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HUDSON RIVER PCBs REASSESSMENT RI/FS
RESPONSIVENESS SUMMARY FOR
VOLUME 2C-A LOW RESOLUTION SEDIMENT CORING REPORT
ADDENDUM TO THE DATA EVALUATION AND INTERPRETATION REPORT

FEBRUARY 1999

For

U.S. Environmental Protection Agency
Region II
and
U.S. Army Corps of Engineers
Kansas City District

Book 2 of 2

TAMS Consultants, Inc.
TetraTech, Inc.

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FEBRUARY 1999

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean Resources Conservation and Assessment
Hazardous Materials Response and Assessment Division
Coastal Resources Coordination Branch
290 Broadway, Rm 1831
New York, New York 10007

August 28 , 1998

Doug Tomchuk
U.S. EPA
Emergency and Remedial Response Division
Sediment Projects/Caribbean Team
290 Broadway
New York, NY 10007

Dear Doug:

Thank you for the opportunity to review the July 1998 Phase 2 Report-Review Copy, Further Site Characterization and Analysis, Volume 2C-A Low Resolution Sediment Coring Report, Addendum to the Data Evaluation and Interpretation Report, Hudson River PCBs Reassessment RI/FS. The following comments are submitted by the National Oceanic and Atmospheric Administration (NOAA).

Comments

The Executive Summary of the Low Resolution Sediment Coring Report highlighted four major findings. The results of the nearshore sediment investigation were reported as additional findings and the significance of these findings was downplayed. It was stated that the implications from the two to three times increase in the estimate of the exposure point concentration would be addressed in the Human Health Risk Assessment. Implications to the Ecological Risk Assessment (ERA) were not discussed. It was suggested that this increased estimate of PCB concentrations in nearshore sediments should not substantially change the human health risk estimate from wading and swimming (pg. 4-44); however, it may have serious implications for human health exposure from consumption of fish and for ultimate remedial decisions. Furthermore, the ERA risk to ecological receptors must consider the potential underestimate of PCBs in the nearshore environment. 1.1

Four nearshore areas were sampled in approximately 4 feet of water. The water depth was chosen since it posed a likely human exposure from wading and swimming. These shallow nearshore areas are also of particular importance to biota because they provide refuge, feeding and spawning habitat for fish and are an important source of contamination to prey species. In addition, PCBs in these sediments may be most affected by daily changes in water level associated with hydropower generation, as well as being vulnerable to scour from large debris (e.g., logs, root masses), ice scour, and other disturbances.

The Low Resolution Coring Report attempted to quantify the potential underestimation of PCB concentrations in nearshore sediments, but conceded that the results usefulness may be limited due to the small sample size (n=11). Using data from all nearshore fine-grained low resolution TIP cores within 50 feet of the shoreline yielded a somewhat larger dataset (n=19) and a higher 95 percent confidence limit (264 ppm PCBs compared to 151 ppm PCBs). Side-scan sonar nearshore samples that overlapped with the shoreline appeared to have been excluded from this analysis even though these are important areas to ecological receptors. The limited characterization of nearshore

sediment PCB concentrations in the Thompson Island Pool has important implications that will need to be addressed in both the Baseline Modeling and the Ecological Risk Assessment.

An estimated 28% loss in PCB sediment inventory from the TIP occurred between 1984 and 1994 was attributed to release to the water column. A minimum loss of a 3,200 kg PCBs was estimated for hot spots below the TID. NOAA recommends that EPA calculate whether the deposits identified in the TIP and elsewhere in the river could have provided the amount of PCBs necessary to maintain the apparently steady-state concentrations in fish in the river. 1.2

Depth to wood chip or cellulose-type material was identified in the field. The authors relied upon the association between the molar ratio of carbon to nitrogen (C/N ratio) as an indicator of wood cellulose (Section 2.4.3). The C/N ratio ranged between 11 and 82 with a median of 40 and a mean of 39; hence, there was a suggestion that wood chips occur throughout much of the Upper Hudson sediments. It would have been useful if all core segments identified with wood chips or cellulose-type material were tabulated along with the depth to wood chip or cellulose-type material, and PCB concentrations. This would have permitted an independent assessment of the relationship between presence and depth of wood chips and PCB maximum concentrations. The problem with relying entirely on the C/N ratio is that only 26 samples were examined with nine samples from the surface segment, seven from the second segment and ten from the third segment. Since a total of 170 cores (371 samples) were collected and analyzed for PCBs, a much larger data set is available that could be stratified by segment depth and sampling location. 1.3

To assess sample homogeneity, two subsamples (sample splits generated in the field) were collected from 9 cores (23 paired samples). The average relative percent difference (RPD) for these split pairs was 36%. It should be noted that this calculated RPD includes analytical variability as well as sample homogeneity. 1.4

Thank you for your continual efforts in keeping NOAA apprised of the progress at this site. Please contact me at (212) 637-3259 or Jay Field at 206-526-6404 should you have any questions or would like further assistance.

Sincerely,

Lisa Rosman
NOAA Coastal Resource Coordinator

cc: Michael Clemetson, DESA/HWSB
Gina Ferreira, ERRD/SPB
Robert Hargrove, DEPP/SPMM
William Ports, NYSDEC
Charles Merckel, USFWS
Anne Secord, USFWS
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State
(LRC - LS)

10.0985

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John P. Cahill
Commissioner

August 31, 1998

Mr. Douglas Tomchuk
United States Environmental Protection Agency
Region II
290 Broadway - 20th Floor
New York, NY 10007-1866

Dear Mr. Tomchuk:

Re: Hudson River PCBs Reassessment RI/FS
Site No.: 5-46-031

The New York State Department of Environmental Conservation (NYSDEC) and the New York State Department of Health (NYSDOH) have reviewed the July 1998 Hudson River PCBs Reassessment RI/FS reports entitled "Volume 2C-A Low Resolution Sediment Coring Report Addendum to the Data Evaluation and Interpretation Report," and "Phase 2 Human Health Risk Assessment Scope of Work." This letter provides the State's comments on the two documents.

The Low Resolution Sediment Coring Report (LRSCR) presents four major findings. Following are the State's general comments corresponding to each of these findings.

Finding 1

"There was little evidence found of widespread burial of PCB-contaminated sediments by clean sediment in the Thompson Island Pool. Burial was seen at some locations, but more core sites showed loss of PCB inventory than showed PCB gain or burial." [Page ES-3]

State Comment

The State agrees that, based on the data contained in the LRSCR, much of the PCB-contaminated sediments in the Thompson Island Pool are not being buried with significant amounts of clean sediment. 1.1

Finding 2

"From 1984 to 1994, there has been a net loss of approximately 40 percent of the PCB inventory from the highly contaminated sediment in the Thompson Island Pool." [Page ES-4]

State Comment

The State agrees that, based on the data contained in the LRSCR, there has been an identifiable PCB inventory loss from the sediments of the Thompson Island Pool. However, based on the data contained in the report, it is difficult to closely quantify the degree of sediment losses. It may be more appropriate for the report to present a range of estimates rather than a single number. This same concern was discussed at the Scientific and Technical Committee meeting on August 18, 1998. 1.2

Finding 3

"From 1976-1978 to 1994, between the Thompson Island Dam and the Federal Dam at Troy, there has been a net loss of PCB inventory in *hot spot* sediments sampled in the low resolution coring program." [Page ES-4]

State Comment

The State agrees that, based on the data contained in the LRSCR, there has been an identifiable PCB inventory loss from the hot spots between the Thompson Island Dam and the Federal Dam at Troy. 1.3

Finding 4

"The PCB inventory for *Hot Spot 28* calculated from the low resolution coring data is considerably greater than previous estimates. This apparent "gain" in inventory is attributed to significant underestimates in previous studies rather than actual deposition of PCBs in *Hot Spot 28.*" [Page ES-4]

State Comment

The State agrees with this finding based on the data contained in the LRSCR. This inaccuracy in past data gathering efforts may also be present in the PCB inventory estimates in other areas where the core depths were not sufficient in the past. However, NYSDEC believes the USEPA evaluation of sediment PCB inventory gain or loss is valid, and not impacted by the earlier data gathering efforts. 1.4

The State also has the following specific comments regarding two other findings of the LRSCR:

1. Page ES-5 and Section 4.1.4 second paragraph — The finding that areas within the Thompson Island Pool (TIP), outside the known hot spot areas of the TIP, have exhibited a large net gain in PCB inventory (up to a 100% increase) is significant because the PCBs are more readily available to fish and other biota. 1.5

2. Section 4.4.3 The revised, sediment PCB concentration estimates for the near shore areas are noteworthy. This portion of the river environment has not been well characterized in past investigations, and this information will be useful to both the ecological and human health risk assessments for the site. 1.6

The following are the State's comments , including the NYSDOH, on the Phase 2 Human Health Risk Assessment Scope of Work:

1. The first sentence of the first full paragraph of page 9 refers to a hypothetical study population being defined as any individual who would consume self-caught fish from the Hudson River "in 1.7

the absence of a fishing ban." This passage should be revised for accuracy to read "...in the absence of a fish possession ban and health advisory."

2. The number of years that a person may eat contaminated fish from the Hudson River is estimated in Section II,2.D entitled "Risk Characterization from the Consumption of Fish." Data on how long people live in a county along the river before moving are used to estimate the number of years a person may eat contaminated fish. A significant number of people are likely to move from one county along the river to another county along the river, thus increasing their length of exposure. The number of years that a person may eat contaminated fish from the Hudson River will be underestimated if this possibility is not considered in estimating exposure. Furthermore, a lifetime exposure should be considered in the exposure distribution.

3. In evaluating risks, both cancer and non-cancer, the reference dose or cancer potency factor for the Aroclor (e.g. Aroclor 1016, Aroclor 1260, etc.) that is most similar to the PCB mixture in the environmental samples should be used. This approach is more scientifically defensible than automatically using default values as suggested in the Integrated Risk Information System guidance.

4. Non-cancer risks are evaluated by comparing exposures to reference doses (ingestion exposure) or reference concentrations (inhalation exposure).Since reference concentrations are not available for the Aroclors, inhalation exposures should be evaluated using reference doses. The risk characterization section of a risk assessment includes a discussion of the uncertainties and limitations of the risk assessment and the uncertainties and limitations, if any, of using reference doses instead of reference concentrations should be included in that section.

As additional information becomes available to the parties, the State would welcome the opportunity to provide comments. The State views the completion of the LRSCR and the Risk Assessment Scope of Work as important Hudson River Reassessment milestones, and is pleased that USEPA is adhering to its Reassessment schedule.

Sincerely,

William Daniels for

William T. Ports
Remedial Section A
Bureau of Central Remedial Action

cc: John Davis, NYSDOL
Robert Montione, NYSDOH
Jay Fields, NOAA
Lisa Rosman, NOAA
Anne Secord, USF&WS

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SARATOGA COUNTY

ENVIRONMENTAL MANAGEMENT COUNCIL

PETER BALET
CHAIRMAN

GEORGE HODGSON
DIRECTOR

August 28, 1998

Mr. Douglas Tomchuk, Project Manager
Hudson River PCB Reassessment
USEPA, Region 2
290 Broadway, 20th Floor
New York, N.Y. 10007-1866

Attn: LRC Comments

Dear Mr. Tomchuk:

Enclosed you will find comments from the Saratoga County Environmental Management Council relative to Hudson River PCB Reassessment Phase 2, "Volume 2C-A Low Resolution Sediment Coring Report" dated July 1998.

As you will note, many of the enclosed comments reinforce concerns stated by some members of USEPA's Scientific & Technical Committee which met August 18, 1998 in Latham, NY that this report does not adequately substantiate the "alarming" statements recently made by EPA regarding the possible need for immediate remedial action in the Upper Hudson River PCB hot spot areas.

The Saratoga County Environmental Management Council, consistent with our July 27, 1998 correspondence to USEPA, ERRD Deputy Director McCabe, strongly recommends that the enclosed comments, as well as all other pertinent scientific information and public comments relative to the Hudson River PCB Reassessment, be subject to the ERG scientific peer review process which is currently underway. The Hudson River is too important a resource not to conduct a comprehensive scientific peer review to provide a sound basis for reaching the important decisions which lie ahead!

Thank you for the opportunity to comment.

Sincerely,

Peter M. Balet

Peter M. Balet
Chairman

PB/gh

cc: Ms. Carol Browner, Administrator, USEPA
Ms. Jeanne Fox, Regional Administrator, Region 2, USEPA
Mr. Richard Caspe, Director, ERRD, Region 2, USEPA
Mr. William McCabe, Deputy Director, ERRD, Region 2, USEPA
Ms. Ann Rychlenski, Public Affairs Specialist, Region 2, USEPA
The Honorable Gerald Solomon
The Honorable Alphonse D'Amato
The Honorable Daniel Moynihan
The Honorable George Pataki
Mr. John Cahill, Commissioner, NYSDEC
Mr. Stuart Buchanan, Region 5 Director, NYSDEC
The Saratoga County Board of Supervisors
Mr. David Wickerham, Administrator, Saratoga County
Hudson River PCB Liaison Group Chairs
SCEMC members & staff

COMMENTS ON VOLUME 2C-A LOW RESOLUTION SEDIMENT CORING REPORT, JULY 1998;

Prepared for the Saratoga County Environmental Management Council

By D. D. Adams, Member-at-Large

1. P. 1-6 & P.1-7: The 1988 NYSDEC report concluded there was no major change in PCB distribution in the Thompson Island Pool (TIP) sediments from 1977 to 1984 despite the 1988 report showing a PCB inventory less than half of the 1977 estimate. The 1988 report concluded that "most of the differences between the 1977 & 1984 PCB mass estimates were due to differences in calculation methods and assumptions". This EPA report in later sections cites an inventory decrease of 30% from the estimated 1984 inventory when compared to the 1994 inventory estimated by EPA. EPA should either provide its explanation as to why the 1988 NYSDEC conclusion of "no change" is invalid or provide EPA's rationale for why the Hudson River behaved differently from 1977 to 1984 vs. 1984 to 1994, causing no change over the first period and a decrease over the second period. 1.1

2. P. 1-7 & P. 2-1: Before any conclusions can be drawn from the low resolution coring (LRC) data, a statistical analysis must be done which predicts the ability of the small number of samples taken by EPA in only a few locations to adequately estimate the PCB mass over a large area with very large spatial variations in PCB concentrations. This analysis should include consideration of the fact that the mean values from the NYSDEC data are based upon an order of magnitude greater number of samples than the EPA data. 1.2

Page 1-7 states the LRC program wasn't designed to duplicate the extensive spatial coverage of the NYSDEC program. Page 2-1 dramatically quantifies this statement by showing that EPA had only 60 core sampling sites in the TIP in the vicinity of the 1984 NYSDEC locations vs 1200 NYSDEC core sites. The meager number of EPA cores hardly seems sufficient to quantify the PCB inventory (and therefore changes to the inventory as put forth later in the report) in the face if existing data which show very large spatial variation in PCB concentrations over very short distances in the TIP. EPA's data also shows this variation as can be seen in Plate 4-23 which indicates a 100:1 difference in concentration in nearby samples and variations of 10:1 in most, if not all, of Plates 4-21 to 4-28. Certainly, the scope of the EPA sampling program is not sufficient to justify the "alarming" statements made by EPA to the public which accompanied the release of the report and called for a study of immediate remedial action. 1.3

3. P. 2-3: What is the area (in square feet, acres, or square mile) that the cores below the Thompson Island dam and the near shore areas represent? 1.4

4. P. 2-10: What is the significance to the modeling effort of the loss of reduction/oxidation potential data and total carbon/total nitrogen data? 1.5

5. P. 2-15: The first paragraph on this page states that cores taken for the LRC report "do not comprise a spatial coverage sufficient to calculate PCB inventories for these areas directly", yet later in the report these data are used to do precisely that since calculation of a "change" in inventory implicitly carries with it the calculation of the inventory itself. This inconsistency reinforces comment "1." 1.6

6. P. 2-16: The statement that the presence of PCB maxima in the top-most core layer shows that PCB burial is not occurring is not justified. High resolution core profiles have shown relatively low PCB concentrations in the first few inches of sediment with the PCB concentration then rising rapidly to a peak before declining to a low level or zero. Inspection of Fig. 2-7 shows that most of the PCB mass in both of these cores would occur within the top 9 inches (about 23 cm) of the cores but yet relatively low PCB concentrations within 2 plus inches of the sediment-water interface. Burial may or may not be occurring (the presence of "hot spots" would seem to indicate it is) but reasoning from the presence of a maximum PCB concentration in an upper 9" core segment cannot be used to make such a conclusion. 1.7

7. P. 2-18: Reference in the last complete paragraph should be to Fig. 2-6 and not Fig. 2-4. Also, the units on the abscissa of the upper figure in Fig. 2-6 appear to be incorrect. 1.8

P. 2-18: An average difference of 36% between replicate samples from the same core sample seems very large. Discussion of why this large difference is unimportant should be provided, especially when the data are later used to estimate a change of only 30%. 1.9

8. P. 2-19: The discussion here at the end of Section 2.4.1 again raises the question of the adequacy of the LRC data set to draw conclusions about PCB inventory change. The difference of 4:1 in one of the outlier replicate samples and the statement that heterogeneity in concentration as well as the ability to homogenize samples will probably be the main source of analytical uncertainty for the PCB results reinforces the concern about whether the number of LRC samples is sufficient to make the conclusions later stated in this report and in the Executive Summary of the report. 1.10

9. P. 3-13, Section 3.2: If the variation of parameters was expected to occur over a narrow range, why weren't these parameters measured on the high resolution cores? While limited in number, these cores could have provided some data to show if the assumption of variation over a narrow range is true. 1.11

10. P. 4-5, top of page: Discussion in Appendix E raises serious questions as to the ability to make a valid comparison of 1984 and 1994 data due to the differences in analytical methods. Rather than go through manipulations in Appendix E, 1994 samples should be analyzed by 1984 methods (or as close as possible to 1984) and a correction factor utilized based upon these results obtained for the 1984 data. If possible, the reverse should also be done (analyze 1984 samples using 1994 methods) and the correction factors compared. 1.12

11. P. 4-7: I do not agree with the statements presented in the last paragraph. Referring back to comment 6., if the top 9 inches and bottom 9 inches of Core 19 (Fig. 4-2) were homogenized, (Note: units on ordinate of Fig. 4-2 should be cm and not inches), the results would be expected to be similar to Core LR-09E and not Core LR-05D. This re-emphasizes the point made in comment 6. that the LRC core profiles do not provide a basis for judging burial or no burial. The homogenized profiles (using same sample layer thickness as LRC cores) of all the high resolution cores should be calculated and plotted and compared to the LRC cores. 1.13

12. P. 4-8, First Paragraph: To conclude that 8 profiles show scour should be substantiated by a table showing the separation distances between these 8 profiles and the 1984 profiles to which they are compared. To assist in the overall review of this report, a table should be included which shows the separation distances between each LRC core and the 1984 core to which it is being compared. This information is important considering that available data indicate significant PCB concentration changes occur over distances of only a few feet. 1.14

13. P. 4-10: In the discussion of Fig. 4-7, the references to the upper and lower figures of Fig. 4-7 should be reversed. Also, are the units on the upper figure correct? 1.15

14. P. 4-18, Last Paragraph of 4.1.3: The implication that more scour occurs in cohesive sediments than in non-cohesive sediments seems to be at odds with what would be expected. How does EPA reconcile this other than uncertainty in the data (which might well explain other differences, put forth by EPA in this report, between previous data and 1994 data)? If EPA believes scour is occurring, does EPA plan to revise the scour model included in the DEIR which predicted little if any scour? 1.16

15. P. 4-21: The discussion on P. 4-21 about corrections needed for the grab samples is another illustration of uncertainty in the EPA comparison of 1994 data to earlier data. There is no way of knowing if the extrapolation to 12"is valid or not. It is suggested the 1.17

grab samples not be included in the analysis. Also, using the concentration of the second layer of the 1994 LRC samples to extend 9" cores to 12" is questioned. Based upon the sharp PCB concentration gradient in the range of 9-12" seen in the high resolution cores, this method of extending from 9" to 12" may greatly underestimate the LWA in the 1994 data.

16. P. 4-22: When choosing between two data sets for the same set of samples based on "convenience" rather than an understanding of reason for the differences is unsound science and casts doubt on any conclusions from the analysis. EPA should investigate the reasons for the differences and if they are unable to justify a choice based upon this investigation, perform the analysis using both sets of data and compare the results. 1.18

17. P. 4-22: Any comparison of PCB inventory based upon the 1976-78 and 1994 data is made uncertain by the lack of solid specific weight (SSW) data for the 1976-78 data. The statement here that total PCBs and SSW show very strong correlation is in contradiction to the statement on P. 3-18 that SSW showed a weak trend with PCB concentration. Also the range of variation in the data in Fig. 3-15 and 4-17 is very large making conclusions about correlation's uncertain and no 2σ or 3σ values are given for the SSW to PCB values shown in Table 4-3. EPA needs to do more to show why the SSW values used for the 1976-78 data are reasonable to use, including a level of uncertainty, to make comparisons of PCB inventories between 1976-78 and 1994 meaningful. 1.19

18. P. 4-24: Fig. 4-18 does not substantiate the statement that the agreement between the NYSDEC and side-scan sonar classifications of sediment is good. In the "fine sand" bin, which is the largest and most important bin for PCB accumulation, the agreement is less than 50% and no discussion is provided about this difference. 1.20

19. P. 4-25: References to Fig. 3-28 should be to Fig. 3-27 and to USEPA results and not to NYSDEC. Also, comparison of Fig. 3-27 and Fig. 4-18 does not appear to back up the statement that division between fine and coarse-grained sediment being consistent between NYSDEC data and EPA data. Fig.3-27 shows a high percentage of fine-grained samples for the EPA data vs. 45% for NYSDEC data. 1.21

20. P. 4-26: The paragraph at the bottom of the page highlights another uncertainty in comparing 1994 inventory data, namely the uncertainty in the boundaries of the hot spots. EPA needs to gather all the uncertainties in all areas of the report's analysis and provide an overall error estimate and then evaluate whether any estimate can be made of PCB loss or gain with any degree of confidence. 1.22

21. P. 4-27: References should be to Figs. 4-19 and 4-20 and not to Figs. 4.2-3 and 4.2-4. 1.23

22. P. 4-33: The conclusion at the bottom of this page regarding loss of PCBs requires that the 1994 data set accurately replicates the 1976-78 data set. For reasons set forth in other comments in this report, conclusions such as set forth here are not justified by the analysis presented to date as set forth in this report. 1.24

23. P. 4-34: The statement at the bottom of page 4-34 and at the top of page 4-35 that Profile 2 of Fig. 4-25 shows burial is not occurring, completely ignores the profiles shown by Fig. 4-24 of the high resolution cores definitely which clearly show very low PCB concentrations in the top several inches of sediment, definitely indicating burial. The "peak" in the upper 12 " of Profile 2 is undoubtedly due to the mixing of the very high concentrations of PCBs buried several inches below the surface with the low concentration sediments near the surface. The low resolution core profiles provide **no** basis for making any conclusion about whether burial is or is not occurring and statements such as "strong PCB profile evidence for long-term sediment loss or lack of burial" should be deleted from a revised issue of this report. 1.25

24. P. 4-35: Statements in the second and third paragraphs on this page seem to be biased toward a conclusion that PCB loss is occurring. Why is it that "long-term storage is clearly not assured" but long-term loss apparently is assured? Why is a PCB inventory increase the result of bad data but all losses are absolutely true? 1.26

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JOHN E. SANDERS
33 Sherman Avenue
Dobbs Ferry, NY 10522
31 August 1998

Via FAX transmission to 637-4284; original sent Priority Mail

Douglas Tomchuk
USEPA - Region 2
290 Broadway - 20th Floor
New York, NY 10007-1966

Attn: LRC Comments

Dear Doug,

I think that the main point about the low-resolution coring is that the results totally destroy the basis for the model GE has been trying to "sell" (i.e. "clean" sediments are covering "dirty" sediments and thus solving the Hudson River PCB-pollution problem). Even GE admits that the river picks up PCBs as it flows down the Thompson Island Pool (TIP), but the key issue still remains to what depth does the flowing water actively interact with the sediments and thus add to or subtract from the sediment load of PCB's. GE may be correct that the deep-lying hot spots are not part of the day-in-day-out game of "put and take" that the river plays with the bottom sediments. The problem may be with all the sediments in the TIP, not merely the hot spots that keep dominating the discussion. What a pity that my repeated suggestions about making relief peels from the vertical faces of cores cut longitudinally (not wafered, as is needed for geochemical analyses) have not attracted any enthusiasm. With a decent set of relief peels in hand, the details of the laminae would show how the sediments and water are interacting. Despite the lack of peels, I think the LRC report provides a solid scientific basis for dispelling GE's myth about "covering with a clean blanket." Too bad we are not loaded up with data about how deep down into the dirty carpet the river keeps thrashing out all those PCB's that go downriver. 1.1

Respectfully submitted,

John E. Sanders

John E. Sanders, Ph. D.
Geologist

JES/s

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UNIVERSITY AT ALBANY

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LC-2

August 29, 1998

Mr. Douglas Tomchuk
USEPA – Region 2
290 Broadway – 20th Floor
New York, NY 10007-1866

ATTN: LRC Comments

Dear Mr. Tomchuck:

In retrospect of the Science and Technical Committee (STC) meeting of August 18, I wish to append a few comments directed at both the DEIR and LRC. For many STC members, the Hudson River reevaluation is not a principal activity and a thorough review of each report in the sequence begs both a revisit to previous work as well as a consideration of current work and comments not included in the report. For this the STC meeting is invaluable, but in my case, a further digestion is necessary.

1) As I noted at the meeting, an evaluation of all contributors to variation is necessary in comparing the 1984 and 1994 sediment cores in order to test or verify any conclusions. If the General Electric Co. (GE) is prepared to run the different GCMS analysis methods for PCB on the same samples this can be accomplished, but I recommend that an independent statistician be engaged to do the required analysis of variance. 2.1

2) Variance estimates for various data used in the DEIR, such as water column sediment and PCB loadings, are needed in order to derive confidence limits for model predictions. Since such estimates are not cited in the DEIR, they may have to be obtained from other data sources if a direct estimation cannot be made. 2.1a

3) Water column PCB and sediment concentration data used in the DEIR are regressed on River discharge or flow for the purposes of model calibration. As I have previously commented, this assumption calibration introduces an added variance since neither of these quantities has a simple relationship to River flow. Further, the Hydro Qual, Inc. study of the Thompson Island pool (TIP) (1997) has pointed out the importance of Moses Kill and Snook Kill discharges to annual sediment in the TIP deposition; a factor not addressed in the DEIR. 2.1b

4) Water column PCB data, and interpretations thereof, used in the DEIR need a thorough overhaul before any meaningful model calibration is possible. The point I have raised about data feedback is particularly pertinent here for it is clear from an inspection of the 1990-1998 data furnished to the NYSDEC by the G.E. Co., that the 1994 EPA sampling data used for the DEIR is not representation. There are several reasons for this, viz:

a) 1994 water sampling was conducted without considering the variability of water column PCB content in space and time at the sample point. This omission is particularly acute at the Rogers Island station where the PCB mass flux into the TIP pool is to be determined. The problem was initially pointed out by Tofflemeier (1984), and further evaluated by O'Brien and Gere (1993) via cross channel and depth sampling, and dye release tests. In this regard, most of the 1990-1998 data was obtained from composited water column samples from both channels at Rogers Island, the bulk being taken on a regular (weekly) basis. 2.2

b) The 1994 sampling occurred during a period of documented DNAPL containing PCB released from workings and by seepage above the TIP. These releases temporarily reversed the previous trend of declining annual PCB loading at low flow in the TIP; however, this effect appears to have ended by 1996 with significantly lower PCB contents subsequently being observed. 2.3

c) The bulk of Hudson River water column sampling has been during low to very moderate flow conditions, and was not regularly conducted on an annual basis prior to the 1990-1998 data. Limited observations during past high discharge events in particular have shown that PCB contents are very variable, and that erratic transient "pulses" of high PCB content may occur during both high and low flow. Because of the lack of close time interval sampling during high discharge events, the PCB mass flux of the event at Ford Edward (and event loading to the T.I. pool) cannot be estimated. However, if the lower PCB contents observed for events in 1996-1998 (Post DNAPL; including a 50-year event, Jan. 8-12, 1998) are confirmed as the norm, then the problem of model calibration becomes much simpler. 2.4

5) PCB mass loading of, and discharge from the TIP are estimated critical to an independent evaluation of the 1984-1994 low-resolution core comparisons, and to a proper interpretation of the operative mechanisms thereto. The lack of data on PCB loadings in high discharge events presents a major difficulty because it appears no distinction can be made between partially dechlorinated PCB released from recently deposited sediment (i.e. <3 years old) and that presumed to be released from older "hot spot" reservoirs. 2.5

While seasonal (water temperature viscosity) and river discharge (less dilution at low flow?) effects in water column PCB may be inferred from the 1990-1998 data, the rate of decrease in concentrations shown in 1996-1998 (including non-detectable levels at the TIP dam, January 6, and 27; December 29, 1997) is inconsistent with an inference that the bulk of PCB loading, 1991-1995, at the TIP dam was by diffusional loss from hot spot sediments deposited prior to the 1976-1978 core sampling. With the apparent "shut-off" of PCBs entering the River above Fort Edward, we can now, possibly for the first time, examine conditions and processes in the TIP without this complication. 2.6

Very truly yours,

George W. Putman

George W. Putman, Ph.D.
Emeritus Faculty

cc: R. Sloan, NYSDEC
W. Nicholson, STC
J. Haggard, GE

August 30, 1998

Douglas Tomchuk
USEPA - Region 2
Attn: LRC Comments
290 Broadway - 20th Floor
New York, NY 10007-1866

Re: Copy of a Letter to Administrator Browner offered as Comment to Low Resolution Coring Report

to: Carol Browner, EPA Administrator
Washington, DC

Dear Ms. Browner;

As chairman of the Agricultural Liaison Group in the Hudson River PCB Reassessment Process, I have been active in this process for the past 8 years. After meeting on August 11th, our Liaison Group members have agreed that I should express our dissatisfaction with the Low Resolution Coring Report and the Community Interaction Program process directly to you.

We must object to suggesting that the results of this report indicate a "crisis" situation that may require accelerating the process. This is ridiculous. The data used is already four years old. Why is it only now becoming a crisis? The methodology of the Core Report is quite controversial and certainly should be peer reviewed. I understand that even the Science and Technical Committee was critical of this report. A number of broad assumptions are made in this while completely ignoring the fact that water column and fish studies continue to show a decrease in PCB levels in the Hudson. How can we possibly declare the river in a "crisis" situation? 3.1

There is no emergency! Fish and water column measurements should obviously be considered more accurate than the sediment studies in determining the immediate risks associated with the river. Calling this an emergency should not be used as an excuse to ignore peer review!

As one of the Community Interaction Groups participating in this process from the start, we were told that we would be part of the process for determining the remediation of the Hudson River. We would be made aware of new information and allowed to comment.

We joined in this process in good faith but have become alarmed at how this process has been handled in the last few years. We learn more about EPA activities on this issue in the newspaper than we do at EPA sponsored meetings. It doesn't appear that we have any influence on this process. Many of our comments go unanswered.

The release of the last two reports has again been a media event. You have publicly stated that PCBs are "likely" human carcinogens. Those of us who have followed this issue know this is not true. Yes, there is some scientific disagreement but the large number of human health studies done certainly indicate that PCBs are NOT carcinogenic. We are appalled that such statements are made by EPA officials before the peer review process has been completed. Early in the process we were promised peer review of the science involved in this issue. These reckless statements certainly point out the continued need for the review process. Conclusions drawn before peer review is completed should not be material for news releases.

This was supposed to be an open and public process. You even told Congress that public input is important. Well, this is public input from a group that has stayed with this process for eight years. We are frustrated and disgusted with secret landfill siting surveys and news releases promoting reckless conclusions drawn from reports that no one else has seen or reviewed.

Our active participation in this long process should warrant us a response to these comments. EPA handling of this process seems to be much more political than scientific and we are frankly not going to sit by quietly as if we have approved of this process!

Sincerely,

Thomas A. Borden

Thomas A. Borden, Chairman
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LC-4

August 31, 1998

Mr. Douglas Tomchuk
U.S. EPA — Region 2
290 Broadway — 20th Floor
New York, NY 10007-1866

Attn: Low Resolution Coring Report Comments

Dear Mr. Tomchuk:

Below are my comments regarding the U.S. Environmental Protection Agency's (EPA) Low Resolution Coring Report (LRCR), dated August 1998, which was presented by TAMS, Inc. at the July 23, 1998, meeting of the Hudson River Joint Liaison Committees. I respectfully request that these comments be made available to any and all interested parties and made part of the administrative record for the Hudson River Superfund site.

I. First and foremost, there is no emergency.

I must stress that the people of the Upper Hudson River in no way believe that there is an "emergency" situation occurring in the Thompson Island Pool.

I have been instrumentally involved in this issue for more than 20 years, during which time I have attended numerous meetings, read thousands of pages of documents and met with many members of the concerned and interested public. Never have I heard mention of an "emergency" situation in the river.

It's really no wonder. By every measure, the Hudson River is better than it has been in decades. Fish levels are declining dramatically; PCB levels in water are also lower than ever before. These improvements certainly are no secret to the public at large. Tourism dollars are once again flooding into communities that lie on the Hudson's shores. Recreational fishermen are traveling from far and wide to fish the Hudson's trophy fishery. New touring boat companies are sprouting up, taking travelers on trips to view the scenic vistas. And I'm sure you are aware that the bald eagle, once considered an endangered species, is now returning and procreating on the banks of the Hudson. The bald eagle is only one example of the health and vitality of the Hudson River's wildlife. 4.1

This does not sound like an emergency situation. Contrary to Regional Administrator Fox's comments, it doesn't sound "startling" either.

If, as EPA concluded from the LRCR, there has been a net loss of 40% of the PCB inventory in the hot spots from 1984 to 1994, we would certainly be seeing it in the fish, the water and the wildlife. This, as stated earlier, just is not the case. Fish and water levels are not increasing; they are decreasing. And, the PCBs in fish do not look like the PCBs buried in the hot spots; they look more like the PCBs that recently entered the Hudson from GE's Hudson Falls plant site. Finally, to my knowledge, no mechanism has been identified that would drive this much material from the hot spots into the water column. As such, EPA should have gone back to the drawing board to see where they had erred, instead of needlessly scaring the public with claims of an "emergency" situation in the Thompson Island Pool. 4.2

II. Politics is prevailing over good science.

Last year, I discovered that EPA had conducted, unbeknownst to the public, a siting study to identify potential sites in the upper river for a PCB landfill. Need I remind the Agency of the public uproar that occurred as a result? In response, EPA revised its schedule for the Hudson River Reassessment to allow for greater public participation, responsiveness summaries and peer review (see below).

The lower river environmental groups, who have been pushing for a destructive dredging and landfilling project for years, strongly criticized the Agency for the schedule revisions. Scenic Hudson and Sloop Clearwater met with the press and mailed hundreds of letters to lower river elected officials in an attempt to persuade EPA to reverse its new schedule. Initially, and thankfully, I thought their efforts had failed. After all, who could argue with greater public participation and independent, scientific oversight on a matter of such grave importance? 4.3

Now, however, we hear that the Agency is most likely going to proceed with a remedial action this fall — read, dredging and landfilling. Looks like the lower river environmental groups won after all. I can't help but wonder if this call to action is some misguided attempt by the Agency to appear hard-hitting and aggressive on the Hudson River, in essence, to satisfy the Agency's political agenda.

Throughout the years I've been participating in this process, I have always been reassured that good science would prevail. Today, I have serious doubts.

III. The Low Resolution Coring Report fails to tell us anything new about the Hudson River.

There are obvious limitations to the analysis EPA conducted in its LRCR.

A) EPA collected only 60 core samples to characterize what is happening in the Thompson Island Pool hot spots. That's approximately one sample every three acres! In its 1984 effort, the New York State Department of Environmental Conservation (DEC) collected more than 400 — more than six times as many. Conditions in the Thompson Island Pool vary greatly, 4.4

even within the hot spots. Sixty samples is nowhere near the appropriate number of samples for this type of evaluation.

B) In 1984, because of limitations in technology, the DEC evaluated core samples for PCBs with three or more chlorines. Today, laboratory detection methods have improved significantly, allowing analysis of all, or total, PCBs. In the report, EPA discussed the importance of correcting its methodology to ensure that the same factor (PCBs with three or more chlorines) was being measured in 1984 and 1994. Yet, the analysis in 1994 included all PCBs, including those with one or two chlorines. Essentially, EPA conducted an apples-to-oranges comparison, where PCBs with three or more chlorines are the apples and total PCBs are the oranges. 4.5

At the recent meeting of the EPA Science and Technical Committee, Ed Garvey of TAMS, Inc., acknowledged that a comparison of PCBs with three or more chlorines in 1984 to PCBs with three or more chlorines in 1994 could lead to the conclusion that 73% of the hot spot PCBs have been lost. Now this is a "startling" discovery — one that everyone knows has not occurred. Therefore, this analysis must be flawed. 4.6

C) EPA analyzed its cores by slicing them into 9-inch slices. As a result, the Agency concluded that the highest PCB levels are within the top 9 inches of sediment and implied that the highest PCB concentrations are now available to fish and other wildlife. From my understanding of the river, fish do not burrow down deep into the river sediment to eat. Only the PCBs in the very top inches of sediment are available to the fish. Therefore, to conclude that the highest PCB concentrations are within the top 9 inches of sediment is not sufficient. EPA must continue its analysis to discover more specifically where, within the top 9 inches, the highest levels of PCBs reside. 4.7

IV. The Low Resolution Coring Report must be peer reviewed prior to being used as justification for a remedial action.

EPA wisely chose to incorporate scientific peer review into its Hudson River Reassessment. This process will be instrumental in providing the public with an independent, technical review of the science behind EPA's reports. I fully support this development, although I do continue to urge the Agency to provide peer reviewers with relevant critiques, prepared by GE and the public, of the reports under evaluation. 4.8

That being said, it is alarming that the Agency is planning to sidestep this critical process. You announced that EPA has begun a "quick-term study" to evaluate if, based on the results of the LRCR, an immediate remedial action is required in the Thompson Island Pool.

As stated earlier, the report has several deficiencies — some of which are critical to the Agency's main conclusions. To depend upon this report, without first peer reviewing it, is nonsense and does not withstand the "laugh test." EPA must continue with the process it committed itself to — first, peer review. Then, if necessary, remedial action. Anything else is foolhardy, rash and not scientifically sound.

V. Even if dredged spoils are not dumped locally, dredging isn't the appropriate answer for the Hudson River.

Finally, you stated that, if EPA determines that dredging is required in the Thompson Island Pool, only "existing permitted landfills" would be considered. You said, "We would not look to site a landfill in the Hudson Valley. We would only go to existing facilities." 4.9

DEC estimated that the Thompson Island Pool hot spots encompass approximately 1.3 million cubic yards of material. To the best of my knowledge, that is much more material than any currently-licensed facility could store. Therefore, EPA must already have an idea of how much material they are planning to recommend for removal by dredging.

This is a conclusion I cannot, and will not, stand for. I need not remind the Agency that more than 60 village, town and city local governments, as well as chambers of commerce and local farm bureaus, unanimously approved resolutions opposing dredging and dumping of Hudson River PCBs. The Agency's attempt to placate the public by casting doubt on the need for a local dump is, unfortunately, transparent. The people of Fort Edward will not suddenly support a dredging project because dredging spoils will not be dumped on our farmland. We will continue to oppose such a project because it is not the correct answer for the Hudson River.

Sincerely,

Merrilyn Pulver

Merrilyn Pulver

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August 31, 1998

Douglas Tomchuk
USEPA - Region 2
290 Broadway - 20th Floor
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Re: LRC Comments

Dear Mr. Tomchuk:

We submit herewith the comments of the General Electric Company ("GE") on the Low Resolution Sediment Coring Report which the U.S. Environmental Protection Agency released for public comment in July, 1998.

Our Executive Summary in short form and our comments at greater length focus on the deficiencies and weaknesses of the Report, in particular the fact that the very limited amount of data collected in 1994 is insufficient to permit any useful or reliable extrapolation to conditions in the so-called "hot spots" or the Thompson Island Pool generally. We will not repeat in this letter the analysis set out in the comments.

This is the appropriate place to address the gist of the comments which we understand that EPA made at its press conference at the time the Low Resolution Coring Report was released. GE was excluded from hearing what EPA, through the press, had to say to the public, but we understand that at least three points were made. EPA stated it was startled by the conclusion TAMS had reached that there had been a net loss of approximately 40% of the PCB inventory from the "hot spots" of the Thompson Island Pool between 1984 and 1994. EPA analogized losses of this magnitude to discovering a leaking drum. Consequently, EPA was considering whether some form of emergency action should be taken prior to completing the Reassessment.

The image of the leaking drum is a powerful one. It summons to mind high concentrations originating in the so-called "hot spots" in the Thompson Island Pool, moving downstream out of the Pool and causing substantial PCB body burdens of fish and an

unacceptable health risk. EPA has also conveyed the idea that conditions are worsening. The net result is the belief that the situation is far more risky and threatening than EPA has believed it to be at any time since the Reassessment began in 1990.

This vivid tale of imminent danger on the Hudson does not withstand scrutiny.

Let's start with the 40% net loss of PCBs from the so-called "hot spots" of the Thompson Island Pool. If the comparison of the 1984 PCB inventory in the Pool to the 1994 PCB inventory in the Pool is carried out in the manner TAMS argues is correct, this number doubles to 80%. The Report points out that in 1984 PCBs were measured as tri-chlorinated and higher homologues; monos and dis were not measured. In 1994 total PCBs were measured. The appropriate comparison between 1984 and 1994 is to compare the tri- and higher PCBs for each year. Although TAMS argues persuasively that this is the appropriate method for comparison, no such comparison is presented in the Report. In fact, at the August 1998 meeting of the Science and Technical Committee, Dr. Edward Garvey, who presented the findings of the Report, responded to a question by saying that he had never performed the comparison. GE found that statement startling. GE performed the comparison of the 1984 PCB inventory to the 1994 inventory on a tri- and higher basis using the data TAMS had selected for comparison. GE did this despite the fact that the company contends there is insufficient reliable data to produce useful or statistically meaningful results. When the comparison is done as TAMS advocated, the conclusion follows that there was a net loss of 80% of the PCB inventory from the TIP between 1984 and 1994.

This result is not startling; it's amazing.

Of course, in considering whether something should be done about this situation, one presumes this course of events continued from 1994 to 1998 (if the course of events has stopped, the analysis of the Report would provide no basis for action today). If 80% of the inventory was lost in ten years, what has happened after another four years? If the loss was at the rate of 8% a year, all the PCBs would have disappeared from the so-called "hot spots." If the losses were declining in the manner of a half-life, something like 10% of the 1984 inventory would remain and would be lost at a rate of 1½% of the 1984 inventory a year. Both of these scenarios result in a low rate of loss at the present time. Rather than increased risks, we would see low and continually decreasing risks in the Upper Hudson. Put another way, if the so-called "hot spot" deposits in the TIP have been scoured out since 1984 so that only somewhere between 0 and 10% of the inventory remains, there isn't anything left in the Thompson Island Pool that is worth chasing. Any action allegedly addressing increased risk from PCBs in the sediments of the Thompson Island Pool cannot rest on the analysis of this Report. It would have to rest on a repudiation of this Report.

Let's sober up and be frank. Nothing remotely like an 80% loss of the 1984 PCB inventory in the TIP has taken place. Since 1991 GE (and before that the U.S. Geological

Survey) has had in place a water monitoring program that measures PCBs entering and leaving the TIP. We know that it is fully capable of detecting substantial additions of PCBs to the water column. That's how GE found the Allen Mill releases in 1991. We also know that if there has been a bias in the reporting of PCBs leaving the TIP, as measured at the Thompson Island Dam from 1991 to 1997, it has been a bias resulting in an overestimate of PCB loss from the TIP. If there had been major losses out of the Pool, we would have known it. In reality, the losses were probably significantly lower than what EPA and GE believed them to be from 1991 to 1997.

The next obvious point is that when you go out and look for the so-called "hot spots" they are still there. GE did a limited coring program this summer reoccupying a number of sites where EPA had taken cores in 1994 and NYSDEC had taken cores in 1984. If there had been a loss of 80% of the PCB inventory from 1984 to 1994 that continued to 1998, there would, of course, be virtually no PCB inventory left. GE found the PCBs where NYSDEC found them in 1984 and EPA found them in 1994.

The real problem here is the one that GE warned EPA of in 1992 and which the Report instinctively recognized in its examination of the so-called "hot spots" below the TIP. In a large and highly heterogeneous mass one cannot extrapolate from a very limited number of data points to calculate the amount of one constituent with any useful degree of reliability. Nevertheless, the Report made such extrapolations. Above the Thompson Island Dam, the extrapolation produced results showing substantial losses of PCBs; below the Dam, the extrapolation produced results showing substantial gains of PCBs in some of the so-called "hot spots," particularly "hot spot" 28. The TAMS Report elected to believe the results of substantial loss and dismiss the substantial gain in PCB inventory in "hot spot" 28. "The PCB inventory for *Hot Spot 28* calculated from the low resolution coring data is considerably greater than previous estimates. This apparent 'gain' in inventory is attributed to significant underestimates in previous studies rather than actual deposition of PCBs in *Hot Spot* 28." The reality is that the results above the Dam are just as implausible as those below the Dam and should be disregarded.

We look forward to discussing this matter with you when you have had the opportunity to consider our comments and to soberly and prudently weigh the reliability and plausibility of this Report against the mass of data and evidence on the fate and transport of PCBs in the Upper Hudson collected by GE and the federal and state governments over many, many years.

We are confident you will reach the conclusion that Region 2's Director of the Emergency and Remedial Response Division did in his cover letter to the Report:

> As with the previous Phase 2 Reports, it is important to recognize that the conclusions in this report, although significant, do not indicate whether or not remedial action is necessary for the PCB-contaminated sediments of the upper Hudson. The numerical analysis (computer modeling) of fate and transport of PCBs, the associated ecological and

human health risk assessments, and a feasibility study must be completed before any such conclusion can be reached.

If you should feel that there is any basis, relying on this Report, to take action on the Hudson prior to completion of the Reassessment, it is essential to conduct the peer review to which EPA is committed before action is taken. The ultimate point of the peer review is to assure sound science in decision making. That requires peer review before the decision is made. We are interested in what the peer reviewers will make of the Report's advocacy of comparing the 1984 inventory to the 1994 inventory on the basis of tri- and higher PCBs and its unexplained omission of that comparison from the Report.

Very truly yours,

Angus Macbeth

Angus Macbeth

cc: Richard Caspe
William McCabe
Melvin Hauptman
Douglas Fischer, Esq.
John Cahill
Frank Bifera, Esq.
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COMMENTS OF THE GENERAL ELECTRIC COMPANY ON

Phase 2 Report – Review Copy
Further Site Characterization and Analysis
Volume 2C Low Resolution Sediment Coring Report
Addendum to the Data Evaluation and Interpretation Report
July 1998

August 31, 1998

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COMMENTS OF THE GENERAL ELECTRIC COMPANY ON THE EPA LOW RESOLUTION CORING REPORT

SECTION I
INTRODUCTION AND EXECUTIVE SUMMARY

A. Introduction

The General Electric Company ("GE") is pleased to submit these comments on EPA's July 1998 "Phase 2 Report – Review Copy, Further Site Characterization and Analysis Volume 2C-A Low Resolution Sediment Coring Report, Addendum to the Data Evaluation and Interpretation Report, Hudson River PCBs Reassessment RI/FS" ("Report"). These comments supplement GE's comments on EPA's 1997 "Data Evaluation and Interpretation Report" ("DEIR"). The DEIR focused on interpretation of high resolution sediment cores and water column data collected by EPA's prime contractor, TAMS Consultants, Inc. ("TAMS"). The 1998 Low Resolution Sediment Coring Report provides TAMS' analysis of low resolution sediment cores obtained in the Upper Hudson River[1] in 1994 and purports to show a 40 percent reduction in PCB mass in the "hot spots" in the Thompson Island Pool ("TIP" or the "Pool") between 1984 and 1994. As these comments demonstrate, the data collected by TAMS and used in the Report cannot be used to determine such a mass change. Further, the methodology and statistics used by TAMS are fundamentally flawed. Because of the substantial uncertainty associated with the data, which is inadequately treated in the report, no judgments about mass changes can be drawn from the low resolution cores. TAMS very substantially overestimates the loss of PCBs from the TIP. The available evidence, including data collected by GE in 1998, demonstrates that burial of PCBs through sediment deposition, rather than loss through erosion, is occurring in the Upper Hudson River.

[1] GE disputes the statement on page 1-3 of the Report that the Hudson River PCBs Superfund Site "encompasses the Hudson River from Hudson Falls ...to the Battery in the New York Harbor." The documents in the administrative record for the addition of the site to the CERCLA National Priorities List explicitly limit the reach of the site to the area above the Federal Dam at Troy, and EPA's post-rulemaking comments to the contrary cannot change this fact.

B. Executive summary

The EPA low resolution coring program is part of a larger effort whose goal is to develop an understanding of the fate of PCBs in the Upper Hudson River. The low resolution coring program used a small subset of the relevant data to infer the fate of PCBs within selected sediments in and downstream of the TIP. Through analysis of these limited data, TAMS drew sweeping conclusions:

- A significant portion of the contaminated sediment in and below the TIP is not being buried; rather the PCBs in these sediments have been lost through erosion or other processes.
- Forty percent of the PCBs in the "highly contaminated" sediments in the TIP were lost between 1984 and 1994.
- More than 50 percent of the PCBs in three of the major "hot spots" downstream of the TIP were lost between the mid-1970s and 1994.

These conclusions are unsupportable. In fact, these conclusions are contradicted by the vast amount of relevant data that were not considered, as well as by other analyses conducted by EPA and by GE.

TAMS' conclusions are incorrect because its analysis suffers from two fundamental defects, as well as numerous other deficiencies and errors. First and foremost, the analysis is based on limited data that are subject to uncertainty sufficient to preclude identifying any trends that may exist within the sediment. Second, the analysis was conducted using incompatible measurements of PCBs; that is, PCBs with three or more chlorines (PCB_{3+}) in 1984 were incorrectly compared with total PCBs in 1994. Using compatible measurements (i.e., PCB_{3+} in both years) results in an implausibly large mass loss, unsupported by the relevant evidence or by the identification of a mechanism likely to cause such a loss.

B.1 Limitations of the data preclude the generation of useful results.

The central objectives of EPA's low resolution sediment coring program were to:

- Obtain new estimates of sediment PCB inventories at selected locations in the Thompson Island Pool to compare against the existing PCB sediment database constructed from the 1984 NYSDEC survey.
- Refine the PCB mass estimates for a limited number of historic *hot spot* locations defined by the 1976-1978 NYSDEC survey in the Upper Hudson below the Thompson Island Dam. (Report, at ES-2).

The starting point for estimating the PCB inventory in the Thompson Island Pool, particularly the "hot spots," is the extensive sediment coring and sediment grab sampling which NYSDEC performed in 1984. NYSDEC collected approximately 1,200 cores and grab samples in the Pool. Despite this extensive data collection, NYSDEC and EPA made three estimates of the PCB mass reflected in the cores and grab samples which varied by 46%, between 23.2 metric tons ("MT") and 14.5 MT. This uncertainty in the actual size of the inventory was largely the result of the heterogeneity of PCB deposition: samples taken in close proximity to each other differed substantially in the concentration or mass of PCBs which they exhibited. This introduced substantial uncertainty into the final results when these PCB numbers were extrapolated to larger areas. 1.1

The uncertainty as to what the inventory was in 1984 meant that any comparison of a 1994 inventory estimate to the 1984 inventory estimate would inevitably have a substantial measure of uncertainty. Given the known heterogeneity of the PCB concentrations in the Pool, a substantially more tightly bounded 1994 inventory estimate could only have been achieved by the collection of very substantial numbers of samples, well in excess of those taken by NYSDEC in 1984. EPA elected not to follow such a course.

The Agency decided to follow an approach that would attempt to duplicate a limited number of the cores and grab samples taken by NYSDEC ten years before and to extrapolate

from those matched pairs of cores to conditions throughout the "hot spots" of the Pool. The matched pairs comparison needed to meet five rigorous conditions in order to provide credible and persuasive results:

1. There could only be insignificant error in the PCB concentration measurements; 1.2
2. The full vertical extent of PCBs had to be captured in both 1984 and 1994 cores;
3. One had to demonstrate that grab samples taken in 1984 could be fairly compared to core samples taken in 1994;
4. The same sediment had to be sampled in 1984 and 1994; and
5. One had to demonstrate that changes in PCB concentrations at sampled locations could be extrapolated to other locations.

These conditions were not, and probably could not be, met.

The measurements of PCB concentrations had substantial error. The Report shows split sediment samples differing by up to 120% with a mean difference of 36% (Report, at 2-18).

The full vertical extent of PCBs was not captured in all of the 1994 samples. By TAMS' calculation, 19% of the cores taken in the Pool failed to capture all of the PCBs (Report, at 2-20).

The 1984 grab samples cannot be fairly compared to the 1994 core samples. The Report acknowledges that the "lack of good depth control adds uncertainty associated with core to grab comparisons" (Report, at 4-7). In fact, both the 1984 and 1994 cores exhibit substantial vertical concentration gradients which make plausible extrapolation from grab depth to core depth impossible; consequently, fair comparison of grab samples to core samples is also impossible.

The same sediment was not sampled in 1984 and 1994. For example, the 1994 locations were known to a precision of ±3 feet. Assuming the same precision for the 1984 locations, the location matching has an error of ±6 feet. Analysis done by GE on data collected in 1990-91 at "hot spot" 5 showed PCB concentration in samples taken 2 to 5 feet apart differed by more than

a factor of 5. EPA's own closely grouped 1994 cores show significant variation in PCB mass and concentrations.

Extrapolation from sampled locations to other locations cannot be shown to be plausible. The 1994 sampling was at a density of one sample every three acres. This was ten times less dense than the 1984 effort. This simply magnifies the substantial uncertainty already present in the 1984 estimates.

EPA was given ample warning of the fundamental defect of collecting insufficient data to allow for a sound estimate of the PCB inventory in the "hot spots" of the Pool. In its comments on the plan for the Low Resolution Sediment Program in 1992, GE stated: 1.2A

> *The fundamental problem with this approach pertains to the feasibility of defining the PCB mass in sediments of a small area of the River ("hot spots") based on a "small" number of cores. The problem of estimating the mass of PCBs in any area of the River by use of a small number of samples in the Upper Hudson River is well known (Tofflemire and Quinn, 1979, Brown; et al., 1988). The basic problem is that the distribution of PCB concentrations is highly heterogeneous. This is illustrated by the data collected by GE at the site referred to as the H-7 site. (the site of the Hudson River Research Station). These data have already been supplied to EPA. GE extensively analyzed the H-7 site in 1990 by employing capillary column PCB analysis of samples collected on an approximately 12-foot by 12-foot sampling grid. The data showed order-of-magnitude changes in PCB concentrations from one location to the next. This indicates the need to obtain a fairly large number of samples to properly characterize the PCB mass in any given area.*[2]

Finally, these defects and limitations in the data are compounded by the use of a number of dubious or erroneous statistical analyses. These are largely addressed in the body of our comments. They are also set out in the attached report, prepared for GE by Dr. Paul Switzer of Stanford University, on the statistical analyses employed by TAMS. Professor Switzer found

[2] Comments of the General Electric Company on the June 1992 Review Copy of the Phase 2 Work Plan and Sampling Plan for the Hudson River PCB Reassessment RI/FS (July 24, 1992) at page 73.

that many of conclusions in the Report are "not well supported by the reported statistics" and "seem to be drawn from interpretations and conjectures that do not have a statistical inferential basis." Dr. Switzer has been a professor in the Statistics Department at Stanford since 1965 and, among numerous other forms of public and professional service, has been, since 1995, a member of EPA's National Advisory Council on Environmental Policy and Technology.

The conclusion is inevitable that the uncertainty in the NYSDEC's 1984 estimate of the PCB inventory in the Pool, compounded by the limited data collected by TAMS in 1994 and the difficulty or impossibility of collecting data which would meet the rigorous conditions necessary for plausible and persuasive conclusions, has led to results which are not supported and cannot be relied on. The actual uncertainty which surrounds the inventory estimates is so great that they cannot be used for meaningful estimates of PCB loss or gain in the Pool.

B.2 Implausible results are contradicted by relevant evidence. 1.3

The results of the analysis undertaken by TAMS are implausible and contradicted by a wide array of relevant evidence.

There are three conditions which the comparison of the 1984 PCB inventory to the 1994 PCB inventory of the "hot spots" in the Thompson Island Pool should meet before analytical information can be useful in increasing our knowledge of the fate and transport of PCBs in the Hudson River and aiding in selecting the appropriate course of action at the end of this Reassessment. We have already addressed the fundamental benchmark for the generation of useful analysis: the estimates of the PCB mass in 1984 and 1994 need to be reliable so that one can have confidence that the comparison of the two reflects actual conditions rather than unfounded speculation. The estimates do not meet that standard.

