonstrated by the U.S.G.S. which has run several cross sectional studies of water-column properties in the Poughkeepsie area[1].)
- Samples will be treated in a manner identical to that of those of the Upper Hudson. However, no samples will be collected for the equilibrium study.

A.3 Phase 2B Sampling

A.3.1 Flow-Averaged Water-Column Sampling

As discussed in the Phase 2 Work Plan, the purpose of this task is to define better the net PCB loads to the Upper Hudson that enter the river as it travels through the remnant deposit area above Fort Edward and to the Thompson Island Dam. This task will involve regular collection of water-column samples at four locations in the Upper Hudson, specifically Glens Falls, Fenimore Bridge at Bakers Falls, Route 197 Bridge at Fort Edward and the Thompson Island Dam, at a frequency of one every other day (see Figure A.2.4). The river sections under

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[1]U.S.G.S. (1973). Water Resources Data - New York Volume 1, Eastern New York, excluding Long Island. Annual Report

study represent regions of known or suspected historic PCB input to the river. Mean differences in PCB levels between sampling stations represent net changes in PCB load resulting from a PCB source in the intervening river section. Actual loadings will be calculated using USGS flow data and the measured PCB values.

The water-column samples will be collected so as to generate a flow-averaged sample. Prior to the collection of any sample in this task, a scale of sample volume to river discharge will be established. This scale will be used to determine the volume of sample to be collected at each station on any sampling day. Prior to the collection of a day's samples, the USGS monitoring stations will be queried electronically to obtain the day's flow conditions. Based on these flow conditions, an appropriate volume of sample will be obtained from each station. At the end of each sampling period the individual samples will be combined, producing a single flow-averaged sample for each station. In this manner, the sample will have sufficient volume to permit the measurement of PCB congeners at the required detection limits.

This technique avoids the inherent day-to-day variability in water-column levels, which has been noted in the historical data, by creating a flow-averaged sample for each location. It also avoids the large analytical costs involved in establishing a sufficiently large database of daily or weekly samples to permit a statistically valid analysis of the mean PCB loads.

The above technique has one disadvantage. It requires that samples be held beyond the USEPA allowed holding times for PCB analyses. For this reason, the data quality objective for these samples will be less than the Data Quality Level (DQL) level 5 applied to most other Reassessment analyses.

The sample analysis will include the determination of the following:

- Dissolved phase PCBs on a congener-specific basis;
- Suspended matter PCBs on a congener-specific basis;
- Total suspended solids; and
- Dissolved organic carbon.

Dissolved oxygen, pH, temperature and conductivity will be measured at each location at the time of sample collection. Samples will be collected for three one-month intervals to generate twelve sample analyses for each of the parameters listed above, excluding duplicates and quality control samples.

A.3.2 Analysis of Archived Water-Column Samples on a Congener-Specific Basis

During the period 1977 to 1986, Hudson River water-column samples were collected by the scientists of the Lamont-Doherty Geological Observatory. These samples were extracted and analyzed for PCBs near the time of collection, using packed-column gas chromatography. The extracts of these samples have been stored by the Observatory and can be reanalyzed on a congener-specific basis. The task will involve the reanalysis of about 100 water-column sample extracts, representing both dissolved phase and suspended matter PCB fractions. The integrity of the archived extracts will be confirmed by comparing the original analytical results, which were obtained by a packed-column gas chromatograph technique, with a comparable analysis in Phase 2. The scientists at the Observatory have reproduced PCB analyses of previously analyzed, archived samples, demonstrating the viability of this procedure.

A.3.3 Low-Resolution Coring of Upper Hudson Sediments

As described in Phase 2 Work Plan, the specific implementation of this task is contingent upon the results of the geophysical investigation in Phase 2A. A detailed description of the number of samples and the general low-resolution coring locations will be released when the analysis of the geophysical data and the existing sediment data are complete.

As part of the low-resolution coring efforts, cores are anticipated to be collected from the throughout the geophysical survey areas, *i.e.*, the Bakers Falls Pool, the river section between Bakers Falls and the former dam site at Fort Edward (particularly at Remnant Deposit 1), the Thompson Island Pool, and the reach above the dam at Ft. Miller and the reach above Lock 5 (see Figure

A.3.1). Additionally, samples may be collected at points farther downstream where biological monitoring stations have existed historically.

As discussed in Section 3 of the Work Plan, low-resolution coring will be applied to estimate river sediment levels for a number of reasons. In areas previously studied, low-resolution coring will be applied to assess the validity of the historic data under current conditions. In other instances, low-resolution coring will be used to estimate sediment PCB mass in areas not extensively studied but potentially important, based on the results of the geophysical surveys. Low-resolution coring may also be used to classify sediment PCB properties in sedimentological zones representing large areas of consistent geophysical properties so as to provide a means to extrapolate to unsampled areas. Lastly, low-resolution coring may be applied to important biological sampling areas where a correlation with current and historic fish levels may be examined. The ultimate goals of the low-resolution coring effort will be decided upon based on the on-going geophysical data analysis as well as the analysis of existing sediment data on PCBs.

In every application, however, the main intent of the low-resolution core collection is the estimation of the total PCB mass in the sediments of a given area, a distinctly different objective from the high-resolution core collection in Phase 2A, which is designed to collect information on current and historic water-column transport as recorded in the sediments. High-resolution core locations are separated by distances of miles, whereas the low-resolution core locations will be comparatively close together and clustered. In addition, for a high-resolution core to be useful, it must be obtained from a zone of high deposition and produce an interpretable radionuclide chronology with depth. A low-resolution core is not subject to these stringent criteria.

The collection of a low-resolution core follows the same techniques used for high-resolution core collection. Once collected, the low-resolution core is subdivided in a different manner from the high-resolution core. Instead of the relatively thin slices obtained from high-resolution cores (2-4 cm thick), low-resolution cores are subdivided into thick sections, approximately 13 cm (5 inches) thick. Low-resolution cores are typically expected to obtain 40 to 50 cm (15 to 20 inches) of sediment, yielding three to four samples per core. The minimum recovery for a low-resolution core is 20 cm (8 inches).

Each core section will be analyzed for the following parameters:

- PCB concentration on a congener-specific basis;
- Radionuclides Beryllium-7 (Be-7) and Cesium-137 (Cs-137);
- Total organic carbon;
- Total organic nitrogen;
- Grain-size distribution; and
- Reduction/oxidation potential (redox).

The redox potential will be a field measurement obtained during core extrusion. The data on total organic carbon and total organic nitrogen levels will be obtained by either direct measurement or by analysis of total carbon, total nitrogen, total inorganic carbon and total organic nitrogen, similar to the high-resolution core sections.

A simpler form of low-resolution coring will be applied to the estimation of PCB levels at the sites slated for an ecological field investigation. See the discussion on the ecological field investigation in Section A.3.6.

A.3.4 Sediment Critical Shear Stress Analysis

Sediments of the Thompson Island Pool and the Remnant Deposit area will be collected for critical shear stress analysis as part of the scourability assessment. The number of samples required for laboratory analysis will be determined based on an assessment of the sediment classes mapped by the geophysical survey and the confirmatory sampling. Large diameter cylindrical (4 to 6 in) or box-coring techniques will be used to collect sediment samples, because these techniques preserve the sediment structure, particularly the surface sediment conditions. An additional sample will be collected with each core sample for grain-size analysis.

The method for shear stress measurement is based on the work of Schünemann and Khül (1991)[2]. It involves the use of a stirring mechanism and a turbidity meter to determine sediment response to shear stress. Figure A.3-2 shows a schematic of the measurement system.

A.3.5 Assessment of In-Situ Degradation

The goal of this task is to determine an effective rate of *in-situ* degradation for PCBs in various regions of the Hudson. In the Phase 2A sampling work, 25 high-resolution cores will be collected from Study Areas A, B, C and D. Many of these coring locations have been studied and cored historically by the scientists of the Lamont-Doherty Geological Observatory (see Figures A.3.3 and A.3.4). The sediments from the historic cores and, in most cases, the sample extracts from these cores, still exist and can be re-analyzed on a congener-specific basis for direct comparison with the Phase 2A sediment core results.

This task will involve the reanalysis of sediment core layer extracts whose time of deposition is fairly well-known. Historic core extracts will only be re-analyzed to correspond with the successful Phase 2A high-resolution sediment cores, *i.e.*, a Phase 2A sediment core will have to yield an interpretable radionuclide deposition history and then have unqualified PCB analytical results before the corresponding historic core extracts are reanalyzed. In most instances, only four to five historic sediment extracts will be run for each coring location. For the Upper Hudson, the sediment layers corresponding to the following events will be reanalyzed, assuming they can be identified in each sediment core pair:

- 1954 appearance of Cesium-137;
- 1963 Cesium-137 maximum;
- Mid-1970s PCB maximum; and
- Time of the historic core collection.

