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December 19, 2000

Mr. Douglas J. Tomchuk
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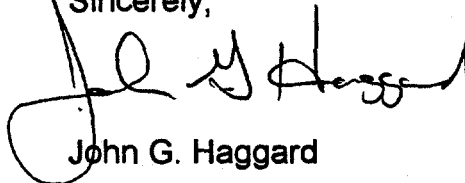
RE: Comments on the Revised Baseline Modeling Report

Dear Mr. Tomchuk:

In January 2000, EPA issued its Revised Baseline Modeling Report ("RBMR") but failed to provide the opportunity for the public to submit comments on this report. The enclosed documents presents GE's comments on the RBMR and highlight issues pertinent to a final remedial decision that were not addressed in the Agency's responsiveness summary to the original May 1999 Baseline Modeling Report. Our comments focus on several key issues: 1) conflicts between the conceptual models of PCB fate and the progression of natural recovery derived from the modeling and the Low Resolution Coring Report; 2) a numerical artifact present in the model's sediment PCB calculation; 3) the reliance on inappropriate suspended solids data in establishing future sediment loading to the river; and 4) the inaccurate characterization of bioaccumulation.

We welcome any comments you may have and request that the Agency consider these comments as it completes the Reassessment RI/FS. Please place a copy of this report into the administrative record. If you have any questions or would like to discuss this further, please do not hesitate to contact me.

Sincerely,



John G. Haggard

JGH/bg
Attachment

cc: Bill Ports – DEC
Bob Montione – DOH

10.3202

COMMENTS OF THE GENERAL ELECTRIC COMPANY ON

Phase 2 Report - Review Copy
Further Site Characterization and Analysis
Volume 2D - Revised Baseline Modeling Report
Hudson River PCBs Reassessment RI/FS
January 2000

November 2000

TABLE OF CONTENTS

SECTION 1 INTRODUCTION	1-1
SECTION 2 INCONSISTENCIES EXIST BETWEEN THE RBMR AND OTHER USEPA REPORT CONCLUSIONS.....	2-1
2.1 LONG-TERM FATE OF THE PCB INVENTORY IN THE TIP	2-2
2.2 FATE OF FLUXED SEDIMENTS FROM THE TIP	2-6
2.3 CONTRIBUTION OF TIP SEDIMENTS TO FRESHWATER HUDSON	2-7
SECTION 3 HUDTOX's PREDICTION OF AN ABRUPT INCREASE IN SURFACE SEDIMENT PCB LEVELS IS A MODEL ARTIFACT	3-1
SECTION 4 THE MODEL USES A BIASED ESTIMATE OF SOLIDS LOAD AT FORT EDWARD AFTER 1990.....	4-1
SECTION 5 ARBITRARY ADDITIONS OF 40 MT/d OF SOLIDS WERE MADE IN THE SCHUYLerville TO STILLWATER AND STILLWATER TO WATERFORD REACHES OF THE RIVER.....	5-1
SECTION 6 THE USEPA APPROACHED THE CALIBRATION OF THE BIOACCUMULATION MODEL INCORRECTLY.....	6-1
6.1 FISHRAND CALIBRATION	6-1
6.1.1 Fish Growth Rate	6-2
6.1.2 Lipid Contents in Fish.....	6-2
6.1.3 Organic Carbon Content of Sediment.....	6-3
6.2 ALTERNATIVE CALIBRATION PARAMETERS	6-4
6.2.1 Dietary Composition.....	6-4
6.2.2 PCB Elimination Rate.....	6-5
6.3 MODELING IMPLICATIONS	6-5
REFERENCES.....	R-1

FIGURES

- Figure 1. USEPA model predicted change in TIP fine sediment PCB inventory
- Figure 2. PCB mass balance in Thompson Island Pool 1984-1994 (number indicate kg of PCBs)
- Figure 3. Comparison of GE model computed cohesive sediment burial rates in low resolution coring analysis cluster area 14 and in the larger area represented by segment 8 of the USEPA Hudtox Model.
- Figure 4. Comparison of GE model computed cohesive sediment burial rates in low resolution coring analysis cluster areas 15 and 17 and in the larger areas represented by segments 11 and 12 of the USEPA Hudtox Model.
- Figure 5. Comparison of GE model computed cohesive sediment burial rates in low resolution coring analysis cluster area 06&07, 08, 09 and 10 and in the larger cohesive sediment areas represented by segments 14, 16 and 17 of the USEPA Hudtox Model.
- Figure 6. Comparison of GE model computed cohesive sediment burial rates in low resolution coring analysis cluster areas 04&18 and 05 and in the larger areas represented by Segments 22, 24, and 25 of the USEPA Hudtox Model.
- Figure 7. Comparison of GE model computed cohesive sediment burial rates in low resolution coring analysis cluster areas 01 and 02&03 and in the larger areas represented by segments 25 and 28 of the USEPA Hudtox Model.
- Figure 8. USEPA Model predicted fate of PCBs leaving TIP fine sediments between 1984 1994.
- Figure 9. USEPA model estimate of the contribution of sources to PCB flux at Troy Dam in 1994.
- Figure 10. Illustration of the numerical simulation of erosion in HUDTOX.
- Figure 11. Illustration of the dependency of HUDTOX sediment PCB calculations in areas of net erosion on the choice of sediment layer thickness.
- Figure 12. Comparison of USGS and GE solids load sampling methods.
- Figure 13. Estimated solids loading at Ft. Edward for post-1990 (1991-1998) period using various rating curves. Error bars represent the 95 % confidence interval.
- Figure 14. Fort Edward solids rating curves using three different data sets.
- Figure 15. USEPA (specified) and GE (calculated) relationships between effective settling speed and flow rate for the cohesive bed in the TIP.
- Figure 16. Total discharge and sediment loads input to tributaries in Schuylerville – Stillwater reach.
- Figure 17. Comparison of supplemental load effects to original rating curve and TIP tributary data for direct drainage area in Schuylerville – Stillwater reach. Flow rates are normalized with respect to mean flow in tributary.
- Figure 18. Comparison of fish growth rates, fish lipid content and sediment organic carbon contents used in FISHRAND with measured values.
- Figure 19. Comparison of FISHRAND calibration results for largemouth bass presented in the original and revised baseline modeling reports.

TABLES

Table 1. Outline of inconsistencies between USEPA reports and the revised USEPA Model	2-1
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SECTION 1

INTRODUCTION

The General Electric Company ("GE") submits these comments on the Revised Baseline Modeling Report ("RBMR"), which presents USEPA's models of PCB fate, transport, and bioaccumulation for the Upper Hudson River ("USEPA's models"). GE has also developed a model of PCB fate, transport, and bioaccumulation for the Upper Hudson River, which has been presented to USEPA.

These models are the most powerful tools available to evaluate the efficacy of potential remedial options. However, they can always be improved. GE has been reviewing USEPA's January release of the RBMR to determine if improvements are needed so that the models can reliably predict the efficacy of considered remedial actions. The major findings are as follows:

- 1) An inconsistency exists between RBMR and previous USEPA report conclusions.

There exists a fundamental inconsistency between the RBMR's conclusion that PCBs are being sequestered and the Low Resolution Coring Report's (LRCR: USEPA, 1998) conclusion that a substantial portion of the PCBs in the fine-grained sediments of the Thompson Island Pool (TIP) have migrated. This inconsistency cannot be reconciled by differences in scale, as USEPA suggests, but is the result of the flawed techniques used in the LRCR. In addition, other inconsistencies exist between the models and the Data Evaluation/Investigation Report (DEIR: USEPA 1997), including conclusions made on the fate of TIP sediments fluxed from the surface layer and the contribution of the TIP sediments to the PCB loadings in the freshwater Hudson.

- 2) HUDTOX's prediction of an abrupt increase in surface sediment PCB levels is an artifact of the model's design.

HUDTOX has forecasted abrupt increases in surface sediment PCB levels in the distant future at several locations in the river. These increases have been portrayed as realistic representations of what may happen in areas subject to net erosion. We have determined that these increases are the result of a numerical artifact of the structure of the model of the sediments, in which the depth of the surface mixed layer is allowed to decline over time and then is abruptly increased. This sudden alteration of the mixed layer depth, which has no biological or physical basis, is responsible for the forecasted abrupt concentration increases.

- 3) The model uses a biased estimate of solids load at Fort Edward after 1990.

In the model, the solids load at Fort Edward was reduced by about 40 percent after 1990. The TSS data collected by the USGS between 1977 and 1998 for the purpose of estimating solids load do not support this reduction. The appearance of a reduction comes from the use of TSS data collected by GE beginning in 1991. The GE data were not collected for the purpose of estimating solids load and misses a portion of the heavier particles that constitute an important part of the solids load at high flow.

- 4) Forty MT/d of solids load was arbitrarily added in the Schuylerville to Stillwater and Stillwater to Waterford reaches of the river

To improve the fit of HUDTOX to TSS and PCB data downstream of the TIP, the solids loads estimated from rating curves were supplemented with an additional load of 40 MT/d. This additional load results in calculated tributary TSS concentrations that exceed a factor of two uncertainty range around the data-based rating curves 83 percent of the time and reach unrealistic levels of several hundred mg/L under low-flow conditions. The need to invoke an unsupportable solids load to achieve model calibration in the region downstream of the TIP is symptomatic of errors in model structure. We believe

that the principal structural error is the use of a constant deposition velocity that overestimates deposition during low-flow and underestimates deposition during high-flow.

- 5) The USEPA approached the calibration of the bioaccumulation model incorrectly.

Arbitrary statistical optimization of select model parameters was used to achieve a best fit of model to data. The resulting parameter values conflict with site-specific data and vary by location for no apparent biological or physical reason.

These issues are significant in that they may affect remedy selection for the site. The inconsistency between the view of PCB fate embodied in the model and that expressed in the DEIR and LRCR pertains to the fundamental issue of whether buried PCBs are or will have a substantive effect of PCB levels in water and biota. As described in this document, the model results demonstrate that the DEIR/LRCR conclusions are incorrect and should not be considered in the evaluation of remedial options. The weaknesses of the modeling cited in this document pertain to the capability to project the response of the river to remediation. More detailed summaries of our analyses of these issues are provided in the following sections.

SECTION 2

INCONSISTENCIES EXISTS BETWEEN THE RBMR AND OTHER USEPA REPORT CONCLUSIONS

The peer review of the RBMR in March 2000 raised the possibility that conflicts exists between the results of the fate and transport model and the results of separate data analyses presented in the Low Resolution Coring Report (LRCR: USEPA, 1998) and the Data Evaluation and Interpretation Report (DEIR: USEPA, 1997). These inconsistencies are summarized in Table 1. Unfortunately, the RBMR fails to acknowledge their existence and presents the inaccurate and misleading conclusion that the model results are in general agreement with the earlier data analyses (RBMR; page 140). As documented below, they are not. The USEPA must recognize the inconsistencies and conduct the technical analyses necessary to develop an accurate and consistent interpretation of PCB fate in the Upper Hudson River.

Table 1. Outline of inconsistencies between USEPA reports and revised USEPA model.

USEPA Reports	Model Results
No widespread burial that would sequester the PCB inventory	Burial sequesters 93% of 1984 fine sediment inventory (apparently permanently)
From 1984 to 1994 about 40% (5-59) of the TIP fine sediment PCB inventory fluxed to the water column	TIP fine sediment inventory was reduced by 3% between 1984 and 1994
Most of the PCBs that fluxed from the sediments were redistributed in the TIP	98% of the PCBs that leave the TIP fine sediments are transported past the TI Dam
Area of the site upstream of TI Dam is the major PCB source to the freshwater Hudson	TIP sediments are a minor component of the PCB load to Lower Hudson
Model results are consistent with the above conclusions	The above results indicate that the model is inconsistent with the conclusions presented in the reports

2.1 LONG-TERM FATE OF THE PCB INVENTORY IN THE TIP

A key conclusion of the model is that burial is sequestering PCBs in the sediment (*Vic Bierman, LimnoTech, Peer Review Presentation, March 2000*). In contrast, a key conclusion of the LRCR is that PCBs in the most highly contaminated areas are not being buried, but are being redistributed by unidentified means within the system (USEPA, 1999). Although these conclusions are plainly inconsistent, USEPA has suggested that the different conclusions result from the differing spatial scales of the two analyses. This implies that the redistribution suggested by the LRCR analysis (presumably caused by net erosion) is occurring at a smaller spatial scale than is discernable by the model. This discussion leads to two fundamental issues:

- First, although it is possible that areas deemed depositional by the model contain regions of net erosion, is the scale of the model so crude that it fails to identify erosional areas which contribute important quantities of PCBs to the water column and biota?
- Second, which analysis is better suited to support remedial decisions – the model's mass balance approach which incorporates all relevant data into a mechanistically-based framework or the LRCR's geochemical approach which examines one type of data that is subject to great variability without mechanistic or mass balance constraints?

The answers to these questions are fundamentally important in the remedial analysis. If, as the LRCR's analysis would suggest, a major fraction of the PCBs entering the water column comes from cohesive sediment areas whose PCB inventory is being made available through mechanisms such as net erosion, then the PCBs in those areas could be a target for a form of remediation different from that selected for depositional areas. Conversely, if, as the model concludes, the bulk of the PCB inventory is sequestered and the dominant sources are upstream inputs and surface sediments in general, then targeting the buried PCB mass for remediation is likely to be ineffective and misguided.

We believe the answers to these two questions are straightforward. Although USEPA's model has its limitations and could be improved, the model's inherent conceptual view is correct. The model accounts for the important sources and sinks of PCBs within the Thompson Island Pool,

as evidenced by its ability to replicate the PCB concentration trends in the sediment and water column. It does so by burying PCBs in the sediment, principally in the cohesive sediments; the highest concentrations of PCBs typically occur below the bioturbated surface layer in the cohesive sediments. All of the cohesive sediment areas are subject to deposition and there is no indication from USEPA's modeling analyses that a significant fraction of the PCB inventory has been mobilized and redistributed from any of these areas. Unfortunately, USEPA did not present analyses of its model results that allow a quantitative comparison to the LRRCR results. We conducted such analyses using a copy of the USEPA model that USEPA provided to us. These analyses show that the model results and the LRRCR conclusions cannot be reconciled. For example, Figure 1 shows the USEPA model prediction for change in PCB inventory from 1984 to 2064, relative to the PCB mass established with 1984 data¹. Only 7% of the 18,000 lb. inventory leaves the sediment over this 80 year period; 93% of the PCB inventory is permanently sequestered as indicated by the plateau in the inventory change.

