Contaminants in Mississippi River Bed Sediments Collected Before and After the 1993 Summer Flood in Navigation Pools 1 to 11

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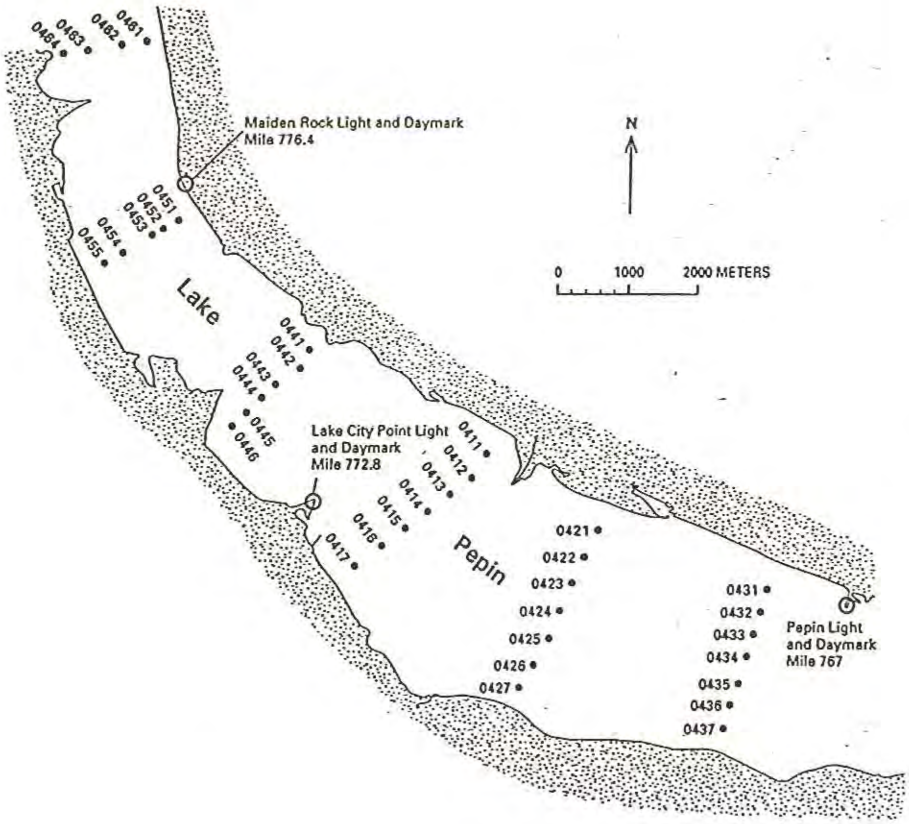

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SUMMARY AND CONCLUSIONS

Surficial sediments were collected from sampling areas located in the lower portions of each Upper Mississippi River navigation pool (Pools 1 to 11) before and after the summer flood of 1993. These surveys provided an opportunity to assess the flood's effect on general physical and chemical characteristics (particle size, total organic carbon and nitrogen) and contaminant concentrations (organochlorines, polynuclear aromatic hydrocarbons, and metals) of surficial bed sediments. The Ontario Ministry of the Environment and Energy's Sediment Quality Guidelines were used as an index to evaluate overall bed sediment contamination. Human health risks were evaluated based on the potential for bioaccumulation and biomagnification in fish.

Sediment grain size and organic matter are important factors influencing the bulk sediment chemical concentrations. The fine-grained organic sediments found in Pool 2, Pool 3, Lake Pepin, and Lake St. Croix have the ability to bind or adsorb greater concentrations of inorganic and organic chemicals than coarse-grained sediments. When evaluated on a bulk concentration basis, inorganic and organic chemicals were normally present at highest amounts from these sites, especially Lake Pepin. However, in order to more accurately evaluate the impact of point and nonpoint source pollutant contributions, sediments were adjusted or normalized for grain size and organic matter content. This was accomplished using manganese (Mn), a surrogate for grain size, and total organic carbon (TOC).

Normalizing bed sediment contaminant data by Mn or TOC indicated greatest contaminant enrichment occurred for the organochlorines (especially polychlorinated biphenyls, PCBs) and polynuclear aromatic hydrocarbons (PAHs) in Pools 1, 2, 3 and 4 (which includes Lake Pepin). Anthropogenic contaminant inputs from the Twin Cities metropolitan area were likely responsible for these observations. TOC- or Mn-normalized metal concentrations in bed sediments revealed less enrichment in bed sediments from Pool 1 through Lake Pepin as compared to organochlorines and PAHs. This may have been due to a difference in sediment sampling depth between the metals and organic contaminant samples. An evaluation of historic bed sediment metals data collected in 1980 indicated substantially greater enrichment of Cd and Pb (normalized by Mn) in surficial sediments from Pool 1 through Lake Pepin as compared to recent sediment data collected from this reach. Point source pollution abatement and the reduction of leaded gasolines have likely contributed to this temporal response.

Contaminant concentrations in bed sediments collected in 1994 (after the flood of 1993) were generally lower than concentrations found in 1991-92. This response was attributed to the deposition of "cleaner" (i.e. less contaminated) sediments over pre-flood sediments. The source of this sediment was likely sediment contributions from the tributaries or from the deltaic or riverine reaches upstream of the sampling areas. There appeared to be two exceptions to this overall response. The DDT metabolite, p,p'-DDD, and dieldrin were two organochlorine compounds that showed greater post-flood concentrations. It was hypothesized that these organic compounds were derived from runoff of contaminated soils from the watershed between the two sampling periods. The environmental significance of increased p,p'-DDD and dieldrin concentrations in post-flood bed sediments was expected to be low since they were present at low concentrations (i.e. < 4 ng/g and < 1 ng/g, respectively) and were substantially below the Low Effect Level (LEL) Sediment Quality Guidelines.

Bed sediment TOC, nitrogen, and metal concentrations exceeded the LEL Sediment Quality Guidelines at most sites. These exceedances were common at sites with organic, fine-grained sediments, especially Pools 2, Pool 3, upper and lower Lake Pepin, and Lake St. Croix. Pre-flood PCB concentrations exceeded the LEL guideline in lower Lake Pepin. Total PAH concentrations were substantially greater than the LEL guideline in sediments collected from Pool 1 (post-flood) and Pool 2 (pre-flood). Exceedance of the LEL guidelines may affect sediment use by some sediment-dwelling organisms according to the Sediment Quality Guidelines. Manganese concentrations exceeded the Severe Effect Level (SEL) Sediment Quality Guideline in sediments from Pool 3 (pre-flood), upper and lower Lake Pepin (pre- and post-flood), and Lake St. Croix (post-flood). The SEL guideline for nitrogen was also exceeded in Lake St. Croix sediments. Exceedance of the SEL is reported to indicate grossly polluted sediment and may indicate a significant adverse impact on sediment-dwelling organisms. Future benthic macro-invertebrate surveys or sediment bioassays may help establish if these organisms are being adversely impacted by the physical characteristics or chemical quality of surficial sediments.

Metal concentrations of surficial bed sediments need to be compared to concentrations found in pre-cultural sediments (deep sediment cores) to more accurately define metal enrichment in surficial sediments and to establish site background concentrations. Background metal concentrations may provide a more "practical" sediment guideline in situations where background concentrations exceed the LEL guideline.

PCB contamination continues to represent the contaminant of greatest environmental risk to humans, especially in the river reach from Pool 2 through Lake Pepin. However, PCB concentrations in bed sediments decreased following the flood through burial by less contaminated sediments. Over the long term, this reduction should result in lower benthic organism bioaccumulation, reduced suspended sediment contamination and lower concentrations of dissolved PCBs. PCB contamination of sport and commercial fisheries should continue to decline providing no new major sources of PCBs are released to the river and PCB-contaminated bed sediments remain undisturbed.

INTRODUCTION

Inorganic and organic pollutants have a strong tendency to adsorb to fine-grained organic sediments (Horowitz 1991, Karickhoff et al. 1979). Contaminated bed sediments represent a major source of exposure to benthic invertebrates. The transfer of many contaminants through the food chain (biomagnification) may contribute to toxicological problems for wildlife and humans. Dissolved and particulate-associated contaminant flux from contaminated bed sediments to overlying water can represent a significant long-term release and result in exceedances of water quality standards .

The U.S. Geological Survey (USGS) began a study of the transport and degradation of pollutants associated with suspended sediment in the Mississippi River in 1987 (Leenheer et al. 1989, Meade and Stevens 1990). This research was focused on the open-river reaches below St. Louis, Missouri. In 1991 and 1992, USGS expanded this work to include the Upper Mississippi River navigation pools from Minneapolis, Minnesota to St. Louis, Missouri. The more recent work included a continuation of the analysis of suspended sediments at selected Upper Mississippi River sites. In addition, representative samples of bed sediments were collected for inorganic and organic contaminant analysis from all navigation pools with the exception of Pool 17 (Moody 1996a,b,c). This work complemented earlier work by the Wisconsin Department of Natural Resources (WDNR) which implemented a long-term suspended sediment contaminant monitoring program in Pools 2, 3 and 4 in 1987 (Sullivan 1995).

The Upper Mississippi River navigation pools are known to trap and store sediments during normal and low flow conditions. Sediments and biological organisms of the Upper Mississippi River have been found to be contaminated with trace metals and PCBs, especially in the river reach below the Twin Cities metropolitan area (Wiener et al. 1984, Sullivan 1988, Dukerschein et al. 1992, Steingraeber et al. 1994, Beauvais et al. 1995). Dredging activities, commercial navigation, recreational boating and natural resuspension processes can result in the remobilization of contaminated sediments. There is little information on how high flows, such as that experienced in the Upper Mississippi River basin in the summer of 1993, influence sediment resuspension and the contaminant concentrations in bed sediments in the navigation pools.

The primary focus of this work was to re-sample bed sediments and to compare these data with pre-flood samples collected in 1991 and 1992 by USGS. Surveys conducted in navigation Pools 1-11 were funded by the U.S. EPA Region 5 through the Wisconsin Flood

Assessment Grant in 1993. The WDNR developed an interagency agreement with USGS, Denver, to assist with their sampling and analysis of contaminants in surficial bed sediments from the Upper Mississippi River navigation Pools 1-11 in 1994. A second part of this project involved a more detailed evaluation of PCB concentrations in sediment (congener analysis) by the WDNR on pre- (stored samples) and post-flood bed sediments. The WDNR initiated an expanded suspended sediment contaminant monitoring program following the flood of 1993 (Sullivan 1995) and some of this information was included in this report.

The primary objectives of this work were to:

- Collect surficial bed sediments in the summer of 1994 following previously established bed sampling methods used by USGS in 1991-92 in the navigation pools of the Upper Mississippi River.

- Repeat comparable chemical analyses of the bed sediments so that the changes in chemical characteristics before and after the flood of 1993 can be determined.

- Determine if the contaminants present in bed sediments represent a threat to human health and/or the environment.

Study Area

Construction of the 9-ft channel project in the Upper Mississippi River in the 1930s resulted in the creation of 29 lock and dams to augment commercial navigation. The addition of these dams changed the hydraulic conditions of the river from a free-flowing system to a series of shallow impoundments. Areas immediately above the dams typically have low current velocity which promotes sediment aggradation (Nielsen et al. 1984, Mc Henry et al. 1984). Mean sedimentation rates in the lower portions of Pools 4-10 have been estimated to be about 1-3 cm/yr based on ^{137}Cs dating (Mc Henry et al. 1984). Substantially lower rates (0.2-1.0 cm/yr) have been calculated when considering long-term bed sediment elevation changes by comparing historic and recent bathymetric surveys (Mc Henry et al. 1984, Korschgen et al. 1987).

Bed sediments were collected from Pool 1 in the Twin Cities metropolitan area to Pool 11 located above Dubuque, Iowa, a distance of approximately 265 river miles. Major tributary inflows in this reach include the Minnesota River at Pool 2, St. Croix River at Pool 3, Chippewa River at Pool 4 and the Wisconsin River at Pool 10 (Figure 1). Lake Pepin, a natural riverine lake, covers a 20 mile long by 1-2 mile wide portion of Pool 4. This lake has an average depth of approximately 18 ft. The lake's morphometric features provide an effective sediment trap in the upper study area. Anthropogenic contaminant inputs from the Twin Cities metropolitan area have resulted in elevated bed sediment contamination in Pools 1 through Lake Pepin (Pool 4), (Wiener et al. 1984, Sullivan 1988, Rada et al. 1990).

METHODS

Field Sampling Methods

Pre-flood bed sediment samples were collected from Upper Mississippi River navigation Pools 1-11 in 1991-92 following the methods described below. Detailed methods and analytical results for pre-flood samples have been provided by Moody (1996a). Where more than one pre-flood bed sediment composite sample was collected from a pool during different sampling periods, an average analyte value was derived. Replicate pre-flood sediment samples were collected from Pool 2 (July and October 1991 and April 1992) and Pool 8 (July 1991 and April 1992). PCB congener analysis of pre-flood sediment samples was performed on dried samples held in storage at 4°C. Organochlorine analyses of pre-flood samples analyzed by the USGS National Water Quality Laboratory, Arvada, Colorado were conducted on both wet (stored at 4°C) and dried samples held in storage and analyzed in 1994.

Post-flood sediment samples were collected from Pools 1-11, except 5A, following the same USGS sampling protocols established in 1991-92 (Moody 1996a). Composite samples of 12-21 individual bed sediment samples were obtained from 2-5 transects located in the lower one-third of each navigation pool. Pool 4 samples were collected from upper and lower Lake Pepin. A composite sediment sample was also collected at the lower end of Lake St. Croix, a riverine lake upstream from Pool 3 for comparative purposes. The St. Croix River has very good to excellent water quality in comparison to other area rivers and is used as a local reference to assess long term water quality trends (Metropolitan Waste Control Commission, 1992). Sampling progressed in a downstream order starting on June 11 in Pool 1 and ending in Pool 11 on June 22, 1994. The general location and number of samples in each pool's composite sample is provided in Table 1. No samples were collected from within the main navigation channel to avoid sampling coarse-grained sediments which generally show low contaminant concentrations and are susceptible to tow boat-induced sediment resuspension. Individual sampling sites were located with electronic positioning equipment to within +/-10 m. A map and horizontal coordinates (latitude/longitude) of transects and sampling sites have been provided by Moody (1996a,c).

Sediment samples were collected with a small stainless steel Van Veen-type dredge (10 cm x 10 cm). The upper 5-10 cm were removed using teflon-lined syringes for contaminant sampling and placed in separate quality-assured (clean) bottles for organochlorine, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCBs) congeners, total organic carbon (TOC) and nitrogen, and grain size analysis. The individual bottles served as the compositing jar for the sweet of analytes. Samples were refrigerated within 3-5 hours after collection. Metal samples were collected separately with a small 2.5-cm diameter plastic gravity coring device designed and built by Harold Wiegner, Minnesota Pollution Control Agency, St. Paul, MN. Sediment cores were frozen within 3-5 hours after collection and remained frozen until processed by the laboratory. Compositing of core samples (top 2 cm of each core) was conducted in the laboratory (Moody 1996a).

Suspended sediment contaminant data were obtained from a previous study that utilized sediment traps (Sullivan 1995). The suspended sediment collections described here were collected in the fall of 1993 and spring of 1994 at several sites between Pool 1 and 11. The data reflect an average where more than one sample was available for a give site.

Analytical Methods

Physical and chemical analyses of pre- and post-flood bed sediment samples followed the same or equivalent analytical methods. Where possible, the same analytical laboratory was utilized on both pre- and post-flood samples. A summary of analytical detection, precision, and accuracy data for general physical and chemical characteristics, organochlorines, PAHs, and metals are provided in Table 2. A separate table lists similar quality assurance/quality control data for PCB congener analysis (Table 3).

A detailed description of all analytical methods is provided by (Moody 1996a,c); however, some additional comments are warranted. Metals were analyzed in bed sediments using a sequential extraction technique (Hayes 1993, Roth et al. 1996a,b). The data represent the sum of sequential extractions for most metals. Metal concentrations for Cd, Cr, and Zn in post-flood bed sediments were derived from total extractions since the former method provided poor detection due to small sample size (Taylor 1995). A comparison of the sum of sequential extraction to total extraction of Buffalo River reference sediment (U.S. National Bureau of Standards No. 2704) revealed similar results for most metals analyzed in this study (Roth et al. 1996b). Therefore, no adjustments to the post-flood bed sediment Cd, Cr, and Zn data were believed warranted. A Lake Pepin reference sediment (collected in 1991, mixed and stored frozen, Smith 1992) was analyzed as an additional quality assurance sample as part of the post-flood laboratory work,

All suspended sediment metals data reported here are based on total extractions. PCB analysis of suspended sediment followed a congener-based method. Additional field and analytical information on these samples have been described by Sullivan (1995). These samples were analyzed by the Wisconsin State Laboratory of Hygiene in Madison, Wisconsin.

Sediment Quality Assessment

The Ontario Ministry of the Environment and Energy's Sediment Quality Guidelines (Persaud et al. 1993) were used as an index to assess bed sediment contamination. These guidelines were used because they included most of the physical and chemical measurements analyzed in this study, provide some protection to sediment dwelling organisms, and are widely recognized. Similar sediment guidelines or criteria from the U.S. EPA are only available for a few organic compounds. The pre- and post-flood sediment samples were compared to the following three classification levels provided in the Sediment Quality Guidelines in an attempt to generalize overall sediment quality:

1. **No Effect Level (NEL)** - The level at which chemicals in the sediment do not affect fish or sediment-dwelling organisms. No biomagnification (food chain transfer) of chemicals is expected. Sediment is considered clean.

2. **Lowest Effect Level (LEL)** - A level of contamination which has no effect on the majority of sediment-dwelling organisms. The sediment is considered to be marginally polluted.

3 **Severe Effect Level (SEL)** - The level at which the sediment is heavily polluted and likely affects the health of sediment-dwelling organisms. Additional testing may be warranted to assess sediment toxicity.

Other Methods

An assessment of the relative changes in bed sediment physical and chemical characteristics between the two sampling periods (i.e. pre- and post-flood) was based on calculating the relative percent difference (R%D):

$$((A - B) / C) \times 100$$

where, A is the post-flood value, B is the pre-flood value and C is the average of A and B.

This approach was used because it allowed a comparison to precision measurements made on replicate samples for a particular analyte reported by the laboratory.

Bed and suspended sediment TOC and Mn data were used to normalized sediment data for organic matter and grain size effects. Organic matter concentrates trace elements by both chemical and physical processes (Horowitz 1991). In addition, there is normally a positive correlation between organic matter and sediment surface area or decreasing grain size. Sediment organic carbon content has been shown to be important in the sorption of nonpolar organic compounds (Karickhoff et al. 1979) and provides a basis for establishing the bioavailability of nonionic organic chemicals to benthic organisms (Di Toro et al. 1991). Manganese oxides are known to "scavenge" trace elements and are present on coatings of mineral grains and fine sediments (Horowitz 1991). This element has been used successfully in the Upper Mississippi River to normalize trace element and PCB data to assess anthropogenic enrichment of bed (Wiener et al. 1984) and suspended sediments (Sullivan 1995). Although grain size data were available, it was believed that Mn would provide a better reflection of grain size in metal samples since it more closely reflected the composite sediment samples analyzed for other metals.

RESULTS and DISCUSSION

General Physical and Chemical Characteristics

General sediment characteristics considered in this evaluation included: sediment grain size (% sand, silt and clay), total volatile solids (TVS), TOC, and total nitrogen (N). The pre- and post-flood sediment data for navigation Pools 1-11 are listed in Table 4 and presented graphically in Figures 2-4. No pre-flood TVS samples were collected so these results were not plotted.

Bed sediment grain size was highly variable between pools (Figure 2). In general, coarse-grained sediments (those dominated by sands) were found in Pools 1 and 6. Samples from Pool 4 (upper and lower Lake Pepin) were primarily composed of clay-sized sediment (60%) while the Pool 9 sediment samples were mainly silt (> 60%). A comparison of pre- and post-flood sediment grain size indicated a noticeable increase (> 35% R%D) in the sand content in samples from Pools 2, 3, 8 and 11 (Table 5). In contrast, only samples from upper Lake Pepin (4U) and Pool 5 showed a large reduction (< -25% R%D) in the post-flood sand composition and these were associated with an increase in silt.

The TOC content of bed sediments was determined by two different laboratories (Moody and Anderson 1996, Moody 1996b). Although specific differences were observed between laboratories and likely reflected method differences (Table 4), the spatial TOC profile provided by the two laboratories were similar (Figure 3). Highest TOC values (> 2%) from both laboratories were found in samples from Lake Pepin and Lake St. Croix, sediments that were comprised of high clay or TVS content (Table 4). As expected, lowest TOC content was found in sediment samples dominated by sand (Pools 1 and 6). In general, relatively small changes in TOC were noted when comparing pre- and post-flood bed sediment samples (Figure 3). The greatest change was noted for Pool 10 which decreased -124% (R%D, Table 5).

Post-flood suspended sediment samples (Table 6) collected with sediment traps had substantially greater TOC content than either pre- or post-flood bed sediment samples (Figure 3). This reflects smaller grain size and greater organic matter content in suspended sediments as compared to bed sediments. The highest suspended sediment TOC content in the study reach was found in samples collected from lower Lake Pepin and was consistent with bed sediment results.

The N content of bed sediments followed a similar spatial profile as observed with clay and TOC. Highest N concentrations (4000 μg/g) were found in samples from upper and lower Lake Pepin (4U and 4L, Figure 4), sites dominated by clay-sized sediment and exhibiting high TOC. This pattern is expected since N is an important component in biogenic material (organic sediments) and fine-grained sediments have greater organic matter content than coarse-grained sediments.