There are two further benchmarks by which to judge the Report:

1. The information obtained from the comparison of the 1984 inventory to the 1994 inventory in the paired samples needs to be consistent with other methods of

measurement which are of equal or greater reliability. If more reliable methods of measurement produce materially different results, little weight can be accorded the results of this program; and

2. If the comparison of reliable 1984 estimates of PCB mass to reliable 1994 estimates of PCB mass indicate a trend of increase or decrease, identification of the mechanism(s) which drive the trends adds great value to the information because it identifies the factors, if any, which should be enhanced, diminished, or changed in order to reach an identified remedial goal.

The central and most startling conclusion of the TAMS Report is that "from 1984 to 1994, there has been a net loss of approximately 40 percent of the PCB inventory from highly contaminated sediments in the Thompson Island Pool" (Report, at ES-2). 1.4A

The validity of this conclusion turns on a simple point. In order to have comparable, reliable estimates of PCB mass in 1984 and 1994, one needs to take account of the fact that, in 1984, only PCBs with three or more chlorine atoms ("PCB_{3+}") were accurately measured while, in 1994, total PCBs could be accurately measured. Obviously, the comparison of the PCB mass in 1994 with that in 1984 must be made using a common measurement of PCB mass. The TAMS Report persuasively argues that the proper comparison of PCB mass is made by comparing PCB_{3+} in 1984 to PCB_{3+} in 1994. Appendix E to the Report is an analysis by Tetra Tech in support of this method.

Any reader of the Report who did not approach it with a trained and highly critical eye would believe that the Report followed what it laid out - quite accurately – to be the appropriate method for comparing PCBs in 1984 to PCBs in 1994. For reasons which are not explained in the TAMS Report, this was not done. Inexplicably, PCB_{3+} for 1984 was compared to total PCBs for 1994. When the method recommended in the Report is in fact used, the net loss of PCB inventory in the Pool from 1984 to 1994 is approximately 80%. 1.4B

A method of calculation that concludes that there was an 80% loss of PCB inventory in the Pool between 1984 and 1994, approximately 10.8 MT, cannot withstand scrutiny.

First, this result must be compared to other reliable methods of calculation. The obvious comparison is to loss of PCBs from the Pool measured by PCBs in the water column downstream of the Thompson Island Dam. Routine measurements of PCBs in the water column at Schuylerville from 1984 to 1993 show a total PCB_{3+} loss of approximately 1.0 MT out of the Thompson Island Pool. Thus, the results of the TAMS' analysis are contradicted by a far more extensive and reliable data set which directly measures loss of PCBs out of the Pool. 1.4C

Second, the Report does not identify any mechanism that would result in an 80% or 10.8 MT loss of PCBs out of the Pool between 1984 and 1994. GE has identified four mechanisms which could possibly lead to mass loss out of the Pool: dechlorination, diffusion, scour, and groundwater advection. Taking all of these mechanisms into account results in an 18% loss of PCB inventory from the Pool from 1984 to 1994. The conservatism of this estimate is underscored by the fact that the direct water column measurements result in an inventory loss of approximately 7%. 1.4D

Third, when the trend established by an 80% loss of the PCB inventory in the Pool between 1984 and 1994 is brought forward to the present, it is apparent that the trend is contradicted by present conditions: 1.4E

- GE conducted a coring program in 1998, reoccupying coring sites used by EPA in 1994. Twelve of GE's coring sites were at locations which, under the TAMS method of analysis, exhibited losses of approximately 80% between 1984 and 1994. Between 1994 and 1998, these locations exhibited an increase of 100% in PCB inventory.

- If an 80% loss of PCBs took place from 1984 to 1994, there are various ways of estimating what the loss over the last four years should have been. If the loss were a consistent mass annually, there would be no PCBs left in the Pool. If the

rate of loss were declining in the nature of a half life, the annual loss of PCBs would now be at the approximate rate of 1½% of the 1984 inventory and would have been preceded in the mid-1980s by annual losses that would have been an order of magnitude greater. Neither of these results is discernible from the measurements of PCBs in the Upper Hudson.

Fourth, there are two obvious corollaries to the proposition that there was an 80% loss of PCB inventory from the Pool between 1984 and 1994: there would not be widespread deposition of fresh sediment across the Pool; there would be evidence of widespread erosion. These are simple points. In 1984, the PCBs in the Pool, particularly in the "hot spots," were largely buried – substantial masses of PCBs occurred several centimeters below the surface of the core. For 80% of the PCB inventory in the Pool to reach the sediment surface and be released into the water column, erosion by some means would be required. Conversely there should not be widespread deposition of new sediment. These corollaries which would support and lend credence to the conclusion of the TAMS Report are not borne out by the facts.

As to burial, GE's 1998 high resolution coring shows the highest PCB concentrations occurring well below the surface of the core. ^{7}Be has a half-life of 53 days and is laid down during periods of higher flow in the Upper River. In 1994, the high flow period occurred in April, and TAMS' cores were analyzed in August. Seventy percent of the surface sediment samples collected indicated the presence of ^{7}Be and, therefore, recent deposition (Report, at 2-21). Moreover, the passage of time between the deposition of ^{7}Be and laboratory analysis of the cores and the depth of TAMS' surficial core segment have the effect of limiting detection of ^{7}Be to deposition levels above approximately 0.5 cm. Consequently, the failure to detect ^{7}Be in the remaining 30% of the core samples does not lead to the conclusion that recent burial did not occur. In short, the 1994 ^{7}Be evidence viewed properly is inconsistent with the proposition that widespread deposition of fresh sediment did not take place at the Thompson Island Pool "hot spots." 1.5A

In 1998, GE found that 11 out of the 12 cores it took, which were finely segmented in the surficial 5 cm, showed a steep gradient from lower surficial concentrations to higher 1.5B

concentrations at depth. Additionally, many of the cores in 1998 had the highest PCB concentrations at greater depth than the matching TAMS' core taken in 1994. Once again, this recent empirical data supports burial, rather than erosion, as the dominant process at the "hot spots" in the Thompson Island Pool.

Turning to erosion, GE looked at the difference in PCB congener composition between the more dechlorinated PCBs which entered the river in the past, approximately more than seven years ago, and the less dechlorinated PCBs which entered the river more recently. In short, dechlorination is a result of exposure to the biological processes active in the river; PCBs entering the river recently exhibit materially less dechlorination than the historic PCBs. These historic dechlorinated PCBs would have to make up a very large proportion of the PCBs in the surficial sediments and the water column if 80% of the "hot spot" inventory in the Pool was lost between 1984 and 1994. 1.5C

Three independent tests of relevant data are inconsistent with the corollary which would support the TAMS report. First, TAMS took high resolution cores in the Pool in 1992; the PCBs leaving the Pool best match the PCB composition of the surficial 2 cms of the TAMS' cores and do not match the composition found below 8 cm. Second, NOAA sampled fish in the Pool in 1993. The composition of the PCBs in the fish indicates that the PCBs were not highly dechlorinated and that the fish had not been exposed to the PCB congener distribution present at lower elevations in the 1984 cores. Finally, the flood event of January 1998 was examined since it was potentially an erosional event. Once again, the PCB composition found in the water column at that time was consistent with the PCBs in the surficial sediments in 1991 and not with the dechlorinated sediments which were present at lower depths. In sum, none of these independent tests of the data yields a result which supports the central conclusion of the TAMS report. 1.5D

The result of this analysis is plain: when the 1984 PCB mass in the Pool is compared to the 1994 PCB mass in the Pool, using TAMS' method of comparing PCB_{+3} to PCB_{+3} in each year and using the data TAMS selected from the 1994 coring program, a mass loss of 80% is obtained. That result is utterly implausible. The result is contradicted by direct measurement of

PCBs in the water column. The 80% loss is not supported by the identification of any mechanism which would lead to that result; in fact, the combination of all feasible mechanisms of loss operating at once lead to a total loss of approximately 18% of the PCB_{3+} estimated in the TIP sediments compared to 80% by the method advocated in the Report. When the trend is extended from 1994 to 1998, it is contradicted by the cores GE took this summer and by the actual rate of PCB loss from the Pool which is taking place now. Finally, the broad proposition of erosion in the Pool and absence of sediment deposition which would be necessary to achieve a loss of 80% of the PCBs in the Pool are inconsistent with the empirical data. 1.5E

The Report's treatment of possible loss or gain in the PCB inventory in the "hot spots" below the Thompson Island Pool illustrates the defects which we have discussed in the context of the Pool. The data collected and employed in the Report were extremely limited with the result that extrapolation from the sample data to conditions throughout the "hot spots" was highly uncertain. However, in a number of instances, the extrapolation resulted in apparent increases in the PCB inventory in the "hot spots." In particular "hot spot" 28 showed a very substantial mass increase. TAMS found these inventory gains to be implausible, particularly that at "hot spot" 28. The lesson to be drawn from this is not that large increases in PCB inventory in "hot spots" is implausible, but that extraordinarily broad conclusions built on a foundation of extremely limited data are suspect and, if not consistent with other more reliable data and analysis, should be disregarded. 1.5F

In short, the results of the Report do not pass muster under the benchmarks which test their value for the purposes of the Reassessment. The conclusion drawn by Richard Caspe in his cover letter to the Report largely hits the mark:

> *...it is important to recognize that the conclusions in this report, although significant, do not indicate whether or not remedial action is necessary for the PCB-contaminated sediments of the upper Hudson. The numerical analysis (computer modeling) of fate and transport of PCBs, the associated ecological and human health risk assessments, and a feasibility study must be completed before any such conclusion can be reached.*

We fail to understand in what regard the conclusions of the Report are significant; the rest of the statement is not disputable.

SECTION II
ACCURATE ESTIMATION OF LOSS OF PCBS FROM THE TIP SEDIMENT IS NOT POSSIBLE USING THE LOW RESOLUTION CORE DATA

The approach used to estimate the loss of PCBs from the TIP sediments makes the following assumptions:

A) The PCB concentration measurements have insignificant error;

B) The full vertical extent of PCBs was captured in the 1984 and 1994 cores;

C) Grab samples taken in 1984 can be compared to core samples taken in 1994;

D) The same sediment was sampled in 1984 and 1994; and

E) Changes observed at sampled locations can be extrapolated to other locations.

All of these assumptions are invalid and render the mass change estimates highly uncertain and useless in estimating the fate of PCBs in the sediments of the TIP. The reasons why the assumptions are invalid are summarized below:

A. The PCB concentration measurements have substantial error.

1.6

The report presents data indicating that PCB measurements of split sediment samples differed by up to 120 percent and that the mean difference was 36 percent (Report, at page 2-18). Despite these data, TAMS made no effort to account for analytical error in its statistical analyses. Instead, its mass change calculations assume no error in the 1984 and 1994 mass estimates. In fact, the analytical error is sufficiently large to render the reported mass changes not statistically different from no change.

The report acknowledges that analytical error compromises the utility of the data:

> *Examining the differences in PCB inventory on an absolute basis was not particularly fruitful, in part because the magnitude of the PCB change can represent both analytical variability as well as real change*. (Report, at 4-15).

The report goes on to suggest that expressing change in relative terms diminishes the analytical variability. This is not true. No mathematical calculation can diminish analytical uncertainty. Therefore, dividing the absolute difference by the 1984 mass estimate does nothing to reduce the component of the change that is due to analytical variability.

B. The full vertical extent of PCBs was not always captured in the 1994 cores. 1.7

The vertical extent of PCBs in the 1994 sediment cores was estimated by visual inspection of each core (Report, at 2-3) or by the depth of penetration. To determine whether the entire PCB inventory had been captured, the bottom segment of each core was analyzed for ^{137}Cs. The absence of detectable ^{137}Cs was considered confirmation that the entire PCB inventory had been captured, and the presence of ^{137}Cs was presumed to indicate that the entire inventory had not been captured (i.e., the core was classified as "incomplete"). Based on this criteria, the full inventory of PCB contamination was not sampled in 19 percent of the cores collected in the TIP and 40 percent of the cores collected below the TIP (Report, at page 2-20). Indeed, GE collected sediment cores in 1998 from 12 of the same locations TAMS sampled in 1994 which indicate that many of the 1994 cores may have failed to capture the full PCB profile. In 4 of the 12 cores collected in 1998, the PCB maxima were deeper than in the corresponding TAMS' core (Figure 1a-1). These data suggest either:

1) the TAMS coring technique failed to capture the full PCB inventory, or
2) spatial heterogeneity in sediment and PCB deposition can produce profound changes in PCB profiles within the same region.

Because the full PCB inventory was not sampled in all cases in 1994, a bias toward greater mass loss is introduced into the mass change calculation. The significance of this error cannot be determined because it is not known whether the 1984 samples captured the full

inventory.[3] Nonetheless, this uncertainty introduces an unknown error into the mass change calculations.

C. Grab samples taken in 1984 cannot be compared to core samples taken in 1994. 1.8

In the Report, fifteen of the 60 1994 sediment cores are compared to grab samples taken in 1984. The 1984 mass at the location of a grab was calculated by assuming that the concentrations measured in the grab could be applied to a depth of 17 or 12 inches, depending on sediment type. The Report acknowledges the weakness of this assumption:

> *The lack of good depth control adds uncertainty associated with core to grab comparisons. Nonetheless, the core-grab pairs can still provide some useful information on the change in sediment inventory.* (Report, at 4-7, Underline added for emphasis).

Despite the acknowledged uncertainty, the core-grab pairs are used along with the core-core pairs in calculating the average percentage change in mass.

Both the 1984 and 1994 cores exhibit substantial vertical concentration gradients. These gradients indicate that it is not appropriate to extrapolate concentrations measured in grab samples to sediments below the depth sampled. The PCB profile at depth cannot be predicted from the grab sample data. As such, it is inappropriate to compare a 1984 grab sample and a 1994 core sample.

D. The same sediment was not sampled in 1984 and 1994. 1.9

The report indicates that the locations of the 1994 samples are known to a precision of ± 3 feet (Report, at 2-5). The 1984 locations are likely to be known with equal or less precision. Thus, location matching has an error of ± 6 feet or more. In addition, reoccupation of the 1984

[3] The vibracoring apparatus used to collect sediment in 1984 was larger and more powerful than the apparatus used in 1994, and likely achieved greater penetration. In fact, the penetration depths in 1984 were about 63% greater than the penetration depths in 1994. Thus, it is likely that the 1984 data provide a better representation of the inventory than do the 1994 data.

locations was not perfect. Fifty percent of the 1994 locations were more than 3 feet from the 1984 location and 30 percent were more than 5 feet from the 1984 location. The combination of the uncertainty of location and the reoccupation error results in location matching errors that likely average about 10 feet or greater.

Given that PCB concentrations vary considerably over short distances, location error introduces significant uncertainty and error into the calculations. This variation is exemplified by the fact that 1984 samples located within zones delineated to minimize spatial variability varied by a factor of two to three (Report, at 2-2). Further, regression analyses of the 1994 data indicate that PCBs were only weakly correlated to sediment properties (Report, at Tables 3-4 to 3-8). The best correlate (percent solids) could account for only 36 percent of the variation in PCB mass per unit area among locations.

The lack of correlation between the matched 1984 and 1994 data is illustrated by cross-plots of these data within individual zones (Figure 2a and b). No relationships are evident. In other words, within individual zones, the changes in mass between 1984 and 1994 are random. Given the proximity of the samples within a zone and TAMS' efforts to define zones so that they represent a homogeneous area (Report, at 2-2), the lack of correlation demonstrates that small-scale spatial variability severely compromises the assumption that the same sediment was sampled in 1984 and 1994.

The only data set available to estimate the correlation of PCB levels on the spatial scale of the 1984-1994 location matching is the H7 site data collected in 1990 and 1991 by GE. At this site in "hot spot" 5, core samples were collected at a spacing of several feet. These data were used to assess the correlation between closely spaced locations. A semi-variogram was computed relating the variance of PCB concentration as a function of distance between samples. Correlation is indicated by a variance that is less than the variance of the full data set. The semi-variogram showed that PCB levels were correlated only within a distance of 5 feet (Figure 3). Beyond 5 feet, the variance was near that of the population. Pairing of data based on location indicated that even within the distance of 5 feet, the correlation was weak (Table 1). Samples

within 2 feet of each other differed in concentration by about a factor of 2 on average. Samples within 5 to 10 feet of each other differed in concentration by about a factor of 20 on average.

The lack of correlation at small spatial scales does not imply that correlation does not exist at larger spatial scales. It is possible to have random variation within a contiguous area, such as the H7 site, and still have larger scale correlation. For example, concentrations may be generally higher in one area than another, even though within each area the individual samples show little correlation. For this reason, correlation at larger spatial scales, such as the 100 to 200 foot scales of the 1984 sample grid, cannot be used to infer correlation at the 1 to 10 foot scale at which the 1984 and 1994 data are matched.

Removal of samples more than 5 feet apart will eliminate comparisons for which no correlation can be claimed. However, it must be recognized that even within a distance of 5 feet, the variation between samples is large and imparts considerable uncertainty to any comparisons. This uncertainty must be carried through the estimation of mass change.

When the data set is corrected so that it is limited to pairs of complete cores that are less than 5 feet apart, 24 pairs of cores remain (Figure 4). A regression of the logarithms of PCB_3-mass has a slope of 0.26 with 95% confidence limits of –0.03 to 0.55. Neither the slope nor the correlation coefficient are significantly different from zero [t(slope/standard error of slope)=1.88 < t(.05,22)=2.07; r=0.37, 0.05<P<0.1]. The probabilities are close to 0.05, suggesting that the relationship between the matched 1984 and 1994 cores is weak, if it exists at all. That is, the 1984 and 1994 data are not truly paired observations, a conclusion that is consistent with the analysis of the 1990 and 1991 H7 cores described previously. The mass loss between 1984 and 1994 should not be estimated using the paired core analysis.

It is more appropriate to estimate mass loss on an area-by-area basis, that is, to treat each core as a sample of the average PCB mass within a specified area at one point in time. Then, within each region, the average mass in 1984 can be compared with the average mass in 1994. The definition of these areas must be based upon an understanding of the spatial variability in

PCB concentrations as well as spatial variability in the physical processes controlling PCB fate in the Hudson River. Examples of areas are the zones delineated in the Report as "hot spots."

An advantage of the areal approach is that more data can be brought to bear on the problem. In 1984, there were 24 complete cores in the Thompson Island Pool that matched a 1994 core that was less than 5 feet away (Figure 4). In contrast, there were 298 total cores collected in 1984, of which 210 were in "hot spots."

However, the area-based approach is also subject to severe limitations, some of which were described above:

(1) Analytical errors may be large enough to preclude identification of real changes in mass.

(2) The sample sizes are still small relative to the variability in mass.

(3) Within each "hot spot," the distribution of sampling locations is not spatially random, so that the 1994 sampling does not represent "hot spot" conditions. As described above, the 1994 cores were collected in the vicinity of 1984 cores that exhibited higher-than-average PCB masses.

(4) Statistical problems are associated with estimating the proportional change in PCB mass within each area.

E. Changes observed at sampled locations cannot be extrapolated to other locations. 1.10

The Report uses the average of the percent mass change estimates at 40 locations in the TIP to infer the percentage mass change in all of the areas of "highly contaminated sediments" in the TIP. These 40 locations are equivalent to a sampling density in the TIP "hot spots" of about 1 sample every 3 acres. Given the spatial heterogeneity discussed above, such extrapolation cannot be made.

Spatial heterogeneity is so great that the PCB mass in TIP sediment in 1984 cannot be determined precisely, despite a sampling density more than ten times greater than that used in

1994. Mass estimates of 23.2 MT (Brown *et al.*, 1988), 19.6 MT and 14.5 MT (USEPA, 1997) have been calculated using different methodologies. The relative percentage difference among these values is as high as 46 percent.

In addition, the 1994 sampling program was not designed to provide an unbiased representation of "hot spot" PCB mass. Samples were not collected randomly, but rather in clusters, and the data used in the analysis selectively focused on areas of elevated concentration. The locations of the low resolution cores collected in 1994:

> *...were selected to represent a range of sediment types and sediment PCB inventories, with emphasis placed on areas of greatest PCB contamination.* (Report, at 2-5).

The resulting data are not representative of the Thompson Island Pool as a whole. The PCB masses in 1984 cores that were matched with 1994 cores are considerably higher than the PCB masses in 1984 cores as a whole (Figure 5). The data are also not representative of PCB masses within "hot spots;" the median PCB mass in matched 1984 cores within "hot spots" is 6-fold greater than the median PCB mass in all 1984 cores within "hot spots" (Figure 6).

The Report acknowledges the insufficiency of the data for evaluation of the TIP as a whole:

> *... the 76 cores analyzed in the TI Pool and 94 cores taken downstream of the TI Pool were intended to characterize local conditions in several areas and do not comprise a spatial coverage sufficient to calculate PCB inventories for these areas directly.* (Report, at 2-15).

The Report then contradicts itself by concluding that the calculated average mass change is applicable to the TIP as a whole.

SECTION III
THE METHODS EMPLOYED CONTAIN ERRORS AND OMISSIONS THAT MASK THE IMPLAUSIBILITY OF TAMS' MASS LOSS ESTIMATE

TAMS' methods contain the following errors and omissions:

A) The sum of PCBs with three or more chlorines (1984) was compared to the sum of all PCBs (1994);

B) The geometric mean was used to estimate the average mass loss; and

C) A bias was introduced by eliminating locations where the PCB inventory in 1984 was less than 10 g/m^2

These errors and omissions invalidate the Report's mass loss estimate of 40 percent. Correcting the mistakes yields two alternate mass loss estimates presented below. One corrected estimate is implausibly large (see Section IV). The second estimate is not significantly different from zero, which demonstrates the overwhelming uncertainty of the TAMS approach.

A. The sum of PCBs with three or more chlorines (1984) was compared to the sum of all PCBs (1994).

1.11

The 1984 sediment PCB measurements included only PCB_{3+}. Consequently, PCB_{3+} is the only appropriate measure by which to compare the 1984 and 1994 PCB data.

TAMS devoted considerable effort to developing the appropriate means for comparing the PCB analysis performed by NYSDEC in 1984 with the analysis it performed in 1994:

> *As part of the Phase 2 investigation, a study was made of the differences between the two [PCB analytical] techniques [1984 NYSDEC and 1994 EPA]. This is documented in Appendix E which describes the quantitation issues relating the 1994 Phase 2 and 1984 NYSDEC PCB data. The recommendation of this analysis was to use the 1984*

quantitation of total PCBs as representative of the sum of congeners in the trichloro through decachloro homolog groups...(Report, at 4-5).

Indeed, Appendix E of the Report, which documents the analysis of the 1984 sediment PCB quantitation, concludes that:

"Total PCBs" reported for the 1984 sediment data (calculated by NYSDEC as a sum of Aroclors) provide a good representation of the sum of tri- and higher-chlorinated congeners. They do not accurately reflect the total of all congeners.

The Report's assessment of the analytical issue of how to compare 1984 NYSDEC and 1994 Phase 2 PCB data indicates that the most appropriate way to compare the two data sets is on a PCB_{3+} basis. This is largely the result of the packed column techniques employed by the NYSDEC contract laboratory, Versar. Versar analyzed sediment PCBs using a packed column gas chromatograph ("GC") method standardized using commercial Aroclors (Brown *et al.*, 1988). Generally, packed columns cannot consistently resolve mono-chlorinated congeners. Additionally, Versar only quantified and reported Aroclors 1242, 1254, and 1260. It did not attempt to quantify the lighter-chlorinated Aroclors. As a result, mono- and dichlorinated congeners resulting from the reductive dechlorination of sediment PCBs were missed in the analysis of 1984 sediments.

Tetra Tech reached its conclusion that the 1984 data represent predominantly tri- and higher homologs by performing what it termed an "as if" numerical experiment (Report, at Appendix E). In this numerical exercise, Tetra Tech interpreted the congener data generated from 241 high resolution sediment coring samples from 1992 as if they were analyzed according to the procedures used by Versar. That is, congeners detected in the 1992 samples that represented the packed column peaks used by Versar (Aroclor 1254 and 1260) and NYSDEC (Aroclor 1242) were summed to generate a representation of the 1984 analysis. While this provides strong evidence that the 1984 analysis scheme represented predominantly PCB_{3+}, potential biases not documented in the 1984 reports may not be adequately represented in this numerical experiment.

GE undertook a laboratory experiment to further evaluate what portion of the PCB spectrum is represented by the 1984 NYSDEC sediment data. This study was designed to analytically evaluate the results of the numerical experiment presented in the Report. GE's laboratory experiment consisted of reanalyzing sample extracts generated during the Focused Sediment Coring component of the 1998 TIP Sediment Coring Program (QEA, 1998a) using packed column GC techniques. Twenty-one sample extracts representing a broad range of PCB concentration and composition were used (Table 2). The extracts were analyzed by Northeast Analytical, Inc. on a packed column GC system equipped with a 6.0-foot by 0.25-inch ID glass column. While this set up deviated slightly from Versar's (Table 3), the resulting chromatograph was generally consistent with Versar's (Table 4).

GE's results support Tetra Tech's conclusion that the 1984 PCB quantitation method represents the PCB_{3+} in the sediment samples. The results of the reanalysis appear in Table 2 and Figure 7. The Versar packed column total PCB method grossly underestimates the total PCB concentration of the samples (Figure 7, panel a). However, comparison of the total PCB quantified by Versar with PCB_{3+} generated on the DB-1 capillary column system yields a nearly perfect linear relationship (r^2=0.98) with a slope of unity.

Both Tetra Tech's numerical experiment and GE's 1998 analytical experiment support the Report's conclusion that the 1984 NYSDEC total PCB results must be compared with PCB_{3+} from the 1994 analysis. Comparison on any other basis is technically invalid.

Despite this conclusion, TAMS performed its analysis using total PCBs from 1994. This analysis is therefore, flawed, because the 1994 data account for mono- and dichlorinated biphenyls not measured in 1984. Although PCB dechlorination may have transformed a limited number of PCB_{3+} to mono- and dichlorinated biphenyls between 1984 and 1994, the preponderance of evidence presented in the technical literature indicates that PCB dechlorination occurs rapidly (Rhee *et al.*, 1993; Fish and Principe, 1994) and that PCBs present within the Hudson River sediments were highly dechlorinated by 1984 (Brown *et al.*, 1984; McNulty, 1997).

Performing the analysis presented in the Report using PCB_{3+} in 1984 and PCB_{3+} in 1994 results in an estimated mass loss of 80% of the PCBs in Thompson Island Pool (n=37, geometric mean of DeltaPCB+2).[4] This result is implausible, as described in Section IV, further demonstrating the Report's flawed methodology.

B. The geometric mean was used to estimate average mass loss. 1.12

The Report estimated mass loss within the Thompson Island Pool and in selected "hot spots" below the Pool using two different statistical methods. In the Thompson Island Pool, TAMS used matched core pairs. TAMS computed percent loss of PCB mass in each core pair and then averaged the percent losses in all pairs throughout the Pool. The statistic used by TAMS was "log(ΔPCB+2)," in which ΔPCB is given by:

$$\Delta PCB = \frac{1994MPA - 1984MPA}{1984MPA}$$

TAMS added a value of 2 to ΔPCB to ensure that all values were greater than zero, to calculate the logarithms. TAMS used the geometric mean of ΔPCB as the average change in sediment PCB inventory in the "highly contaminated" sediments of the TIP.

Below the Thompson Island Pool, TAMS computed "hot spot" average mass for 1976-78 and 1994, using the minimum variance unbiased estimator of the arithmetic mean (MVUE; Report, at 4-30). Then, TAMS computed mass change in the "hot spot" as the difference between the 1976-78 and 1994 averages.

These two methods are inconsistent, and in fact can result in very different estimates of mass change. The arithmetic mean of the proportional change is more appropriate than the geometric mean. Indeed, when discussing mass change below the Pool, TAMS states that the

[4] The sample size reported here (37) differs from that of TAMS (40), because PCB data for 3 cores could not be found in the Hudson River Database Version 3.5.

arithmetic mean must be used to compute the average mass in a "hot spot" (Report, at 4-28). Similarly, the arithmetic mean should be used to compute the total proportion of the PCB mass that has disappeared.

In a log normally distributed group of numbers, the geometric mean is equal to the median, that is, the value such that 50 percent of the data are higher and 50 percent are lower. The geometric mean reduces the contribution of high values to the estimate of the mean. For example, consider two hypothetical estimates of the ratio of 1994 mass per unit area ("MPA")/1984MPA: 0.1 and 0.9. The arithmetic average of these two numbers is 0.5; the geometric mean is 0.3. The geometric mean is lower than the arithmetic mean, which is generally the result in a skewed group of numbers. Both ΔPCB and log(ΔPCB+2) calculated by TAMS are skewed (Figure 8), and indeed the geometric mean of log(ΔPCB+2) using the Report's 40 paired values (-40%) is lower than the arithmetic mean (-30%). The arithmetic mean is the more appropriate estimate to use.

Using the arithmetic mean of PCB_{3+} rather than the geometric mean, results in an estimated mass loss of 79% of the PCBs in the Thompson Island Pool (n=37, 95% confidence limits 73% to 85%).[5]

Thus, even after correcting these errors, the resulting mass loss from 1984 to 1994 is implausible, as described in Section IV.

C. A bias was introduced by eliminating locations where the PCB inventory in 1984 was less than 10 g/m^2.

1.13

In the Report, the PCB mass loss in the Pool was computed using only those sample pairs in which the 1984 core contained >10 g/m^2. TAMS explained its selection of data by asserting, without support, that:

[5] The sample size reported here (37) differs from that of TAMS (40), because PCB data for 3 cores could not be found in the Hudson River Database Version 3.5.

...the greater-than-10-g/m^2 group corresponds to sediments typically found in hot spot areas (Report, at 4-13).

In fact, cores with concentrations less than 10 g/m^2 comprise approximately 55 percent of all cores collected within "hot spots" in the Pool (Figure 6). Thus, by excluding cores with <10 g/m^2, the Report's analysis did not represent the "hot spots" as a whole.

In addition, excluding 1984 samples with <10 g/m^2 creates a bias in the analysis. According to the Report, the analysis must include a demonstration that the 1994 PCB mass is significantly different from the 1984 PCB mass. In other words, PCB mass did change between 1984 and 1994. TAMS removed all cores with less than 10 g/m^2 from the 1984 core set, but not from the 1994 core set, implying that cores with less than 10 g/m^2 *were not* representative of "hot spots" in 1984, but *were* representative of "hot spots" in 1994. There is no basis for this assumption, and the removal of those cores caused the 1984 data to be biased high relative to the 1994 data, resulting in an inflated estimate of mass loss.

To illustrate the result of this bias, GE calculated mass loss using the arithmetic mean of PCB_{3+}, including matched samples regardless of concentration. As described in Section II, only complete cores separated by less than 5 feet (n=24) were included. This resulted in an estimated PCB mass loss of 21% with 95% confidence limits ranging from a gain of 31% to a loss of 73%. However, this value, like the 80% figure, is not an unbiased, correct estimate of the mass loss: analytical error was not included in the analysis, the sampling locations were not random, and the data were not truly paired.

To summarize, using the statistical methods presented in the Report, with the correct measure of PCB mass as discussed by TAMS (PCB_{3+} in 1994), the calculated mass change (80%) is implausible. In addition, applying several corrections to the analysis results in a radically different conclusion: the 1994 mass estimate cannot be differentiated from the 1984 estimate. This illustrates our primary conclusion: the data set is so limited and the variability is so great that the 1994 low resolution core data cannot be used to estimate PCB mass loss with any confidence.

SECTION IV
THE CORRECTED ESTIMATE OF MASS LOSS IS IMPLAUSIBLE

Having established that PCB_{3+} is the appropriate basis for comparing the 1984 and 1994 PCB analytical data, TAMS should have presented its PCB loss estimates on this basis. Had it done so, it would have recognized that the loss of PCB_{3+} between 1984 and 1994 (80%) is not supported by other independent estimates of mass loss, particularly water column PCB_{3+} loading estimates. Based on this, TAMS should have concluded that it is not possible to estimate mass change accurately by comparing the results of sediment sampling and analysis conducted in a spatially heterogeneous system by using different methodologies ten years apart.

A. TAMS' approach results in 80% loss of PCB_{3+}.

1.14

TAMS' approach for estimating the change in "hot spot" inventory within the TIP was based upon sediment core MPA calculations:

$$MPA = \sum_{i=1}^{n} C_i \quad L_i \quad \rho_{bi}$$

where, the product of concentration (C, $[M/L^3]$), sediment core section thickness (L, [L]), and dry bulk density (ρ_b,$[M/L^3]$) is summed for all core sections (i=1 to n) over the entire core length. To estimate MPA for the PCB_{3+} ("MPA_{3+}"), C is based upon:

1984 C_{3+} = 0.934*Aroclors, Total (Report, at Appendix E)

1994 C_{3+} = Total PCB - (Mono PCB + Di PCB)

TAMS calculated the change in PCB mass between paired 1984 and 1994 sediment cores using the following equation:

$$\Delta PCB = \frac{1994\ MPA - 1984\ MPA}{1984\ MPA}$$

TAMS incorrectly used MPA_{3+} for 1984 data, while the 1994 MPA was based upon total PCB data. As outlined in Section III, the appropriate comparison of the two data sets is to calculate ΔPCB using MPA_{3+} calculations for both the 1984 and 1994 cores (i.e., ΔPCB_{3+}).

TAMS biased its data set by designating "hot spot" sediment cores as pairs in which the 1984 MPA_{3+} was greater than 10 g/m^2. Change in "hot spot" mass was therefore estimated using a measure of the average ΔPCB. TAMS used the variable log (ΔPCB+2) for combining calculated mass changes for the set of "hot spot" core pairs. The factor of 2 was added to avoid taking the logarithm of numbers less than or equal to 0. TAMS' mass loss estimate was calculated by taking the arithmetic mean of (log (ΔPCB +2)), and transforming it back to a percentage:

$$MASS\ LOSS = \left(10^{AVG\ (\log(\Delta PCB + 2))} - 2\right) x\ 100\%$$

This is equivalent to a geometric mean of (ΔPCB+2). The inappropriateness of using a geometric mean to calculate mass changes is discussed in Section IV. It is used here only for comparison with TAMS' estimate of mass change.

TAMS used this approach to estimate that PCB mass loss in the TIP from 1984 to 1994 was approximately 40%. However, if the calculation is made using the more appropriate comparison of PCB_{3+} for the same set of 1984 and 1994 core pairs, the PCB_{3+} mass loss is estimated at 80% (Table 5) – an implausible result.

Based upon kriging analyses, EPA estimated the entire TIP PCB inventory to be approximately 14.5 MT (EPA, 1997). Because this estimate was made using 1984 NYSDEC sediment data, the PCB_{3+} mass within the TIP can be estimated using Tetra Tech's regression

analysis (Report, at Appendix E). Applying the factor of 0.934 results in a PCB_{3+} inventory of 13.5 MT within the TIP. Assuming that most of the sediment PCB inventory exists within the "hot spots," the 1984 to 1994 PCB_{3+} mass loss estimated using TAMS' approach would exceed 10 MT, a conclusion contradicted by all other available data. Mass loss of this magnitude cannot be supported by known fate and transport mechanisms, or by water column PCB loading data collected over the 1984-1994 period.

B. No fate and transport mechanism can account for the mass loss estimated using TAMS' method. 1.15

Fate and transport mechanisms that result in a net loss of sediment PCB mass include dechlorination, diffusion to the water column, scour, and groundwater advection. Approximations for each of these mechanisms are developed below to estimate the magnitude of expected PCB_{3+} mass loss in TIP sediment from 1984 to 1994.

Dechlorination

Microbially mediated dechlorination of PCBs in sediments occurs when meta- and para-substituted chlorines are substituted by hydrogen under reducing conditions. As a result of dechlorination, higher molecular weight ("MW") PCBs are transformed to PCBs that have a lower MW. Based upon the Report's ΔMW analysis (Report, at 3-9), TAMS estimated that the average total PCB mass loss in the Upper Hudson attributable to dechlorination is 12%.

An estimate for the PCB_{3+} mass loss due to dechlorination was developed using data presented in McNulty, 1997. McNulty compared high resolution sediment cores taken from the same location within the TIP in 1983 and 1991. Core sections were first matched using ^{137}Cs dating so that sediments deposited at the same time could be compared between the two cores. Congener PCB data were then used to evaluate composition changes over the 1983-1991 period. PCB_{3+} dechlorination mass loss from the McNulty data was based upon sediments deposited in approximately 1968, having total PCB concentration in excess of 500 ppm. The homolog composition for this sediment layer, as measured in 1983 and 1991, is plotted in Figure 9. Also

plotted is the change in homolog weight percent. Decreases in di-, tri-, and tetrachlorinated biphenyls are accompanied by a large increase in monochlorinated biphenyls. Based upon this limited data set, the PCB_{3+} mass loss due to dechlorination between the 1980s and 1990s was 10%, which is consistent with TAMS' total PCB average of 12%. Therefore, dechlorination can be expected to account for approximately 10% of the PCB_{3+} mass loss, or 1.4 MT, between 1984 and 1994.

Diffusion

Diffusion results in the transport of PCBs from the sediments due to a concentration gradient between the surface sediment pore water and the overlying water column. Diffusion is the primary sediment-water column exchange mechanism during low flow periods. Mass transfer by diffusion is temperature dependent, increasing during warmer periods.

An estimate of the 1984 to 1994 PCB_{3+} mass loss attributable to diffusion was determined using the observed water column loading across the TIP during the summer 1997 low flow period. Data from 1997 were considered because 1996 data collected at the TID-WEST station were influenced by a sampling bias (QEA, 1998c). Calculation of the summer 1997 TIP water column PCB loading (W_{wc}) from paired Fort Edward (C_{fe}) and unbiased TID water column PCB data (C_{tid}) was based on the following equation:

$$W_{wc} = Q_{fe}(C_{tid} - C_{fe})$$

where Q_{fe} is Fort Edward flow ($L^3\ T^{-1}$).

As shown in Table 6, the average summer 1997 PCB load gain across the TIP was approximately 0.5 kg/d. The PCB_{3+} portion of this load is approximately 44% or 0.2 kg/d. Using this value as a conservative estimate of the daily PCB_{3+} sediment PCB flux throughout the

year, the total mass transfer from TIP sediments during 1984 to 1994 is 730 kg. This total accounts for only 5% of the estimated 13.5 MT PCB_{3+} inventory in the TIP.

Scour

Sediment scour occurs as an event-driven process (Ager, 1981; Lick, 1992). As flows become elevated within the river, shear stress at the sediment-water interface increases. When the critical shear stress is reached for a given sediment deposit, the surficial layers become resuspended into the water column and are transported downstream.

Because the largest resuspension events occur at the largest flow rates, an upper bound estimate of sediment PCB scour within the TIP is based upon a 100-year flood event. Predictions developed from EPA's Hudson River depth of scour model (EPA, 1996) were used to predict the PCB mass eroded from cohesive sediments within the TIP (i.e., "hot spots") during a 100-year flood event. EPA estimated that approximately 25 kg of PCBs would be mobilized during such an event (EPA, 1996). If this value is used as an upper bound estimate of the yearly TIP "hot spot" sediment PCB scour, the total PCB scour from 1984 to 1994 is approximately 250 kg. This total mass represents only 2% of the total estimated TIP inventory of 13.5 MT. This loading is conservatively high since it is based upon total PCBs in the TIP surface sediments; the PCB_{3+} component of this is approximately 20-30% less (based upon 0-2 cm data from the EPA high resolution cores).

Groundwater Advection

The upward flow of groundwater through surface sediments and into the TIP water column results in a net loss of sediment PCBs. As groundwater travels through PCB-contaminated sediments, the interstitial pore water reaches an equilibrium with PCBs in the surficial sediment. The net PCB mass transport due to groundwater advection depends on the rate of upward groundwater flow and the surface sediment pore water PCB concentration.

As documented in QEA, 1998c, field sampling data indicate that spring 1997 groundwater-induced PCB flux is approximately 30 g/day. Assuming this loading represents an average for the entire year, groundwater advection from 1984 to 1994 results in the transport of an estimated 110 kg of PCBs from the TIP sediments to the water column. This represents less than 1% of the initial 1984 TIP inventory estimated in the DEIR. This estimate is conservatively high due to the assumption that the spring 1997 measurements are representative of groundwater flux for the entire year, even though they were collected during a period in which the hydraulic gradient between surface water and groundwater was expected to be at its greatest. Furthermore, this estimate was developed for total PCBs, and, as with the diffusion estimate, the PCB_{3+} fraction of this mass loss would be 44% less.

Total of Mass Loss Mechanisms

When the upper bound estimates of sediment PCB mass loss for the fate and transport mechanisms discussed above are compared with the PCB_{3+} inventory estimated from the DEIR, the total mass loss attributable to these mechanisms can account for only 18% of the inventory. This value is graphically compared in Figure 10 with the value of 80%, which was estimated for PCB_{3+} mass loss using TAMS' approach. In conclusion, known mechanisms responsible for PCB_{3+} mass transport from sediment "hot spots" cannot account for the 1984 to 1994 mass loss estimated using TAMS' approach for paired sediment core data.

C. There is no evidence of TAMS' mass loss in water column PCB data. 1.16

TAMS' estimated 10.8 MT of PCB_{3+} mass loss from the TIP was compared with that developed from water column data collected between 1984 and 1993. PCB analytical data generated by the USGS (1984 - 1990) at the Schuylerville Station and GE (1991 - 1993) at the Thompson Island Dam station were used to develop this estimate. The packed column method employed by USGS represents a PCB_{3+} analysis (HydroQual, 1998). Therefore, the USGS data (1984-1990) were used as reported in the EPA database to develop an estimate of the PCB_{3+} mass loss. The 1991 - 1993 data were corrected to PCB_{3+} by subtracting the mono- and dichlorinated biphenyls from the reported totals (O'Brien & Gere, 1993).

The water column loading from the TIP was estimated as the difference between PCB loading measured at the Schuylerville/Thompson Island Dam station and the Roger's Island station (Table 7). These estimates are considered upper bound estimates of the loading across the TIP because load gains between the Thompson Island Dam and Schuylerville (QEA, 1998c) are also included in this estimate. From 1984 to 1993, the upper bound estimate of PCB_{3+} mass loss from the TIP sediments is approximately 1 MT. This represents only approximately 7% of TAMS' estimate of total PCB_{3+} mass in the TIP in 1984 and is inconsistent with the 80% mass loss calculated using TAMS' analysis of the 1994 low resolution sediment coring data.

D. The loss rate indicated by comparing PCB_{3+} in 1984 and 1994 is not supported by the change in PCB_{3+} mass between 1994 and 1998.

The PCB_{3+} loss rate from the TIP is not supported by changes in PCB_{3+} mass between 1994 and 1998. TAMS states that the correct basis for comparing the 1984 NYSDEC and 1994 TAMS data is on a PCB_{3+} basis. This results in an estimated 80% change in PCB_{3+} mass, a PCB_{3+} half-life of approximately 4 years within the TIP. While there may not be an identifiable mechanism to account for such a loss (see Section IVB), if the loss was real, the trend in PCB_{3+} mass loss should continue. GE conducted an analysis in 1998 to evaluate the current status and trend in PCB_{3+} within the TIP. If the trend in PCB_{3+} observed between 1984 and 1994 was continuing, the 1998 PCB_{3+} concentration should be half that observed in 1994. The opposite was, in fact, occurring; there was mass gain or no change between 1994 and 1998.

D.1 Overview of the 1998 Sediment Coring Program 1.17

The principle objective of the 1998 sediment coring program (QEA, 1998a and b) was to evaluate the validity of postulated changes in PCB_{3+} between 1984 and 1994, using sampling and analytical techniques employed by TAMS in 1994. The 1998 program included 12 coring locations within the TIP sampled both in 1984 and 1994. Coring stations were located in the field using Differential Global Positioning System (GPS) technology. This location system was tested in the field and shown to be accurate to less than 1 foot. The field crew was able to

position the coring vessel to within 2 feet of the target coordinates reported in the EPA database for the 1994 cores. Therefore, the separation distance between the 1994 TAMS core and 1998 GE core was no greater than 3 feet.

In contrast to the 1994 cores collected by TAMS, the surface sediment portion of the 1998 cores were finely sectioned. While TAMS segmented its cores into approximately 9-inch segments, the 1998 GE cores were segmented into 1-cm segments within the first 0-5 cm of the sediment core. This finer segmentation near the sediment-water interface provides data necessary to directly assess PCB burial. Below the 0-5 cm segment, the 1998 GE cores were segmented into 23-cm sections to correspond to the 1994 9-inch segments. All core sections were analyzed for total organic carbon, moisture content, bulk density, and capillary column PCBs in accordance with the work plan (QEA, 1998a and b). Additionally, the 1-cm segments within the 0-5 cm portion of the core were analyzed for ^{137}Cs and ^{7}Be.

D.2 Temporal Changes in PCB_{3+} between 1984, 1994, and 1998 1.17A

For the 12 coring stations sampled within the TIP in 1998, changes in PCB_{3+} between 1984, 1994, and 1998 were calculated using TAMS' methodology (see Section IVA). The results are presented as average mass change estimates for the periods 1984-1994 and 1994-1998 (Figure 11). The PCB_{3+} mass change estimate between 1984 and 1994 for this subset of 12 locations (approx. 80%) is consistent with the entire 1994 TAMS data set. Thus, these coring stations are representative of the entire data set used by TAMS to estimate PCB mass changes within the TIP. In contrast to the mass change observed between 1984 and 1994, PCB_{3+} mass was observed to increase by about 90% between 1994 and 1998 (Figure 12). The inconsistency in this trend (mass loss between 1984 and 1994 and mass gain between 1994 and 1998) is indicative of the inherent uncertainties undermining TAMS' approach to calculating PCB_{3+} mass loss using this type of matched coring data.

The inconsistency and variability in PCB_{3+} mass changes between 1984 and 1998 is further supported by the temporal trends in MPA_{3+} for each of four "hot spot" areas (Figure 13). In "hot spots" 8, 9, 14, and 16, a steep decline in MPA_{3+} appears to occur between 1984 and

1994. However, this trend reverses between 1994 and 1998. In "hot spot" 16, the 1998 estimate of MPA_{3+} appears to be consistent with TAMS' 1994 data, suggesting no apparent change in this "hot spot" between 1994 and 1998.

The apparent change in conditions within the 12 locations from mass loss between 1984 and 1994 to mass gain or no change between 1994 and 1998 can not be supported by any known PCB fate and transport process (see Section IVB). If these areas represent potential scour areas, as TAMS has contended, then the scour process should have continued between 1994 and 1998. That the data do not support a continuing scour process demonstrates the inherent uncertainties associated with trying to quantitatively compare sediment core sampling and analysis results from approximately the same locations over a 10-year period. Sources of errors in this analysis are of unknown magnitude because they most likely relate to spatial heterogeneity in surface sediment PCB concentration and unverifiable differences in sampling and analysis protocols. Consideration of only the two data sets in which these uncertainties are minimized (1994 and 1998) suggests that there has been a mass gain in PCBs between 1994 and 1998. TAMS' report inappropriately glosses over the uncertainties that pervade its analysis.

E. If the loss rate indicated by comparing PCB_{3+} is real, little of the PCBs that are bioaccumulated remain in the Thompson Island Pool. 1.17B

The fish in the Upper Hudson River contain almost no mono- and dichlorobiphenyl, a consequence of the relatively low bioaccumulation potential of these PCBs. Fish PCB body burdens consist almost entirely of tri-, tetra-, penta- and hexachlorobiphenyl. Thus, changes in the PCB levels in fish are controlled entirely by changes in their exposure to PCB_{3+}. The core-pairs indicate that 79% of the PCB_{3+} inventory disappeared from the "highly contaminated" sediments between 1984 and 1994. Extending this rate to 1998 results in a total loss since 1984 of about 90%. If this loss is real (and we do not believe that it is), little PCB_{3+} would be left in the sediment, indicating a high rate of natural recovery and little benefit to PCB levels in fish from remediation of the sediments.

PCB levels in TIP fish are now the lowest they have ever been (based on 1997 data), but it is not clear that this reduction is the result of a substantial inventory reduction in the sediments. Levels peaked in 1992 or 1993. Since that time, there has been a rapid decline in concentration. Between 1993 and 1997, largemouth bass lipid-based PCB concentrations declined by 75 percent from about 2,500 ppm to 600 ppm. Similar declines have occurred in pumpkinseed (80%) and brown bullhead (75%). The rapidity of these declines is partially the consequence of a recovery from high loadings in the early 1990s. Because current levels are about 60% of the levels observed in the years immediately preceding the high loadings, the decline likely also reflects a decline in surface sediment PCB levels in response to virtually eliminating residual loadings from the Hudsons Falls area.

SECTION V
WIDESPREAD BURIAL OF PCB-CONTAMINATED SEDIMENT BY CLEAN SEDIMENT DOES OCCUR IN THE THOMPSON ISLAND POOL

Rigorous data and modeling analysis indicate that widespread burial is occurring within the TIP. While there may be regions, particularly along the edges of the sediment deposits, that may undergo occasional scour, based upon EPA's sediment transport modeling, such loss processes are limited both in frequency and magnitude (EPA, 1996). The widespread occurrence of burial is supported by TAMS' surface sediment ^{7}Be data and surface sediment PCB concentration and GE's 1998 composition profiles.

A. Detected ^{7}Be indicated deposition ranging from 0.2 to 3.0 cm/yr. Non-detect ^{7}Be indicated deposition less than 0.5 cm/yr.

1.18

^{7}Be is a naturally occurring isotope with a half life of 53 days. It is produced by cosmic radiation entering the earth's atmosphere. ^{7}Be enters the water column through atmospheric deposition in the form of precipitation with higher concentrations generally occurring in spring or early summer (Olsen et al., 1986). Due to its relatively short half life, the presence of ^{7}Be in surface sediments generally indicates that suspended matter has been recently deposited.

TAMS found that ^{7}Be was present in 70% of the surface sediment samples (0-1"):

> *Of the 169 cores analyzed for ^{7}Be, 119 cores [70%] indicated the presence of ^{7}Be and, therefore, recent deposition...* (Report, at 2-21)

These data indicate, as TAMS stated, that these areas are depositional. However, due to the ^{7}Be decay rate and the time between probable ^{7}Be deposition and TAMS' measurement of the element, TAMS cannot conclude that lack of ^{7}Be in 30% of the coring sites is evidence for a lack of burial. Moreover, it is possible to assess the magnitude of sediment burial indicated by the

^{7}Be detected in each of the sediment cores and the upper bound estimate for burial in cores with non-detect ^{7}Be based on:

1) the laboratory's ability to quantify ^{7}Be,

2) an estimate of ^{7}Be concentrations in settling particles, and

3) our understanding of sediment transport processes.

Deposition Rates Indicated by ^{7}Be Presence

The deposition rate necessary to produce the ^{7}Be concentrations within TAMS' 1-inch surface sediment segment was calculated for each of the cores with detectable ^{7}Be as follows:

$$d_{dep} = \frac{[^{7}Be_{t}]\, d_{seg}}{[^{7}Be_{0}]\, e^{-\frac{\ln 2}{t_{1/2}} t}}$$

where:

d_{dep} is the depth of sediment deposition occurring during the spring high flow period,

$[^{7}Be_{t}]$ is the detected ^{7}Be concentration reported in the EPA database,

d_{seg} is the depth of the Low Resolution Sediment Core segment used for ^{7}Be analysis (2.54 cm),

$[^{7}Be_{0}]$ is the concentration of ^{7}Be on particles deposited during the high flow event,

$t_{1/2}$ is the half life for ^{7}Be (53 days), and

t is the time elapsed between the high flow period in 1994 (April 17) and the date of ^{7}Be analysis as reported in the EPA database.

To perform this calculation, a number of assumptions were required. First, it had to be assumed that all significant sediment deposition occurs during the spring high flow period, which is consistent with GE's understanding of sediment fate and transport processes (QEA, 1998c; Appendix B). However, limited amounts of deposition may occur during other periods of the year. Second, the concentration of ^{7}Be on particles deposited during the spring high flow period

had to be estimated. Water column particulate phase ^{7}Be concentrations cited in several sources of literature range from an average of approximately 45,000 pCi/kg in Lake Constance (Vogler et al., 1996) to an average of approximately 5,500 pCi/kg in the Hudson-Raritan Estuary (Olsen et al., 1986). A value of 20,000 pCi/kg was selected as a conservative estimate of the water column particulate phase ^{7}Be concentration (conservative in the sense that this value will produce a lower deposition rate).

The results of this calculation are presented for each of the low resolution cores with a detectable ^{7}Be concentration (Table 8). The depth of deposition required to produce the ^{7}Be detected in the surficial 1 inch of the cores ranged over an order of magnitude, from 0.2 to 3.0 cm. These estimates were developed into averages for each of the sampled "hot spots" within the Upper Hudson River (Figure 14). On average, this analysis indicates that the "hot spot" areas were subject to significant deposition ranging from 0.5 to 1.5 cm/year in 1994. This estimate is limited by the above assumptions but it indicates that in 70% of the sampled areas, significant ^{7}Be and, therefore, sediment deposition, occurred in 1994.

Lack of Surface Sediment ^{7}Be

The fact that 30% of the top 1-inch segments of the cores lacked detectable ^{7}Be cannot be used to indicate a lack of burial in these areas, as TAMS indicated. The data can only support the conclusion that burial has not occurred in sufficient amounts to produce detectable ^{7}Be concentrations. This is due to several factors, including:

1) the ^{7}Be decay rate,

2) the elapsed time between ^{7}Be deposition and sample analysis, and

3) mixing of deposited ^{7}Be and non-^{7}Be-containing sediments within the 2.54 cm segment collected by TAMS.

GE calculated estimates of the minimum required depth of sediment deposition necessary to achieve detectable levels of ^{7}Be in the surficial 2.54 cm section of the low resolution sediment cores. The bulk of sediment deposition occurs during the spring high flow period (on or around April 17, 1994), and ^{7}Be concentration of depositing particles was 20,000 pCi/kg. Accounting

for radioactive decay, the concentration of ^{7}Be in the top 1 inch of sediment was calculated and plotted as a function of depth of sediment deposited using the following equation:

$$[^{7}Be_d] = [^{7}Be_0]\, e^{-kt} * \left(\frac{D_d}{2.54}\right)$$

where:

D_d is the depth of sediment deposited [cm]

$^{7}Be_d$ is the ^{7}Be concentration [pCi/kg] in the top 1-inch section for a given depth of sediment deposited (D_d [cm]),

C_0 is the initial particulate phase ^{7}Be concentration (20,000 pCi/kg),

t is the elapsed time (145 days) between the date of deposition (April 17, 1994) and the median ^{7}Be analysis date (September 6, 1998), and

k is the decay coefficient given by the equation:

$$k = \frac{\ln(2)}{t_{1/2}}$$

where $t_{1/2}$ is the half life of ^{7}Be (53 days).

The ^{7}Be concentration in the top 1 inch of sediment is plotted as a function of depth of sediment deposited in Figure 15. Since the detection limit of ^{7}Be varied from sample to sample in the Low Resolution Sediment Coring Program, it was necessary to compute an average detection limit using the 50 samples classified as non-detect. The horizontal lines in Figure 15 represent the mean detection limit ± 95% confidence interval about the mean. As shown, in order to detect ^{7}Be in the top 1 inch of sediment, at least 0.5 cm of sediment had to be deposited on or around April 17, 1994. In other words, up to 0.5 cm of sediment could have been deposited without producing detectable levels of ^{7}Be in the top 1 inch of sediment.

B. Cores collected in 1998 consistently exhibit a buried peak PCB concentration with a decline at the sediment core surface, a pattern consistent with burial. 1.18A

One of the lines of evidence TAMS presents to support its conclusion that PCB deposits are not being buried is that the PCB maxima occur within the top 9 inches of the sediment cores. Sediment-water interactions and fish PCB exposure through the food chain occur in the top few centimeters, so TAMS' core segmentation scheme was too coarse to support definitive conclusions regarding the importance of burial in sequestering PCBs from the water and biota. To remedy this situation, GE collected sediment cores in 1998 from many of the same locations where TAMS collected cores and segmented them into 1-cm segments within the surficial 5 cm (see Section IVD.1 for further details). This allowed the assessment of the burial process on a much finer scale than that of the 1994 TAMS' cores.

The results of the 1998 sediment coring program are presented graphically in Figures 1a-1l. Most of the 1998 data (11 out of 12) indicate the presence of a steep PCB concentration gradient between the 0-5 cm segment and underlying segments. This trend indicates that the higher PCB concentrations at depth in the cores are being buried by solids containing much lower PCB concentrations. Moreover, in many of the 1998 cores, the PCB maxima occur well below TAMS' maxima. This suggests that TAMS' coring program did not capture the full extent of the PCB bearing sediments at these sites, or that spatial heterogeneity on the scale of several feet may produce profound changes in sediment PCB profiles. In any event, the 1998 data indicate that PCBs are being actively buried within the "hot spots" of the Upper Hudson River.

The vertical profiles of PCB composition further support the conclusion that PCBs are being actively buried within sediment deposits of the Upper Hudson River. Vertical trends in PCB composition indicate that surface sediments (0-5 cm) contain PCBs which more closely resemble the Aroclor 1242 congener pattern than deeper sediments which have undergone extensive reductive dechlorination. Figure 16 presents vertical sediment profiles of the PCB molar dechlorination product ratio (MDPR; Report). The MDPR is defined as:

$$MDPR = \frac{\Sigma\, BZ_{1,4,8,10,19}}{\sum_{i=1}^{209} BZ_i}$$

where:

BZ refers to the numbers assigned PCB congeners by Ballschmiter and Zell (1980).