Figure 2 provides a further illustration of the discrepancy between the LRRCR and USEPA's modeling results in terms of PCB inventory. The conclusions in the LRRCR indicate that close to 40% of the PCBs in the cohesive sediments eroded to the water column from 1984 to 1994. The USEPA model, however, calculates a significantly different percentage with only 3% of the cohesive PCBs fluxing to the water column. The model results are consistent with data, while the LRRCR calculation cannot be reconciled with other inputs and outputs.

The only condition under which the conclusions of the modeling and the geochemical analysis might not be contradictory is one in which the locations targeted in the geochemical analysis deviate from the average condition represented by the model in a manner that would yield net erosion. Such deviation would be possible if the locations targeted in the geochemical analysis experienced velocities (and shear stresses) that: 1) were higher than the average for the model area; and 2) were of sufficient magnitude to cause an erosion flux that exceeded the depositional flux.

¹ These model results and others presented subsequently were obtained through our use of the USEPA model HUDTOX and were not reported in the RBMR.

USEPA has made no attempt to determine whether such deviation exists. Such a determination can be made using the USEPA hydrodynamic and sediment erosion model, which has spatial resolution comparable to, or finer than, that of the geochemical analysis (see Figures 3-2 and 3-3 of the RBMR; USEPA, 2000). The General Electric hydrodynamic and sediment transport model, whose results were used by USEPA in calibrating its model, also has sufficient resolution to examine conditions on the scale of the geochemical analysis. As shown for each of the 1994 sampling clusters on which the geochemical analysis relies (Figures 3 to 7), the GE model indicates that the targeted locations are **not** erosional and tend to have greater deposition rates than the averages for the larger areas represented by the HUDTOX model.

As both USEPA's and GE's models conclude and as all of the field data show, the bulk of the buried PCB mass in the most highly contaminated areas has not migrated to the sediment surface where it could be released and redistributed:

- The flux of PCBs from sediments inferred from the increase in water column PCB load between Rogers Island and Schuylerville is much lower than the LRC Report indicates. GE, 1998 at 31. This flux is accurately described by the Region's and GE's models using physical and chemical mechanisms that do not include the mobilization of the buried PCB inventory.
- Sediment sampling shows no evidence that the PCB mass within the TIP has been redistributed. Instead, the data show a continuous decline over time in surface sediment PCB concentrations in both areas of high and low contamination that is replicated by GE's and the Region's models. GE, 1998 at Figs. 4-44 and 4-45; USEPA, 2000 at Fig. 7-15.
- The PCB composition of the surface sediments shows that the PCBs were derived from a relatively unweathered source. Had the migration of buried PCBs from the bulk of the inventory been the predominant source, the surface sediments would have a highly weathered and dechlorinated composition.
- The PCB composition in the water column shows no evidence of a major contribution from the dechlorinated PCBs characteristic of the bulk of the buried PCB mass in the most highly contaminated areas. GE, 1998 at 46-48.

- 1998 sediment data collected by GE contradict the conclusion that the areas analyzed in the LRC lost significant PCB mass. GE, 1998 at 32-24.
- If the buried mass of highly concentrated PCBs were at the surface, one also would expect to see at the surface the high ^{137}Cs concentrations peaks characteristic of material deposited in the 1960s and 1970s and shown to be associated with the bulk of the PCB mass in the most highly contaminated areas. Yet, few, surface sediments have such high ^{137}Cs concentrations. GE, 1998 at 48.
- Almost all finely sectioned sediment cores confirm that the highest concentrations and bulk of the PCB mass remain buried below the surface sediments. GE, 1998 at 40.
- The PCB composition in fish indicates that they have not been exposed to the dechlorinated PCBs characteristic of the bulk of the buried PCB mass in the most highly contaminated areas. GE, 1998 at 47.

An obvious question is why did the LRRCR conclude that PCBs in the most highly contaminated areas are not being buried if the modeling and the data cited above are at variance with such a conclusion? The answer lies in the flawed methodology of the LRRCR analysis (GE, 1998). The analysis relies on comparisons between sediment PCB data collected in 1984 and 1994. Unfortunately, the comparisons are not valid because the 1984 samples chosen for the comparison were not randomly picked from all the data lying within designated areas, but were chosen because they had among the highest PCB levels in the data set. Further, the ability to see statistically meaningful differences between the 1984 and 1994 samplings was severely impaired because of the extreme variability among samples and the relatively small sample size. Finally, the statistical analysis of the data did not account for all of the sources of variance and may have underestimated the uncertainty of the estimated mass change². The reported uncertainty is already so large (4 to 59 percent) that the analysis has little power to determine what has occurred to the PCB inventory between 1984 and 1994.

² USEPA could have obtained an appropriate confidence interval for the year-to-year change by conducting an analysis of variance using a two-way classification by cluster and by year.

In sum, conflict between the PCB inventory conclusions of the LRCR and USEPA's model is irreconcilable. Either the conclusion reached applying the mechanistically-based, mass-balance approach used by the models is correct (that is, that the vast bulk of the PCBs in the cohesive sediments are being buried) or the LRCR's non-mechanistic and limited geochemical analysis is correct (that is, that a substantial fraction of the PCBs in the cohesive sediments are not being buried). This is a central issue that should be resolved in order to aid the decision-making process at this site.

Given the weakness inherent in the statistical data comparison approach and the methodology errors, the LRCR conclusions cannot be used to understand PCB fate within the sediments of the TIP. The only available tool is the mechanistically-based models that reconcile all the data using known processes.

2.2 FATE OF FLUXED SEDIMENTS FROM THE TIP

Another issue of concern is the fate of resuspended TIP sediments - do they travel over the dam to lower reaches or are they just redistributed within the TIP. On the basis of the LRCR the USEPA concluded that most of the PCBs fluxed from the fine sediments in the TIP were redeposited within the reach and did not travel downstream. However, the USEPA modeling results from 1984 to 1994 show the opposite story - only 2% of the fluxed PCBs remain within the TIP, while 97% travel over the dam to lower reaches and 1% are volatilized (Figure 9). It is important to note that the 2% redistributed within the TIP constitutes only 0.06% of the total PCB inventory in the fine sediments in 1984³. In direct contradiction to this finding the RBMR states on page 141: "...HUDTOX ... suggest[s] that there has also been a significant amount of redistribution of Tri+ mass within Thompson Island Pool from historical hot spots." We believe that our analysis of the HUDTOX results demonstrates that this statement is false. The RBMR must be revised to present a clear and accurate assessment of the model conclusions on this issue.

2.3 CONTRIBUTION OF TIP SEDIMENTS TO FRESHWATER HUDSON

Of major concern to the USEPA and others is the origin of the PCBs seen in lower, freshwater Hudson. The DEIR concluded that the TIP is the major source of PCBs to the lower Hudson. However, analysis of USEPA's model shows that TIP sediments are actually a minor component of the load to the Lower Hudson River. Estimates from the model indicate that in total, 63% of the PCBs transported from the Upper Hudson to the Lower Hudson in 1994 originated from downstream of the Thompson Island Dam, while TIP sediments account for only 17% of the load at Troy Dam in that year (Figure 9). Of this 17%, less than one quarter comes from the cohesive sediments.

³ This result was obtained from the USEPA model by running the model with the upstream source and PCB concentration in non-cohesive sediment set to zero and examining the PCB flux to non-cohesive sediments that the model computes due to PCB flux from cohesive sediments.

SECTION 3

HUDTOX's PREDICTION OF AN ABRUPT INCREASE IN SURFACE SEDIMENT PCB LEVELS IS A MODEL ARTIFACT

USEPA's HUDTOX model forecasts abrupt increases in surface sediment PCB (Tri+) concentrations in several localized areas in the TIP cohesive sediments (Figure 8-4a, Revised Baseline Modeling Report, Vol. 2D-Book 2 of 4) and the non-cohesive sediments of the Stillwater reach (Figure 8-4c, Revised Baseline Modeling Report, Vol. 2D-Book 2 of 4) after 40 to 50 years. USEPA contends in the RBMR that these increases are realistic predictions of what may happen in areas subject to net erosion. USEPA believes these increases are a demonstration of a process that would "slow or interrupt apparent rates of recovery" (Vol. 2D- Book 1 of 4, Section 8.3.1, p. 160). The increases are not real, but are an artifact of the numerical model used to describe the sediment and the manner in which the model results are presented.

The model employs a 4 cm mixing depth. However, in areas of erosion or deposition, the model changes the depth of the surface mixed layer over time (i.e., the depth subject to significant bioturbation) as a consequence of the sediment segmentation scheme and the numerical procedure. Where net erosion is calculated, the depth of the topmost segment declines until it reaches a defined minimum value of a few millimeters. At that time, what remains of the top segment is incorporated in the segment below it, and the sediment segments are renumbered by the model (Figure 10). Because particle mixing is calculated for a specified number of segments (e.g., the top two segments in the non-cohesive sediments of the Stillwater reach), the model abruptly changes the depth of sediment subject to mixing. In the case of the non-cohesive area of the Stillwater reach that is calculated to undergo net erosion, the mixed layer declines from 4 cm to almost 2 cm, instantly increases to 4 cm and then begins to decline again. The sudden incorporation of a sediment segment that was previously below the mixing layer and not subject to PCB loss results in the calculation of a sharp increase in PCB concentration within the mixed layer (Figure 8-4c of the RBMR). The reason the increase occurs after 40-50 years is that the net erosion rate is approximately 0.04 cm/year, so it takes about 50 years until that next lower 2 cm thick segment is redefined as part of the "top two segments." This abrupt increase,

however, is not realistic, because in reality, the PCBs in the underlying layer will be made slowly available over the entire 40 year period, not instantly in the 40th year.

The effect is less dramatic for the cohesive sediments in the TIP because there is mixing in the top 4 segments (8 cm initially). Hence, the impact of the third segment suddenly becoming part of the top two segments and the fifth segment being suddenly introduced into the surface mixed layer is dampened. The former third segment was already mixed with the second segment and the former fifth segment is mixed with three segments instead of one segment. Close examination of Figure 8-4a (RBMR) reveals that the increase is more gradual than in the case where there is only mixing in the top two layers. This is expected, as mixing slowly brings PCBs from the former fifth segment to the top two segments.

The numerical artifact of declining and then instantaneously increasing the depth of the surface mixed layer is exacerbated by the manner in which the model results are presented. The predicted concentrations in Figures 8-4, (a-e) **do not** represent the top 0-4 cm of sediment as stated in Section 8.3. Instead, they represent an average of the top two sediment segments. Because the depth of the topmost layer changes, the depth of sediment represented in the figures changes also. The presented results in an area of net erosion track a progressively thinner layer of surface sediment (i.e., from 4 to 2 cm) and then instantly a thicker layer (i.e., 4 cm) that again becomes progressively thinner.

That the predicted increases are due to the model's numerical procedures rather than a real phenomenon is demonstrated by examining how the predicted increases change as the resolution of the numerical grid is changed. QEA ran its bed model using USEPA's parameters for particle mass transfer, net erosion, and molecular mass transfer as well as a mixing depth of 4 cm as was used in the Stillwater Reach. The model was run with a segment thickness of 2 cm as well as 0.2 cm to demonstrate that the apparent increase is easily reproducible and a function of layer thickness. We were able to reproduce the sudden increase when using 2 cm layers (Figure 11). As the sediment model segmentation was refined, the sharp increases due to this numerical artifact began to disappear. As shown in Figure 11, use of segments 0.2 cm thick results in near complete elimination of the increases.

SECTION 4

THE MODEL USES A BIASED ESTIMATE OF SOLIDS LOAD AT FORT EDWARD AFTER 1990

A critical component of long-term simulations of PCB fate and transport in the Upper Hudson River, and particularly in the TIP, is the specification of solids loading at Fort Edward. Sedimentation rates and PCB surficial bed concentrations are directly affected by the Fort Edward solids load. Therefore, the accuracy of the model depends upon an accurate estimation of the Fort Edward solids load.

USEPA has hypothesized that a large decrease in the solids loading at Fort Edward occurred after 1990 (USEPA 2000). Various causes for the loading decrease were proposed, including capping of remnant deposits by General Electric (GE) in 1990. Several analyses were presented to support the hypothesis that the annual loading rate after 1990 has decreased by 38% when compared to the 1977-90 period.

Both USEPA and GE have estimated Fort Edward solids loading during periods when data are unavailable using rating curves developed from total suspended solids (TSS) concentration and flow rate data collected at the Rogers Island sampling station located at the upstream limit of the TIP (QEA 1999, USEPA 2000). Flow rates are measured by the U.S. Geological Survey (USGS) at the Fort Edward gauging station and are typically reported as daily-average values. The two primary TSS data sources are: 1) USGS, which has collected samples from 1977 to the present and 2) GE, which has collected samples since 1990. There are significant differences in the TSS sampling equipment and procedures used by USGS and GE (Figure 12), and these differences affect the interpretation of TSS concentration data. There are two reasons why only the USGS data should be used to assess sediment loadings.

First, the USGS methodology is specifically designed to measure sediment loads, whereas GE's methodology is not. GE samples are taken at three locations in the water column: 0.2, 0.5 and 0.8 times the depth (e.g., in 2 m of water, the bottom GE sample would be 40 cm

above the sediment bed). The USGS method, in contrast, utilizes a sampler that samples continuously throughout the water column, from the surface to within 6 cm of the sediment bed. Thus, the GE method does not produce a vertically-averaged TSS concentration that adequately samples near-bed sediments, where a major fraction of the suspended sand load is located. In addition, the USGS sampler is a flow-through device that is specifically designed for sampling suspended sediment. A Kemmerer sampler is used by GE to collect TSS samples. The design of this device is such that suspended sands, with relatively high settling speeds, may not be adequately sampled. Second, the USGS methodology has remained constant throughout the relevant period (i.e., 1977 to the present), whereas GE's different methodology was introduced in 1990. It is far preferable to use a consistent data set than to rely on data collected from two different methodologies. Thus, it is appropriate to rely on the USGS data set to establish solids loading over time at Fort Edward.

