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THE DEVELOPMENT OF TOXICITY INDICES FOR ASSESSING THE QUALITY OF THE ILLINOIS RIVER

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ABSTRACT

Individual toxicant concentrations in the Illinois River were expressed as fractions of their 96-hr LC50 values to bluegills, yielding their component toxicities in bluegill toxic units (BGTU's). A solution having a toxicity of 1.0 BGTU was defined as being lethal to 50 percent of the bluegills exposed to it for 96 hr. River toxicants included aldrin, undissociated ammonia (ammonia$_{(u)}$), arsenic, cadmium, hexavalent and trivalent chromium, copper, cyanide, fluoride, linear alkylate sulfonate (LAS), lead, mercury, phenols, and zinc. Component toxicities at different locations on the river were summed to produce the toxicity index, or total toxicity, of the river. Preliminary mean toxicity indices developed from previously published data during 1972 and 1973 ranged from 0.045 to 0.168 BGTU's, on the Illinois and Des Plaines rivers. However, maximum component toxicities of ammonia$_{(u)}$ and cyanide during this period reached 0.630 and 0.467 BGTU's, respectively. LAS, copper, fluoride, and zinc also contributed to the preliminary river toxicity indices. Mean toxicity indices developed during field tests, in which bluegills were exposed directly to river water, and the lack of mortality at these tests, indicated that the Illinois River is not normally acutely toxic to fish. The 96-hr LC50 values of ammonia$_{(u)}$ and LAS to bluegills were found to be 1.65 and 6.5 mg/liter, respectively, using continuous-flow bioassays with dilution water similar in hardness, alkalinity and pH to Illinois River water.

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THE DEVELOPMENT OF TOXICITY INDICES FOR ASSESSING THE QUALITY OF THE ILLINOIS RIVER.

Keywords -- toxicity*/bioindicators/water pollution effects/Illinois River*/
water quality

OBJECTIVES AND SCOPE

The primary objectives of this project were to compile toxicity indices for the Illinois River and to determine if these indices could accurately estimate the quality of the river for fish life. An important reason for undertaking this project was to determine if the considerable bulk of chemical and physical data now being generated by river monitoring agencies could be used directly to describe the biological quality of the Illinois River, thus providing a tool that could be applied to the protection of the aquatic life in the river.

The specific objectives of the project were to:

1) relate data on the lethal levels of toxicants to the concentrations of these toxicants in the Illinois River, by means of river toxicity indices.
2) conduct field tests to determine the validity of expressing the toxicity of the river using toxicity indices.
3) conduct continuous-flow toxicant bioassays to determine to what extent the general water quality of the Illinois River influenced the acute toxicity of the toxicants and to investigate the lethal effects of combinations of toxicants.
4) assess the daily variability of zinc, copper, and lead concentrations in the Illinois River, and to relate the variations of these toxicants, if possible, to water levels and the turbidity of the river.

The bioassay phase of this project was only partially completed. Although ammonia and linear alkylate sulfonate (LAS) bioassays were conducted, no combinations of toxicants were tested. The other phases of this project were satisfactorily completed.

INTRODUCTION

The Illinois River (Figure 1) once supported an enormous commercial and sport fishery (Mills, Starrett, and Bellrose, 1966), but the environmental conditions of the river are now severely degraded and the commercial fishery of the river is only a fraction of its former size. One factor that may have been partly responsible for the degradation of the river was the presence of toxic materials in the river. Although many studies have been carried out to measure toxicant concentrations in the Illinois River (Mathis and Cummings, 1971; Sullivan and Swisher, 1969; Illinois State Water Survey, 1972), and toxicant concentration data for the Illinois River were published yearly by the Illinois Environmental Protection Agency (1972; 1973), the relationships between the concentrations of toxicants and their lethal effects on aquatic organisms in the river have remained largely speculative.

Fish in the Illinois River are exposed simultaneously to a wide variety of toxicants originating from municipal, industrial, and agricultural sources. Toxic materials dealt with in this study included undissociated ammonia ($ammonia_{(u)}$), arsenic, cadmium, chromium, copper, cyanide, fluoride, mercury, lead, linear alkylate sulfonate (LAS), pesticides, phenols, and zinc. Separating the lethal effects of one of these toxicants from another in the river appeared to be particularly difficult. Instead, this study involved the estimation of the total joint toxicity of these materials in the Illinois River by establishing toxicity indices for different locations along the river.

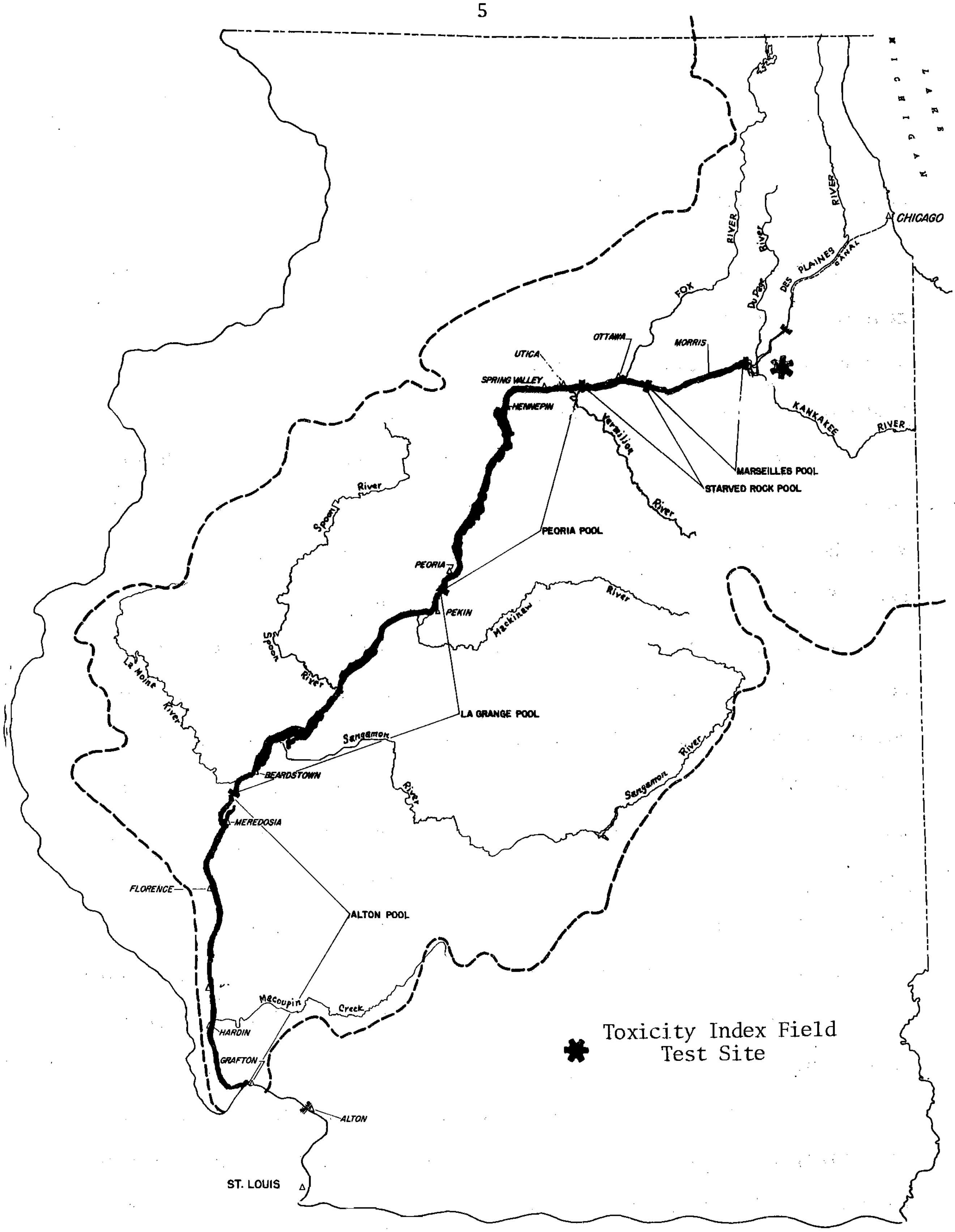

Figure 1. The Illinois River and its major tributaries. The river is divided into navigational pools by a series of locks and dams. The heavy dashed line represents the river's drainage basin.

METHODS

Selection of Previously Published LC50 Values

The bluegill, Lepomis macrochirus, was used as the reference organism of the indices because it is a natural inhabitant of the Illinois River, and because of the large volume of data available on the acute toxicity of various materials to bluegills.

A thorough review of the literature was made to determine 96-hr LC50's of the toxicants listed previously to bluegills. These values were the concentrations of the toxicants that were lethal to 50 percent of the bluegills exposed to them for 96 hours.

All efforts were made to use LC50 data from the literature that were applicable to the Illinois River, such as those calculated in experiments where hard alkaline water with a pH near 8.0 was used as dilution water. These values are presented in Table 1. To make certain that literature values were reasonably accurate, 96-hr LC50's for $ammonia_{(u)}$ and LAS were experimentally determined (see method below) using continous-flow bioassays and dilution water similar in hardness, alkalinity, and pH to Illinois River water. No bluegill LC50 data were available for fluoride; however, a median 96-hr LC50 between those reported for carp, Cyprinus carpio, and rainbow trout, Salmo gairdnerii, was assumed applicable for bluegills. When the LC50 data was reported as a salt, as for arsenic and mercury, the concentrations were converted to apply to the toxic ion only. Although the mercury LC50 reported by Willford (1966) was determined over a 48-hr period, the lack of acute toxicity data for mercury necessitated the use of this value in the

Table 1. 96-hr LC50 Values of Suspected River Toxicants in Dilution Water Similar in Quality to Illinois River Water.