---

[2]Shünemann M. and H. Khül, A device of erosion-measurements on naturally formed, muddy sediments: the EROMES System, GKSS 91Mw/19, GKSS Research Centre, Germany, 1991.

For the Lower Hudson, these same sediment layers will be analyzed plus the layer corresponding to:

- 1971 Cesium-137, Cobalt-60 maximum

The integrity of the stored sediment extracts will be confirmed by comparison of the reanalysis results with the packed column results originally obtained. The two sets of results should agree for total PCB concentration and the concentration of the individual homolog groups.

This task will involve up to 15 pairs of historic and Phase 2A high-resolution cores. It is likely that not all historic core locations will be successfully re-cored in Phase 2A, so that the actual number of core pairs will be lower. Based on five cores from the Upper Hudson and ten cores from the Lower Hudson, up to 70 sediment extracts will be re-analyzed. No other analytical work is required for this task. Like the reanalysis of water-column samples, the data-quality level for these results will be less than level 5.

A.3.6 Sediment Sampling for the Ecological Risk Assessment

The purpose of this task is to provide current, quantitative data on the concentrations of PCBs in sediment samples along the Upper and Lower Hudson. These data will be used in the exposure assessment component.

The field sampling program will consist of physical and biological sampling constituents. Sampling is proposed at fifteen (15) stations along the Hudson; two (2) background stations in Study Area A, four (4) stations in Study Area B, seven (7) stations in Study Area C, and two (2) stations in Study Area D (Figures A.3.5 and A.3.6). Table A.1.3 lists the approximate locations of these stations and justification for their selection.

Locations were selected on the basis of reflecting mainstream conditions, rather than local conditions. Areas below tributaries and local runoff do not reflect mainstream conditions, and were therefore not selected as proposed sampling stations. An on-site determination will be made to ensure that the selected stations are depositional areas, and that adequate amounts of fine-grain sizes and organic material are present to ensure detection of PCBs, if present. An effort will be made to integrate high-resolution core data with data obtained in ecological sediment sampling. NYSDEC fish sampling stations were also considered when selecting prospective sampling stations because of the possibility of linking sediment and fish data.

An initial field survey will be done prior to beginning work at proposed stations to ensure that each station is likely to fulfill sampling needs. The locations of the stations may be changed slightly based on the results of the initial survey, data taken during the high-and low-resolution sediment sampling programs, and recommendations by NYSDEC, NOAA or other agencies.

The proposed field work at each station consists of:

1) Five (5) sediment samples taken at each station to be analyzed for PCBs (congener level), total organic carbon (TOC), and grain size. Proposed sampling depth is 5 cm, which encompasses the major zone of infauna biological activity.

2) Temperature, dissolved oxygen, pH, and conductivity/salinity will be measured in the field. This information will assist in establishing site-specific characteristics of each habitat.

3) An overview of the habitat including an analysis of vegetation and habitat suitability for endangered and threatened species will be done. A general ecological evaluation of each station will be made based on field data and observations, and information obtained from various agencies and groups.

The sediment sampling program in the Upper and Lower Hudson will provide data for the exposure assessment component and will be used in conjunction with the correlation analysis approach to estimate PCB levels in fish.

A.3.7 Benthic Invertebrate Community Survey

An ecological survey of benthic invertebrates will be done at three (3) stations in the Upper Hudson. This study will analyze a community diversity index, species abundance, and biomass at each station. These surveys will also assist in characterizing the potential impacts of remedial action, such as dredging, on the biotic community in the Upper Hudson. Baseline, maximum impact, and mid-range impact stations will be extensively sampled.

Seven (7) five cm deep cores will be taken at each station. Multiple samples will increase the power of the statistical tests and improve the reliability of the results. The collected samples will sent to a laboratory, weighed, sorted, counted, and identified to the species level. Biomass measurements by major taxa will be used to estimate the available standing stock in each area. Sampling is planned for the late fall/winter, when organisms tend to remain in the sediments, rather than in the vicinity of macrophytes.

Proposed sampling stations and their rationale are provided below.

Summary of Benthic Sampling Locations

Station Location	Justification for Selection
RM 210	Background (control) sampling stations; provides an estimate of baseline benthic community.
RM 189	Thompson Island Dam, highest detected levels of PCBs found here; serves as area of maximum impact.
RM 175	Stillwater Pool; depositional area downstream, estimates impacts of lower PCB concentrations.

Sediment samples will be taken concurrently at each station, in order to correlate sediment PCB concentrations with the macroinvertebrate communities.

A.3.8 Time-of-Travel Study

As discussed in the Work Plan, the water-column sampling in the Upper Hudson is intended to follow a single, relatively large parcel of water as it travels through the Upper Hudson. While estimates can be made of the travel time based on U.S.G.S. hydrologic records at the various flow-monitoring locations in the Upper Hudson, it is possible to measure the time-of-travel directly using a dye study.

Due to scheduling constraints and sampling difficulties, the water-column monitoring and the dye studies will not be performed concurrently. Initially, because of project schedule limitations, one- or two-water column transects will be performed prior to the completion of the dye study. The dye study itself will be used to estimate a set of travel times, based on flow conditions which will then be applied to the water-column transect station collection schedule.

The time-of-travel study will involve the following major components:

- The initial study begins with the recording of U.S.G.S. instantaneous flow measurements at the hydrologic monitoring stations in the Upper Hudson.
- A fluorescent dye is then released to the water column roughly 2 to 3 miles upstream of the first monitoring point.
- At each monitoring station downstream, a fluorimeter is used to monitor the first arrival of the dye and the time of its maximum concentration. These parameters can be used together to estimate the time-of-travel of the center of the parcel of water as well as the rate of longitudinal mixing beginning at the point of release.
- Ultimately, the flow and fluorimetry data will be used to calculate the time-of-travel for the flow conditions monitored.

TABLE A.1.1
SUMMARY OF PHASE 2A ANALYTICAL PROGRAM[14]

SEDIMENT PROGRAM

TASK	NUMBER OF LOCATIONS	NUMBER OF SAMPLES PER LOCATION	PCB CONGENER ANALYSIS	TOTAL CARBON AND NITROGEN ANALYSIS	TOTAL INORGANIC CARBON ANALYSIS[6]	GRAIN-SIZE DISTRIBUTION	RADIONUCLIDE ANALYSIS[5]	TOTAL ORGANIC NITROGEN ANALYSIS
Confirmatory Sampling Sediment Cores and Grab Samples[2]	176	1-3	--	300	--	300	--	--
High-Resolution Sediment Coring[1]	25[3]	15-20	375-500	375-500	375-500	400-525[13]	375-500	200-250
SEDIMENT TOTAL	201	--	375-500	675-800	375-500	700-825	375-500	200-250

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TABLE A.1.1 (CONTINUED)
SUMMARY OF PHASE 2A ANALYTICAL PROGRAM

WATER-COLUMN PROGRAM[6]

TASK	NUMBER OF TRANSECTS	NUMBER OF SAMPLES PER TRANSECTS	DISSOLVED PHASE PCB CONGENER ANALYSIS	SUSPENDED MATTER PCB CONGENER ANALYSIS	DISSOLVED ORGANIC CARBON ANALYSIS[9]	TOTAL SUSPENDED MATTER ANALYSIS
Water-Column Monitoring						
Upper Hudson						
--Field-Filtered Samples	7	11[8]	77	77	77	77
--Laboratory-Filtered Samples	2[7]	11[8]	22	22	22	-
Lower Hudson						
--Field-Filtered Samples	3	3	9	9	9	9
WATER COLUMN TOTAL	10	--	108[11]	108[11]	108	86

TASK	TOTAL WATER COLUMN PCB ANALYSIS	CHLOROPHYLL-A ANALYSIS	TOTAL CARBON ANALYSIS ON SUSPENDED MATTER
Water-Column Monitoring			
Upper-Hudson			
-- Field-Filtered Samples	77	77	77
-- Laboratory-Filtered Samples	--	--	--
Lower Hudson			
-- Field-Filtered Samples	--	9	9
WATER COLUMN TOTAL	77[12]	86	86

TABLE A.1.1 (Continued)
SUMMARY OF PHASE 2A ANALYTICAL PROGRAM

Notes

1. Eight high-resolution cores have been collected to date. Sediment samples will be analyzed for redox potential in the field.