A comparison of pre- and post-flood bed sediment N results indicated no or relatively small changes in the N composition (Table 5), especially when laboratory precision (± 27-50%) is considered (Table 2). The N content of bed sediments was noticeably less than post-flood suspended sediment samples (Figure 4) and reflects differing TOC levels and grain size between the two sediment matrices.

Total organic carbon- and Mn-normalized bed sediment N values exhibited an increasing trend between Pool 1 and Lake Pepin. A similar trend was observed with post-flood suspended sediments (Figure 4). The increased enrichment of N (relative to TOC and Mn concentrations) in bed and suspended sediments along this gradient may be associated with inorganic N loadings from point and nonpoint sources and nitrogen utilization within the riverine pools. In particular, the assimilation of inorganic nitrogen by algae may provide particulate organic matter that is enriched with nitrogen.

Sediment Quality Guidelines for TOC indicate a LEL and SEL of 1 and 10%, respectively (Table 7). Bed sediments from Pools 2-5 and 9 exceeded the LEL guideline in both pre- and post-flood samples (Huffman Laboratory data). Other sites exceeding LEL for TOC included the pre-flood samples from Pools 5A and 10 and the post-flood sample from Lake St. Croix. Although the LEL for TOC was exceeded in several pools, the TOC content of bed sediments did not appear to negatively influence fingernail clam, mayfly, midge and oligochaete densities based on an independent multi-agency benthic invertebrate survey of several pools (Pools 4,5,7,8,9, and 11) conducted in the fall of 1994 (Nelson 1995). For example, highest fingernail clam and oligochaete densities (4,218 and 464 organisms/m^2, respectively) were reported for Pool 9 which had a sediment TOC content equal to the LEL guideline. There were no sediment TOC values exceeding the SEL.

The LEL and SEL Sediment Quality Guidelines for N are 550 and 4800 μg/g, respectively (0.055 and 0.48%, Table 7). Almost all sites had at least one bed sediment sample exceeding the LEL with the exception of Pools 1 and 6, which were comprised primarily of sands. The decomposition of sedimentary organic N to ammonia by heterotrophic bacteria

(Wetzel 1975) can result in elevated ammonia N concentrations in sediment pore waters and release to overlying water. This may increase the potential for sediment toxicity problems associated with un-ionized ammonia N. This is expected to be more important during low summer flows when water column pH is greater due to increase photosynthetic activity by phytoplankton and other aquatic plants. The N content of bed sediments did not exceeded the SEL.

Organochlorine Compounds

There were 17 organochlorine compounds (OCls) analyzed in pre- and post-flood sediments (Table 4). Of these 17, only 6 were found at levels above the reported laboratory detection limits. The 6 compounds listed by their relative abundance included: PCBs, technical chlordane, p,p'-DDE, p,p'-DDD, p,p'-DDT, and dieldrin.

Highest bed sediment OCl concentrations were found in the upper study area extending from Pool 1 to lower Lake Pepin. Concentrations of detected OCls declined to low or undetectable levels below Lake Pepin (Figure 5-9). Highest OCl concentrations were found for PCBs in pre-flood samples from Lake Pepin (110-150 ng/g). Separate analyses for PCBs by two different laboratories using an Aroclor-based method (Hrinko and Moody 1996, Rostad et al. 1996) versus congener analysis (Sullivan and Lodge 1996) yielded generally similar spatial results (Figures 8 and 9). Post-flood suspended sediment PCB concentrations (Figure 9) were greater than post-flood bed sediment concentrations. However, TOC- and Mn- normalized suspended sediment PCB concentrations were very similar to corresponding bed sediment values from the same area. This suggests a close linkage between PCBs in suspended sediments and bed sediments as a result of sediment-water partitioning, sediment resuspension and sedimentation processes.

Post-flood technical chlordane, p,p'-DDE, p,p'-DDT and PCB concentrations in bed sediments generally declined from pre-flood values. This was particularly notable for PCBs and technical chlordane (Table 5). In contrast, there appeared to be greater concentrations of dieldrin and p,p'-DDD in post-flood sediments. Dieldrin concentrations in post-flood sediments were found slightly above the detection level and this compound was only detected in sediments from Pools 2, 3 and Lake Pepin. The post-flood increase in the DDT metabolite p,p'-DDD appeared to be more significant and was especially notable when the data were normalized by the TOC or manganese content (Figure 6). The post-flood p,p'-DDD data from Lake Pepin did not show this increase but actually had slightly lower p,p'-DDD concentrations. However, the greater post-flood concentrations for six other Pools (2, 3, 6, 8, 9 and 11) suggests this increase was real. It is suspected this input originated from the runoff of p,p'-DDD contaminated soils from watershed and may be flood-related. Resuspension of buried (more contaminated) pool sediments was not expected to a be the source of the p,p'-DDD since sediment scouring would have likely increased the PCB content of post-flood surficial sediments as well, but this was not observed.

Normalizing most OCls by TOC or Mn provided a similar longitudinal profile and indicated greatest OCl enrichment in the Pool 2 through Lake Pepin reach (Figure 5-9). In general, the longitudinal profile of these OCls was consistent with previous PCB contaminant studies in the Upper Mississippi River which have indicated greatest contamination in aquatic organisms and sediment collected from Pool 2 through Lake Pepin (Steingraeber et al. 1994, Sullivan 1988).

An evaluation of the percent composition of PCB homologues, derived from congener data (Table 9), in bed sediments indicated both temporal and spatial changes (Figure 10). Tetra- and penta-chlorinated biphenyls showed an increase in composition while the di- and tri-chlorinated biphenyls decreased in post-flood samples. This temporal change in composition was particularly evident at Pool 2 and may reflect a recent input and different type (homologue composition) of PCBs entering Pool 2 between 1991 and 1994. The post-flood data also indicated a spatial change in the percent composition of PCB homologues from Pool 2 through Lake Pepin. A decrease in the composition of lower chlorinated PCBs (tri- and tetra-) and an increase in the higher chlorinated PCBs (hexa-, hepta-, octa- and nona-) were measured in surficial sediments from this river reach in the post-flood samples. This spatial distribution of PCB homologues was not observed in the pre-flood samples and did not match that reported in suspended sediments (Sullivan 1995). In general, varying source inputs, differential homologue partitioning, volatilization and degradation makes interpretation difficult.

Lake St. Croix sediment had a greater percentage of penta-chlorinated biphenyls in comparison to the Mississippi River samples (Figure 10) and likely reflected different source inputs. Sediment from Lake St. Croix had noticeably lower TOC-normalized PCB homologue concentrations than the Mississippi River system from Pools 2 through Lake Pepin and reflects lower anthropogenic PCB inputs from the St Croix River watershed.

Sediment Quality Guidelines are available for all 6 of the detected OCls measured in bed sediments. Almost all sediment samples that had detectable OCls were below the LEL guidelines (Table 7). Only the pre-flood total PCB sample (congener sum) collected from lower Lake Pepin (4L) exceeded the 7000 ng/g organic carbon (OC) LEL guideline by 13%. Based on the Sediment Quality Guidelines, lower Lake Pepin would be considered to be marginally polluted with respect to PCBs and potential impacts to some sediment dwelling organisms are likely. Most of the pre- and post-flood sediment PCB samples collected from Pool 2 through Lake Pepin exceeded the NEL (1000 ng/g OC) which would indicate increased risk of biomagnification of PCBs through the food chain. Technical chlordane and dieldrin were below the NEL guidelines for all samples and would indicate little biomagnification potential based on the Sediment Quality Guidelines.

The analysis of OCls in fish collected from the study reach has normally revealed low or non-detectable concentrations with the exception of PCBs (Amrhein 1995, King 1995, Iowa Department of Natural Resources 1990). Historically, the greatest PCB contamination in fish has been found in the Pool 2 through Lake Pepin reach (Sullivan, 1988) and has warranted the issuance of fish consumption advisories by Minnesota and Wisconsin for more than 15 years.

Fish tissue (skin-on filets) concentrations of carp (about 13-17 inches in length) collected from Pool 2 and Lake Pepin in 1994 for a separate study (King 1995) revealed the same 6 OCls found in bed sediments. In addition, their order of abundance in fish generally matched that found in bed sediments. Highest organochlorine concentration in carp were attributed to PCBs collected from Lake Pepin (300 ng/g wet wt) and would trigger a consumption advisory in Minnesota (Shubat 1994). However, since bed sediment PCB concentrations declined after the flood, lower benthic organism PCB burdens, reduced suspended sediment and dissolved concentrations, and lower contamination of other aquatic organisms can be expected in the future. This will depend on no major increases in point and nonpoint source PCB contributions and continued burial of contaminated sediments with "cleaner" material.

Polynuclear Aromatic Hydrocarbons

Pre- and post-flood sediments were analyzed for 16 polynuclear aromatic hydrocarbons (PAHs). These included: naphthalene, acenaphthalene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, indeno [123-cd]pyrene and dibenzo[a,h]anthracene (Barber and Writer 1996, Barber et al. 1996). Most of these individual PAHs were not detected or were present at concentrations below 0.2 μg/g. Individual PAHs exhibiting the highest concentrations in pre-flood sediments (2-5 μg/g) included: fluoranthene, pyrene, benzo[a]anthracene, and chrysene. The sum of the above 16 PAHs (i.e. those exceeding the detection limit) were used to define the total PAH concentration. Fluoranthene and pyrene were considered individually in this evaluation since they represented the two most abundant PAHs present in bed sediments (Table 4).

Highest concentrations of total PAHs were found in pre-flood sediments from Pools 1 (16.9 μg/g) and 2 (14.2 μg/g), (Figure 11). Pre-flood PAH concentrations were noticeably lower (2.2-3.4 μg/g) between Pool 3 and lower Lake Pepin (4L). Total PAH concentrations in both pre- and post-flood sediments below Lake Pepin were normally less than 0.5 μg/g. Normalizing PAHs by TOC or Mn indicated a similar longitudinal profile as found for the organochlorines. These data suggest a substantial enrichment of PAHs in Pools 1 and 2 in comparison to sediments from the lower navigation pools and Lake St. Croix. The sources of these PAHs are most likely from inputs from the Twin Cities metropolitan area (Writer and Barber 1995).

A comparison of pre- and post-flood total PAH concentrations revealed a decline in post-flood samples at all pools that exhibited pre-flood concentrations exceeding 1 μg/g (Figure 11). This temporal change was greatest in sediments collected from Pools 1,2 and 6 (Table 5). Temporal changes in PAH concentrations below Pool 6 were not considered important since concentrations were low (< 0.6 μg/g). The decline in post-flood PAH concentrations, at least in Pools 1 through Pool 6, suggest a dilution (burial) by sediments with lower PAH concentrations.

Pre- and post-flood bed sediment total PAH concentrations from Pools 1 and 2 exceeded the LEL Sediment Quality Guideline of 400 μg/g OC (Table 7). Similarly, the LEL was exceeded for fluoranthene and pyrene at these sites. Additional exceedances of the LEL for pyrene were found at lower Lake Pepin (pre-flood) and Pool 6 (pre- and post-flood) sediments. The pre-flood sample from Pool 6 was also greater than the LEL for fluoranthene. Although bulk fluoranthene and pyrene concentrations from Pool 6 were low, normalizing the data by TOC resulted in high normalized concentrations since the TOC content of Pool 6 was low (0.2-0.4%). The greater TOC content of bed sediments and relatively low PAH concentrations of other samples collected below Lake Pepin, resulted in low TOC-normalized PAH concentrations. Exceedances of the LEL Sediment Quality

Guideline indicate marginal PAH pollution and potential adverse impacts to some sediment dwelling organisms, especially in Pools 1 and 2. The maximum TOC-normalized PAH concentrations (1000-1300 μg/g OC) were found in Pool 1 and 2 but were substantially below the SEL guideline (10,000 μg/g OC).

Metals

Eight metals (Cd, Cr, Cu, Fe, Pb, Mn, Hg, and Zn) were analyzed in pre- and post-flood surficial sediments (Table 4). Highest metal concentrations in bed sediments were found in samples collected from Lake Pepin. Metal concentrations in Pool 2, 3 and Lake St. Croix sediments were also elevated in comparison to samples collected below Lake Pepin (Figures 12 to 19). The spatial pattern of post-flood suspended sediment metals concentrations generally matched those found in post-flood bed sediments. However, concentrations of Pb, Mn and Zn in suspended sediment were normally greater than those found in bed sediments. Sediment grain size, especially the clay composition, was an important factor influencing the bed sediment metal concentrations. This was particularly true for Lake Pepin sediments which had an average clay content of about 60% or about 3 to 4 times greater than other sites (Figure 2).

Normalizing bed sediment metals data by TOC and Mn, provided distinctly different longitudinal profiles than bulk metal concentrations (Figures 12-19). Total organic carbon-normalized metals data generally indicated higher values in Pools 1 or 2 and 6 through 11 as compared to Pools 3 through 5A. This was markedly different from the normalized OCl and PAH data which showed greater enrichment of these contaminants in bed sediments between Pools 1 through Lake Pepin. These data indicated the anthropogenic enrichment of metals in surficial bed sediments collected in pools adjacent to and immediately downstream of the Twin Cities area was generally lower than the organic chemicals evaluated in this study. It is possible that the greater enrichment found for OCls and PAHs may have been due to a deeper sampling strata (0-10 cm) as compared to metal samples (0-2 cm). Sampling a deeper sediment strata may have encountered greater OCl and PAH concentrations associated with historic anthropogenic inputs.

Manganese-normalized metals data had less variation in the longitudinal profile than TOC-normalized or bulk metal concentrations. There were some exceptions worth noting. Manganese-normalized Cd data indicated greater enrichment in Pools 1 through Lake Pepin. In addition, Pool 1 had substantially higher Mn-normalized post-flood values of Cu and Cr and greater pre- and post-flood values for Pb and Fe. The post-flood Mn- and TOC-normalized Hg values in Pool 2 were also elevated. A previous longitudinal bed sediment metal investigation in the Upper Mississippi River (Pools 1-10) conducted in 1980 indicated more extensive enrichment of Cd, Hg, and Pb (Mn-normalized data) in Pools 1 through Lake Pepin (Wiener et al. 1984). Their study also indicated maximum Mn-normalized concentrations of Cd and Pb that were about 10 and 1.4 times greater, respectively, than those found in this study. Point source pollution abatement and the reduction of lead additives to gasoline were probable factors responsible for these temporal changes.

Post-flood bed sediment metal concentrations at most sites were normally lower than pre-flood data. The only major exception was Pool 5 which had greater concentrations of 6 metals post-flood and may have been influenced by a large increase (71% R%D) in the silt content (Table 5). The decrease in metal concentrations observed at most sites post-flood was likely attributable to a dilution of bed sediments with coarser-grained sediments of lower metal content that were deposited during high flows. The source of this sediment is likely from tributary inflows or zones of sediment scour or resuspension upstream from the sampling sites. This is consistent with suspended sediment metals data which indicated lower metal concentrations on a dry weight basis during periods of high Mississippi River flow (Sullivan 1995).

Pre-flood sediment metal concentrations from upper and lower Lake Pepin (4U and 4L) exceeded the LEL Sediment Quality Guidelines for all eight metals analyzed in this study (Table 7). Post-flood sediments from Lake Pepin had slightly fewer exceedances of metal LEL guidelines. Most sites had a least one LEL exceedance in both pre- and post-flood samples. The only exceptions were the coarse-grained sediments collected from Pool 1 (pre-flood) and Pool 6 (post-flood). The most common metals exceeding the LEL were Cr, Cu, and Mn. The least common were Pb, Hg and Zn.

The SEL guideline for Fe was exceeded in pre- and post-flood sediments from lower Lake Pepin. Pre-flood manganese concentrations exceeded the SEL guideline in Pool 3, in pre- and post-flood sediments from upper and lower Lake Pepin, and in post-flood sediments from Lake St. Croix. The large number of exceedances of SEL guideline for Mn may suggest a problem with using this element to normalize for grain size effects. However, correlation analysis of Mn and clay content (all data) was high ($r=0.93$) and was similar to that of Fe and clay ($r=0.95$). Fe is another element that has been utilized to normalize for grain size effects and it was highly correlated to Mn ($r=0.96$).

In general, the metals data indicated a moderate level of contamination at many sites, including Lake St. Croix, when compared to the Sediment Quality Guidelines (Table 7). A similar response was not observed with the OCls and PAHs. This likely reflects the difference in the derivation of Sediment Quality Guidelines for organic contaminants versus metals. OCl and PAH guidelines are based on organic carbon normalization, whereas metal guidelines are based on bulk metal concentrations. A comparison of surficial bed sediment metals data to background metal concentrations (deep sediment core samples) may provide a better index to present day anthropogenic enrichment of metals in bed sediments and may help evaluate the need for sediment toxicity studies.

REFERENCES

Amrhein, J., 1995. Personal communication. Wisconsin Department of Natural Resources, Madison, WI.

Barber, L.B. and Writer, J.H., 1996. Sterols, polynuclear aromatic hydrocarbons, and liner alkylbenzene sulfonates. In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments in the navigation pools of the Upper Mississippi River after the flood of 1993, Chapter 2, U.S. Geological Survey Open-File Report 96-xxx.

Barber, L.B., and Writer, J.H., Tabor, C.F., and Leenheer, J.A., 1996. Sterols, polynuclear aromatic hydrocarbons, and linear alkylbenzene sulfonates. In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments and water in the navigation pools of the Upper Mississippi River, July 1991-April 1992, Chapter 2, U.S. Geological Survey Open-File Report 95-708.

Beauvais, S.L., Wiener, J.G., and Atchison, J.G., 1995. Cadmium and mercury in sediment and burrowing mayfly nymphs (Hexagenia) in the Upper Mississippi River, USA. Arch. Environ. Contam. Toxicol. 28, 178-183.

Di Toro, D.M., Zarba, C.S., Hansen, D.J., Berry, W.J., Swartz, R.C., Cowan, C.E., Pavlou, S.P., Allen, H.E., Thomas, N.A., and Paquin, P.R., 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. Environ. Toxicol. and Chem. Vol 10, p. 1541-1583.

Dukerschein, J.T., Wiener, R.G., Rada, R.G., and Steingraeber, M.T., 1992. Cadmium and mercury in emergent mayflies (Hexagenia bilineata) from the Upper Mississippi River. Arch. Environ. Contam. Toxicol. 23, p. 109-116.

Hayes, H.C., 1993. Metal associations in suspended sediments and bed sediments from the Mississippi River. Masters Thesis, Colorado School of Mines, Golden, CO.

Horowitz, A.J., 1991. A primer on sediment-trace element chemistry. Second Ed., Lewis Publishers, Inc., Chelsea, MI, 136 p.

Hrinko, D.E., and Moody, J.A., 1996. Organochlorine compounds, In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments in the navigation pools of the Upper Mississippi River after the flood of 1993, Chapter 4, U.S. Geological Survey Open-File Report 96-XXX.

Iowa Department of Natural Resources, 1990. Report of the analysis of fishes collected during 1989 from the regional ambient fish tissue monitoring sites in Iowa. Water Quality and Planning Section, Des Moines, IA. 47 p.

Karickhoff, S.W., Brown, D.S., and Scott, T.A., 1979. Sorption of hydrophobic pollutants on natural sediments. Water Research. Vol. 13, p. 241-248.

King, P., 1995. Person communication. Minnesota Pollution Control Agency, St. Paul, MN.

Korschgen, C.E., Jackson, G.A., Muessig, L.F., and Southworth, D.C., 1987. Sedimentation in Lake Onalaska, Navigation Pool 7, Upper Mississippi River, since impoundment. Water Resources Bulletin Vol. 23(2):221-226.

Leenheer, J.A., Meade, R.H., Taylor, H.E., and Pereira, W.E., 1989. Sampling, fractionation and dewatering of suspended sediment from the Mississippi River for geochemical and trace-contaminant analysis. In: Mallard, G.E., and Ragone, S.E. eds., U.S. Geological Survey Toxic Substances Hydrology Program- Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 501-512.

Mc Henry, J.F., Ritchie, J.C., Cooper, C.M., and Verdon, J., 1984. Recent rates of sedimentation in the Mississippi River. In: Wiener, J.G., Anderson, R.V., and McConville, D.R., Contaminants in the Upper Mississippi River. Proceedings of the 15th annual meeting of the Mississippi River Research Consortium. Butterworth Publishers, Stoneham, MA, p 99-117.

Meade, R.H., and Stevens, H.H., Jr., 1990. Strategies and equipment for sampling suspended sediment and associated toxic chemicals in large rivers-with emphasis on the Mississippi River: Science of the Total Environment, Vol. 97/98, p. 125-135.

Metropolitan Waste Control Commission 1992. 1990 Water quality summary report. Water Quality Monitoring Division, Quality Control Department Report QC-90-239. St. Paul, MN, 16 p.

Moody, J.A., ed., 1996a. Hydrologic, sedimentologic and chemical data describing surficial bed sediments and water in the navigation pools of the Upper Mississippi River, July 1991-April 1992, U.S.Geological Survey Open-File Report 95-708.

Moody, J.A., 1996b. Sampling strategy, hydrology and sediment. In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments in the navigation pools of the Upper Mississippi River after the flood of 1993, Chapter 1, U.S. Geological Survey Open-File Report 96-XXX.

Moody, J.A., ed., 1996c. Hydrologic, sedimentologic and chemical data describing surficial bed sediments in the navigation pools of the Upper Mississippi River after the flood of 1993, U.S. Geological Survey Open-File Report 96-xxx.

