

Distribution of Potentially Toxic Metals in Bed
Sediments and Crayfish of the Upper Wisconsin River

A Thesis

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ABSTRACT

The stratigraphic distributions of mercury, cadmium, lead, zinc, and copper in bed sediments of the Upper Wisconsin River from Brokaw to the Lake DuBay Dam (main study area) were studied. Organic content, texture, and cesium-137 profiles in sediment cores were also determined. Mercury was measured in whole crayfish (Orconectes spp.) collected in the same reaches of river. The Rainbow Flowage, located on the Upper Wisconsin River upstream from point discharges of metal-containing effluents, was selected as a reference site.

Organic content of surficial sediments in the main study and reference areas ranged from <1 to 20.4% on a dry weight basis. Textural character of the sediments varied from sand and silty sands to clayey silts and silty clays. Effects of grain size and organic content on metal concentrations were minimized by determining the ratio of the metal in question with aluminum, a conservative element. Surface sediments of each site in the main study area had significantly greater grain-size corrected levels of mercury, cadmium, lead, zinc, and copper than sediments in the reference area. Median corrected levels of cadmium, lead, zinc, and copper in surficial sediments of the main study area were 2.5- to 3.0-fold greater than in those of the reference area, whereas median corrected concentrations of mercury were at least 10-fold greater in the main study area. Stratigraphic profiles of the five metals were generally similar among sediment cores from the main study area. Radiocesium dating of core strata revealed that metal deposition generally began increasing during the early 1950s, reached a maximum during 1950-1962, and decreased to lower, but still enriched, levels in surficial sediments. Metal concentrations in core profiles from the

reference area were small in comparison to the main study area and demonstrated little vertical variation. Sediment Enrichment Factors indicated moderate enrichment of main study area sediments with cadmium, lead, zinc, and copper and substantial enrichment of those sediments with mercury.

Total mercury burdens in whole crayfish ranged from 0.05 to 1.1 $\mu\text{g/g}$ dry weight. Mercury concentrations in whole crayfish collected during 1981 were similar to, or greater than, concentrations observed in crayfish collected during 1975. Mercury burdens were greatest in crayfish from Lake DuBay and smallest in crayfish from the above Brokaw study site. Availability of mercury to biota in this system may be enhanced by high methylation rates, despite burial of the most mercury-contaminated strata of sediments.

INTRODUCTION

The Wisconsin River flows southward through the northern portion of Wisconsin and then southwestward to the Mississippi River. The character of the Upper Wisconsin River has been extensively changed by the construction of several power dams that form a series of impoundments in this segment of the river. Several municipal sewage treatment plants and pulp and paper mills discharge wastes into the river. As a result of these developments, the Upper Wisconsin River has experienced low dissolved oxygen levels, slimes, and odors. In addition to these water quality problems, toxic compounds have also been detected in the Upper Wisconsin River.

Elevated mercury levels were detected in sediments and crayfish from the Wisconsin River during the 1970s. The highest concentrations of mercury were located downstream of pulp and paper mills and a chlorine-caustic soda plant (Konrad 1971). Use of phenylmercuric acetate (PMA) as a slimicide by the paper industry decreased in 1958; however, several mills continued to use PMA until 1970 when the Wisconsin Department of Natural Resources advised that use of mercuric slimicides be discontinued. Sheffy's (1978) results suggested that mercury in the Wisconsin River was biologically available and accumulating in impoundments downstream from discharge points. This phenomenon has been reported in other riverine systems receiving mercury in effluents from the pulp and paper industry (Jackson 1979). Studies of mercury methylation in riverine sediments containing organic wastes from paper mills (Kudo et al. 1977) and in reservoirs (Phillips and Medvick 1981) strongly suggest that a significant proportion of the mercury in the Upper Wisconsin River could be in the highly toxic

methylated form. Characteristics of impoundments on the Wisconsin River, such as Lake DuBay, that favor high rates of bacterial methylation of mercury include: (1) high rates of primary production, (2) periods of high flow that mobilize methyl mercury formed in sediments, and (3) sufficient mixing to prevent thermal stratification and maintain mildly oxidized bottom waters (Phillips and Medvick 1981). Also noteworthy are the findings of Jacobs and Keeney (1974), who studied in situ methylation of mercury in Wisconsin and Fox River sediments treated with mercuric chloride and PMA. They found that formation of methylmercury was greatest in Wisconsin River sediments treated with PMA and hypothesized that rates of methylation of mercury were higher in Wisconsin River sediments because of their acidic nature and high organic content.

Data on metal concentrations in Upper Wisconsin River sediments, collected by the Upper Wisconsin River Basin 208 Task Force, suggested that reservoirs in this stretch of river were also polluted with metals other than mercury (Appendix 1). Application of United States Environmental Protection Agency criteria for harbor sediments to these data indicated moderate pollution with copper, lead, and chromium and moderate to heavy pollution with zinc and manganese.

Sediment analyses have become a widespread method for assessing metal pollution in inland waters (Forstner and Wittmann 1981). Contamination of bed sediments by toxic metals can greatly affect the distribution, species composition, and abundance of benthic organisms in natural waters (Eyres and Pugh-Thomas 1978; Wentzel et al. 1977). In addition, toxic metals in surficial sediments can be available for direct uptake by crayfish and other biota (Kudo and Mortimer 1979).

This study was conducted to evaluate the degree of metal contamination in sediments and crayfish of the Upper Wisconsin River from Brokaw to the Lake DuBay dam. The specific objectives of this study were to:

1. determine the present distribution of five potentially toxic metals (mercury, cadmium, lead, zinc, and copper) in sediments of the Upper Wisconsin River from Brokaw to the Lake DuBay dam;
2. provide a historical perspective on input intensities of the five metals to the studied reach of river; and
3. compare recent (1981) mercury concentrations in crayfish to levels measured during 1974-75, after reductions in mercury discharges to the river.

DESCRIPTION OF THE STUDY AREA

The studied reach of the Upper Wisconsin River is located in the Northern Highlands geographical province of Wisconsin (Martin 1965) and extends from the Lake DuBay dam to above Brokaw (Fig. 1). In this stretch of the river, numerous tributaries form a dendritic drainage system, which is overlain by Pleistocene glacial drift that mantles an eroded Precambrian surface of granitic rock (USDA 1979a). The watershed draining to Lake DuBay has an area of about 12,700 km² (USDA 1979b).

Soils in the northern portion of the Upper Wisconsin River basin consist of well-drained sandy upland soils, while heavier loamy upland soils predominate in the central part of the basin. Land use of the entire Wisconsin River basin during 1977 included 42% in forest, 29% in cropland, 12% in grassland, 4% in urban development, 6% in other uses, and 6% in water and Federal land (USDA 1979c).

Wisconsin River water is soft and weakly buffered. Annual mean alkalinity, hardness, and pH near Wausau are about 28 mg/L (as CaCO₃), 40 mg/L (as CaCO₃), and 6.8, respectively. Water quality in the main study area is classified as having intermittent or significant standards violations, most notably with low dissolved oxygen (Christianson 1979; Coble 1982). Slimes, odors, and other aesthetic degradations are common, and water quality problems generally occur within five to ten miles of major point sources, frequently pulp and paper mills (USDA 1979a). Sixteen pulp and paper mills discharge wastes into a 260-km stretch of the river.

Upper Wisconsin River water contains high concentrations of nitrogen and phosphorus (Mechenich 1980), which support algal blooms, particularly in the slower moving waters of the reservoirs. Phosphorus

is the nutrient most limiting to phytoplankton (Mechenich 1980).

Phytoplankton densities within impoundments on the Upper Wisconsin River are high, with Melosira, Aphanizomenon, and Cyclotella being the dominant taxa (Sullivan 1980).

Four dams (DuBay, Mosinee, Rothschild, and Wausau) form a series of reservoirs in the main study area. Lake DuBay (Fig. 2), the largest reservoir in the study area, has a surface area of 28.5 km², a volume of 1.04 x 10⁸ m³, and a mean depth of 3.7 m. The turnover time is 9.8 days, and the average annual trapping efficiency is approximately 28%. A sewage treatment plant (RM 248.8) and a pulp and paper mill (RM 248.9) discharge wastes into Lake DuBay. Lake DuBay also receives highly eutrophic water from the Big Eau Pleine reservoir, which significantly affects water quality in the lake (USEPA 1974; Buchanan 1976; Kaster 1976; Kaminski 1977; Shaw 1978). Lake DuBay is eutrophic, and massive blooms of the blue-green alga Aphanizomenon are common during the summer (Mechenich 1980; Sullivan 1980).

The Mosinee Flowage, formed by the Mosinee dam (RM 248.9), has a surface area of 5.57 km², a volume of 1.04 x 10⁸ m³, and a mean depth of 2.1 m (Fig. 3). The turnover time is 1.4 days. This segment of the river receives wastes from one pulp and paper mill (RM 258.2) and one sewage treatment plant (RM 257.8).

Lake Wausau, formed by the Rothschild dam, has a surface area of 7.76 km², a volume of 1.72 x 10⁷ m³, and a mean depth of 2.2 m (Fig. 4). It has a turnover time of 2 days and a trapping efficiency of 18%. The drainage basin for this reservoir covers 10,360 km². One sewage treatment plant (RM 263.8) is located along this stretch of the river.

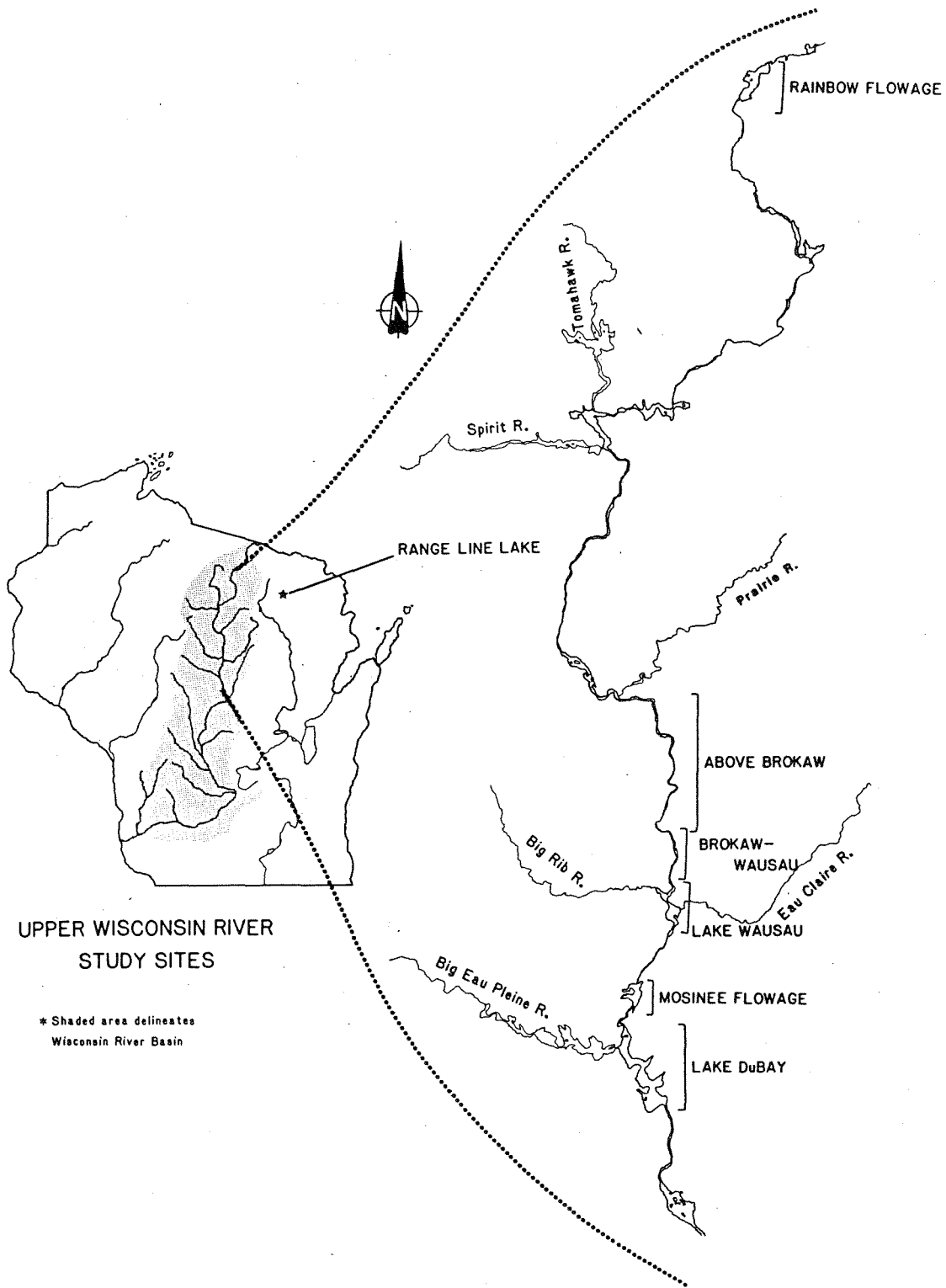


Figure 1. Study areas on the Upper Wisconsin River.

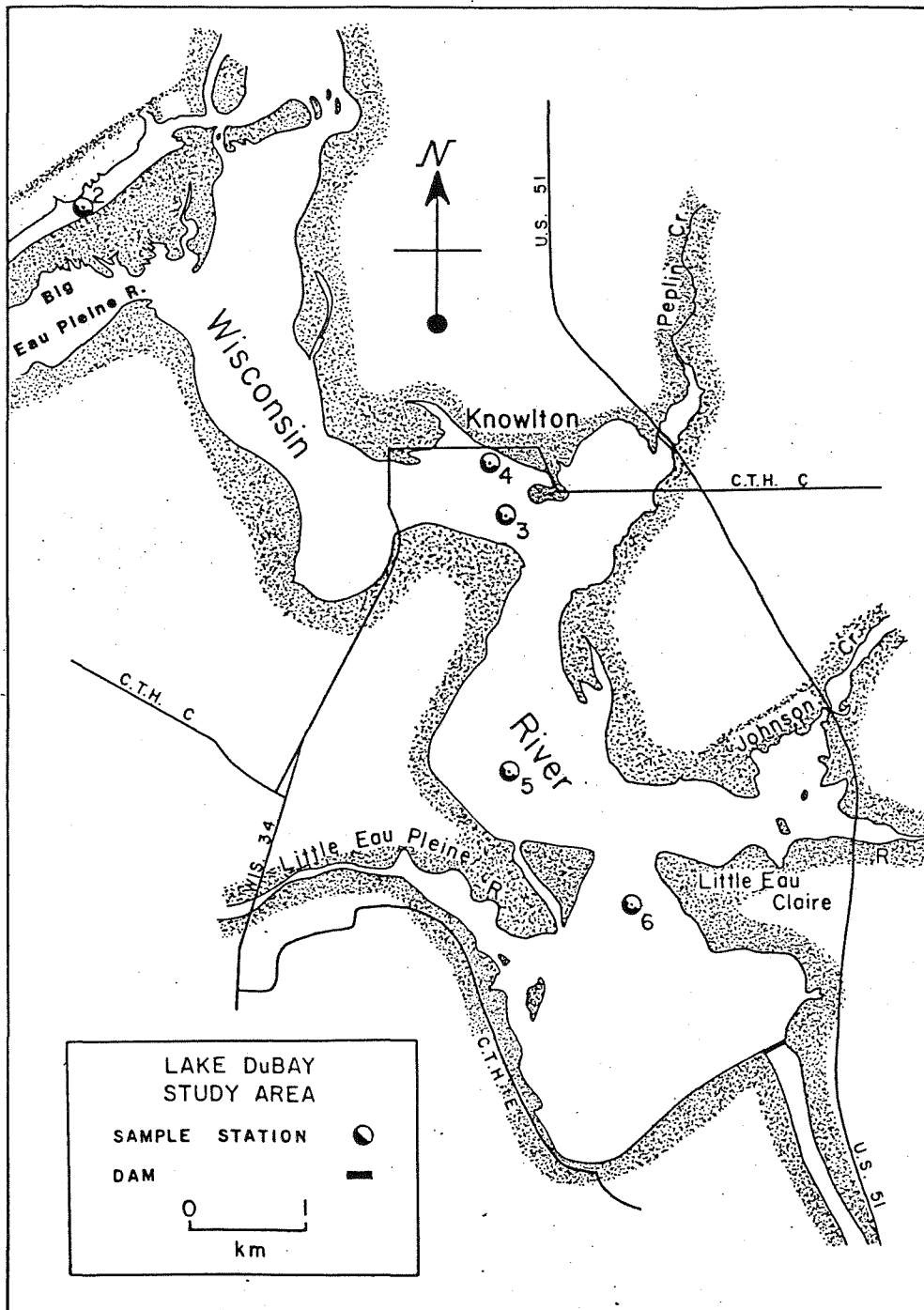


Figure 2. Lake DuBay study area with sediment sampling locations D2, D3, D4, D5, and D6 shown.

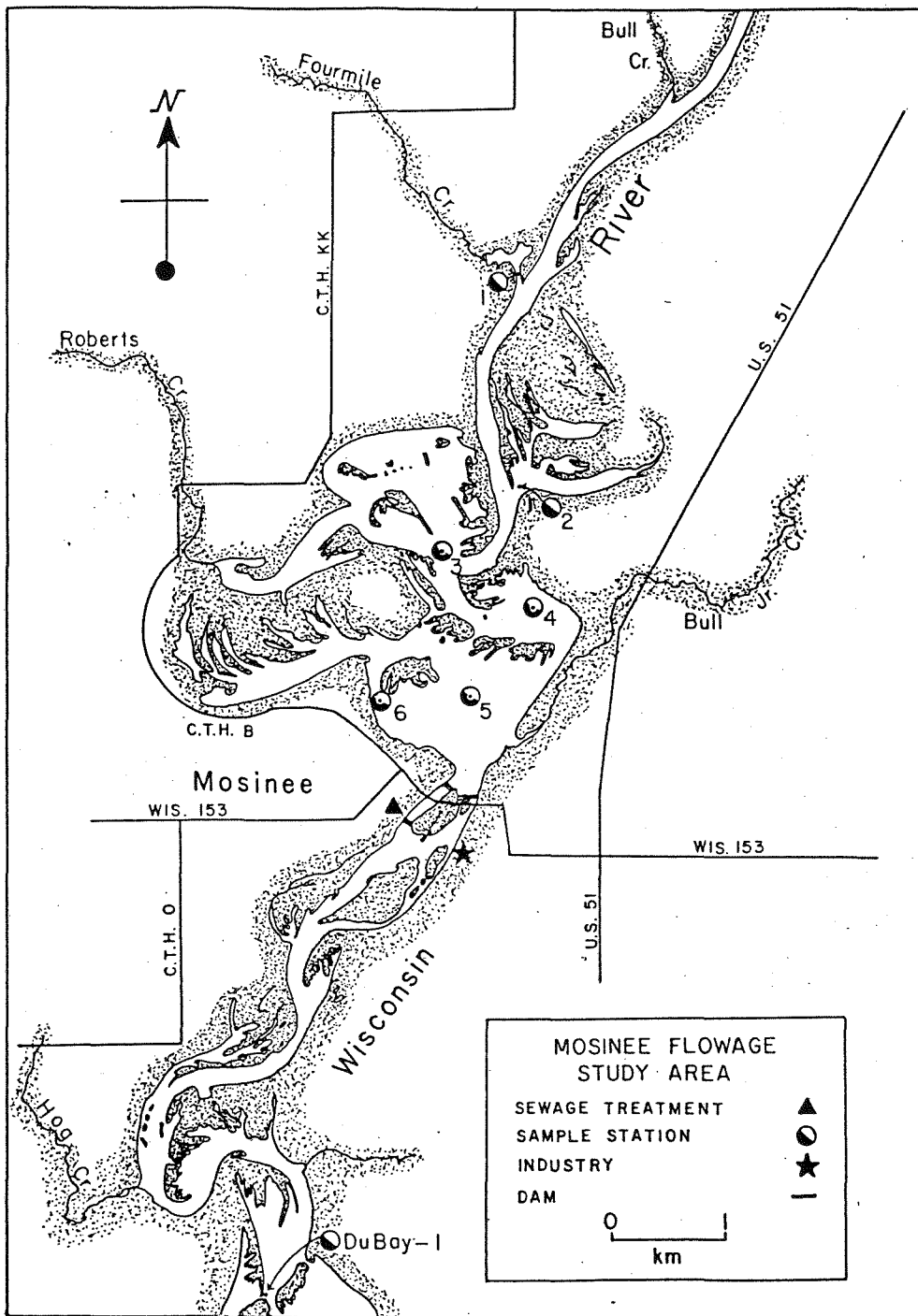


Figure 3. Mosinee Flowage study area with sediment sampling locations D1, M1, M2, M3, M4, M5, and M6 shown.

