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June 30, 1993

Mr. William Bolen
U.S. Environmental Protection Agency
Region V
Waste Management Division
IL/IN Remedial Response Branch HSRL-6J
77 West Jackson Boulevard
Chicago, IL 60604

Re: Waukegan Manufactured Gas and Coke Plant (WCP) Site
Response to Comments on the April 1993 Phase I Technical Memorandum

Dear Mr. Bolen:

On behalf of Mr. Patrick Doyle of North Shore Gas Company, we are submitting this response to your letter of May 21, 1993, which transmitted U.S. Environmental Protection Agency (U.S. EPA) and Illinois Environmental Protection Agency (IEPA) comments on the April 1993 RI/FS Phase I Technical Memorandum, Waukegan Manufactured Gas and Coke Plant Site, Waukegan, Illinois. This letter is the complete response to the comments in your letter of May 21, 1993, and is considered to amend and modify the April 1993 Phase I Technical Memorandum. As you stated, we will not need to republish and resubmit the Phase I Technical Memorandum.

In addition to addressing specific comments, this letter proposes modifications to some elements of the Phase II work plan. The modifications consist of updating the Site Health and Safety Plan so that it addresses new Phase II tasks and reflects the current knowledge of the site; ensuring the success of the pumping test by building more flexibility into the pumping test design in the event that actual site conditions are not as expected; modifying the locations and construction of the piezometers to optimize information collection during the pumping test and to benefit from existing piezometers on Outboard Marine Corporation (OMC) property; modifying the standard operating procedure for field soil pH; correcting the parameter list for groundwater samples; and correcting the project schedule to resolve conflicts.

RESPONSE TO U.S. EPA COMMENTS

<u>Comment 1</u>: We understand this comment is related to the water level information available for wells near the OMC Plant No. 2 facility north of the WCP site. The water level data, well construction information, and boring logs shown in the Warzyn reports supplied to us by the U.S. EPA (Subsurface

Investigation, North Ditch Area [C-9177] and Hydrogeologic Investigation [C-8342]) and the JRB report (Technical and Witnessing Case Support, Hydrogeology Study of Groundwater - Final Report, 1981) will be further reviewed and evaluated prior to drafting the Remedial Investigation Report. This information has been used to select water level monitoring points for the Phase II investigation program to select water level monitoring points. Changes made to the investigation program are detailed below under "Piezometer Location and Construction."

<u>Comment 2</u>: This comment refers to a misstatement in the Phase I Technical Memorandum. The second sentence in the fifth paragraph of Section 2.4.2.2, Hydrogeologic Model Development, will be changed to read as follows: This pattern of flow differs from that inferred from the water table elevation contour interpretations shown on Figures 2.2-5 through 2.2-8, which indicate flow toward the south<u>west</u> from the northeast corner of the site.

<u>Comment 3</u>: The three references cited in Table 2.4-6 were chosen from the list of references in Attachment 1 because they reported naturally occurring concentration ranges for the greatest number of inorganic compounds in soils and because they summarized much of the data reported by other authors. Other references considered, but not selected, included mineral exploration guides or agricultural studies that reported concentrations for only certain elements of interest, references that reported only an average concentration instead of a range of values, references that reported values for specific geographic areas unrelated to the site, and references that were summarized in other references. We would appreciate any additional information the U.S. EPA may have on other references that should be considered.

In Section 2.4.4.2, Other Compounds, the following will be added following the first sentence in the second paragraph: The concentration ranges were selected from widely recognized references which incorporate data from a number of studies and provide a relatively comprehensive list of compounds.

<u>Comment 4</u>: In the discussion of the horizontal distribution of phenol in Section 2.4.5.1, Distribution of MGP/Coking and Creosote Compounds, the last sentence will be changed to read as follows: The source of phenol in the sample from Well MW-3D is unknown at this time <u>and will be investigated during Phase II sampling</u>.

<u>Comment 5</u>: In the discussion of the horizontal distribution of arsenic in Section 2.4.5.1, Distribution of MGP/Coking and Creosote Compounds, the following sentence will be added to the end of the paragraph: The potential source of arsenic in samples from Wells MW-5D and MW-6D will be investigated during Phase II sampling.

Comment 6: The last sentence before the semicolon in the first paragraph of Section 2.4.5.3, Identification of Phase II Analytical Parameters for Groundwater, will be changed to read as follows: The second round of Phase II groundwater samples, to be collected from all the Phase I and Phase II monitoring wells, will be analyzed for the chemical parameters listed below: ...

Comment 7: The words "at the" will be deleted from the first sentence of the first paragraph in Section 2.4.6, Ecological Survey.

Comment 8: The second to last sentence of the third paragraph of Section 3.3.1, Monitoring and Pumping Well Installation, will be changed to read as follows: If shallow soils in the immediate vicinity of the MW-9 well nest are contaminated with oil or tar, the MW-9 well nest will be deleted from the investigation program.

The last sentence of the third paragraph of Section 3.3.1, Monitoring and Pumping Well Installation, will be deleted. Sampling of oil or dense nonaqueous-phase liquids (DNAPL) from wells is discussed in Item 10 of the IEPA comment responses presented below.

Comment 9: After the first sentence in the second paragraph of Section 3.3.4, Permeability Testing, the following sentence will be added: The proposed locations for the collection of these three samples are shown on Figure 3.2-1.

Comment 10: The first sentence of the fourth paragraph in Section 3.3.4, Permeability Testing, will be changed to read as follows: The water pumped from Well PW-1 during the pumping test will be pumped into a storage tank on site and stored in the tank for the entire duration of the pumping test.

Comment 11: The last two sentences of the eighth bullet under Section 3.5.1, General Remediation Evaluation Parameters, will be replaced with the following sentence: TCLP samples will be placed in a stainless steel bowl, objects larger than 1/2 inch in size will be removed, and the samples will be promptly packaged in laboratory containers.

Comment 12: Revised Tables 3.6-1 and 3.6-2 are in Attachment 2. The tables have been revised to include the following: risk assessment and concurrent ecological assessment duration of ten weeks; risk assessment and ecological assessment to begin after U.S. EPA approval of the Preliminary Characterization Summary; and agency review periods of 30 days for all comments or approvals. Exceedence of the schedules for U.S. EPA activities will result in equal extensions of the total project time. The critical links are illustrated on enclosed Table 3.6.2. The schedule has been corrected to resolve schedule conflicts, as described below under "Schedule."

It is understood that PRC Environmental Management, Inc. (the U.S. EPA oversight contractor) will be conducting the ecological assessment. To assist PRC in collection of relevant ecological assessment information, a copy of the January 1992 draft Waukegan Area of Concern Remedial Action Plan (RAP) is enclosed in Attachment 3. The draft RAP summarizes the recent water quality sampling, sediment sampling, and fish flesh sampling results for the area, summarizes the major pollutants of concern for the area, and identifies uses of the area that have been impaired.

Comment 13: In Table 2.4-7, the results for methylene chloride and carbon disulfide for the background soil samples were inadvertently switched. The table will be corrected to read as follows:

	FREQUENCY OF DETECTION (Maximum Concentration in µg/kg)
Parameter	BS
Methylene chloride	ND
Carbon disulfide	3/9 (4)

This correction does not affect the text in Sections 2.4.3, Background Soil Quality Summary, and 2.4.4.4, Identification of Phase II Analytical Parameters for Soil.

Comment 14: General water quality parameters will be analyzed in order to assess potential treatability alternatives. In the August 1992 Phase I Technical Memorandum, a short list of parameters (BOD/COD, oil and grease, total suspended solids) for assessing treatability alternatives was to be run on the second round of groundwater samples from all the wells. The April 1993 Phase I Technical Memorandum moved the sampling up to the first sampling event and expanded the parameter list to include sulfate, sulfide, chloride, acidity, alkalinity, total hardness, total dissolved solids, and total organic carbon. The wells for which this longer list of parameters will be analyzed were selected to be representative of the various areas around the site: MW-9S and MW-9D for the gas plant/coke plant process area; MW-7S and MW-7D for the northeast pond area; MW-12S and MW-12D for the area east of the plant process area; MW-10S and MW-10D for the area south and southwest of the process area; and MW-6S and MW-6D for the former creosote plant area. This program is designed to give broad aerial coverage of the investigation area and provides an opportunity to review the data prior to the second round of sampling.

Comment 15: Appendix I does not state that the base of the sand aquifer is horizontal. Appendix I states that a horizontal base was assumed for the purposes of groundwater flow modeling. This assumption is appropriate for the groundwater flow modeling for two reasons. First, the slope of the top of the till surface is reasonably flat, sloping at approximately 0.5 percent from Monitoring Well MW-6D to MW-4D. Second, the effect of that slope on the transmissivity of the aquifer (transmissivity is used by the model in its calculations) is small compared to the effect of other factors, such as hydraulic conductivity. Hydraulic conductivity estimates are only order of magnitude estimates. For example, a change in saturated aquifer thickness from 22 to 28 feet at a constant hydraulic conductivity of 6 feet per day would result in a change in transmissivity from 130 to 170 feet squared per day. This change in transmissivity (an increase by less than a factor of 1.5) is far less than the order of magnitude uncertainty in the estimate of hydraulic conductivity. Consequently, it would not be justifiable to refine the model to account for the slight slope of the till surface, given the level of other uncertainties inherent in the preliminary modeling.

Appendix I states that all simplifying assumptions about the hydrogeologic conditions of the site that were made during development of the groundwater flow model would be reevaluated with the additional hydrogeologic data to be collected during the Phase II investigation. If the Phase II data confirms a slope on the base of the aquifer and if modeling that slope will improve the quality of the modeled results and conclusions that can be drawn from the modeling, the slope will be modeled.

Comment 16: The comment states that the model used hydraulic conductivity values of 6 feet per day (2.1×10^{-3} cm/s) on-site and 20 feet per day (7.1×10^{-3} cm/s) off-site. However, the groundwater modeling used a 6-foot per day hydraulic conductivity value not only for on-site areas, but also for all off-site areas for which model results were used to help preliminary assessments of groundwater flow. Thus, a uniform hydraulic conductivity was used for the entire peninsula where the site is located, as well as for the OMC Plant No. 2 property as far north as the North Ditch.

The hydraulic conductivity value of 6 feet per day was the geometric mean of all the available hydraulic conductivity values for the modeled area of interest. The hydraulic conductivity, the defined boundary conditions, and the infiltration are the parameters that controlled the groundwater flow solution produced by the model for the area of interest.

There was no attempt in the Phase I preliminary modeling to accurately model groundwater flow patterns in areas that do not affect the solution in the area of interest, i.e., the vicinity of the site and OMC Plant No. 2. This is consistent with the stated objectives of the Phase I preliminary modeling, which were to provide an initial evaluation of steady-state groundwater flow patterns, to provide guidance in locating new monitoring wells, to identify data gaps, and to design the Phase II pumping test. The 20-foot per day hydraulic conductivity outside the area of interest was an arbitrary assumption that was not adjusted during final calibration of the preliminary model, in the knowledge that this assumption would not affect the solution at the site. These matters are all briefly reviewed, in a level of detail appropriate to the preliminary modeling effort and its purposes, in Appendix I, especially paragraphs 1 and 6.

Comment 17: The sixth paragraph in Section 2.4.2.2, Hydrogeologic Model Development, much of Section 3.3.5, Hydrogeologic Model Development, and the seventeenth paragraph in Appendix I all address this comment.

Comment 18: A laboratory standard operating procedure for cation exchange capacity is in Attachment 4.

Comment 19: A laboratory standard operating procedure for weak acid dissociable cyanide is in Attachment 4.

RESPONSE TO IEPA COMMENTS

1. Disposal of Groundwater Produced During Well Development, Sampling, and Pumping Test.

The IEPA has stated that this water may potentially be a pollution control waste, regulated under special waste regulations in 35 Illinois Administrative Code Subtitle G, Section 809. If this characterization of the water is correct, the water could not be discharged except to a publicly owned treatment works (POTW) or under the terms of an NPDES or other discharge permit. Without agreeing or disagreeing with the IEPA comment, Barr Engineering Company has contacted the North Shore Sanitary District (NSSD) and obtained their concurrence that, in principle, site water can be pretreated and discharged to their system. Barr is attempting to obtain permits from the IEPA and NSSD for discharge of these waters to the NSSD. The Phase II field work cannot being until the necessary permits have been obtained.

We anticipate that the same pretreatment program envisioned for discharge to the NSSD would satisfy the requirements to spray-irrigate the water on-site. Management of the water on-site by spray irrigation would not require a formal permit under Superfund. We believe the substantive requirements for on-site management of the water have been addressed with the plan to treat the water with activated carbon and electro-chemical precipitation as described in the Phase I Technical Memorandum.

During the Phase I work, the discharge of well development and well purging water, as well as the management of other investigation-derived wastes, was performed pursuant to the Work Plan approved by the IEPA and U.S. EPA on November 15, 1991. The management of these materials was consistent with the U.S. EPA "Guide to Management of Investigation-Derived Wastes."

2. Fire Training and Storage of Petroleum and PCBs On-Site by OMC.

More thorough information regarding these matters will be sought from OMC for inclusion with the Remedial Investigation Report.

3. Analytical Parameter Reporting.

During the conference call on June 7, 1993, William Bolen of the U.S. EPA, Tracy Fitzgerald and Jerry Willman of the IEPA, and James Langseth of Barr Engineering Company agreed that the proposed parameter list in Table 2.4-8 would be satisfactory.

4. Drilling in Highly Contaminated Areas.

   a. Borings.

   At the request of the IEPA, borings will be grouted with bentonite slurry, rather than neat cement grout. The slurry will be tremied into the borehole.

   If we have information on the relative merits of these two approaches, we will provide it to the IEPA and the U.S. EPA.

   b. Wells.

   The only well location considered likely to encounter oil or tar is the MW9S/MW9D pair. As stated on page 71 of the Phase I Technical Memorandum: "If soils in the immediate vicinity of the MW9 well nest are contaminated with oil or tar that appears likely to flow into the well, the MW9 well nest will be deleted from the investigation program." We agreed that this would be a satisfactory program for handling this contingency.

5. Soil Cuttings and Purge Water from Off-Site Installations.

It was agreed that purge water would be transported back to the site and managed as described above (item 1) for all purge water and well development water. All off-site soil cuttings will be brought back to the site and managed as described in item 6 below.

6. Soil Cuttings On-Site.

Soil cuttings which are visibly clean and do not register readings on hand-held air quality screening devices when monitored within 3 inches of the surface of the soil will be left on the ground on-site within the fenced area. Off-site soil cuttings brought back to the site that meet these criteria will also be placed on-site adjacent to other soil cuttings. Soil cuttings not meeting these criteria will be placed in drums for future management.

7. Surface Samples for Volatile Organic Compound Analysis.

We agreed that VOC analysis of the 0 to 6-inch surface soil samples is for the purpose of risk assessment and, therefore, would be performed as provided in the Phase I Technical Memorandum. VOC information has already been obtained from the seventeen shallow soil samples (2 to 4-foot depth) collected during the Phase I investigation.

8. Identification of the Soil Stockpile Referred to in Section 3.2.3.1.

The identification of the soil stockpiles is adequately presented in Section 3.2.3.1, Soil Stockpile Soil Samples, and Section 3.2.3.2, Designated Soil Stockpile Characterization.

9. Wells in Areas with Free-Flowing Contaminants.

This issue was addressed under item 4 above.

10. Sampling Oil or DNAPL from Wells.

Prior to purging a well, a probe will be inserted to the full depth of the well and observed for the presence of DNAPL. In the event DNAPL is discovered, an effort will be made to sample the DNAPL if there is sufficient depth of product to make sampling physically feasible. It should be recognized that the water quality data from wells containing DNAPL is likely to be inconsistent over time and not representative of the concentrations of dissolved phase contaminants that might be transported with groundwater.

Additional guidance on DNAPL investigation is provided in Attachment 5.

11. Groundwater Discharge at the Site.

This issue was addressed under item 1 above.

12. PCB Analysis as Referenced under Section 2.4.4.4(1).

As agreed at the March 5, 1993 meeting, samples from new monitoring wells MW11S and MW11D will be analyzed for PCBs (as are all first round samples from the site monitoring wells). Analysis of soil samples for PCBs will be performed on samples from the existing sand stockpile and designated soil stockpile as provided in the Phase I Technical Memorandum.

OTHER MODIFICATIONS TO THE PHASE II WORK PLAN

Site Health and Safety Plan

Amendments to the October 1991 Site Health and Safety Plan are in Attachment 6. The first amendment updates the project tasks, the work zones, the personal protective equipment, the potential chemical hazards on-site, the air monitoring procedures, and the water safety procedures for the Phase II investigation. The second amendment updates changes in project personnel.

The appendices to the safety plan have also been updated. However, a copy of the appendices is not enclosed because the appendices are not project specific. The appendices constitute a standard Barr document that summarizes Barr standard operating procedures and Barr safety policies for all Barr projects. The appendices will be available on-site during the Phase II field work.

Pumping Test Design

The current pumping test design consists of pumping a 4-inch diameter pumping well at a rate of 15 gallons per minute for 24 hours and observing drawdown continuously in Monitoring Wells MW-1S and MW-1D and Piezometers P-104 and P-106 and at discrete time intervals in Monitoring Wells MW-6S, MW-6D, MW-9S, and MW-9D and Piezometer P-103. This design was based on hydraulic conductivity estimates obtained from the slug tests. If the hydraulic conductivity of the sand aquifer is actually an order of magnitude greater than estimated by the slug tests, meaningful drawdown may not be obtained from the observation wells at a pumping rate of 15 gallons per minute. In order to ensure the success of the pumping test in the event that actual site conditions are not as expected, the pumping test design is being modified to allow for greater pumping rates and more flexibility in the field. The following modifications will address this matter:

1. Increase the diameter of the pumping well from 4 inches to 6 inches in order to allow submersible pumps of a greater capacity to be lowered into the well.

2. Determine the actual pumping rate by means of a step drawdown test at the pumping well after installation of the well.