Toxicant	96-hr LC50 (in mg/liter)	Reference
$Ammonia_{(u)}$	1.65	$ammonia_{(u)}$ bioassay
Arsenic	17.5*	Guilderhus (1966)
Cadmium	45.1*	Pickering and Henderson (1966)
Chromium (trivalent)	71.9	Pickering and Henderson (1966)
Chromium (hexavalent)	133.0	Pickering and Henderson (1966)
Copper	10.2	Pickering and Henderson (1966)
Cyanide	0.15	Doudoroff, et al. (1966)
Fluoride	44.5*	Neuhold and Sigler (1960)
Lead	442	Pickering and Henderson (1966)
LAS	6.5	LAS bioassay
Mercury	9.54	Willford (1966)
Pesticides		Tarzwell (1958)
Aldrin	0.0130	
DDT	0.0160	
Dieldrin	0.0079	
Heptachlor	0.0190	
Phenol	28.5	Anonymous (1960)
Zinc	40.9	Pickering and Henderson (1966)

* estimated values. See text for explanation.

indices. The 96-hr LC50 for cadmium to bluegills was derived by assuming that the toxicity of cadmium to bluegills was affected to the same extent by water hardness as was the toxicity of cadmium to green sunfish, *Lepomis cyanellus*, a close relative of the bluegill. A review of the toxicants used in this study, their lethal toxicities, and how their toxicities were affected by different water characteristics was presented by Lubinski (manuscript in preparation).

Calculation of Toxicity Indices

The 96-hr LC50 values presented in Table 1, and Illinois Environmental Protection Agency data (1972; 1973) were used to develop preliminary toxicity indices for 17 locations on the Illinois and Des Plaines rivers. To establish a toxicity index for the Illinois River at a particular location, each toxicant concentration in the river was expressed as a fraction of its 96-hr LC50 to bluegills, yielding its component toxicity in bluegill toxic units (BGTU's), following the method of Brown (1968), which summarized and reviewed by Sprague (1970). A solution having a toxicity of 1.0 BGTU was defined as being lethal to 50 percent of the bluegills exposed to it for 96 hr. The acute lethal effects of all of the toxicants in the river were assumed to be additive, and thus the component toxicities were summed to produce the toxicity index, or total toxicity of the river. Mean toxicity indices over a two-year period were developed, as well as maximum toxicity indices to estimate the worst possible conditions in the rivers during this period. To develop the maximum toxicity indices, the maximum concentrations of the toxicants that occurred at the different locations were used.

Ammonia concentrations were measured by the Illinois Environmental Protection Agency as ammonia nitrogen, which includes all of the forms of ammonia nitrogen that occur in the river. However, only $ammonia_{(u)}$ is toxic to fish, and therefore the ammonia nitrogen concentrations reported were converted to $ammonia_{(u)}$ using the tables presented by Skarheim (1973), the pH values reported, and assuming a temperature of 25 C, and a total dissolved solids concentration of 500 mg/liter. The methylene blue active substances (MBAS) concentrations reported by the Illinois Environmental Protection Agency were multiplied by 0.15 to estimate the actual amounts of LAS in the rivers (Sullivan and Swisher, 1969). All cyanide concentrations were considered to be in the form of molecular cyanide.

Bioassays with $Ammonia_{(u)}$ and LAS

The test organisms were young-of-the-year bluegills, obtained from the Illinois Natural History Survey, Urbana, Illinois, and transported to the Illinois Department of Conservation Field Headquarters at Havana, Illinois (Figure 2). They were held in an oval 1900 liter tank (Figure 3), and were acclimated and tested in well water that was similar in hardness, alkalinity, and pH to Illinois River water. The temperature during acclimation and testing was 22 C (± 4 C). The bluegills were fed crushed catfish food daily, and Gordon Formula (Innes, 1966) as a weekly supplement. All fish used appeared to be in good health. The sizes of the bluegills used in the bioassays are given below.

Bioassay	No. of bluegills	mean total lengths in cm (ranges in parentheses)
$Ammonia_{(u)}$	60	5.2 (3.7-6.7)
LAS	60	4.8 (3.9-5.4)

The bioassay procedures and the methods used to develop the toxicity curves for $ammonia_{(u)}$ and LAS were outlined by Sprague (1973). A proportional diluter (Mount and Brungs, 1967) was used to deliver five concentrations of the toxicant tested plus a control of well water to

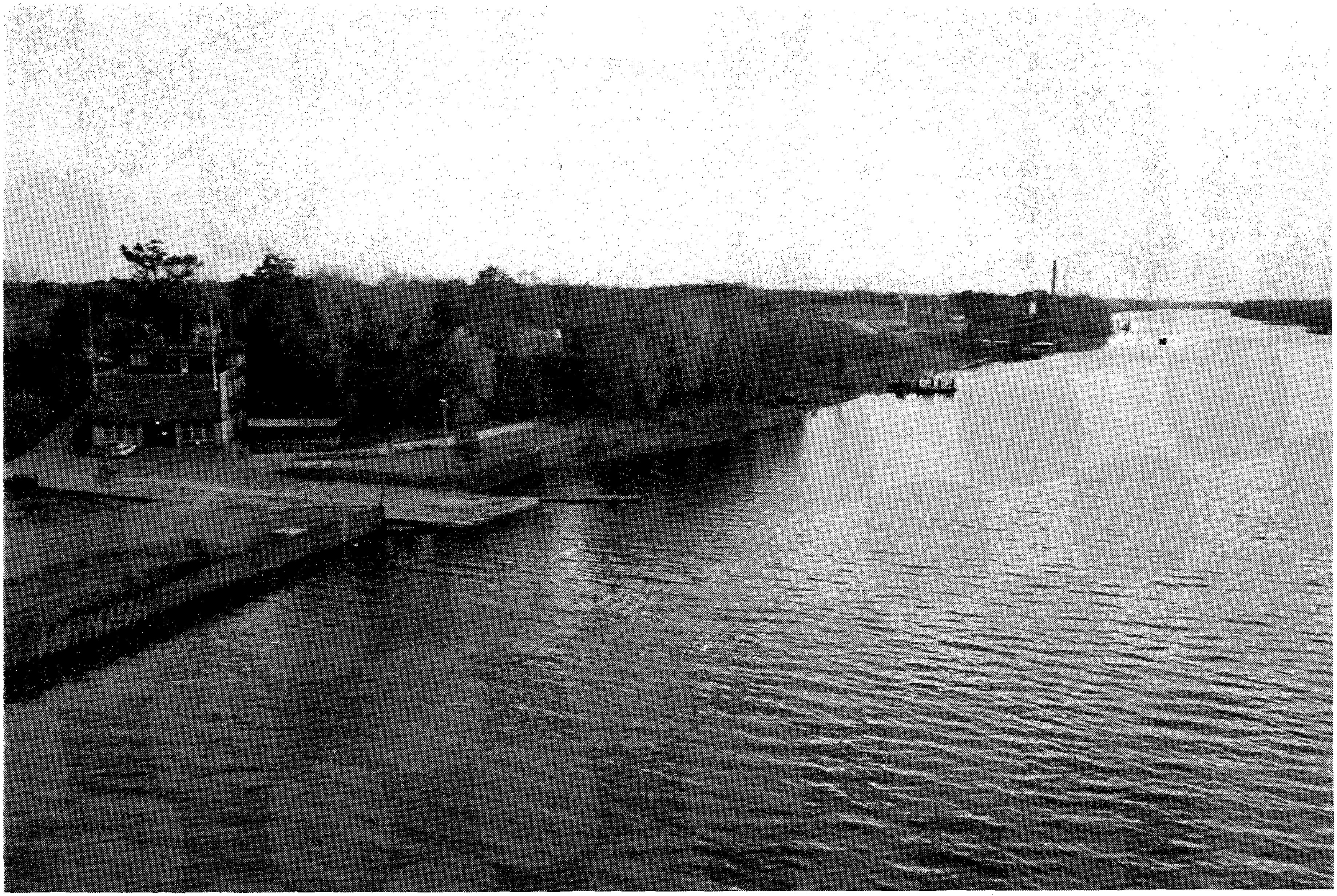

Figure 2. The Illinois River at Havana. This is a view of the Illinois River looking downstream from the Rt. 136 Bridge. The toxicant bioassays were carried out at the Illinois Department of Conservation Field Headquarters at the left. Farther downstream, the smokestack of the Illinois Power Company marks approximately where the river monitoring was conducted. The Illinois River was at pool stage when this picture was taken.