2. The confirmatory-sample collection effort was completed in June, 1992. Grab samples generate 1 sample per location. Core samples generate up to 3 samples per core, one core per location. Approximately 50% of the locations yielded sediment cores and 50% yielded grab samples.

3. Twelve locations to be placed in the Lower Hudson, thirteen in the Upper Hudson.

4. All water-column stations will include field measurements of conductivity, temperature, pH and dissolved oxygen.

5. Samples to be analyzed by Lamont-Doherty Geological Observatory for radionuclides, including Cesium-137(Cs-137), Beryllium-7 (Be-7), and Cobalt-60 (Co-60).

6. Total organic carbon data to be obtained by a difference method, subtracting a total inorganic carbon measurement from a total carbon measurement.

7. These represent duplicates of the samples collected for one low-flow transect and one high-flow transect.

8. This total includes seven samples from the Upper Hudson, one each from the Hoosic River, Mohawk River and Champlain Canal, and one background sample per transect.

9. These data will be obtained from two separate measurements of dissolved organic carbon, one based on a persulfate digestion and one based on a complete combustion of the sample.

10. 200 to 400 samples will be analyzed for grain-size distribution by a laser particle analyzer technique. A subset of these samples (about 50) will be run for grain-size distribution by the standard ASTM method.

11. Samples derived from 20 liter aliquots.

12. Samples derived from one liter aliquots.

13. 375 to 500 (one for each core slice) samples will be run using a laser particle analyzer based technique for a small sample volume. 25 samples (roughly one for each core) will be run using a laser particle analyzer based technique for a large sample volume.

14. Sample quantities listed in the table do not include field-duplicate samples or other quality-control samples.

TABLE A.1.2
SUMMARY OF PHASE 2B ANALYTICAL PROGRAM[6]

WATER-COLUMN SAMPLING

TASK	DISSOLVED PHASE PCB CONGENERS	SUSPENDED MATTER PCB CONGENERS	DISSOLVED ORGANIC CARBON	TOTAL SUSPENDED SOLIDS	pH DISSOLVED O_2 TEMPERATURE CONDUCTIVITY[1]
Flow-Averaged Water Sampling	12	12	12	12	300
Analysis of Water Sample Archives	50[2]	65[2]	--	--	--
TOTAL	62	77	12	12	300

SEDIMENT SAMPLING

TASK	PCB CONGENERS	TOTAL CARBON/ TOTAL NITROGEN	TOTAL INORGANIC CARBON	RADIO-NUCLIDES	TOTAL ORGANIC NITROGEN	GRAIN-SIZE DISTRIBUTION
Low-Resolution Coring	[4]	[4]	[4]	[4]	[4]	[4]
Critical-Shear Stress	--	--	--	--	--	[3]
In-situ Degradation	70	--	--	--	--	--
Ecological Field Investigation	75	75	75	--	--	75

TASK	CRITICAL SHEAR STRESS	REDOX POTENTIAL
Low-Resolution Coring	--	[4]
Critical-Shear Stress	[5]	--
In-situ Degradation	--	--

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TABLE A.1.2 (Continued)
SUMMARY OF PHASE 2B ANALYTICAL PROGRAM

Notes

1. These parameters will be measured at the time of sample collection.

2. These samples represent about 50 dissolved phase/suspended matter pairs plus 15 additional suspended matter samples.

3. Samples collected for critical shear stress analysis will also be run for grain-size analysis.

4. The number of samples will be determined after the completion of the geophysical surveys.

5. The number of samples collected for critical shear stress analysis will depend upon an analysis of the results of the geophysical survey and confirmatory sampling. The samples for critical shear stress analysis will be collected during the low-resolution coring effort.

6. Sample quantities listed in the table do not include field-duplicate samples or other quality-control samples.

TABLE A.1.3
SUMMARY OF SEDIMENT SAMPLING LOCATIONS

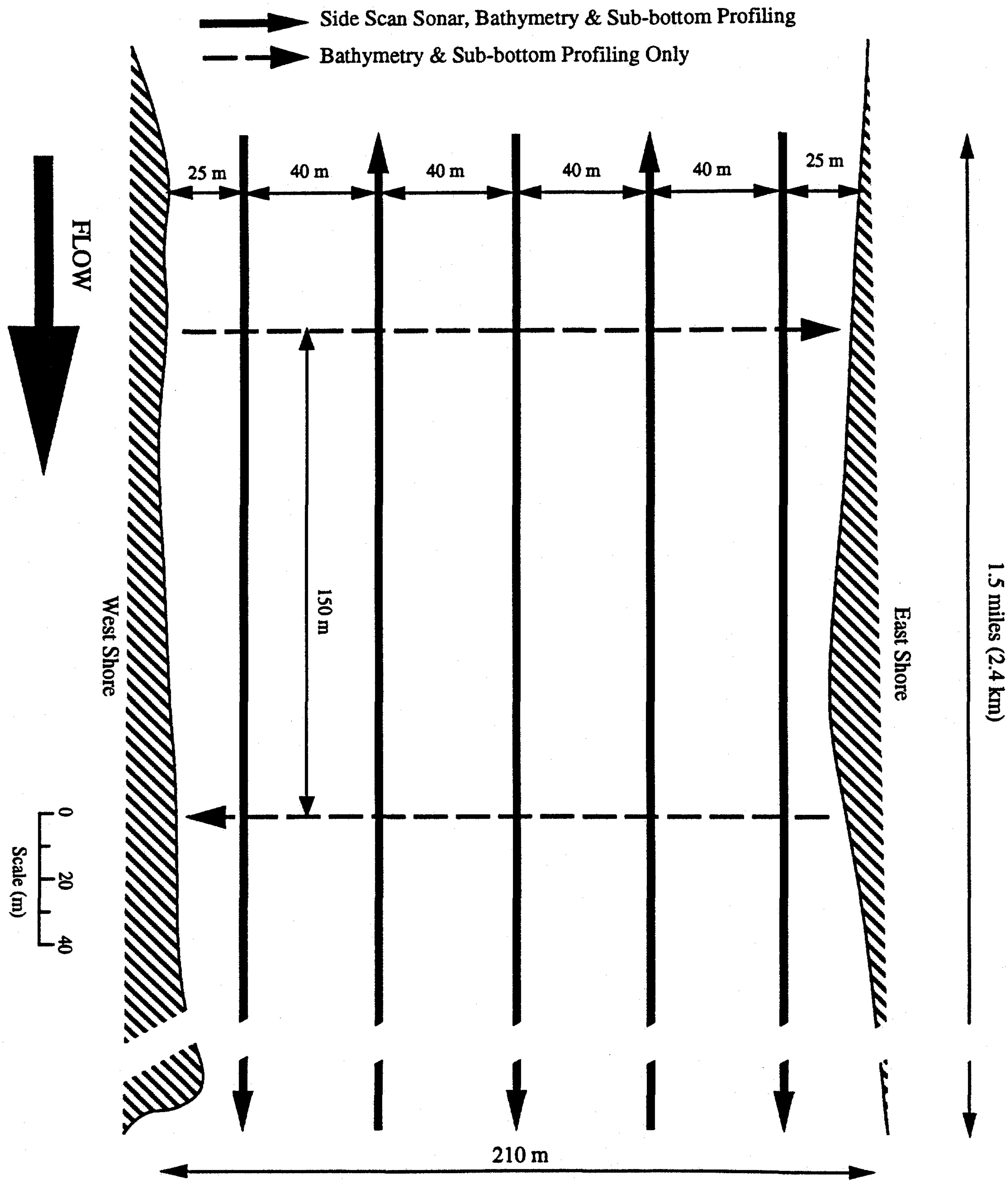
Station Location	Justification for Selection
RM 210	Background sample, above Sherman Island Dam.
RM 203	Background sample, baseline conditions for upper river.
RM 195	Area of original discharge from Hudson Falls plant.
RM 189	Thompson Island Dam, highest detected concentrations of PCBs. NYDEC fish collections occur behind Griffin Island.
RM 175	Stillwater Pool is a NYDEC fish collection location.
RM 158	Above Lock 1 Dam. Major NYDEC fish collections take place between Lock 1 and Federal Dam.
RM 142	Papscanee Marsh, northernmost major wetland area. Important area for growth and reproduction of many bird and fish species. NYDEC Yearling pumpkinseed collection located nearby.
RM 135	Below Shad Island at lower end of Binnen Kill. This area serves as a major nursery area for post-larval and young-of-the year fish. Shortnose sturgeon have been found here.
RM 123	Stockport Creek and Flats, one of four federally designated Hudson River Estuarine Sanctuaries. Sampling is proposed at the Little Nutten Hook area, reputed to have bald eagle nesting nearby.
RM 118	Rogers Island area. This area is used as a spawning, nursery, forage area for both anadromous and freshwater fish. NYDEC fish collections have come from the mouth of Catskill Creek and Ramshorn Marsh. The variety of habitats present also provide favorable nesting areas for waterfowl and passerine bird species.
RM 100	Tivoli Bays, a Hudson River Estuarine Sanctuary. Habitat of rare species, possible area of shortnose sturgeon. Sediment samples will be taken outside of bays, possibly in main river near Magdalen Island and Cruger Island.