Should the groundwater removed from the pumping well during the pumping test have to be stored and treated on-site and then discharged to the sanitary sewer, it may be necessary to reduce the duration of the pumping test from 24 hours to 12 or 8 hours, if the actual pumping rate increases by a factor of 2 or 3. Because the drawdown data obtained from the observation wells will only be used to estimate hydraulic conductivity and not the storage coefficient, the duration of the pumping test is not as important as stressing the aquifer adequately.

There is some uncertainty as to whether boundary effects of the slip wall will be observed in the water level data from Monitoring Wells MW-1S and MW-1D.

Therefore, Piezometer P-106 will be installed approximately 20 feet south of the pumping well instead of east of the pumping well. The symmetry of the response curves for Monitoring Wells MW-1S/MW-1D and Piezometer P-106 can then be compared in order to determine whether boundary effects of the slip wall have been observed. An additional piezometer, Piezometer P-107, will be installed north of the pumping well as close as possible to the slip wall. Piezometer P-107 will be in line with Wells MW-1S and MW-1D, Piezometer P-106, and the pumping well. The construction of Piezometer P-107 will be identical to that of P-106, and water levels in Piezometer P-107 will be monitored continuously during the pumping test. Boundary effects of the slip wall may or may not be observed in the water level data obtained from Piezometer P-107 during the pumping test, depending on the duration and flow rate of the test. However, water level measurements from this piezometer will be examined (along with water level data from the Harbor and Wells MW-6S and MW-5S) to estimate relative resistance values for the slip and harbor walls.

Piezometer Locations and Construction

Piezometers P-105 will not be installed as proposed. Information obtained from the OMC Plant No. 2 PCB investigation indicates that OMC currently has two piezometers (Z-1 and Z-2) located in the vicinity of proposed Piezometer P-105. The locations of these piezometers are shown on the figure in Attachment 7. These two piezometers will be monitored during the Phase II program in place of P-105. Construction logs for these piezometers will be included in the Remedial Investigation Report.

Piezometers P-106 and P-107 will be constructed of 2-inch diameter PVC instead of 1-inch diameter PVC as stated in the Phase II work plan. A larger diameter will ensure that the transducer (the probe that will be used during the pumping test to record water levels) can be lowered into the piezometers without problems. A larger diameter will also allow a water level marker to be lowered into the piezometers while the transducer is in place.

Phase II Groundwater Quality Parameters

Amenable cyanide was inadvertently left off of the list of Phase II groundwater quality parameters in the Phase II work plan. All groundwater samples obtained from the monitoring wells during the second monitoring event and all groundwater samples obtained from the HydroPunch tool during installation of the soil borings will be analyzed for amenable cyanide in addition to the other Phase II parameters. The Phase II analytical parameters for groundwater samples are listed in the table in Attachment 8.

In the Phase II work plan, it was stated that the groundwater samples would be analyzed for the volatile organic compounds in EPA Method 8240. This list of parameters is slightly different than the Contract Laboratory Protocol Target Compound List (CLP TCL) of volatile organic compounds analyzed during the Phase I investigation. The parameters trichlorofluoromethane, vinyl acetate, 2-chloroethylvinylether, 1,3-dichlorobenzene, 1,4-dichlorobenzene, and 1,2-dichlorobenzene are on the Method 8240 list, but not on the CLP TCL. It was our intention to keep the volatile organic parameter list consistent during both phases of the remedial investigation. For this reason, the groundwater samples from the Phase II investigation will be analyzed for the CLP TCL volatile organic compounds instead of the Method 8240 compounds. The Phase II analytical parameters for groundwater samples are listed in the table in Attachment 8.

Surface Water Sampling

The same changes to the list of analytical parameters that were made to the groundwater sampling program will be made to the surface water sampling program. The changes were described in the preceding section.

Field Soil pH

The use of a pH meter instead of litmus paper is proposed for the measurement of soil pH in the field. According to ASTM D4972-89 Standard Test Method for pH of Soils, the pH meter calibrated with buffer solutions is more accurate than the litmus paper. The revised Attachment 4a Standard Operating Procedure for the Field Measurement of Soil pH is in Attachment 9.

Schedule

The schedule for the RI/FS work is shown in Table 3.6-1. An illustration of the schedule for the remaining work is in Table 3.6-2. The revised schedule for the RI/FS work provides 30-day periods for U.S. EPA review of all deliverables, and provides ten weeks following approval of the Preliminary Characterization Summary for completion of the draft risk assessment and ecological assessment.

The revised schedule also resolves task start/finish conflicts that were introduced by the extension of the risk assessment schedule. The start date of the risk assessment/ecological assessment was revised to follow the approval of the Preliminary Characterization Summary. The start date for the Screened Alternatives and Proposed ARARs Technical Memorandum was revised to follow the final revisions to the risk assessment/ecological assessment and the approval of the Remedial Investigation Report. These start/finish dependencies are indicated on Figure 3.6-2 by vertical arrows. An additional benefit of these schedule revisions is the elimination of the concurrent review of the draft Remedial Investigation report and the Technologies and Screening Process Technical Memorandum by the U.S. EPA and IEPA. Start/finish relationships for other sequential tasks, such as receiving U.S. EPA review and comment on the Alternatives Array Summary prior to beginning the Comparative Analysis of Alternatives, are not shown with vertical arrows. The technical memoranda in the Remedial Alternatives Development and Screening task and in the Alternatives Evaluation task are naturally sequential. Each technical memorandum is dependent on the comment and guidance provided from the U.S. EPA review of the previous technical memorandum. Because of the explicit and natural time dependencies in the schedule, extension of scheduled U.S. EPA review time and/or completion of the risk assessment/ecological assessment will result in commensurate extension of the remaining tasks in the schedule.

This letter constitutes the final addenda to the April 1993 Phase I Technical Memorandum. The Phase I Technical Memorandum will not be resubmitted.

Please contact me with any questions regarding this letter.

Sincerely,

James R. Langseth

KAF:crs
Enclosures
c: Tracy Fitzgerald
Patrick Doyle
Jerry Picha
Rick Hersemann
Margaret Skinner
Marianne Grammer
Steve Armstrong
Dan Bicknell
Jerry Maynard
James Campbell
Russell Selman
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Attachments

Attachment 1

Soil Chemistry References

ATTACHMENT 1

SOIL CHEMISTRY REFERENCES

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Attachment 2

Revised Project Schedule

ATTACHMENT 2

TABLE 3.6-1

ESTIMATED DURATION OF PROJECT TASKS
REVISION 3

ACTIVITY	START	TASKS	START DATE	TASK DURATION (WEEKS)	CUMULATIVE DURATION[1,2] (WEEK NUMBER)	COMPLETION DATE
Phase I Field Investigation	Work Plan Approved and Site Access Obtained	Investigation Support	2/26/92[2]	8	8	4/23/92
		Test Trenching	3/9/92	6	7	4/17/92
		Surficial Soil/Background Sampling	3/2/92	4	4	3/28/92
		Monitoring Wells/Soil Borings	3/9/92	6	7	4/17/92
		Groundwater Sampling/Slug Tests	4/6/92	1	6	4/10/92
		Ecological Survey	5/27/92	5	18	6/30/92
		Sample Analysis/Validation	3/92	18	22	7/92
		Data Evaluation/Modeling	3/92	18	22	7/92
		Phase I Tech Memo	5/28/92	13	26	8/28/92
		Revised ARARs/PRG Tech Memo	7/16/92	5	27	9/5/92
		EPA Review	8/30/92	23	50	2/8/92
		EPA Review Meeting	3/5/93	0	53	3/5/93
		Phase I Tech Memo Revisions	3/6/93	4	59	4/13/93
		EPA Review	4/14/93	4	64	5/21/93
		Phase I Tech Memo Revisions	5/21/93	5	69	6/30/93
		EPA Review and Approval	7/1/93	4	74	7/30/93
Phase II Field Investigation	Phase I Tech Memo Approved	Investigation Support	9/30/92	58	89	11/12/93
		Monitoring Wells	8/30/93	4	82	9/24/93
		Soil Borings	9/27/93	5	87	10/29/93
		Groundwater Sampling #1	9/27/93	1	83	10/1/93
		Sample Analysis/Validation #1	8/30/93	11	89	11/12/93
		Pumping Test	11/1/93	1	88	11/5/93
		Groundwater Sampling #2	11/8/93	1	89	11/12/93
		Sample Analysis/Validation #2	11/15/93	8	97	1/7/94
		Data Evaluation	8/30/93	24	102	2/11/94
	Sample Validation Complete	Preliminary Characterization Summary	1/10/94	5	102	2/11/94
		EPA Review and Approval	2/14/94	4	106	3/11/94

ATTACHMENT 2 (Cont.)

TABLE 3.6-1

ESTIMATED DURATION OF PROJECT TASKS
REVISION 3

ACTIVITY	START	TASKS	START DATE	TASK DURATION (WEEKS)	CUMULATIVE DURATION[1,2] (WEEK NUMBER)	COMPLETION DATE
Risk Assessment and Ecological Assessment	Preliminary Characterization Summary Approved	Risk Assessment and Ecological Assessment	3/14/94	10	116	5/20/94
RI Report, Remedial Technologies Screening, Risk Assessment Review	Preliminary Characterization Summary Approved	Prepare Draft RI Report	3/14/94	8	114	5/6/94
		Prepare Tech Memo on Technologies and Screening Process	3/14/94	12	118	6/3/94
		EPA Review of Draft RI	5/9/94	4	118	6/3/94
		PRP Review of Risk Assessment	5/23/94	4	120	6/17/94
		EPA Review of Tech Memo on Technologies and Screening Process	6/6/94	4	122	7/1/94
		Revisions to Draft RI	6/6/94	4	122	7/1/94
		EPA Risk Assessment Revisions	6/20/94	4	124	7/15/94
		EPA Review and Approval of Revised RI	7/5/94	4	126	7/29/94
Alternatives Development and Screening, Alternatives Evaluation, FS Report	EPA Risk Assessment Completed and Revised RI Approved	Prepare Tech Memo on Screened Alternatives and Proposed ARARS	8/1/94	9	135	9/30/94
		EPA Review of Tech Memo on Screened Alternatives and Proposed ARARs	10/3/94	4	139	10/28/94
		Prepare Tech Memo on Alternatives Array Summary	10/31/94	5	144	12/2/94
		EPA Review of Tech Memo on Alternatives Array Summary	12/5/94	4	148	12/30/94
		Prepare Tech Memo on Comparative Analysis of Alternatives	1/2/95	8	156	2/24/95
		EPA Review of Tech Memo on Comparative Analyses of Alternatives	2/27/95	4	160	3/24/95
		Prepare Draft FS Report	3/27/95	10	170	6/2/95
		EPA Review	6/5/95	4	174	6/30/95
		Revisions to Draft FS/ Submittal of Final FS	7/3/95	5	179	8/4/95
PROJECT TOTAL:					41 Months	

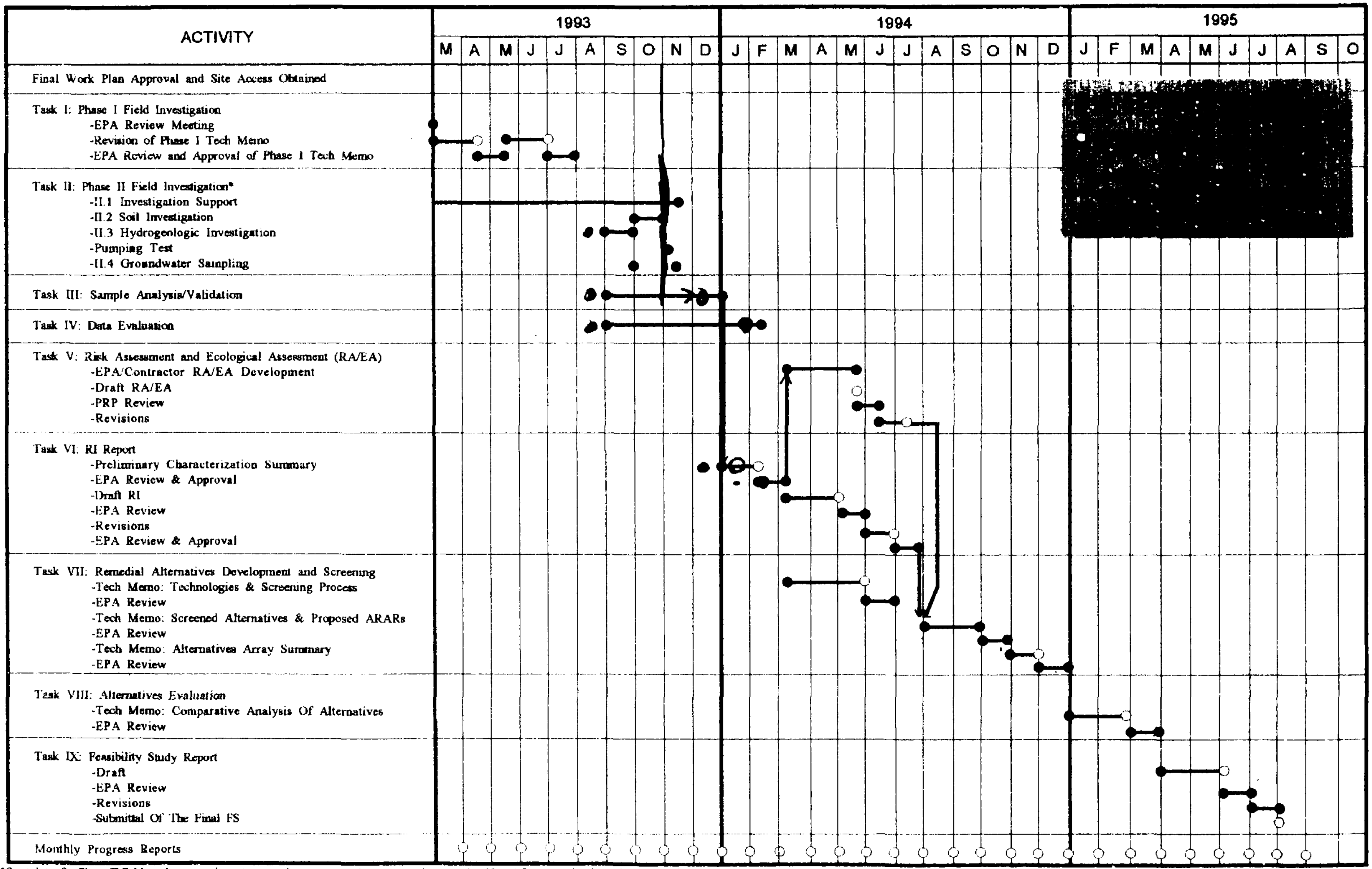
---

[1] Accounts for concurrent tasks.

[2] Based on full site access having been granted on February 26, 1992.

((

ATTACHMENT 2
TABLE 3.6-2
ESTIMATED REMAINING PROJECT SCHEDULE, REVISION 3



[redacted]

*Start dates for Phase II field work are contingent on regulatory approvals or appropriate permits (if any) for managing investigation- derived wastes.

Attachment 3

Waukegan Area of Concern
Remedial Action Plan

WAUKEGAN
AREA OF CONCERN
REMEDIAL ACTION PLAN

Prepared for
Illinois Environmental Protection Agency
2200 Churchill Road
Springfield, Illinois 62794

and

1701 First Avenue
Maywood, Illinois 60153

by
Hey and Associates, Inc.
545-B North Milwaukee
Libertyville, Illinois 60048

DRAFT

January 8, 1992

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1. SUMMARY

The Great Lakes Water Quality Agreement (GLWQA) requires that State and Provincial Governments designate geographic Areas of Concern (AOC) on the Great Lakes where conditions have caused or are likely to cause the impairment of beneficial uses. The Agreement further requires that the Remedial Action Plan (RAP) must be submitted to the public and the International Joint Commission (IJC) for review and comment at three stages:

I. when a definition of the problem at the AOC has been completed;
II. when remedial and regulatory measures are selected; and
III. when monitoring indicates that identified beneficial uses have been restored.

The International Joint Commission (IJC), the United States Environmental Protection Agency (USEPA), and the Illinois Environmental Protection Agency (IEPA) designated Waukegan Harbor as an Area of Concern (AOC) in 1981. This designation was prompted by the discovery of high levels of PCBs in harbor sediments.

To assist in the RAP development process a Citizen's Advisory Group (CAG) was formed by the IEPA in 1990 to provide recommendation to the IEPA on the development and implementation of the RAP. The CAG is made up of business, civic, education, environment, government, industry, and recreational interests in the area. As part of the overall environmental assessment process, the CAG and the IEPA have worked together to identify potential pollution sources in the Waukegan area beyond PCB contamination in the harbor.

The Waukegan AOC is located in Lake County, Illinois on the west shore of Lake Michigan. An Expanded Study Area (ESA), which includes the Waukegan AOC, approved by the IEPA and the Waukegan Citizens Advisory Group (CAG) is bounded by the Dead River on the north, the bluff line which parallels Sheridan Road on the west, the former U.S. Steel property on the south, and the Lake Michigan shoreline on the east.

This Stage I RAP identifies impaired uses in the Waukegan ESA which include fish consumption restriction, benthos degradation, dredging restrictions, loss of fish and wildlife habitat and beach closings (Table 1.1.). Supportive data and discussion are found in the completed Stage I document.

Cleanup of PCBs in harbor sediment began in November 1990 through the federal Superfund program. Separate actions were taken to prevent contaminants from an abandoned industrial facility, a tar pit, and leaking underground storage tanks from causing further degradation of the harbor and near shore area. Stage II of the RAP will focus on selecting additional remedial and regulatory measures needed to restore beneficial uses in the ESA. This will require close coordination between the public sector, industry, academia, and government at all levels. Prioritization of remedial and regulatory measures will be of prime importance in view of the limited amount of funding available for anticipated efforts in the ESA.

The RAP will be updated to reflect the results of ongoing sampling, remedial action, and any changes in the ecosystem.

Table 4.2. Use Impairment within the Waukegan Expanded Study Area.