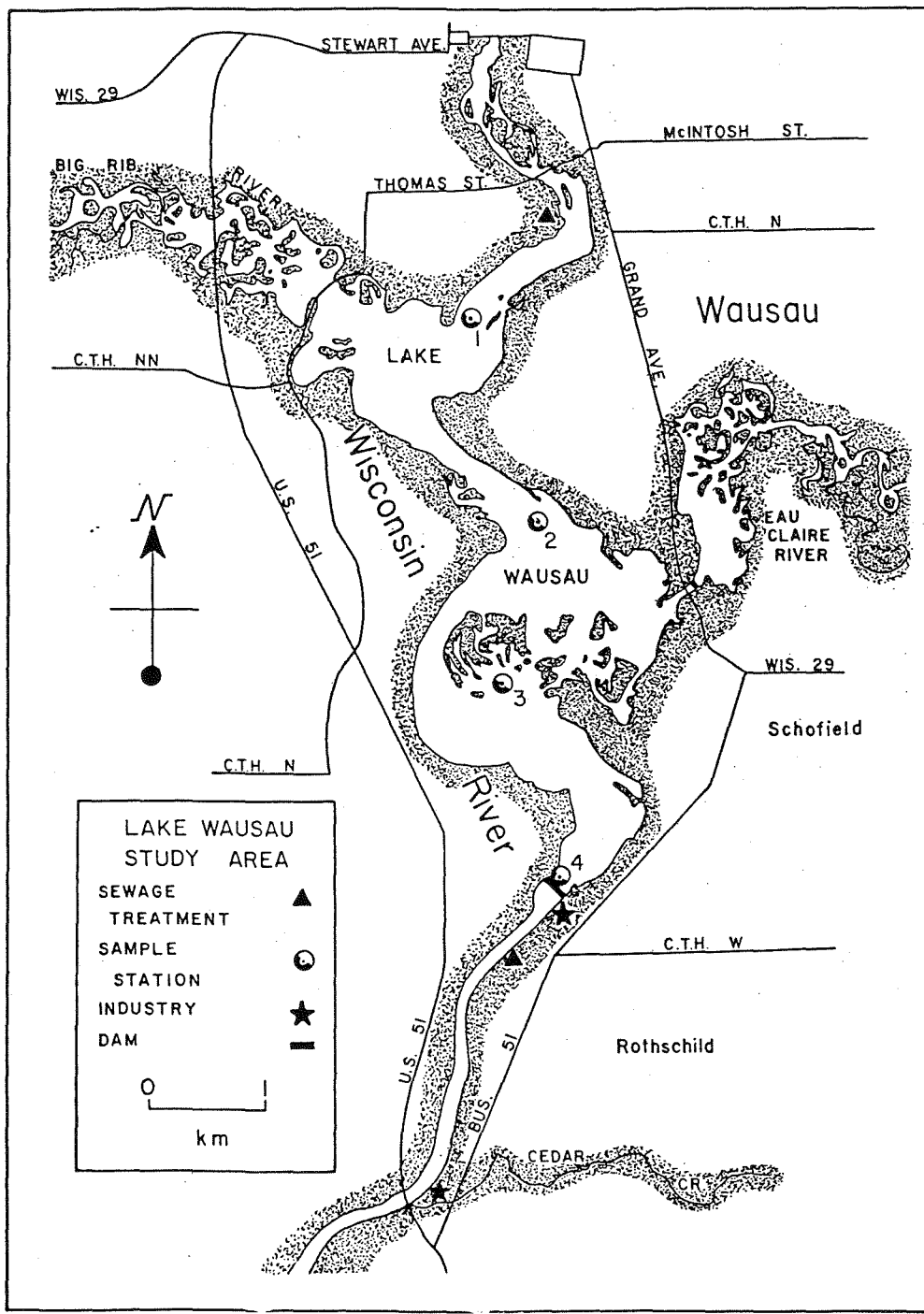


Figure 4. Lake Wausau study area with sediment sampling sites W1, W2, W3, and W4 shown.

One municipal sewage treatment plant (RM 270.4) and a pulp and paper mill (RM 271.0) discharge wastes in the river between Wausau and Brokaw (Fig. 5). Upstream of Brokaw, the Wisconsin River is relatively free-flowing and not impeded by dams (Fig 6).

The Rainbow Flowage (Figs. 1 and 7) and Range Line Lake were selected as reference sites. The Rainbow Flowage has a surface area of 18.1 km², a volume of 6.19×10^7 m³, and a maximum depth of 8.2 m. Mean discharge is 1.69×10^6 m³/day.

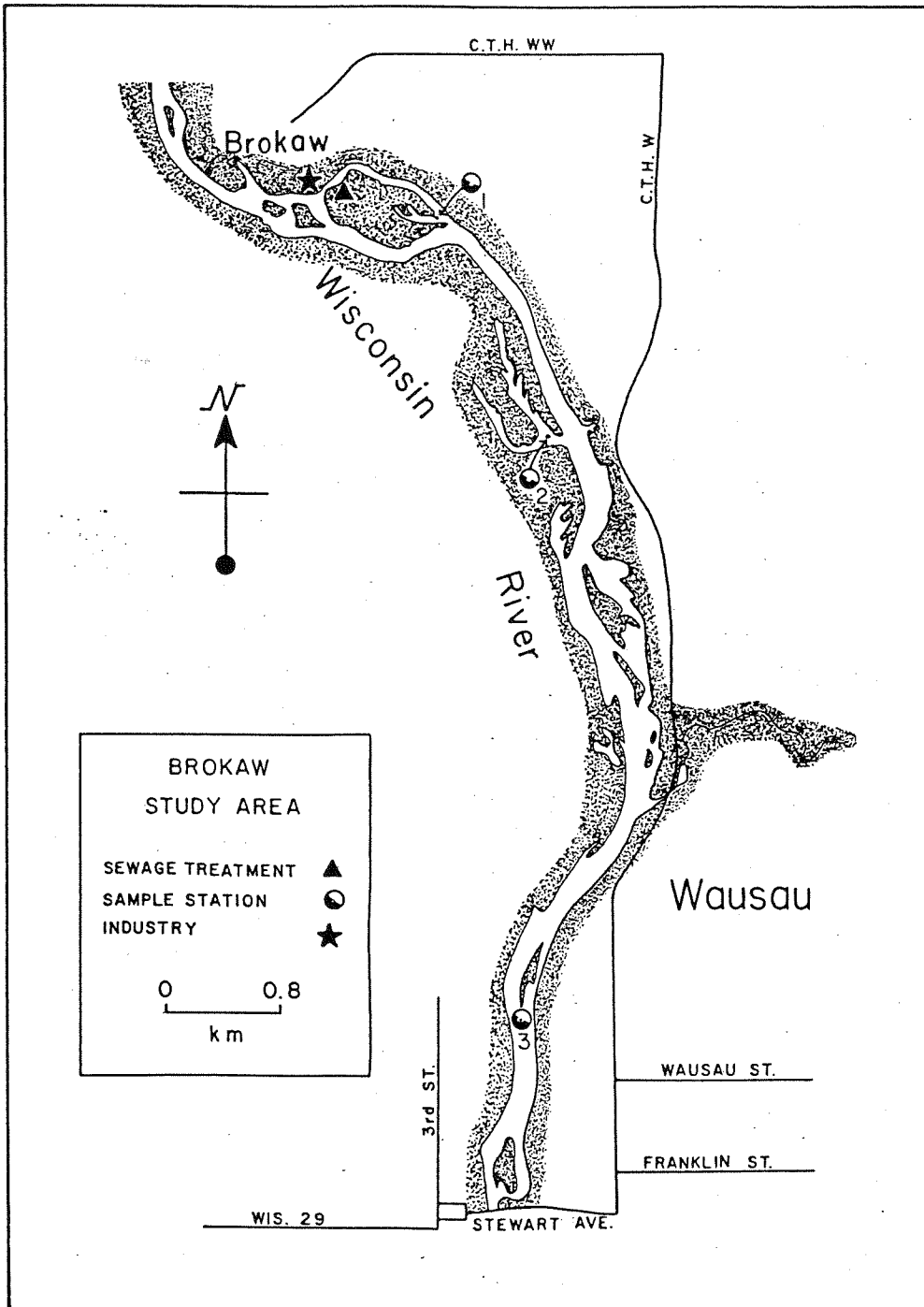


Figure 5. Brokaw to Wausau study area with sediment sampling sites B1, B2, and B3 shown.

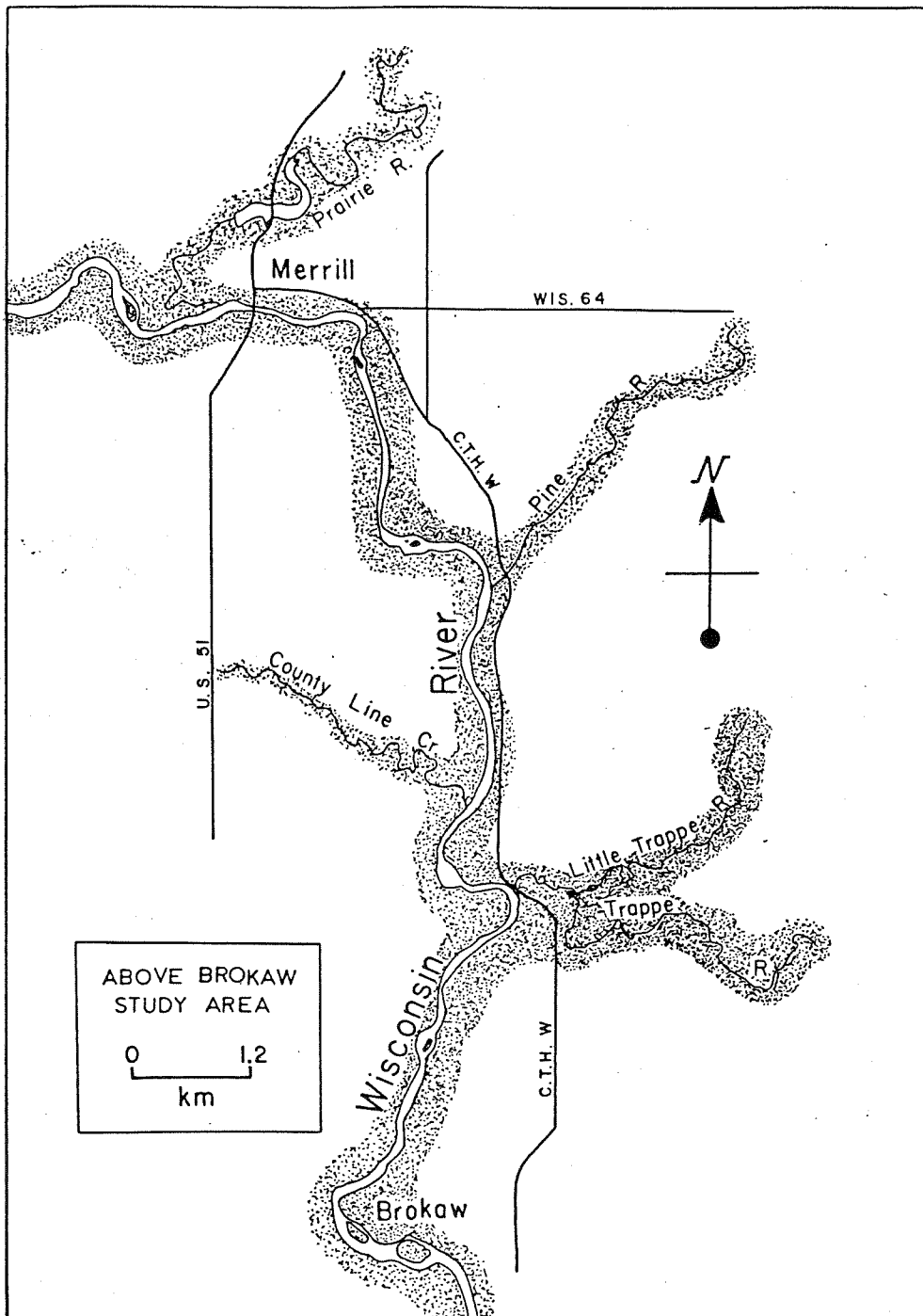


Figure 6. Study area above Brokaw where crayfish samples were taken.

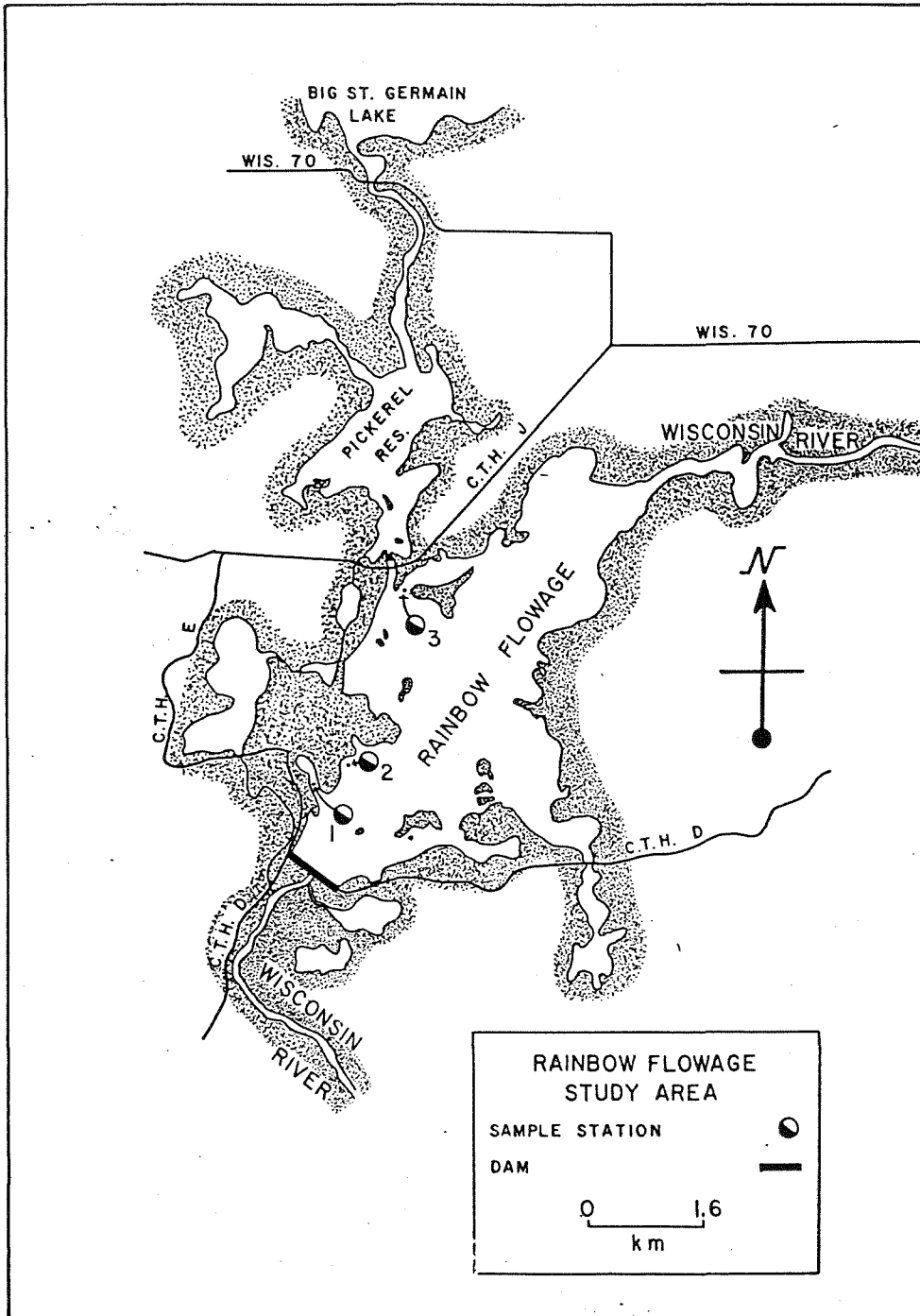


Figure 7. Rainbow Flowage control site with sediment sampling sites R1, R2, and R3 shown.

METHODS

Determination of Sedimentation Rates with Cesium-137

Background. Cesium-137 is a fission product, does not occur naturally, and has a half-life of 33 years. Atmospheric nuclear weapons testing by the United States during 1952 and the Soviet Union during 1962-1963 resulted in fallout of cesium-137 on the land masses of the world. Once deposited on the soil of lake drainage basins, the Cs-137 became rapidly adsorbed onto fine particles such as clays. These particles were transported to lake sediments by erosional processes, resulting in a depositional pattern of Cs-137 in sediments. Peaks of cesium-137 corresponding to the dates of nuclear testing can be found in the sediments. Because of the time lag between atmospheric nuclear testing, fallout, and transport to lake sediments, Cs-137 peaks mark the dates of approximately 1954 and 1964. There should be very little Cs-137 in the soils and sediments deposited prior to 1950. The initial increase in Cs-137 usually corresponds to about 1954 and the maximal level of Cs-137 usually corresponds to about 1964. Another less defined peak, which corresponds to about 1958, may also be observed (J. R. McHenry, pers. comm.).

Ideally, cesium-137 can be used to determine sedimentation rates in both riverine and lacustrine systems (McHenry et al. 1983). The application of this method assumes that the sediments have not been disturbed and that sedimentation rates have been constant since deposition of the cesium-137. These assumptions are more easily met with lakes than rivers, but the method has been successfully employed for estimating sedimentation rates in reservoirs, such as those studied here (McHenry et al. 1983).

Collection and analyses. Sediment cores were collected from nine locations in the Upper Wisconsin River during July 1981. One sampling location was located between Brokaw and Wausau (B1), one in Lake Wausau (W2), two in Mosinee Flowage (M2, M4), and three in Lake DuBay (D2, D3, D5). The sediment cores were collected with a 2-inch (i.d.) gravity core sampler (Wildco model 2424 A35). Core samples were held on ice in the field and frozen in the laboratory.

Prior to analysis, core samples were partially thawed to facilitate extrusion from core liners. Each core sample was cut into 5- to 7-cm segments. A homogenized aliquant of each sediment core was placed into a plastic petri dish (15.5-cm diameter) and analyzed for cesium-137. Core segments were analyzed by gamma-ray spectrometry and a hyperpure germanium detector (Ortec model 8002-0330E) coupled to a low level a/B counting system (Canberra model 2200). The scintillation crystal, preamplifier, and sample were housed in a steel cave lined with lead, copper, and steel. Samples were counted for 4000 seconds. Background counts were subtracted from raw data prior to data analysis.

Collection and Analyses of Sediments

Sediment cores were collected during August 1981 from the Upper Wisconsin River between Brokaw and the Lake DuBay Dam (RM 271 to 235, Fig. 1). Three sampling stations were located between Brokaw and Wausau, four in Lake Wausau, six in Mosinee Flowage, and six in Lake DuBay. Sediments from three stations on the Rainbow Flowage were used as reference samples because this reach of river has not received direct (other than atmospheric) anthropogenic inputs of metals.

The sediment cores were collected with a 2-inch (i.d.) gravity corer equipped with clear, acid-washed, CAB plastic liners (Wildco model 2424 A35). After collection, samples were stored on ice in the field and frozen upon return to the laboratory. Prior to analysis, the cores were extruded, sliced into 7-cm intervals (or as indicated), and stored in plastic bags. Each sample was homogenized by stirring with a glass rod, air-dried at room temperature, and triturated with porcelain mortar and rubber-tipped pestle. Sediment samples were separated into subsamples with a sediment sample splitter (Model US LSS-72).