The correspondence of the hypothesized loading change and the introduction of a second data source, i.e., GE data, into the loading analysis leads to the necessity to determine whether the change is due to differences in sampling and laboratory analysis between the two data sources. Various techniques can be used to evaluate whether the introduction of the GE data into the loading analysis causes an artifactual reduction in solids loading that is not real. The most direct technique is to determine whether the single data source, i.e., USGS data, that covers both the 1977-90 and post-1990 periods supports the conclusion of a reduction in solids loading. USEPA attempted such a comparison by a paired sample analysis in which the pairs were generated by matching 1977-90 and post-1990 data on the basis of river flow. Few details were provided in USEPA (2000) on how the analyses were conducted or the results of those analyses. However, USEPA concludes that "these results show that the use of time stratification in computing the Fort Edward solids load is supported, at both high and low flows, regardless of whether or not GE data are included." An attempt was made to repeat part of the USEPA analysis, where USGS TSS concentration data from the 1977-90 and post-1990 periods were compared based on flow rate. Unfortunately, exactly how that analysis was performed could not be ascertained. No unique procedure exists for this analysis, the results depend upon the assumptions used in the analysis.

A more robust test of the loading-change hypothesis involves comparison of 1977-90 and post-1990 solids rating curves developed from the USGS data. This comparison is critical because, ultimately, rating curves are used to calculate solids loading. Two different methods were used to compare these two rating curves. First, the average annual solids loading for the post-1990 period (1991-1998) was calculated using both rating curves (Figure 13). This approach eliminates any potential effects due to hydrograph variations. The resulting loading rates were 33,300 and 26,600 MT/yr for the 1977-90 and post-1990 rating curves, respectively. Thus, the post-1990 rating curve yields an average annual load that is 20% lower than the 1977-90 rating curve. A large fraction of that difference is attributable to low-flow loading (post-1990 is 28% lower), whereas the post-1990 high-flow load is only 15% lower than the 1977-90 loading. Second, the two high-flow rating curves were statistically compared and were not significantly different at a 95% confidence level. For the low-flow regime, minimal correlation existed between TSS concentration and flow rate, so, consistent with USEPA's approach, mean values were determined for each period. It was determined that the average low-flow TSS concentrations were statistically different, but the difference was not large, with mean values of 4 and 3 mg/l for the 1977-90 and post-1990 periods, respectively. Therefore, differences exist between the 1977-90 and post-1990 periods in Fort Edward solids loading; statistically significant differences occur under low-flow conditions, with relatively small differences observed during high-flow conditions.

What is critical to note about this analysis is that high-flow solids loading has a much larger impact on sedimentation than sediment loads brought in during low-flow periods, i.e., episodic deposition occurs in the Upper Hudson River with most of the annual sedimentation occurring during relatively rare high-flow events. Thus, careful analysis of the USGS data shows that the solids loading during high flow at Fort Edward did not decline after 1990, and only a small drop in solids loading occurred during low flow after 1990.

It appears that USEPA's hypothesized reduction in solids loading after 1990 is due to the Agency's reliance on the GE data, as illustrated by comparing the USGS post-1990 rating curve with the GE post-1990 rating curve. Comparing the two data sets in this manner is crucial because: 1) all of the data are used, not just a limited number of paired measurements and 2) differences in solids loading estimates can be quantified. Large differences between the resulting

rating curves, particularly in the high-flow regime, are evident in Figure 14. These rating curves were used to calculate Fort Edward solids loading for an eight-year period, from January 1, 1991 to December 31, 1998 (Figure 13). The rating curve developed from the GE data produced a total solids load for this period that was 24% lower than the USGS rating curve overall, with a much larger difference during high-flow periods (54% lower) than during low-flow periods (17% higher). The apparent low-bias of the GE TSS concentration data during high-flow conditions probably results from the configuration of the sampling device and the sampling procedure, as described previously (Figure 12). Thus, the GE TSS concentration data should not be used for calculating total suspended solids loading at Fort Edward.

This analysis indicates that USEPA's conclusion concerning temporal changes in solids loading at Fort Edward is incorrect. Inclusion of the GE data in the development of the post-1990 rating curve causes an underestimation of Fort Edward solids loading. For example, the USEPA rating curve for the post-1990 period yielded an average annual solids load of 21,500 MT/yr. for the 1991-1998 period, which is 20% lower than the load estimated using the post-1990 USGS rating curve (Figure 13). Use of solids loading inputs to HUDTOX that are too low during post-1990 and projection periods will reduce predicted sedimentation rates, affect the calculated rate of natural recovery and may incorrectly skew the efficacy of various remedial actions. Therefore, the use of an artificially low solids load at Fort Edward introduces an error into USEPA's model and probably contributed to the need to add an arbitrary additional solids load of 40 MT/d (see Section 3).

SECTION 5

ARBITRARY ADDITIONS OF 40 MT/d OF SOLIDS WERE MADE IN THE SCHUYLERVILLE TO STILLWATER AND STILLWATER TO WATERFORD REACHES OF THE RIVER

Sediment resuspension and deposition are primary controlling factors in determining PCB fate and transport in the Upper Hudson River. Accurate simulation of these processes is essential in the development and application of an Upper Hudson River PCB fate model. USEPA's sediment transport model suffers from weaknesses that undermine its accuracy, particularly downstream of the TIP. This inaccuracy apparently led USEPA to add an arbitrary tributary solids loading downstream of the TIP. A more realistic representation of solids dynamics, particularly downstream of the TIP, is feasible and will improve the accuracy of model projections.

Similar deposition formulations were applied to cohesive and non-cohesive bed areas in HUDTOX. Effective settling speeds used in HUDTOX were temporally constant and spatially variable, with a higher value in cohesive areas than in non-cohesive areas. This approach overlooked three important phenomena that affect deposition: 1) variable bottom shear stress or, equivalently, flow rate (i.e., probability of deposition effects); 2) changes in composition of water column solids (i.e., relative amounts of clay, silt and sand in suspension); and 3) flocculation of clay and silt particles. An example of these effects on effective settling speed is illustrated in Figure 15, which shows results from the GE sediment transport model for a cohesive bed area in the TIP (QEA 1999). The effective settling speed relationship shown on Figure 15 is typical for the Upper Hudson River, with relatively low settling speeds during low-flow conditions due to most of the suspended load being composed of flocculating clay and silt particles. During high-flows, there are significant increases in suspended sand content causing the effective settling speed to increase by more than an order of magnitude. Even though the HUDTOX effective settling speed for cohesive bed areas (4.15 m/day) may approximate a long-term average value, it is too high during low-flow and too low during high-flow (Figure 15).

Accurate estimation of tributary sediment loading to the Upper Hudson River is important for any analysis of long-term PCB fate in the river. USEPA and GE made considerable efforts to construct accurate solids mass balances for the Upper Hudson River and develop credible methods for estimating tributary solids loading (QEA 1999, USEPA 2000). While there is some uncertainty in the estimated tributary solids loads, the estimation techniques appear to produce reasonably accurate tributary loads (QEA 1999).

To calibrate its model, USEPA adjusted solids loadings from the tributaries downstream of the TIP (USEPA 2000), especially during low-flow conditions. Unfortunately, the RBMR does not provide sufficient information to determine the cause and extent of the initial calibration difficulties. Thus, USEPA input an additional tributary solids load of 40 metric tons/day (MT/day) to both the Schuylerville-Stillwater and Stillwater-Waterford reaches during the final calibration. Although USEPA portrays this load increase as being within the uncertainty range of the estimated tributary loads (USEPA 2000), a closer examination reveals that the magnitude of the supplemental solids loading was not trivial during low-flow periods, i.e., below mean tributary flow rate. While the increase in long-term solids loading was about 26 and 17% for the two reaches, respectively (USEPA 2000), the relative increase in tributary solids loading was much greater during low-flow conditions. Figure 16b shows a temporal comparison of the tributary loading for the Schuylerville-Stillwater reach specified by: 1) time-variable rating curves (developed from the solids load analysis referenced above and used during initial model calibration) and 2) constant load of 40 MT/day. During low-flow conditions, the supplemental load is significantly greater than the original rating curve load. The magnitude of this disparity in the Schuylerville-Stillwater reach is illustrated in Figure 16c, which shows the temporal variation of the ratio of the final calibration rating curve loading (initial rating curve load plus supplemental load) to the initial rating curve loading. This ratio increases as the flow decreases, with maximum values of about 70X and 12X for the Schuylerville-Stillwater and Stillwater-Waterford reaches, respectively. The ratio is greater than two 83% of the time between 1977 and 1999 for the Schuylerville-Stillwater reach. Assuming that uncertainty about the rating-curve-estimated loading is about a factor of two, then this percentage represents the portion of time during which the assumption of a constant supplemental solids loading of 40 MT/day is **not** within the assumed uncertainty range of the tributary solids loading.

Analysis of tributary TSS concentrations required to produce an additional load of 40 MT/day provides a further illustration that this loading was unrealistic during low-flow conditions. With the additional load, low-flow TSS concentrations were as high as 500 and 190 mg/l for the Schuylerville-Stillwater and Stillwater-Waterford reaches, respectively. These concentrations are much higher than observed TSS concentrations during low-flow periods for Upper Hudson River tributaries. Further illustration of the unrealistically high TSS concentrations resulting from the additional tributary load is presented on Figure 17 for the direct drainage area in the Schuylerville-Stillwater reach. This figure shows TSS concentration as a function of flow rate determined from three sources: 1) original rating curve (with factor of two uncertainty range); 2) additional constant load (18 MT/day for this tributary); and 3) low-flow TSS data for Snook and Moses Kill. Clearly, the additional load produced unrealistically high TSS concentrations during low-flow conditions.

Adjustment of tributary sediment loading to achieve adequate calibration of the model is an indication that HUDTOX does not accurately simulate sediment transport in the Upper Hudson River, particularly downstream of the TIP. Sediment resuspension and deposition dynamics were incorrectly represented in the model, primarily due to the use of formulations that are too simplistic and inaccurate.

Non-cohesive suspended load transport in rivers has been studied extensively and is relatively well understood. Numerous mechanistic models, of varying levels of complexity, have been developed to simulate resuspension and bed armoring processes for non-cohesive beds. These models have been successfully developed and applied to various rivers, including the GE model of the Upper Hudson River (QEA 1999). Instead of using these formulations, USEPA selected a non-mechanistic formulation that is not based on any site-specific or experimental data nor based on a peer-reviewed theoretical framework. Problems with the USEPA approach are: 1) neglect of bed armoring processes that can significantly affect erosion rates during a flood; 2) omission of effects of bottom shear stress variation on erosion rate, i.e., non-cohesive erosion rate is a non-linear function of bottom shear stress (flow rate); and 3) spatial and temporal variations in non-cohesive bed properties were not adequately addressed.

While the above discussion highlights problems in the sediment transport formulations used in HUDTOX, part of the problem results from USEPA's use of two separate model frameworks for the Upper Hudson River: one for the TIP and another one for the seven reaches downstream of the TIP. The TIP model appears to produce reasonable results, even though some of the processes (as discussed above) are not properly described. The model's success in the TIP is due primarily to: 1) use of TIP-specific erosion data and bottom shear stress information; 2) use of GE sediment transport model results to calibrate/validate HUDTOX; and 3) use of a hydrodynamic model to generate realistic cohesive resuspension functions. In contrast, in the reaches downstream of the TIP, USEPA did not use site-specific erosion data, even though such data were available. Significant variability exists in reach-average cohesive resuspension parameters for the seven reaches downstream of the TIP; up to an order of magnitude difference in resuspension parameters was observed for the downstream reaches (QEA 1999). USEPA also did not develop and apply a hydrodynamic model(s) for the reaches below the TIP; a hydrodynamic model is needed to calculate bottom shear stresses, a critical parameter for the Lick equation and calculation of cohesive resuspension. Although USEPA claims that the simplified transport model used downstream of the TIP is warranted because of data limitations and uncertainties in those reaches, GE's model demonstrates that it is possible to develop a defensible, mechanistic sediment transport model for the **entire** Upper Hudson River.

Realistic and accurate simulation of sediment transport processes is crucial for understanding the long-term fate of PCBs in the Upper Hudson River. USEPA's sediment transport model for the Upper Hudson River suffers from several problems, primarily downstream of the TIP. These problems can be addressed and should improve the accuracy of model projections.

SECTION 6

THE USEPA APPROACHED THE CALIBRATION OF THE BIOACCUMULATION MODEL INCORRECTLY.

The USEPA developed three bioaccumulation models as part of the Further Site Characterization of the Upper Hudson River: the Bivariate Statistical Model, the Probabilistic Bioaccumulation Food Chain Model, and the mechanistic FISHRAND Model. Of the three models, FISHRAND is the only model that mechanistically describes PCB transfer through the food web and was appropriately used in the risk assessment. Unfortunately, this model inaccurately represents the physiology and bioenergetics of the fish species it simulates and the characteristics of the PCBs and sediments to which the fish are exposed. The inaccuracies result from the approach USEPA used to calibrate the model, and consequent use of values for several key model parameters that are inconsistent with the available site data.

The USEPA apparently chose calibration parameters on the basis of a statistical optimization without proper reference to site-specific data, and as a result the parameter values are inconsistent with these data. Although USEPA's Bayesian approach is appealing conceptually, its application has led to parameter distributions that are at variance with data and biological understanding. Thus, while the calibration may appear satisfactory based on the relationship between calculated and measured fish PCB levels, final estimates for some key parameters are not consistent with data collected throughout the Upper Hudson River, because much of the site-specific data was not considered during calibration. Consequently, the ability of FISHRAND to predict future PCB concentrations in fish is compromised.

6.1 FISHRAND CALIBRATION

Fish growth rate, fish lipid content, organic carbon in the sediment, and K_{OW} were selected as calibration parameters and were adjusted to optimize the fit of the model to Upper Hudson River PCB measurements in the fish. Site-specific data are available to constrain these

parameters, and these data conflict with the final values used in the model. In addition, values for these parameters were chosen independently for each reach of the river, resulting in independently calibrated models for each reach that are inconsistent with each other.

6.1.1 Fish Growth Rate

USEPA's model framework includes a default weight-based relationship for estimating growth rates. During calibration, USEPA modified a default parameter of this relationship on a species- and reach-specific basis, with no supporting analyses. USEPA did not consider site-specific growth data collected by the NYSDEC and others in the Upper Hudson River. The calibration adjustments result in largemouth bass growth rates in Thompson Island Pool and Stillwater that are 6 and 19 times greater, respectively, than indicated by the data. (Figure 18; Volume 2D, Book 4, Tables 6-2 and 6-3). Thus, not only are the growth rates at variance with the data, they were determined independently for each reach of the river. Growth rates of the other modeled species were modified in a similar manner (Volume 2D, Book 4, tables 6-2 and 6-3).

