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IN–PLACE POLLUTANTS IN TRAIL CREEK AND MICHIGAN CITY HARBOR, INDIANA

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The work reported here represents the efforts of a large number of individuals. Dr. Thomas McComish and Mr. Greg Asbury of Ball State University were essential to the project in ways that could not be foreseen at the outset. Their tireless cooperation in the field, and their knowledge of the study area, were of great benefit. Especially valuable was their arranging the use of the facilities of the Indiana Department of Natural Resources as a base of operations. Mr. Robert Koch of IDNR, in addition to allowing our use of the facilities, was most helpful in sharing his knowledge of the aquatic habitats of the Michigan City area.

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Chemical analysis of sediments, waters, and elutriates were performed by several laboratories in the Boston area. Arsenic and PCB analyses were performed by Herbert V. Shuster, Inc. Ammonia, TKN, oil and grease, and heavy metals analyses were performed by Interex Corp. All other analyses, as well as elutriates and metal digests, were done at JBF, primarily by Margolia Gilson.

The difficult task of conducting sediment bioassays was performed by Dr. John Gannon and Mr. Daniel Mazur of the University of Michigan Biological Station in Pellston. This effort produced useful data with techniques that required some development because of the lack of standard methods for sediment bioassays. Sediment bioassays remain a research topic, and these workers encountered and overcame several obstacles to produce useful results.

Within JBF, much credit must go to Stephen Greene, without whose crafty organization the field work on this project could not have been completed in a successful and timely way. Jaret Johnson was Project Manager.

I. INTRODUCTION

Increasing attention in recent years has been given to the effects that in-place pollutants in bottom sediments may exert on benthic communities and on aquatic systems in general. Systems of in-place pollutants result from the fact that many pollutants such as heavy metals and pesticides are sparingly soluble in water and are often sorbed onto suspended particulates and hydrous iron oxides that sink to the bottom. One critical question that must be addressed is whether the amelioration of pollutant discharges may be counteracted by in-place pollutants remaining from previous years. In other words, even "zero discharge" may not yield healthy aquatic ecosystems unless in-place pollutants are removed or inactivated.

Recognizing these important issues, Congress enacted Title I, Section 115, of the Federal Water Pollution Control Act of 1972, PL 92-500, requiring the following action of the Environmental Protection Agency:

IN-PLACE TOXIC POLLUTANTS

> Sec. 115. The Administrator is directed to identify the location of in-place pollutants with emphasis on toxic pollutants in harbors and navigable waterways and is authorized, acting through the Secretary of the Army, to make contracts for the removal and appropriate disposal of such materials from critical port and harbor areas. There is authorized to be appropriated $15,000,000 to carry out the provisions of this section, which sum shall be available until expended.

To identify the locations of in-place pollutants, the EPA let a contract to JBF Scientific Corporation. The scope of that contract included collection of existing data on in-place pollutants and the setting of priorities defining critical waterways. The final report (1) did set those priorities while pointing out that the locations on the priority list were tentative because of the inadequacy of available data. To augment the data base, the EPA has let two site-specific studies that included field and laboratory investigations. The first study (2), begun in the Spring of 1976, investigated Baltimore Harbor, a large marine embayment with a good pre-existing data base, intensive industrial activity, and very active port traffic. This second site study has assessed Michigan City Harbor and Trail Creek, Indiana. Michigan City offers an excellent contrast to Baltimore Harbor with respect to Section 115 because the water is fresh, there were few data on in-place pollutants, industrial activity and its wastewater discharges are less extensive, and harbor traffic consists almost exclusively of small recreational boats.

A. PURPOSE AND SCOPE

The purpose of this study was to define and assess the in-place pollutants in Trail Creek/Michigan City Harbor and, based on that definition and assessment, to evaluate potential corrective actions.

Michigan City Harbor and Trail Creek are likely to undergo maintenance dredging in the near future for navigation enhancement. The navigation channel to be dredged includes most of the study area, and a confined upland area is planned as a result of considerable study by the U.S. Army Corps of Engineers' Chicago District. These facts have influenced the scope of the investigation in the following ways:

1) Any recommendation from this study must take into account the future maintenance dredging of the navigation channel. Even if dredging did not prove to be the best option from the standpoint of Section 115, dredging is a virtual certainty given the shoaling of the waterway and its effect on recreational boating and the local economy.

2) Areas outside the navigation channel have been investigated, and have been considered for possible inclusion in the dredging to be done. For these areas, all other corrective actions (e.g. burial or chemical treatment) are active choices, as is the choice of leaving the polluted sediments in-place.

The following two sections consist of a summary, and conclusions and recommendations. The report then presents a description of the study area, the procedures and results of the field work, interpretation of the results, and assessment of corrective actions that might be taken.

II. SUMMARY

Michigan City Harbor and its upstream extension, Trail Creek, are important waters in many ways. They are stocked with, and provide migratory runs for, salmonid species forming a vital sport fishery in the Indiana waters of Lake Michigan. They are the base of a large recreational boating community, and of an active commercial fishery.

Trail Creek flows slowly through the urban area of Michigan City, and pollutants that have been discharged over the years have settled to the bottom of these quiescent waters. This study was undertaken to evaluate the effects of the resultant deposits of in-place pollutants, and to determine what if any corrective action should be taken.

Field sampling of waters, sediments, and macrobenthos was conducted. During the field work, waters and sediments were also collected for laboratory bioassays. Other laboratory work included physical and chemical analyses of the sediments, chemical analyses of site water, and detailed assessment of the macrobenthos. These efforts showed that the sediments of much of Trail Creek and Michigan City Harbor are toxic to several species of desirable aquatic organisms, and conducive to extreme dominance of a few species that are known to tolerate grossly polluted benthic environments. Although the overlying waters also show some signs of pollution, the fact that salmonid migrations are supported indicates that severely toxic discharges have been abated and are now evidenced primarily by the in-place pollutants that were deposited in past years.

It therefore appears that removal of these deposits would be a fruitful and worthwhile operation. Before such action under Section 115, however, the importance of a large landfill on the bank of Trail Creek as a potential source of future pollutants should be assessed. If that landfill can be proven unimportant, then hydraulic pipeline dredging followed by disposal in a confined disposal facility (or several small facilities) is recommended. The cost of such a program could exceed $4 million, but some fraction of this could probably be provided from funds that the Corps of Engineers will spend in any event to maintain depths for navigation in the study area.

III. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The waters of Trail Creek show signs of continuing degradation by heavy metals, oxygen demanding substances, and ammonia nitrogen. Nonetheless, the stream supports salmonid migrations.

2. The sediments in Trail Creek and Michigan City Harbor contain high levels of in-place pollutants from the entrance to the Yacht Basin upstream to the local wastewater treatment plant. The in-place pollutants in this reach do not form localized "hot spots", but are relatively uniformly distributed. The deposits of in-place pollutants consist of oily organic silt with high water content. Below the deposits is a hard, consolidated clay stratum. The pollutants of concern are organic (volatile) solids, oil and grease, and heavy metals. PCB is present, but not in unusually high concentrations.

3. The macrobenthos in Trail Creek and Michigan City Harbor typify a severely degraded benthic habitat. Little difference in benthic animal assemblages was observed among stations within the polluted reach. Stations near the harbor exhibited slightly more benthic species diversity than stations farther upstream. Increased diversity, however, was not related to lower concentrations of in-place pollutants.

4. Bioassays with four selected sediments overlain by clean water in aquaria showed a significant range of toxicity. Toxicities of sediment samples did correlate with the concentration of several pollutants, suggesting that the bioassays provided a finer distinction regarding the degree of sediment pollution than was provided by studies of macrobenthos.

5. Sources of in-place pollutants cannot be distinguished between a large landfill and a nearby wastewater treatment plant. An investigation of leachate and runoff from the landfill would be required to make this distinction. Direct industrial discharges to Trail Creek do not appear to be a problem.

6. The maintenance dredging for navigation purposes planned by the Corps of Engineers, Chicago District will affect approximately half of the polluted area and will remove about one quarter of the volume of in-place pollutants.

B. RECOMMENDATIONS

1. Although the data developed in this study provide some insight regarding the sources of in-place pollutants, the role of a large landfill could not be ascertained. Definition of the importance of this landfill would require long-term studies of leachate and runoff. This definition should be done before taking any action to remove in-place pollutants. If the landfill is an important source, abatement of that source should precede Section 115 action.

2. Action to remove in-place pollutants from Trail Creek and Michigan City Harbor is recommended, if the landfill is not an important source of pollutants or if it can be abated as a source. The only other likely past source of in-place pollutants, a wastewater treatment plant across Trail Creek from the landfill, has upgraded its processes in recent years. Therefore, Section 115 action should not be frustrated by accumulation of in-place pollutants in the future.

3. Dredging, followed by confined disposal of the dredgings, is the only proven reliable method for dealing with in-place pollutants. The total cost of disposal facility construction, of hydraulic pipeline dredging, and of operation and maintenance of disposal facilities, would probably exceed $4 million. In a joint program of navigational maintenance and Section 115 action, some of this cost (perhaps 10 to 30%) may be recovered from Department of the Army funds for navigation project maintenance dredging.

4. If such a dredging program is undertaken, the thickness of the in-place pollutant deposits between the Franklin St. Bridge and the wastewater treatment plant should be more clearly defined. Because vessels of sufficient size to take deep cores cannot navigate within this reach, a means should be devised to take cores from each of the four bridges crossing the waterway in the subject stream reach.

IV. MICHIGAN CITY HARBOR/TRAIL CREEK DESCRIPTION

Trail Creek, with Michigan City at its mouth, is one of the few inlets on the Indiana shore of Lake Michigan (Figure 1). Trail Creek in Michigan City is narrow, with a width of approximately 150 meters near its mouth and only four to five meters at the upstream end of the study area (Figure 2). Within the downstream reaches used for recreational boating, currents are generally slow (<0.3 m/sec), but the smaller channel upstream of the municipal wastewater treatment plant carries a consistently higher downstream current. Water levels in southern Lake Michigan exert a strong seiche effect on Trail Creek. The flow of the surface waters of Trail Creek often is reversed in the study area. Such flow reversals were observed during the field sampling phase of this study.

The most numerous shoreline developments on Trail Creek are facilities supporting recreational boating. Other prominent facilities include the Northern Indiana Public Service Company's (NIPSCO) Michigan City Generating Station, public water supply and wastewater treatment plants, two manufacturing facilities, a commercial fishing operation, and a U.S. Coast Guard station.

A. USES OF THE WATER RESOURCE

The recommendations of this study must be realistic in view of present and anticipated uses of the water resources of Trail Creek and Michigan City Harbor.

1. Navigation

Recreational boating and commercial fishing based in Michigan City are very important factors in the local economy. Much of the recreational boating activity is stimulated by salmon and trout fishing in the Indiana waters of Lake Michigan. Access is available through launching ramps as well as through the many local marinas. Approximately 640 slips and nine launching lanes are provided, as well as services such as marine fuel and oil, ice, potable water, and boat hoists.

Although Michigan City's waterborne commerce formerly included significant tonnages of salt and grains, this traffic declined and ceased between 1965 and 1970. Fresh fish is the only commercial cargo presently handled through Michigan City Harbor. Landings between 1965 and 1974 ranged from 51 to 371 tons, with the later years consistently showing landings above 100 tons.

Because neither the recreational fleet nor the commercial fishing vessels require a deep draft channel, the Corps of Engineers does not intend to maintain the authorized 18-foot depth near the mouth of Trail Creek. However, shoaling of the inner reaches of Trail Creek has resulted in plans by the Corps of Engineers, Chicago District, for maintenance dredging. If funds are available for constructing a confined disposal facility on land adjacent to Trail Creek, maintenance dredging will take place in 1978 or 1979. Figure 3 shows the project depths to be maintained.

