Appendix J

Connecticut 1-D Analysis

APPENDIX J

CT 1-D Analysis

The polychlorinated biphenyl (PCB) fate, transport, and bioaccumulation model developed by the U.S. Environmental Protection Agency (EPA) does not extend below Rising Pond Dam, and therefore, cannot be used to predict the response of the River to various potential remedial scenarios below that impoundment. For this reason, GE developed a semi-quantitative one-dimensional (1-D) framework (hereafter referred to as the Connecticut [CT] 1-D Analysis) that incorporates the available data from the CT section of the River, as well as predictions from the EPA Downstream Model (i.e., the model developed by EPA for the portion of the river between Woods Pond Dam and Rising Pond Dam), to provide estimates of future changes in PCB concentrations in the water column, surface sediment, and fish in the four major impoundments in the CT portion of the River (i.e., Bulls Bridge Dam impoundment, Lake Lillinonah, Lake Zoar, and Lake Housatonic).

J.1. Overview of Approach

As described in the Corrective Measures Study (CMS) Proposal (ARCADIS BBL and Quantitative Environmental Analysis, LLC [QEA], 2007), the CT 1-D Analysis focused on the Bulls Bridge Dam impoundment, since this location contains high-resolution (i.e., finely-segmented) sediment cores with radionuclide dating, and is one of the routine fish sampling sites used in GE's biennial fish sampling in the CT portion of the River (Blasland, Bouck & Lee, Inc. [BBL] and QEA, 2003). The CT 1-D Analysis described in this Appendix simulates the response of water column, surface sediment, and fish PCB concentrations in the Bulls Bridge Dam impoundment to changes in PCB loads passing over Rising Pond Dam based on the following approach:

- Water column PCB concentrations passing over Rising Pond Dam, as predicted by the EPA model, were used in conjunction with an "attenuation factor" to estimate the particulate-phase PCB concentrations of sediments depositing in the Bulls Bridge Dam impoundment in the future. In this analysis, the term "attenuation factor" refers to an empirical multiplier that accounts for decreases in PCB concentrations from upstream to downstream in the River that result from dilution (due to inputs of flow and sediment from the watershed) as well as other loss mechanisms such as deposition and volatilization (details are described in Section 2.2.3 below).

- These estimated particulate-phase PCB concentrations were then used in conjunction with a sediment deposition rate for the Bulls Bridge Dam impoundment (as determined from a high-resolution sediment core) as input to a 1-D model of the sediment column that calculates surficial sediment PCB concentrations in that impoundment. This model is similar in structure to the bed component of the Environmental Fluid Dynamics Code

(EFDC) model developed by EPA for the River between the Confluence and Rising Pond Dam (see Section 2 below for a description of the setup and calibration of the 1-D bed model) and uses the principle of mass balance to simulate the fate and transport of PCBs in the system.

- The 1-D bed model performs a time-variable mass balance calculation to predict future changes in surface sediment PCB concentrations based on future changes in PCB deposition (i.e., reductions in the PCB load passing Rising Pond Dam that result from the implementation of remediation in Reaches 5 through 8 for the various sediment alternatives).

- The water column and sediment PCB concentrations computed for the Bulls Bridge Dam impoundment in this analysis were then multiplied by an impoundment specific attenuation factor (as described in Section 3 below) to provide estimates of PCB concentrations in the three impoundments downstream of Bulls Bridge Dam: Lake Lillinonah, Lake Zoar, and Lake Housatonic.

For fish, the EPA food chain model (FCM) developed for Reach 8 was then used to simulate the bioaccumulation of contaminants by fish in the CT impoundments based on the computed water column and sediment concentrations (as directed by EPA in its conditional approval of the CMS Proposal). PCB concentrations in smallmouth bass (i.e., the species for which the most robust temporal and spatial data coverage exist in CT) were extrapolated from the existing FCM predator model. Development and calibration of the CT FCM is described in Section 4 below.

J.2. Bulls Bridge Sediments

J.2.1 Model Description

As described above, a 1-D sediment bed model (similar in structure to the bed component of the EFDC model developed by EPA for Reaches 5 through 8) was developed to simulate changes in surficial sediment PCB concentrations in the Bulls Bridge Dam impoundment over time. This model represents a single column of sediment, for which solids fluxes and water column PCB concentration time-series are specified as boundary conditions, and uses a mass balance to calculate sediment PCB concentrations and fluxes over time. This model was developed by QEA, and has been used previously at other sites to evaluate sediment mixing depths and diffusive transport rates of contaminants through sediment and sediment capping materials (e.g., Alcoa 2003).

The 1-D bed model developed in this application simulates sediment PCB concentrations over a total depth of 150 cm. The bed was segmented into 150 1-cm layers at the beginning of the simulation. The thickness of the top-most and bottom-most layers in the model vary over time based on the magnitude of sediment deposition. As additional sediments are deposited, the thickness of the top layer increases until reaching a critical value (i.e., 1.1 cm), at which point this surface layer is split into two; at the same time, the bottom two layers are combined into a "deep reservoir."

Fate processes simulated by the 1-D bed model include sediment mixing (due to biological activity), diffusion of dissolved-phase PCBs within the pore water and to the water column, and three-phase equilibrium partitioning among dissolved-phase, dissolved organic carbon (DOC)-bound, and particulate-phase PCBs. In this model, the water column compartment is not simulated (water column concentrations are provided as inputs); therefore short-term sediment erosion and deposition processes are not calculated, but rather are accounted for as a net solids flux (i.e., the combined effect of erosion and deposition) to the bed over time.

The sediment bed model calibration spanned the 42-year period between 1963 and 2004. The 1963 date represents the assumed date of peak Cesium-137 observed in a finely-segmented sediment core collected from the Bulls Bridge Dam impoundment; only one finely-segmented sediment core has been collected from this impoundment that has a Cesium-137 depth profile sufficient for dating of the deposited sediments (core BBD-CS-02 collected in 1998; BBL and QEA, 2003). The 2004 date represents the end of the EPA model validation period.

As described above, this model requires solids fluxes and water column PCB concentration time-series as inputs. These inputs were derived over the 42-year model calibration period as follows:

1963 – 1980: Due to a lack of data over this time period, water column particulate-phase PCB concentrations were assumed to remain constant, and were estimated based on the average sediment concentration from core sections corresponding to this time period in the dated high resolution sediment core collected from this impoundment (i.e., core BBD-CS-02).

1980 – 1990: Due to a lack of data over this time period, water column particulate-phase PCB concentrations were again considered to be constant, and were based on the average sediment concentration from core sections corresponding to this time period in the same dated high resolution core collected from the Bulls Bridge Dam impoundment, as discussed further below.

1990 – 2004: This time period corresponds to the calibration period used in the EPA Downstream Model; therefore, water column PCB concentrations in the Bulls Bridge Dam impoundment were estimated based on the water column PCB concentration passing Rising Pond Dam (predicted by the EPA model), modified by an attenuation factor that accounts for reductions in PCB concentration between Rising Pond and Bulls Bridge. The development of this attenuation factor (which was refined during calibration of the 1-D model) is described below.

J.2.2 Inputs

A summary of the non-time-variable inputs/coefficients used in the 1-D bed model is provided in Table J-1. When available, site-specific data from the Bulls Bridge Dam impoundment were used to develop the necessary inputs;[1] Figure J-1 shows the sediment sampling locations within this impoundment. However, there were several inputs for which no impoundment-specific data existed. In these cases, inputs from the calibrated and validated EPA model of Rising Pond were used (as noted in Table J-1).

[1] Since the extent of this impoundment is not well defined, aerial photography was used to identify the likely depositional region upstream of Bulls Bridge Dam. The extent of this area is shown in Figure J-1 and defines the Bulls Bridge Dam impoundment for this analysis.

Table J-1. Non-Time-Variable Inputs/Coefficients Used in the 1-D Bed Model

Model Input	Parameter	Value	Units	Data Source
Sediment	Bulk Density	0.99	g/cm^3	Site-specific data
	Porosity	0.61	---	Site-specific data
	Organic carbon fraction (f_{oc})	0.99	%	Site-specific data
	Dissolved Organic Carbon	16.5	mg/L	Same as Primary Study Area (PSA) and Downstream Models
	Sediment A_{doc} (DOC-binding effectiveness coefficient)	0.10	---	Same as PSA and Downstream Models
	Sediment-water mass transfer coefficient (K_f)	1.52	cm/d	Same as PSA and Downstream Models
	Diffusion coefficient in porewater	0.86	cm^2/d	Same as PSA and Downstream Models
	Sediment mixing rate (top 7 cm)	1.4E-09	m/s	Same as Downstream Model
	Sediment mixing rate (7 to 14 cm)	1.4E-10	m/s	Same as Downstream Model
	Sediment mixing rate (below 14 cm)	0	m/s	Same as Downstream Model
	Net settling rate	1.3	cm/yr	Site-specific data
Water Column	log K_{oc}	6.5	L/kg	Same as PSA and Downstream Models
	Water column A_{doc}	0.01	---	Same as PSA and Downstream Models
	Dissolved Organic Carbon (DOC)	6.5	mg/L	Same as PSA and Downstream Models
	Organic carbon fraction (f_{oc})	8.2	%	Site-specific data

Notes:
g/cm^3 = gram(s) per cubic centimeter
--- = not applicable
% = percent
mg/L = milligram(s) per liter
cm/d = centimeter(s) per day
cm^2/d = squared centimeter(s) per day
m/s = meter(s) per second
cm/yr = centimeter(s) per year
L/kg = liter(s) per kilogram

J.2.2.1 Sediment Bed Inputs

Sediment bed parameters that were derived from site-specific data collected within the Bulls Bridge Dam impoundment include bulk density, porosity, and sediment total organic carbon (TOC). These values were assumed to be constant with depth, and were assumed to remain constant over the duration of the model simulation. Bulk density and porosity were estimated from historical sediment data collected from the surficial 6 inches of sediment in the Bulls Bridge Dam impoundment by first calculating a length-weighted average for each individual core, and then averaging over the impoundment. This resulted in an average bulk density equal to 0.99 g/cm^3. Similarly, the average sediment organic carbon fraction (f_{oc}) was calculated using the same method, resulting in an average f_{oc} used in the model of approximately 1%. Average bed porosity (0.61) was calculated based on the average dry bulk density and an assumed solids specific density of 2.65 g/cm^3.

As discussed in the model description, PCB data from the GE high resolution core BBD-CS-02 were used to estimate the average sediment PCB concentrations in sediments deposited between 1963 and 1980. The average concentration from the dated core sections corresponding to this period (i.e., 1.77 milligrams/kilogram [mg/kg] from the 32-45 cm depth interval; see Figure J-2) was used as the sediment PCB initial condition for all layers in the model. This value also was used for the water column particulate-phase PCB inputs over this time period, as described below.

In addition to the bed parameters described above, the 1-D model requires the specification of a sedimentation rate to simulate sediment deposition in the model. The sedimentation rate calculated for high resolution core BBD-CS-02 (1.3 cm/yr, as described in the RCRA Facility Investigation Report [RFI Report; BBL and QEA, 2003]) was used in the 1-D bed model.

J.2.2.2 Water Column Inputs

The 1-D bed model requires specification of a time series of total suspended solids (TSS) and water column PCB concentrations, which are used to calculate the PCB concentration of depositing sediments. Water column PCB and solids inputs were specified differently over the 42-year calibration period for each of the three time periods described above (i.e., 1963-1980, 1980-1990, and 1990-2004). Figures J-3 and J-4 present the water column TSS and PCB boundary conditions for the 42-year calibration period, respectively. The TSS and PCB concentrations shown in these figures have been scaled by attenuation factors that account for changes in TSS and PCB concentrations between Rising Pond and Bulls Bridge Dam, as discussed below.

During the periods from 1963-1980 and 1980-1990, few water column PCB data were collected from the Bulls Bridge Dam impoundment (only four samples, all of which were non-detect at a detection limit of 22 nanograms per liter [ng/L]); further, only a limited amount of TSS and sediment PCB data exist from this time period. Consequently, water column particulate-phase PCB concentrations were derived from average sediment concentrations in core sections corresponding to each respective time period in the dated high resolution core described above (1998 GE core BBD-CS-02). This approach assumes that particulate-phase PCBs in the water column prior to 1990 were consistent with sediments deposited over the same period as determined by core dating. Three-phase partitioning was used to back-calculate average whole-water PCB concentrations using the particulate-phase concentrations for both periods. The average whole-water PCB concentrations calculated in this manner were 42 ng/L for the period from 1963-1980 and 8.3 ng/L for the period from 1980–1990 (Figure J-4).

