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TOXICITY OF SEDIMENTS IN THE ILLINOIS WATERWAY: IMPLICATIONS FOR THE PROPOSED INCREASES IN DIVERSION OF LAKE MICHIGAN WATER INTO THE ILLINOIS WATERWAY

by

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Havana, Illinois 62644

PROJECT COMPLETION REPORT
Illinois Department of Transportation
Division of Water Resources
STIL-TRWRTOXSED39483

This report was prepared for the Chicago Office, U.S. Army Corps of Engineers, which funded the research. The findings, conclusions, recommendations, and views expressed in this report are those of the researchers and should not be considered as the official position of the Chicago Office, U.S. Army Corps of Engineers or Division of Water Resources, Illinois Department of Transportation.

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ACKNOWLEDGEMENTS

Dr. Anthony A. Paparo, Department of Zoology and School of Medicine, Southern Illinois University, Carbondale, Illinois, conducted the bioassays with gills from fingernail clams using special apparatus which he developed. Dr. David L. Gross, Geologist, and Dr. Richard A. Cahill, Associate Chemist, Illinois Geological Survey, Champaign, Illinois, assisted with the sampling in 1983 and Dr. Cahill supervised the chemical analyses, which were performed at no cost to this project. Mr. Paul Mohrhardt, Project Manager, Mr. Ed Hanses, Chief, and Charlene Smith, Biologist, Environmental and Social Analysis Branch, Chicago Office, U.S. Army Corps of Engineers, provided much helpful advice, and suggested several locations to sample on the North Branch of the Chicago River. We are grateful to Irwin Polls, Biologist, Metropolitan Sanitary District of Greater Chicago, who also offered advice on sampling locations; Mr. Jack Grubaugh and Bryan Hickman, Technical Assistants, Illinois Natural History Survey, River Research Laboratory, Havana, Illinois, and Mr. Larry Durham, Summer Intern, Eastern Illinois University, Charleston, Illinois, for their help in collection of samples; to Lloyd LeMere, Illustrator, and Leslie A. Woodrum, Photographer, Illinois Natural History Survey, Champaign, Illinois, for preparing the graphs and maps used in this report; and to Victoria Atchley and Katie Roat, Secretaries, Illinois Natural History Survey, River Research Laboratory, Havana, Illinois, who typed and helped edit the data sheets and this report.

ABSTRACT

Toxicity of the sediments in the Illinois Waterway, as measured by the gill response of fingernail clams, increases in the upstream direction. The normal metachronal beating of the cilia on the gills is replaced by abnormal, synchronous beating, lowered or highly variable beating rates, and even complete ciliary arrest in some sediments. The greatest toxicity to date has occurred in sediments from the Des Plaines River at Joliet -- these sediments cause complete ciliary arrest on the gills of fingergnail clams in 10-25 minutes of exposure. Two sediment samples were taken from downtown Chicago in the North Branch of the Chicago River, but these samples were less toxic than the one from Joliet, so an additional source of toxicity may lie between Joliet and the North Branch of the Chicago River.

The toxic sediments and periodic low oxygen levels probably are responsible for the paucity or complete absence of benthic macroinvertebrates in parts of the upper Illinois Waterway, and the sediments are a potential threat to organisms in downstream reaches -- a threat which could be realized if the sediments are ever scoured and transported downstream.

INTRODUCTION AND BACKGROUND

In their report on the projected effects of increased diversion of Lake Michigan water on the Illinois Valley, Havera et al. (1980) concluded that benthic macroinvertebrate communities in the Chicago area waterways and in much of the Illinois Waterway downstream for a distance of 200 miles are limited by some factor associated with polluted sediment. Hence, diversion alone may not improve conditions for this important group of organisms. In fact, under certain conditions, diversion could actually worsen conditions for benthic organisms. If less toxic surficial sediments in the Chicago waterways now cap more toxic sediments, increased diversion could scour away the surficial layers and expose the more toxic layers. Increased diversion might also increase the rate at which toxic sediments are transported downstream, thus extending the zone where the benthic communities are degraded or absent. On the other hand, pollution control measures undertaken during the last ten years may have removed some of the toxic materials which become bound to sediment particles. In this case, the surficial layers of sediment may be becoming less toxic and gradual improvement in sediment quality combined with improvements in water quality, brought about by increased diversion, could restore the benthos of the Illinois Waterway.