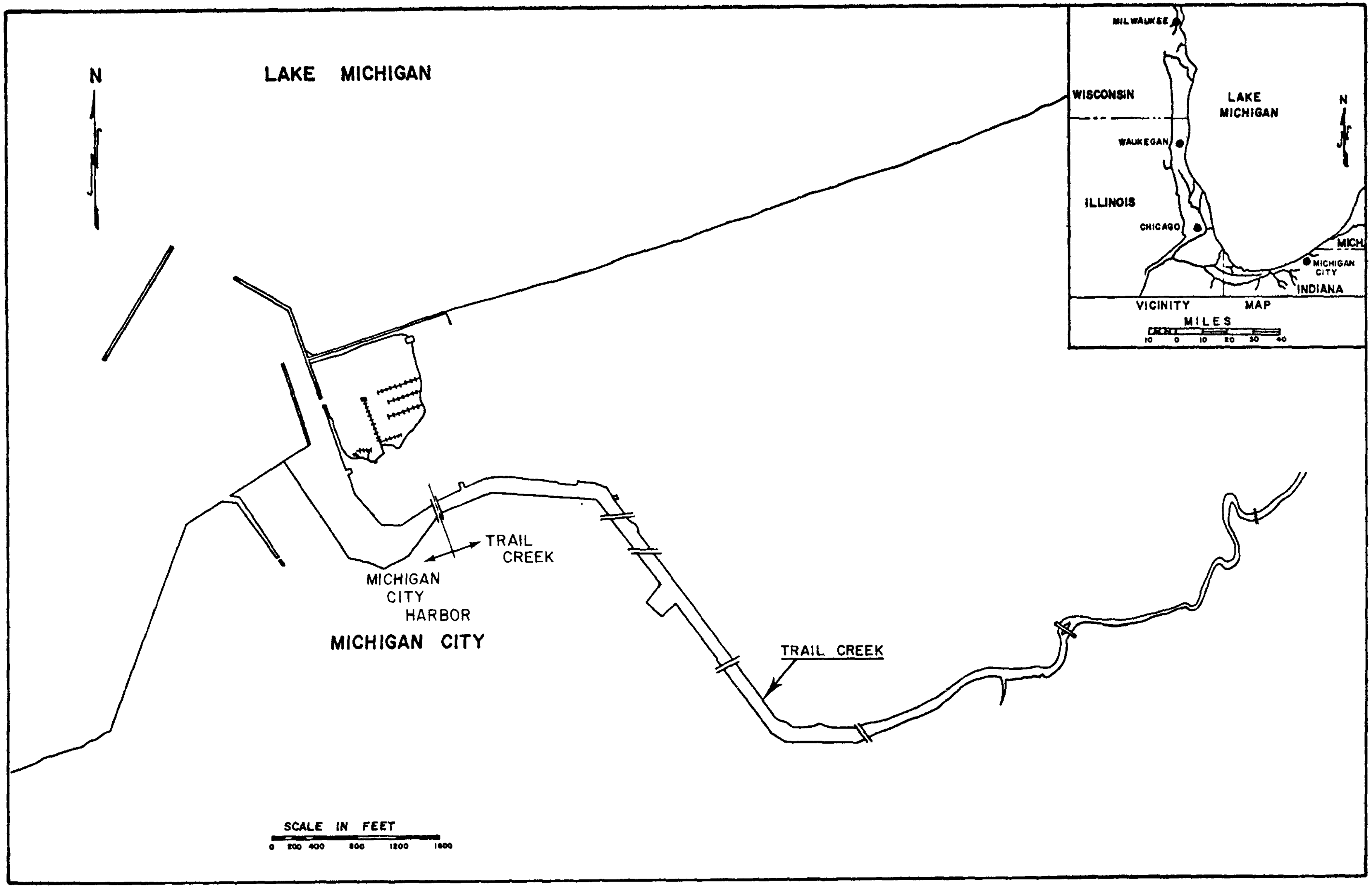

Figure 1. Trail Creek, Michigan City Harbor, Indiana

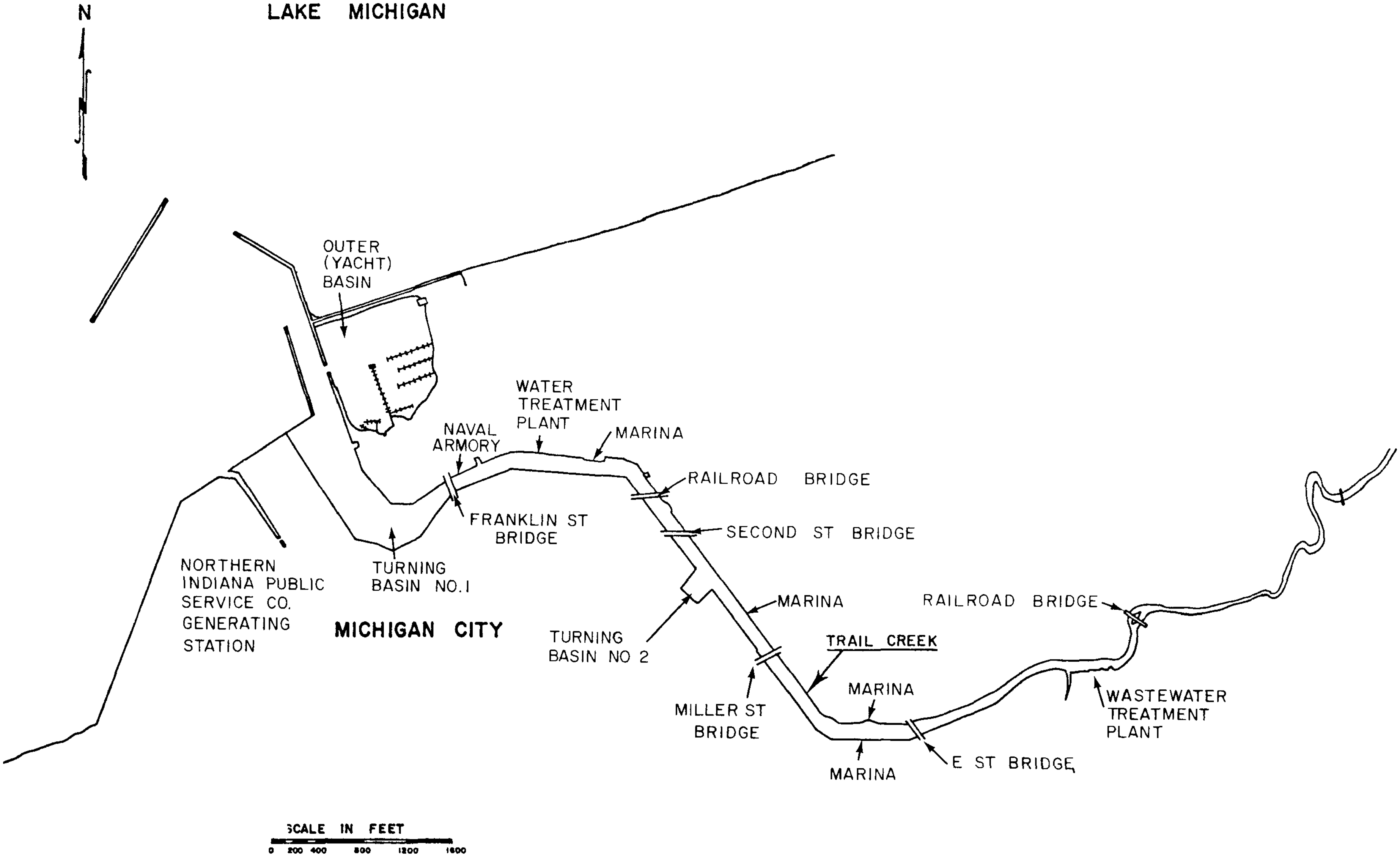

Figure 2. Shoreline Activities and Other Features of the Study Area

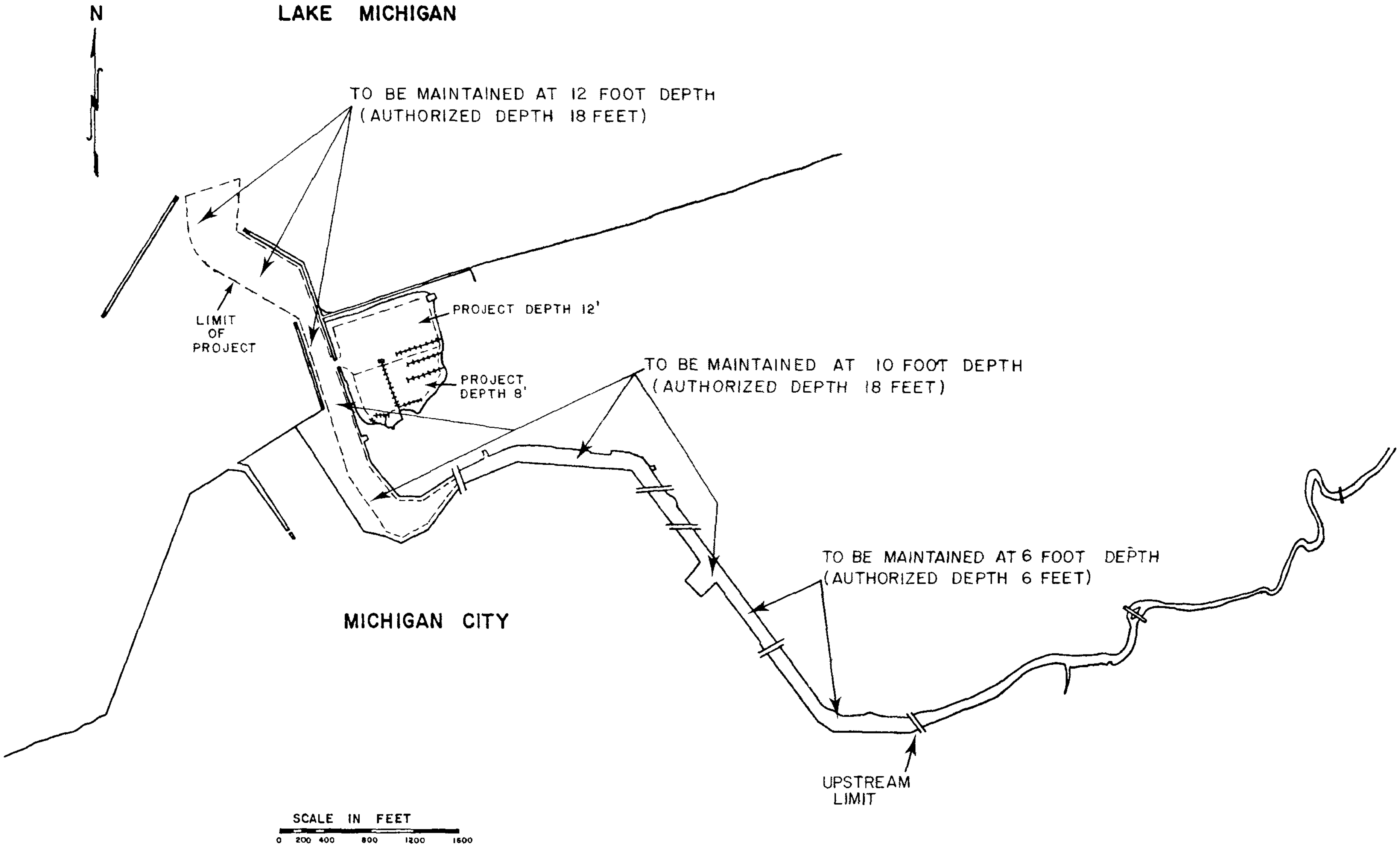

Figure 3. Depths to be Provided by Maintenance Dredging

2. Cooling

The NIPSCO Michigan City Generating Station's cooling water intake structures are adjacent to Turning Basin No. 1, on the shoreline of the power plant property. The volume of water pumped through the plant typically ranges from 100 to 225 million gallons per day (mgd), based on daily operating data from July to December 1976 (3). Cooling water is discharged to Lake Michigan, west of Trail Creek, outside the area under consideration in this report.

Physical and chemical water characteristics near the intake (Turning Basin No. 1) are shown later in this report to be more characteristic of Lake Michigan water than of Trail Creek water. This observation cannot lead to a conclusion regarding the plant's effect on the movement of Trail Creek water without further study. Two possibilities exist:

a. Turning Basin No. 1 at the cooling water intake is affected by the intake in that Lake Michigan water is drawn "abnormally" far upstream into Trail Creek, OR,

b. Turning Basin No. 1 contains a high proportion of Lake Michigan water because of the hydrologic characteristics of the site, and the cooling water intake has little effect.

Understanding of the generating station's hydrologic effects, as well as its thermal effects resulting from the discharge of cooling water to Lake Michigan, should be improved as a result of a program nearing completion by the University of Notre Dame. That program, sponsored by NIPSCO, will include "identification of boundaries of individual water masses and movements of these water masses in the vicinity of the generating station" (3). The final report from that project should be released in the Fall of 1978.

3. Propagation of Fish and Wildlife

Trail Creek is the largest Indiana stream tributary to Lake Michigan, and is very important to the fish stocking program of the Indiana Department of Natural Resources (IDNR). A recently developed salmonid fish hatchery near Michigan City provides stocks of coho and chinook salmon and lake, steelhead, and brown trout. Many of the young from this hatchery are released into Trail Creek in the spring (several thousand were released during the sampling work on this study). Salmonids migrate up Trail Creek from Lake Michigan to spawn in the fall. Salmonids are the focus of intense recreational fishing activity using boats berthed at or launched from Michigan City. Much fishing is also done from waterside structures such as breakwaters. Fish resources of Lake Michigan near Michigan City have been reported by McComish (4). That study did not include Michigan City Harbor/Trail Creek, and therefore is only of indirect interest to this report.

4. Wastewater Disposal; Drainage

The Michigan City Wastewater Treatment Plant effluent is discharged to Trail Creek from the plant site, which is noted in Figure 2. Several industries discharge to the municipal collection system. These industries have been characterized by a sampling program that has resulted in a series of "industrial users," "industrial surveillance," and "industrial pre-treatment" reports that were made available to this study by the Michigan City Sanitary District. Plating operations contribute small amounts of cyanide and heavy metals to the sewerage system, but the Michigan City Sanitary District monitors these discharges closely. Because of dilution and pretreatment, little or no effect on the treatment plant or Trail Creek is evident. Another industry's discharge is high in suspended solids (primarily rubber), but the treatment plant has reported no trouble in removing these materials from the wastewater.

Stormwater overflows have been a problem in the combined collection system at Michigan City, but the Sanitary District has been constructing new storm sewers in a separation program begun in 1962. This separation program is alleviating the problem of raw sewage overflows during periods of high rainfall. As in all urban areas, however, the separated stormwater can still be expected to cause water quality problems in receiving waters (i.e. Trail Creek). Prominent among these potential problems are biochemical oxygen demand (BOD), suspended and settleable solids, bacteria, and oil and grease.

Four other direct discharges to Trail Creek have also been identified:

- The Michigan City Water Works filter backwash enters Trail Creek approximately 600 ft upstream of the Franklin Street Bridge (Figure 2). A study found that the suspended solids concentration of the backwash was a maximum of 87 mg/ℓ. Suspended solids concentrations in Trail Creek returned to background levels within 30 minutes after backwash events (5).

- Wastewater from air pollution control devices at a manufacturer of castings enters a storm sewer that discharges to Trail Creek 500 yards upstream of the wastewater treatment plant.

- A small metal fabricator has its own treatment facilities, and is planning to join the municipal collection system.

- A plastics manufacturer has a large septic system near Trail Creek, with possible entry of leachate into the stream.

None of these discharges appears to be a significant source of in-place pollutants.

B. PREVIOUS STUDIES OF THE AQUATIC ENVIRONMENT

The following discussion is a brief background to the prior knowledge about the aquatic environment of Trail Creek in Michigan City. Much of this report's reference to earlier work appears in the next chapter on field and laboratory studies, and is intended to lend perspective to the data developed in this study.

Previous studies have included biological sampling, sediment sampling, and water sampling. Biological studies have been conducted by the University of Notre Dame to assess the effects of the NIPSCO Michigan City Generating Station on fish (3,6,7). Reports received to date have contained abundant data regarding fish and ichthyoplankton sampling, temperature, conductivity, pH, dissolved oxygen, and residual chlorine. The final report, containing interpretations of these data, is expected to be released in mid-1978.

Other biological work has been conducted by Ball State University. These studies (4,8,9) have emphasized zooplankton, macrobenthos, and fish in the nearshore Indiana waters of Lake Michigan, but have not sampled the area discussed in this report.

Water quality in Trail Creek at Michigan City is monitored monthly by the State Board of Health, Division of Water Pollution Control. Some of their data for 1975 (the most recent year for which data have been published) are presented in Table 1, for two stations identified on Figure 2 (Franklin St. and E St. bridges). The data show undesirably high levels of several constituents. For most parameters, water quality is slightly better at the downstream station (Franklin Street Bridge), probably reflecting the dilution of Trail Creek water by Lake Michigan water. One exception is fecal coliforms, which were consistently higher at Franklin Street than at E Street, which is within sight of the Wastewater Treatment Plant outfall. This trend probably reflects the importance of combined sewer overflows and of urban runoff in bacterial contamination of Trail Creek.

Sediments in Trail Creek were sampled and analyzed by Region V of the U.S. Environmental Protection Agency in 1970 and 1975. Their data are shown in Tables 2 and 3 for stations identified on Figure 4. At the time of submittal of the initial report on Section 115 to EPA (1), the 1975 sampling had not been done. On the basis of the 1970 data (Table 2) showing very high levels of several parameters including arsenic, Michigan City was included in a group of six "Priority 1" waterways across the United States most strongly needing further action under Section 115. These data also were valuable in this study for identifying likely "hot-spots" of in-place pollutants and for planning the field work accordingly. For example, both sets of data indicated that the most serious apparent problems with in-place pollutants were upstream of Turning Basis No. 1. Sampling stations in this work were therefore more closely spaced upstream of that location, and more widely spaced lakeward of that location.

Table 1. 1975 Water Quality Data for Trail Creek

E Street Bridge	BOD_5	Suspended Solids	Volatile Suspended Solids	NH_3	Phos-phorous	Oil & Grease	Fecal Coliform (MPN/100 mℓ)	Specific Conductance (μmhos/cm)	Pb	Zn
Minimum	1.6	3	1	0.80	0.09	1.0	10	450	0.020	0.040
Maximum	3.9	51	24	4.00	0.52	29.0	1700	600	0.050	0.170
Average	2.5	19	7	2.27	0.21	13.7	172	527	0.032	0.092
Franklin Street Bridge										
Minimum	1.4	1	1	0.20	0.03	1.0	10	250	0.020	0.030
Maximum	3.2	32	12	2.50	0.41	29.0	4700	580	0.030	0.230
Average	2.3	12	4	1.22	0.12	11.9	1216	413	0.024	0.070

Source: Indiana State Board of Health and Indiana Stream Pollution Control Board (10).

All units in mg/ℓ unless otherwise noted

Table 2. Bulk Sediment Analysis Results from
EPA Region V Sampling in 1970

Station: Parameter	70-2	70-3	70-4	70-5	70-6
Oil and Grease	391	172	217	1,354	16,870
Ammonia-N	None found	None found	None found	236	845
Nitrate-N	0.44	0.13	0.13	0.50	0.79
Organic-N	None found	81	68	1,077	4,823
COD	3,975	4,420	3,285	33,120	316,380
Total Phosphorous	56.8	95.1	126	772	8,695
Total Iron	2,182	2,572	3,111	8,095	31,937
Lead	13	21	11	33	244
Zinc	16	20	17	925	10,897
Mercury	0.06	0.02	0.06	0.20	1.8
Total Solids (%)	67.7%	78.3%	76.0%	59.8%	25.4%
Volatile Solids (%)	0.3%	0.5%	2.2%	3.9%	18.6%
Specific Gravity (no units)	1.6881	1.9846	2.0004	1.4883	1.1652
Arsenic	350	400	500	2,200	9,660

All units in mg/kg dry weight unless otherwise noted.

Table 3. Bulk Sediment Analysis Results from EPA Region V Sampling in 1975

PARAMETER	MCTY 75-1	MCTY 75-2	MCTY 75-3	MCTY 75-4	MCTY 75-5	MCTY 75-6	MCTY 75-7
Volatile Solids %	5.40	8.2	15.5	13.6	19.9	17.4	15.8
Chem. Oxy. Demand	73,000	111,000	224,000	202,000	309,000	274,000	254,000
T. Kjel. Nitrogen	1800	3100	5200	4300	7100	4200	5400
Oil-Grease	2500	4300	11,000	7300	15,000	12,000	15,000
Mercury	*	*	*	*	*	0.1	0.1
Lead	90	150	270	190	200	240	325
Zinc	360	870	2060	1430	2050	2000	2340
T. Phosphorous	720	1600	3600	3300	6300	3900	4700
Ammonia Nitrogen	93	160	360	270	390	460	380
Manganese	510	610	790	620	810	680	690
Nickel	55	75	0.0150	105	160	150	140
Arsenic	6	9	14	13	12	10	8
Barium	70	130	270	200	275	250	280
Cadmium	63	19	58	36	81	45	61
Chromium	56	120	300	200	320	270	290
Magnesium	23,000	22,000	17,000	13,000	9800	13,000	9900
Copper	56	200	260	190	180	170	215
Iron	17,000	24,000	36,000	26,000	25,000	27,000	25,000

*Below detection limit (0.1 mg/kg)

All values in mg/kg dry weight unless otherwise noted.

Table 3 (cont.) Bulk Sediment Analysis Results from EPA Region V Sampling in 1975

PARAMETER	MCTY 75-8	MCTY 75-9	MCTY 75-11	MCTY 75-12
Volatile Solids %	12.0	16.4	9.4	16.6
Chem. Oxy. Demand	195,000	265,000	129,000	250,000
T. Kjel. Nitrogen	4200	5200	3200	4500
Oil-Grease	11,000	15,000	7000	14,000
Mercury	*	0.1	*	*
Lead	360	270	130	290
Zinc	7160	2470	705	2710
T. Phosphorous	3300	5700	2100	5000
Ammonia Nitrogen	300	210	340	190
Manganese	710	710	560	750
Nickel	130	170	90	160
Arsenic	8	10	5	14
Barium	260	325	155	380
Cadmium	44	78	22	80
Chromium	235	360	125	370
Magnesium	12,000	11,000	5800	11,000
Copper	185	215	90	220
Iron	23,000	29,000	19,000	28,000

*Below detection limit (0.1 mg/kg)

All values in mg/kg dry weight unless otherwise noted

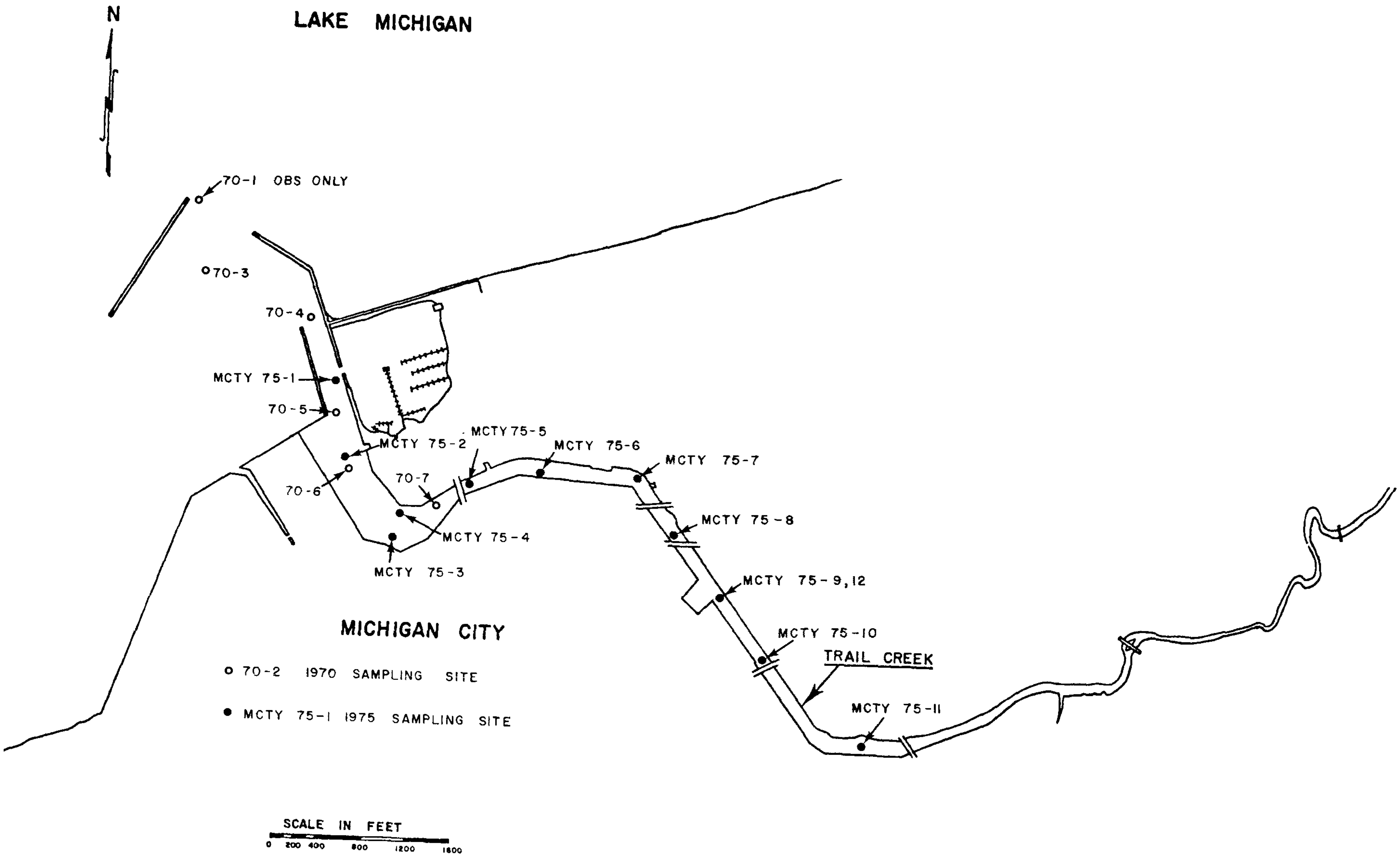

Figure 4. Stations Occupied by EPA Region V Sampling Efforts

V. FIELD AND LABORATORY STUDIES

A. FIELD SAMPLE COLLECTION

All samples for this project were collected between April 14 and 17, 1977. The field crew consisted of cooperating groups from JBF Scientific, Ball State University, and the University of Michigan (Ann Arbor). Logistic support was provided by the Indiana Department of Natural Resources (IDNR). The station locations are shown in Figure 5.

1. Sampling Methods and Materials

The water depths in the area under study varied from a few cm up to about 8 m. The approach to the field work was to use the best equipment that could be brought to each sampling station. Accordingly, three platforms were used. In deep water (>2 m), the Research Vessel MYSIS of the University of Michigan was used. This platform offered the full complement of sampling equipment and shipboard processing that was desired. For intermediate depths (1 to 2 m) a 19-foot research vessel operated by Ball State University was used. A small flat-bottom skiff made available by the IDNR allowed access to very shallow upstream areas. The principal difference among platforms was in the ability to take sediment cores and in the physical difficulty of retrieving ponar grabs.

a. Sampling Methods Common to All Stations

Water samples were taken with Van Dorn samplers and were subdivided, preserved, and stored for laboratory analysis of separate subsamples for separate parameters. All samples were taken from 1 meter above the bottom except for stations with less than 1 m water depth. Samples at those stations were taken at mid-depth. The handling of these separate water samples is described in Table 4. Field measurements were also made as described in that table.

Samples of benthic organisms were collected with a ponar grab with bite dimensions of 22 x 22 cm. A single grab was collected at each sample station by lowering the sampler onto the substrate at an impact speed of about 0.3 m per second and retrieving as quickly as possible to the boat. In the flat-bottom skiff, retrieval was by hand because no winch could be fitted. Immediately after removal of the sampler from the water it was placed in a large tub lined with a polyethylene bag. The sampler was then opened and contents were emptied and washed from the sampler into the bag with site water. Each bag was then marked for station identification and tightly tied.

All benthic biological samples were washed onboard the RV MYSIS (including samples taken from the smaller boats) using an elutriation device ("Critter Catcher") and washing small debris and substrate materials through nitex screen of 0.5 mm square mesh dimensions. Organisms and large debris particles retained were collected in labeled jars and preserved in about 10 percent formalin.