In addition, only four samples collected during this (pre-1990) time period from Bulls Bridge were analyzed for TSS and water column particulate organic carbon (POC). Based on these data, an average value of 8.2% was specified for the water column organic carbon fraction (f_{oc}; equal to POC divided by TSS) during this time period. While these four samples were the only available information to estimate water column f_{oc}, it was judged that the use of these four samples was insufficient for estimating an average TSS concentration for this pre-1990 period. Therefore, TSS data collected by the U.S. Geological Survey (USGS) at Gaylordsville (located approximately 2.5 miles downstream of Bulls Bridge Dam) during 1979 were used to estimate an average TSS concentration of 20 mg/L, which was used in the model to represent pre-1990 conditions.[2] This assumes that TSS concentrations at Gaylordsville are representative of those observed at Bulls Bridge; this assumption was deemed sufficient for this analysis given the proximity of these two locations.

During the period from 1990-2004 (corresponding to the calibration period used in the EPA Downstream Model), water column PCB and TSS concentrations in the Bulls Bridge Dam impoundment were estimated based on the water column concentrations passing Rising Pond Dam as predicted by the EPA model, multiplied by an attenuation factor as described below.

J.2.2.3 Model Calibration Attenuation Factors

Attenuation factors were developed to account for gains/losses of TSS and PCBs between Rising Pond and the Bulls Bridge Dam impoundment to facilitate 1-D sediment model calibration. Two attenuation factors were needed:

- A TSS attenuation factor to reflect the observed increase in sediment yield (load per unit watershed area) between Rising Pond and Bulls Bridge Dam.

- A water column PCB attenuation factor to account for reductions in PCB concentration between Rising Pond and Bulls Bridge Dam (due to increased flows resulting in dilution, and loss of PCBs due to volatilization and sorption, and the subsequent settling of particulate-bound PCBs).

[2] The 1979 USGS study is the only comprehensive TSS study that has been conducted at the Gaylordsville gaging station. During this study, 218 TSS samples were collected, a majority of which were collected over a 6-month period (from April to September 1979).

Development of the TSS attenuation factor was achieved by comparing flows at these two locations (using the USGS flow records from Great Barrington [USGS Gage #01197500] and Gaylordsville [USGS Gage #01200500], which were assumed to be representative of flow conditions at Rising Pond Dam and Bulls Bridge Dam, respectively), in conjunction with a comparison of the available TSS data from just downstream of Bulls Bridge Dam (USGS TSS data collected in 1979 at Gaylordsville) with the EPA model-predicted TSS concentrations exiting Rising Pond. As described above, this method implicitly assumes that TSS concentrations at Gaylordsville are similar to those at Bulls Bridge Dam, which was deemed sufficient for this analysis given the proximity of these two locations. The method used to determine the TSS attenuation factor was as follows:

- USGS daily average flow data were used to compute average yearly flows at the two locations described above (Gaylordsville and Great Barrington; top panel of Figure J-5). The ratio of annual average flow at these two stations averaged over the period of 1979-2006 yielded a flow increase factor of 3.2 (bottom panel of Figure J-5).

- A separate comparison of daily average flow values from 1979 and other years between 1990 and 2004 (i.e., the EPA model calibration period) was conducted to find a year containing flows that were similar in magnitude to those observed in 1979. A comparison of the distribution of daily average flows in 1979 at Gaylordsville to those predicted by the EPA model in 2003 is shown in Figure J-6 (note that flows shown for 2003 represent model-predicted flows at Rising Pond Dam that have been scaled up based on the factor of 3.2 estimated from Figure J-5). This comparison was used to establish that flow conditions in 1979 and 2003 were generally similar (i.e., flow conditions during the 1979 TSS sampling were similar to those in 2003, indicating that any observed differences in solids between the USGS data collected in 1979 and the model-predicted TSS in 2003 are likely the result of an increased solids yield between Rising Pond and Gaylordsville, and not a difference in flow conditions).

- TSS at both locations (binned according to flow in 500 cubic feet per second [cfs] increments) are plotted versus flow in Figure J-7. The left panel shows that at a given flow rate, the TSS concentrations predicted by the EPA model at Rising Pond Dam are lower than those measured at Gaylordsville, especially for flows exceeding 5,000 cfs. This indicates that the solids yield from the watershed between Great Barrington and Gaylordsville must increase. This is consistent with the observations by the USGS in its 1994-1996 loading study (USGS 2000), which concluded that an approximately three-fold increase in solids yield occurred between Great Barrington (20.6 tons/yr/mi^2) and Ashley Falls (58.4 tons/yr/mi^2), a USGS gaging station near the Massachusetts (MA)/CT border. Application of a multiplication factor of four to the Rising Pond TSS values (to account for the increase solids yield) is needed to obtain agreement between the two TSS data sets, particularly at higher flows (Figure J-7, right panel). Given that

Bulls Bridge Dam is further downstream than Ashley Falls, this 4X increase is not inconsistent with the USGS study.

Based on this analysis, the TSS attenuation factor used to calibrate the Bulls Bridge Dam 1-D model was set to four – i.e., TSS concentrations in the Bulls Bridge Dam impoundment for years including and after 1990 were calculated by multiplying the model-predicted concentrations at Rising Pond Dam by a factor of four.

Similarly, water column PCBs exiting Rising Pond were multiplied by an attenuation factor to account for the reduction in PCB concentrations between Rising Pond and Bulls Bridge that result from the PCB loss mechanisms described above. While PCBs in the Bulls Bridge Dam impoundment were expected to be lower for these reasons, no data are available to estimate the PCB attenuation factor; therefore, this factor was used as the primary calibration parameter in the 1-D model.

J.2.3 Calibration

The results from the 1-D sediment model calibration are shown on Figure J-8, in which a time-series of surface sediment PCB concentrations in the Bulls Bridge Dam impoundment is shown. This figure demonstrates that there is a reasonably good agreement between the surface sediment PCB data in the Bulls Bridge Dam impoundment and the model output using a calibrated value of 0.1 for the PCB attenuation factor (described above).[3]

Accordingly, the 1-D model for the Bulls Bridge Dam impoundment based on this calibration was used to project future PCB concentrations in this location under the various sediment alternatives studied in the CMS – i.e., future PCB concentrations predicted by the EPA model at Rising Pond Dam were multiplied by 0.1 to estimate water column PCB concentrations in the Bulls Bridge Dam impoundment.

J.3. Development of Attenuation Factors for Downstream CT Impoundments

Surface sediment PCB concentrations in the impoundments downstream of Bulls Bridge Dam are relatively low and appear to be largely affected by dilution of PCBs that originate from upstream. Therefore, PCB concentrations in the three impoundments downstream of Bulls Bridge Dam (i.e., Lake Lillinonah, Lake Zoar, and Lake Housatonic; see Figure J-9) were estimated from PCB concentrations calculated at Bulls Bridge Dam (Section 2.2.3), reduced by impoundment-specific dilution factors that reflect the flow increase at each impoundment relative to the Bulls Bridge Dam impoundment. Subsequently, the resulting

[3] Note that the calibrated PCB attenuation factor (0.1) produces a greater reduction in surface sediment PCB concentrations than it would if only dilution due to increases in flow were considered (0.37). This difference likely results from a combination of increasing solids yield and PCB loss via deposition and/or volatilization.

water column and sediment PCB concentrations calculated for each impoundment were then used in the EPA Food Chain Model to evaluate fish PCB concentrations in these downstream CT impoundments (as described in Section 4 below).

The attenuation factors for Lake Lillinonah and Lake Zoar were estimated from the flows measured by the USGS gaging stations between Bulls Bridge and the Stevenson Dam (at the downstream end of Lake Housatonic; Table J-2). Daily average flow data collected between 2003 and 2007 were used in this flow analysis, as these were the only years containing a complete data set at each gaging station. Daily average flow within each impoundment was determined as follows:

- Bulls Bridge Dam flow was calculated by subtracting the Tenmile River flow (USGS Gage #01200000) from the Housatonic River flow at Gaylordsville (Figure J-9).
- Lake Lillinonah flow was calculated by summing flow in the Housatonic River at Gaylordsville with flow from the Still River (USGS Gage #01201487) and Shepaug River (USGS Gage #01202501; Figure J-9).
- Lake Zoar flow was set equal to the flow measured in the Housatonic River at the Stevenson Dam (USGS Gage #01205500; Figure J-9).

The average flow representative of each impoundment was calculated by averaging the daily average flows described above over the period from 2003 to 2007. These average flows were subsequently divided by the average flow at Bulls Bridge to calculate the impoundment-specific attenuation factors. Table J-2 below summarizes the average flows and the corresponding attenuation factors within each impoundment.

The Lake Housatonic attenuation factor could not be estimated from the flow data because there were no USGS gaging stations within or just downstream of that impoundment. Therefore, the Lake Housatonic attenuation factor was estimated based on changes in drainage area in that region. Geographic Information System (GIS) analysis determined that the ratio of drainage areas for Lake Housatonic and Lake Zoar is approximately 1.075; this value was therefore multiplied by the Lake Zoar attenuation factor to estimate the attenuation factor for Lake Housatonic.

Table J-2. Summary of Gaging Stations, Average Flows and Attenuation Coefficients for CT Impoundments

Impoundment	Bulls Bridge	Lake Lillinonah	Lake Zoar	Lake Housatonic
Gaging Station(s)	Housatonic River at Gaylordsville, Tenmile River	Housatonic River at Gaylordsville, Still River, Shepaug River	Housatonic River at Stevenson	---
Average Flow (cfs)	1666	2295	3261	3506[1]
Flow Attenuation Factor[2]	1	1.4	2.0	2.1

Notes:

[1] Flow estimated from drainage area increase.

[2] Flow attenuation factors are relative to Bulls Bridge. As such concentrations at downstream impoundments are estimated by dividing the results for the Bulls Bridge Dam impoundment by the attenuation factors listed above.

J.4. Food Chain Model (FCM) Development and Calibration

As directed by EPA in its April 13, 2007 conditional approval letter for the CMS Proposal, GE used EPA's FCM from Reach 8 (Rising Pond) to simulate the bioaccumulation of PCBs in fish within the Connecticut impoundments. Fish species used in EPA's model include largemouth bass, brown bullhead, white sucker, sunfish, and cyprinids. Largemouth bass are the modeled predatory species in the FCM; however, for the Connecticut portion of the river, smallmouth bass data are most prevalent. Therefore, model predictions of largemouth bass were used as a surrogate for smallmouth bass for calibration of the model.[4]

[4] EPA noted in its Specific Comment #126 on the CMS Report that GE's use of the largemouth bass model as a surrogate for smallmouth bass is reasonable provided that the lipid contents of Connecticut smallmouth bass are similar to largemouth bass upstream of Woods Pond Dam. Figure J-10 provides a comparison between distributions of lipid content in smallmouth bass from Connecticut and largemouth bass collected upstream of Woods Pond Dam, using all available GE and EPA fillet data. This figure demonstrates that the central tendency in lipid content between the two species is relatively similar (approximately 1% for both species); the arithmetic mean lipid content is approximately 1.4% for largemouth bass and 1.2% for smallmouth bass. Further, while the lipid content in largemouth bass collected from the PSA is generally more variable, the range in lipids between the two species is relatively consistent.

J.4.1 Inputs

FCM parameters, including food energy parameters, growth rates, respiration rates, assimilation efficiencies, elimination rates, and feeding preferences for modeled species, were unchanged in this application of the model, and are described in detail in EPA's Final Model Documentation Report (EPA, 2006b).

Exposures to the modeled biota include PCBs from the water column and surface sediment, both on a dissolved-phase and particulate organic-carbon normalized basis. These concentrations were developed in the 1-D Analysis as described in Section 2. Attenuation factors derived from flow differences, as described in Section 3, were applied to the Bulls Bridge Dam impoundment water column and sediment PCB concentrations to simulate exposure concentrations to the biota in the downstream CT impoundments (Lake Lillinonah, Lake Zoar, and Lake Housatonic).

FCM simulations were performed for the time period between 1963 and 2004 (the same as the CT sediment bed model calibration period described above) to predict PCB concentrations in biota in the four Connecticut impoundments. The resulting PCB concentrations were compared to fish data collected by GE from the same timeframe, where available, at each impoundment. These data were measured on a fillet basis, and therefore needed to be converted to whole-body concentrations (which the model computes). For purposes of this comparison, the measured fillet PCB concentrations were multiplied by a factor of 2.3 to convert the data to a whole-body basis, consistent with the method used by EPA in the Ecological Risk Assessment (ERA; EPA, 2004a) and in the FCM calibration (EPA 2004b; EPA 2006a).

