International Joint Commission
Great Lakes Water Quality Board

Sediment Remediation
Case Studies

Contaminated sediment is a major problem and well recognized in remedial action plans (RAPs) and lakewide management plans (LaMPs). During the IJC's 1995-1997 biennial priorities cycle, the Water Quality Board's Sediment Priority Action Committee (SedPAC) prepared a sediment white paper that summarized the contaminated sediment problem, specified key obstacles, identified options to address key obstacles, and presented recommendations regarding value-added contributions the IJC could make to help address current obstacles to sediment remediation. During the IJC's 1997-1999 biennial priorities cycle, SedPAC will be undertaking projects on: economic and environmental benefits of sediment remediation; and guidance for making decisions regarding management of contaminated sediment. In an effort to communicate information in a timely fashion, three case studies on environmental benefits of sediment remediation are presented here. Additional work is underway under the direction of SedPAC. For more information, please contact the IJC's Great Lakes Regional Office.

PAH CONTAMINATED SEDIMENT REMEDIATION IN THE MAIN STEM, BLACK RIVER

LOCATION AND PHYSICAL DESCRIPTION

The Black River enters the south shore of Lake Erie at Lorain Harbor, in north-central Ohio between Cleveland and Sandusky (Figure 1). This river system drains approximately 1,210 km^2 of Lorain, Medina, Ashland, Huron, and Cuyahoga Counties. The geographic limits of the Area of Concern (AOC) are considered to be the entire river basin.

The Black River drainage basin is dominated by agricultural and rural land uses (89%); residential, commercial, and recreational uses make up the remaining 11% and are concentrated in the lower regions of the river. Although USS/KOBE Steel Company is the primary industry in the lower river (between RM 5.4 (8.7 km) and 3.3 (5.4 km)), several other major facilities are located further upstream.

The Area of Concern has 45 National Pollutant Discharge Elimination System (NPDES) permitted dischargers; 26 industrial and 19 municipal. Of the industrial dischargers, only one is considered to be "major" (discharging >1 million gallons/day) by the U.S. Environmental Protection Agency (EPA); that facility is USS/KOBE Steel. Until 1982, USS operated a coking facility which is considered to have been the major source of PAH and metal contamination within the area.

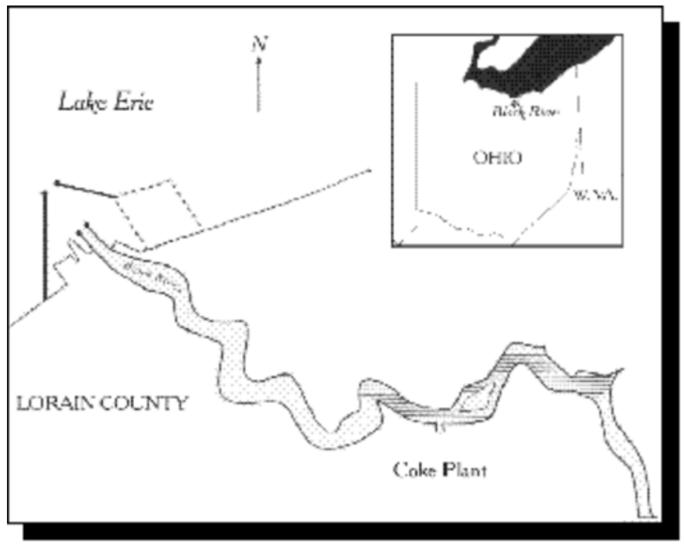

Figure 1. Location of Black River AOC. The shaded portion represents the area of fish sampling designed to evaluate the effectiveness of sediment remediation.

PROJECT GOALS AND OBJECTIVES

A 1985 Consent Decree (U.S. District Court - Northern District of Ohio 1985) mandated USS/KOBE Steel Company to remove 38,000 m^3 of PAH-contaminated sediment from the mainstem of the Black River. The goal of the sediment remediation project was to remove PAH-contaminated sediment in order to eliminate liver tumors in resident brown bullhead populations.

SEVERITY AND GEOGRAPHICAL EXTENT OF PROBLEM

1980 sediment tests confirmed the presence of elevated levels of cadmium, copper, lead, zinc, cyanide, phenols, PAHs, oils, and grease in sediment adjacent to the former USS steel coke plant outfall. PAH concentrations in this area totaled 1,096 mg/kg (Baumann et. al. 1982). Tests also confirmed the presence of low levels of pesticides (DDT and its metabolites) in both the mainstem and the harbor regions (Black River Remedial Action Plan Coordinating Committee 1994). As a result, all mainstem and harbor sediment dredged during U.S. Army Corps of Engineers maintenance operations required disposal in a confined disposal facility. This sediment exceeded U.S. EPA's Heavily Polluted Classification for Great Lakes Harbor Sediments.

High sediment PAH levels corresponded to a high frequency of liver tumors in resident populations of brown bullheads (Black River RAP Coordinating Committee 1994). Although sediment PAH levels had declined since the USS's coking facility was shut down, levels were still of concern.

DESCRIPTION OF REMEDIAL ACTIONS

Sediment remediation occurred as a result of an enforcement action upstream of the federal navigational channel in the vicinity of the coke plant outfall (Figure 1). Dredging of the sediment began in 1989. The operation utilised a closed, watertight, clamshell dredge to reduce the loss of sediment to the water column. To prevent the spread of oil, an oil bloom was erected. The sediment was moved from a dredge barge to a containment cell on the USS/KOBE site using specially designed vehicles. Although the sediments were not considered hazardous waste, the disposal site had special design requirements to clean all hazardous waste from the cell, line it, allow for dewatering of the dredged sediment and collection of the decanted water for treatment, capping after the dredged materials were deposited, and post-closure monitoring. Without these conditions, the placement of the dredged sediment in the cell would have exacerbated existing ground water contamination and violated Resource Conservation and Recovery Action (RCRA) requirements for closure. A contingency plan, in the event of a spill, was defined and environmental monitoring was conducted prior to, during, and following dredging. A total of 38,000 m^3 of sediment were removed during the operation. This action was completed in December 1990.

COST

Under the Consent Decree, USS/KOBE Steel paid $1.5 million for the dredging and containment of the sediment.

REGULATORY CONSIDERATIONS

USS/KOBE Steel was required to comply with the 1985 Consent Decree (U.S. District Court - Northern District of Ohio 1985). The Consent Decree was issued to deal with violations of the Clean Air Act, but included several supplementary environmental requirements, one of which was the dredging of the PAH-contaminated sediment. In additional, disposal of dredged sediment had to comply with U.S. RCRA requirements. The dredging project also required permits under the Clean Water Act for NPDES, Section 404 dredge and fill, and a Section 401 water quality certification.

CLEAN-UP TARGETS AND ENDPOINTS

The primary cleanup target was the removal of sediment in the area of the former USS coke plant to "hard bottom", or the underlaying shale bedrock. No quantitative environmental targets or endpoints were established, although post-dredging sampling was required to test for remaining areas of elevated PAH concentrations.

POST-PROJECT EVALUATION OF EFFECTIVENESS

Sediment

Prior to dredging, PAH concentrations ranged from 8.8-52.0 mg/kg within Black River sediment. As a result of dredging, PAH concentrations in sediment declined (Table 1).