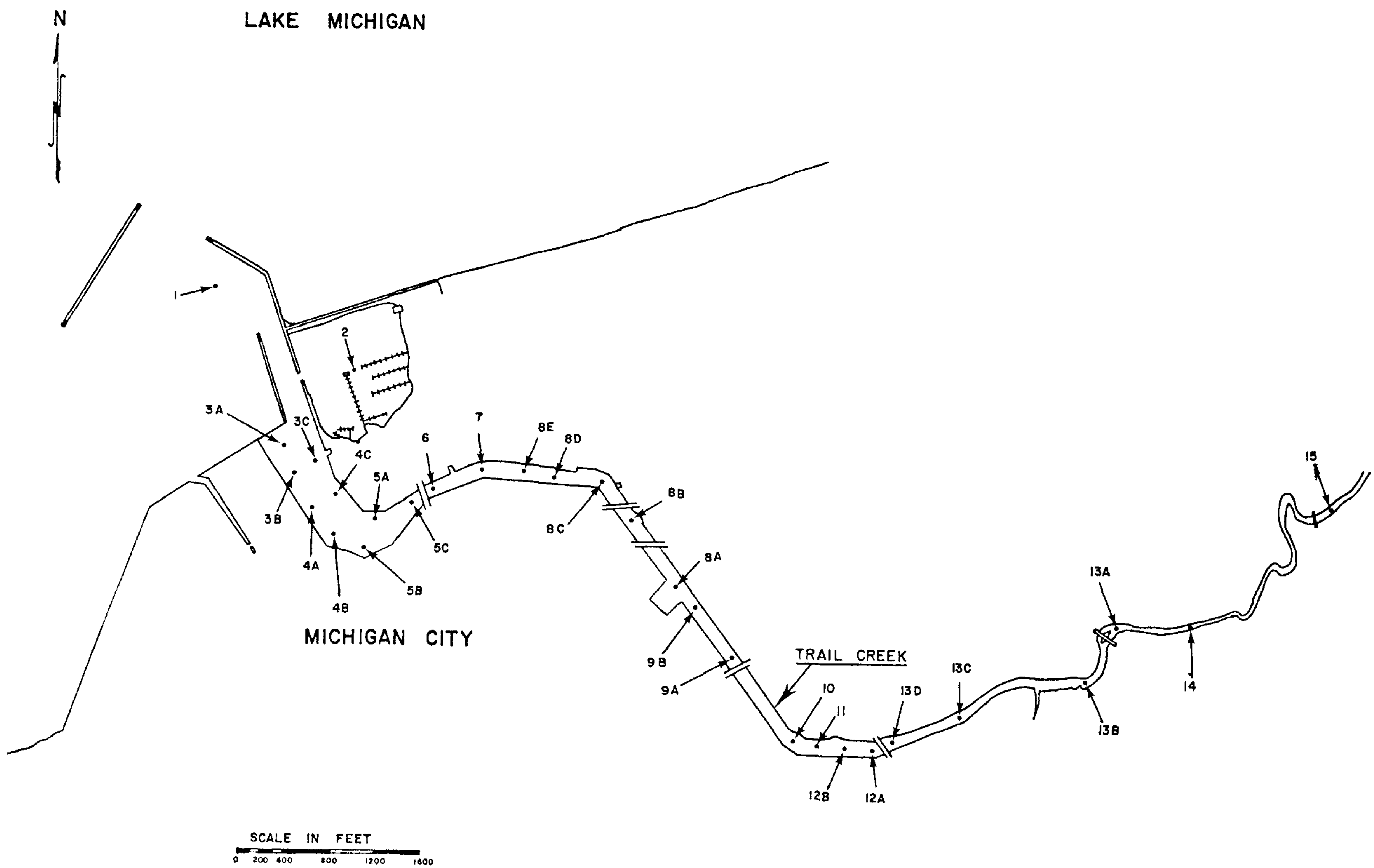

Figure 5. Station Locations Used in this Study

Table 4. Samples Collected at Michigan City/Trail Creek at Each Station: Purpose and Handling

Sample Description	Type of Container and Preservation	Purpose
WATER (conductivity, temperature, DO, pH in field)	1-quart glass - cap lined with aluminum foil	PCB and Arsenic
	1-quart glass (5 mℓ H_2SO_4)	Oil and Grease
	1-pint polypropylene (2.5 mℓ H_2SO_4)	Ammonia-N
	1-pint polypropylene	Metals
	Four 5-gallon polyethylene containers from one central site	Elutriate Test Water
	Three 5-gallon polyethylene containers from one site near mouth of Trail Creek	Site Water for Bioassays
SEDIMENT PONAR GRABS (Immediate Oxygen Demand in field on surficial sediments)	Mason jars	Benthic Analysis
	5-gallon polycarbonate bucket shipped and stored at $4^{o}C$.	Bioassay
	2-quart polycarbonate wide mouth	Particle Size and Elutriate Test, Percent Solids
SEDIMENT CORES sample top, middle, bottom	Three 1-quart glass - wide mouth cap lined with aluminum foil	Blend and Divide from each in laboratory: Sample Bottle - PCB and Arsenic 1-pint glass wide mouth - TKN, Oil and Grease Remainder - Percent Solids, Volatile Solids, Metals Digestion

b. Coring Methods Used with Each Vessel

Stations occupied with the MYSIS were represented by cores taken with a gravity coring device as described schematically in Figure 6. A core retainer was used to avoid loss of core material during retrieval. As each core was brought on board, the following procedure was observed:

- Remove core liner from pipe core-tube
- Drill small hole immediately above sediment-water interface to allow supernatant water to escape
- Measure core length
- Extrude core from core liner, subdividing into samples of 10 to 25-cm increments (3 samples maximum).

A clean core liner of acrylic material was used for each coring event. Despite the use of 182 kg of lead and 300-cm core liners, the longest core retrieved was 76 cm. Some cores terminated in a layer of hard clay, but others were found to contain organic sediment to the base of the core. Relationships between the length of the core sample and the length of *in situ* sediment represented (always greater than the sample length) are discussed in Appendix A.

Cores were taken from the smaller boats with a coring device similar in all respects to that used on the MYSIS except for size and weight. The core liner was 61 cm long and 5 cm in diameter. The direct pushing force of an oar was used to achieve penetration because the usable weights and fall distances were inadequate.

B. ANALYSES OF CHEMICAL AND PHYSICAL PROPERTIES

1. Methods and Materials

The many types of analyses that were performed in the laboratory involved several procedures that require detailed, specialized description. Those descriptions, including procedures for quality control, appear in Appendix B. Before proceeding to the discussion of results in the text, one procedure - the elutriate test - should be described briefly.

The elutriate test involves shaking a sample of sediment with added water, followed by settling, filtering of the water, and analysis of the filtrate. Instead of shaking, aeration may be used to provide mixing. Both mixing methods were used in this study. The main reason for performing an elutriate test is to simulate the interaction of a sediment with water at a dredged material disposal site or with water in a hydraulic pipeline. The latter situation was simulated in this project. Dredging at Michigan City would most likely use a hydraulic pipeline dredge, and any release of pollutants to the carrier water in the dredged slurry is of interest.

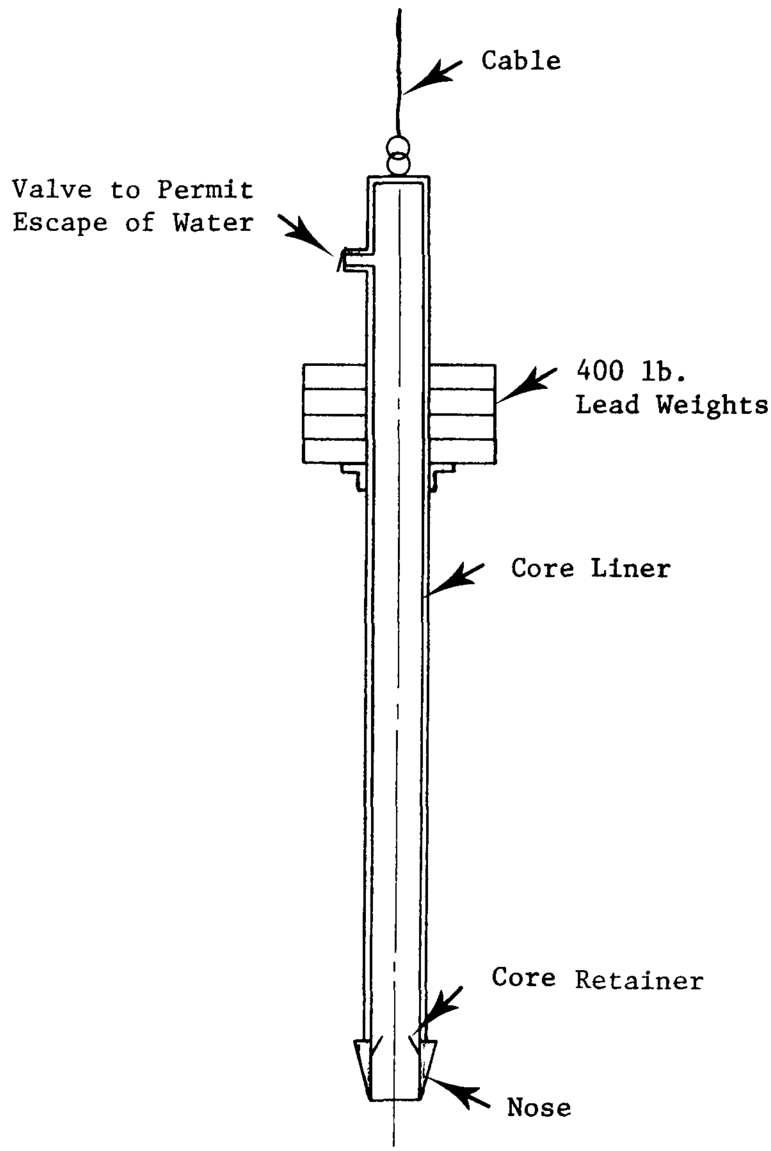

Figure 6. Schematic of Gravity Sediment Corer

Data from the chemical and physical laboratory investigations appear in the accompanying tables: Table 5, Water Analyses; Table 6, Sediment Analyses; Table 7, Elutriate Analyses. Selections of stations for bioassays and for intensive benthos evaluations were based on these data. The rationale behind those selections is discussed below.

a. Water Analyses

The water quality data shown in Table 5 were developed for several purposes:

- To assess the total aquatic system rather than only the sediments
- To characterize waters used in bioassay and elutriate tests
- To compare present water quality with past conditions as revealed by earlier data and by the sediment characteristics. This comparison is useful for inferences as to whether the sources of in-place pollutants are still important.

(1) Dissolved Oxygen. Upstream of the wastewater treatment plant and immediately downstream, D.O. levels were at or near saturation. Between the E Street and Franklin Street Bridges, levels were as low as 50% of saturation. D.O. concentrations were higher lakeward of the Franklin Street Bridge, but because water temperatures were lower, the water remained slightly undersaturated. Dissolved oxygen concentrations, while below saturation, are not so low as to jeopardize biota or other uses of Trail Creek. Without a mathematical model for dissolved oxygen in Trail Creek it is difficult to separate the causes of the oxygen deficit and their relative importances. However, it appears unlikely that the wastewater treatment plant outfall is the sole cause of the deficit. Benthic oxygen demands are also probably significant.

(2) Ammonia nitrogen. The species NH_3 + NH_4^+ were observed at quite high levels between the wastewater treatment plant and Franklin Street Bridge. These substances reflect the breakdown of organic nitrogen, and indicate organic pollution. EPA's most recent water quality criteria document (11) recommends a maximum of 0.02 mg/ℓ as un-ionized NH_3; at the pH and temperatures in Trail Creek, the observed values of NH_3 and NH_4 (above 2 mg/ℓ) indicate violation of this criterion.

(3) Heavy metals. Of the metals selected for water analyses, nickel, lead and zinc appeared to be at levels worthy of concern. EPA criteria (11) stipulate that these metals should be present in concentrations less than 0.01 times the 96-hour LC50 for the most sensitive local organisms. Since most bioassays with salmonids have found 96-hour LC50's for these metals typically less than 10 mg/ℓ, the values shown in Table 5 - especially for lead - can be considered as violating the Federal criteria. The cadmium levels shown may also be of concern; although concentrations are low, the hazard of even low levels of cadmium is great.

Table 5. Water Analyses
(All Values in mg/ℓ Except pH, conductivity, and temperature)

Station	pH	Dissolved Oxygen	Conductivity μmhos	Temperature °C	NH_3-N	PCB	Cd	Cu	Ni	Pb	Zn	As
1	7.2	8.4	200	10	0.40	<0.01	0.002	0.02	0.15	0.88	0.09	<0.1
2	7.2	8.4	250	16	0.31							
3a	7.1	8.3	260	12			0.02	0.01	0.18	0.71	0.10	
4a	7.1	8.5	205	11								
5a	7.3	8.4	210	12	0.33		0.03	0.03	0.10	0.50	0.06	<0.1
6	7.3	8.2	260	13								
7	7.3	6.7	340	15								
8a	7.2	6.1	410	15	1.33	<0.01	0.02	0.02	0.15	0.63	0.21	<0.1
8b	7.4	5.5	430	17								
8c	7.1	5.0	450	17	2.20		0.01	0.03	0.09	0.79	0.24	
8d	7.1	4.8	450	17								
8e	7.2	4.7	430	17	1.92		0.04	0.02	0.19	0.97	0.15	<0.1
9a	7.2	5.4	720	15								
9b	7.3	6.4	405	15								
10	7.1	6.4	400	15	0.95		0.04	0.02	0.16	0.74	0.26	<0.1
11	7.3	6.8	405	15								
12a	7.3	6.4	410	15								
12b	7.4	6.7	410	15								
13c	7.1	8.9	385	16	2.57		0.04	0.04	0.12	0.64	0.31	
13d	7.3	10.4	410	17	3.03	<0.01	0.02	0.02	0.23	0.85	0.34	<0.1
14	7.3	10.4	405	17								
15	7.4	10.2	400	17	0.17		0.002	0.01	0.18	2.80	0.16	

Table 6. Bulk Analyses of Bottom Sediment

(all values mg/kg dry weight unless otherwise noted)

Station No.	Depth Range Below Water/ Sediment Interface (cm)	Percent Solids	Percent Volatile Solids	Particle Size: Percent Sand	Particle Size: Percent Silt	Particle Size: Percent Clay	Immediate Oxygen Demand (mg O_2/gm dry wt)	TKN	Oil and Grease	PCB	Arsenic	Cadmium	Copper	Nickel	Lead	Zinc
1	0-10	68.8	0.8	92.8	5.6	1.6	<0.1	100	1200	<0.01	< 0.1	1	1	9	21	29
2	0-15	45.6	5.6	17.2	62.6	20.2	0.46	3500	3500	<0.01	10.9	7	22	55	170	1400
3A	0-11	67.3	1.9	66.4	26.6	7.0	0.25	1200	2800	0.14	5.4	5	10	30	180	230
3B	0-13	51.0	5.1				0.4			0.12	1.3					
3C	0-18	39.5	10.4				0.94			0.35	2.4					
4A	0-20	41.7	8.9	8.5	70.5	21.0	0.77	13400	6000	1.10	11.3	26	27	86	250	1900
4A	20-40	44.1								0.45	3.6					
4A	40-60	46.3	9.2					4800	4300	<0.01	12.5	11	38	84	280	600
5A	0-13	29.7	17.0	3.0	78.8	18.2	1.31	10800	7700	0.69	21.6	67	65	219	410	2900
5B	0-25	31.3	14.9	2.0	80.2	17.8	1.02	670	9300	0.40	1.3	53	16	105	360	1600
5C	0-23	31.5	15.3	0	87.3	12.7	1.21	860	9800	0.32	1.9	49	14	136	280	1600
6	0-25	25.4	18.7	0	86.0	14.0	1.61	27600	12600	0.38	1.9	82	79	255	430	3350
6	25-50	30.4	17.8					440	3800	0.69	1.8	78	23	153	540	2800
6	50-74	31.0	17.8					370	1100	<0.01	1.3	46	14	93	390	1800
7	0-18	24.8	18.7	10.3	76.9	12.8		13700	15300	0.53	10.5	63	71	179	430	3180
7	36-53	22.6	2.1					5900	14200		21.7	60	68	230	360	2800
8A	0-10	37.9	15.0	88.0	5.7	6.3	0.9	8400	10600	0.33	16.7	41	56	178	510	2400
8B	0-10	31.1	16.5	13.0	72.3	14.7	1.09	10300	17000	<0.01	15.8	59	87	167	470	3500
8C	0-22	42.9	13.0	13.8	75.4	10.8	0.89	7200	13500	0.72	10.7	42	77	135	540	3400
8C	22-43	47.3	10.1					6600	7400		11.6	35	57	93	370	2700
8D	0-18	32.0	15.7	2.0	83.0	15.0	1.06	940	6600	0.88	1.8	46	16	142	410	1500
8E	0-15	25.0	18.2	26.8	71.0	2.2	1.12	800	5600	<0.01	2.1	54	17	120	580	1200
9A	0-23			15.7	73.3	11.0		1100	1200		0.8	70	23	193	440	3000
9B	0-10	60.1	1.9	91.1	7.2	1.7	0.1	1800	1700	0.04	3.8	5	15	47	130	2100
10	0-10	41.9	10.5	43.0	53.4	3.6	0.64	670	6200		0.8	37	14	116	230	1300
11	0-10	34.2	12.3	54.0	37.3	8.7	0.41	5600	13500	0.32	8.8	55	72	119	450	4700
11	10-20	27.8	18.4					13300	14400		17.3	74	76	133	590	4590
12A	0-13	37.5	13.2	22.0	74.5	3.5	0.67	930	8300	<0.01	1.4	35	14	152	210	1300
12A	13-25	54.2	5.7					4200	4100		4.2	21	28	114	140	1100
12B	0-13	72.3	4.3	24.3	68.4	7.3	0.76	1700	1800	<0.01	2.1	6	15	34	83	280
13B	0-8	36.4	13.3	10.0	67.5	22.5	0.74	960	1900		0.7	6	2	16	9.3	32
13C	0-8	79.5	1.3	97.5	1.2	1.3	<0.1	380	1100	<0.01	3.7	7	17	31	110	300
13D	0-8	70.0	3.6	1.0	93.0	6.0	0.47	1600	2100	0.15	2.4	8	18	50	85	260
14	0-8	80.1	0.5	96.2	2.7	1.1	<0.1	370	370	<0.01	2.3	1	2	17	3.1	50

A = Aerated
S = Shake

Table 7. Elutriate Test Results

All Values in mg/ℓ Except pH

Sample	NH_3-N	Cd	Cu	Ni	Pb	Zn	PCB	As	pH	DO	Shake pH	Shake DO
1A	0.19	0.01	0.01	0.13	<0.04	0.02	<0.01	<0.1	7.8	8.1	—	—
1S	0.21	0.24	0.01	0.06	2.00	0.05	—	—	7.7	8.0	—	—
2A	0.21	0.02	0.01	0.02	<0.04	0.03	<0.01	<0.1	7.1	0.8	—	—
2S	2.0	0.03	<0.01	0.11	<0.04	0.03	—	—	7.1	2.8	—	—
3AA	64	0.24	0.01	0.15	0.50	0.02	<0.01	<0.1	7.1	6.8	7.1	7.6
4AA	41	0.05	0.06	0.04	0.08	0.04	<0.01	<0.1	6.9	0.6	6.9	3.6
5AA	160	<0.01	0.03	0.14	0.31	0.06	<0.01	<0.1	7.5	1.7	—	—
5AS	18	0.02	0.02	0.11	0.48	0.22	—	—	7.2	0.4	—	—
7A	120	0.04	<0.01	0.48	0.47	0.05	<0.01	<0.1	6.9	0.6	—	—
7S	61	0.01	0.04	0.06	0.06	0.08	—	—	6.8	3.0	—	—
8AA	54	<0.01	0.06	0.11	0.21	0.06	<0.01	<0.1	7.1	2.6	6.8	2.8
8CA	40	<0.01	0.03	0.16	0.58	0.03	<0.01	<0.1	7.1	1.0	7.0	1.6
11A	42	0.02	0.01	0.27	0.45	0.02	<0.01	<0.1	7.9	5.2	7.5	4.8
13CA	33	<0.01	<0.01	0.09	0.29	0.04	<0.01	<0.1	7.9	9.4	7.3	8.4
13DA	44	0.02	0.04	0.05	0.65	0.07	<0.01	<0.1	7.7	1.8	—	—
13DS	98	<0.01	0.03	0.20	0.24	0.30	—	—	7.2	0.4	—	—
14A	2.0	0.01	0.01	0.02	0.80	0.01	<0.01	<0.1	8.1	9.2	7.6	8.8
8A (Site Water)	0.18	0.01	0.02	0.05	0.37	0.11	<0.01	<0.1	7.3	—	—	—

In summary, the water analyses showed organic and toxic pollutants to be present in the water column, indicating a potential hazard to aquatic biota and causing dissolved oxygen depletion.

b. Bulk Sediment Analyses

Considerable scientific debate has taken place in recent years over the value of bulk sediment chemical analyses for assessing the probable environmental impacts of dredging and dredged material disposal. It has been argued and demonstrated (12,13) that bulk sediment analyses are a poor predictive tool for evaluating release of pollutants to the water during dredging or disposal. Elutriate tests are generally favored by most investigators for such evaluations. However, a focus on short-term release to the water does not address the issue of in-place pollutants. Bulk sediment chemistry is the most appropriate and convenient way to describe sediment properties and to relate them to organisms present and to sediment bioassay data. The elutriate test in this context is a useful but secondary method of sediment characterization.