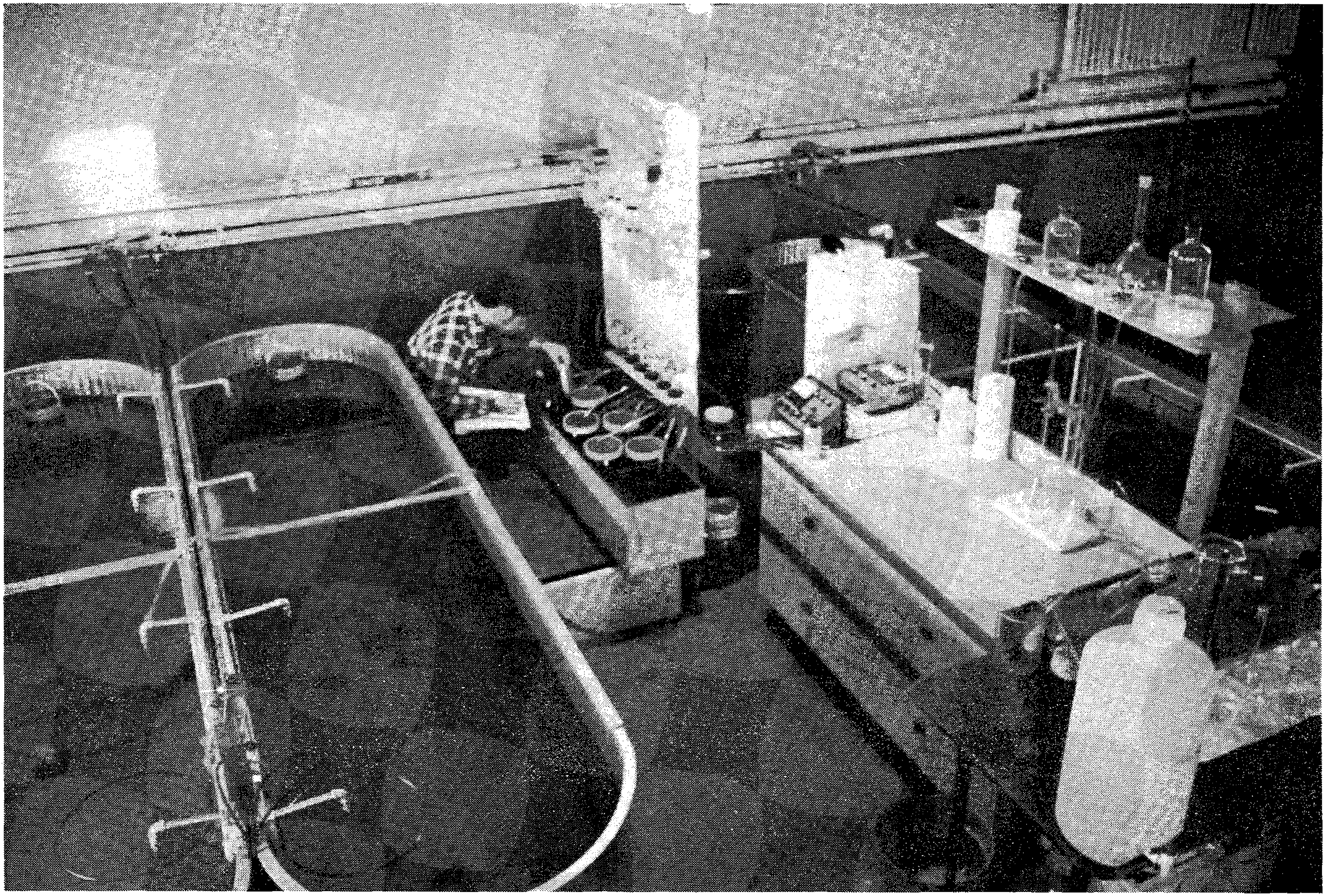

Figure 3. Bioassay facilities. The large tanks at the left of this picture were used to hold bluegills and to supply dilution water to the proportional diluter (center). The test tanks were being checked for bluegill mortalities during the LAS bioassay.

the bottom of six 3.78-liter glass jars that were used as test tanks (Figure 3). The tanks were immersed in a water bath to reduce temperature variations during the tests. The well water used during the bioassays exhibited the following characteristics: hardness, 126-278 mg/liter as $CaCO_3$; total alkalinity, 184-216 mg/liter as $CaCO_3$; pH, 7.7-8.1; specific conductance, 530-540 micromhos/cm. The flow rate to the diluter, which delivered 250 ml to each tank per cycle, was adjusted to yield a 95 percent replacement of the solutions in the tanks every 6 hr. This flow rate was increased to yield a 95% replacement in 5 hr during the $ammonia_{(u)}$ bioassay in an attempt to raise the low dissolved oxygen concentrations observed.

$Ammonia_{(u)}$ concentrations were calculated from the amounts of A.C.S. grade ammonium chloride used, the pH values and temperatures of the test solutions, and tables of undissociated ammonia present in aqueous solutions presented by Skarheim (1973). Sulframin-85 powder (Whitco Chemical Corporation, New York) was used as the source of LAS. This compound contained 73 percent LAS, 22 percent sodium sulfate, and 5 percent inert ingredients. The average hydrocarbon chain length of the LAS was 11.2. The LAS concentrations in the test tanks were measured using the methylene blue active substances test (American Public Health Association, 1971).

River Monitoring at Havana

Because the Illinois Environmental Protection Agency sampled toxicants only 4 to 13 times each year at the various river locations, zinc, copper, lead concentrations in the Illinois River at Havana (Figure 2) were sampled daily to determine variations in the concentrations of these metals and to relate these, if possible, to water levels and the turbidity of the river.

Between March 18, and June 11, 1974, daily water samples were collected in the middle of the channel of the Illinois River at Havana, Illinois, river mile 118.7 (Figure 2). River miles in this study refer to the distances between locations along the Illinois and Des Plaines rivers and the mouth of the Illinois River at Grafton, Illinois, as determined by the U.S. Army Engineer District (1970). These samples were collected in 250 ml polyethylene bottles, acidified with 2 ml of concentrated hydrochloric acid, and filtered. The samples were later analyzed for zinc, copper, and lead concentrations by the Illinois Natural History Survey, Urbana, Illinois, using atomic absorption spectrophotometry. River turbidity and water levels were also observed daily, using a Secchi disc and the water level gauge at the Illinois Power Company. Water and air temperatures were checked with a mercury thermometer.

Field Tests of the Validity of the Toxicity Index

The validity of expressing the toxicity of the Illinois River using toxicity indices was determined by conducting field tests in which bluegills, whose total lengths are given below, were directly exposed to Illinois River and tributary water in cages and in an aerated pool while several toxicant concentrations, including pesticides, were monitored.

Field Test and Location description	No. of bluegills	mean total lengths in cm (ranges in parentheses)
Dresden Field Test		
Des Plaines River Cage	50	4.0 (3.0-5.5)
Des Plaines River Aerated Pool	50	3.9 (3.4-5.0)
Kankakee River Cage	50	4.1 (3.5-5.5)
Beardstown Field Test		
Illinois River Cage	50	4.6 (3.0-6.3)
Illinois River Aerated Pool	50	5.1 (3.9-6.5)
Sangamon River Cage	50	4.6 (3.8-5.9)

The pool was used to expose bluegills to aerated river water to separate the possible lethal effects of low dissolved oxygen concentrations in the rivers from those of the toxicants. After the tests, toxicity indices were compiled for the field test locations and compared to the mortalities observed during the tests.

Modified fish holding bags were used to expose bluegills directly in the rivers (Figure 4). The bags were made of soft nylon netting, cylindrical in shape with metal rings at the top and bottom, 50 cm deep, and 30.5 cm in diameter. Plastic coated wire screening was wired around the bags to the upper and lower rings to protect the bags from debris in the river and to enable them to retain their shape in the current. The cages were supported at the surface by styrofoam floats, and anchored using plastic rope and cinder blocks. A drawstring opening at the top

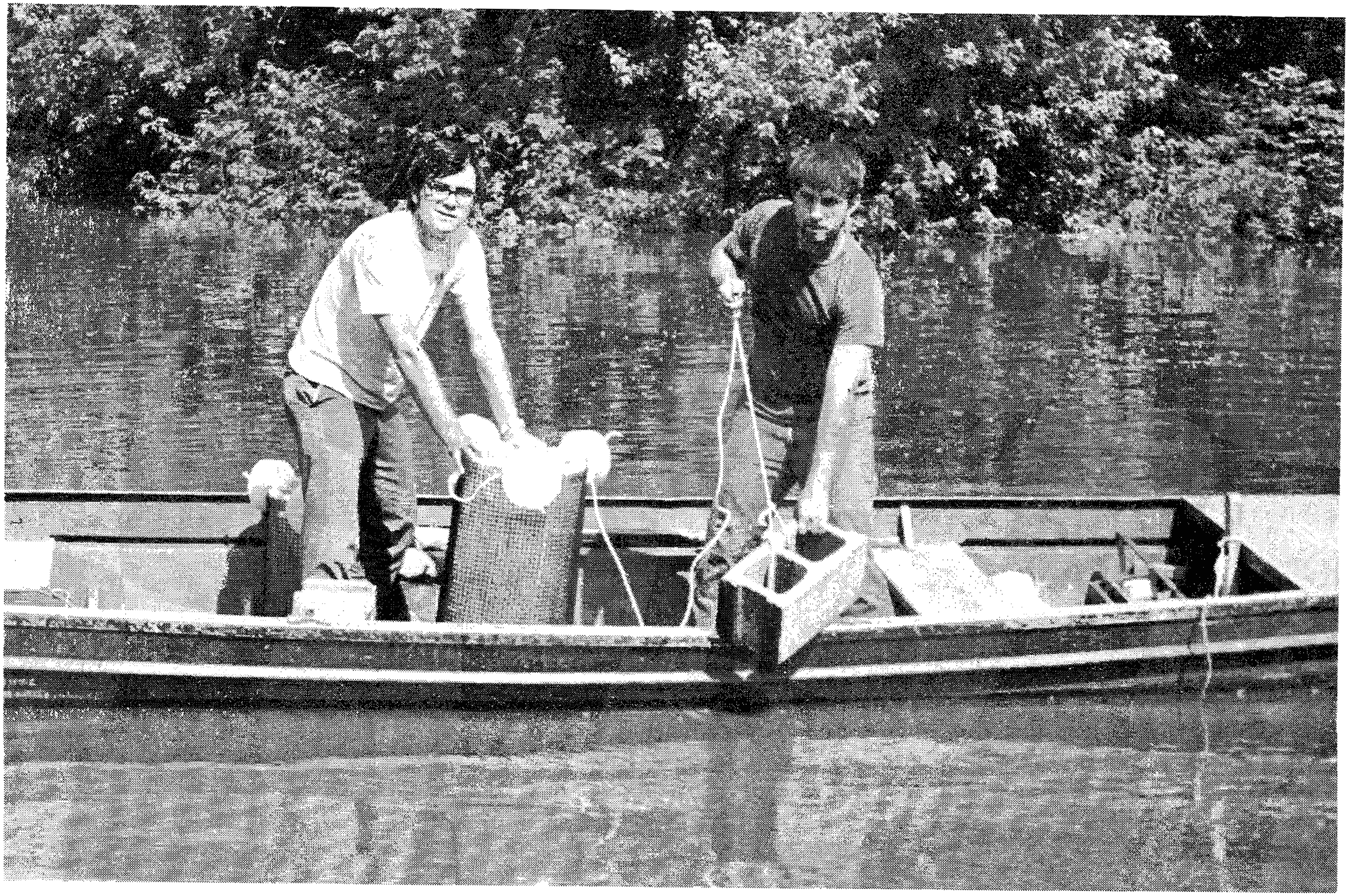

Figure 4. Positioning a cage (modified commercial holding bag) during one of the toxicity index field tests. the upper end of each cage, which floated at the surface of the rivers, had a drawstring opening for the addition and removal of bluegills. The cages were camouflaged with tree branches so as not to attract boaters or fishermen.

of each bag was used to place bluegills inside the cages. The second type of apparatus,consisting of a plastic wading pool 91.5 cm in diameter and 20.3 cm deep, was used to expose the bluegills to artificially aerated water (Figure 5). Two portable battery-powered bait aerators supplied air to river water that was periodically pumped into the pool. Drain holes were cut into the sides of the pool, 18 cm from the bottom, and covered with plastic-covered hardware cloth to prevent fish from escaping while water was being pumped into the pool. Approximately 40-50 liters of river water was pumped into the pool three times daily. The capacity of each cage was 37 liters, while the capacity of the pool was 95 liters.