		Use Is Impaired	Use Is Unimpaired	Unknown[1]
i	Restriction on Fish and Wildlife Consumption			
	Fish	X		
	Wildlife			X
ii	Tainting of Fish and Wildlife Flavor			X
iii	Degradation of Fish and Wildlife Populations (diversity and abundance, including reproduction problems)			
	Fish			X
	Wildlife			X
iv	Fish Tumors and Other Deformities		X	
v	Bird or Animal Deformities or Reproductive Problems			X
vi	Degradation of Benthos	X		
vii	Restrictions on Dredging Activities	X		
viii	Eutrophication or Undesirable Algae		X	
ix	Restrictions on Drinking Water Consumption or Taste and Odor Problems			X[2]
x	Beach Closings	X		
xi	Degraded Aesthetics		X	
xii	Added Costs to Industry		X	
xiii	Degradation of Phytoplankton and Zooplankton Populations			
	Phytoplankton	X		
	Zooplankton	X		
xiv	Loss of Fish and Wildlife Habitat			
	Fish Habitat	X		
	Wildlife Habitat	X		

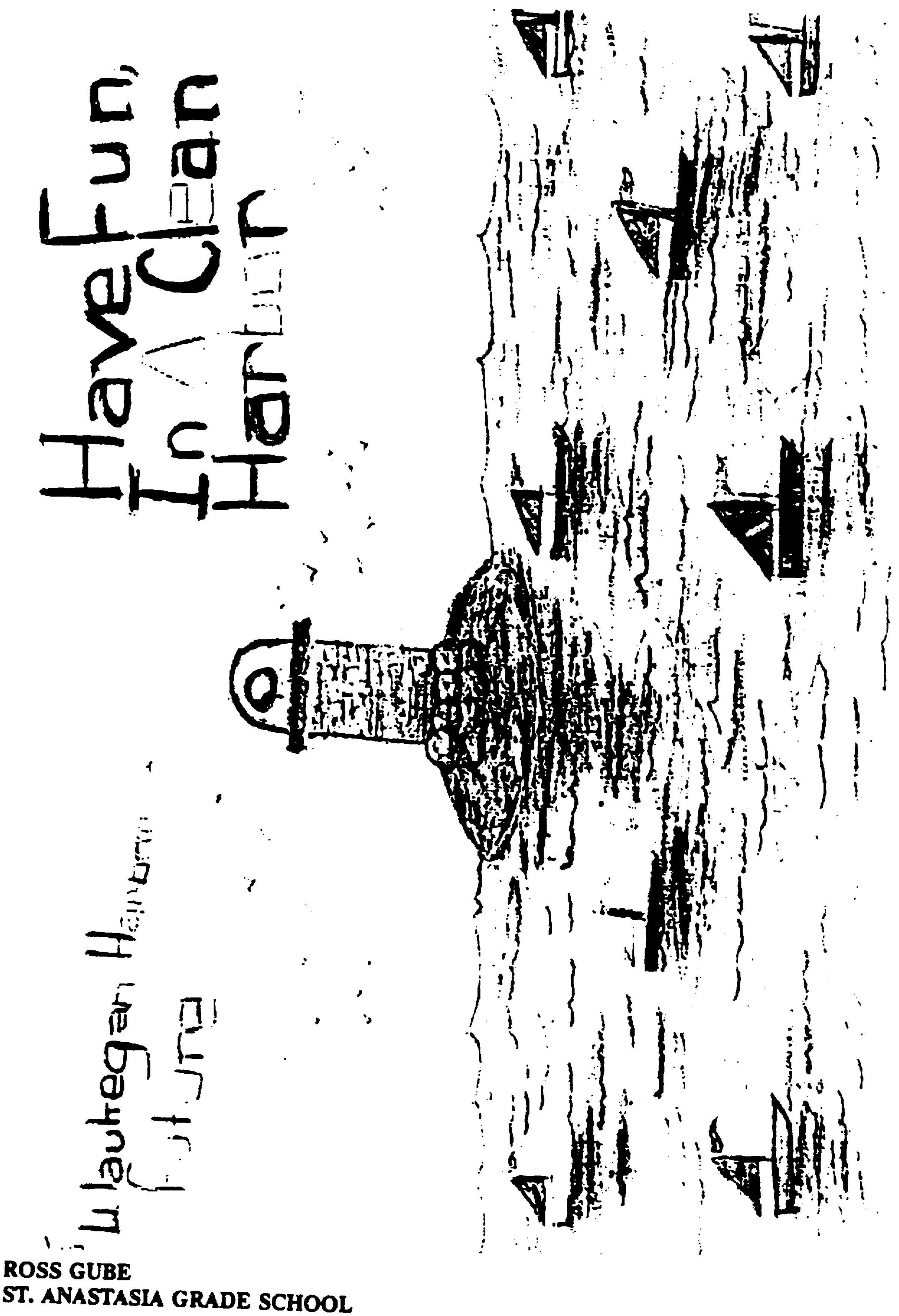
[1] Additional data collection is required before a determination can be made

[2] Preliminary evaluations indicate the old emergency intake located in Waukegan Harbor may be impaired, however, future use of this intake is highly unlikely. Additional monitoring is scheduled in 1992.

Table 1.1. Impaired Uses in the Waukegan Expanded Study Area.

Impaired Use	Causes	Sources
Fish consumption restrictions	PCBs	Contaminated sediments Ambient water quality Atmospheric deposition
Degradation of benthos	PCBs	Contaminated sediments
Dredging restrictions	PCBs	Contaminated sediments
Beach closings	fecal coliform	Waukegan River
Loss of fish and wildlife habitat	PCBs	Contaminated sediments

Revised



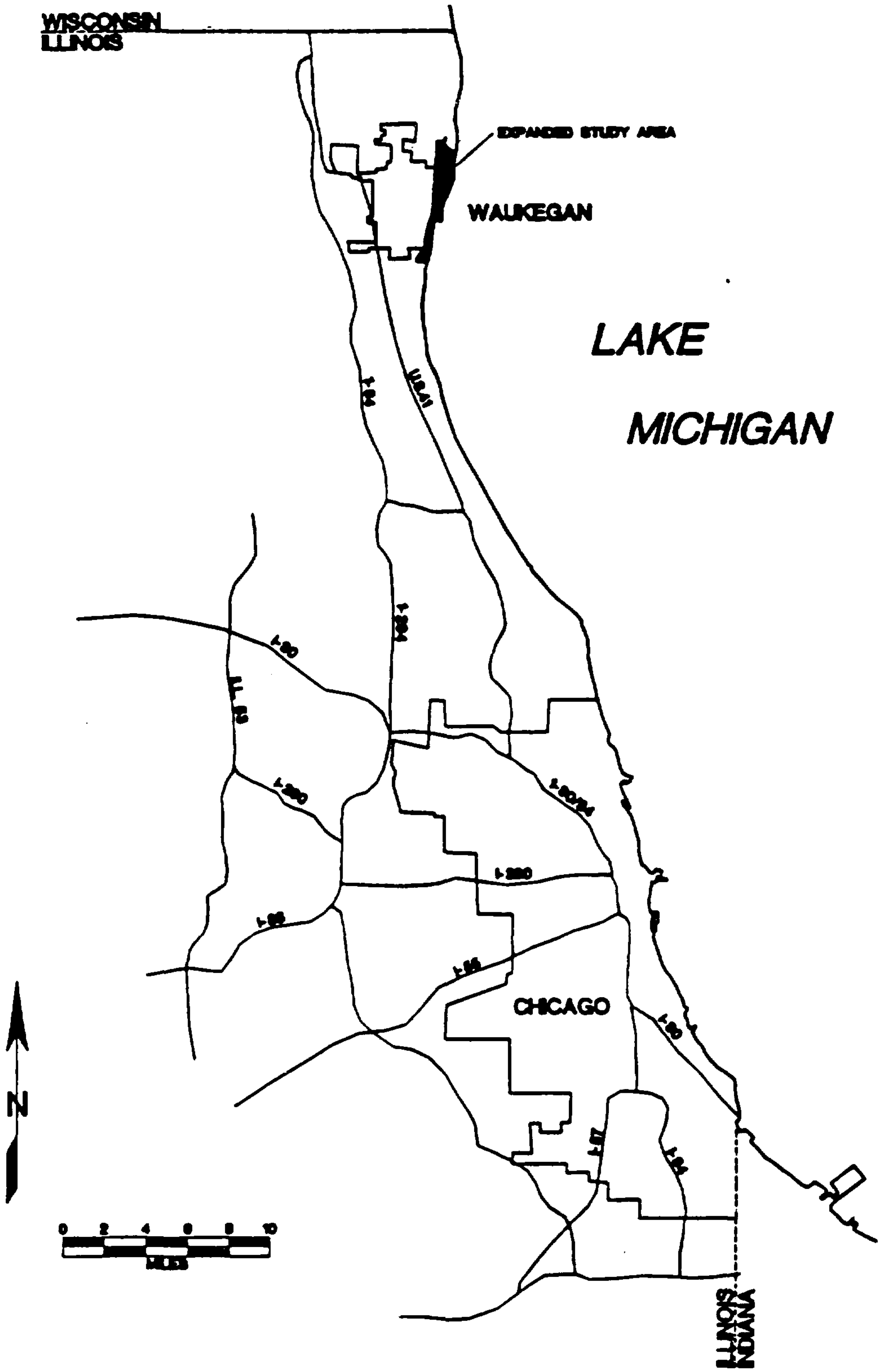
ROSS GUBE
ST. ANASTASIA GRADE SCHOOL

2. INTRODUCTION

The International Joint Commission (IJC), the United States Environmental Protection Agency (USEPA) and the Illinois Environmental Protection Agency (IEPA) designated Waukegan Harbor as an Area of Concern (AOC) in 1981. This designation was prompted by the discovery of high levels of polychlorinated biphenyls (PCBs) in harbor sediments. In 1975 and 1976, PCBs were identified in several discharges into the harbor from Outboard Marine Corporation (OMC). The AOC is located on the west shore of Lake Michigan in Waukegan, Illinois, about 37 miles north of Chicago and 10 miles south of the Wisconsin state border (Figure 2.1.).

The Great Lakes Water Quality Agreement (the Agreement) and the Great Lakes Critical Program Act require states to prepare a Remedial Action Plan (RAP) for their respective AOCs. The Agreement also requires public consultation in all RAP development and implementation actions. As part of the process to prepare the RAP for the Waukegan AOC, the Waukegan Citizens Advisory Group (CAG) was formed in the summer of 1990. The CAG has provided useful information to the IEPA and has actively assisted with the preparation of the RAP (refer to Chapter 9 for more information about CAG and the RAP development). For example, the CAG raised concerns about a variety of industrial sites in the vicinity of the harbor that may be impairing beneficial uses. Consequently, while the original AOC included only the harbor, the IEPA, with input and advise from the Waukegan CAG, expanded the study area to include potential sources of contamination other than PCBs which may affect both Waukegan Harbor and near-shore Lake Michigan in the area adjacent to the harbor. This combined effort has lead to investigation and remediation planning for non-PCB sources of contamination. The results of this expanded review are described elsewhere in this RAP document. For purposes of clarity and brevity throughout the remainder of this document, the expanded area which was approved by the CAG and the IEPA and which includes the AOC will be designated the Waukegan Expanded Study Area (ESA).

Figure 2.1. Regional Location of the Waukegan Expanded Study Area.



2.1. BACKGROUND

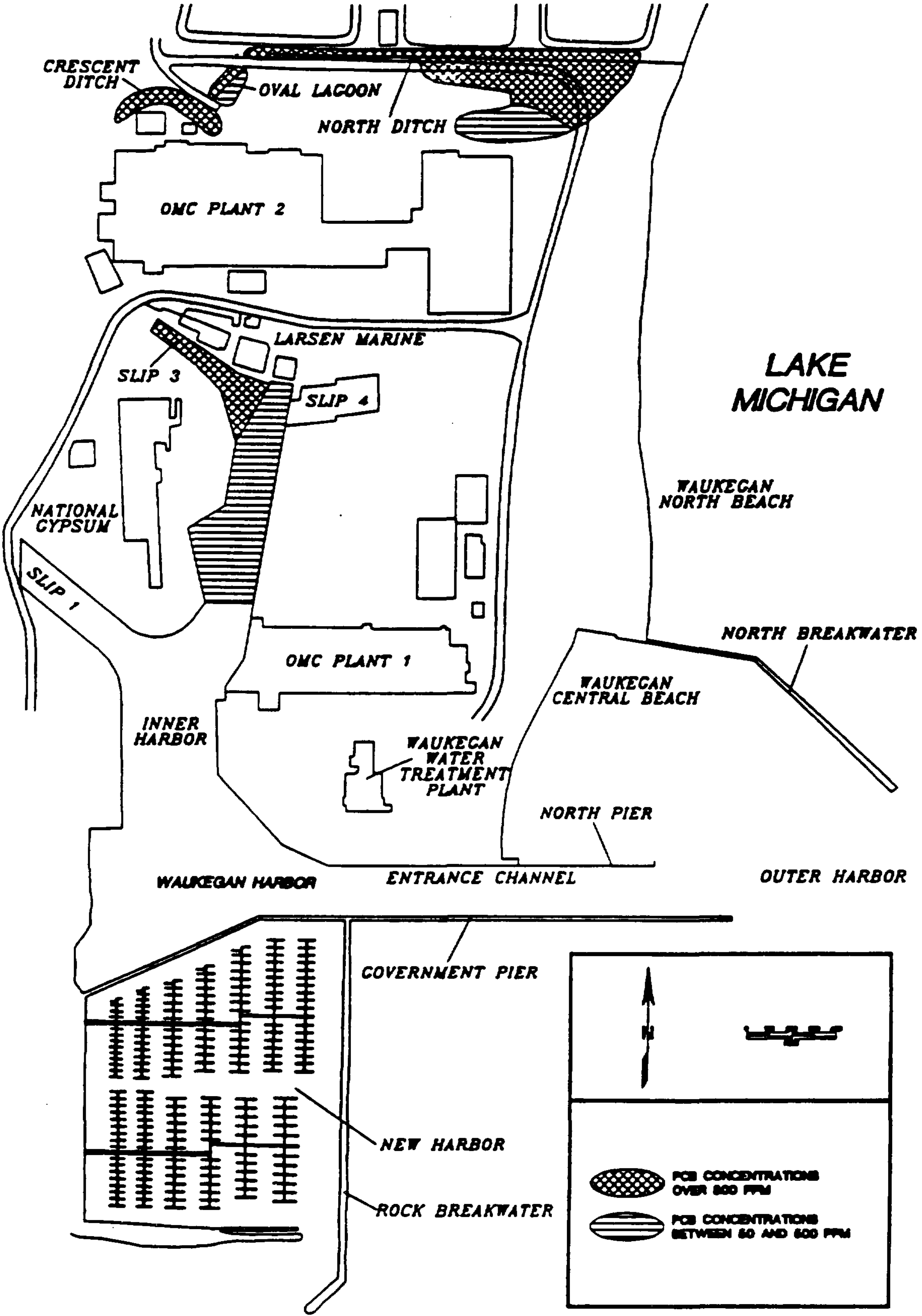
From approximately 1961 to 1972, OMC purchased a hydraulic fluid used in the die-casting works that contained PCBs, some of which ultimately escaped through floor drains. At OMC, the floor drains discharged to an oil interceptor system which discharged to the North Ditch. Some of the PCBs escaped from a portion of the oil interceptor, diversion and pump system and were released to the Waukegan Harbor. The harbor area discharge was located in the western edge of slip 3, and the north property discharge was to the crescent ditch (Figure 2.2.). This discharge pipe to the harbor was sealed in 1976. As a result of OMC discharges, it is estimated that there are over 700,000 pounds of PCBs on OMC property and approximately 300,000 pounds of PCBs in Waukegan Harbor (Figure 2.2.).

Investigation of the sediments in the Waukegan Harbor was made in 1977 and a thorough investigation of both the harbor and the OMC property was completed in 1979 and 1980 by the USEPA. A feasibility study was completed by USEPA in 1984 and the Record of Decision (ROD) selecting on-site containment with off-site disposal of select soils was issued in May 1984.

The same year the engineering design work for the selected remedial action was initiated. However, in late 1985, design work on the project was suspended due to litigation between OMC and USEPA regarding access to OMC property. Such access was essential to continue the engineering design process.

While this litigation was pending before the courts, Congress enacted the Superfund Amendments and Reauthorization Act (SARA). The SARA amendments call for the preference for "permanent remedies which reduce the mobility, toxicity, or volume of hazardous substances." Although RODs signed before October 1986 are not required to meet these new requirements, USEPA reevaluated the 1984 ROD to develop a remedy consistent with SARA.

Figure 2.2. Extent of PCB Contamination In and Around Waukegan Harbor.



About the time USEPA began reviewing the remedy set forth in the 1984 ROD, USEPA and OMC agreed to end the ongoing access litigation. Shortly thereafter, OMC submitted a proposal to clean up the site. The negotiations between OMC, USEPA, and the IEPA since late 1986 have resulted in a Consent Decree initiated in April of 1989 (U.S. District Court, 1988). Construction on the remedy at the Superfund site began on November 15, 1990.

Development of the RAP began with the formation by the IEPA of the Waukegan CAG. Recognizing that sources of non-PCB contamination are present near the harbor, a list of these potential sources of contamination was prepared by CAG members and IEPA staff (Table 2.1.). Preliminary sampling of the harbor area and investigations of some of these potential sources of contamination began in the fall of 1990. Subsequently, drafting of the RAP started early the following year.

Identification of beneficial uses that have been impaired in the Waukegan ESA include restrictions on fish consumption, degradation of the benthos, restrictions on dredging activities, beach closings, and loss of fish and wildlife habitat. It should be noted that a restriction on fish consumption is also in existence for selected species of fish for all of Lake Michigan.

2.2. PURPOSE AND OBJECTIVES

The purpose of the RAP process is to provide a coordinated approach to environmental management that will ultimately contribute to the successful rehabilitation of Lake Michigan and the Waukegan ESA. This approach requires the integration of available data on environmental conditions, socioeconomic influences, and political/institutional frameworks. This plan also identifies sources of degradation and resultant use impairments related to sources other than PCBs in Waukegan Harbor. Environmental issues in the Waukegan ESA are identified in Chapter 4. Status of remediation and recommendations for restoration of impaired uses are based on currently available data and pollution control programs and priorities. The data contained in Chapter 4 will be reviewed and appended periodically to

Table 2.1. **Potential Sources of Contamination within the Waukegan ESA** (Lapish, 1991).