Restoration of benthic communities is one of the keys to restoration of the Illinois Waterway. The communities provide "tertiary" treatment of man's organic waste, converting it from an oxygen demand problem into biomass usable by higher level consumers such as bottom-feeding fish and diving ducks, which are valued by man.

It is clearly of great importance to have a direct measure of the vertical and longitudinal distribution of toxicity in the sediments of the upper Illinois Waterway. The chemistry of sediment is very complex, and chemical analysis of sediment alone cannot reliably predict biological effects. In particular, most sediments contain a mixture of toxicants, and the interactions of these toxicants are for the most part unknown.

We measured the toxicity of sediments from 5 locations in the upper Illinois Waterway, using a representative organism from the benthic community which once occurred in the upper Waterway, the fingernail clam, *Musculium transversum*. In addition, both toxicity and concentrations of heavy metals were measured in sediment samples from two locations.

METHODS

The measured response was the rate of ciliary beating (in beats per second) of gills excised from fingernail clams. The method has been thoroughly developed and tested, and has been described in detail in several publications (Sparks et al., 1981; Sandusky et al., 1978; Anderson et al., 1978; and Anderson, 1977). Briefly, the bioassay technique used two coupled microscopes, with a stroboscopic light serving as the substage light source for both microscopes. The rate of ciliary beating was measured by manually synchronizing the rate of flashing of the light with the rate of beating of the lateral cilia which beat in a metachronal pattern. Synchronization was achieved when the metachronal wave appeared to stand still. The beating was shown on a digital display. Very low beating rates could not be measured with the above apparatus. In these cases, a shutter mechanism and a high intensity light source, similar to a movie projector, was used. This apparatus has been developed by Dr. Anthony A. Paparo at Southern Illinois University, on several joint projects with Dr. Sparks. Dr. Paparo performed all the bioassays reported herein.

Since large populations of fingernail clams were not available in the Illinois Waterway, the clams were obtained from the Keokuk Pool on the Mississippi River, using a boat specially rigged with a dredge, crane, and pressure-sieving system, provided by the Illinois Natural History Survey. Clams were collected on 17 June 1982 and 19 April 1983 and placed in aerated Mississippi River water in insulated containers. In 1982 the clams were shipped air freight and reached Dr. Paparo on the Dauphin Island Sea Lab, Dauphin Island, Alabama, within 24 hours. In 1983 Mr. Blodgett delivered the clams to Dr. Paparo at Southern Illinois University, Carbondale, Illinois, 42 hours after collection.

Surficial (approximately 0-3 inches) sediment samples were taken with a ponar dredge. We used varying lengths of 3-inch diameter PVC pipe (depending on water depth) to take sediment samples to a sediment depth of 18 inches. The plastic corer had been aged for six weeks in a farm pond to reduce contamination of the samples with plasticizers. Each core was extruded on a measuring board with a ramrod and divided into layers, which were transferred to 450-ml glass jars and sealed. Samples for bioassays were stored on ice or refrigerated until shipped in insulated containers, via air freight to Dauphin Island in 1982 and via car to SIU in 1983. No more than 24 hours elapsed from the time the samples were collected until they reached Dr. Paparo.

A total of 20 sediment samples were tested using the gill bioassay and 9 samples were analyzed for heavy metals (Table 1). All samples were taken from backwaters or pools, where sediments were known to be accumulating, avoiding areas that were dredged or naturally scoured. The location of samples taken for bioassays are given in Table 1 and plotted on Figure 1.

Dr. Paparo suspended the sediments in physiological saline solution at concentrations (2.1-3.9 particles per liter) and densities (29.3-78.4 mg per liter) well below levels which affected clam gills mechanically, by abrasion or clogging (Anderson et al., 1978). In addition, Dr. Paparo prepared control suspensions of yeast cells, made up to the same particle concentrations as the sediment samples (Table 2). The beating rate of the gills was measured at the beginning of exposure to the test solutions or control solutions, and at 5-minute intervals thereafter for 30 minutes, at which time the tests ended.