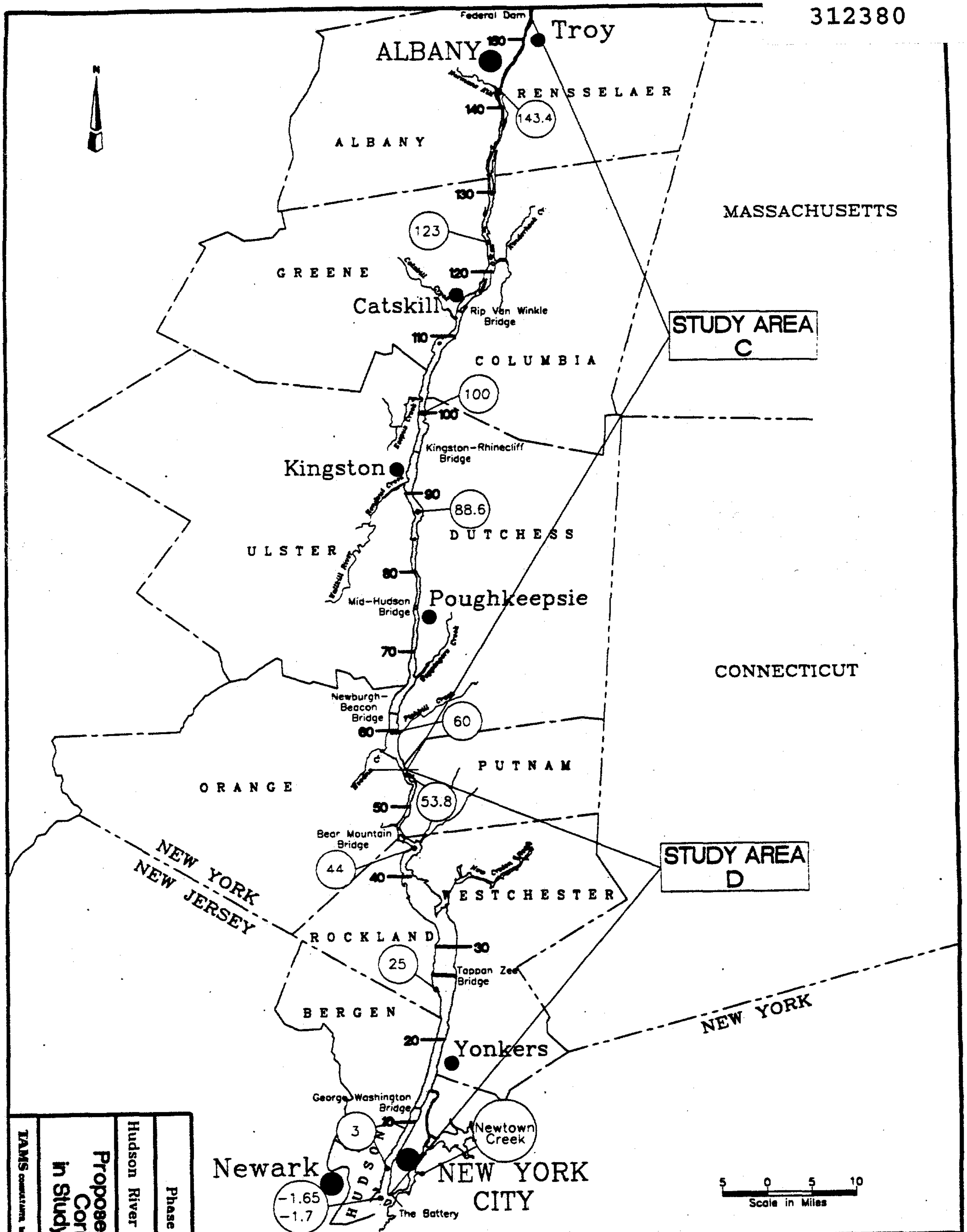
TABLE A.1.3 (CONTINUED)
SUMMARY OF SEDIMENT SAMPLING LOCATIONS

Station Location	Justification for Selection
RM 88	Esopus Meadows, shallow (less than 3 m deep) freshwater, tidal flat area. Spawning, nursery, and forge area for anadromous and freshwater fish species. May also serve as a forage area for shortnose sturgeon wintering in the adjacent deepwater channel. NYDEC fish collections have occurred across the river from Vanderburgh Cove.
RM 58	North of Moodna Creek, spawning habitat for many fish species of concern. Valuable habitat for marsh-nesting birds, ospreys and bald eagles have been sighted in the area.
RM 40	Iona Island, a Hudson River Estuarine Sanctuary and a National Landmark (U.S. Dept. of Interior). Numerous anadromous and resident fish species are found here.
RM 24	Piermont Marsh, a Hudson River Estuarine Sanctuary. This is the only sizable intertidal brackish marsh within the Hudson estuary. A diverse assemblage of fish and wildlife species occurs here.

Figure A.2.1

Schematic of Proposed Geophysical Survey Grid





Legend

(60)	Location of Proposed Core
100	River Mile

Note:

1. Study Area C: Federal Dam to River Mile 55
2. Study Area D: River Mile 55 to The Battery

Figure A.2.2

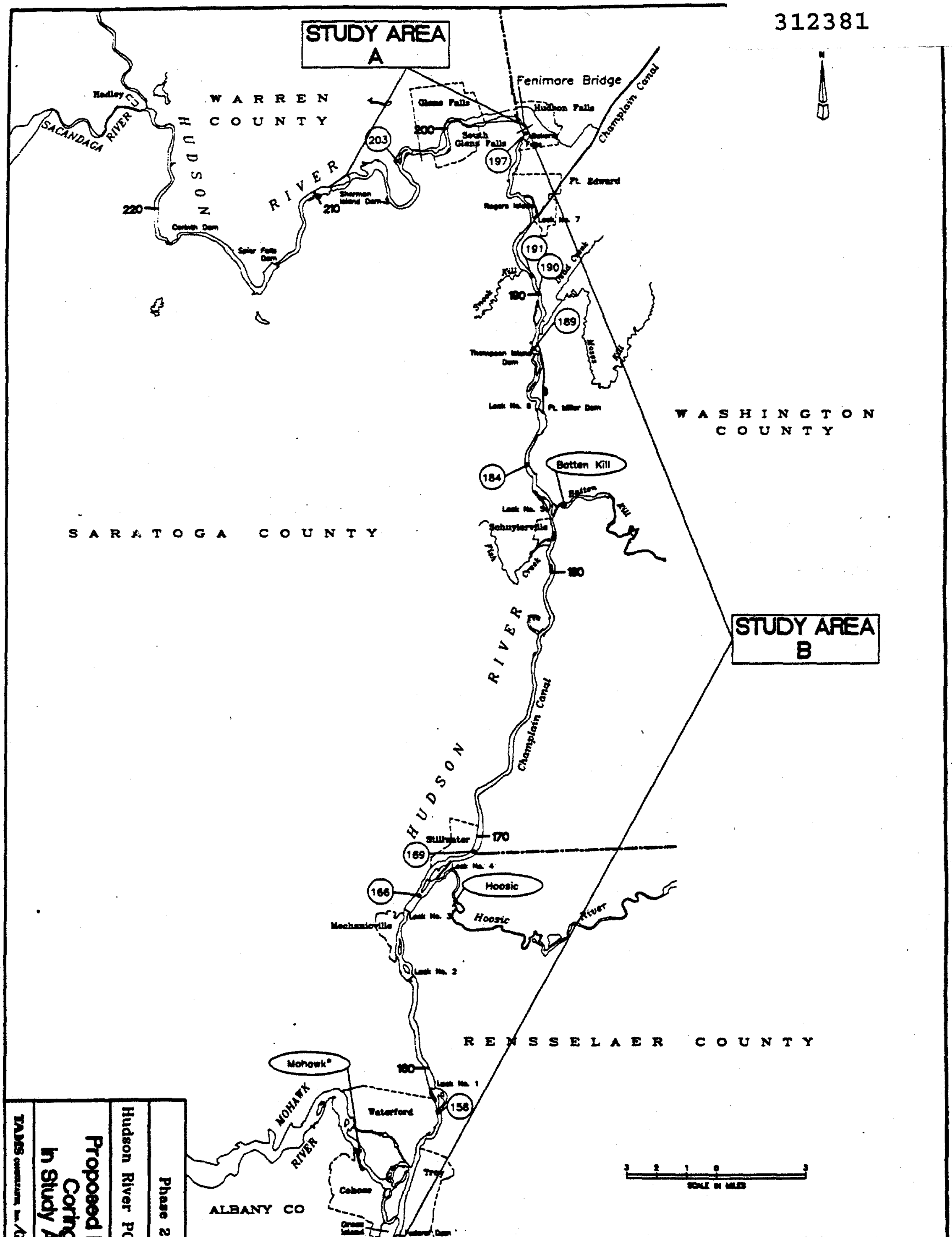
Phase 2 Sampling Plan

Hudson River PCB Reassessment RI/FS

Proposed High-Resolution Coring Locations in Study Areas C and D

TAMS Consultants Inc./Gradient Corporation

Figure A.2.2



Legend

(189) Location of Proposed Core

180 River Mile

Note:

1. Study Area A: Sherman Island Dam to Fenimore Bridge
2. Study Area B: Fenimore Bridge to Federal Dam
3. Actual demarcation between Study Areas A and B is just north of Fenimore Bridge so that Study Area B includes the old Hudson Falls Treatment Plant outfall.

* Note: Mohawk has two proposed core locations near this point.

Phase 2 Sampling Plan

Hudson River PCB Reassessment RI/FS

Proposed High-Resolution Coring Locations in Study Areas A and B

TAMS Consultants, Inc./Gradient Corporation

Figure A.2.3

Figure A.2.3

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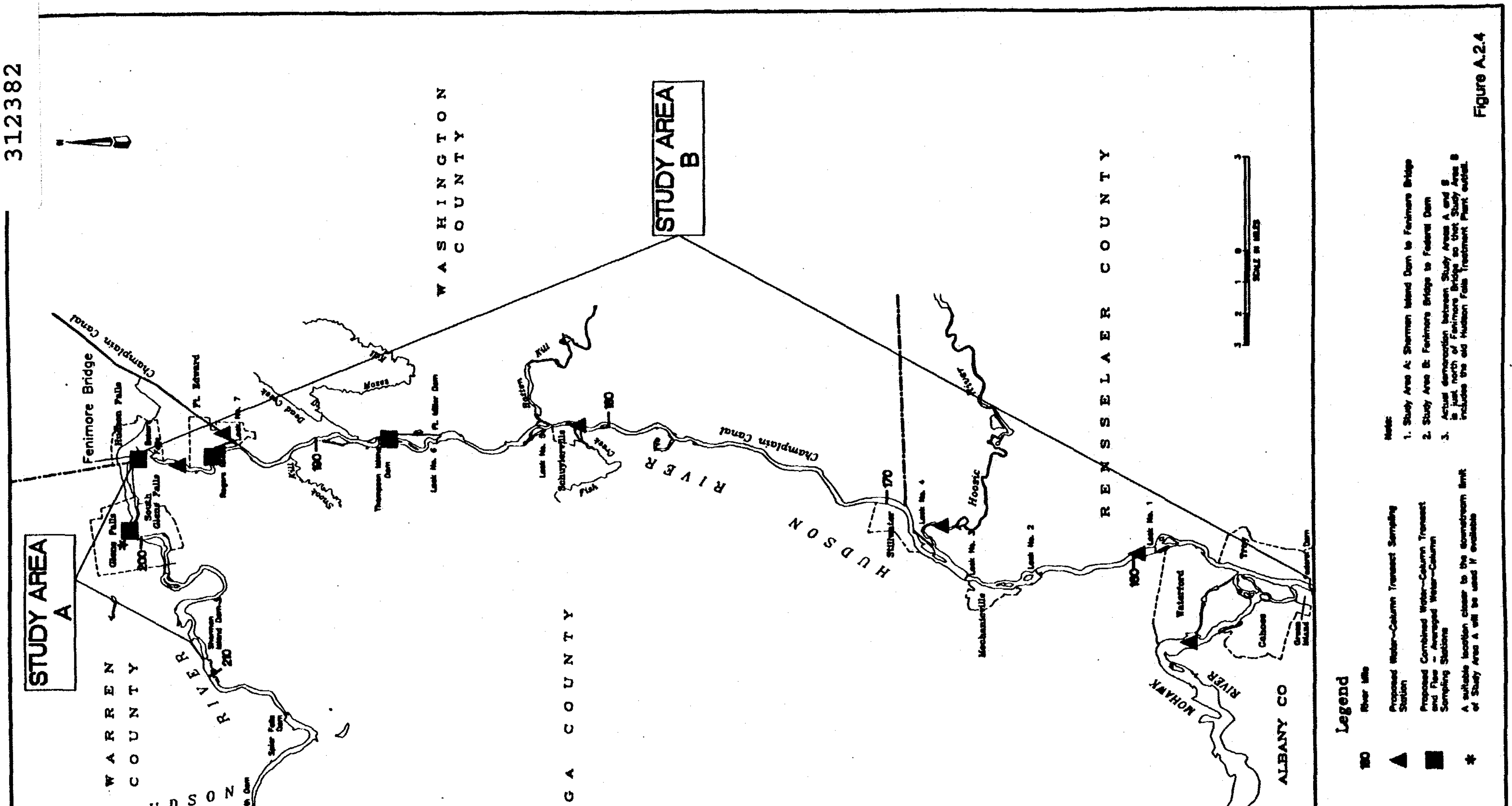