The Great Lakes Surveillance Branch of Region V, EPA, has developed a classification system for sediment quality based primarily on bulk analyses (14). This system has been defended by Bowden on very appropriate grounds (15):

> "The bulk sediment approach has been widely criticized as not being scientifically sound. We acknowledge that there may be some merit to these criticisms, but we adhere to the system for the following three reasons:
>
> 1. No suitable alternative system has been developed.
>
> 2. The fundamental assumption that adverse impact on the environment is related to degree of anthropogenic contamination has not been refuted and is probably sound.
>
> 3. The critics do not appear to understand how the guidelines are applied. The criticism is based on attempts to find correlations between individual parameters and toxicity or releases to the water column. In no case have we seen any author evaluate bulk sediment data as an overall family of data rather than as individual parameters. Thus far, our overall classifications agree remarkably well with bioassays using organisms indigenous to the lakes..."

With this background, bulk sediment properties shown in Table 6 can be discussed. The discussion begins in general terms to identify zones of highest contamination then proceeds to a more specific description of noteworthy stations.

(1) Percent Solids and Particle Size. In general, higher percent solids and larger proportions of sand relative to silt and clay were observed at the lakeward stations and at stations upstream of the E Street Bridge. The intermediate stations between stations 5A and 12A produced fine-grained sediments with high water content. The fine-grained sediments tended to be more polluted, as the following discussions show.

(2) Organic Pollutants. Percent volatile solids, Immediate Oxygen Demand, and TKN (Total Kjeldahl Nitrogen) are indicators of organic matter in sediments. The Immediate Oxygen Demand (IOD) test (see Appendix B for specification) is an indirect method of assessing organic deposition. It is a simple yet effective measure of the oxygen consuming potential of a sediment that is mixed with water. The reduced iron, manganese, and sulfide species responsible for this oxygen consumption are associated with low Eh (redox potential) caused by anaerobic decomposition of organic matter in the sediments. All three of these parameters (volatile solids, TKN, and IOD) were found to indicate the highest degree of organic pollution between Turning Basin No. 1 and the E Street Bridge. Most of the stations within this reach had values of these parameters many times higher than stations farther upstream or downstream. Organic contamination such as this could occur because of natural conditions (settling of detritus) or from the historic discharges of wastewater and urban stormwater to Trail Creek. Because detritus such as leaf litter was observed in very few sediment samples, it is not likely that the organic sediment components are primarily natural.

(3) Oil and Grease. At most stations between Turning Basin No. 1 and the E Street Bridge, oil was clearly detectable in the sediments by sight and smell. The act of taking sediment samples often caused an oily sheen to appear on the water surface. These observations are corroborated by the data in Table 6, showing elevated concentrations of oil and grease between Stations 4A and 11.

The most severe oil and grease contamination was found at Stations 7, 8A, 8B, 8C, and 11. These stations all are near marinas, indicating the effects of power boat activities. Engine maintenance at the marinas may be a source of oily materials, possibly through accidental spills and runoff of oily soil and storage yard debris during storms.

(4) PCB. Polychlorinated biphenyl distribution in Trail Creek sediments is scattered; although the highest concentrations occur in the same reach as the highest concentrations of other pollutants, some stations in this reach (e.g. 8B and 8E) produced samples with PCB below detection limits. Review of Table 6 and Figures 2 and 5 shows that most of the higher values occurred between the railroad bridge and Turning Basin No. 1. The presence of any PCB is undesirable, but the concentrations found are not unusually high for an urban area (1).

(5) Arsenic. The pollutant most influential in the inclusion of Michigan City as a Priority 1 location in the first report on Section 115 was arsenic. Data available at the time of that report showed arsenic concentrations in the thousands of mg/kg dry weight. This study found a maximum arsenic concentration of 21.7 mg/kg dry weight. It is interesting to note that most stations for which more than one core depth interval was analyzed for arsenic showed more arsenic in the deeper sediment than on the surface (Table 6). This trend may indicate that the source of arsenic is diminishing or has ceased. (One possibility is aerially transported fly ash, reduced in recent years by air pollution control equipment at the NIPSCO station). No other pollutants showed kind of trend with depth intervals in the sediment cores.

(6) Other Heavy Metals. All the other heavy metals investigated showed the same tendency toward relatively high concentrations between Turning Basin No. 1 and the E Street Bridge. The concentrations in this reach of Trail Creek are typical of heavily polluted urban waterways in the U.S. The levels of cadmium and zinc in Table 6 are seen by a review of the data in the first Section 115 report to be among the highest in the country (1).

A review of all stations for which more than one core depth interval was analyzed (Stations 4A, 6, 7, 8C, 11, and 12A) does not indicate consistent trends of heavy metals with depth. With the possible exception of arsenic, pollutant concentrations did not vary consistently with depth in the cores. Thus, throughout the history of deposition of polluted sediments, little change appears to have taken place.

c. Elutriate Tests

Laboratory tests were performed to assess the short-term availability of in-place pollutants to the water when intimately mixed with the water as would occur during hydraulic dredging, open-water disposal of dredged materials, or other turbulent mixing event. Test methods are given in Appendix B. Briefly, elutriate tests involve shaking sediments with clean water, settling and filtering the water, and analysis of the filtrate. The results, shown in Table 7, yield the following brief interpretations.

(1) Ammonia. The NH_3 - NH_4^+ species were released to the aquatic phase in large amounts by the sediments from the polluted reach between Turning Basin No. 1 and the E Street Bridge. The greatest releases were from Stations 5A and 7 (Table 7). These stations both had high values of TKN in the bulk analyses (Table 6), so the release of ammonia nitrogen from these samples in the elutriate test is not surprising.

(2) Heavy Metals. Release of heavy metals was inconsistent, as a review of Table 7 shows. Often the elutriate contained lower metal concentrations than site water (for example, Zn at most stations). This type of behavior is often observed in the elutriate test, and is generally attributed to adsorption of metal ions to clay particles.

(3) PCB. Detectable levels of PCB were not released in any elutriate tests.

(4) Aeration vs. Shaking. Agitation for the elutriate tests was provided by two means for some stations, to determine whether aeration rather than mechanical shaking produced consistently different results. The two procedures used to suspend the sediments did not reveal consistent trends with regard to any tendency for either procedure to release more or less pollutant to the aquatic phase. For example, Table 8 compares the two agitation methods for Stations 7 and 13D.

Table 8. Comparison of Aerated vs. Mechanically Shaken Elutriate Tests for Two Stations

Station	Agitation Method that Resulted in Higher Levels of Each Parameter							
	NH_3-N	Cd	Cu	Ni	Pb	Zn	pH	Do
7	A (Aeration)	A	S	A	A	S	A	S
13D	S (Shake)	A	A	S	A	S	A	A

As an earlier discussion noted, elutriate tests are not of primary importance in assessing in-place pollutants, but do have potential use for assessing dredging and disposal options. Because the focus here is on in-place pollutants, the elutriate test results do not weigh heavily in the following summary of sediment testing.

d. Summary of Physical and Chemical Analyses

The preceding discussion reveals general patterns of water and sediment characteristics. More specific trends will now be described, forming the rationale for selection of stations to be investigated through bioassays and benthos studies.

Themost important inference that can be gained from reviewing the data is that Trail Creek and Michigan City Harbor are not characterized by intense, localized "hot spots." Rather, the entire reach from Turning Basin No. 1 to the wastewater treatment plant exhibits a fairly uniform bottom type with regard to in-place pollutants. Upstream and lakeward of this reach are areas much less affected by anthropogenic sediment contaminants.

Despite the absence of intense "hot spots", several stations within the polluted reach of Trail Creek are anomalously low in one or more pollutants. Stations 8B and 8E, for example, did not contain detectable quantities of PCB. Similarly, some stations were low in arsenic relative to surrounding stations. No correlations were apparent between these observations and station location or other sediment parameters.

Because the stations within the polluted reach were fairly uniform in physical and chemical characteristics, it was not necessary to use any complex indexing schemes for selecting priority stations for biological studies. A simple rank-ordering was performed for the stations with highest concentrations of pollutants in surficial sediments. This rank-ordering (Table 9), while providing a convenient summary of relative sediment pollution, was a further indication that in-place pollutants are widespread rather than confined to "hot spots".

The following stations were selected for analysis of benthos:

- Station 4A, with the highest PCB content but relatively low values of other pollutants except arsenic and TKN.

- Stations 6, 7, and 8B, representing the most contaminated stations (most pollutants ranked in Table 9). Station 8B was of particular interest because of a PCB concentration below the detection limit.

- Station 11, which showed high burdens of heavy metals and oil and grease, in comparison with neighboring upstream stations.

- Station 13D, a relatively "clean" station downstream of the wastewater treatment plant outfall and upstream of the Federally authorized navigation channel.

The particularly interesting stations in the above group: 4A, 8B and 11, were selected for bioassays, together with Station 1, a relatively uncontaminated area at the mouth of the harbor which served as a control.

C. INVESTIGATION OF BENTHIC ASSEMBLAGES

These investigations were conducted by Dr. Thomas McComish and his students at the Department of Biology, Ball State University, Muncie, Indiana.

1. Methods and Materials

In the laboratory, all macrobenthos were separated from debris in each sample by hand. The procedure involved placing a small amount of the sample in a 90 mm diameter gridded petri desh, adding water and slowly searching through all debris. After sight recognition, each organism was removed with a forceps, counted and sorted into an appropriate vial with about 10 percent formalin as a preservative.

The identification procedure varied according to the group involved. Chironomids were first examined wet using a dissecting microscope at 12.5 to 80X. Then each head capsule was removed and mounted on a microscope slide in polyvinyl lactophenol and a cover was added. Head capsules were examined at 100 to 400X using a compound microscope. Chironomids were

Table 9. Rank-ordering of Stations by Concentration of Each Parameter Measured

Parameter Rank (e.g. 1 = Highest concentration of all stations.
Blank = Not among 8 stations most concentrated in that pollutant)

Station	Volatile Solid	IOD	TKN	Oil & Grease	PCB	As	Cd	Cu	Ni	Pb	Zn
2						5					
3c		8			8						
4a			3		1	4		8			
5a	4	2	4		4	1	3	6	2		7
5b		7		8	6		8				
5c	7	3		7							
6	1T	1	1	5	7		1	2	1	7T	4
7	1T		2	2	5	7	4	5	4	7T	5
8a	8		6	6		2		7	5	3	8
8b	5	5	5	1		3	5	1	6	4	2
8c			7	3T	3	6		3		2	3
8d	6	6			2				8		
8e	3	4					7			1	
9a							2		3	6	6
9b											
10											
11			8	3T		8	6	4		5	
12a									7		
12b											
13b											

identified only to genus with the aid of appropriate keys but primarily Mason (16). Other arthropods, molluscs and leeches were identified from wet mounts using the dissecting microscope noted above and suitable taxonomic keys.

Oligochaetes were extremely numerous in samples necessitating subsampling for specimens to identify. The procedure was to place all of the worms from a sample onto a tray (25 x 40 cm) gridded into 1000 numbered square centimeters. Care was taken to spread the specimens evenly over the tray. Next a table of random numbers was used to select a specific numbered square centimeter from the tray. All worms were removed from the centimeter and enumerated. Additional square centimeters in the grid were selected using this procedure until about 100 intact specimens were accumulated for a sample. Then the worms for each subsample were mounted in CMC-10 (Turtox), a non-resinous mounting medium with clearing agent, and a cover slip was added. Specimens were identified to species when possible using suitable taxonomic keys, but mainly Hiltunen (17), and a compound microscope at 100 to 1000X. Peloscolex multisetosus multisetosus, P. m. longidentus and Limnodrilus udekemiames were identified in all life stages (mature and immature). The remaining species (see Table 10) were only identifiable as adults. Immature tubificids which were not identifiable were listed only as with or without capilliform chaetae.

2. Results and Discussion

Oligochaetes dominated the bottom fauna on a numerical (Table 10) and percent composition (Table 11) basis. The number per ponar grab ranged from over 10,000 at station 8b to about 400 at station 7 with a mean for all stations of about 3,000. Large numbers of oligochaetes relative to other benthic organisms is clearly shown by percent composition which ranged from 96.9 at station 7 to 100.0 at station 8b.

The oligochaete fauna was dominated by Limnodrilus spiralis, L. hoffmeisteri, and Tubifex tubifex at most stations. The population level of T. tubifex was particularly high (8,900 per grab, or an estimated 185,000 per m^2) at station 8b and the average for all stations was over 1,800 per grab. T. tubifex was, however, absent at station 13d. L. spiralis and L. hoffmeisteri population levels were generally lower than . tubifex. The maximum and average numbers for these two species respectively were 1500 (estimated 31,000 per m^2) and 640, and 400 (estimated 8,000 per m^2) and 190.

A single species of carnivorous midge, Procladius sp. dominated the chironomid fauna (Table 10). It was present at all stations but in very low numbers (1 to 11, mean of 6). The three genera of midges in samples comprised only from 0.1 to 2.5 percent abundance at stations.

Other taxa represented included: a single mayfly specimen (Hexagenia limbata) which was probably a transient carried by currents from elsewhere, a single gammarid (Crangonyx gracilis), a single crayfish, individual specimens of two leeches (Helobdella stagnalis, and Dina sp.), and sphaerid clams (Pisidium sp.) in very low numbers (2 to 4 per grab).

Table 10. Macrobenthic organisms in Ponar grab samples collected at stations in the Trail Creek Study Area, Michigan City, Indiana in April, 1977

Taxa	Number per Grab at Station					
	4a	6	7	8b	11	13d
Annelida	2142	2237	443	10416	5702	2737
Oligochaeta	2142	2237	432	10415	5702	2737
Tubificidae	2142	2237	432	10415	5702	2737
Ilyodrilus templetoni	45	25	6	--	--	--
Limnodrilus cervix	156	--	--	--	108	--
Limnodrilus claparedeianus	89	25	6	--	--	--
Limnodrilus hoffmeisteri	381	402	153	115	51	57
Limnodrilus spiralis	66	327	179	469	1290	1526
Limnodrilus udekemianus	--	76	60	--	--	27
Peloscolex multisetosus longidentus	135	125	--	--	108	--
Peloscolex multisetosus multisetosus	111	25	--	--	376	--
Tubifex tubifex	446	577	11	8904	1129	--
Unidentifiable immature	713	655	17	927	2640	1070
With capilliform chaetae	334	378	6	698	1237	85
Without capilliform chaetae	379	277	11	229	1403	985
Hirudinea	--	--	1	1	--	--
Glossiphoniidae	--	--	1	--	--	--
Helobdella stagnalis	--	--	1	--	--	--
Erpobdellidae	--	--	--	1	--	--
Dina sp.	--	--	--	1	--	--

Table 10 (Continued)

Taxa	Number per Grab at Station					
	4a	6	7	8b	11	13d
Arthropoda	1	7	13	5	3	13
Crustacea	--	--	2	--	--	--
Amphipoda	--	--	1	--	--	--
Gammaridae	--	--	1	--	--	--
Crangonyx gracilis	--	--	1	--	--	--
Decapoda	--	--	1	--	--	--
Unidentifiable	--	--	1	--	--	--
Insecta	1	7	11	5	3	13
Ephemeroptera	--	--	--	--	--	1
Ephemeridae	--	--	--	--	--	1
Hexagenia limbata	--	--	--	--	--	1
Diptera	1	7	11	5	3	12
Chironomidae	1	7	11	5	3	12
Tanypodinae	1	7	11	5	3	12
Procladius sp.	1	7	9	5	2	11
Psectrotanypus sp.	--	--	1	--	--	--
Alabesmyia sp.	--	--	--	--	1	--
Unidentifiable	--	--	1	--	--	--
Chironominae	--	--	--	--	--	1
Chionomus sp.	--	--	--	--	--	1
Mollusca	4	2	--	--	--	--
Pelecypoda	4	2	--	--	--	--
Sphaeridae	4	2	--	--	--	--
Pisidium sp.	4	2	--	--	--	--

Table 11. Percent composition and total taxa for macrobenthic organisms in Ponar grab samples collected at stations in the Trail Creek Study Area, Michigan City, Indiana in April, 1977

Taxa	Station					
	4a	6	7	8b	11	13d
Annelida	99.8	99.6	97.1	100.0	99.9	99.5
Oligochaeta	99.8	99.6	96.9	100.0	99.9	99.5
Hirudinea	--	--	0.2	T	--	--
Arthropoda	T*	0.3	2.9	T	0.1	0.5
Crustacea	--	--	0.4	--	--	--
Insecta	T	0.3	2.5	T	0.1	0.5
Ephemeroptera	--	--	--	--	--	T
Diptera	T	0.3	2.5	T	0.1	0.5
Mollusca	0.2	0.1	--	--	--	--
Pelecypoda	0.2	0.1	--	--	--	--
Total Taxa**	10	10	11	5	8	7

*T = Trace; less than 0.1%

** Number of different taxa classified at least to genus.

Diversity at all stations was very low. The total taxa, which included organisms identified at least to genus, ranged from 5 to 11 (Table 11). Diversity of organisms was highest (10 to 11) at downstream stations 4a, 6, and 7 and lowest (5 to 8) at upstream stations 8b, 11, and 13d. These data tend to show slightly improved environmental conditions at downstream stations, probably because of the dilution effect of lake water entering the creek during reverse flow. This dilution apparently outweighs the fact that in-place pollutants were generally more concentrated at the downstream stations. In general, however, the biota show severe limitation in diversity at all stations.

The low diversity together with high numbers of oligochaetes and the indicator species predominating indicate conditions of high organic enrichment at all stations. Brinkhurst (18) presents data for European rivers with "bad" organic pollution. Tubificids which were population dominants for this degree of pollution included *T. tubifex*, *L. hoffmeisteri* and *L. udekemianus*. These species, together or in part, were major components of the oligochaete communities at stations sampled in Trail Creek. Brinkhurst also points out that *T. tubifex* and *L. hoffmeisteri* "are the most resistant (oligochaetes) to organic and inert mineral pollution in Britain".

Additional evidence for conditions of poor water quality and environmental conditions (e.g. substrate components) is the few oligochaete species at stations. Downstream stations 4a, 6, and 7 had from 6 to 8 oligochaete species present while more upstream stations had only 3 to 6 oligochaete species. Further, the only crustaceans (*Crangonyx gracilus* and an unidentifiable crayfish) and molluscs (*Pisidium* sp.) sampled were at the downstream stations. These data support the possibility of slightly improved downstream conditions probably because of dilution with cleaner Lake Michigan water. Brinkhurst (18) points out that as environmental conditions improve toward "normal", more oligochaete species are found. Such was the case for Trail Creek downstream compared to upstream stations. It should be emphasized, however, that all stations indicate "bad" to "gross" pollution as defined by Brinkhurst (18) for stream conditions.

Relationships between these findings and the physical-chemical data are investigated in the next section of the report (Section VI).

D. SEDIMENT BIOASSAYS

These studies were performed by the University of Michigan Biological Station at Pellston. Because the description of methods and materials is quite detailed, it appears in Appendix C.

1. Introduction

The purpose of this investigation was to design and conduct acute static bioassays to determine the effects of Michigan City Harbor sediments on biota. Although laboratory bioassay procedures for waterborne toxicants are well-established (19,20) only a few sediment bioassays have been conducted (21,22,23). Because of the dynamic nature of chemical equilibria at the sediment-water interface (24), laboratory test conditions should be maintained as closely as possible to those in the field.