Table 1. 1980 (during coke plant operations), 1984 (coking facility closed, pre-dredging), and 1992 (post-dredging) levels of four common PAHs in Black River sediment

PAH compound	1980[a]	1984[b]	1992[c]
Phenanthrene	390.0	52.0	2.6

Fluoranthrene	220.0	33.0	3.7
Benzo(a)anthracene	51.0	11.0	1.6
Benzo(a)pyrene	43.0	8.8	1.7

USS coking facility closed down 1982
Dredging occurred in 1989-1990

[a]Baumann et. al. (1982)
[b]Fabacher et. al. (1988)
[c]Black River Remedial Action Plan Coordinating Committee (1994)

Brown Bullheads

PAH levels in brown bullheads, which had been monitored since the early 1980s (Baumann et. al. 1982; Baumann and Harshbarger 1997), suggest some very interesting relationships between liver neoplasms and the dredging of sediment. Figure 2 illustrates the prevalence of hepatic tissue conditions (cancer, non-cancer neoplasm, altered hepatocytes, normal) found in fish of age 3 during 1982 (during coke plant operations), 1987 (after coke plant closing, prior to dredging), 1992 (exposed to dredging as age 1), 1993 (exposed to dredging as young of year), and 1994 (hatching after dredging was completed) studies.

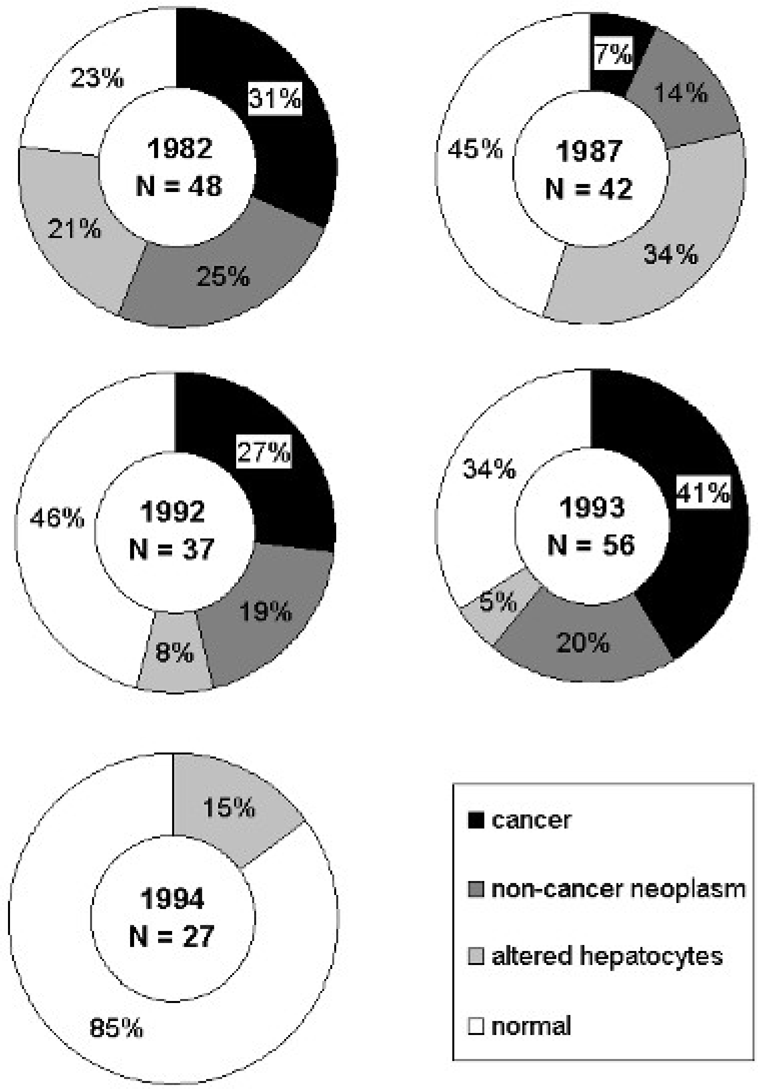

Figure 2. Percentage of age 3 brown bullheads from the Black River having various liver lesions (Baumann and Harshbarger [in press])

The incidence of liver cancer in bullheads of age 3 decreased between 1982 and 1987, corresponding with decreased PAH loadings following the coke plant closure in 1982. There is general consensus that the increase in liver cancer found in the 1992 and 1993 surveys is a result of PAH redistribution which occurred during the 1990 dredging efforts. No instance of liver cancer was found in 1994 samples of age 3 brown bullheads. Further, the percent of normal liver tissues increased from 34% to 85% between 1993 and 1994. This elimination of liver tumors and the increase in the percentage of normal tissues in the resident brown bullhead populations, as a result of sediment remediation, provides substantial evidence of the efficacy of the remedial strategy.

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KEY REFERENCES

Baumann, P.C., W.D. Smith, and M. Ribick. 1982. Hepatic tumor rates and polynuclear aromatic hydrocarbon levels in two populations of brown bullhead (*Ictalurus nebulosus*). Polynuclear Aromatic Hydrocarbons. Sixth International Symposium on Physical and Biological Chemistry. eds. Cook, M.W., A. J. Dennis, and G.L. Fisher. BaTelle Press. Columbus, Ohio. Pp. 93-102.

Baumann, P.C. and J.C. Harshbarger. 1995. Decline in liver neoplasms in wild brown bullhead catfish after coking plant closes and environmental PAHs plummet. Environmental Health Perspectives. 103(2):168-170.

Baumann, P.C. and J.C. Harshbarger. [in press]. Liver Neoplasm Trends in Black River Bullhead. 18 pp.

Black River Remedial Action Plan Coordinating Committee. 1994. Black River Remedial Action Plan Stage One Report: Impairment of beneficial uses and sources of pollution in the Black River Area of Concern. Ohio Environmental Protection Agency and the Black River Coordinating Committee, 9880 South Murray Ridge Road, Elyria, Ohio.

Fabacher, D.L., C.J. Schmitt, J.M. Besser, and M.J. Mac. 1988. Chemical Characterization and Mutagenic Properties of Polycyclic Aromatic Compounds in Sediment from Tributaries of the Great Lakes. Environmental Toxicology and Chemistry 7:529-543.

Hartig, J.H. and M.A. Zarull. 1991. Methods of restoring degraded areas in the Great Lakes. Reviews of Environmental Contamination and Toxicology 117:128-154.

U.S. District Court - Northern District of Ohio. 1985. Consent Decree with USS/KOBE Steel.

U.S. EPA-Great Lakes National Program Office. 1993. A summary of contaminated sediment activities within the United States Great Lakes Areas of Concern.

COLLINGWOOD HARBOUR SEDIMENT REMOVAL DEMONSTRATION PROJECT

LOCATION AND PHYSICAL DESCRIPTION

Collingwood Harbour is situated on the south shore of Nottawasaga Bay, which constitutes the southern extension of Lake Hurons Georgian Bay. The harbour covers 0.8 km^2, with a maximum depth of 6.4 m and an estimated volume of 28.7 X 10^{-4} km^3. Exchange between the harbour and surrounding waters is limited since the harbour is positioned at the south end of Nottawasaga Bay with only one opening to the bay. The harbour is surrounded by the Town of Collingwood, which has a permanent resident population of 14,685. The harbour includes a wetland complex, a wastewater treatment plant outfall, marinas, grain terminal, and former shipyards.

PROJECT GOALS AND OBJECTIVES

The project goal was to remove and dispose of sediment that failed the biological assessment criteria. This included approximately 8,000 m^3 of contaminated sediment from shipyard slips and adjacent areas in the harbour, demonstrating an innovative removal technology for the first time in North America. Project objectives included removing all sediment that resulted in chronic toxicity or impaired benthic community structure, and improve conditions for benthos in support of the Public Advisory Committee's goals for the future quality of the harbour environment.