PCBs that have been completely dechlorinated and contain only congeners 1, 4, 8, 10, and 19 possess an MDPR of 1.0. This ratio has been used by EPA to determine the dechlorination status of sediment bound PCBs (EPA, 1997, 1998).

The MDPR of surficial sediment (0-5 cm) collected in 1998 is consistently lower than that corresponding to the 5-23 cm depth or the 0-9 inch depth of the 1994 cores. Surface sediment PCBs general possess an MDPR of between 0.2 and 0.4. In contrast, PCBs within the 5-23 cm segments and TAMS' 1994 0-9 inch segments have an MDPR which generally falls within the 0.6 to 0.8 range. This indicates that the PCBs at the sediment surface have not undergone dechlorination as extensively as the deeper sediments. Therefore, PCB–containing sediments being deposited within these regions of the river more closely resemble the Aroclor 1242 pattern associated with the discharges from the vicinity of the Hudson Falls plant site (O'Brien & Gere, 1994; EPA, 1997).

Similar to the MDPR, the ratio of DB-1 peaks 46 to 32 can be used as an indicator of the dechlorination status of sediment PCBs. Peak 46 contains a tetrachlorobiphenyl that is sensitive to dechlorination (BZ# 74) and peak 32 contains a tetrachlorobiphenyl which is relatively resistant to dechlorination (BZ# 49). Therefore, the ratio of these peaks decreases with dechlorination. The profiles presented in Figure 17 generally depict a decreasing peak 46 to 32 ratio with sediment depth, indicating that the surface sediment PCBs are less dechlorinated than deeper sediments. This observation is important because, unlike the surface sediment gradient in MDPR, the peak 46 to 32 ratio cannot be produced by simple elution of the lighter chlorinated biphenyls from the surface sediment. This is because both peak 46 and peak 32 are tetrachlorinated biphenyls with similar chemical properties, subjecting them to similar physical-

chemical fate processes within the sediments. Therefore, the changes in the peak 46 to 32 ratio are the direct result of dechlorination of recently deposited PCBs.

1.18B

C. Data analysis and modeling of the 1994 spring flood indicates widespread net deposition in fine-grained sediments.

Construction of a mass balance for the 1994 spring flood in the Thompson Island Pool using data collected from March 30 through April 29 indicates that 457 MT of sediment were exported from this reach. This type of data analysis can only be used to estimate global losses due to net erosion from the TIP sediment bed (or global gains due to net deposition). Results from this analysis cannot be used to infer net erosion or deposition in specific bed types, e.g., cohesive or non-cohesive, or areas of the TIP.

A sediment transport model, which has been extensively calibrated and validated, is an effective diagnostic tool for quantitatively evaluating net deposition and erosion from various areas in the TIP during the 1994 spring flood (Appendix B). The model predicts a total of 345 MT of sediment were exported from the TIP during the 30-day period considered here, which agrees with the measured value. Closer examination of the model results, however, show that net erosion did not occur in all areas of the TIP during this flood. The non-cohesive portion of the TIP sediment bed, which comprises approximately 80% of the total area in this reach, experienced a net loss of 1,244 MT. This net erosion corresponds to a decrease in the mean elevation for the non-cohesive bed of 0.08 cm. Conversely, 899 MT of net deposition occurred in the cohesive bed of the TIP, which is equivalent to an average increase of 0.26 cm of the cohesive bed elevation. Prediction of net deposition in the TIP cohesive bed area during this flood is consistent with observed depositional patterns in fine-grained areas of the Upper Mississippi River during major flooding in 1993 (Barber and Writer, 1998).

D. Sediment transport modeling indicates that the areas with non-detectable ^{7}Be are depositional, but the deposition rate is less than that in areas with detectable ^{7}Be.

The TIP sediment transport model was coupled to a ^{7}Be fate and transport model to investigate the relationship between ^{7}Be concentrations and deposition rates in the Pool. The ^{7}Be fate and transport model, which was calibrated using ^{7}Be concentration data collected in 1994, can predict the spatial distribution of ^{7}Be in the TIP with reasonable accuracy. These models were then used to examine sediment deposition and ^{7}Be concentration distributions in the TIP for the 6-month period prior to ^{7}Be core sampling in July 1994.

A majority of the non-detectable ^{7}Be samples in cohesive bed areas of the Pool were collected in "hot spot" 14; the rest of the non-detectable ^{7}Be cores were randomly distributed in areas with detectable ^{7}Be. The predicted mean deposition for the non-detectable ^{7}Be core locations in "hot spot" 14 was 0.16 cm (for the 6-month period from January to July 1994), with deposition occurring at all of the core locations. The model predicted a mean deposition of 0.69 cm for the detectable ^{7}Be samples in the TIP during this 6-month period, which is 4.3 times higher than the deposition that occurred at the non-detectable ^{7}Be cores in "hot spot" 14. Thus, non-detectable ^{7}Be concentrations in cohesive bed areas are found in areas of relatively low deposition, at least for the time period under consideration.

SECTION VI
EXISTING DATA SHOW NO EVIDENCE OF EXPOSURE OF PREVIOUSLY BURIED PCBS VIA EROSION

1.19A

A. PCBs increase in a nearly linear fashion as water passes through the TIP, indicating a nearly uniform areal flux from sediments within the Pool.

Surveys conducted within the TIP revealed that PCBs increase in a nearly linear fashion as water passes through the TIP, indicating a nearly uniform areal flux from sediments within the Pool. These surveys were conducted within the TIP to detect potential areas that may be contributing a disproportionate quantity of PCBs to the water column load (O'Brien & Gere, 1998). In summary, the surveys consisted of sampling along lateral transects established every 0.25 to 0.5 miles between Roger's Island and the Thompson Island Dam, with sampling stations at three positions across each transect: east shore, west shore, and center channel. Transects were sampled from upstream to downstream so as to correspond with the flow of river water. Stations along each transect were sampled simultaneously and consisted of vertically stratified composite samples collected from three depths and were analyzed for PCBs and TSS.

The surveys exhibited similar spatial trends in total PCB concentration within the center channel (O'Brien & Gere, 1998; Figure 18). PCB concentrations were generally at or near the method detection limit of 11 ng/L at the Roger's Island sampling station and increased gradually to approximately 30 ng/l over the first 2 miles of the TIP, to River Mile 193. Over the four-mile section of the TIP between River Mile 193 and 189, center channel PCB concentrations increased by approximately 40 to 60 ng/L. At average flows of approximately 4,000 cubic feet per second (cfs) observed during the surveys, this increase represented a mass loading rate of 0.4 - 0.6 kg day^{-1}. These mass loading rates represent sediment areal flux rates of approximately 0.3 to 0.4 mg m^{-2} day^{-1} across this region of the TIP. These data do not contain any evidence of enhanced PCB flux within the sediment "hot spot" areas. The mass loading rate is generally consistent with the load expected from the entire TIP sediment area, considering 1991 surface sediment PCB concentrations.

Spatial patterns in water column PCB concentrations depend upon spatial variations in sediment PCB flux. The flux of PCBs from surface sediments to the water column depends on the organic carbon normalized PCB concentration, the sediment-water exchange coefficient, and the PCB partition coefficient (QEA, 1998c). Regions of the river with equal surface sediment organic carbon normalized PCB concentrations and composition contribute equally to the water column PCB load. Data gathered by NYSDEC in 1984 indicate that mean organic carbon normalized PCB_{3+} concentrations are similar inside and outside the sediment "hot spot" areas (Table 9).[6] Moreover, organic carbon normalized total PCB concentrations were similar for both coarse-grained and fine-grained sediments collected in 1991 from the TIP (Table 9). Therefore, coarse-grained and fine-grained sediment areas and "hot spot" and "non-hot spot" areas are expected to have similar sediment pore water PCB concentrations and, through the process of sediment diffusion, similar areal PCB fluxes. Such conditions would produce the pattern of gradually increasing water column PCB concentrations observed within the center channel during the surveys (Figure 18). The sediment data suggest that the "non-hot spot" areas dominate water column PCB loadings because they constitute the vast majority of the river bottom. 1.19B

The surveys did not reveal any localized regions of elevated surface sediment PCBs within the Pool that are disproportionately contributing to the water column PCB load. PCB loadings characterized using center channel data uninfluenced by localized hydrodynamics depict an approximately uniform increase in PCB mass loading that is consistent with surface sediment exchange processes and the 1991 surface sediment PCB concentrations.

[6] In this analysis, 1984 organic carbon concentrations were estimated as 40% of the reported volatile solids concentration.

B. The composition of the TIP load is consistent with the surface sediment PCB composition considering equilibrium partitioning and sediment pore water exchange processes. 1.20

The composition of the TIP load is consistent with known and understood sediment-water exchange processes and the composition of surface (0-5 cm) sediments. The composition of the summer low-flow (June - August 1997) average TIP load was calculated as the difference in water column derived PCB peak loading across the TIP using unbiased data (QEA, 1998c) collected from Fort Edward and the vicinity of the Thompson Island Dam. The source of this loading was assessed by calculating the required composition of a surface sediment source, assuming equilibrium partitioning between sediments and pore water and a diffusive mass transport mechanism. Specifically, the approach included:

1) Calculation of TIP water column PCB peak (based on a DB-1 capillary column) loadings from paired Fort Edward (C_{fe}) and unbiased TID water column PCB data (C_{tid}) in accordance with the following equation:

$$W_{wc} = Q_{fe}(C_{tid} - C_{fe})$$

where:

Q_{fe} is Fort Edward flow ($L^3\ T^{-1}$), and

2) Calculation of the sediment-phase PCB composition assuming the load calculated using the above equation originates from surface sediments and is transported to the water column via diffusional processes. This load was calculated on a DB-1 peak basis in accordance with the following equation:

$$C_s = \frac{W_{wc} f_{oc} k_{oc}}{k_f A_s (1 + m_{doc} k_{doc})}$$

The parameters used in the calculation are summarized in Table 10.

Back calculating the particulate-phase PCB concentration of surface sediments yields the PCB DB-1 congener peak distribution in Figure 19. This PCB source best matches the surface sediment PCB composition as represented by the 0-2 cm sections of the EPA high resolution cores collected from the TIP in 1992 (Figure 19). In contrast, the source of the TIP load does not appear to match the composition of PCBs found at depths greater than 8 cm (Figure 19). This analysis indicates that the source of the TIP PCB load is surface sediments as expressed through a diffusive flux mechanism.

C. The composition of PCBs in fish is consistent with exposure to relatively undechlorinated PCBs found in surface sediments and not the dechlorinated PCBs found in buried sediments. 1.21

Fish sampled in the TIP in 1993 by NOAA were analyzed for PCBs by congener. These data were used to investigate whether the fish had been exposed significantly to dechlorinated PCBs. The approach involved using the ratio of dechlorination sensitive and dechlorination resistant congeners that had similar bioaccumulation potential to fingerprint the PCB. Figure 20 shows ratios for two congener pairs: BZ 56:BZ 49; and BZ 60:BZ 49. Results for BZ 74:BZ 49 were similar; data is not shown. These pairs have ratios in TIP sediments that are sensitive to the extent of dechlorination (Figure 20). In these panels, the congener ratios in sediment samples collected by EPA as part of the High Resolution Core Sampling in 1992 are plotted against the level of chlorination. The horizontal dashed lines on the panels indicate the congener ratio in Aroclor 1242. In the least dechlorinated sediments (highest number of chlorines per biphenyl) the ratio is about equal to that of Aroclor 1242. As the chlorination level decreases (moving to the right on the panels), the congener ratio decreases dramatically. The congener ratios in six species of fish are shown in the right panels of Figure 20. In all of the species, the ratios are

similar to that seen in the undechlorinated sediment. There is no evidence that the fish were exposed to dechlorinated sediments.

D. The PCB composition in the water column during erosion events is consistent with the relatively undechlorinated PCBs found in surface sediments and not the dechlorinated PCBs found in the buried sediments. 1.22

A large flood event occurred in the Upper Hudson River in January of 1998. That flood had a peak flow of about 36,000 cfs at Fort Edward, equating to a 12- to 14-year return period. The estimated flow in the TIP tributaries suggests that they experienced rarer flows than the main stem, possibly equating to a 50- or 100-year return period. Samples taken at the TI Dam and Schuylerville at the peak flow and on the downward limb of the flood were analyzed for PCBs. The PCB composition of these samples was estimated by comparing the ratio of dechlorination sensitive and dechlorination resistant chromatogram (DB-1 Column) peaks. These peak ratios were compared to those found in surface sediments in 1991 (0-5 cm) and in deeper dechlorinated sediments. For all three of the peak ratios evaluated (50/32; 43/32; 74/61), the values were consistent with the surface sediments and inconsistent with the dechlorinated sediments (Figure 21). Thus, these data exhibit no evidence that previously buried dechlorinated sediments have become exposed through erosion.

E. ^{137}Cs levels in the low resolution cores give no indication that scour sufficient to account for a significant loss of PCB mass has occurred. 1.23

If a significant portion of the deeply buried, highly contaminated PCBs has been scoured out of Thompson Island Pool "hot spots," then the ^{137}Cs concentrations observed in the low-resolution cores should provide an indication that the sediments near the surface are of sufficient age to have lost the appropriate mass of PCBs.

Figure 22 illustrates average temporal profiles of both total PCBs and ^{137}Cesium for the high resolution Cores HR-019, HR-020, HR-023, and HR-026 located in the TIP. The top and

bottom of each core section was dated by first computing a deposition rate for each core according to the following equation:

$$Deposition\ Rate = \frac{D_{Cs}}{T_{col} - T_{pk}}$$

where D_{Cs} is the ^{137}Cs peak depth [cm], T_{col} is the year in which the sample was collected (1992), and T_{pk} is the assumed year in which the ^{137}Cs peak occurred (1963). Using these deposition rates, the top and bottom of each core section was dated using the following equation:

$$Section\ Date = 1992 - \frac{D_{section}}{Deposition\ Rate}$$

where $D_{section}$ is the top or bottom depth of each core section [cm]. The top and bottom dates were then averaged to determine a composite date for each section.

The data were grouped in five-year increments and plotted at the midpoint. Everything prior to 1950 was plotted at 1950. The dotted horizontal lines represent the ^{137}Cs levels in the surface sediments (0-1 inch) of each low-resolution core exhibiting "evidence for sediment scour," according to Table 4-1 of the Report.

All of the ^{137}Cs levels measured in the low resolution "scour" cores are consistent with post-1975 levels measured in the high-res cores. None of the "scour" cores lie within the error bars of the pre-1975 hi-res data. However, the bulk of PCB mass resides before 1975. Thus, the ^{137}Cs values provide no indication that scour down into the bulk of the PCB mass has occurred. Such scour would be required if 40 to 80 percent of the PCB mass had been lost between 1984 and 1994.

SECTION VII
ACCURATE ESTIMATION OF THE CHANGE IN PCB MASS IN "HOT SPOTS" BELOW THE TIP IS NOT POSSIBLE USING THE AVAILABLE DATA

1.24

In estimating the mass change in seven "hot spots" below the TIP, TAMS log-transformed the data in order to use parametric statistics to test for significant differences between the 1976-78 and 1994 PCB mass estimates. For those "hot spots" having statistically significant mass changes, absolute mass changes were estimated from the differences in the arithmetic mean estimates of the masses. In performing this later calculation, TAMS failed to consider the uncertainty of calculated mass changes. The standard error of the calculated mass change is the square root of the sum of the squares of the standard errors of the mean mass estimates. The results of such a calculation are presented in Table 11. As the table shows, the mean mass change has an uncertainty range that crosses no change for all of the "hot spots."

A) None of the mean mass changes is statistically different from no change.

The uncertainty of the mass change calculations is, in part, due to the small number of samples. Because of the extreme spatial heterogeneity of sediment PCB levels, a large number of samples is necessary. The 1984 study of the TIP sediments was conducted using a sampling density of 3 to 4 samples per acre. As was noted in Section II, the estimate of PCB mass in TIP sediments in 1984 has considerable uncertainty. The Low Resolution Coring Study involved collecting between 4 and 14 samples in each of seven "hot spots." Based on the areas of these "hot spots," the sampling density averaged about 0.5 samples per acre, almost an order of magnitude less than that of 1984. This crude sampling makes estimation of mass problematic. Further, the sampling conducted in 1976-78 was also relatively crude, so that the estimate of the mass present at that time is highly uncertain.

In addition to the quantified uncertainty, EPA's mass estimates contain additional uncertainty resulting from two assumptions. The impact of these assumptions on the overall

uncertainty was not included in the comparison of 1976-78 and 1994 mass estimates. These assumptions are as follows:

1) PCB measurements in grab samples can be extrapolated to deeper depths to estimate inventory at the locations of the grab samples, and
2) The sediment density in 1976-78 samples can be estimated from the relationship between PCB concentration and sediment density found in 1994 samples.

Both of these assumptions are made with no independent data from which they may be tested. They impart unknown uncertainty to the results which undermines the significance of any observed differences.

Perhaps the best indication of the overall uncertainty of the approach TAMS used is the result obtained for "hot spot" 28. The implausibly large increase in mass in this "hot spot" is dismissed. Arguments are presented that reflect the inherent uncertainty in comparing data from dissimilar sampling programs. These arguments apply in general and accurately indicate the futility of the approach. Further, the small sample sets contribute to difficulty in interpreting the result in "hot spot" 28. In fact, the mean mass increase in "hot spot" 28 has uncertainty bounds that cross no change (Table 11).

SECTION VIII
DECHLORINATION ANALYSES ARE FLAWED AND INSENSITIVE

The report makes three major conclusions regarding PCB dechlorination in the Hudson River:

A) Dechlorination occurs at *meta* and *para* positions only.

B) The mean mass loss [of PCBs on a mass basis] is less than 10% assuming Arolor 1242 was the original mixture of PCBs.

C) The degree of dechlorination increased with the log of the PCB concentration.

A. Dechlorination occurs at *meta* and *para* positions only. 1.25

The report does not acknowledge the dramatic effects of these processes on physicochemical and toxicological properties of PCBs as described in Appendix D of GE's comments to the DEIR (GE, 1997) including:

- Reduced toxicity;
- Reduced carcinogenicity;
- Reduced exposure via aerobic degradation; and
- Reduced bioconcentration.

B. The mean mass loss (of PCBs on a mass basis) is less than 10% assuming Arolor 1242 was the original mixture of PCBs. 1.26

The approaches to measuring mass loss in the Report are identical to those used in the DEIR, thus the flaws and insensitivities are identical to those indicated in GE's comments to the DEIR. They are briefly discussed here.

The simplistic dechlorination indices developed in the DEIR and used in the Report ignore known processes that can dramatically affect the PCB congener distribution. These include partitioning of lower-chlorinated congeners to the water column, evaporation, biodegradation and uncertainties regarding the mixture of Aroclors originally adsorbed onto the sediment. Therefore, these approaches do not provide definitive information about PCB dechlorination and have no scientific merit.

In addition, the MDPR is insensitive due to the selection of only "terminal dechlorination products" to assess the extent of dechlorination. It is only capable of detecting extensive dechlorination in sediments that carry out nearly, but not complete, removal of *meta* and *para* chlorines. It ignores dechlorination of the most abundant congener in Aroclor 1242 (2,4'-dichlorobiphenyl) which represents ~12% on a mass basis.

C) The degree of dechlorination increased with the log of the PCB concentration. 1.27

Samples with PCB concentrations >30 ppm exhibited various levels of dechlorination, while samples with concentrations <30 ppm were relatively unaltered.

An outcome of the flaws and insensitivies discussed above is the enormous uncertainty associated with regressions of dechlorination with PCB concentration, leading to the erroneous conclusion that PCBs are not predictably dechlorinated at concentrations less than 30 ppm. This uncertainty is graphically represented in the regressions of Figures 4-22 and 3-8 of the DEIR and the Report, respectively. The 95% confidence limits encompass 50% of the dechlorination range. This conclusion misrepresents the data, which clearly show that the majority of Hudson River sediments show some degree of dechlorination on careful examination. In addition, the "removal of cross-contaminated samples" from the data set examined in the Report is not scientifically valid and misrepresents the heterogeneity of microbially mediated processes in the Hudson River.

SECTION IX
ESTIMATION OF THE FATE OF SEDIMENT PCBS REQUIRES INTEGRATION OF ALL OF THE DATA AND APPLICATION OF THE QUANTITATIVE MASS BALANCE MODELS

1.28

To allow objective, quantitative evaluation of potential remedial measures in the Hudson River, GE and EPA have sponsored the development of state-of-the-art PCB fate, transport, and bioaccumulation models. It is through the application of such tools that sound remedial action decisions regarding PCB-containing sediments can be formulated and quantitatively evaluated. In the absence of such tools, decisionmakers are forced to rely on potentially biased conceptual models that may be supported by a subset of the database, but can not be accurate due to their inconsistency with other portions of the data record. For example, while comparison of the 1984 and 1994 PCB_{3+} data would suggest that approximately 80% of the PCB_{3+} were lost from the TIP between 1984 and 1994, this loss is inconsistent with PCB_{3+} loading estimates based upon water column monitoring over the same period (Section IV). Because models are developed and calibrated against the entire data record, numerous data constraints are applied to minimize inaccurate assessments of the river conditions and dynamics.

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TABLES

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Table 1
Ratio of PCB Levels in Paired Samples from the H7 ("Hot Spot" 5) Site at Various Distances of Separation

Distance Between Paired Samples (feet)	Average Ratio of the Paired Samples (High/Low)
0 – 2	2.1
2 – 5	5.5
5 – 10	21.5

Table 2

GE 1998 Hudson River PCB Sediment Samples Analyzed by both Capillary Column GC and Packed Column GC Methods

FS Sample ID	Depth Interval (cm)	DB-1 Capillary Col. Total PCBs (ug/g)	DB-1 Capillary Col. PCBs[1],(ug/g)	Total Chlorines per Biphenyl	Versar/NYSDEC[2] Packed Column Total PCBs (ug/g)
FS-08-1	46-67	1055.50	177.32	1.85	137
FS-08-2	23-46	785.24	140.24	1.87	104
FS-08-3	0-1	27.06	12.42	2.34	12.9
FS-08-3	3-4	82.61	27.28	2.09	29.4
FS-08-3	5-23	683.47	133.41	1.91	121
FS-08-4	0-1	27.16	14.64	2.49	15.7
FS-08-4	23-46	680.70	127.84	1.90	115
FS-09-1	3-4	4.11	1.35	2.01	1.42
FS-09-3	1-2	8.68	2.28	1.78	2.56
FS-09-3	23-46	69.61	13.94	1.92	12
FS-09-4	46-69	118.42	26.12	1.94	27.8
FS-09-2	0-1	2.46	1.05	2.22	1.07
FS-09-2	23-49	514.73	79.37	1.81	73.7
FS-14-1	3-4	99.92	18.73	1.83	21.1
FS-14-1	4-5	375.49	61.84	1.84	70.3
FS-16-3	0-1	6.14	3.26	2.53	4.16
FS-16-3	4-5	13.17	6.17	2.37	8.54
FS-16-3	5-23	60.73	11.33	1.95	13.1
FS-16-1	0-1	3.13	1.70	2.55	2.3
FS-16-2	4-5	1.63	1.07	2.81	1.33
FS-16-2	5-23	21.03	7.02	2.22	7.88

[1]Summation of tri- through decachlorinated biphenyls

[2]Total PCB is the sum of Aroclors 1242 + 1254 + 1260 where 1242 was calculated by NYSDEC's 1984 method using peak #'s 28, 47 and 58 and Aroclors 1254 and 1260 were calculated using the chromatogram divisions reported in Webb & McCall(1973).

Table 3
Comparison of PCB Analytical and Quantitation Methods Used for 1984 and 1998 Sediment Samples

Date	Laboratory	Column	Quantitation of Total PCBs
1984	Versar, Inc. Springfield, VA	1.8m x 2mm or 1mm ID glass column 3% OV-1 on 100/120 Gas Chrom Q. Ramp 180-210 C 5% methane in argon, 50 mL/min	Quantitation of 1254, 1260 (Webb & McCall, 1973) NYSDEC recalc. 1242 by scaling average of the weighted responses of three peaks: T-PCB=1242(NYSDEC)+1254(Versar)+1260(Versar)
1998	Northeast Analytical, Inc. Schenectady, NY	2m x 4mm ID glass column 1.5% SP-2250/1.95% SP-2401 on 100/120 mesh Supelcoport Ramp 155-225 C 53 mL/min Nitrogen	Followed same quantitation scheme used by NYSDEC for Aroclor 1242. Used Webb & McCall Wt% to calculate 1254 and 1260
		30m x 0.25 mm ID capillary column DB-1 (J&W bonded polydimethylsilicone) Ramp 50-220 C 30 cm/sec. Helium	Summation of individual PCB congeners represented in 118 DB-1 peaks.

Table 4

Northeast Analytical, Inc. Packed Column PCB Quantitation Scheme

NEA QUANT. PEAK	RRT Relative to DDE	AROCLOR 1242			AROCLOR 1260			VERSAR/NYSDEC 1984 QUANT. PEAKS
		WEIGHT % Webb & McCall	WEIGHT % NEA	CHLORINES A1242	WEIGHT % Webb & McCall	WEIGHT % NEA	CHLORINES A1260	
1 (A1242)	11	1.1	1.1	1				
2 (A1242)	16	2.9	2.9	2				
3 (A1242)	21	11.3	1.4	2				
4 (A1242)	21		9.9	2				
5 (A1242)	28*	11	11	2,3				A1242*/Recalc Total*
6 (A1242)	32	6.1	6.1	3				
7 (A1242)	37	11.5	11.5	3				
8 (A1242)	40	11.1	11.1	3				
9 (A1242)	47*	8.8	8.8	4				A1242*/Recalc Total*
10 (A1242)	54	6.8	6.8	3,4				
11 (A1242)	58*	5.6	5.6	4				A1242*/Recalc Total*
12 (A1242)	70*	10.3	10.3	4,5	2.7	2.7	5	
13 (A1242)	78	3.6	6.3	4				
	84	2.7		5	4.7	4.7	5	
14 (A1242)	98	1.5	1.5	5	3.8	7.1	5,6	A1254
15 (A1260)	104	2.3	2.3	5				A1254
	117				3.3			A1254
16 (A1260)	125	1.6	1.6	5.6	12.3	12.3	5,6	A1254
17 (A1260)	146	1	1	5.6	14.1	14.1	6	A1254
18 (A1260)	160				4.9	4.9	6,7	A1254
19 (A1260)	174				12.4	12.4	6	A1254
20 (A1260)	203				9.3	9.3	6,7	A1260
21 (A1260)	232					6.5	6,7	A1260
22 (A1260)	244				9.8	3.3	7	A1260
23 (A1260)	280				11	11	7	A1260
24 (A1260)	332				4.2	8.2	7	A1260
	372				4		8	A1260
25 (A1260)	448				0.6	0.6	8	A1260
26 (A1260)	528				1.5	1.5	8	A1260

*Webb & McCall RRT peaks 28, 47, & 58 were used by NYSDEC to recalibrate Aroclor 1242 amounts by denoting each of these three peaks as total concentration for calibration and calculating the average of the three measured "Total" values in samples analyzed. The sum of this Aroclor 1242 concentration and the Aroclor 1254 and Aroclor 1260 values reported by Versar is the Total PCB concentration for samples analyzed.

Table 5

Calculation of PCB Mass Change in Sampled Locations Using TAMS Approach

Low Res Core ID	Total MPA (g/m^2)		MPA_{3+} (g/m^2)		log (DPCB +2)	
	1984	1994	1984	1994	TAMS	PCB_{3+}
LR-01A	32.1	6.2	30.0	2.9	0.08	0.04
LR-01B	26.1	4.8	24.4	2.4	0.08	0.04
LR-02A	221.3	12.2	206.7	4.1	0.02	0.01
LR-02B	55.0	22.7	51.4	10.3	0.16	0.08
LR-02C	157.3	0.8	146.9	0.5	0.00	0.00
LR-03A	17.0	0.1	15.9	0.1	0.00	0.00
LR-03B	26.6	12.2	24.8	2.9	0.17	0.05
LR-03C	19.6	0.2	18.3	0.1	0.01	0.00
LR-04A	71.7	24.7	66.9	7.3	0.14	0.04
LR-04B	89.2	67.3	83.3	2[illegible].1	0.26	0.09
LR-04C	222.1	88.3	207.4	23.7	0.15	0.05
LR-04D	42.2	82.2	39.4	23.6	0.49	0.20
LR-05A	26.7	36.0	24.9	10.1	0.39	0.15
LR-05B	56.5	23.2	52.8	5.2	0.16	0.04
LR-05C	28.7	39.4	26.8	9.2	0.39	0.13
LR-05D	55.2	119.3	51.5	32.9	0.52	0.21
LR-06A	15.8	15.7	14.8	5.6	0.31	0.14
LR-06B	40.5	96.4	37.8	30.5	0.55	0.26
LR-06C	15.9	0.6	14.9	0.3	0.02	0.01
LR-07A	44.0	5.3	41.1	2.2	0.05	0.02
LR-07B	21.3	9.3	19.9	3.5	0.17	0.07
LR-07C	50.1	29.3	46.8	11.4	0.21	0.09
LR-07D	18.6	3.5	17.4	1.8	0.08	0.04
LR-09A	11.9	14.4	11.1	5.5	0.36	0.17
LR-09B	13.8	0.1	12.9	0.1	0.00	0.00
LR-09C	25.0	24.3	23.4	6.1	0.31	0.10
LR-09D	79.7	6.3	74.4	2.0	0.04	0.01
LR-09E	45.2	14.0	42.2	4.1	0.12	0.04
LR-09F	10.8	7.9	10.1	3.5	0.25	0.13
LR-10A	50.1	42.7	46.8	8.2	0.28	0.07
LR-10B	100.7	42.6	94.0	11.6	0.16	0.05
LR-10C	83.6	37.1	78.1	8.5	0.17	0.05
LR-10D	58.7	30.5	54.8	11.7	0.19	0.08
LR-11A	113.2	186.9	105.7	60.3	0.44	0.20
LR-11B	66.5	58.7	62.1	13.2	0.29	0.08
LR-11C	51.4	74.6	48.0	11.8	0.41	0.10
LR-18A	69.0	20.7	64.4	5.4	0.12	0.03
AVERAGE	**57.6**	**34.1**	**53.8**	**9.8**	**0.20**	**0.08**
CORRESPONDING MASS CHANGE					**-40%**	**-80%**

Notes:

Data set based upon core pairs within TIP having 1984 Tri+ MPA > 10 g/m2

TAMS log (DPCB + 2) is based upon 1984 PCB3+ and 1994 Total PCBs

Tri+ log (DPCB + 2) is based upon PCB3+ for 1984 and 1994

Table 6
Average PCB Load Increase Across TIP During the Summer 1997 Low-Flow Period

Date	Fort Edward Flow (cfs)	Total PCBs (ng/L)		TIP Load		
		Fort Edward	TI Dam	Total (kg/d)	% PCB_{3+}	PCB_{3+} (kg/d)
6/17/97	2800	31.7	105.3	0.5	34.1	0.2
6/30/97	2800	17.7	175.1	1.1	33.1	0.4
7/14/97	2000	13.7	91.8	0.4	52.4	0.2
7/28/97	1500	18.6	66.7	0.2	52.1	0.1
8/13/97	1600	14.6	57.4	0.2	46.1	0.1
AVERAGE	**2140**	**19.3**	**99.3**	**0.46**	**43.6**	**0.18**

Notes:
Data Source: GE Database
Flows are USGS Daily Average
Fort Edward is Rt. 197 Bridge Station
TI Dam is TIP-18C station

Table 7
Water Column Derived Estimates of Annual PCB_{3+} Loading from TIP Sediments

YEAR	Estimated Loading Past		Estimated Loading from TIP Sediments Metric Tons
	Thompson Isl Dam Metric Tons	Ft. Edward Metric Tons	
1984	0.45	0.36	0.09
1985	0.19	0.15	0.05
1986	0.19	0.18	0.01
1987	0.20	0.19	0.01
1988	0.10	0.07	0.03
1989	0.15	0.10	0.05
1990	0.25	0.20	0.04
1991	0.71	0.41	0.31
1992	0.85	0.58	0.27
1993	0.43	0.25	0.18
TOTAL	3.11	2.25	0.86

Notes:

1) 1/84-4/91 based on PCB concentration and river flow rating curves for Fort Edward and Schuylerville stations.

2) 4/91-12/93 based on interpolation of approximately weekly data collected from FE and TID stations.

Table 8

Estimated Amount of Deposition Occuring During 1994 High Flow Event (4/17/94) to Obtain Observed Detectable ^{7}Be Values[1,2]

TAMS Low Resolution Core ID	"Hot Spot"	Day ^{7}Be Counted	^{7}Be Correction (pCi/kg)	Estimated Depth of Material Deposited (cm)
LR-01D	16	8/23/94	1520.0000	1.0
LR-02A	16	8/29/94	2190.0000	1.6
LR-03B	16	9/2/94	2080.0000	1.6
LR-03C	16	8/30/94	771.0000	0.6
LH-25A	25	9/15/94	1840.0000	1.7
LH-25B	25	9/17/94	617.0000	0.6
LH-25E	25	9/14/94	596.0000	0.5
LH-25G	25	9/18/94	824.0000	0.8
LH-25H	25	9/17/94	907.0000	0.8
LH-25I	25	9/18/94	583.0000	0.5
LH-25J	25	9/19/94	875.0000	0.8
LH-28B	28	9/18/94	720.0000	0.7
LH-28C	28	9/12/94	1850.0000	1.6
LH-28D	28	9/12/94	991.0000	0.9
LH-28F	28	9/10/94	1680.0000	1.4
LH-28G	28	9/17/94	472.0000	0.4
LH-28I	28	9/12/94	957.0000	0.8
LH-28J	28	9/12/94	1510.0000	1.3
LH-28K	28	9/9/94	589.0000	0.5
LH-28L	28	9/14/94	978.0000	0.9
LH-28M	28	9/16/94	1220.0000	1.1
LH-28N	28	9/16/94	966.0000	0.9
LH-31A	31	9/9/94	1441.0000	1.2
LH-31B	31	9/13/94	1537.0000	1.4
LH-31E	31	9/14/94	1520.0000	1.4
LH-31F	31	9/11/94	991.0000	0.9
LH-31G	31	9/12/94	3143.0000	2.7
LH-31H	31	9/13/94	875.0000	0.8
LH-31J	31	9/14/94	2517.0000	2.2
LH-34C	34	8/31/94	973.0000	0.7
LH-34E	34	9/2/94	548.0000	0.4
LH-34G	34	9/8/94	2348.0000	1.9
LH-34I	34	9/10/94	640.0000	0.5
LH-34J	34	9/10/94	3577.0000	3.0
LH-34K	34	9/9/94	1116.0000	0.9
LH-34L	34	9/8/94	637.0000	0.5
LH-34M	34	9/7/94	922.0000	0.8
LH-35C	35	9/9/94	1196.0000	1.0
LH-35D	35	9/12/94	794.0000	0.7
LH-37E	37	9/20/94	503.0000	0.5
LH-37F	37	9/19/94	1352.0000	1.3
LH-37G	37	9/19/94	1957.0000	1.9
LH-37J	37	9/20/94	779.0000	0.8
LH-37K	37	9/19/94	884.0000	0.8

Table 8

Estimated Amount of Deposition Occuring During 1994 High Flow Event (4/17/94) to Obtain Observed Detectable ^{7}Be Values[1,2]

TAMS Low Resolution Core ID	"Hot Spot"	Day ^{7}Be Counted	^{7}Be Correction (pCi/kg)	Estimated Depth of Material Deposited (cm)
LH-37O	37	9/20/94	501.0000	0.5
LH-39A	39	9/16/94	859.0000	0.8
LH-39B	39	9/19/94	565.0000	0.5
LH-39C	39	9/20/94	1719.0000	1.7
LH-39D	39	9/14/94	815.0000	0.7
LH-39E	39	9/21/94	494.0000	0.5
LH-39F	39	9/17/94	1242.0000	1.2
LH-39G	39	9/16/94	1205.0000	1.1
LH-39H	39	9/22/94	679.0000	0.7
LH-39I	39	9/21/94	1070.0000	1.0
LH-39J	39	9/23/94	776.0000	0.8
LH-39K	39	9/24/94	1670.0000	1.7
LH-39L	39	9/22/94	610.0000	0.6
LH-39M	39	9/22/94	412.0000	0.4
LH-39N	39	9/30/94	889.0000	1.0
LH-41A	41	9/21/94	1802.0000	1.8
LH-41B	41	9/22/94	1302.0000	1.3
LH-41C	41	9/24/94	1100.0000	1.1
LH-42A	42	9/21/94	2657.0000	2.6
LH-43A	43	9/21/94	1346.0000	1.3
LH-43C	43	9/23/94	793.0000	0.8
LR-17A	Near Shore	8/22/94	748.0000	0.5
LR-17B	Near Shore	8/19/94	349.0000	0.2
LR-17D	Near Shore	8/20/94	1610.0000	1.0
LR-17E	Near Shore	8/19/94	589.0000	0.4
LR-16A	WC GRIFFIN ISL.	8/5/94	813.0000	0.4
LR-16B	WC GRIFFIN ISL.	8/30/94	2490.0000	1.8
LR-16C	WC GRIFFIN ISL.	8/23/94	411.0000	0.3
LR-16D	WC GRIFFIN ISL.	8/29/94	2750.0000	2.0
LR-16E	WC GRIFFIN ISL.	8/23/94	1420.0000	1.0
LR-19A	WC GRIFFIN ISL.	9/6/94	789.0000	0.6

Notes:

[1] Particulate phase ^{7}Be concentration at time of deposition assumed to be 20,000pCi/kg

[2] ^{7}Be decay coefficient is 0.013 days^{-1} (half-life of 53 days)

Table 9
TIP Organic Carbon Normalized Surface Sediment PCB Concentrations:
1) Both Inside and Outside NYSDEC "hot spots" in 1984 (0-2.5 In.), and
2) for Coarse Grained and Fine Grained Sediments Collected in 1991 (0-5 cm)

Sediment Survey	Location/ Sediment Type	# Observations	Mean PCB Concentration (mg kg oc^{-1})	Std. Deviation (mg kg oc^{-1})
1984 NYDEC	**Inside "hot spots"[1]**	155	2045	2069
	Outside "hot spots"	117	2030	1827
1991 GE	**Coarse Sediments**	16	2941	1824
	Fine Sediments	41	2185	2265

1) These statistics excludes one sample collected in 1984 which contained 331,000 mg PCB/kg oc^{-1}.

Table 10

Parameters Used in the Calculation of Surface Sediment PCB Source Signature

Parameter	Description	Value	Units	Source
K_f	Sediment-water Exchange Coefficient	2	cm day $^{-1}$	GE Model Calibration
A_s	Surface Sediment Area	$2x10^6$	m^2	GE Hudson River GIS
m_{doc}	Pore Water DOC	33.7	mg L^{-1}	GE 1991 Sediment Survey
K_{oc}	Temperature Corrected Partition Coefficient	Varies w/ Temp. and Congener Peak	L kg^{-1}	EPA Phase 2 Data as calculated in GE (1997)
f_{oc}	Fraction Organic Carbon	1.82	%	GE 1991 Sediment Survey
K_{doc}	DOC Partition Coefficient	0.1 K_{oc}	L kg^{-1}	—

Table 11
Calculated Mean and Range (95% confidence limits) of Estimated Mass Changes in "Hot Spots"

"Hot Spot"	Mean Mass Change (g/m^2)[1]	Range of Mass Change (g/m^2)
25	0	+28 to –28
28	175	+347 to –3
31	-43	+5 to –90
34	-10	+4 to –24
35	2	+16 to –12
37	1-0	+1 to –21
39	27	+67 to –13