TABLE 1

Sampling Dates, Locations, Depths, and
Type of Analysis

Date	Location	River Mile	Sampler P=Ponar C=Corer	Sample Depth (inches)	Sample No.	Analysis B=Bioassay C=Chemical
6 July 1982	Turner Lake	215	C	0-3	1	B
			C	9-12	2	B
6 July 1982	Turner Lake	215	C	0-3	3	B
			C	9-12	4	B
13 July 1982	Brandon Road	286	C	0-3	5	B
			C	9-12	6	B
13 July 1982	Brandon Road	286	C	0-3	7	B
			C	9-12	8	B
19 July 1982	Starved Rock	231	C	0-3	9	B
			C	9-12	10	B
19 July 1982	Starved Rock	231	C	0-3	11	B
			C	9-12	12	B
3 August 1982	North Branch, Chicago River	326	C	0-3	13	B
			C	9-12	14	B
3 August 1982	North Branch, Chicago River	327	C	0-3	15	B
			C	9-12	16	B
19 April 1983	Lake Depue	211	P	0-3	17	C
			C	1-1.6	18	C
			C	3-4.3	19	C
20 April 1983	Turner Lake	215	P	0-3	20	C
			C	0-3	21	B
			C	3-9	22	C
			C	9-12	23	B
			C	12-18	24	C
20 April 1983	Brandon Road	286	P	0-3	25	C
			C	0-3	26	B
			C	3-9	27	C
			C	9-12	28	B
			C	12-18	29	C
Total No. Samples					29	20B 9C