SEVERITY AND GEOGRAPHIC EXTENT OF PROBLEM

In the 1980s, sediment was found to have metals and PCBs in excess of provincial open water disposal guidelines (Figure 1, Table 1). Sediment testing carried out in 1974, 1983, 1986, 1988 and 1991 showed that sediment quality has generally improved over time (Collingwood Harbour RAP Team and Public Advisory Committee, 1992). Sediment from only a small, localized portion of the harbour was found to be contaminated, mainly due to historical use of the harbour as a center for the repair and construction of Great Lakes vessels. Levels of PCBs, zinc, lead, phosphorus, Kjeldahl nitrogen and several metals in surficial sediment (3 cm depth and above) exceeded the provincial guidelines for open-water disposal of dredged material in 1986. Near the Collingwood Shipyards, sediment contamination was found to be more extensive inside the turning basin than outside the harbour. In 1986, dredging was conducted for navigational purposes. A general decline in contaminant levels was observed in 1987 most likely due to sediment removal. Twelve stations were sampled -- nine within the harbour and three in Nottawasaga Bay. By 1987, only one station remained with zinc, copper and lead levels marginally above the provincial guidelines lowest effect level, which currently replaces the open water disposal guidelines. PCBs were below the detection limit.

Figure 1. Sediment sampling station locations

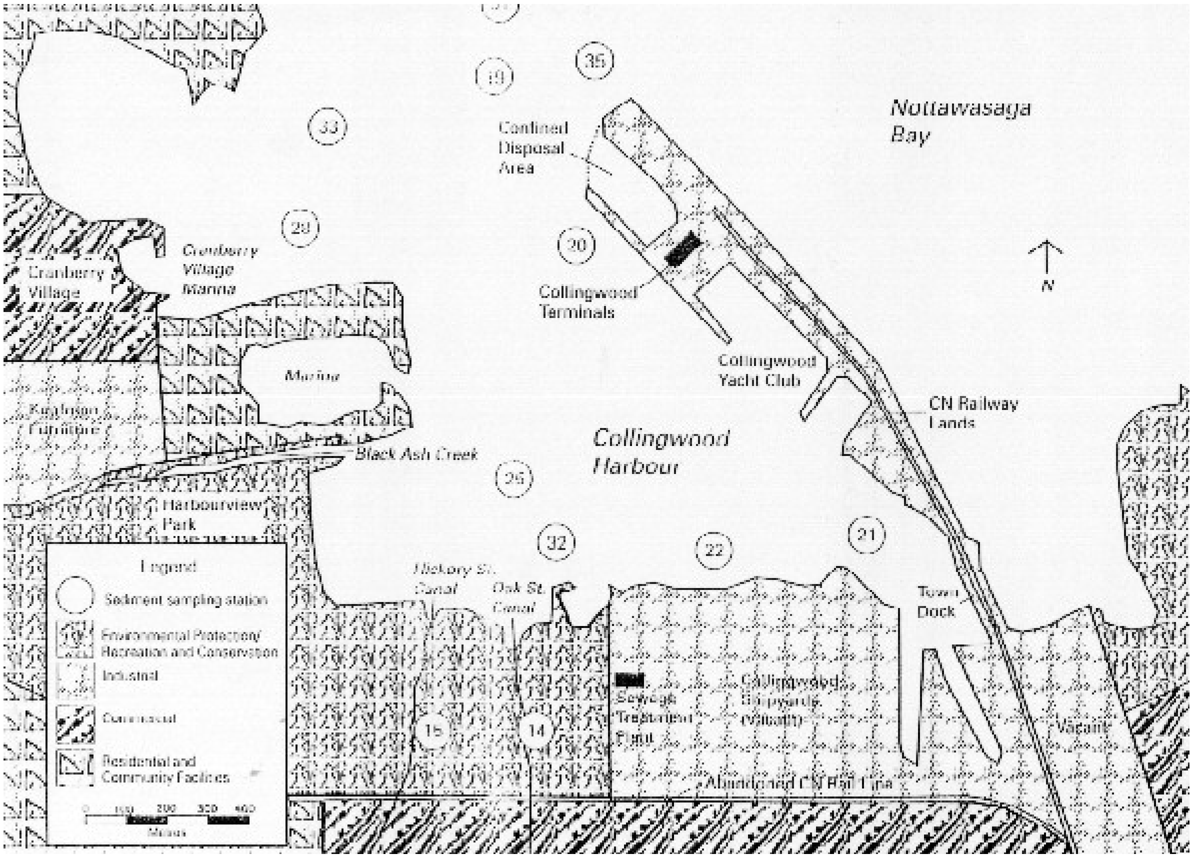

Table 1. Mean concentrations of metals, PCBs, oil and grease in Collingwood Harbour sediments, pre-(1986) and post-(1987) dredging *(All values are in mg/kg or parts per million, except for PCBs which are in g/kg or in parts per billion)*

Station		PCBs	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Fe	Oil & Grease
19	(1986)	66	.46	22	25	.07	12	34	53	11,025	1,093
	(1987)	<43	.54	25	25	.06	13	30	30	12,000	519
20	(1986)	65	.64	30	41	.12	17	58	97	13,500	2,875
	(1987)	93	.61	24	31	.08	15	45	83	14,000	1,187
21	(1986)	192	13.5	36	72	.24	19	133	195	17,000	3,175
	(1987)	160	.77	31	59	.12	17	110	190	16,500	2,509
22	(1986)	55	.33	18	26	.11	9	48	69	9,300	2,370
	(1987)	<20	<.28	17	16	.13	6	29	57	7,400	9,027/280
23	(1986)	103	.62	28	49	.23	16	79	115	15,000	4,700
	(1987)	105	.60	29	38	.13	16	80	120	15,000	1,162
25	(1986)	40	.42	18	25	.12	10	34	51	10,200	2,450
	(1987)	<20	.39	19	14	.03	6	20	40	8,600	2,191

28	(1986)	33	.38	17	22	.09	10	25	46	9,150	2,250
	(1987)	<20	.43	23	24	.04	13	32	65	12,500	2,499
30	(1986)	93	.61	27	43	.14	18	56	94	15,500	2,018
	(1987)	<53	.71	27	33	.08	14	44	76	14,000	833
32	(1986)	22	.22	14	7	.03	4	10	19	7,156	934
	(1987)	<20	.31	16	10	.02	5	13	29	7,200	319
387	(1986)	<20	.29	18	19	.02	11	10	26	10,350	2,612
	(1987)	<20	.45	20	15	.01	10	10	30	9,400	530
388	(1986)	<20	.26	15	9	.03	6	5	10	21,240	596
	(1987)	<20	<.30	15	6	<.01	4	6	12	7,000	142
393	(1986)	<20	.32	11	11	.06	4	14	31	6,450	1,468
	(1987)	<20	<.30	16	10	.02	6	14	35	7,700	487
Dredging Guideline		**50**	**1.0**	**25**	**25**	**0.3**	**25**	**50**	**100**	**10,000**	**1,500**
Lowest Effect Level		**70**	**0.6**	**26**	**16**	**0.2**	**16**	**31**	**120**	**20,000**	

Source: Collingwood Harbour RAP Team and Public Advisory Committee (1992)

Based on multiple lines of evidence proided by laboratory bioassays and field observations of invertebrates and sport fish collected during the late 1980s and early 1990s, it was determined that sediment contamination and impacts were confined to the Canada Steamship Limited (CSL) slips and water lots adjacent to at the shipyard property (Figure 2). Sediment samples collected outside the CSL slips generally met the biological requirement that toxicity was not significantly different from reference values.