Organisms indigenous to Lake Michigan which were readily adaptable to laboratory conditions were selected for the tests. Four species were included, representing different trophic levels and habitats: Pontoporeia affinis Lindstrom, Cyclops bicuspidatus thomasi Forbes, Daphnia galeata mendotae Birge, and Salmo gairdneri Richardson. The amphipod Pontoporeia affinis was selected because it is a sensitive indicator of polluted conditions and is an abundant species in the benthos of Lake Michigan offshore waters (22). The copepod Cyclops bicuspidatus thomasi was chosen because it is the most abundant crustacean plankter in Lake Michigan (25) and is often most prevalent near the sediment-water interface (25). The cladoceran Daphnia galeata mendotae was selected because Daphnia have frequently been used as freshwater test organisms in laboratory bioassay and comparative literature is readily available (19). This planktonic species is common throughout Lake Michigan (26). Salmo gairdneri (rainbow trout) was chosen as the fourth species because it is commonly stocked in nearshore waters of Lake Michigan and is widely used in bioassay tests.

2. Overview of Methods

Although detailed procedures are given in Appendix C, the general methods are described here for the reader seeking a less thorough description.

Two types of tests were performed: a sediment preference test with Pontoporeia, and toxicity tests with all four organisms. The sediment preference test involved the following major steps:

- Place sediments from 27 stations in small containers, open at top
- Place containers on the bottom of a large aquarium filled with clean water
- Scatter 100 organisms evenly over the water surface
- Tabulate live and dead individuals in each container after 48 hours.

Because Pontoporeia prefers clean sediments, the number of individuals selecting a sediment in this type of test provides some insight regarding the relative suitability of each station to support "desirable" benthic life.

Static bioassays were conducted in apparatus containing sediment from a sampling station, with clean lake water over the sediment. Very little work has been reported in the literature on solid phase bioassays of this type. A manual discussing bioassays of dredged materials has recently been published by EPA and the Corps of Engineers (27), and the solid phase bioassays described there have no variance of water:sediment ratios. The criterion for assessing the dredged material is a comparison of percent mortalities observed with dredged material to mortalities observed with a clean control sediment. Prater and Anderson (23) used a similar approach.

Such a selection of a single water:sediment ratio provides little opportunity for quantitative assessments (e.g. LC50 computations). Therefore, a range of water:sediment ratios was used in this work for each station and for each organism tested. In accordance with standard practice, the same size aquaria were used for all sediment bioassays with each species. Therefore, sediment area was constant and equal to the plan area of the aquarium used for each species. "Concentration" was varied by varying the volume of water over the sediment. The controlled variable in these tests was therefore not the suspected toxicant, but the diluent water. Therefore, the ratio

$$\frac{\text{volume of water}}{\text{surface area of sediment}}$$

is used to derive inferences regarding the toxicity of each sediment.

No literature has been found on such sediment bioassays with variable "concentration." The use of the above ratio therefore has no precedent; it was used simply to be consistent with standard bioassay practice wherein the controlled variable (normally an added toxicant, but in this case the dilution water) is the numerator in the expression for "concentration." As a result of the use of this type of ratio, and in contrast to conventional bioassays, higher LC50 values indicate higher toxicity.

3. Results and Discussion

a. Sediment Preference Test

Duplicate tests were run, referred to here as Trial One and Trial Two. Upon termination of Trial One, 67 individuals had selected sediments, with 42% found in the open-lake sediments from Station 1, and the remainder scattered in 9 of the Harbor sediments. Upon termination of Trial Two, 79 individuals were present in the sediments, with 54% occurring in the open-lake sediments and the remainder found in 15 of the Harbor sediments (Table 12).

The sediment preference test can be useful in determining whether land or water disposal is more suitable for harbor dredgings because alteration of the substrate and introduction of toxic substances at the disposal site are probably the primary factors which cause adverse effects on the benthos. The test is of less direct use to this study of in-place pollutants, because the physical character of sediments is important in the preference of mobile organisms. That is, even unpolluted harbor sediments may be avoided by Pontoporeia simply because they are too fine-grained. The primary applications of the test to this study are two:

Table 12. Results of Sediment Preference Tests with *Pontoporeia*

Station No.	Trial One Live	Trial One Dead	Trial Two Live	Trial Two Dead
1	7	0	2	0
1	8	1	7	2
1	1	1	5	1
1	0	0	3	0
1	6	1	7	0
1	2	1	15	0
Totals	24	4	39	3
2	3	0	3	0
3a	7	0	4	1
3b	0	0	0	1
3c*	0	0	0	0
4a	4	1	0	1
4b	2	1	1	0
4c	0	0	4	0
5a	0	0	1	1
5b*	0	0	0	0
5c	1	0	1	0
6	0	0	4	0
7	3	0	2	1
8a*	0	0	0	0
8b*	0	0	0	0
8c	0	0	1	0
8d	1	0	0	0
8e	4	1	0	0
9 *	0	0	0	0
9b*	0	0	0	0
10	0	0	1	0
11 *	0	0	0	0
12a*	0	0	0	0
12b	0	0	1	0
13b	11	0	2	0
13c	0	0	5	2
13d*	0	0	0	0
Totals	36	3	30	7

*Sediments which did not contain any *Pontoporeia* after either trial.

- As a simple estimator for overall substrate suitability

- As a quick and approximate guide to toxicity of a large number of sediment samples.

Tests with Michigan City Harbor sediments indicated that *Pontoporeia* displayed greatest preference for open-lake sediments. Those Harbor sediments selected by *Pontoporeia* did not appear to adversely affect this species, since mortality was low or absent in the preference tests.

Gannon and Beeton (22) conducted similar sediment preference tests on sediments from harbors of Lakes Michigan, Erie, and Ontario and observed that *Pontoporeia* preferred those sediments with the highest proportion of sand, lowest chemical oxygen demand, and lowest amounts of volatile solids, phosphate-phosphorus, and ammonia-nitrogen. They suggested that *Pontoporeia* may be especially sensitive to petroleum hydrocarbons since dead amphipods were usually covered with oil. However, other potential toxicants such as heavy metals, chlorinated hydrocarbons, or pesticides may be causative factors. These potential relationships are explored in Section VI, where bioassay data are related to sediment analyses.

b. *Bioassays*

The three test sediments displayed the same increasing order of toxicity (4a-11-8b) in all bioassays (Tables 13-15). Extending the duration of assays with *Pontoporeia* and *Daphnia* from 48 to 96 hours resulted in a slight increase in mortality although the slope function remained nearly the same. Mortality at maximum test concentrations employed averaged 25.7% for Station 4a sediments, 53.3% for Station 11, and 97.2% for Station 8b (Tables 13-15).

Mortality was sufficiently high in Station 8b sediments to calculate LC 50 values with all test organisms. Based on LC 50 values, *Salmo* were most sensitive to 8b sediments, followed by *Daphnia*, *Pontoporeia*, and *Cyclops*.

Sediments from Station 11 were less toxic than 8b sediments. Mortality was sufficiently high in the 96-hour assays with *Daphnia* and both 48 and 96-hour assays with *Pontoporeia* to calculate LC50 values. In remaining tests with this sediment, LC 50 values were estimated by extrapolation. *Salmo* was most sensitive to Station 11 sediments, followed by *Pontoporeia*, *Daphnia* and *Cyclops*.

Sediments from Station 4a were least toxic. The LC 50 values were estimated by extrapolation for all test organisms. *Salmo* was least sensitive to sediments from Station 4a, with no mortality occurring in any of the test concentrations. *Cyclops* were most sensitive, followed by *Pontoporeia* and *Daphnia*.

Behavior of the organisms under test conditions frequently indicated physiological stress. *Pontoporeia* tended to burrow immediately when

Table 13. Summarized Data for Sediment Bioassays with *Pontoporeia affinis*

Station	Maximum Percent Mortality	LC50 (liters/m^2)	Slope Function
48-hour Bioassay			
4a	31	6.2* (8.5-4.5)+	0.46
8b	100	20.5 (23.0-18.2)	0.71
11	72	17.0§ (17.2-16.1)	--
96-hour Bioassay			
4a	37	8.6* (11.5-6.4)	0.37
8b	100	23.5 (27.0-20.4)	0.71
11	96	96.0§ (20.1-18.0)	--

*Extrapolated value from concentrations less than the LC 50
+Lower and upper 95% confidence limits.
§Estimated LC50 determined by the moving average-angle method of Harris (28)

Table 14. Summarized Data for Sediment Bioassays with *Daphnia galeata mendotae*

Station	Maximum Percent Mortality	LC50 (liters/m^2)	Slope Function
48-hour Bioassays			
4a	28	2.7* (5.6-1.3)+	0.13
8b	100	30.3§ (35.2-25.4)	--
11	35	8.6* (13.6-5.4)	0.40
96-hour Bioassays			
4a	40	6.6* (11.0-4.0)	0.17
8b	100	41.2§ (45.2-37.2)	--
11	69	13.3§ (15.1-12.0)	--

*Extrapolated value from concentrations less than the LC 50.
+Lower and upper 95% confidence limits.
§Estimated LC50 determined by the moving average-angle method of Harris (28).

Table 15. Summarized Data for 48-hour Sediment Bioassays with *Cyclops bicuspidatus thomasi* and *Salmo gairdneri*

Station	Maximum Percent Mortality	LC50 (liters/m2)		Slope Function
Cyclops bicuspidatus thomasi				
4a	18	6.7*	(8.6-5.2)+	0.61
8b	100	17.5	(20.3-15.1)	0.59
11	18	8.1*	(11.6-5.7)	0.49
Salmo gairdneri				
4a	0	--	--	--
8b	83	94.5	(111.2-80.3)	0.64
11	30	44.5*	(58.6-33.8)	0.58

*Extrapolated value from concentrations less than the LC 50

+Lower and upper 95% confidence limits.

introduced into the test vessels but generally left the sediments when physiologically stressed. Dead individuals were found lying on the sediment surface. Daphnia rarely experienced entrapment in the surface film at the air-water interface while in culture or during test conditions with open-lake sediments, but entrapment occurred frequently under toxic test conditions. This apparently resulted from erratic swimming behavior elicited by physiological stress. Behavioral indications of stress in Cyclops could not be observed because of their very small size and burrowing nature. Active movements of Salmo kept the sediments agitated. This sediment disruption resulted in such a high turbidity level with sediments 8b and 11 that individuals could be observed only when near the surface. Prior to death, stressed individuals were present near the surface, whereas healthy individuals were primarily near bottom.

It is quite likely that suspended sediments were a significant factor in the results for Salmo, especially in view of the fact that Station 4a, which did not have high turbidity in the Salmo tests, produced no mortalities. Tests with Stations 1 and 4a for Salmo, and for all stations with the other three organisms, were characterized by consistently clear water.

Sediments 4a and 11 were considerably less toxic than 8b sediments. The relatively low mortalities do not appear to be artifacts resulting from experimental design. Bioassays could not be run at any higher concentrations than were actually employed, since this would have resulted in water volumes being inadequate for maintenance of organisms.

The results of the physical, chemical and biological investigations are interrelated in Section VI.

VI: INTERPRETATION: CHARACTERIZATION OF ZONES WITHIN THE CREEK AND HARBOR

Having described in an objective and quantitative way the characteristics and effects of Trail Creek sediments, this report must interpret those findings. This interpretation is needed to define areas or zones with certain sets of characteristics so that priorities can be assigned for any recommended action.

A. RELATIONSHIPS AMONG BIOLOGICAL AND PHYSICAL-CHEMICAL DATA

1. Macrobenthos Investigation

The results of the detailed studies of macrobenthos, presented in Section V, showed that even at stations that were relatively "clean" from a chemical standpoint, the benthic assemblages indicated severe organic pollution. Annelida comprised more than 97% of the organisms at all six stations selected for detailed study (Table 10), and the total taxa ranged from 5 to 11. Little difference was noted between stations, although conditions at the downstream stations appeared to show slightly improved conditions relative to the upstream stations.

Chemically, there is no apparent corresponding evidence that the three downstream stations (4A, 6, and 7) were any lower in in-place pollutants than the three upstream stations (8B, 11, and 13D). Two possible interpretations may be made:

a) Benthic environments in the entire reach between stations 4A and 13D are so polluted that none of the benthic assemblages is significantly "healthier" than any other. OR,

b) The downstream benthic assemblages are, in fact, slightly less improverished than those upstream. The dilution by lake water, enhanced by the seiche effect, permits a slightly more diverse benthic community to exist.

Formal resolution of this question is not possible with the data available, and it is probably not a worthwhile goal. It is clear that the entire reach from Station 4A to Station 13D (at least) is characterized by a poor benthic habitat, and fine gradations within this reach have little significance. A clearer distinction among stations was provided by the bioassay data.

2. Bioassays

The approach used to interpret bioassay data in view of sediment quality has been simply to plot LC50 vs. concentration of in-place pollutants. From this effort, some possible relationships between sediment toxicity and pollutant concentrations have appeared. Several sediment contaminants, however, have not been shown by this effort to exert toxicity. The most likely reason for not demonstrating the toxicity of known pollutants in the sediment is that the concentrations of such substances were not sufficient to exert independent, discernible toxic effects in the presence of more dangerous concentrations of other substances. Another possibility is that antagonistic effects among sediment contaminants were exerted in some samples. That is, the presence of one pollutant may have decreased the toxicity of another. Such effects sometimes occur with combinations of heavy metals, although synergistic effects are also possible among other combinations.

Some of the correlations between LC50 and pollutant concentration are shown in Figures 7 (lead), 8 (cadmium), 9 (percent volatile solids) and 10 (oil and grease). For these parameters, concentrations and toxicities both increase monotonically in the station sequence 1, 4A, 11, 8B. (In viewing the graphs, it is important to note that LC50 is expressed in $1/m^2$, as explained in Section V. Therefore, in contrast to conventional bioassays, higher LC50 values indicate higher toxicity.)

No one of the plots of Figures 7 through 10 should be taken as proof of a particular substance's exertion of toxicity in these tests. Many of the parameters are highly intercorrelated in Michigan City and in other waterways. Therefore, only one or two of the parameters might be important, with the others implicated only circumstantially because of their correlation with the causative toxicants.

One illustration of this possibility is in Figure 11, showing an "effect" of percent solids similar to the trends of known pollutants shown in Figures 7 through 10. Lower percent solids would appear to exert higher "toxicity" if this Figure were taken out of context. In fact, low-solids-content sediments in urban areas tend to consist of large concentrations of recently settled fines, organics, and ferrous iron and manganese oxides, all of which are likely to have high concentrations of sorbed toxic pollutants. On the other hand, it can be argued that low solids content could exert its own effects through the ease by which solids can be resuspended from such fluffy sediments. Such may have been the case in some *Salmo* tests, but with the other organisms the water remained clear.

Despite the cited uncertainties, it can be stated with some confidence that one or more of the parameters represented by Figures 7 through 11 were responsible for the observed toxicity, at least in part. This statement cannot be made for other investigated pollutants. For example, the station with highest PCB concentration (4A) produced relatively little toxicity while a station with undetectable PCB (8B) was the most toxic of those tested (Figure 12). Similarly inconsistent effects were noted for zinc, arsenic, TKN, immediate oxygen demand, and percent clay.

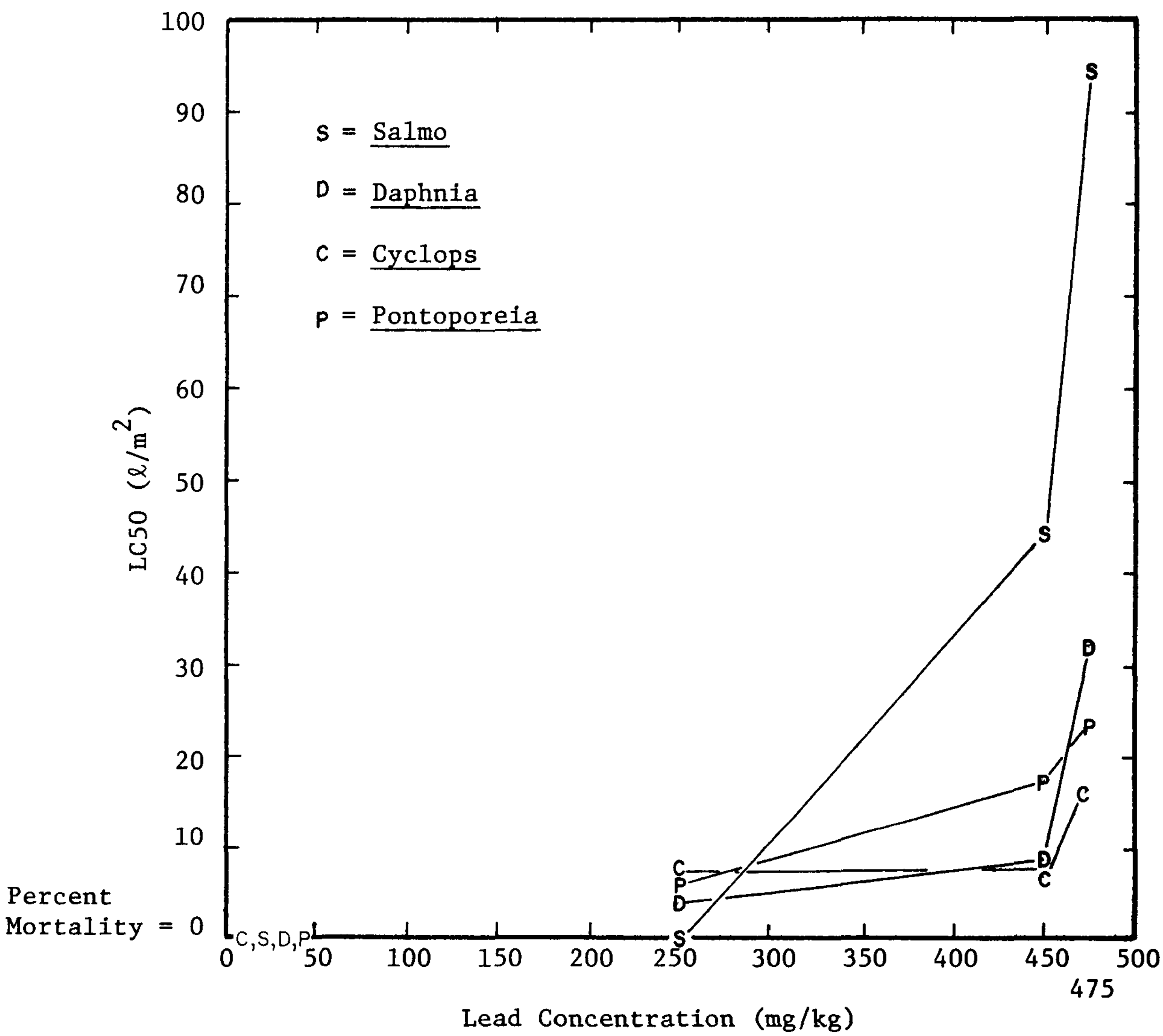

Figure 7. Apparent Effect of Lead Concentration on Toxicity of Michigan City Sediments

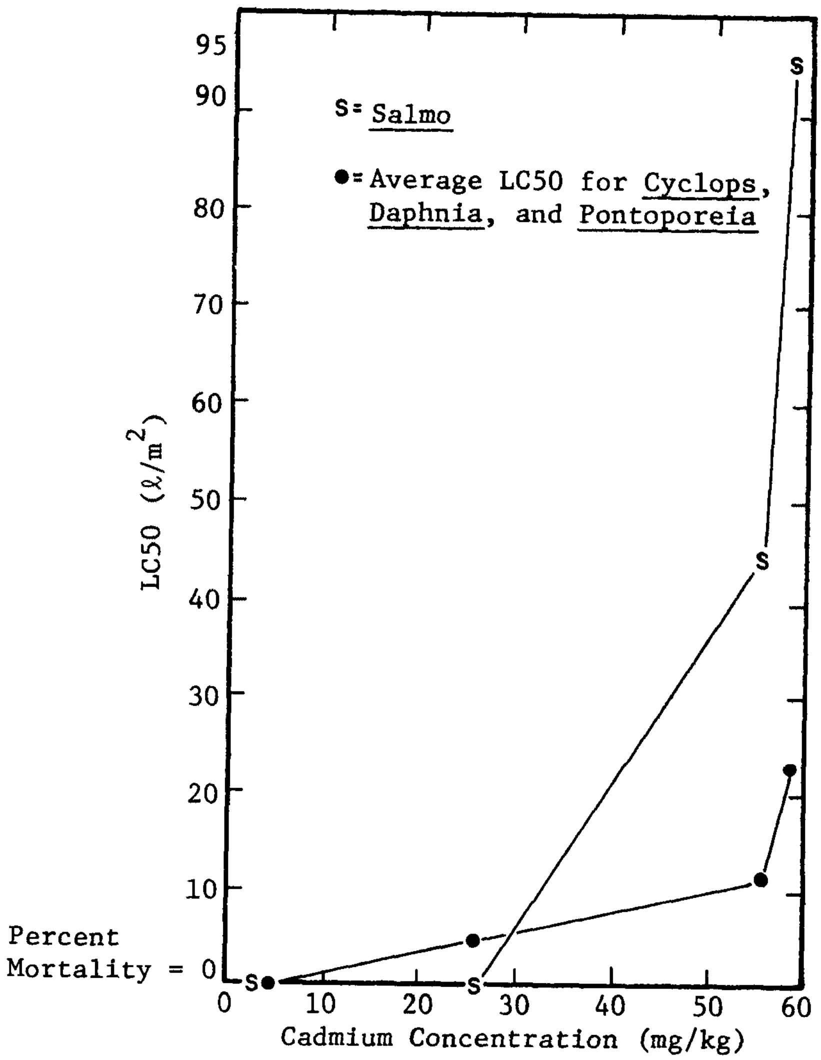

Figure 8. Apparent Effect of Cadmium Concentration on Toxicity of Michigan City Sediments