6.1.2 Lipid Contents in Fish

There are three problems with USEPA's estimation of fish lipid contents. First, calibration resulted in lipid contents different from the best estimates based upon the data collected by NYSDEC during their PCB monitoring program. For example, the fraction lipid in the largemouth bass used at Stillwater (geometric mean = 0.006 g lipid/g wet weight) is less than ½ of the mode of the data (0.014). In contrast, a value more similar to the data (0.011) is used in Thompson Island Pool. Lipid contents for the other modeled species are also modified independently of the data and independently for each reach, for example spottail shiner (Figure 18).

Second, USEPA uses a constant lipid fraction for each species throughout the simulation, even though the data indicate that lipid content varies considerably. USEPA states that it is possible to obtain close to perfect agreement between model predictions and observed body burdens by inputting the observed lipid concentrations for each year. However, the Agency does

not use this method, because, it claims, it limits the ability of the model to forecast fish tissue PCB concentrations, since future variation in lipid content is unknown (Volume 2D, Book 3, p. 36). This is incorrect. Historical lipid contents are known; therefore they should be used. Ignoring existing historical data does not make predictions more robust.

Third, the lipid contents used for largemouth bass and brown bullhead in FISHRAND are based on fillet samples collected by NYSDEC. However, FISHRAND simulates bioaccumulation of whole fish, and therefore, lipid contents for fillet samples must be converted to whole-body equivalents prior to incorporation into the model; the lipid content on a whole-body basis is approximately 2.5 times the fillet lipid content (QEA, 1999). This error results in the overestimation of PCB elimination in the modeled fish.

6.1.3 Organic Carbon Content of Sediment

The organic carbon contents of the sediments (f_{OC}) used in the calibrated model differ from the values used in HUDTOX, which are based upon the 1991 GE sediment data (Volume 2D, Book 1, p. 109; Book 2, Table 6-32). The f_{OC} values used in Thompson Island Pool and Stillwater are approximately twice and $\frac{1}{2}$ the average values used in HUDTOX, respectively (Figure 18). Using a lower carbon content at Stillwater increases the carbon-based PCB concentration, resulting in greater accumulation throughout the food web and a greater contribution of sediment-based PCBs to the food web. In effect, PCBs in Thompson Island Pool and Stillwater sediments are assumed to be $\frac{1}{2}$ and twice as bioavailable as the organic carbon data indicate, respectively.

Octanol-Water Partition Coefficient

USEPA incorrectly uses one average partition coefficient (K_{OW}) value to describe both accumulation at the base of the water column food web and elimination in fish. This ignores differences in congener composition in the two media and processes. The average K_{OW} values used in the two media are likely to differ, and values should be based upon the available site data.

Calibration results in log (K_{OW}) values of 6.60 and 6.47 for Thompson Island Pool and Stillwater, respectively (Volume 2D, Book 4, Tables 6-2 and 6-3). The average Log(K_{POC}) value used by USEPA to describe PCB₃₊ partitioning in the water column is 5.85 (Book 2, Table 7-4). This value is based upon an analysis of data collected by USEPA in the Upper Hudson River. Thus, the K_{OW} values used in FISHRAND are 4 to 6 times greater than the value used in HUDTOX, resulting in an unrealistically large degree of bioaccumulation from the water column. Because K_{OW} does not apparently affect bioaccumulation from the sediments in FISHRAND, this inaccuracy causes an unrealistic overestimation of the importance of water column-based PCBs to the food web.

The K_{OW} values used in FISHRAND in Thompson Island Pool and Stillwater differ by approximately 35 percent. The lower K_{OW} value at Stillwater results in lower bioaccumulation at the base of the food web and faster elimination of PCBs in the fish, both of which act independently to reduce computed PCB levels in the fish in Stillwater relative to Thompson Island Pool.

Finally, the USEPA states correctly that average K_{OW} for PCBs in fish can be estimated using PCB congener composition data measured in fish, and this would have been a reasonable approach (QEA 1999).

6.2 ALTERNATIVE CALIBRATION PARAMETERS

In order to match the fish PCB data, USEPA had to choose values for its calibration parameters that are inconsistent with the site data. These parameters can and should be constrained by site data. There are other parameters that are relatively unconstrained by site data that are therefore more appropriate choices for calibration (QEA 1999), in particular dietary composition and PCB elimination rate.

6.2.1 Dietary Composition

The proportion of benthic and water column invertebrates in the diet of the forage fish is

estimated qualitatively by USEPA, using "best professional judgement and a careful analysis of all the available data" (Volume 2D, Book 3, p. 79). The site-specific diet and community composition data do not permit the diets of the important fish to be constrained tightly. In developing the GE bioaccumulation model, QEA (1999) estimated bounds for the dietary composition based upon a quantitative analysis of the field data, and then calibrated the model by adjusting diet within those bounds.

6.2.2 PCB Elimination Rate

FISHRAND calculates gill elimination as a diffusive process, which probably overestimates the true elimination rate in chronically exposed fish (QEA 1999). The true elimination rate cannot at this point be tightly constrained by the available experimental data, and therefore is an appropriate calibration parameter. For example, QEA (1999) introduced a multiplier in the diffusion formulation which was adjusted in the process of calibration.

6.3 MODELING IMPLICATIONS

FISHRAND appears to be a well-calibrated model, judging from the relationship between computed and observed fish PCB levels. However, the values chosen for key parameters conflict with site data and differ among reaches. In essence, USEPA has developed two completely different models, calibrated independently in the two locations.

The calibration results presented in the original Baseline Modeling Report (BMR) and the Revised Baseline Modeling Report (RMBR) demonstrate the impact these differences have on model results. Calibration simulations from the BMR and the RMBR are presented in Figure 19. In the original BMR calibration, predicted PCB concentrations in largemouth bass in Thompson Island Pool and Stillwater were similar. In contrast, in the RMBR, computed largemouth bass levels are lower at Stillwater than in the Thompson Island Pool, and closer to measured PCB levels in Stillwater. The dietary compositions did not change from the BMR to the RMBR and are the same throughout the river. However, as mentioned above, different values were used for several parameters. Thus, the improvement in the calibration was achieved by changing the

process of bioaccumulation and the bioavailability of PCBs in these two locations, in ways for which there is no support. As a result, both the degree of bioaccumulation and the relative importance of sediment and water column PCB to the food web appear to be incorrect. This means that projected fish PCB levels are likely to be incorrect.

The reliability of the model could be significantly improved by recalibrating in a consistent fashion in all locations using parameter values that are consistent with all of the available site data. Recalibration would provide a model that more accurately estimates the extent of bioaccumulation, as well as the relative importance of sediment and water column-based PCBs to the food web. This, in turn, would provide a more reliable model.

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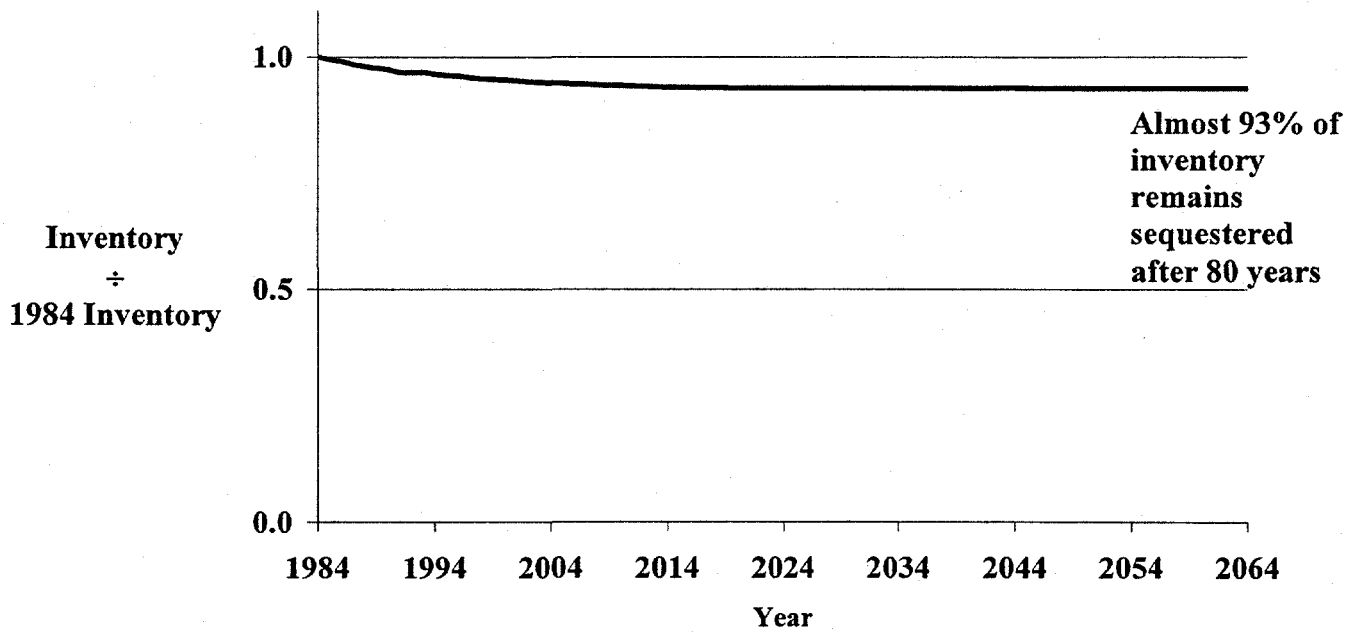
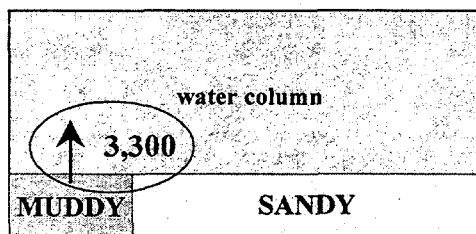


Figure 1. USEPA model predicted change in TIP fine sediment PCB inventory

**Low Resolution Core Report
(LRCR)**
~ 40% of 8,200 kg PCB
inventory left muddy sediments



EPA Model

3% of the PCB inventory left
muddy sediments

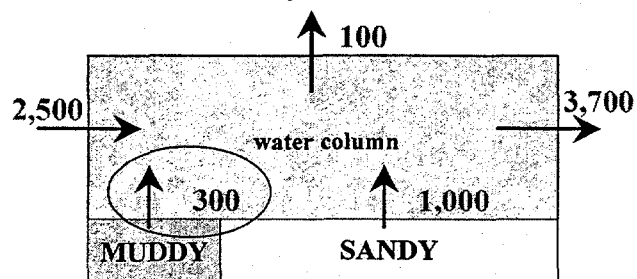
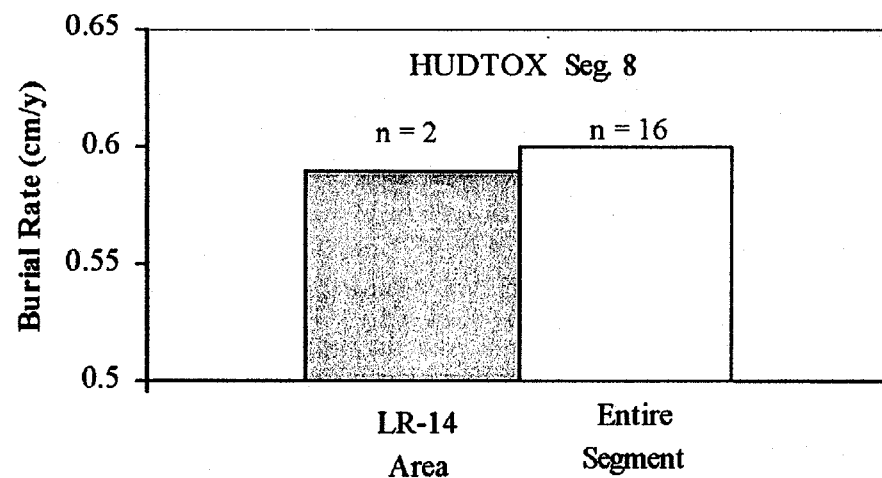
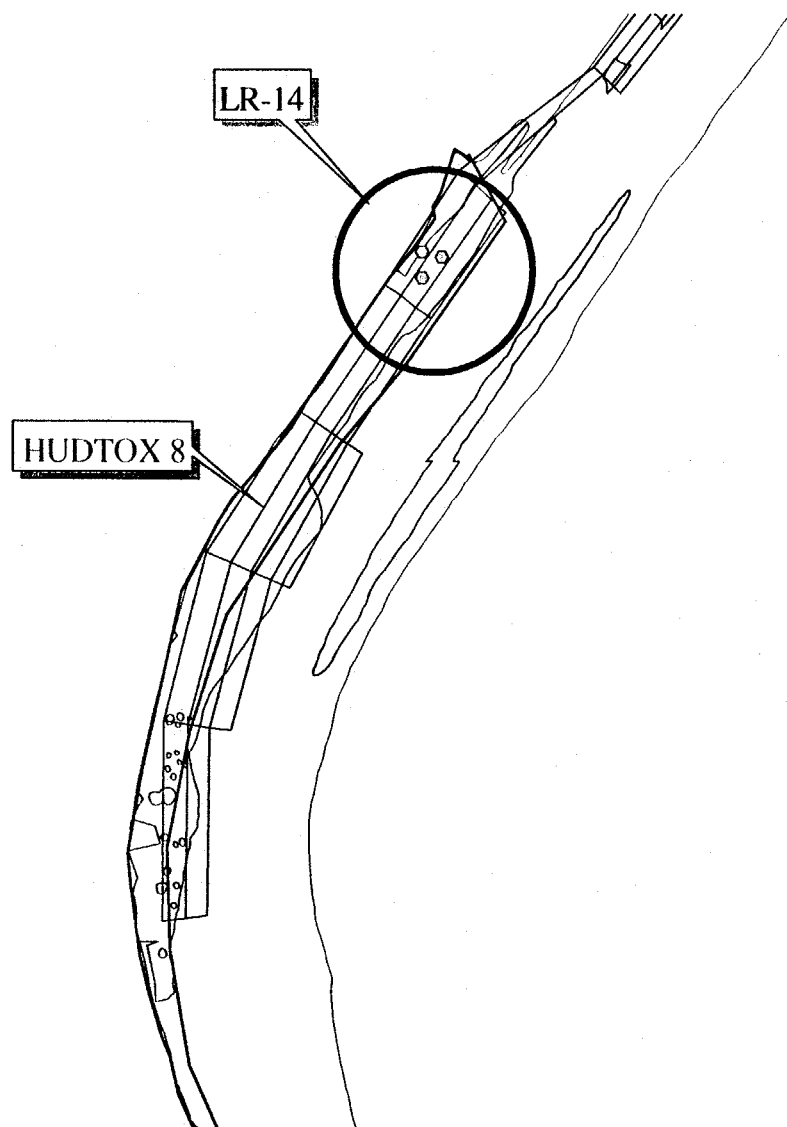