[1] Negative values indicate mass loss

FIGURES

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Figure 1a

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

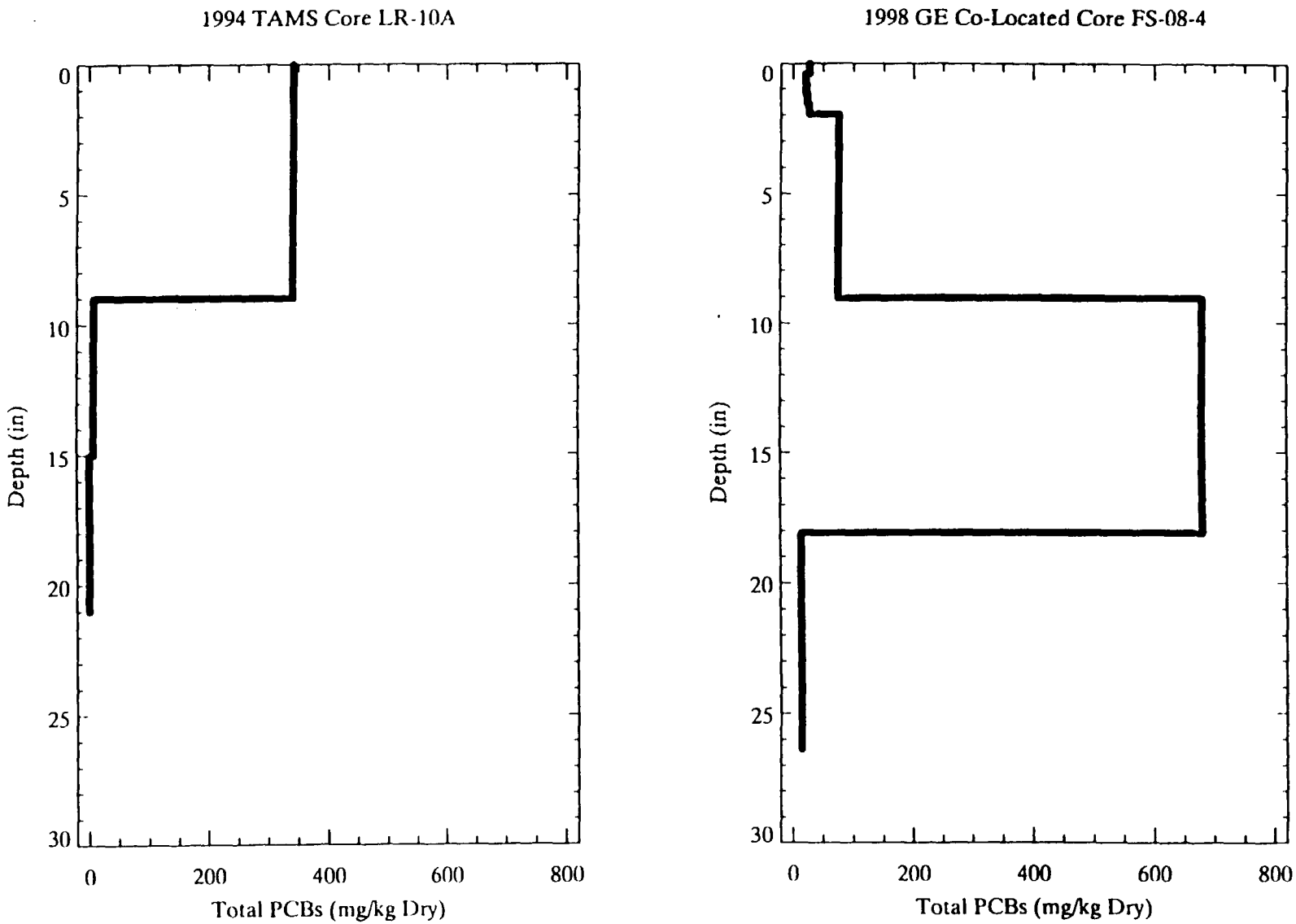


Figure 1b

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

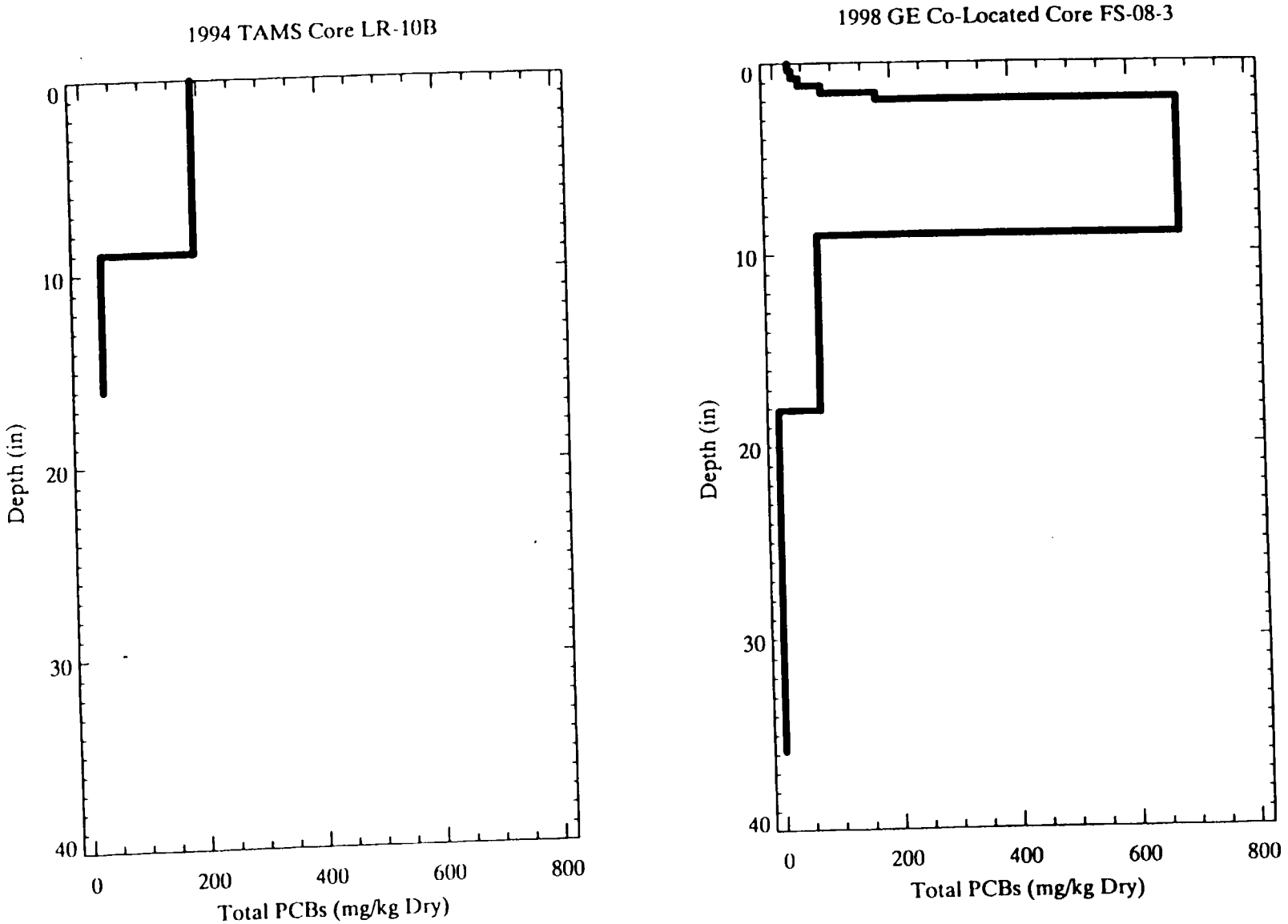


Figure 1c

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

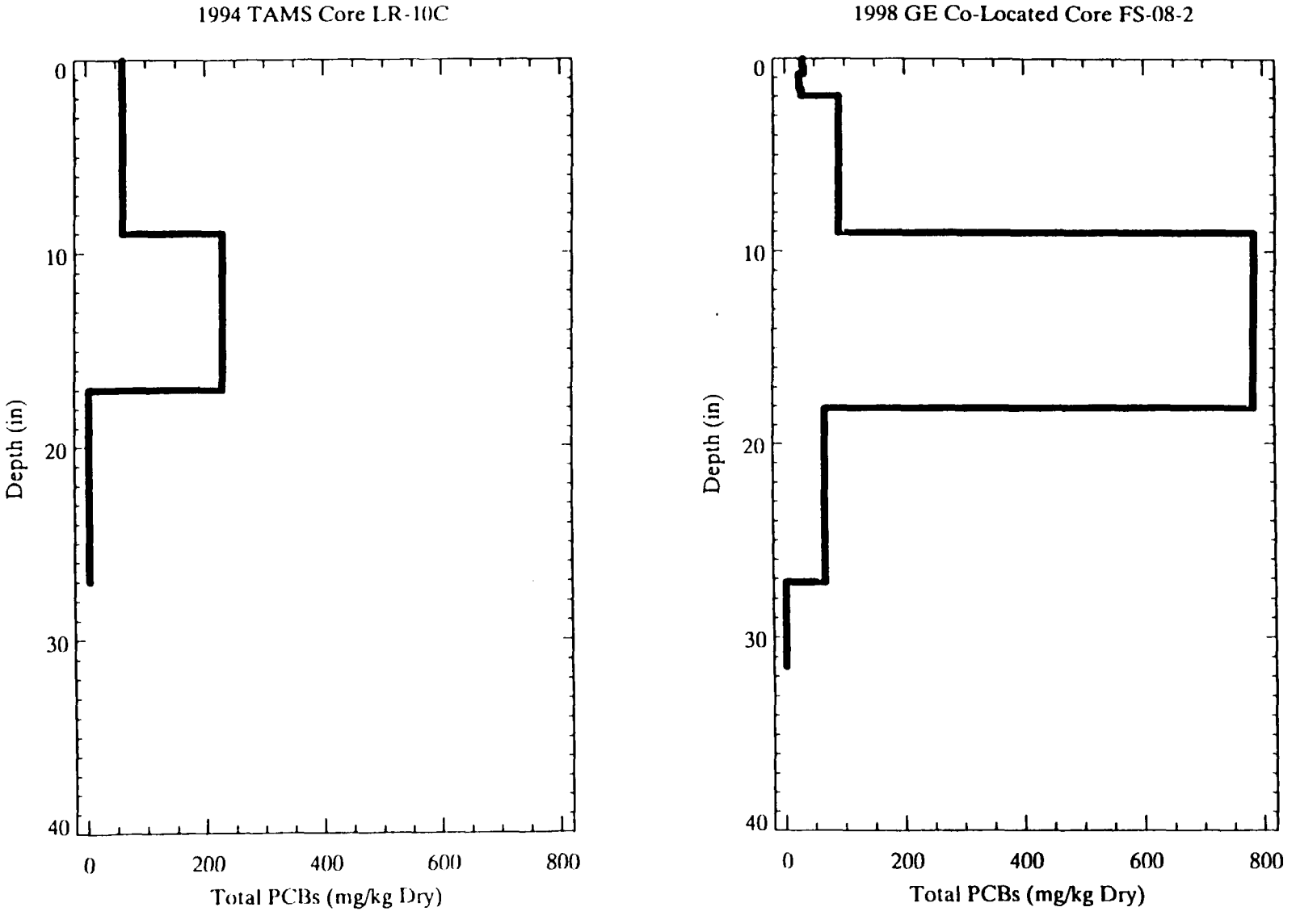


Figure 1d

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

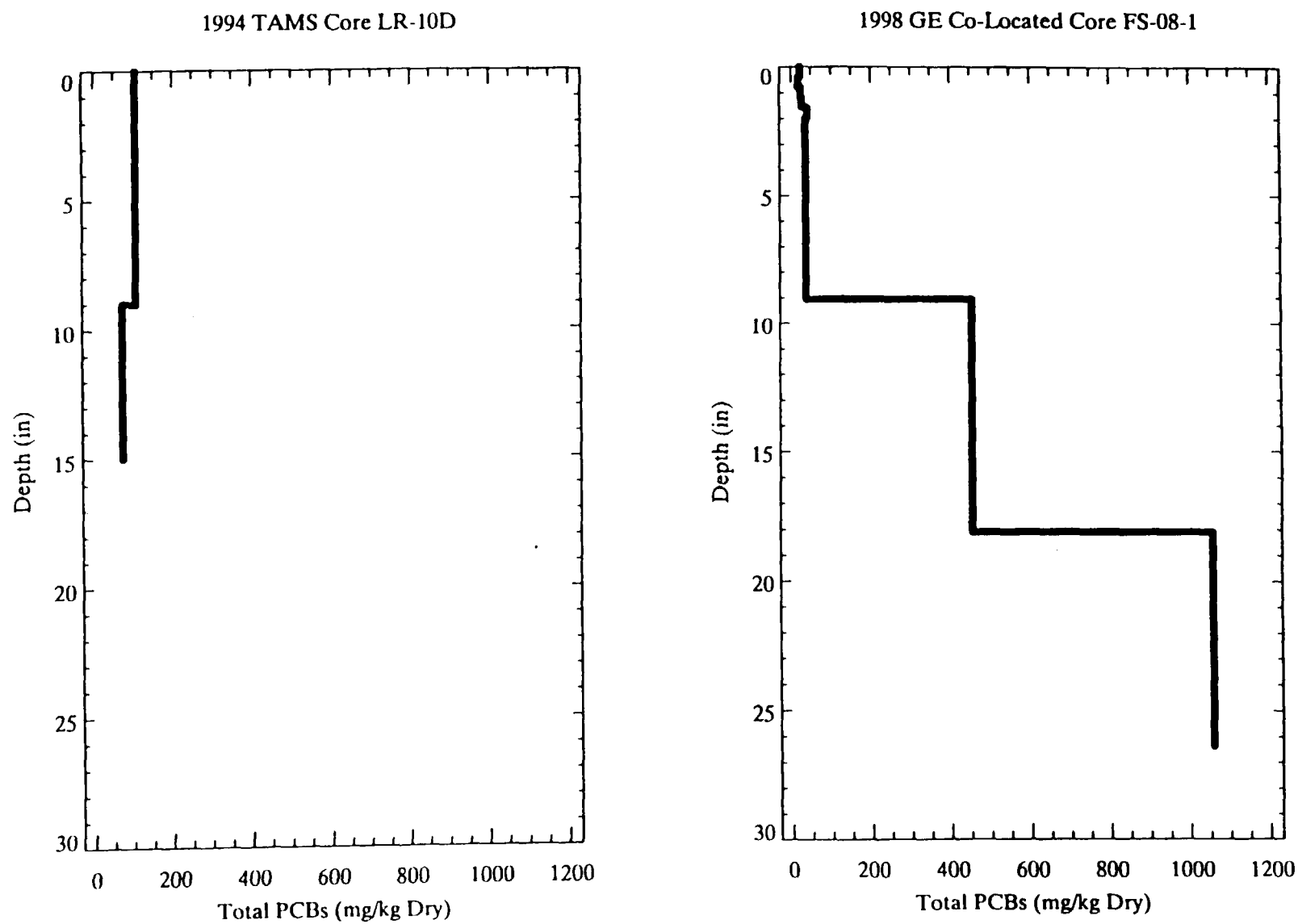


Figure 1e

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

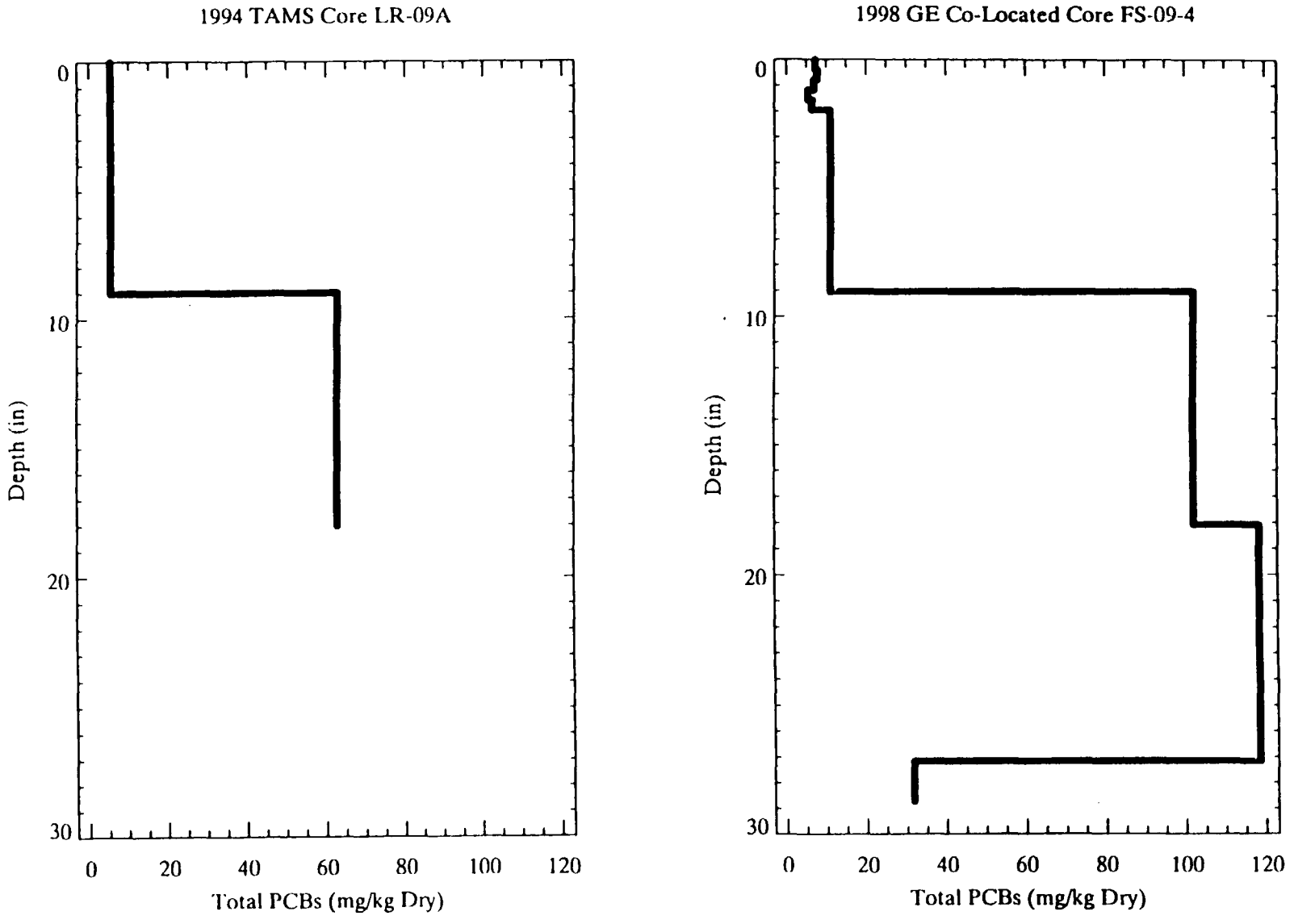


Figure 1f

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

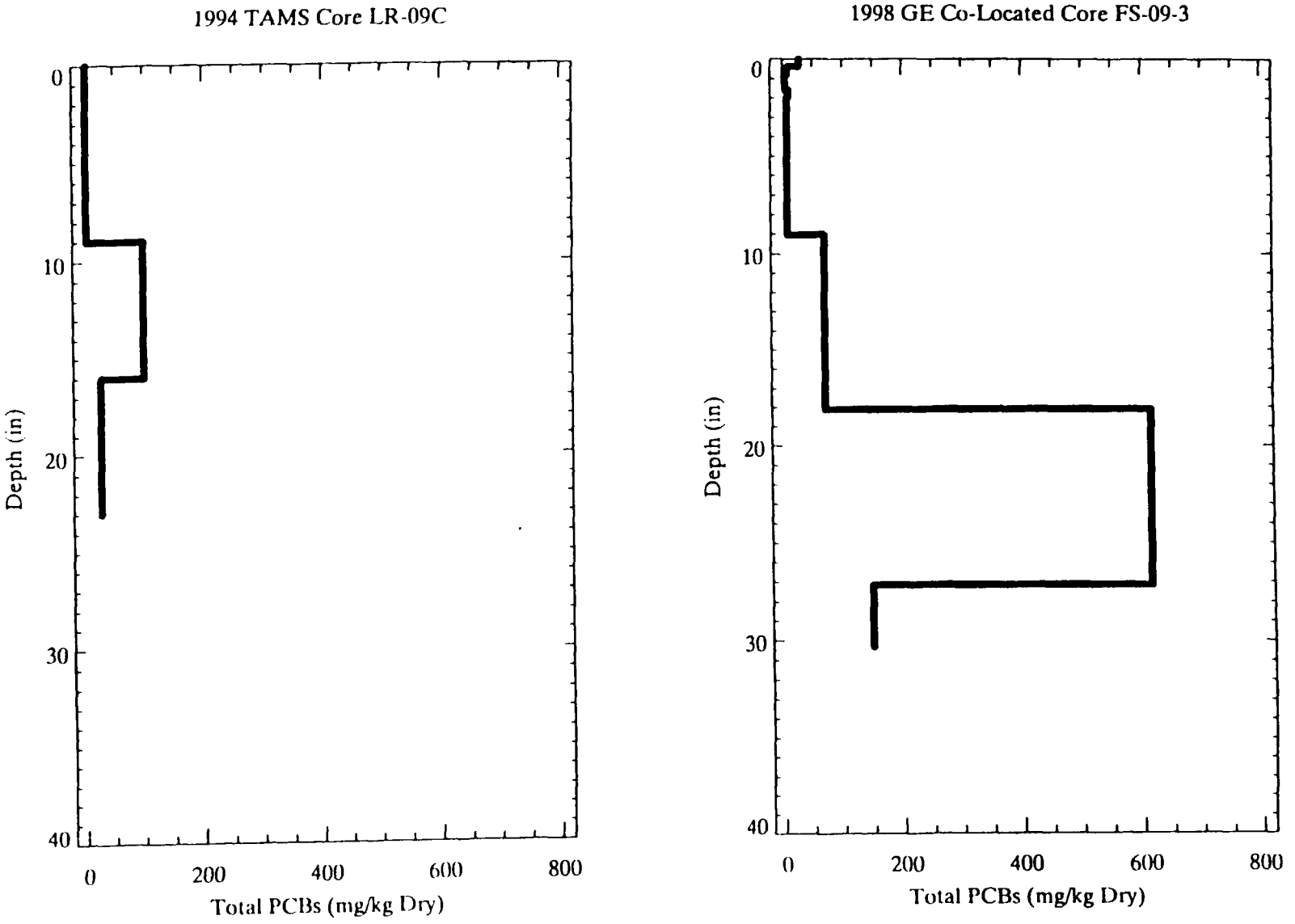


Figure 1g

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

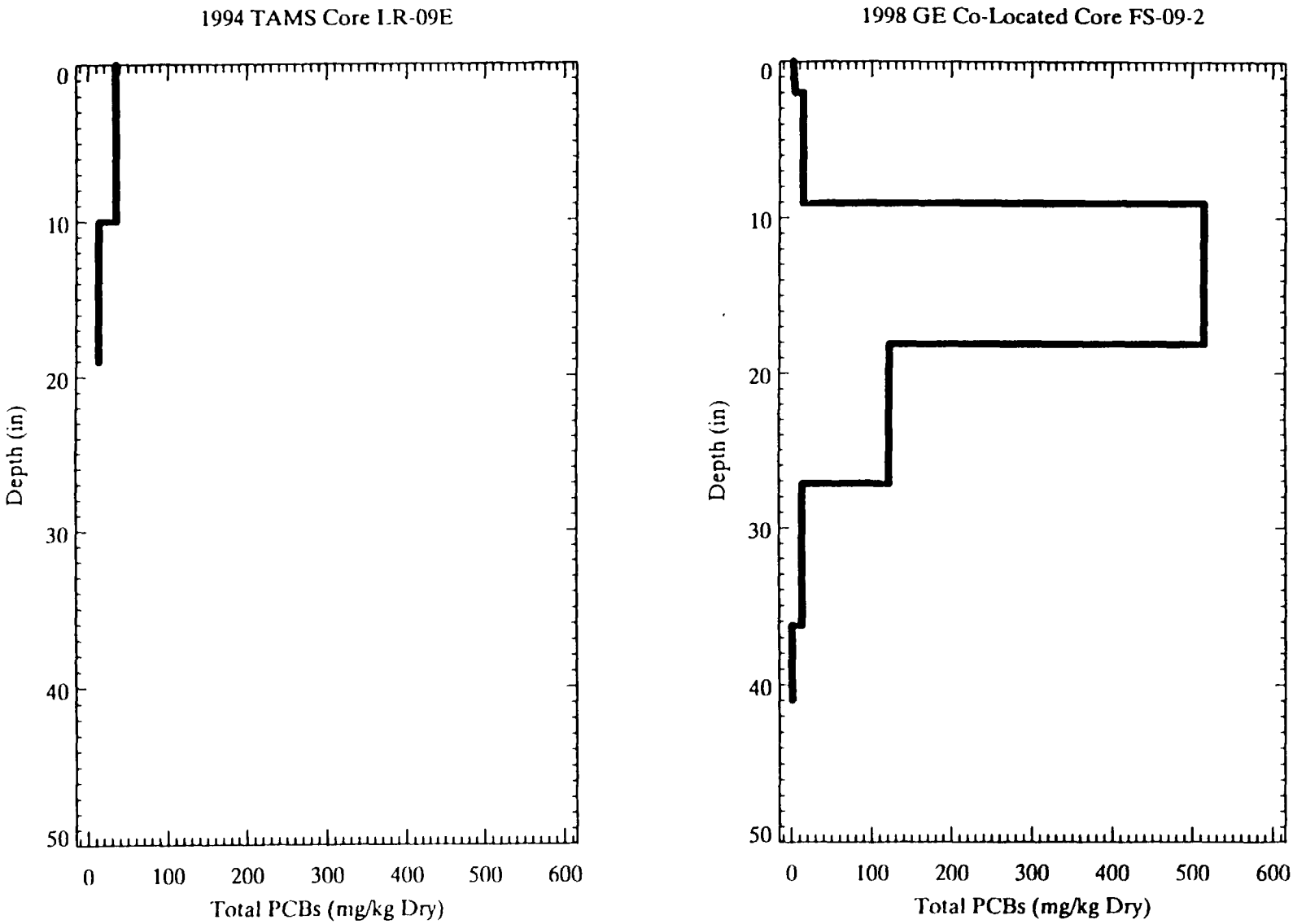


Figure 1h

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

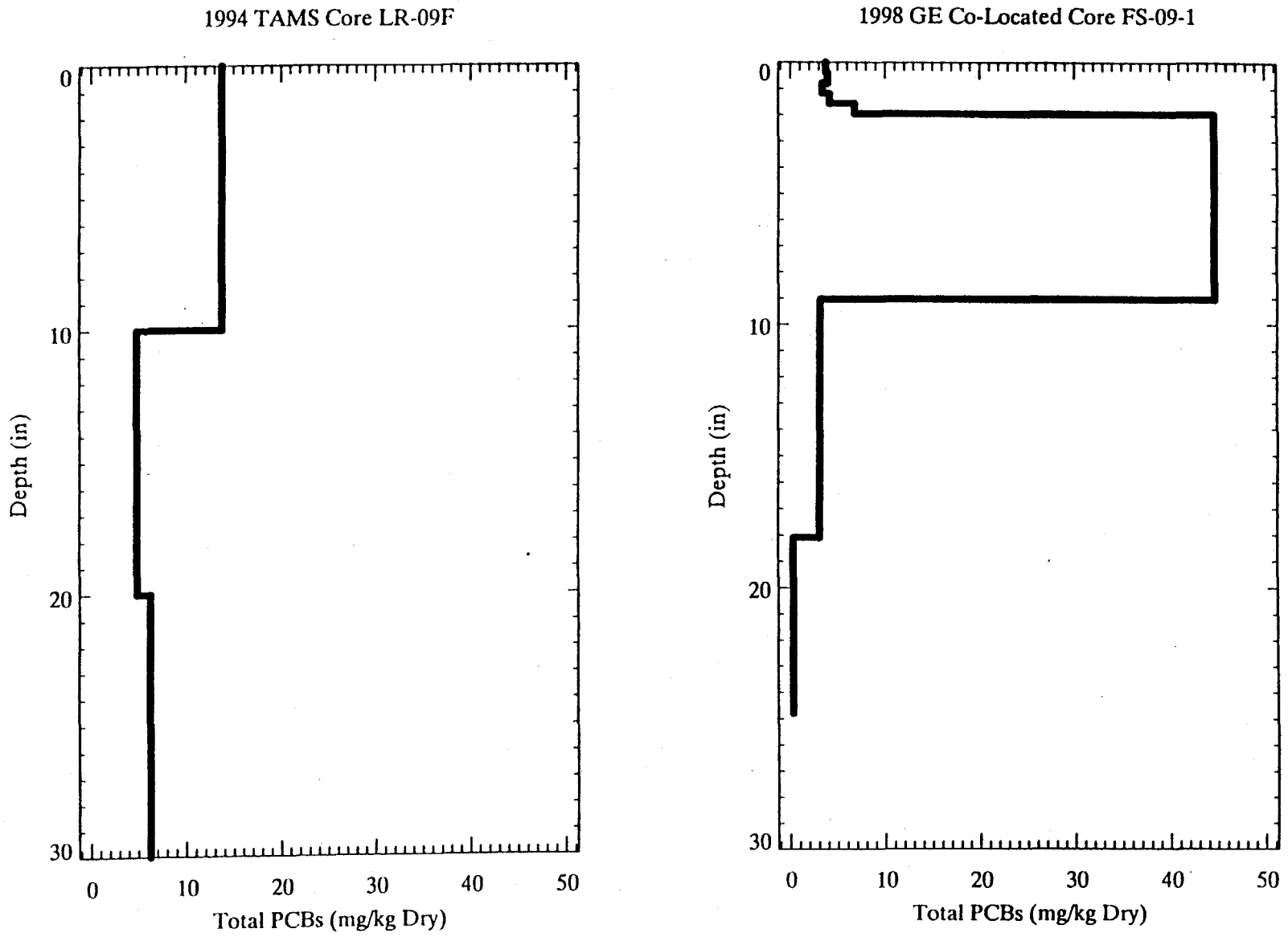


Figure 1i

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

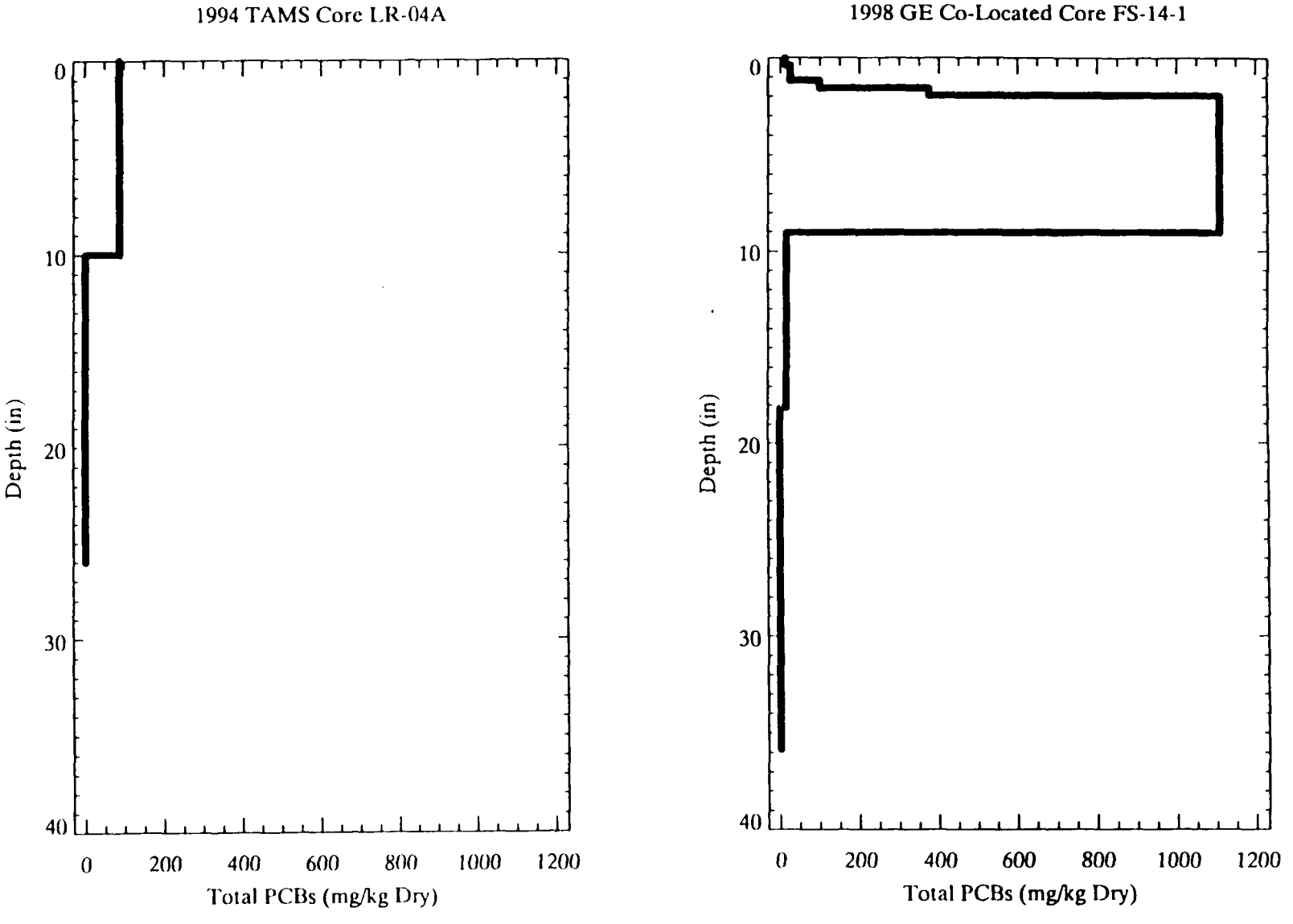


Figure 1j

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

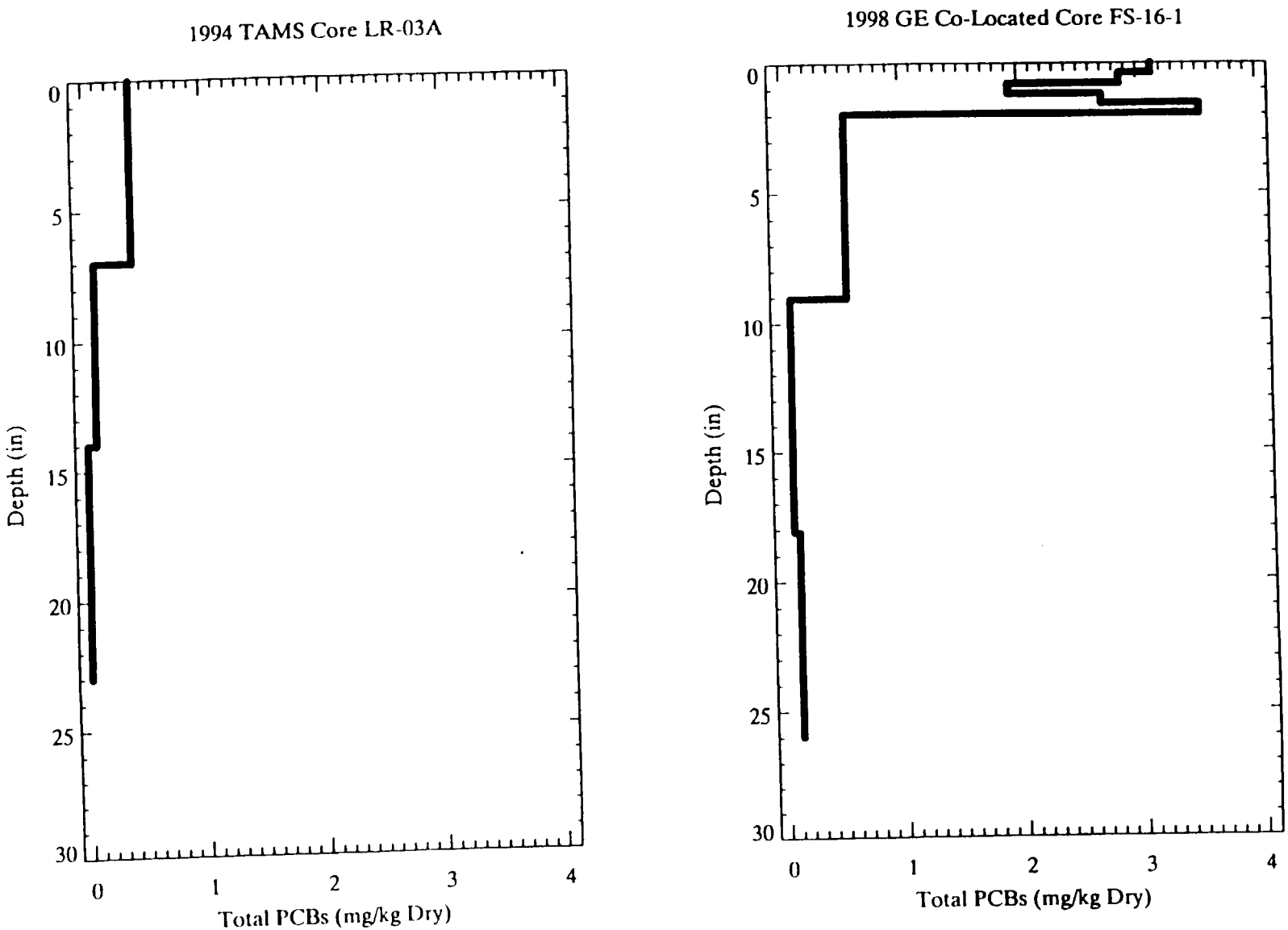


Figure 1k

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

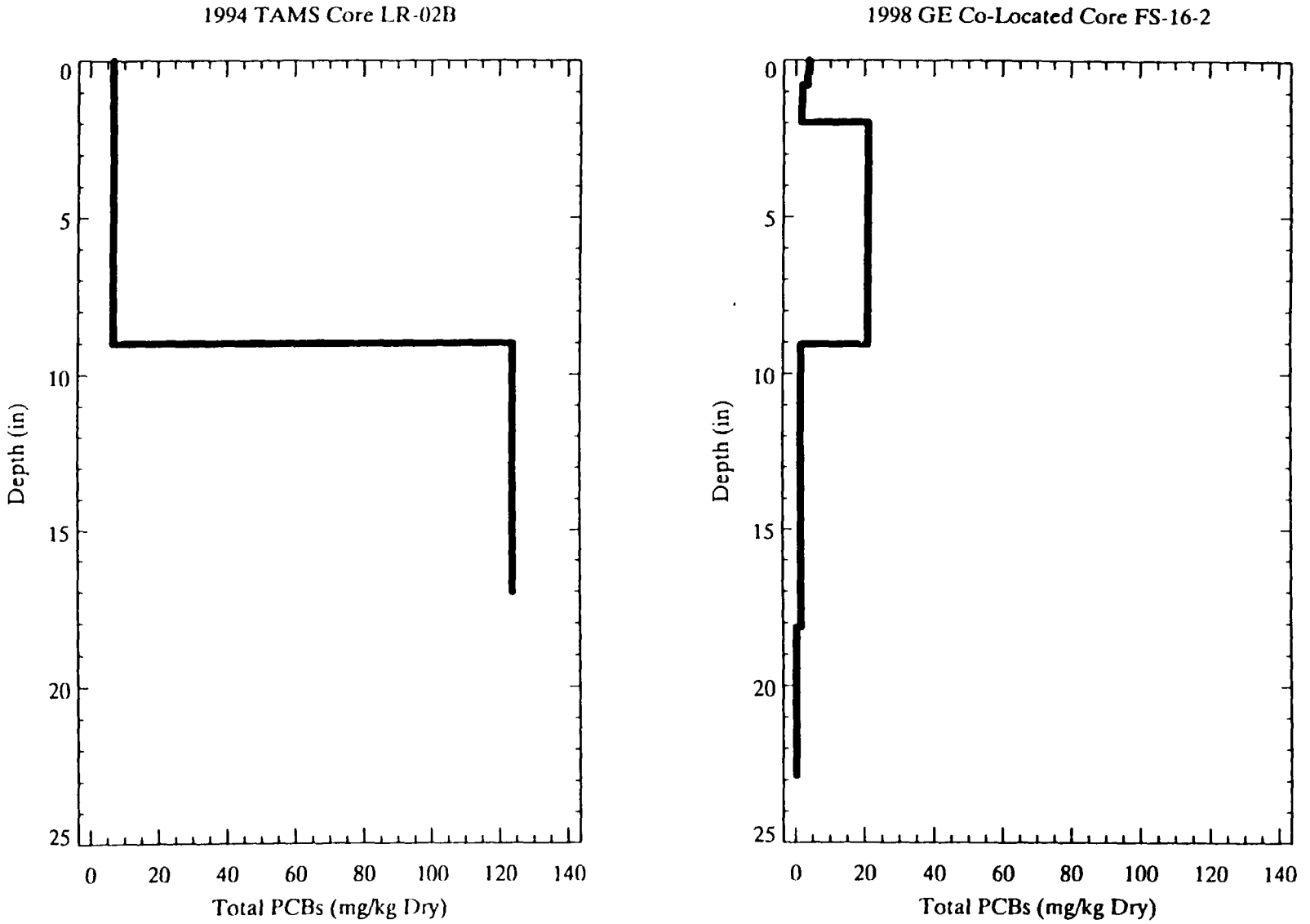


Figure 11

PCB Depth Profiles for 1994 and Colocated 1998 Sediment Cores

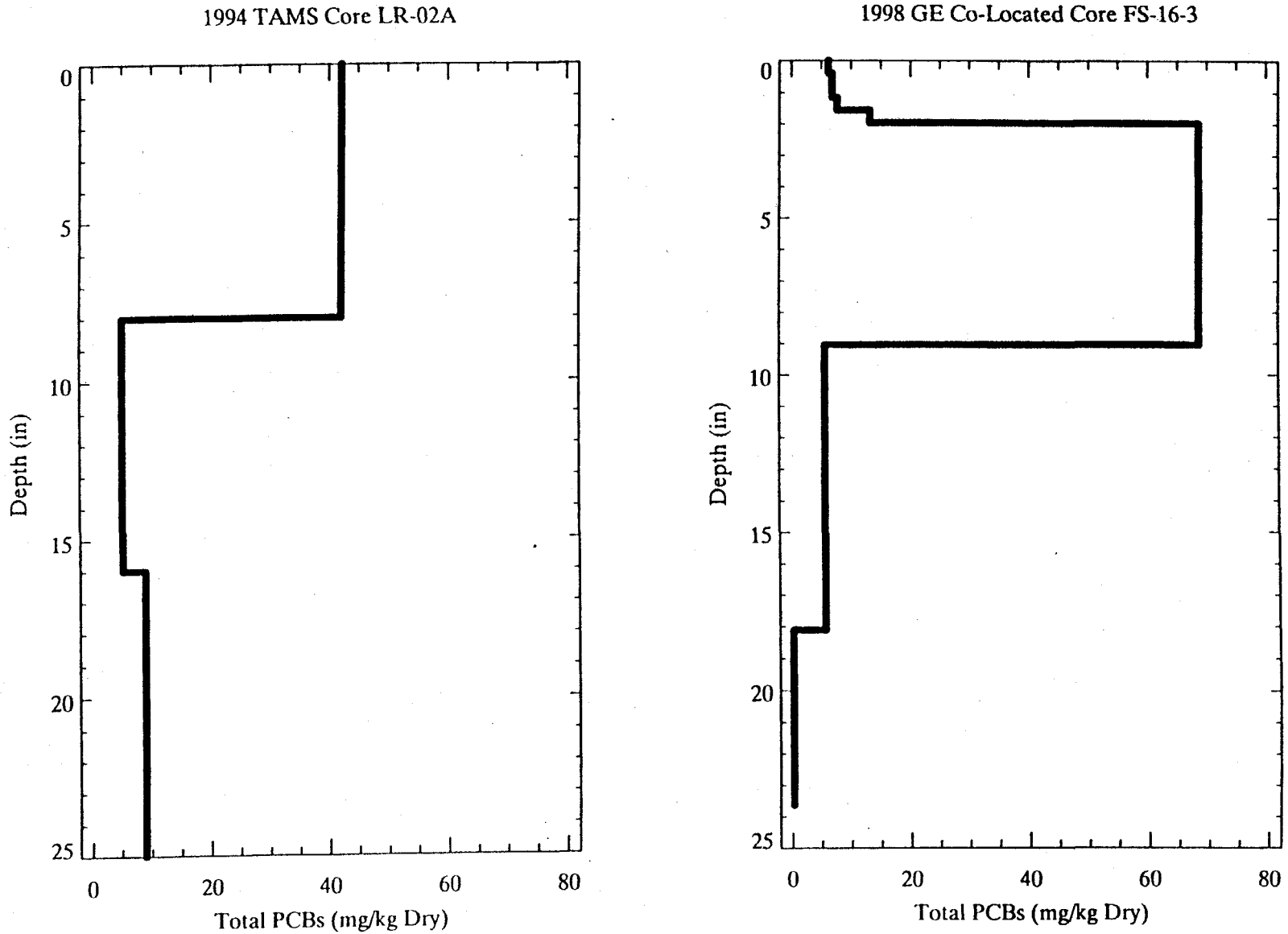


Figure 2a

Comparison of 1984 and 1994 estimates of PCB mass within TAMS low resolution zones 1 through 6.
Note: 1) Only samples matched by TAMS are presented

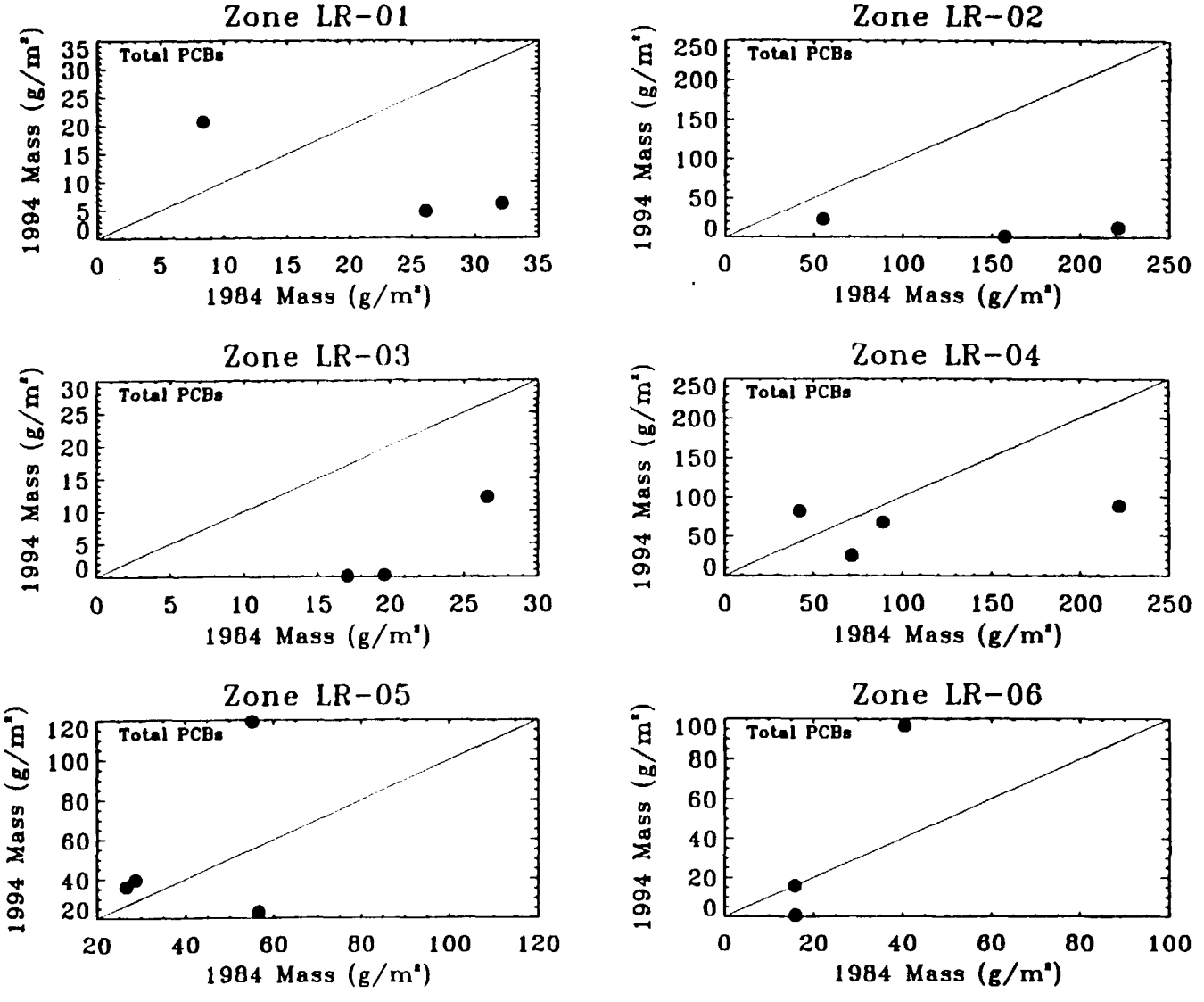


Figure 2b

Comparison of 1984 and 1994 estimates of PCB mass within TAMS low resolution zones 7 through 12.
Note: 1) Only samples matched by TAMS are presented

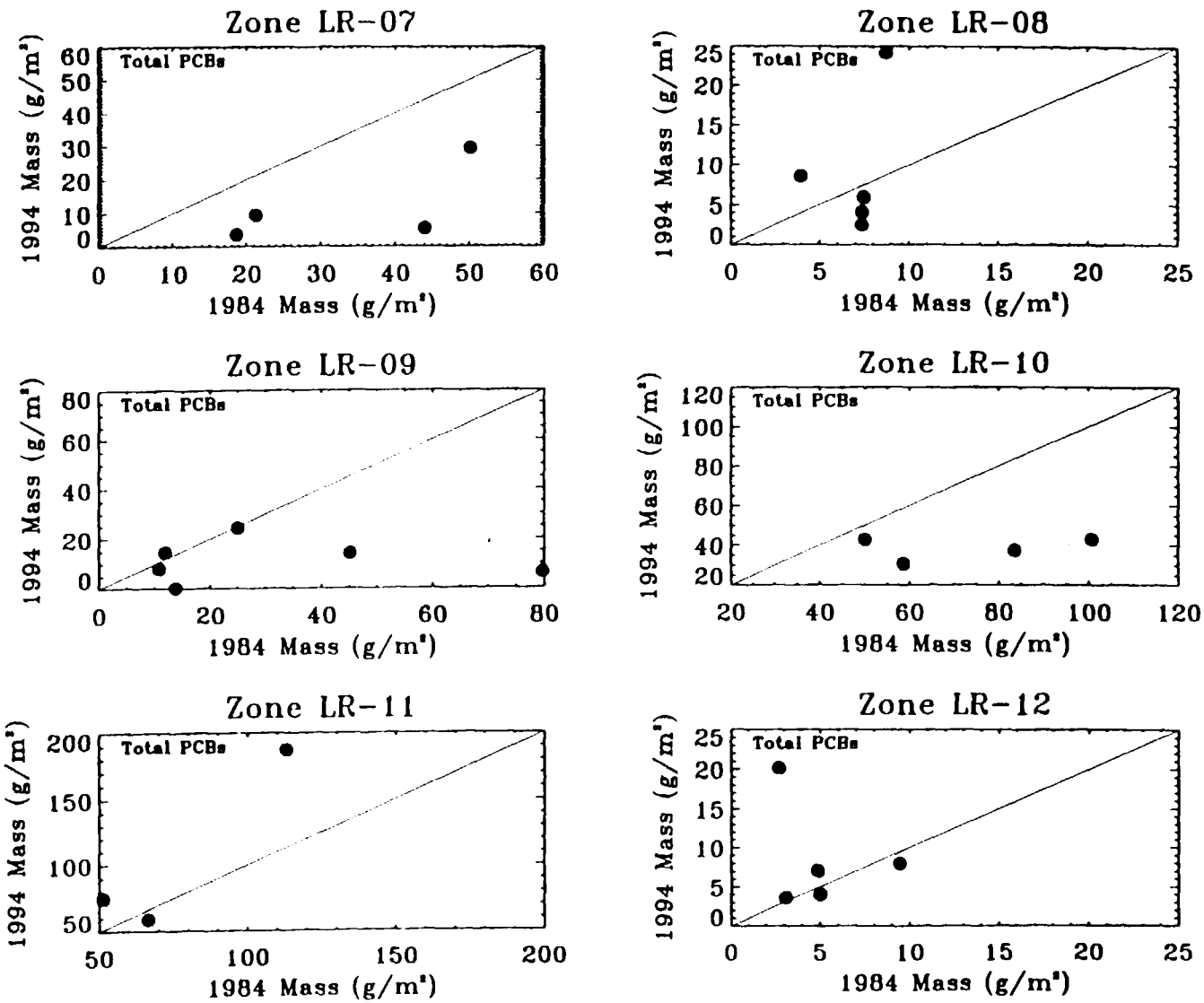


Figure 3

Semi-variogram of 1990/91 GE Data Collected from the H7 site ("Hot Spot" 5) illustrating variance of data versus separation distance. Dashed line indicates variance of full 1990/91 GE data at H7 site.

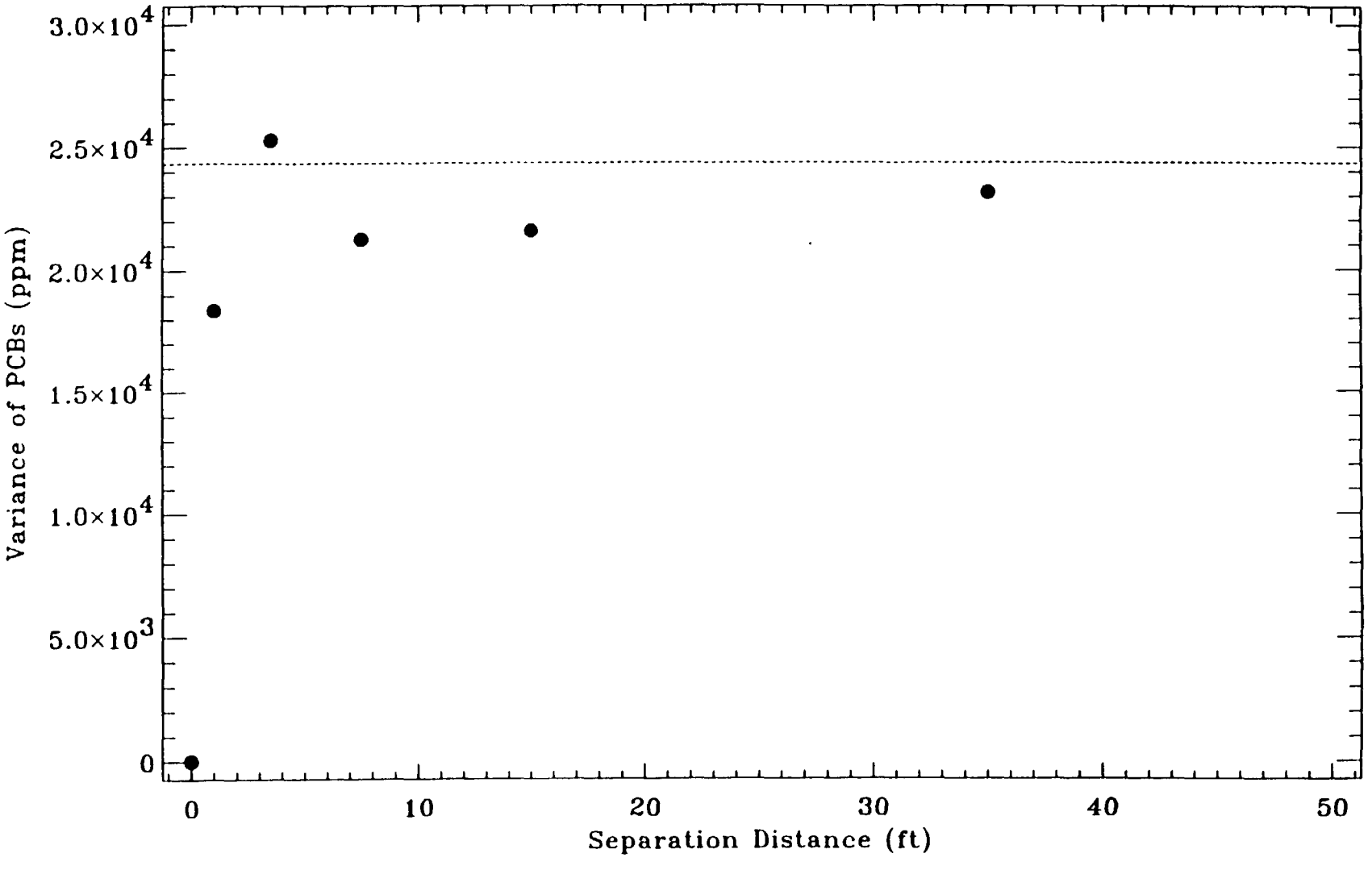


Figure 4

Regression analysis of 1984 and 1994
PCB3+ mass per unit area estimates
for paired sediment cores separated by 5 feet or less

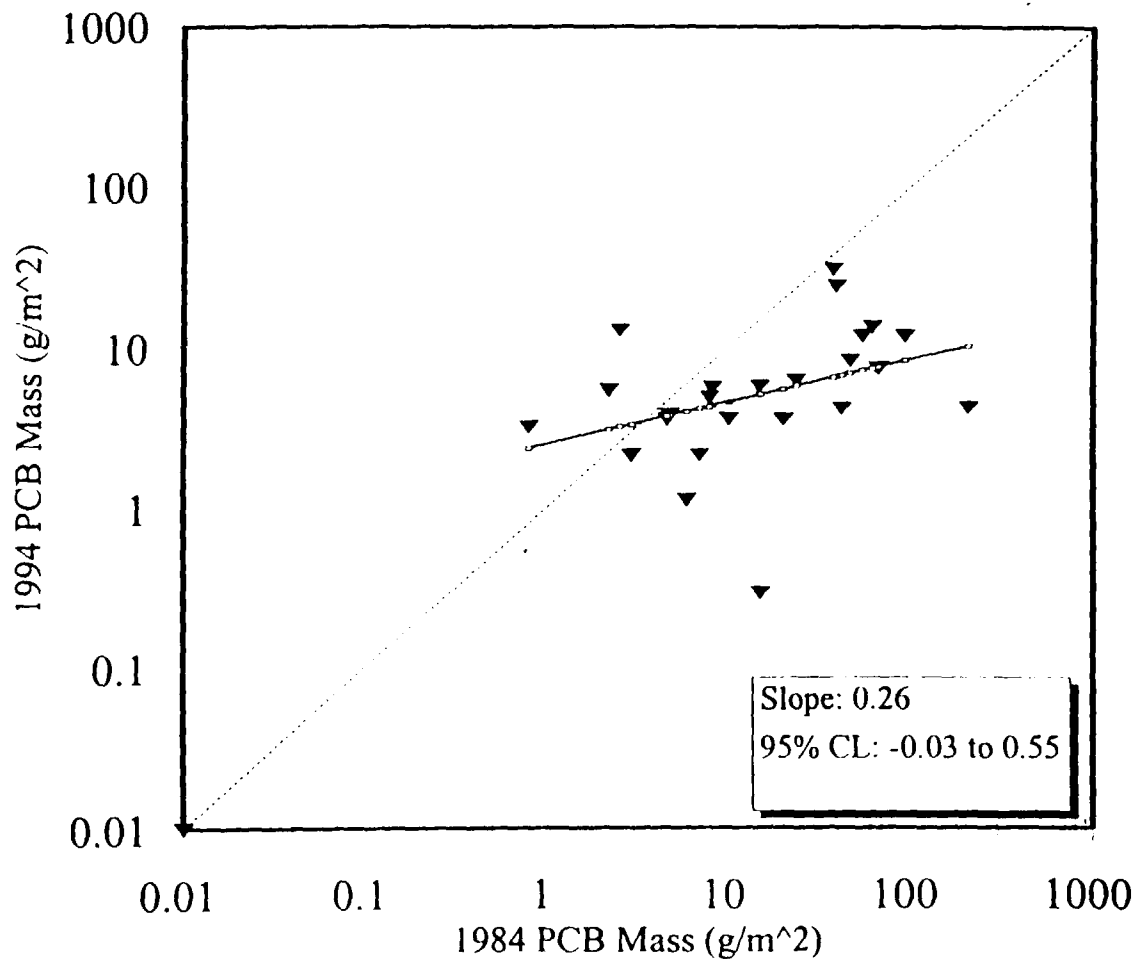


Figure 5

Probability distribution of estimated PCB mass for cores collected from TIP in 1984.

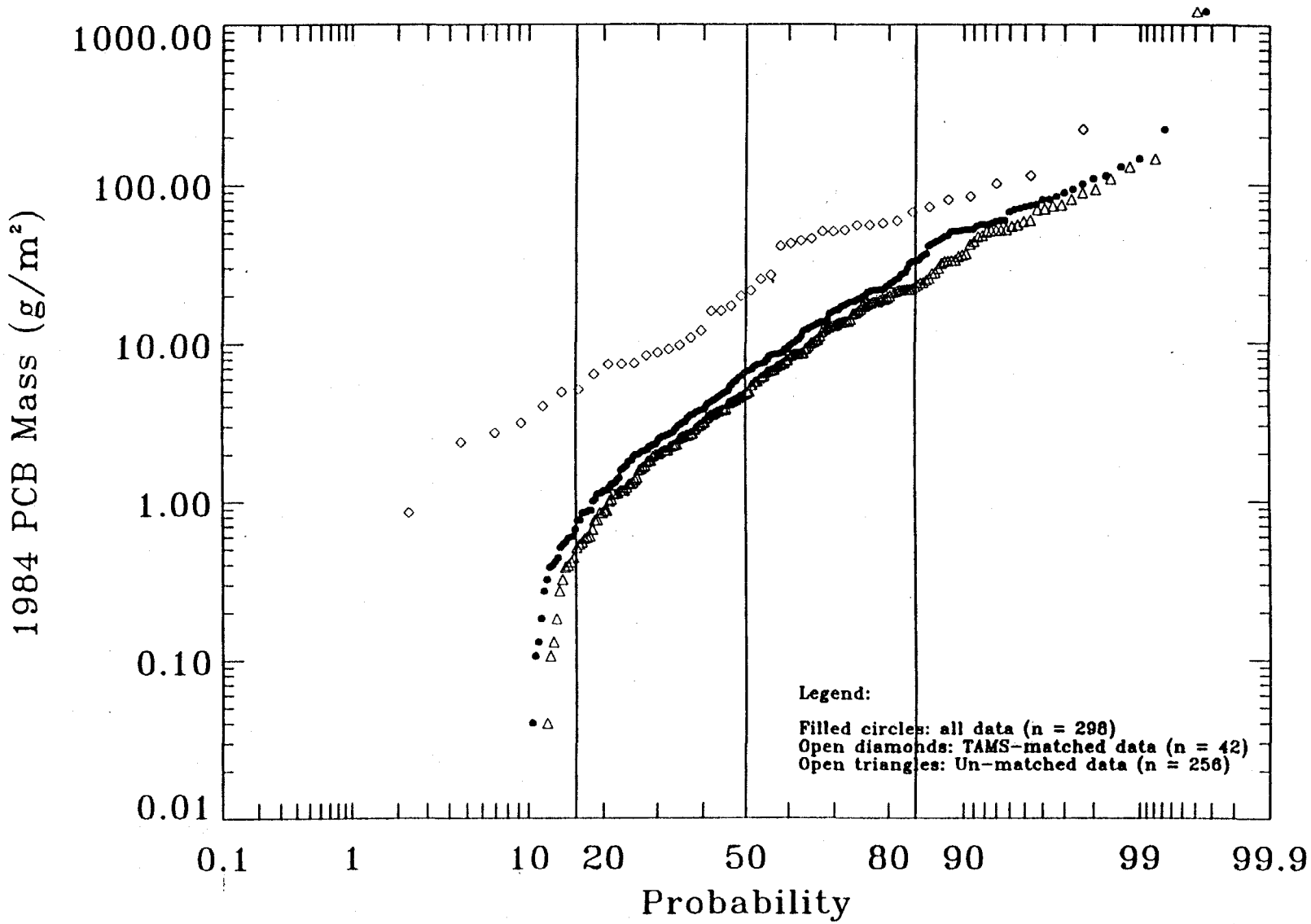


Figure 6

Probability distribution of estimated PCB mass for cores collected in 1984 from within 1976–1978 NYSDEC defined "hot spot" areas of TIP.

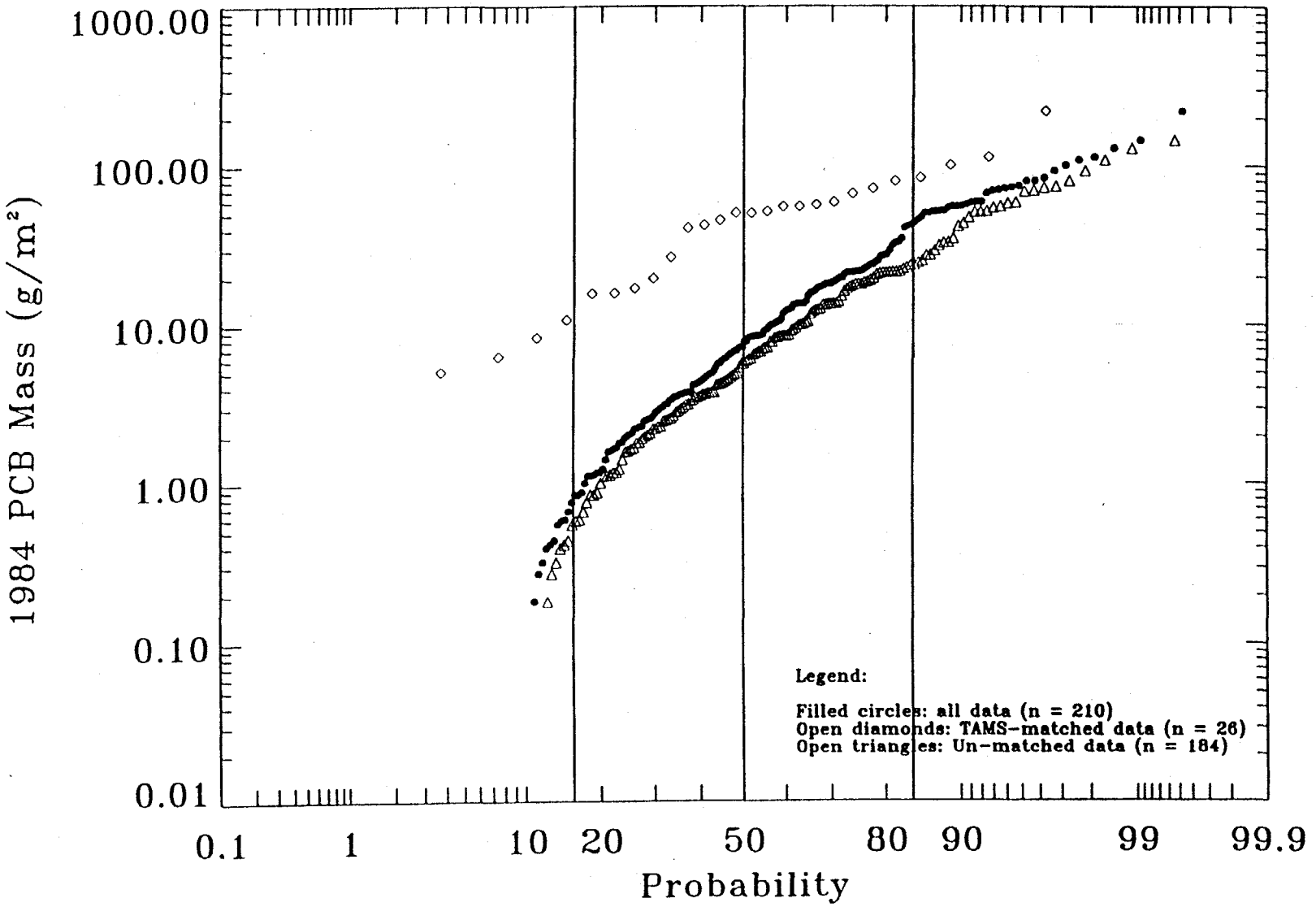
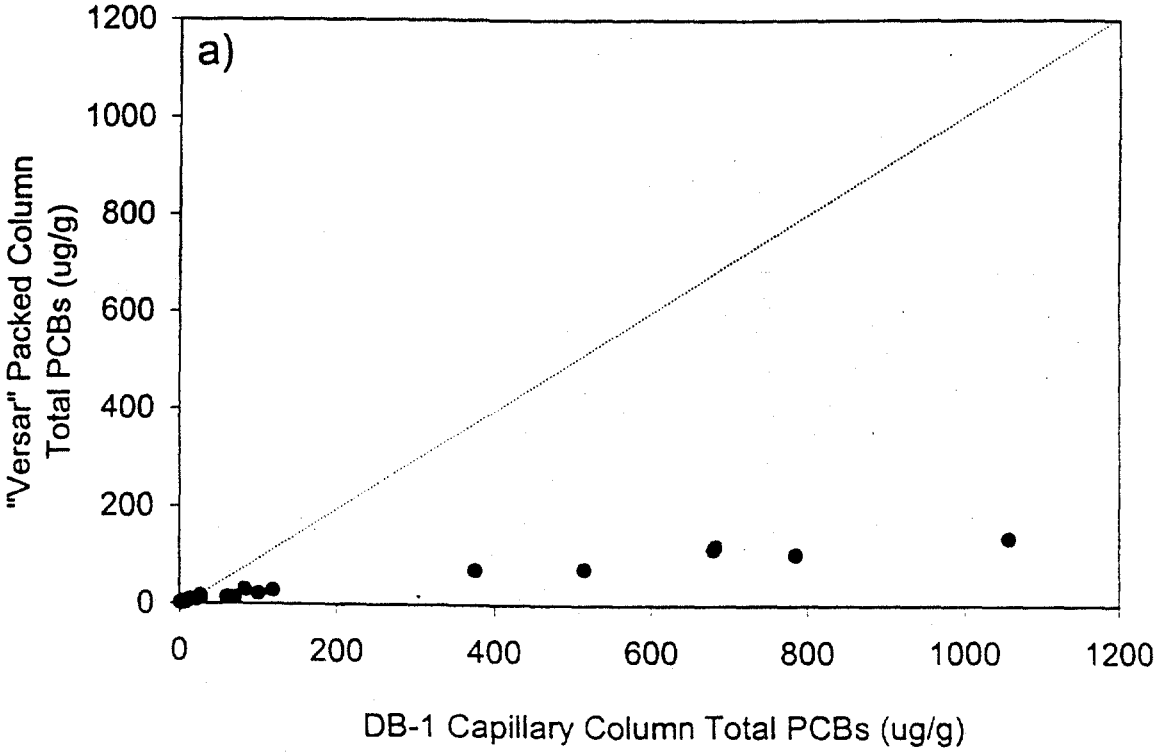


Figure 7

Comparison of "Versar" Packed Column and Capillary Column PCB Quantification Techniques a)Packed Column Total PCBs vs DB-1 Total PCBs and b)Packed Column Total PCBs vs DB-1 derived PCBs ≥ Trichlorobiphenyls