Sediment particle size distribution was determined by the sieve-pipet method (USGS 1969). The size graduation scale for sediment texture was defined as follows: sand, 2000-62 μm ; silt, 62-4 μm ; clay, <4 μm . Total organic content of the sediments was determined by weight loss after hydrogen peroxide oxidation (Jackson 1958).

Analyses of aluminum, cadmium, copper, lead, and zinc were conducted on a common digestate (USEPA 1981). One-gram aliquants of sediment were placed into 250-mL flasks and digested in 50 mL of deionized-distilled water, 5 mL of concentrated Ultrex[®] HCl, and 0.5 mL of concentrated Ultrex[®] HNO₃. Samples were heated (not boiled) on a hot plate until the volume was reduced to approximately 25 mL. After cooling, digestates were filtered through Metricel[®] 0.45- μm membrane filters and diluted to 50 mL with deionized-distilled water.

Analyses for mercury were performed on 0.2 to 3.0 g of air-dried sediments (USEPA 1979). Samples were placed in 300-mL fleakers[®] and digested in 5 mL of concentrated Ultrex[®] H₂SO₄, 2 mL of concentrated Ultrex[®] HNO₃, and 5 mL of saturated, reagent grade KMnO₄ solution. Samples were then covered with aluminum foil and autoclaved at 121°C and

15 lbs for 15 minutes. Digestates were cooled and diluted to 100 mL with deionized-distilled water. Six mL of sodium chloride-hydroxylamine sulfate solution was added to reduce excess permanganate.

Metal concentrations in diluted digestates were measured with an Instrumentation Laboratory model 257 atomic absorption spectrophotometer equipped with a model AVA 440 automated cold vapor generator. An air-acetylene flame was used in determinations of cadmium, copper, lead, and zinc, whereas a nitrous oxide-acetylene flame was used in determinations of aluminum. Non-atomic background interferences were minimized during lead and zinc analyses with a deuterium background corrector. The cold vapor technique was used to measure mercury concentrations.

All standard solutions for atomic absorption analyses were prepared from 1000 µg/mL certified standard solutions obtained from the Fisher Scientific Company. Sampling equipment and laboratory glassware were consecutively rinsed with a 50% (by volume) solution of HNO₃, tap water, a 50% solution of HCl, tap water, and deionized-distilled water.

Collection and Analyses of Crayfish

Crayfish were collected during July and August 1981 from each of the six study areas located on the Upper Wisconsin River. Samples from the Rainbow Flowage were used as references, because this stretch of river received no direct inputs of metals. Crayfish were collected by hand or with baited traps and stored on ice in the field. Upon returning to the laboratory, crayfish were weighed, placed in plastic bags, and frozen at -4°C. Prior to analysis, whole crayfish were lyophilized at -60°C, triturated with a porcelain mortar and pestle to a

fine powder, weighed to obtain dry weight of samples, and stored in dessicated, acid-washed glass bottles.

Analyses of mercury were performed on 0.2-0.4 g of lyophilized, whole crayfish. Crayfish samples placed in 300-mL fleakers® that contained 5 mL of concentrated Ultrex® H₂SO₄, 2 mL of concentrated Ultrex® HNO₃, and 5 mL of saturated, reagent grade KMnO₄ solution (USEPA 1979). Samples were then covered with aluminum foil and autoclaved at 121°C and 15 lbs for 15 minutes. After cooling, the digestates were diluted to 100 mL with deionized-distilled water. Excess permanganate was reduced by the addition of 6 mL of sodium chloride-hydroxylamine sulfate solution.

Mercury concentrations in diluted digestates were measured by the cold vapor technique with an Instrumentation Laboratory model 257 atomic absorption spectrophotometer equipped with a model AVA 440 automated cold vapor generator. All standard solutions for mercury analysis were prepared from 1000-µg/mL certified standard solutions obtained from the Fisher Scientific Company. Sampling equipment and laboratory glassware were consecutively rinsed with a 50% (by volume) solution of HNO₃, tap water, a 50% solution of HCl, tapwater, and deionized-distilled water.

Quality Assurance

Sediments. Procedural blanks and calibration standards were taken through digestion and storage procedures to evaluate contamination from reagents and containers. A United States National Bureau of Standards (NBS) reference material (Standard Reference Material 1645 river sediment) and spiked sediment samples were analyzed with each batch of samples to verify procedures and analyses. Approximately 10% of the sediment samples were analyzed in triplicate to estimate precision.

Crayfish. Procedural blanks were taken through digestion and storage procedures to evaluate contamination from reagents and containers. Two NBS reference materials, bovine liver (Standard Reference Material 1577) and oyster tissue (Standard Reference Material 1566), were analyzed in conjunction with crayfish samples to validate procedures and analyses. Approximately 5% of the crayfish samples were digested and analyzed in triplicate to estimate precision.

Statistical Analyses of Data

The non-parametric Mann-Whitney rank sum test was used to evaluate metal enrichment in surficial sediments of the main study area as compared to the control area (Rainbow Flowage). Homogeneity of variances for mercury concentrations in crayfish among sampling locations could not be achieved by logarithmic transformation of data. Therefore, the mercury concentrations were rank transformed and the ranks were evaluated by one-way analysis of variance (Conover and Iman 1981). After one-way analysis of variance, paired comparisons of mean ranks of mercury concentrations were conducted by Tukey's honestly significant difference (hsd) procedure, which has an experimentwise error rate (Steel and Torrie 1980), and Student-Newman-Keuls test modified for unequal sample sizes (Zar 1974). Because sample sizes among locations were unequal, the harmonic mean of the number of samples among locations was used in estimation of confidence intervals for Tukey's hsd test (Bancroft 1968).

RESULTS AND DISCUSSION

Quality Assurance

Sediments. Results of our analyses of NBS river sediment agreed well with certified concentration values, and recoveries from spiked Wisconsin River samples ranged from 97 to 105% (Table 1). Precision during analyses of NBS river sediment was less than 5% (relative standard deviation, RSD) for copper, zinc, lead, and cadmium; precision was 12.6% for mercury (Table 1). During analyses of Wisconsin River sediments, precision (RSD) ranged from 5.6 to 8.4% for copper, zinc, lead, and cadmium, and was 23.3% for mercury. The lower precision for Wisconsin River sediments was expected due to sample variability caused by the presence of extraneous materials such as small wood chips and fibers. In contrast, NBS river sediments were quite homogenous, because they were composed only of matter <180 μm diameter.

Crayfish. Results of analyses of mercury in NBS bovine liver and oyster tissue agree well with certified concentration values, and precision (RSD) during analyses of NBS reference materials ranged from 15 to 23.9% for mercury (Table 2). Mean recovery of mercury from spiked crayfish samples was 94.8% (Table 2). Precision during mercury analyses of triplicate crayfish samples average approximately 10% (RSD).

Textural and Organic Composition of Sediments

Textural character of the sediments in the study areas ranged from sand and silty sands to clayey silts and silty clays (Fig. 8). Means and ranges of surficial sediment composition are presented in Table 3,

Table 1. Results of quality assurance procedures for metal analyses in sediments.

Procedure	Copper	Zinc	Lead	Cadmium	Mercury
<u>Analysis of NBS river sediment</u>					
Certified concentration range ($\mu\text{g/g}$)	109 \pm 19	1,720 \pm 169	714 \pm 28	10.2 \pm 1.5	1.1 \pm 0.5
Our results					
Mean ($\mu\text{g/g}$)	105	1642	715	10.4	1.04
RSD (%) ^a	3.9	2.6	2.7	4.9	12.6
n	18	18	18	18	39
<u>Recovery from spiked samples</u>					
Mean recovery (%)	99.1	98.3	99.6	97.6	104.6
RSD (%)	5.6	6.5	8.4	5.6	23.3
n	36	36	45	41	34

^aRelative standard deviation.

Table 2. Results of quality assurance procedures during mercury analyses of crayfish samples.

Procedure	Mercury
<u>Analysis of NBS bovine liver</u>	
Certified concentration range ($\mu\text{g/g}$)	0.016 ± 0.002
Our results	
Mean concentration ($\mu\text{g/g}$)	0.017
RSD (%) ^a	15.1
n	3
<u>Analysis of NBS oyster tissue</u>	
Certified concentration range ($\mu\text{g/g}$)	0.057 ± 0.015
Our results	
Mean concentration ($\mu\text{g/g}$)	0.056
RSD (%)	23.9
n	10
<u>Recovery from spiked samples</u>	
Crayfish	
Mean recovery (%)	94.8
RSD (%)	7.7
n	9
<u>Precision during analysis of triplicate samples</u>	
Crayfish	
Mean RSD (%)	9.6
Range (%)	3.3-29.4
n	22

^aRelative standard deviation.

^bCalculated from analyses of NBS reference materials.

Texture Key

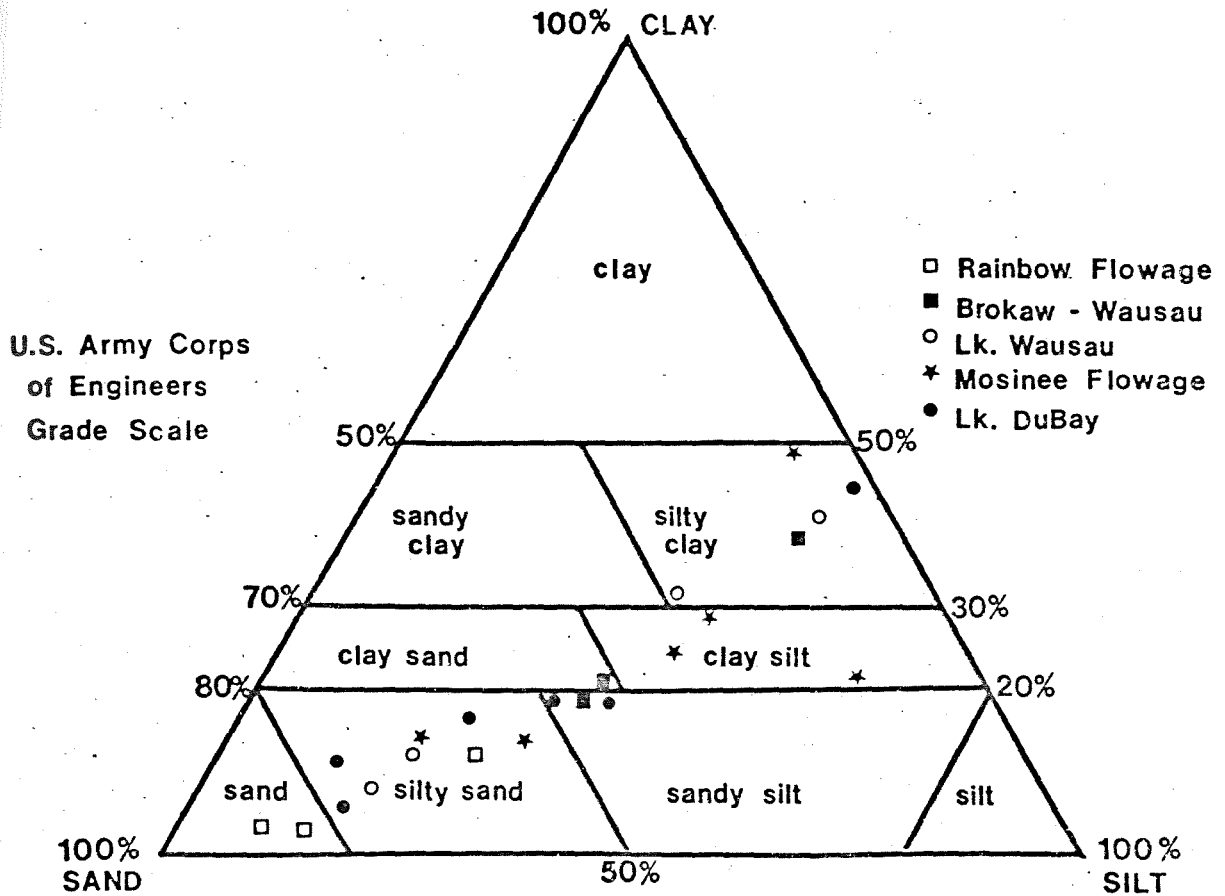


Figure 8. Textural classification of surficial sediments in the Upper Wisconsin River.

Table 3. Means and ranges (in parentheses) of organic, sand, silt, clay content, and dry weight metal concentrations of surficial sediments in the Upper Wisconsin River.

	Lake DuBay (n=6)	Mosinee Flowage (n=6)	Lake Wausau (n=4)	Wausau- Brokaw (n=3)	Rainbow Flowage (n=3)
Organic Content (%)	12.6 (1.9-20.4)	14.5 (8.2-17.1)	11.4 (5.8-16.6)	13.9 (8.5-20.4)	3.0 (0.9-4.8)
Sand Content (%)	51.3 (2.9-78.4)	32.6 (7.3-63.4)	45.1 (8.4-74.4)	32.3 (11.9-43.9)	77.0 (59.8-88.1)
Silt Content (%)	29.0 (12.3-52.0)	41.5 (21.0-65.3)	32.5 (18.0-51.2)	41.6 (36.2-49.8)	16.7 (8.7-27.6)
Clay Content (%)	19.7 (5.7-45.2)	25.9 (13.8-49.3)	22.4 (7.6-40.4)	26.0 (19.9-38.3)	6.3 (3.1-12.6)
Copper ($\mu\text{g/g}$)	29.9 (7.5-41.6)	35.2 (16.8-47.0)	24.2 (15.5-31.1)	34.1 (20.6-56.5)	4.9 (2.3-7.8)
Zinc ($\mu\text{g/g}$)	154.2 (30.0-242.7)	187.2 (144.5-228.0)	156.1 (103.0-199.1)	217.3 (123.5-402.0)	26.0 (11.5-37.4)
Cadmium ($\mu\text{g/g}$)	1.4 (0.6-2.3)	1.8 (1.2-2.2)	1.6 (1.2-2.6)	1.5 (0.9-2.3)	0.2 ($<0.1-0.4$)
Lead ($\mu\text{g/g}$)	37.6 (7.0-55.3)	51.9 (39.3-64.9)	49.0 (31.8-66.5)	53.0 (31.3-76.8)	8.5 (4.8-12.6)
Mercury ($\mu\text{g/g}$)	0.5 (0.02-1.6)	0.6 (0.3-1.0)	0.3 (0.2-0.4)	0.8 (0.2-1.8)	0.04 ($<0.01-0.08$)

and raw data for all locations are presented in Appendix 2. Bed sediments from Rainbow Flowage were predominantly sands and silty sands (Table 3). In contrast, sediments from the sampling stations between Brokaw and Wausau were mainly clayey sands and silty clays; clay content was higher at upstream than at downstream sites (Appendix 2). Lake Wausau sediments varied from silty sands to silty clays, and clay concentrations of the sediments generally increased with distance downstream in the reservoir. In reservoirs, fine silts and clays are often entrained for longer periods and transported to downstream depositional areas having lower current velocities. McHenry et al. (in press) reported a similar trend with regard to the distribution of clay in Lake Pepin of the Upper Mississippi River. Sediments from Mosinee Flowage were composed of silty sands, clayey silts, and silty clays, and the highest clay concentrations were found in depositional areas outside of the main channel (M1, M2, M3, and M6). Silty sands and sandy silts were the primary sediment types in Lake DuBay. The highest clay concentrations in Lake DuBay were found immediately above the Lake DuBay dam (D6), an area with high sedimentation rates.

Organic content of surficial sediments of the entire study area ranged from less than 1% to a maximum of 20.4% on a dry weight basis (Table 3). Rainbow Flowage sediments contained the least organic matter of the study sites, averaging 3.0% with a range of 0.9 to 4.8%. In the Brokaw to Wausau stretch of the river, sediments had a relatively high organic content with a mean of 13.9% and a range of 8.5 to 20.4%; organic content was higher at upstream than at downstream sites. Surficial sediments from Lake Wausau ranged from 5.8 to 16.6% organic

matter with a mean content of 11.4%, and organic content of the sediments increased with distance downstream in the lake. Large amounts of processed wood chips and fibers were present in sediments throughout Lake Wausau. The organic content of the Mosinee Flowage sediments was relatively constant among stations, except at a station (M4) located within the active river channel where current was swifter than at the other stations. Average organic content of surficial sediments in the Mosinee Flowage was 14.5% with a range of 8.2 to 17.1%, and wood chips and fibers were present in sediments throughout the area. Lake DuBay sediments also contained processed wood chips and fibers, and averaged 12.6% organic matter, ranging from 1.9 to 20.4%. The sediments with highest organic content in Lake DuBay were at Station D1, located at the tip of a peninsula, and at Station D6, located immediately above the Lake DuBay dam.

Depositional Pattern of Cesium-137 in Core Profiles

Raw cesium-137 data are presented in Appendix 3. The cesium-137 depositional pattern at B1 indicates that the increase in Cs-137 in the 21 to 26-cm stratum of the profile corresponds to the year 1954 (Fig. 9). The 16 to 21-cm stratum approximates the beginning of the 1960s. Sedimentation at site W2 was apparently a more rapid rate than at site B1. Cesium-137 first appeared in the deepest segment of the core sample (35-40 cm), which corresponds to about 1954. The peak observed in the 21 to 28-cm stratum probably corresponds to 1964. A new cycle of erosion from the watershed is suggested by the relatively large level of Cs-137 in the surface sediments. The initial appearance of Cs-137 in the sediment core at M2 (about 1954) occurred deeper in the profile than at W2, probably because M2 was less affected by main channel flow

Cesium/Aluminum Ratio

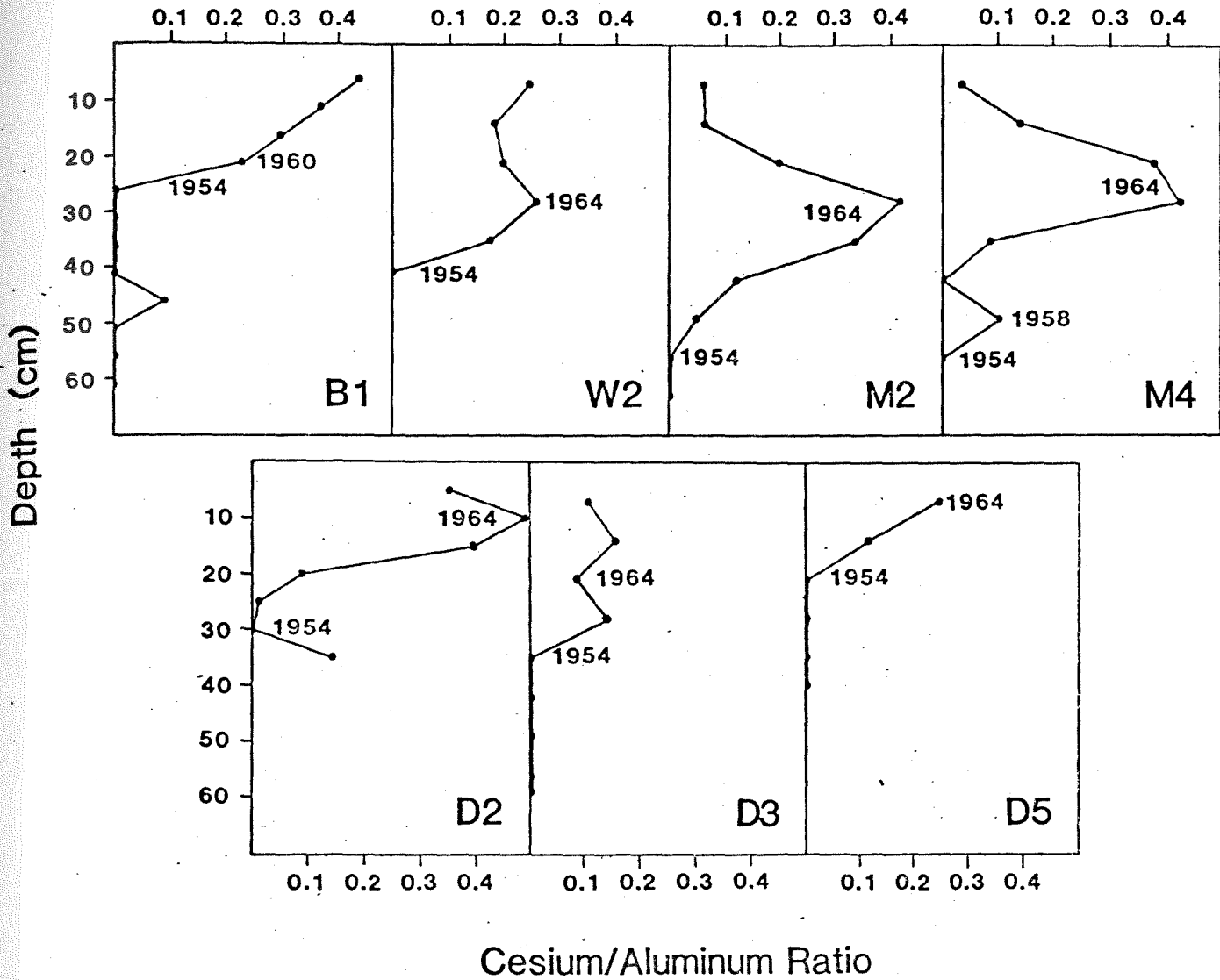


Figure 9. Depositional pattern of Cs-137 in bed sediments at selected sampling locations in the Upper Wisconsin River, August, 1981. Approximate dates of sediment deposition are given on the profiles.

than W2 (Figs. 3 and 4). The levels of Cs-137 are about equal in the 21 to 28-cm and 28 to 35-cm strata at M2; therefore, it is difficult to determine which stratum corresponded to 1964. The profile at M4 was similar to M2, except that the Cs-137 peaks at M4 corresponding to 1964 appeared slightly shallower in the profile than at M2. A 1958 peak was also apparent at M4. The 1954 and 1964 Cs-137 markers were recognizable in all three Lake DuBay sites (D2, D3, D5). Site D3 had the highest sedimentation rate of these stations, and D5 had the smallest sedimentation rate. The data indicate that very little sedimentation has occurred at D5 since 1964.