Moody, J.A., and Anderson, C.J., 1996. Sampling strategy, hydrology and sediment characteristics. In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments and water in the navigation pools of the Upper Mississippi River, July 1991-April 1992, Chapter 1, U.S.Geological Survey Open-File Report 95-708.

Nelson, E., 1995. Unpublished data. U.S. Fish and Wildlife Service. Winona, MN.

Nielsen, D.N., Rada, R.G., and Smart, M.M., 1984. Sediments of the Upper Mississippi River: Their sources, distribution and characteristics. In: Wiener, J.G., Anderson, R.V., and McConville, D.R., Contaminants in the Upper Mississippi River. Proceedings of the 15th annual meeting of the Mississippi River Research Consortium. Butterworth Publishers, Stoneham, MA, p 67-98.

Persaud, D., Jaagumagi, R., and Hayton, A., 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Water Resources Branch, Ontario Ministry of the Environment and Energy, 24 p.

Rada, R.G., Wiener, J.G., Bailey, P.A., and Powell, D.E. 1990. Recent influxes of metals into Lake Pepin, a natural lake on the Upper Mississippi River. Arch. Environ. Contam. Toxicol. Vol. 19, p. 712-716.

Roth, D.A., Antweiler, R.C., Briton, T.I., and Taylor, H.E., 1996a. Major and trace elements. In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments in the navigation pools of the Upper Mississippi River after the flood of 1993, Chapter 3, U.S. Geological Survey Open-File Report 96-xxx.

Roth, D.A., Hayes, H.C., Antweiler, R.C., Brinton, T.I., Garbarino, J.R., Peart, D.B., and Taylor, H.E. 1996b. Major elements, trace elements and nutrients. In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments and water in the navigation pools of the Upper Mississippi River, July 1991-April 1992, Chapter 4, U.S. Geological Survey Open-File Report 95-708.

Rostad, C.E., Sullivan, J.F., Hrinko, D.E., Bisop, L.M., and Moody, J.A., 1996. Organochlorine compounds, In: Moody, J.A., ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments and water in the navigation pools of the Upper Mississippi River, July 1991-April 1992, Chapter 3, U.S.Geological Survey Open-File Report 95-708.

Shubat, P., 1994. Criteria used to issue fish consumption advice: 1994 Minnesota fish consumption advisory. HRA Series FSH-94-001 draft report. Minnesota Department of Health. St. Paul, MN.

Smith, S. 1992. Unpublished report. U.S. Fish and Wildlife Service, Twin Cities Field Office, Bloomington, MN.

Steingraeber, M.T., Schwartz, T.R., Wiener, J.G., and Lebo J.A., 1994. Polychlorinated biphenyl congeners in emergent mayflies from the Upper Mississippi River. Environ. Sci. Technol., Vol. 28(4):707-714.

Sullivan, J.F., 1995. Contaminants in Mississippi River suspended sediment. Unpublished report. Wisconsin Department of Natural Resources, La Crosse, WI. 65p.

Sullivan, J.F., 1988. A review of the PCB contamination problem of the Upper Mississippi River System. Unpublished report. Wisconsin Department of Natural Resources, La Crosse, Wisconsin. 50 pp.

Sullivan, J.F. and Lodge, K.B., 1996. Polychlorinated biphenyl congeners, In: Moody, J.A. ed., Hydrologic, sedimentologic and chemical data describing surficial bed sediments in the navigation pools of the Upper Mississippi River after the flood of 1993, Chapter 3, U.S. Geological Survey Open-File Report 96-XXX.

Taylor, H., 1995. Personal communication. U.S. Geological Survey, Denver, CO.

Wetzel, R.G., 1975. Limnology. W.B. Saunders Company. Philadelphia, PA. 743 p.

Wiener, J.G., Jackson, G.A., May, T.M., and Cole, B.P., 1984. Longitudinal distribution of trace elements (As, Cd, Cr, Hg, Pb and Se) in fishes and sediments in the Upper Mississippi River. In: Wiener, J.G., Anderson, R.V., and McConville, D.R., Contaminants in the Upper Mississippi River. Proceedings of the 15th annual meeting of the Mississippi River Research Consortium. Butterworth Publishers, Stoneham, MA, p. 139-170.

Writer, J.H., and Barber L.B., 1995. Effect of the 1993 Mississippi River flood on bed sediment distribution of municipal contaminants. Society of Environmental Toxicology and Chemistry, 2nd SETAC World Congress, Vancover, British Columbia.

Table 1. Approximate location of bed sediment transects and number of samples in the composite bed sediment sample for each pool or site.

River Pool or Site *	Transect Locations River mile	No. of Transects	No. of samples in pool composite	
			Pre-flood 1991-92	Post-flood 1994
1	848.0-849.2	3	12	12
2	816.1-821.1	2	18	18 a
3	797.3-798.1	3	16	15
SC	1.3-4.2	5	ns	15 b
4U	774.0-778.0	3	15	15
4L	768.0-772.0	3	21	20
5	739.8-744.7	3	18	18
5A	729.8	2	14	ns
6	714.9-721.1	3	20	20
7	702.7	2	20	20
8	682.1-684.7	3	20	19 a
9	648.0-655.0	3	18	18
10	615.0-617.2	3	20	20
11	585.1-591.9	3	20	20

* - SC = Lake St. Croix, 4U = Upper Lake Pepin, 4L = Lower Lake Pepin.

a - Duplicate sample was collected.

b - 14 samples for organochlorines, polynuclear aromatic hydrocarbons, polychorinated biphenyls, total organic carbon and nitrogen.

ns - No sample

Table 2. Summary of laboratory quality assurance and quality control data for sediment analyses conducted by several laboratories used in this study.

Compound/Parameter	(1) Lab	Detection Limit	(2) Precision		(3) Accuracy	
			%	Method	%	Method
General Physical & Chemical Characteristics						
Sand (%)	USGSL	na	5	R%D	98	R%D
Silt (%)	USGSL	na	5	R%D	98	R%D
Clay (%)	USGSL	na	5	R%D	na	
Total volatile solids (%)	Huff.	na	10	R%D	4	R%D
Total organic carbon (%)	Huff.	0.05	6-15	RSD#	99	%Rec
Total organic carbon (%)	WSLOH	0.02	6.8	R%D	na	
Total Nitrogen $\mu g/g$	Huff.	100	27-50	RSD#	100	%Rec
Organochlorine Compounds						
Lindane (ng/g)	NWQL	0.1	11	RSD	78	%Rec
Heptachlor (ng/g)	NWQL	0.1	10	RSD	73	%Rec
Aldrin (ng/g)	NWQL	0.1	1.1	RSD	75	%Rec
Heptachlor epoxide (ng/g)	NWQL	0.1	2.5	RSD	74	%Rec
Technical chlordane (ng/g)	NWQL	1.0	5.7	RSD	70	%Rec
Endosulfan I (ng/g)	NWQL	0.1	2.6	RSD	67	%Rec
Dieldrin (ng/g)	NWQL	0.1	2.2	RSD	79	%Rec
p,p' - DDE (ng/g)	NWQL	0.1	5.3	RSD	82	%Rec
Endrin (ng/g)	NWQL	0.1	na		63	%Rec
Perthane (ng/g)	NWQL	1.0	na		103	%Rec
p,p' - DDD (ng/g)	NWQL	0.1	5.8	RSD	91	%Rec
p,p' - DDT (ng/g)	NWQL	0.1	5.8	RSD	77	%Rec
p,p' - Methoxychlor (ng/g)	NWQL	0.1	na		103	%Rec
Mirex (ng/g)	NWQL	0.1	32	RSD	68	%Rec
Toxaphene (ng/g)	NWQL	10	na		71	%Rec
Gross PCNs (ng/g) +	NWQL	1.0	na		na	
Gross PCBs (ng/g) +	NWQL	1.0	3.1	RSD	99	%Rec
Polynuclear Aromatic Hydrocarbons (PAHs)						
Fluoranthene ($\mu g/g$)	NRP/PTI	na	na		na	
Pyrene ($\mu g/g$)	NRP/PTI	na	na		na	
Total PAHs ($\mu g/g$)	NRP/PTI	na	105	RSD	na	
Metals *						
Cadmium ($\mu g/g$)	NRP	0.1	3.1	RSD	92	%Rec
Chromium ($\mu g/g$)	NRP	7	6.8	RSD	92	%Rec
Copper ($\mu g/g$)	NRP	0.9	6.4	RSD	110	%Rec
Iron (mg/g)	NRP	0.22	6.4	RSD	97	%Rec
Lead ($\mu g/g$)	NRP	0.09	4.8	RSD	100	%Rec
Manganese ($\mu g/g$)	NRP	2	6.4	RSD	100	%Rec
Mercury ($\mu g/g$)	NRP	0.01	7.7	RSD	102	%Rec
Zinc ($\mu g/g$)	NRP	10	4.9	RSD	99	%Rec

1 - Laboratories: NWQL = USGS, National Water Quality Lab, Arvada, CO; Huff = Huffman Laboratories, Inc., Golden CO; USGSL = USGS Sediment Laboratory, Iowa City, IA; WSLOH = Wisconsin State Laboratory of Hygiene, Madison; NRP = USGS, National Research Program, Boulder, CO; PTI = PTI Environmental Services, Boulder, CO.

2 - Precision data - R%D = Relative percent difference, RSD = Relative standard deviation

3 - Accuracy data - R%D = Relative percent difference from known value, %Rec = Percent spike recovery.

* - Metal detection limits are based on total digestions, accuracy and precision data are based on the sum of sequential extractions.

- Two values are listed for high and low concentrations.

\+ - PCNs - Polychlorinated naphthalenes, PCBs - Polychlorinated biphenyls (aroclor-based).

na - Not available

Table 3. Quality assurance and quality control information for PCB congener analysis at the Wisconsin State Laboratory of Hygiene, Madison, Wisconsin. Precison and accuracy data reflect an average over several years ending August 18, 1993. Data listed in order as reported by the laboratory.

IUPAC* No.	Chlorine substitution	(1) LOD ng/g	(2) LOQ ng/g	(3) Precision N	(3) Precision %	(4) Accuracy N	(4) Accuracy %
7	2,4	0.20	0.70	30	6.7	45	85.9
6	2,3′	0.45	1.5	36	8.5	44	89.7
5/8	2,3/2,4′	1.3	4.3	42	8.3	45	87.3
19	2,2′,6	0.30	1.0	30	10.0	42	69.0
18	2,2′5	0.35	1.2	41	5.8	45	87.3
17	2,2′,4	0.30	1.0	41	5.1	45	87.4
24/27	2,3,6/2,3′,6	0.30	1.0	36	5.9	44	85.5
16/32	2,2′,3/2,4′,6	0.40	1.5	42	7.4	44	85.9
26	2,3′,5	0.35	1.2	40	9.6	44	90.0
28/31	2,4,4′/2,4′,5	1.4	4.6	43	7.0	44	90.7
33	2′,3,4	0.45	1.5	36	8.8	45	89.8
22	2,3,4′	0.60	2.0	39	8.4	45	91.7
45	2,2′,3,6	0.30	1.0	38	7.0	45	83.0
46	2,2′,3,6′	0.35	1.2	35	6.3	45	82.7
52	2,2′,5,5′	0.30	1.0	44	4.8	45	92.3
49	2,2′,4,5′	0.30	1.0	42	5.0	45	91.1
47/48	2,2′,4,4′/2,2′,4,5	0.50	1.6	38	5.1	45	89.0
44	2,2′,3,5′	0.30	1.0	42	5.3	45	91.2
37/42	3,4,4′/2,2′,3,4′	0.40	1.3	40	7.4	45	91.1
41/64/71	2,2′,3,4/2,3,4′,6/2,3′,4′,6	0.50	1.6	39	7.4	45	88.1
40	2,2′,3,3′	0.30	1.0	37	6.1	45	87.7
74	2,4,4′,5	0.30	1.0	43	8.0	45	94.8
70/76	2,3′,4′,5/2′,3,4,5	0.45	1.5	45	7.6	45	96.4
66/95	2,3′,4,4′/2,2′,3,5′,6	0.60	2.0	43	6.1	45	93.2
91	2,2′,3,4′,6	0.40	1.3	39	5.5	45	96.1
56/60	2,3,3′,4′/2,3,4,4′	0.80	2.6	43	7.8	45	94.3
84/92	2,2′,3,3′,6/2,2′,3,5,5′	0.70	2.3	39	6.2	44	93.8
101	2,2′,4,5,5′	0.30	1.0	45	7.0	44	97.1
99	2,2′,4,4′,5	0.30	1.0	42	6.5	44	94.8
97	2,2′,3′,4,5	0.30	1.0	40	4.9	44	96.1
87	2,2′,3,4,5′	0.35	1.2	42	8.7	44	98.0
85	2,2′,3,4,4′	0.35	1.0	32	5.4	45	98.4
136	2,2′,3,3′,6,6′	0.20	0.70	21	6.1	45	94.6
77/110	3,3′,4,4′/2,3,3′,4′,6	0.40	1.3	45	7.4	44	96.1
82	2,2′,3,3′,4	0.30	1.0	36	7.8	44	93.8
151	2,2′,3,5,5′,6	0.30	1.0	40	9.8	45	93.4
135/144	2,2′,3,3′,5,6′/2,2′,3,4,5′,6	0.30	1.0	36	9.1	45	92.5
149	2,2′,3,4′,5′,6	0.30	1.0	41	7.0	45	93.6
118	2,3′,4,4′,5	0.45	1.5	44	8.5	44	95.6
146	2,2′,3,4′,5,5′	0.35	1.2	33	6.2	44	102.0
132/153	2,2′,3,3′,4,6′/2,2′,4,4′,5,5′	0.45	1.5	44	8.8	45	95.4
141	2,2′,3,4,5,5′	0.30	1.0	31	7.1	45	93.0
137/176	2,2′,3,4,4′,5/2,2′,3,3′,4,6,6′	0.30	1.0	45	10.0	45	95.5
138/163	2,2′,3,4,4′,5′/2,3,3′,4′,5,6	0.40	1.3	45	10.0	45	96.8
178	2,2′,3,3′,5,5′,6	0.40	1.3	22	13.0	45	94.6
182/187	2,2′,3,4,4′,5,6′/2,2′,3,4′,5,5′,6	0.40	1.3	40	9.8	45	94.3
183	2,2′,3,4,4′,5′,6	0.40	1.3	32	12.0	45	95.4
185	2,2′,3,4,5,5′,6	0.30	1.0	13	7.6	45	94.9
174	2,2′,3,3′,4,5,6′	0.30	1.0	39	8.3	45	93.7
177	2,2′,3,3′,4′,5,6	0.35	1.2	34	8.2	45	95.5

Table 3. Continued.

IUPAC* No.	Chlorine substitution	(1) LOD ng/g	(2) LOQ ng/g	(3) Precision		(4) Accuracy	
				N	%	N	%
171/202	2,2′,3,3′,4,4′,6/2,2′,3,3′,5,5′,6,6′	0.30	1.0	27	11.0	45	96.2
172/197	2,2′,3,3′,4,5,5′/2,2′,3,3′,4,4′,6,6′	0.50	1.6	14	14.0	45	93.9
180	2,2′,3,4,4′,5,5′	0.35	1.2	41	8.4	45	96.0
199	2,2′,3,3′,4,5,6,6′	0.30	1.0	5	7.6	45	92.6
170/190	2,2′,3,3′,4,4′,5/2,3,3′,4,4′,5,6	0.70	2.3	32	9.0	45	95.4
201	2,2′,3,3′,4,5,5′,6	0.50	1.6	39	11.0	45	95.3
196/203	2,2′,3,3′,4,4′,5,6′/2,2′,3,4,4′,5,5′,6	0.70	2.3	38	10.0	45	94.8
195/208	2,2′,3,3′,4,4′,5,6/2,2′,3,3′,4,5,5′,6,6′	0.70	2.3	30	13.0	45	93.8
194	2,2′,3,3′,4,4′,5,5′	0.50	1.6	36	12.0	45	96.5
206	2,2′,3,3′,4,4′,5,5′,6	0.40	1.3	39	17.0	45	93.8
128	2,2′,3,3′,4,4′	0.50	1.6	nd	nd	nd	nd
167	2,3′,4,4′,5,5′	0.50	1.6	nd	nd	nd	nd

* - International Union of Pure and Applied Chemists (IUPAC)
1 - Limit of detection (LOD)
2 - Limit of quantitation (LOQ)
3 - Average absolute difference between duplicate sediment samples
4 - Average percent recoveries of sediment samples spiked with standard solutions
nd - No Data

Table 4. Bed sediment data collected before and after the 1993 flood on Upper Mississippi River. Pre- data from 1991-92. Post- data from June 1994. Data are averages where more than one sample was analyzed and values less than detection or reporting limits were assumed to be zero.

Compound/Parameter	Lab[1]	Pool 1		Pool 2		Pool 3		Upper Lake Pepin		Lower Lake Pepin		Pool 5		Pool 5A	
		Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
General Physical & Chemical Charateristics															
Sand (%)	USGSL	97	97	30	50	23	82	17	1	16	14	71	54	40	ns
Silt (%)	USGSL	2	1	50	37	57	15	26	36	18	20	18	39	43	ns
Clay (%)	USGSL	1	2	20	13	20	3	57	63	66	66	11	7	17	ns
Total volatile solids (%)	Huff.	ns	1.9	ns	7.7	ns	8.1	ns	14.7	ns	13.9	ns	3.9	ns	ns
Total organic carbon (%)	Huff.	<0.1	0.4	1.4	1.1	1.9	1.6	3.0	3.6	3.5	3.8	1.0	1.0	1.7	ns
Total organic carbon (%)	WSLOH	ns	0.5	1.3	1.4	1.5	1.3	ns	2.6	1.9	2.1	ns	1.3	ns	ns
Total Nitrogen (%)	Huff.	<0.01	0.02	0.1	0.1	0.2	0.2	0.4	0.4	0.4	0.1	0.1	0.2	0.1	ns
Organochlorine Compounds															
Lindane (ng/g)	NWQL	ns	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	ns	<0.1	ns	ns
Heptachlor (ng/g)	NWQL	ns	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	ns	<0.1	ns	ns
Aldrin (ng/g)	NWQL	ns	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	ns	<0.1	ns	ns
Heptachlor epoxide (ng/g)	NWQL	ns	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	ns	<0.1	ns	ns
Technical chlordane (ng/g)	NWQL	ns	1.0	3.5	1.0	3.0	<1.0	4.0	2.0	4.0	2.0	ns	<1.0	ns	ns
Endosulfan I (ng/g)	NWQL	ns	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	ns	<0.1	ns	ns
Dieldrin (ng/g)	NWQL	ns	<0.2	0.1	0.2	0.1	0.3	0.3	0.6	<0.1	0.4	ns	<0.2	ns	ns
p,p′ - DDE (ng/g)	NWQL	ns	0.4	1.2	0.8	1.2	1.1	2.5	0.9	0.9	1.0	ns	0.1	ns	ns
Endrin (ng/g)	NWQL	ns	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	ns	<0.1	ns	ns
Perthane (ng/g)	NWQL	ns	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<3.0	<1.0	<1.0	ns	<1.0	ns	ns
p,p′ - DDD (ng/g)	NWQL	ns	0.5	1.0	1.6	1.0	3.8	1.6	0.9	1.2	1.0	ns	0.1	ns	ns
p,p′ - DDT (ng/g)	NWQL	ns	<0.1	0.4	0.1	0.7	0.2	0.3	<0.3	0.4	<0.1	ns	<0.1	ns	ns
p,p′ - Methoxychlor (ng/g)	NWQL	ns	<0.2	<0.1	<0.2	<0.1	<0.2	<0.9	<0.5	<0.1	<0.2	ns	<0.2	ns	ns
Mirex (ng/g)	NWQL	ns	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	ns	<0.1	ns	ns
Toxaphene (ng/g)	NWQL	ns	<10	<10	<10	<10	<10	<10	<30	<10	<10	ns	<10	ns	ns
Gross PCNs (ng/g)	NWQL	ns	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<3.0	<1.0	<1.0	ns	<1.0	ns	ns
Gross PCBs (ng/g)	NWQL	ns	5	36	14	56	33	110	21	52	20	ns	4	ns	ns
Total PCBs - cong. sum (ng/g)	WSLOH	ns	2.3	54	28	56	42	ns	79	150	93	ns	5.5	ns	ns
Polynuclear Aromatic Hydrocarbons															
Fluoranthene (μg/g)	NRP/PTI	4.2	0.6	3.7	0.4	0.9	0.2	0.8	0.3	1.6	0.4	<0.1	0.03	<0.1	ns
Pyrene (μg/g)	NRP/PTI	4.8	0.6	4.0	0.5	0.9	0.2	1.4	0.3	1.8	0.4	<0.1	0.03	<0.1	ns
Sum of 16 PAHs (μg/g)	NRP/PTI	16.9	5.3	14.2	2.5	3.4	2.5	2.2	1.6	3.4	2.1	<0.1	0.2	<0.1	ns
Metals[2]															
Cadmium (μg/g)	NRP	<1.3	0.3	<1.3	0.8	1.3	0.8	2.4	1.3	2.3	1.6	<1.3	0.4	<1.3	ns
Chromium (μg/g)	NRP	17	20	37	40	47	40	68	60	92	80	17	20	34	ns
Copper (μg/g)	NRP	12	18	30	30	44	23	57	38	59	43	17	21	26	ns
Iron (mg/g)	NRP	12	9.1	20	14	24	14	36	34	43	40	15	15	19	ns
Lead (μg/g)	NRP	13	10	18	12	23	12	38	30	45	32	9.0	12	12	ns
Manganese (μg/g)	NRP	280	190	850	540	1390	690	1640	1690	1880	2100	430	640	710	ns
Mercury (μg/g)	NRP	0.036	0.032	0.103	0.183	0.136	0.095	0.295	0.167	0.281	0.137	0.038	0.052	0.063	ns
Zinc (μg/g)	NRP	27	24	70	52	97	52	148	140	166	150	34	38	48	ns

Table 4 continued.