Two field tests were conducted during the project. For the Dresden field test, conducted between July 7 and 11, 1974, one cage was located in the Kankakee River, while the other cage and the aerated pool were set up on the Des Plaines River. This site was selected because the Kankakee and Des Plaines rivers join to form the beginning of the Illinois River. The Kankakee River is a relatively clean stream, while the Des Plaines River receives effluent from Chicago sewage plants via the Chicago Sanitary and Ship Canal. For the Beardstown field test, conducted between July 23 and 27, 1974, one cage was located in the Sangamon River, while the other cage and the aerated pool were set up on the Illinois River. This site is representative of conditions in the middle section of the Illinois River. Low water levels encountered during the Beardstown field test, that were primarily due to the increased impoundment of river water above Beardtown for navigational purposes, made it necessary to move the Sangamon River cage downstream several times.

The aerated pool was filled with river water and aerated overnight

Figure 5. The aerated pool used in the field tests. This apparatus consisted of a plastic wading pool, and battery-powered bait aerators (right foreground). River water was periodically pumped into the pool with a 12-volt portable pump (left).

before each test. The cages and pool were camouflaged so as not to attract boaters and fishermen. Bluegills were distributed to the cages and aerated pool early in the morning on the first day of each test, which lasted for 96 hr. River water temperatures, pH values, dissolved oxygen concentrations, and total alkalinities were determined using methods outlined by the American Public Health Association (1971). Specific conductances were determined using a portable Beckman conductivity meter. Turbidities were measured using a Secchi disc. A Gurley meter was used to determine the current velocity of the Illinois River at the Beardstown field test.

Three types of water samples were taken periodically during the tests and later analyzed by the Illinois Natural History Survey, Urbana, Illinois, for several river toxicant concentrations and characteristics. Water samples for zinc, copper, and lead analyses were collected and treated as described previously under river monitoring. Glass bottles (1-liter) were used to collect water samples that were later analyzed for pesticide concentrations by gas chromatography. Plastic flasks (200-ml) were used to collect water samples to be later analyzed for ammonia nitrogen concentrations using the phenate method (American Public Health Association, 1971). The last two types of samples were kept under refrigeration until they could be analyzed.

RESULTS

Preliminary Illinois and Des Plaines River Toxicity Indices

The mean component toxicities and toxicity indices developed for 17 locations on the Illinois and Des Plaines rivers are presented in Table 4. Component toxicities less than 0.0005 BGTU's were considered negligible. $Ammonia_{(u)}$, LAS, cyanide, copper, fluoride, and zinc contributed to the mean toxicity indices of the rivers. However, none of the mean toxicities approached 1.0 BGTU,or a level that would have been lethal to 50 percent of the bluegills in the rivers in 96 hours of exposure. The highest mean toxicity index of 0.168 BGTU was calculated at the Havana location and was primarily due to a high cyanide component toxicity. Mean $ammonia_{(u)}$ component toxicities were generally higher at the upstream locations, but other mean component toxicities showed no apparent upstream-downstream trends.

The maximum component toxicities and toxicity indices for the same locations are presented in Table 5. The maximum toxicity indices ranged from 0.706 to 0.158 BGTU's, at the Rt. 66 Bridge on the Des Plaines River and at Beardstown, respectively. Cadmium, trivalent chromium, lead, and phenol contributed to the maximum toxicity indices at some of the locations, in addition to the toxicants already mentioned. Maximum $ammonia_{(u)}$ component toxicities of cyanide, copper and zinc, however, were calculated at locations in the middle or lower river.

Maximum and mean toxicity indices calculated at the different locations were plotted against river miles (Figure 6).

Table 4. Mean Component Toxicities and Toxicity Indices in BGTU's During 1972 and 1973* at 17 Locations Along the Illinois and Des Plaines** Rivers. Location Descriptions are Followed by Their River Miles with Kilometers in Parentheses. Continued on Page 21a.

River Toxicant	96-hr LC50 (mg/liter)	LOCATION: Hardin R.M. 21.7 (34.9)	Florence R.M. 56.0 (90.1)	Meredosia R.M. 71.2 (114.4)	Beardstown R.M. 87.9 (141.4)	Havana R.M. 119.7 (192.6)	Pekin R.M. 152.9 (246.0)	Creve Coeur R.M. 157.6 (253.6)	Peoria R.M. 165.8 (266.8)	Lacon R.M. 189.2 (304.4)
$Ammonia_{(u)}$	1.65	0.018	0.006	0.006	0.006	0.012	0.024	0.018	0.030	0.018
Arsenic	17.5	--	--	--	--	--	--	--	--	--
Cadmium	45.1	--	--	--	--	--	--	--	--	--
Chromium-hexavalent	133.0	--	--	--	--	--	--	--	--	--
Chromium-trivalent	71.9	--	--	--	--	--	--	--	--	--
Copper	10.2	0.004	0.007	0.008	0.008	0.002	0.018	0.012	0.011	0.007
Cyanide	0.15	0.006	--	0.033	--	0.120	0.033	0.013	--	--
Fluoride	44.5	0.007	0.009	0.011	0.007	0.011	0.013	0.015	0.011	0.013
Lead	442	--	--	--	--	--	--	--	--	--
LAS	6.5	0.020	0.023	0.022	0.021	0.023	0.024	0.023	0.024	0.022
Mercury	9.54	--	--	--	--	--	--	--	--	--
Phenol	28.5	--	--	--	--	--	--	--	--	--
Zinc	40.9	--	--	--	--	--	0.002	0.005	0.002	--
Mean Toxicity Index		0.055	0.045	0.080	0.042	0.168	0.114	0.086	0.078	0.060

*data obtained from the Illinois Environmental Protection Agency (1972; 1973)
**River mile 277.8 (447.0) is in the Des Plaines River.
--less than 0.0005 BGTU's

Table 4. (continued)

River Toxicant	96-hr LC50 (mg/liter)	LOCATION Hennepin R.M. 207.5 (333.9)	Spring Valley R.M. 218.4 (351.4)	Utica R.M. 229.6 (369.4)	Ottawa R.M. 239.7 (385.7)	Seneca R.M. 252.7 (406.6)	Morris R.M. 263.5 (424.0)	Dresden R.M. 271.5 (436.8)	Rt. 66 Bridge R.M. 277.8 (447.0)
Ammonia$_{(u)}$	1.65	0.018	0.024	0.036	0.024	0.036	0.042	0.024	0.066
Arsenic	17.5	--	--	--	--	--	--	--	--
Cadmium	45.1	--	--	--	--	--	--	--	--
Chromium-hexavalent	133.0	--	--	--	--	--	--	--	--
Chromium-trivalent	71.9	--	--	--	--	--	--	--	--
Copper	10.2	0.003	0.004	0.002	0.004	0.004	0.001	0.007	0.004
Cyanide	0.15	0.020	0.006	--	--	0.013	--	--	--
Fluoride	44.5	0.009	0.009	0.009	0.011	0.009	0.011	0.011	0.013
Lead	442	--	--	--	--	--	--	--	--
LAS	6.5	0.015	0.016	0.015	0.014	0.016	0.015	0.013	0.022
Mercury	9.54	--	--	--	--	--	--	--	--
Phenol	28.5	--	--	--	--	--	--	--	--
Zinc	40.9	0.002	--	--	--	0.002	--	--	0.002
Mean Toxicity Index		0.067	0.059	0.062	0.053	0.080	0.069	0.055	0.107

*data obtained from the Illinois Environmental Protection Agency (1972; 1973)
**River mile 277.8 (447.0) is in the Des Plaines River
--less than 0.0005 BGTU's

Table 5. Maximum Component Toxicities and Toxicity Indices in BGTU's During 1972 and 1973* at 17 Locations Along the Illinois and Des Plaines** Rivers. Location Descriptions are Followed by Their River Miles with Kilometers in Parentheses. Continued on Page 22a.