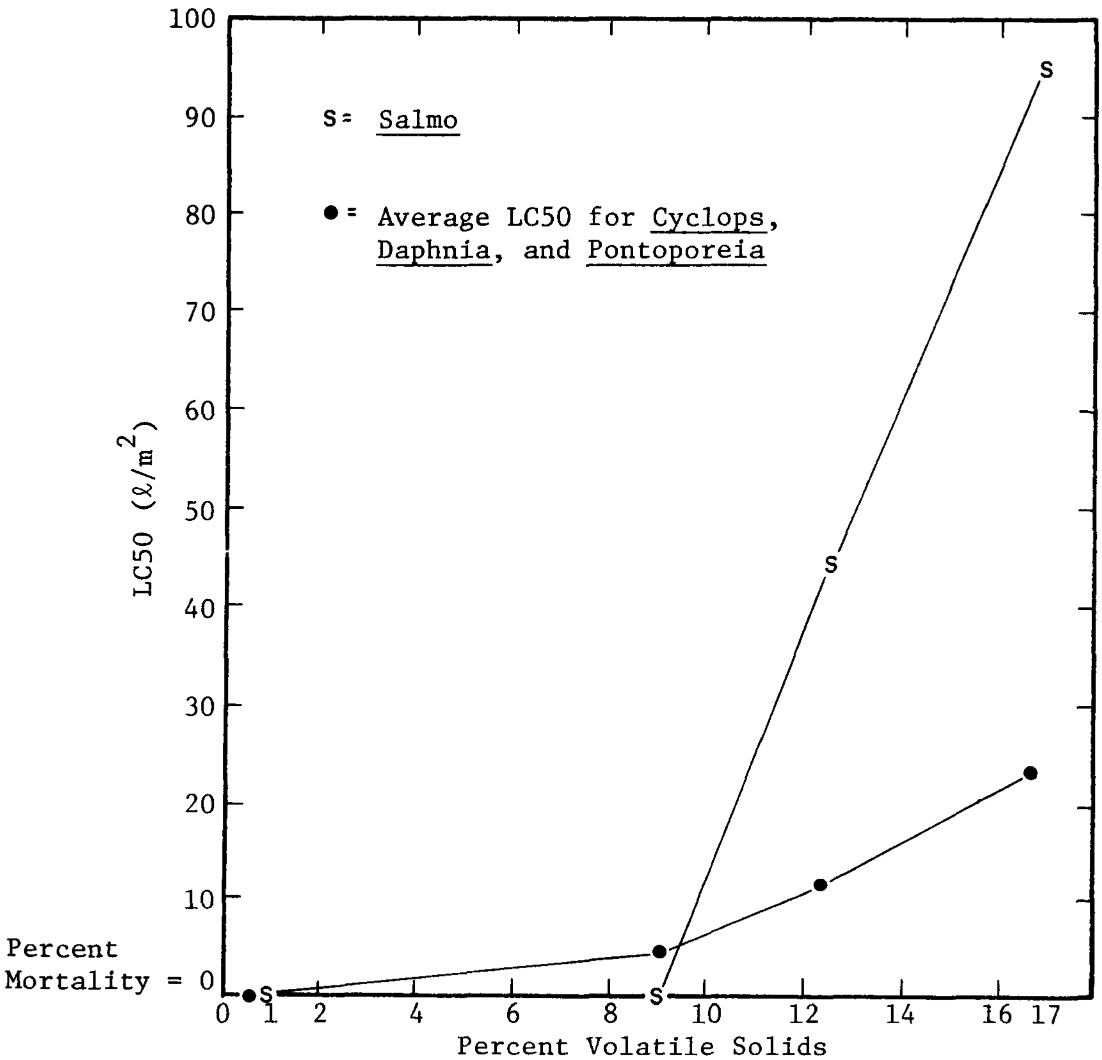

Figure 9. Apparent Effect of Volatile Solids on Toxicity of Michigan City Sediments

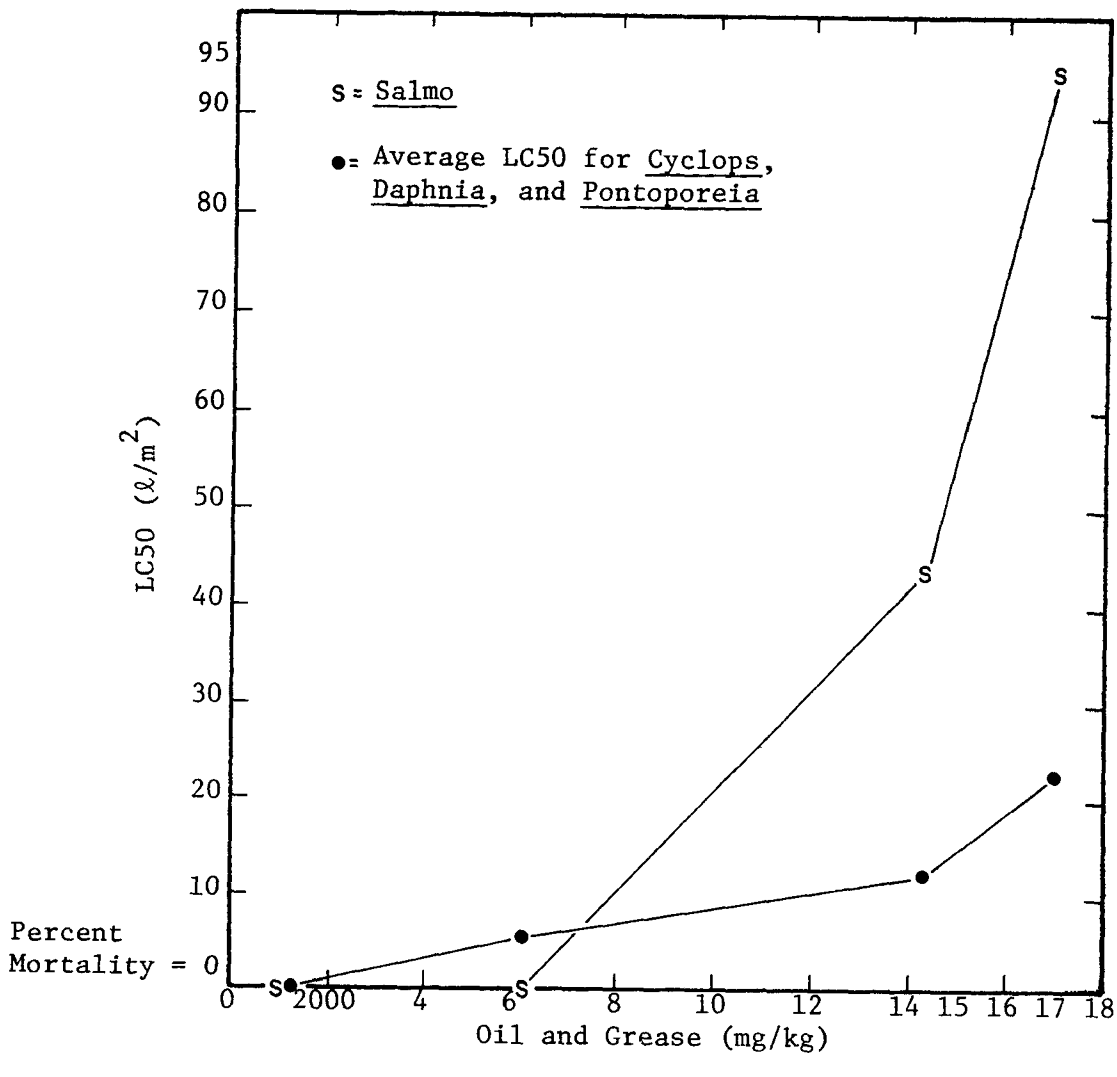

Figure 10. Apparent Effect of Oil and Grease Concentration on Toxicity of Michigan City Sediments

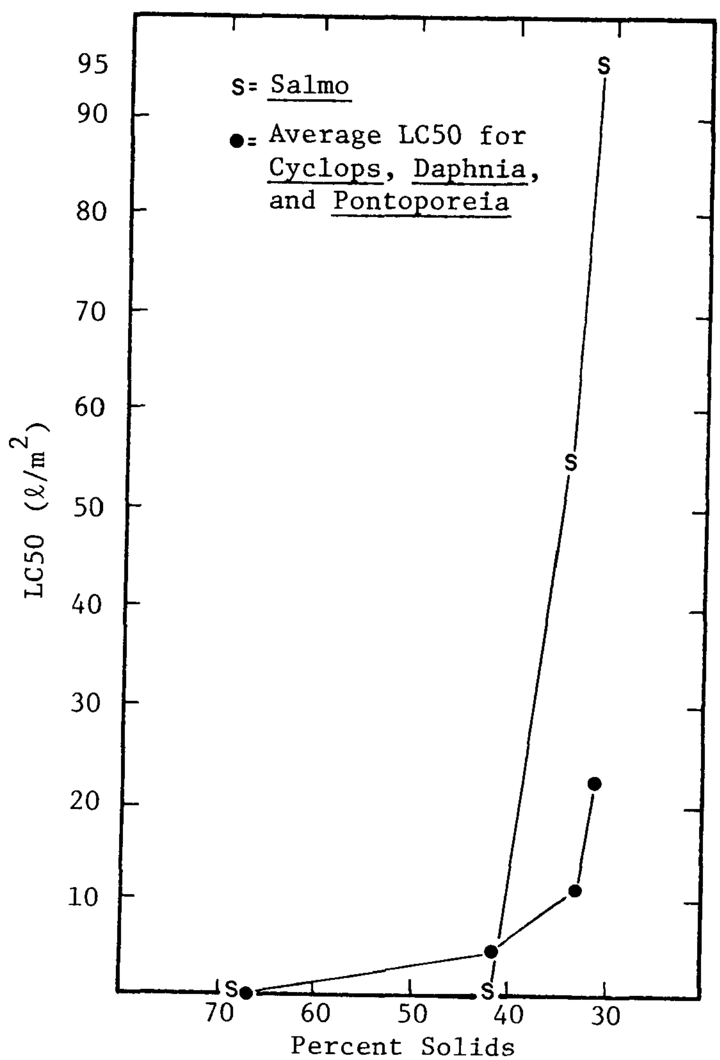

Figure 11. Apparent Effect of Percent Solids on Toxicity of Michigan City Harbor Sediments

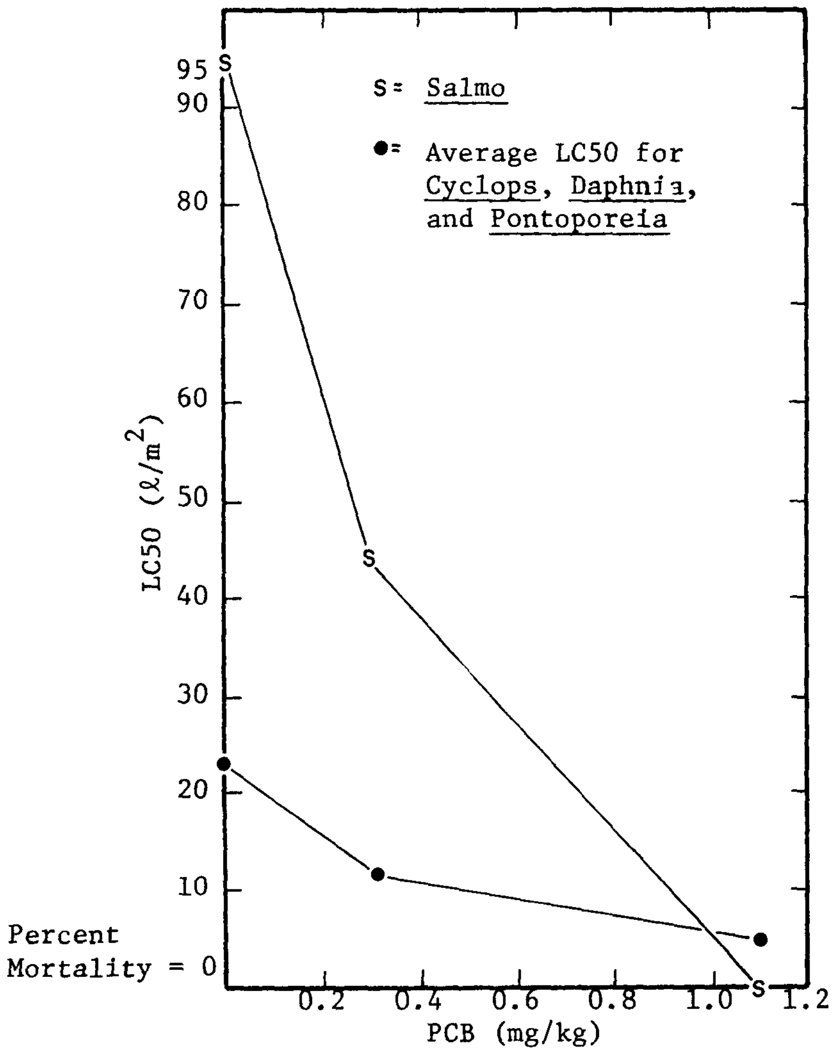

Figure 12. Relationship Between PCB Concentration and LC50 of Michigan City Harbor Sediments

B. RANKING OF ZONES WITHIN THE HARBOR

1. Criteria

a. Biological

To rank the zones in Trail Creek/Michigan City Harbor on an environmental basis, one must relate the laboratory investigations conducted in this study to each other and to the real conditions in the area. Investigation of the benthic organisms present appears to be the most direct method of assessment. However, recent and continuing mitigations of pollutant discharges to Trail Creek may be improving the aquatic system faster than the benthic communities can adjust, thereby slightly lessening the validity of macrobenthic studies. Bioassays seem to be a more direct test of the present effects of the sediments, but have some degree of deviation from the real world in that:

- Some trout tests involved unrealistically high levels of suspended solids because of resuspension by fish activity.
- Some organisms tested, while being appropriate for bioassays in their sensitivity to pollution, may be too sensitive for any urban waterway. In other words, other organisms could perhaps form a very desirable aquatic community in Trail Creek but would not yield a significant number of mortalities in bioassays of the type used in this study.

Therefore, to summarize the biological investigations in terms of criteria, the following observations are made:

- The environment for macrobenthos appears undesirable at least from Station 4A to Station 13D. No criteria significantly differentiating "desirable" from "undesirable" can arise from these data.
- Toxicity to a variety of organisms ranges from nil at control Station 1 to a maximum at Station 8B, with 4A and 11 (in that order) as intermediates. Several criteria could arise from these data:
  - A threshold value could be selected for LC50, above which all sediments would be considered "polluted".
  - All sediments except Station 1 could be considered "polluted" because some toxicity was observed at those stations.
  - The entire study area could be considered acceptable, implying that the toxicities observed were not significant.

In the absence of a generally accepted method for assessing these types of biological data, it appears that the logical criterion should be that only zero toxicity should be accepted. Given the uniformly poor quality of the macrobenthic community, the bioassay data seem to provide a level of differentiation that is not significant.

b. Chemical

Prater and Anderson (23), in their paper on sediment bioassays, cited bulk analysis criteria developed in EPA Region V for Great Lakes Harbors (14). Some of the pollutants listed in those criteria are shown in Table 16, with the ranges of conditions observed at Michigan City. The last column in Table 16, giving stations located with the aid of Figure 5, shows most of Trail Creek between the Yacht Basin and the Wastewater Treatment Plant to be "heavily polluted."

2. Rankings

By two sets of criteria -- the Region V chemical criteria and the macrobenthic evaluations -- the entire reach from the wastewater treatment plant downstream to the Yacht Basin is well described as heavily polluted with respect to bottom sediments. The bioassay data show some differences in toxicity within this reach. Those differences, while statistically significant (there is very little overlap of the 95% confidence limits on LC50 from station to station), do not appear important in the overall context of this study. That is, while Station 4A's toxicity was low in relation to Stations 8B and 11, the sediments at Station 4A must be considered poor habitat by any rational criteria.

Therefore, no rankings of isolated "hot spots" have emerged from this study. The surface sediments of Trail Creek and Michigan City Harbor from the wastewater treatment plant to the Yacht Basin should be considered a single deposit of several in-place pollutants. Trail Creek upstream of the wastewater treatment plant is relatively uncontaminated, as is the mouth of the Harbor lakeward of the Yacht Basin entrance. The Yacht Basin itself (Station 2) appears to be a unique zone chemically. It has several in-place pollutants above the Region V "Heavily polluted" level, but appears less contaminated relative to the upstream areas. Except for TKN, oil and grease, PCB, and cadmium, these sediments are similar to those at Station 4A and therefore should be grouped with the polluted reach.

C. SOURCES OF IN-PLACE POLLUTANTS

Trail Creek has a clean, sandy benthic habitat upstream of a large landfill and the municipal wastewater treatment plant, which are in close proximity to each other. Downstream of these two obvious sources of pollutants, there lies a large, relatively uniform deposit of in-place pollutants. Because of the absence of any severe "hot spots" within the polluted area, it can be inferred that no important point sources such as present or historic industrial outfalls are causing problems.

Table 16. EPA Region V Bulk Analysis
Guidelines (14), Compared with Michigan City Data

Parameter	Nonpolluted	Moderately polluted	Heavily polluted	Reach (Station to Station) in Study Area tha is "Heavily Polluted" by these Guidelines*
Volatile solids	<5%	5%-8%	>8%	3C - 13B
COD	<40 000	40 000-80 000	>80 000	
Total Kjeldahl Nitrogen	<1 000	1 000-2 000	>2 000	4A - 12A
Oil and Grease	<1 000	1 000-2 000	>2 000	2 - 13D
Lead	<40	40-60	>60	2 - 13C
Zinc	<90	90-200	>200	2 - 13C
Mercury	<1.0	N.A.	>1.0	
Ammonia	<75	75-200	>200	
Cyanide	<0.10	0.10-0.25	>0.25	
Phosphorus	<420	420-650	>650	
Iron	<17 000	17 000-25 000	>25 000	
Nickel	<20	20-50	>50	2 - 12A
Manganese	<300	300-500	>500	
Arsenic	<3	3-8	>8	Scattered stations
Cadmium			>6	2 - 13D
Chromium	<25	25-75	>75	
Barium	<20	20-60	>60	
Copper	<25	25-50	>50	Scattered stations

All values expressed as mg/kg dry weight unless otherwise noted.

*Some stations within the indicated stream reaches may be below the "Heavily polluted" guideline for one or more pollutants, but these few exceptions do not seriously reduce the uniformly polluted stream reaches indicated.

Detailed investigations of the wastewater treatment plant and of the landfill are beyond the scope of this study. Techniques for identifying sources are limited to inferences based on the location of in-place pollutants in relation to likely sources. Because the landfill and the wastewater treatment plant are in the same area upstream of the in-place pollutants, their relative impact cannot be determined. It can be stated with some confidence that no single source other than these two is very important, because there is little change in the character of in-place pollutants throughout the polluted reach. Pollutants entering Trail Creek in the landfill/treatment plant area appear to flocculate and settle to the bottom over a long reach of Trail Creek and Michigan City Harbor.