Compound/Parameter	Lab[1]	Pool 6		Pool 7		Pool 8		Pool 9		Pool 10		Pool 11		Lake St. Croix	Lk. Pepin Reference Sediment
		Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Post-	
General Physical & Chemical Charateristics															
Sand (%)	USGSL	90	92	54	60	48	69	13	13	58	59	27	49	40	ns
Silt (%)	USGSL	6	2	30	35	39	24	71	70	25	30	55	43	40	ns
Clay (%)	USGSL	4	6	16	5	13	7	16	17	17	11	18	8	20	ns
Total volatile solids (%)	Huff.	ns	1.2	ns	3.6	ns	3.7	ns	5.9	ns	4.4	ns	5.1	9.2	16.3
Total organic carbon (%)	Huff.	0.4	0.2	0.7	0.9	0.8	0.7	1.0	1.0	1.7	0.4	0.9	0.7	2.5	4.7
Total organic carbon (%)	WSLOH	ns	0.3	ns	0.7	1.0	0.6	1.0	1.3	ns	ns	0.9	0.9	2.3	2.8
Total Nitrogen (%)	Huff.	<0.01	0.01	0.1	0.1	0.1	0.05	0.1	0.1	0.1	0.05	0.1	0.06	0.2	0.5
Organochlorine Compounds															
Lindane (ng/g)	NWQL	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1
Heptachlor (ng/g)	NWQL	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1	ns	<0.1	<0.1	<0.2	ns	<0.5
Aldrin (ng/g)	NWQL	<0.1	<0.1	ns	<0.1	<0.2	<0.1	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.5
Heptachlor epoxide (ng/g)	NWQL	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1	ns	<0.1	<0.1	<0.2	<0.1	<0.1
Technical chlordane (ng/g)	NWQL	<1.0	<1.0	ns	<1.0	<1.0	<1.0	1.0	<1.0	ns	<1.0	<1.0	<1.0	<1.0	4
Endosulfan I (ng/g)	NWQL	0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.3
Dieldrin (ng/g)	NWQL	0.1	<0.2	ns	<0.2	<0.1	<0.2	0.1	<0.2	ns	<0.2	0.1	<0.2	<0.2	0.4
p,p' - DDE (ng/g)	NWQL	<0.1	0.1	ns	0.3	0.2	0.2	0.4	0.3	ns	0.2	0.2	0.2	0.7	2.3
Endrin (ng/g)	NWQL	<1.0	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1
Perthane (ng/g)	NWQL	<1.0	<1.0	ns	<1.0	<1.0	<1.0	<1.0	<1.0	ns	<1.0	<1.0	<1.0	<1.0	<1.0
p,p' - DDD (ng/g)	NWQL	0.1	0.3	ns	1.0	0.1	0.4	0.2	1.0	ns	0.1	0.1	0.4	0.4	1.7
p,p' - DDT (ng/g)	NWQL	<0.1	<0.1	ns	0.1	<0.1	<1.0	<0.1	0.1	ns	<0.1	<0.1	<0.1	0.1	0.3
p,p' - Methoxychlor (ng/g)	NWQL	<0.1	<0.2	ns	<0.2	<0.1	<0.2	<0.1	<0.2	ns	<0.2	<0.1	<0.2	<0.2	<4
Mirex (ng/g)	NWQL	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1	ns	<0.1	<0.1	<0.1	<0.1	<0.1
Toxaphene (ng/g)	NWQL	<10	<10	ns	<10	<10	<10	<10	<10	ns	<10	<10	<10	<10	<10
Gross PCNs (ng/g)	NWQL	<1.0	<1.0	ns	<1.0	<1.0	<1.0	<1.0	<1.0	ns	<1.0	<1.0	<1.0	<1.0	<1.0
Gross PCBs (ng/g)	NWQL	<2	3	ns	7	5	4	13	6	ns	3	9	3	6	150
Total PCBs - cong. sum (ng/g)	WSLOH	ns	nd	ns	2.4	4.5	1.0	8.6	2.4	ns	ns	8.2	nd	22.6	280
Polynuclear Aromatic Hydrocarbons (PAHs)															
Fluoranthene (µg/g)	NRP/PTI	0.4	0.1	<0.1	0.1	<0.1	0.04	<0.1	0.1	<0.1	0.02	0.2	0.1	0.2	ns
Pyrene (µg/g)	NRP/PTI	0.3	0.1	<0.1	0.1	0.2	0.03	0.2	0.1	<0.1	0.02	0.2	0.1	0.2	ns
Sum of 16 PAHs (µg/g)	NRP/PTI	1.1	0.2	<0.1	0.3	0.4	0.2	0.2	0.4	<0.1	0.1	0.4	0.5	1.7	ns
Metals[2]															
Cadmium (µg/g)	NRP	<1.3	0.2	<1.3	0.4	<1.3	0.4	<1.3	0.6	<1.3	0.4	<1.3	0.3	0.6	4.1
Chromium (µg/g)	NRP	14	10	33	20	28	26	24	60	34	20	26	20	50	110
Copper (µg/g)	NRP	16	7	33	21	24	15	32	23	29	16.0	22	17	26	70
Iron (mg/g)	NRP	12	9.8	20	14	16	13	25	20	20	15	17	13	29	52
Lead (µg/g)	NRP	7.5	4.0	13	10	11	10	16	16	14	10	13	12	21	62
Manganese (µg/g)	NRP	490	240	570	460	653	435	760	800	740	560	770	580	1240	2750
Mercury (µg/g)	NRP	0.047	0.017	0.065	0.030	0.050	0.049	0.068	0.071	0.070	0.046	0.082	0.064	0.100	0.384
Zinc (µg/g)	NRP	22	14	63	30	44	28	56	65	62	37	57	47	69	210

[1] Laboratories: NWQL = USGS, National Water Quality Lab, Arvada, CO; Huff = Huffman Laboratories, Inc., Golden, CO; USGSL = USGS Sediment Laboratory, Iowa City, IA; WSLOH = Wisconsin State Laboratory of Hygiene, Madison, WI; NRP = USGS, National Research Program, Boulder, CO; PTI = PTI Environmental Services, Boulder, CO

[2] Metals data represent sum of sequential extractions with the exception of post-flood data for Cr, Cd, and Zn which represent total digestions.
ns = No sample analyzed, nd = no congeners detected (<0.4 ng/g).

Table 5. Relative percent difference of pre- (1991-92) and post-flood (1994) sediment data collected on the Upper Mississippi River. A negative value indicates a reduction in the post-flood results in comparison to pre-flood data.

Compound/Parameter	Lab*	Mississippi River Pool 1	2	3	4U	4L	5	6	7	8	9	10	11
General Physical & Chemical Charateristics													
Sand	USGSL	0	50	113	-174	-11	-26	2	10	36	-3	2	58
Silt	USGSL	-67	-30	-117	32	11	73	-108	15	-48	-1	17	-25
Clay	USGSL	67	-45	-148	10	-1	-47	43	-99	-65	4	-40	-73
Total organic carbon	Huff.	.	-24	-17	18	8	0	-67	25	-13	0	-124	-25
Total organic carbon	WSLOH	.	7	-14	.	10	.	.	.	-50	26	.	0
Total Nitrogen	Huff.	.	0	0	0	-120	67	.	0	-67	0	-67	-50
Organochlorine Compounds													
Lindane	NWQL	.	.	.	.		.	.	.	.	.	.	.
Heptachlor	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Aldrin	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Heptachlor epoxide	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Technical chlordane	NWQL	.	-111	.	-67	-67	.	.	.	.	.	.	.
Endosulfan I	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Dieldrin	NWQL	.	67	100	67	.	.	.	.	.	.	.	.
p,p' - DDE	NWQL	.	-40	-9	-94	11	.	.	.	0	-29	.	0
Endrin	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Perthane	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
p,p' - DDD	NWQL	.	46	117	-56	-18	.		.	120	133	.	120
p,p' - DDT	NWQL	.	-120	-111	.	.	.	.	.	.	.	.	.
p,p' - Methoxychlor	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Mirex	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Toxaphene	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Gross PCNs	NWQL	.	.	.	.	.	.	.	.	.	.	.	.
Gross PCBs (Aroclor-based)	NWQL	.	-88	-52	-136	-89	.	.	.	-22	-74	.	-100
Total PCBs - (congener sum)	WSLOH	.	-63	-29	.	-47	.	.	.	-127	-113	.	.
Polynuclear Aromatic Hydrocarbons (PAHs)													
Fluoranthene	NRP/PTI	-150	-161	-127	-91	-120	.	-120	.	.	.	.	-67
Pyrene	NRP/PTI	-156	-156	-127	-129	-127	.	-100	.	-148	-67	.	-67
Sum of 16 PAHs	NRP/PTI	-105	-140	-31	-32	-47	.	-138	.	-67	67	.	22
Metals													
Cadmium	NRP	.	.	-48	-59	-36	.	.	.	.	.	.	.
Chromium	NRP	16	8	-16	-12	-14	16	-33	-49	-7	86	-52	-26
Copper	NRP	40	0	-63	-40	-31	21	-78	-44	-46	-33	-58	-26
Iron	NRP	-27	-35	-53	-6	-7	0	-20	-35	-21	-22	-29	-27
Lead	NRP	-26	-40	-63	-24	-34	29	-61	-26	-10	0	-33	-8
Manganese	NRP	-38	-45	-67	3	11	39	-68	-21	-40	5	-28	-28
Mercury	NRP	-12	56	-35	-55	-69	31	-94	-74	-2	4	-41	-25
Zinc	NRP	-12	-30	-60	-6	-10	11	-44	-71	-44	15	-51	-19

4U = Upper Lake Pepin, 4L = Lower Lake Pepin

* Laboratories: NWQL = USGS, National Water Quality Lab, Arvada, CO; Huff = Huffman Laboratories, Inc., Golden, CO; USGSL = USGS Sediment Laboratory Iowa City, IA; WSLOH = Wisconsin State Laboratory of Hygiene, Madison, WI; NRP = USGS, National Research Program, Boulder, CO; PTI = PTI Environmental Services, Boulder CO

. = Unable to calculate a relative % difference due to missing sample or results less than detection limit.

Table 6. Suspended sediment contaminant data collected from the Minnesota and Mississippi Rivers using glass sediment traps by the Wisconsin Department of Natural Resources with assistance from the Minnesota Pollution Control Agency. Samples analyzed by the Wisconsin State Laboratory of Hygiene, Madison, Wisconsin. Data obtained from Sullivan, 1995.

Trap Location	1 STORET ID No.	River Mile	2 Trap Collect yr mo dy	3 Exp days	4 Gross Accum cm	5 Sed. Rate cm/d	TVS %	TOC %	6 Tot. PCB ng/g	Cd µg/g	Cr µg/g	Cu µg/g	Pb µg/g	Mn µg/g	Hg µg/g	Zn µg/g	NH4-N µg/g	TKN µg/g	TP µg/g
Fall Samples Collected in 1993																			
Minnesota River	483055	3.5	93 10 20	34	10.0	0.29	2	0.8	< 1	0.23	12	7	6	470	0.03	32	12	690	710
Coon Rapids Dam	483053	866	93 11 17	72	1.5	0.02	-	8.3	55	0.33	24	28	24	3300	0.13	130	-	-	-
St. Anthony Falls	483054	853	93 11 17	72	3.0	0.04	12	5.2	83	0.50	21	29	39	2300	0.12	120	400	7500	2400
St. Paul	483056	839	93 11 17	72	8.0	0.11	4	1.6	5.8	0.27	14	12	13	950	0.04	49	96	1900	1000
Lock & Dam 2	483026	815	93 10 20	34	7.0	0.21	7	3.0	80	0.94	23	21	16	1400	0.11	91	62	3700 #	1600 #
Lock & Dam 3	483027	797	93 11 15	68	7.0	0.10	7	3.0	92	1.04	24	23	32	1800	0.16	95	130	4300	1700
Lock & Dam 3 rep	483027	797	93 11 15	68	7.0	0.10	8	3.4	99	1.08	27	24	18	1700	0.13	92	170	3900 #	1400 #
Lock & Dam 4	063029	753	93 11 15	68	3.5	0.05	8	2.5	25	0.59	27	19	29	1600	0.09	79	240	5400	2900
Lock & Dam 5	063051	738	93 11 15	61	3.3	0.05	9	3.9	43	0.70	28	18	20	2500	0.09	90	76	5900 #	2400 #
Lock & Dam 8	633038	679	93 11 17	62	5.2	0.08	8	3.0	23	0.62	29	17	16	1600	0.09	86	49	4700 #	2200 #
Spring Samples Collected in 1994																			
Minnesota River	483055	3.5	94 6 6	42	11.6	0.28	2	0.9	< 1	0.19	9	8	15	540	< 0.02	37	74	950	570
Champlin, Mn.	483068	871	94 6 6	83	8.8	0.11	1	0.4	< 1	0.04	7	4	3.8	480	< 0.02	19	5	260	190
St. Anthony Falls	483054	853	94 6 6	82	6.6	0.08	3	1.2	11	0.13	11	8	16	690	0.04	52	89	1500	540
Lock & Dam 1	483066	848	94 6 6	82	8.4	0.10	7	3.7	27	0.26	15	14	27	1500	0.08	72	200	3100	850
St. Paul	483056	839	94 6 6	42	11.3	0.27	4	1.7	1.5	0.27	12	12	18	1200	0.04	55	150	2000	760
Lock & Dam 2	483026	815	94 6 6	83	6.4	0.08	5	2.5	67	0.72	18	18	18	1100	0.08	73	95	2000	920
Lock & Dam 3	483027	797	94 6 1	58	8.3	0.14	8	2.6	66	0.99	33	23	19	1300	0.12	95	256 @	4000 #	1200 #
Lock & Dam 3 rep	483027	797	94 6 1	58	8.5	0.15	7	2.4	66	0.99	31	23	22	1200	0.12	94	252 @	3500 #	1200 #
Lower Lake Pepin	473015	766	94 6 30	79	3.7	0.05	14	4.9	143	0.96	27	26	41	3200	0.10	160	1700	10000	2500
Lock & Dam 4	063029	753	94 6 1	58	6.1	0.11	8	2.8	16	0.49	36	21	19	1200	0.08	83	274 @	4100 #	1700 #
Lock & Dam 5	063051	738	94 6 1	58	6.7	0.12	8	2.4	15	0.52	18	8	11	670	0.06	51	282	3800	1200
Lock & Dam 8	633038	679	94 6 2	58	6.8	0.12	5	2.1	5.3	0.42	25	13	16	920	0.06	69	191	2300	880
Lock & Dam 9	123016	648	94 6 2	58	7.2	0.12	7	2.0	9.5	0.56	34	17	19	1300	0.10	88	251	3500	1200
Lock & Dam 11	223263	583	94 6 4	58	11.1	0.19	5	1.5	2.0	0.49	22	12	16	780	0.04	55	192	2200	760

1 - U.S. EPA's Storage and Retieval (STORET) computer data base system
2 - Date of sediment trap collection
3 - Sediment trap exposure period
4 - Gross sediment accumulation in trap
5 - Sedimentation rate
6 - Sum of PCB congeners at or above the method detection limit
@ - Holding time exceedance, results are approximate
# - Spike quality control exceeded matrix group, results are approximate
nd - Not detected
na - Not available
\- - No sample

Table 7. Comparison of surficial bed sediment data to the Provincial Sediment Quality Guidlines, Ontario Ministry of the Environment and Energy (Pursaud et al. 1993). B represents pre-flood data and A represents post-flood samples.

Compound/Parameter	(1) NEL	(2) LEL	(3) SEL	Pool/Site *																										
				1		2		3		4U		4L		5		5A		6		7		8		9		10		11		SC
				B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	A
General Physical & Chemical Charateristics																														
Total organic carbon (%)	na	1	10	–	–	+	+	+	+	+	+	+	+	+	+	+	.	–	–	–	–	–	–	+	+	+	–	–	–	+
Total Nitrogen (%)	na	0.055	0.48	–	–	+	+	+	+	+	+	+	+	+	+	+	.	–	–	+	+	+	–	+	+	+	–	+	+	+
Organochlorine Compounds																														
Lindane (ng/g OC)	20	300	1000	.	o	o	o	o	o	o	o	o	o	.	o	.	.	o	o	.	o	o	o	o	o	.	o	o	o	o
Aldrin (ng/g OC)	na	200	8000	.	–	–	–	–	–	–	–	–	–	.	–	.	.	–	–	.	–	–	–	–	–	.	–	–	–	–
Heptachlor epoxide (ng/g OC)	na	500	5000	.	–	–	–	–	–	–	–	–	–	.	–	.	.	–	–	.	–	–	–	–	–	.	–	–	–	–
Technical chlordane (ng/g OC)	500	700	6000	.	o	o	o	o	o	o	o	o	o	.	o	.	.	o	o	.	o	o	o	o	o	.	o	o	o	o
Dieldrin (ng/g OC)	60	200	91000	.	o	o	o	o	o	o	o	o	o	.	o	.	.	o	o	.	o	o	o	o	o	.	o	o	o	o
p,p' - DDE (ng/g OC)	na	500	19000	.	–	–	–	–	–	–	–	–	–	.	–	.	.	–	–	.	–	–	–	–	–	.	–	–	–	–
Endrin (ng/g OC)	50	300	130000	.	o	o	o	o	o	o	o	o	o	.	o	.	.	o	o	.	o	o	o	o	o	.	o	o	o	o
p,p' - DDD (ng/g OC)	na	800	6000	.	–	–	–	–	–	–	–	–	–	.	–	.	.	–	–	.	–	–	–	–	–	.	–	–	–	–
p,p' - DDT (ng/g OC)	na	800	71000	.	–	–	–	–	–	–	–	–	–	.	–	.	.	–	–	.	–	–	–	–	–	.	–	–	–	–
Mirex (ng/g OC)	na	700	130000	.	–	–	–	–	–	–	–	–	–	.	–	.	.	–	–	.	–	–	–	–	–	.	–	–	–	–
Gross PCBs - Aroclor-based (ng/g OC)	1000	7000	530000	.	–	–	–	–	–	–	o	–	o	.	o	.	.	o	–	.	o	o	o	–	o	.	o	–	o	o
Tot. PCBs - cong. sum (ng/g OC)	1000	7000	530000	.	o	–	–	–	–	.	–	+	–	.	o	.	.	.	o	.	o	o	o	o	o	.	.	o	o	o
Polynuclear Aromatic Hydrocarbons																														
Fluoranthene (µg/g OC)	na	75	1020	m	+	+	–	–	–	–	–	–	–	–	–	–	.	+	–	–	–	–	–	–	–	–	–	–	–	–
Pyrene (µg/g OC)	na	49	850	m	+	+	–	–	–	–	–	+	–	–	–	–	.	+	+	–	–	–	–	–	–	–	–	–	–	–
Sum of 16 PAHs (µg/g OC)	na	400	10000	m	+	+	–	–	–	–	–	–	–	–	–	–	.	–	–	–	–	–	–	–	–	–	–	–	–	–
Metals																														
Cadmium (µg/g)	na	0.6	10	–	–	–	+	+	+	+	+	+	+	–	–	–	.	–	–	–	–	–	–	–	+	–	–	–	–	+
Chromium (µg/g)	na	26	110	–	–	+	+	+	+	+	+	+	+	–	–	+	.	–	–	+	–	+	+	–	+	+	–	+	–	+
Copper (µg/g)	na	16	110	–	+	+	+	+	+	+	+	+	+	+	+	+	.	+	–	+	+	+	–	+	+	+	+	+	+	+
Iron (%)	na	2	4	–	–	+	–	+	–	+	+	•	•	–	–	–	.	–	–	+	–	–	–	+	+	+	–	–	–	+
Lead (µg/g)	na	31	250	–	–	–	–	–	–	+	–	+	+	–	–	–	.	–	–	–	–	–	–	–	–	–	–	–	–	–
Manganese (µg/g)	na	460	1100	–	–	+	+	•	+	•	•	•	•	–	+	+	.	+	–	+	+	+	–	+	+	+	+	+	+	•
Mercury (µg/g)	na	0.2	2	–	–	–	–	–	–	+	–	+	–	–	–	–	.	–	–	–	–	–	–	–	–	–	–	–	–	–
Zinc (µg/g)	na	120	820	–	–	–	–	–	–	+	+	+	+	–	–	–	.	–	–	–	–	–	–	–	–	–	–	–	–	–

1 - No effect level. Contamination below this level is not believed to affect sediment dwelling organims. Derived using a 1 % TOC content.
2 - Lowest effect level. A level of contamination which has no effect on the majority of sediment-dwelling organisms. Derived using a 1% TOC content.
3 - Severe effect level. A level of contamination which is considered heavily polluted and likely to effect the health of sediment dwelling organisms.
* - 4U = Upper Lake Pepin, 4L = Lower Lake Pepin, SC = Lake St. Croix
m - Not determined, TOC data less than detection
na - Not available
. - No sample
o - < NEL
– - > NEL (if available) or < LEL
\+ - > LEL or < SEL
• - > SEL

Table 8. PCB congener and total organic carbon (TOC) content of surficial bed sediments collected in October 1991 (pre-flood). Dried, split, and then analyzed by the Wisconsin State Laboratory of Hygiene in Madison, Wisconsin in 1994.