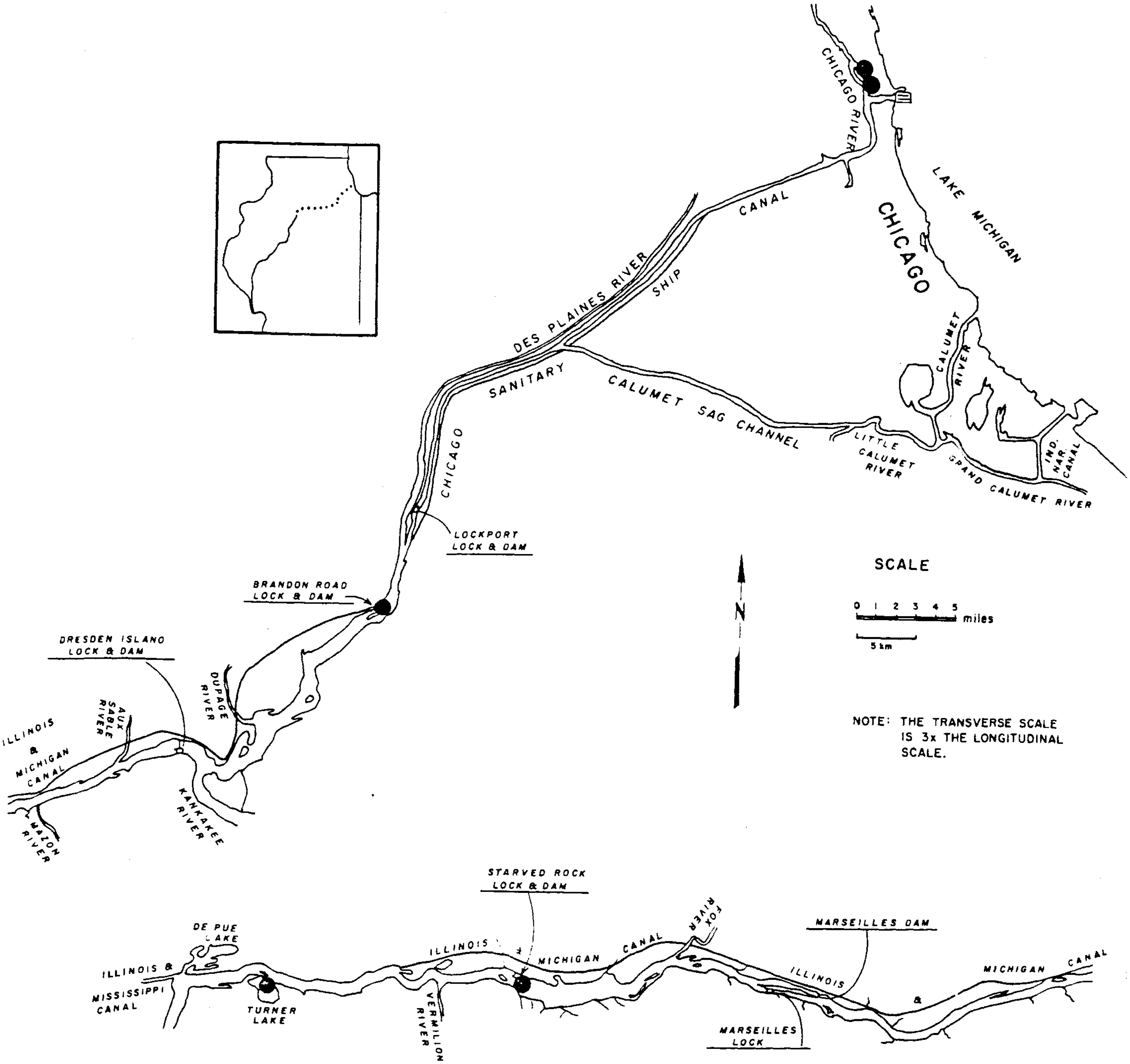

Figure 1. Map of study area. The study reach is shown as a dotted line on the insert map of Illinois. The upper portion of the detailed figure shows the reach from Lake Michigan downstream to the Mazon River (Illinois River mile 263.6), and the lower portion shows the reach from Mazon River to Lake Depue (river mile 210.9). Sediment samples for bioassays were taken at locations marked by black dots.

TABLE 2

Physical Characteristics of Sediment
Suspensions Tested on Fingernail Clam Gills

Values are means of 5 determinations ± standard deviations

Sample Number	Particle Size (μm)	Density (mg/l)	Concentration (Particles/1x10^6)
1	5.2 ± 0.9	61.3 ± 9.1	2.3 ± 0.6
2	4.6 ± 1.0	59.6 ± 4.8	2.7 ± 0.4
3	3.8 ± 0.6	42.9 ± 6.6	2.2 ± 0.3
4	4.1 ± 0.9	48.6 ± 4.2	2.5 ± 0.2
5	2.9 ± 0.6	53.4 ± 7.3	2.7 ± 0.3
6	3.1 ± 1.1	63.4 ± 8.1	2.4 ± 0.4
7	6.3 ± 1.2	29.3 ± 2.4	2.3 ± 0.4
8	5.9 ± 0.8	32.4 ± 2.9	2.2 ± 0.7
9	7.2 ± 0.6	72.3 ± 14.2	2.5 ± 0.1
10	6.8 ± 1.1	78.4 ± 10.2	2.4 ± 0.6
11	2.9 ± 0.5	39.6 ± 12.2	2.1 ± 0.3
12	3.4 ± 0.9	48.6 ± 9.9	2.3 ± 0.7
13	4.9 ± 0.2	53.8 ± 3.9	2.5 ± 0.5
14	4.6 ± 0.9	61.1 ± 7.0	2.4 ± 0.3
15	5.4 ± 1.1	50.1 ± 4.1	2.3 ± 0.4
16	5.9 ± 0.4	46.4 ± 2.8	2.2 ± 0.6
21	4.9 ± 1.1	59.2 ± 3.2	2.8 ± 0.9
23	3.8 ± 0.8	46.3 ± 2.6	3.3 ± 0.5
26	4.5 ± 1.2	60.1 ± 1.9	3.9 ± 0.4
28	5.2 ± 0.9	52.5 ± 3.8	3.0 ± 0.2
Y1	6.8 ± 0.4	46.3 ± 5.6	2.5 ± 0.6
Y2	7.2 ± 0.5	59.1 ± 2.9	2.7 ± 0.4

Note: Y = Yeast suspension, used as a control. Y1 was the control for bioassays in 1982, Y2 for bioassays in 1983.

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RESULTS AND DISCUSSION

VERTICAL PATTERN OF TOXICITY

Surficial sediments (0-3 inches deep) were slightly more toxic than deeper sediments (9-12 inches deep, Figures 2 and 3). Note that the surficial sediments from river mile 286 caused ciliary arrest in 20 minutes whereas the deeper sediments took 25 minutes (Figures 2 and 3). Sediments from both depths also caused abnormal synchronous or erratic beating of the cilia. We assume that the deeper sediments are older than the surficial sediments, hence, the toxicity may have increased since the time the 9-12 inch layer was deposited. It would be useful to have a chronology of the sediments, but sediments were not dated in this study.