The determination of probable future deposition of in-place pollutants is contingent on ascertaining the relative effects of the landfill and the wastewater treatment plant. Some informed observations can be made, however. The wastewater treatment plant has upgraded its processes and has intensified its surveillance of industrial sewer users in recent years. The process upgrading has featured chemical precipitation using alum for phosphate removal, and was installed in 1973. Before installation of chemical treatment, effluent phosphate concentrations averaged 10 mg/ℓ. Now, effluent phosphate averages less than 0.5 mg/ℓ (29). The more toxic pollutants described in this project are not monitored at the treatment plant, but an efficient system of this type should enhance removal of a variety of substances, especially those occurring in suspended or colloidal form and likely to settle out in the receiving water. Therefore, the present in-place pollutant deposits represent a historical discharge that is now improved. Any landfill leachate entering Trail Creek probably contains only dissolved pollutants because particulate matter should be removed by the soil's effect in filtering leachate. Many of these substances may become sorbed to natural stream particulates and possibly suspended solids released by the nearby treatment plant, so these substances are likely to settle to the bottom upon reaching the more quiescent downstream areas. Another potential means of contamination by the landfill is direct erosion from rainfall and runoff. If the landfill should be found by further investigation to be a major source of in-place pollutants in Trail Creek, pollution abatement would pose a major problem. No action to ameliorate the in-place pollutants should be undertaken before this question of sources is resolved.

VII. ASSESSMENT OF POTENTIAL CORRECTIVE ACTIONS

The previous section showed that the in-place pollutants in the sediments of Trail Creek/Michigan City Harbor exert adverse effects on the aquatic system. Several options are available for responding to the conditions of polluted sediments in Michigan City Harbor/Trail Creek. These options can be generally categorized as:

- No action
- Dredging
- Covering

Each option has costs and benefits (except for "no action"). The following assessments attempt to evaluate these factors in a manner that is realistic considering the present and potential uses of the water resource under study.

Of utmost importance is the plan by the U.S. Army Corps of Engineers' Chicago District to perform maintenance dredging in the near future, with upland disposal and filtration of the return water from the diked disposal area. With knowledge of that plan, this study has sought to accomplish the following tasks in arriving at recommendations:

- Evaluate the Corps' plans in the context of Section 115 of PL92-500.

- Evaluate modification to the Corps' plans. For example, consider dredging a greater or lesser area to a greater or lesser depth.

- Evaluate options that do not include any dredging.

A. DREDGING

It is useful to describe the dredging procedures commonly used in the United States in a brief and general way before discussing the site-specific aspects of the dredging option.

Dredges can be classified as mechanical or hydraulic. Mechanical dredges operate much like land-based excavation equipment, simply digging sediment from the bottom and transferring it to a hold. The hold is normally in a barge, which transports the material to a disposal site. The most commonly used mechanical dredge is the clamshell. A clamshell dredge consists of a crane-pulley-cable system mounted on a barge. The cables support and control a set of iron jaws that are dropped, open, into the sediment where they are closed, enveloping a sediment mass that is then brought to the surface and dumped into a barge.

Hydraulic dredges operate by dislodging sediments and pumping them, slurried with ambient water, through a pipe. Although there are many variants, the most commonly used dredges of this type are the cutterhead and the hopper dredge. A hopper dredge is an independent vessel and normally pumps sediments into its hold ("hoppers") for transport to the disposal site. A cutterhead dredge has a spinning array of iron teeth that mechanically dislodge sediments adjacent to the suction pipe inlet. The slurried sediment is pumped through a discharge pipeline to the disposal area, either in water outside the channel or in a diked area.

1. Present Plans for Dredging at Michigan City

The Corps of Engineers plans to maintain the navigation project at Michigan City with a cutterhead dredge, discharging to a confined upland disposal site. There are few data available regarding the water quality effects of the various dredge plants because most aquatic investigations have emphasized open-water disposal. The available data do indicate, however, that the planned dredging and disposal methods are the least disruptive of the generally available options involving dredging and disposal.

The scope of planned maintenance dredging is best explained by excerpts from the Corps' Draft Environmental Impact Statement (30):

> "Project features to be maintained will consist of:
>
> An entrance channel starting at the detached breakwater and continuing to the second turning basin at Blocksom & Co. This channel will be maintained at a 12-foot depth lakeward of the entrance to the small-boat outer basin, and at a 10-foot depth from the entrance to the outer boat basin upstream to the second turning basin at Blocksom & Co.
>
> A channel in Trail Creek 6 feet deep from turning basin No. 2 to the E Street bridge.
>
> Turning basin No. 1 at Cargill Grain Co., which will be maintained at a 10-foot depth.
>
> Turning basin No. 2 at Blocksom & Co., which will also be maintained at a 10-foot depth.
>
> . . .
>
> After the navigation channels have been surveyed, dredging activities are conducted to remove channel shoals that have decreased channel depths to levels that are less than desired depths. Based on past experience at Michigan City Harbor, it is anticipated that the portion of the harbor channel from the entrance to the small-boat outer basin upstream to the limit of the project in Trail Creek will require the removal of approximately 5,000 cubic yards of sediment per year to

maintain safe navigation depths. In order to remove accumulated sediments in the most economical manner, this portion of the channel will not be dredged annually, but only once every five years with each dredging operation requiring the removal of approximately 25,000 cubic yards of sediment. Dredging in this portion of the navigation project is expected to be performed by a contract hydraulic dredge. The frequency of dredging operations in the channel from the entrance to the small-boat outer basin lakeward to the detached breakwater to maintain the desired 12 foot depth is unknown due to past experience being confined to maintenance of an 18-foot channel. This area will be dredged as the need arises to maintain the 12 foot depth and to provide for safe navigation. This area will be dredged by the Corps of Engineers or by a contractor using a clamshell or dipper dredge and scows to transport the dredged material.

. . .

During 1968, 1969, and 1970, the harbor entrance channel was dredged by a dipper dredge and the dredged material was deposited in an open-lake disposal area in the amount of 25,000 to 48,000 cubic yards per year. In 1971 and 1972, the entrance channel was maintained by a dipper dredge with the dredged materials being deposited near the shoreline west of the harbor area in the amount of 24,900 cubic yards in 1971 and 5,800 cubic yards in 1972. No maintenance dredging has been performed since 1972, when it became apparent that deep-draft commerce needing the 18-foot project depth would not return.

Disposal of Dredged Material Unsuitable for Unrestricted Disposal

Material to be removed from the portion of the channel from the entrance to the small-boat outer basin upstream to the E Street bridge has been classified by the Administrator of the USEPA as unsuitable for unrestricted or open-lake disposal. Under Section 123 of the River and Harbor Act of 1970 (PL 91-611), the Corps of Engineers is required to confine polluted dredged materials in a diked disposal facility to eliminate any further degradation of water quality by open-lake disposal. A contained disposal facility will therefore be built on a site that has been approved by all local, state and Federal regulatory agencies. Section 123 provides that the capacity of the site will be sufficient to contain a 10-year period of dredged material. Engineering analysis and past experience at Michigan City have shown that approximately 5,000 cubic yards of sediments must be dredged annually to maintain desired depths in the channels. Therefore, the contained disposal facility has been designed with a 50,000 cubic yard capacity to accommodate two dredging operations of 25,000 cubic yards each.

. . .

During dredging operations, the hydraulic dredge will discharge directly into the contained disposal facility through a pipeline extending between the hydraulic dredge and the contained disposal facility. This pipeline will float directly to the disposal site. The pipeline will carry a slurry of approximately 90 percent water and 10 percent sediment. When the slurry is pumped into the contained disposal facility, the water will exit the site through the sand filter leaving behind the drying sediments. Water quality monitoring of the contained disposal facility will be made before, during, and after disposal operations to monitor the effectiveness of the sand filter and dike. This water quality monitoring program will include sampling of physical, chemical, and biological parameters in coordination with the USEPA, State of Indiana Department of Natural Resources (DNR), and the Indiana Stream Pollution Control Board. Immediate remedial action will be taken should the monitoring reveal any water quality problems.

. . .

Disposal of Dredged Material Suitable for Unrestricted Disposal

Dredged material to be removed from the harbor entrance channel extending from the entrance to the small-boat outer basin lakeward to the detached breakwater has been classified by the Administrator of the USEPA as suitable for unrestricted or open-lake disposal. The Chicago District's experience in maintaining the authorized 18-foot channel at Michigan City Harbor indicates that this entrance channel may not need to be dredged frequently to maintain the proposed 12-foot depth. However, some dredging at irregular periods will be needed. Disposal of the sediments from the entrance channel, consisting of clean sand deposited by lake currents and storms as littoral drift, will be disposed of in an open-lake disposal area which has been approved by the Indiana DNR."

2. Relationship of Dredging Plans to In-Place Pollutants

Figure 13 shows the areal extent of in-place pollutant deposits that are not included in the planned maintenance dredging. The approximate areas of these deposits are: Yacht basin, 55,000 sq m; area to the west of the navigation channel opposite the city wharf (near Turning Basin No. 1), 25,000 sq. m; E Street Bridge to wastewater treatment plant, 17,000 sq m; Total 97,000 sq. m. The area to be dredged is approximately 106,000 sq m, practically equal to the polluted area outside the proposed maintenance project.

At least as important as area is the depth of cut planned for the dredging project and that which would be required to remove in-place pollutants. These depths are needed to compute the volumes (in situ) of material to be dredged either under present plans for the navigation channel or under any proposed plans for dredging to remove in-place pollutants.

To calculate the thickness of material to be removed, the following procedures have been used:

a. The study area was divided into six parts, based on such factors as water depth and location in or out of the authorized channel.

b. For dredging to maintain desired depths, the actual average water depth in each area was subtracted from the desired depth.

c. For dredging to remove in-place pollutants, the thickness of the deposit was estimated from actual field data where possible. Where the coring device struck hard clay, its progress was halted. The length of soft core material retrieved, multiplied by 2 (see Appendix A), was taken as the deposit thickness. In the polluted area lakeward from Franklin Street Bridge, this thickness was fairly constant, averaging approximately 1.3 meters. From Franklin Street Bridge upstream, the small craft that could be used and the limited depth of fall of the corer prevented the corer from penetrating the entire thickness of in-place pollutant deposits. In these areas, the deposit thickness was assumed at 1.5 meters, an estimate based on the thickness observed lakeward of Franklin Street Bridge.

The results of these computations are summarized in Table 17.

The estimates of material to be dredged shown in Table 17 permit the following observations.

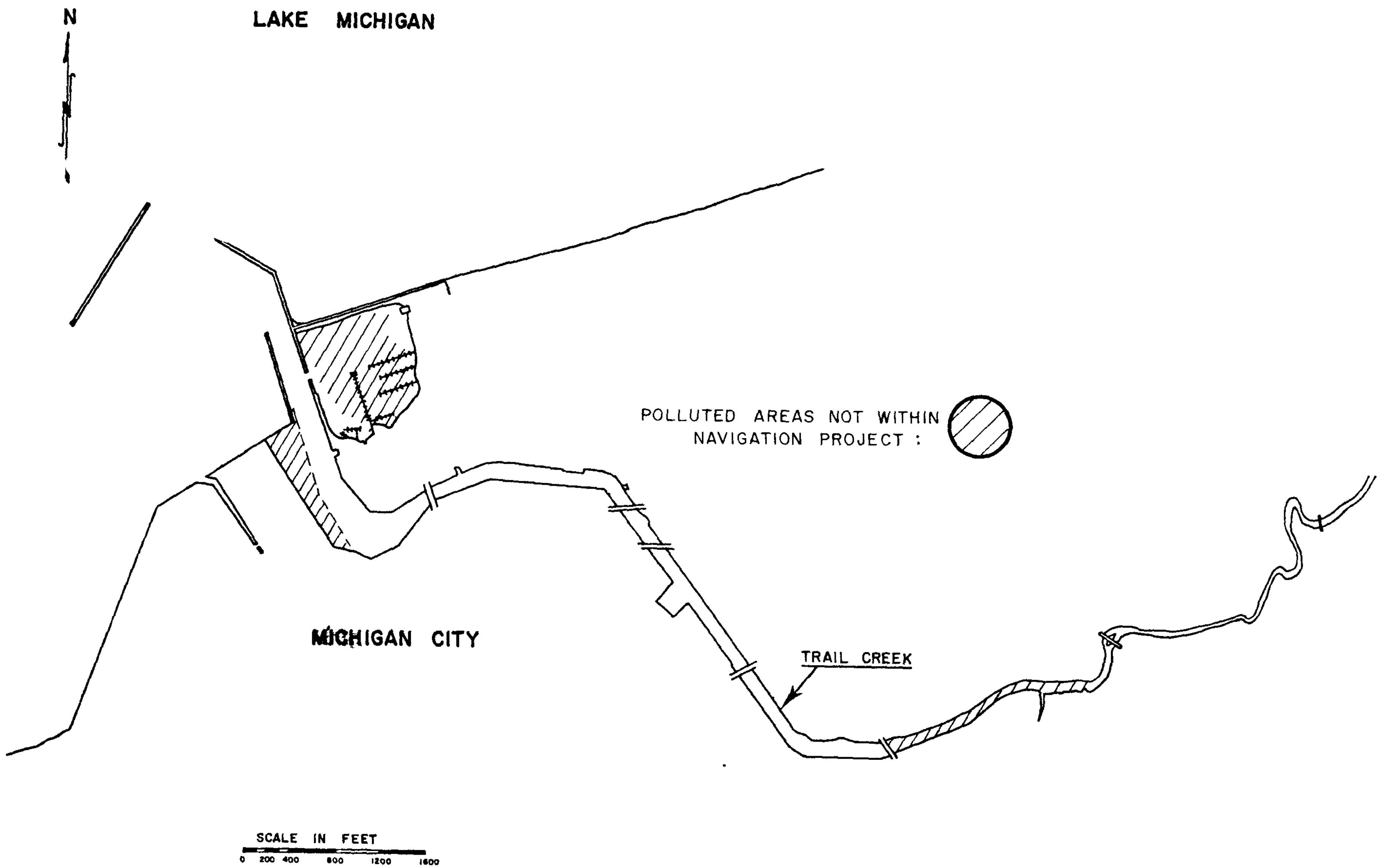

Figure 13. In-Place Pollutant Areas Outside Navigation Project

Table 17. Summary of Areas and Volumes of In-Place Pollutants Compared to Proposed Maintenance Dredging

Location	Area (sq m)	Sediment Thickness (m)		Volume (cu m)	
		Maintain Navigation Only	Remove Pollutants	Maintain Navigation Only	Remove Pollutants
Yacht Basin	55,000	0	0.7	0	39,000
Yacht Basin to Franklin St. Bridge, in channel	46,000	0	1.3	0	60,000
Yacht Basin to Franklin St. Bridge, outside Channel	25,000	0	1.3	0	33,000
Franklin St. Bridge to Turning Basin No. 2	38,000	1.4	1.5*	53,000	57,000
Turning Basin No. 2 to E Street Bridge	22,000	0.8	1.5*	18,000	33,000
E St. Bridge to Waste-water Treatment Plant	17,000	0	1.5*	0	26,000
Total to maintain desired navigation depths only				71,000	
Total to maintain navigation and remove in-place pollutants					248,000

*Estimates based on other parts of the study area.

a. Corps of Engineers Volume Estimates

The estimates quoted earlier in this section used historical information. Experience has shown a deposition rate of approximately 5,000 cubic yards per year, and PL 91-611 requires a capacity for a 10-year period of dredged material. Therefore, the planned 50,000 cubic yard capacity (38,000 cu m) seems to be in accordance with the statute. It should be recognized that computations based on our soundings (which agree with 1976 soundings by the Corps' Chicago District) indicate that substantially more volume than this must be dredged to restore the planned depths. While the planned capacity of the confined disposal area may equal 10 years' sedimentation at Michigan City, it is less than the present deposit in the navigation channel. The only maintenance within the last 10 years has been in the entrance channels.

b. Depth of Cut

With the possible exception of the reach between Franklin Street and E Street, maintenance dredging will not reach the bottom of in-place pollutant deposits.

c. Volume of In-Place Pollutants

Although many alternatives to the proposed disposal area were considered by the Corps (31), none was capable of handling such a large volume as 248,000 cubic meters (324,000 cu yd). It is unlikely that a site can be found near the study area that could accommodate a confined disposal area of this size. If dredging is to be the means for removal of in-place pollutants, the disposal site choice will be between:

- A large area, distant from Trail Creek, involving one long and difficult transport route, or
- Several smaller areas, closer to Trail Creek, involving several transport routes and shifting from one to another as each facility is filled.

Cost estimates for facilities to hold 50,000 cu yd were performed by the Corps of Engineers (29). Construction costs, based on February 1976 price levels, ranged from $264,000 to $1,308,000. The high figure represents an offshore diked facility; disposal areas on land were estimated to cost less than $300,000. Operation and maintenance costs, including hydraulic pipeline dredging, ranged from $4.60 to $6.90 per cu yd. The higher figure reflects higher transport costs for an offshore diked disposal area. Only a few acceptable sites were located, even with the 50,000 cu yd volume criterion. Many sites proposed were unacceptable because of wetland protection or anticipated difficulties in procurement from private landowners. If sites could be located for confined disposal of all polluted materials, construction costs would probably be above

$2 million ($\frac{324,000}{50,000}$ x $300,000) and operating costs would be of a similar magnitude (324,000 x $5 to $6 per cu yard). The total construction cost plus operating cost would thus be approximately $4 million.

With these difficulties and high costs, it is logical to inquire about the availability of processes that could be used to detoxify the dredged material so that it might be acceptable for disposal in Lake Michigan. Moore and Newbry (32) investigated this possibility for dredged materials in general:

- Biological treatment was found ineffective because the BOD of the dredged materials examined represented only a small fraction of the oxygen demand. Variability of the material in its physical and chemical characteristics was also found to be a detriment to biological treatment.
- Chemical treatment was found useful, but only for the liquid fraction after separation into solid and liquid fractions. Such treatment would therefore be in addition to, rather than a substitute for, diked disposal.
- Physical treatment by vacuum filtration or sedimentation often can be used, but would offer little or no benefit in comparison to the diked disposal option at Michigan City.

These findings offer no attractive alternatives to diked disposal for Michigan City's in-place pollutants.

B. COVERING

Covering refers to the operation of leaving in-place pollutants where they are, and covering them with a substance that prevents or retards upward migration of pollutants. The covering material may itself provide desirable benthic habitat (e.g. clean sand), or it may only be intended to seal the bottom sediments (e.g. polymer film overlay).

A large number of covering options exists, including combinations of materials and emplacement methods. Before investigating detailed options, however, it is useful to investigate the specific environment of Trail Creek/Michigan City Harbor as to the practicality of covering the bottom.

1. Practical Considerations

The immediate impression received by a visitor to the study area is that the entire waterway upstream to the E Street Bridge is devoted to boat traffic. There is no reason to expect this use of the waterway to decline. This navigational use requires certain channel depths. Experience has shown that shoals form in Trail Creek within Michigan

City, necessitating periodic dredging operations. It can therefore be expected that periodic maintenance dredging will occur for the foreseeable future.

This situation leaves only one option that could include covering of the bottom in the navigation channel: dredging of present sediments below authorized depth, followed by covering, with future maintenance dredging limited to the recently deposited sediments above the cover. Outside the navigation channel, a wider range of options exists; however, a piecemeal approach to different harbor zones is likely to be costly in comparison to a more unified approach to ameliorating in-place pollutants.

2. Possible Covering Methods

If covering is seriously considered, either after dredging in the navigation channel or independently outside the navigation channel, several methods may be applicable.

a. Cover Materials

Four categories of burial materials can be considered: inert materials, chemically active materials, sorbents, and sealing agents.

(1) Inert Materials. Included in this category are coarse materials such as sand, gravel, crushed stone, and crushed glass. Fine-grained materials that may be useful include commercially and naturally available clays and diatomaceous earth. Fine-grained materials should be effective in retarding leaching of the spilled material. Recommended cover thicknesses vary with both the material (clays being much less permeable than sands and gravels, for example) and the benthic life of the area. Potential benthic activity has been suggested as an important factor in determining covering depths because some species can enhance leaching by their burrowing activity in the cover material. Approximately 10 to 20 cm is the minimum effective cover if such organisms are likely to colonize the cover material.

(2) Chemically Active Materials. One covering strategy that could be considered is the placement of a chemical compound over the in-place pollutants. This compound would be "active" with respect to the in-place pollutants; i.e. it would react with those pollutants to form less toxic products. This approach has some promise in areas with a specific in-place pollutant, such as the site of a hazardous material spill. At Michigan City, however, the in-place pollutants of concern are a diverse mixture of substances. It is very improbable that a mixture of chemically active covering compounds could be developed that would be effective against all the observed in-place pollutants.