(a) IUPAC No.	(b) PCB Hom.	PCB Congeners ng/g Pool 2	Pool 3	Pool 4L	Pool 8	Pool 9	Pool 11	Lk Pepin Ref. Sed.
7	2	-	-	-	-	-	-	-
6	2	-	-	-	-	-	-	-
5/8	2	2.9	3.5	2.3	-	2.7	2.6	1.4
19	3	-	-	-	-	-	-	-
18	3	0.69	0.72	-	-	-	-	-
17	3	-	-	-	-	-	-	-
24/27	3	-	-	-	-	-	-	-
16/32	3	2.0	1.9	0.94	1.4	1.5	3.3	-
26	3	-	-	0.36	-	-	-	-
28/31	3	2.2	2.4	3.1	-	-	-	5.6
33	3	-	0.57	-	-	-	-	-
22	3	-	-	0.63	-	-	-	-
45	4	-	-	-	-	-	-	-
46	4	-	-	-	-	-	-	-
52	4	1.0	1.1	2.4	-	-	-	4.6
49	4	0.89	0.74	1.8	-	-	-	3.4
47/48	4	1.0	0.65	1.4	-	-	-	2.8
44	4	0.72	0.86	1.7	-	-	-	3.3
37/42	3/4	0.64	0.65	1.6	-	-	-	3.2
41/64/71	4	-	0.63	1.3	-	-	-	2.9
40	4	-	-	0.95	-	-	-	0.53
74	4	-	0.41	-	-	-	-	2.5
70/76	4	1.4	1.8	3.7	-	-	-	8.7
66/95	4/5	3.4	4.2	11	0.78	0.89	0.62	23
91	5	0.61	0.57	1.6	-	-	-	3.1
56/60	4	-	0.96	2.1	-	-	-	4.8
84/92	5	1.4	1.7	4.1	-	-	-	7.7
101	5	2.0	2.4	6.7	0.33	0.42	-	13
99	5	1.0	1.1	3.8	-	-	-	7.8
97	5	0.75	0.90	2.7	-	-	-	5.6
87	5	1.1	1.4	4.2	-	-	-	8.9
85	5	-	-	-	-	-	-	-
136	6	-	-	0.39	-	-	-	-
77/110	4/5	4.3	5.0	15	0.66	0.82	0.57	31
82	5	0.32	0.41	1.1	-	-	-	2.4

Table 8. Continued.

(a) IUPAC No.	(b) PCB Hom.	PCB Congeners ng/g Pool 2	Pool 3	Pool 4L	Pool 8	Pool 9	Pool 11	Lk Pepin Ref. Sed.
151	6	0.54	0.51	1.5	-	-	-	2.9
135/144	6	0.41	0.41	1.2	-	-	-	2.4
149	6	1.8	2.0	5.3	-	0.33	-	10
118	5	3.3	3.6	9.5	-	0.49	-	22
146	6	0.84	0.61	2.2	-	-	-	4.3
132/153	6	5.1	4.4	13	0.66	0.75	0.53	25
141	6	-	-	-	-	-	-	-
137/176	6/7	-	-	-	-	-	-	-
138/163	6	5.5	5.0	15.0	0.67	0.75	0.54	30
178	7	-	-	0.43	-	-	-	0.86
182/187	7	0.77	-	1.6	-	-	-	2.8
183	7	0.53	0.41	1.3	-	-	-	2.6
185	7	-	-	-	-	-	-	0.59
174	7	0.57	0.51	1.6	-	-	-	3.1
177	7	0.50	-	1.2	-	-	-	2.5
171/202	7/8	-	-	0.60	-	-	-	1.2
172/197	7/8	-	-	0.63	-	-	-	1.2
180	7	2.0	1.4	4.3	-	-	-	8.8
199	8	-	-	-	-	-	-	-
170/190	7	2.2	1.6	5.0	-	-	-	11
201	8	0.54	-	1.5	-	-	-	2.9
196/203	8	-	-	1.8	-	-	-	3.5
195/208	8/9	-	-	1.2	-	-	-	2.4
194	8	-	-	0.94	-	-	-	2.0
206	9	-	-	0.83	-	-	-	1.7
128	6	1.0	0.94	3.3	-	-	-	6.8
167	6	-	-	0.70	-	-	-	1.5
TOC %		1.30	1.53	1.94	1.00	1.02	0.90	2.52
Congener sum ng/g		53.9	56.0	150	4.5	8.65	8.16	298
TOC-Norm. ng/g OC		4148	3658	7706	450	848	907	11837
No. > LOD (c)		34	35	47	6	9	6	45
No. > LOQ (d)		11	13	27	0	1	1	40

a - International Union of Pure and Applied Chemists
b - PCB homologue (biphenyl chlorination level)
c - Number of congeners reported above the limit of detection (LOD)
d - Number of congeners reported above the limit of quantitation (LOQ)
4L = Lower Lake Pepin

Table 9. PCB congener and total organic carbon (TOC) content of surficial bed sediments collected in June 1994 (post-flood). Analyzed by the Wisconsin State Laboratory of Hygiene in Madison, Wisconsin.

(a) IUPAC No.	(b) PCB Hom.	PCB Congeners ng/g														
		Pool 1	Pool 2	Pool 2 rep	Pool 3	Pool 4U	Pool 4L	Pool 5	Pool 6	Pool 7	Pool 8	Pool 8 rep	Pool 9	Pool 11	Lake St. Croix	Lk Pepin Ref. Sed.
7	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5/8	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.45
17	3	-	-	-	-	-	0.32	-	-	-	-	-	-	-	-	0.61
24/27	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16/32	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28/31	3	-	1.6	1.8	-	2.5	2.4	-	-	-	-	-	-	-	-	5.3
33	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.79
45	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52	4	-	1.0	1.2	1.2	1.8	1.8	-	-	-	-	-	-	-	0.86	4.6
49	4	-	1.2	1.2	0.93	1.5	1.5	-	-	-	-	-	-	-	0.34	3.3
47/48	4	-	1.5	1.7	0.97	1.8	1.5	-	-	-	-	-	-	-	0.57	2.8
44	4	-	0.69	0.73	0.89	1.4	1.3	-	-	-	-	-	-	-	-	3.1
37/42	3/4	-	0.59	0.65	0.54	1.0	1.1	-	-	-	-	-	-	-	-	2.6
41/64/71	4	-	-	0.58	0.65	1.1	1.1	-	-	-	-	-	-	-	-	2.8
40	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.51
74	4	-	-	-	-	-	0.95	-	-	-	-	-	-	-	-	2.1
70/76	4	-	1.6	1.8	2.3	3.5	3.2	-	-	-	-	-	-	-	1.2	7.2
66/95	4/5	0.60	2.7	3.1	4.6	7.2	8.1	1.2	-	-	-	0.74	-	-	2.9	21
91	5	-	0.58	0.93	0.70	1.2	1.3	-	-	-	-	-	-	-	0.40	3.3
56/60	4	-	-	-	0.81	1.6	1.7	-	-	-	-	-	-	-	0.86	3.8
84/92	5	-	0.97	0.93	1.6	2.3	2.6	-	-	-	-	-	-	-	1.1	7.2
101	5	-	1.3	1.5	2.2	3.4	4.1	0.50	-	0.34	-	-	0.35	-	1.4	12
99	5	-	0.70	0.77	1.2	2.1	2.5	-	-	-	-	-	-	-	0.79	7.1
97	5	-	0.46	0.49	0.82	1.4	1.7	-	-	-	-	-	-	-	0.54	4.9
87	5	-	0.70	-	1.4	2.3	2.7	-	-	-	-	-	-	-	1.2	7.6
85	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
136	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
77/110	4/5	0.40	2.7	3.4	4.6	7.8	9.5	1.1	-	0.83	0.43	0.47	0.83	-	2.7	26
82	5	-	-	-	0.31	0.56	0.64	-	-	-	-	-	-	-	-	2.0

Table 9. Continued.

(a) IUPAC No.	(b) PCB Hom.	PCB Congeners ng/g														
		Pool 1	Pool 2	Pool 2 rep	Pool 3	Pool 4U	Pool 4L	Pool 5	Pool 6	Pool 7	Pool 8	Pool 8 rep	Pool 9	Pool 11	Lake St. Croix	Lk Pepin Ref. Sed.
151	6	-	-	-	0.42	0.77	0.96	-	-	-	-	-	-	-	-	3.0
135/144	6	-	-	-	0.35	0.68	0.82	-	-	-	-	-	-	-	-	2.4
149	6	-	0.98	1.0	1.6	2.7	3.3	0.37	-	-	-	-	-	-	1.0	9.9
118	5	-	1.6	1.6	2.7	4.7	5.2	0.60	-	-	-	-	-	-	1.3	15
146	6	-			0.48	0.98	1.3	-	-	-	-	-	-	-	-	3.8
132/153	6	0.47	2.2	2.2	3.6	6.5	7.8	0.84	-	0.60	-	-	0.64	-	2.2	23
141	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
137/176	6/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
138/163	6	0.42	2.3	2.5	3.9	7.3	9.0	0.88	-	0.66	0.42	-	0.62	-	2.1	26
178	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.81
182/187	7	-	-	-	-	0.66	0.69	-	-	-	-	-	-	-	-	2.6
183	7	-	-	-	-	0.72	0.75	-	-	-	-	-	-	-	0.42	2.3
185	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
174	7	-	-	-	0.42	0.81	0.96	-	-	-	-	-	-	-	-	2.7
177	7	-	-	-	-	0.71	0.87	-	-	-	-	-	-	-	-	2.5
171/202	7/8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2
172/197	7/8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
180	7	0.39	0.67	0.68	1.2	2.3	2.6	-	-	-	-	-	-	-	0.73	7.1
199	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
170/190	7	-	-	0.76	1.1	2.4	2.8	-	-	-	-	-	-	-	-	7.8
201	8	-	-	-	-	0.83	0.96	-	-	-	-	-	-	-	-	2.6
196/203	8	-	-	-	-	1.0	1.1	-	-	-	-	-	-	-	-	3.2
195/208	8/9	-	-	-	-	-	0.78	-	-	-	-	-	-	-	-	2.0
194	8	-	-	-	-	-	0.56	-	-	-	-	-	-	-	-	1.5
206	9	-	-	-	-	0.52	0.55	-	-	-	-	-	-	-	-	1.5
128	6	-	-	-	0.75	1.4	1.8	-	-	-	-	-	-	-	-	5.5
167	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.94
TOC %		0.51	1.38	1.34	1.32	2.61	2.12	1.30	0.26	0.70	0.52	0.64	1.30	0.93	2.30	3.09
Congener sum ng/g		2.28	26.0	29.5	42.2	79.4	92.8	5.49	nd	2.43	0.85	1.21	2.44	nd	22.6	259
TOC-Norm. ng/g OC		451	1887	2203	3200	3044	4378	422	nd	347	163	189	188	0	983	8395
No. > LOD (c)		5	20	21	28	35	39	7	0	4	2	2	4	0	19	46
No. > LOQ (d)		0	9	11	11	20	19	0	0	0	0	0	0	0	6	37

a - International Union of Pure and Applied Chemists
b - PCB homologue (biphenyl chlorination level)
c - Number of congeners reported above the limit of detection (LOD)
d - Number of congeners reported above the limit of quantitation (LOQ)
nd = Not detected (<0.4 ng/g), 4U = Upper Lake Pepin, 4L = Lower Lake Pepin

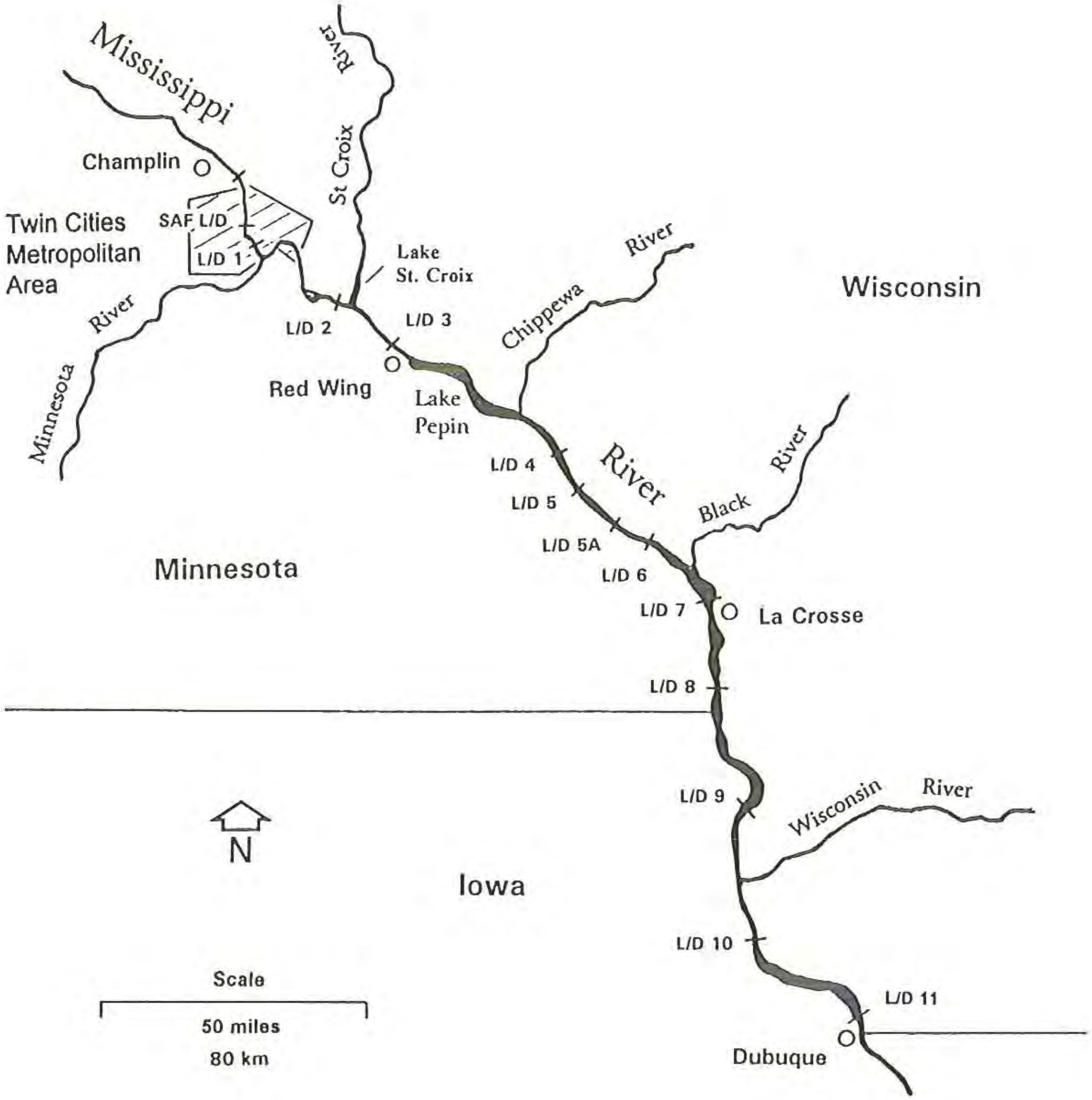
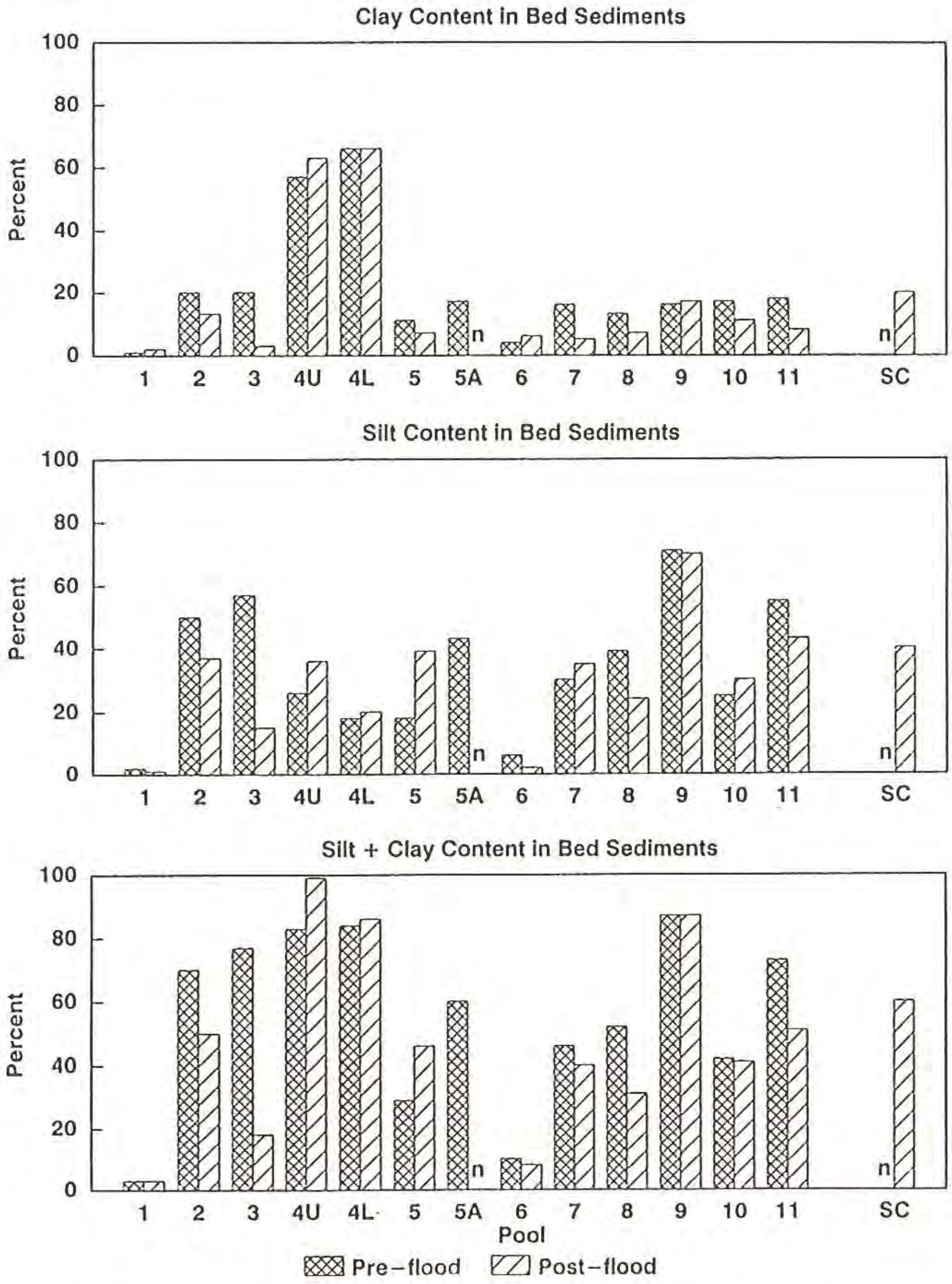


Figure 1. Upper Mississippi River study area showing the location of navigation lock and dams (L/D) and major tributary inflows from St. Anthony Falls (SAF), Minneapolis, MN to Dubuque, IA.

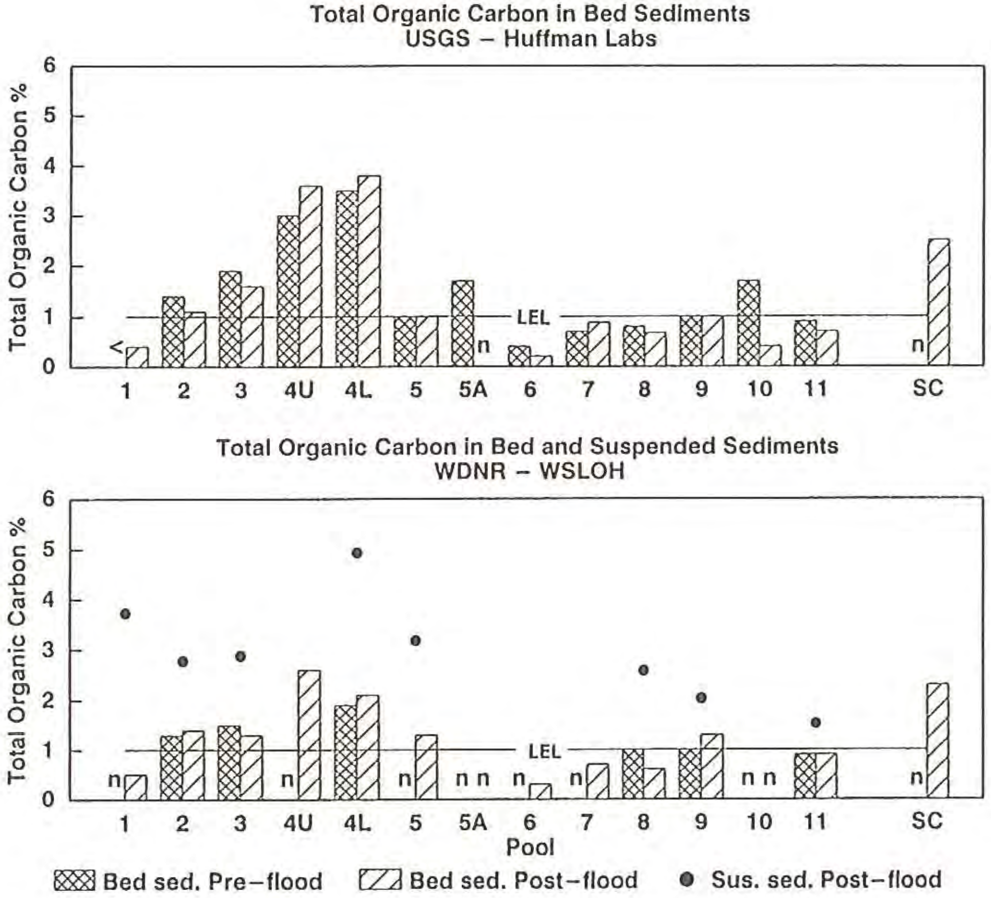


Clay Content in Bed Sediments

Silt Content in Bed Sediments

Silt + Clay Content in Bed Sediments

Figure 2. Clay, silt and silt + clay content of surficial bed sediments collected from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. The letter "n" means no sample was collected. Samples collected from Pool 4 were obtained from upper (4U) and lower (4L) Lake Pepin.