The use of a small diameter coring device and the nature of sediments in this study likely resulted in compaction of the sediment cores. Therefore, one cannot estimate absolute sedimentation rates, but can only address relative rates of sedimentation. However, approximate dates (usually 1954 and 1964) can be associated with specific strata in the core profiles, enabling an estimation of times of metal input to the sediments.

Metals in Sediments

Comparisons of metals in surface bed sediments among areas. The absolute concentrations of all metals were lower in the reference area (Rainbow Flowage) than in the main study area (Table 3, Appendix 2).

Metal content of surface sediments is strongly related to texture and organic content. Shimp et al. (1971), Kemp et al. (1976), Jaffee and Walters (1977), and Bailey and Rada (in press) observed positive correlations between organic content and metal concentrations in sediments. These relations may be due to direct complexing and adsorption of metals to organic matter or to simultaneous accumulations

of metals and organic materials in fine-grained sediments (Forstner and Wittmann 1981). Furthermore, DeGroot et al. (1971), Oliver (1973), Jaffee and Walters (1977), Salomons and DeGroot (1978), and Bailey and Rada (in press) have observed the preferential occurrence of trace metals in the fine-grained fraction of sediments. Consequently, metal concentrations in bulk sediments with varying textural and organic characteristics cannot be directly compared. The need to minimize grain size effects was particularly apparent when the texture of Rainbow Flowage sediments (mainly sand) was compared to that in the experimental areas (Table 3).

To minimize grain size effects, a ratio was calculated between the concentration of each metal under consideration (cadmium, copper, lead, zinc, and mercury) and the concentration of aluminum (Al), a conservative element (Bruland et al. 1974). Aluminum is strongly bound to clays (Kemp et al. 1976). Consequently, aluminum content is correlated with the clay content of sediments and therefore, with the surface area of sediments. The ratio of the concentration of each metal to aluminum concentration can be used to minimize particle size effects and to assess relative enrichment of sediments with the metal in question. Minimizing grain-size effects also reduces effects of organic matter content on metal concentrations because of the relations between organic matter, metals, and fine-grained sediments.

Relative to the Rainbow Flowage, surficial sediments of each downstream area were enriched with cadmium, copper, lead, zinc, and mercury (Table 4, Fig. 10). A comparison of median [metal]/[Al] ratios for each metal revealed that the reference site, Rainbow Flowage, was

Table 4. Medians and ranges of [metal]/[aluminum] ratios for surficial bed sediments of the Upper Wisconsin River. Ratios were calculated from concentrations (by weight) of each metal and aluminum and represent values multiplied by 10^4 .

Sample site	[Metal]/[Aluminum] ($\times 10^4$)				
	Cadmium	Copper	Lead	Zinc	Mercury
Rainbow Flowage (n=3)	0.29 (<0.01-0.49)	6.4 (4.6-9.7)	13 (8.0-16)	36 (32-37)	0.02 (0.01-0.09)
Brokaw to Wausau (n=3)	0.95 (0.58-1.3)	19 (13-33)	37 (20-45)	93 (80-230)	0.26 (0.13-1.0)
Lake Wausau (n=4)	1.1 (0.93-1.4)	18 (15-19)	34 (31-43)	110 (99-140)	0.23 (0.20-0.35)
Mosinee Flowage (n=6)	1.1 (0.80-1.8)	25 (12-28)	34 (25-45)	120 (88-180)	0.32 (0.22-0.78)
Lake DuBay (n=6)	0.97 (0.72-1.1)	21 (9.8-30)	28 (9.2-33)	120 (39-130)	0.25 (0.02-1.3)

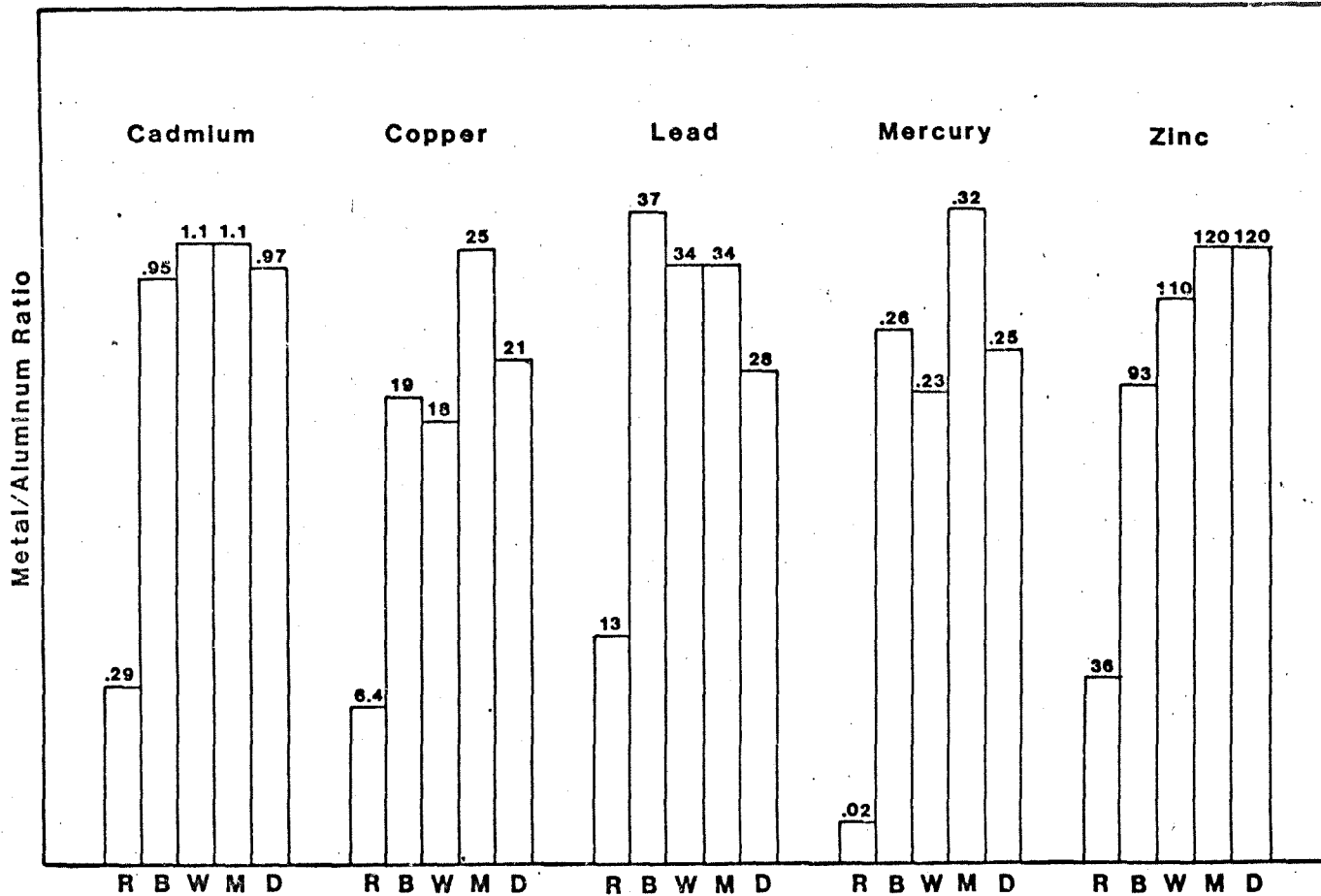


Figure 10. Median [metal]/[aluminum] ratios for surficial bed sediments of the Upper Wisconsin River (R = Rainbow Flowage, B = Brokaw to Wausau, W = Lake Wausau, M = Mosinee Flowage, D = Lake DuBay).

significantly less enriched with cadmium, copper, lead, zinc, and mercury than were all of the main study areas (Table 5). Median ratios for surface sediments in the main study areas were generally 2.5 to 3.0 times greater than ratios of Rainbow Flowage for cadmium, copper, lead, and zinc. Median ratios for mercury were, however, at least ten-times greater in the downstream experimental areas than in the Rainbow Flowage. Furthermore, each downstream area except Lake Wausau had one sampling station with substantially greater mercury to aluminum ratios than the other sampling stations within that area (Table 4, Appendix 4). For example, mercury to aluminum ratios observed in surface sediments from stations B1, M6, and D1 were 1.3×10^{-4} , 0.78×10^{-4} , and 1.3×10^{-4} , respectively. These stations were substantially enriched with mercury in surface sediments in comparison to the Rainbow Flowage.

Comparisons of metals in stratigraphic profiles. Metal concentrations and [metal]/[aluminum] ratios for core profiles of bottom sediments at each station are presented in Appendices 2 and 4, respectively. Although variations occurred, stratigraphic profiles for all metals studied were similar for all study areas except the Rainbow Flowage, the reference area (Figs. 11-15). Maximal enrichment in cores from the main study area was detected in subsurface-sediments, but significant enrichment was also observed in surface sediments. Minimal concentrations were located deep in the sediment core beneath the most enriched strata.

[Metal]/[aluminum] ratios and metal concentrations in core profiles from the Rainbow Flowage were small and demonstrated little vertical

Table 5. Results of statistical comparisons (Mann-Whitney rank sum test) of [metal]/[aluminum] ratios of the reference area (Rainbow Flowage) to each experimental area. The following hypotheses were tested:

H_0 : Ratio of metal (Rainbow) \geq Ratio of metal (experimental area)

H_a : Ratio of metal (Rainbow) $<$ Ratio of metal (experimental area)

The table lists the probability values (P) for accepting the alternate hypothesis (H_a) for comparisons of the reference area to each experimental area.

Experimental area	Cadmium	Copper	Lead	Zinc	Mercury
Brokaw-Wausau	≤ 0.05	≤ 0.05	≤ 0.05	≤ 0.05	≤ 0.05
Lake Wausau	≤ 0.05	≤ 0.05	≤ 0.05	≤ 0.05	≤ 0.05
Mosinee Flowage	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
Lake DuBay	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025

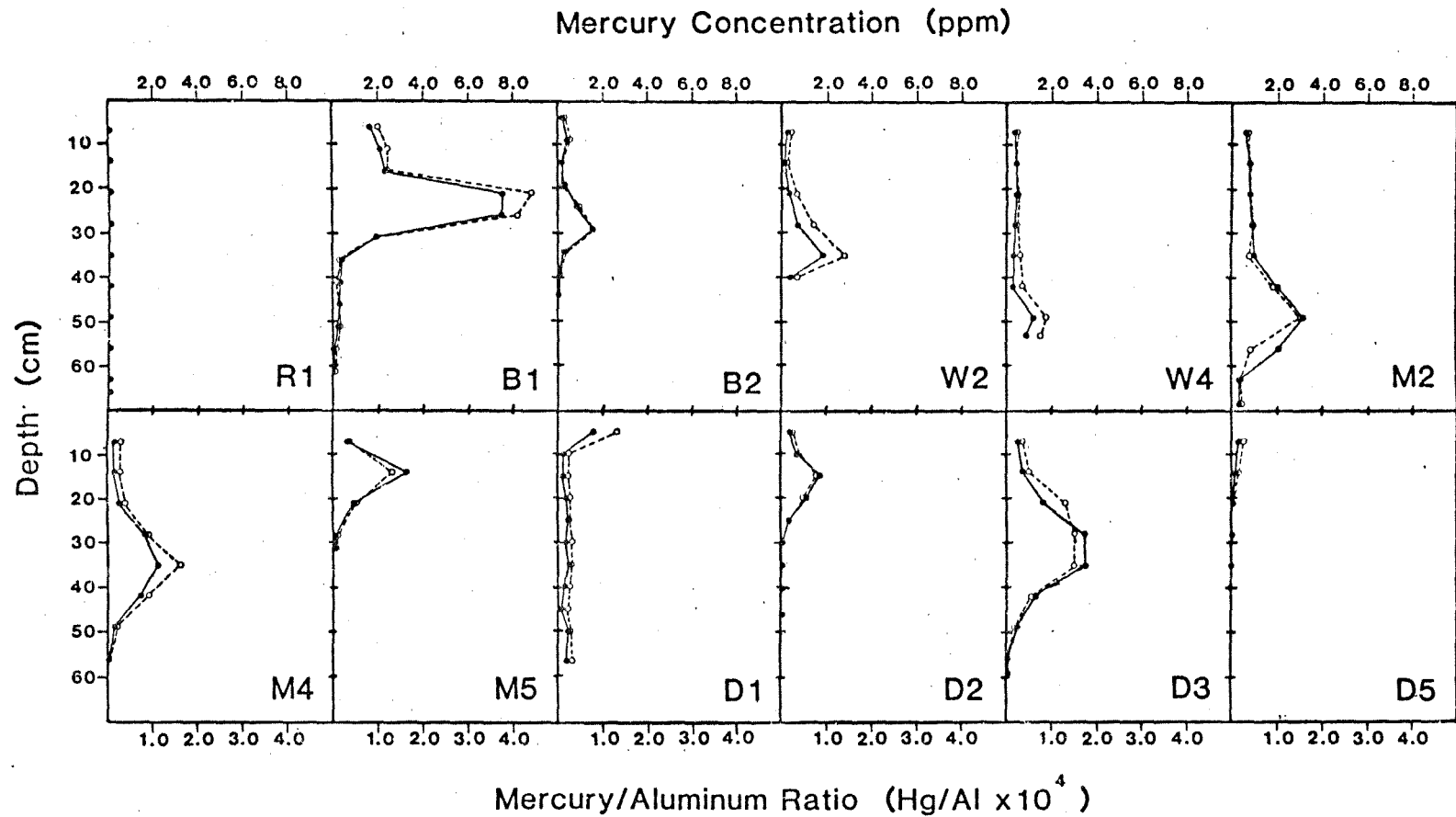


Figure 11. Stratigraphic profiles of mercury concentrations (—) and mercury/aluminum ratios (---) at selected sampling locations on the Upper Wisconsin River, August 1981.

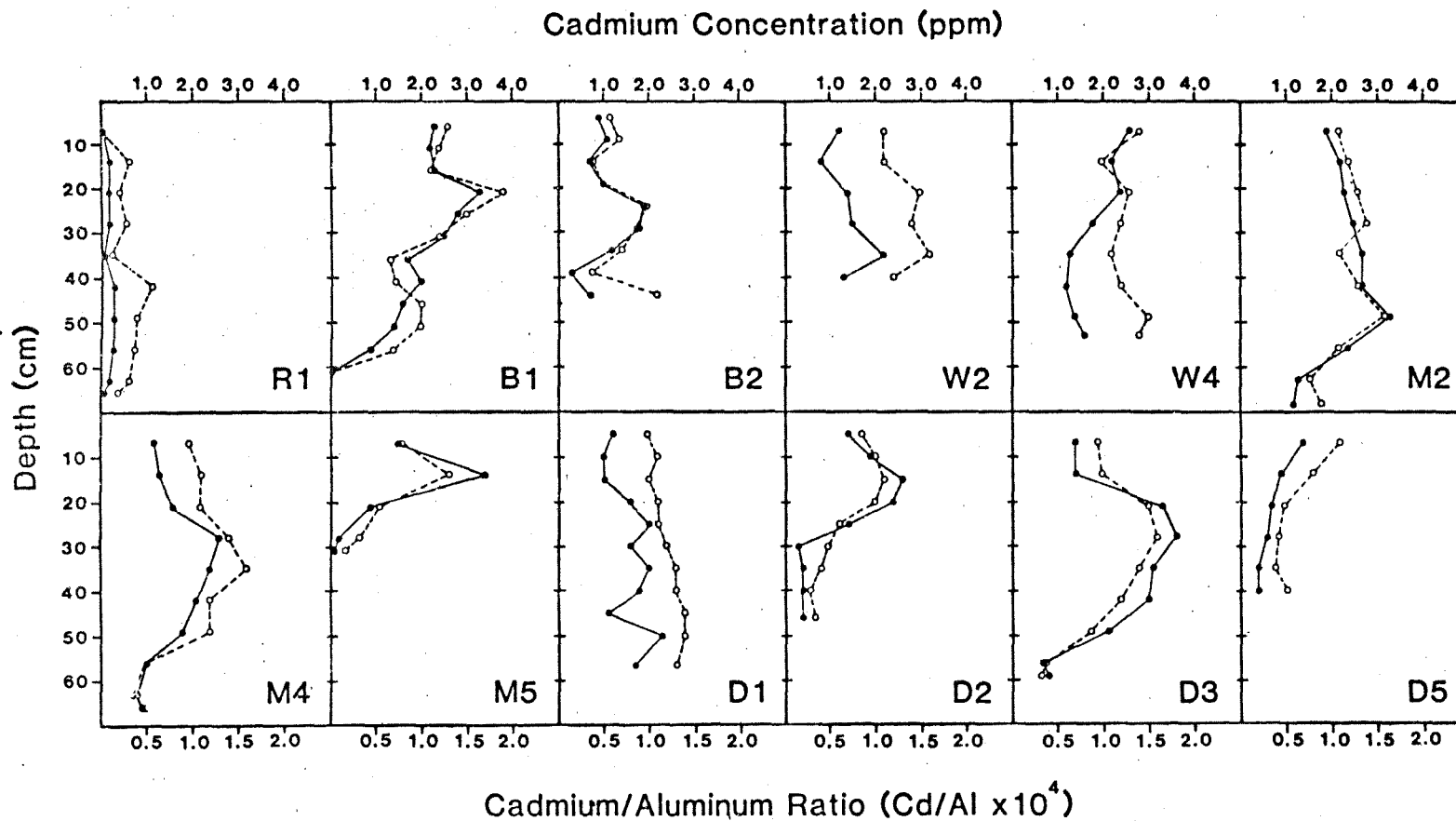


Figure 12. Stratigraphic profiles of cadmium concentrations (—) and cadmium/aluminum ratios (---) at selected sampling locations on the Upper Wisconsin River, August 1981.