Common Name	Current Owner
Outboard Marine Corporation	Outboard Marine Corporation
Johns-Manville	Johns-Manville
North Shore Gas Co. Chevrolet Saginaw Coke Plant	Outboard Marine Corporation
U.S. Steel Property	MCL Development
Greiss Pfleger Tanning Co.	Commonwealth Edison Company
Diamond Scrap Yard	Bank of Waukegan
Waukegan Paint and Lacquer Site	Waukegan Paint and Lacquer
Alloy Engineering and Casting	Alloy Engineering and Casting
North Shore Gas Co. Tar Pit	North Shore Sanitary District
E.J.&E. Rail Yards	E.J.&E. Rail Road

update information and, if appropriate, identify new issues and impacted areas.

2.3. INTENDED USE

Development and implementation of a RAP and determination of whether impaired uses have been restored is an ongoing, iterative process. The RAP brings together information and provides suggestions that should help to focus activities which aim to restore and maintain beneficial uses. It is intended for concerned citizens, state and local organizations with an involvement in Waukegan Harbor and the lakeshore area, and those individuals and organizations who use the harbor and lakeshore for economic and recreational benefit. The RAP should be used as a technical management document that provides a platform for continuing analysis and decision-making. It contains a review of available data, defines impaired uses and data needs, and prioritizes investigations and remedial actions. Every attempt is being made to identify information pertaining to the critical environmental issues affecting this ESA. Suggestions and additions from the CAG and the general public are welcomed.

2.4. REFERENCES

International Joint Commission (IJC). 1978. Great Lakes Water Quality Agreement of 1978. International Joint Commission, United States and Canada, Office Consolidation, September 1989.

Lapish, S. 1991. Report presented to the Waukegan Citizens Advisory Group, August 5, 1991.

U.S. District Court. 1988. Consent Decree: United States of America and People of the State of Illinois v. Outboard Marine Corporation, Inc. Northern District Court of Illinois, Eastern Division, October 1988.

U.S. Environmental Protection Agency (USEPA). 1984. Superfund Record of Decision (EPA Region V), Outboard Marine Corporation Site, Waukegan, Illinois, May 1984. U.S. Environmental Protection Agency, Washington, D.C., May 1984.

3)

SANDRA BROWN
JACK BENNY JUNIOR HIGH SCHOOL

3. ENVIRONMENTAL SETTING

This chapter describes the location, natural features, land uses, and water uses of the Waukegan Expanded Study Area (ESA). This chapter also summarizes the groundwater, surface water and near shore limnology, and includes sections on recreational, commercial, and industrial activities that characterize the area. Information was gathered from state and federal reports and additional sources presented in the list of references.

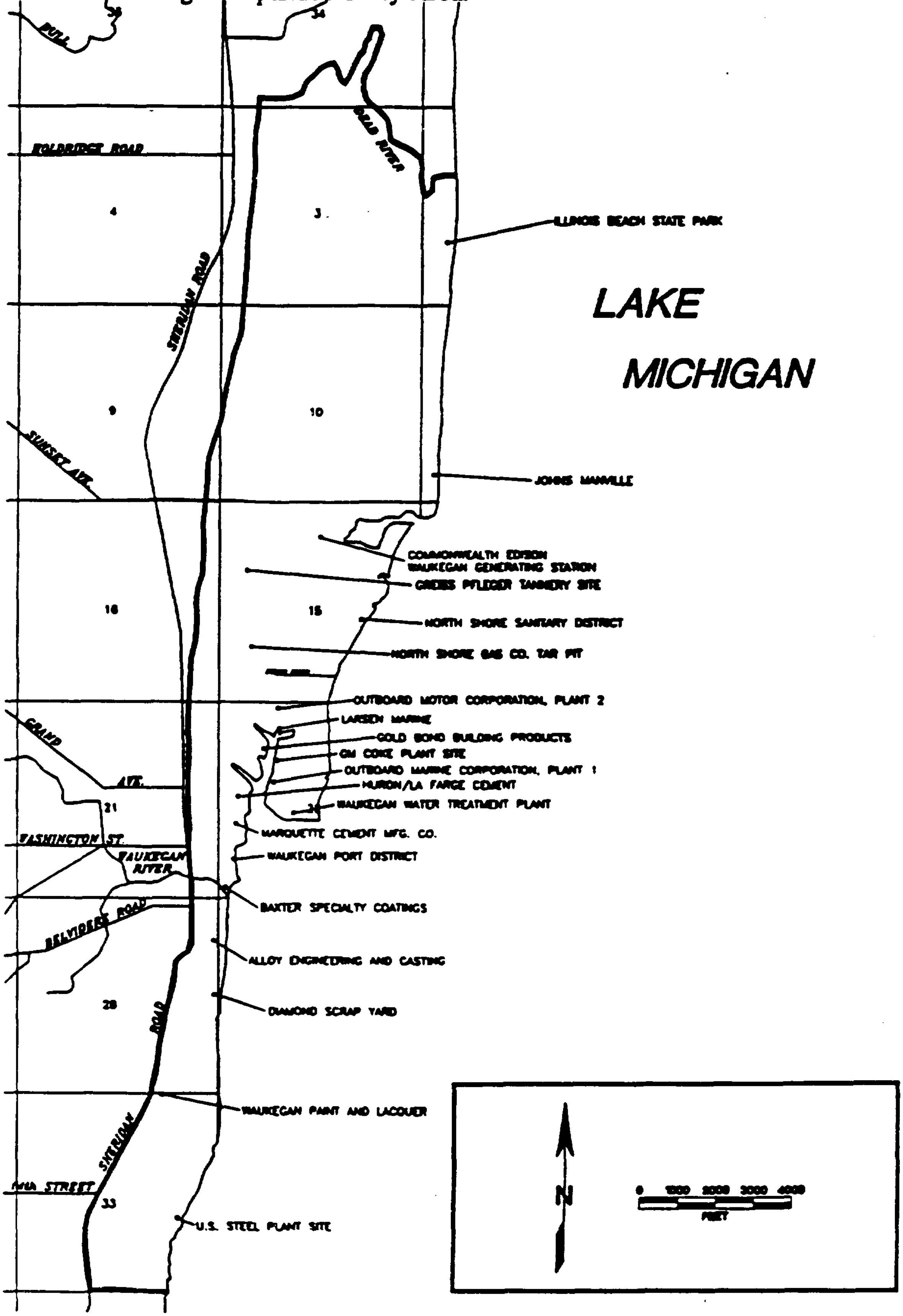
3.1. LOCATION

The Waukegan ESA is located in Lake County, Illinois on the west shore of Lake Michigan. The ESA, as defined by the Illinois Environmental Protection Agency (IEPA) with input and advise from the Waukegan Citizens Advisory Group (CAG), is bounded by the Dead River on the north, the bluff line which parallels Sheridan Road on the west, the former U.S. Steel Property on the south, and the Lake Michigan shoreline on the east (Figure 3.1.). The Waukegan River bisects the study area and is a tributary to Lake Michigan approximately 1/4 mile south of the Waukegan Port District boat launching area. The North Ditch is a smaller tributary to Lake Michigan, located north of the Outboard Marine Corporation (OMC) property, which drains part of the study area north of Waukegan Harbor.

3.2. NATURAL FEATURES

Waukegan Harbor is largely a manmade structure constructed in the late 19th and early 20th centuries. A natural inlet and portions of adjacent wetlands were filled to form the present shape of the harbor area. Waukegan Harbor is about 37 acres and water depths generally vary from 14 to 21 feet. The harbor sediments consist of 1 to 10.5 feet of very soft organic silt (muck) overlying 9 feet of medium dense, fine to coarse sand. A very stiff silt (glacial till) that typically ranges from 50 to more than 100 feet thick underlies the sand. The entire harbor is bordered by 20 to 25 foot long steel sheet piling, except at the Waukegan Port District boat launching areas and at the retaining wall near the harbor

Figure 3.1. The Waukegan Expanded Study Area.



mouth. The sheet piles generally extend into the sand layer above the glacial till.

3.3. DRAINAGE BASIN SIZE

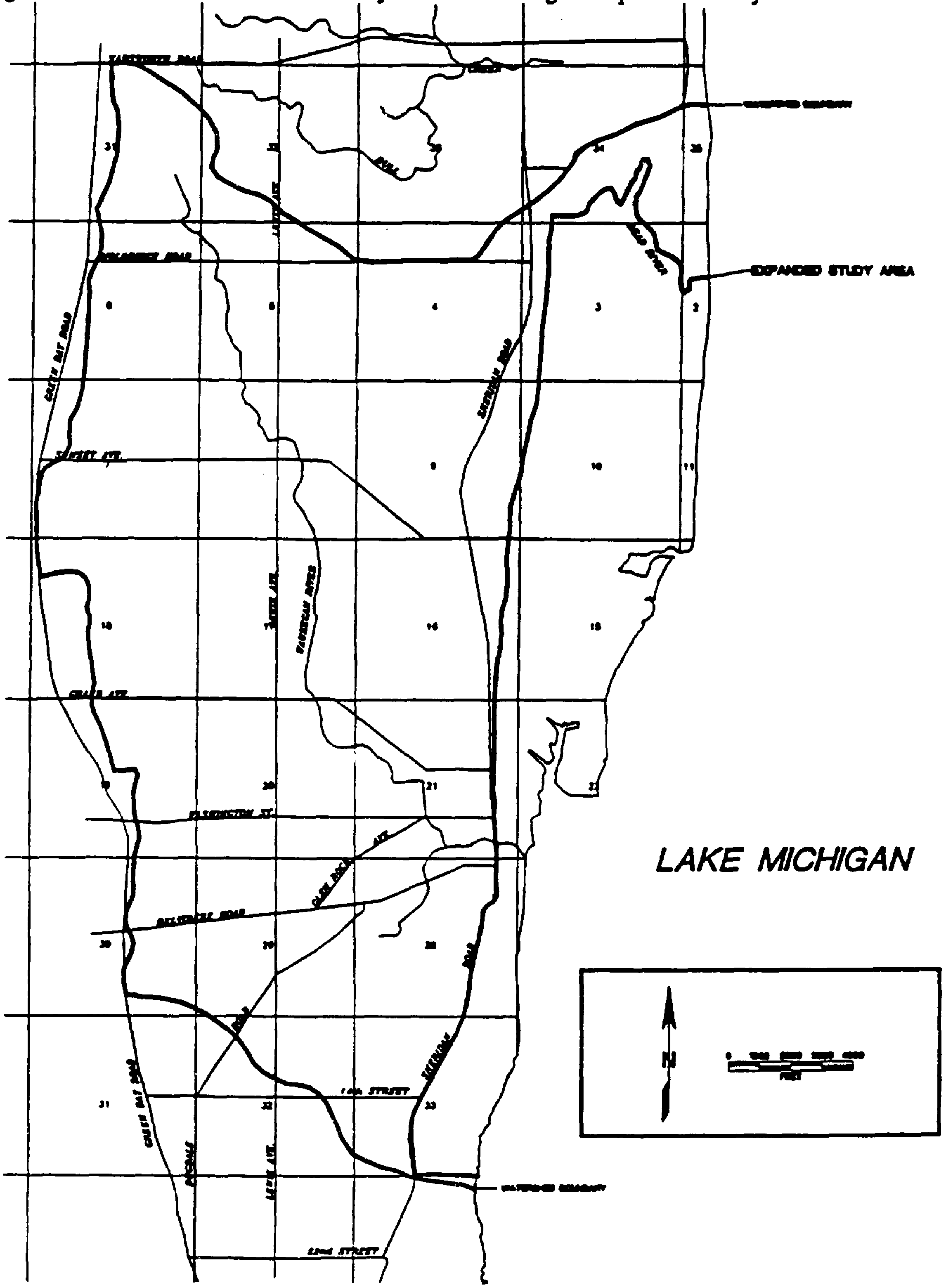
The Waukegan Harbor drainage area is defined as being bounded by the North Ditch to the north, the Zion city moraine bluff to the west and the government pier to the south (O'Gata, 1975). Waukegan Harbor drains approximately 0.47 square miles of industrial, commercial municipal and open/vacant lands (Figure 3.2.).

The 5.8 stream miles of the Waukegan River in the study area discharge to Lake Michigan and drain approximately 9.68 square miles of land (Healy, 1979). A small tributary of Lake Michigan drains surface runoff from about 0.11 square miles of Outboard Marine Corporation (OMC) and North Shore Sanitary District (NSSD) property. This drainage system, which includes the North Ditch, also drains surface runoff from areas west of OMC property and the railroad tracks, including a large portion of the City of Waukegan stormwater runoff via the Gillette Avenue storm sewer which discharges to the west end of the North Ditch. The North Ditch drainage system consists of the 600 by 20 foot Crescent Ditch; the 240 foot Oval lagoon; and the 2,000 by 10 to 20 foot North Ditch.

3.4. TOPOGRAPHY

The general topography throughout the ESA is relatively flat. Some slight variations exist between filled areas and natural ground. One partially filled depression, a tar pit on the NSSD property, is within this area along with some closed depressions on the Johns-Manville property (an asbestos disposal pit, sludge disposal pit, and miscellaneous disposal pit), and the filled Greenwood Avenue disposal site. One manmade mound in the area is the Johns Manville primary asbestos disposal area which is approximately 40 feet above natural ground. Additional manmade high areas include a gypsum storage pile on the Gold Bond Building Products property adjacent to the harbor, and a coal pile on the Commonwealth Edison property located approximately 1.3 miles northeast of the harbor area (Vitale, 1991).

Figure 3.2. The Watershed Tributary to the Waukegan Expanded Study Area.



On the west side of the expanded study area, bluffs rise approximately 60 feet. The business and residential areas of Waukegan are situated on these bluffs.

3.5. HYDROLOGY

The 100-year, 24-hour precipitation event in Waukegan is 6.40 inches and the 2-year, 24-hour event is 2.80 inches (ISWS, 1989).

The Waukegan Harbor has a tributary area of 0.47 square miles and receives stormwater runoff at seven discharge points as well as from overland flow. The expected annual yield from an urbanized watershed of this type would be about 14 inches (NIPC, 1977). This translates to a mean annual discharge of 0.50 cubic feet per second.

The Waukegan River has a watershed of 9.68 square miles and receives numerous stormwater discharges from its highly urbanized watershed. Assuming a yield of 14 inches, this watershed would yield about 10 cubic feet per second as an annual average.

The North Ditch discharge has been measured at 1.8 cfs by the U.S. Department of the Interior. This value was calculated from measurements taken between March and September, 1979. The maximum measured discharge was 5.3 cubic feet per second. Based on a watershed of 0.34 square miles (0.11 square miles of OMC and NSSD property and 0.23 square miles discharging through the Gillette Avenue storm sewer) and an annual yield of 14 inches, this watershed would have a mean annual discharge of 0.35 cubic feet per second.

Components of the hydrologic budget around each of the above watersheds is discussed in greater detail in Chapter 6.

3.6. GEOLOGY

The uppermost deposits throughout the expanded study area alternate between fill material, natural material, and a mix of fill and natural material. The fill material appears to consist of naturally occurring material probably hauled into the area from other areas farther from the lake and man-made demolition debris. The naturally occurring material consists of medium grained sand with gravel and near lake deposits of Glacial Lake Chicago. These materials are of the Equality Formation and reportedly range in thickness from 25 to 40 feet (IEPA, 1991; Malhorta and Assoc., 1985).

Below the Equality Formation is the Wadsworth Till. This unit is relatively thick ranging from 50 to 75 feet and consists of mostly gray clay and sandy clay till with some pebbles and cobbles. Underneath the till resting on top of the bedrock is a sand and gravel deposit that ranges from 3 to 20 feet in thickness.

Silurian age dolomite comprises the uppermost bedrock in this area. This shallow bedrock is fractured which contributes to groundwater movement through this unit. Rainfall seeps through the glacial till and imported fill to replenish groundwater levels in the Silurian dolomite. Underneath the Silurian dolomite is Maquoketa Group shales which act as an aquitard separating the Silurian dolomites from the deeper bedrock units.

There are three major "deep" bedrock units below the Maquoketa Shale that are significant sources of drinking water. These are the Glenwood - St. Peter Sandstone, the Ironton - Galesville Sandstone, and the Mt. Simon Sandstone. The deepest of these units is the Mt. Simon which is approximately 1,600 feet deep in this area.

3.7. HYDROGEOLOGY

Although the City of Waukegan obtains raw water for treatment and distribution from an intake located in Lake Michigan, some businesses located near the harbor reportedly obtain groundwater through one or more private wells on their property. The Remedial

Investigation for the Johns-Manville disposal area identified six private wells on or near the site.

Soil sampling and monitoring well installation near the harbor indicates that the water table is frequently in the range of 1-3 feet from the ground surface. The presence of cattails and smartweed (phreatophytic vegetation) is further evidence of near surface groundwater. Artesian wells have been reported near the harbor (Vitale, 1991).

Lake Michigan and Waukegan Harbor appear to serve as discharge areas for surficial groundwater. However, several factors could affect the groundwater levels and flow direction. These factors include: the presence of silt below the sandy near shore lake deposits; the water level in the north ditch (near OMC); the use of water from the industrial canal by Johns-Manville; and fluctuations of the lake level.

Hydraulic conductivity will vary between compacted, imported fill material and the natural in-place material. In general, relatively fast hydraulic conductivities would be expected where medium grain sand, gravel, and lake sediments are present.

Slug tests (a method of in-situ hydraulic conductivity measurement based on water level fluctuations in piezometers following the addition of a known volume of water) conducted by consulting firms on the Johns-Manville and OMC properties found conductivities ranging from 1.6×10^{-2} cm/sec (45.4 ft/day) to 2.5×10^{-2} cm/sec (70.9 ft/day) and 2.0×10^{-4} cm/sec (0.6 ft/day) to 9.0×10^{-3} cm/sec (25.5 ft/day), respectively.