Total Organic Carbon in Bed Sediments
USGS – Huffman Labs

Total Organic Carbon in Bed and Suspended Sediments
WDNR – WSLOH

Figure 3. Total organic carbon content of surficial bed sediments collected from the Upper Mississippi River navigation pools and Lake St. Croix (SC) before and after the 1993 summer flood. Samples analyzed by Huffman Laboratory Inc., Golden, CO and the Wisconsin State Laboratory of Hygiene (WSLOH), Madison, WI. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected and "<" means less than the detection limit. LEL represents the lowest effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

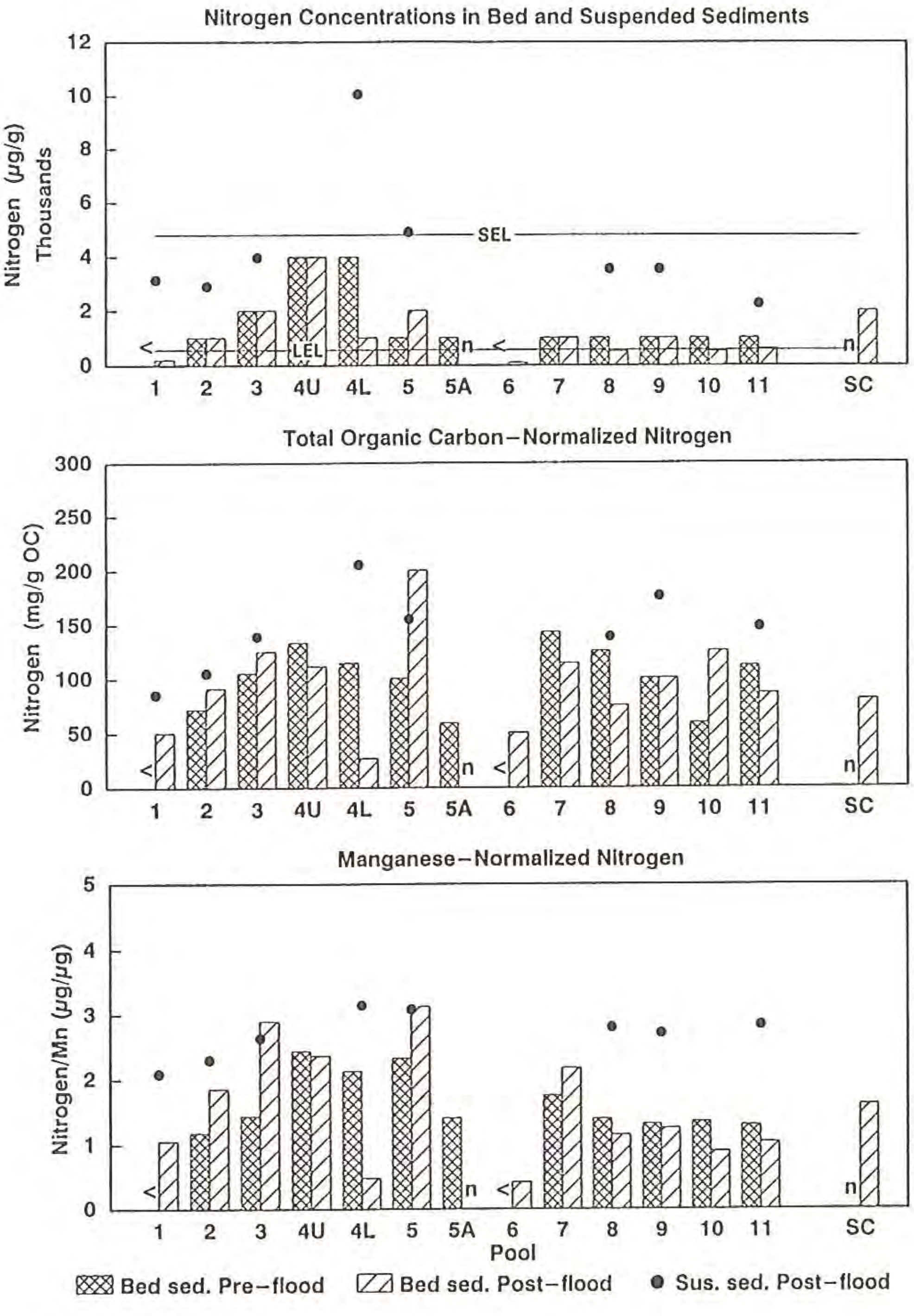


Figure 4. Nitrogen, TOC-normalized nitrogen and manganese-normalized nitrogen content of surficial bed and suspended sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected and "<" means less than the detection limit. LEL represents the lowest effect level and SEL the severe effect level Sediment Quality Guidelines obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

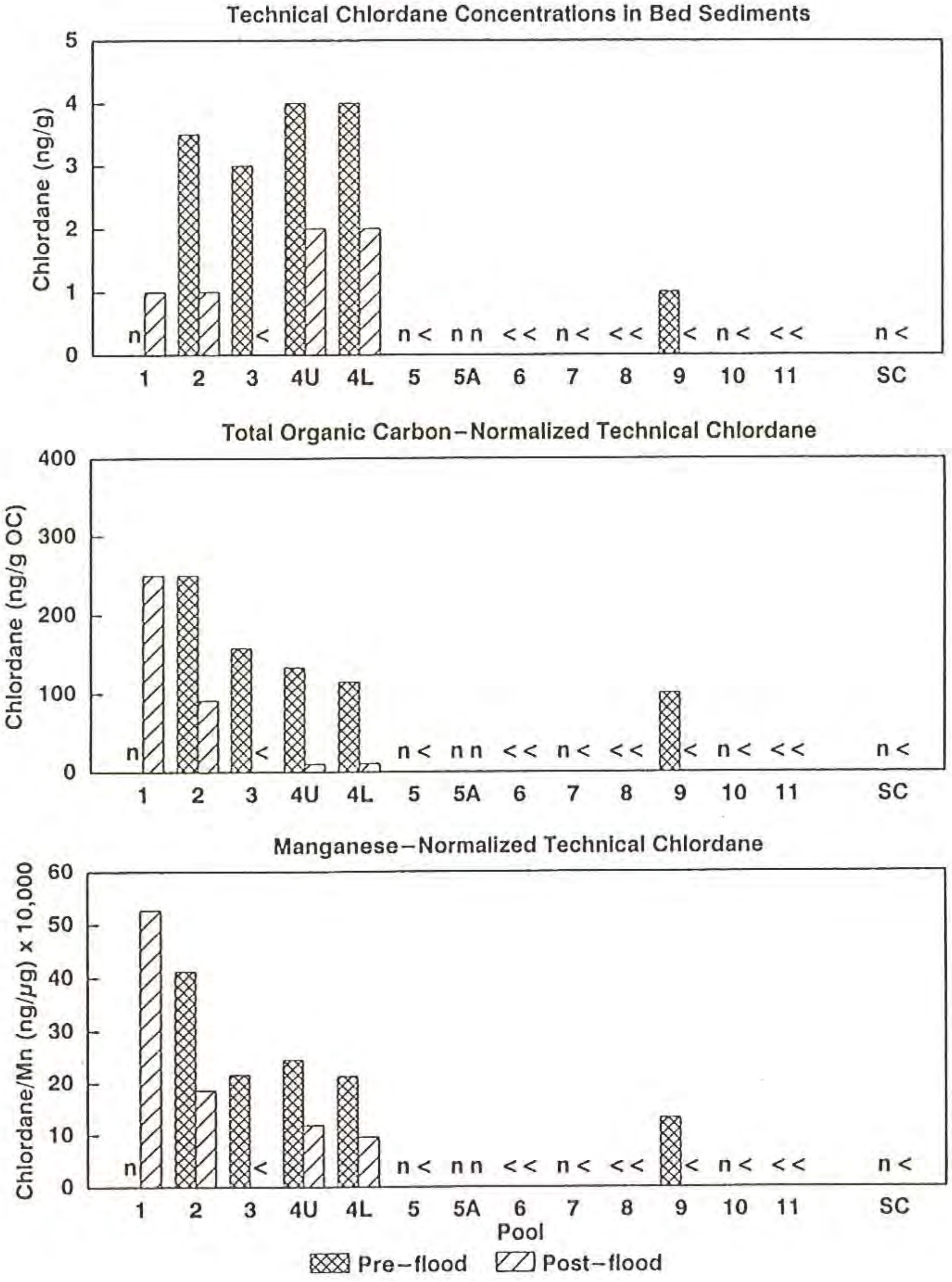


Figure 5. Technical chlordane, TOC-normalized chlordane and manganese-normalized chlordane content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. The letter "n" means no sample was collected and " < " means less than the detection limit. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

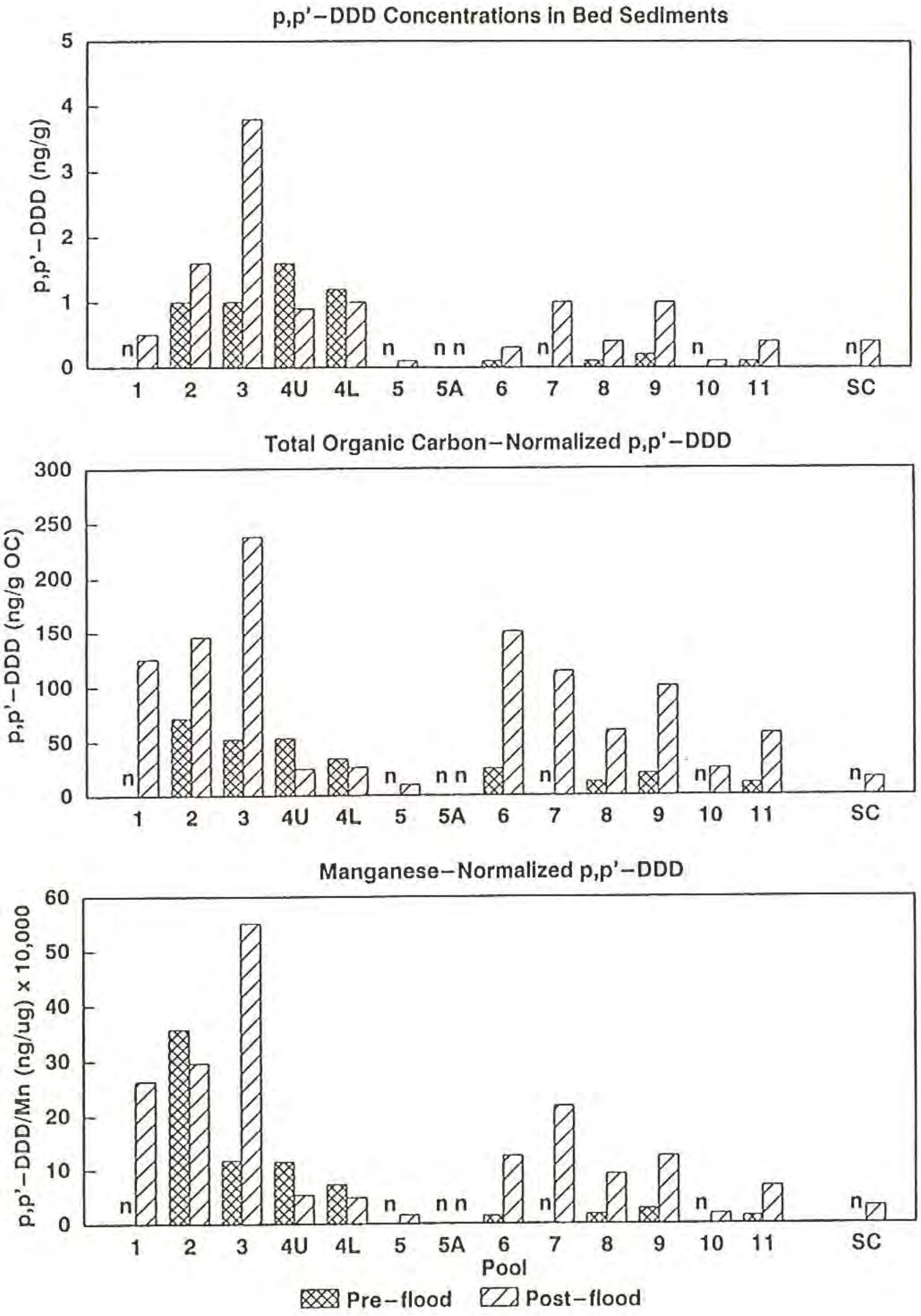


Figure 6. p,p'-DDD, TOC-normalized p,p'-DDD and manganese-normalized p,p'-DDD content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. The letter "n" means no sample was collected. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

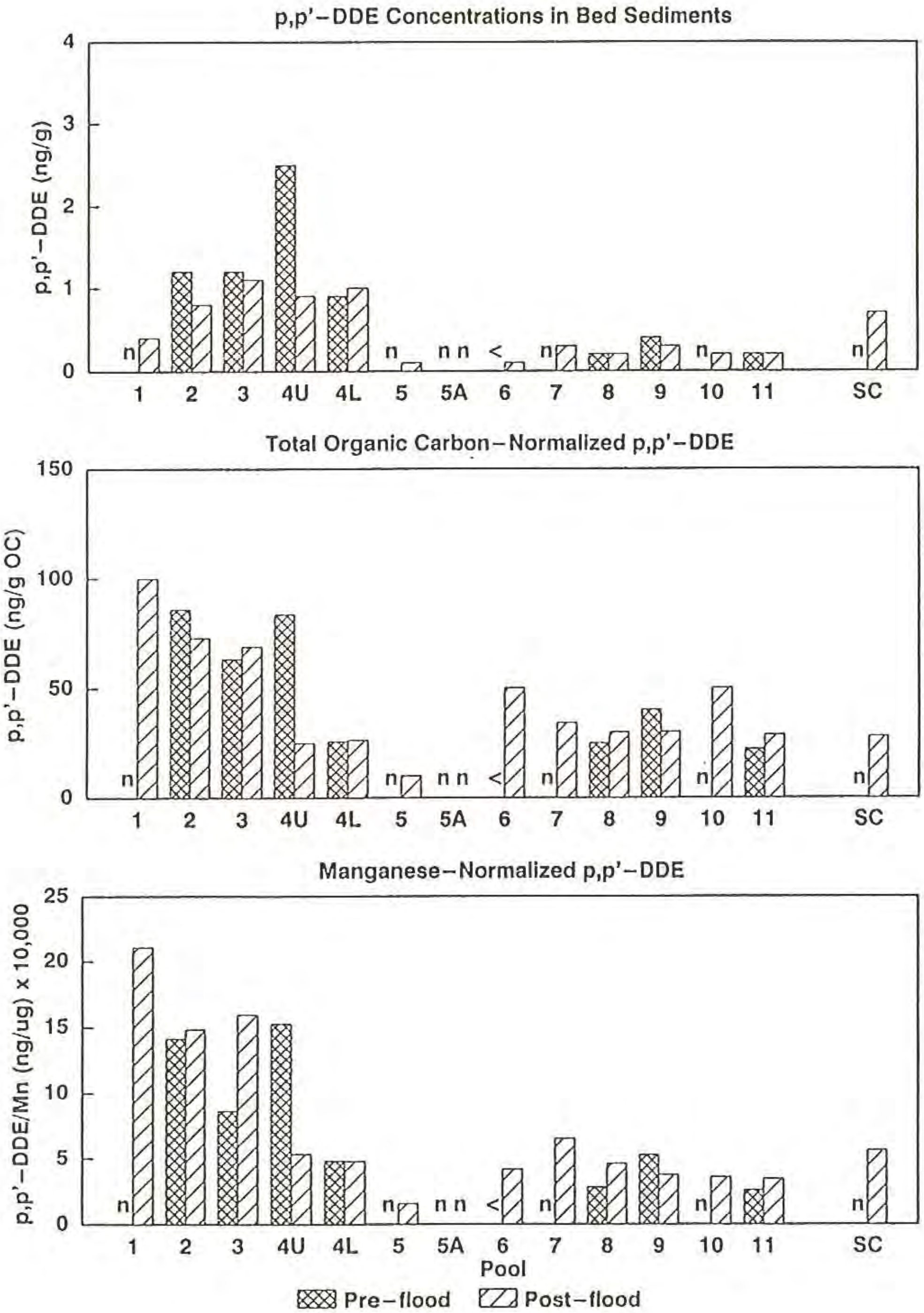


Figure 7. p,p'-DDE, TOC-normalized p,p'-DDE and manganese-normalized p,p'-DDE content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. The letter "n" means no sample was collected and "<" means less than the detection limit. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

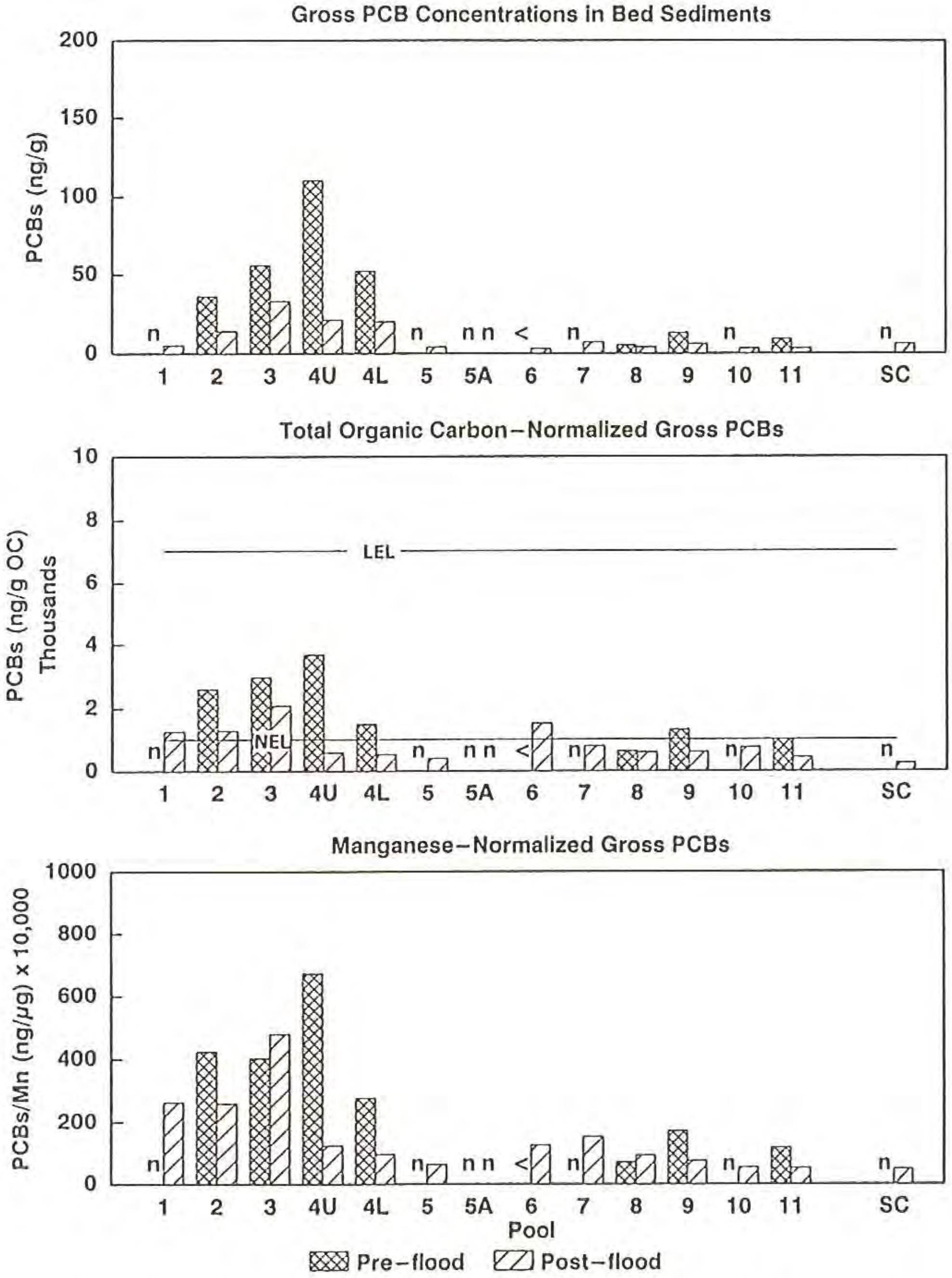


Figure 8. Gross PCB (Aroclor-based method), TOC-normalized PCB and manganese-normalized PCB content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. The letter "n" means no sample was collected and "<" means less than the detection limit. NEL represents the no effect level and LEL the low effect level Sediment Quality Guidelines obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