J.4.2 Results

The calibration results were first graphically compared to site-specific fish PCB data (converted to a whole-body equivalent) to evaluate the reasonableness of the calculation. The model simulation results were compared to measured PCB data for smallmouth bass, bullhead, and sunfish at Bulls Bridge, Lake Lillinonah, Lake Zoar, and Lake Housatonic (where available) from the beginning of the fish sampling program (in the late 1970s) through 2004 on both a wet-weight basis (Figures J-11 through J-13) and a lipid-normalized basis (Figures J-14 through J-16).[5] Cyprinid data from Connecticut were not available and white sucker data were only available from the Connecticut reaches for a single year (1979) and therefore were not compared to modeled PCB concentrations due to the limited data set.

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[5] Additional fish data were collected in the Connecticut portion in the River in 2006 and 2008 but are not shown on the figures since the model simulation ends in 2004.

The calculated wet-weight PCB concentrations in smallmouth bass are somewhat lower than the measured concentrations (converted to whole-body concentrations) in 1990-1996 and 2004 at Bulls Bridge, but are within the range of the data for other years at that location and for all years at Lake Lillinonah and Lake Zoar (Figure J-11). Generally, the predicted lipid-normalized PCB concentrations in smallmouth bass are somewhat lower than observed concentrations (converted to whole-body concentrations) at Bulls Bridge and Lake Zoar, but are within the range of the data at those locations and at Lake Lillinonah (Figure J-14). These comparisons indicate that the FCM-calculated concentrations provide a fairly reasonable representation of measured smallmouth bass PCB concentrations (converted to whole-body concentrations) at these three locations.[6] There are no contemporary smallmouth bass PCB data within Lake Housatonic to assess the FCM performance in that impoundment.

While very few bullhead data were collected in the Connecticut portion of the River since 1990, the modeled concentrations appear to provide a reasonable representation of PCB concentrations on a wet-weight and lipid-normalized basis at Bulls Bridge and Lakes Lillinonah and Zoar (Figures J-12 and J-15, respectively). There are insufficient data to make this comparison for Lake Housatonic.

For sunfish, there are also limited measured data since 1990. However, based on the data that exist, including those collected from 1979-1989, FCM predictions are within the range of the measured PCB concentrations (converted to whole-body concentrations) on both a wet-weight and a lipid-normalized basis at Bulls Bridge and Lakes Lillinonah and Zoar (Figures J-13 and J-16, respectively). The model slightly over-predicts the measured PCB concentrations (converted to whole-body concentrations) on a wet-weight basis at Bulls Bridge, Lake Lillinonah, and Lake Zoar in certain years, but matches the data well on a lipid-normalized basis. Again, there are insufficient data to make this comparison for Lake Housatonic.

In order to assess overall model bias and precision, the same quantitative model performance metrics used by EPA in its Final Model Documentation Report to evaluate bias and precision of the FCM (described on pages 4-116 to 4-119 in EPA [2006b]) were applied in the evaluation of the CT 1-D Analysis estimates. As described in the FMD,

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[6] In its Specific Comment #129 on the CMS Report, EPA stated that the under-prediction of PCB concentrations in bass at Bulls Bridge suggests that the Bulls Bridge attenuation factor may have been set too low. However, there is no apparent bias in the model predictions for the other species simulated at Bulls Bridge, which could suggest a difference in food web structure or physiological parameters between this reach and the upstream reaches (Woods Pond and Rising Pond) for which FCM was calibrated (no adjustment of FCM parameters was made during development of the CT 1-D Analysis). Moreover, the predicted concentrations in fish at Bulls Bridge are based solely on the water column and sediment exposures predicted by the CT 1-D Analysis. Increasing the sediment concentrations to account for an apparent low bias in the Bulls Bridge bass by increasing the attenuation factor (as suggested by EPA) would compromise the sediment calibration and would be inconsistent with the data used to establish the attenuation factor.

EPA's FCM Phase 2 Calibration was evaluated using a model bias (MB*) statistic (Arnot and Gobas, 2004), which was derived on both a species-specific and reach-specific basis. This MB* statistic is the geometric mean of the ratio of simulated and measured PCB concentrations, and is a measure of the systematic overprediction (MB > 1) or underprediction (MB < 1) of the model (EPA, 2006b). In addition, EPA evaluated the overall model accuracy and precision using the mean absolute percent error (MAPE) metric. Table J-3 presents these statistics on both a wet-weight and a lipid-normalized basis.

Table J-3. Summary of Quantitative Model Performance Metrics Used to Evaluate CT 1-D Analysis

Basis	Comparison Type	Group	Number of Tissue PCB Measurements	Model Bias (MB*) Statistic[1]	Model Accuracy/ Precision (MAPE[2]) Statistic
Wet-Weight	All Data		659	1.26	60%
	By Reach	Bulls Bridge	206	1.01	56%
		Lake Lillinonah	237	1.22	55%
		Lake Zoar	192	1.54	65%
		Lake Housatonic	24	2.27	85%
	By Species	Smallmouth bass	414	0.97	50%
		Bullhead[3]	100	1.36	61%
		Sunfish[4]	145	2.56	86%
Lipid-Normalized	All Data		525	0.67	65%
	By Reach	Bulls Bridge	164	0.65	59%
		Lake Lillinonah	202	0.63	69%
		Lake Zoar	159	0.75	65%
		Lake Housatonic	0	--	--
	By Species	Smallmouth bass	360	0.57	66%
		Bullhead[3]	60	0.95	51%
		Sunfish[4]	105	0.95	67%

Notes:

[1] MB > 1 indicates systematic overprediction, and MB < 1 indicates systematic underprediction.

[2] MAPE = Mean average percent error.

[3] Includes brown and yellow bullhead, where available.

[4] Includes pumpkinseed, bluegill, redbreast sunfish, and redear sunfish, where available.

The overall model bias statistic is 1.26 on a wet-weight basis (indicating a slight overprediction) and 0.67 on a lipid-normalized basis (indicating somewhat of an underprediction); this calibration thus provided a balance between wet-weight and lipid-normalized concentrations. For comparison, the model bias statistics for EPA's calibration of the FCM in the PSA and Reach 7/8 ranged from 0.8 to 1.3 by reach and from 0.8 to 2.3 by species. Thus, the CT 1-D FCM calibration was judged to be of similar quality to EPA's calibration in the upstream reaches. Similar to EPA's FCM, some variations in MB* are observed among species and reaches. The overall MAPE is 60% on a wet-weight basis, and 65% on a lipid-normalized basis. For comparison, overall MAPE for EPA's calibration of FCM for Reaches 5-8 was approximately 50% for all data and ranged from 30% to 71% by reach. Given the large uncertainty in the CT 1-D Analysis methodology, this level of combined accuracy/precision was considered acceptable for this extrapolation.

Overall, the application of FCM to the CT impoundments based on the exposure concentrations estimated using the CT 1-D analysis appears to provide a sufficient fit to the data such that the model can be used to develop future predictions in the CT portion of the river.

J.5. Summary

Although much less sophisticated than EPA's model for the Confluence to Rising Pond Dam, the CT 1-D analysis described above provides a means of estimating future changes in PCB concentrations within the four major Connecticut impoundments of the River in response to remedial actions performed upstream. The method predicts water column, surface sediment, and fish PCB concentrations within Bulls Bridge Dam impoundment, Lake Lillinonah, Lake Zoar, and Lake Housatonic based on the PCB loading passing over Rising Pond Dam as predicted by the EPA model. The method is based on the first principle of conservation of mass, maximizes the use of available sediment and fish data collected from these impoundments, and leverages the fish bioaccumulation modeling work performed by EPA in the Massachusetts reaches of the River to predict responses in CT.

It should be recognized, however, that the results from the CT 1-D Analysis are very uncertain due to the empirical, semi-quantitative nature of the analysis, as well as the significant data limitations. For example, the sediment bed model was calibrated against a single sediment core collected from the Bulls Bridge Dam impoundment, which yielded a single deposition rate and average PCB concentration in sediments deposited between 1963 and 1980 (see Section 2.2.1). While this core exhibited an interpretable Cesium-137 profile that supported the model application, it likely does not represent the full range of sediment deposition conditions in the impoundment. Likewise, extrapolation of the EPA model predictions of water column TSS and PCB concentrations at Rising Pond Dam to the Bulls Bridge Dam impoundment was accomplished using simple attenuation factors that were parameterized based on data from 1979 or by calibration (see Sections 2.2.3 and 2.3). A similar approach based on flow dilution was used to extrapolate the results from the Bulls Bridge Dam impoundment to downstream impoundments. This simplified approach does not account for the many processes affecting PCB fate and transport and consequently adds to the uncertainty in the calculation. For these reasons, while the CT 1-D Analysis provides a means of generally assessing the impact of the different sediment alternatives on the CT impoundments, the resulting estimates cannot be regarded as reliable predictions of specific PCB concentrations and thus cannot be used as a reliable way of making fine distinctions among the alternatives, particularly when the concentrations are low and generally similar.

J.6. References

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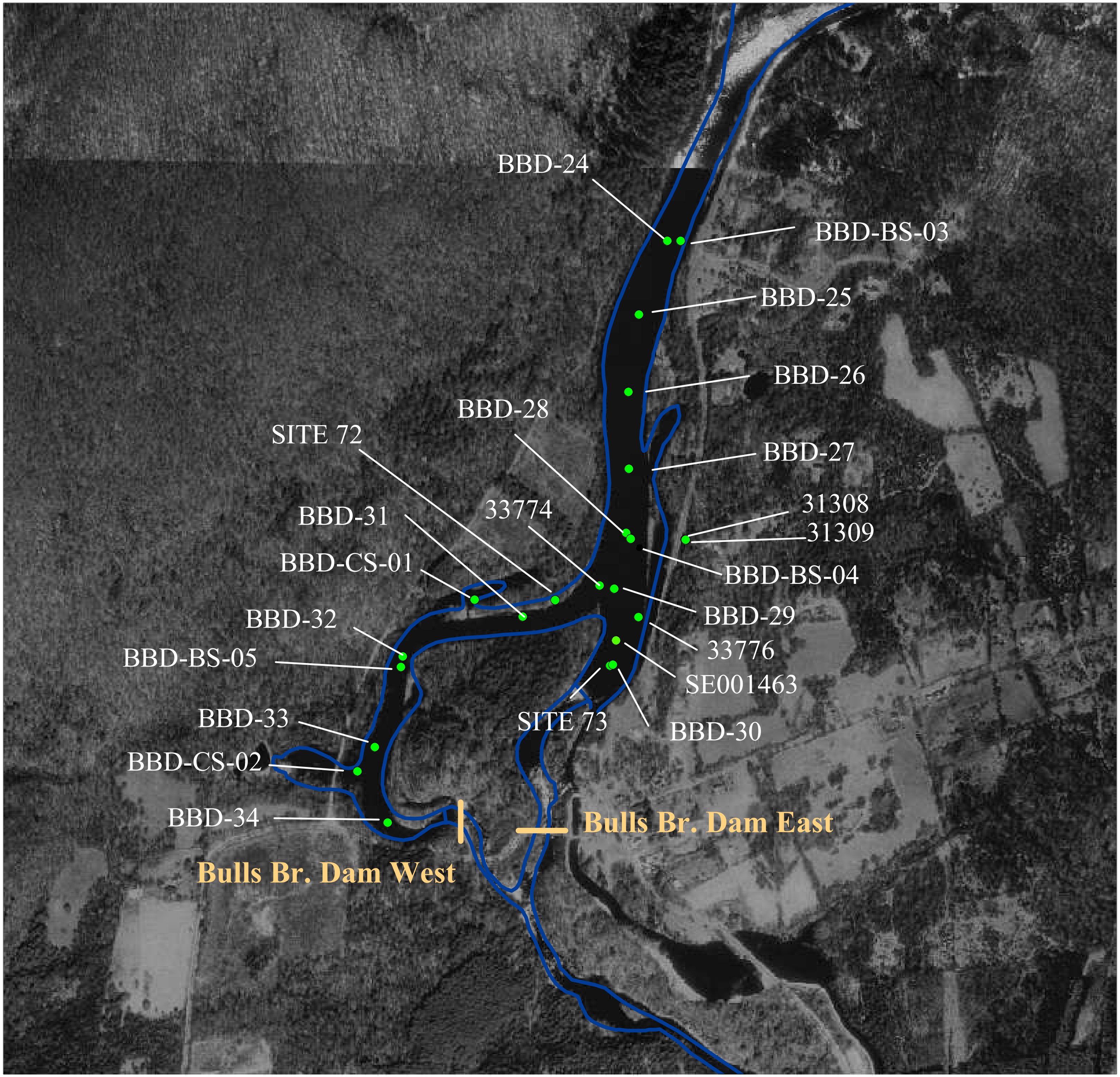

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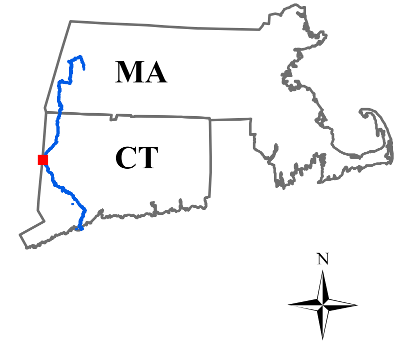

Scale

0 0.1 0.2 Miles

Legend

Sampling Locations

Shoreline

Notes:
Data collected by: BBL (1998), LMS (1992, 1986), USGS, CAES (1980) and USEPA (2001).
Sampling locations (labeled with sample IDs) are areas where samples were collected from top 6 in of sediments.