Figure 2. PCB mass balance in Thompson Island Pool 1984-1994 (numbers indicate kg of PCBs)



Note: n indicates number of GE model grid elements

- EPA Low Resolution Core Clusters
- EPA HUDTOX Segments
- 1994 Low Resolutions Cores
- GE Model Cohesive Grid Elements
- Shoreline
- Cohesive Sediments

Figure 3. Comparison of GE model computed cohesive sediment burial rates in Low Resolution Coring Analysis Cluster Area 14 and in the larger area represented by Segment 8 of the EPA Hudtox Model

0.1 0 0.1 0.2 Miles



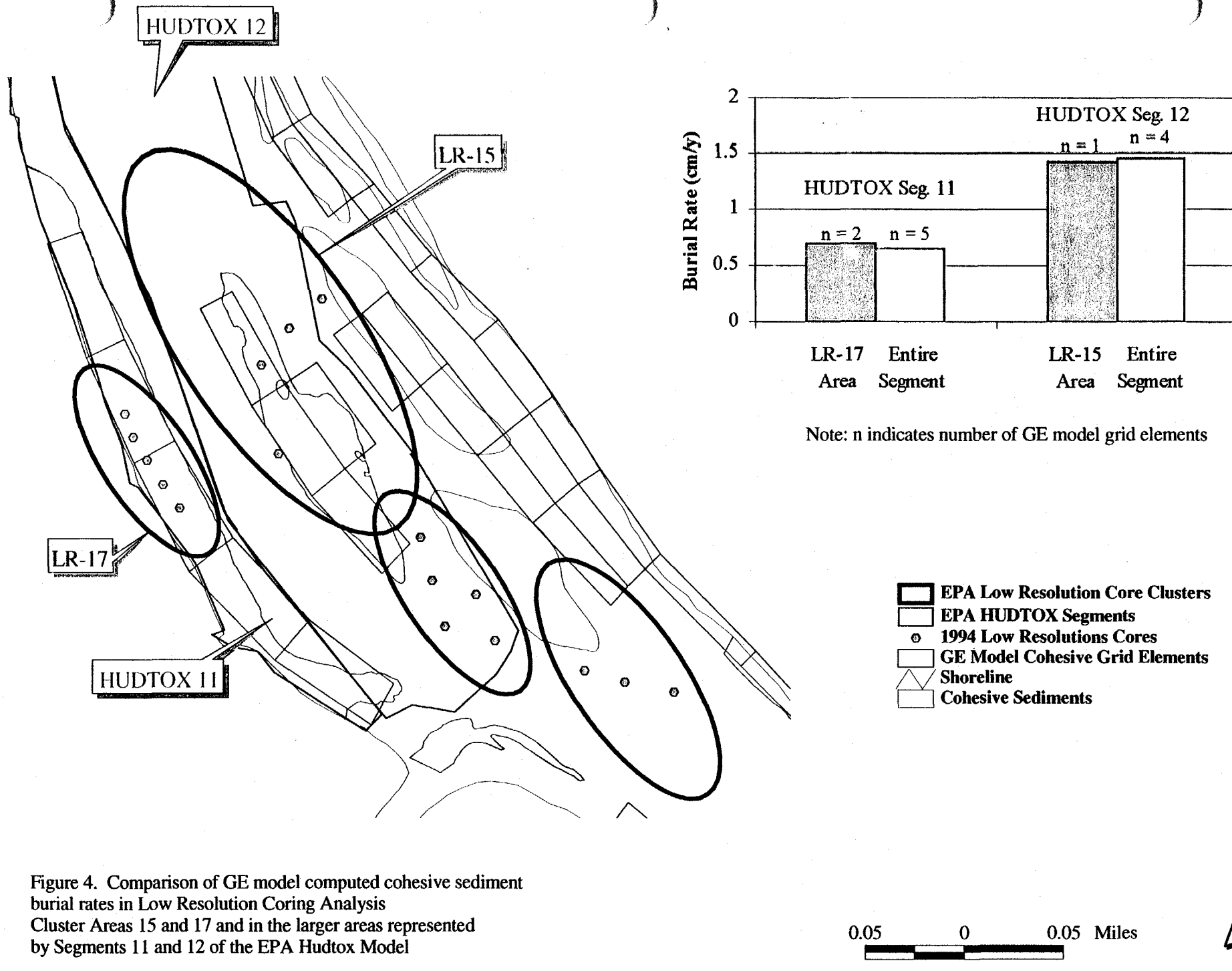
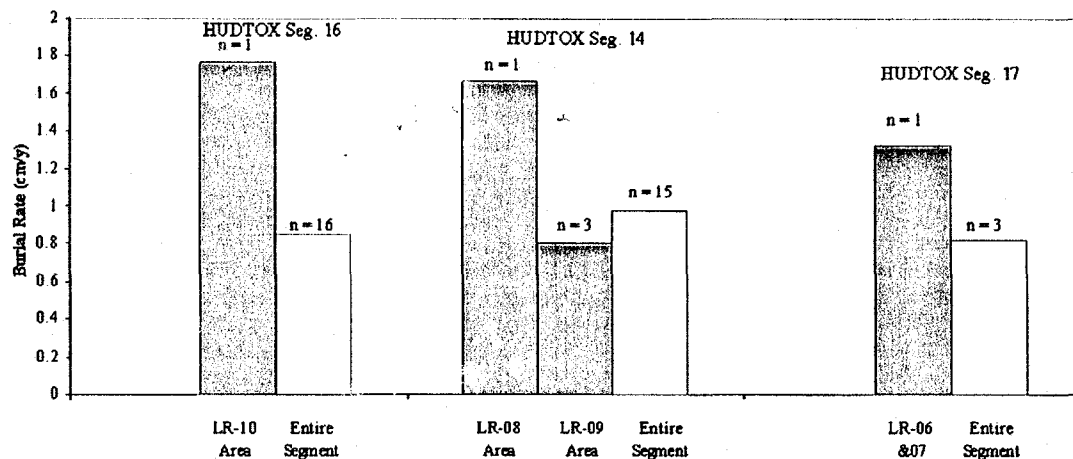
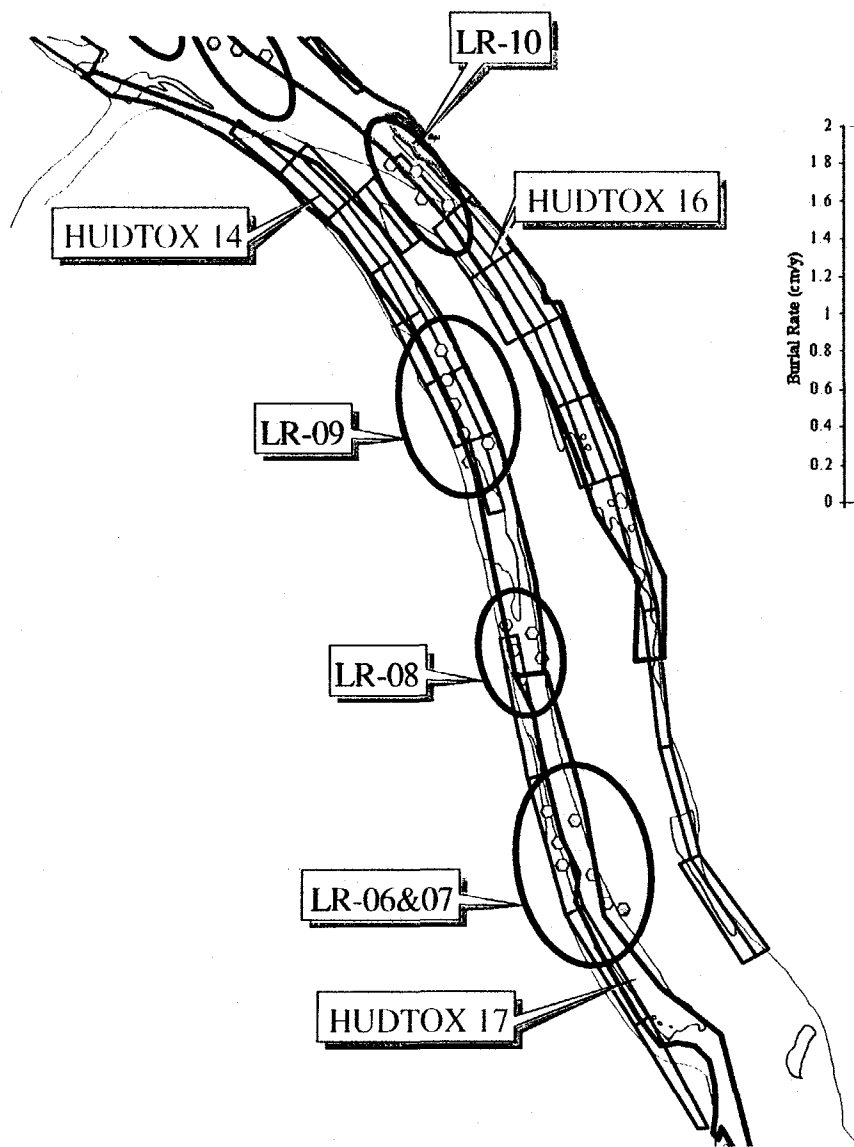


Figure 4. Comparison of GE model computed cohesive sediment burial rates in Low Resolution Coring Analysis Cluster Areas 15 and 17 and in the larger areas represented by Segments 11 and 12 of the EPA Hudtox Model



Note: n indicates number of GE model grid elements

- EPA Low Resolution Core Clusters
- EPA HUDTOX Segments
- 1994 Low Resolutions Cores
- GE Model Cohesive Grid Elements
- Shoreline
- Cohesive Sediments

Figure 5. Comparison of GE model computed cohesive sediment burial rates in Low Resolution Coring Analysis Cluster Areas 06&07, 08, 09, and 10 and in the larger cohesive sediment areas represented by Segments 14, 16, and 17 of the EPA Hudtox Model