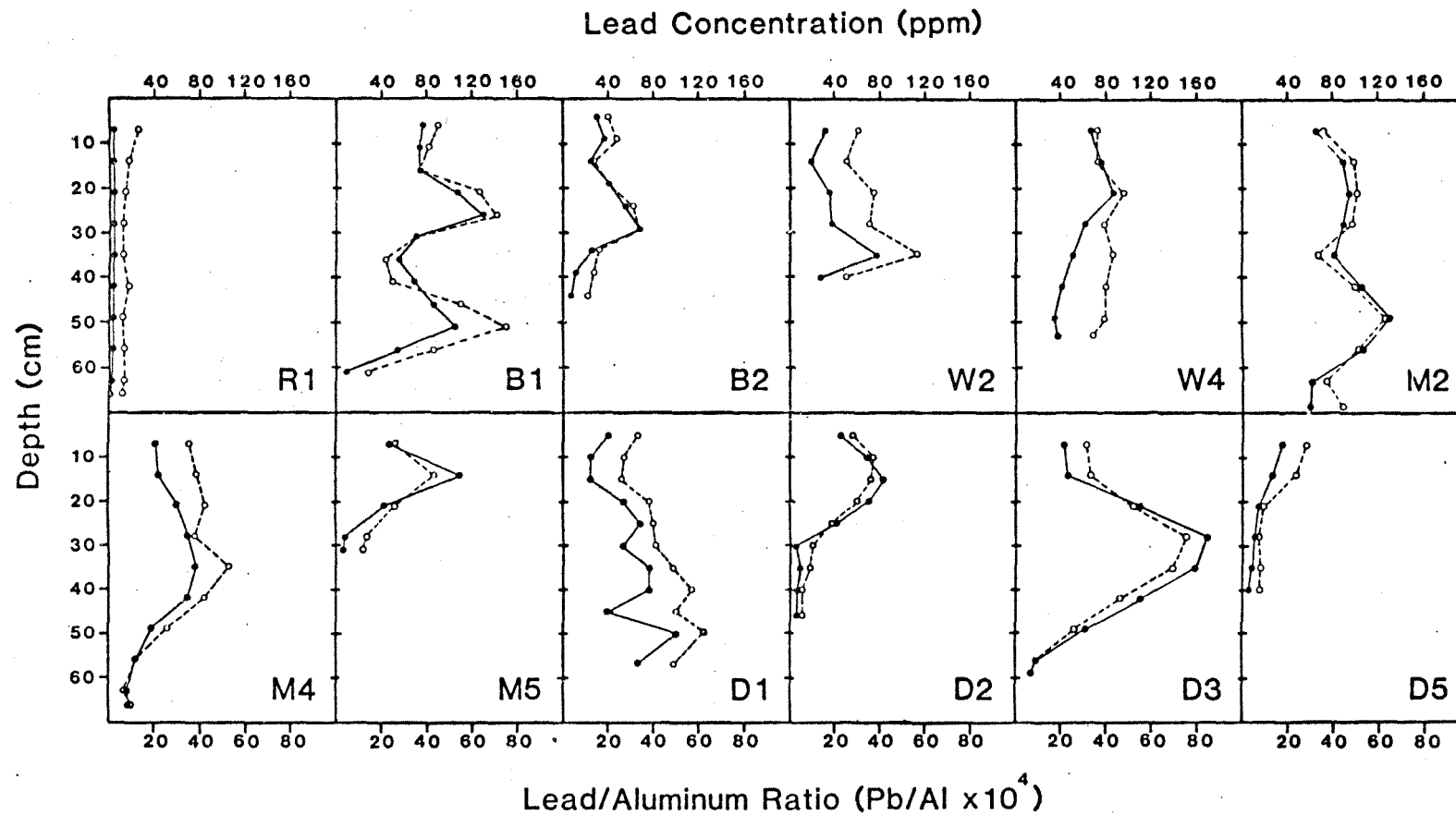


Figure 13. Stratigraphic profiles of lead concentrations (—) and lead/aluminum ratios (---) at selected sampling locations on the Upper Wisconsin River, August 1981.

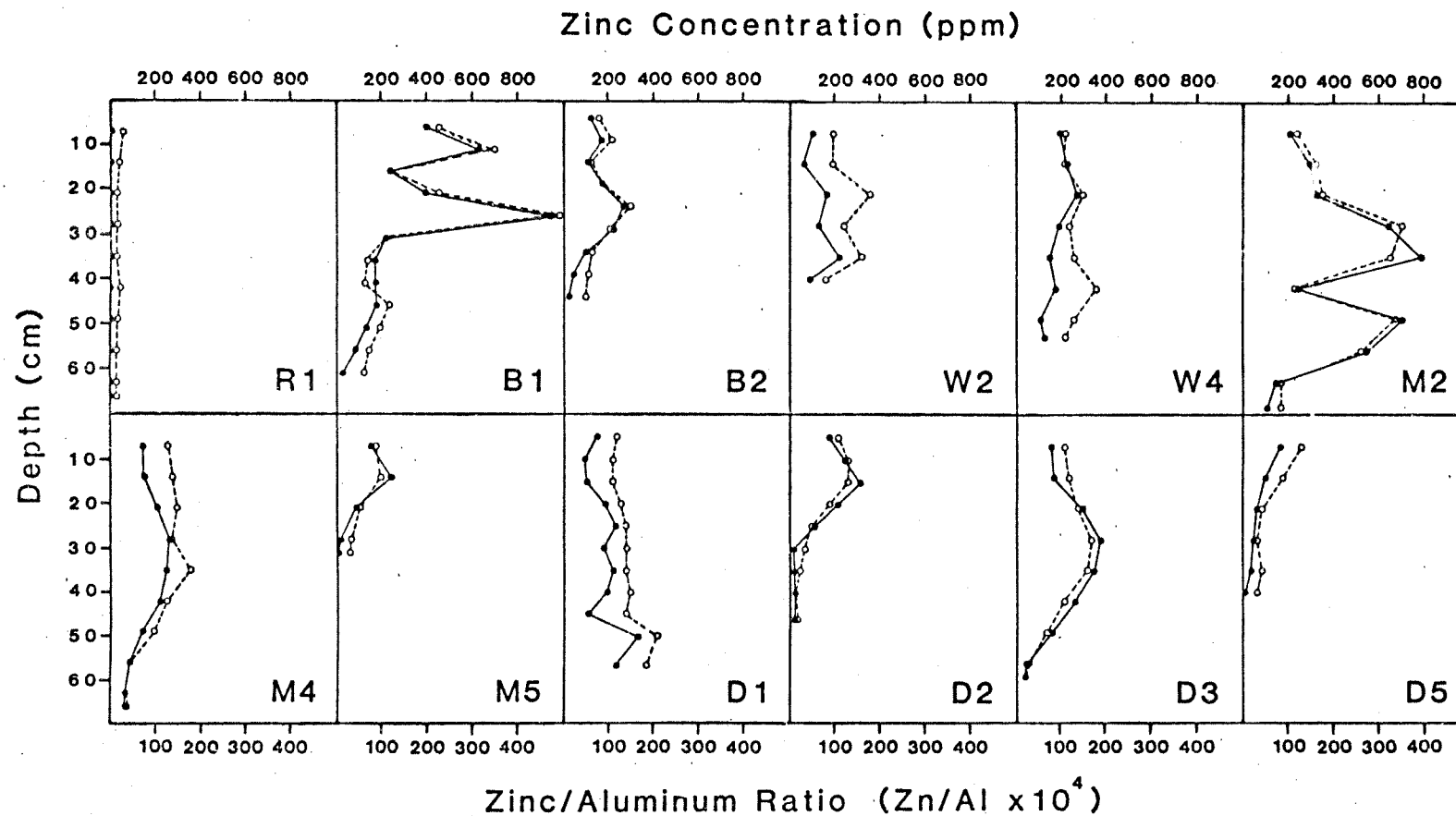


Figure 14. Stratigraphic profiles of zinc concentrations (—) and zinc/aluminum ratios (---) at selected sampling locations on the Upper Wisconsin River, August 1981.

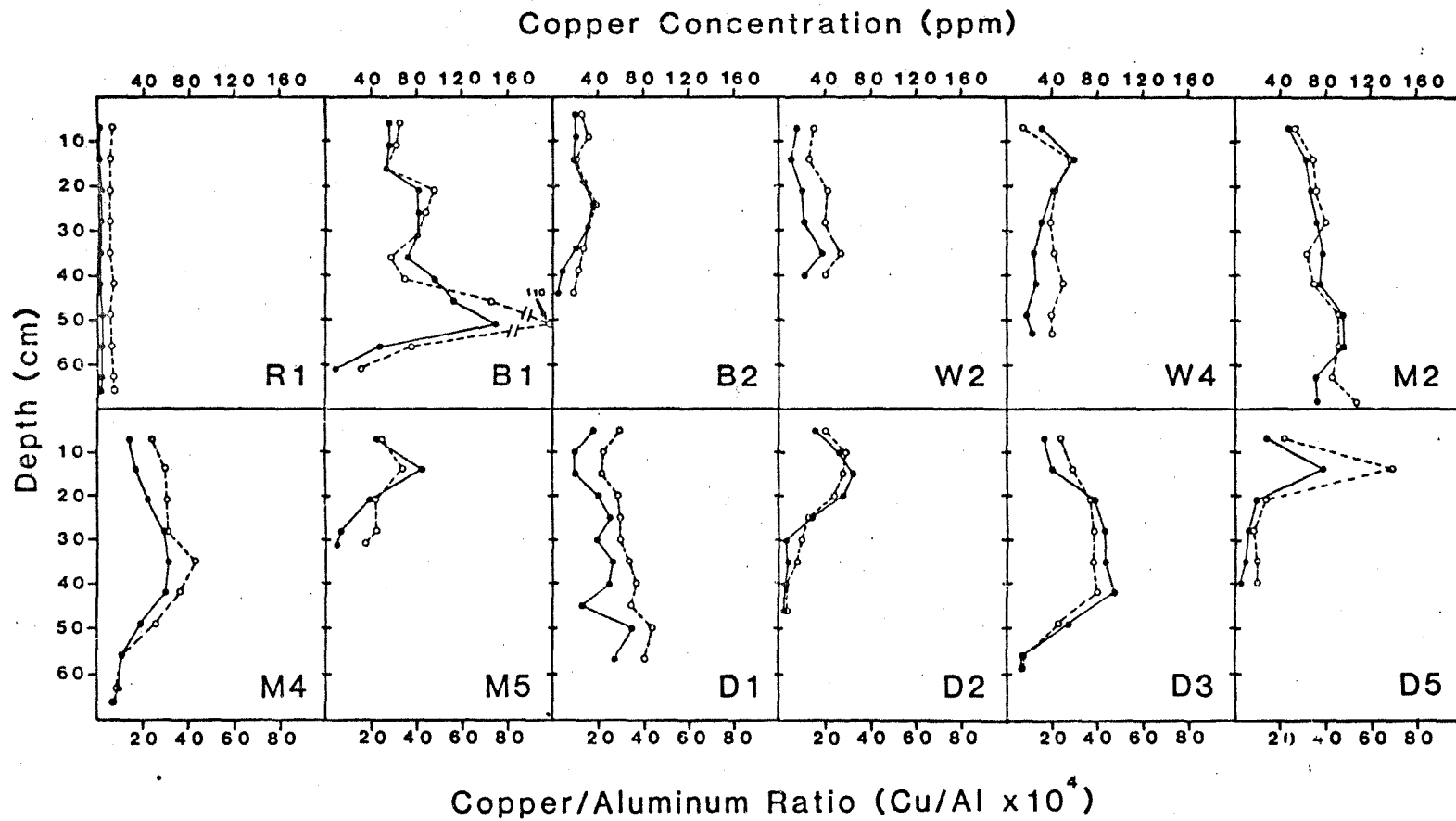


Figure 15. Stratigraphic profiles of copper concentrations (—) and copper/aluminum ratios (---) at selected sampling locations on the Upper Wisconsin River, August 1981.

variation. Metal to aluminum ratios at station R2 were larger at the surface than at deeper strata but were still very small. These results suggest that anthropogenic inputs of metals to the Rainbow Flowage have been minimal.

Stations in the Brokaw to Wausau reach of river, particularly B1, had the highest mercury content (7.6 $\mu\text{g/g}$) and the greatest mercury to aluminum ratio (4.44×10^{-4}). Station B1 was located approximately 0.8 km downstream from the discharge points of a sewage treatment plant and a pulp and paper mill. Based on Cs-137 dating techniques, it appears that mercury concentrations at station B1 were small (0.03-0.29 $\mu\text{g/g}$) in sediments deposited prior to approximately 1954 (below 36 cm; Fig. 11). The mercury content increased sharply after 1954, reached a peak of 7.6 $\mu\text{g/g}$ about 1960 (16-26 cm), and decreased to levels that were still considerably above background near the sediment surface. The maximal concentrations of cadmium (3.3 $\mu\text{g/g}$), lead (130 $\mu\text{g/g}$), and zinc (950 $\mu\text{g/g}$) at Station B1 were also among the highest levels observed. Profiles for cadmium and lead were similar with peaks in the 16- to 26-cm and 41- to 51-cm strata. Two peaks were also observed in the zinc profile, both in the upper 26 cm of sediment. The copper profile had one major peak, which was located at a depth of 46 to 51 cm (Fig. 15). Metal profiles at stations B2 and B3 were similar to that at B1, but they had smaller maxima located deeper in the profile. The lesser enrichment of sediments at stations B2 and B3 relative to B1 may be a result of their location farther downstream from the sewage treatment plant and pulp and paper mill.

The maximal metal to aluminum ratios of all metals studied were located deeper in the sediment profiles of Lake Wausau (W2 and W4) than

in the Brokaw to Wausau sites, probably because Stations W2 and W4 are depositional areas with low current velocities. The apparent time of initial major increases in mercury, cadmium, lead, zinc, and copper was between 1950 and 1954 (Figs. 11-15). After the 1954 peak, metal input intensities generally decreased to present levels.

Large amounts of mercury were present in sediment profiles of the Mosinee Flowage (Fig. 11). The greatest mercury/aluminum ratios and mercury concentrations were observed at M2 and M4. Station M2 was located approximately 9 km downstream from two major point sources (Fig. 3) and exhibited peak concentrations of mercury in the 42 to 49-cm stratum. Figures 11 to 15 show that stratigraphic profiles of cadmium, lead, zinc, and copper generally resembled those of mercury at M2. Cesium dating techniques demonstrated that the deposition of these metals to sediments greatly increased during the early 1950s, reached a maximum in 1954-60, and then decreased until approximately 1964 (21-35 cm, where minor peaks in the metal/aluminum ratios occurred). An exception to this trend was that the second zinc peak (ca 1964) was approximately equal in magnitude to the earlier peak (ca 1954-1960). The largest mercury and zinc concentrations in the sediment profiles at station M2 were 3.2 and 792 $\mu\text{g/g}$, respectively. At station M4, mercury concentrations increased from background levels of 0.04 $\mu\text{g/g}$ during 1954 to 58 to maximum levels of 2.3 $\mu\text{g/g}$ during about 1960 to 62 and then decreased to 0.3 to 0.4 $\mu\text{g/g}$ mercury in surficial sediments (Fig. 11). Cadmium and lead exhibited similar profiles, reaching maximum concentrations of 2.6 and 77 $\mu\text{g/g}$, respectively, during the period of 1960 to 62. Peak input intensities of zinc and copper also occurred at that time. Another large mercury to aluminum ratio (1.3×10^{-4}) was

observed 7 to 14 cm below the sediment water interface at station M5; high concentrations of cadmium (3.4 $\mu\text{g/g}$) and lead (109 $\mu\text{g/g}$) also occurred at this station (Appendices 2 and 4).

Sampling stations D1, D2, and D3 in Lake DuBay had high mercury to aluminum ratios (Fig. 11). Mercury concentrations and mercury to aluminum ratios increased sharply from low background levels during 1954 to 64 in sediment cores from D2 and D3. Gradual declines in mercury concentrations have occurred since this period. Stratigraphic profiles for cadmium, lead, zinc, and copper at D2 and D3 closely resembled the mercury profile (Figs. 11-15). Station D1, located approximately 7 km downstream from a sewage treatment plant and a paper mill, had relatively uniform mercury levels throughout most of the sediment column. However, a sharp increase in mercury concentrations and mercury to aluminum ratios occurred within the top 5 cm of the sediment core. Cesium-137 data are not available for D1. In contrast to mercury, the greatest concentrations of cadmium, lead, zinc, and copper were detected deep in the sediments (40- to 50-cm stratum). At station D5, gradual increases in mercury, cadmium, lead, and zinc from low background levels to maximal concentrations at the sediment surface were measured (Figs. 11-14). Copper profiles resembled those for the other metals, except for a peak of 70 $\mu\text{g/g}$ in the 7 to 14-cm stratum (Fig. 15).

Caution should be used when interpreting data from samples collected with a small diameter, gravity core sampler. First, an unknown amount of sediment compaction occurs during penetration of the sampler through the sediments. Consequently, the actual lengths of the stratigraphic profiles are probably underestimated. In other words, a

core segment reported as 42 to 49 cm would probably represent a wider (less compacted) stratum from a deeper depth. Second, the use of small diameter gravity coring devices may result in the loss of some surface sediments, especially if the surface sediments are unconsolidated (Baxter et al. 1981).

Sediment Enrichment Factors. Enrichment factors can be used to evaluate whether metal inputs into a body of water have increased in relation to an earlier, background level (Heit et al. 1981). These factors are useful for determining metal enrichment within a specific body of water, because they incorporate variations in regional lithology, fluvial regimes, and sediment texture.

Kemp et al. (1976) introduced a ratio, normalized to aluminum, designated as the sediment enrichment factor (SEF):

$$\text{SEF} = \frac{\frac{E_m - E_b}{Al_m - Al_b}}{\frac{E_b}{Al_b}}$$

where: E_m = maximum metal concentration in the core,

E_b = observed background metal concentration,

Al_m = aluminum concentration in strata of maximum metal concentration, and

Al_b = aluminum concentration in strata of background metal concentration.

Enrichment factors less than 1 indicate negligible metal enrichment, whereas values between 1 and 2 are suggestive of some anthropogenic input (Heit et al. 1981). Enrichment factors between 2 and 10 have been used as indicators of moderately enriched sediments, with mixed input from industrial effluents and sewage (domestic and agricultural)

as probable metal sources (Forstner and Wittmann 1981). Only cores which penetrated to sediment strata representing background concentrations of metals were utilized to calculate the enrichment factors in this study.

Sediment enrichment factors for this study indicated highly variable input intensities for all metals studied (Table 6). Mercury enrichment at most locations was much greater than that of the other metals, with maximal SEF values of 149, 79, and 72 occurring at sites B1, M4, and D3, respectively. The largest SEFs for mercury at most stations were associated with subsurface sediments and were indicative of grossly contaminated sediments. The SEFs for mercury in surface sediments were smaller than those of deeper strata, but were still indicative of substantial enrichment (e.g., stations B1, M4, and D3). Sediment enrichment factors for copper, zinc, and lead indicated moderate enrichment of Upper Wisconsin River sediments. Input intensities of cadmium were generally lower than the other metals, although SEF values were commonly greater than 2.

Comparison with other areas and background levels. As discussed, mercury, cadmium, lead, zinc, and copper concentrations in sediments were higher at all Upper Wisconsin River stations than at the relatively nonpolluted Rainbow Flowage control site. In this section, metal enrichment of surficial sediments from the Upper Wisconsin River is further evaluated by comparison to metal concentrations in samples from other locations (Table 7). Metal content of shale has been suggested as a global standard for estimating background concentrations (Forstner and Salomons 1980; Forstner and Wittmann 1981). Surficial sediments from the Upper Wisconsin River were enriched with mercury, cadmium, lead and

Table 6. Sediment Enrichment Factors (SEF) for metals in the Upper Wisconsin River. The top number is the SEF of the surface sediments and the bottom number is the maximal SEF of the sediment core. All data were rounded to the nearest 0.5.

Element	Brokaw		Lake	Mosinee Flowage			Lake DuBay			
	1	2	Wausau 1	2	4	5	2	3	5	
Hg	S ^a	16	2	1	<0.5	14	<0.5	11	35	8
	M ^b	72	19	1	5	79	4	37	149	8
Cd	S	1	-- ^c	--	<0.5	1	3	2	2	2
	M	2	--	--	1	3	6	2	4	2
Pb	S	2	<1	<0.5	<0.5	3	1	4	4	3
	M	4	2	1	1	4	3	6	11	3
Zn	S	3	1	--	<0.5	2	2	5	4	3
	M	7	2	--	3	3	2	6	6	3
Cu	S	1	<1	--	--	2	<0.5	5	3	1
	M	6	1	--	--	5	1	8	6	6

^aS denotes SEF of surficial sediments.

^bM denotes the maximal SEF of the sediment core.