		LOCATION								
River Toxicant	96-hr LC50 (mg/liter)	Hardin R.M. 21.7 (34.9)	Florence R.M. 56.0 (90.1)	Meredosia R.M. 71.2 (114.4)	Beardstown R.M. 87.9 (141.4)	Havana R.M. 119.7 (192.6)	Pekin R.M. 152.9 (246.0)	Creve Coeur R.M. 157.6 (253.6)	Peoria R.M. 165.8 (266.8)	Lacon R.M. 189.2 (304.4)
Ammonia(u)	1.65	0.309	0.145	0.085	0.061	0.067	0.352	0.261	0.442	0.103
Arsenic	17.5	--	--	--	--	--	--	--	--	--
Cadmium	45.1	--	--	--	--	--	--	--	--	--
Chromium-hexavalent	133.0	--	--	--	--	--	--	--	--	--
Chromium-trivalent	71.9	0.002	--	--	--	--	--	--	--	--
Copper	10.2	0.015	0.013	0.018	0.048	0.010	0.049	0.034	0.045	0.022
Cyanide	0.15	0.067	--	0.133	--	0.467	0.133	0.133	--	--
Fluoride	44.5	0.013	0.013	0.013	0.013	0.020	0.020	0.022	0.016	0.022
Lead	442.0	--	--	--	0.001	--	0.001	0.001	0.001	--
LAS	6.5	0.037	0.040	0.042	0.032	0.034	0.034	0.032	0.032	0.034
Mercury	9.54	--	--	--	--	--	--	--	--	--
Phenol	28.5	0.001	--	--	0.001	0.001	--	--	0.001	--
Zinc	40.9	0.002	0.002	0.002	0.002	0.002	0.005	0.012	0.007	0.002
Maximum Toxicity Index		0.446	0.213	0.293	0.158	0.601	0.594	0.495	0.544	0.183

*data obtained from the Illinois Environmental Protection Agency (1972; 1973)
**River mile 277.8 (447.0) is in the Des Plaines River.
--less than 0.0005 BGTU's

Table 5. (continued)

River Toxicant	96-hr LC50 (mg/liter)	LOCATION							
		Hennepin R.M. 207.5 (333.9)	Spring Valley R.M. 218.4 (351.4)	Utica R.M. 229.6 (369.4)	Ottawa R.M. 239.7 (385.7)	Seneca R.M. 252.7 (406.6)	Morris R.M. 263.5 (424.0)	Dresden R.M. 271.5 (436.8)	Rt. 66 Bridge R.M. 277.8 (447.0)
Ammonia$_{(u)}$	1.65	0.345	0.212	0.242	0.176	0.212	0.436	0.357	0.630
Arsenic	17.5	--	--	--	--	--	--	--	--
Cadmium	45.1	--	--	--	--	--	--	0.002	--
Chromium-hexavalent	133.0	--	--	--	--	--	--	--	--
Chromium-trivalent	71.9	--	--	--	--	--	--	--	--
Copper	10.2	0.010	0.020	0.006	0.012	0.008	0.005	0.024	0.009
Cyanide	0.15	0.067	0.067	--	--	0.067	--	--	--
Fluoride	44.5	0.011	0.016	0.013	0.018	0.013	0.020	0.018	0.027
Lead	442.0	--	--	--	--	--	--	--	--
LAS	6.5	0.023	0.031	0.031	0.023	0.031	0.025	0.032	0.035
Mercury	9.54	--	--	--	--	--	--	--	--
Phenol	28.5	--	--	--	--	--	--	0.004	--
Zinc	40.9	0.002	0.005	0.002	0.002	0.002	0.002	0.002	0.005
Maximum Toxicity Index		0.458	0.351	0.294	0.231	0.333	0.488	0.439	0.706

*data obtained from the Illinois Environmental Protection Agency (1972; 1973)
**River mile 277.8 (447.0) is in the Des Plaines River.
--less than 0.0005 BGTU's

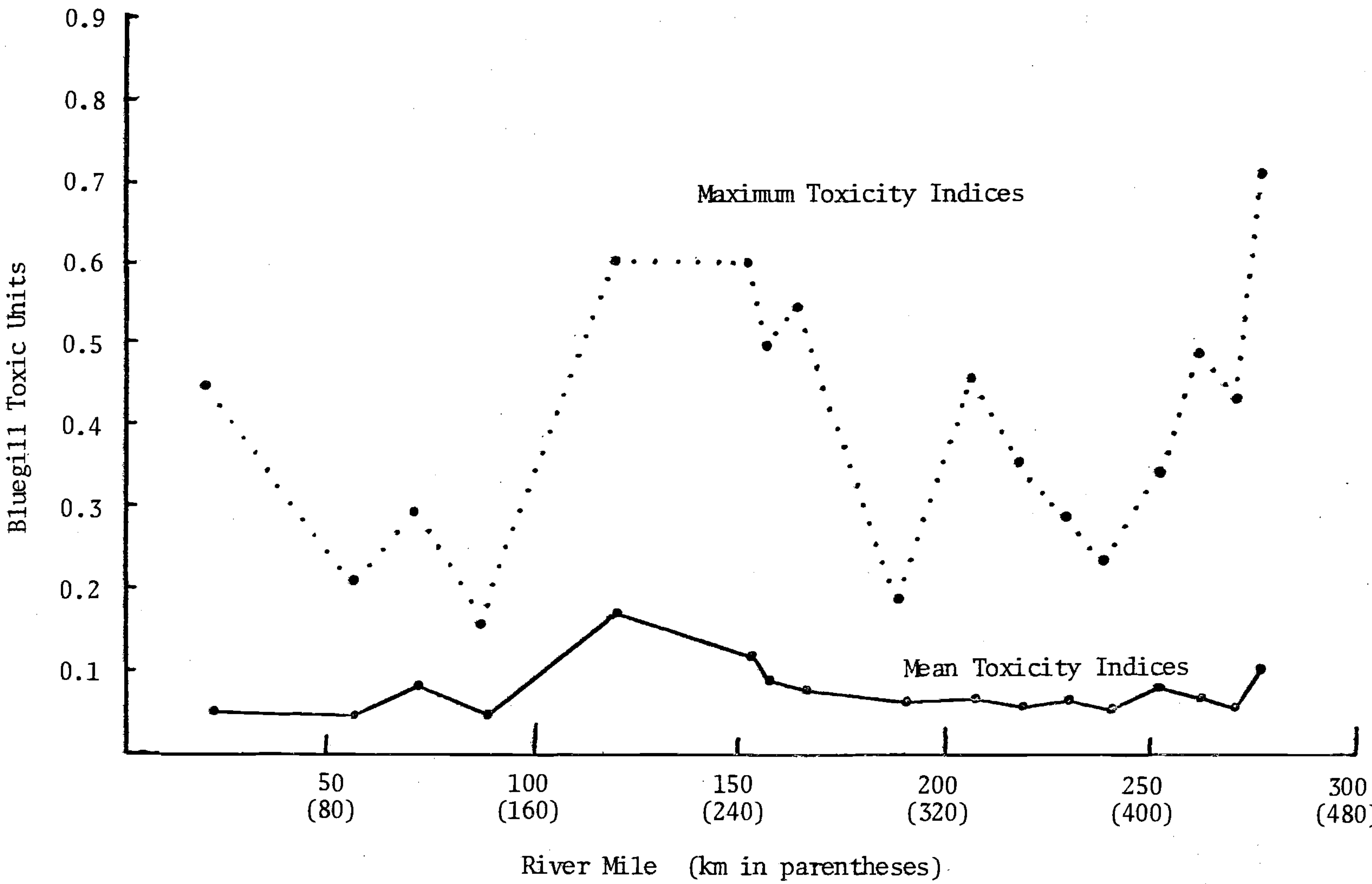

Figure 6. Illinois and Des Plaines rivers mean and maximum toxicity indices in BGTU's.

Bioassays

The test conditions and mean $ammonia_{(u)}$ concentrations observed during the $ammonia_{(u)}$ bioassay are summarized in Table 6. The test conditions and mean LAS concentrations observed in the test tanks during the LAS bioassay are summarized in Table 7. The dissolved oxygen concentrations during the $ammonia_{(u)}$ bioassay decreased noticeably, but the low oxygen levels did not result in any mortalities in the control tank and were probably not low enough to cause mortalities in the test tanks containing $ammonia_{(u)}$. Ammonia stress apparently caused the fish to consume more oxygen, reducing the oxygen levels. Once the fish began to die, and were removed, oxygen levels went up.

The toxicity curves of $ammonia_{(u)}$ and LAS to bluegills are presented in Figures 7 and 8. The lethal effects of both toxicants had ended before the end of the tests. The 96-hr LC50 values determined for $ammonia_{(u)}$ and LAS were 1.65 and 6.5 mg/liter, respectively. These values compare favorably with those found in the literature. For instance, a 96-hr LC50 value of ammonia nitrogen of 23.7 mg/liter to bluegills was reported in hard water at 30 C (Anonymous, 1960). Assuming a pH of 8.0, this value of ammonia nitrogen would correspond approximately to an $ammonia_{(u)}$ value of 1.5 mg/liter. In addition, Hokanson and Smith (1971) reported 96-hr LC50 values of LAS to bluegills of 2.85 to 4.25 mg/liter in waters of varying hardness.

River Monitoring

The river monitoring phase of the project was planned to compare daily zinc, copper, and lead concentrations in the Illinois River at flood and pool stages. Between March 18, and June 11, 1974, however,

Table 6. Test Conditions During the Ammonia$_{(u)}$ Bioassay.

test tank	temperature range (C)	pH range	dissolved oxygen range (mg/liter)	total alkalinity range (mg/liter as $CaCO_3$)	mean ammonia$_{(u)}$* concentration (mg/liter)
1	23.0-25.0	7.6-8.1	5.60-7.88	212-224	2.16
2	23.1-25.5	7.5-8.1	3.67-7.17	216-222	1.43
3	23.1-24.9	7.6-8.1	4.30-7.11	216-222	0.86
4	23.0-25.0	7.7-8.2	3.82-7.04	208-224	0.55
5	23.0-25.1	7.8-8.0	4.40-6.40	216-232	0.27
6	23.0-25.0	7.8-8.1	4.41-6.85	216-228	0.00

*calculated concentrations from Skarheim (1973)

Table 7. Test Conditions During the LAS Bioassay.

test tank	temperature range (C)	pH range	dissolved oxygen range (mg/liter)	total alkalinity range (mg/liter as $CaCO_3$)	mean LAS concentration* (mg/liter)
1	19.0-22.0	8.0-8.1	7.9-8.1	180-184	35.2
2	18.9-22.0	8.0-8.2	7.7-8.6	180-181	18.7
3	18.9-22.0	8.0-8.2	7.7-8.5	180-183	10.6
4	18.9-22.0	8.0-8.1	6.2-8.7	180-185	7.9
5	19.0-22.0	8.0-8.1	6.3-8.7	180-184	4.0
6	19.0-21.8	8.1	7.1-8.7	184-185	0.0

*determined using the methylene blue active substances test (American Public Health Association, 1971)