0.1 0 0.1 0.2 Miles



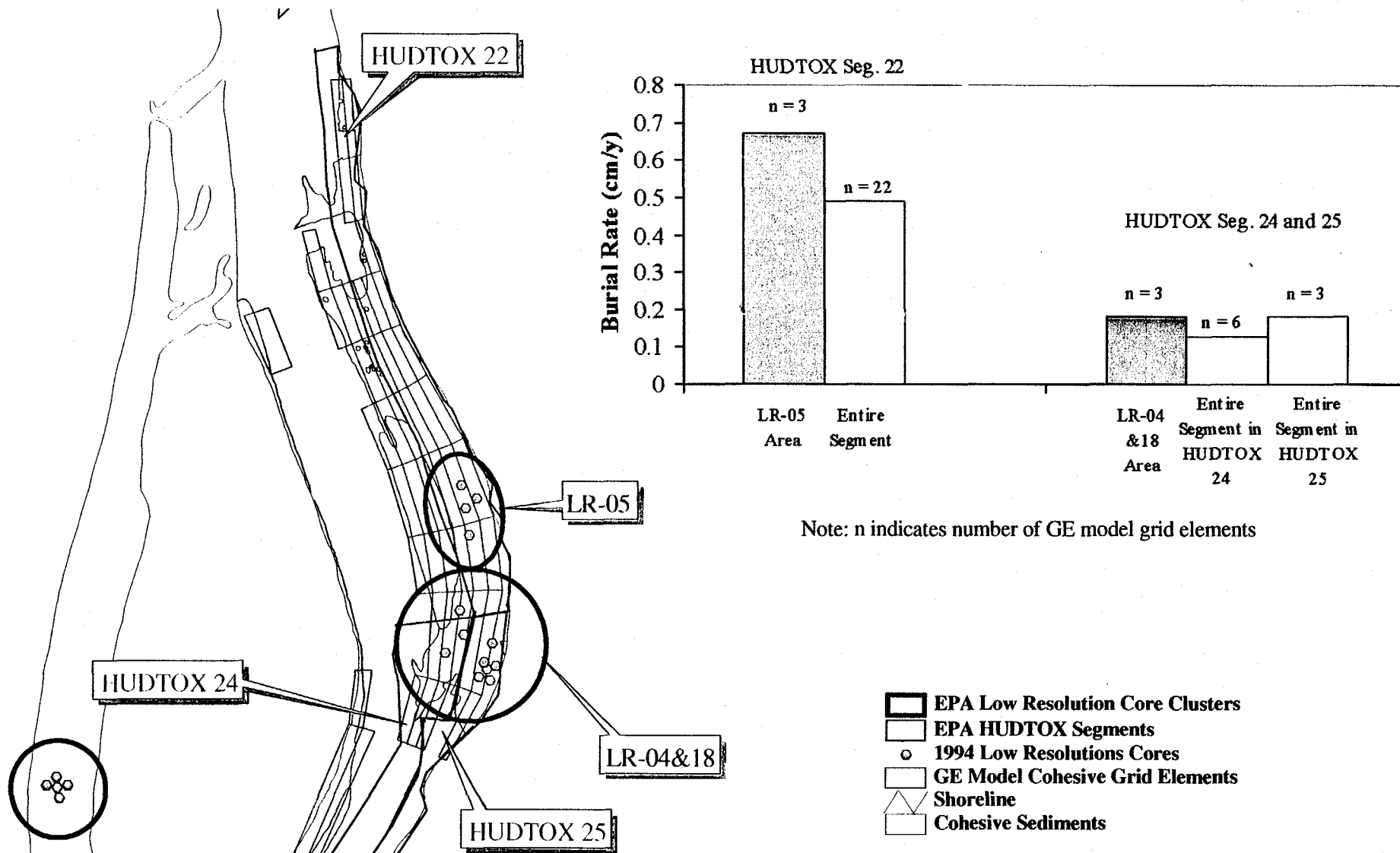
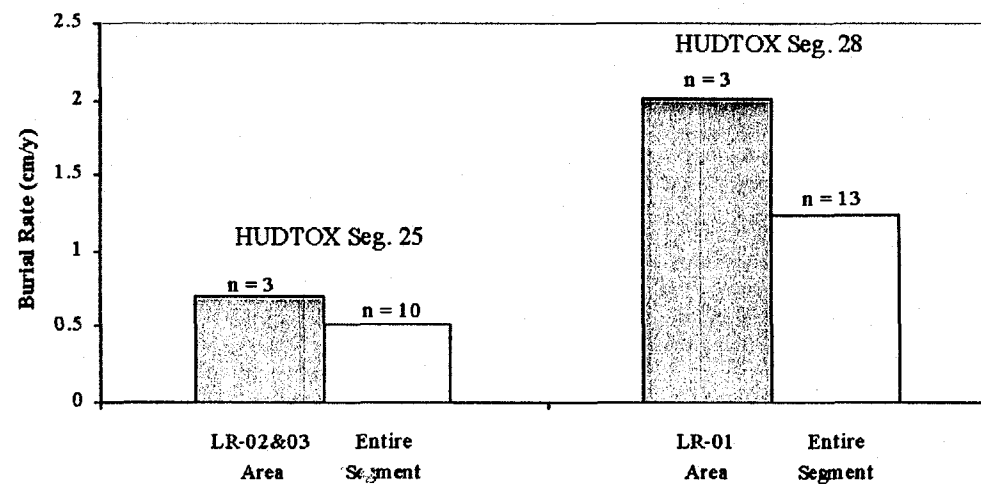
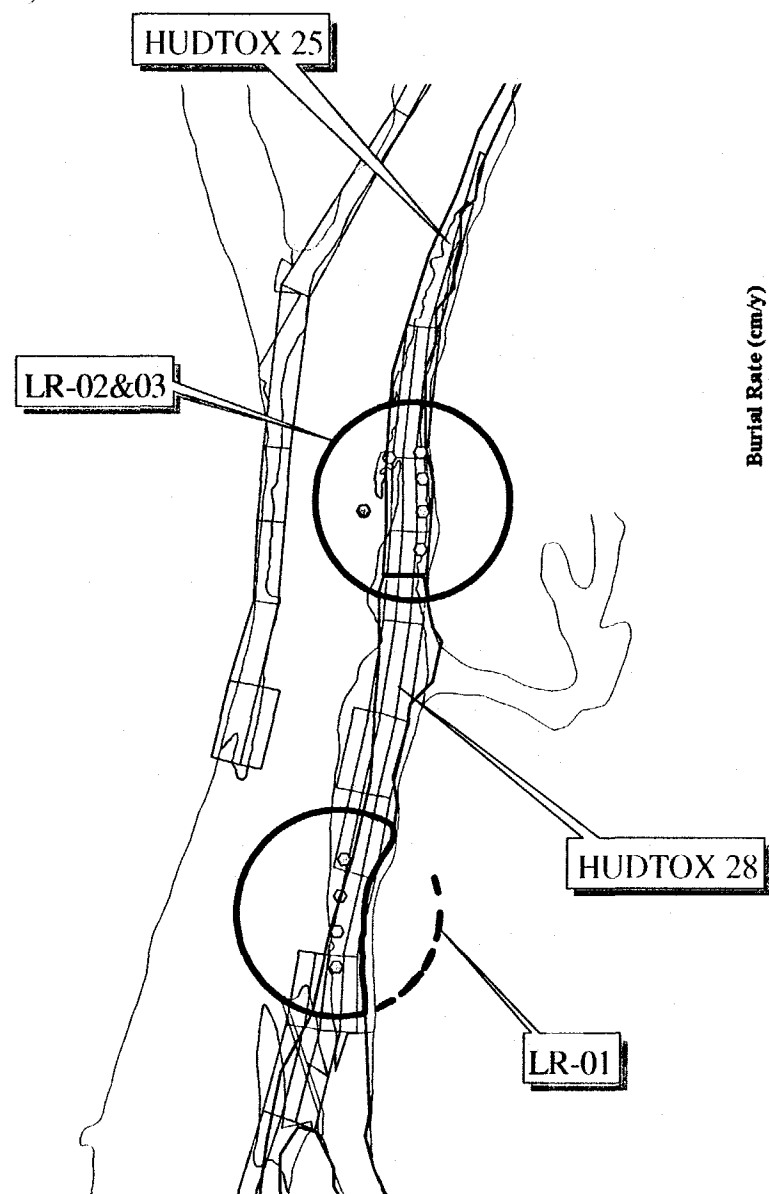


Figure 6. Comparison of GE model computed cohesive sediment burial rates in Low Resolution Coring Analysis Cluster Areas 04&18 and 05 and in the larger areas represented by Segments 22, 24, and 25 of the EPA Hudtox Model

0.07 0 0.07 0.14 0.21 Miles





Note: n indicates number of GE model grid elements

- EPA Low Resolution Core Clusters
- EPA HUDTOX Segments
- 1994 Low Resolution Cores
- GE Model Cohesive Grid Elements
- Shoreline
- Cohesive Sediments

Figure 7. Comparison of GE model computed cohesive sediment burial rates in Low Resolution Coring Analysis Cluster Areas 01 and 02&03 and in the larger areas represented by Segments 25 and 28 of the EPA Hudtox Model

0.05 0 0.05 0.1 0.15 Miles



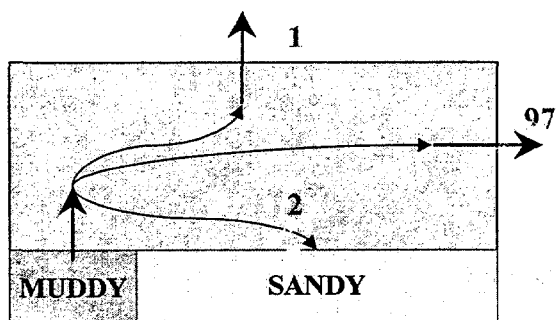


Figure 8. USEPA model predicted fate of PCBs leaving TIP fine sediments between 1984 and 1994 (numbers indicate percentage distribution)

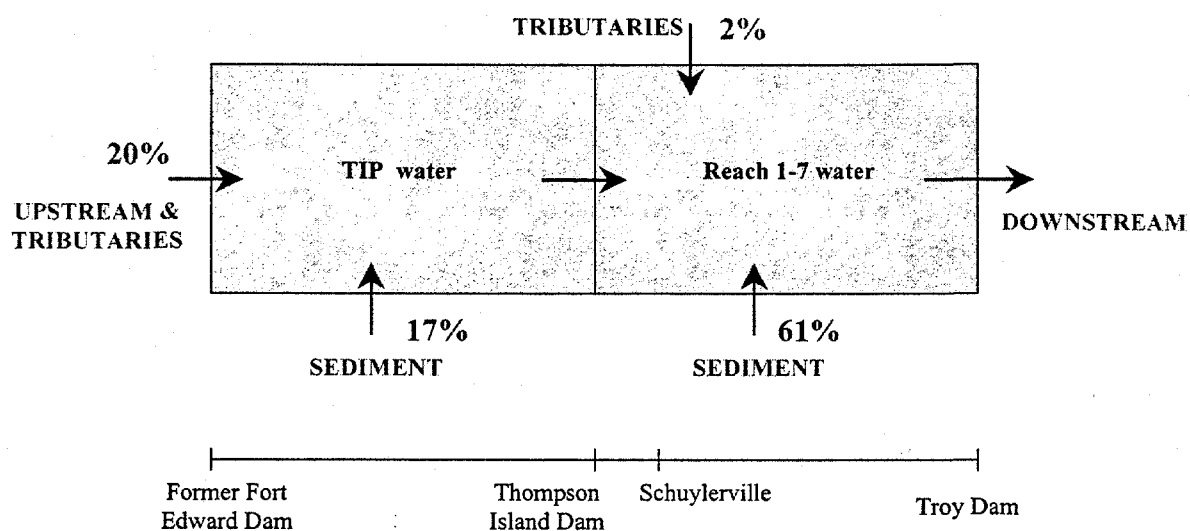


Figure 9. USEPA model estimate of the contribution of sources of PCB flux at Troy Dam in 1994.

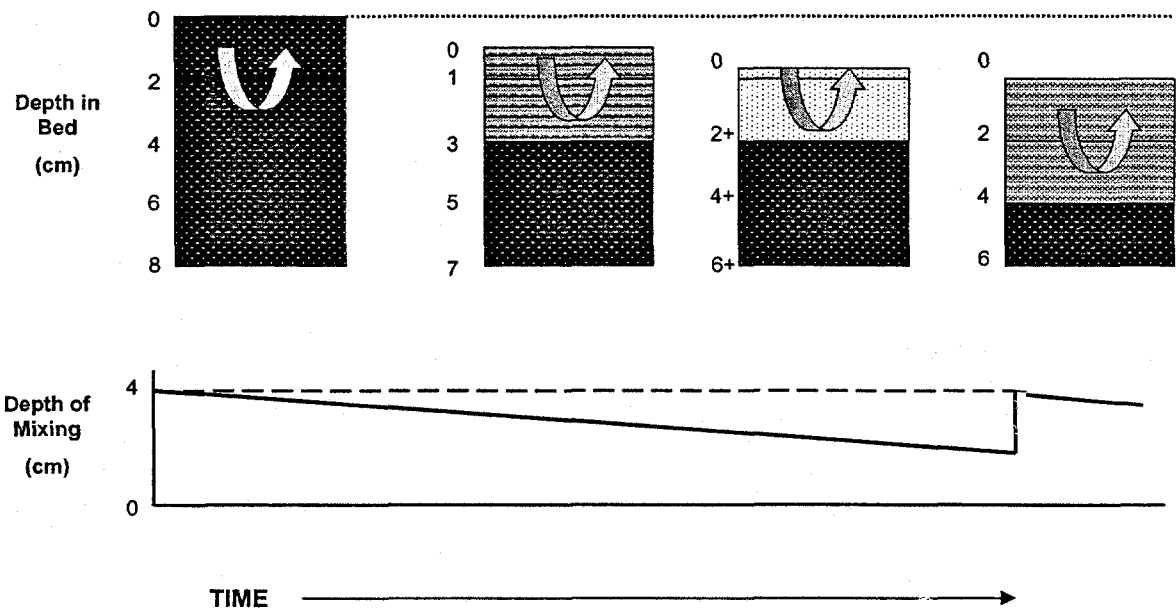


Figure 10. Illustration of the numerical simulation of erosion in HUDTOX.

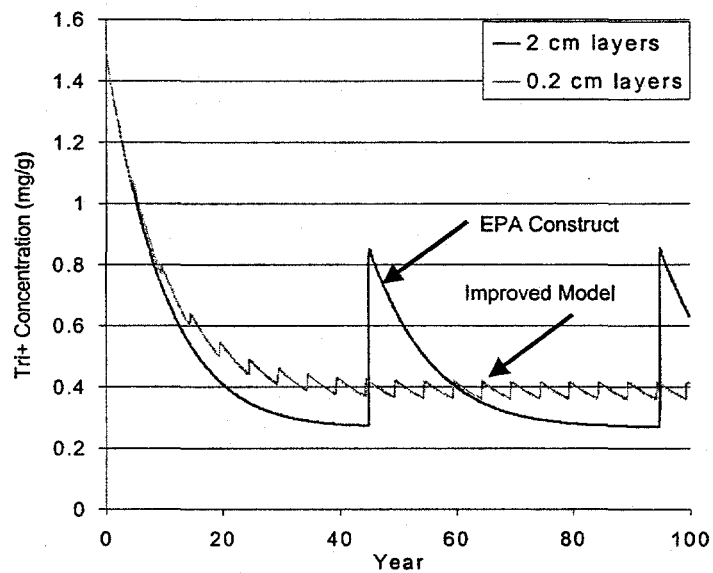


Figure 11. Illustration of the dependency of HUDTOX sediment PCB calculations in areas of net erosion on the choice of sediment layer thickness.

**USGS METHOD
("FISH" SAMPLER)**

**COMPOSITE SAMPLE COLLECTED
THROUGHOUT WATER COLUMN,
SURFACE TO RIVER BED**

**GE METHOD
(KEMMERER BOTTLE)**

**COMPOSITE SAMPLE MADE
UP FROM ALIQUOTS
COLLECTED AT 3 DEPTHS**

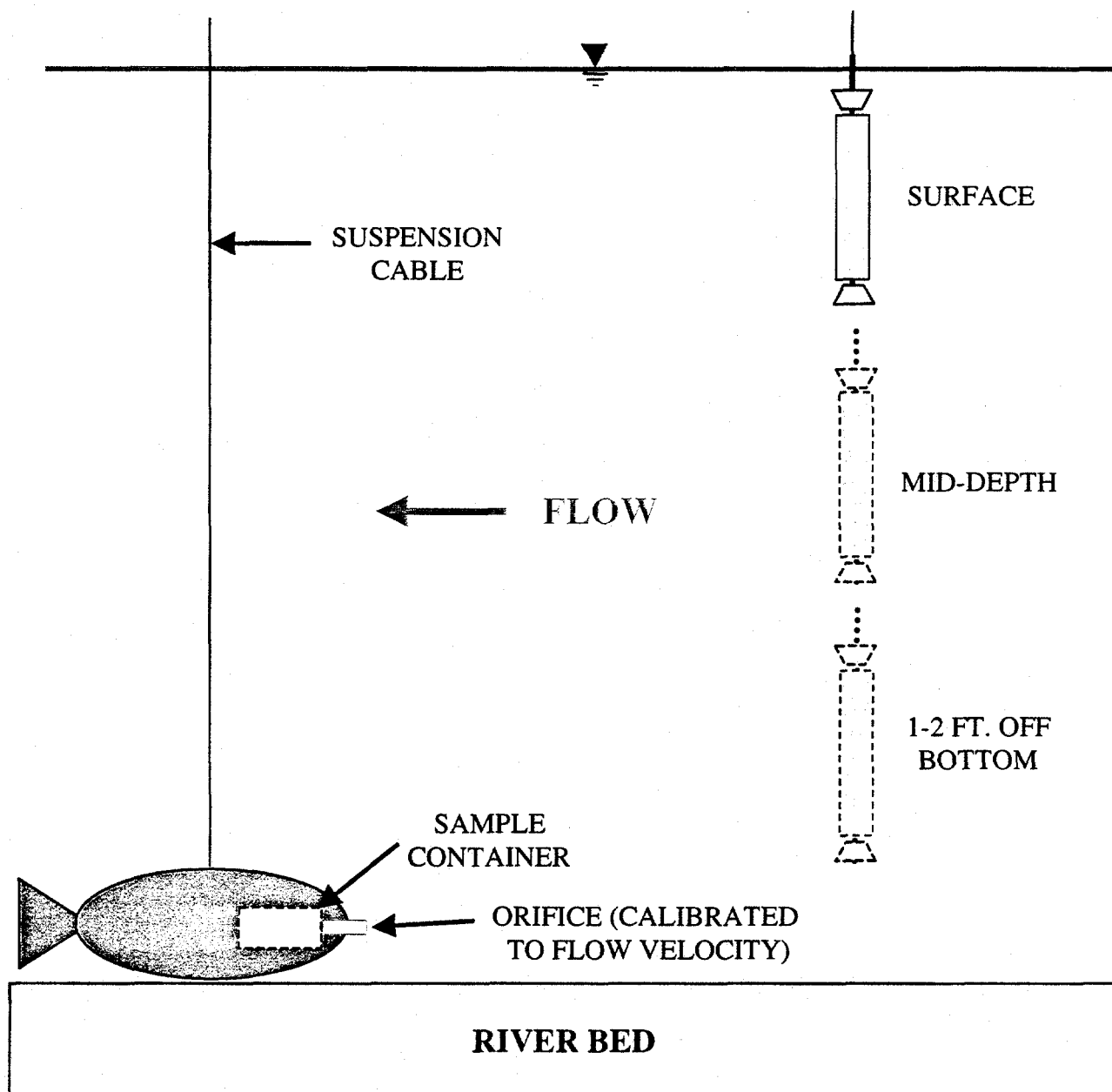


Figure 12. Comparison of USGS and GE solids load sampling methods.