3.8. AIR QUALITY

Waukegan, Illinois is located in Air Quality Control Region (AQCR) #67 of the Metro Chicago Interstate AQCR. The air quality of this AQCR is determined on the basis of the National Ambient Air Quality Standards (NAAQS) set forth in the Clean Air Act of 1970 as amended in 1990. Federal and State standards are identical with the exception of standards for ozone (O_3) and lead (Pb).

Air quality is monitored at Waukegan by the IEPA. When the measured concentration of a pollutant in a particular area does not exceed the primary standard or the secondary standard, the area is designated as an attainment area for that pollutant. Waukegan is an attainment area for nitrogen dioxide (NO_2), sulfur dioxide (SO_2), total suspended particulates (TSP), and lead. Lake County is classified as a nonattainment area for the ozone primary standard (no secondary standard has been set). Waukegan is unclassified for carbon monoxide (CO) because no monitoring data is available.

According to the 1984 Record of Decision (ROD) approximately 12 to 40 pounds of PCBs are released from the harbor into the local airshed each year. Existing air contamination from the North Ditch waters is estimated at 15 pounds per year (USEPA, 1984).

3.9. WETLANDS

There are no wetlands within the immediate drainage area of Waukegan Harbor. Several types of natural and excavated wetlands are located near the north and west of Waukegan Harbor (Figure 3.3.). Of these 17.5 acres are classified as Lake Shore Community. These wetlands are recognized as Lake Michigan beach area and include the Waukegan North and Central public beaches. The remaining natural wetlands near the harbor are classified as marsh (3.1 acres) or pond (3.1 acres) and are located along the Lake Michigan shoreline immediately north of Waukegan Harbor. Most of these wetlands are located on NSSD property. Excavated wetlands comprise 4.8 acres of ponds and 2.3 acres of wet meadows (USDI, 1981a; USDI, 1981b). The final, most extensive wetlands are located at the extreme north end of the ESA immediately south of the Dead River. These wetland areas are part of the Illinois State Beach Park.

3.10. URBAN, OPEN SPACE, AND SPECIAL USE AREAS

Land use areas in Lake County Illinois were classified by the Lake County Board in 1987 and the City of Waukegan in 1987 (Figure 3.4.). Land surrounding the northern portion of Waukegan Harbor has been classified as urban while the beach areas and water filtration

Figure 3.3. Wetlands Within the Waukegan Expanded Study Area.

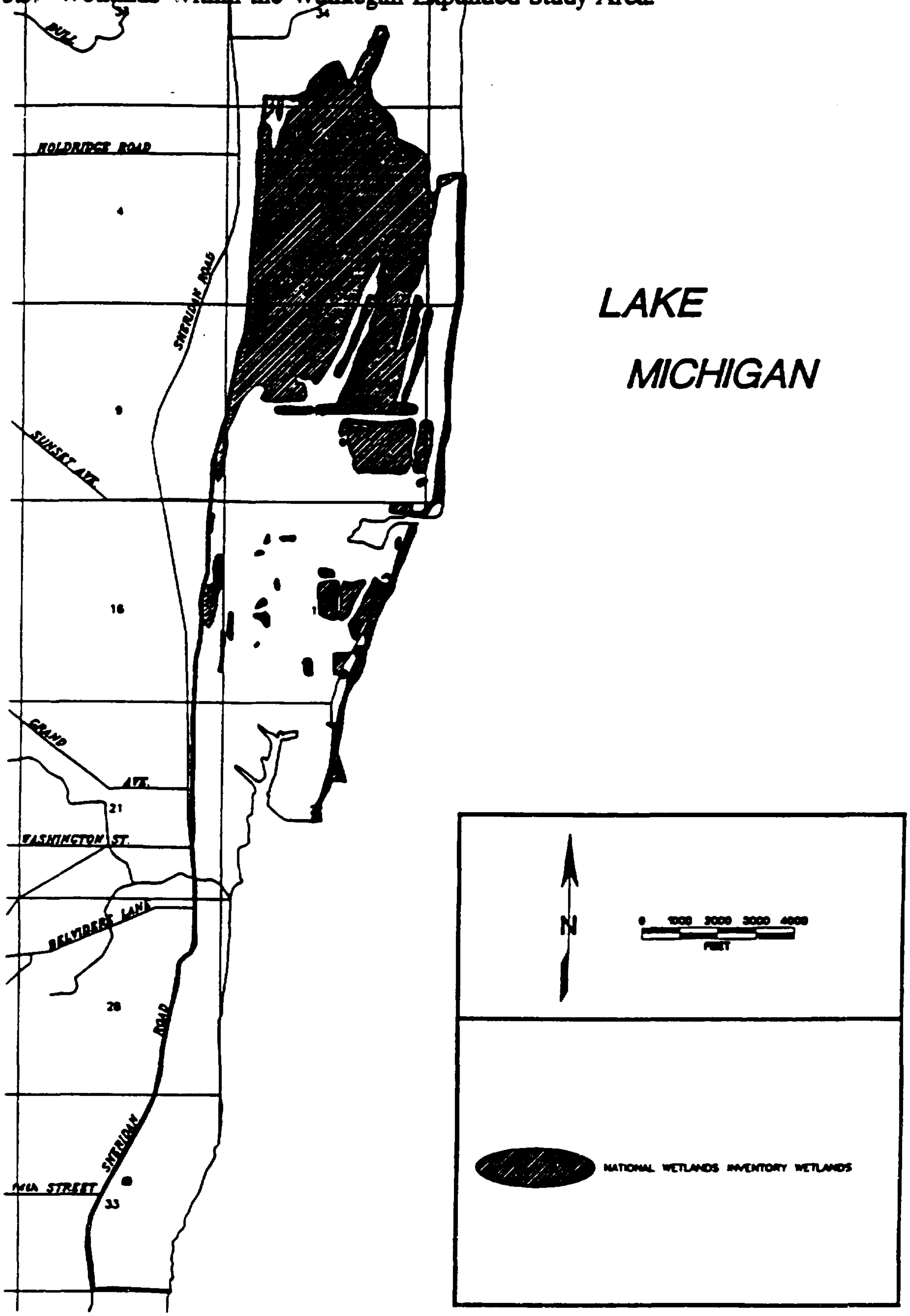
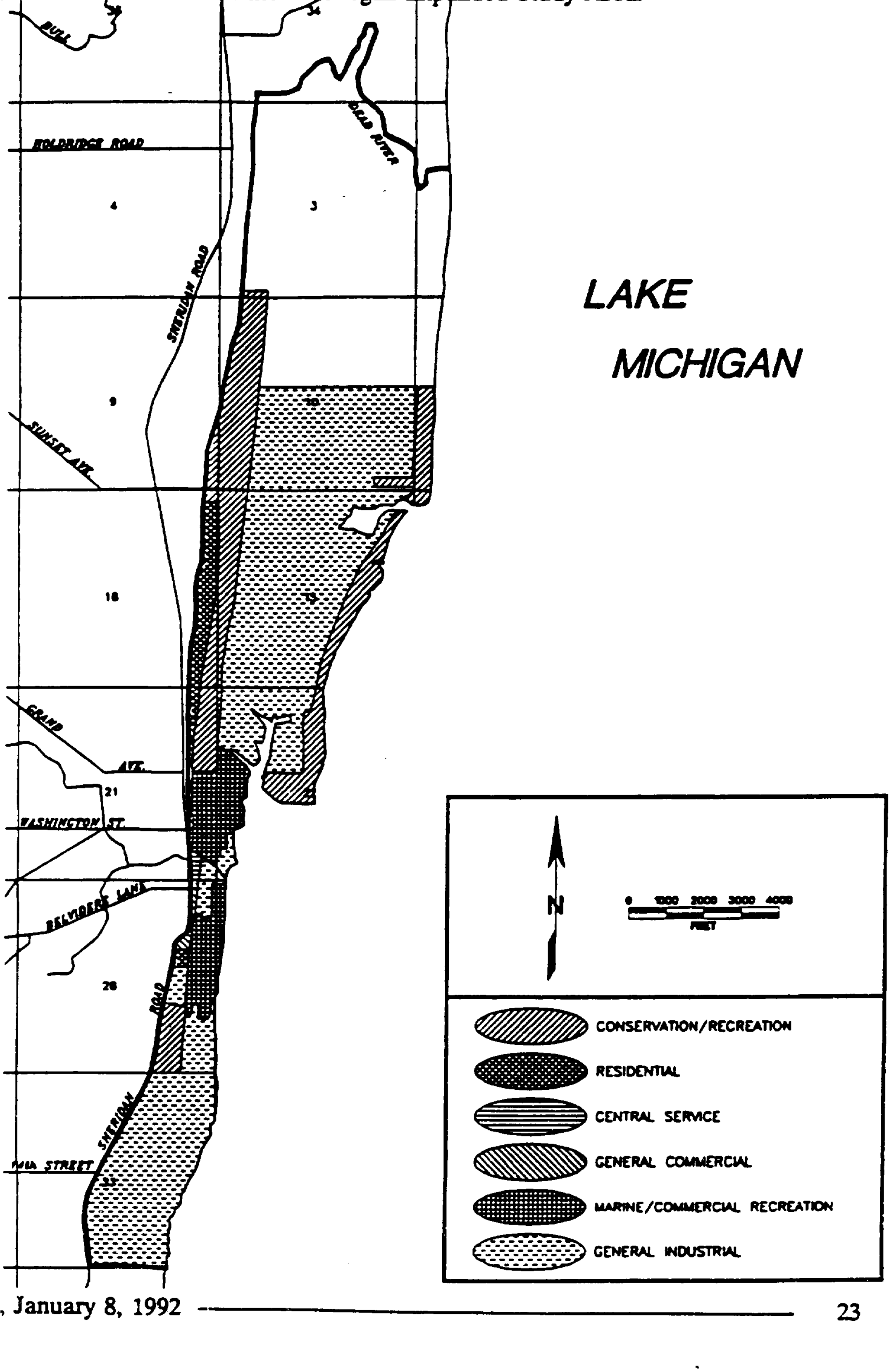


Figure 3.4. Land Use Within the Waukegan Expanded Study Area.



plant properties have been classified as open space areas. The remaining land in the immediate harbor area is classified as special use (Lake County) or industrial (City of Waukegan). The Waukegan Port District property is located within this special use area. According to the Lake County Board, urban areas are intended to provide for both residential and non-residential needs including commercial, office, research, light to heavy industrial, institutional, and recreational uses. Urban areas are intended to meet subregional and community needs and provide a city-type of lifestyle. Open space districts include State, County, and local parks and recreational lands which are presently publicly owned or are included in the acquisition plans of State or local park and Forest Preserve districts. Open space districts are intended to fulfill all needs for community-wide and regional public recreation areas. Special districts were designed to deal with a variety of uses that do not easily fit into any of the other categories (City of Waukegan, 1987; Lake County Board, 1987).

3.11. SEWER SERVICE AREAS

The City of Waukegan provides storm and sanitary sewers while the NSSD provides, operates and maintains the interceptor sewers and wastewater treatment facilities in the ESA. The system in the vicinity of the North Ditch consists of a 54-inch diameter gravity sanitary sewer and a 48-inch diameter gravity combined sewer which carry influent to the wastewater treatment plant and a 54-inch diameter force main which carries effluent from the plant to the Des Plaines River (Farrell, 1991). These sewers are located parallel to each other in an east-west direction just north of the south property line of the NSSD Waukegan treatment plant which parallels the North Ditch. There is a sanitary sewer traversing the vacant lot owned by OMC. Another sewer runs north from the water filtration facilities near the harbor mouth along the beach to the NSSD treatment plant. This sewer was installed in 1978 to carry filter-backwash solids to the NSSD facility for treatment.

Seven storm sewers discharge to the inner harbor (a 10 inch line discharging into slip 3 was sealed in 1976). There is a 30 inch line to slip 1, a 12 inch line along Clayton Street, and a 24 inch line at Madison Street. These three storm discharges take runoff from portions of the metropolitan Waukegan area. In the new harbor area there is a 21 inch line draining the Waukegan Port Authority parking lot to the north. An additional 27 inch line drains the parking lot to the south discharging to Lake Michigan (Figure 3.5.). Storm sewer lines which drain the Gold Bond property and discharge into slip 3 will be rerouted as part of the OMC remediation. A single storm sewer will serve that property and will discharge to the harbor.

3.12. UNSEWERED AREAS

No area is unsewered in the ESA.

3.13. INDUSTRIAL

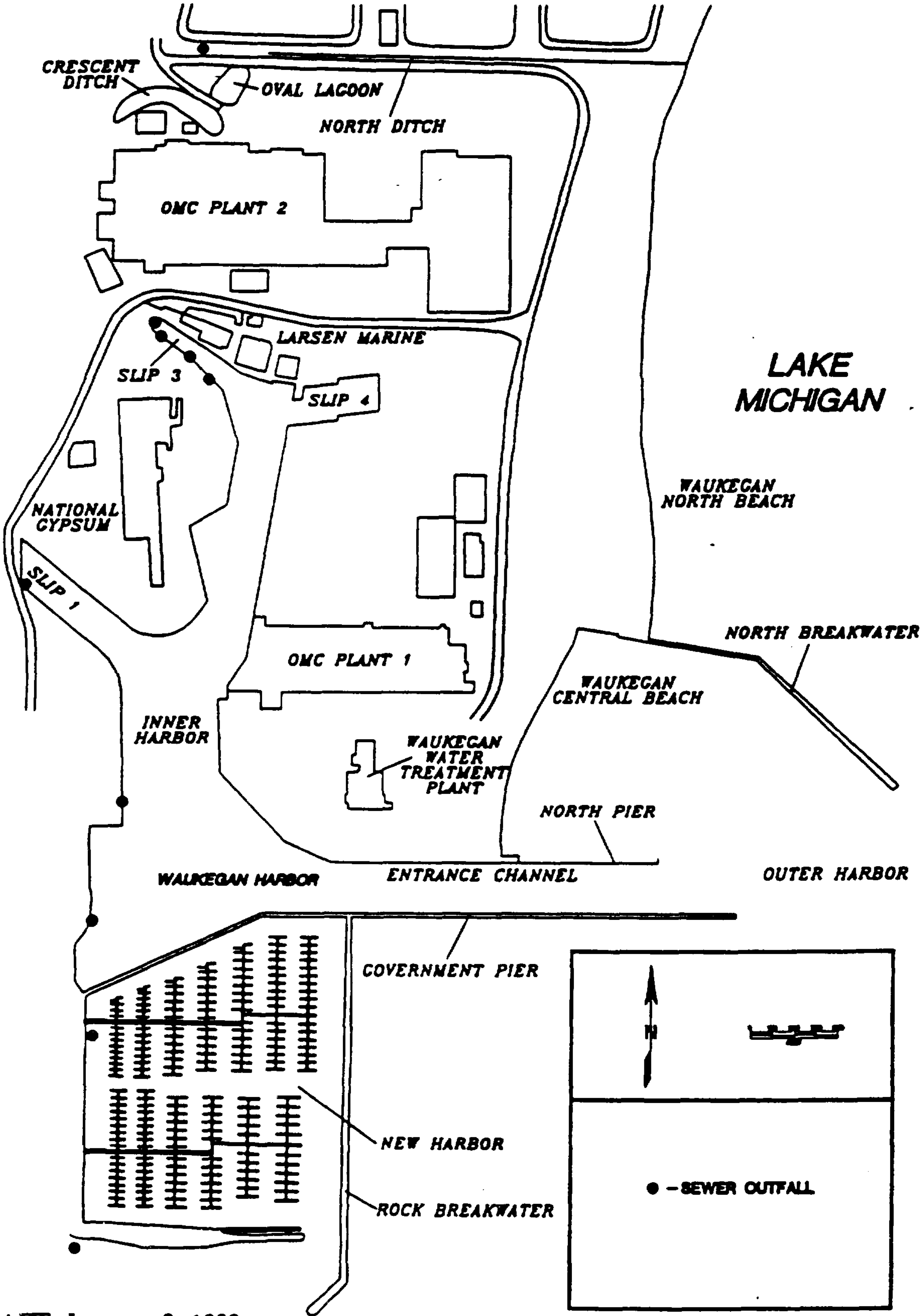
The land use throughout the Waukegan ESA is primarily industrial. OMC, Gold Bond Building Products, Huron/LaFarge, Lone Star Industries, Dexter Corporation, and St. Mary's Cement are adjacent to Waukegan Harbor. Johns-Manville, Dexter Corporation, Lake Shore Foundry and Hansen Manufacturing are among the active businesses in the ESA. Diamond Salvage, Alloy Engineering and Casting, U.S. Steel, and the Greiss-Pfleger Tannery are closed industrial sites in the study area.

Access to water, land, and rail transportation contributed and helped to maintain this area as the industrial hub of Waukegan. Railroad yards and light industrial facilities span virtually the entire length of the Waukegan ESA.

3.14. RECREATIONAL USES

A substantial number of people use the area around Waukegan Harbor for sailing, picnicking, fishing, or sightseeing. The public beaches to the north and east of the harbor are used for swimming, sunbathing, volleyball, and public events. Recreational facilities in the harbor area, in addition to the boat mooring and public launching areas, include the Waukegan Yacht Club, the Warren G. Sivert Park, and the government pier. The Yacht

Figure 3.5. Storm Sewer Discharges in and near Waukegan Harbor (Kallis, 1991).



Club owns a clubhouse adjacent to the harbor and had about 400 members as of 1990. The Yacht Club sponsors several events during the year that bring large numbers of people to the harbor area. The biggest of these is the annual Chicago to Waukegan sailboat race which is held in July. Over 600 boats participated in this race in 1990. The Warren G. Sivert Park is a small park immediately west of the boat mooring area. There are several small concession stands in this area that sell food, beverages, ice, and fishing supplies. Public restrooms and picnic tables are available at the park. The government pier is used for sight-seeing, walking, sunbathing, birdwatching, and fishing. This pier ends at the lighthouse that marks the entrance to the harbor.

The public beaches to the north and east of the harbor are manned during the summer by lifeguards and are supervised by a beach director and security director. There are picnic pavilions with grills and a bathhouse with washrooms and showers. There also is a concession stand at the north end of the beach area and a snack bar at the south end. Beach use is free to Waukegan residents while nonresidents must pay a fee.