Figure J-1.
Sediment sampling locations within the BBD impoundment.

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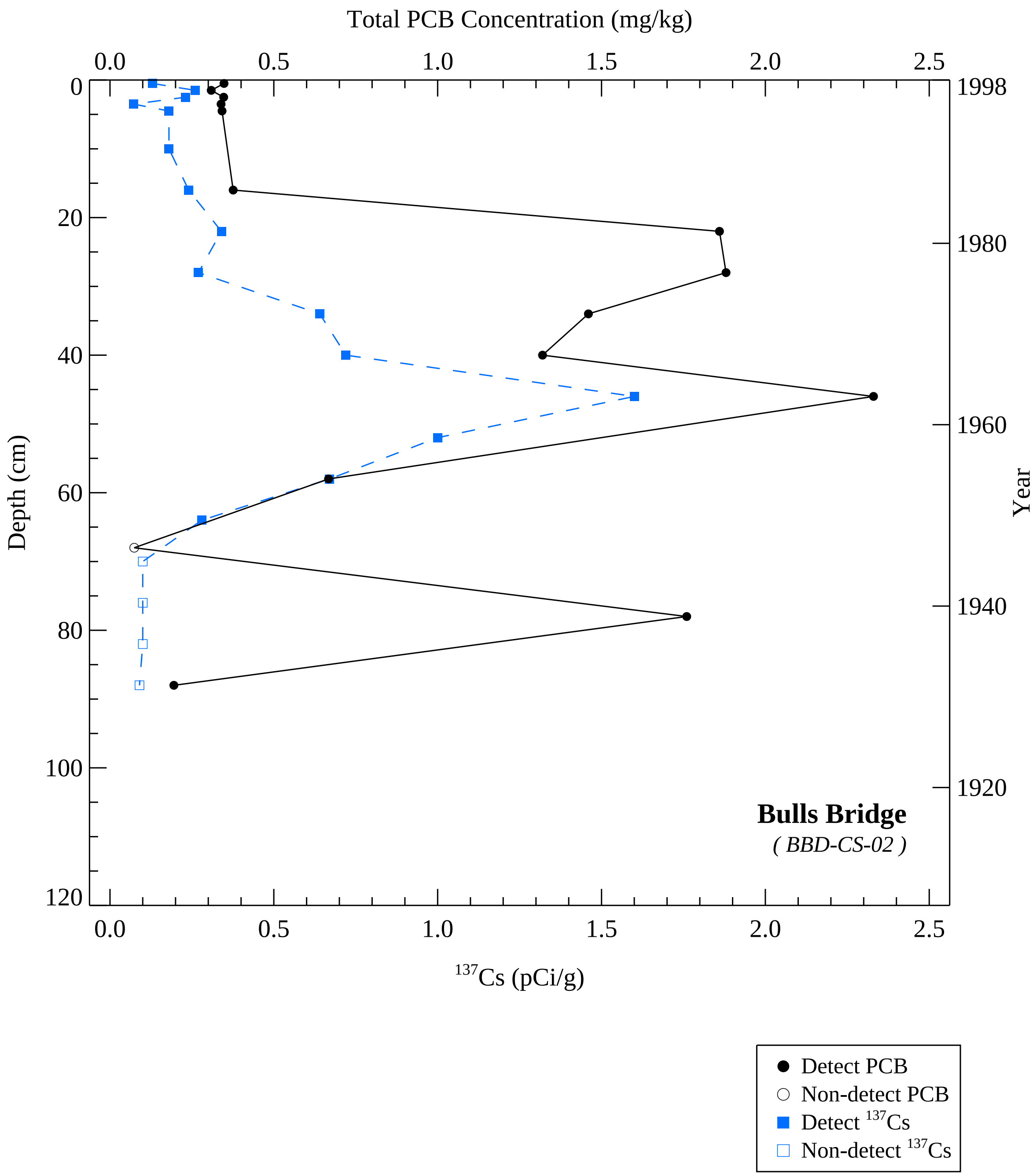

Figure J-2. PCB and ^{137}Cesium data from GE high resolution core (BBD-CS-02) collected at Bulls Bridge.

Notes: Sample (BBLID 7771) collected from 9-11 cm depth interval with total PCB=0 mg/kg was excluded from analysis. Non-detect data plotted at 1/2 MDL.

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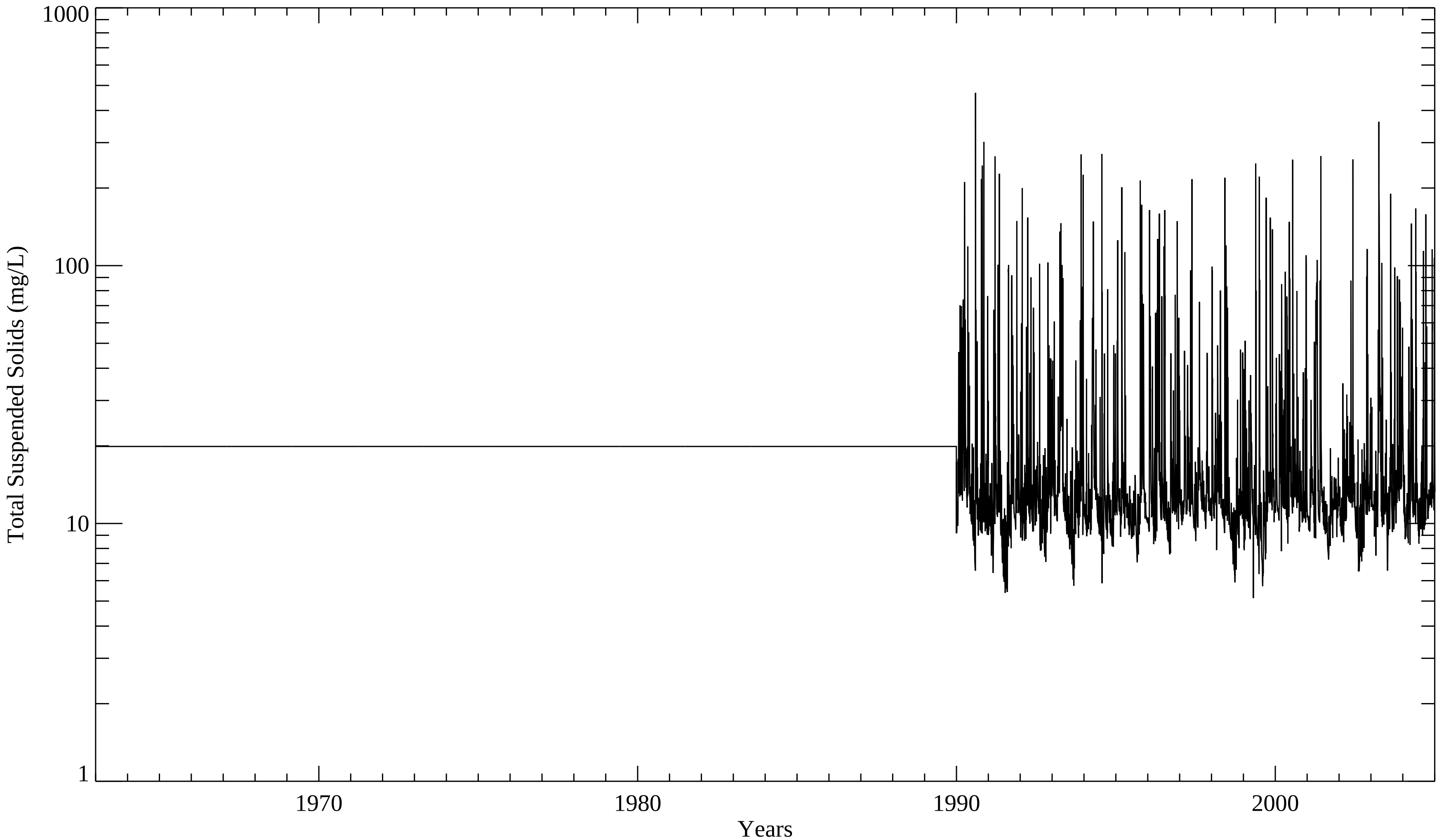

Figure J-3. Temporal profile of calculated water column TSS concentrations at Bulls Bridge from 1963 to 2004.

1963-1990 TSS concentration is an average of USGS data collected in 1979 at Gaylordsville.
1990-2004 TSS concentrations were calculated from downstream model output for Rising Pond and mutliplied by four to account for increased solids yield.

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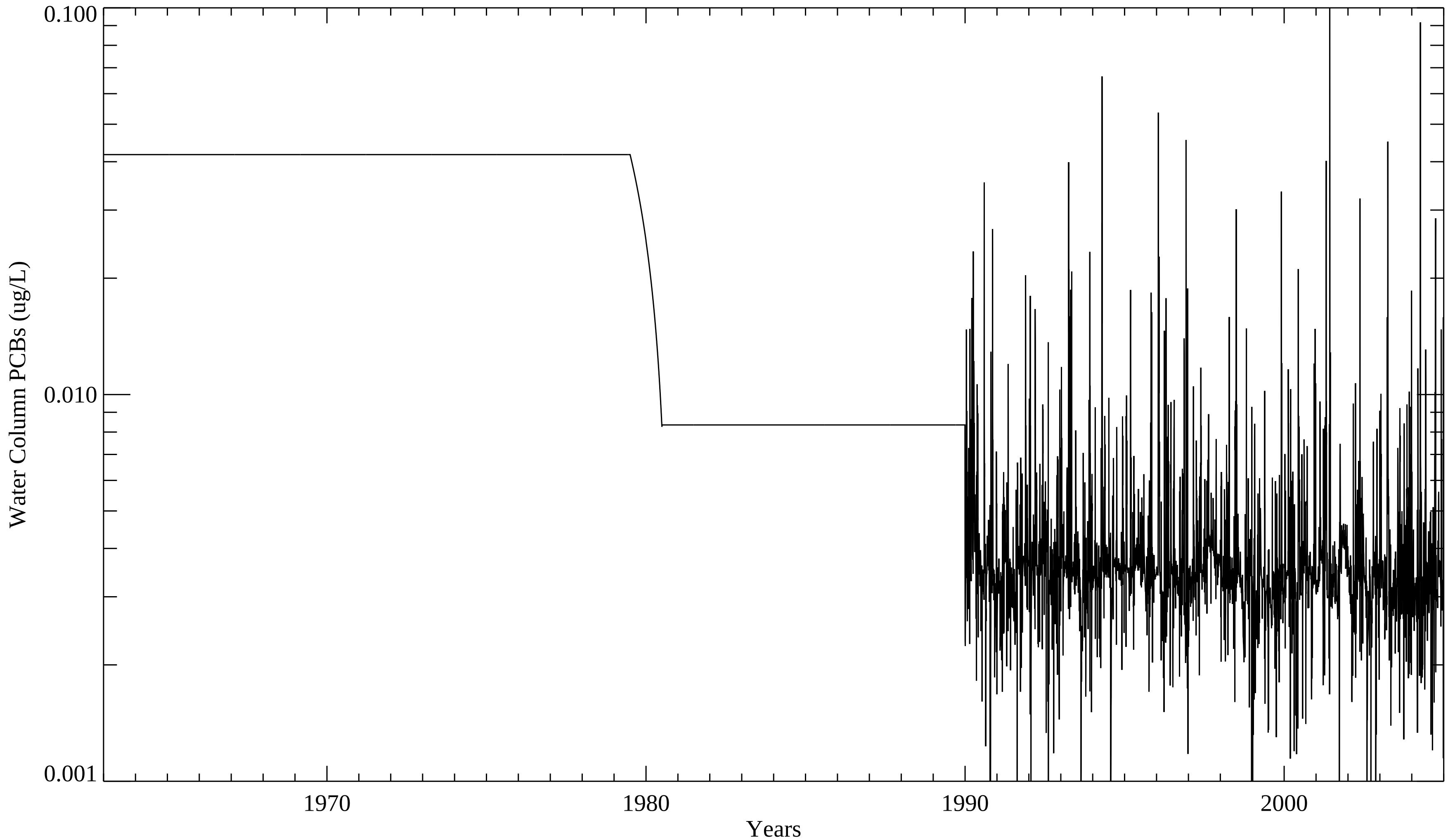

Figure J-4. Temporal profile of calculated water column PCB concentrations at Bulls Bridge between 1963 and 2004.