^cHyphens denote that the sediment core sample did not penetrate to background levels for the element in question.

Table 7. Average metal content of surficial sediments in the Upper Wisconsin River relative to average metal content of shale and bottom sediments from other areas. USEPA criteria for metal pollution of harbor sediments are also shown.

	Average metal concentration ($\mu\text{g/g}$ dry weight)					Reference
	Mercury	Cadmium	Lead	Zinc	Copper	
Upper Wisconsin River						This study
Rainbow Flowage	0.04	0.2	8.5	26	4.9	
Brokaw to Wausau	0.8	1.5	53.0	217	34.1	
Lake Wausau	0.3	1.6	49.0	156	24.2	
Mosinee Flowage	0.6	1.8	51.9	187	35.2	
Lake DuBay	0.5	1.4	37.6	154	29.9	
Northern Wisconsin lakes						Syers et al. (1973) Iskandar and Keeney (1974)
Surface	0.33	2.46	19.6	84.8	30.8	
Background	0.13	1.2	4.0	58.0	30.0	
Southern Wisconsin lakes						Syers et al. (1973) Iskandar and Keeney (1974)
Surface	0.48	3.5	57.4	102.0	198.0	
Background	0.13	2.0	15.0	33.0	38.0	
Lake Erie (background)	0.004	0.14	--	7.0	18.0	Forstner and Wittmann (1981)
Lake St. Clair	--	1.7	26.0	45.2	16.3	Thomas et al. (1975)
Lacustrine sediments	0.35	0.4	34.0	118.0	45.0	Forstner and Wittmann (1981)
Ottawa River	0.28	--	26.0	84.0	28.0	Oliver (1973)
Upper Mississippi River	--	2.2	19.8	71.8	18.5	Bailey and Rada (in press)
Average shale	0.4	0.3	20.0	95.0	45.0	Turekian and Wedepohl (1961)
EPA Harbor Criteria						USEPA (1977)
Low Pollution	--	--	<40	<90	<25	
Moderate Pollution	--	--	40-60	90-200	25-50	
High Pollution	>1	>6	>60	>200	>50	

zinc, relative to shale. Cadmium concentrations of the Upper Wisconsin River sediments were 5-times greater, whereas lead and zinc concentrations were approximately 2-times greater than average concentrations in shale (Table 7). On the average, mercury concentrations in surficial sediments from the Upper Wisconsin River were approximately 1.5-times greater than concentrations reported for shale. Maximal concentrations of mercury in surface sediments at stations B1 and D1 were \geq 4-times the average mercury content of shale (Table 3, Appendix 2). Copper concentrations in shale and Upper Wisconsin River sediments were similar. Because of the variability in regional lithology, fluvial regimes, sediment texture, and organic content, comparisons of metal concentrations for a particular site to global averages should be used with caution.

Background concentrations of metals in sediments can also be estimated by analyses of deep core samples and of surface sediments in relatively non-polluted areas. Mercury, zinc, and lead concentrations were approximately 5-, 4-, and 3-times greater, respectively, in surficial sediments of the Upper Wisconsin River than in uncontaminated strata of sediment cores from northern and southern Wisconsin lakes (Table 7). Mercury, zinc, and copper concentrations were greater in Upper Wisconsin River sediments relative to uncontaminated strata of Lake Erie sediments.

According to the U.S. Environmental Protection Agency's criteria for harbor sediments (Table 7), surficial sediments from the Upper Wisconsin River were moderately polluted with cadmium and lead and moderately to heavily polluted with copper, zinc, and mercury. Mercury, lead, and zinc concentrations were greater in Upper Wisconsin River

sediments than in uncontaminated strata of sediments from northern and southern Wisconsin lakes and in sediments from the Ottawa River. At station B1, mercury, lead, and zinc concentrations of 1.76, 76.8, and 402 $\mu\text{g/g}$, respectively, were observed in the surficial sediments. Maximal concentrations of mercury (7.5 $\mu\text{g/g}$), lead (130 $\mu\text{g/g}$), and zinc (950 $\mu\text{g/g}$) were found 16 to 21 cm below the sediment surface. At station M2 of the Mosinee Flowage, mercury, lead, and zinc concentrations of 0.75, 64.9, and 216 $\mu\text{g/g}$, respectively, were found in surficial sediments, while maximal concentrations of mercury (3.2 $\mu\text{g/g}$) and lead (130 $\mu\text{g/g}$) were found 42 to 49 cm below the surface. The largest zinc concentration (790 $\mu\text{g/g}$) occurred at a depth of 28 to 35 cm. Concentrations of copper were greater in surficial sediments from the Upper Wisconsin River than in sediments of Lake St. Clair and the Upper Mississippi River. At station B1, the copper concentration was 56.5 $\mu\text{g/g}$ in surficial sediments and the maximum concentration (150.4 $\mu\text{g/g}$) was 46 to 51 cm below the sediment surface. A copper concentration of 78.4 $\mu\text{g/g}$ occurred 7 to 14 cm below the surface at Lake DuBay station D5, whereas surficial sediments contained 28.4 $\mu\text{g/g}$ of copper. Cadmium concentrations in Upper Wisconsin River sediments were similar to those in sediments of Lake St. Claire, the Upper Mississippi River, and southern Wisconsin lakes. Surficial sediments at stations D3 and D6 of Lake DuBay had cadmium concentrations of 1.4 and 2.5 $\mu\text{g/g}$, respectively. The maximal cadmium concentration of 3.7 $\mu\text{g/g}$ occurred 49 to 56 cm below the surface in core D3. At station D4, the maximal cadmium concentration (2.6 $\mu\text{g/g}$) was in the surficial sediments, and cadmium concentration decreased with depth in the core.

In a survey of mercury concentrations in the Wisconsin River, Konrad (1971) reported that mercury levels in surficial sediments between Brokaw and the Lake DuBay dam were not elevated above background levels. Mercury concentrations ranged from $<0.05 \mu\text{g/g}$ to $0.18 \mu\text{g/g}$ on a dry weight basis. In the present study, concentrations of mercury in surface sediments of the Brokaw to DuBay stretch of river were generally 2- to 9-times greater than reported by Konrad (1971). The differences between the two studies probably resulted from differences between sampling locations. Konrad (1971) collected samples near the river thalweg where active riverine processes, such as scouring, occur. In contrast, most sediment samples in our study were collected in depositional areas where metals accumulate. Furthermore, in the 1971 report, mercury concentrations were not corrected for variations in sediment grain sizes.

Metals in Crayfish

A total of 58 crayfish, Orconectes virilus and O. rusticus, were collected from the main study area and the reference area (Rainbow Flowage) on the Upper Wisconsin River. Raw data for dry weight and mercury concentration of individual crayfish are presented in Appendix 5. Dry weights of crayfish collected for mercury analysis varied significantly among sampling locations ($P < 0.01$, one-way ANOVA by ranks; Table 8). Other investigators have observed positive correlations between mercury burdens and body weights of crayfish (Vermeer 1972; Sheffy 1978). In our study, no such correlation was observed between mercury concentrations and dry weights of crayfish within any single sampling location or with crayfish from all study areas combined ($P > 0.05$).

Table 8. Means and ranges (in parentheses) of dry weights and mercury concentrations of whole crayfish from sampling stations on the Upper Wisconsin River.

Location	n	Dry weight (g)	Hg concentration ($\mu\text{g/g}$ dry weight)
Rainbow Flowage	8	6.2 (3.6-8.9)	0.41 (0.33-0.63)
Above Brokaw	10	3.8 (2.5-5.4)	0.07 (0.05-0.11)
Brokaw to Wausau	10	2.7 (1.6-4.3)	0.56 (0.43-0.67)
Lake Wausau	10	0.8 (0.3-1.3)	0.51 (0.41-0.62)
Mosinee Flowage	10	3.0 (1.2-6.6)	0.48 (0.31-0.79)
Lake DuBay	10	4.7 (2.8-6.7)	0.80 (0.59-1.11)

One-way analysis of variance (by rank) indicated significant location effects on mercury concentrations in crayfish ($P < 0.05$). Two multiple comparison procedures (Tukey's hsd procedure and Student Newman-Keuls test) were used to evaluate where location effects occurred. Tukey's hsd procedure, which is more conservative than the SNK procedure, indicated that mercury burdens were greatest in crayfish from Lake DuBay and smallest in crayfish from the above Brokaw study area (Table 9). Mercury concentrations were not judged to be significantly different among crayfish from the Brokaw to Wausau reach, Lake Wausau, Mosinee Flowage, and Rainbow Flowage; however, the difference between ranks of the Brokaw to Wausau and Rainbow Flowage samples was at the end of the hsd interval, i.e., almost significantly different at an α of 0.05. Similar results were obtained with the less conservative SNK procedure except that this procedure demonstrated a significant difference between mercury concentrations in crayfish between the Brokaw to Wausau reach and the Rainbow Flowage (Table 9).

Crayfish are less mobile than vertebrates, such as fish and may be more indicative of localized conditions (Vermeer 1972). In this study, difficulties were encountered collecting crayfish from the sediment sample sites of greatest mercury contamination. Therefore, crayfish mercury values for these study areas may not reflect the extent of mercury contamination in the sediments. However, in study areas where crayfish were collected from the sediment sample sites, the pattern of mercury accumulation in crayfish was similar to that in the sediment. For example, crayfish and bed sediments were both collected from D3. The surface concentration and SEF for mercury in sediments at D3 were among the highest observed during the study; the average concentrations

Table 9. Mean mercury concentrations (rank-transformed) in whole crayfish at each study area on the Upper Wisconsin River during 1981. Mean ranks in rows that do not contain a common letter in their superscripts were judged to be significantly different ($\alpha = 0.05$).

Procedure	Location					
	LD	BW	LW	MF	RB	AB
Tukey's <u>hsd</u>	53.3 ^a	36.2 ^b	28.7 ^b	28.1 ^b	23.5 ^b	6.0 ^c
Student Newman-Keuls	53.3 ^a	36.2 ^b	28.7 ^{bc}	28.1 ^{bc}	23.5 ^c	6.0 ^d

of mercury in crayfish was the highest of all study sites. In contrast, mercury concentrations were lowest in crayfish from the above Brokaw site where the substrate was cobble and washed sand. Although sediments were not collected in this area, one would not expect mercury to accumulate in cobble-type sediments because of the inverse relationship between mercury and sediment particle size.

Sheffy (1978) analyzed mercury in abdominal muscle of crayfish collected in 1975 from the Upper Wisconsin River. His analyses were conducted on undried (wet) tissue and reported as $\mu\text{g/g}$ wet weight, whereas ours were conducted on freeze-dried whole crayfish and reported as $\mu\text{g/g}$ dry weight. Therefore, to make the two data sets comparable, we performed a simple linear regression between dry weight (X) and wet weight (Y) of our crayfish and determined the following equation: wet weight of crayfish = $0.78 + 2.73 \times$ dry weight of crayfish ($n = 48$, $r^2 = 0.88$). This equation was used to convert the mean concentrations of mercury in crayfish from Lake Wausau, Lake DuBay, and the Brokaw-Wausau reach of river from dry to wet weight values. Comparison of our data to that of Sheffy (Table 10) indicates that mercury burdens in crayfish in 1981 were probably equal to or greater than those in 1975. We analyzed whole crayfish, whereas Sheffy analyzed abdominal muscle tissue where mercury concentrations are commonly greatest in crayfish (Johnels et al. 1967; Armstrong and Hamilton 1973). As stated, caution must be exercised when comparing data based on crayfish from different studies, in which samples may have been collected from different points within a given flowage.

Table 10. A comparison of mercury concentrations ($\mu\text{g/g}$ wet weight) in abdominal muscle of crayfish collected during 1975 (Sheffy 1978) to mercury concentrations ($\mu\text{g/g}$ wet weight) in whole crayfish during 1981 (this study).

Location	1975		1981	
	Mean concentration	n	Mean concentration	n
Brokaw to Wausau	0.10	3	0.19	10
Lake Wausau	0.07	3	0.15	10
Lake DuBay	0.18	4	0.27	10

SUMMARY AND CONCLUSIONS

The use of PMA has decreased since 1958 when the Food and Drug Administration banned the presence of mercury in paper used for food wraps (Konrad 1971). However, several mills continued to use PMA until the Wisconsin DNR, in May, 1970, advised that use of PMA as a slimicide be discontinued.

Elevated mercury levels were first detected in sediments and crayfish from the Wisconsin River during the 1970s. The greatest mercury concentrations in sediments and crayfish were found downstream of paper mills and a chlor-alkali plant. More recent data on metal concentrations in Upper Wisconsin River sediments, collected by the Upper Wisconsin River Basin 208 Task Force during 1977-1978, suggested that reservoirs in this stretch of river were also polluted with metals other than mercury. Application of the U.S. Environmental Protection Agency's criteria for harbor sediments (USEPA 1981) to their data indicated moderate pollution with copper, lead, chromium, and moderate to heavy pollution with zinc and manganese.

Four dams on the studied reach of river form a series of shallow reservoirs (range of mean depth, 2.1-3.4 m) with average residence times ranging from 1.4 to 36.6 days. Nineteen sediment cores were collected in the four reservoirs or side-channel areas during August 1981 with a 5.1-cm (inner diameter) gravity corer. Three sediment cores were collected from the Rainbow Flowage, a reference site. Crayfish were collected by hand or with baited traps from each of the six study areas and the Rainbow Flowage reference site during July and August, 1981.

The major sampling sites are listed below, in order from upstream to downstream. An "X" denotes the types of samples collected and analyzed from each site.

	<u>Sediment cores</u>	<u>Crayfish</u>
Reference Site		
Rainbow Flowage	X	X
Main Study Area Sites		
Above Brokaw	--	X
Brokaw to Wausau	X	X
Lake Wausau	X	X
Mosinee Flowage	X	X
Lake DuBay	X	X

Textural composition of sediments varied widely among sites, ranging from sand to silty clays. Concentrations of mercury, cadmium, lead, zinc, and copper in sediments were much lower in the reference area (Rainbow Flowage) than in the main study area. However, metal concentrations in bulk sediments with differing textural characteristics cannot be directly compared, because of the known preferential occurrence of metals in the fine-grained fraction of sediments. The need to minimize grain size effects was particularly apparent when the texture of Rainbow Flowage sediments (mainly sand) was compared to that in the main study area, which were composed primarily of silt and clay. To adjust for grain size effects, a ratio was calculated between the concentration of each metal under consideration (mercury, cadmium, lead, zinc, and copper) and the concentration of aluminum, a conservative element. Aluminum is strongly bound to clays, and aluminum content is consequently correlated with the clay content or surface area of sediments. The metal to aluminum ratio therefore provided a measure of the relative enrichment of sediments with the metal in question.

Analysis of metal/aluminum ratios revealed that surficial sediments at each site in the main study area were significantly ($P < 0.05$) enriched with mercury, cadmium, lead, zinc, and copper, relative to the reference site, the Rainbow Flowage. Median ratios for cadmium, lead, zinc, and copper in surficial sediments were generally 2.5- to 3.0-fold greater at sites in the main study area than at the reference site, whereas median ratios for mercury were at least 10-fold greater.

Stratigraphic profiles of all metals studied were generally similar in sediment cores from the main study area, although variation occurred among cores and metals. Maximal concentrations and enrichment of metals at most of those sites occurred in subsurface sediments, indicating burial of the most metal-contaminated strata. For example, maximal mercury concentrations in sediment cores from the main study area generally ranged from about 1.0 to 7.0 $\mu\text{g/g}$ dry weight and generally occurred at depths of 10 to 50 cm in the core profiles. However, significant enrichment of all metals was also observed in surficial sediments in the main study area relative to metal levels in deep, precultural sediments. The maximum observed concentration of mercury (7.6 $\mu\text{g/g}$ dry weight) occurred about 0.8 km downstream from a sewage treatment plant and pulp and paper mill in the Brokaw to Wausau site; high concentrations of cadmium (3.3 $\mu\text{g/g}$), lead (130 $\mu\text{g/g}$), and zinc (950 $\mu\text{g/g}$) were also observed in cores from this site. Metal/aluminum ratios and absolute metal concentrations in sediments from the Rainbow Flowage were small (e.g., <0.01 - 0.08 $\mu\text{g/g}$ dry weight for mercury) and exhibited little vertical variation, indicating that anthropogenic inputs to the control area have been minimal.

Sediment enrichment factors were utilized in this study to evaluate metal enrichment in present day sediments as compared to an earlier, background level. The largest SEFs for mercury were associated with subsurface sediments although surface SEF values still indicated substantial enrichment. Maximum sediment enrichment factors for cadmium, lead, zinc, and copper varied between 1 and 11 and are indicative of moderate enrichment.

Radiocesium dating of core profiles revealed that deposition of the metals studied generally began increasing during the early 1950s and that maximum metal deposition in sediments generally occurred sometime during the period from 1950 to 1962. Therefore, the use of phenyl mercuric acetate as a slimicide by pulp and paper mills on this stretch of river was probably discontinued before the Wisconsin DNR's advisory of May 1970.

Surficial sediments of the Upper Wisconsin River has larger concentrations of mercury, cadmium, lead, and zinc relative to average concentrations of these metals in shale, a global background standard. Similarly, mercury, lead, zinc, and copper concentrations were greater in surficial sediments from the Upper Wisconsin River than in sediments from certain other locations. Enrichment of cadmium in sediments from the Upper Wisconsin River was similar to that in sediments from other areas.

Ranges of total mercury concentrations and dry weights of whole crayfish (n = 58) were 0.05-1.11 $\mu\text{g/g}$ dry weight and 0.30-8.9 g, respectively. In this study, a significant correlation was not observed between mercury concentrations and dry weights of crayfish. Comparisons of this data (1981) to previous data (1975) collected by Sheffy (1978)

revealed that mercury burdens in crayfish from the main study area have remained constant or have increased since 1975. This suggests that mercury in the sediments is still biologically available, despite burial of the most mercury-contaminated strata of sediments. Results of a concurrent study (1981) on mercury methylation in Upper Wisconsin River sediments indicates that mercury availability to biota in the main study area is enhanced by rapid methylation rates in surficial sediments (Callister 1983; Callister and Winfrey, University of Wisconsin-La Crosse, unpublished data).

One-way analysis of variance (by rank) revealed significant variation in mercury concentration among study sites for crayfish. Application of Tukey's hsd procedure to the data, revealed that mercury concentrations were significantly greater (about 2-times) in crayfish from Lake DuBay than from the control site, Rainbow Flowage. However, Tukey's procedure did not reveal significant differences among mercury concentrations in crayfish from the Brokaw to Wausau, Lake Wausau, Mosinee Flowage, and the Rainbow Flowage reference site. Although mercury enrichment of sediments from the Rainbow Flowage was very low, Tukey's procedure revealed that mercury concentrations in crayfish from Rainbow Flowage were significantly greater than mercury levels of crayfish from the Above Brokaw study site. The Rainbow Flowage contains softer water with a lower pH than the main study; consequently, the availability of mercury to crayfish in the Rainbow Flowage could be greatly enhanced by water chemistry factors that affect speciation and availability of this metal. The more robust Student-Newman-Keuls test, when applied to the data, revealed similar results except that this procedure indicated a significant difference between mercury levels in

crayfish between the Brokaw to Wausau reach and the Rainbow Flowage reference site.

In conclusion, sediments from a stretch of the Upper Wisconsin River extending from Brokaw to the Lake DuBay dam are substantially enriched with mercury, cadmium, lead, zinc, and copper, relative to an upstream reference site. The most metal-contaminated strata of sediments in the main study area were generally deposited sometime during the early 1950s to about 1962 and were subsequently buried by continued sedimentation. Surficial sediments (0-7 cm deep) in the main study area are also enriched with mercury, cadmium, lead, zinc, and copper relative to precultural sediments in the core profiles and to surficial sediments in the upstream reference site. Mercury concentrations in whole crayfish collected during 1981 were similar or greater than values measured in crayfish during 1975. Availability of mercury to biota in this system may be enhanced by high methylation rates, despite burial of the most mercury-contaminated strata of sediments. Management practices for this river system should incorporate measures to minimize disturbance of highly contaminated sediments, which would increase exposure of resident biota to toxic metals.