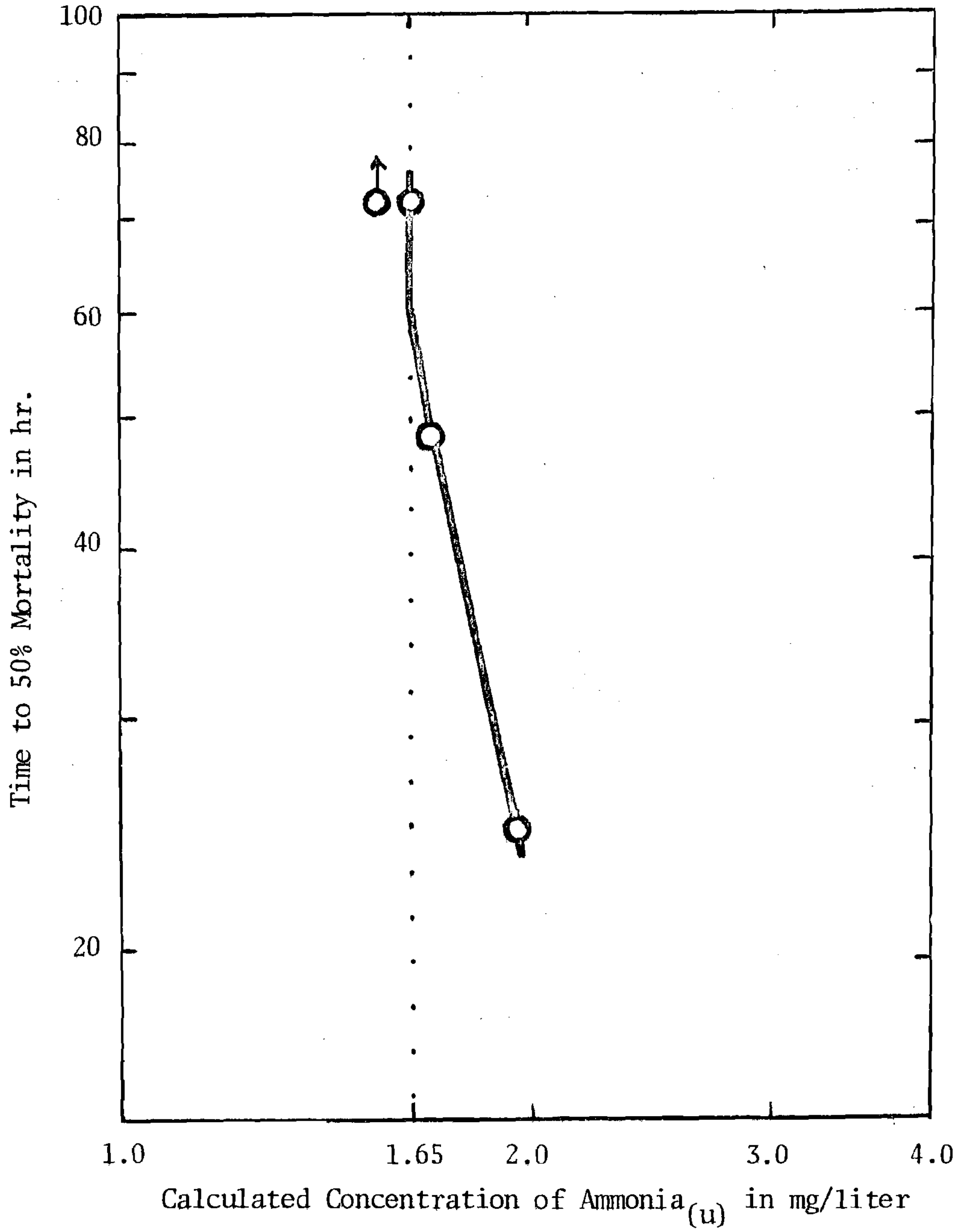

Figure 7. The acute toxicity curve of ammonia$_{(u)}$ to bluegills.

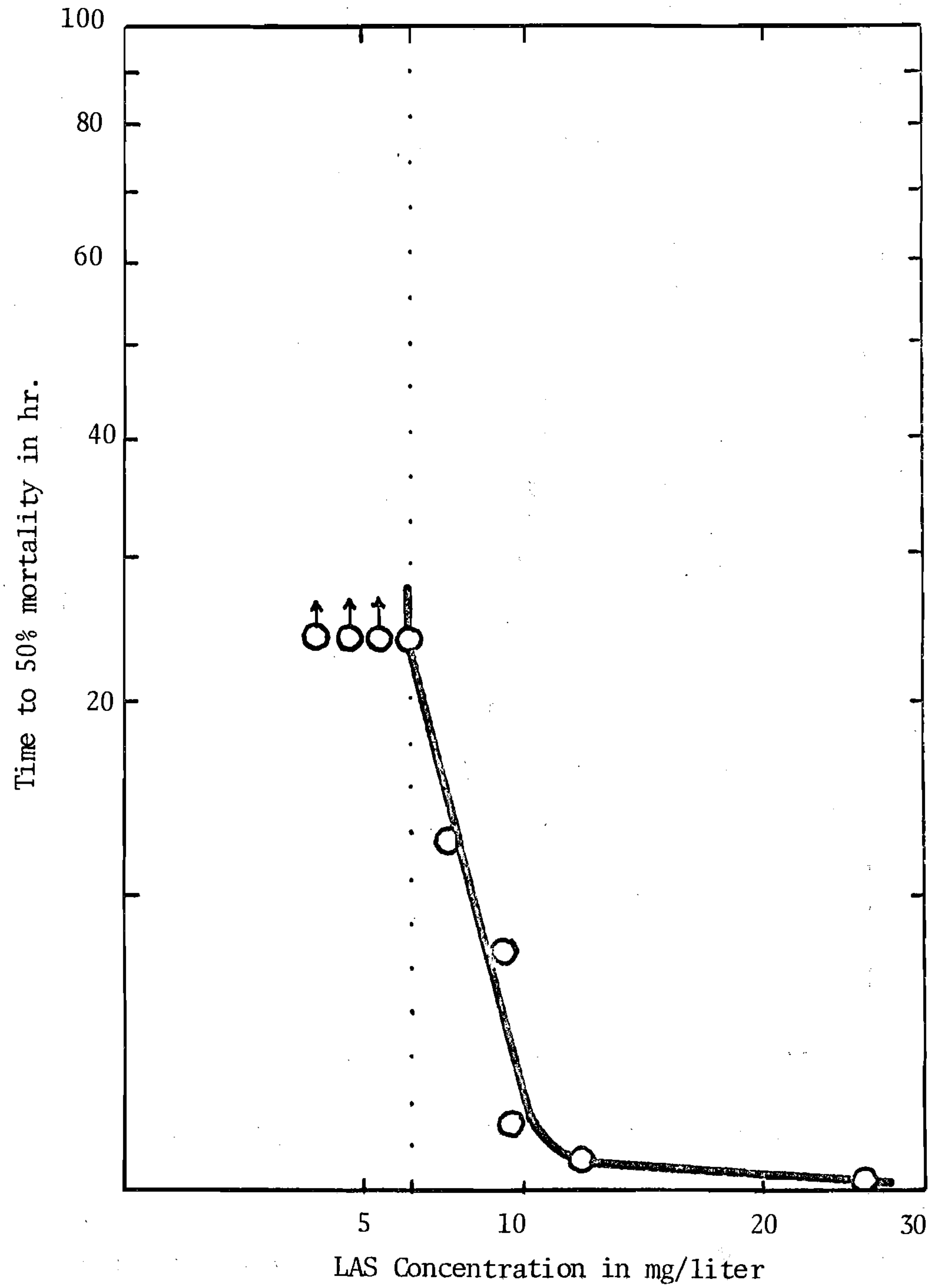

Figure 8. The acute toxicity curve of LAS to bluegills.

the water levels of the river at Havana remained high, varying between approximately 1 ft (0.3 m) below to 8 ft (2.4 m) above flood stage. During this period, heavy metal concentrations in the river ranged as follows: zinc, 0.01-0.09 mg/liter; copper, less than 0.005-0.050 mg/liter; lead, less than 0.01-0.03 mg/liter. Within these ranges, no correlation was found between the concentrations of these toxicants and Illinois River water levels. Similarly, no correlation was found between the concentrations of these toxicants and river turbidities, as measured by Secchi disk readings which ranged from 5 to 30 cm.

Field Tests

The ranges of the river parameters and the toxicant concentrations determined during the Dresden field test are summarized in Table 8. The pH values and dissolved oxygen concentrations of the Kankakee River differed from that of the Des Plaines River. The low dissolved oxygen concentrations of the Des Plaines River were raised by artificially aerating the river water in the Des Plaines River aerated pool, but malfunctions of the aerators caused the dissolved oxygen levels to drop several times during the test. $Ammonia_{(u)}$ concentrations were higher in the Des Plaines River than in the Kankakee River. Aldrin, the only pesticide found in the rivers, however, was present in higher concentrations in the Kankakee River.

The mean toxicity indices established for the Kankakee and Des Plaines rivers during the Dresden field test are presented in Table 9. Because of the high toxicity of aldrin, it contributed the highest mean component toxicity calculated in the Kankakee River. $Ammonia_{(u)}$ contributed most to the mean toxicity indices of the Des Plaines River.

Table 8. River Parameter and Toxicant Concentration Ranges During the Dresden Field Test.

	Des Plaines River Cage	Des Plaines River Aerated Pool	Kankakee River Cage
River Parameter			
Temperature (C)	28.8-32.8	22.1-30.0	26.0-30.0
Dissolved oxygen (mg/liter)	3.58-7.33	4.14-7.86	7.38-10.05
pH	7.4-7.7	7.5-8.2	8.4-8.6
Total alkalinity (mg/liter as $CaCO_3$)	188-206	182-198	206-236
Specific conductance (micromhos/cm)	760-875	660-875	550-630
Limit of visibility	19-45	---	24-32
Toxicant (mg/liter)			
$Ammonia_{(u)}$	0.045-0.132	0.029-0.105	0.005-0.018
Aldrin	0.00000	0.00000-0.00006	0.00034-0.00300
Copper	0.015-0.019	0.016-0.024	0.006-0.011
Lead	0.074	0.074-0.082	0.066-0.082
Zinc	0.051-0.067	0.061-0.092	0.022-0.030

Table 9. Mean Component Toxicities and Toxicity Indices in BGTU's, and Observed Bluegill Mortality During the Dresden Field Test.