1963-1990 PCBs were calculated from high resolution core data (BBD-CS-02).
1990-2004 PCBs were calculated from downstream model output for Rising Pond divided by 10 to account for dilution.

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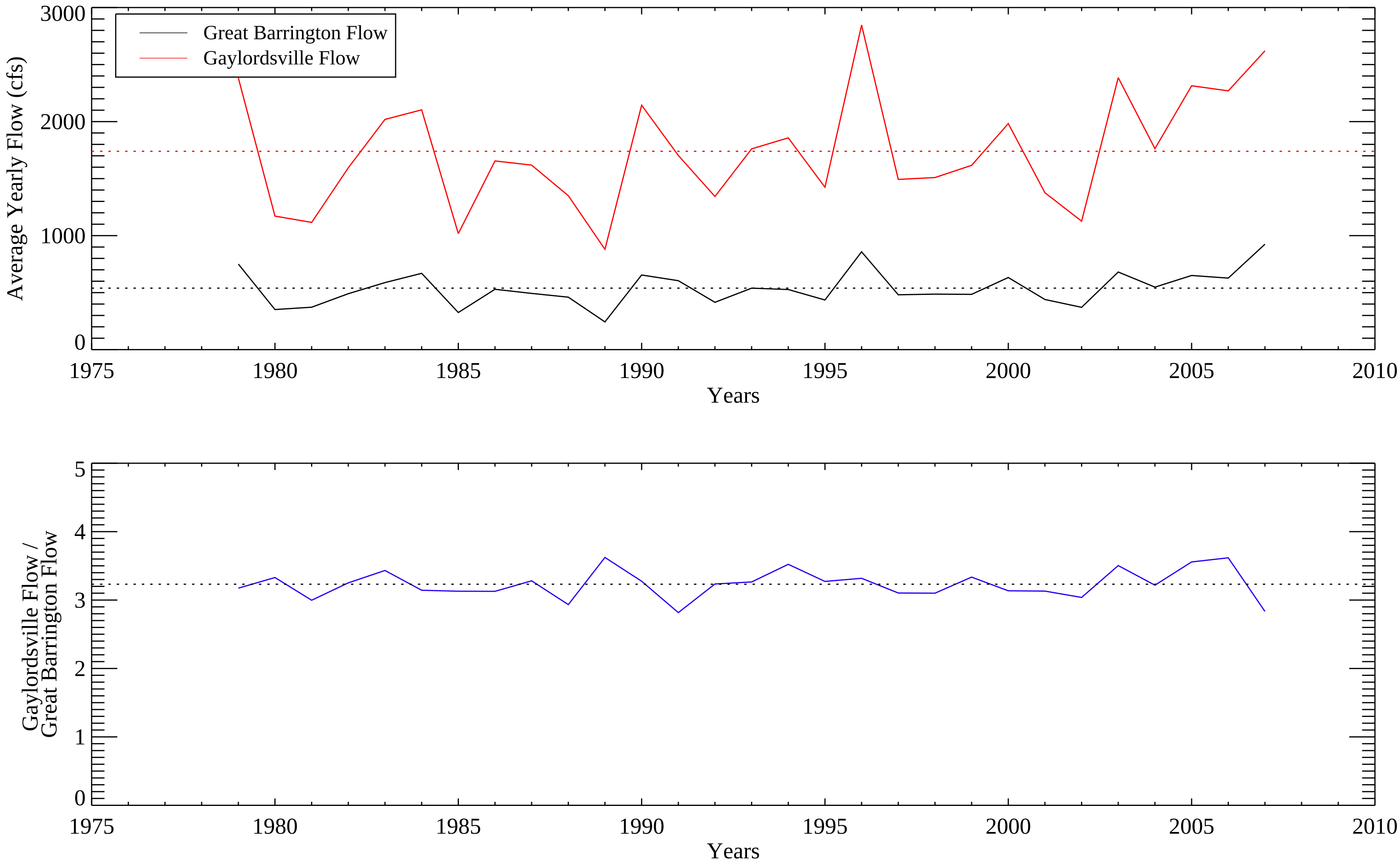

Figure J-5. Temporal plots of annual average USGS flow data at Great Barrington and Gaylordsville.

Note: Dotted lines represent average of annual flows (top panel) and ratios (bottom panel).

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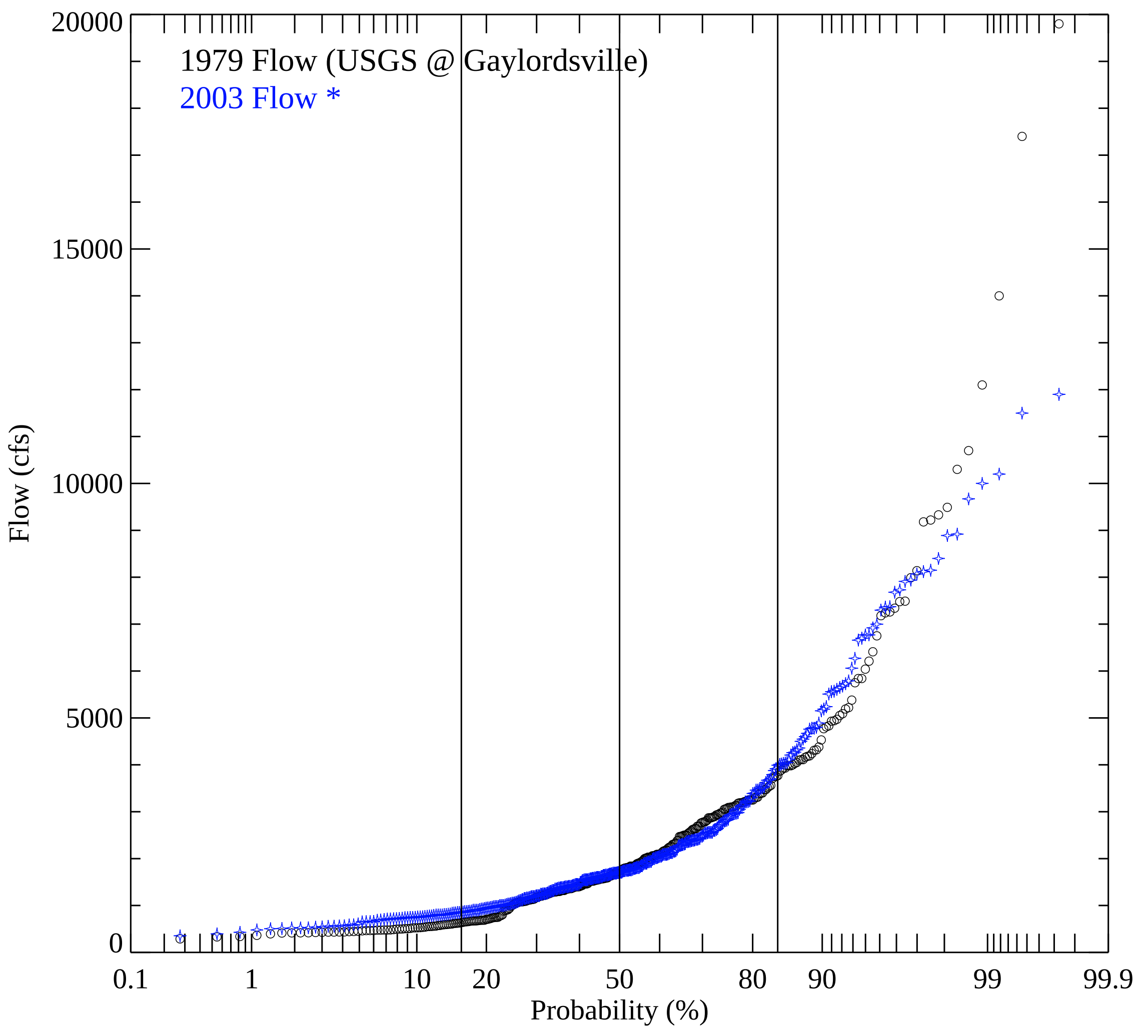

Figure J-6. Comparison of daily average flows at Gaylordsville between 1979 and 2003.

* 2003 flows are EPA Downstream model flows at Rising Pond multiplied by 3.2 to account for the flow difference between Rising Pond and Bulls Bridge.

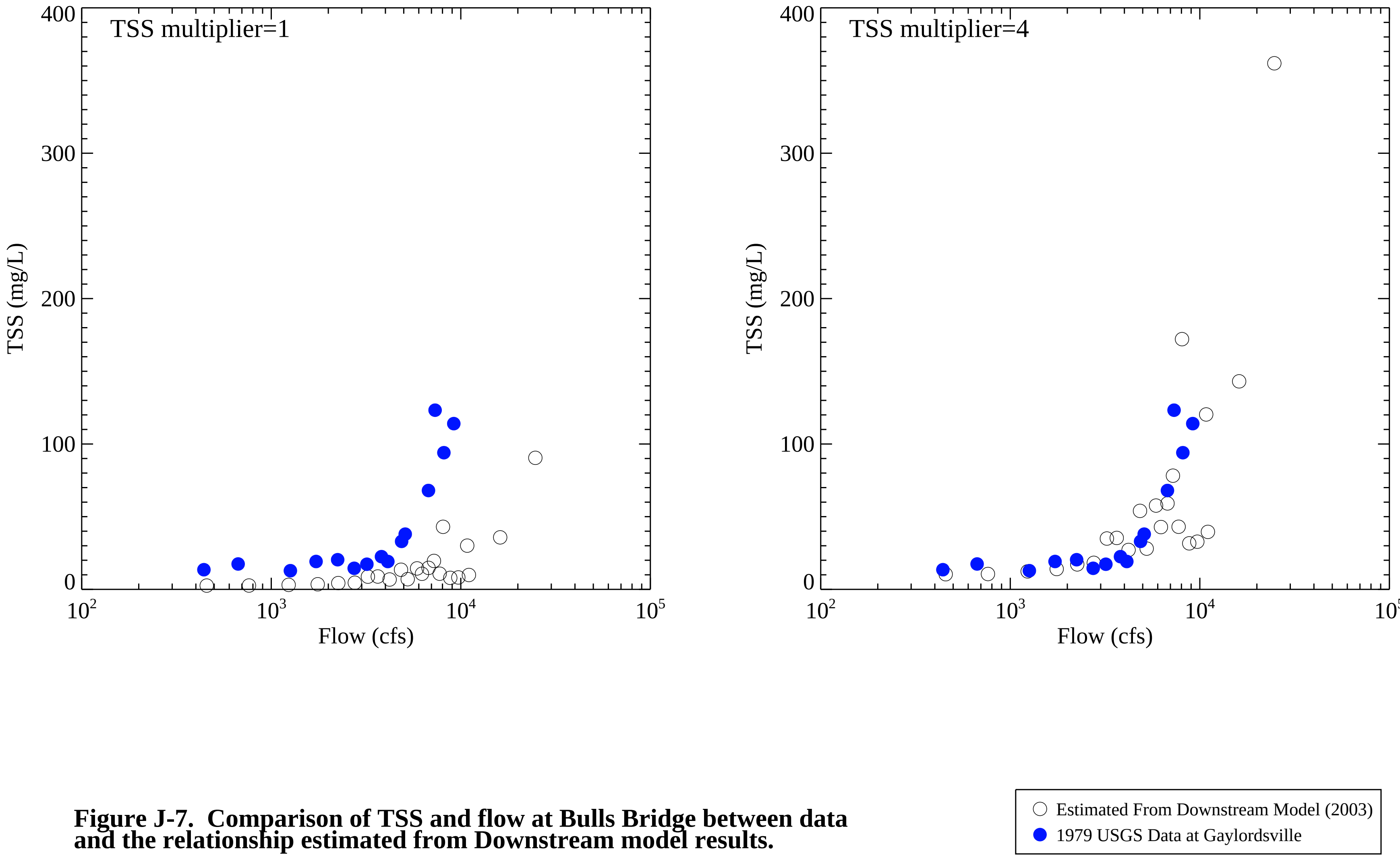

Figure J-7. Comparison of TSS and flow at Bulls Bridge between data and the relationship estimated from Downstream model results.

Rising Pond flows calculated by the Downstream model were multiplied by 3.2 to approximate Bulls Bridge conditions. For both data sets the TSS values were averaged in 500 cfs bins.