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Appendix I. Concentrations of selected trace metals in sediments (<2-mm fraction) collected from the Upper Wisconsin River during the winter of 1977-78. Data are mean concentrations with standard deviation given in parentheses. Metal concentrations indicative of moderately polluted and heavily polluted sediments (according to USEPA criteria for harbor sediments) are indicated by one and two underscores, respectively.

Location	n	Concentration ($\mu\text{g/g}$ dry weight) ¹						
		Copper	Cadmium	Lead	Zinc	Chromium	Manganese	Nickel
Above Brokaw	3	11.7(2.9)	3.7(2.1)	33(22.5)	71.3(31.6)	<u>28.3</u> (20.2)	<u>324</u> (80)	12.3(1.5)
Lake Wausau	4	17.0(11.6)	3.0(2.0)	23.8(18.5)	<u>118</u> (74)	<u>32.0</u> (15.6)	244(209)	14.0(1.8)
Mosinee Flowage	3	<u>40.3</u> (26.3)	3.7(2.9)	<u>59.6</u> (43.4)	<u>238</u> (168)	<u>37.3</u> (16.6)	<u>329</u> (210)	15.0(6.2)
Lake DuBay	4	<u>38.0</u> (27.7)	3.5(1.7)	<u>45.2</u> (36.8)	<u>232</u> (167)	<u>63.0</u> (35.2)	<u>560</u> (177)	17.5(11.3)

¹Data collected by the Upper Wisconsin River Basin 208 Task Force.

Appendix II. Sediment texture, organic content, and metal concentrations of bottom sediments collected from the Upper Wisconsin River during August 1981.

Location	Station	Depth (cm)	Textural comp. (%)			Organic content (%)	Metal concentrations (dry weight)						
			Clay	Silt	Sand		Cu (µg/g)	Zn (µg/g)	Cd (µg/g)	Pb (µg/g)	Hg (µg/g)	Al (mg/g)	
Rainbow Flowage	1	0-7	3.3	8.7	88.1	3.4	2.3	11	0.0	4.8	0.01	3.6	
	1	7-14	4.5	9.4	86.1	1.0	2.5	10	0.2	4.0	0.01	4.5	
	1	14-21	5.7	11.5	82.8	1.8	3.3	13	0.2	4.6	0.01	6.7	
	1	21-28	5.2	11.6	83.2	0.9	3.7	14	0.2	4.6	0.01	7.0	
	1	28-35	5.2	11.3	83.5	0.7	3.8	13	0.1	4.5	0.02	7.2	
	1	35-42	3.2	9.5	87.3	0.4	3.8	13	0.3	4.7	0.01	5.2	
	1	42-49	4.0	7.6	88.4	1.7	4.5	15	0.3	4.9	0.01	7.6	
	1	49-56	2.6	7.5	89.9	0.5	4.1	12	0.3	4.9	0.01	6.7	
	1	56-63	2.8	6.5	90.7	0.3	4.1	12	0.2	3.9	0.01	6.1	
	1	63-66	2.3	6.7	91.0	0.4	3.4	9	0.1	3.1	0.01	4.8	
	2	0-7	12.6	27.6	59.8	0.9	7.8	29	0.4	12.6	0.08	8.1	
	2	7-14	4.1	12.4	83.4	3.7	3.9	19	0.4	7.2	0.02	4.4	
	2	14-21	5.3	10.5	84.2	2.2	5.0	25	0.2	6.5	0.02	7.6	
	2	21-28	4.2	9.1	86.8	1.5	4.6	21	0.3	5.3	0.01	7.5	
	2	28-35	5.5	11.8	82.7	1.4	3.8	15	0.2	4.2	0.02	5.4	
	2	35-42	6.5	15.9	77.6	1.4	4.6	18	0.2	5.1	0.02	6.1	
	2	42-49	4.8	11.8	83.4	1.2	4.1	18	0.3	5.2	0.01	5.3	
	2	49-56	5.8	10.5	83.6	1.2	4.4	20	0.3	5.4	0.01	7.7	
	2	56-63	6.3	10.2	83.5	1.5	6.9	24	0.4	7.4	0.02	9.9	
	2	63-70	6.3	12.2	81.5	2.3	7.1	22	0.3	4.2	0.02	9.1	
	3	0-7	3.1	13.7	83.2	4.8	4.6	37	0.3	8.0	0.02	10.1	
	3	7-14	4.5	8.7	86.9	2.3	4.3	24	0.3	6.3	0.02	10.3	
	3	14-21	8.8	5.2	86.9	2.1	5.7	25	0.3	5.6	0.03	11.5	
	3	21-28	4.4	7.0	88.6	1.8	6.5	26	0.3	6.1	0.02	10.5	
	3	28-35	3.3	3.4	93.4	0.9	5.0	15	0.3	3.7	0.02	7.1	
	3	35-42	2.6	4.3	93.1	1.1	5.8	14	0.3	4.5	0.01	7.0	
	3	42-49	3.2	4.1	92.7	0.6	5.7	13	0.2	3.9	0.02	6.7	
	3	49-56	2.2	3.4	94.4	0.9	5.4	10	0.3	3.6	0.01	5.9	
	3	56-63	2.8	1.4	95.8	2.7	5.2	10	0.2	3.8	0.01	6.1	
	3	63-68	2.9	3.0	94.1	2.4	4.5	8	0.2	3.6	0.01	5.1	
	Brokaw	1	0-6	38.3	49.8	11.9	20.4	56.5	402	2.3	76.8	1.76	17.2
		1	6-11	45.4	46.5	8.2	19.7	56.2	631	2.2	73.9	2.09	17.9
		1	11-16	35.4	58.3	6.3	16.8	54.2	240	2.3	73.9	2.34	19.8
1		16-21	35.8	46.2	18.1	19.6	81.6	398	3.3	106.7	7.55	17.0	
1		21-26	38.2	45.9	15.9	20.0	81.8	950	2.8	130.3	7.48	18.5	
1		26-31	37.4	43.8	18.8	18.4	81.0	222	2.5	70.5	1.93	20.3	
1		31-36	33.4	55.4	11.3	15.7	72.6	178	1.7	55.1	0.38	25.0	
1		36-41	28.6	49.3	22.1	19.7	96.4	177	2.0	69.1	0.29	27.2	
1		41-46	21.9	34.9	43.2	21.8	113.1	182	1.6	85.7	0.26	15.5	
1		46-51	30.3	38.3	31.4	29.7	150.4	140	1.4	105.2	0.20	14.1	
1		51-56	21.2	40.4	38.4	15.6	48.1	92	0.9	54.5	0.10	12.7	
1		56-61	5.4	14.2	80.5	6.9	9.2	36	0.0	8.3	0.03	5.8	

Appendix II. Continued.

Location	Station	Depth (cm)	Textural comp. (%)			Organic content (%)	Metal concentrations (dry weight)					
			Clay	Silt	Sand		Cu (µg/g)	Zn (µg/g)	Cd (µg/g)	Pb (µg/g)	Hg (µg/g)	Al (mg/g)
Brokaw (cont.)	2	0-4	20.0	38.9	41.1	8.5	20.6	124	0.9	31.3	0.21	15.4
	2	4-9	16.8	32.8	50.4	9.4	25.6	168	1.1	38.5	0.47	15.9
	2	9-14	19.3	40.0	40.7	7.5	19.6	108	0.7	24.6	0.20	17.2
	2	14-19	29.7	32.3	38.0	10.2	27.7	175	1.0	40.1	0.27	20.0
	2	19-24	37.3	37.3	25.3	14.7	36.2	271	1.9	57.9	0.82	18.4
	2	24-29	29.3	40.5	30.2	11.2	31.7	223	1.8	67.9	1.63	20.8
	2	29-34	20.3	38.0	41.8	6.8	21.8	103	1.2	25.1	0.25	16.1
	2	34-39	8.8	20.1	71.1	5.3	9.0	46	0.3	11.3	0.05	7.8
	2	39-44	7.4	14.8	77.9	1.9	5.6	31	0.7	7.0	0.03	6.1
	3	0-5	19.9	36.2	43.9	12.8	25.2	126	1.3	50.9	0.36	13.6
	3	5-10	20.9	38.7	40.4	14.2	27.5	190	1.5	50.1	0.31	13.6
	3	10-15	15.2	22.6	62.3	8.2	21.3	158	1.1	41.3	0.25	11.0
	3	15-20	34.7	46.3	19.0	13.0	40.6	446	1.7	67.0	0.50	18.1
	3	20-25	34.9	45.5	19.6	17.3	53.0	857	2.5	72.9	1.07	18.6
	3	25-30	26.4	34.2	39.4	13.8	35.4	169	1.7	47.0	1.69	15.0
	3	30-35	19.2	31.6	49.1	10.3	26.5	117	1.2	31.6	0.19	12.2
	3	35-40	27.3	45.6	27.1	15.6	39.2	116	1.4	35.7	0.20	16.2
	3	40-45	16.2	31.9	51.9	10.3	16.9	67	0.7	17.8	0.06	12.4
	3	45-50	34.9	48.7	16.4	11.6	26.9	81	1.4	13.7	0.04	19.2
	3	50-58	30.8	43.2	26.0	15.1	21.9	78	1.1	10.3	0.08	17.3
Lake Hausau	1	0-7	7.6	18.0	74.4	5.8	19.4	139	1.2	43.4	0.36	10.1
	1	7-14	6.1	19.0	75.0	3.3	15.6	84	1.0	24.2	0.46	8.6
	1	14-21	9.9	22.3	67.8	6.4	17.3	82	1.0	27.5	0.20	10.0
	1	21-28	18.5	47.9	33.5	8.8	14.7	73	1.0	18.9	0.09	15.3
	1	28-35	9.8	25.7	64.5	1.5	10.3	50	0.8	8.9	0.08	11.6
	1	35-41	8.3	26.6	65.1	1.3	9.9	46	0.8	8.1	0.03	11.0
	2	0-7	10.4	21.8	67.8	8.3	15.5	103	1.2	31.8	0.22	10.4
	2	7-14	5.7	12.6	81.7	5.6	9.9	67	0.8	18.2	0.10	7.4
	2	14-21	12.6	16.4	71.0	13.7	19.6	170	1.4	34.3	0.32	9.3
	2	21-28	9.3	20.0	70.7	8.1	21.4	131	1.5	36.8	0.74	10.5
	2	28-35	20.4	37.1	42.5	24.7	37.2	219	2.2	77.0	1.87	13.8
	2	35-40	8.3	28.0	63.7	20.1	22.3	86	1.3	27.5	0.36	10.9
	3	0-7	31.0	39.0	30.0	14.7	31.1	183	1.6	54.5	0.41	16.6
	3	7-14	15.5	24.3	60.2	8.0	19.6	135	1.1	46.0	0.39	11.2
	3	14-21	10.6	24.4	65.0	2.7	10.9	40	0.4	23.8	0.07	13.3
	3	21-28	11.2	29.3	59.6	3.1	11.8	53	0.4	11.5	0.04	15.6
	3	28-35	13.4	36.7	50.0	3.1	14.0	56	0.6	11.9	0.04	17.1
	3	35-42	15.0	40.4	44.6	4.7	14.6	67	0.8	13.5	0.04	18.5
	3	42-49	15.3	40.2	44.6	5.2	15.2	71	0.8	7.7	0.03	17.1
	3	49-56	17.7	36.4	45.9	4.7	17.0	89	1.0	14.1	0.04	19.8
3	56-63	17.5	38.6	43.9	4.7	14.7	68	0.8	12.9	0.04	17.7	
3	63-67	19.0	40.5	40.5	10.1	14.2	60	1.0	13.8	0.08	18.9	

Location	Station	Depth (cm)	Textural comp. (%)			Organic content (%)	Metal concentrations (dry weight)					
			Clay	Silt	Sand		Cu (µg/g)	Zn (µg/g)	Cd (µg/g)	Pb (µg/g)	Hg (µg/g)	Al (mg/g)
Lake Wausau (cont.)	4	0-7	40.4	51.2	8.4	16.6	31.0	199	2.6	66.5	0.39	18.7
	4	7-14	37.0	54.6	8.4	20.4	59.6	227	2.2	75.3	0.40	21.0
	4	14-21	42.7	39.3	17.9	15.0	40.5	272	2.4	86.5	0.43	18.4
	4	21-28	26.3	29.0	44.7	9.2	29.6	192	1.8	61.0	0.38	15.6
	4	28-35	15.8	24.0	60.3	7.8	24.6	154	1.3	49.7	0.35	11.6
	4	35-42	18.5	18.9	62.6	7.9	25.6	180	1.2	41.2	0.35	10.2
	4	42-49	15.2	16.5	68.3	4.6	17.7	112	1.4	33.9	1.25	8.8
	4	49-53	30.9	40.9	28.2	9.8	23.3	127	1.6	39.8	0.89	11.8
Mosinee	1	0-7	21.4	65.3	13.3	14.0	16.8	145	1.7	39.3	0.31	14.1
	1	7-14	27.1	73.8	5.1	14.7	20.0	159	1.7	31.5	0.34	14.3
	1	14-21	27.8	67.5	4.7	15.9	22.9	151	1.8	32.5	0.51	8.1
	1	21-28	27.4	67.2	5.4	13.8	23.4	127	1.7	29.0	0.27	17.0
	1	28-35	34.8	58.9	6.3	16.0	21.1	112	1.5	27.9	0.23	16.7
	1	35-42	33.1	54.1	12.8	14.3	30.7	82	1.3	23.3	0.08	19.6
	1	42-49	35.5	40.4	24.4	7.7	9.3	28	0.6	10.5	0.07	17.4
	1	49-56	34.3	18.7	47.0	9.1	7.9	18	0.4	9.2	0.05	15.4
	1	56-62	13.6	15.3	71.2	5.0	4.1	9	0.4	4.5	0.02	6.2
	2	0-7	30.1	44.0	25.9	17.1	47.0	216	1.9	64.9	0.65	17.9
	2	7-14	38.3	42.3	19.4	19.1	62.6	296	2.2	89.0	0.79	17.8
	2	14-21	37.9	44.9	17.2	17.5	66.8	328	2.3	94.2	0.82	18.5
	2	21-28	34.8	44.4	20.9	17.3	72.0	644	2.5	88.6	0.93	18.1
	2	28-35	41.6	45.7	12.7	17.6	78.1	790	2.7	80.7	1.07	24.1
	2	35-42	41.0	43.1	15.9	18.1	74.9	248	2.7	105.7	2.12	21.3
	2	42-49	44.3	42.2	13.5	20.9	95.5	709	3.3	129.9	3.24	20.8
	2	49-56	36.6	52.9	10.6	17.3	95.8	559	2.4	106.1	2.06	20.9
	2	56-63	23.5	37.4	39.2	12.0	71.4	146	1.3	61.2	0.35	16.6
	2	63-69	18.2	33.2	48.6	8.9	72.4	114	1.2	58.8	0.37	13.3
	3	0-7	49.3	43.3	7.3	17.1	39.4	228	2.2	62.0	0.53	20.1
	3	7-14	45.8	49.5	4.7	17.0	44.0	263	2.3	66.6	0.57	19.6
	3	14-21	45.7	53.2	1.0	17.3	48.0	303	2.4	75.5	0.67	23.2
	3	21-28	20.3	1.9	77.8	16.5	53.1	321	2.6	76.1	0.89	25.2
	3	28-35	54.1	40.6	5.4	19.0	52.6	260	2.9	67.8	1.56	22.1
	3	35-42	62.6	34.8	2.6	16.9	51.4	218	2.9	64.0	1.42	20.8
	3	42-49	46.8	50.9	2.3	14.2	43.0	172	2.2	47.7	0.46	22.5
	3	49-56	42.6	51.9	5.5	15.5	45.1	166	2.3	46.9	0.43	25.0
	3	56-65	27.8	50.0	22.1	12.2	26.5	114	1.4	27.6	0.13	19.1
	4	0-7	13.8	32.5	53.8	8.2	29.1	154	1.2	42.8	0.36	11.8
	4	7-14	14.5	32.0	53.5	8.3	34.0	158	1.3	45.2	0.32	11.5
	4	14-21	17.7	37.1	45.3	15.2	45.0	212	1.6	61.4	0.55	14.4
	4	21-28	23.5	52.8	23.7	15.6	58.0	264	2.6	70.7	1.68	18.6
4	28-35	33.1	66.9	27.5	15.7	62.5	257	2.4	77.2	2.28	14.5	
4	35-42	26.4	52.8	20.8	2.0	59.9	224	2.1	69.9	1.54	16.8	
4	42-49	25.3	58.0	16.7	13.7	38.7	150	1.8	39.1	0.37	15.0	
4	49-56	26.8	60.5	12.7	11.0	22.5	97	1.0	23.7	0.13	20.2	
4	56-63	29.0	61.0	11.1	10.5	18.8	75	0.8	16.8	0.04	22.8	
4	63-66	22.0	63.6	14.4	5.3	13.0	70	0.9	17.2	0.05	16.7	

Appendix II. Continued.

Location	Station	Depth (cm)	Textural comp. (%)			Organic content (%)	Metal concentrations (dry weight)						
			Clay	Silt	Sand		Cu (µg/g)	Zn (µg/g)	Cd (µg/g)	Pb (µg/g)	Hg (µg/g)	Al (mg/g)	
Mosinee (cont.)	5	0-7	15.6	21.0	63.4	15.1	45.9	158	1.5	47.0	0.62	18.0	
	5	7-14	36.7	22.1	41.2	19.9	85.8	245	3.4	108.7	3.27	25.1	
	5	14-21	8.1	5.9	86.0	5.6	38.9	90	0.9	43.4	0.87	16.6	
	5	21-28	0.0	0.0	100.0	1.1	14.3	21	0.2	8.4	0.09	6.2	
	5	28-31	0.0	0.0	100.0	0.5	10.0	17	0.1	6.5	0.06	5.4	
	6	0-7	25.3	42.9	31.8	15.4	34.3	222	2.2	55.4	0.96	12.2	
	6	7-14	22.8	33.9	43.3	20.8	28.2	176	1.7	42.7	0.89	11.8	
	6	14-21	33.3	27.1	39.6	26.7	22.6	98	1.2	28.0	0.39	13.4	
	6	21-28	31.1	30.3	38.5	19.5	18.6	56	0.9	21.6	0.13	18.7	
	6	28-35	11.0	18.2	70.8	6.8	9.0	25	0.4	8.4	0.03	11.3	
	6	35-37	5.0	8.8	86.2	0.7	5.1	23	0.3	4.5	0.01	6.3	
	Lake DuBay	1	0-5	12.5	12.3	75.3	20.4	36.7	146	1.2	40.0	1.58	12.2
		1	5-10	7.3	9.1	83.6	8.1	21.2	99	1.0	25.0	0.22	9.3
		1	10-15	9.1	12.9	78.1	10.6	20.7	104	1.0	24.8	0.23	9.3
		1	15-20	20.1	30.2	49.7	18.0	40.6	186	1.6	53.4	0.38	14.2
		1	20-25	29.3	22.0	48.7	18.7	52.0	238	2.0	68.5	0.44	17.2
		1	25-30	21.6	23.7	54.8	15.8	39.3	183	1.6	52.8	0.39	12.9
		1	30-35	28.9	32.9	38.2	16.1	54.1	225	2.0	76.9	0.49	15.7
1		35-40	25.1	25.0	49.8	18.4	50.5	199	1.8	76.2	0.37	13.5	
1		40-45	11.6	9.0	79.4	7.6	27.1	113	1.1	39.2	0.17	7.8	
1		45-50	36.2	23.2	40.6	19.6	71.4	335	2.3	100.1	0.45	16.1	
1		50-57	18.3	16.9	64.8	12.7	54.9	241	1.7	66.8	0.42	13.5	
2		0-5	18.7	37.8	43.5	11.8	31.9	176	1.4	44.6	0.37	15.7	
2		5-10	32.1	37.6	30.3	10.4	52.7	244	1.9	68.9	0.69	18.4	
2		10-15	42.8	47.3	9.9	15.6	64.4	308	2.6	82.7	1.73	23.0	
2		15-20	43.4	51.8	4.8	17.1	56.1	212	2.4	69.5	1.13	23.5	
2		20-25	46.8	33.7	19.5	18.5	28.5	111	1.4	41.6	0.31	22.2	
2		25-30	3.9	5.6	90.5	0.7	5.2	18	0.3	5.4	0.02	5.2	
2		30-35	14.0	14.5	71.5	3.2	7.7	23	0.4	9.4	0.03	9.9	
2		35-40	17.8	17.8	64.4	1.5	4.3	23	0.4	7.5	0.03	13.6	
2		40-46	12.2	15.5	72.3	0.8	4.1	22	0.4	6.5	0.03	11.5	
3		0-7	17.6	23.5	58.9	9.2	33.4	161	1.4	43.4	0.52	14.1	
3		7-14	19.0	28.4	52.6	9.4	40.5	168	1.4	45.9	0.71	14.1	
3		14-21	35.0	41.5	23.6	14.7	77.6	300	3.3	109.4	2.65	21.1	
3		21-28	35.4	48.0	16.7	18.0	85.7	385	3.6	168.7	3.46	22.6	
3		28-35	34.2	44.9	20.9	18.6	86.9	356	3.1	157.6	3.44	22.9	
3		35-42	48.5	44.0	7.6	21.5	94.7	268	3.0	110.2	1.28	23.9	
3		42-49	40.1	49.6	10.3	19.3	55.6	169	2.1	61.9	0.45	23.7	
3		49-56	21.0	47.3	31.6	6.9	14.3	57	0.7	18.7	0.06	18.9	
3		56-59	21.2	51.7	27.1	3.6	13.4	54	0.8	13.9	0.04	22.1	

Appendix II. Continued.