The City also sponsors festivals each year at the beach that include food, music, games, and fireworks. The City expects between 70,000 and 80,00 people to attend these festivals annually.

3.15. AGRICULTURAL

No land in the Waukegan ESA is used for agricultural purposes. Cement silos previously used for grain storage stand empty today.

3.16. WATER SUPPLY

The City of Waukegan maintains a drinking water intake about one mile off shore in Lake Michigan. No PCBs have been found in the raw or finished water at the Waukegan Public Water Supply. Results of annual testing of raw and finished drinking water are presented in Appendix A.

3.17. COMMERCIAL FISHING

A summary of the Illinois commercial fishery for Lake Michigan for the period of April 1988 through March 1989 was summarized by the Illinois Department for Conservation (IDOC; Hess, 1989). A total harvest of 62,005 pounds of bloaters (dressed weight) and 188,921 pounds of yellow perch (round weight) was reported for the period by the four licensees in the limited entry commercial fishery for Illinois. Although commercial fishing for trout and salmon is not allowed in Illinois, it is estimated that 12,981 lake trout and 16,695 other trout and salmon (primarily small chinook salmon) may have been killed in commercial nets during the 1988-89 license year as a result of fishing for other species.

3.18. SPORT FISHING

In 1989 and 1990, the IDOC stocked over 300,000 salmon and trout in the new harbor just south of Waukegan Harbor (Table 3.1.). Numbers of salmon stocked have exceeded 250,000 each year with the majority being chinook, and about 50,000 trout (steelhead and brown) have been added each year.

A survey of sport fishing in the Illinois portion of Lake Michigan was conducted between April and September of 1989 by the Illinois Natural History Survey (Horns and Brofka, 1990). The survey included all types of sport fishing except charter boat and smelt fishing. According to the survey the area of Lake Michigan in the vicinity of Waukegan Harbor attracted 21,484 pedestrian trips and 12,830 launched boats during the survey period. Estimated expenditures for sport fishing by pedestrians and launched boats combined totaled $768,370 for the survey period. At Waukegan Harbor, the 1989 estimate of pedestrian angler hours was 92,597 while launched boats added an additional 68,802 angler hours.

In 1988, the Waukegan charter boat fishery continued to contribute a substantial catch for the Illinois portion of Lake Michigan. The Waukegan area catch was 1.9 times greater than the Chicago area catch. Angler hours from charter boats in 1988 totalled 71,606 in Chicago and 87,430 in Waukegan area waters. The total 1988 catch of trout and salmon by charter

Table 3.1. Number of Salmon and Trout Stocked in the Waukegan Harbor-New Harbor Area by the Illinois Department of Conservation in 1989 and 1990.

	Salmon		Trout		
Year	Coho	Chinook	Steelhead	Brown	Annual Total
1989	24,380	240,273	26,475	25,152	316,280
1990	100,300	175,000	30,990	27,443	333,733

boats totalled 19,523 fish in Chicago and 37,455 fish in Waukegan. Fish per angler hour was 0.27 for Chicago and 0.43 for Waukegan (Hess and Trudeau, 1990).

3.19. CONTACT RECREATION

During July and August of 1990, Waukegan area beaches were closed periodically due to elevated bacteria counts. An intensive reconnaissance of the area by the NSSD for possible sources of contamination concluded that the Waukegan River was the source of fecal contamination. Further sampling of the Waukegan River was recommended to pinpoint illegal discharges to the river (Farrell and Budzinski, 1990).

3.20. COMMERCIAL NAVIGATION AND RECREATIONAL BOATING

The Waukegan Port District operates the Waukegan Harbor. The Port District's gross revenues during 1990 totalled $ 2,161,499. The sources of their revenues are shown below:

Gasoline and oil	$ 54,384
Lease income	90,580
Percentage of gross	3,576
Gift Shop sales	9,433
Vending sales	10,845
Ice sales	12,422
Miscellaneous	15,154
Slip fees	1,669,945
Transient fees	40,743
Launch and park fees	22,956
Key card sales	455
Tenant work orders	10,469
Dock boxes and bumpers	32,910
Ad sales	3,600
Winter dry storage	4,810
Charter permits	13,425

Interest income	165,792
Total	**$ 2,161,499**

During 1990, there were approximately 75 commercial ship dockings at Waukegan Harbor. The Port District currently serves three commercial clients: Huron/LaFarge Corporation, St. Mary's Cement, and Gold Bond Building Products (National Gypsum). Gold Bond Building Products is located on the northwest side of the harbor between slips 3 and 1. Huron/LaFarge Corporation is located south of slip 1 (Figure 3.1.). During 1990, 515,168 tons of bulk cement and gypsum rock were hauled into the harbor. Since each of the three commercial clients supply building materials for the construction industry in the Chicago metropolitan area, their need for raw materials is directly related to the level of construction activity taking place.

Many types of recreation facilities and opportunities are available in the Waukegan Harbor area; the foremost of these is fishing. The IDOC Division of Fisheries and Wildlife has estimated that Waukegan Harbor and offshore area experience the heaviest fishing pressure of any area along the Illinois coastline of Lake Michigan. Although the majority of the recreational uses of the harbor are related to fishing, a substantial amount of pleasure boating, sailing, picnicking, and other water-related activities also take place.

Eight public boat launching ramps at the harbor are open for use on April 1 of each year. Demand for the boat slips has leveled off due to the opening of the North Point Marina in Zion.

A considerable amount of boat-launching activity occurs at the harbor. During the period April 1990 through October 1990, 1500 boat launching tickets were sold (a $9 fee is charged). This does not account, however, for the approximately 97 season-pass holders who have unlimited boat launching privileges.

Larsen Marine Service, Inc. located at the north end of Waukegan Harbor is the largest lakefront yacht dealer in the Chicago metropolitan area. Before Winthrop Harbor Marina opened, Waukegan Harbor was the only protected public harbor along the northern Illinois shoreline. As of 1990, Waukegan Harbor can accommodate 1008 power boats (993 through the Waukegan Port District and 15 at Larsen Marine). Larsen Marine is the only marine sales and services company located directly on Waukegan Harbor. The company provides yacht brokerage for new and used power boats and sailboats and offers complete marine repair services. A crane operated boat hoist is also available for removal and storage of all size classes of boats. These services are of considerable importance to recreational boaters in the region because there are no similar commercial facilities on the northern Illinois coastline.

As of 1990, there were 41 registered charter boat captains working out of the Waukegan Harbor.

3.21. WASTE DISPOSAL (MUNICIPAL, INDUSTRIAL, UNCONTROLLED)

All Lake County Illinois municipal and industrial treated wastewater discharges were diverted away from Lake Michigan to the Des Plaines River Basin during the period 1974 through 1978. The chronology of diversions are summarized below:

1974	Highland Park STP (all flows); Lake Forest STP (Dry weather flows); Lake Bluff STP (Dry weather flows).
1975	Lake Bluff STP (Wet weather flows); United States Steel-South Works (Process wastewater).
1976	North Chicago STP (Dry weather flows); Great Lakes Naval Training Center STP (all flows); Abbott Laboratories (Process wastewater)
1977	Fort Sheridan STP (all flows); United States Steel-Waukegan Works (Process wastewater): Chicago's Jardine and South Water Purification Plants (backwash).
1978	Lake Forest STP (wet weather flows); Waukegan STP (Dry weather flows).

Excess wet weather flows continue to be discharged into Lake Michigan from NSSD's North Chicago and Waukegan treatment plant after settling and disinfection. The contribution from the North Chicago plant to these stormwater overflows was further reduced in 1990 by the completion of a transfer line and retention basin at NSSD's Gurnee facility. Excess flow is pumped to Gurnee for treatment rather than discharge to Lake Michigan.

Abbott Laboratories and Commonwealth Edison Company's Waukegan station non-thermal discharges are in compliance with their respective National Pollution Discharge Elimination System (NPDES) permits. The Illinois Pollution Control Board granted a 45 day provisional variance to Commonwealth Edison's Zion station on December 20, 1990. However, Commonwealth Edison was able to complete changes at this station, thus removing the need for a variance. The Highwood water filtration plant continues to discharge backwash water directly to the Lake Michigan.

3.22. WATER QUALITY STANDARDS, GUIDELINES, OBJECTIVES

Subtitle C of Title 35 of the State of Illinois Administrative Code provides four use designation categories for Illinois' lakes and streams. Each category has a specific set of water quality standards.

General use water quality standards for Illinois surface water resources were established for protection of aquatic life, primary (e.g. swimming) and secondary (e.g. boating) contact recreation, agricultural and industrial uses. The majority of Illinois streams and lakes come under the general use designation. A somewhat stricter set of standards applies to Public Food and Processing Water Supplies. These standards apply at any point at which water is withdrawn for use as potable water supply or for food processing. Even more stringent standards were established to protect Lake Michigan. A fourth set of standards applies to streams designated as Secondary Contact and Indigenous Aquatic Life waters. This is the most limited designated use and applies only to certain streams in the Chicago area. Illinois water quality standards are presented in Table 3.2. Revised General Use Standards were established for several metals in February 1990 (Table 3.3.) as well as comprehensive narrative toxics controls to protect human health, aquatic life, and wildlife. All Illinois water quality standards have been fully approved by the USEPA.

The Great Lakes Water Quality agreement of 1978 (as amended by Protocol signed November 18, 1987) called for the maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. It is the intent of this agreement to provide for the protection of the full and unimpaired uses of the Great Lakes System. Impairment to beneficial uses is measured by impacts on any of the fourteen basic uses listed as follows:

(i) restrictions of fish and wildlife consumption;
(ii) tainting of fish and wildlife flavor;
(iii) degradation of fish wildlife populations;
(iv) fish tumors or other deformities;
(v) bird or animal deformities or reproduction problems;
(vi) degradation of benthos;
(vii) restrictions on dredging activities;
(viii) eutrophication or undesirable algae;
(ix) restrictions on drinking water consumption, or taste and odor problems;
(x) beach closings;
(xi) degradation of aesthetics;
(xii) added costs of agriculture or industry;
(xiii) degradation of phytoplankton and zooplankton populations; and
(xiv) loss of fish and wildlife habitat.

Illinois Water Quality Standards, as they apply to Lake Michigan, are consistent with these objectives.

Table 3.2. Illinois Water Quality Standards.

Parameter	Units	General Use	Public and Food Processing Water Supply	Lake Michigan	Secondary Contact and Indigenous Aquatic Life
pH	SU	6.5 min 9.0 max	6.5 min 9.0 max	7.0 min(d) 9.0 max(d)	6.0 min 9.0 max
Dissolved Oxygen	mg/l	5.0 min	5.0 min	90.% saturation(d)	4.0 min
Arsenic	µg/l	1000	50	50	1000
Barium	µg/l	5000	1000	1000	5000
Boron	µg/l	1000	1000	1000	---
Cadmium	µg/l	50	10	10	150
Chloride	mg/l	500	250	12.0 (d)	---
Chromium	µg/l	1050	50	50	1300
Copper	µg/l	20	20	20	1000
Cyanide	mg/l	0.025	0.025	0.025	0.10
Fluoride	mg/l	1.4	1.4	1.4	15.0
Iron (Total)	µg/l	1000	1000	1000	2000
Iron (Dissolved)	µg/l	---	---	---	500
Lead	µg/l	100	50	50	100
Manganese	µg/l	1000	150	150	1000
Mercury	µg/l	0.5	0.5	0.5	0.5
Nickel	µg/l	1000	1000	1000	1000
Phenols	µg/l	100	1.0	1.0	300
Selenium	µg/l	1000	10	10	1000
Silver	µg/l	5.0	5.0	5.0	100
Sulfate	mg/l	500	250	24.0(d)	---
Total Dissolved Solids	mg/l	1000	500	180 (d)	1500
Zinc	µg/l	1000	1000	1000	1000
Fecal Coliform					
May-Oct.	#/100ml	200(f)	2000	20	---
Nov-April	#/100ml	---	2000	20	---
Fecal Coliform (Beach)	#/100ml	---	---	500(e)	---
Ammonia Nitrogen	mg/l	1.5/15(b)	1.5/15(b)	0.02	---
Un-ionized Ammonia	mg/l	0.04(a)	0.04(a)	---	.01
Nitrate Nitrogen	mg/l	---	10.0	10.0	---
Oil and Grease	mg/l	---	0.01	0.01	15.0
Total Phosphorus	mg/l	0.05(c)	0.05(c)	0.007	---
Aldrin	µg/l	1.0	1.0	1.0	---
Dieldrin	µg/l	---	1.0	1.0	---
Endrin	µg/l	---	0.2	0.2	0.2
Total DDT	µg/l	---	50.0	50.0	50.0
Total Chlordane	µg/l	---	50.0	50.0	3.0
Methoxychlor	µg/l	---	100.0	100.0	---
Toxaphene	µg/l	---	100.0	100.0	---
Heptachlor	µg/l	---	0.1	0.1	---
Heptachlor epoxide	µg/l	---	0.1	0.1	---
Lindane	µg/l	---	4.0	4.0	---
Parathion	µg/l	---	100.0	10.0	---
2,4-D	µg/l	---	100.0	100.0	---
Silvex	µg/l	---	10.0	10.0	---

mg/l = milligrams per liter
µg/l = micrograms per liter

(a) Unless total ammonia nitrogen is less than 1.5 mg/l
(b) The allowable concentration varies in accordance with water temperature and pH values. In general, as both temperature an pH decrease, the allowable value of ammonia nitrogen increases. Un-ionized ammonia nitrogen must not exceed 0.04 mg/l within the given range of total ammonia nitrogen values.
(c) Standard applies to lakes and reservoirs and at the point of entry of any stream to lake or reservoir.
(d) Lake Michigan Standard (35 Ill. Adm. Code 302).
(e) Swimming Criterion
(f) Waterbody reaches physically unsuited for primary contact uses and not found in urban areas or parks may be designated as unprotected whereby no fecal coliform standard applies.

Table 3.3. Acute and Chronic General Use Water Quality Standards.

Constituent (μg/l)	Acute Standard[a]	Chronic Standard[b]
Arsenic (total)	360	190
Cadmium (total)	exp(1.128(lnH)-2.918)	exp(0.7852(lnH)-3.490)
Chlorine (total residual)	19	11
Chromium (total hexivalent)	16	11
Chromium (total trivalent)	exp(0.819(lnH)+3.688)	exp(0.819091nH)+1.561)
Copper (total)	exp(0.9422(lnH)-1.464)	exp(0.8545(lnH)-1.465)
Cyanide (weak acid dissociable)[c]	22	5.2
Lead (total)	exp(1.273(lnH)-1.460) but not to exceed 100 μg/l	—[d]
Mercury (total)	0.5	—

where: exp = base of natural logarithms raised to parenthetic power

lnH = natural logarithm of hardness of the receiving water in mg/l

(a) not to be exceeded except where a zone of initial dilution is granted

(b) not to be exceeded by the average of at least four consecutive samples collected over any period of at least four days.

(c) Standard Methods 4500-CN I. STORET No. 718.

(d) No standard proposed.

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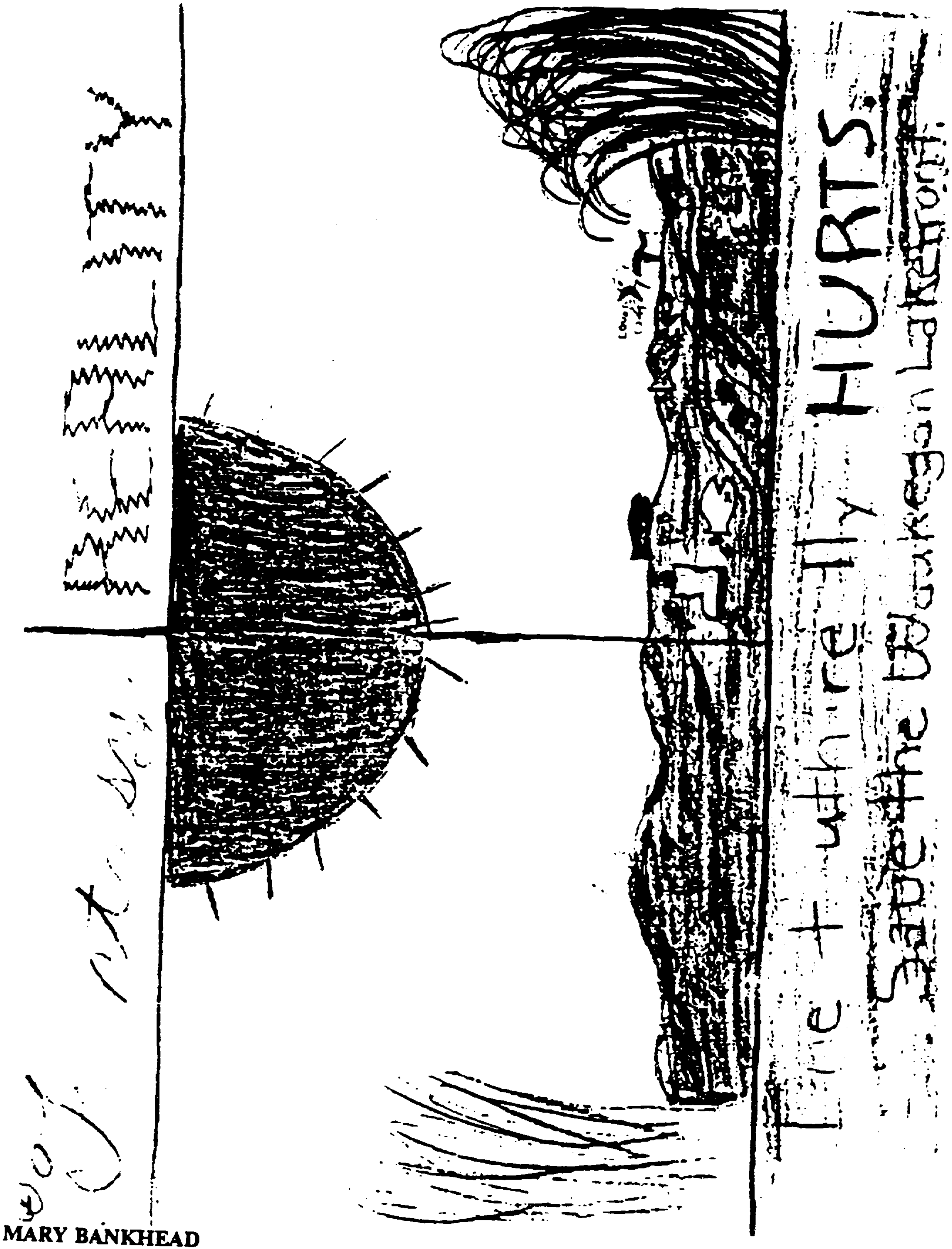

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4. DEFINITION OF THE PROBLEM

Remedial Action Plans (RAPs) rely on an "ecosystem approach" for identifying remediation needs and plans within the Expanded Study Area (ESA). The ecosystem approach considers the impairment of beneficial water resource uses within the ESA as well as contaminant sources and loadings. The International Joint Commission (IJC, 1991) has developed criteria for the identification of use impairments (Table 4.1.). Use impairments identified within the Waukegan ESA were determined through the application of these criteria.