River Toxicant and its 96-hr LC50	Des Plaines River Cage	Des Plaines River Aerated Pool	Kankakee River Cage
$Ammonia_{(u)}$ 1.65 mg/liter	0.053	0.049	0.007
Aldrin 0.013 mg/liter	--	0.002	0.129
Copper 10.2 mg/liter	0.002	0.002	0.002
Lead 442 mg/liter	--	--	--
Zinc	0.001	0.002	--
Toxicity Index	0.056	0.055	0.138
Mortality observed after 96 hr	0%	0%	0%

--less than 0.0005 BGTU's

The mean toxicity indices of both rivers, however, were below those that would have caused 50 percent of the bluegills exposed to them to die over a 96-hr period, and no bluegill mortalities were observed during the Dresden field test (Table 9).

The ranges of the river parameters and the toxicant concentrations determined during the Beardstown field test are summarized in Table 10. The water quality of the Sangamon River differed from that of the Illinois River, particularly in terms of pH values and dissolved oxygen concentrations, paralleling the situation at the Dresden field test. Two important differences were observed between the Dresden and Beardstown field tests. The velocity of the Illinois River at the Beardstown field test ranged from 1.2 to 1.8 ft/sec (0.4-0.6 m/sec), which was greater than the observed velocities in either the Des Plaines, Kankakee, or Sangamon rivers. The current was strong enough to tilt the Illinois River cage at a 45-degree angle, a condition also not observed in other rivers. The second difference observed between the Dresden and Beardstown field tests was increased turbidity, reflected in the lower Secchi disk readings in the Illinois and Sangamon rivers than in the Des Plaines and Kankakee rivers. At the Beardstown field test, aldrin and zinc concentrations were higher in the Illinois River than in the Sangamon River, while lead, copper, and $ammonia_{(u)}$ concentrations were similar in both rivers.

The mean component toxicities and toxicity indices developed for the Illinois and Sangamon rivers during the Beardstown field test are presented in Table 11. The mean toxicity indices developed for both the Illinois and the Sangamon rivers were below those developed for the Des Plaines and Kankakee rivers; however, bluegill mortalities were observed

Table 10. River Parameter and Toxicant Concentration Ranges During the Beardstown Field Test.

	Illinois River Cage	Illinois River Aerated Pool	Sangamon River Cage
River Parameter			
Temperature	26.0-28.9	22.1-26.1	23.3-29.8
Dissolved oxygen (mg/liter)	4.45-6.94	3.13-7.02	6.60-10.10
pH	7.9-8.1	8.0-8.2	8.2-8.6
Total alkalinity (mg/liter as $CaCO_3$)	224-264	228-266	240-272
Specific Conductance (micromhos/cm)	700	700	650
Limit of visibility (cm)	8-13	---	9-17
Toxicant (mg/liter)			
$Ammonia_{(u)}$	0.001-0.007	0.002-0.020	0.003-0.034
Aldrin	0.00001-0.00020	0.00006-0.00010	0.00001
Copper	0.014-0.017	0.012-0.017	0.012-0.016
Lead	0.075-0.094	0.075-0.084	0.065-0.094
Zinc	0.039-0.830	0.080-0.620	0.028-0.060

Table 11. Mean Component Toxicities and Toxicity Indices in BGTU's, and Observed Bluegill Mortality During the Beardstown Field Test.

River Toxicant and its 96-hr LC50	Illinois River Cage	Illinois River Aerated Pool	Sangamon River Cage
Ammonia$_{(u)}$ 1.65 mg/liter	0.002	0.004	0.006
Aldrin 0.013 mg/liter	0.008	0.006	---
Copper 10.2 mg/liter	0.001	0.001	0.001
Lead 442 mg/liter	---	---	---
Zinc 40.9 mg/liter	0.005	0.007	0.001
Toxicity Index	0.016	0.018	0.008
Mortality observed after 96 hr	22%	0%	12%

---less than 0.0005 BGTU's

in both the Illinois River and Sangamon River cages (Table 11). The causes of these mortalities were probably stresses that were placed on the bluegills other than toxicant concentrations. The stress probably responsible for the mortalities observed in the Illinois River cage was the current of the Illinois River. The stress probably reponsible for the mortalities observed in the Sangamon River cage was the extra handling of the fish that took place when low water levels forced us to move this cage several times. These assumptions are supported by the fact that no bluegill mortalities were observed in the Illinois River aerated pool.

DISCUSSION

The preliminary mean toxicity indices compiled for the different locations along the Illinois and Des Plaines rivers, and the mean toxicity indices calculated during the field tests, indicated that the toxicants dealt with do not normally occur in the Illinois River in concentrations high enough to cause acute lethal effects to fish in the river. This was also indicated by the lack of bluegill mortality during the field tests. The maximum toxicity indices compiled for the Illinois and Des Plaines rivers, however, indicated that at particular times, $ammonia_{(u)}$ and cyanide were present in the rivers at levels as high as 0.630 and 0.467 BGTU, respectively. These toxicant levels probably stress fish in the rivers severely, but mortalities produced by such toxicant levels would also be dependent on the periods of exposure. Other toxicants that commonly contributed to the preliminary toxicity indices were LAS, copper, fluoride, and zinc.

Higher $ammonia_{(u)}$ component toxicities in the Des Plaines River and at the upper locations in the Illinois River were probably related to their proximity to the Chicago Sanitary and Ship Canal, which carries municipal wastes from the Metropolitan Sanitary District of Greater Chicago to the Des Plaines River. The tendency of the component toxicities of cyanide, copper, and zinc to be higher at locations in the middle and lower parts of the Illinois River may have been related to industrial effluents originating in the highly industrialized Peoria-Pekin area. The component toxicities of LAS and fluoride showed little variation along the river. However, several assumptions had to be made in order to include these toxicants in the toxicity indices, both in calculating fluoride toxicity to bluegills, and in calculating LAS concentrations from the reported MBAS concentrations. Therefore, more data is necessary concerning these toxicants to accurately determine their possible lethal effects to fish in the Illinois River. Aldrin, the only pesticide monitored during the field tests, contributed a mean component toxicity of 0.129 BGTU in the Kankakee River. Its presence may be related to the use of land adjacent to the Kankakee River for agricultural purposes, and indicates the potential hazard of agricultural run-off to fish in the Illinois River since pesticides can accumulate, via the food chain, to much higher levels in organisms than occur in the water.

Combinations of some toxicants in low concentrations have been shown to have less than additive lethal effects on fish (Sprague, 1970). Low dissolved oxygen concentrations, however, are known to increase the toxicity of most toxicants to fish, and therefore, the low dissolved oxygen concentrations that are common in the Illinois and Des Plaines rivers may increase the lethal effects of the toxicants present in the river. The effects of dilution and the adsorption of toxicants onto silt particles in the Illinois River during this study were unknown. The river monitoring phase of this project investigated these effects on a minor scale, but it showed no correlations between water level variations, or turbidity, and zinc, copper, and lead concentrations in the Illinois River. To illustrate the possible effects of dilution in the Illinois River, weekly water level averages at Havana during 1971-1974 are presented in Figure 9. The water levels of the river during 1974 indicate that the river was above its low-flow stage during the river monitoring and field test phases of this project. If the lethal effects of toxicants to fish are greatest during low-flow periods, the toxicity indices de-