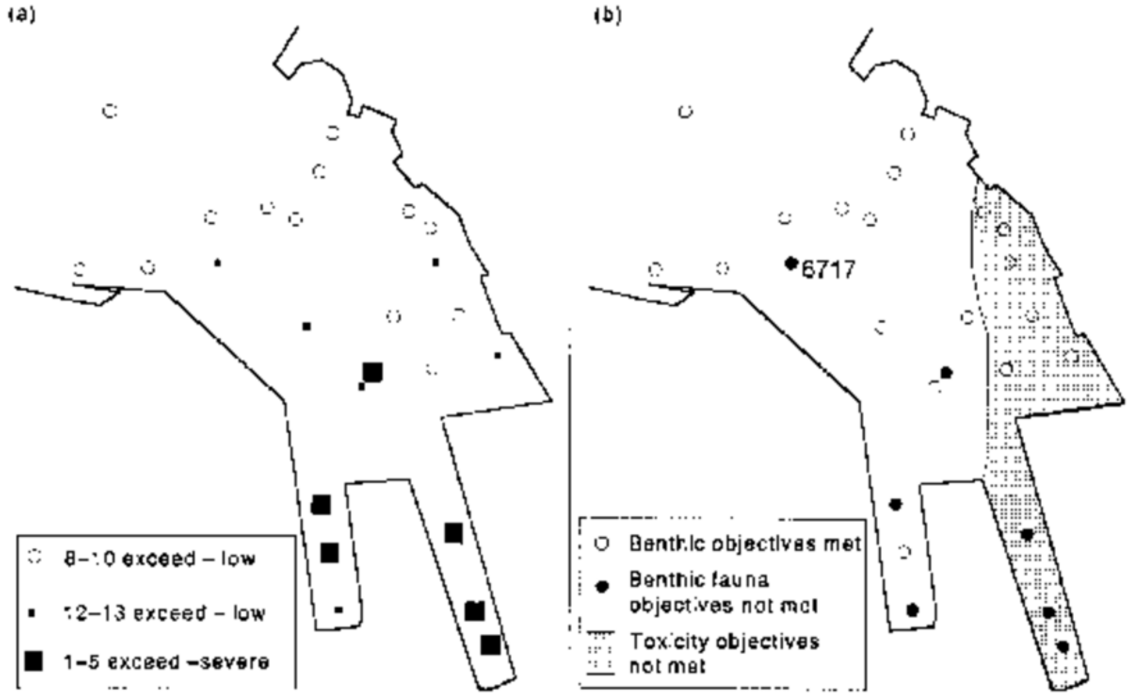

Fig. 2. Comparison of (a) chemical guidelines and (b) biological sediment guidelines in Collingwood Harbour.

DESCRIPTION OF REMEDIAL ACTIONS

Based on sediment chemistry, benthic community structure, and sediment bioassays, Collingwood Harbour was selected as a demonstration site to test an innovative removal technology. By November 1993, approximately 8,000 m^3 of sediment from the shipyard slips and adjacent areas in the harbour were removed using the Pneuma airlift pumping system. The pumping system is based on a principal of using static water head and compressed air inside cylinders. Each of three cylinders is rapidly filled with slurry by counter pressure due to a hydrostatic head and induced vacuum. When one cylinder is filled, compressed air acts as a piston and the slurry is then forced through a check valve to the discharge pipeline. The pump has no rotating parts or mechanisms in contact with the sediment, minimizing sediment resuspension problems. Contaminated sediment was removed from the harbour slips and transported through a pipeline to a confined disposal facility (CDF) 1.2 km away. A silt curtain located at the north end of each slip was used to confine any possible particle resuspension due to unforeseen dredging complications. The silt curtain was constructed of geotextile material, with the top connected to a floating boom which was monitored daily for any indications of damage. Turbidity, suspended solids, and total organic carbon concentrations were minimal. Using this technology, a full-scale cleanup of contaminated sediment remaining in the harbour has been completed. The pumping system was found to be most efficient when semi-submerged in sediment. After cleanup, the Pnuema Pump was used by Transport Canada to supply fill and cap material for the CDF with excellent results achieved ahead of schedule. The partners involved in the cleanup were Environment Canada (Great Lakes Cleanup Fund), the Town of Collingwood, Transport Canada, the Ontario Ministry of Environment and Energy, Collingwood Terminals, the Aquateers of Base Borden, and CSL (Canada Steamship Lines) Equity.

COST

The total project cost was approximately $1.36 million for the Collingwood project where $425,000 was contributed by Environment Canada's Cleanup Fund. The remaining costs were divided among the other partners.

REGULATORY CONSIDERATIONS

Concentrations of metals, trace organic contaminants, and nutrients in sediment within the harbour turning basin had to meet Ontario Ministry of Environment guidelines for management of contaminated sediment (i.e. the lowest effect level) if unrestricted dredge disposal was to resume. Due to the fact that there is no expected need to dredge over the next 30 years, then sediment quality should support healthy benthic communities. For areas that had contaminant concentrations in sediment in excess of the lowest effect level, biological tests had to be performed to make a determination on the toxicological properties of these materials.

CLEANUP TARGETS AND ENDPOINTS

Sediment-related targets included:

- the absence of acute and chronic toxic effects of sediment-associated contaminants on benthic communities in harbour;
- the benthic community outside the turning basin should not be significantly different from control sites similar in the physical and chemical characteristics of shallow, silty sand substrates with no oxygen limitation;
- the benthic biomass should be representative of mesotrophic conditions (i.e. within a range of 25 to 50 gm^{-1} wet weight) outside the turning basin; and
- mesotrophic benthic species (i.e. mayfly, fingernail clam and the oligochaetes Lyodrilus templetoni and Spirosperma ferox) should be present where suitable substrates are located.

Site-specific guidelines for benthos are established from a reference site database (i.e. biological attributes and environmental variables) using multivariate techniques, such as cluster and ordination analysis (Reynoldson and Zarull 1993). Reference site benthic communities are grouped using cluster analysis. The site environmental variables, which are not affected or minimally affected by anthropogenic activity, are then used as predictors to group the sites into the appropriate biological clusters. The benthic community structure and the same nine environmental variables (depth, NO_3, silt, aluminum, calcium, loss on ignition, alkalinity, sodium, pH) are measure at the test sites. Using the environmental predictors and the discriminant model (derived from the reference site database), each site is assigned to a biological cluster. The benthic invertebrate data are then similarly analyzed. If the site lies outside the reference site cluster, then that site is judged to be impaired.

In the Great Lakes, 335 sites have been sampled and the multivariate "model" developed from this database correctly predicts benthic invertebrate communities with 90% accuracy (Reynoldson et al. 1995). In addition, acute and chronic measures of "toxicity" (including growth and reproduction) performed at these same sites provide measures of background performance for the appropriate, indigenous organisms that are to be used in assessing sediment toxicity.

Ontario Ministry of Environment has also released biologically-based, sediment contaminant concentration guidelines for use in assessing bottom sediments in Areas of Concern, to assess the need for source control and for use in assessing dredged material disposal. These chemical concentration guidelines are also supported through the use of site-specific bioassays (OMOE 1992).

Sediment bioassays, an essential adjunct to chemical guidelines, provide confirmation that sediment is the cause of the impact, rather than the water column or other factors. As with community structure, a reference site (bioassay) database has been established (Reynoldson et al. 1995). Examples of quantitative endpoints for standard sediment bioassays performed at "clean" sites (based on the value at the 5th percentile on the normal distribution curve below which toxicity is indicated) include:

- Chironomus riparius 10-day bioassay: 68% survival in all sediments and growth of 0.22 mg dry weight per individual;

- Hexagenia <u>limbata</u> 21-day bioassay: 84% survival in all sediments, growth of 0.38 mg dry weight per individual in unfed organisms and growth of 0.58 mg dry weight in fed organisms;
- Hyallella <u>azteca</u> 28-day bioassay: 75% survival and growth of 0.22 mg dry weight in all sediments; and
- <u>Tubifex</u> <u>tubifex</u> 28-day bioassay: 24 cocoons and 21 young per adult if unfed and 31 cocoons or 35 young per adult if fed.