Phase 2 Sampling Plan

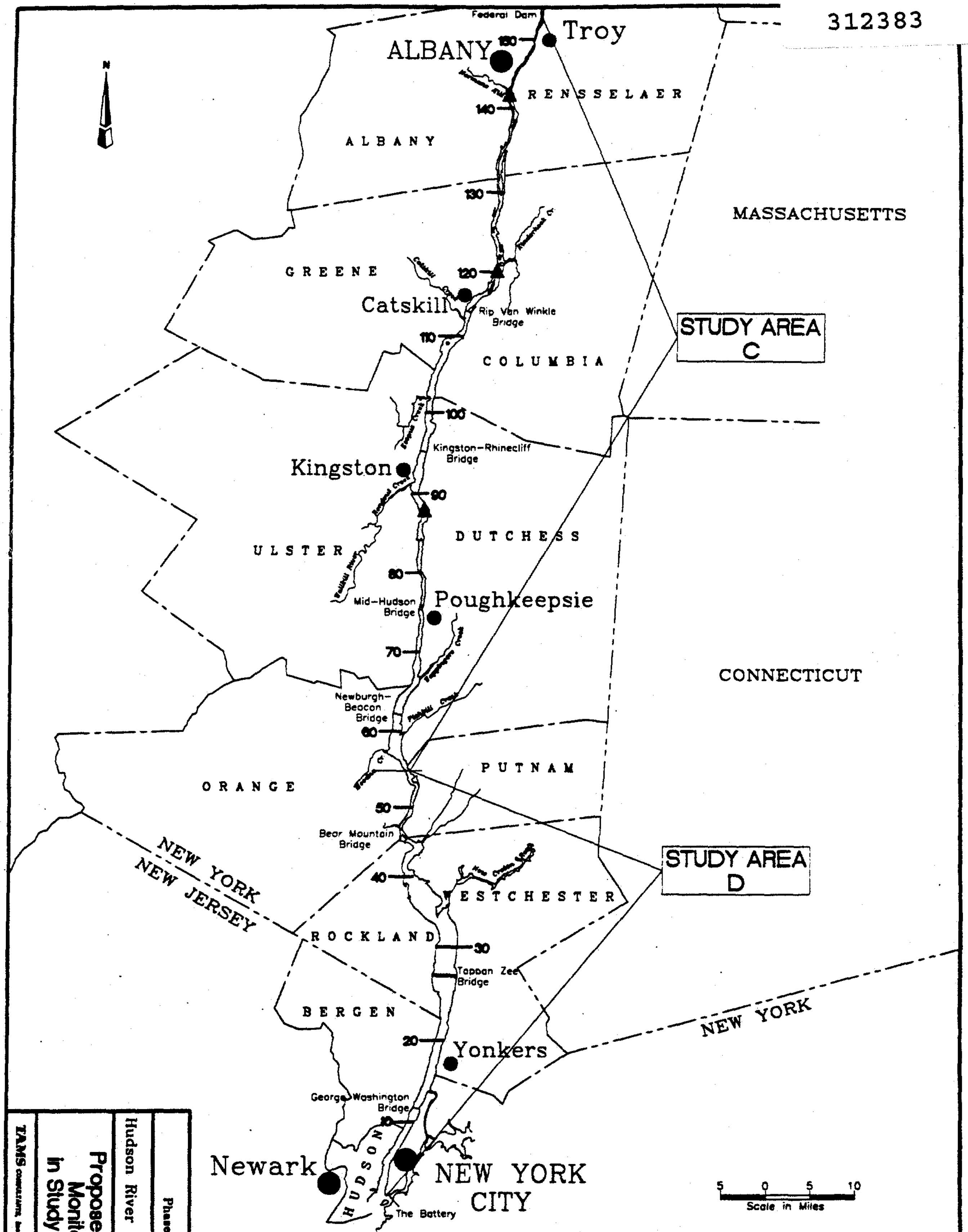
Hudson River PCB Reassessment RI/FS

Proposed Water-Column Monitoring Stations in Study Areas A and B

TAMS Consultants, Inc./Gradient Corporation

Figure A.2.4

312383



Phase 2 Sampling Plan

Hudson River PCB Reassessment RI/FS

Proposed Water-Column Monitoring Stations in Study Areas C and D

TAMS Consultants, Inc. / Gradient Corporation

Figure A.2.5

Legend

100 River Mile

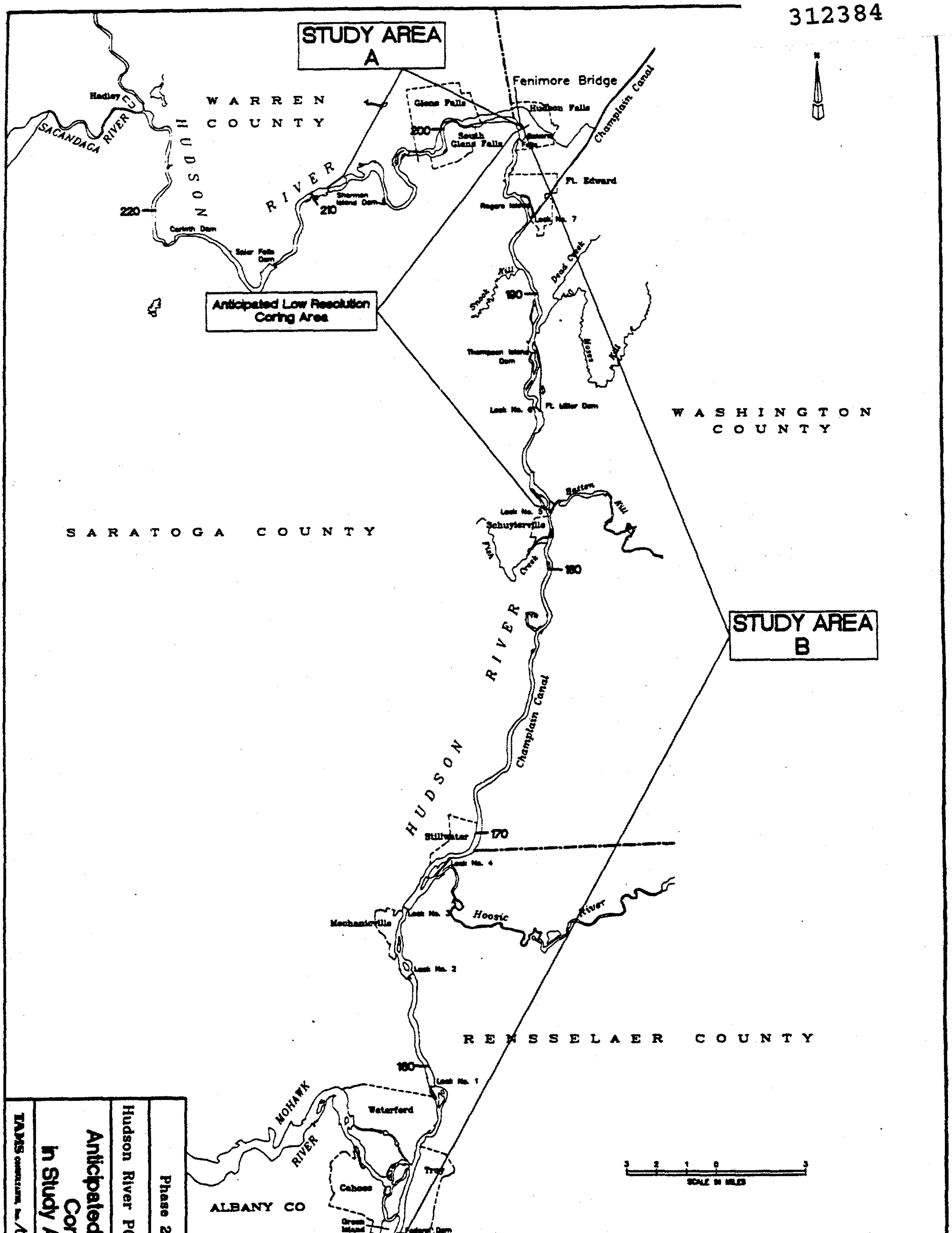
▲ Proposed Water-Column Transect Sampling Station

Note:

1. Study Area C: Federal Dam to River Mile 55
2. Study Area D: River Mile 55 to The Battery

Figure A.2.5

312384



Legend

160 River Mile

Note:
1. Study Area A: Sherman Island Dam to Fenimore Bridge
2. Study Area B: Fenimore Bridge to Federal Dam
3. Actual demarcation between Study Areas A and B is just north of Fenimore Bridge so that Study Area B includes the old Hudson Falls Treatment Plant outfall.