LONGITUDINAL PATTERN OF TOXICITY

There were pronounced differences in the toxicity of sediments from different locations, measured as percent depression of ciliary beating rate from normal in a 30 minute exposure (Figure 4). Toxicity increased upstream from river mile 215 to 286. However, the samples from the North Branch of the Chicago River (miles 326 and 327) were intermediate in toxicity, compared to sediments from miles 215 and 231 (Figure 4). It appears that a substantial addition to toxicity occurs between miles 286 and 326, followed by dilution or breakdown as the toxicant is carried downstream. Concentrations of heavy metals in the sediments from Brandon Road (river mile 286) were much higher than in Turner Lake or in an average of 93 samples taken from 14 lakes in downstream areas of the Illinois

Waterway (Table 3). There is some evidence, however, that heavy metals may not be the major contributor to toxicity in the sediments of the upper Illinois Waterway. Although concentrations of metals in sediments from Lake Depue were much higher than in Turner Lake (Table 3), Sparks, Sandusky, and Paparo (1983) showed that Lake Depue sediments were less toxic to clam gills than Turner Lake sediments. Organic contaminants are probably important contributors to the toxicity of the upper Illinois Waterway. The sediments from Brandon Road contained substantial amounts of PCBs, although the preliminary analyses were not precise enough to distinguish and quantify the various types of PCBs (Personal communication, 1 August 1983, Dr. Richard Cahill, Associate Chemist, Illinois Geological Survey, Champaign, Illinois). The Cal-Sag Channel enters the Illinois Waterway between miles 326 and 286, and Harrison et al. (1981) found higher levels of PCBs in Cal-Sag sediments (average concentration equalled 7.0 mg/kg) than in the Des Plaines River (average = 1.6 mg/kg), or Illinois Waterway (average = 0.5 mg/kg) sediments.

We feel that the best method to determine the major toxic constituents of the sediments from the upper Illinois Waterway is to chemically fractionate the sediments from Brandon Road and test these fractions on fingernail clam gills. Samoiloff et al. (1983) provided a good example of this method, applied to sediments from Tobin Lake, Saskatchewan.