Location	Station	Depth (cm)	Textural comp. (%)			Organic content (%)	Metal concentrations (dry weight)					
			Clay	Silt	Sand		Cu ($\mu\text{g/g}$)	Zn ($\mu\text{g/g}$)	Cd ($\mu\text{g/g}$)	Pb ($\mu\text{g/g}$)	Hg ($\mu\text{g/g}$)	Al (mg/g)
Lake DuBay (cont.)	4	0-7	5.7	15.9	78.4	1.9	7.5	30	0.6	7.0	0.02	7.6
	4	7-14	7.0	21.9	71.2	1.9	9.5	37	0.6	7.7	0.02	10.1
	4	14-21	5.0	18.0	77.0	1.1	9.0	34	0.7	7.9	0.02	9.3
	4	21-28	4.8	13.2	81.1	0.5	6.8	28	0.5	6.9	0.02	7.0
	4	28-35	4.7	13.9	81.4	0.2	6.9	28	0.5	6.7	0.02	7.2
	4	35-42	8.2	23.2	68.6	0.8	9.2	39	0.8	8.6	0.02	9.8
	4	42-49	5.7	16.9	77.5	1.0	7.6	32	0.6	7.3	0.01	8.1
	4	49-56	6.8	24.1	69.1	1.0	10.4	42	0.7	9.8	0.02	11.7
	4	56-63	8.8	28.3	62.9	1.0	11.0	44	0.7	9.8	0.02	12.2
	4	63-65	5.0	17.7	77.4	0.8	8.6	33	0.6	7.4	0.02	8.6
	5	0-7	18.4	32.7	48.9	12.4	28.4	169	1.4	35.6	0.34	12.9
	5	7-14	24.5	33.2	42.3	30.0	78.4	101	0.9	25.7	0.19	11.2
	5	14-21	18.4	40.2	41.4	11.8	20.2	66	0.7	13.4	0.05	14.4
	5	21-28	12.7	30.6	56.7	5.8	12.4	52	0.6	10.5	0.05	14.6
	5	28-35	11.5	28.4	60.1	2.5	10.3	43	0.4	8.1	0.04	10.2
	5	35-40	5.3	12.8	81.9	0.8	6.7	21	0.4	5.1	0.02	6.6
	6	0-7	45.1	52.0	2.9	19.8	41.6	243	2.3	55.3	0.40	20.4
	6	7-14	50.8	48.2	1.0	17.9	40.1	248	2.4	59.1	0.40	18.8
	6	14-21	49.1	45.6	5.2	19.6	67.1	308	2.6	68.0	0.45	25.7
	6	21-28	46.6	48.7	4.7	25.1	60.1	332	2.8	82.3	0.55	21.4
	6	28-35	44.7	48.7	6.6	17.5	72.6	373	2.9	97.4	0.68	23.0
	6	35-42	46.0	49.6	4.4	20.2	75.5	413	3.1	100.9	0.83	24.6
	6	42-49	46.6	46.1	7.3	21.0	91.2	430	3.5	123.7	0.97	23.3
	6	49-56	43.8	43.8	12.4	19.7	89.5	359	3.7	108.7	1.51	23.5

Appendix III. Counts of cesium-137 decay (per 4000 sec) and ratios of cesium-137 to aluminum concentrations in sediments collected from the Upper Wisconsin River during August 1981.

Location	Station	Depth (cm)	Cs-137 (counts/g)	Ratio (Cs-137/Al)
Brokaw	1	0-6	5.0	0.29
	1	6-11	4.4	0.25
	1	11-16	4.0	0.20
	1	16-21	2.6	0.15
	1	21-26	0	0
	1	26-31	0.4	0.02
	1	31-36	0	0
	1	36-41	0	0
	1	41-46	1.0	0.06
	1	46-51	0	0
	1	51-56	0	0
1	56-61	0	0	
Lake Wausau	2	0-7	1.9	0.20
	2	7-14	2.7	0.26
	2	14-21	2.5	0.18
	2	21-28	0	0
	2	28-35	2.6	0.25
	2	35-40	1.4	0.19
Mosinee Flowage	2	0-7	2.2	0.13
	2	7-14	4.6	0.13
	2	14-21	5.7	0.40
	2	21-28	8.6	0.85
	2	28-35	12.0	0.68
	2	35-42	4.1	0.25
	2	42-49	1.9	0.11
	2	49-56	0.3	0.02
	2	56-63	0	0
	4	0-7	0.4	0.36
	4	7-14	1.7	0.15
	4	14-21	5.5	0.38
	4	21-28	8.0	0.43
	4	28-35	1.3	0.09
	4	35-42	0	0
	4	42-49	1.6	0.11
	4	49-56	0	0

Appendix III. Continued.

Location	Station	Depth (cm)	Cs-137 (counts/g)	Ratio (Cs-137/Al)
Lake DuBay	2	0-5	3.7	0.24
	2	5-10	6.1	0.33
	2	10-15	5.4	0.23
	2	15-20	1.4	0.06
	2	20-25	0.2	0.01
	2	25-30	0	0
	2	30-35	1.0	0.10
	3	0-7	1.5	0.11
	3	7-14	2.2	0.16
	3	14-21	1.8	0.09
	3	21-28	3.2	0.14
	3	28-35	0	0
	3	35-42	0	0
	3	42-49	0	0
	3	49-56	0	0
	5	0-7	3.2	0.25
	5	7-14	1.3	0.12
	5	14-21	0	0
	5	21-28	0	0
	5	28-35	0	0
	5	35-40	0	0

Appendix IV. Ratios of copper, zinc, cadmium, lead, and mercury concentrations to aluminum concentrations in sediments collected from the Upper Wisconsin River during August 1981.

Location	Station	Depth (cm)	Elemental ratios ($\times 10^4$)					
			Cu/Al	Zn/Al	Cd/Al	Pb/Al	Hg/Al	
Rainbow Flowage	1	0-7	6	32	0.00	13	0.02	
	1	7-14	6	22	0.33	9	0.02	
	1	14-21	5	19	0.22	7	0.01	
	1	21-28	5	20	0.28	7	0.01	
	1	28-35	5	17	0.13	6	0.02	
	1	35-42	7	24	0.57	9	0.01	
	1	42-49	6	20	0.39	7	0.01	
	1	49-56	6	18	0.37	7	0.01	
	1	56-63	7	19	0.32	6	0.01	
	1	63-66	7	18	0.21	6	0.02	
	2	0-7	10	36	0.49	16	0.09	
	2	7-14	9	44	0.83	16	0.04	
	2	14-21	7	33	0.30	9	0.02	
	2	21-28	6	28	0.37	7	0.01	
	2	28-35	7	28	0.27	8	0.03	
	2	35-42	8	29	0.32	8	0.03	
	2	42-49	8	35	0.47	10	0.01	
	2	49-56	6	26	0.32	7	0.01	
	2	56-63	7	25	0.40	8	0.02	
	2	63-70	8	24	0.33	5	0.02	
	3	0-7	5	37	0.29	8	0.01	
	3	7-14	4	23	0.29	6	0.01	
	3	14-21	5	22	0.21	5	0.02	
	3	21-28	6	25	0.28	6	0.01	
	3	28-35	7	21	0.35	5	0.02	
	3	35-42	8	21	0.42	6	0.01	
	3	42-49	9	19	0.30	6	0.03	
	3	49-56	9	18	0.42	6	0.01	
	3	56-63	9	17	0.29	6	0.01	
	3	63-68	9	16	0.35	7	0.01	
	Brokaw	1	0-6	33	230	1.30	45	1.00
		1	6-11	31	350	1.20	41	1.20
		1	11-16	27	120	1.10	37	1.20
1		16-21	48	230	1.90	63	4.40	
1		21-26	44	510	1.50	71	4.10	
1		26-31	40	110	1.20	35	0.94	
1		31-36	29	71	0.66	22	0.15	
1		36-41	35	65	0.71	25	0.10	
1		41-46	73	120	1.00	55	0.16	
1		46-51	110	99	0.99	75	0.14	
1		51-56	38	73	0.70	43	0.07	
1	56-61	16	63	0.00	14	0.05		

Appendix IV. Continued.

Location	Station	Depth (cm)	Elemental ratios ($\times 10^4$)				
			Cu/Al	Zn/Al	Cd/Al	Pb/Al	Hg/Al
Brokaw (cont.)	2	0-4	13	80	0.58	20	0.13
	2	4-9	16	110	0.69	24	0.29
	2	9-14	11	63	0.40	14	0.11
	2	14-19	14	88	0.50	20	0.13
	2	19-24	20	150	1.00	31	0.44
	2	24-29	15	107	0.86	33	0.78
	2	29-34	14	64	0.71	16	0.15
	2	34-39	12	59	0.38	14	0.06
	2	39-44	9	50	1.10	11	0.04
	3	0-5	18	93	0.95	37	0.26
	3	5-10	20	140	1.10	37	0.22
	3	10-15	19	140	0.95	38	0.22
	3	15-20	22	250	0.90	37	0.27
	3	20-25	28	460	1.30	39	0.57
	3	25-30	24	110	1.10	31	1.10
	3	30-35	22	95	0.96	26	0.15
	3	35-40	24	72	0.88	22	0.12
	3	40-45	14	54	0.56	14	0.05
	3	45-50	14	42	0.70	7	0.02
	3	50-58	13	45	0.60	6	0.04
Lake Wausau	1	0-7	19	140	1.20	43	0.35
	1	7-14	18	98	1.10	28	0.54
	1	14-21	17	82	0.95	27	0.20
	1	21-28	10	48	0.62	12	0.06
	1	28-35	9	43	0.68	8	0.06
	1	35-41	9	42	0.72	7	0.02
	2	0-7	15	99	1.10	30	0.21
	2	7-14	13	91	1.10	25	0.13
	2	14-21	21	180	1.50	37	0.34
	2	21-28	20	120	1.40	35	0.70
	2	28-35	27	160	1.60	56	1.40
	2	35-40	20	80	1.20	25	0.33
	3	0-7	19	110	0.93	33	0.24
	3	7-14	18	120	0.94	41	0.34
	3	14-21	8	30	0.30	18	0.05
	3	21-28	8	34	0.25	7	0.02
	3	28-35	8	33	0.35	7	0.02
	3	35-42	8	36	0.40	7	0.02
	3	42-49	9	42	0.46	5	0.01
	3	49-56	9	45	0.49	7	0.02
	3	56-63	8	38	0.46	7	0.02
	3	63-67	8	32	0.50	7	0.04

Appendix IV. Continued.

Location	Station	Depth (cm)	Elemental ratios (x10 ⁴)				
			Cu/Al	Zn/Al	Cd/Al	Pb/Al	Hg/Al
Lake Wausau (cont.)	4	0-7	17	110	1.40	36	0.20
	4	7-14	28	110	1.00	36	0.19
	4	14-21	22	150	1.30	47	0.23
	4	21-28	19	120	1.20	39	0.24
	4	28-35	21	130	1.10	43	0.30
	4	35-42	25	180	1.20	40	0.34
	4	42-49	20	130	1.50	39	1.40
	4	49-53	20	110	1.40	34	0.75
Mosinee	1	0-7	12	100	1.20	28	0.22
	1	7-14	14	110	1.20	22	0.23
	1	14-21	28	190	2.20	40	0.63
	1	21-28	14	74	0.96	17	0.15
	1	28-35	13	67	0.89	17	0.13
	1	35-42	16	42	0.63	12	0.04
	1	42-49	5	16	0.31	6	0.04
	1	49-56	5	11	0.25	6	0.03
	1	56-62	7	15	0.56	7	0.03
	2	0-7	26	121	1.10	36	0.36
	2	7-14	35	166	1.20	50	0.44
	2	14-21	36	178	1.30	51	0.44
	2	21-28	40	356	1.40	49	0.51
	2	28-35	32	328	1.10	34	0.44
	2	35-42	35	116	1.30	50	1.00
	2	42-49	46	341	1.60	62	1.60
	2	49-56	46	267	1.10	51	0.48
	2	56-63	43	88	0.78	37	0.21
	2	63-69	54	86	0.90	44	0.28
	3	0-7	20	110	1.10	31	0.26
	3	7-14	22	130	1.20	34	0.29
	3	14-21	21	130	1.00	33	0.29
	3	21-28	21	130	1.00	30	0.35
	3	28-35	24	120	1.30	31	0.71
	3	35-42	25	100	1.40	31	0.68
	3	42-49	19	76	0.97	21	0.20
	3	49-56	18	66	0.89	19	0.17
	3	56-65	14	59	0.73	14	0.06

Appendix IV. Continued.

Location	Station	Depth (cm)	Elemental ratios ($\times 10^4$)					
			Cu/Al	Zn/Al	Cd/Al	Pb/Al	Hg/Al	
Mosinee (cont.)	4	0-7	24	130	0.97	36	0.30	
	4	7-14	30	140	1.10	39	0.27	
	4	14-21	31	150	1.10	43	0.38	
	4	21-28	31	140	1.40	38	0.90	
	4	28-35	43	180	1.60	53	1.60	
	4	35-42	36	130	1.20	42	0.91	
	4	42-49	26	100	1.20	26	0.24	
	4	49-56	11	48	0.47	12	0.06	
	4	56-63	8	33	0.35	7	0.01	
	4	63-66	8	42	0.51	10	0.02	
	5	0-7	25	88	0.80	26	0.34	
	5	7-14	34	97	1.30	43	1.30	
	5	14-21	23	54	0.54	26	0.52	
	5	21-28	23	34	0.32	14	0.15	
	5	28-31	18	31	0.18	12	0.11	
	6	0-7	28	180	1.80	45	0.78	
	6	7-14	24	150	1.40	36	0.75	
	6	14-21	17	73	0.89	21	0.29	
	6	21-28	10	30	0.46	12	0.06	
	6	28-35	8	22	0.37	7	0.02	
	6	35-37	8	37	0.47	7	0.01	
	Lake DuBay	1	0-5	30	120	0.98	33	1.30
		1	5-10	23	110	1.10	27	0.23
		1	10-15	22	110	1.00	26	0.24
		1	15-20	29	130	1.10	38	0.26
		1	20-25	30	140	1.10	40	0.25
		1	25-30	30	140	1.20	41	0.30
		1	30-35	34	140	1.30	49	0.31
1		35-40	37	150	1.30	57	0.27	
1		40-45	35	140	1.40	50	0.21	
1		45-50	44	210	1.40	62	0.27	
1		50-57	41	180	1.30	49	0.31	
2		0-5	20	110	0.85	28	0.23	
2		5-10	29	130	1.00	37	0.37	
2		10-15	28	130	1.10	36	0.75	
2		15-20	24	90	0.99	30	0.48	
2		20-25	13	50	0.60	19	0.13	
2		25-30	10	34	0.47	10	0.03	
2		30-35	8	23	0.40	10	0.03	
2		35-40	3	17	0.29	6	0.02	
2		40-46	4	19	0.34	6	0.02	

Appendix IV. Continued.

Location	Station	Depth (cm)	Elemental ratios (x10 ⁴)				
			Cu/A1	Zn/A1	Cd/A1	Pb/A1	Hg/A1
Lake DuBay (cont.)	3	0-7	24	110	0.95	31	0.36
	3	7-14	29	120	0.99	33	0.50
	3	14-21	37	140	1.50	52	1.30
	3	21-28	38	170	1.60	75	1.50
	3	28-35	38	160	1.40	69	1.50
	3	35-42	40	110	1.20	46	0.53
	3	42-49	23	71	0.86	26	0.19
	3	49-56	8	30	0.38	10	0.03
	3	56-59	6	24	0.33	6	0.01
	4	0-7	10	39	0.72	9	0.02
	4	7-14	9	37	0.61	8	0.01
	4	14-21	10	37	0.70	9	0.02
	4	21-28	10	40	0.71	10	0.02
	4	28-35	10	39	0.62	9	0.02
	4	35-42	9	40	0.76	9	0.02
	4	42-49	9	40	0.67	9	0.01
	4	49-56	9	36	0.60	8	0.01
	4	56-63	9	36	0.57	8	0.01
	4	63-65	10	38	0.69	9	0.02
	5	0-7	22	130	1.10	28	0.26
	5	7-14	70	90	0.80	23	0.16
	5	14-21	14	46	0.48	9	0.03
	5	21-28	9	36	0.41	7	0.03
	5	28-35	10	42	0.39	8	0.03
	5	35-40	10	31	0.52	8	0.03
	6	0-7	20	120	1.10	27	0.19
	6	7-14	21	130	1.30	31	0.21
	6	14-21	26	120	0.99	26	0.18
	6	21-28	28	150	1.30	38	0.25
	6	28-35	32	160	1.30	42	0.29
	6	35-42	31	170	1.20	41	0.33
	6	42-49	39	180	1.50	53	0.41
	6	49-56	38	150	1.60	46	0.64

Appendix V. Mercury concentrations and dry weights of individual crayfish from sampling locations on the Upper Wisconsin River.

Location	Crayfish Identification Number	Dry Weight (g)	Hg Concentration ($\mu\text{g/g}$ dry weight)
Rainbow Flowage	1	6.2	0.39
	2	8.2	0.41
	3	5.6	0.63
	4	8.9	0.37
	5	3.6	0.35
	6	6.7	0.34
	7	4.1	0.49
	8	6.1	0.33
Above Brokaw	1	5.1	0.07
	2	5.4	0.05
	3	2.9	0.06
	4	4.0	0.08
	5	2.5	0.10
	6	4.3	0.06
	7	4.3	0.05
	8	3.3	0.08
	9	3.4	0.09
	10	2.8	0.11
Brokaw to Wausau	1	4.3	0.49
	2	2.6	0.64
	3	1.6	0.58
	4	4.3	0.54
	5	2.2	0.43
	6	2.2	0.57
	7	3.1	0.52
	8	2.7	0.67
	9	1.9	0.57
	10	2.3	0.61
Lake Wausau	1	0.6	0.56
	2	1.3	0.55
	3	1.2	0.53
	4	1.0	0.62
	5	0.8	0.50
	6	0.9	0.41
	7	0.9	0.52
	8	0.9	0.58
	9	0.3	0.43
	10	0.4	0.45

Appendix V. Continued.

Location	Crayfish Identification Number	Dry Weight (g)	Hg Concentration ($\mu\text{g/g}$ dry weight)
Mosinee Flowage	1	4.3	0.61
	2	1.2	0.79
	3	6.6	0.58
	4	2.8	0.53
	5	2.8	0.45
	6	2.9	0.34
	7	3.9	0.31
	8	1.4	0.34
	9	2.3	0.37
	10	1.9	0.56
Lake DuBay	1	6.7	0.59
	2	6.3	0.66
	3	5.8	0.76
	4	3.6	0.76
	5	5.4	1.11
	6	4.3	0.81
	7	4.4	0.91
	8	4.1	0.63
	9	3.7	0.85
	10	2.8	0.99