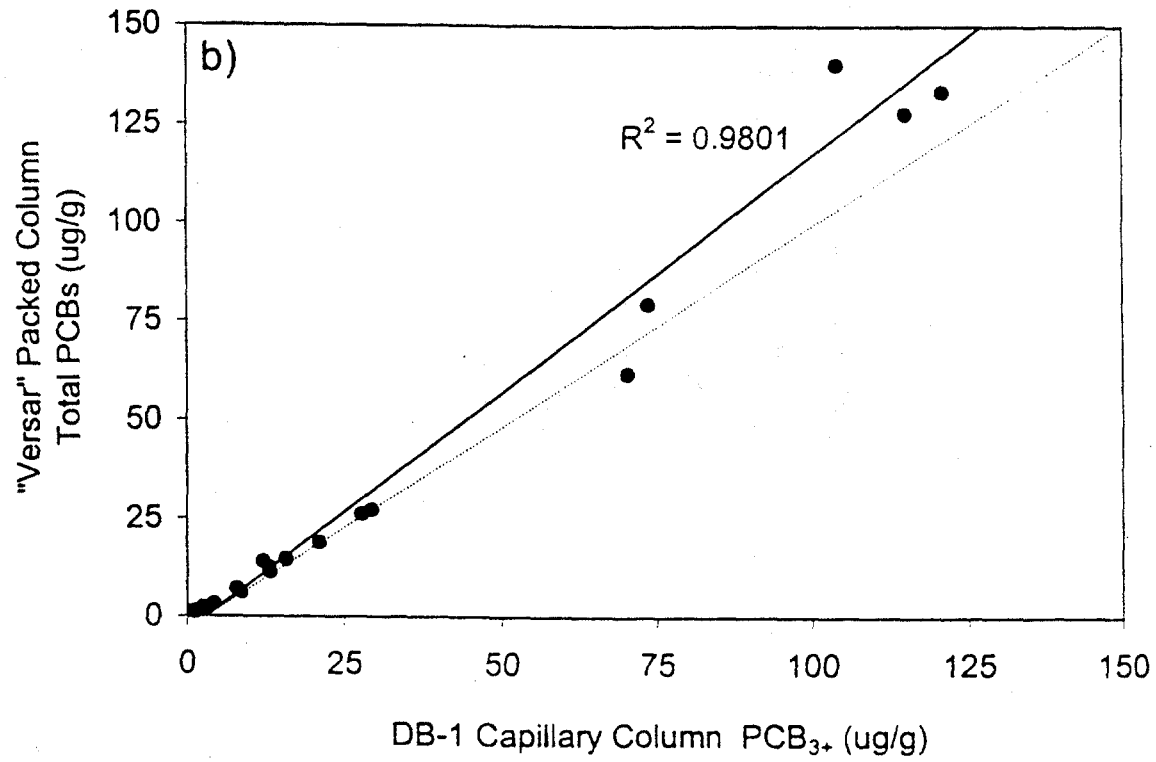
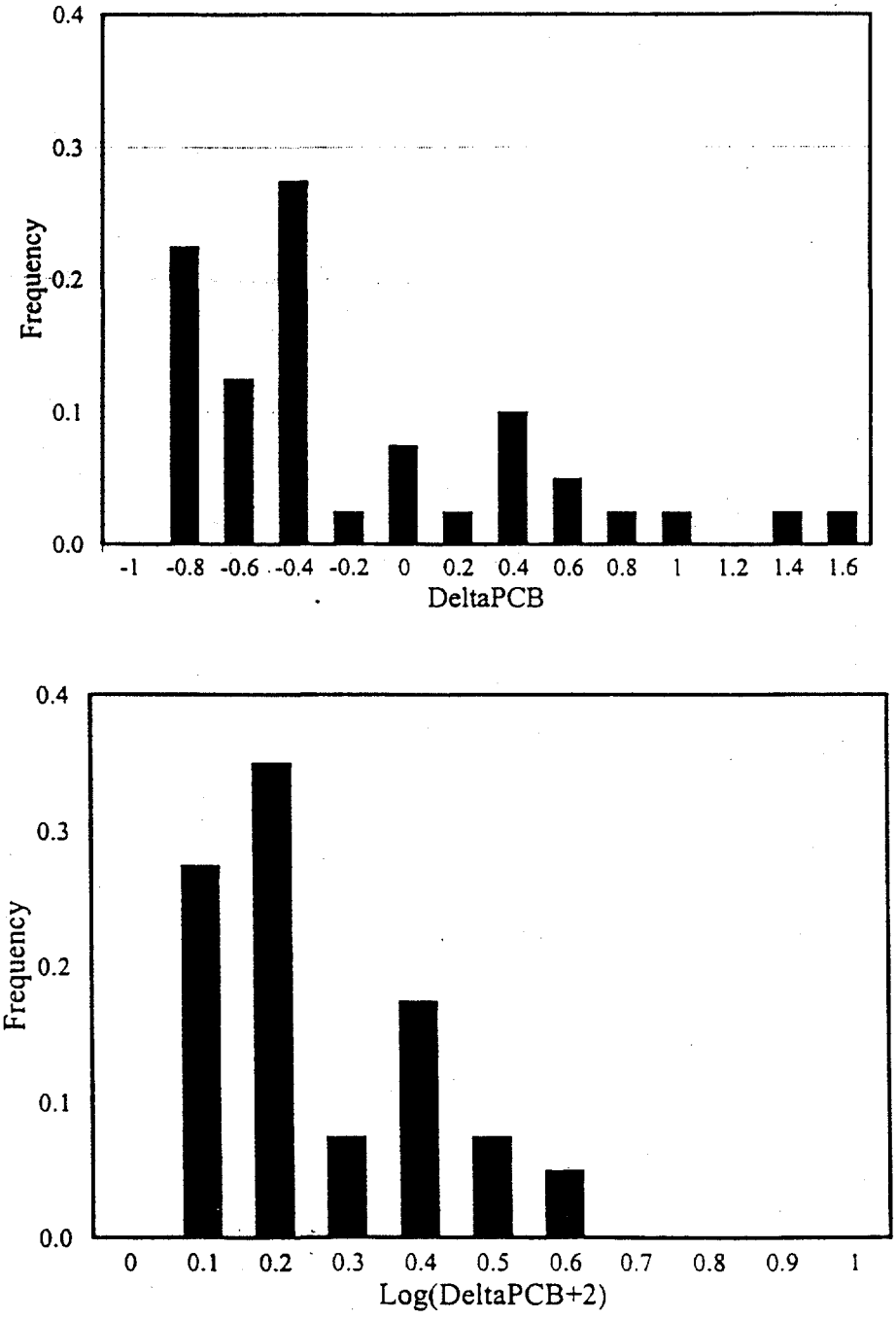


Figure 8

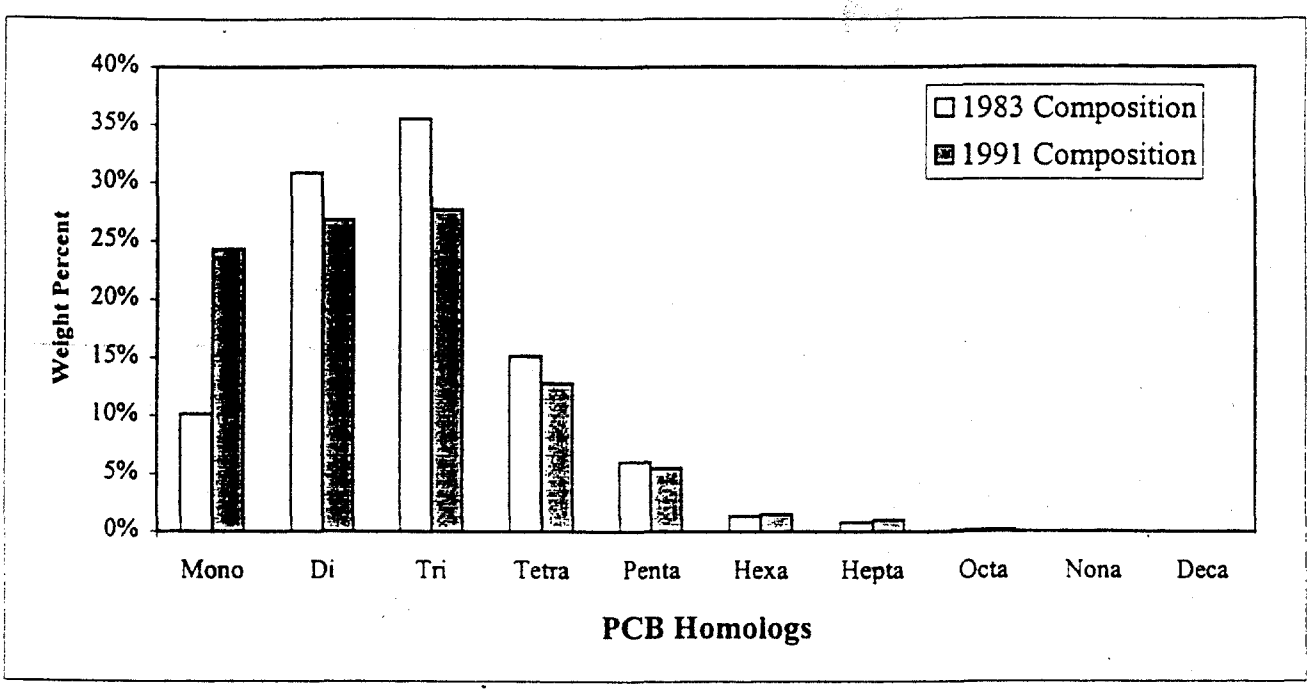
Frequency distribution of DeltaPCB and log(DeltaPCB+2) between 1984 and 1994 within Thompson Island Pool calculated by TAMS

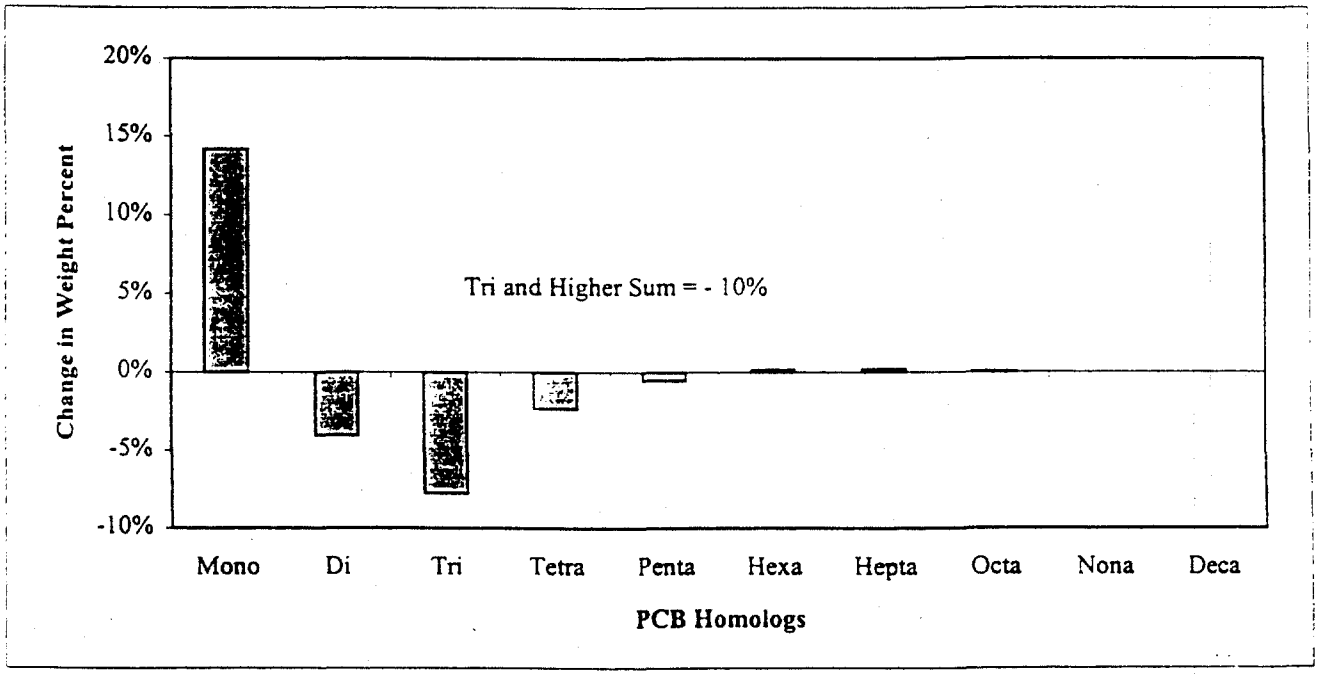


Note: Only cores with mass >10 g/m^2 in 1984 were included.
N=40

Figure 9

PCB Composition of TIP Sediment Deposited in Approximately 1968 assessed from Core Sections Collected in 1983 and 1991 (Total Concentration > 500 ppm).





Data Source: McNulty, 1997

Figure 10
Comparison of TIP Sediment PCB3+ Mass Loss Attributable to Fate and Transport Mechanisms with that Estimated using TAMS' Method

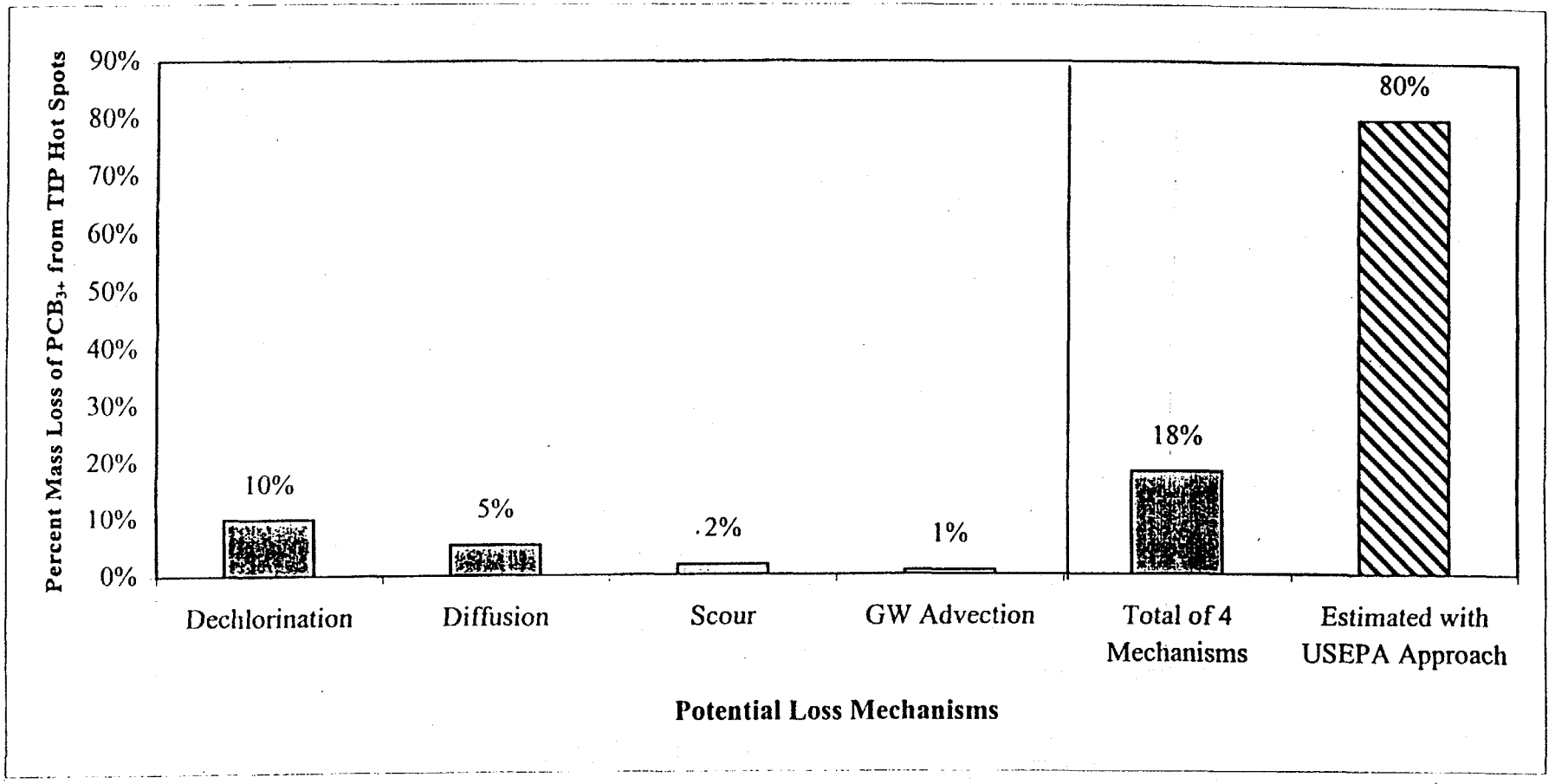


Figure 11

Calculated PCB_{1+} Mass Per Unit Area for Colocated 1984, 1994, and 1998 Sediment Cores in Thompson Island Pool

Note: Data Represent Cores with Separation Distance Less than 5 ft; Posted Mass Change is Based upon TAMS` Approach

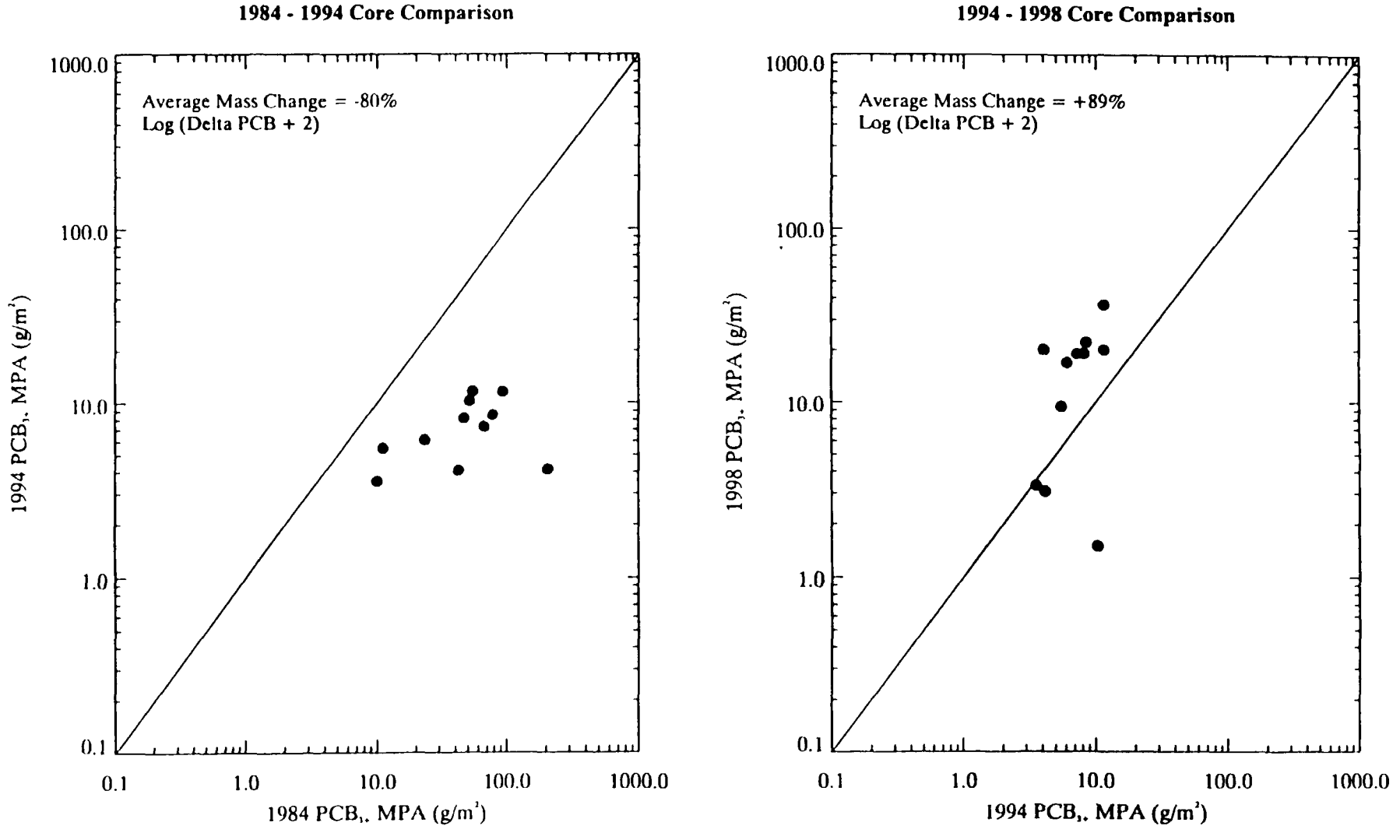


Figure 12

Changes in TIP Sediment PCB_{3+} Mass Estimated from Differences in Calculated MPA for Colocated Sediment Cores Collected in 1984, 1994, and 1998

Note: Only Cores with 1984-1994 Separation <= 5 feet Considered for Calculations

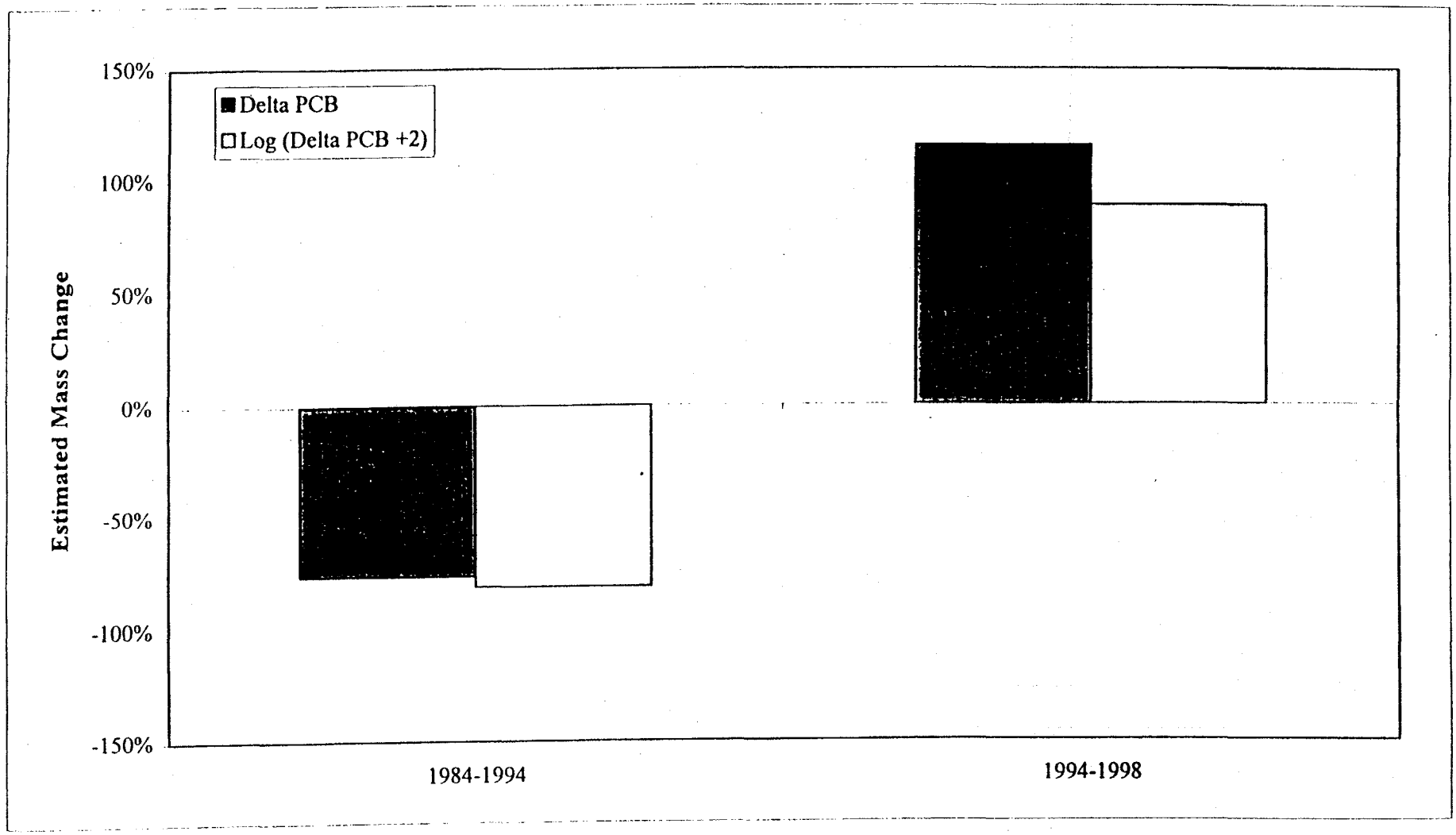
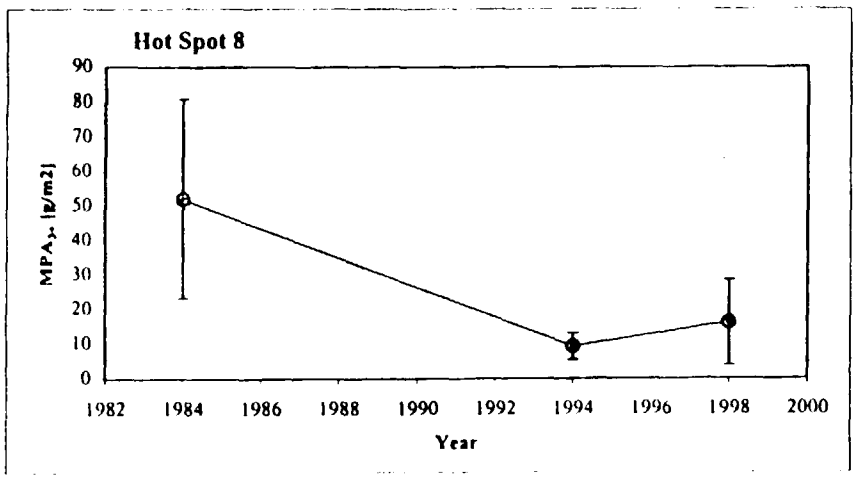
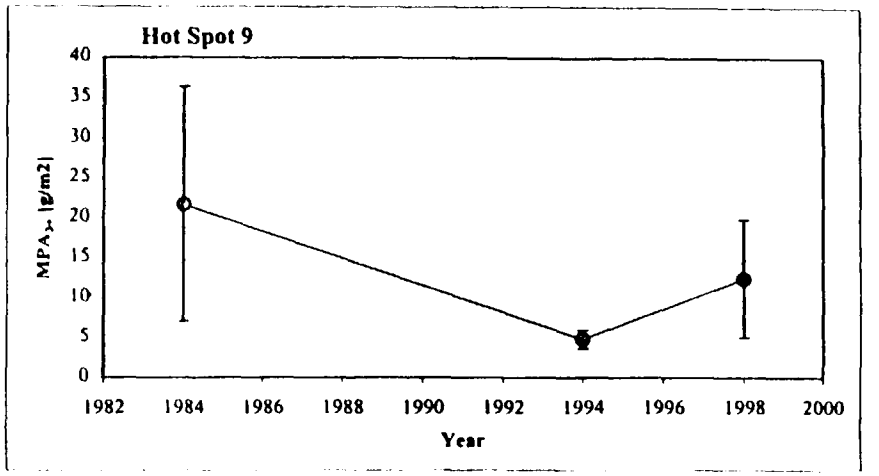
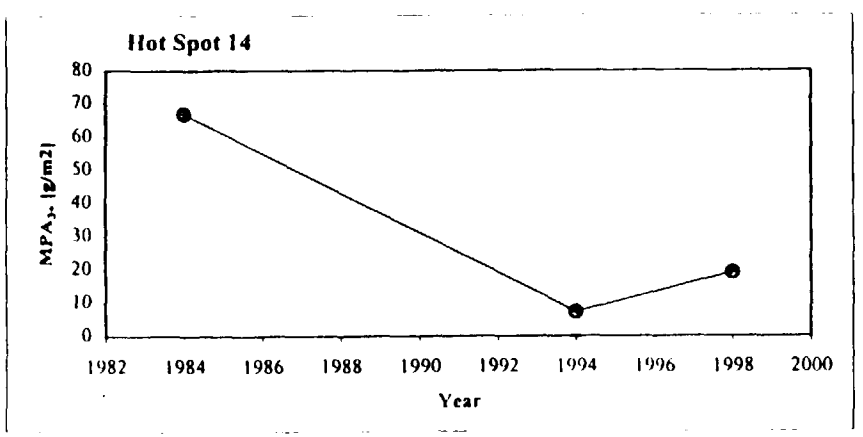


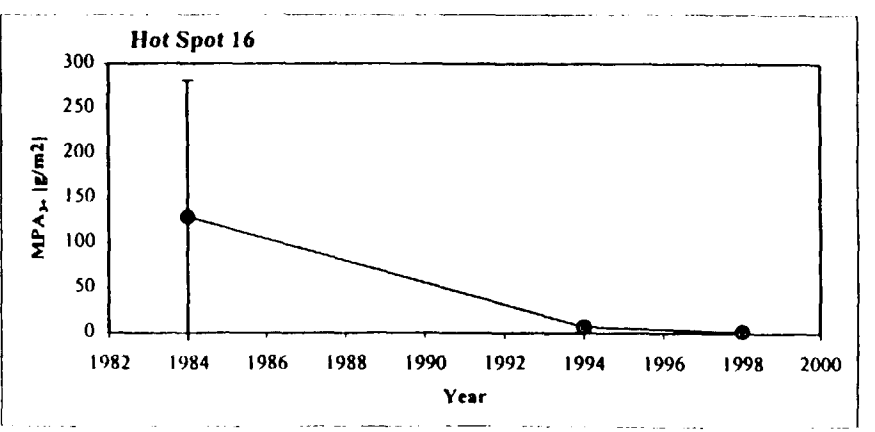
Figure 13

Temporal Profiles of Mean (+/- 95% Confidence Interval) PCB_{3+} Mass per Unit Area for Co-Located 1984, 1994, and 1998 Sediment Cores Within Four "Hot Spot" Areas







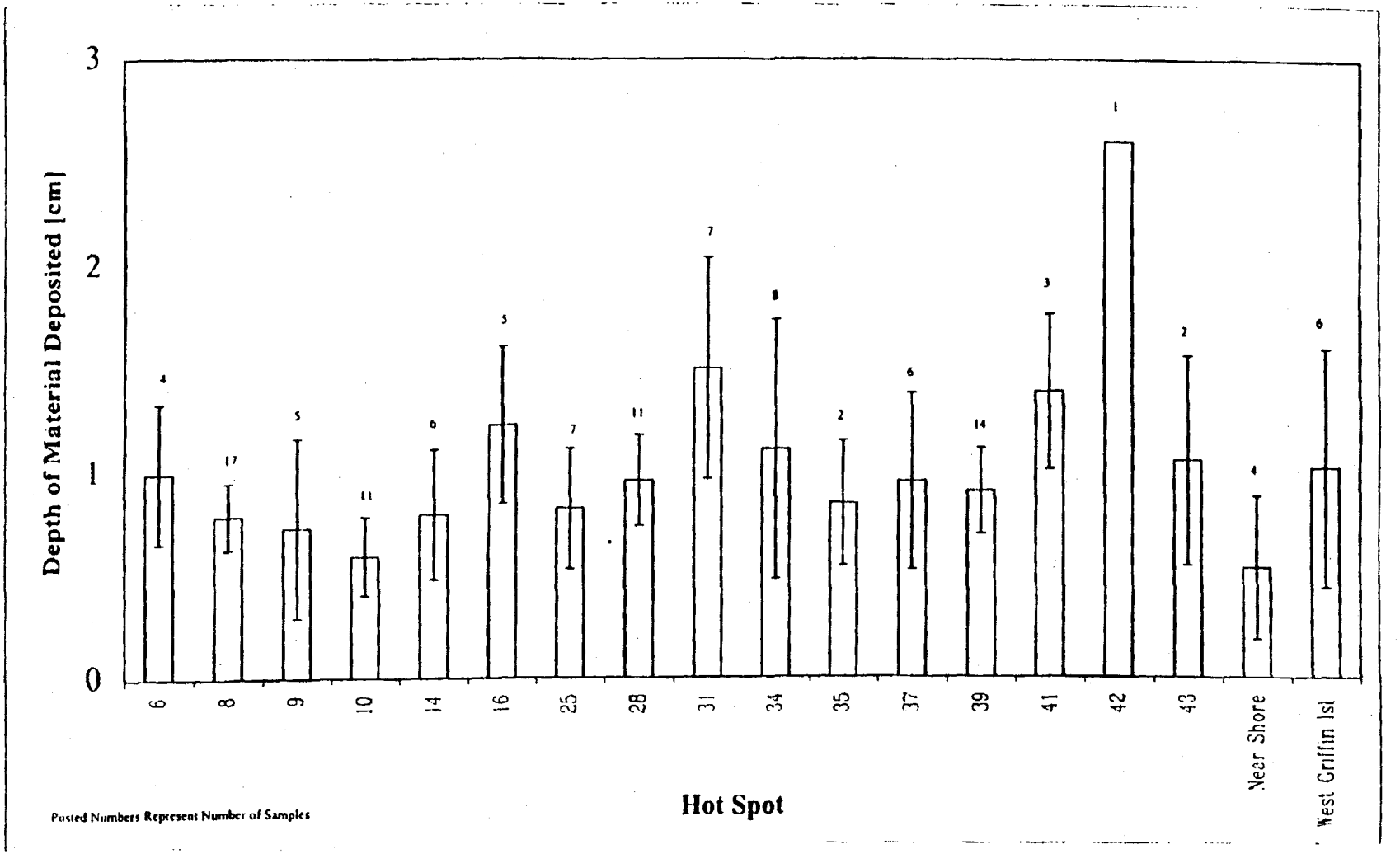


Note. Averages only include co-located cores within 5 feet

10.1110

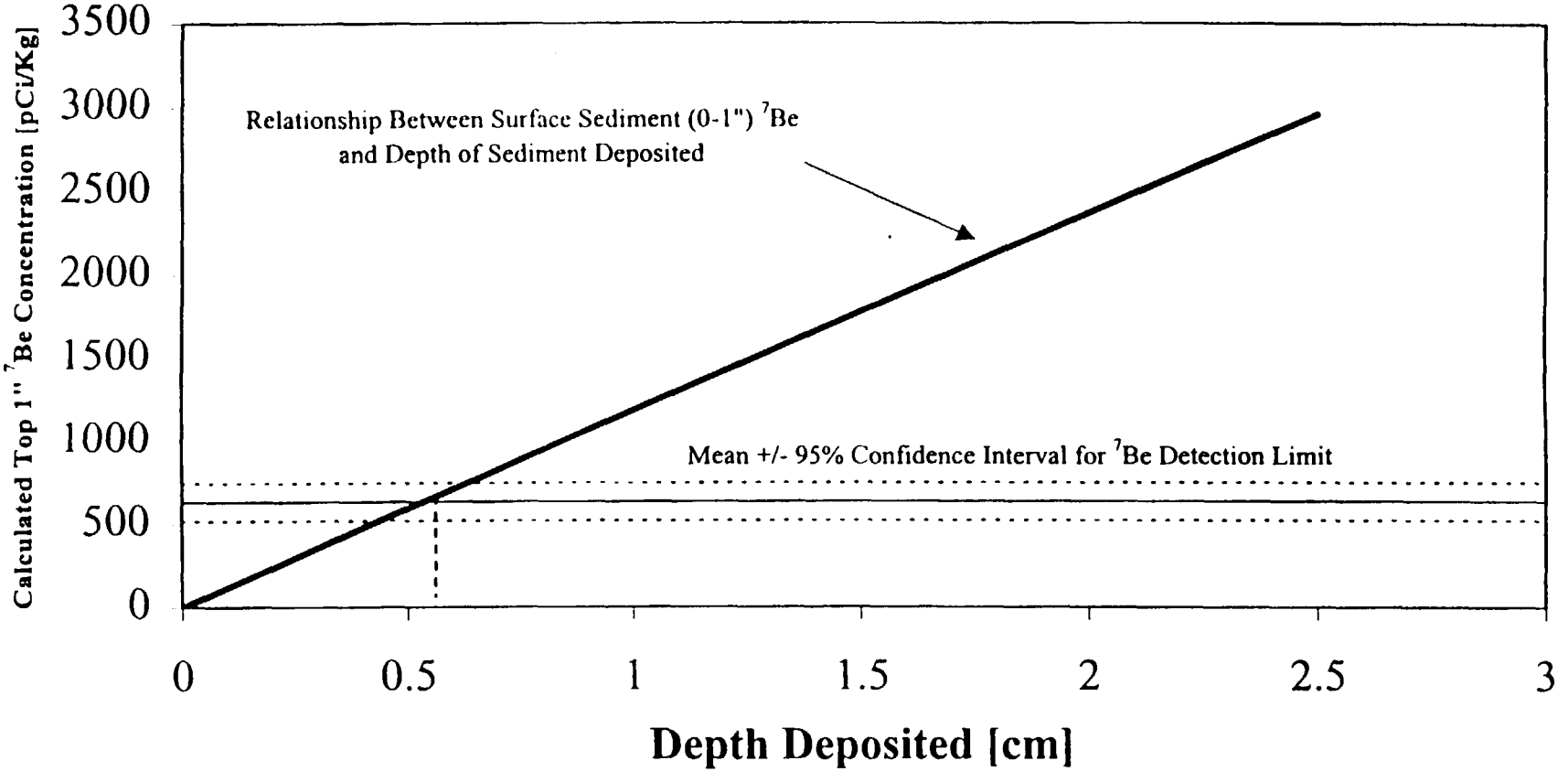
Figure 14

Computed Depth of Sediment Deposition Necessary to Produce Observed Levels of ^{7}Be in the Top 1" Section of the 1994 Cores



Notes: Water Column Particulate Phase ^{7}Be Concentration Assumed to be 20,000 pCi/kg
Date of Sediment Deposition Assumed to be April 17, 1994

Figure 15

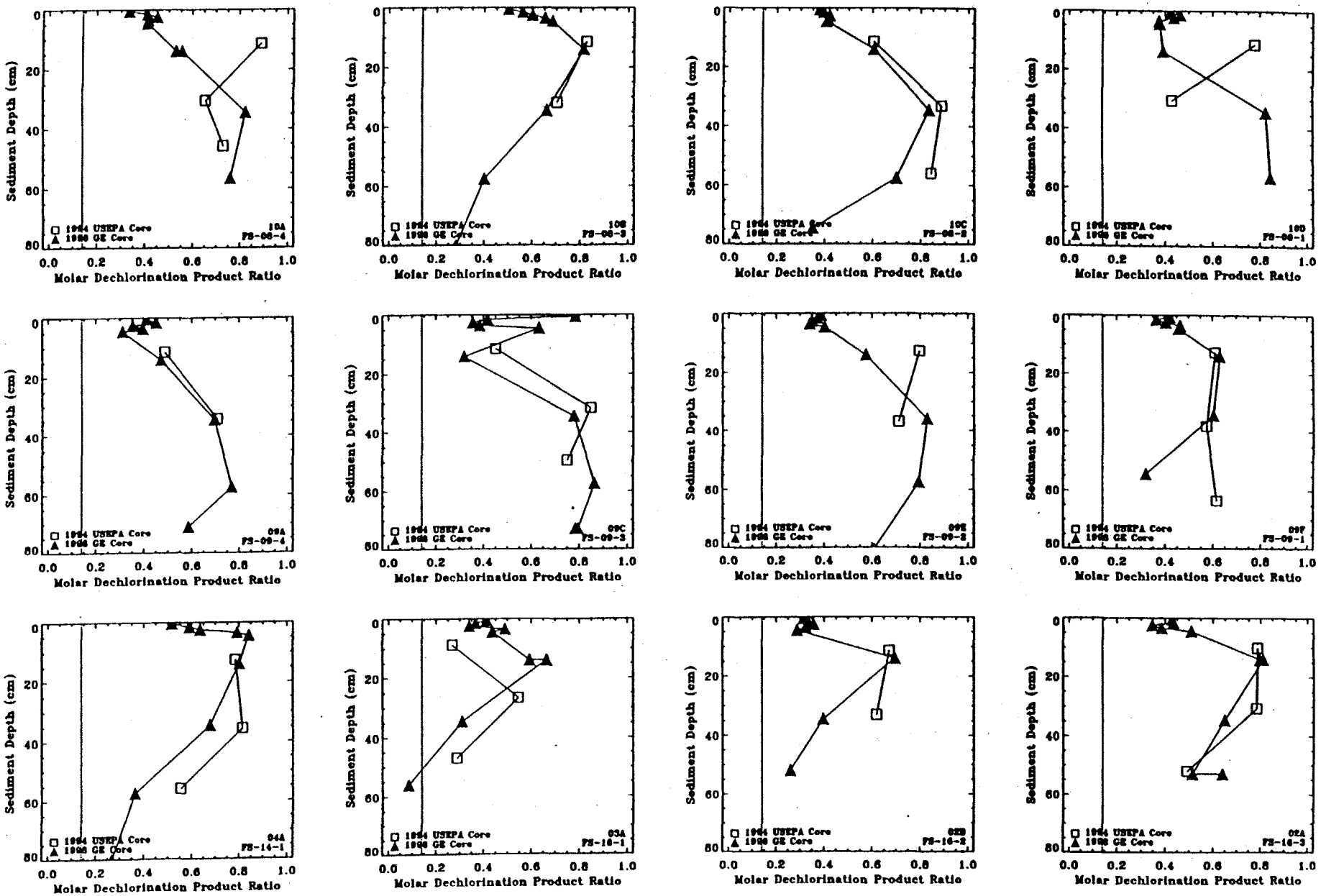


Notes: Assumed Date of Deposition: April 17, 1994

Assumed Initial ^{7}Be Concentration of 20,000 pCi/kg

Figure 16

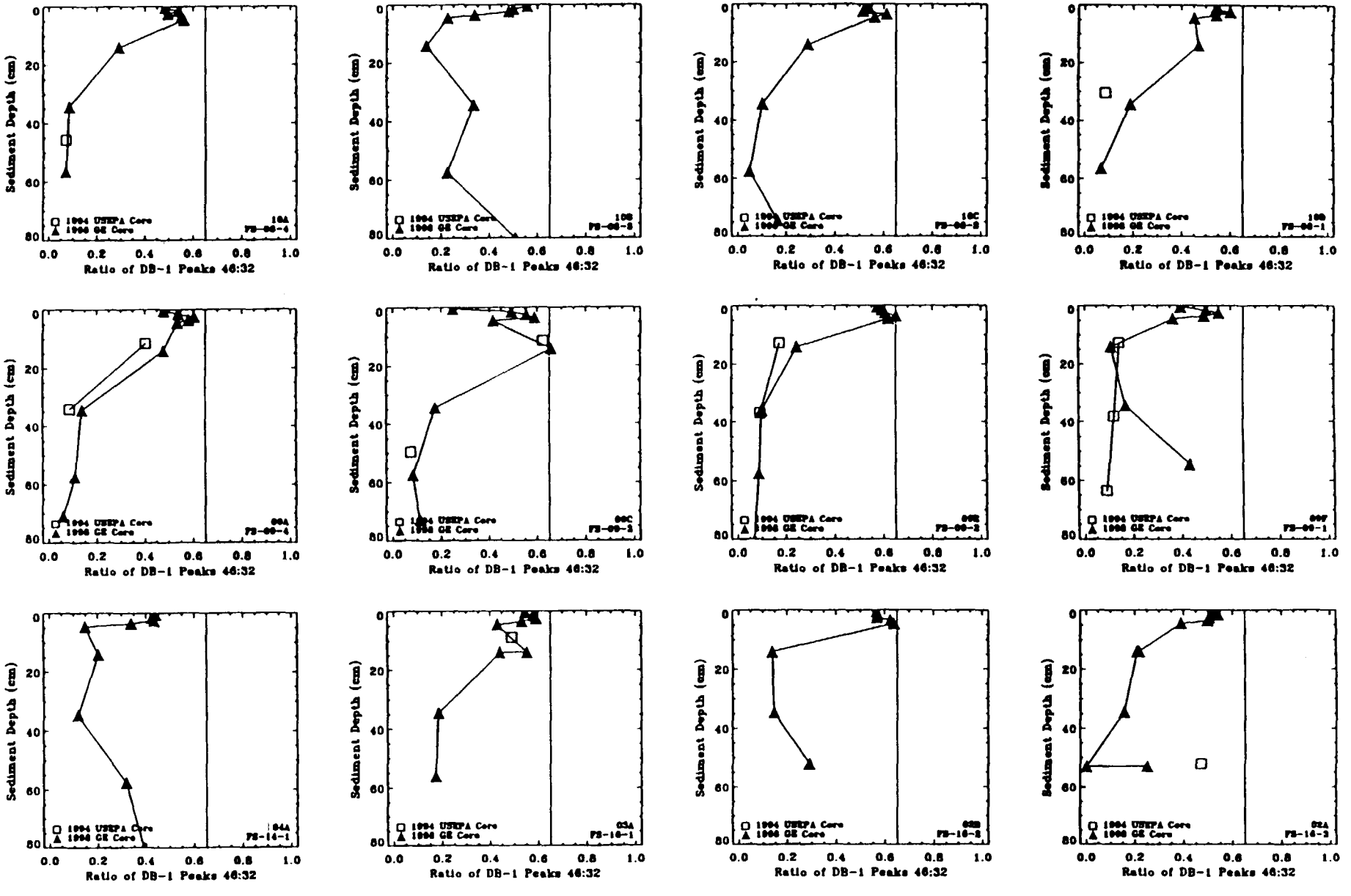
PCB Molar Dechlorination Product Ratio (see text for definition) Depth Profiles for Colocated 1994 TAMS and 1998 GE Sediment Cores Collected in Thompson Island Pool



Vertical Lines Represent Aroclor 1242

Figure 17

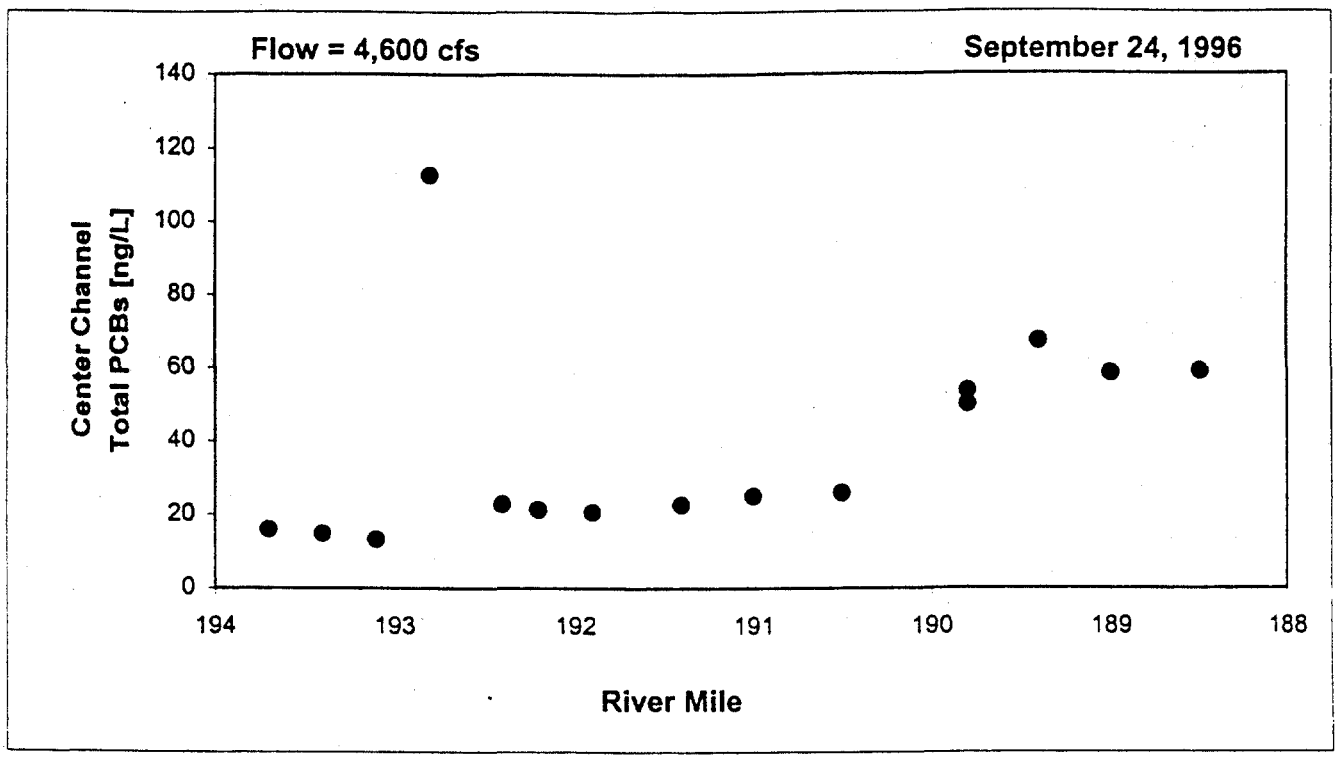
Ratio of DB-1 Peaks 46:32 Depth Profiles for Colocated 1994 TAMS and 1998 GE Sediment Cores Collected in Thompson Island Pool

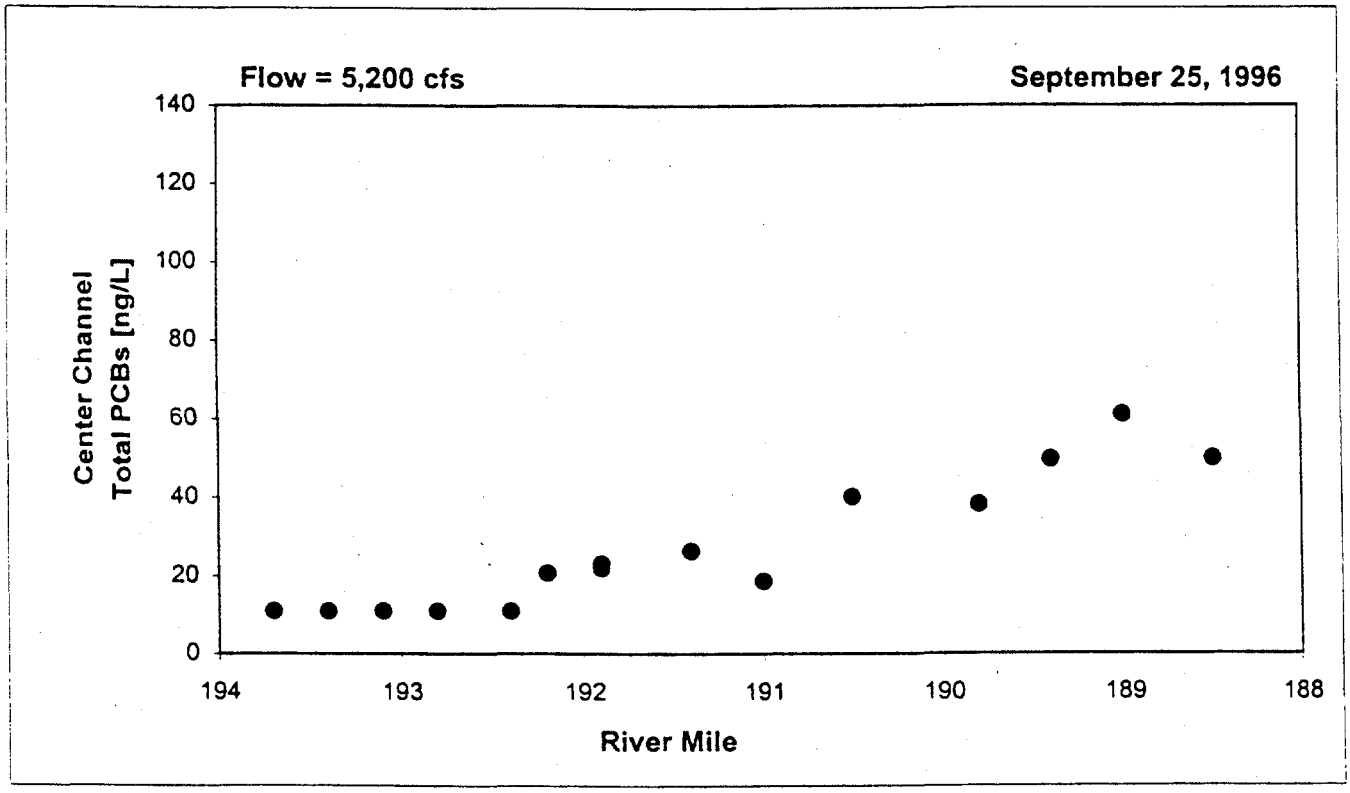


Note: Vertical Lines Represent Aroclor 1242

Figure 18

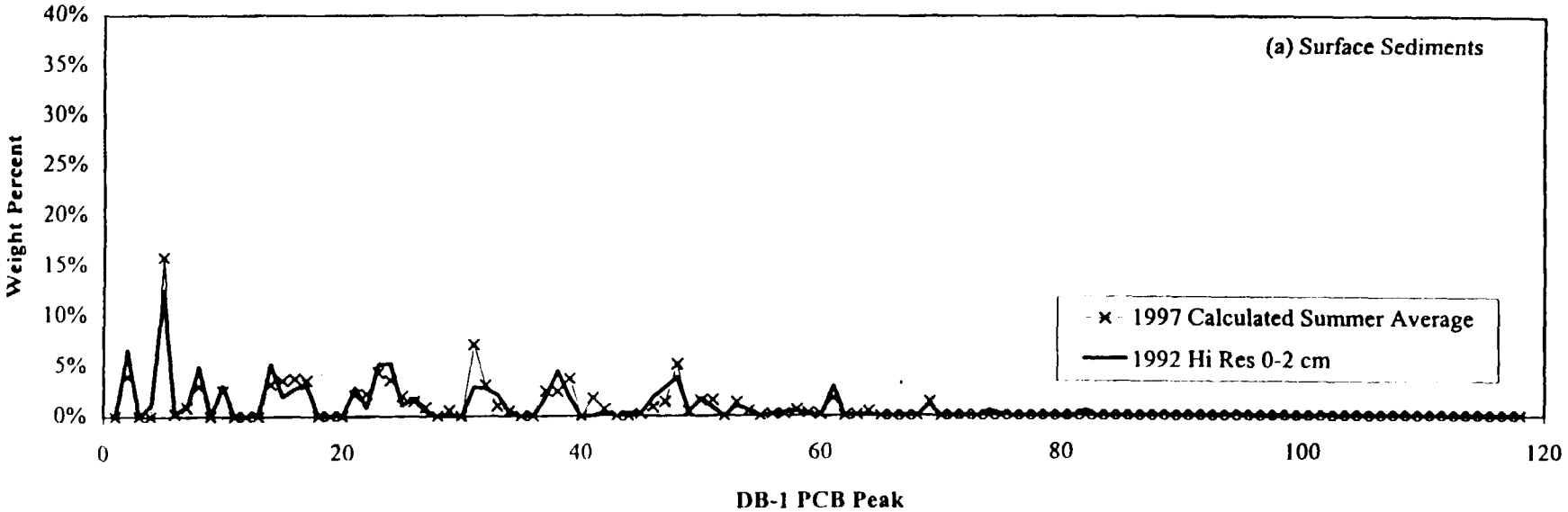
TIP Center Channel PCB Concentrations





Figur 9

Comparison of PCB Peak Compositions for Calculated Diffusional Sediment Source (1997 Summer Average) with (a) Surface and (b) Deep Sediments from 1992 EPA High Resolution Cores Collected from TIP



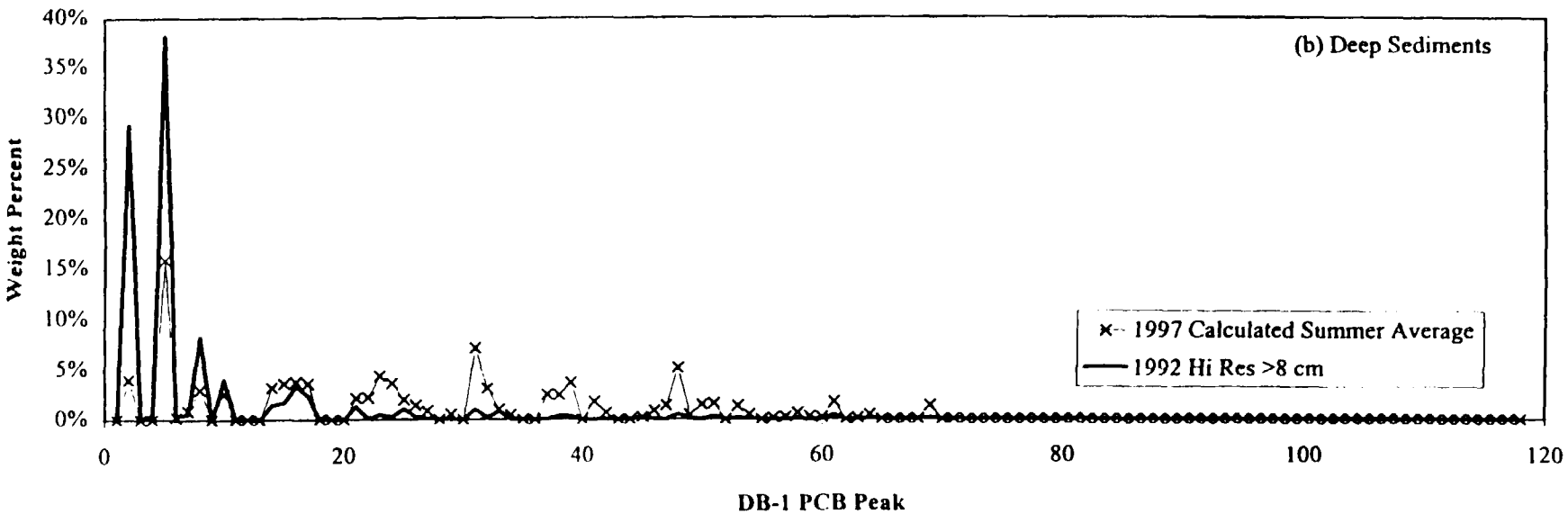


Figure 20

PCB congener ratios calculated for fish and sediment collected from the Thompson Island Pool

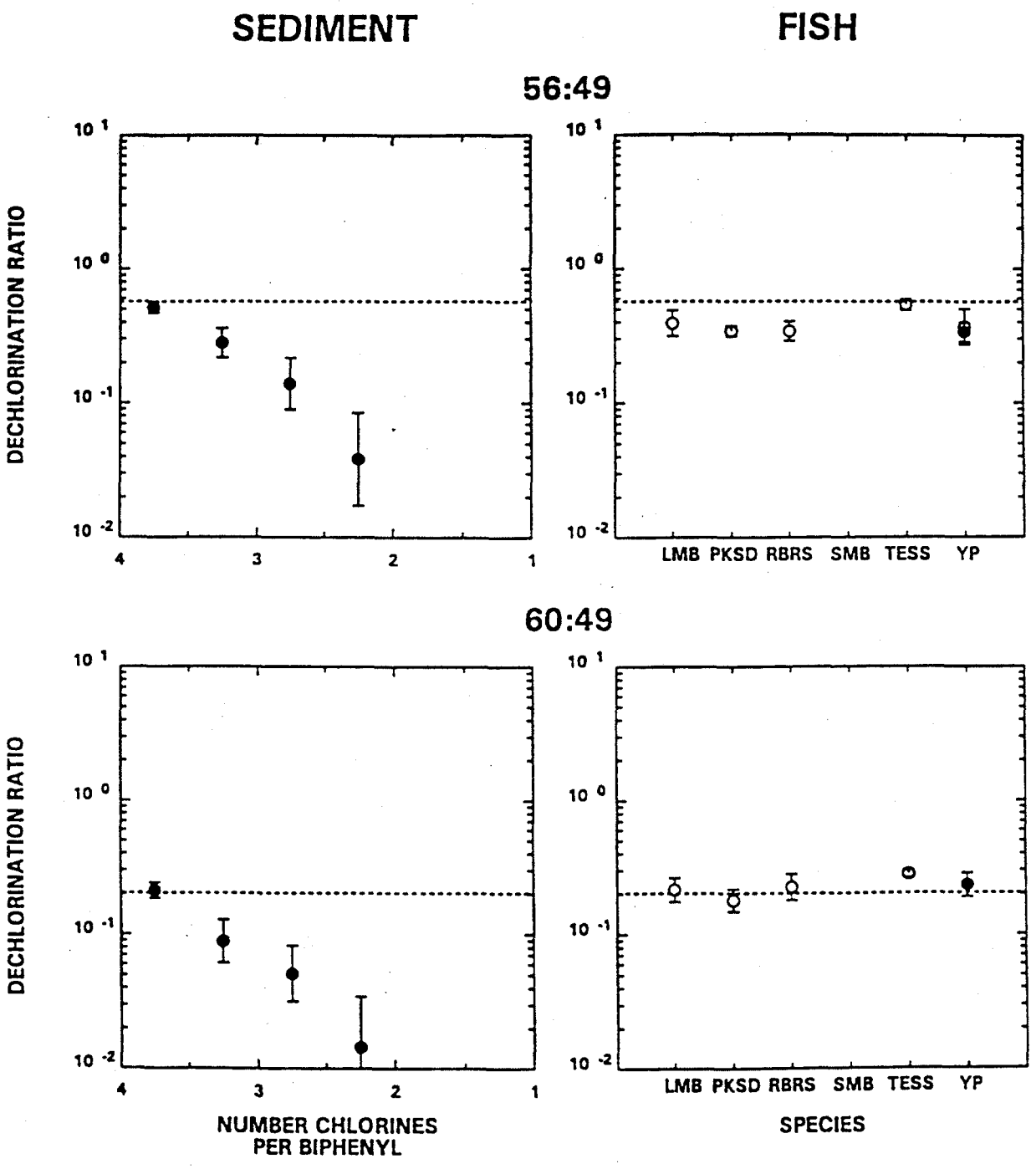


Figure 21

Temporal trends in DB-1 capillary column peak ratios from three stations on the Upper Hudson River during the January 1998 high flow event.