The OMOE restricts open-water disposal based on chemical parameters alone, however the model developed by Environment Canada proposes that if the community criteria (CC) and the bioassay criteria (BC) are met, then open water disposal of sediment is acceptable. The Environment Canada model is strictly a proposal therefore the provincial jurisdiction currently prevails for dredging activities around the Basin.

Chronic low level toxicity problems were found within the shipyard slips and in a smaller zone northwest of the slips (Figures 4 and 5). Reproduction, although reduced, did continue during bioassay exposures. Based on community structure, oligochaetes are abundant at those sites in the harbour that elicited low level toxicity. Part of the reduction in reproduction could be attributed to the higher clay content of these sites, which makes burrowing activity more difficult and food less accessible. However, tubificids have shown sensitivity to metal contamination, therefore a remedial strategy has been implemented.

POST PROJECT EVALUATION OF EFFECTIVENESS

Monitoring data collected after sediment removal was completed show a sharp decline in metal concentrations in the dredged zones. Sediment that resulted in chronic toxicity or impaired benthos was removed from the harbour environment. The site is receiving deposion of clean material and recolonization will be monitored routinely. Since this type of environmental benefit has not been measured in conjunction with known environmental clean-ups elsewhere, no information is available to determine the rate of benthic recolonization. The Collingwood post-project monitoring of this phenomenon will generate valuable data upon which to predict environmental benefits at other locations.

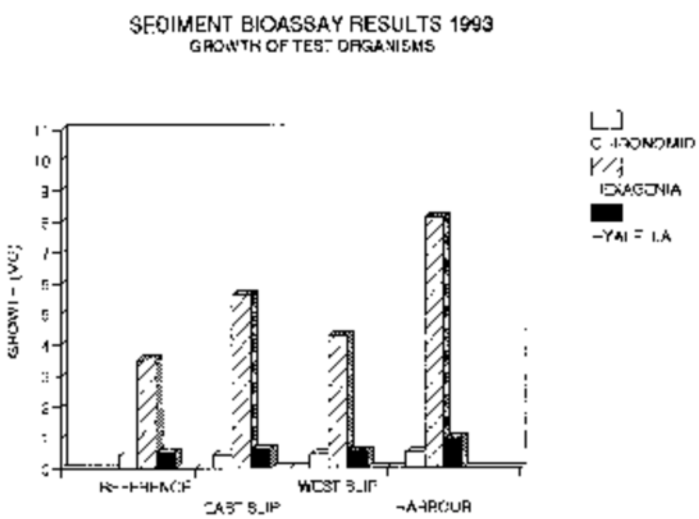

Figure 3. Growth of test animals, average of 18 (slips) and 60 (harbour) samples (Collingwood Harbour RAP Team and PAC 1992)

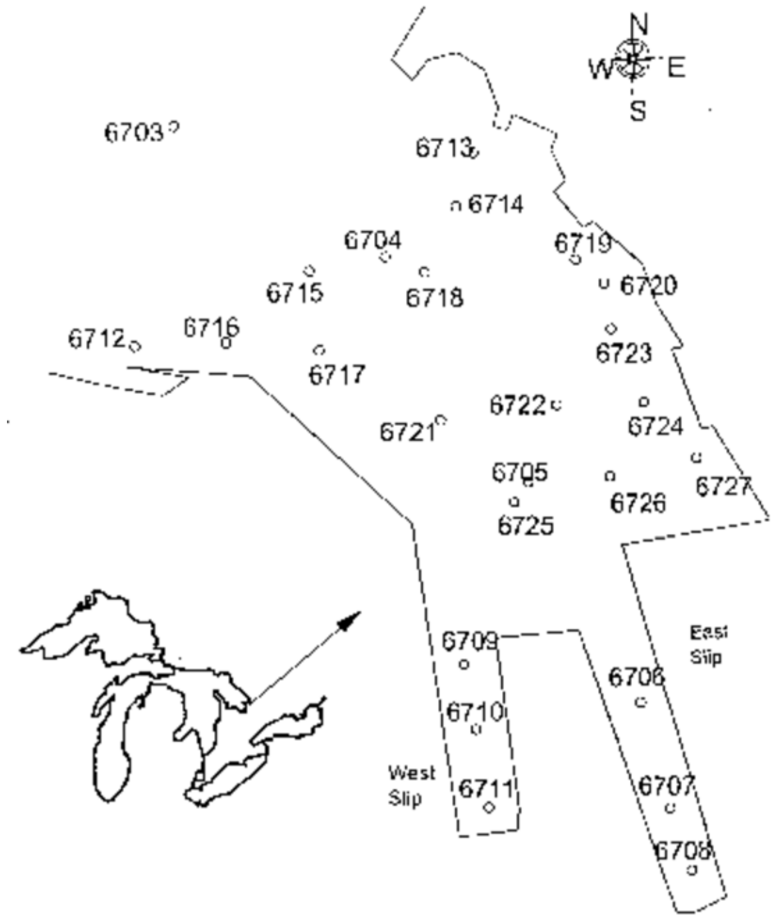

Figure 4
Collingwood Harbour sample locations, 1992-93 (Collingwood Harbour RAP Team and Public Advisory Committee, 1992).

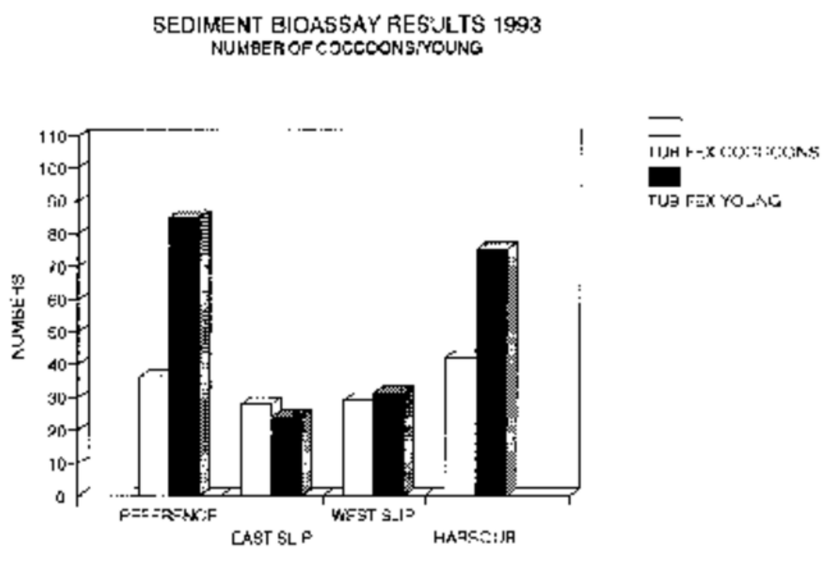

Figure 5. Reduced number of young worms in shipyard slip sediment (Collingwood Harbour RAP Team and PAC 1992)

Sediment bioassays conducted by the Collingwood Harbour RAP Team *elsewhere in the harbour* have confirmed no growth inhibition (Figure 3). The absence of growth inhibition is one line of evidence that indicates sediment is not eliciting toxicity. The 1990 mussel biomonitoring and analysis of native benthic invertebrates support the findings on toxicity and bioaccumulation (Collingwood Harbour RAP Team and

Public Advisory Committee, 1992). Benthic community structure is comparable to refrence sites of similar environmental properties and remote from pollutant sources. The presence of mesotrophic indicator species confirms the harbour sediment can support a healthy benthos (Krantzberg 1995). Based on bioassay information, field observation on native benthic invertebrates, young of the year spottail shiners, sport fish and introduced mussels, it was concluded that concentrations of biologically available contaminants Collingwood Harbour *outside the clean-up zone* are not toxicologically significant and do not impair goals, uses, or Great Lakes Water Quality Agreement beneficial uses. As stated in the RAP stage 3 publication:

> *"Benthic community structure and biomass resemble control sites of comparable physical and chemical characteristics, and sediment bioassays confirm no toxicity, in accordance with International Joint Commission delisting guidelines and requirements for healthy, self-sustaining fish and wildlife communities."*

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KEY REFERENCES

Collingwood Harbour Remedial Action Plan Team and Public Advisory Committee. 1992. Collingwood Harbour Remedial Action Plan Stage 2 Report. Ontario Ministry of Environment and Energy, Toronto, Ontario; Environment Canada, Ministry of Natural Resources, and the Collingwood Harbour Public Advisory Committee, 275 First St., Collingwood, Ontario.