Figure A.3.1

Phase 2 Sampling Plan

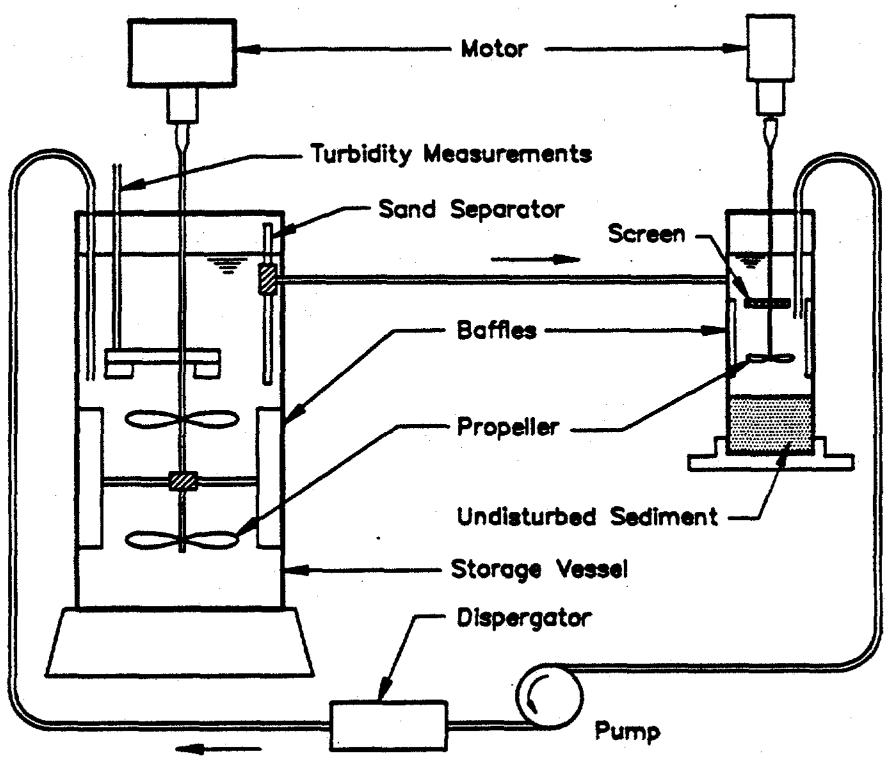
Hudson River PCB Reassessment RI/FS

Anticipated Low-Resolution Coring Area in Study Areas A and B

TAMS Consultants, Inc./Gradient Corporation

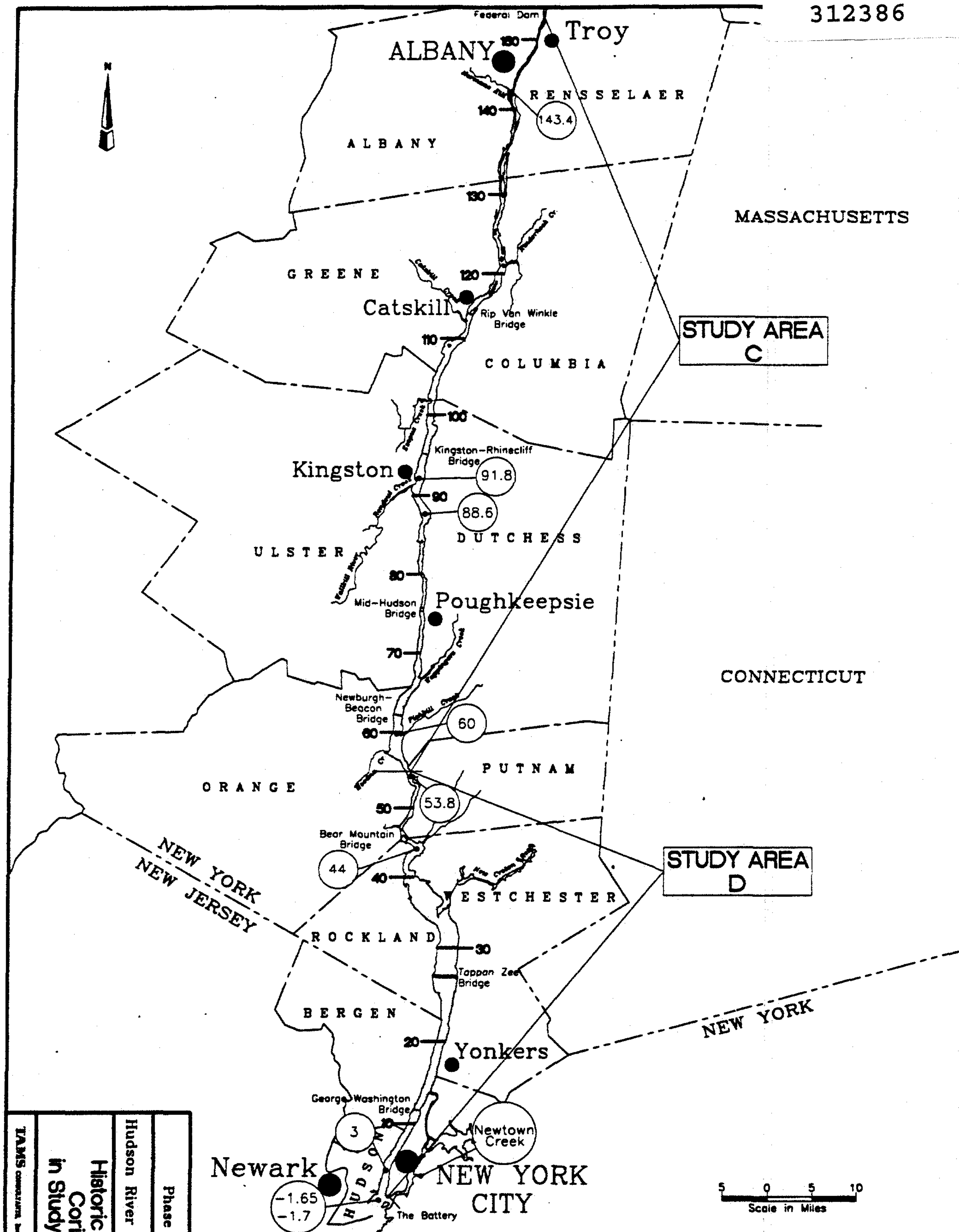
Figure A.3.1

Figure A.3.2
Critical Shear Stress Measurement System



LABORATORY SETUP TO MEASURE EROSION
(Not To Scale)

From Schünemann et al, 1991



Legend

60 Location of Historic Sediment Core

100 River Mile

Note:

1. Study Area C: Federal Dam to River Mile 55

2. Study Area D: River Mile 55 to The Battery

Figure A.3.3

Phase 2 Sampling Plan

Hudson River PCB Reassessment RI/FS

Historic High-Resolution Coring Locations in Study Areas C and D

TAMS Consultants, Inc. / Gradient Corporation

Figure A.3.3

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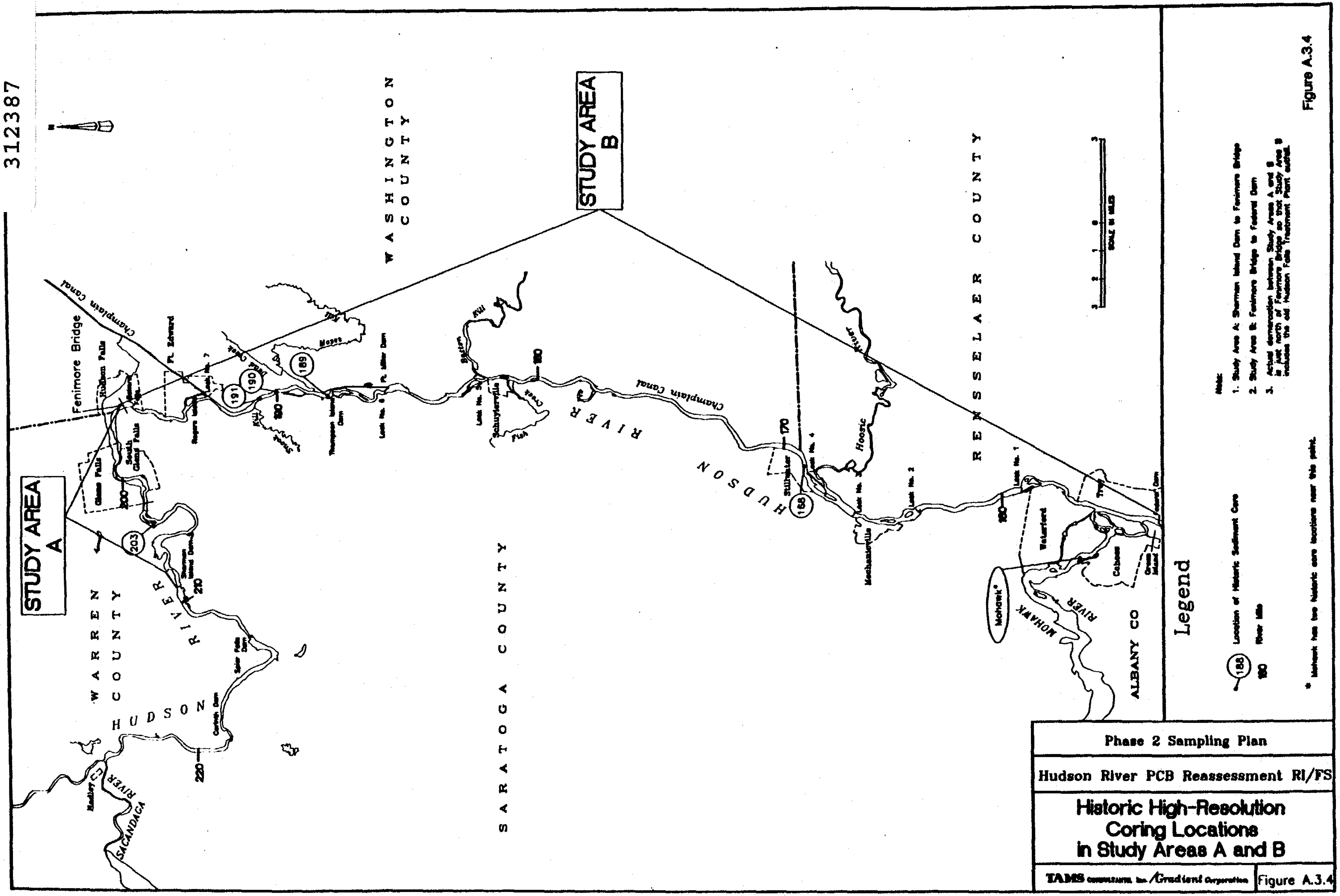