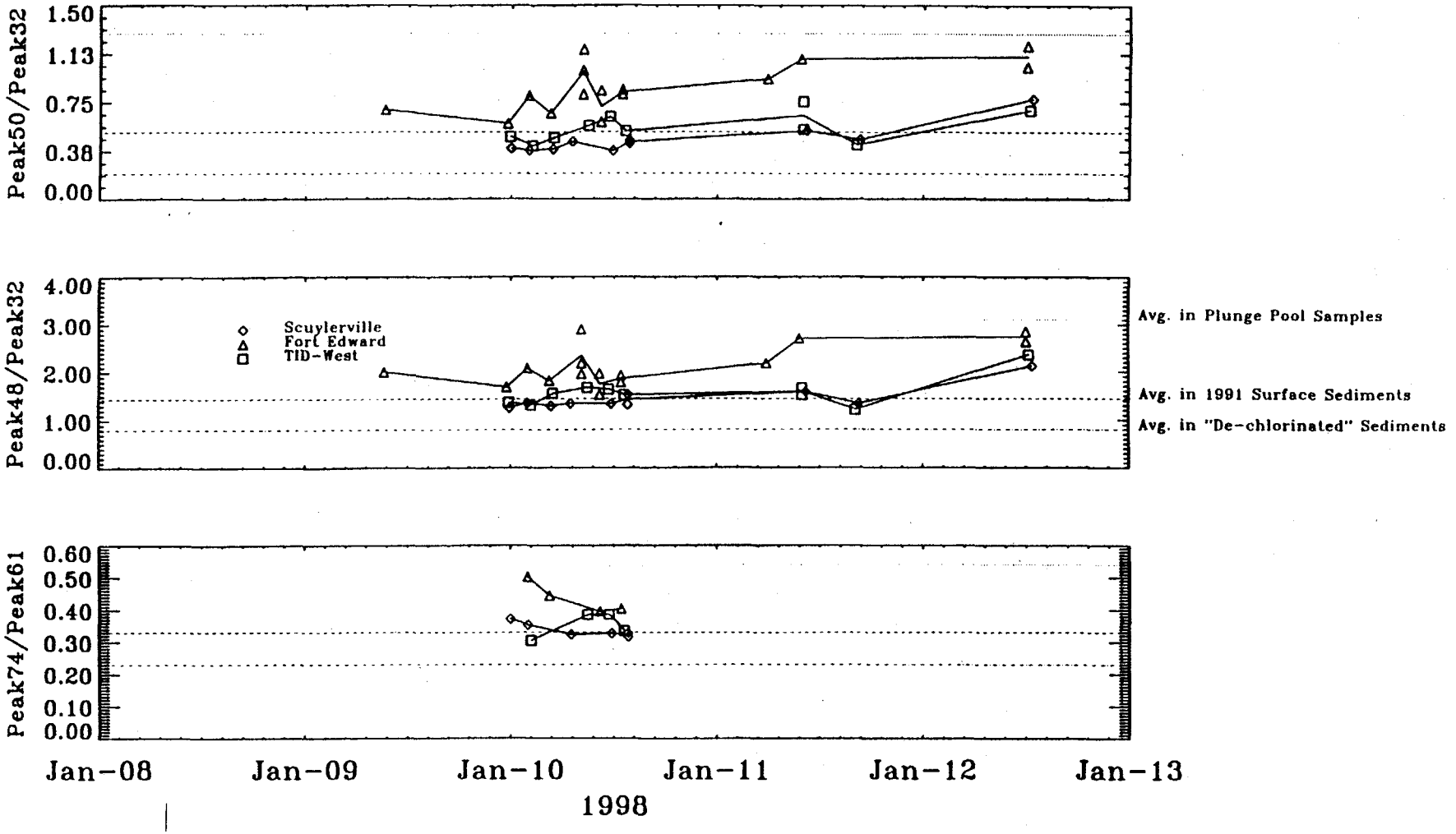
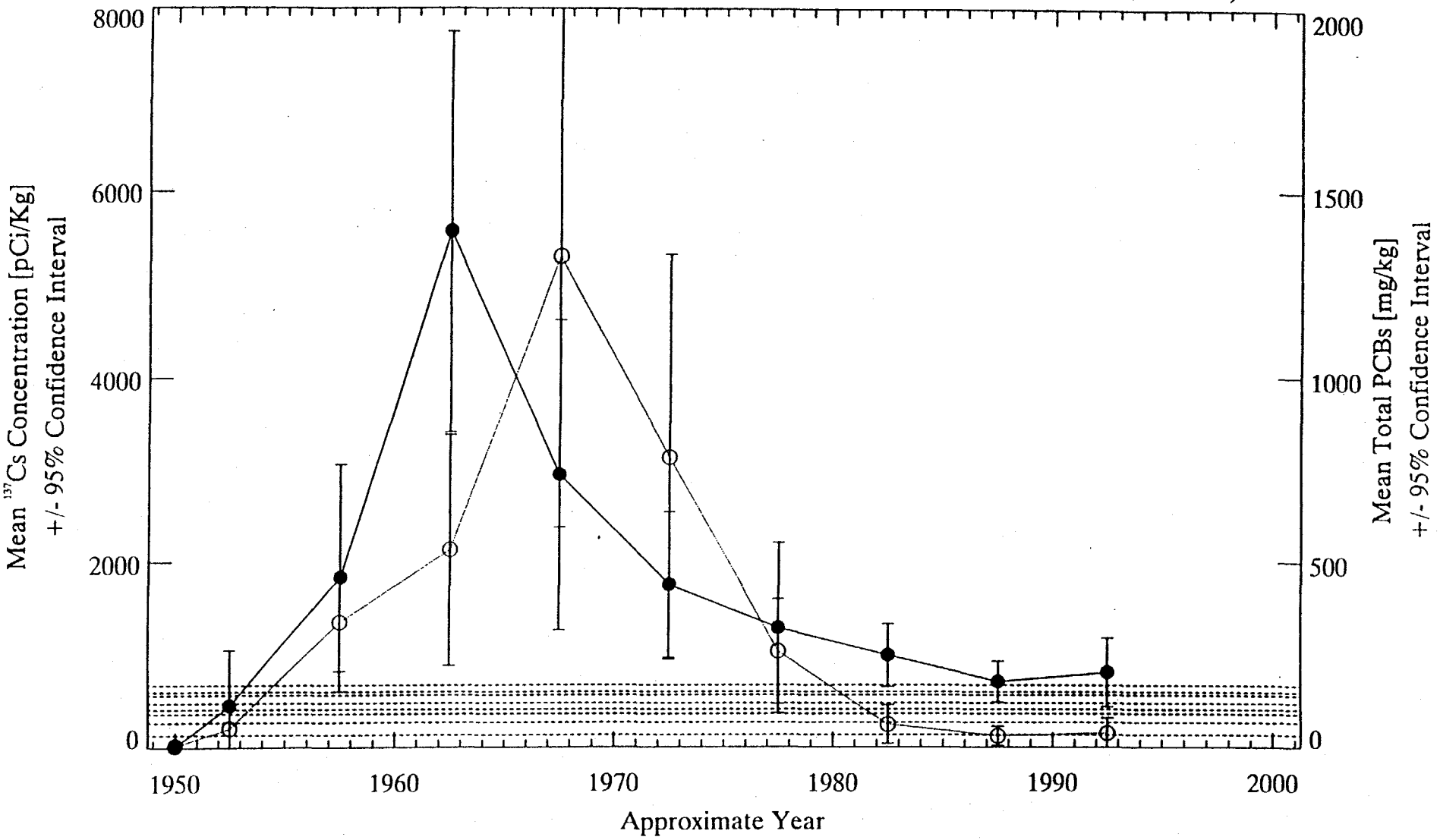


Figure 22

Average ^{137}Cs (filled symbols) and PCB (open symbols) Profiles Calculated from Thompson Island Pool High Resolution Sediment Cores (HR-019, 020, 023, and 026)



Notes:

1) Data Binned in 5 Year Intervals and Plotted at Midpoint

2) Horizontal dashed lines represent surface sediment (0-1") ^{137}Cs concentrations detected in cores TAMS identified as indicative of scour between 1984-1994 (03A, 04A, 09D, 10B, 10D, 11B, 11C, 12C)

APPENDIX A.

COMMENTS OF DR. PAUL SWITZER

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75 Pearce Mitchell Place
Stanford, CA 94305
August 24, 1998

John Haggard
General Electric Company
1 Computer Drive South
Albany, NY 12205

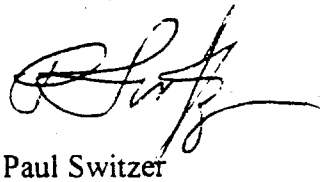
RE: HUDSON RIVER

Dear John,

I read the report material which you sent to me relating to Hudson River PCBs, viz., Volume 2C-A Book 1 and Book 2 *Low Resolution Sediment Coring Report* by TAMS *et al.*, dated July, 1998, prepared for the U.S.E.P.A., together with portions of Volume 2C *Data Evaluation and Interpretation Report*, by the same authors, dated February, 1997, containing material related to geostatistical analyses of the 1984 Hudson River PCB data. I also have seen the two reports you sent to me on geostatistical analyses prepared by Davis and Olea for General Electric Company, dated December 14, 1990, and February, 25, 1991 .

In my view, there are a number of important lapses both in the design of the Hudson River PCB study and the analyses of the data that are briefly described in my report accompanying this letter. In short, many of the stated conclusions of the July, 1998, report by TAMS *et al.* are not well supported by the reported statistics. Rather, these conclusions seem to be drawn from interpretations and conjectures that do not have a statistical inferential basis.

Sincerely,



Paul Switzer

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COMMENTS ON

1998 U.S.E.P.A
LOW RESOLUTION SEDIMENT CORING REPORT

prepared by

PAUL SWITZER

August, 1998

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ISSUES OF DATA SELECTION

1. Since not all core locations from the earlier surveys were to be resampled in 1994, care should be taken that those selected for the 1994 survey are representative of the zones for which PCB inventory estimates are desired. For example, a form of random or systematic selection or areally stratified random selection would remove the possibility of selection bias. Instead, the sampling method used is a poorly documented form of what statisticians call "purposive" sampling – here a misguided attempt to create zones of reduced sediment variability at the expense of unbiased representation of the 1984 sample locations. 1.29

2. Seven hot spots were defined by combining certain of the original twelve dredge locations from the 1984 survey. It is not clear whether the decision to combine dredge locations was made before or after the 1994 data were available. If after the data were available, then another source of selection bias is created because combining data can be used to purposively exaggerate statistical significance. This effect can be seen, for example, by comparing Figure 4-21 with Figure 4-22. 1.30

3. Not all of the 1994 data that were collected were used in the statistical estimates. An important issue is the removal of nearly 40% of the data because of potential cross-contamination from higher to lower segments of a core. The severe data rejection rule conforms to *a priori* ideas of what a core sequence should look like rather than relying on explicit evidence of cross-contamination. Because the fraction of data removed from the analysis is large, the susceptibility to selection bias is also large. Calculations showing that some statistics are not seriously affected by this form of data screening do not adequately address this issue. 1.31

4. It was reported that the lowest concentration data were excluded from "many of the subsequent analyses" [page 2-16] so that the remaining data would look like a lognormal distribution. The fact that the low concentration data are hard to quantify does not change the fact that they are nevertheless informative. Trimming data to achieve a desired distributional shape violates important statistical principles related to selection bias. 1.32

5. As an example of how purposive data selection can create an impression of a statistical relationship compare the weak associations in Figure 3-2 with the strong associations indicated by the selected data subset of Figure 3-8. This example shows clearly the perils of censoring data rather than modeling data. 1.33

CALIBRATION ISSUES

1. The SSW correction [see Figure 4-17 and Table 4-3] applied to the 1984 data is itself based on the PCB measurements. The net effect is to introduce an implicit non-linear rescaling into the PCB data which is difficult to analyze. This dry soil weight SSW factor should be based on some physical parameter other than PCB itself. Furthermore, stronger evidence is needed to demonstrate that such a recalibration of the 1976-78 data makes them comparable to the 1994 data. 1.34

2. The measurement methods for the 1976-78 survey, the 1984 survey, and the 1994 survey are different [see comments on page 4-21, for example]. However, there are no cross-calibration data presented which analyze the same samples by both methods. By implication, the subsequent statistical analyses assumed that relative calibration errors were strictly zero. How could the 1994 study have been undertaken without such calibration information? 1.35

3. The extrapolation of grab samples to make them comparable to 12-inch core segments is not well documented in the report. The "factor" used for extrapolation appears to be something like the mean PCB ratio between the top four inches and the top 12 inches seen in core samples [page 4-21]. Of course, such extrapolation introduces additional error beyond the measurement error associated with core sampling but the extrapolation error is not accounted for in the analysis. 1.36

THE REGRESSION FALLACY

1.37

Surprisingly, the report does not recognize the "regression" fallacy. The report makes much of the observation that lower 1984 concentration locations tended to be followed by later increases while higher 1984 concentrations tend to be followed by decreases. This kind of analysis is found throughout the report without any recognition of the "regression-toward-the-mean" effect: for *any* collection of paired measurements which are positively correlated, which these data emphatically are, higher initial concentrations will tend to show a decrease on average and lower initial concentrations will tend to show an increase on average -- *in the absence of any distributional changes*! [See Fig 4-11 to Fig 4-16 for example, as well as much of Section 4 and statements in the Executive Summary]. This fallacy may be understood by simply supposing that the true concentrations were *exactly* the same in 1984 and 1994 and that reported concentration differences were due entirely to analytic variability. Even in this case, splitting the data into two parts as the authors have done would demonstrate that higher 1984 concentrations tend to be followed by lower 1994 concentrations and vice-versa.

The geostatistical evidence from the 1984 survey shows that very short-scale spatial variability is often comparable to total variability [see Figures 4-9 to 4-12 and 4-14 to 4-16 in the 1997 report]. This fact, by itself, can be used to show that even small location errors induce a large spurious regression effect that would account for most of the reported 1994 PCB decrease at locations with high 1984 PCB.

ISSUES RELATED TO STATISTICAL CALCULATIONS

1. The MVUE method for estimation of means requires an exact lognormal model. Otherwise the method is biased. For example, the MVUE is sensitive to procedures for handling low concentration data. Censoring and BDL data create special problems for the MVUE method. The straightforward sample average is less sensitive to prior assumptions about the distribution of the data. 1.38A

2. The lognormal unbiasedness correction was inconsistently applied. For example, compare formulas on page 4-28 and in Table 4-13. In the latter case, the supposed MVUE ["minimum variance unbiased estimate"] for the near-shore sediments is neither unbiased nor minimum variance, even if the data were sampled from a precisely lognormal population distribution. 1.38B

3. While data were collected on covariate parameters such as grain size, the estimates of PCB inventory change did not incorporate the covariate information in any statistical model. It is not clear where or how the relationship between fine grain sediments and elevated PCB was used to improve estimates of PCB inventory [page 3-34]. 1.38C

4. Simply reporting correlations between individual covariate parameters and PCB measures, without regard to the multivariate nature of the data, does not take advantage of the potentially more powerful but widely used multivariate statistical methods such as partial correlation or multiple regression analysis. See the discussion on page 3-15 as an example. Failure to examine the multivariate statistics can also lead to mistaken interpretations such as that found on 3-19 "The correlation of ΔMV and MDPR values is largely a ramification of the correlation with total PCB" , as well as a similar confused statement about correlations on page 3-25. 1.38D

5. Hot spot PCB quantity differences between the 1976-78 and 1994 surveys are assessed by the ratio Δ_t described on page 4-40. The explicit claim is that differences "of more than a factor of two are considered significant and likely to be beyond the level of uncertainty". I could find absolutely no statistical basis for this claim and no supporting analysis! 1.38E

6. Upper 95% upper confidence limits were used to compare sediments in Table 4-13. Differences among these upper limits may be due to mean differences, variability differences, or differences in the number of samples, or some combination of these. It is misleading to make such comparisons. 1.38F

7. The report contains no statistical analysis of variance components that could be used to make better judgements regarding the significance of observed differences. Some examples of large random components of variability include the following. On Page 2-18 we read that split-pair samples differed by 36% on average. Table A-3 suggests that field replicate-pair congener analyses differ by more than 20% about half the time. Geostatistical studies of the 1984 survey report that "it was not unusual for samples taken only a few meters apart horizontally to exhibit order-of-magnitude differences in PCB concentrations" [page 4-25, 1997 report]. The reported variograms indicate that very short-scale spatial variability in sediment PCB is often comparable to the total variability observed between different sample locations. Without adequate accounting for random error components, it is hard to appreciate reported differences between the earlier and later PCB surveys. 1.38G

8. Statistical analyses of the Δ_M ratio measure of PCB molar inventory change are based on adding the arbitrary constant 2.0 to all ratios and then taking the logarithm. It is not reported how sensitive are the analyses to this particular fudge factor 2.0 . However, it is likely that the low end of the distribution is noticeably affected by this added factor, thereby affecting statistics in the context of a lognormal model. 1.38H

9. It appears that zonal PCB inventory estimates were obtained simply by multiplying averages of core-based concentrations [g/m^2] by estimates of zonal areas. These estimates take no account of the spatial configuration of the cores within zones and make no use of the geostatistical considerations. Although the 1994 data are not sufficient to develop the appropriate geostatistics, the geostatistical models based on the more extensive 1984 survey could have and should have been used. 1.38I

10. Estimates of PCB inventory, inventory changes, and dechlorination losses [see Table 4-8 as an example] are not accompanied by statistical estimates of uncertainty. Good statistical practice dictates the quantification of uncertainty – first as a measure of the adequacy of the underlying information and second as a tool in rational decision making. The uncertainty associated with inventory estimates derives from sampling variability, measurement error, and spatial interpolation errors, all of which propagate to the final inventory estimates. 1.38J

INCONSISTENCIES

1. The ^{7}Be data sometimes did, and sometimes did not show association with PCB levels or imputed scour of PCB, depending on how the data were divided or otherwise manipulated. See pages 3-23 and 4-38 for example. Nevertheless, the Executive Summary states categorically that "beryllium-7 was shown to be a statistically significant indicator of inventory loss" [ES-3]. For hot spots the report states that " [^{7}Be] evidence for recent deposition apparently contradicts the strong PCB profile evidence for long-term loss sediment loss or lack of burial" [page 4-35]. 1.39A

2. It is reported that the molar inventory changes between the 1984 and 1994 surveys [page 4-14] indicate no statistically detectable trend. However, the report also claims that a relative measure of molar change, Δ_M , shows statistically detectable decreases, probably reflecting the regression fallacy described earlier. In this connection, the report makes the inaccurate statement on page 4-15 that for relative measures of change "much of the analytic variability can be diminished in importance relative to real change". 1.39B

3. The high-resolution 1984 survey did not confirm that the amount of implied dechlorination is proportional to total PCB or that it followed the same dechlorination pattern as the low-resolution 1994 data [pages 3-5, 3-9, 3-35]. 1.39C

CONCLUSIONS VERSUS DATA

1. Statistical analyses were not used to support frequent statements regarding lack of burial. Indeed, high resolution core data [Figure 4-24 is an example] indicate that the concentration peak can rise and fall sharply within a 9" or 12" segment, representing one or more decades of deposition. The fact that the top segment of a low-resolution core shows higher concentration than the succeeding segment does not, by itself, imply that the peak concentration is at the surface and that burial is absent. On page 3-10 the report itself states that "it is likely that a low-resolution core segment would span a range of two or more orders of magnitude...over a nine inch interval". 1.40A

2. The simple "sign test" shows that the frequency of locations with PCB increases versus those with decreases is not statistically different from 50%. There are many examples, such as the comparisons in Figures 4-4 and 4-21. The point is that the limited size of the 1994 survey makes the results look much like the results of coin tossing. The non-statistical rationalizations in the report, however salient, should not be confused with statistical inference. 1.40B

3. Many far-reaching statements in the report are not actually derived from a statistical analysis of the data, even though such non-statistical hypotheses and conjectures are intertwined with statistical reporting. Examples of such are statements referring to scour, resuspension or redistribution of sediments, dechlorination limits, underestimation of prior inventory, probable losses due to incomplete cores, and the relation of Aroclors to PCB concentrations. 1.40C

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APPENDIX B.

DESCRIPTION OF THE GENERAL ELECTRIC CO. SEDIMENT TRANSPORT MODEL

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SECTION 1
INTRODUCTION

Understanding the fate and transport of PCBs, both qualitatively and quantitatively, in the Thompson Island Pool (TIP) is of critical importance when considering various remedial action scenarios in this reach of the Upper Hudson River. Modeling has been shown to be an effective method for quantitatively evaluating PCB fate and transport processes in a riverine system. A comprehensive PCB fate and transport modeling framework will contain three sub-models that are coupled together: (1) hydrodynamic; (2) sediment transport; and (3) PCB fate and transport.

As part of a larger effort to quantitatively evaluate PCB fate and transport in the Upper Hudson River, a coupled hydrodynamic/sediment transport model has been developed, calibrated, validated and applied to better understand sediment transport processes in the TIP. The model used in this study (SEDZL) has been successfully applied to other riverine systems, including: Lower Fox River, Wisconsin (Gailani et al., 1991); Saginaw River, Michigan (Cardenas et al., 1995); Buffalo River, New York (Gailani et al., 1996); Pawtuxet River, Rhode Island (Ziegler and Nisbet, 1994) and Watts Bar Reservoir, Tennessee (Ziegler and Nisbet, 1995). The current study has produced significant improvements to SEDZL in the areas of cohesive sediment deposition and non-cohesive suspended load transport.

The purpose of this report is to present: (1) descriptions of the hydrodynamic and sediment transport models; (2) calibration and validation results; and (3) an evaluation of sediment transport processes in the TIP. The next section provides an overview of the hydrodynamic model. Section 3 discusses the development, calibration and validation of the sediment transport

model. The final section of the report discusses some results from the modeling effort and the implications for PCB fate and transport in the TIP.

SECTION 2
HYDRODYNAMIC MODEL DEVELOPMENT AND CALIBRATION

2.1 Model Structure

The Thompson Island Pool is relatively shallow (approximate mean depth of 7 ft) and the flow is unstratified. These conditions make it possible to assume that the water column is vertically well-mixed. Thus, the two-dimensional, vertically-averaged equations are an accurate approximation to the general three-dimensional equations of motion for an incompressible fluid. The hydrodynamic equations (conservation of mass and momentum) applied to the Thompson Island Pool are (Ziegler and Nisbet, 1994):

$$\frac{\partial \eta}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0 \qquad (2\text{-}1)$$

$$\frac{\partial (uh)}{\partial t} + \frac{\partial (u^2 h)}{\partial x} + \frac{\partial (uvh)}{\partial y} = -gh\frac{\partial \eta}{\partial x} - C_f q u + \frac{\partial}{\partial x}\left(hA_H \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y}\left(hA_H \frac{\partial u}{\partial y} \right) \qquad (2\text{-}2)$$

$$\frac{\partial (vh)}{\partial t} + \frac{\partial (uvh)}{\partial x} + \frac{\partial (v^2 h)}{\partial y} = -gh\frac{\partial \eta}{\partial y} - C_f q v + \frac{\partial}{\partial x}\left(hA_H \frac{\partial v}{\partial x} \right) + \frac{\partial}{\partial y}\left(hA_H \frac{\partial v}{\partial y} \right) \qquad (2\text{-}3)$$

where the total water depth is $h = h_o + \eta$; h_o = equilibrium water depth; η = water surface displacement from that equilibrium; u and v = velocities in the x- and y-directions, respectively; $q = (u^2 + v^2)^{1/2}$; C_f = spatially variable bottom friction factor; A_H = horizontal eddy viscosity; and g = acceleration due to gravity. Equations (2-1) to (2-3) were transformed from Cartesian coordinates to orthogonal, curvilinear coordinates in order to more accurately resolve the complex geometry and bathymetry of the Thompson Island Pool. The resulting equations were then solved numerically.

The bottom friction factor in Equations (2-2) and (2-3) is dependent on the local water depth and effective bottom roughness (Blumberg and Mellor, 1983):

$$C_f = MAX\left[\frac{k^2}{\left(\ln\frac{h}{2z_o}\right)^2} \quad , \quad C_{f,\min}\right] \tag{2-4}$$

where k = von Karman's constant (= 0.4); $C_{f,min}$ = minimum bottom friction factor; and z_o = effective bottom roughness.

2.2 Application to the Thompson Island Pool

The TIP hydrodynamic model extends from the Route 197 bridge at Rogers Island (HRM 194.4) to Thompson Island dam (HRM 188.5). This six-mile reach has been discretized using 68 longitudinal and 10 lateral grid elements (Figure 2-1). The hydrodynamic effects of the jetty at the entrance to the Champlain Canal near HRM 189 have been included in the model.

Bathymetric data collected by General Electric in 1991 were used to specify values of h_o for model input. The 1991 bathymetric survey collected depth soundings at about 107,000 points throughout the TIP at river flows within a range from about 1,700 to 2,700 cfs. The average equilibrium water depth (h_o) in a particular grid element was calculated using the 1991 sounding data located within that grid element. The resulting bathymetric distribution used for model input is presented on Figure 2-2.

The hydrodynamic model requires the specification of two types of time-variable boundary conditions: (1) inflows from upstream and tributary sources and (2) stage height at Thompson Island dam. Flow rates measured by the U.S.

Geological Survey (USGS) at the Rogers Island gauging station were used as input at the upstream boundary of the model. The mean flow rate at this location is approximately 5,200 cfs and the 100-year flood has been estimated to be 47,300 cfs.

A 161 mi^2 drainage basin contributes tributary flow to the TIP between Rogers Island and Thompson Island dam, primarily through Snook Kill (75 mi^2) and Moses Kill (55 mi^2). The remaining 19% of the basin is considered to be direct drainage. No permanent gauging stations are located on these streams and limited flow data exist for either tributary. A modified drainage area proration method has been developed to estimate tributary flows to the TIP using flow data collected at the USGS gauging stations located on Kayaderosseras and Glowegee Creeks. This procedure is very similar to the tributary flow estimation method implemented by the USEPA modeling team (Limno-Tech, 1998). The estimated mean flow rates for Snook and Moses Kills are 105 and 77 cfs, respectively.

Stage heights measured at the Crockers Reef gauge (gauge 118) by Champlain Canal personnel were used to develop a relationship between flow rate and water surface elevation at the Thompson Island dam. This rating curve was used to specify time-variable water surface elevation at the downstream boundary of the model.

2.3 Model Calibration and Validation Results

The hydrodynamic model contains two adjustable parameters: horizontal eddy viscosity (A_H) and effective bottom roughness (z_o). Generally, hydrodynamic models are run with the minimum value of A_H needed to ensure numerical stability, which was 1 m^2/s for the TIP. No adjustment of A_H was made during model calibration or validation.

The model was calibrated and validated using water surface elevation data collected at locations upstream of the Thompson Island dam. The effective bottom roughness was adjusted to achieve the best agreement between observed and predicted upstream water surface elevations during the calibration process, which used data collected during November 1990 when flow rates ranged between 7,000 and 8,000 cfs. Spatially variable z_o values were used, depending on local bed type, with z_o set at 1,500 μm in non-cohesive sediment bed areas ($C_{f,min}$ = 0.0035) and 75 μm in cohesive sediment bed areas ($C_{f,min}$ = 0.0020). The distribution of cohesive and non-cohesive bed areas in the TIP is discussed in Section 3.

The hydrodynamic model was validated using water surface elevation obtained during the 1983 flood. These data were collected by Champlain Canal personnel at gauges located near Crockers Reef (gauge 118) and at the entrance to the Champlain Canal near Rogers Island (gauge 119). The 1983 flood had the highest daily average flow rate (34,100 cfs) measured at the Rogers Island gauge since the gauge became operational in 1977. Results of the validation simulation (Figure 2-3) indicate that the model does a very good job of predicting water surface elevations throughout the TIP. Successful calibration and validation of the model demonstrates that: (1) model geometry and bathymetry are accurately represented and (2) bottom friction factors used in the model are realistic and accurate.

SECTION 3
SEDIMENT TRANSPORT MODEL DEVELOPMENT, CALIBRATION AND VALIDATION

3.1 Model Structure

Suspended sediment particles in a river have a large range of sizes, from less than 1 μm clays to fine sands on the order of 250 μm. Simulation of the entire particle size spectrum is impractical. However, the particles may be broadly segregated into two groups: silts and clays that may interact and form flocs and sands that are transported as discrete particles. The model uses this approach to approximate the particle size spectrum. "Class 1" particles include all the cohesive particles, i.e., clays and silts, with disaggregated particle diameters of less than 62 μm, while the "class 2" particles include coarser, non-cohesive sediments, primarily fine sands with diameters between 62 and 250 μm.

A valid assumption in the Thompson Island Pool is that the water column is well-mixed and that suspended fine-grained sediment concentrations are approximately uniform in the vertical direction. For these conditions, the two-dimensional, vertically-averaged sediment transport equation for size-class k (k = 1,2) is applicable (Ziegler and Nisbet, 1994):

$$\frac{\partial(hC_k)}{\partial t} + \frac{\partial(uhC_k)}{\partial x} + \frac{\partial(vhC_k)}{\partial y} = \frac{\partial}{\partial x}\left(hK_H \frac{\partial C_k}{\partial x}\right) + \frac{\partial}{\partial y}\left(hK_H \frac{\partial C_k}{\partial y}\right) + E_k - D_k \qquad (3\text{-}1)$$

where C_k = concentration of suspended sediment of size-class k; K_H = horizontal eddy diffusivity; E_k = resuspension (erosion) flux of size-class k; and D_k = deposition flux of size-class k. Results from the hydrodynamic model provide information about the transport field in Equation (3-1), i.e., u, v and h. Similar to

the hydrodynamic equations, Equation (3-1) has been transformed into an orthogonal, curvilinear coordinate system and then solved numerically.

Cohesive sediments suspended in the water column can have a wide range of particle sizes, from clay particles smaller than 1 μm up to ~50 μm silts. In addition, the cohesive nature of these particles cause the discrete particles to aggregate and form flocs which can vary greatly in size and effective density. Variations in concentration and shear stress affects both floc diameter and settling speed (Burban et al., 1990). Modeling the settling characteristics, and associated depositional fluxes, of cohesive sediments in a natural water system can thus be difficult.

One way to model cohesive deposition is to use multiple size classes to simulate particle/floc heterogeneity in the water column. Difficulties with this approach include: (1) specification of composition of sediment loading from tributaries; (2) obtaining data for model calibration/validation; and (3) computational constraints.

Previous modeling studies (Ziegler and Nisbet, 1994, 1995; Gailani et al., 1996) have shown that an effective approximation is to treat suspended cohesive sediments as a single class. This approach assumes that the settling and depositional characteristics of cohesive sediments can be represented by average values of a distribution of properties. Using this approximation, the deposition flux of cohesive (class 1) sediments to the sediment bed can be expressed as (Ziegler and Nisbet, 1994):

$$D_1 = P_1 W_{s,1} C_1 \qquad (3\text{-}2)$$

where $W_{s,1}$ = cohesive sediment settling speed and P_1 = probability of deposition for cohesive sediments.

Settling speeds of cohesive flocs in freshwater have been measured over a large range of concentrations and shear stresses (Burban et al., 1990). The Burban settling speed data for cohesive flocs in freshwater have been analyzed in an attempt to develop a formulation that can be used to approximate the effects of flocculation on settling speed. This analysis indicates that the settling speed is dependent on the product of the concentration (C_1) and the water column shear stress (G) at which the flocs are formed, resulting in the following relationship:

$$W_{s,1} = 3.3\left(C_1 G\right)^{0.12} \tag{3-3}$$

where the units of $W_{s,1}$, C_1, and G are m/day, mg/l and dynes/cm^2, respectively. See Figure 3-1 for a comparison of Equation (3-3) with Burban et al. (1990) data. For a depth-averaged model, as used in this study, the relevant shear stress for use in Equation (3-3) is the bottom shear stress (τ_b), i.e., $G = \tau_b = C_f q^2$.

Modeling suspended cohesive sediments as a single class, with an effective $W_{s,1}$ given by Equation (3-3), makes it necessary to utilize a probability of deposition (P_1) to parameterize the effects of particle/floc size heterogeneity and near-bed turbulence on the deposition rate. The complex interactions occurring in the vicinity of the sediment-water interface cause only a certain fraction of the settling cohesive sediments, represented by P_1, to become incorporated into the bed (Krone, 1962; Partheniades, 1992). An experimentally-based formulation that realistically represents the effects of variable floc size on probability of deposition was developed by Partheniades (1992), which can be expressed as:

$$P_1 = 1 - (2\pi)^{-1/2} \int_{-\infty}^{Y} e^{-\frac{w^2}{2}} dw \tag{3-4}$$

where:

$$Y = 2.04 \ln\left[0.25\left(\frac{\tau_b}{\tau_{b,\min}} - 1\right)e^{1.27\tau_{b,\min}}\right] \qquad (3\text{-}5)$$

and $\tau_{b,min}$ = bottom shear stress below which $P_1 = 1$ (dynes/cm^2), see Figure 3-2.

Class 2 particles, i.e., non-cohesive fine sands, suspended in the water column are assumed to have an effective settling speed ($W_{s,2}$) that corresponds to an effective particle diameter (d_2). The depositional flux for this sediment class is then:

$$D_2 = P_2 W_{s,2} C_2 \qquad (3\text{-}6)$$

where P_2 = probability of deposition for non-cohesive sediments. Details concerning methods for calculating $W_{s,2}$ and P_2 are presented in HydroQual (1997b). The relationship between $W_{s,2}$ and d_2, which was developed by Cheng (1997), is shown on Figure 3-3.

Only a finite amount of material can be resuspended from a fine-grained, cohesive sediment bed that is exposed to a constant bottom shear stress. This phenomenon, referred to as bed armoring, has been observed and quantified in a number of laboratory (Parchure and Mehta, 1985; Tsai and Lick, 1987; Graham et al., 1992) and field studies (Hawley, 1991; Amos et al., 1992). The amount of fine-grained sediment resuspended from a cohesive deposit is given by (Gailani et al., 1991):

$$\epsilon = \frac{a_o}{T_d^m}\left(\frac{\tau_b - \tau_{cr}}{\tau_{cr}}\right)^n \quad , \quad \tau_b \geq \tau_{cr} \qquad (3\text{-}7)$$

where ϵ = net mass of resuspended sediment per unit surface area (mg/cm^2); a_o = site-specific constant; T_d = time after deposition in days; m and n are dependent upon the deposition environment; and τ_{cr} = effective critical shear stress. Note that ϵ is referred to as the resuspension potential.

Experimental results show that the total amount of sediment is not resuspended instantaneously but it is eroded over a time period on the order of one hour (Tsai and Lick, 1987; MacIntyre et al., 1990). Thus, the total resuspension rate (E_{tot} with units of mg/cm^2-s) is given by:

$$E_{tot} = \frac{\epsilon}{3600} \tag{3-8}$$

where E_{tot} is assumed to be constant until all available sediment is eroded. Once the amount ϵ has been resuspended, E_{tot} is set to zero until additional sediment is deposited and available for resuspension or until the shear stress increases (Gailani et al., 1991). The resuspension rate of class k (E_k) sediment from the cohesive bed is then given by:

$$E_k = f_k E_{tot} \tag{3-9}$$

where f_k = fraction of class k sediment in the surficial layer of the cohesive bed.

A three-dimensional model of the cohesive sediment bed realistically simulates the effects of bed consolidation with depth and horizontal variations in bed composition. The layered bed model conserves mass, with mass flux occurring only at the sediment-water interface due to deposition and resuspension. Vertical variations of sediment bed consolidation, or equivalently porosity, are accounted for by discretizing the bed into seven layers. The time after deposition of the layers increases linearly from one day at the surface, which is composed of freshly deposited sediment, to seven days old in the

bottom layer. Once deposited sediments have reached the seven-day-old layer, their age no longer increases; all deposited sediments with ages greater than or equal to seven days are treated as being seven days old. Previous laboratory studies (Tsai and Lick, 1987; MacIntyre et al., 1990) indicate that consolidation effects on resuspension are minimal after seven days of consolidation, and are the basis for setting the maximum age of deposited sediments at seven days. Consolidation effects on resuspension are accounted for in Equation (3-7) by the $(T_d)^{-m}$ term, which causes the resuspension potential (ϵ) to decrease as the bed consolidates with time. The critical shear stress, τ_{cr}, is assumed to be constant in all layers of the bed. The model properly accounts for changes in bed composition, i.e., f_1 and f_2, due to resuspension and deposition during the course of a simulation.

A model that predicts suspended load transport in the non-cohesive bed areas of the TIP has been developed and used in this study. A complete description of that model is presented in HydroQual (1997b). One of the important aspects of the non-cohesive suspended load model is the concept of bed armoring, which limits erosion during a flood due to grain size heterogeneity in the surface layer of the sediment bed. The thickness of this surface layer, called the active layer, is of critical importance in applying this model to the TIP. An expression for the active layer thickness has been developed by van Niekerk et al. (1992) that is a linear function of the local bottom shear stress. A modified form of their formulation has been used in this study (HydroQual, 1997b):

$$T_a = \begin{cases} 2D_{50} & , \quad \tau_b < \tau_{c50} \\ 2D_{50}\left[B\left(\dfrac{\tau_b}{\tau_{c50}}\right) + (1-B)\right] & , \quad \tau_b \geq \tau_{c50} \end{cases} \qquad (3\text{-}10)$$

where T_a = active layer thickness; τ_{c50} = critical shear stress for initiation of bed load, based upon the parent bed d_{50}; and B = adjustable constant. Note that Equation (3-10) reduces to the original van Niekerk et al. (1992) equation when B = 1. A potential advantage of Equation (3-10) is that varying hydrodynamic conditions affect the active layer thickness, with T_a increasing as the current velocity (and τ_b) increases, which causes the amount of sediment that is available for resuspension to increase. The dependence of T_a on τ_b is not well known and the constant (B) in Equation (3-10) was adjusted during model calibration to account for local conditions in the TIP.

3.2 Application to the Thompson Island Pool

A side-scan sonar study was conducted by USEPA in the TIP (Flood, 1993). Information from the side-scan sonar survey has been used to determine the distribution of various sediment bed types, e.g., fine, coarse and rock, in that reach of the Upper Hudson River (Figure 3-4). The TIP sediment transport model requires as input a bed map that separates the bed into three types of sediment: (1) cohesive; (2) non-cohesive; and (3) rock or hard bottom. The side-scan sonar information on TIP bed types was used to generate this bed map, which is shown on Figure 3-5.

A review of bulk bed property data for cohesive sediments in the TIP indicated no definite spatial trends. Average values, based on available data, were then used to specify the dry density (0.87 g/cm^3) and initial composition (f_1 = 0.32) in the cohesive bed areas.

A field study was conducted during November 1990 to measure in situ resuspension potential of cohesive sediments in the TIP (HydroQual, 1995). An analysis of that data indicated that an appropriate value for the exponent n in Equation (3-7) is 2.94. The data also exhibited a spatial variation in the site-

specific constant, a_o, with lower a_o upstream of HRM 191 (approximately). Thus, a_o = 0.035 for cohesive sediments upstream of HRM 190.7 and a_o = 0.107 for cohesive sediments downstream of that location (Figure 3-6). Cohesive sediments immediately downstream of the jetty at the entrance to the Champlain Canal, at about HRM 189, were more easily resuspendable and a_o = 0.239 in that small area. All of these a_o values are for ϵ in mg/cm^2. Values of τ_{cr} = 1 dyne/cm^2, m = 0.5 and $T_{d,max}$ = 7 days were used in these calculations of a_o (HydroQual, 1995) and all model simulations.

An average dry density of 1.1 g/cm^3 was applied to non-cohesive sediments in the TIP based on bulk property data. Similar to the cohesive sediments, no evident spatial trend in non-cohesive sediment dry density was observed in the data.

The non-cohesive suspended load transport model requires specification of median particle diameter (d_{50}) and suspendable sediment fractions (i.e., f_1 and f_2) in the non-cohesive bed of the TIP. The non-cohesive transport model is sensitive to local values of d_{50}, f_1 and f_2. TIP data for these quantities are highly variable. Hence, it was necessary to develop spatial distributions for d_{50}, f_1 and f_2 to realistically simulate non-cohesive suspended load transport in the TIP.

As would be expected, a relationship exists between median particle diameter (d_{50}) and fraction of suspendable sediment ($f_{sus} = f_1 + f_2$) in the non-cohesive bed. Note that f_{sus} represents the fraction of non-cohesive bed sediment with d < 425 μm (i.e., clay, silt, fine sand and medium sand). Grain size distribution data collected in the non-cohesive bed area of the TIP were analyzed and the following relationship was determined (Figure 3-7):

$$d_{50} = 135\, f_{sus}^{-1.67} \qquad (3\text{-}11)$$

where d_{50} has units of μm.

Credible spatial distributions for d_{50}, f_1 and f_2 could not be developed directly from the data; the bed property data were too sparse to use various interpolation/extrapolation methods. Spatial distributions were estimated by hypothesizing that a relationship exists between local bottom shear stress and d_{50}, i.e., $d_{50} = f(\tau_b)$. The hydrodynamic model was used to predict the bottom shear stress distribution for the non-cohesive bed at a given flow rate (30,000 cfs). The functional relationship between d_{50} and τ_b was adjusted until the predicted and measured distributions of d_{50} agreed reasonably well (Figure 3-8). The resulting function is given by:

$$\begin{aligned} d_{50} &= 140 e^{16.6\tau_n^2} \quad , \quad \tau_n < 0.45 \\ &= 9000 \tau_n^{1.02} \quad , \quad \tau_n \geq 0.45 \end{aligned} \tag{3-12}$$

where τ_n = normalized bottom shear stress (τ_b/τ_{max}); τ_{max} = maximum bottom shear stress in non-cohesive bed area at given flow rate; and d_{50} has units of μm. The predicted spatial distribution of d_{50} is presented on Figure 3-9.

This process was validated as follows. Similar to Equation (3-11), a log-linear correlation between f_2 and d_{50} was observed in the data (R^2= 0.80):

$$f_2 = 22\, d_{50}^{-0.66} \tag{3-13}$$

where d_{50} has units of μm. Predicted d_{50} values, using Equation (3-12), were used in Equation (3-13) to generate a predicted distribution of f_2 in the TIP. The resulting comparison with observed f_2 values is presented on Figure 3-8. The average predicted and measured f_2 values in the TIP non-cohesive bed area were 0.29 and 0.34, respectively. The good agreement between predicted and measured f_2 indicates that this procedure yields valid spatial distributions of d_{50} and f_2. Non-cohesive bed data did not indicate a strong relationship between d_{50}

and f_1. Thus, an average f_1 value of 0.065 was used throughout the TIP non-cohesive bed.

The spatial distributions of d_{50}, f_1 and f_2 that were estimated using the above procedure are initial conditions for the model. The non-cohesive sediment bed model tracks temporal changes in f_1 and f_2 in each grid element due to resuspension and deposition. The data-based relationship between d_{50} and f_{sus}, Equation (3-11), was then used to dynamically adjust d_{50} during a simulation.

Sediment loading at the upstream boundary of the model (Fort Edward) and from the TIP tributaries was estimated using total suspended solids (TSS) data collected at those locations. Sediment rating curves, which relate TSS to flow rate, were developed using available data for the Hudson River at Fort Edward, Snook Kill and Moses Kill. To correct for bias introduced when performing log-linear regression analyses on the data, the minimum variance unbiased estimator (MVUE) method of Cohen et al. (1992) was used. The resulting rating curves for Fort Edward, Snook Kill and Moses Kill are shown on Figures 3-10, 3-11 and 3-12, respectively. Sediment loading from TIP direct drainage was estimated using a rating curve that was the average of the rating curves for Snook and Moses Kills.

The composition of the incoming sediment loads at the upstream boundary and tributaries also had to be specified. The fraction of class 1 (clay/silt) and class 2 (fine sands) in the sediment loads was estimated from data. The USGS has collected particle size distribution data at Schuylerville (32 observations), Stillwater (20 observations) and Waterford (80 observations). No correlation between sand content and flow (or TSS) exists at these three locations. The mean sand fractions at Schuylerville, Stillwater and Waterford were 0.26, 0.19 and 0.16, respectively. This trend of downstream fining is consistent with observed trends in other rivers. Based on these data, the assumption was made that the sand content of sediment loads at Fort Edward

and Snook Kill was 0.25 for all flow rates. The sand content of sediment loads from Moses Kill and TIP direct drainage was assumed to be zero. Initial model testing showed that unrealistic amounts of sediment were predicted to be deposited at the mouth of Moses Kill whenever sand was included in the sediment loading for that tributary. An examination of the geometry/bathymetry of Moses Kill near its confluence with the Hudson River suggests a depositional zone that would likely trap most suspended sands and significantly reduce the sand load from the tributary to the river. Sediment loading from TIP direct drainage was assumed to originate from direct runoff and very small streams. The hydraulic characteristics of these sediment sources prevent the transport of significant quantities of sand from the direct drainage area to the Hudson River.

3.3 Model Calibration Results

The eddy diffusivity (K_H) initially was set equal to the eddy viscosity (A_H) used in the hydrodynamic model, i.e., 1 m^2/s. Model validation, to be discussed in detail in the following sub-section, using data and observations from the 1997 spring flood indicated that the model produced more realistic results when an anisotropic K_H was used. The value of K_H in the lateral (cross-channel) direction was reduced to 0.1 m^2/s to better reproduce observed patterns of suspended sediment plumes from Snook and Moses Kills during the 1997 spring flood.

The sediment transport model was calibrated using TSS data collected during the 1994 spring flood. The 40-day simulation period extended from March 22 to April 30, 1994. Maximum daily average flow rate at Fort Edward during this period was 27,700 cfs (Figure 3-13). This period was unique because TSS data were collected at Fort Edward, Snook Kill, Moses Kill and three locations in the TIP, see HydroQual (1997a) for a detailed discussion of the data. The most continuous set of TSS data collected at these six locations in the TIP was

collected during the 30-day period from March 31 through April 29. Model calibration efforts focussed on this period.

Model parameters governing cohesive sediment resuspension and deposition were determined using TIP field data and were not adjusted during model calibration. Settling speeds for cohesive (class 1) sediments were calculated using Equation (3-3). The probability of deposition parameter $\tau_{b,min}$ used in Equations (3-4) and (3-5) was set at 0.1 dyne/cm^2 and not adjusted during calibration.

Model calibration involved determining a consistent set of values for the following four parameters: 1) d_2, the effective diameter of suspended class 2 particles; 2) B, the constant in the non-cohesive bed active layer thickness equation; 3) $d_{50}(x,y)$, the spatially variable median diameter of sediment in the non-cohesive bed; and 4) $f_2(x,y)$, the spatially variable fraction of class 2 sediment in the non-cohesive bed.

Because suspended class 2 particles are not likely to be coarser than the largest fine sands (i.e., diameter < 250 μm), values of d_2 were restricted to the range of 62 to 250 μm. Initial values for $d_{50}(x,y)$ and $f_2(x,y)$ were generated using Equations (3-12) and (3-13). Determination of consistent parameter values involved finding values of d_2 and B that produced accurate erosion and deposition fluxes for bed characteristics (d_{50} and f_2) expected to exist at the time of the calibration flood. The following iterative procedure was employed:

1. Use the spatial distributions of d_{50} and f_2 that were generated by Equations (3-12) and (3-13) as initial conditions for the non-cohesive bed during the 1994 calibration simulation. Denote these estimated bed property distributions as ${}^0d_{50}(x,y)$ and ${}^0f_2(x,y)$.
2. Adjust d_2 and B to achieve the best agreement between predicted and observed sediment transport information during the 30-day period from

March 30 through April 29 (descriptions of model-data comparisons are provided below). Denote parameter values for the first 1994 calibration iteration as ${}^{1}d_2$ and ${}^{1}B$.

3. Run a long-term simulation (which extends from 1977 to 1998 and is described in Section 3.4) using ${}^{1}d_2$ and ${}^{1}B$. The initial bed property distributions used in the long-term run were ${}^{0}d_{50}(x,y)$ and ${}^{0}f_2(x,y)$.
4. Equation (3-11) was used to dynamically calculate d_{50} as f_{sus} (= f_1 + f_2) changed due to resuspension and deposition during the long-term simulation. The model was then run from 1977 to March 21, 1994 and the predicted non-cohesive bed property distributions at the end of that simulation, i.e., ${}^{94.1}d_{50}(x,y)$ and ${}^{94.1}f_2(x,y)$, were output.
5. The model was re-calibrated using the predicted bed property distributions ${}^{94.1}d_{50}(x,y)$ and ${}^{94.1}f_2(x,y)$ as initial conditions. Denote the best-fit parameter values determined during the second 1994 calibration iteration as ${}^{2}d_2$ and ${}^{2}B$.
6. The long-term simulation (1977 to 1994) was repeated using ${}^{2}d_2$ and ${}^{2}B$. The initial bed property distributions used in the second long-term run were ${}^{0}d_{50}(x,y)$ and ${}^{0}f_2(x,y)$. Denote the bed property distributions at the end of this simulation (March 21, 1994) as ${}^{94.2}d_{50}(x,y)$ and ${}^{94.2}f_2(x,y)$.
7. A validation simulation was performed by running the 1994 spring flood using the parameter values ${}^{2}d_2$ and ${}^{2}B$, with ${}^{94.2}d_{50}(x,y)$ and ${}^{94.2}f_2(x,y)$ as initial conditions. The differences in the model predictions between the second and final iteration were small, indicating that "convergence" had been achieved. The values of ${}^{2}d_2$ and ${}^{2}B$ were 90 μm and 0.02, respectively.

The calibration process involved comparing predicted and observed TSS at three locations in the TIP: (1) upstream of Snook Kill; (2) McDonald's dock; and (3) Thompson Island Dam. Results of the final calibration are presented on Figure 3-13.

Comparisons between predicted and observed TSS are a standard method of calibrating and validating a sediment transport model (e.g., Gailani et al., 1991; Ziegler and Nisbet, 1994). However, this method does not necessarily ensure that the model realistically and accurately simulates resuspension and deposition fluxes in the TIP. The reason for this uncertainty is that external solids loadings, from upstream and tributary sources, may dominate predicted/observed TSS in the TIP, with deposition and resuspension causing relatively small changes in water column sediment concentrations. Large changes in model parameters, creating large changes in deposition and resuspension, may cause relatively small changes in predicted TSS.

To reduce the uncertainty in model parameterization of deposition and resuspension processes, and thus to improve the predictive capabilities of the sediment transport model, a new calibration methodology was developed. The authors are not aware of the proposed method being used previously to calibrate or validate a sediment transport model. This procedure involves constructing a sediment mass balance for the TIP using the total sediment load input from upstream and tributary sources (L_{in}) and the output sediment load at Thompson Island dam (L_{out}) to calculate the net resuspension/deposition in the TIP (L_{net}), i.e., $L_{net} = L_{in} - L_{out}$. Thus, for a given time period, net deposition occurs if $L_{net} > 0$ and net resupension occurrs if $L_{net} < 0$.

Sufficient data were collected during the 30-day period from March 31 to April 29, 1994 to make credible estimates of L_{net} on an hourly basis. The results of this data-based analysis showed that net erosion occurred during this period and 457 metric tons of sediment were transported out of the TIP. Closer examination of data indicated that the 30-day period under consideration could be separated into two distinct sub-periods: (1) tributary deposition and (2) mainstem flood. From March 31 to April 10, flow rates in the Hudson River were non-flooding (< 10,000 cfs) but high flow events occurred in the tributaries. Snook and Mose Kills transported large quantities of sediment into the TIP during

this sub-period and, because flow rates in the Hudson River were relatively low, significant deposition occurred. The mass balance results indicate that 387 metric tons of sediment were deposited during the tributary deposition sub-period. Net erosion occurred during the mainstem flood sub-period, extending from April 11 to 29, with 844 metric tons of sediment lost from the TIP.

Note that this type of data analysis can only be used to estimate global losses or gains due to net erosion or deposition from the TIP sediment bed. Results from this analysis cannot be used to infer net erosion or deposition in specific bed types, e.g., cohesive or non-cohesive, or areas of the TIP.

Comparisons between predicted and observed cumulative L_{net} for the final calibration, during the entire 30-day period and the two sub-periods are presented on Figure 3-14. These results show that the model can predict temporal variations in L_{net} with good accuracy. The model predicts a total of 345 metric tons of sediment were exported from the TIP during the 30-day period, which is 25% lower than the data-based estimate. During the tributary deposition sub-period, 523 metric tons of deposited sediment were predicted, corresponding to a 35% over-prediction when compared to the observed value. The model is within 3% of the data-based estimate of net erosion during the mainstem flood sub-period.

Very good agreement between predicted and data-based estimates of cumulative L_{net} during the 1994 spring flood demonstrates that: (1) deposition and resuspension processes have been realistically and accurately formulated in a global sense and (2) the model is an effective diagnostic tool for quantitatively evaluating net deposition and erosion from various areas of the TIP. While the model and data indicate net erosion occurred during this 30-day period, closer examination of the model results show that net erosion did not occur in all areas of the TIP. The non-cohesive portion of the TIP, which comprises about 80% of the total bed area in this reach, experienced a net loss of 1,244 metric tons. This

net erosion corresponds to a decrease in the mean non-cohesive bed elevation of 0.08 cm. Conversely, 899 metric tons of net deposition occurred in the TIP cohesive bed, which is equivalent to an average increase in the cohesive bed elevation of 0.26 cm. The spatial distribution of sediment deposition caused by this flood is presented on Figure 3-15. Prediction of net deposition in the TIP cohesive bed area during this flood is consistent with observed depositional patterns in fine-grained areas of the Upper Mississippi River during major flooding in 1993 (Barber and Writer, 1998).

The potential impact of the initial non-cohesive bed distribution on model results was investigated by repeating the final calibration run with the initial bed distributions ${}^{0}d_{50}(x,y)$ and ${}^{0}f_{2}(x,y)$. The results of this simulation are presented on Figure 3-16. Using ${}^{0}d_{50}(x,y)$ and ${}^{0}f_{2}(x,y)$ primarily affected the mainstem flood sub-period, with erosion increasing from 868 to 1,215 metric tons (40% increase).

3.4 Model Validation Results

Three simulations were conducted to validate the sediment transport model: (1) 1997 spring flood; (2) 1993 spring flood; and (3) 21-year (1977 to 1998) period. No adjustments of model parameter values were made during the validation simulations. Only model boundary conditions, e.g., flow rates and sediment loadings, were changed to reflect the time-varying conditions during each validation period.

The spring flood that occurred in early May 1997 had a relatively low peak flow, with a maximum flow rate at Fort Edward of approximately 17,000 cfs. General Electric collected TSS data at Fort Edward, Snook Kill, Moses Kill and Thompson Island dam between May 2 and 6, which was the period when a high flow event occurred on Snook and Moses Kills. Comparisons of predicted and

observed TSS at Thompson Island dam during this five-day period are shown on Figure 3-17. Model results were in excellent agreement with measured TSS on both the western and eastern shores of the dam. Note that TSS data were collected at 3-hour intervals on May 3 and 4 (days 29-31) and once per day on May 2, 5 and 6. Linear interpolation was used to estimate measured TSS at the dam for times between each data point during this period and the resulting time series is shown on an hourly basis on Figure 3-17.