Collingwood Harbour Remedial Action Plan Team and Public Advisory Committee. 1994. Collingwood Harbour Remedial Action Plan Stage 3 Document. Ontario Ministry of Environment and Energy, Toronto, Ontario; Environment Canada, Ministry of Natural Resources, and the Collingwood Harbour Public Advisory Committee, 275 First St., Collingwood, Ontario.

Krantzberg, G. 1995. Using the burden of evidence approach for sediment management; Case study: Collingwood Harbour. In: The Lake Huron Ecosystem: Ecology, Fisheries and Management. (Eds. M. Munawar, T. Edsall and J. Leach). pp. 365-395. Academic Publ. Amsterdam.

Ontario Ministry of Environment (OMOE). 1992. Guidelines for the protection and management of aquatic sediment quality in Ontario. Toronto, Ontario, Canada.

Reynoldson, T.B. and M.A. Zarull. 1993. An approach to the development of biological sediment guidelines. In: Ecological Integrity and the Management of Ecosystems. Eds. G. Francis, J. Kay, and S. Woodley. St. Lucie Press, Florida.

Reynoldson, T.B., R.C. Bailey, K.E. Day, and R.H. Norris. 1995. Biological guidelines for freshwater sediment based on **BE**nthic **A**ssessment of **S**edimen**T** (the **BEAST**) using a multivariate approach for predicting biological state. Aus. J. Ecology. 20: 198-219.

PCB CONTAMINATED SEDIMENT REMEDIATION IN WAUKEGAN HARBOR

LOCATION AND PHYSICAL DESCRIPTION

Waukegan Harbor is situated in Lake County, Illinois on the western shore of Lake Michigan. Constructed by filling a natural inlet and portions of adjacent wetlands, Waukegan Harbor has water depths varying from 4.0 to 6.5 m. The harbor sediment is composed of soft organic silt (muck) which lies over medium dense, fine to coarse sand.

In 1990, approximately 75 commercial ship dockings were present in the Harbor. The majority of the materials brought through the Harbor were building/construction materials for nearby Chicago industries (Hey and Associates 1993).

Although substantial recreational use occurs in the area around the harbor, land use in the Waukegan Harbor area is primarily industrial. Of the major facilities present, the Outboard Marine Corporation (OMC) was identified as the primary source of PCB contamination in Harbor sediments. In 1972 OMC dismantled a coke oven gas plant (previously built and owned by the North Shore Coke and Chemical Company) to construct their own facilities for manufacturing recreational marine products. U.S. Environmental Protection Agency (EPA) investigations in 1976 revealed high levels of polychlorinated biphenyls (PCBs) in Waukegan Harbor sediments and in soil close to OMC outfalls. Concurrently, high levels of PCBs (above the U.S. Food and Drug Administration action levels of 2.0 ppm PCB) were also found in resident fish species. As a result, in 1981, the U.S. EPA formally recommended that no fish from Waukegan Harbor be consumed. Subsequently, the Lake County Health Department posted signs warning residents that consumption of fish from the northern Harbor could be dangerous to human health.

PROJECT GOALS AND OBJECTIVES

With the discovery of Waukegan Harbor's PCB problem in 1976, the U.S. EPA and Illinois EPA became involved in a lengthy litigation process with OMC and, as a result of the requirements of the 1980 Comprehensive Environmental Response Compensation and Liability Act (Superfund), and its 1986 Amendments, a Consent Decree was entered by the U.S. Justice Department in District Court in 1989. The Consent Decree called for remediation of the contaminated sediments greater than 50 ppm PCBs.

SEVERITY AND GEOGRAPHIC EXTENT OF PROBLEM

Early investigations of harbor sediment indicated that approximately 136,000 kg of PCBs were in the harbor proper (IJC 1989). In the most highly contaminated areas of the harbor (Slip #3), PCB concentrations in sediments were as high as 500,000 mg/kg (Figure 1). Severely contaminated areas totaled about 19 ha, including the Upper Harbor, Slip #3 and land on the northern edge of OMCs property (IJC 1987).

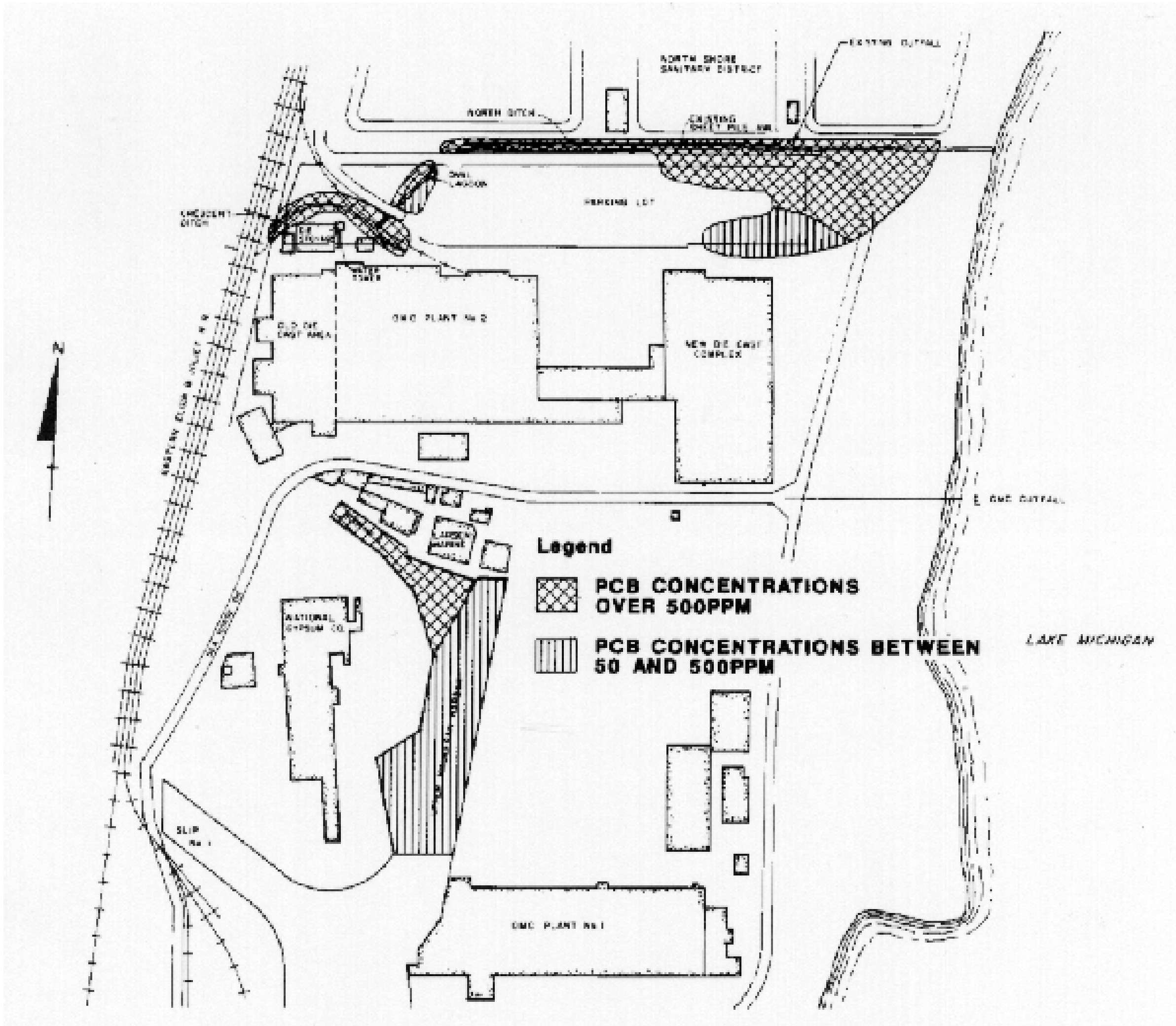

Figure 1. OMC site before remedial action (U.S. EPA 1988)