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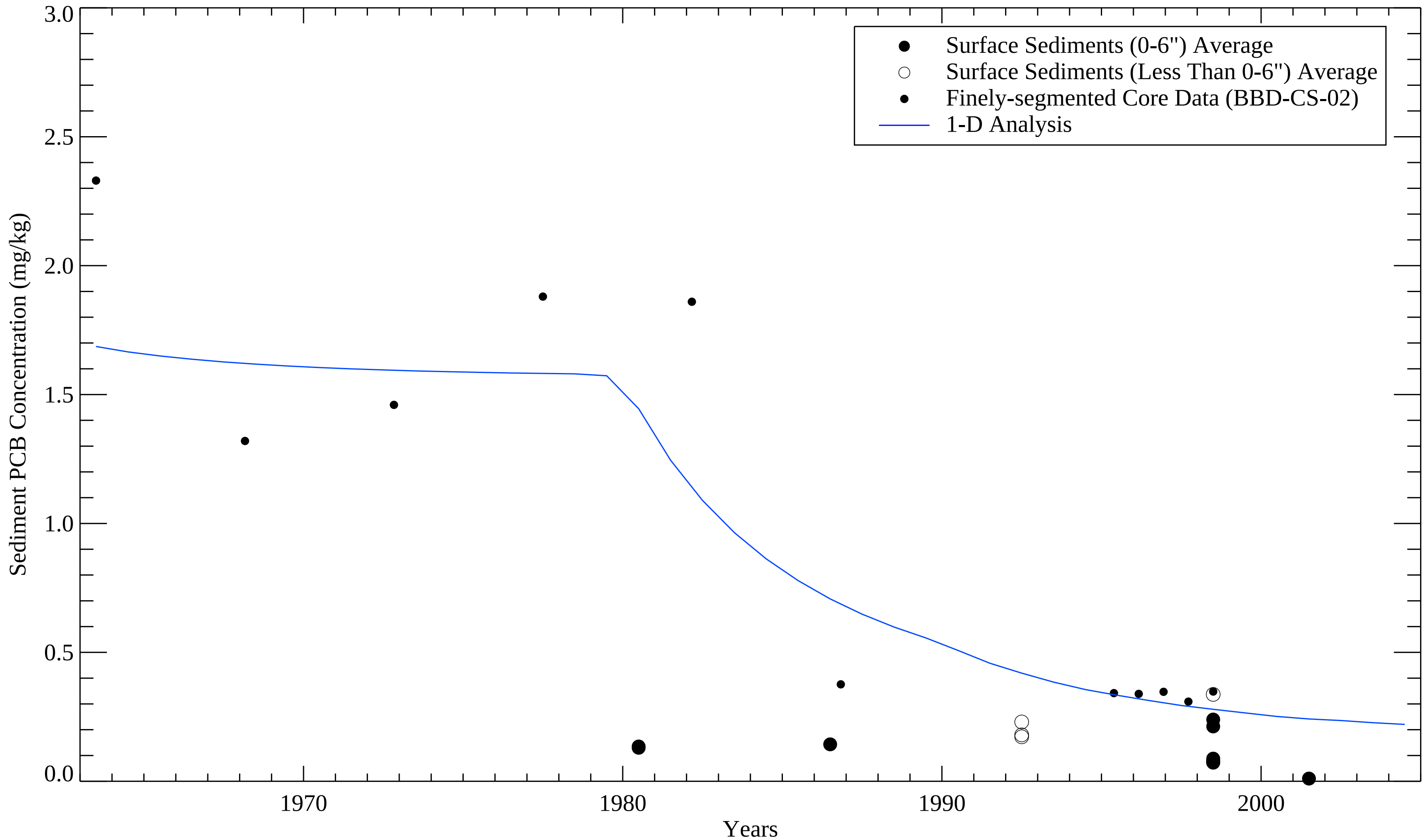

Figure J-8. Comparison of surface (0-6") sediment PCB concentrations calculated from the 1-D Analysis with data collected at Bulls Bridge.

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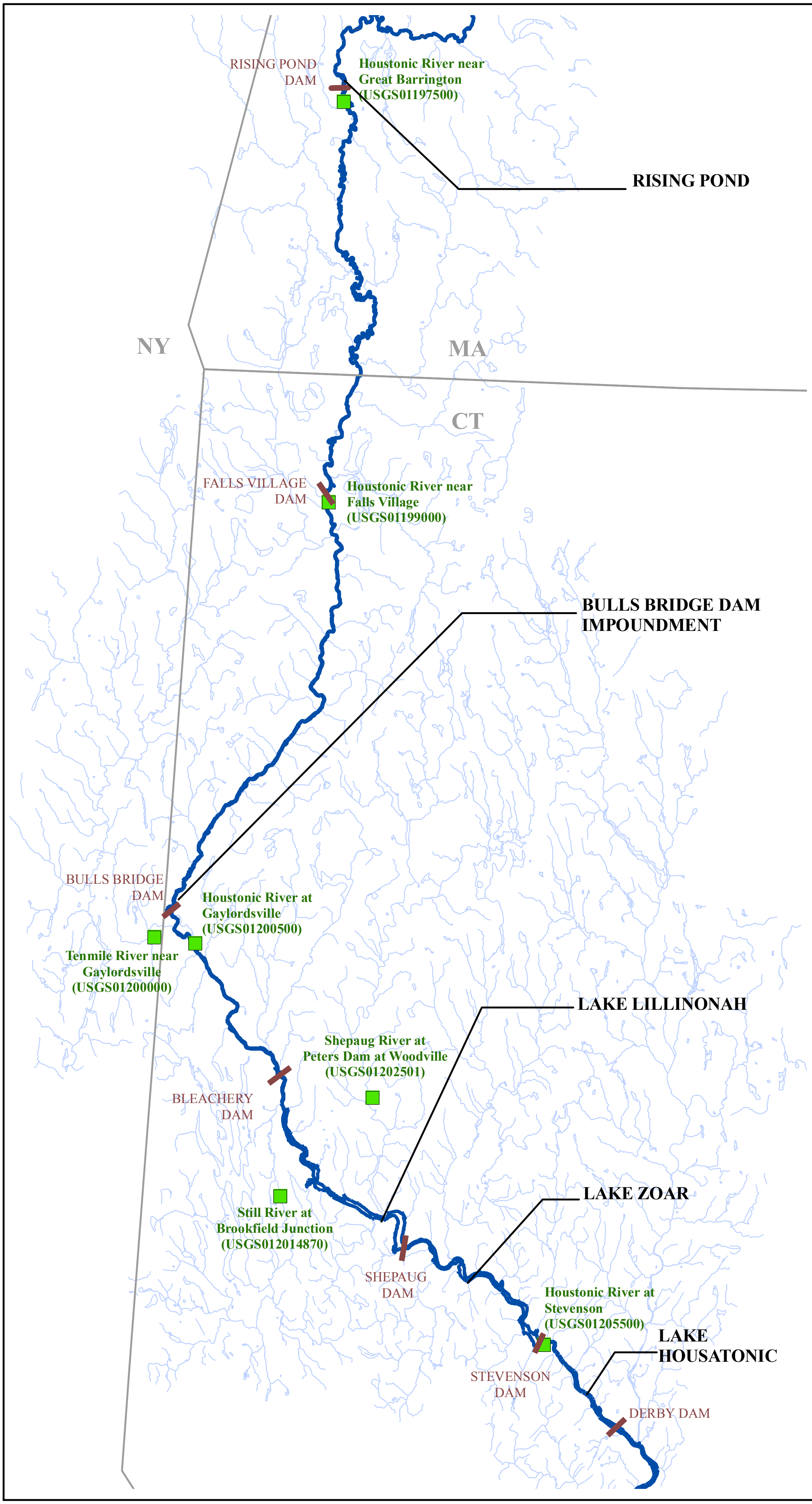

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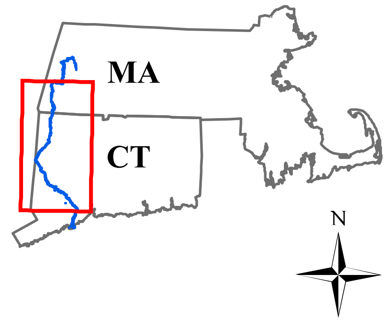

Scale

100 50 0 Miles

Legend

- Major Dams
- State Boundaries
- USGS Gaging Stations
- Housatonic River
- Watershed

Figure J-9.
Map of major USGS gaging stations between Rising Pond Dam, MA and Lake Housatonic, CT.

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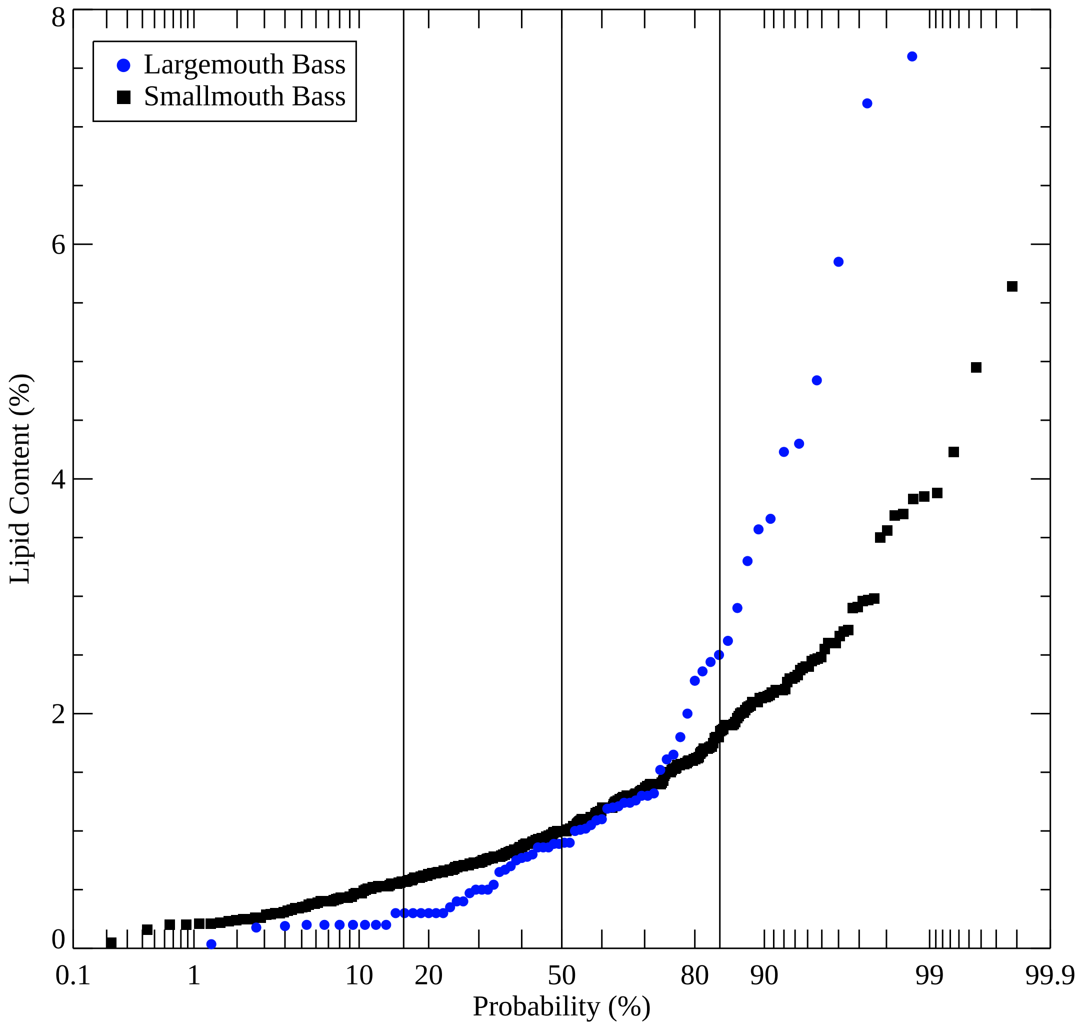

Figure J-10. Probability distribution of lipid content for largemouth bass (collected in the PSA) and smallmouth bass (collected in CT).