Peak flow during the 1993 spring flood was comparable to the 1994 flood, with a maximum flow rate at Fort Edward of approximately 29,000 cfs. A limited amount of TSS data were collected at Fort Edward and Thompson Island dam between March 22 and May 6, 1993, which was the 45-day period simulated. No TSS data were obtained from the tributaries, so sediment loads from Snook and Moses Kills were estimated using the sediment rating curves discussed in Section 3.2. Comparisons between predicted and measured TSS concentrations at the dam are shown on Figure 3-18. The data are somewhat limited but the model appears to perform reasonably well.

As discussed in the previous sub-section, long-term calculations were performed in an iterative method as part of the model calibration process. A final long-term simulation was conducted to further validate the sediment transport model. This calculation was over 21 years long, starting on January 1, 1977 and ending on March 24, 1998. The hydrograph at Fort Edward during this period is presented on Figure 3-19.

Sediment loading to the TIP was determined using a combination of data and sediment rating curves. At Fort Edward, TSS data were used on all days for which data were available. On days that data were not collected at Fort Edward, TSS concentration was estimated using a sediment rating curve (Figure 3-10). Tributary sediment loads were estimated using sediment rating curves (Figures 3-11 and 3-12). The total annual sediment loads to the TIP resulting from this

procedure for 1977 to 1997 are shown on Figure 3-20. The total sediment load input to the TIP during the long-term simulation period was approximately 805,000 metric tons, for an average of 37,900 metric tons/year.

Predicted areas of erosion and deposition at the end of the long-term simulation are shown on Figure 3-21. Deposition rates for this approximate 21-year period are presented on Figure 3-22. Net erosion depths are displayed on Figure 3-23.

The locations of three high-resolution sediment cores collected by USEPA are also indicated on Figure 3-22 (HR cores 19, 20 and 23). Geochronologic dating of those cores, using ^{137}Cs, indicates average sedimentation rates of 0.9, 1.1 and 1.4 cm/yr at HR cores 19, 20 and 23, respectively. The predicted mean sedimentation rates for the grid elements that contained HR cores 20 and 23 are 0.5 and 1.1 cm/yr, respectively. Core 23 is located at the mouth of Moses Kill and the relative error of the predicted sedimentation rate at this location is –21%. At core 20, the predicted rate is 55% lower than the observed rate. However, the predicted rate for the grid element immediately upstream of this core is 0.95 cm/yr, which is only 14% lower than the core 20 rate. Net erosion was predicted in the grid element containing core 19, but the grid element directly upstream had a predicted rate of 1.7 cm/yr. These validation results indicate that the sediment transport model can predict long-term sedimentation rates with reasonably good accuracy.

Performing a sediment mass balance on the TIP, i.e., calculate L_{net} for the long-term simulation period, shows that the model predicts that about 68,000 metric tons of sediment were deposited during the period from 1977 to 1998. This depositional mass corresponds to a long-term trapping efficiency of 8.5% for the TIP. Most of the deposition occurs in the cohesive bed areas of the pool, with 87% (nearly 59,000 metric tons) being deposited in those areas. This amount of deposition translates to an average sedimentation rate of 0.8 cm/yr for

the cohesive bed in the TIP. This sedimentation rate equates to an average deposition of about 17 cm (6.6 inches) over the 21-year period simulated. Net deposition also occurs for the TIP non-cohesive bed, but only at an average rate of 0.02 cm/yr.

SECTION 4
SEDIMENT TRANSPORT PROCESSES IN THE THOMPSON ISLAND POOL

Sediment transport processes in the TIP involve complex interactions between external sediment loading and sediment dynamics in cohesive and non-cohesive bed areas. Understanding these processes, both qualitatively and quantitatively, is of critical importance when considering PCB fate and transport in this reach. Unfortunately, the dynamics of TIP deposition and resuspension are not clearly discernible from data analyses. A general understanding of the processes controlling sediment transport in the TIP can only be achieved when data are combined with a credible model, as has been done in this study.

The sediment transport model developed for the TIP is a physically comprehensive model that simulates the resuspension, deposition and transport of cohesive and non-cohesive sediments. Various TIP data sets have been used to develop a model that contains only two parameters that were adjusted, within realistic bounds, during a rigorous calibration process. Successful calibration and validation of the model, for short-duration, high-flow events and a decadal time-scale simulation, strongly suggests that this model realistically and accurately simulates sediment transport in the TIP. Thus, the model can be confidently used as a diagnostic tool to better understand TIP sediment transport processes.

4.1 Importance of the Non-Cohesive Sediment Bed

The non-cohesive bed area is an important component of the overall sediment transport system operating in the TIP. Suspended fine sands (class 2 sediments in the model) are deposited in the non-cohesive bed, primarily between Rogers Island and Snook Kill, during low to moderate flows. These

previously deposited fine sands are resuspended during high flow events and transported downstream by river currents. The coarser suspended sediments can be then be re-deposited in the cohesive bed areas. TIP cohesive deposits are located in relatively low energy environments during floods and are depositional zones for fine sands suspended in the water column. Thus, the non-cohesive bed effectively acts as a reservoir for coarser suspended sediment; material accumulates during low to moderate flows, it is then released back to the water column during a flood and enhances deposition in cohesive bed areas.

4.2 Long-Term Sedimentation in Cohesive Deposits

Modeling results clearly demonstrate that the TIP is a net depositional environment, as would be expected of a run-of-the-river reservoir, and that widespread deposition is occurring in the cohesive ("hotspot") bed areas of the TIP. While net erosion was predicted to have occurred in approximately 7% of the cohesive bed area between 1977 and 1998 (with an average erosional depth of 1 cm), significant net deposition (average rate of 0.8 cm/yr) occurred over most of the cohesive bed (93%). These results are consistent with both the observed decrease in surficial PCB bed concentrations since 1977 and the occurrence of maximum PCB bed concentrations at depth, i.e., less-contaminated sediments are entering the TIP and burying historical PCB deposits.

4.3 Erosion During Rare Floods

The impact of a 100-year flood on the TIP was simulated using the calibrated sediment transport model. The peak flow rate for a 100-year flood at Fort Edward has been estimated to be 47,300 cfs, on a daily average basis. A hydrograph for the simulated 100-year flood was developed by analyzing the

hydrographs of nine floods in the TIP that occurred between 1977 and 1997. The resulting flood hydrograph extended over eight days, with the peak flow occurring on day 4 of the simulation. Sediment loadings during the flood, from both upstream and tributary sources, were estimated using sediment rating curves discussed in Section 3.2. Note that both erosion and deposition were accounted for in this simulation.

The model predicted that a total of 2,166 metric tons of sediment would be transported out of the TIP during the 100-year flood. Of this total, 952 and 1,214 metric tons of net erosion occurred in the cohesive and non-cohesive bed areas, respectively. These masses correspond to mean erosional depths of 0.69 and 0.09 cm for the cohesive and non-cohesive bed, respectively. Maximum erosional depths for both bed types were approximately 7.5 cm. The spatial distribution of predicted erosional depths at the end of the 100-year flood is presented on Figure 4-1. Note that net deposition was predicted at some locations in the TIP.

These results indicate that an extreme flood will not scour deep enough into the sediment bed to expose historical deposits with elevated PCB levels. The impact of a 100-year flood on average surficial PCB concentrations in the TIP, which are of importance when considering effects on biota, will be examined in the near future.

4.4 Resuspension During Low Flows

The long-term simulation, from 1977 to 1998, indicates that resuspension, from both cohesive and non-cohesive bed areas, is negligible during low flow conditions, i.e., flow rates less than 3,000 cfs. This characteristic is caused by a combination of two factors: (1) bottom shear stresses are less than critical values for initiation of erosion in most of the TIP and (2) cohesive and non-

cohesive bed armoring effects significantly limit erosion in areas where $\tau_b > \tau_{cr}$. Thus, increases in water column PCB loads between Fort Edward and Thompson Island dam during low flow conditions cannot be attributed to resuspension of contaminated sediments from the sediment bed.

SECTION 5
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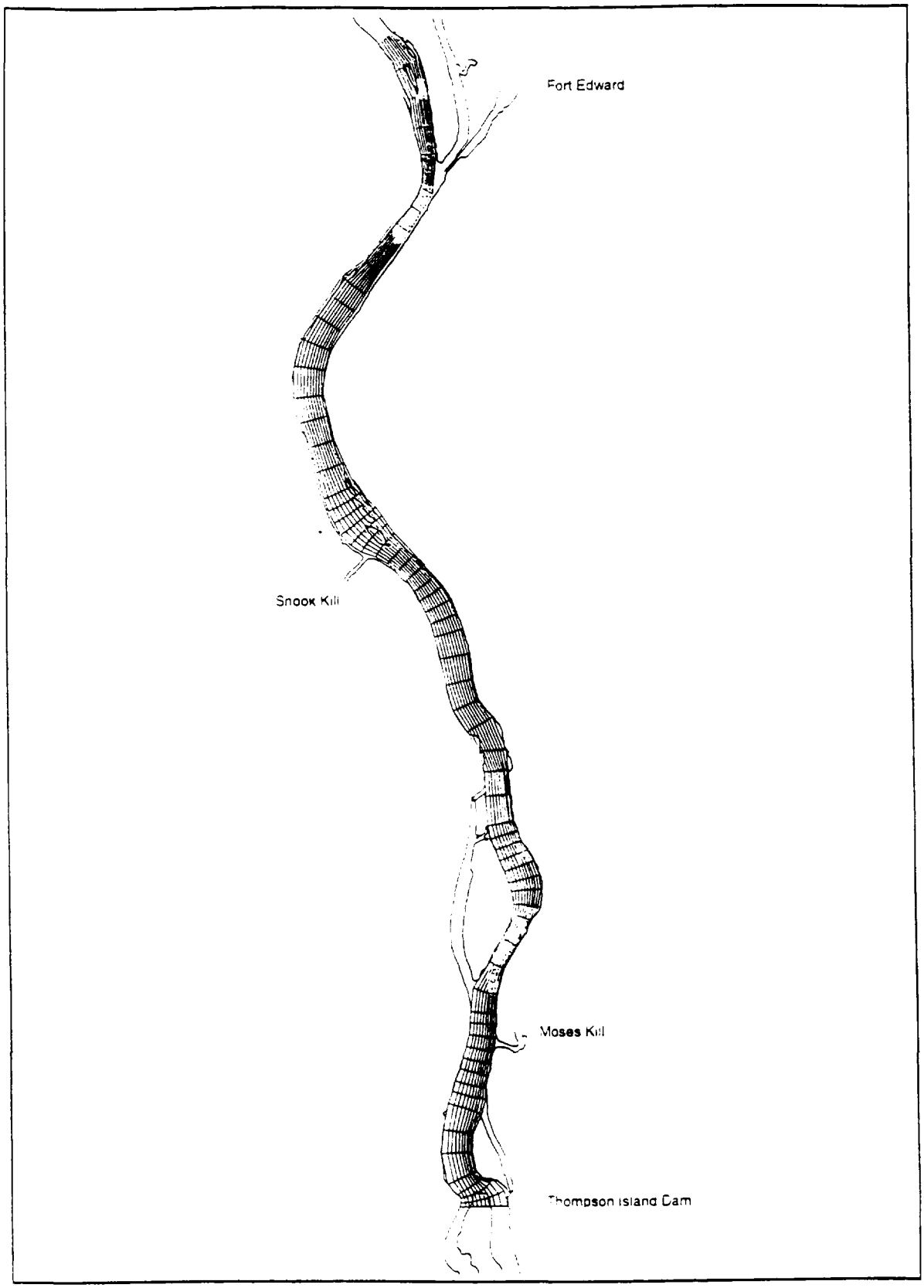


Figure 2-1. Numerical grid for the Thompson Island Pool.

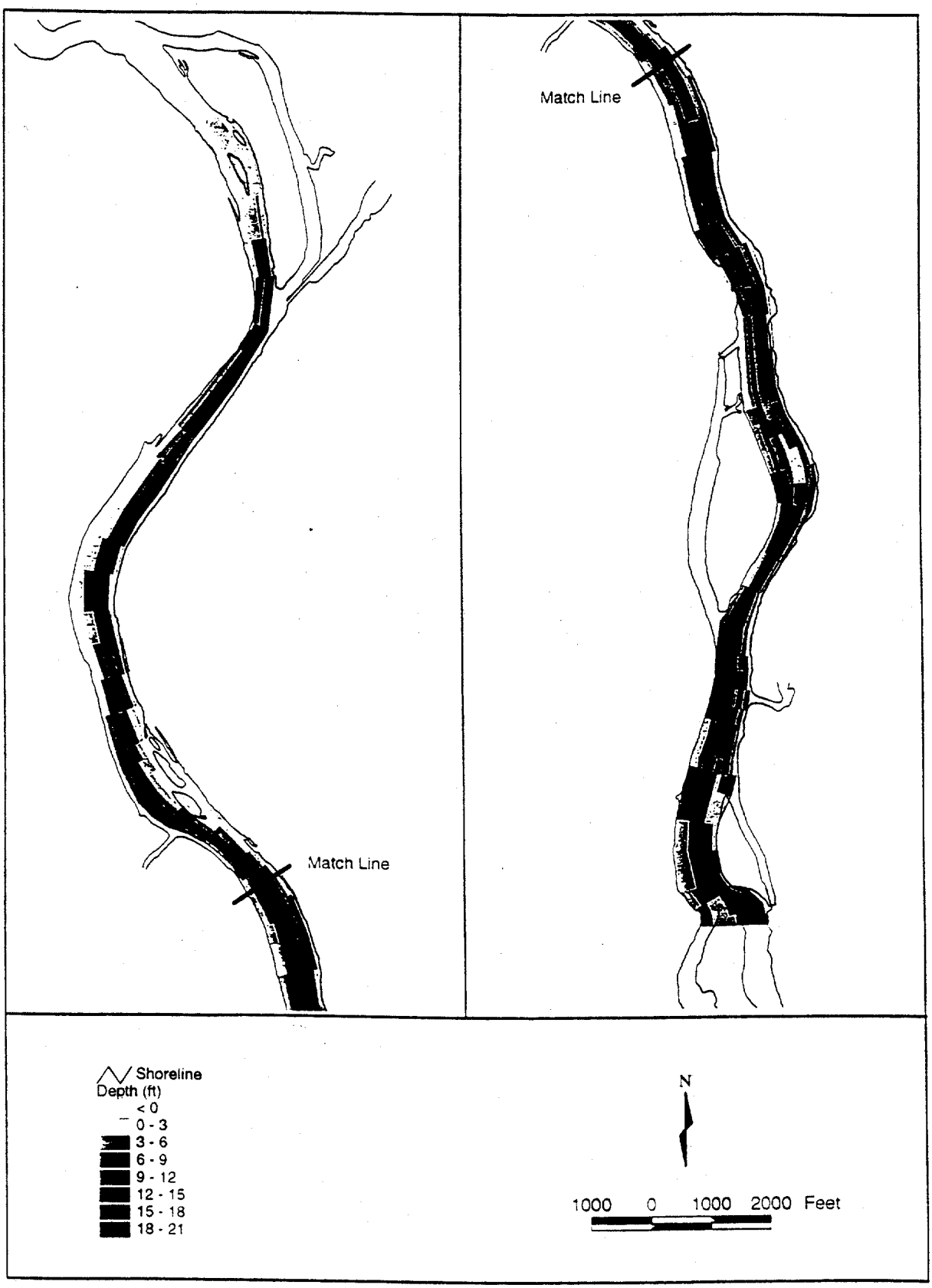


Figure 2-2. Thompson Island Pool bathymetry. Data were averaged in each grid element for model input.

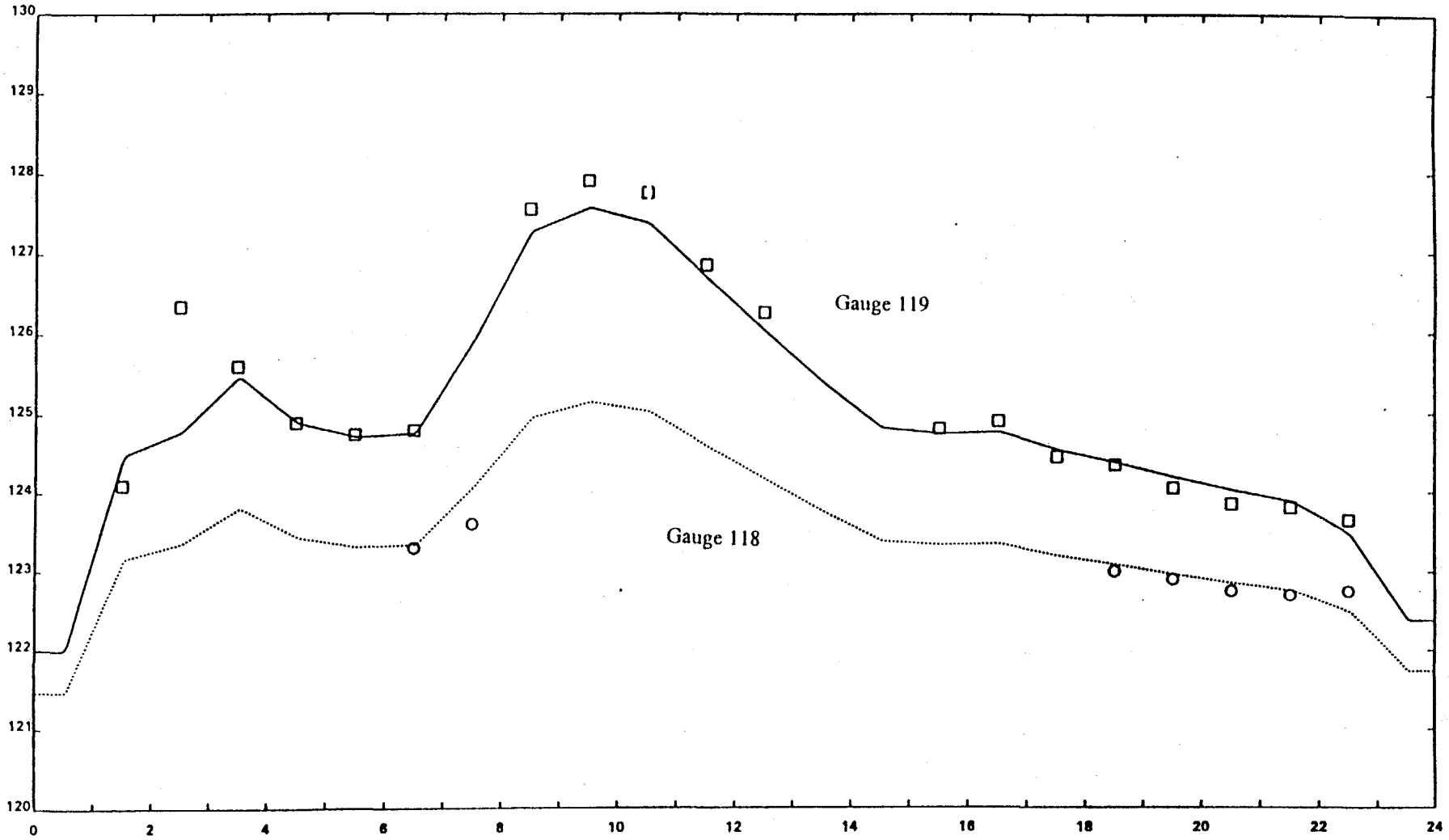


Figure 2-3. Comparison of predicted (solid line) and observed stage heights at gauges 118 and 119 during the 1983 flood.

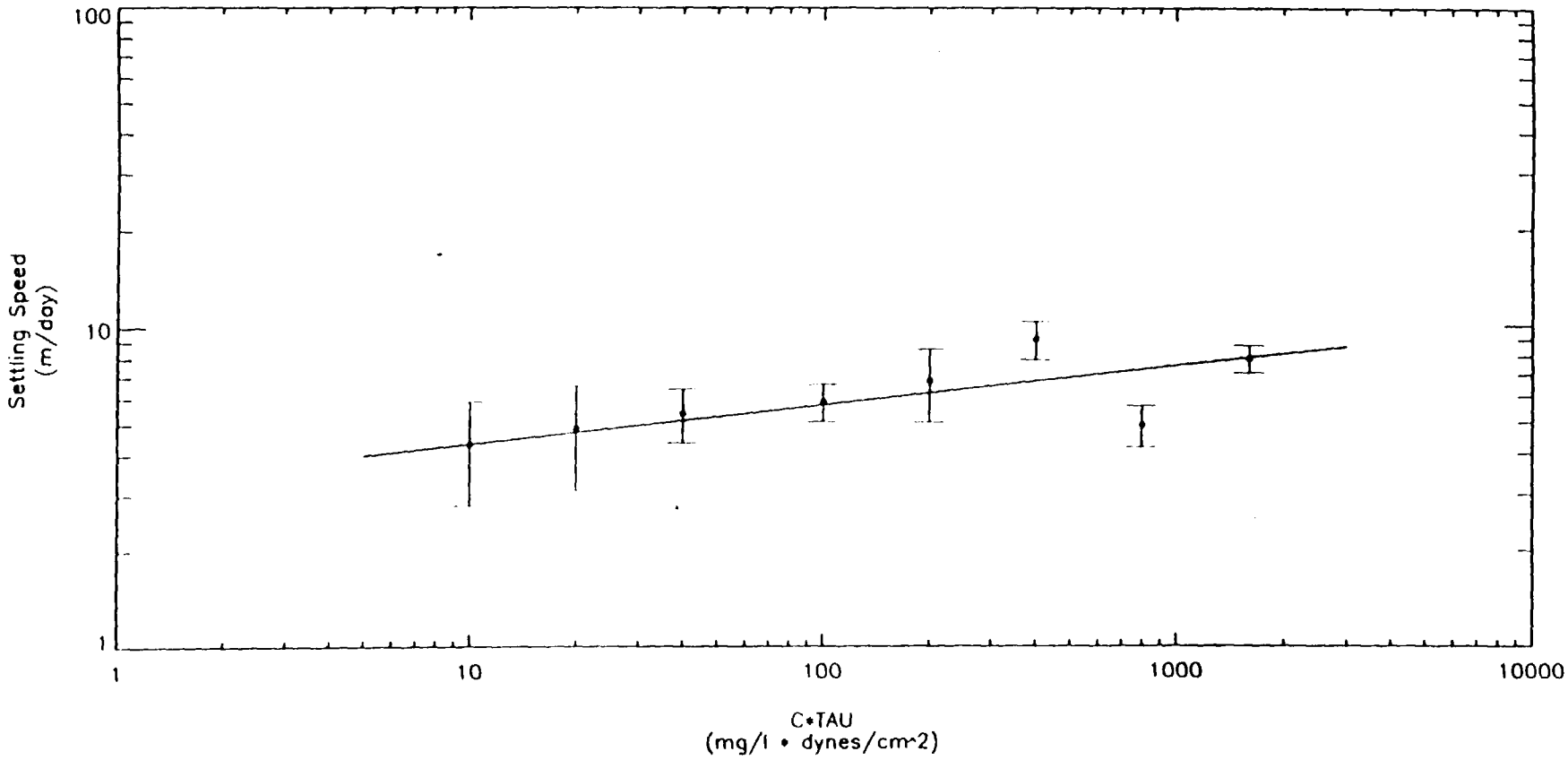


Figure 3-1. Settling speed function for cohesive (class 1) sediments (solid line) and floc settling speed data (mean ± 95% confidence interval) used to construct function.

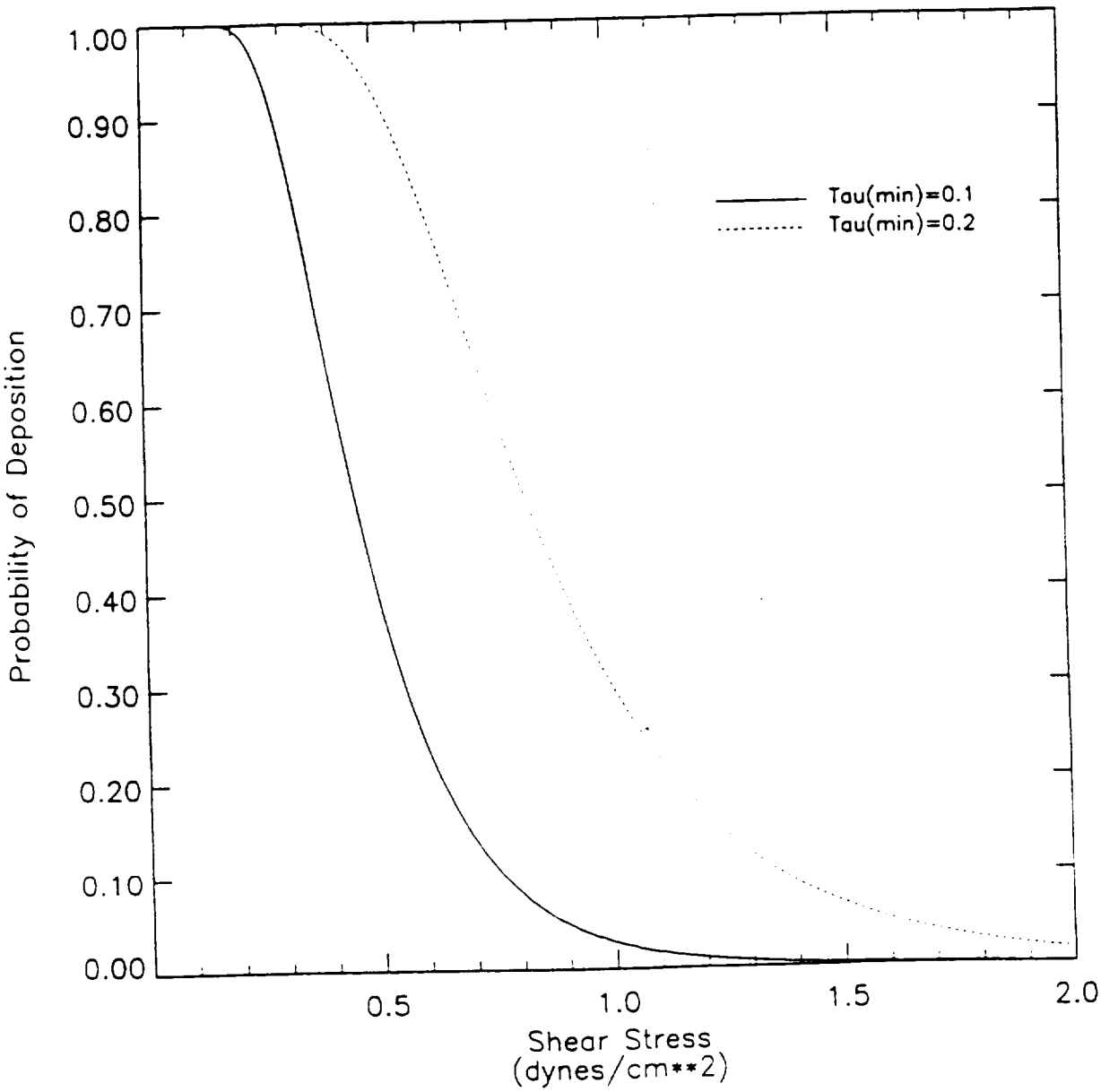


Figure 3-2. Probability of deposition function for cohesive (class 1) sediments.

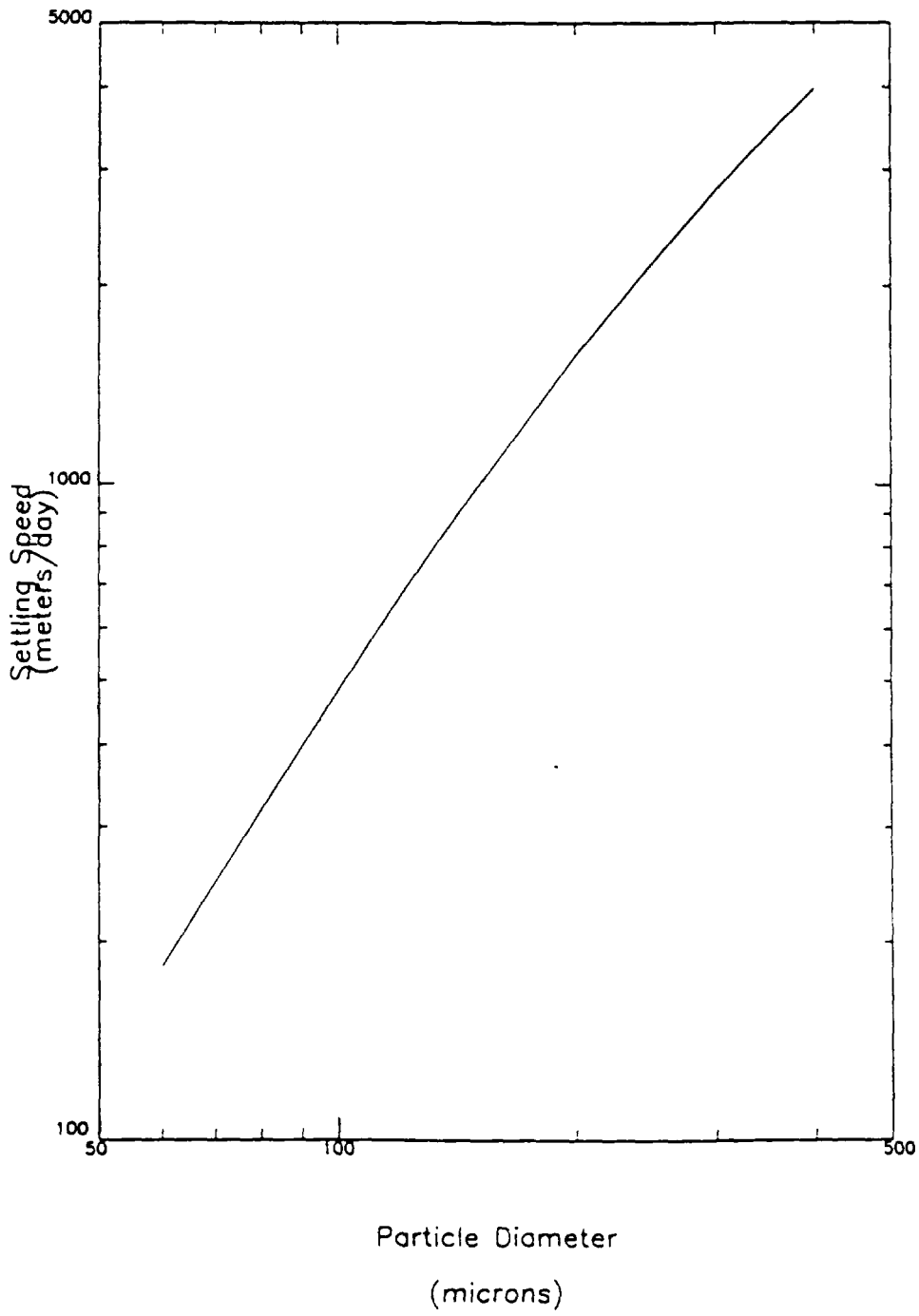


Figure 3-3. Settling speed of sand particles (class 2) as a function of particle diameter.

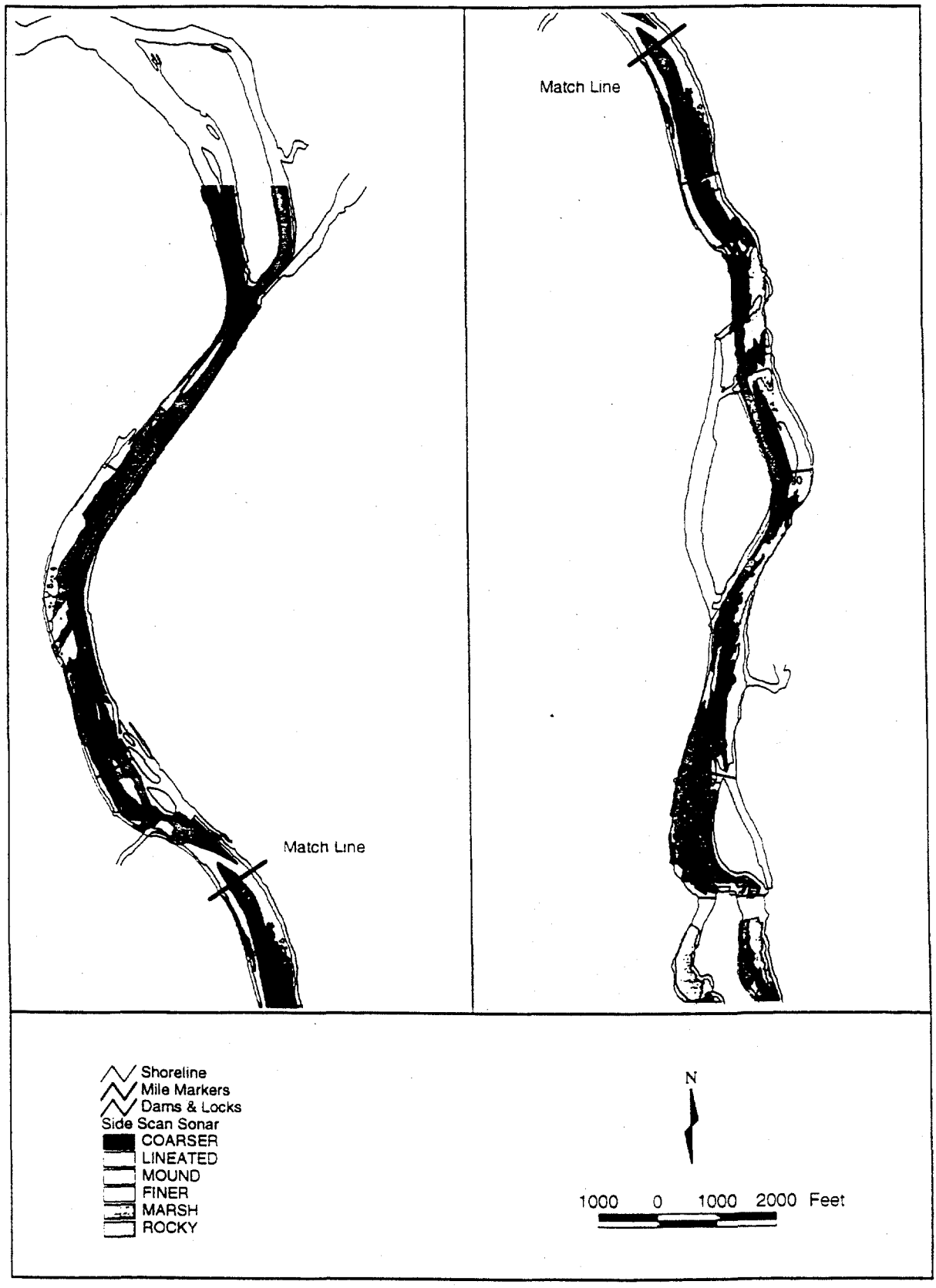


Figure 3-4. Thompson Island Pool bed map based on side scan sonar information.

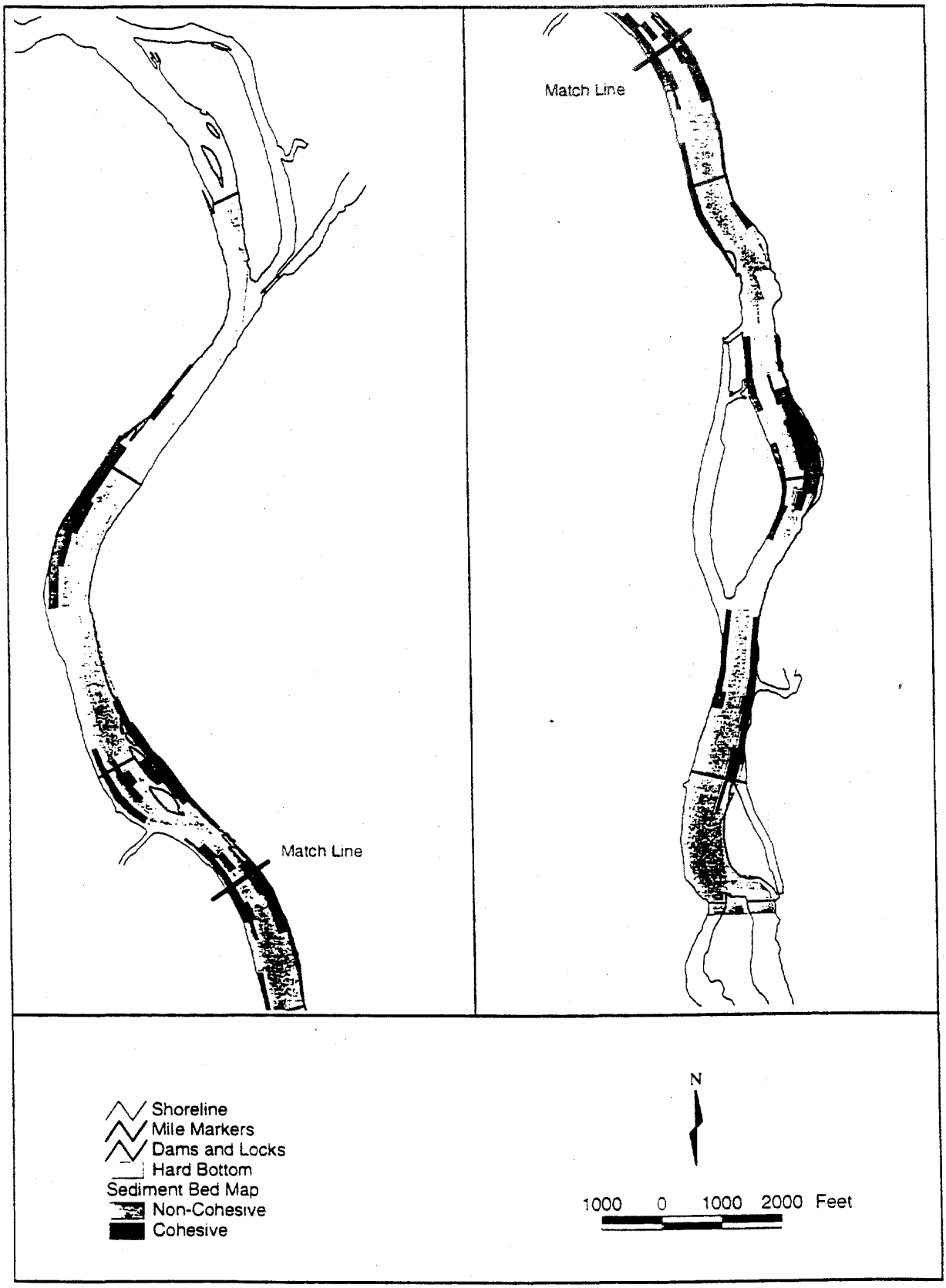


Figure 3-5. Thompson Island Pool bed map used for model input.

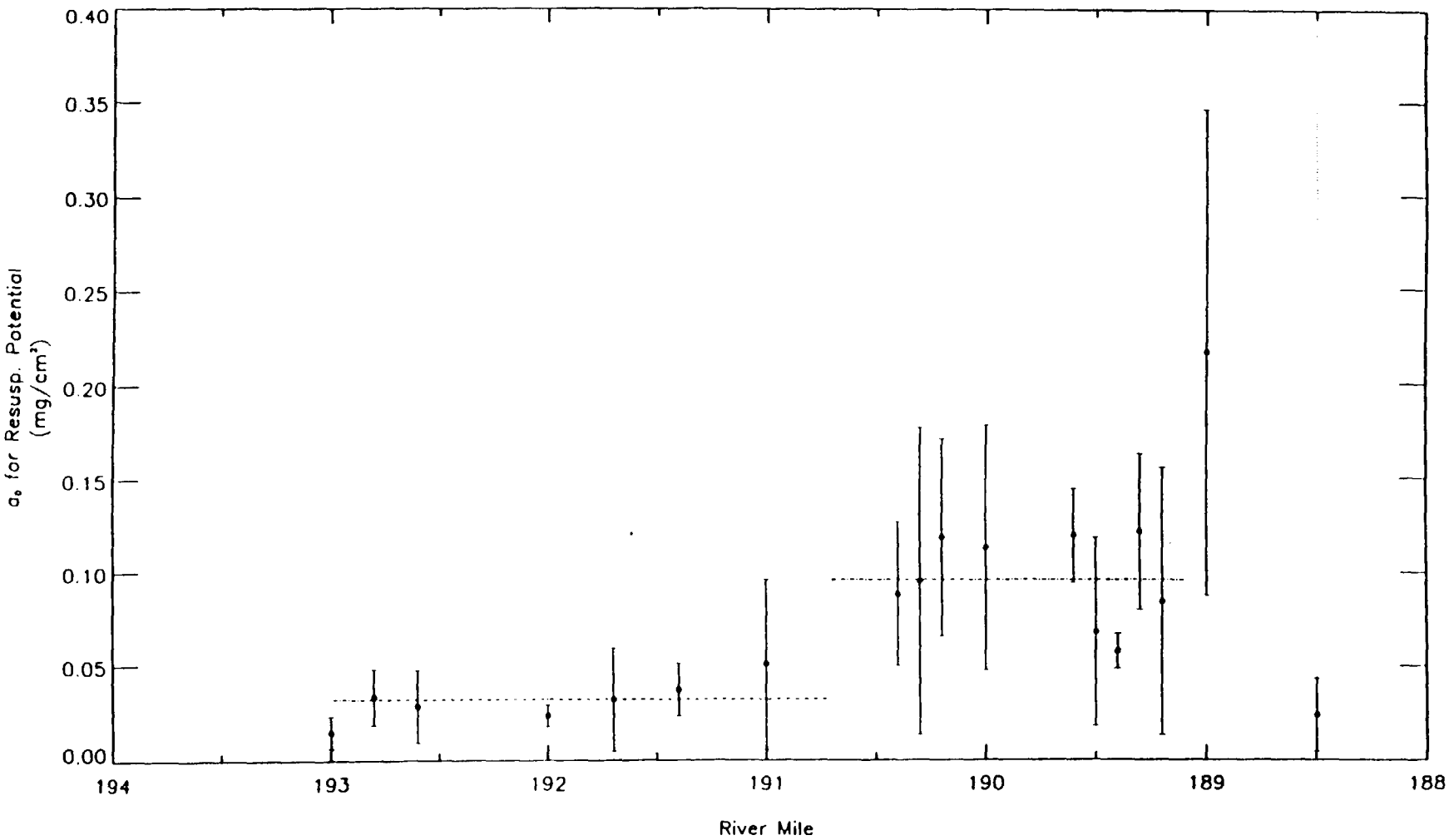


Figure 3-6. Spatial distribution of resuspension potential parameter (a_o) used as model input. TIP shaker data (mean ± 95% confidence interval) used to determine model input are also shown.

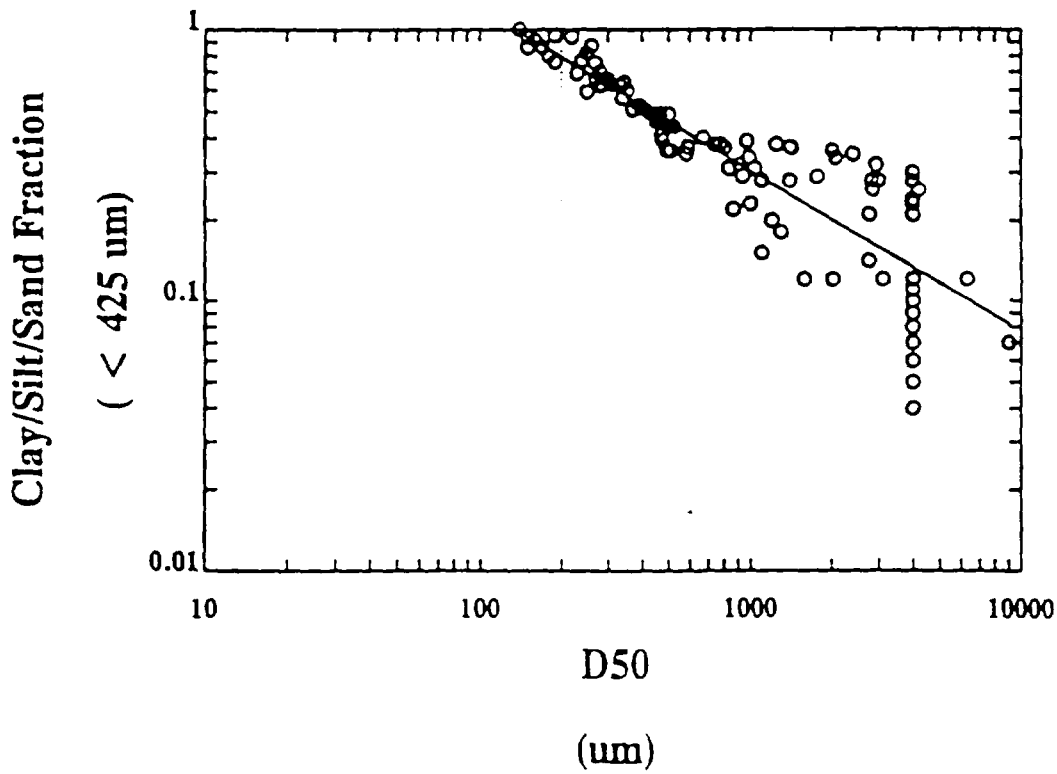
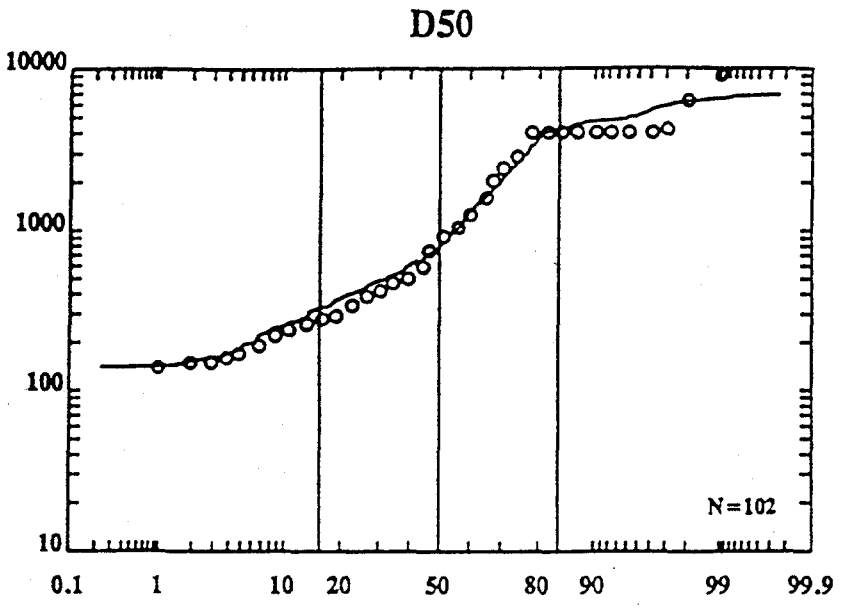


Figure 3-7. Relationship between fraction of suspendable sediment (d_2 < 425 µm) and median particle diameter (d_{50}) for the non-cohesive sediment bed in the Thompson Island Pool.



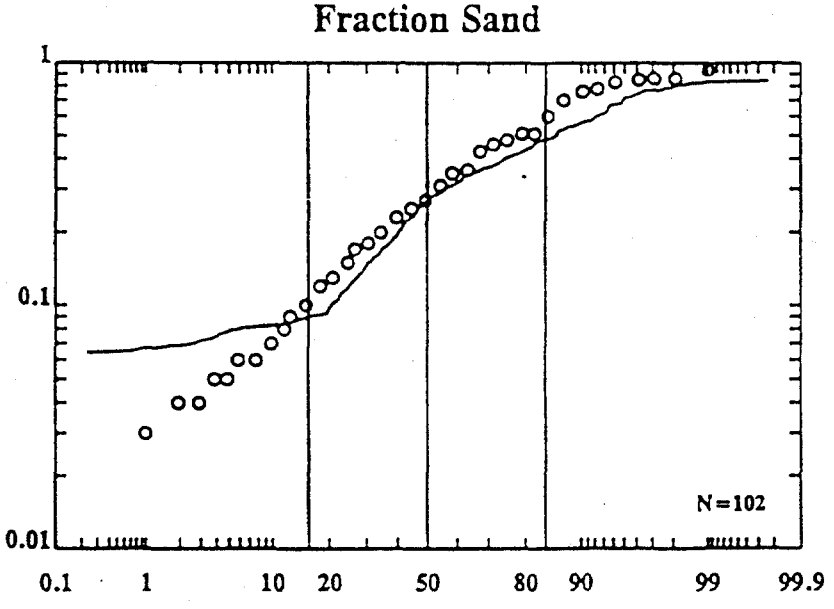


Figure 3-8. Comparison of predicted (solid line) and measured distributions of median particle diamater (d_{50}) and sand fraction for the non-cohesive sediment bed in the Thompson Island Pool.

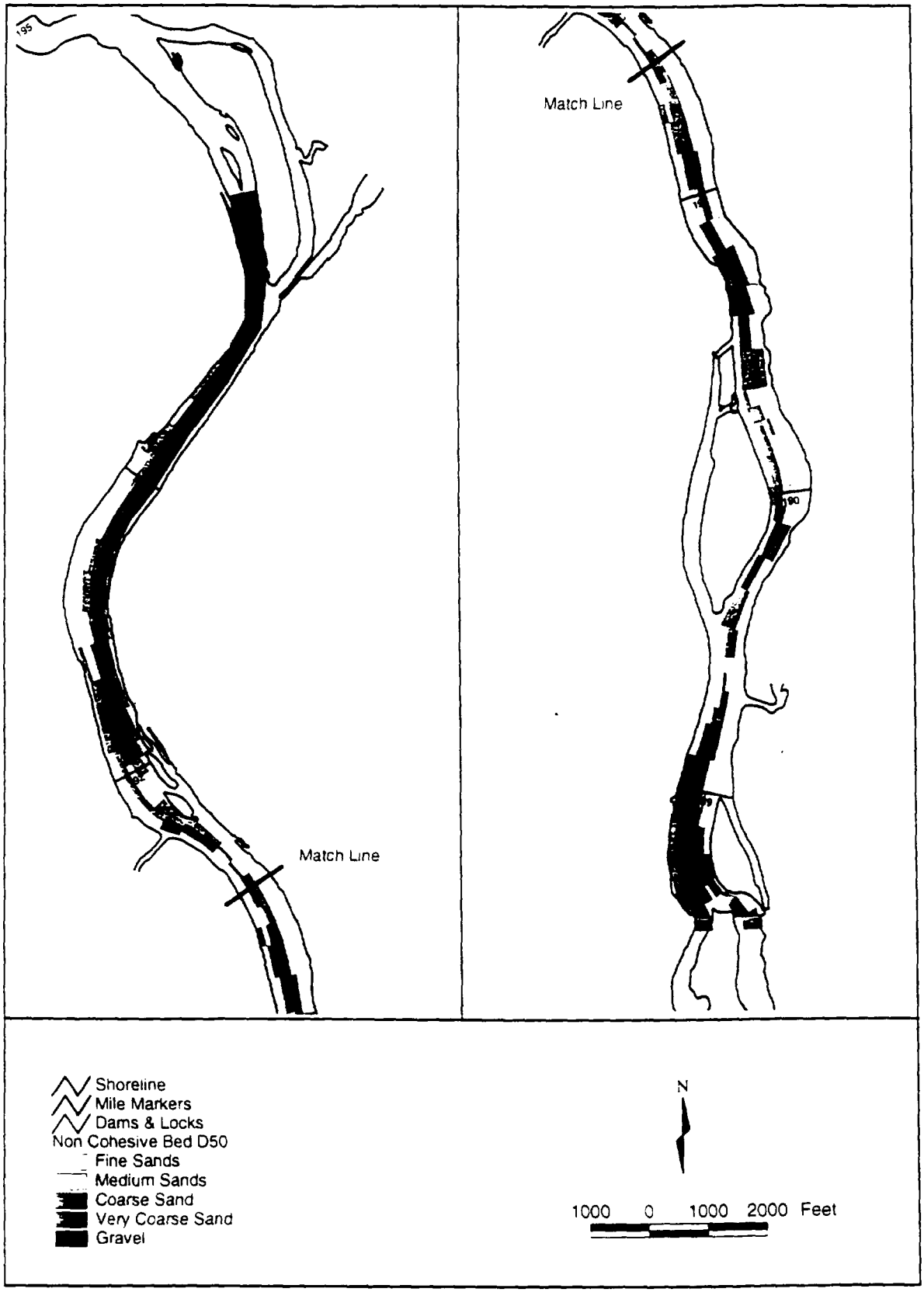


Figure 3-9. Estimated spatial distribution of median particle diameter (d50) used as model initial conditions for the non-cohesive sediment bed in the Thompson Island Pool.

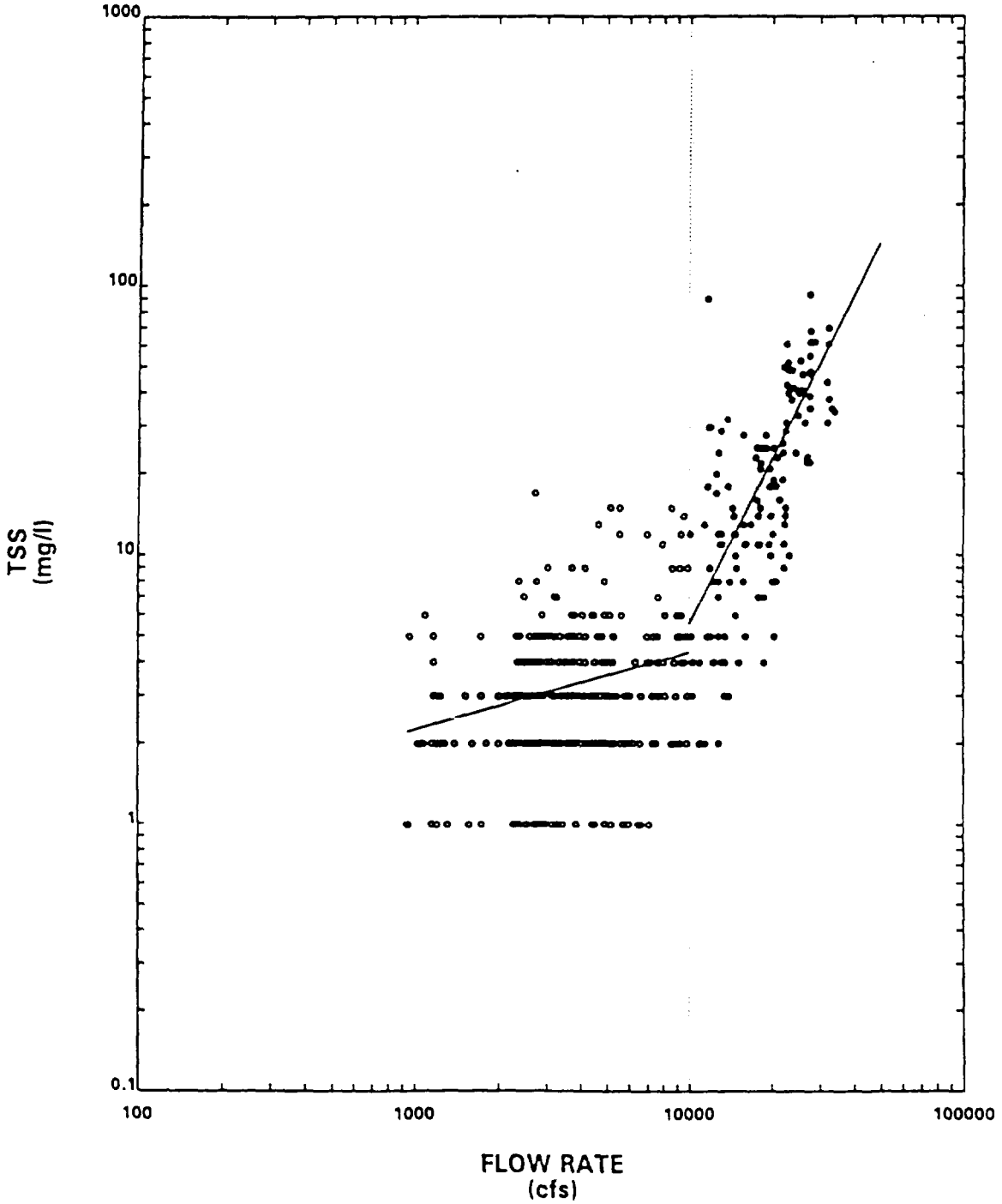


Figure 3-10. Sediment rating curve (solid line) for upstream boundary at Fort Edward.