DESCRIPTION OF REMEDIAL ACTIONS

Remedial efforts in the Harbor began in 1990 with harbor dredging conducted in 1992. As a result of the Consent Decree, OMC provided approximately $20-25 million for remediation which included the construction of three containment cells (Figure 2). 24,500 m^3 of PCB contaminated sediment was removed from the Harbor using a hydraulic dredge. Approximately 2,000 m^3 of PCB-contaminated sediment, in excess of 500 mg/kg PCBs, was removed from Slip #3 (a "hot spot" that accounts for the majority of the PCBs on the site) and thermally extracted onsite to at least 97% (Taciuk Process). 11,521,400 kg of material were treated and 132,500 litres of PCBs were extracted and taken off site for destruction. The treated sediment was placed in one of the OMC containment cells. Upper harbor sediment was dredged and put in the Slip #3 containment cell. Soils in excess of 10,000 mg/kg of PCBs were also excavated and treated onsite by thermal extraction (Hartig and Zarull 1991).

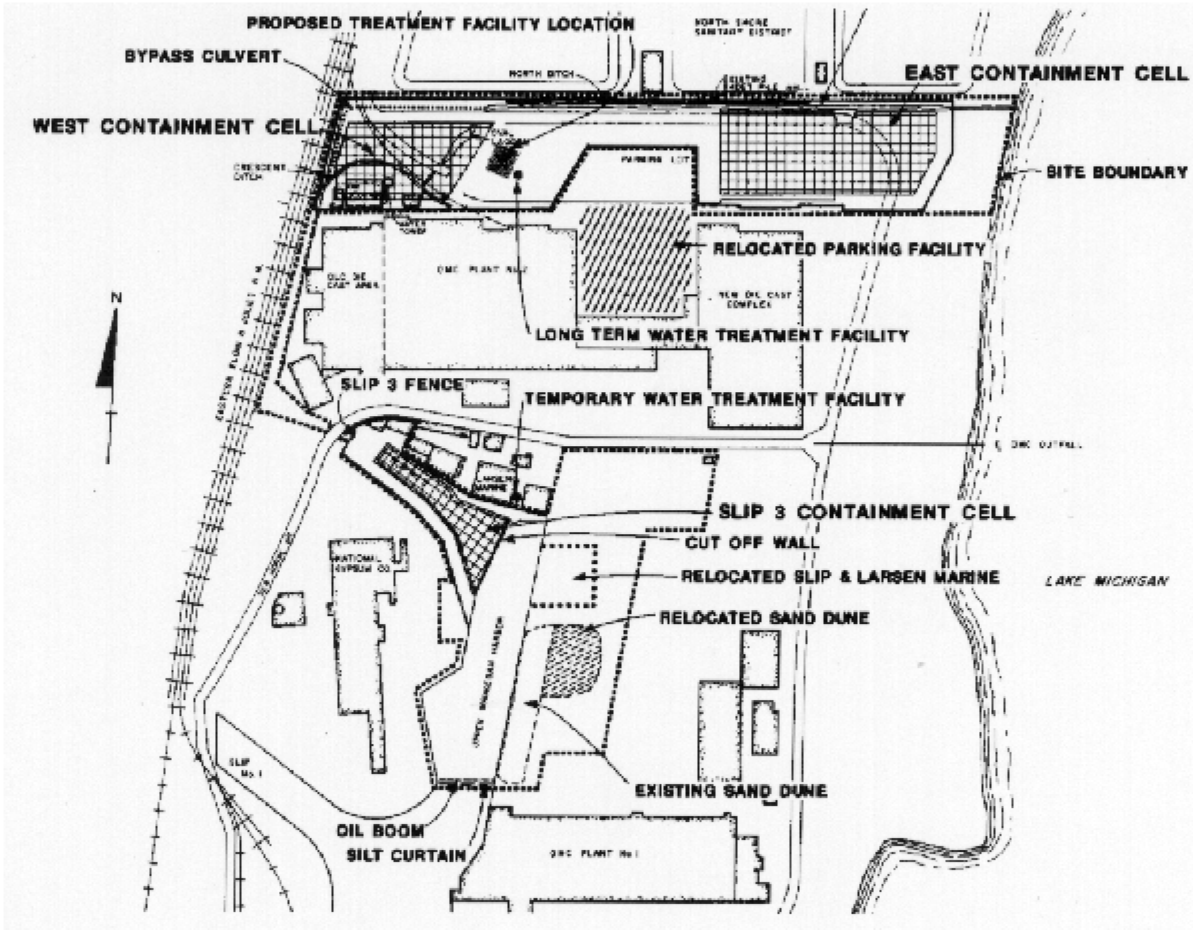

Figure 2. OMC site after remedial action completed (U.S. EPA 1988)

Extracted PCBs were transported to an offsite facility for high-temperature combustion (>2200^{o}F) in accordance with the U.S. Toxic Substances Control Act. No soils or sediments that exceeded 50 mg/kg PCBs remained onsite, except those within the containment cells.

Following completion of the soil and sediment remediation, the cells were closed and capped with a high density polyurethane liner and a soil cover (Figure 3). Extraction wells in each cell maintain an inward hydraulic gradient, to prevent PCB migration. The cells are operated and maintained by OMC. To offset the loss of slip #3, a new slip (#4) was dredged and opened to the public in July 1991.

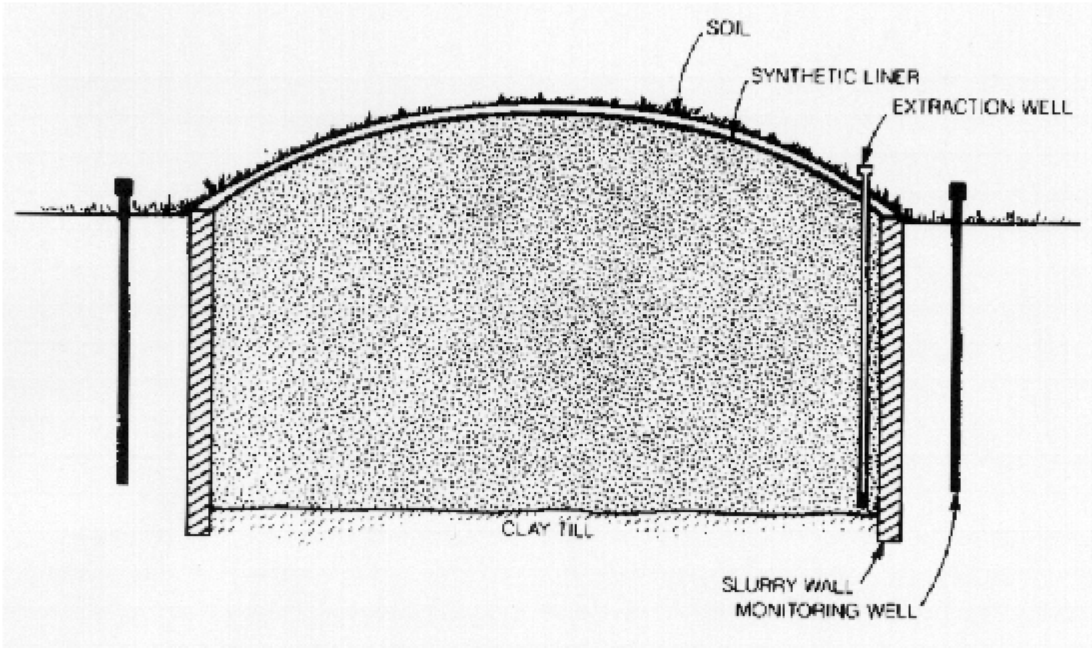

Figure 3. Containment cell cross section (U.S. EPA 1988)

COST

Under the Consent Decree, the Outboard Marine Corporation paid an estimated $20-25 million for remedial actions they conducted under the 1989 consent decree.