Once the use impairments were defined, the causes of the impairments were identified using existing environmental monitoring data. Data reviewed included water quality, sediment quality, biomonitoring (bioassay), benthic community assessments and environmental contaminant monitoring data for sediments and fish.

The organization of this chapter reflects the above described use impairment procedure. Section 4.1., Impaired Uses, describes use impairments identified through documented observations. Sections 4.2. through 4.4., Water Quality, Sediment Quality, and Biota, discuss the nature and extent of contamination associated with the identified use impairments.

4.1. IMPAIRED USES

Five use impairments have been identified for the Waukegan ESA based on the listing criteria approved by the International Joint Commission (IJC, 1991) as shown in Table 4.2.: fish consumption restrictions, benthos degradation, restrictions on dredging, beach closings, and loss of fish and wildlife habitat.

4.1.1. Restrictions on Fish and Wildlife Consumption

In 1981, the U.S. Environmental Protection Agency (USEPA) recommended that fish caught in Waukegan Harbor not be eaten (USEPA, 1981). The Lake County Health Department

Table 4.1. Guidelines for Recommending the Listing and Delisting of Great Lakes Areas of Concern (IJC, 1991).

USE IMPAIRMENT	LISTING GUIDELINE	DELISTING GUIDELINE	RATIONALE	REFERENCE
RESTRICTIONS ON FISH AND WILDLIFE CONSUMPTION	When contaminant levels in fish or wildlife populations exceed current standards, objectives or guidelines, or public health advisories are in effect for human consumption of fish or wildlife. Contaminant levels in fish and wildlife must be due to contaminant input from the watershed.	When contaminant levels in fish and wildlife populations do not exceed current standards, objectives or guidelines, and no public health advisories are in effect for human consumption of fish or wildlife. Contaminant levels in fish and wildlife must be due to contaminant input form the watershed.	Accounts for jurisdictional and federal standards; emphasizes local watershed sources.	Adapted from Mack, 1988
TAINTING OF FISH AND WILDLIFE FLAVOR	When ambient water quality standards, objectives, and guidelines, for the anthropogenic substance(s) known to cause tainting, are being exceeded or survey results have identified tainting of fish or wildlife flavor.	When survey results confirm no tainting of fish or wildlife flavor.	Sensitive to ambient water quality standards for tainting substances; emphasizes survey results	See American Public Health Association (1980) for survey methods
DEGRADED FISH AND WILDLIFE POPULATIONS	When fish and wildlife management programs have identified degraded fish or wildlife populations due to a cause within the watershed. In addition, this use will be considered impaired when relevant, field-validated, fish or wildlife bioassays with appropriate quality assurance/quality controls confirm significant toxicity from water column or sediment contaminants.	When environmental conditions support healthy, self-sustaining communities of desired fish and wildlife at predetermined levels of abundance that would be expected from the amount and quality of suitable physical, chemical and biological habitat present. An effort must be made to ensure that fish and wildlife objectives for Areas of Concern are consistent with Great Lakes ecosystem objectives and Great Lakes Fishery Commission fish community goals. Further, in the absence of community structure data, this use will be considered restored when fish and wildlife bioassays confirm no significant toxicity from water column or sediment contaminants.	Emphasizes fish and wildlife management program goals; consistent with Agreement and Great Lakes Fishery Commission goals; accounts for toxicity bioassays.	Adapted from Maney and Pacific, 1988; Wisconsin DNR, 1987; United States and Canada, 1987; Great Lakes Fishery Commission, 1980.
FISH TUMORS OR OTHER DEFORMITIES	When the incidence rates of fish tumors or other deformities exceed rates at unimpacted control sites or when survey data confirm the presence of neoplastic or preneoplastic liver tumors in bullheads or suckers.	When the incidence rates of fish tumors or other deformities do not exceed rates at unimpacted control sites and when survey data confirm the absence of neoplastic or preneoplastic tumors in bullheads or suckers.	Consistent with expert opinion on tumors; acknowledges background incidence rates.	Adapted from Mack and Smith, 1988; Black, 1983; Baumann et al., 1982
BIRD OR ANIMAL DEFORMITIES OR REPRODUCTIVE PROBLEMS	When wildlife survey data confirm the presence of deformities (e.g. cross-bill syndrome) or other reproductive problems (e.g. egg-shell thinning) in sentinel wildlife species.	When the incidence rates of deformities (e.g. cross-bill syndrome) or reproductive problems (e.g. egg-shell thinning) in sentinel wildlife species do not exceed background levels in inland control populations.	Emphasizes confirmation through survey data; makes necessary control comparisons.	Adapted from Kubiak, 1988; Miller, 1988; Wiemeyer et al., 1984
DEGRADATION OF BENTHOS	When the benthic macroinvertebrate community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when toxicity (as defined by relevant, field-validated, bioassays with appropriate quality assurance/quality controls) of sediment-associated contaminants at a site is significantly higher than controls.	When the benthic macroinvertebrate community structure does not significantly diverge from unimpacted control sites of comparable physical and chemical characteristics. Further, in the absence of community structure data, this use will be considered restored when toxicity of sediment-associated contaminants is not significantly higher than controls.	Accounts for community structure and composition; recognizes sediment toxicity; uses appropriate control sites.	Adapted from Reynoldson, 1988; Henry, 1988; IJC, 1988

Table 4.1. (continued) Guidelines for Recommending the Listing and Delisting of Great Lakes Areas of Concern (IJC, 1991).

USE IMPAIRMENT	LISTING GUIDELINE	DELISTING GUIDELINE	RATIONALE	REFERENCE
RESTRICTIONS ON DREDGING ACTIVITIES	When contaminants in sediments exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities.	When contaminants in sediments do not exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities.	Accounts for jurisdictional and federal standards; emphasizes dredging and disposal activities.	Adapted from IJC, 1988
EUTROPHICATION OR UNDESIRABLE ALGAE	When there are persistent water quality problems (e.g. dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, etc.) attributed to cultural eutrophication.	When there are no persistent water quality problems (e.g. dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, etc.) attributed to cultural eutrophication.	Consistent with Annex 3 of the Agreement; accounts for persistence of problems.	United States and Canada, 1987
RESTRICTIONS ON DRINKING WATER CONSUMPTION OR TASTE AND ODOR PROBLEMS	When treated drinking water supplies are impacted to the extent that: 1) densities of disease-causing organisms or concentrations of hazardous or toxic chemicals or radioactive substances exceed human health standards, objectives or guidelines; 2) taste and odor problems are present; or 3) treatment needed to make raw water suitable for drinking is beyond the standard treatment used in comparable portions of the Great Lakes which are not degraded (i.e. settling, coagulation, disinfection).	For treated drinking water supplies: 1) when densities of disease-causing organisms or concentrations of hazardous or toxic chemicals or radioactive substances do not exceed human health objectives, standards or guidelines; 2) when taste and odor problems are absent; and 3) when treatment needed to make raw water suitable for drinking does not exceed the standard treatment used in comparable portions of the Great Lakes which are not degraded (i.e. settling, coagulation, disinfection).	Consistency with the Agreement; accounts for jurisdictional standards; practical; sensitive to increased cost as a measure of impairment.	Adapted from United States and Canada 1987
BEACH CLOSINGS	When waters, which are commonly used for total-body contact or partial-body contact recreation, exceed standards, objectives, or guidelines for such use.	When water, which are commonly used for total-body contact of partial-body contact recreation, do not exceed standards, objectives, or guidelines for such use.	Accounts for use of waters; sensitive to jurisdictional standards; addresses water contact recreation; consistent with the Agreement.	Adapted from United States and Canada, 1987; Ontario Ministry of the Environment, 1984
DEGRADATION OF AESTHETICS	When any substance in water produces a persistent objectionable deposit, unnatural color or turbidity, or unnatural odor (e.g. oil slick, surface scum).	When the waters are devoid of any substance which produces a persistent objectionable deposit, unnatural color or turbidity, or unnatural odor (e.g. oil slick, surface scum).	Emphasizes aesthetics in water; accounts for persistence.	Adapted from the Ontario Ministry of the Environment, 1984
ADDED COSTS TO AGRICULTURE OR INDUSTRY	When there are additional costs required to treat the water prior to use for agricultural purposes (i.e. including, but not limited to, livestock watering, irrigation and crop-spraying) or industrial purposes (i.e. intended for commercial or industrial applications and noncontact food processing).	When there are no additional costs required to treat the water prior to use for agricultural purposes (i.e. including, but not limited to, livestock watering, irrigation and crop-spraying) and industrial purposes (i.e. intended for commercial or industrial applications and noncontact food processing).	Sensitive to increased cost and a measure of impairment.	Adapted from Michigan DNR, 1977
DEGRADATION OF PHYTOPLANKTON AND ZOOPLANKTON POPULATIONS	When phytoplankton or zooplankton community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when relevant, field-validated, phytoplankton or zooplankton bioassays (e.g. *Ceriodaphnia*; algal fractionation bioassays) with appropriate quality assurance/quality controls confirm toxicity in ambient waters.	When phytoplankton and zooplankton community structure does not significantly diverge from unimpacted control sites of comparable physical and chemical characteristics. Further, in the absence of community structure data, this use will be considered restored when phytoplankton and zooplankton bioassays confirm no significant toxicity in ambient waters.	Accounts for community structure and composition; recognizes water column toxicity; uses appropriate control sites.	Adapted from IJC, 1987
LOSS OF FISH AND WILDLIFE HABITAT	When fish and wildlife management goals have not been met as a result of loss of fish and wildlife habitat due to a perturbation in the physical, chemical, or biological integrity of the Boundary Waters, including wetlands.	When the amount and quality of physical, chemical, and biological habitat required to meet fish and wildlife management goals have been achieved and protected.	Emphasizes fish and wildlife management program goals; emphasizes water components of Boundary Waters.	Adapted from Manny and Pacific, 1988

Table 4.2. Impaired Uses in the Waukegan Expanded Study Area.

Impaired Use	Causes	Sources
Fish consumption restrictions	PCBs	Contaminated sediments Ambient water quality Atmospheric deposition
Degradation of benthos	PCBs	Contaminated sediments
Dredging restrictions	PCBs	Contaminated sediments
Beach closings	fecal coliform	Waukegan River
Loss of fish and wildlife habitat	PCBs	Contaminated sediments

currently has posted the harbor area warning that consumption of fish taken from the "North" portion of Waukegan Harbor may be dangerous to human health. Contamination of fish tissue is discussed in Section 4.4. Hunting is not allowed in the ESA because it is in an urban area. There have been no studies of contaminants in wildlife in the ESA (Millar, 1991).

Proper handling and processing of fish has been shown to reduce fillet concentrations of organic compounds (Hazleton Laboratories America, Inc., 1986). Removal of the skin, belly and back fat, and lateral vein from chinook salmon fillets resulted in average reductions in PCBs, DDT and metabolites, Dieldrin, Chlordane, and benzene hexachloride (BHC) and all isomers of roughly 70 percent.

4.1.2. Tainting of Fish Flavor

There have been no reports of tainted flavor in fish flesh in or near the area of concern. A fish flavor study using American Public Health Association (1980) methods has not been conducted (Hess, 1991).

4.1.3. Degradation of Fish and Wildlife Population

REVISED 2/19/92 & 3/31/92

There is no available information on impacts to fish and wildlife populations in the Waukegan ESA. Detailed fish and wildlife population studies have not been conducted in the Waukegan ESA. Detailed population studies in the area have been restricted to the collection of samples for fish contaminant analysis (Hess, 1991).

Surveys of charter boat sport catch from the Illinois waters of Lake Michigan show greater total catch in Waukegan area waters than in Chicago area waters (Hess and Trudeau, 1990). In 1987 and 1988, overall charter boat sport catch near Waukegan was approximately 140 and 190 percent greater than near Chicago. Individual species of sport fish which were more commonly caught off Waukegan included coho salmon, chinook salmon, rainbow trout, and brown trout.

As with charter boat fishing, pedestrian catch in the Waukegan area is greater than in other areas along the Lake Michigan shoreline in Illinois (Horns and Brofka, 1990). Pedestrian catch of brown trout, rainbow trout, coho salmon, and chinook salmon from both the Commonwealth Edison Waukegan Generating Station and the Waukegan Harbor area were greater than from six other locations along the Illinois shoreline. Catch of yellow perch was greater at the Waukegan locations than from five of the six other locations.

4.1.4. Fish Tumors or Other Deformities

REVISED 2/19/92

There have been no reports of fish tumors or other abnormalities in Waukegan area fish. Annual electrofishing surveys have been conducted by the Illinois Department of Conservation (IDOC) in the boat harbor south of government pier to collect fish for contaminant analysis. Examinations of subsamples of collected fish have not identified any internal or external tumors or abnormalities. It is not expected that fish tumors or other abnormalities are a problem in the ESA since no reports or observations have been documented (Hess, 1991).

4.1.5. Bird or Animal Deformities or Reproduction Problems

REVISED 2/19/92

There is no available information on bird or animal deformities or reproduction problems in the Waukegan ESA (Millar, 1991).

4.1.6. Degradation of Benthos

Polluted conditions which presently exist within Waukegan Harbor have impacted benthos populations. In 1972, the Illinois Environmental Protection Agency (IEPA) conducted a benthic survey of Waukegan Harbor at four stations and, based on this survey, classified each station as polluted (Figure 4.1.). Benthic life (Table 4.3.) consisted of Oligochaete (aquatic worms), Sphaeriidae (fingernail clams), Hirudinea (leeches), Tendipedidae (midges), Prosobranchia (gilled snails), and Amphipods (scuds). Pollution tolerant forms, specifically aquatic worms, predominated at each location indicating environmental

Revisions of
2/19/92

4.1.3. Degradation of Fish and Wildlife Population

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Contaminant concentrations similar to those found within the Waukegan ESA have been correlated with declines in fish and wildlife populations throughout the Great Lakes. Specifically, organochlorine compounds in the Great Lakes have been linked to reduced populations of double-crested cormorant and bald eagle. Double-crested cormorant populations in the Great Lakes declined in the 1970s as a result of eggshell thinning associated with DDT. Recovery of the double-crested cormorant began in the 1980s and, currently, basin-wide cormorant populations are 20 times greater than at any other time this century (Government of Canada, 1991). Bald eagles, as long-lived top predators, are particularly susceptible to bioaccumulation and suffered population declines in the Great Lakes starting in the 1940s (Government of Canada, 1991). Lake trout declines in Lake Michigan have been circumstantially associated with environmental contaminants. Other species which have experienced population declines associated with water and sediment quality contamination are otter, black-crowned night-heron, and possibly mink.

Surveys of charter boat sport catch from the Illinois waters of Lake Michigan show greater total catch in Waukegan area waters than in Chicago area waters (Hess and Trudeau, 1990). In 1987 and 1988, overall charter boat sport catch near Waukegan was approximately 140 and 190 percent greater than near Chicago. Individual species of sport fish which were more commonly caught off Waukegan included coho salmon, chinook salmon, rainbow trout, and brown trout.

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4.1.5. Bird or Animal Deformities or Reproduction Problems

There is no available information on bird or animal deformities or reproduction problems in the Waukegan ESA (Millar, 1991). Specific studies in the ESA appear warranted.

Studies have shown that levels of toxicity similar to those levels found in Waukegan Harbor have produced adverse effects, reproductive failure and gross deformities, on wildlife. Ranch raised mink experienced reproductive failure and elevated kit mortality when fed PCB-containing fish (Government of Canada, 1991; Fitchko, 1986). Organochlorine compounds, especially DDT and DDE, are correlated with eggshell thinning and reproductive failure in double-crested cormorant and bald eagle (Government of Canada, 1991). Contaminant-associated reproduction failure in herring gulls was attributed to altered egg incubation behavior in adult gulls. Deformities attributed to contaminant exposure include feminization of male herring gull embryos; bill deformities in common terns; tail, leg, and mouth deformities in snapping turtle; and, most notably, crossed bills in double-crested cormorants (Government of Canada, 1991).

Figure 4.1. Benthos Sampling Locations.