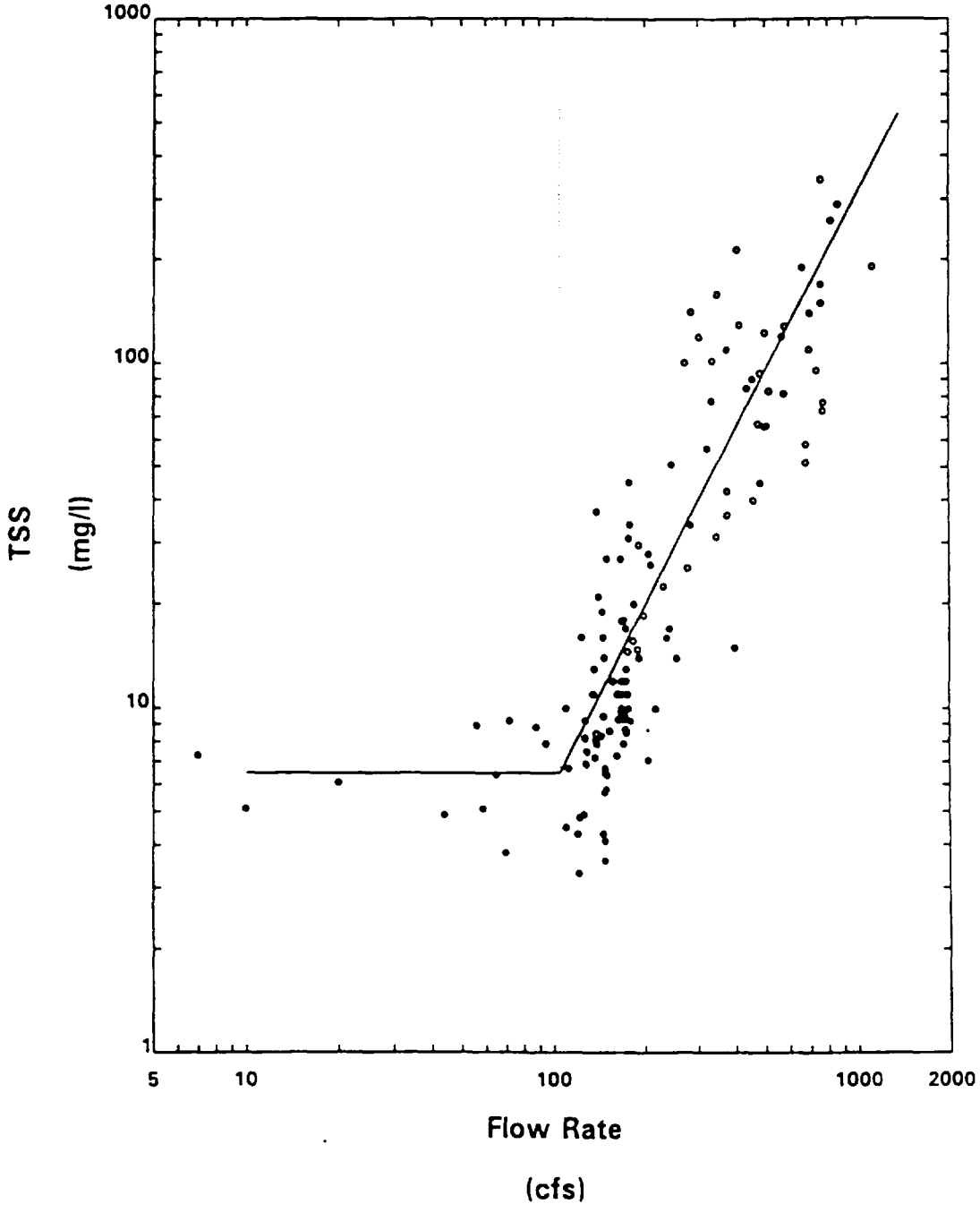


Figure 3-11. Sediment rating curve for Snook Kill.

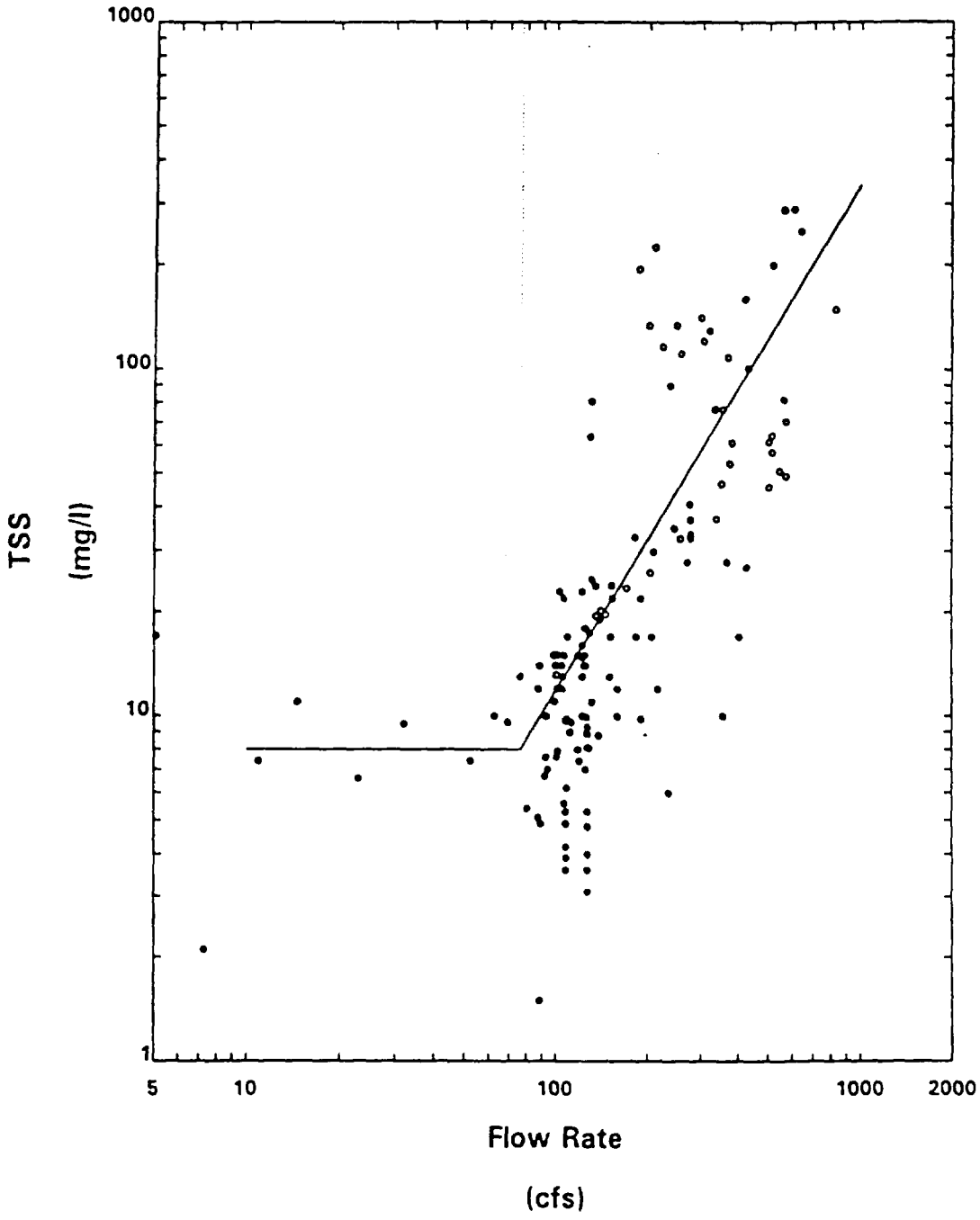


Figure 3-12. Sediment rating curve for Moses Kill.

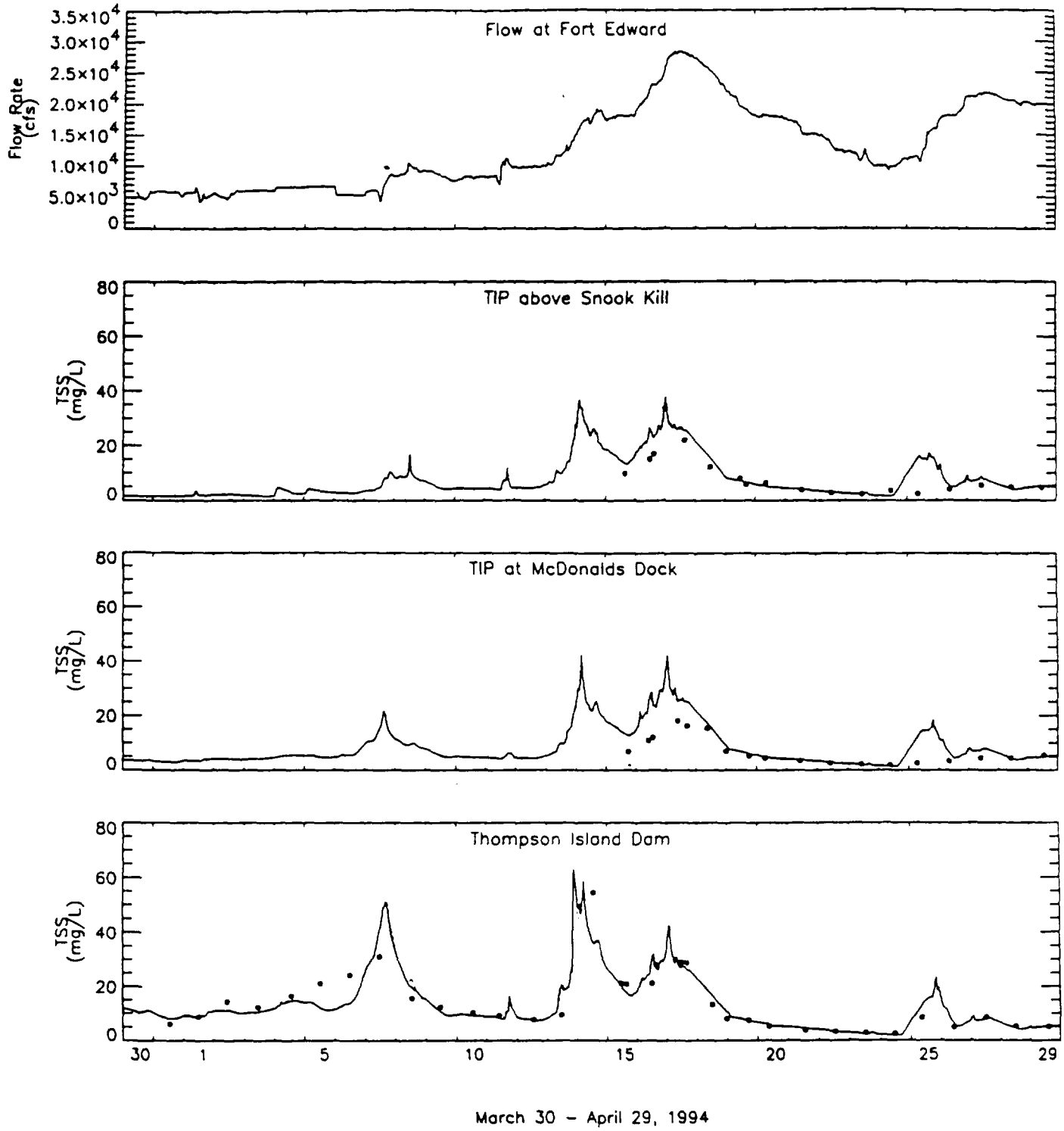


Figure 3-13. Comparison of predicted (solid line) and observed suspended sediment concentrations at three locations in the Thompson Island Pool during the 1994 spring flood.

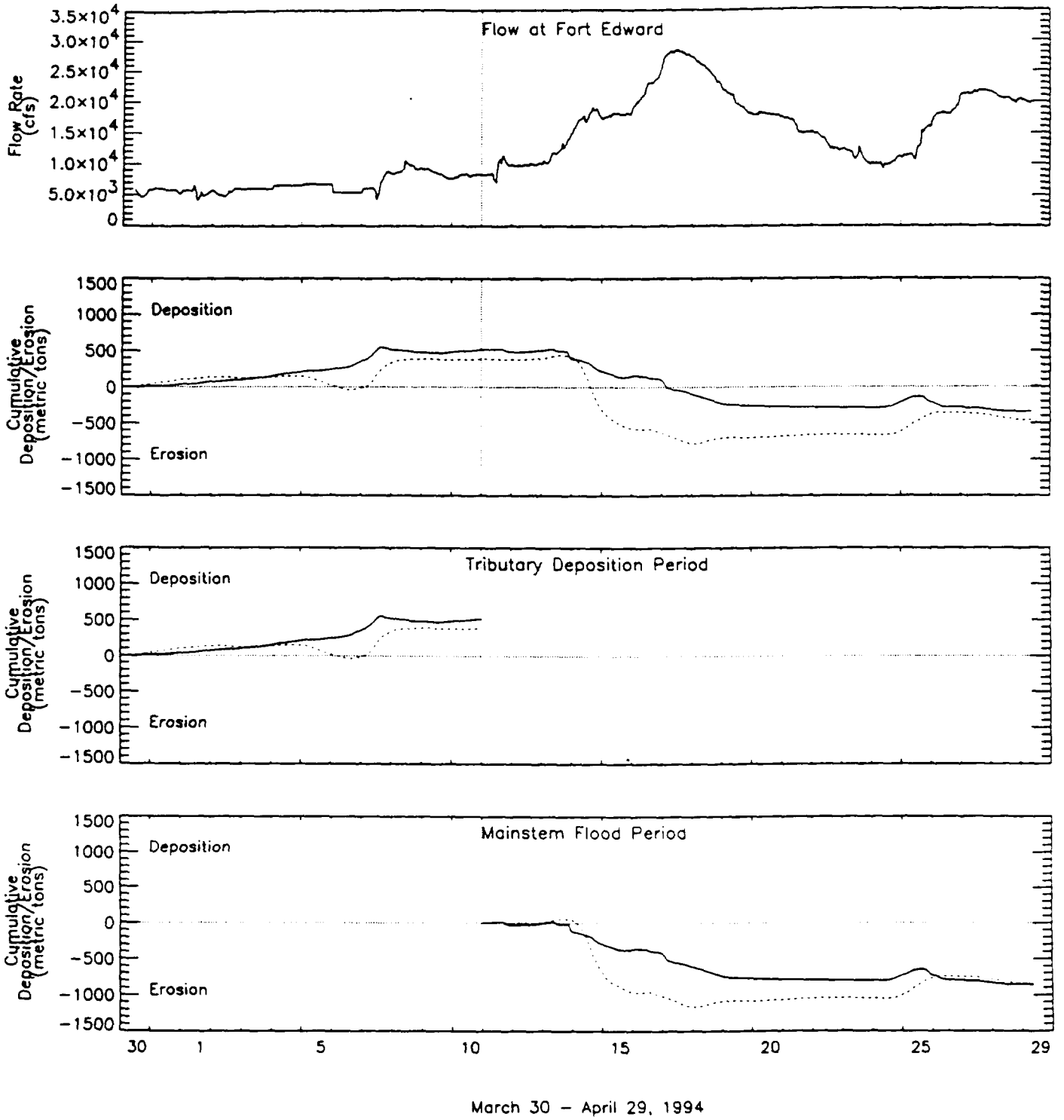


Figure 3-14. Comparison of predicted (solid line) and data-based (dashed line) changes in TIP sediment bed mass during the 1994 spring flood. Initial conditions for non-cohesive bed properties calculated during long term simulation.

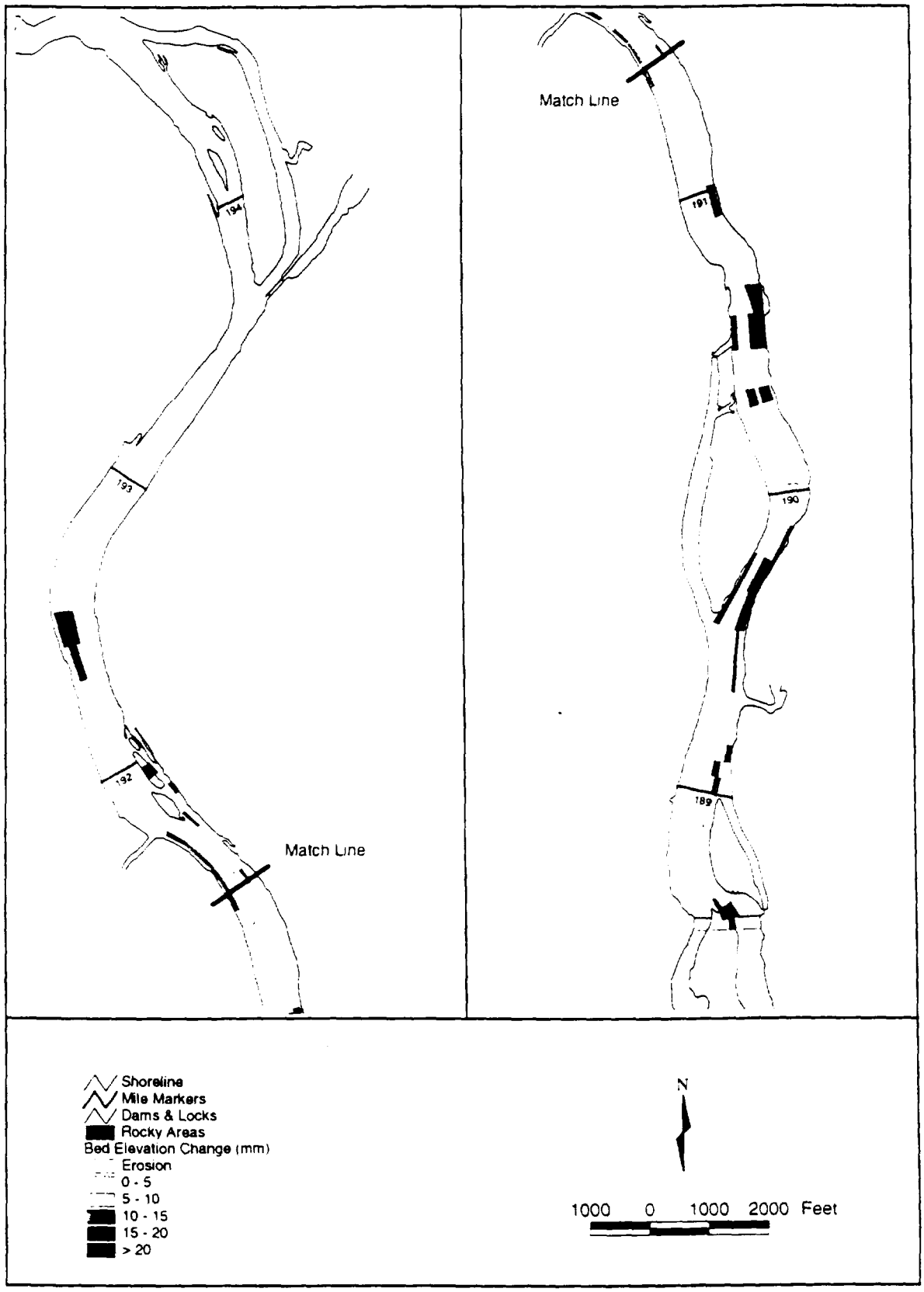


Figure 3-15. Predicted deposition (in mm) that occurred during the 1994 spring flood.

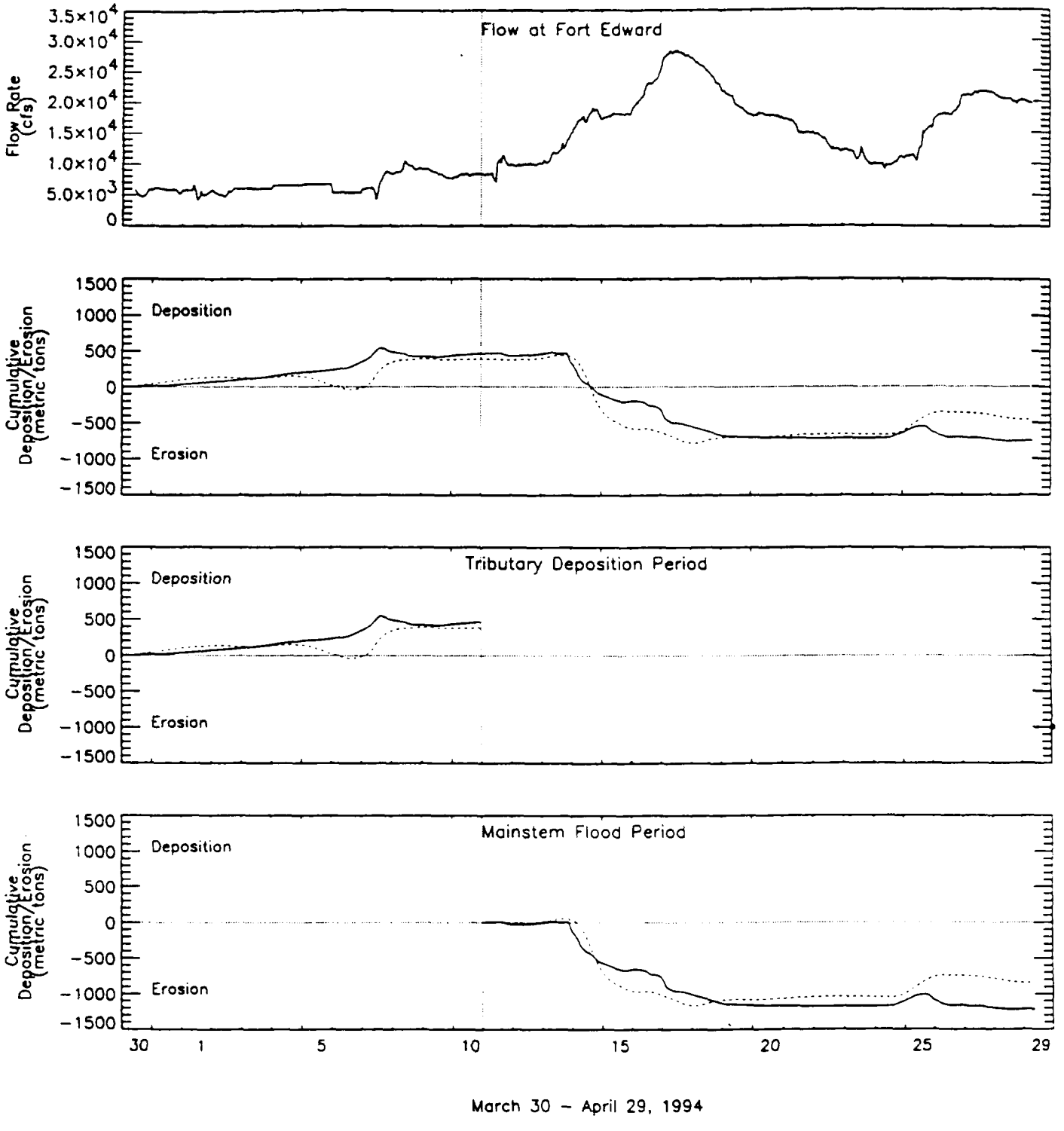


Figure 3-16. Comparison of predicted (solid line) and data-based (dashed line) changes in TIP sediment bed mass during the 1994 spring flood. Initial conditions for non-cohesive bed properties estimated as shown on Figures 3-8 and 3-9.

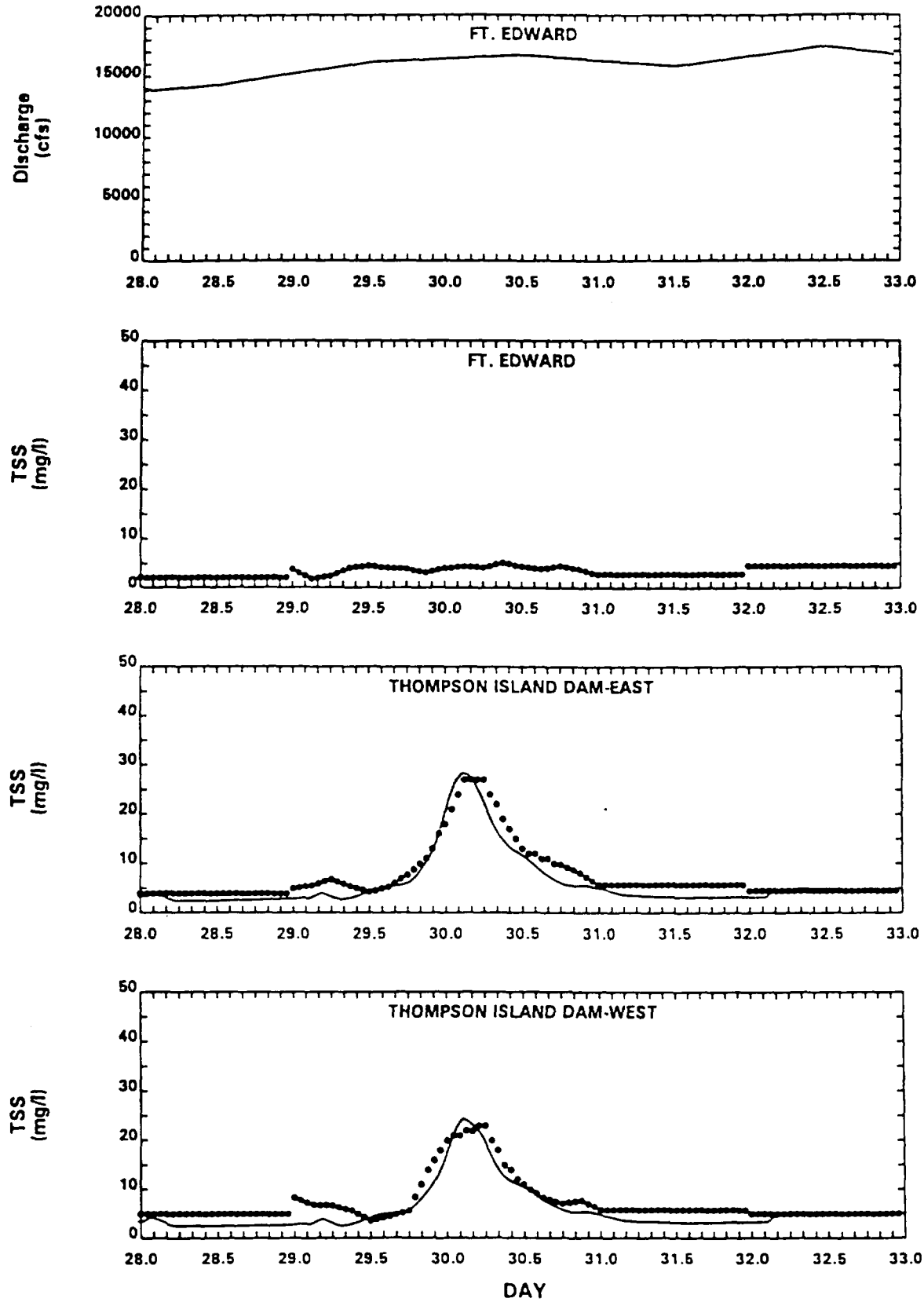


Figure 3-17. Comparison of predicted (solid line) and measured suspended sediment concentrations at the Thompson Island dam during the 1997 spring flood (May 2 to 6, 1997).

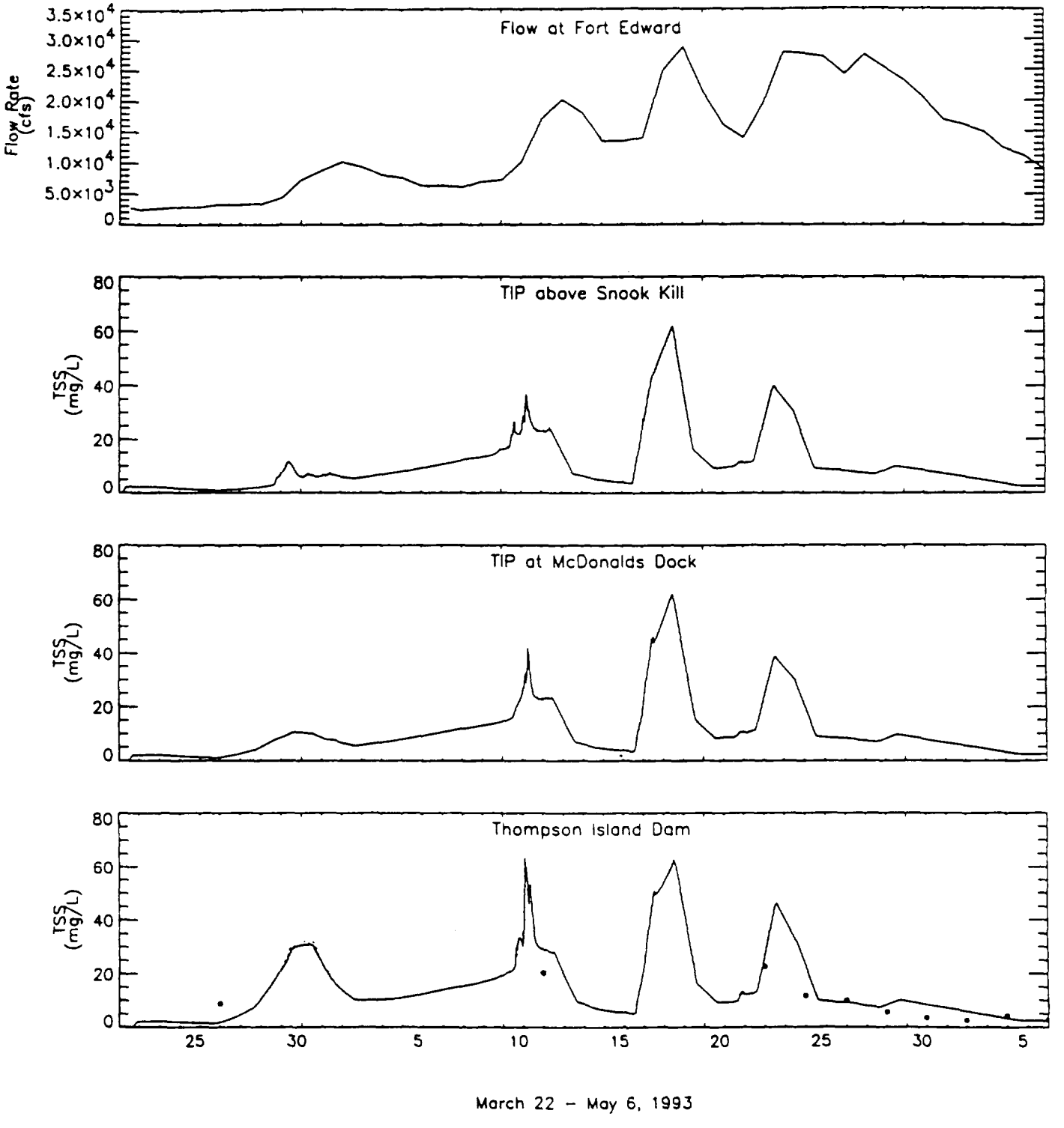


Figure 3-18. Comparison of predicted (solid line) and measured suspended sediment concentrations at the Thompson Island dam during the 1993 spring flood.

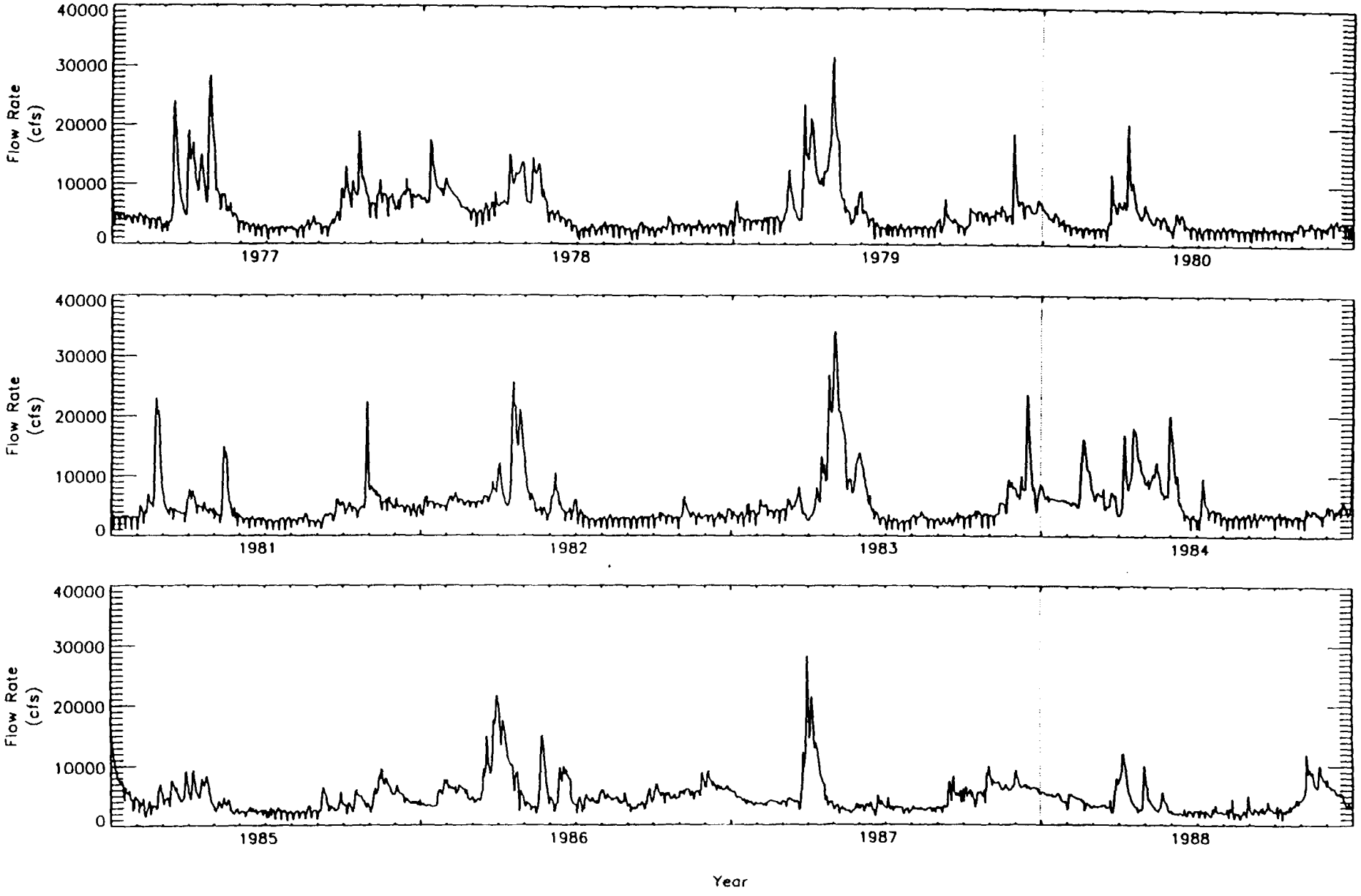


Figure 3-19a. Daily average flow rate at Fort Edward from 1977 to 1988.

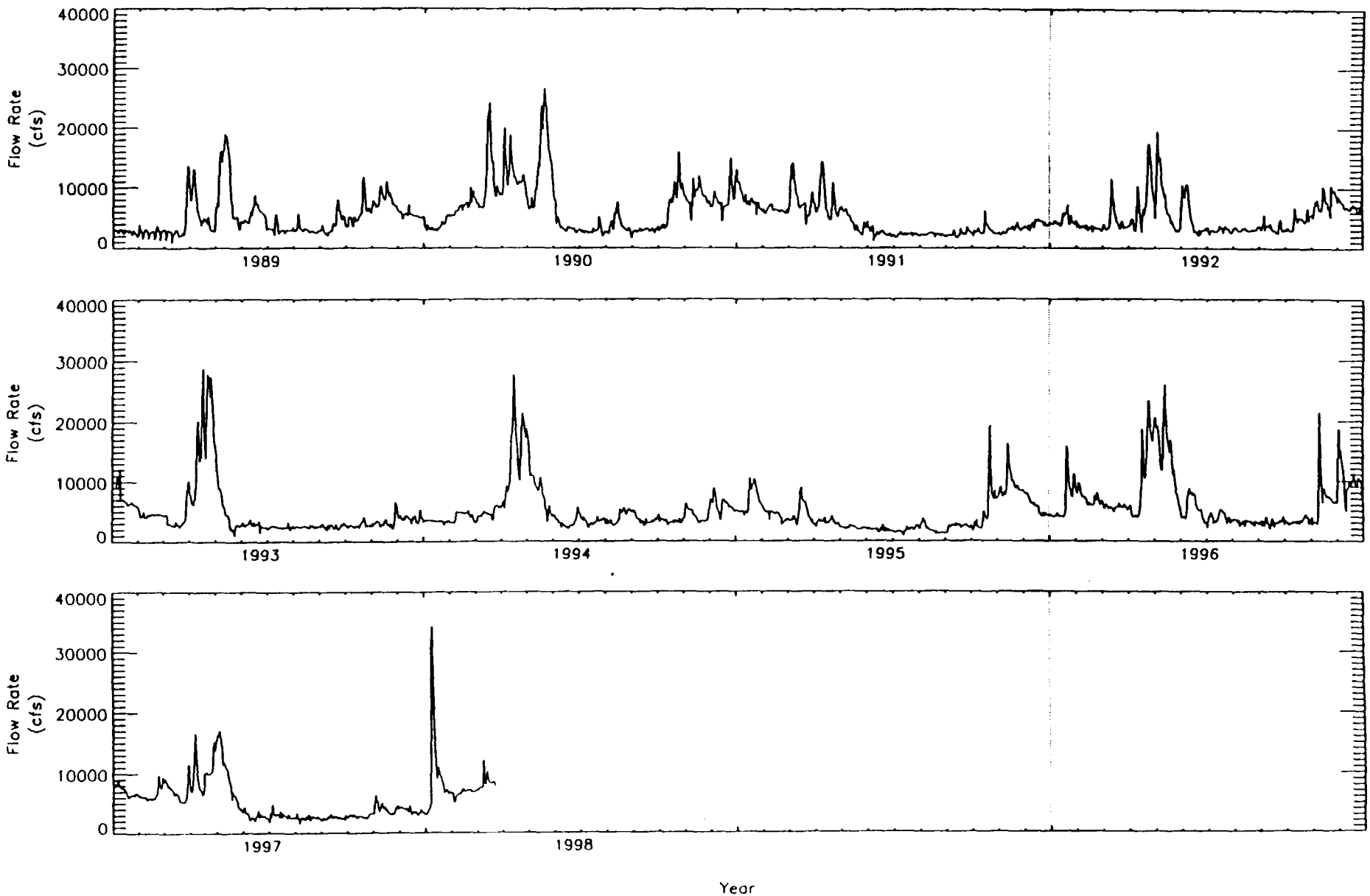


Figure 3-19b. Daily average flow rate at Fort Edward from 1989 to 1998.

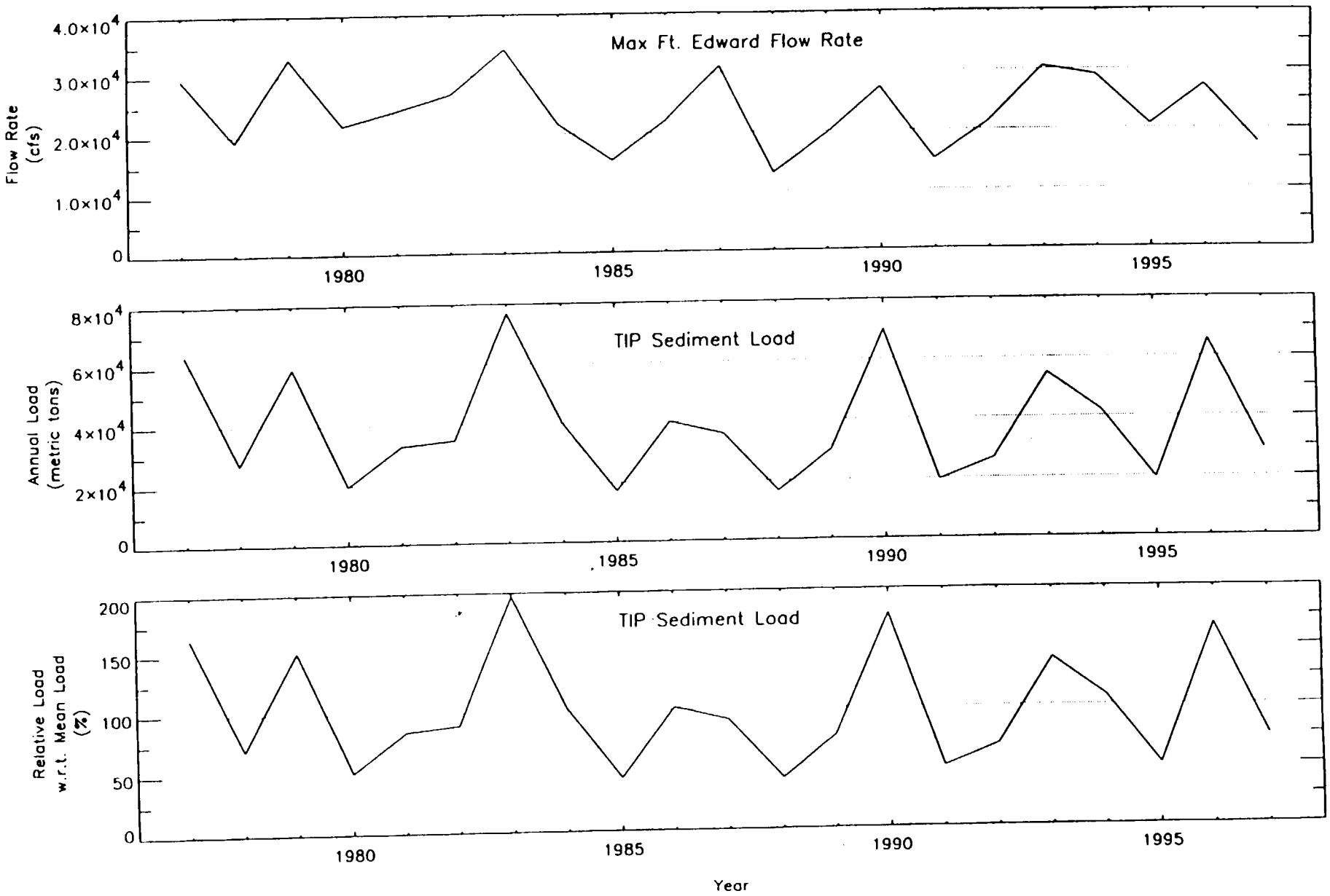


Figure 3-20. Maximum annual flow rate at Fort Edward, total TIP annual sediment load and relative annual sediment load for 1977 to 1997.

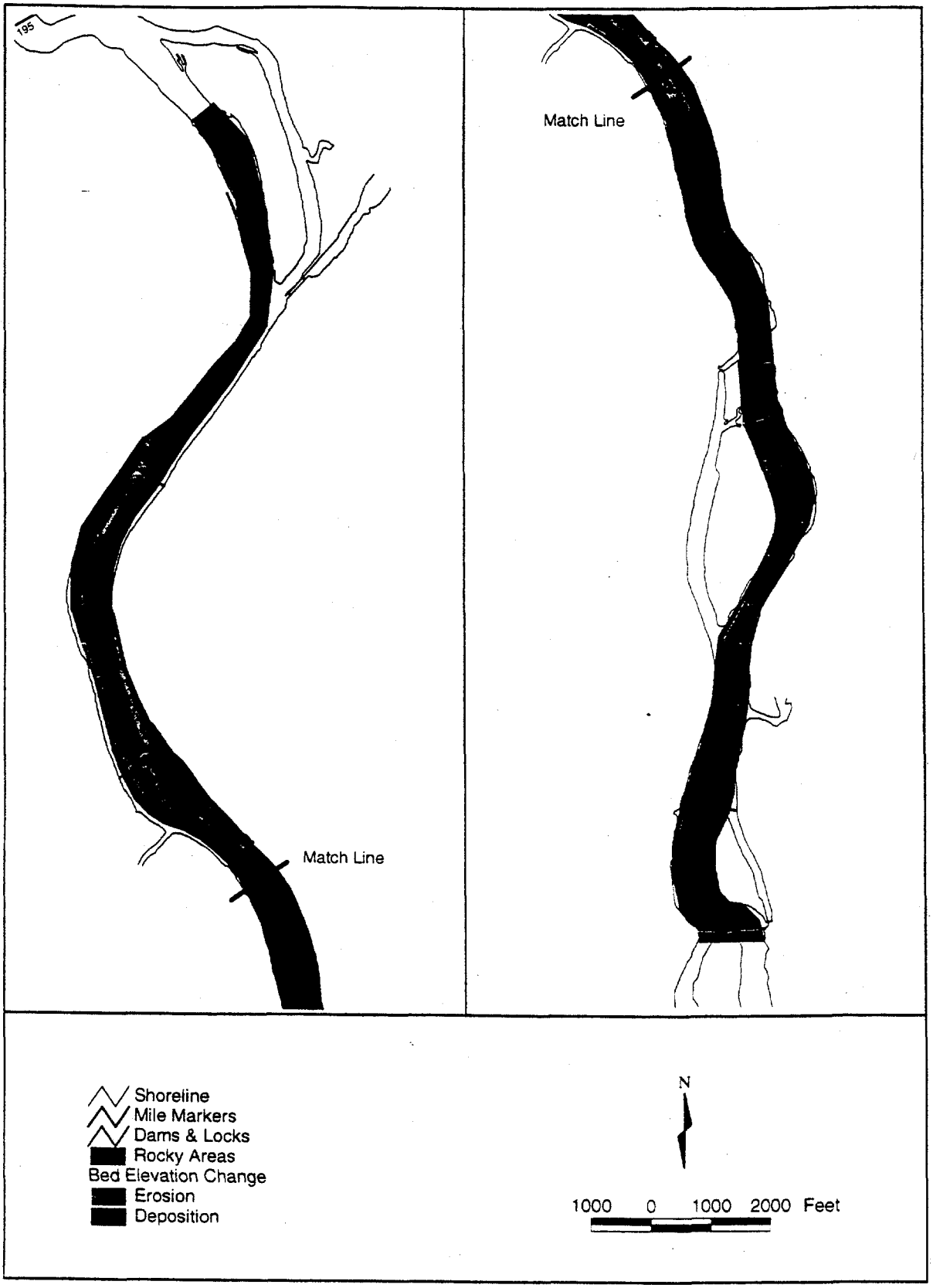


Figure 3-21. Predicted deposition and erosion areas at end of long term simulation (1977 to 1998).

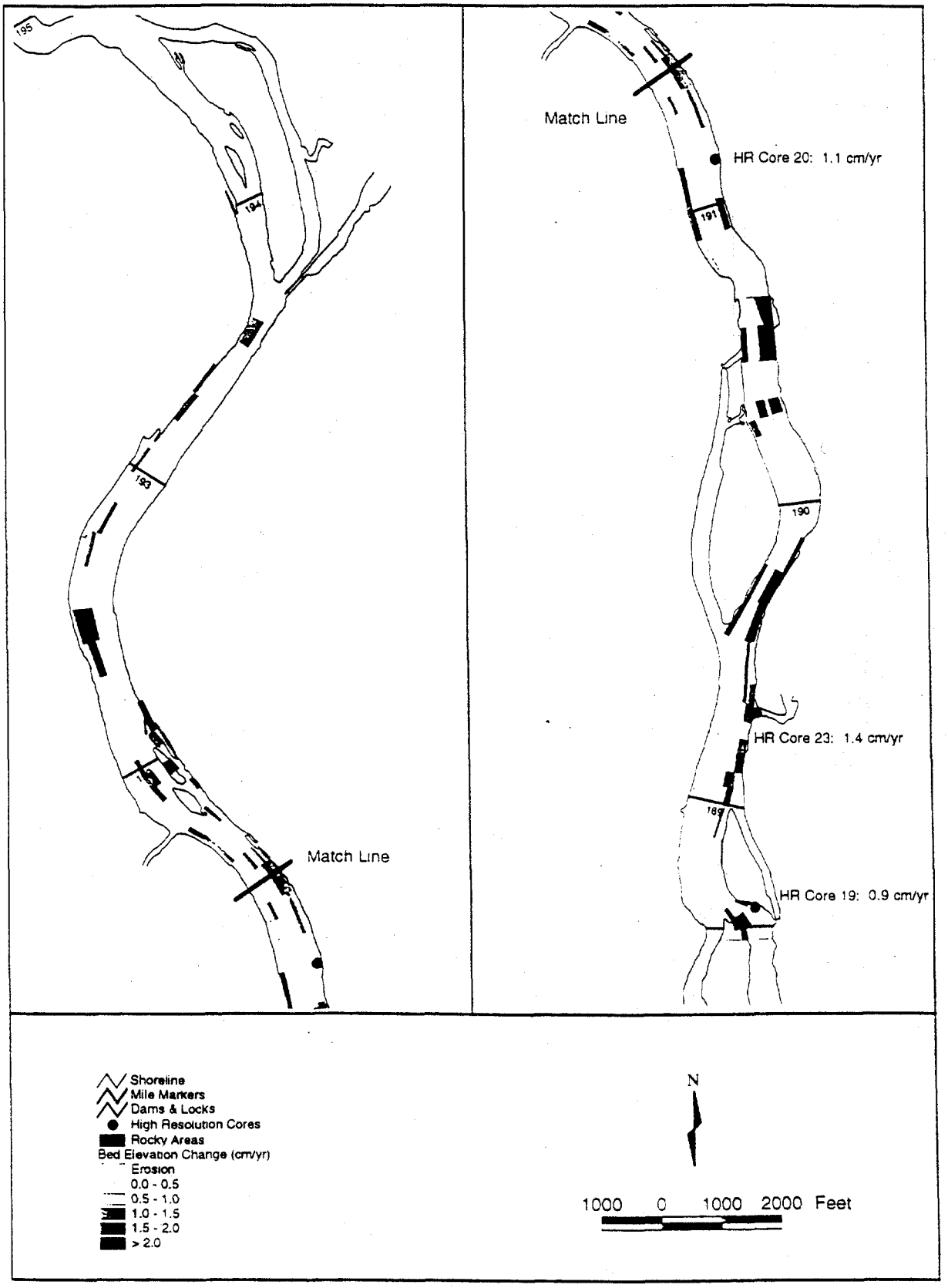


Figure 3-22. Predicted average deposition rates (cm/yr) for 21-year period (January 1977 to March 1998). Measured deposition rates at three high resolution core locations are also shown.

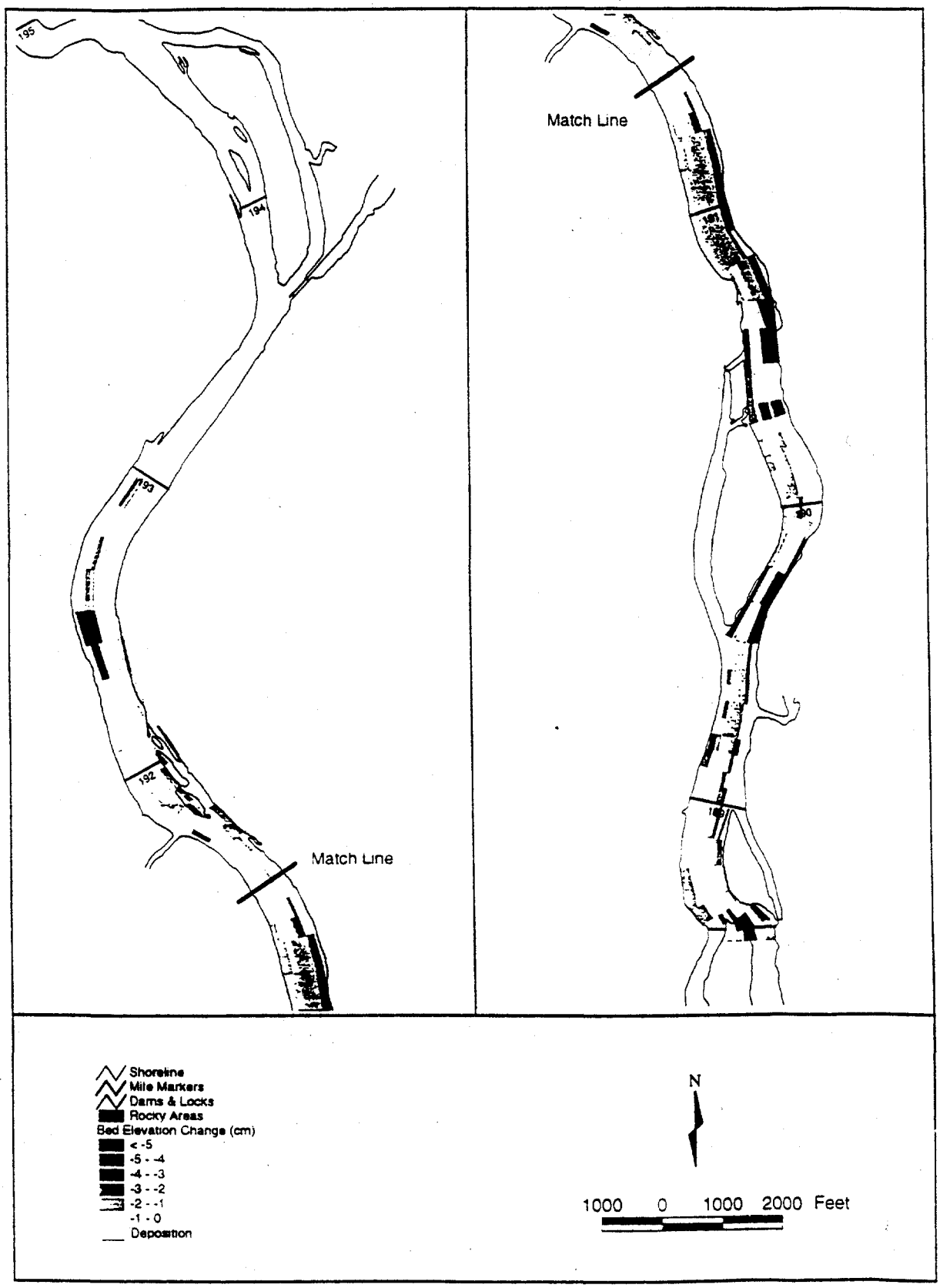


Figure 3-23. Predicted erosion depths (cm) for 21-year period (January 1977 to March 1998).

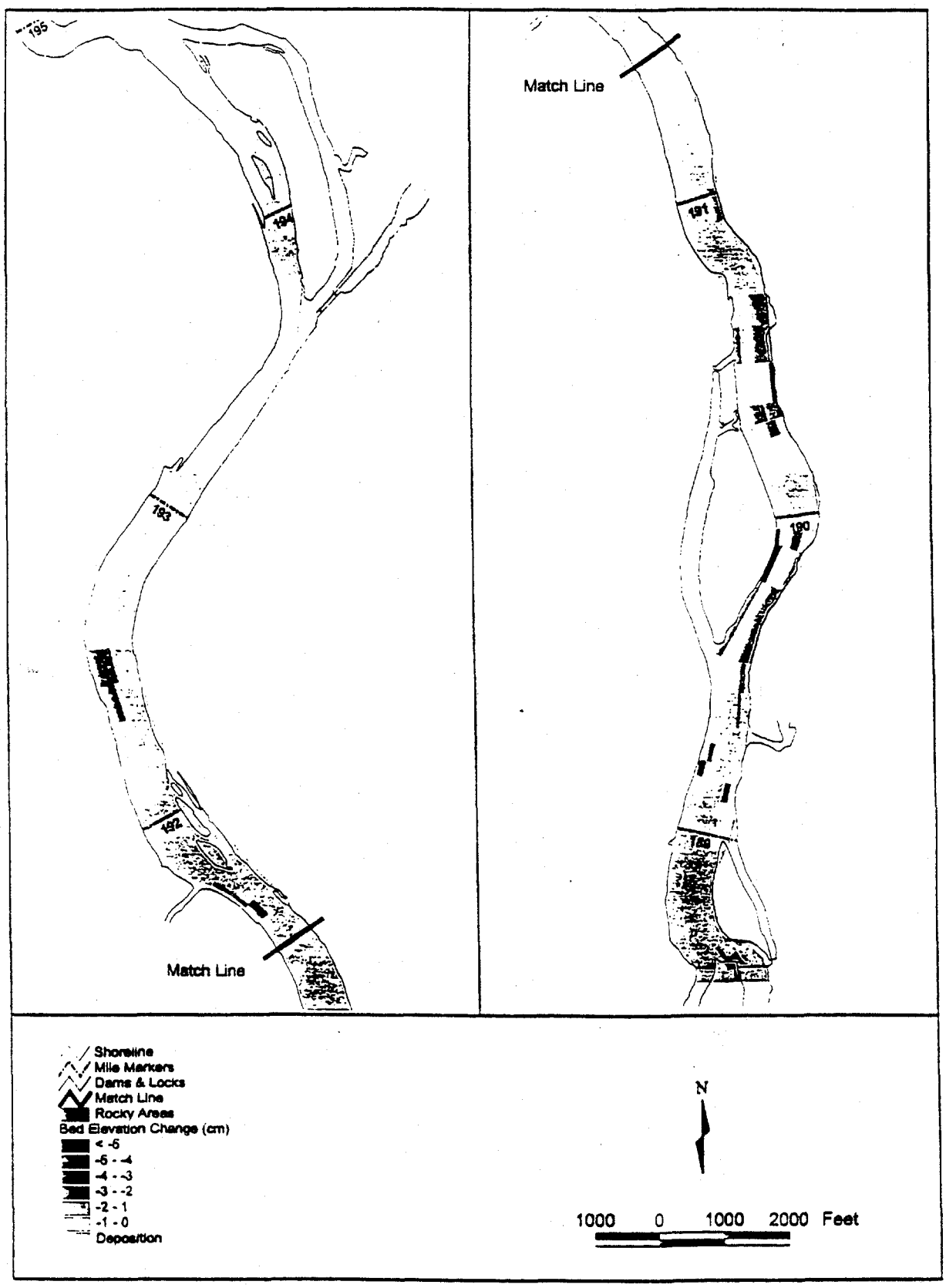


Figure 4-1. Predicted erosion depths (cm) for 100 year flood.