REGULATORY CONSIDERATIONS

OMC was required to comply with the 1989 Consent Decree and all Superfund requirements. In addition, extracted PCBs had to be transported and incinerated in accordance with requirements of the U.S. Toxic Substances Control Act.

CLEANUP TARGETS AND ENDPOINTS

The primary cleanup target was the removal, containment, and treatment of contaminated sediments in and around the OMC property in order to meet the 50 mg/kg PCB determined under the consent decree.

POST PROJECT EVALUATION OF EFFECTIVENESS

Fish

Fish flesh sampling, conducted after the inner harbor was dredged in 1992, through the Superfund remediation in 1993 shows a substantial decrease for PCB concentrations in carp fillets. Figure 4 presents trend data for PCBs in Waukegan Harbor carp fillets (Clark 1997). PCB levels in 1993 fish show that dredging did not cause significant PCB suspension. Contaminant levels in 1993 fish averaged 5 fold lower than those tested in 1983 and 1991.

Historical information on PCB levels in fish is limited and not standardized for trend analysis. However, a review of the available data, although not subject to statistical analysis, supports the overall trend of decreasing PCB contamination of fish following sediment remediation (Table 1).

As a result of the dramatic decline in PCBs in fish, the posted Waukegan Harbor fish advisories were removed, although fish advisories still exist for carp and other harbor fish. The Illinois Lake Michigan

Lakewide Advisory is protective of human health as PCB concentrations in Waukegan Harbor fish are considered to approximate fish found elsewhere in Lake Michigan.

Sediment

Approximately 136,000 kg of PCBs were removed through the Superfund action. Sediment sampling indicates that about 900 kg of PCB-contaminated sediment remains in the navigational channel of the harbor. This PCB contamination and silting has resulted in cargo carrier restrictions on ships passing into the channel. The Department of Transportation has observed disturbance of navigational sediments by prop wash. U.S. Army Corps of Engineers, working with the Waukegan Port Authority, plans to remove those sediments interfering with navigation. Once completed, this action will eliminate the majority of the 900 kg of PCBs still present in harbor sediments.

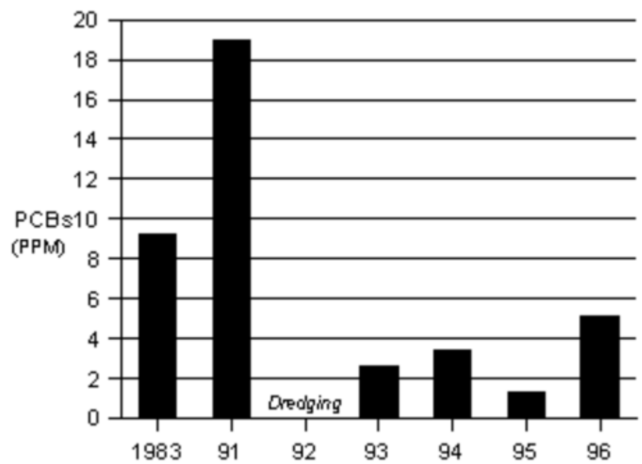

Figure 4. PCB levels in Waukegan Harbor carp fillets

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KEY REFERENCES

Clark, J. Milton. 1997. "Policy Implications" - a presentation to the Great Lakes Roundtable - "Achieving the Future". Niagara-on-the-Lake. October 31.

Hartig, J.H. and M.A. Zarull. 1991. Methods of Restoring Degraded Areas in the Great Lakes. Reviews of

Environmental Contamination and Toxicology. 117:127-154.

Hey and Associates. 1993. Waukegan Remedial Action Plan - Stage 1 Final Report. Libertyville, Illinois. 106 pp. + appendices.

International Joint Commission. 1989. Progress in developing and implementing remedial action plans for Areas of Concern in the Great Lakes Basin - Appendix A. Great Lakes Water Quality Board. Windsor, Ontario. 196 pp.

International Joint Commission. 1987. Report on Great Lakes Water Quality, Great Lakes Water Quality Board. Windsor, Ontario. 236 pp.

International Joint Commission. 1983. Report on Great Lakes Water Quality - Appendix A - Areas of Concern in the Great Lakes Basin: 1983 Update of Class 'A' Areas. Great Lakes Water Quality Board. Windsor, Ontario. 113 pp.

U.S. EPA. 1988. Cleanup of Outboard Marine Corporation/Waukegan Harbor Site. Office of Public Affairs. Chicago, Illinois. 8 pp.

Table 1 - Qualitative comparison of PCB levels in Waukegan fish

Year	Species	PCBs (mg/kg)	Description of Sample	Reference or Source
1978	carp	26.5	whole	U.S. EPA
	alewife	1.8	whole	U.S. EPA
	white sucker	3.6	whole	U.S. EPA
1979	carp	38.5	whole	U.S. EPA
	carp	18.4	whole	U.S. EPA
	carp	8.2	whole	U.S. EPA
	alewife	1.8	whole	U.S. EPA
	white sucker	26.8	whole	U.S. EPA
1983	carp	9.2	fillet	U.S. EPA
1991	carp	19.0	fillet	Illinois EPA
	alewife	10.0	whole	Illinois EPA
1992	alewife	0.17	whole	Illinois EPA
1993	carp	2.6	fillet	Illinois EPA
	carp	2.4	fillet	Illinois EPA
	carp	6.39	fillet	Illinois EPA
	carp	1.84	fillet	Illinois EPA

	carp	1.66	fillet	Illinois EPA
	carp	0.60	fillet	Illinois EPA
	alewife	0.10	whole	Illinois EPA
	alewife	0.17	whole	Illinois EPA
1994	carp	3.45	fillet	Illinois EPA
1995	carp	1.3	fillet	Illinois EPA
	carp	1.71	fillet	Illinois EPA
	carp	1.29	fillet	Illinois EPA
	carp	0.99	fillet	Illinois EPA
	alewife	0.05	whole	Illinois EPA
	alewife	0.24	whole	Illinois EPA
	alewife	0.44	whole	Illinois EPA
	white sucker	0.26	whole	Illinois EPA
	white sucker	0.37	whole	Illinois EPA
	white sucker	0.52	whole	Illinois EPA
1996	carp	4.4	fillet	Illinois EPA
	carp	8.00	fillet	Illinois EPA
	alewife	0.4	fillet	Illinois EPA
	white sucker	0.17	fillet	Illinois EPA
	white sucker	0.36	whole	Illinois EPA
	white sucker	0.86	whole	Illinois EPA
	white sucker	0.77	whole	Illinois EPA
	white sucker	0.90	whole	Illinois EPA
	white sucker	0.30	whole	Illinois EPA