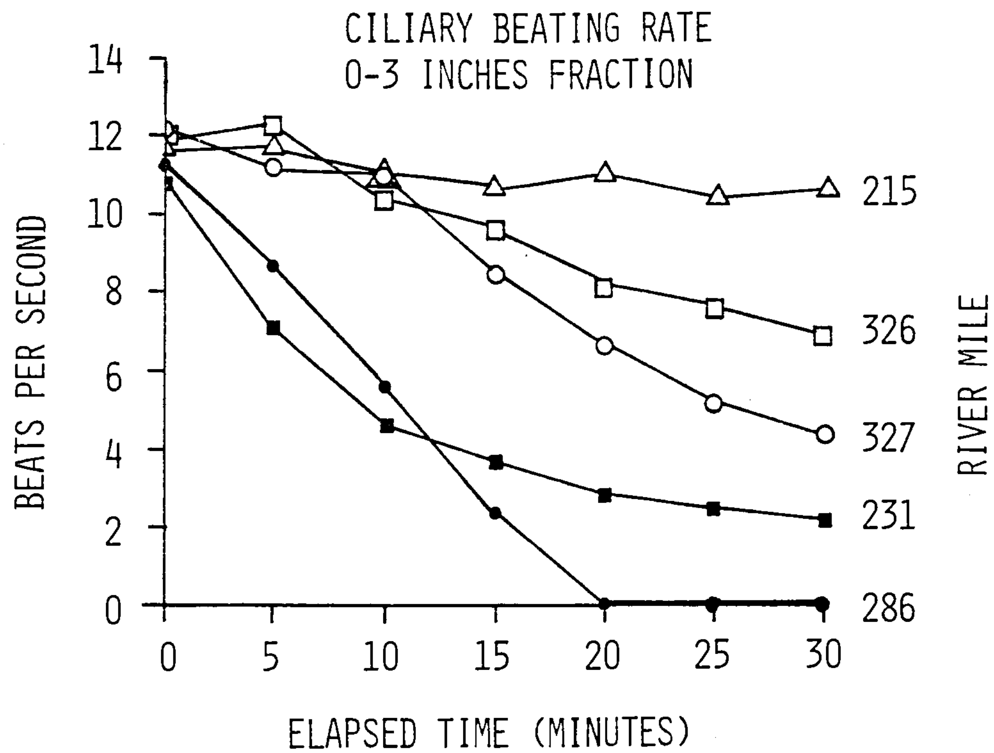

Figure 2. Beating rate of lateral cilia on clam gills exposed to surficial sediments (0-3 inches deep) from 5 locations on the upper Illinois Waterway. Sediment samples collected July, 1982.

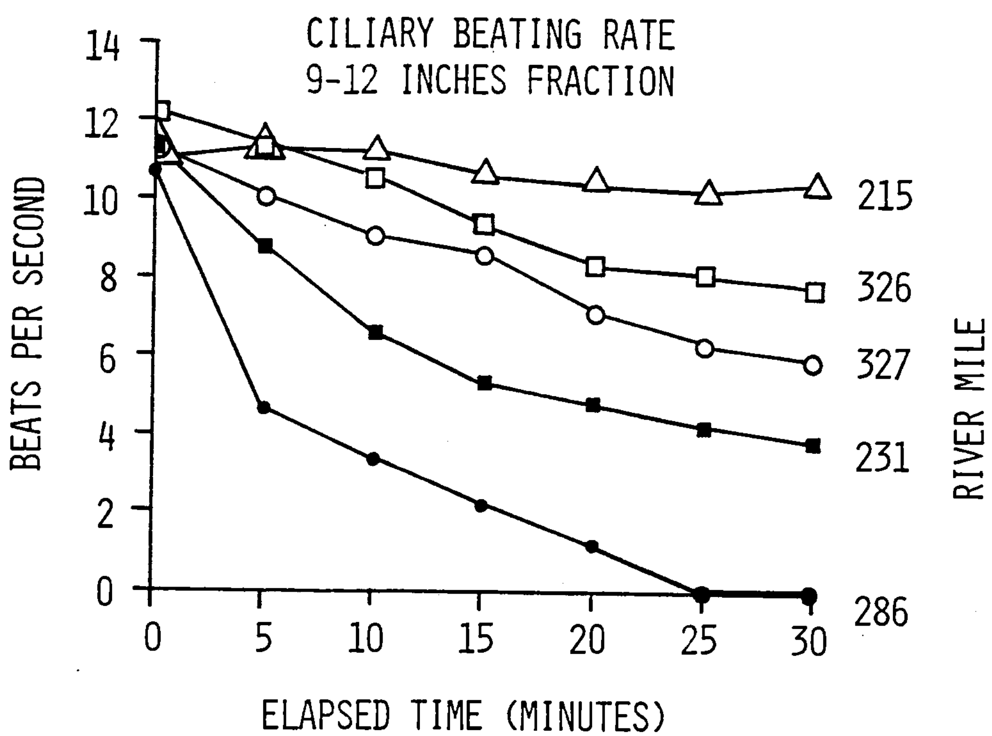

Figure 3. Beating rate of lateral cilia on clam gills exposed to deeper sediments (9-12 inches deep) from 5 locations on the upper Illinois Waterway. Sediment samples collected July, 1982.