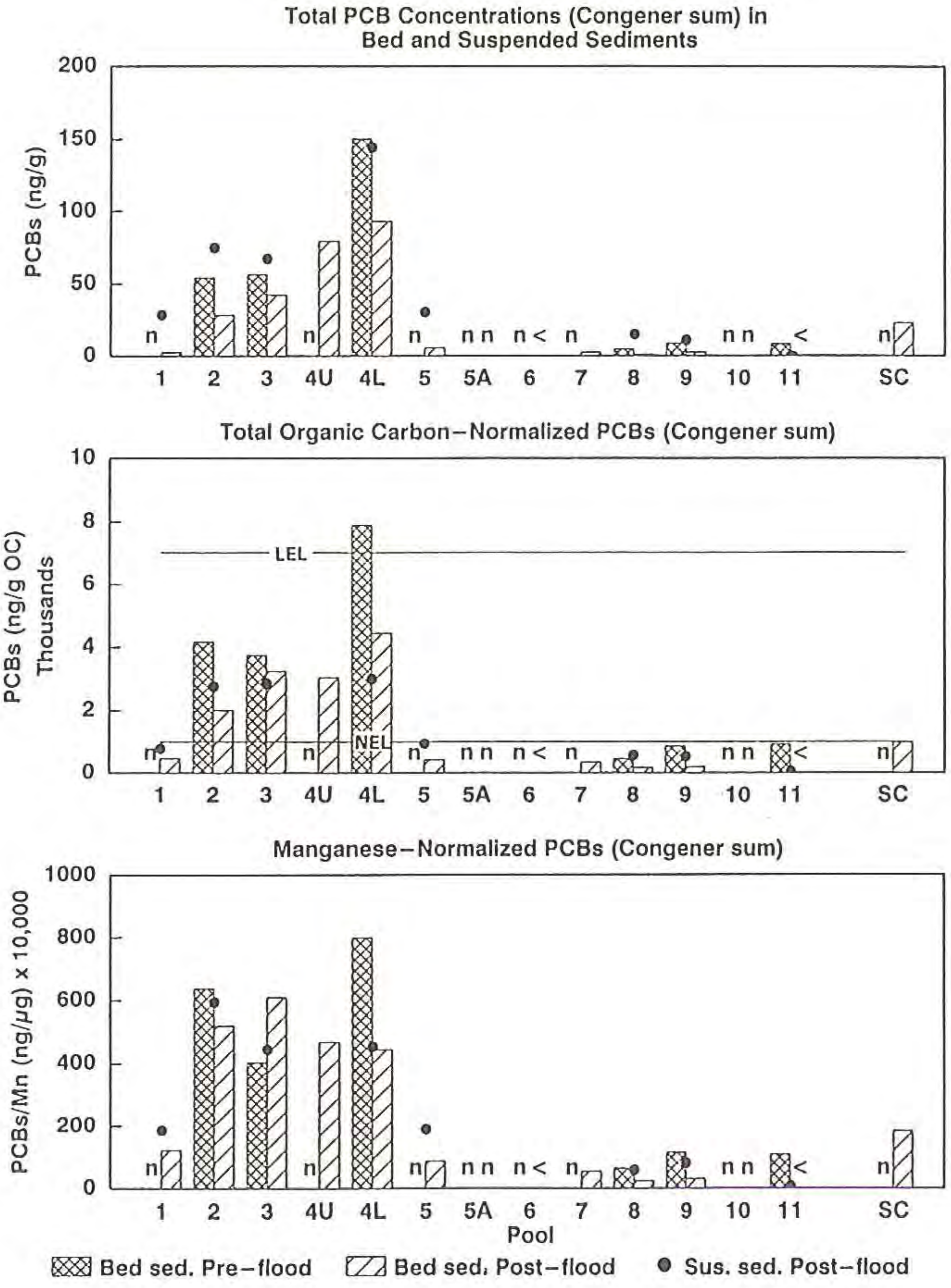


Figure 9. Total PCB (congener-sum), TOC-normalized PCB and manganese-normalized PCB content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected and "<" means less than the detection limit. NEL represents the no effect level and LEL the low effect level Sediment Quality Guidelines obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

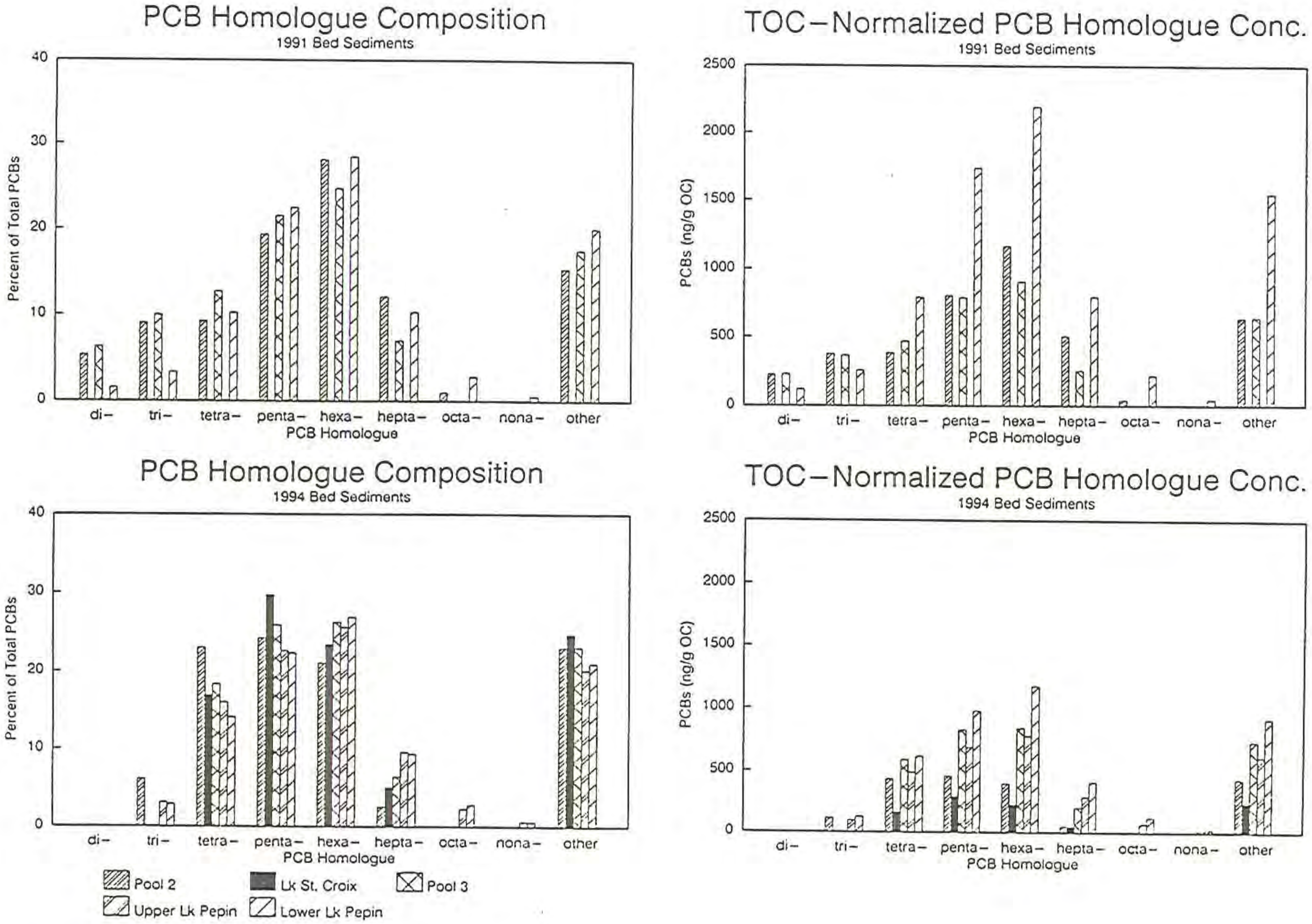


Figure 10. PCB homologue composition and TOC-normalized homologue content of surficial bed sediments collected from the Upper Mississippi River (above Lock and Dam 4) and Lake St. Croix. Co-eluting PCB congeners representing multiple homologues are marked "other".

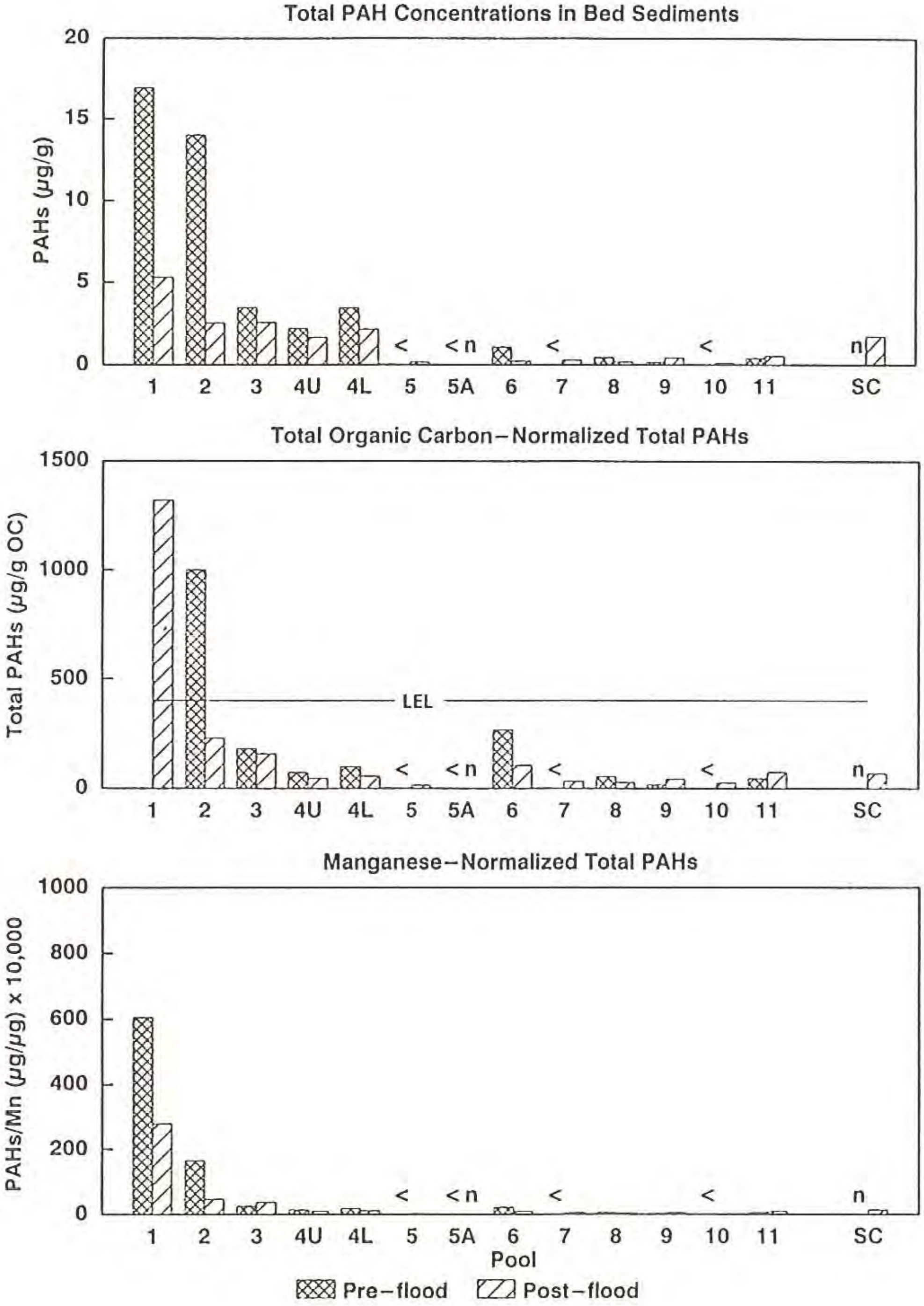


Figure 11. Total PAH, TOC-normalized PAH and manganese-normalized PAH content of surficial bed sediments collected from the Upper Mississippi River Lake St. Croix (SC) before and after the 1993 summer flood. The letter "n" means no sample was collected and "<" means less than the detection limit. LEL represents the low effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

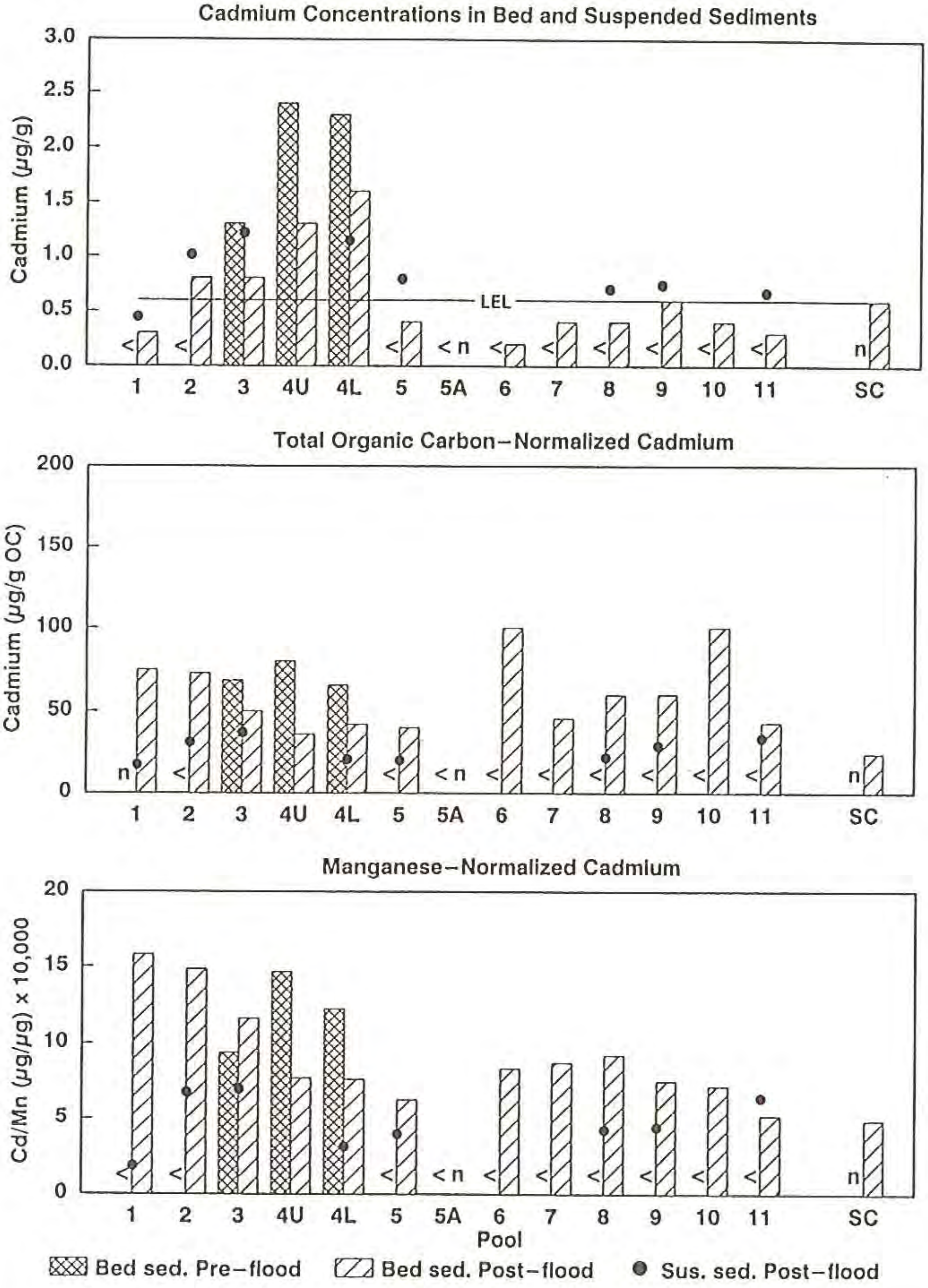


Figure 12. Cadmium, TOC-normalized cadmium and manganese-normalized cadmium content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected and "<" means less than the detection limit. LEL represents the low effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

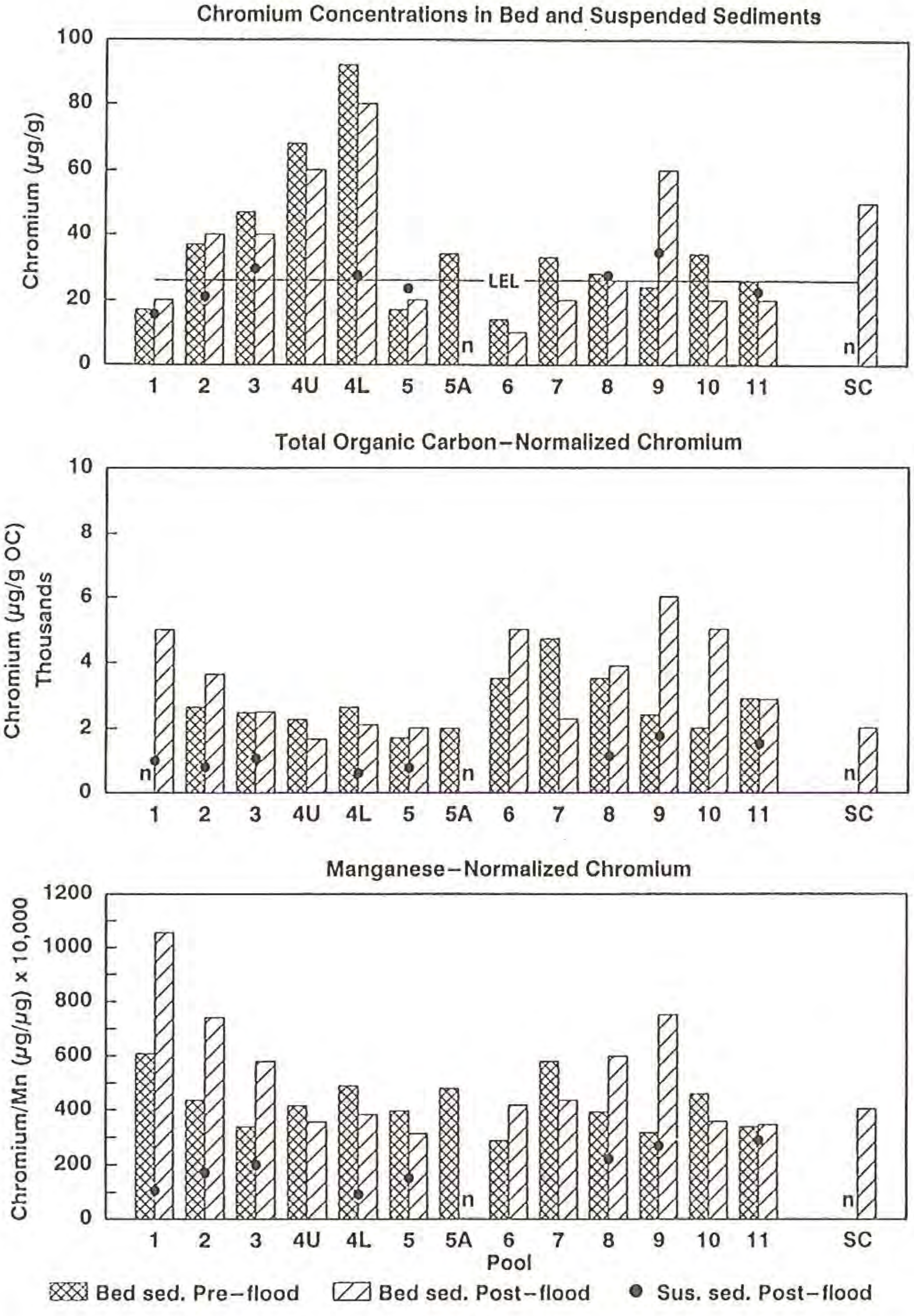


Figure 13. Chromium, TOC-normalized chromium and manganese-normalized chromium content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected. LEL represents the low effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