(3) Sorbents. Sorption processes have long been considered among the most promising treatment methods for spills of hazardous

materials in water. Activated carbon and several ion exchangers have been evaluated for response to hazardous chemical spills (33, 34). These substances have the same problems as those noted above for the chemically active materials, however.

(4) Sealing Agents. Grouts, cements, soil sealants, polymer covers, and gels have been investigated for this report. These substances are advantageous because they seal off the entire mass of in-place pollutants and are not specific in acting toward any one substance or class of substances. They are expensive, however. Grouting and cementing can be applied over in-place pollutants using materials ranging from modified Portland cement to simple mixtures of pozzolanics such as lime, fly ash, and diatomaceous earth. Techniques could range from hand application to pressurized grouting systems such as are used in the off-shore oil industry. Such techniques produce a solid cover. Soil sealants might be used in the covering of in-place pollutants. These are expanding Bentonite clays, and would be difficult to put in place and keep in place. Mixing of clays with coarser-grained materials such as gravel might inhibit erosion. The material could be pressure injected onto the bottom or dispersed on the surface according to supplier's instructions. Expense and tendencies for erosion limit the potential of soil sealants.

A barge-mounted concept of roller deployment for performed polymer films has been proposed (35, 36, 37). Costs would be three to four cents per square foot (based on 1972 prices, certainly higher today).

Application of gelling agents to seal off polluted sediments has not been made, though work on land and surface spills provides hope that such materials could be developed (34, 38). The key problem with such a concept would be to find a gelling agent with sufficient specific gravity to remain on the bottom. It is likely that highly portable application devices could be developed.

3. Assessment of Covering Concepts

None of the covering methods described above has ever been used on a large scale. Some small-scale attempts have been made to cover mercury-laden sediments in Sweden, but these have met with limited success. With this lack of field success, it is difficult to justify a recommendation to attempt covering the in-place pollutants at Michigan City. There are several conceptual difficulties in predicting success of the covering option:

- Emplacement techniques and equipment presently available cannot assure complete coverage.

- The available materials that are sufficiently impermeable to retard leaching (clays, cements, grouts) are either susceptible to erosion or are so permanent that they foreclose on future options for use of the waterway.

- The available materials that would stay in place (sands, gravels) are too permeable to retard leaching.

- Because of the absence of field experience, costs cannot be estimated with any confidence.

Accordingly, covering cannot be recommended for actual implementation at Michigan City unless and until field demonstrations have been conducted. The intent of Section 115 is action, while the technology of covering is still in the research stage.

C. SUMMARY OF POTENTIAL CORRECTIVE ACTIONS

This section has shown that the state-of-the-art for covering and for treatment of dredged materials is not sufficiently well advanced to warrant action in a field situation such as at Michigan City. It has also pointed out that maintenance dredging for navigation purposes can be expected to continue periodically. Accordingly, dredging followed by confined disposal of in-place pollutants should be coordinated with channel maintenance for effective implementation of Section 115 action at Michigan City.

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APPENDIX A

RELATIONSHIP BETWEEN CORE LENGTH AND DEPTH OF SEDIMENT SAMPLED

In a classic piece of work reported in 1941, K.O. Emery and R.S. Dietz (A-1) developed a gravity coring device very similar to that used in this study from the RV MYSIS. The cited paper includes very detailed observations on the mechanics of sediment coring. These observations are germane to this report because of the need to interpret core sample lengths with respect to the *in situ* depth of sediment represented. Some of Emery and Dietz's discussions are summarized here and applied to the Michigan City Harbor/Trail Creek coring effort. Reference to the original paper is highly recommended for more detailed discussion.

Before investigating the factors that Emery and Dietz found important, it is necessary to note some factors that they found were not important. The fact that cores are shorter than the depth sampled is *not* primarily caused by:

- Loss of sediment from the core-tube. This investigation used a core retainer, preventing the escape of sediment during retrieval.

- Compaction/escape of water. Emery and Dietz could explain only a 3% length reduction from this mechanism. This study found core samples to have water contents similar to ponar grabs, which should approximate *in situ* water content.

- "Slumping" within the core-tube. The inner diameter of the core nose is smaller than that of the core liner. Therefore, the sediment cylinder that enters the core liner can "slump" or shorten as it expands laterally to fill the core liner. Emery and Dietz found that this mechanism could account for only about half of the observed shortening of cores.

- Collection of only the top layers of sediment. When a coring device is retrieved with 100 cm of mud on the outside but only 50 cm of core, one potential explanation is that after 50 cm, the corer kept penetrating but no more sediment entered. Emery and Dietz showed by theoretical arguments and experimental evidence that this does not happen.

The mechanics of coring that are important in deciding how much depth a core or core increment represents are briefly described as follows: As the coring device proceeds through the sediment, the sediment layers are downwarped and thrust aside. In addition, the core inside the core liner develops frictional resistance, as does the sediment outside the corer-tube.

Near the surface of the sediment, there is relatively low resistance to penetration (low percent solids) and low friction (short lengths of sediment-corer contact). At depth, where the sediment becomes denser (higher percent solids), both the resistance to penetration and the frictional resistance to core entry into the tube increases. That is, it is more difficult for sediment to enter it. Emery and Dietz found that in most recently sedimented deposits, these factors increase in approximate equivalence with depth such that the incremental core length per incremental depth penetrated is approximately constant throughout the length of a core. That is, if the top 6 cm of core represent 11 cm of sediment, then the bottom 6 cm of core also represents 11 cm of sediment.

Another finding of Emery and Dietz was that hundred of cores ranged from 40% to 70% in the ratio

$$\frac{\text{core length}}{\text{depth penetrated}}$$

The average was 50%.

In this study, where a corer similar to that of Emery and Dietz was used, it has been assumed that all increments of any one core represent consistent penetration increments, and that the ratio of core length to depth penetration for those increments and for each core as a whole is 50%.

Reference

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APPENDIX B

ANALYTIC METHODS FOR WATER AND SEDIMENT

Analysis of water and sediment samples was performed by JBF and several other laboratories in the Boston area. Selection of each laboratory was based on its specific capability to perform each analysis that was assigned.

Each laboratory had its own internal quality control procedures. In addition, JBF provided blind replicates to confirm that the expected precision of each method was being achieved, and blind spiked samples to confirm the expected accuracies.

Arsenic in Water

These analysis were performed by Herbert V. Shuster, Inc., Boston, Mass. The gaseous hydride method was used, with sodium borohydride to produce arsine, which was analyzed by atomic absorption spectrophotometry. The method is described in Ref. (B1).

Arsenic in Sediment

Digestions of sediments were performed by JBF (see "Heavy Metals in Sediment - a. Digestion", below). Digests were analyzed by H. V. Shuster, Inc. with the method for water described above.

Ammonia in Water

These analyses were performed by Interex Corporation of Natick, Mass. The Nesslerization method (direct, following distillation) was used (B2).

Heavy Metals in Sediment and Water

a. Digestion

All samples for metals were digested in accordance with Ref. (B3) by JBF. The procedure ("Metals", Section 4.1.3 in the reference) features nitric acid digestion followed by solution in warm hydrochloric acid.

b. Analysis

All digests for metals were analyzed by atomic absorption spectrophotometry. With the exception of arsenic, all analyses were performed by direct aspiration of the digest in accordance with Ref. (B3).

Immediate Oxygen Demand in Sediment

This test was performed in the field by JBF, with a procedure described in Ref. (B4). Because the method is not described in standard analytic references, it is described below.

Sample Collection and Handling

Care must be taken to avoid oxidation of the sample before test. The sample for testing, therefore, should be extracted from the mass of the sediment in the sampling device with minimal air contact. A disposable plastic syringe (10 or 20 cc) is inserted into the interior of the sediment mass for handling the sediment and delivering it to the test container. When the sediment is reasonably compacted, the bottom of the syringe is cut off and the cylinder is used to bore a sample. If the sediment has a larger water content, a smaller hole is bored through the bottom of the cylinder and the sediment drawn into the syringe. Even a diluted hydraulic dredge slurry can be accommodated in a properly prepared syringe. Once the sample is in the syringe, it can be weighed without undue exposure to the air, and the sample can be discharged directly into the test container. This is done below the water surface to avoid contact with air.

Dilution Medium for Sediment

Large variations in water quality are possible at potential dredging sites and disposal areas. Therefore, it seems appropriate to use one or two standard types of dilution water for the IOD test. It is not necessary to use nutrient-enriched media as in the BOD methods because the oxygen-demanding phenomena in the IOD test are largely nonbiogenic. No matter what dilution water is used, it should be close to saturation with respect to air at the test temperature. It should also be free of oxygen-demanding substances. Tap water (source: Lake Michigan) was used in this project.

In all the previous IOD tests, a single dilution was made with a recommended quantity of sediment. This practice ignores the fact that the concentration of DO can be measured more accurately at higher oxygen concentrations. A typical DO meter response is 90 percent in 10 sec at a constant (30°C) temperature. However, at low DO values the 90 percent reading takes 30 sec to reach. Because the accuracy of the DO reading may be $\pm$ 0.3 mg/ℓ, a small oxygen depletion should be avoided. These problems can be avoided by conducting the laboratory IOD test on at least two, preferably three, different dilutions. The results from dilutions showing 40 to 70 percent depletion are the most reliable and should be the only results considered acceptable.

Time

Fifteen minutes has been arbitrarily selected as the IOD test time. This time can be maintained as the standard if the oxygen-depletion criteria stated above are adhered to by making the proper sediment dilutions. Using a longer time interval makes the test more cumbersome from an analytical viewpoint. Under some special circumstances it may be instructive to follow the DO concentration past the 15-min limit. However, this time interval is suitable for the purposes of a standardized IOD test.

Mixing

Mixing at the membrane surface of the DO probe is necessary to obtain an accurate reading. A BOD mixing accessory is available from many DO meter vendors which would induce a current in the vicinity of the probe membrane. This current would not, however, maintain the bulk of the sediments in suspension. A magnetic stirrer can be used for this purpose. However, it must be used with the proper precautions. Because magnetic stirrers tend to give off heat, they can raise the water temperature in the container within the 15-min testing period. Suitable insulation can be used to reduce this effect. Proper correction on the instrument for the temperature changes that do take place is necessary for accurate DO measurements. When using the magnetic stirrer to induce a current across the membrane surface, it must be remembered that the water in the center of the BOD bottle is swirling at a slower rate than at the perimeter. A sufficient stirring rate can be obtained by placing the probe in the dilution water and finding a stirrer setting that does not cause any appreciable change in the meter readings when the setting is increased or decreased slightly.

Calculation

For the IOD on a sediment dry weight basis, the calculation is as follows:

$$\text{IOD mg/kg} = \frac{\text{mg/kg IOD (wet basis}}{\text{\% solids (decimal fraction)}}$$

where: $$\text{mg/kg IOD (wet basis)} = \frac{(DO_{initial} - DO_{final}) \times 0.3}{\text{grams of sediment in aliquot}}$$

The 0.3 term (300 m) is the volume of a standard BOD bottle.

Oil and Grease in Sediment

Interex Corporation performed these analyses using Freon as the solvent in the Soxhlet extraction procedure (B2).

PCB in Water and Sediment

Herbert V. Shuster, Inc. performed these analyses in accordance with Ref. (B5). The method was modified by use of acetonitrile/petroleum ether instead of DMF/hexane and liquid/solid chromatographic cleanup with Floresil PR in place of alumina.

TKN in Sediment

These tests were done by Interex Corporation using the standard Kjeldahl method with Nessler finish (B2).

Particle Size Distribution in Sediment

JBF performed these tests using ASTM Method D422-63 (Reapproved 1972).

Percent Solids and Percent Volatile Solids in Sediment

JBF performed these tests using *Standard Methods* (B2).

REFERENCES - APPENDIX B

B1. Fernandez, F.J. "Atomic Absorption Determination of Gaseous Hydrides Utilizing Sodium Borohydride Reduction," Atomic Absorption Newsletter, 12, 4, July-Aug. 1973.

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B3. "Methods for Chemical Analysis of Water and Wastes", Report No. EPA-625-/6-74003, U.S. Environmental Protection Agency, Washington, D.C., 1974.

B4. Neal, R.W., Pojasek, R.B., and Johnson, J.C., "Oxygenation of Dredged Material by Direct Injection of Oxygen and Air During Open-Water Pipeline Disposal," Report No. D-77-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Oct. 1977.

B5. "Analysis of Environmental Materials for Polychlorinated Biphenyls," Monsanto Chemical Co. Laboratory Analytical Chemistry Method 71-35 as revised November 1970.

APPENDIX C

BIOASSAY METHODS

Stock Cultures

Cyclops bicuspidatus thomasi, *Daphnia galeata mendotae* and *Pontoporeia affinis* were collected from Northern Lake Michigan with a 0.5-m diameter No. 6 mesh (239 μm) net. *Cyclops* and *Daphnia* were obtained by towing the net vertically through the epilimnion. *Pontoporeia* were collected at night by towing the net horizontally near bottom. This method is most effective, since *Pontoporeia* migrate from the sediments into the water column at night (C1). All net tows were made at slow speeds (0.5 m/sec) to minimize damage to the organisms.

Collections were immediately transported to the Biological Station's Lakeside Laboratory and specimens were isolated for monoculture. *Daphnia* were removed from the plankton samples with a glass pipette (Pasteur type) and transferred to 475-ml glass jars. *Cyclops* were segregated by concentrating 4,000 to 8,000 organisms in a 1-liter bottle and adding 3 to 6 ml of an aqueous food suspension (described below). The container was sealed and held for 12 hours. This technique decreased the dissolved oxygen level, resulting in the death of all organisms except *Cyclops* and *Holopedium*. *Holopedium* were removed and the *Cyclops* were transferred to 3.8 liter glass jars. Both *Cyclops* and *Daphnia* were maintained in filtered (25 μm) Lake Michigan water (from Little Traverse Bay). *Pontoporeia* were separated from the smaller crustaceans by passing the tow sample through a No. 30 (600 μm) sieve. *Pontoporeia* were then transferred to 20.8-liter aquaria containing Lake Michigan water and sediments (from Little Traverse Bay).

The culture vessels containing these organisms were kept in a refrigerated incubator (Forma Scientific Model 23) with controlled temperatures of 6-9°C for *Pontoporeia* and 12-15°C for *Cyclops* and *Daphnia*. Aeration of the culture water was provided prior to transfer of *Daphnia* to minimize their entrapment in the surface film. Continual aeration was provided for *Cyclops* (2-4 ml/min.) and *Pontoporeia* (80-120 ml/min.). Water was changed daily for *Daphnia*, twice weekly for *Cyclops*, and biweekly for *Pontoporeia*.

Pontoporeia and *Cyclops* were fed a ground mixture of Glencoe fish pellets and Cerophyl (20 to 1 by weight) which was freshly prepared each week and kept under refrigeration. *Pontoporeia* were fed by sprinkling the mixture over the water surface three to four times per week (∿0.5 g/100 individuals). For *Cyclops*, the mixture was prepared as an aqueous suspension (4 g of this mixture in 100 ml deionized water) which was then filtered through a 54-μm mesh screen. *Cyclops* were fed the filtrate three times weekly (1 ml/3.8 liters culture medium).

Daphnia were more difficult to maintain in the laboratory. Cultures would die off within approximately 7 to 14 days when being fed the Glencoe fish pellet-Cerophyl suspension and mixed algae cultures. *Daphnia* cultures were maintained successfully with the following technique supplied by J. Marshall[1]: Daphnia were fed Chlamydomonas reinhardtii[2] daily ($\sim 2 \times 10^6$ cells/vessel). The success of this method lies principally in maintaining the food supply in continuous suspension. The mobility of Chlamydomonas reinhardtii in the culture medium permits efficient ingestion of this small flagellate by the filter-feeding Daphnia. This provided adequate populations of 90-160 organisms/vessel.

Salmo gairdneri were obtained from the Michigan Department of Natural Resources Oden Fish Hatchery as fingerlings (7 to 10 cm) and rapidly transported (<30 min.) to the Biological Station laboratory. The fish were promptly transferred to 19-liter glass containers placed in a continuously running cold water bath (11 to 12°C) in the aquarium room. Acclimation to the Douglas Lake water supply came in two steps. The fish were initially placed in a 1 to 1 ratio of Douglas Lake and Fish Hatchery water for 24 hours, then transferred to 100% Douglas Lake water. Water temperature in the laboratory was maintained within 0.5°C of the Fish Hatchery water. The water supply was aerated (80-170 ml/min.) to ensure adequate oxygen levels (saturated conditions). The high feeding levels at the Fish Hatchery caused high metabolic waste accumulation requiring daily water renewal.

Salmo were fed 3/32-inch (0.24 cm) Glencoe fish pellets (0.3-5 g fish^{-1} day^{-1}). They were allowed to acclimate for one week before testing.

Laboratory physiocochemical conditions for the test organisms were maintained as closely as possible to those observed in the field. Temperature, dissolved oxygen and pH were regularly monitored. Temperature and dissolved oxygen were measured with a YSI model 51B oxygen meter and pH was determined with a Beckman model H-5 pH meter. Temperature was maintained within a range of 1.0°C, dissolved oxygen within 2 mg/liter (near saturation), and pH within 0.5 units. Organisms were not fed during laboratory experiments.

Test Materials and Equipment

All test chambers were glass. Only tygon or glass tubing (for aeration) entered the test vessels. Sediments were handled only with stainless steel and polyethylene instruments.

Sediments and site water were collected by a JBF Scientific Corporation field crew on 14-17 April 1977. They were stored and transported in a refrigerated condition. They were received at the Biological Station on 18 April 1977 and promptly stored in a walk-in cooler with temperature regulated between 0 and 4°C.

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[1] J. Marshall, Argonne National Laboratory, Argonne, IL.

[2] From the Culture Collection of Algae, Department of Botany, University of Texas, Austin, TX.

Water collected at the control station site was used for assays with Cyclops, Daphnia and Pontoporeia. Filtered (64 μm) Douglas Lake Water was used for experiments with Salmo. Chemical characteristics of the various water supplies used for cultures are listed in Table C-1.

Table C-1. Chemical Characteristics of Water Supplies Used in Maintenance and Culture of the Test Organisms

Chemical Variable	Lake Michigan (C2)	Douglas Lake (C3)	Fish Hatchery (C4)
pH	8.5	8.5	8.1
Alkalinity* (as $CaCO^3$)	109	115.3	164
Conductivity§	261	249.5	300
Total - p**	--	18.7	20
NO_3 - N**	129	53.4	600
NH_3 - N**	15	33.9	20
Ca*	37.4	31.2	42
Mg*	--	11.0	14
K*	--	0.7	0.7
Na*	--	2.3	--
Cl*	7.2	5.4	2
SiO_2	0.3	1.0	8

*mg/liter

§µmhos/cm @25°C

**µg/liter

REFERENCES - APPENDIX C

C1. Marzolf, G.R., "Vertical Migration of Pontoporeia affinis (Amphipoda) in Lake Michigan," Proc. 8th Conf. Great Lakes Research, Univ. of Michigan, Great Lakes Res. Div., Pub. No. 13, 1965.

C2. Schelske, C.L. and J.C. Roth, "Limnological Survey of Lakes Michigan, Superior, Huron and Erie," Univ. of Michigan, Great Lakes Res. Div., Publ. No. 17, 108 p., 1973.

C3. Gannon, J.E., Univ. of Michigan Biological Station, unpublished data.

C4. Newton, M.E. and M. Wuerthele, "Analysis of Selected Michigan Fish Hatchery Water Supply and Discharge Samples, Water Resour. Comm. Michigan Dept. Nat. Resour., Lansing, 1970.

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16. ABSTRACT

The sediments of much of Trail Creek and Michigan City Harbor are toxic to several species of desirable aquatic organisms and condusive to extreme dominance by a few species that are known to tolerate grossly polluted benthic environments. Although the overlying waters also show some signs of pollution, salmonid migrations do pass through the area. This indicates that severely toxic discharges have been abated and are now evidenced by the in-place pollutants that were deposited in past years. It appears that removal of these deposits would be a fruitful and worthwhile operation. However, before such action is taken, the importance of a large landfill as a potential source of future pollutants should be assessed. If the landfill is shown to be unimportant, dredging with disposal in a land-based, confined disposal area is recommended. The cost of such a program could exceed $4 million, but cost sharing with the Corps of Engineers in their navigation maintenance program in the Creek and Harbor would significantly reduce the section 115 funds required.

17. KEY WORDS AND DOCUMENT ANALYSIS

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