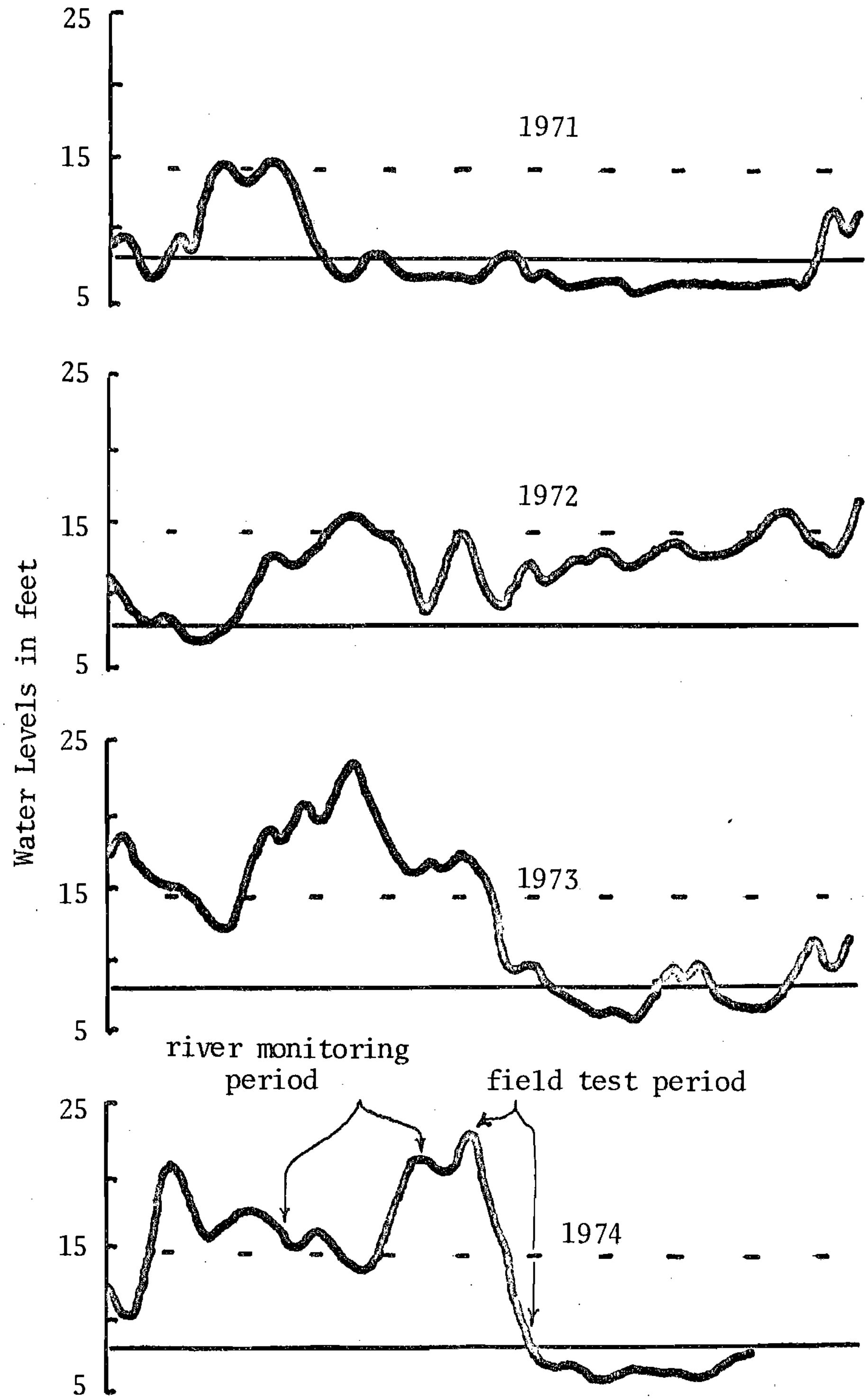

Figure 9. Illinois River weekly water level averages at Havana. Solid lines represent pool stages, dotted lines represent flood stages (Department of Commerce, 1971; 1972; 1973; 1974).

veloped during the field tests may have underestimated the toxicity of the river at the low-flow stage reached later in 1974. Likewise, the preliminary toxicity indices developed for the Illinois and Des Plaines rivers from 1972-1973 data may have underestimated the toxicity of the river reached during the low-flow period of 1971.

Finally, it should be noted that the toxicity indices presented in this study were not calculated to indicate "safe" levels of toxicants in the Illinois River. It has become common practice to assume that maintaining toxicant concentrations below one-tenth of their 96-hr (or 48-hr) LC50 values for a species, safeguards that species (Illinois Pollution Control Board, 1973). However, this assumption has several limitations, particularly when evaluating lethal effects of slow-acting toxicants or of those subject to biological magnification in food chains. Therefore, although some of the toxicants dealt with in this study, such as mercury and chromium, did not appear to contribute to the acute toxicity of the river, they may have long-term effects on the fish populations in the Illinois River.

SUMMARY

1) The toxicity indices developed during this project indicated that concentrations of the toxicants dealt with do not normally occur at levels high enough to cause fish in the Illinois River to die. The lack of bluegill mortalities observed in the field supported this conclusion.

2) On particular occasions, the component toxicities of ammonia$_{(u)}$ and cyanide in the Illinois River were high enough to stress fish in the river severely, however, the lengths of time the fish were exposed to these toxicants, and therefore their possible lethal effects, were unknown.

3) Ammonia$_{(u)}$ contributed more to the toxicity of the river at its upstream locations, probably due to the proximity of these locations to the municipal effluents of the Metropolitan Sanitary District of Greater Chicago.

4) Cyanide, copper, and zinc contributed more to the toxicity of the Illinois River at its mid- and downstream locations, possibly, due to the added loads of industrial wastes the river receives in the Peoria-Pekin area.

5) The effects of dilution and the adsorbtion of toxicants onto silt particles in the river during this study were unknown, but may have resulted in some underestimation of the toxicity of the river.

6) The 96-hr LC50 values determined for ammonia$_{(u)}$ and LAS to bluegills during this study agreed favorably with those reported for these toxicants in the literature. This indicates that toxicity data for other toxicants, generated in experiments in which water similar in quality to Illinois water is used, can be directly applied to the Illinois River.

LITERATURE CITED

American Public Health Association. 1971. Standard methods for the examination of water and wastewater. 13th ed. Amer. Public Health Association, Washington, D.C. 874 p.

Anonymous. 1960. The sensitivity of aquatic plant life to certain chemicals commonly found in industrial wastes. Academy of Natural Sciences. Philadelphia.

Brown, V. M. 1968. The calculation of the acute toxicity of mixtures of poisons to rainbow trout. Water Research 2:723-733.

Doudoroff, P., G. Leduc, and C. R. Schneider. 1966. Acute toxicity to fish of solutions containing complex metal cyanides, in relation to concentrations of molecular hydrocyanic acid. Transactions of the American Fisheries Society 95:6-22.

Guilderhus, P. A. 1966. Some effects of sublethal concentrations of sodium arsenite on bluegills and the aquatic environment. Transactions of the American Fisheries Society 95:289-296.

Hokanson, K. F. and L. L. Smith, Jr. 1971. Some factors influencing toxicity of linear alkylate sulfonate (LAS) to the bluegill. Transactions of the American Fisheries Society 100:1-12.

Illinois Environmental Protection Agency. 1972. Water quality network 1972 summary of data. Vol. 2,3.

Illinois Environmental Protection Agency. 1973. Water quality network 1973 summary of data. Vol. 2,3.

Illinois Pollution Control Board. 1973. Water pollution regulations of Illinois. Illinois Environmental Protection Agency. 42 p.

Illinois State Water Survey. 1972. Preliminary report: a water quality investigation of the Upper Illinois Waterway. 45 p.

Innes, W. T. 1966. Exotic aquarium fishes. Metaframe Corporation, New Jersey. 593 p.

Lubinski, K. S. In preparation. The development of toxicity indices for assessing the quality of the Illinois River. Unpublished Master's Thesis, Western Illinois University, Macomb, Illinois.

Mathis, B. J., and T. F. Cummings. 1971. Distribution of selected metals in bottom sediments, water, clams, tubificid annealids, and fishes of the middle Illinois River. University of Illinois Water Resources Center, Research Report No. 41.

Mills, H. B., W. C. Starrett, and F. C. Bellrose. 1966. Man's effect on the fish and wildlife of the Illinois River. Illinois Natural History Survey Biological Notes, No. 57.

Mount, D. I. and W. A. Brungs. 1967. A simplified dosing apparatus for fish toxicity studies. Water Research 1:21-29.

Neuhold, J. M. and W. F. Sigler. 1960. Effects of sodium fluoride on carp and rainbow trout. Transactions of the American Fisheries Society 89:358.

Pickering, Q. H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warm water fishes. Air and Water Pollution 10:453-463.

Skarheim, H. P. 1973. Table of the fraction of ammonia in undissociated form for pH 6-9. University of California. Sanitary Engineering Research Laboratory Report 73-5.

Sprague, J. B. 1970. Measurement of pollutant toxicity to fish. II. Utilizing and applying bioassay results. Water Research 4:3-32.

Sprague, J. B. 1973. The ABC's of pollutant bioassay using fish, p. 6-30. In J. Cairns, Jr. and K. L. Dickson (ed.), Biological methods for the assessment of water quality. American Society for Testing and Materials, Philadelphia.

Sullivan, W. T. and R. D. Swisher. 1969. MBAS and LAS surfactants in the Illinois River, 1968. Environmental Science and Technology 3:481-483.

Tarzwell, C. M. 1958. The toxicity of some organic insecticides to fishes. Proceedings of the Twelfth Annual Conference of the Southeastern Association of Game and Fish Commissioners. No. 116,233-239.

U.S. Army Engineer District. 1970. Charts of the Illinois Waterway. U.S. Army Engineer District, Chicago, Illinois.

U.S. Department of Commerce. 1971-1974. Missouri-Mississippi river summary and forecasts. National Oceanic and Atmospheric Administration, Kansas City, Missouri.

Willford, W. A. 1966. Toxicity of 22 therapeutic compounds to six fishes. Investigations in fish control No. 20. In U.S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife Resources, Publication 35.

RELATION OF THIS RESEARCH TO WATER RESOURCES PROBLEMS

Physical-chemical information on particular rivers and bioassay information on the toxicity of chemicals to aquatic organisms is accumulating more and more rapidly, and both types of information are useful in assessing the quality of water for the protection of aquatic species. This research demonstrated a method for relating these types of information.

Many water quality standards have been based on tests that were designed to investigate the effects of single factors in aquatic environments, whereas organisms in a river are exposed to many factors simultaneously. The method used in this research can take into consideration the joint action of all of the toxicants that can be identified in a river, although the assumption that the toxicants are additive in their effects needs further testing.

Two specific recommendations for improving the usefulness of chemical information for predicting biological effects can be made. First, because $ammonia_{(u)}$ is toxic to aquatic life rather than ammonia nitrogen, efforts should be made to monitor and report this value regularly. Second, because MBAS concentrations can include interferring factors besides LAS, more specific tests for LAS should be included in monitoring programs. The fact that both LAS and $ammonia_{(u)}$ contributed commonly to the toxicity of the Illinois River, strengthens these recommendations.

PUBLICATIONS RESULTING FROM THIS RESEARCH

Anonymous. 1974. Toxicity of the Illinois River. Illinois Natural History Survey Reports. No. 134.

Lubinski, K. S. and R. E. Sparks. 1974. A preliminary toxicity index for the Illinois River. (Abstract). Presented before the aquatic science section of the 1974 meeting of the Illinois State Academy of Science.

Lubinski, K. S. and R. E. Sparks. 1974. The use of toxicity indices to assess the quality of the Illinois River. (Abstract). Submitted for presentation at the 36th annual meeting of the Association of Southeastern Biologists, 1974.

Lubinski, K. S. and R. E. Sparks. In preparation. The development of toxicity indices to assess the quality of the Illinois River.

THESES RESULTING FROM THIS RESEARCH

Lubinski, K. S. In preparation. The development of toxicity indices to assess the quality of the Illinois River. Unpublished Master's Thesis, Western Illinois University, Macomb, Illinois.

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