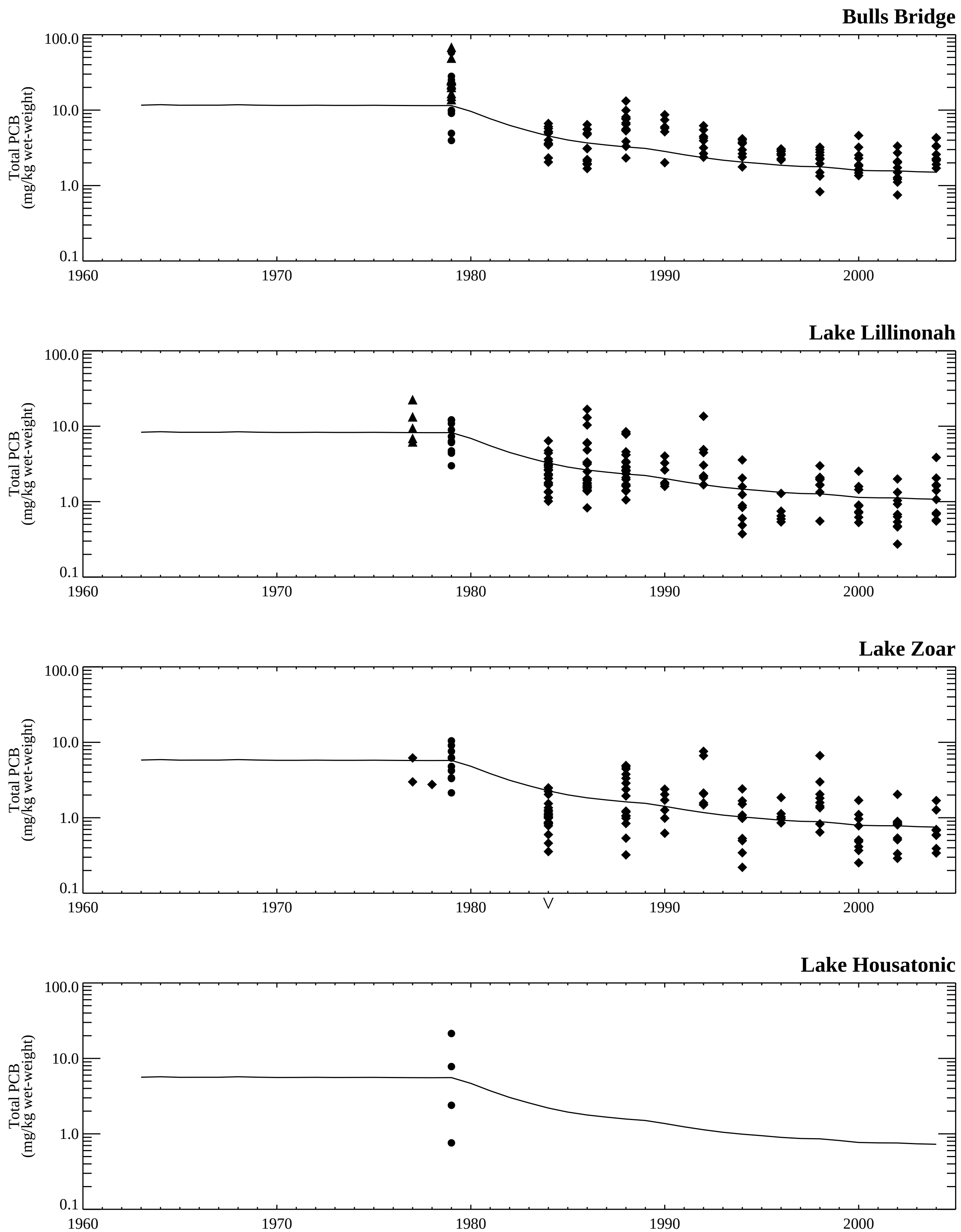

Figure J-11. Wet-weight PCB concentrations in smallmouth bass estimated from the CT 1-D Analysis.

—— 1-D Analysis
● Fillet (skin off)
◆ Fillet (scales off/skin on)
▲ Fillet (scales on/skin on)

Notes: FCM run TV_EPA040; Deposition model run 35
Model output is autumn averaged PCB concentration (Aug. 28 - Oct. 26) for game fish, age 6+.
Fillet to whole body conversion factor = 2.3. SMB fish ages > 3 (when determined);
Prep for 2004 individual samples assumed to be fillet.

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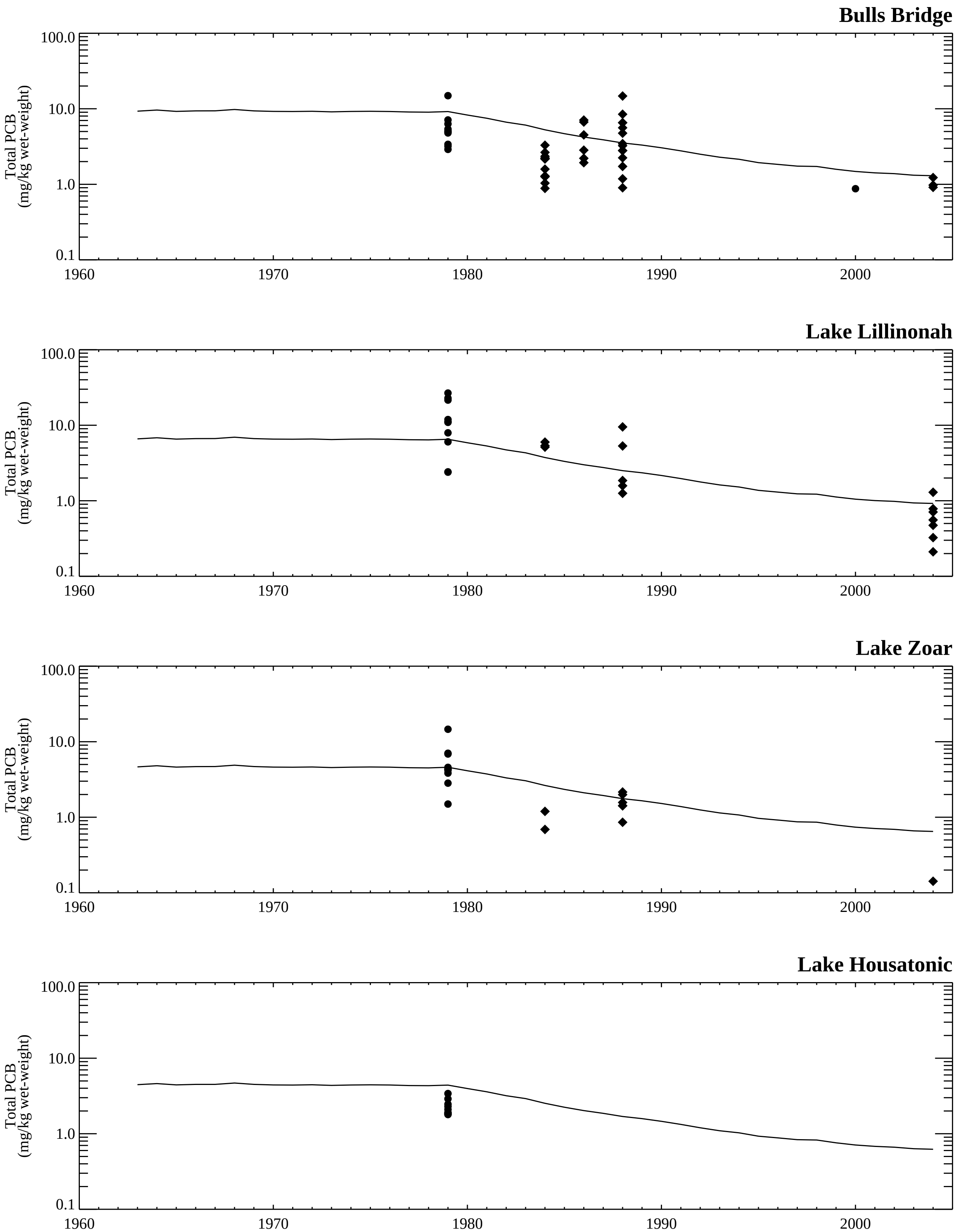

Figure J-12. Wet-weight PCB concentrations in bullhead (brown and yellow bullhead, where available) estimated from the CT 1-D Analysis.

——— 1-D Analysis
● Fillet (skin off)
◆ Fillet (scales off/skin on)
▲ Fillet (scales on/skin on)

Notes: FCM run TV_EPA040; Deposition model run 35
Model output is autumn averaged PCB concentration (Aug. 28 - Oct. 26) for game fish, age 6+.
Fillet to whole body conversion factor = 2.3. SMB fish ages > 3 (when determined);
Prep for 2004 individual samples assumed to be fillet.

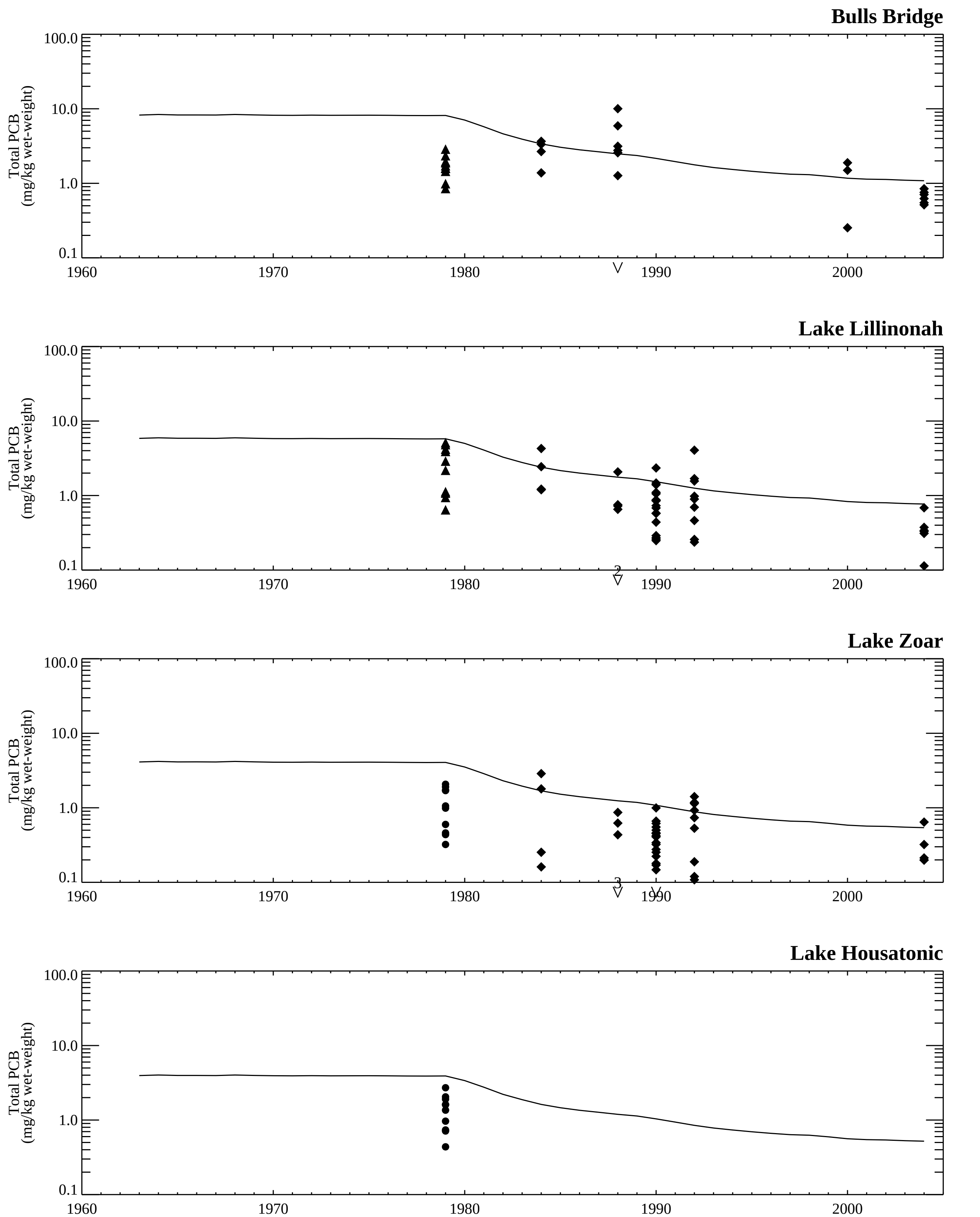

Figure J-13. Wet-weight PCB concentrations in sunfish (pumpkinseed, bluegill, redbreast sunfish, and redear sunfish, where available) estimated from the CT 1-D Analysis.

Notes: FCM run TV_EPA040; Deposition model run 35
Model output is autumn averaged PCB concentration (Aug. 28 - Oct. 26) for game fish, age 6+.
Fillet to whole body conversion factor = 2.3. SMB fish ages > 3 (when determined);
Prep for 2004 individual samples assumed to be fillet.