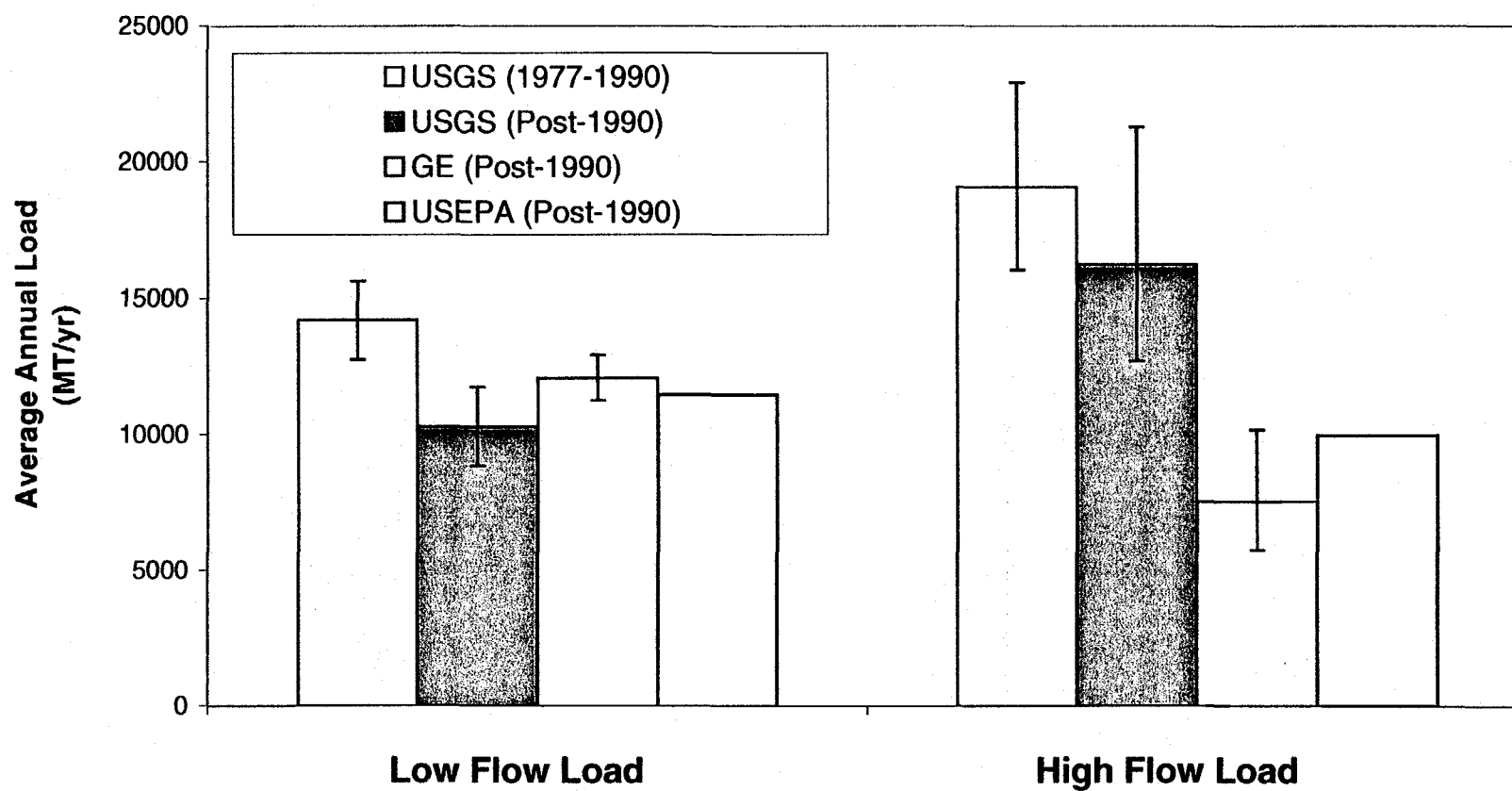


Figure 13. Estimated solids loading at Ft . Edward for post-1990 (1991-1998) period using various rating curves. Error bars represent the 95 % confidence interval.

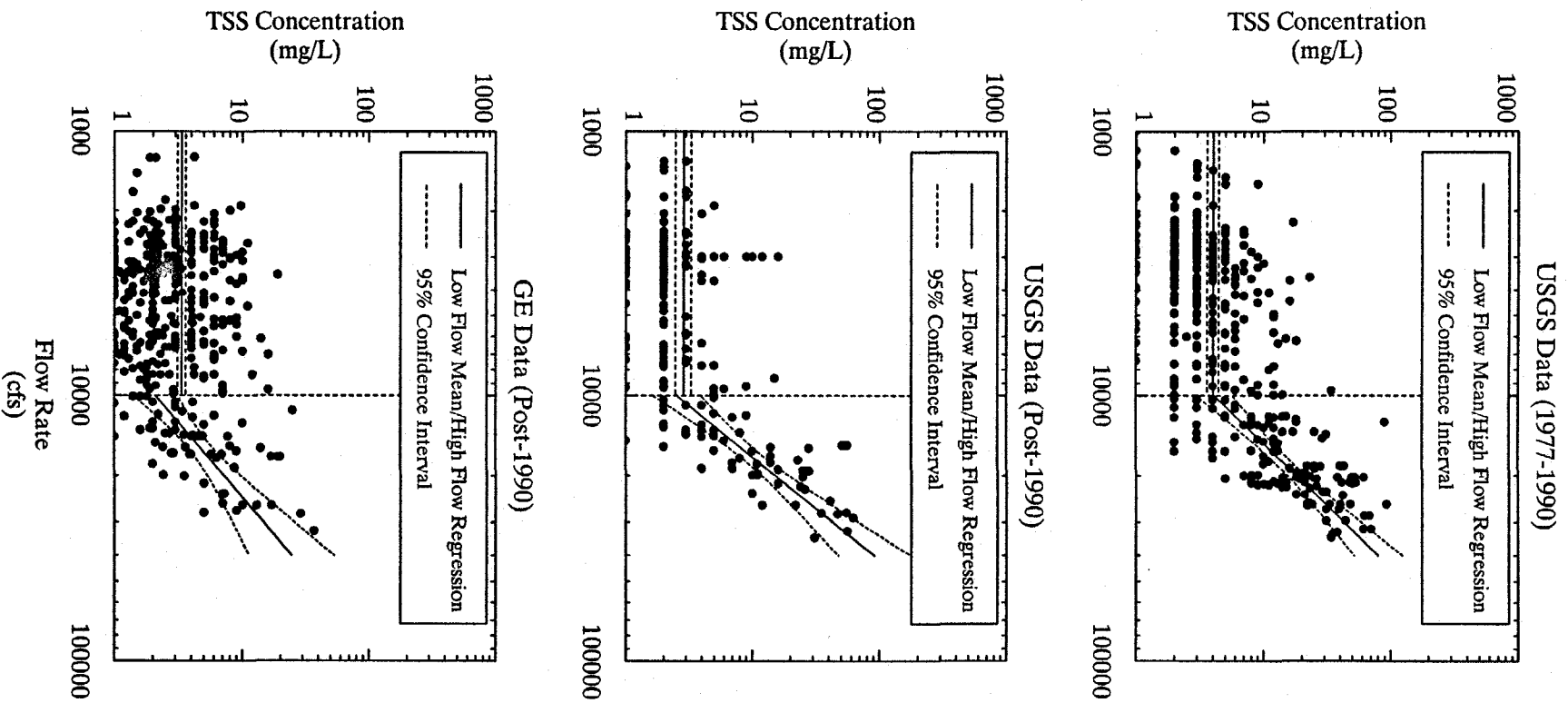


Figure 14. Fort Edward solids rating curves using three different data sets.

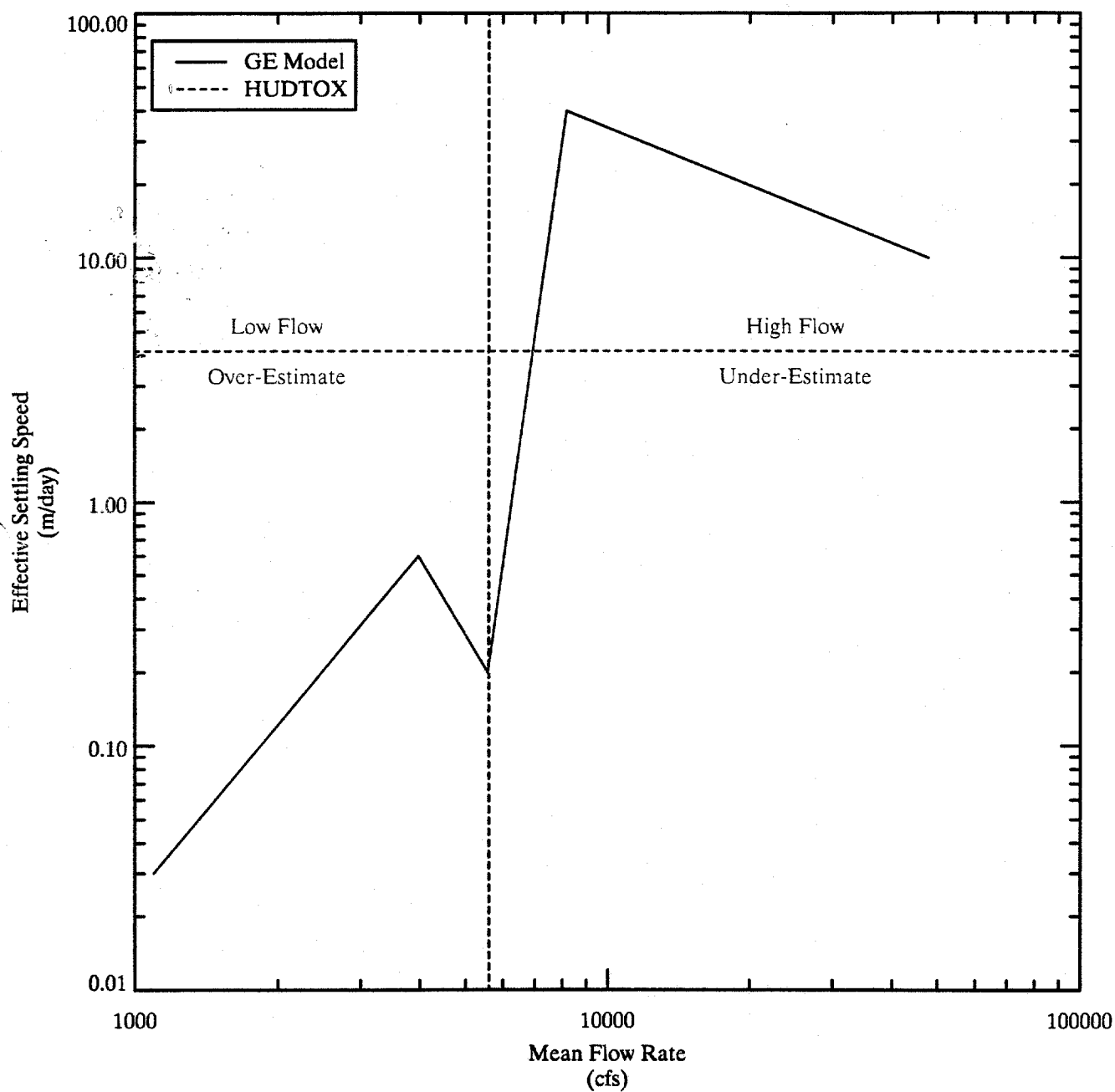


Figure 15. USEPA (specified) and GE (calculated) relationships between effective settling speed and flow rate for the cohesive bed in the TIP.