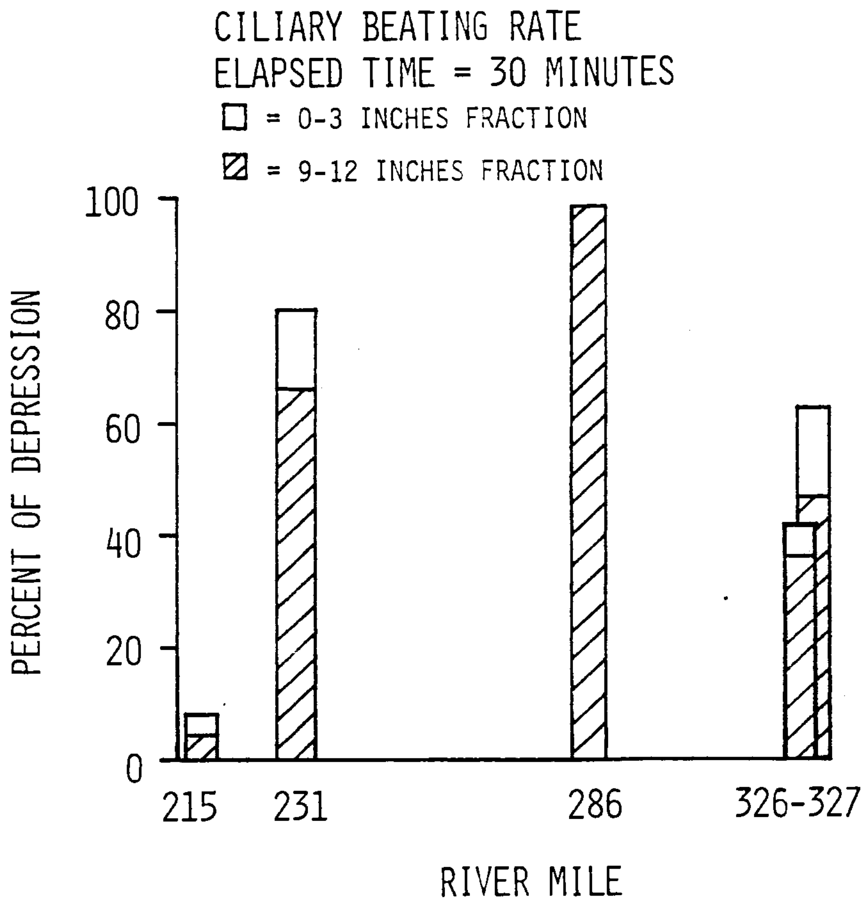

Figure 4. Percent depression of ciliary beating rate of gills exposed 30 minutes to sediments from 5 locations on the Illinois Waterway.

TABLE 3

Concentration (ppm) of Heavy Metals in Sediments from Three Locations on the Upper Illinois Waterway

Location	Sampler P=Ponar C=Corer	Depth (inches)	Lead	Zinc	Cadmium	Silver	Tin	Copper	Nickel	Chromium	Arsenic	Antimony
Turner Lake	P	0-3	60	242	1.6	<1	<5	60	30	112	11	1.5
	C	3-9	65	265	2.5	<1	<5	68	40	110	11	1.4
	C	12-18	80	328	4.3	<1	<5	63	41	135	11	1.7
Brandon Road	P	0-3	609	2627	64	12	31	453	220	670	24	13
	C	3-9	435	1695	37	6	22	324	299	454	16	9
	C	12-18	738	2330	73	12	34	500	284	700	16	14
Lake DePue	P	0-3	86	2110	13	3	<5	87	47	192	13	2.2
	C	1-1.6	53	370	2	<1	<5	57	35	98	13	1.2
	C	3-4.3	65	1043	6	<1	<5	81	38	98	11	1.2
Average of 93 samples from 14 lakes along the Illinois Waterway			65	464	7.0	--	2.2	54	42	114	13	2.3

Source: Dr. Richard Cahill, Assoicate Chemist, Illinois Geological Survey, Champaign, Illinois.

COMPARISON OF 1982 AND 1983 RESULTS

Results using sediment samples and fingernail clams collected in 1983 generally paralleled results obtained with clams and sediments taken from the same locations a year earlier (Figure 5). The deep (9-12 inch) sediments from Turner Lake appeared to be slightly more toxic in 1983 than in 1982 (B, Figure 5). There was a greater difference in adjacent cores taken in the same year at Brandon Road than between the cores taken in different years (D, Figure 5). In the latter case, one 1982 sample caused complete ciliary arrest in 10 minutes, while the other took 25 minutes. The 1983 sample fell in between, at 15 minutes. The effects of sediments from the surficial layers at both locations are remarkably consistent (A and C, Figure 5).