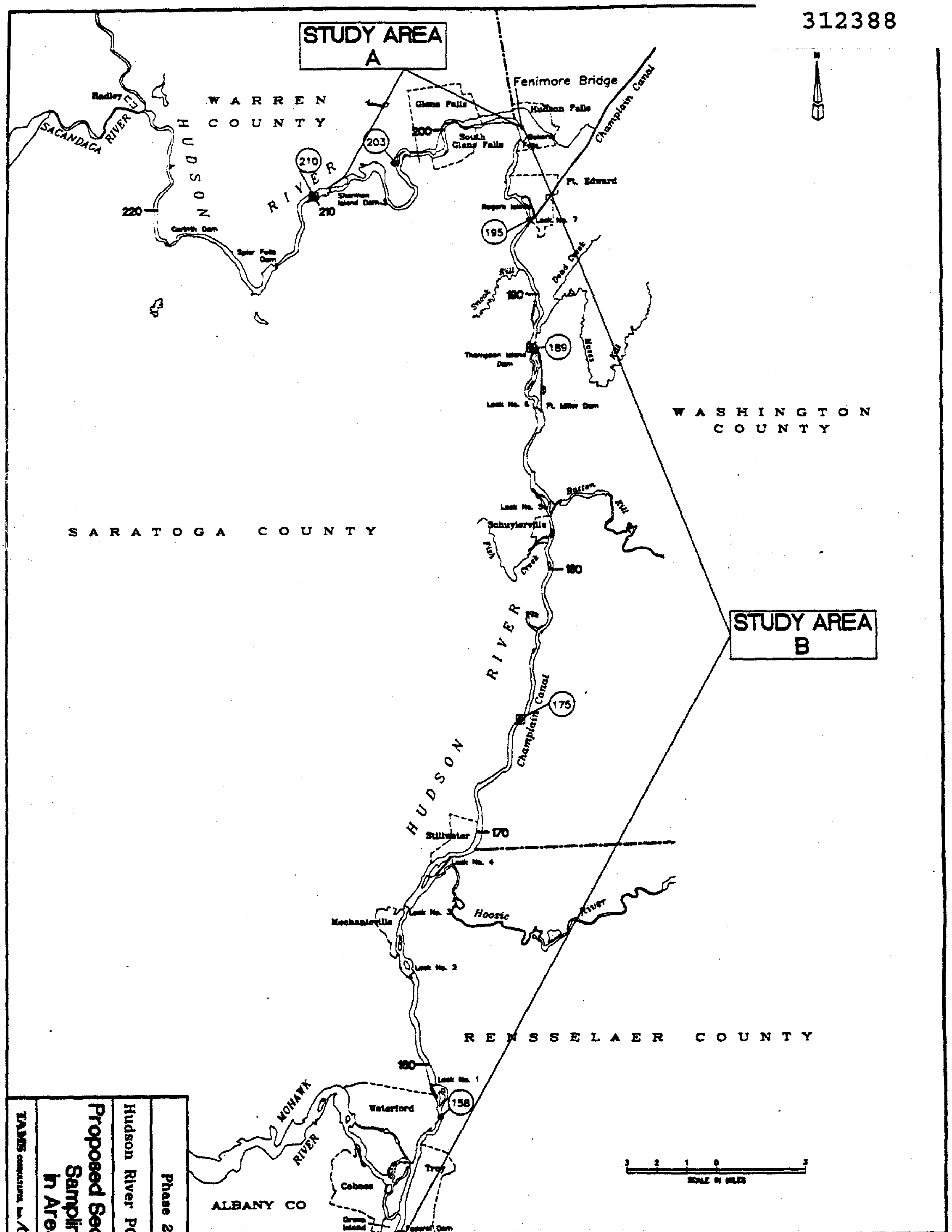
Phase 2 Sampling Plan

Hudson River PCB Reassessment RI/FS

Historic High-Resolution Coring Locations in Study Areas A and B

TAMS Consultants, Inc. / Gradient Corporation | Figure A.3.4

312388



Legend

189 Location of Proposed Sediment Sample

210 Location of Proposed Combined Sediment and Benthic Sample

190 River Mile

Note:

1. Study Area A: Sherman Island Dam to Fenimore Bridge
2. Study Area B: Fenimore Bridge to Federal Dam
3. Actual demarcation between Study Areas A and B is just north of Fenimore Bridge so that Study Area B includes the old Hudson Falls Treatment Plant outfall.

Figure A.3.5

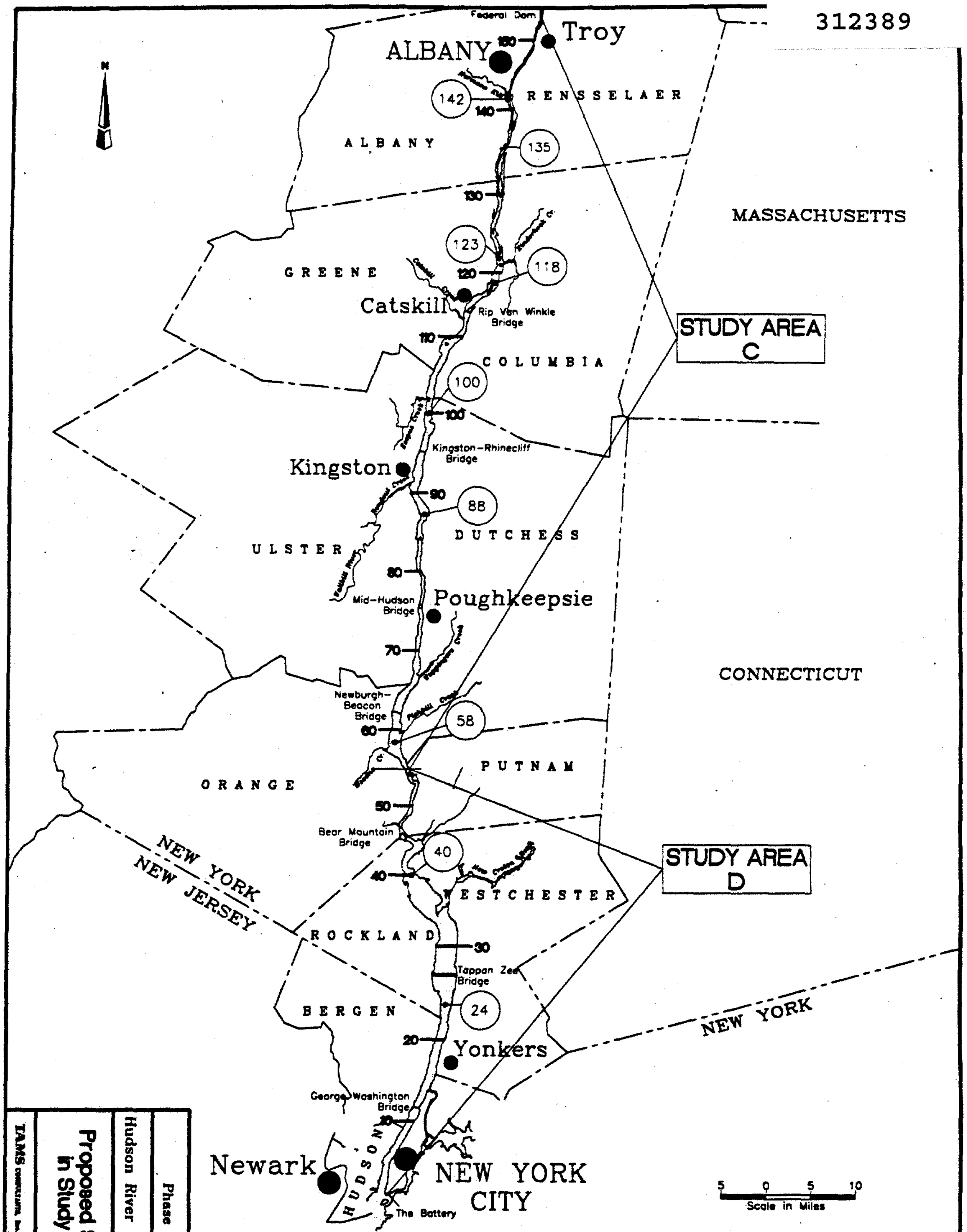
Phase 2 Sampling Plan

Hudson River PCB Reassessment RI/FS

Proposed Sediment and Benthic Sampling Locations in Areas A and B

TAMS Consultants, Inc./Gradient Corporation

Figure A.3.5



Phase 2 Sampling Plan

Hudson River PCB Reassessment RI/FS

Proposed Sediment Sampling in Study Areas C and D

TAMS Consultants, Inc./Gradient Corporation

Figure A.3.6

Legend

(88) Location of Proposed Sediment Samples

100 River Mile

Note:

1. Study Area C: Federal Dam to River Mile 55
2. Study Area D: River Mile 55 to The Battery

Figure A.3.6

Phase 2: Sampling Plan

Hudson River PCB Reassessment RI/FS

Proposed Geophysical Survey Locations

TAMS CONSULTANTS, Inc. / Gradient Corporation | Plate A.1

Source:
MALCOLM PIRNIE, INC.