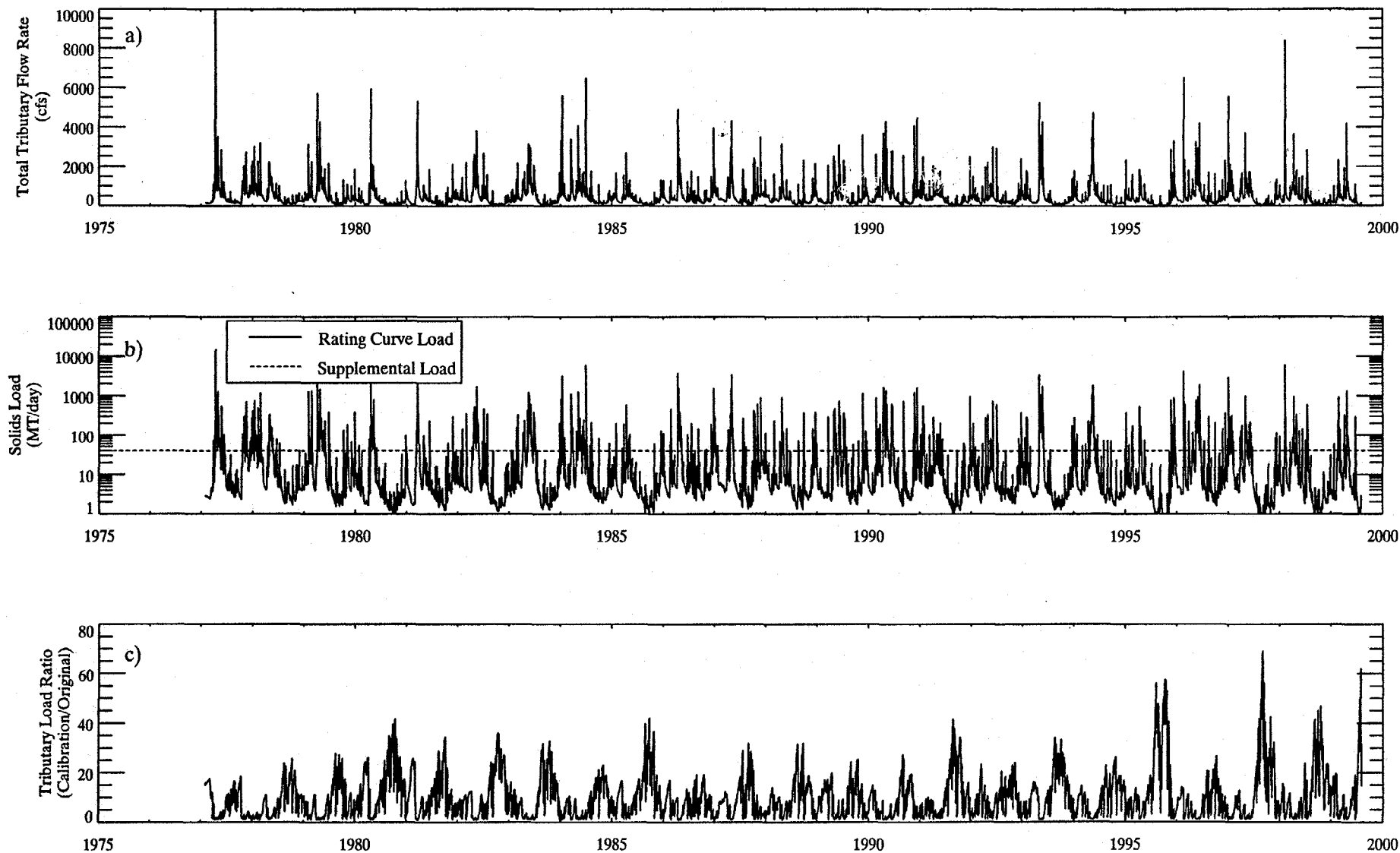


Figure 16. Total discharge and sediment loads input to tributaries in Schuylerville - Stillwater reach.

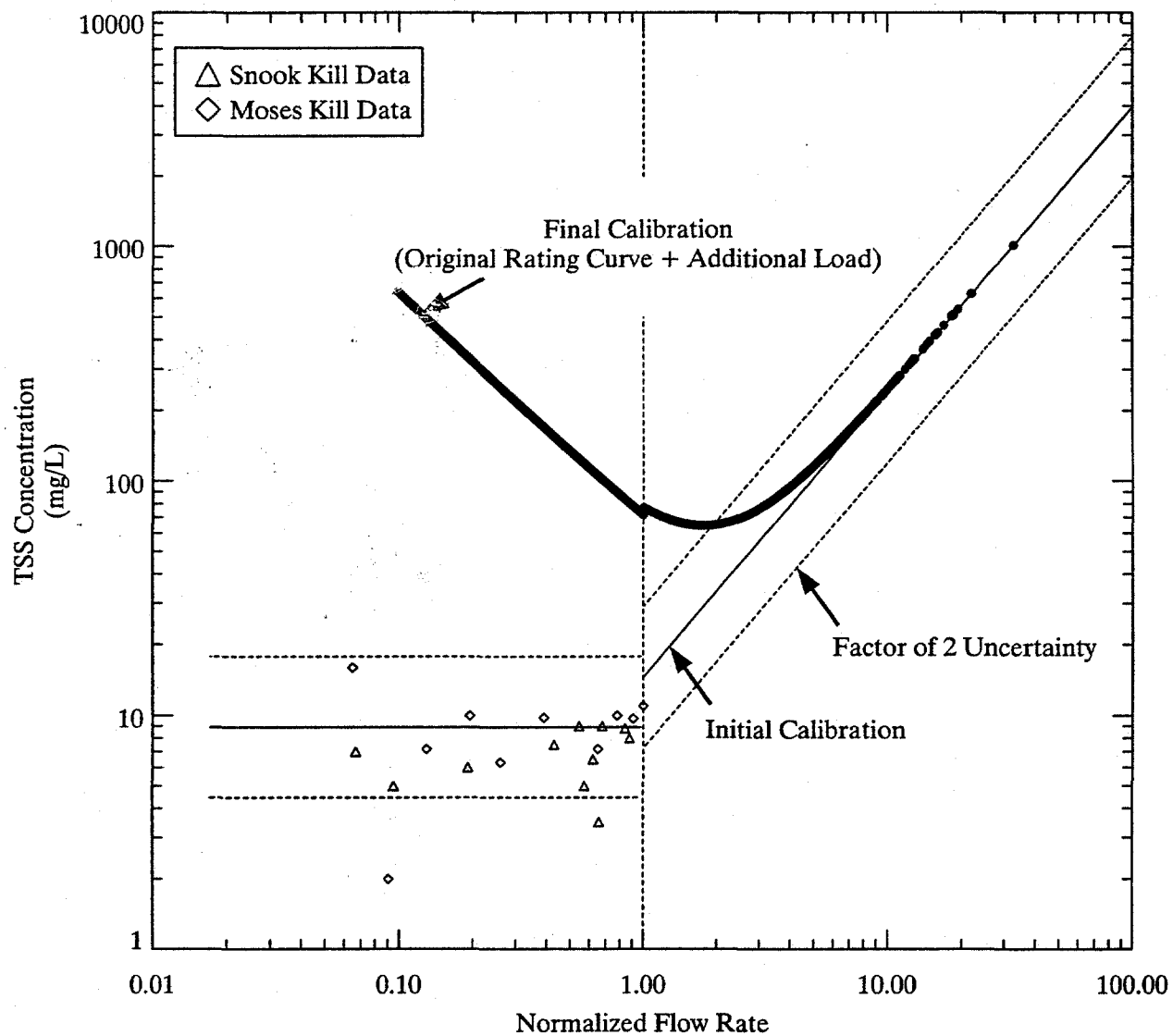
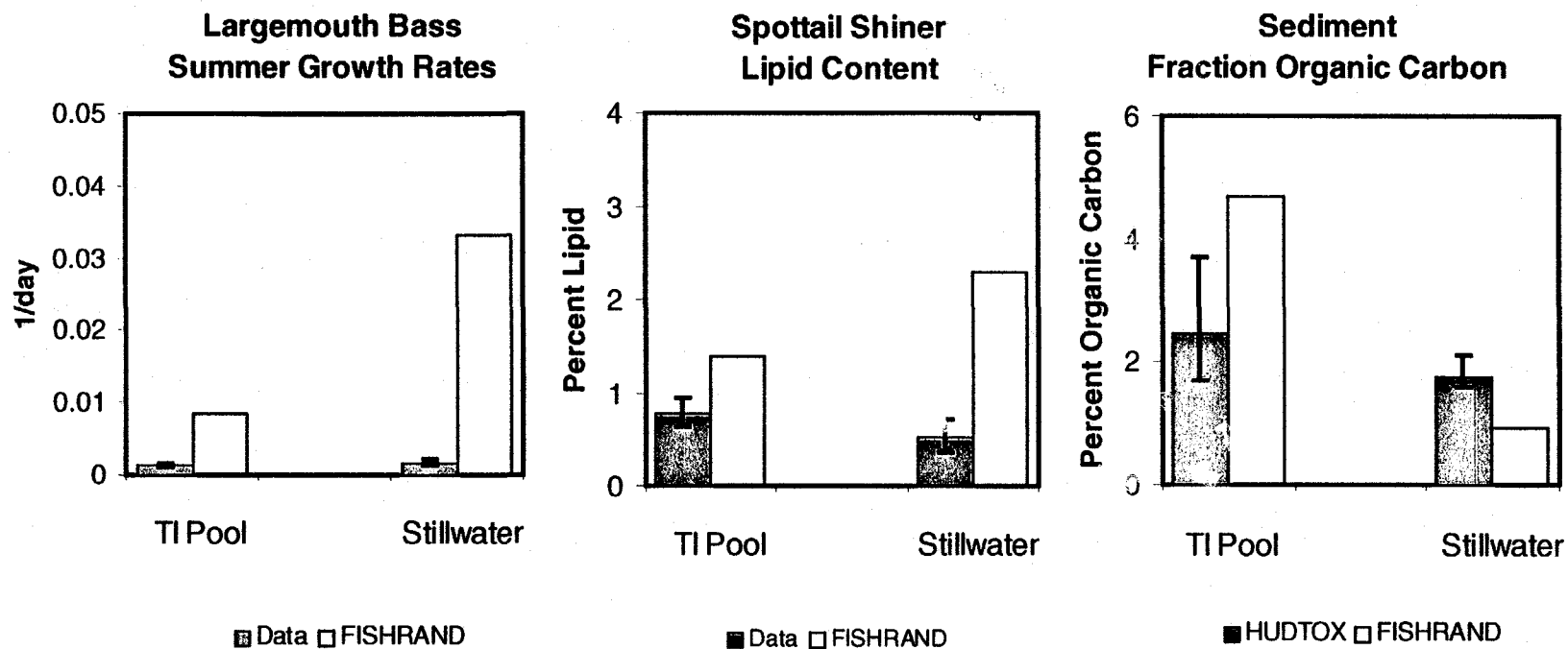
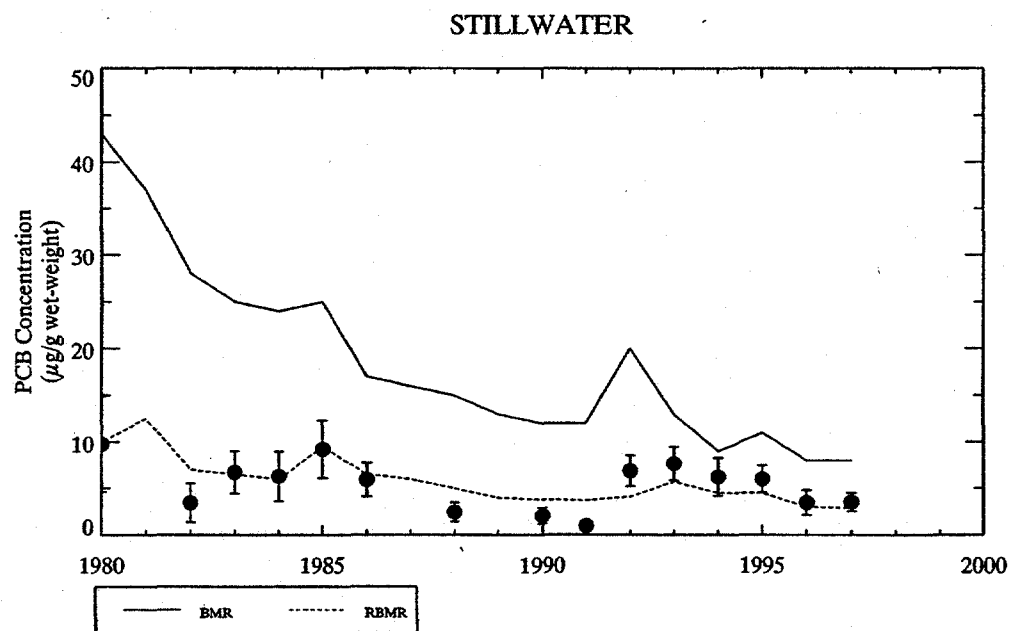
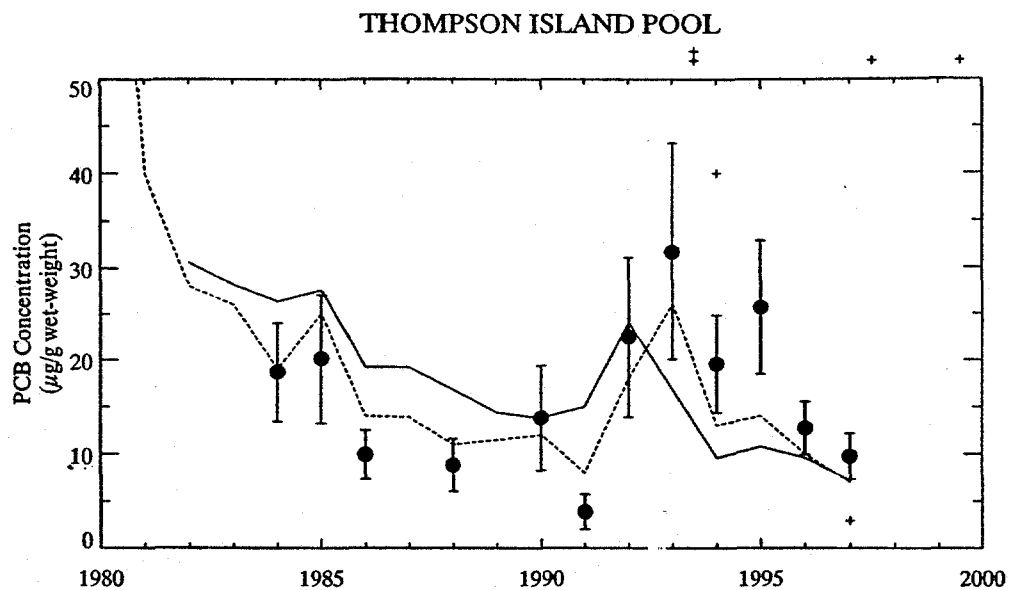


Figure 17. Comparison of supplemental load effects to original rating curve and TIP tributary data for direct drainage area in Schuylerville - Stillwater reach. Flow rates are normalized with respect to mean flow in tributary.



Data: mean +/- 2 standard errors
HUDTOX: average and range of segment-specific values, based on 1991 data

Figure 18. Comparison of fish growth rates, fish lipid content and sediment organic carbon contents used in FISHRAND with measured values.



DATA SOURCES: NYSDEC (circles); GE (diamonds)
 Data are arithmetic means $\pm$ 2 standard errors
 Crosses indicate values excluded from annual averages

Figure 19. Comparison of FISHRAND calibration results for largemouth bass presented in the Original and Revised Baseline Modeling Reports.