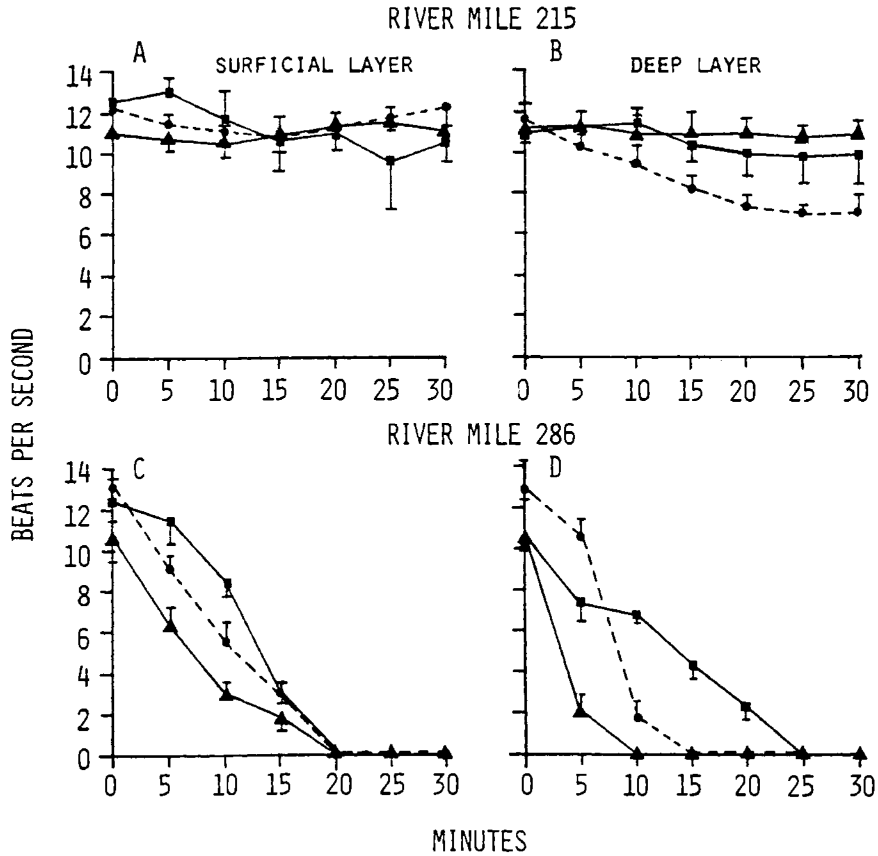

Figure 5. Comparison of 1982 (solid lines) and 1983 (broken lines) results. Black squares show results using one of the 1982 duplicate samples, and black triangles show the results using the other 1982 samples. Single samples only were taken in 1983 (black circles). Upper graphs show effects of surficial sediments (A) and deep (9-12 inch) sediments (B) from Turner Lake. Lower graphs show effects of surficial (C) and deep (D) sediments from Brandon Roads.

SUMMARY

1. Toxicity of the sediments in the upper Illinois Waterway, as measured by the gill response of fingernail clams, increases in the upstream direction from river mile 215 (Turner Lake) to mile 286 (Brandon Roads). Sediments from the North Branch of the Chicago River at river miles 326 and 327 were less toxic than those from Brandon Roads, but more toxic than sediments from Turner Lake. These results suggest that there is a major toxic addition to the upper Illinois Waterway somewhere between miles 286 and 326.

2. Surficial sediments (0-3 inches deep) appeared to be slightly more toxic than deeper sediments (9-12 inches deep). Hence, there appeared to be no evidence for a recent decline in toxicity of the sediments attributable to improved waste treatment in the Chicago-Joliet area. A difinitive test of this hypothesis would require dating and testing of sediments, including sediments from much deeper layers than we tested. Formation of toxic products, such as hydrogen sulfide, under anaerobic conditions would also have to be taken into account.

3. The toxic sediments in the upper part of the Illinois Waterway are probably limiting to benthic macroinvertebrates in these reaches and are a potential threat to aquatic organisms in downstream reaches. This study did not determine under what conditions sediments in the upper Waterway could be scoured and transported downstream.

4. The toxic components in the upper Illinois Waterway could be positively identified by chemically fractionating the sediments from Brandon Roads and testing the fractions on fingernail clam gills. Such information would be extremely useful in prioritizing programs to clean up toxic discharges in the upper Illinois Waterway.

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