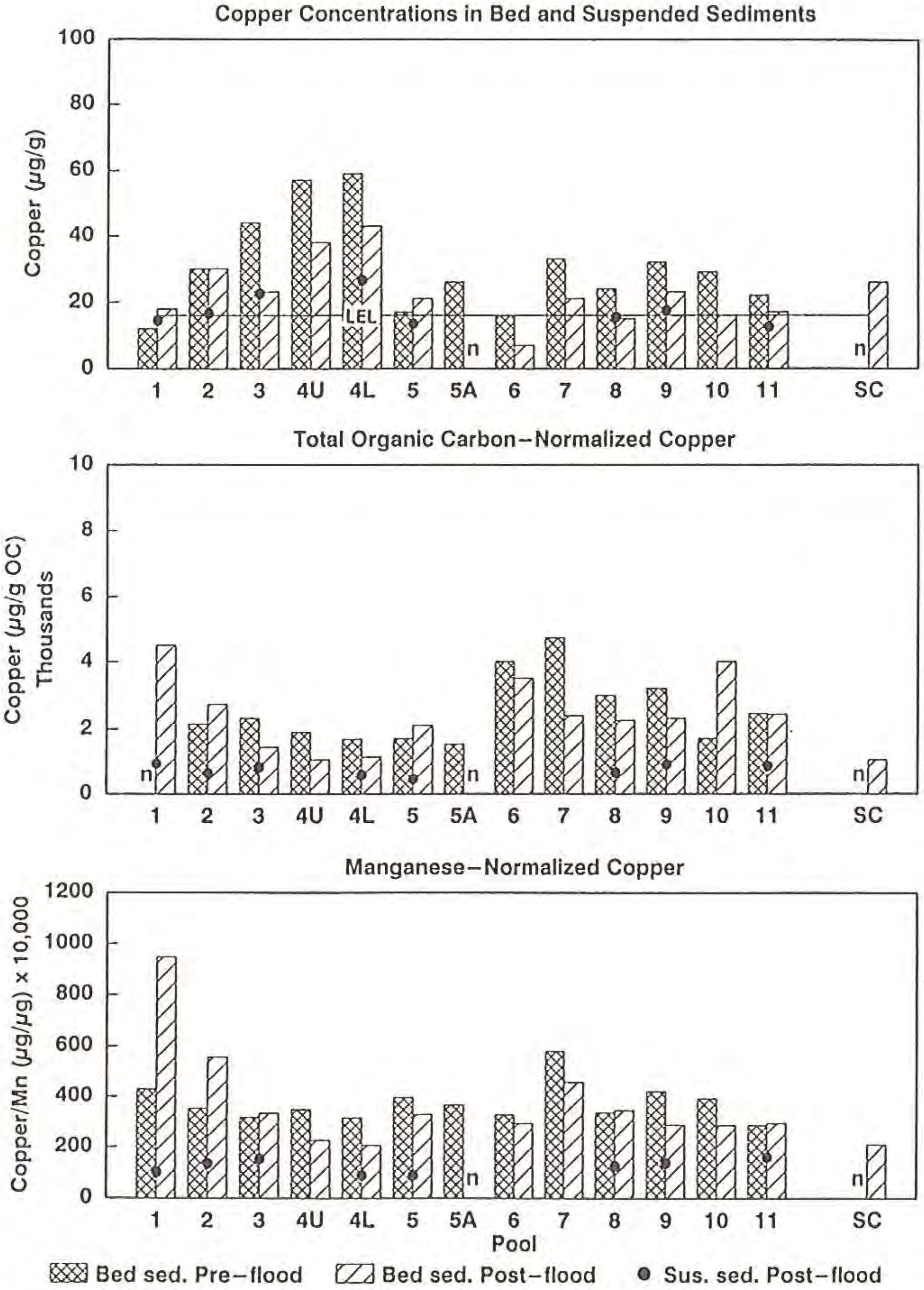


Figure 14. Copper, TOC-normalized copper and manganese-normalized copper content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected. LEL represents the low effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

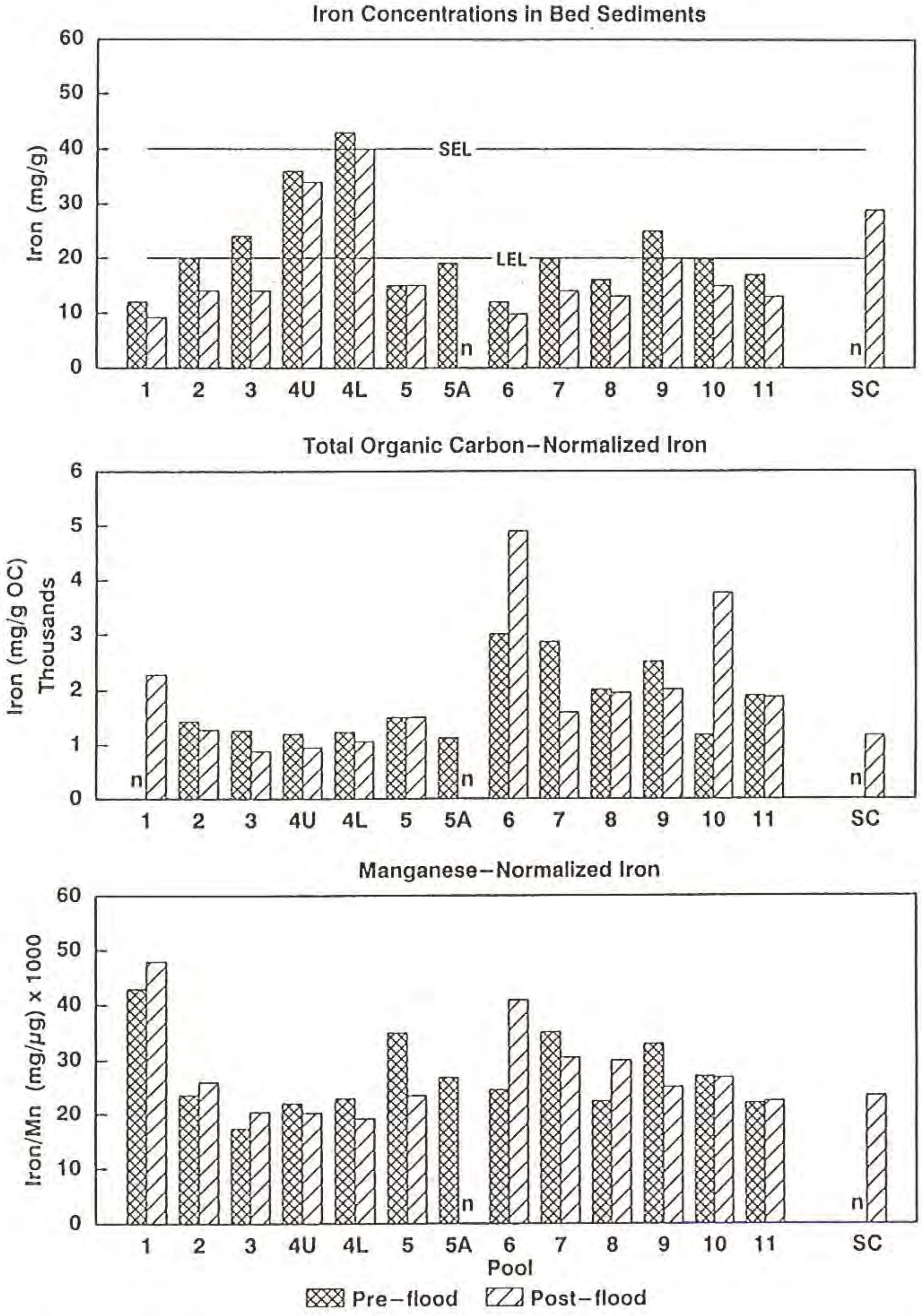


Figure 15. Iron, TOC-normalized iron and manganese-normalized iron content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. The letter "n" means no sample was collected. LEL represents the low effect level and SEL the severe effect level Sediment Quality Guidelines obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

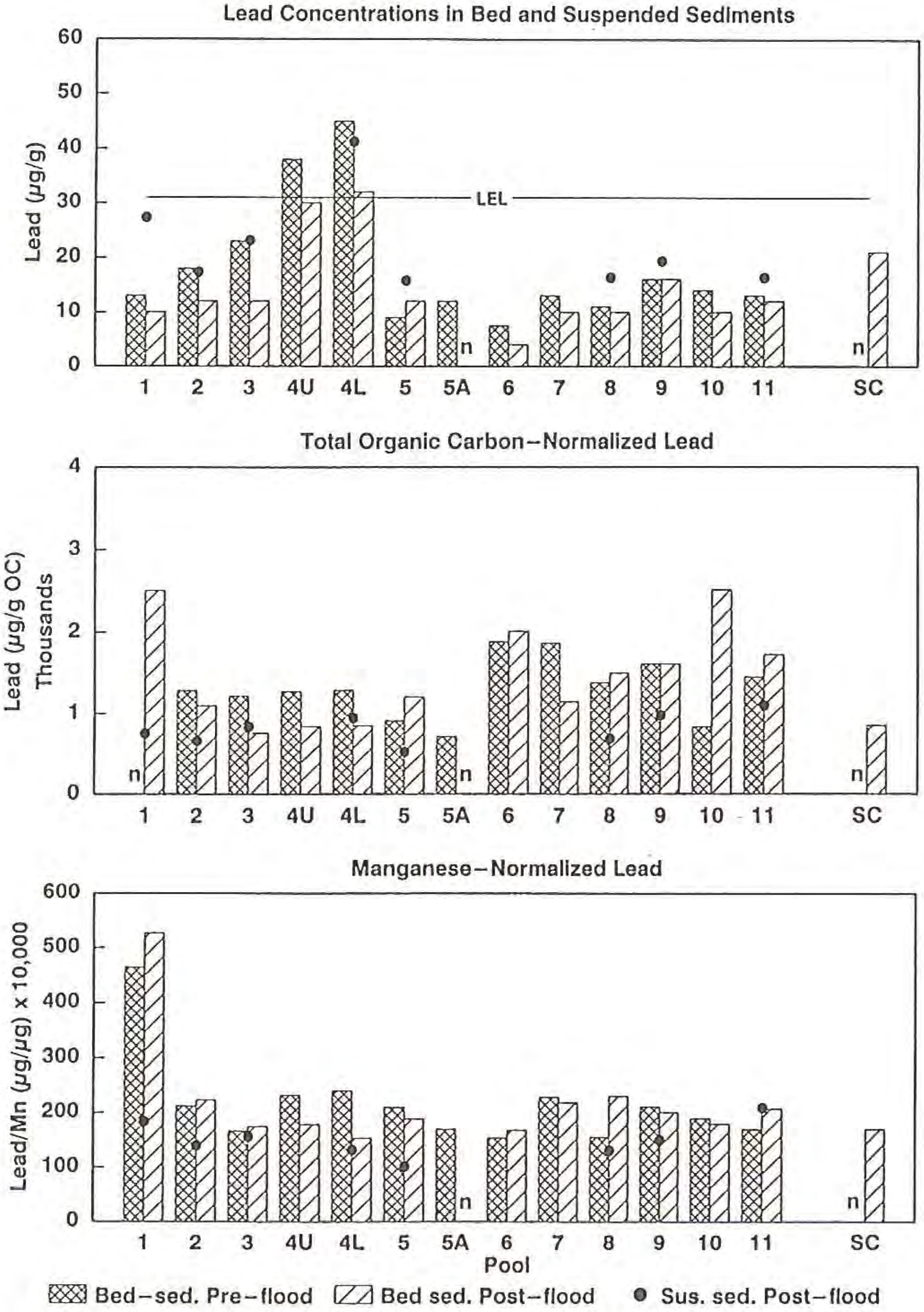


Figure 16. Lead, TOC-normalized lead and manganese-normalized lead content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected. LEL represents the low effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

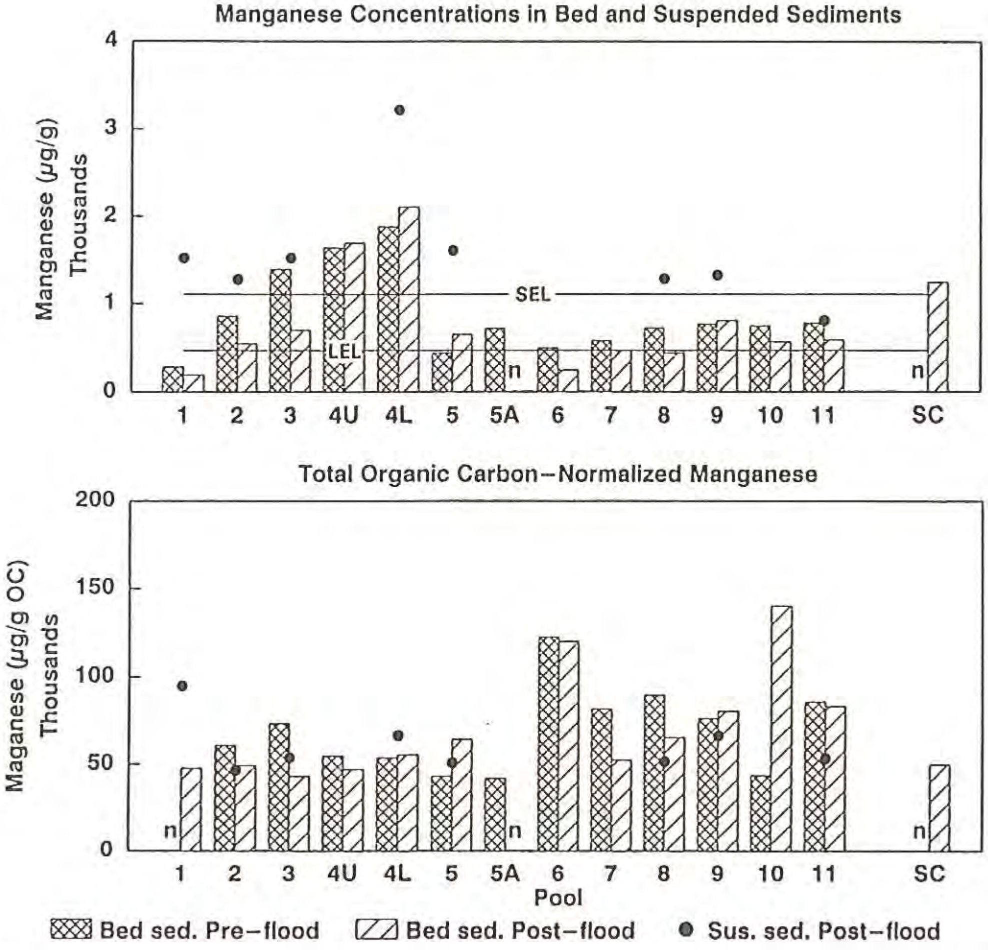


Figure 17. Manganese and TOC-normalized manganese content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected. LEL represents the low effect level and SEL the severe effect level Sediment Quality Guidelines obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

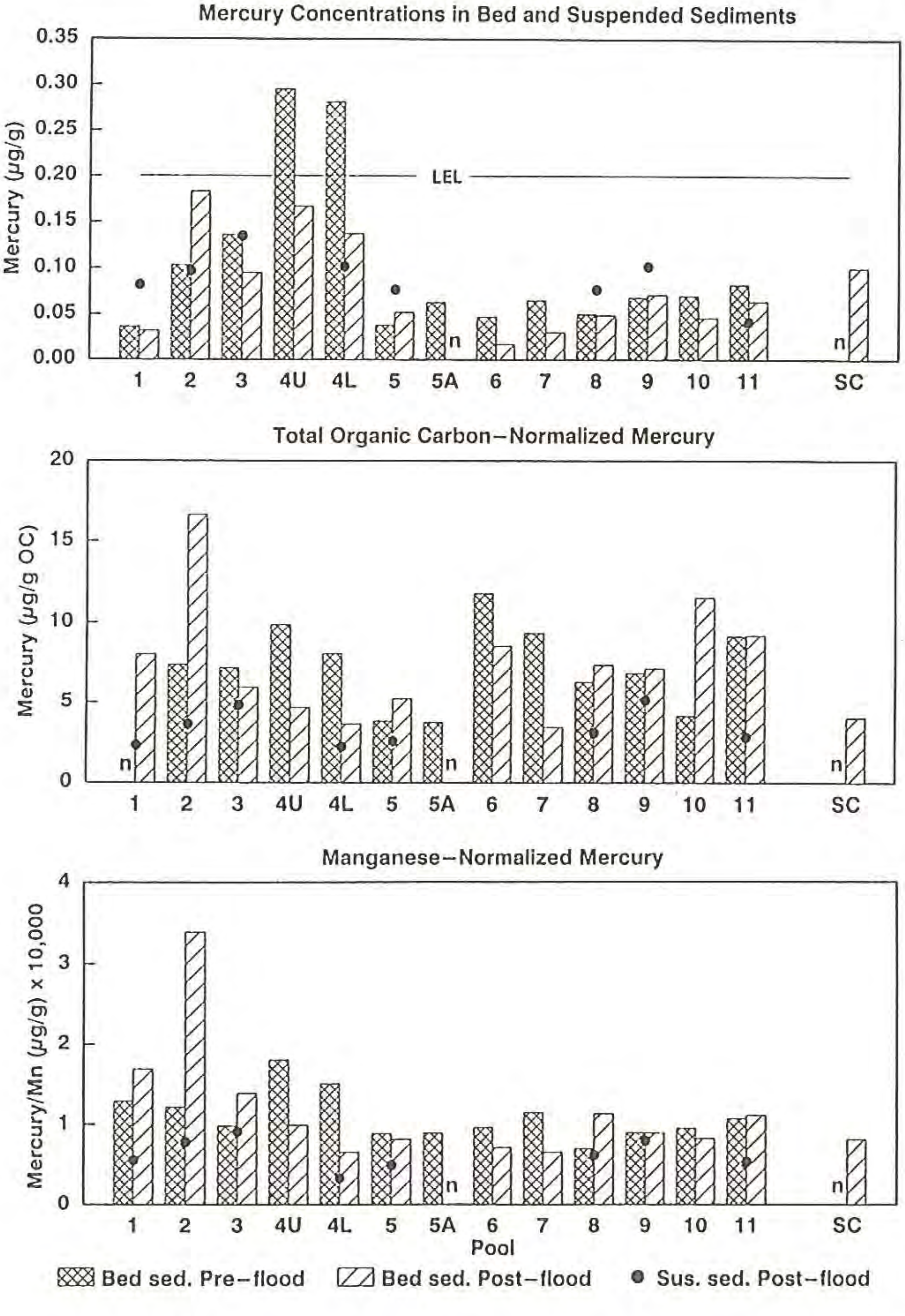


Figure 18. Mercury, TOC-normalized mercury and manganese-normalized mercury content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected. LEL represents the low effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.

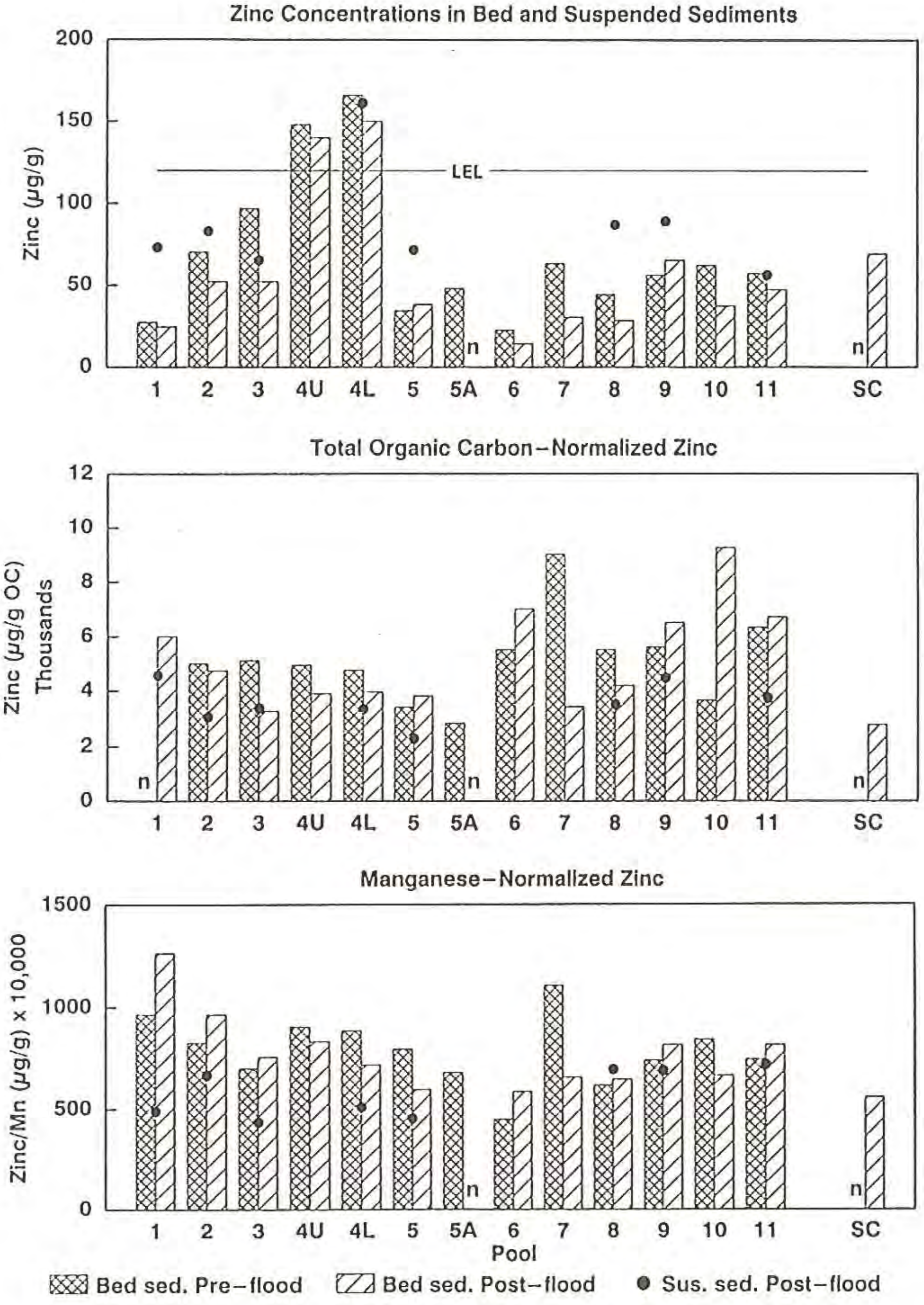


Figure 19. Zinc, TOC-normalized zinc and manganese-normalized zinc content of surficial bed sediments from the Upper Mississippi River and Lake St. Croix (SC) before and after the 1993 summer flood. Post-flood suspended sediment data for the Mississippi River (solid dots) were obtained from Sullivan (1995). The letter "n" means no bed sediment sample was collected. LEL represents the low effect level Sediment Quality Guideline obtained from the Ontario Ministry of the Environment and Energy. Pool 4 samples were collected from upper (4U) and lower (4L) Lake Pepin.