—— 1-D Analysis
● Fillet (skin off)
◆ Fillet (scales off/skin on)
▲ Fillet (scales on/skin on)

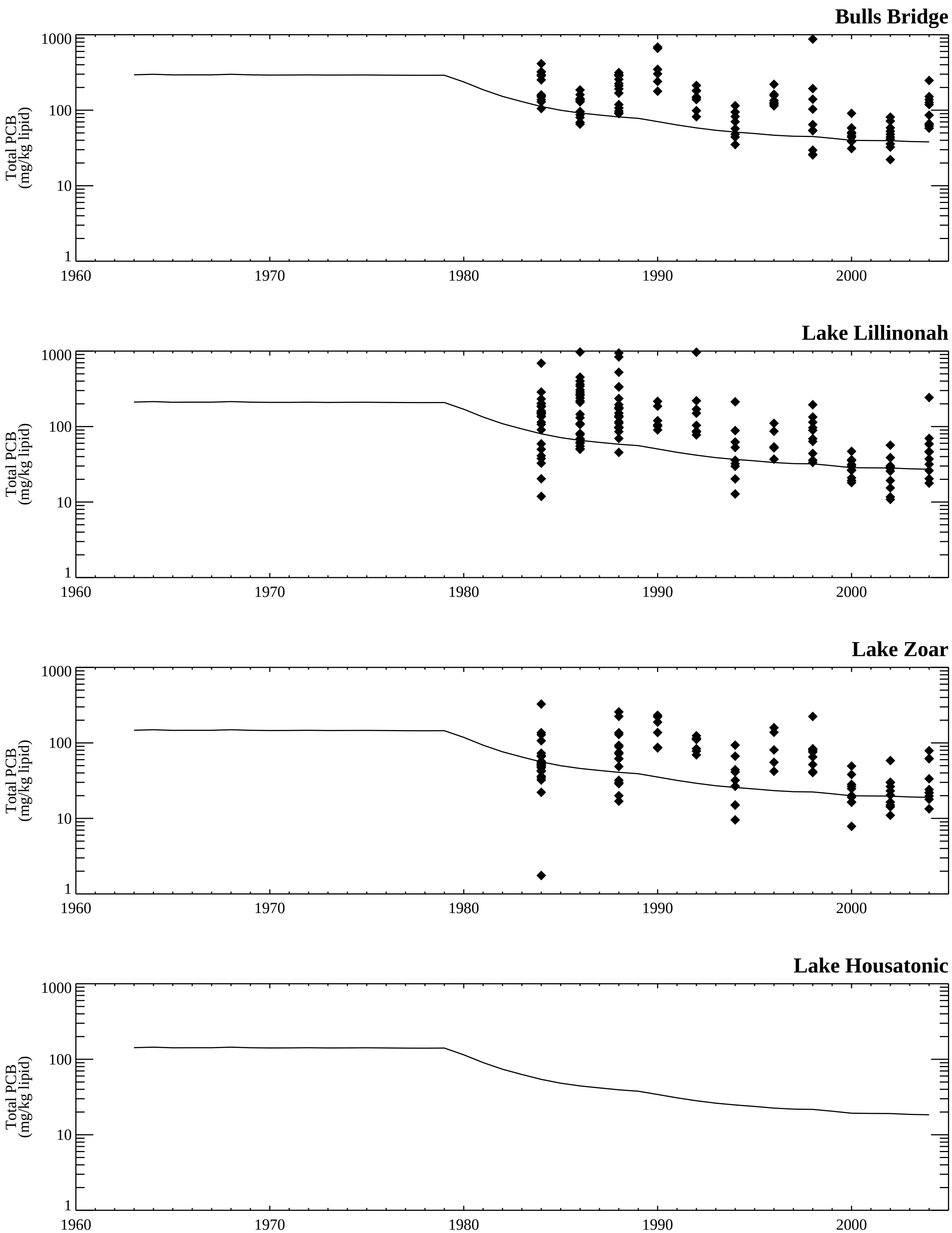

Figure J-14. Lipid-normalized PCB concentrations in smallmouth bass estimated from the CT 1-D Analysis.

Notes: FCM run TV_EPA040; Deposition model run 35
Model output is autumn averaged PCB concentration (Aug. 28 - Oct. 26) for game fish, age 6+.
SMB fish ages > 3 (when determined);
Prep for 2004 individual samples assumed to be fillet.

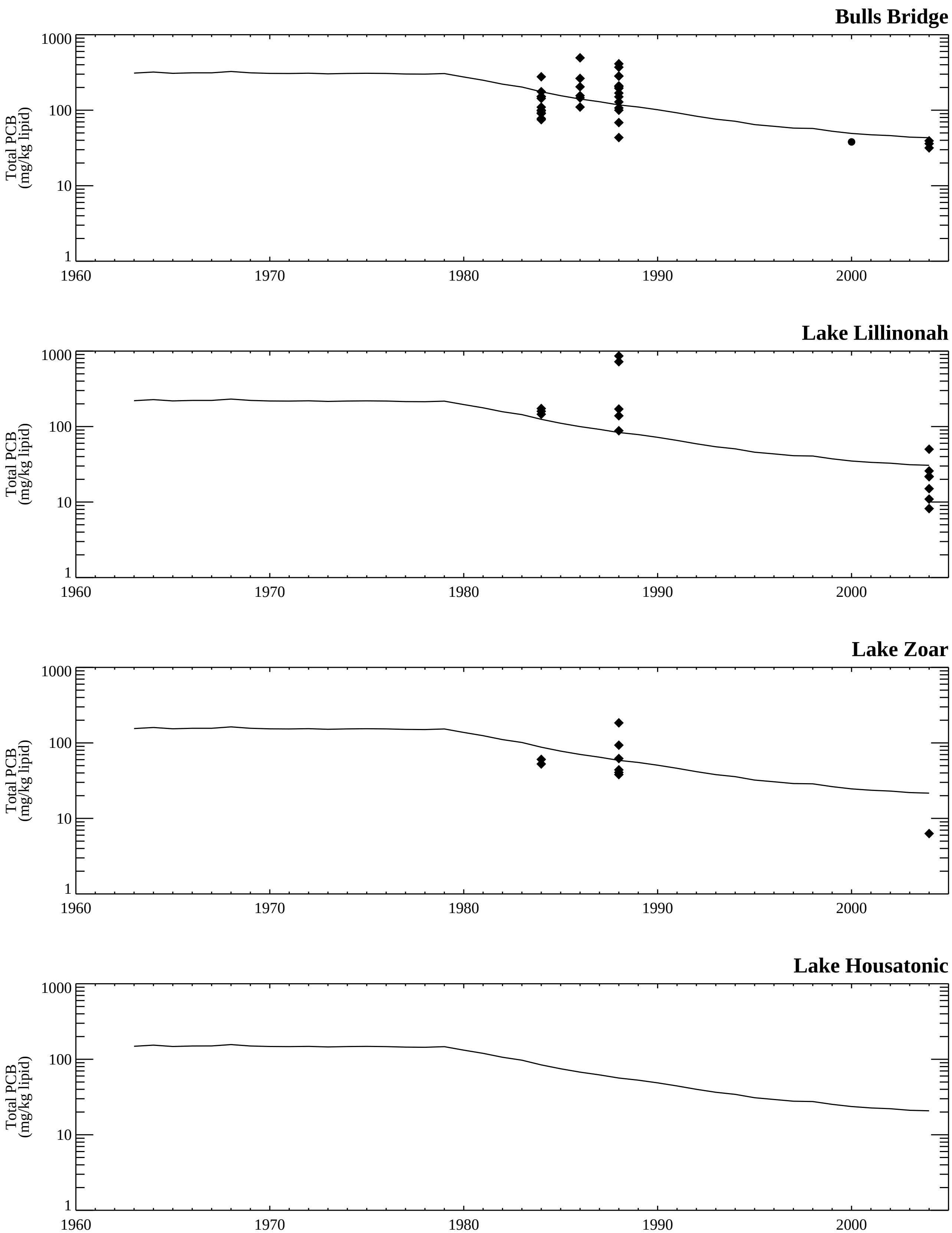

Figure J-15. Lipid-normalized PCB concentrations in bullhead (brown and yellow bullhead, where available) estimated from the CT 1-D Analysis.

—— 1-D Analysis
● Fillet (skin off)
◆ Fillet (scales off/skin on)
▲ Fillet (scales on/skin on)

Notes: FCM run TV_EPA040; Deposition model run 35
Model output is autumn averaged PCB concentration (Aug. 28 - Oct. 26) for game fish, age 6+.
SMB fish ages > 3 (when determined);
Prep for 2004 individual samples assumed to be fillet.

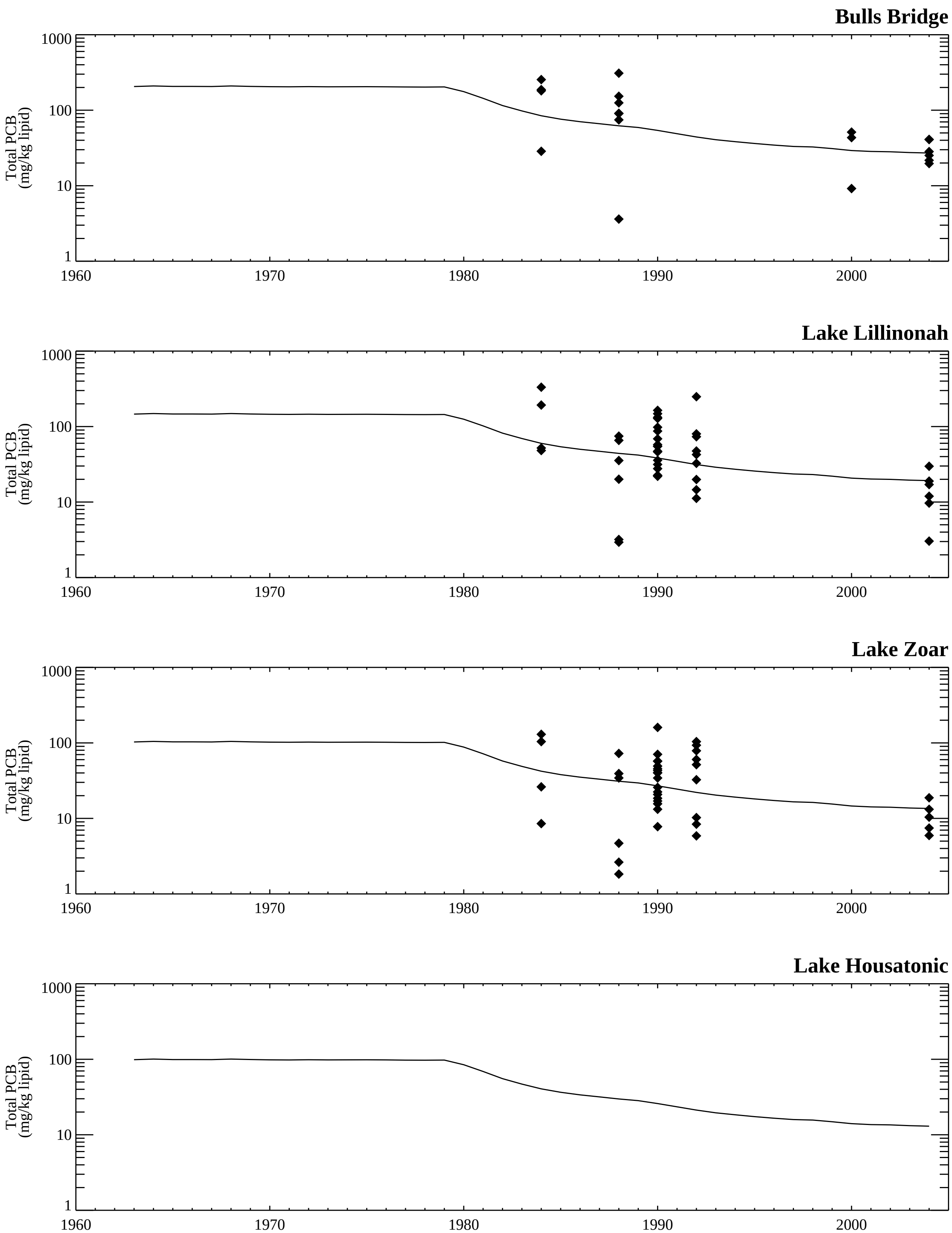

Figure J-16. Lipid-normalized PCB concentrations in sunfish (pumpkinseed, bluegill, redbreast sunfish, and redear sunfish, where available) estimated from the CT 1-D Analysis.

1-D Analysis
● Fillet (skin off)
◆ Fillet (scales off/skin on)
▲ Fillet (scales on/skin on)

Notes: FCM run TV_EPA040; Deposition model run 35
Model output is autumn averaged PCB concentration (Aug. 28 - Oct. 26) for game fish, age 6+.
SMB fish ages > 3 (when determined);
Prep for 2004 individual samples assumed to be fillet.