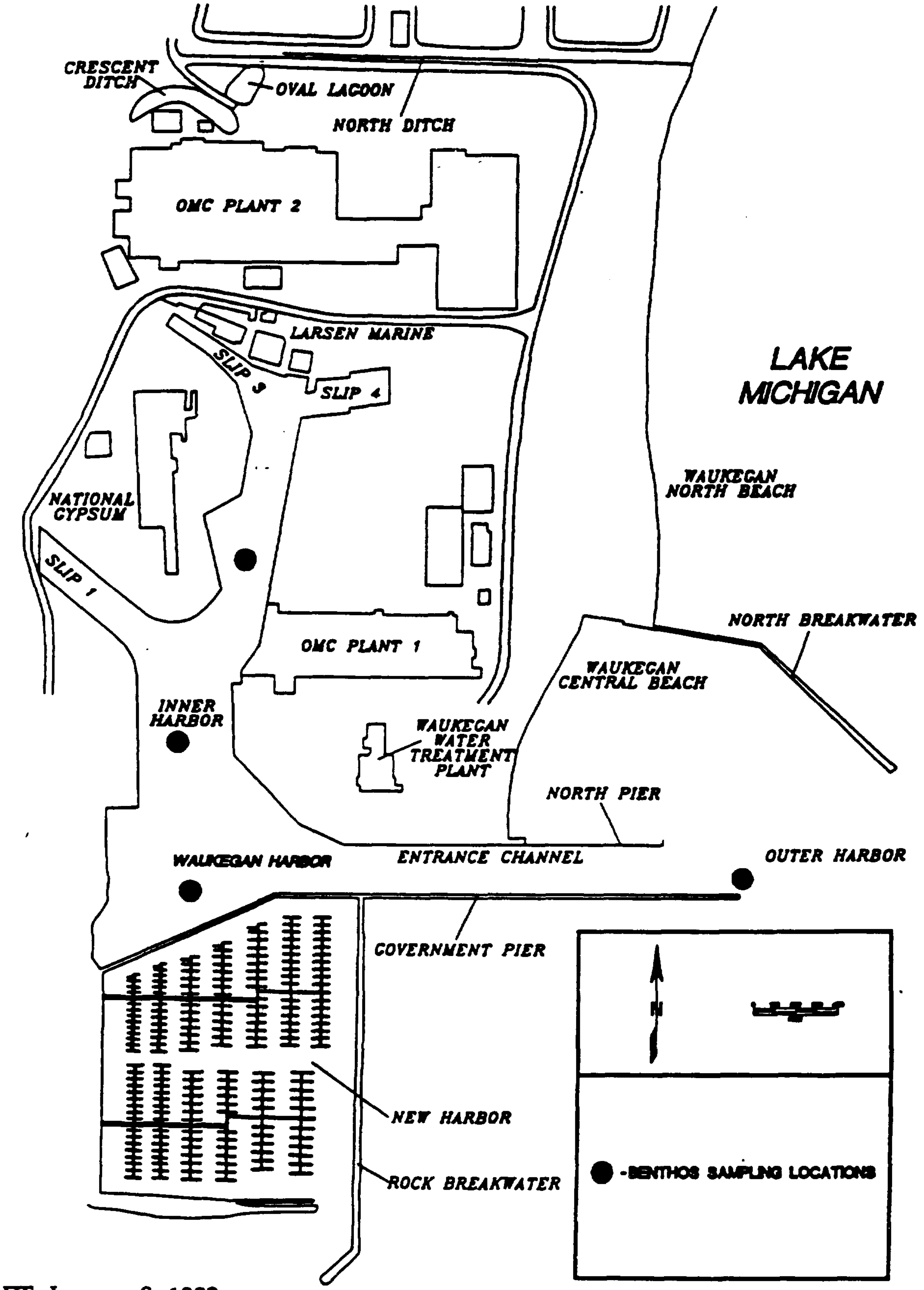


Table 4.3. Benthic Organisms Observed in Waukegan Harbor (IEPA, 1972).

	Station			
Organism	1	2	3	4
Caddisfly larvae	0	0	0	0
Scuds	7	2	0	0
Aquatic sow bugs	0	0	0	0
Fingernail clams	2100	12	1110	150
Gilled snails	14	0	7	0
Midge larvae	7	0	0	85
Flatworm	0	0	0	0
Pulmonate snails	0	0	0	0
Leeches	36	7	392	14
Aquatic worms	3900	105	6800	13600

degradation (IEPA, 1972).

In 1973, additional benthic surveys were accomplished by the IEPA near the mouth of the Dead River, in near-shore areas near the North Shore Sanitary District (NSSD) sewage treatment plant, and the mouth of the Waukegan River in Lake Michigan (IEPA, 1973). Benthos populations around the Dead River were classified as balanced and were dominated by scuds. Several sampling locations immediately off-shore of the NSSD facility were found to be devoid of benthic life. However, samples within 0.5 miles of the shoreline were found to have balanced benthic populations. It should be noted that since the date of this study, effluent from the NSSD facility has been routed away from Lake Michigan and to the Des Plaines River. The resulting reduction of nutrient and biodegradable loads to the lake should have improved the benthic environment at the NSSD facility. However, current data concerning benthic populations near the NSSD facility are not available. Eleven of fifteen sampling locations near the mouth of the Waukegan River were classified as either polluted or semipolluted.

Sediment samples for benthic invertebrate analysis were taken from nearshore Lake Michigan near the Waukegan generating station in 1972 and 1973 (CEC, 1972; CEC, 1973). Sampling depths ranged from 10 to 40 feet. Samples were dominated by aquatic worms, scuds, and fingernail clams.

A 1987 benthic survey was conducted by the Illinois Natural History Survey (Ross et al., 1989) within Waukegan Harbor and in Lake Michigan immediately outside the harbor. As with earlier benthic studies, dominant species included aquatic worms and fingernail clams. Biomass, based on the dry weight of collected samples, was lower in areas of marked contamination.

The toxicity of Waukegan Harbor sediments to various benthic organisms was evaluated by Marking et al. (1981). Sediment samples were vigorously shaken with water and allowed to settle for one hour. The remaining suspension was decanted and used for the toxicity tests. The suspension was aerated during exposure to prevent further sedimentation.

Species mortality was recorded after 96 hours of exposure. Benthic organisms tested included water fleas, scuds, mayfly nymphs, midge larvae, snails, and fingernail clams. All species except fingernail clam experienced increased mortality attributed to sediment exposure. Water flea mortality of 100 percent was observed for some samples.

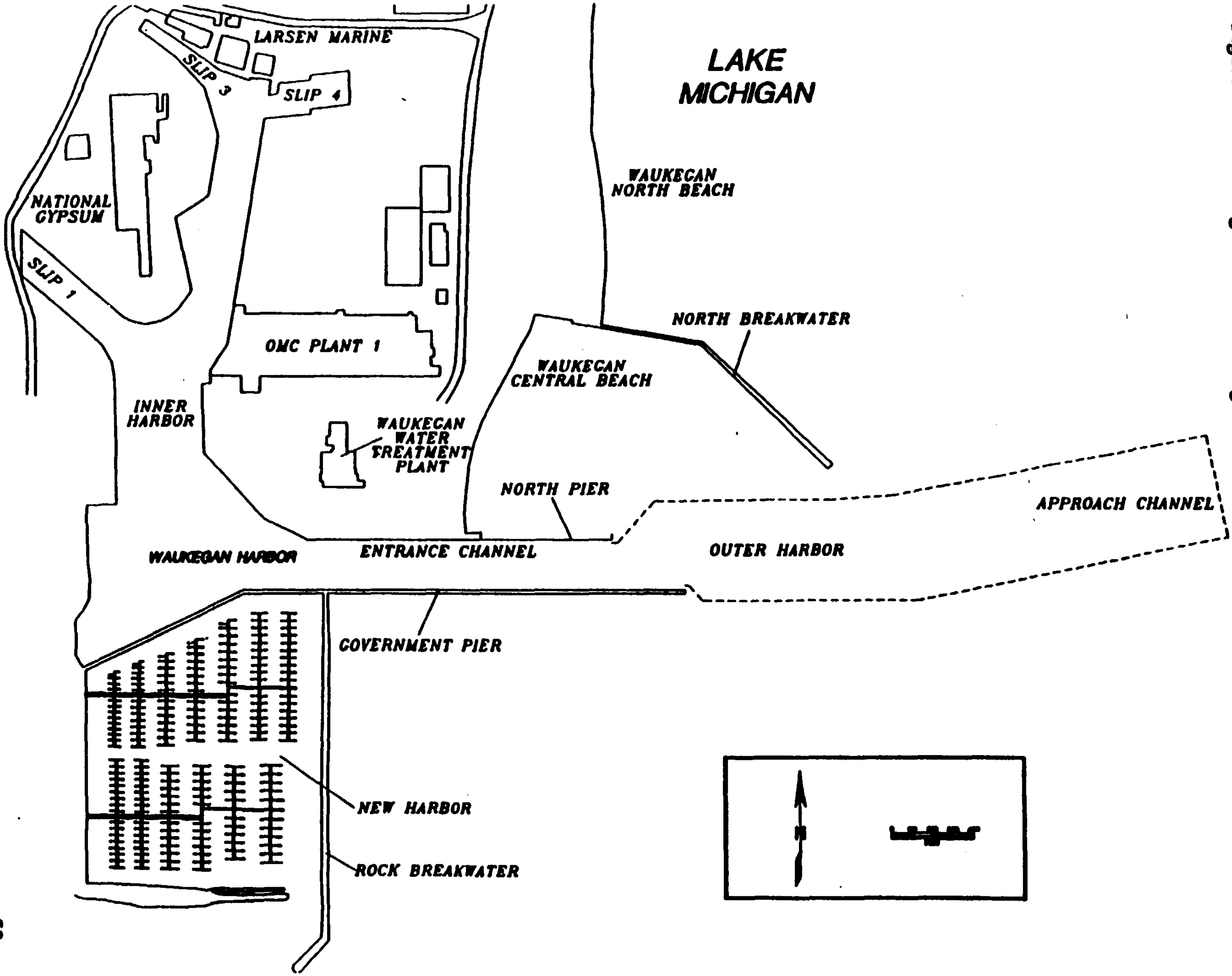
4.1.7. Restrictions on Dredging Activities

Both the inner and outer areas of Waukegan Harbor (Figure 4.2.) are affected by sediment accumulation. Accumulated sediment in the inner harbor is estimated to be between 1 and 10 feet thick (Ross et al., 1989). The breakwaters and piers which define and protect the outer harbor trap sandy sediments which are eroded from the beaches at Illinois Beach State Park north of Waukegan and carried by the littoral drift (Norby, 1981). The U.S. Army Corps of Engineers (ACOE) has dredged the outer areas of Waukegan Harbor as recently as 1991. Dredged materials removed from the outer harbor areas were clean sandy sediments which were suitable for unconfined lake disposal or use as nourishment materials for beaches.

Dredging of the inner portions of Waukegan Harbor, west of North Pier, was discontinued after 1972 because the sediments were classified as polluted (ACOE, 1989). Since that time, the ACOE has investigated alternatives for confined disposal facilities (ACOE, 1986; ACOE, 1989). None of the proposed confined disposal facility alternatives have received approval.

There has been an increased cost to industry due to a lack of dredging in the harbor. The inner (old) harbor area is authorized to be dredged to 23 feet and was last dredged to 18 feet in 1972. The inner harbor is now about 16 feet deep and is scheduled for only partial dredging as part of the OMC Superfund clean up. Representatives of industries which rely on the harbor for transportation of raw and finished materials reported problems associated with lack of dredging to the Waukegan Citizens Advisory Group (CAG, 1991). Three of the four participating industries must currently alter normal shipping procedures to accommodate shallow water depths in the harbor. Of these three, two local building product manufacturers have indicated that lack of dredging has cost their companies a sum

Figure 4.2. Waukegan Harbor Navigation Areas.



of roughly 0.5 million dollars per year in additional shipping costs. These increased shipping costs are related to the number of deliveries required. Since water depths in the harbor have been reduced by sedimentation, shipping vessels may not safely navigate the harbor when they are fully loaded. Consequently, ships may only be loaded to approximately 70 percent of capacity requiring a greater number of dockages.

4.1.8. Eutrophication or Undesirable Algae

Eutrophication is the accumulation of nutrients in a water body and is commonly associated with increased high biotic productivity (Cole, 1979). Water quality constituents related to eutrophication are those which are required as macronutrients for production of plant material, particularly nitrogen and phosphorus.

Water quality samples collected from Waukegan Harbor in November, 1990 yielded a mean total phosphorus concentration of 0.018 mg/L and a mean total ammonia concentration of 0.37 mg/L (Table 4.4.). Although these nutrient levels exceed State of Illinois Standards, no undesirable algae growths have been reported or observed.

4.1.9. Restrictions on Drinking Water Consumption or Taste and Odor Problems

Two city of Waukegan water intakes (including an emergency intake) are located east of the harbor in the lake. The main intake is a 48 inch pre-stressed concrete pipe line that runs in an east southeast direction for 6,244 feet from the steel tank on the south side of government pier (Figure 4.2.). The emergency intake is a 24 inch line running approximately 1000 feet out from the tank. The location of the emergency intake is about 125 feet south of the Government pier and 100 feet east (Lapish, 1990). An additional emergency intake (15 inch line) is located in the entrance channel to the harbor (Kroop, 1991). Since an emergency intake which draws Lake Michigan water is available for use, it is quite unlikely that the City would ever utilize the emergency intake located in the harbor. Currently, both emergency intakes are valved shut.

Table 4.4. Comparison of Mean Water Quality Concentrations from the Waukegan Harbor Area and Lake Michigan, 1990. (Samples were collected and analyzed by the Illinois EPA).

Parameter	Standard	Waukegan Harbor Area (1)	Lake Michigan North Shore (2)
Water Temperature (C)	--	7.1	15
pH (units)	7.0 - 9.0 a	7.0	--
Dissolved Oxygen (mg/L)	5.0 c	8.3	--
DO Percent Saturation	90 a	70.4 *	--
Conductivity (µS/cm) 3	300 a	321 *	287
Total Phosphorus (mg/L)	0.007 a	0.018 *	0.004
Total Ammonia (mg/L)	0.02 a	0.37 *	0.01
Un-ionized Ammonia (mg/L) 4	0.04 c	0.000	--
Total Kjeldahl Nitrogen (mg/L)	--	0.6	0.2
Nitrite + Nitrate (mg/L)	--	0.29	0.24
COD (mg/L)	--	15	4
Turbidity (NTU)	--	11.7	2.0
Total Suspended Solids (mg/L)	--	12	2
Volatile Solids (mg/L)	--	4	2
Chloride (mg/L)	12 a	15 *	11
Sulfate (mg/L)	24 a	30 *	22
Cyanide (mg/L)	0.022 c	0.021	0.005 K
Fluoride (mg/L)	1.4 c	0.13	0.09
Phenols (µg/L)	1.0 b	15 *	3 K
Fecal Coliform (No./100mL)	20 a	24 *	8 K

1 Seven stations, November,1990.
2 Five stations (1N, 3N, 5N, 7N, 9N), May & September, 1990.
3 Conductivity x 0.6 = TDS (mg/L)
4 Calculated
a Lake Michigan Standard (35 IL Adm Code 302)
b Public Water Supply Standard (35 IL Adm Code 302)
c General Use Standard (35 IL Adm Code 302)
K Less than
* Violated Standard

There are no restrictions on drinking water for the City of Waukegan. Samples of finished water and raw water from the main intake are collected annually and tested for constituents identified in the Safe Drinking Water Act (USEPA, 1986). Results of this annual sampling are included in Appendix A. In addition, finished water is analyzed daily for bacteria, turbidity, residual chloride, and fluoride and raw water is analyzed daily for turbidity and temperature (Kroop, 1991). Water quality continues to meet standards set forth by the Safe Drinking Water Act (USEPA, 1986).

There have been no complaints regarding taste and odor since 1988 when harbor water entered the raw water intake due to drain and sump problems. Following reconstruction of the drain and sump and initiation of activated carbon treatment in 1988, no taste and odor complaints were reported. Use of granular activated carbon for treatment of drinking water is typical of public drinking water supplies in Cook and Lake counties which rely of surface water resources (IEPA, 1991a).

4.1.10. Beach Closings

The Illinois Pollution Control Board (IPCB) and the Illinois Department of Public Health have set water quality standards for swimming based on fecal coliform counts. Fecal coliform is present in the feces of humans and other warm-blooded animals. Its presence in water indicates the possible presence of pathogenic organisms. The IPCB standard for full contact recreation is a geometric mean less than or equal to 200 counts per 100 mL and no more than 10 percent of the samples shall exceed 400 counts per 100 mL (35 IL Adm. Code 302). The Lake County Health Department samples Lake Michigan beaches in the county daily during the swimming season (June through August). The criteria used for closing a beach is consecutive samples with fecal coliform counts greater than 500 per 100 mL water or total coliform counts greater than 5000 per 100 mL water (IDPH, 1987). The Lake Michigan water quality standard of a geometric mean of 20 counts fecal coliform per 100 mL water (Table 4.3.) is applied for environmental evaluations rather than public health concerns related to beach closures.

Two city beaches, Waukegan North and Waukegan Central are located immediately north of the harbor entrance. The Waukegan beaches have exceeded swimming standards occasionally between 1983 and 1991 (Table 4.5.). Generally, Waukegan North beach has greater levels of fecal coliform than Waukegan Central beach. These beaches were closed periodically between July 16 and August 20, 1990 due to elevated coliform bacteria counts. Waukegan North beach experienced thirteen days with coliform counts (total coliform or fecal coliform) above Lake County Health Department limits for full contact use resulting in beach closings on nine occasions. Waukegan Central beach experienced nine days with coliform counts above health department limits resulting in five beach closings (Farrell and Budzinski, 1990). In 1991, Waukegan North beach experienced two closings while Waukegan Central had no closings (Colwell, 1991). An intensive reconnaissance of the area conducted in 1990 by the North Shore Sanitary District found that the Waukegan River was the source of fecal contamination; further sampling of the Waukegan River was recommended to locate the source of contamination (Farrell and Budzinski, 1990).

A recent inspection by the IEPA found several stormwater and sanitary sewer cross-connections resulting in pollutional discharges to the Waukegan River (Kallis, 1991). The City of Waukegan was requested to correct any pollutional discharge in a compliance inquiry letter dated April 24, 1991 (Marek, 1991).

Although the Waukegan River has been identified as the primary source of fecal coliform contamination at municipal beaches, there is the potential that additional nearby stormwater discharges and combined sewer overflow during periods of heavy rainfall could contribute fecal coliform.

4.1.11. Degradation of Aesthetics

As defined by the IJC (IJC, 1991), aesthetics within the ESA may be considered degraded when a "persistent objectionable deposit, unnatural color or turbidity, or unnatural odor" is observed in water. There is no available information on degradation of aesthetics, as defined by the IJC, in the Waukegan ESA.

Table 4.5. Summary of Beach Closings and Fecal Coliform Bacteria (No./100mL) at Lake Michigan Beaches in Waukegan, Illinois, 1983 Through 1991.

	Waukegan North	Waukegan Central	Total
Year	Days Closed	Days Closed	Days Closed
1987	2	3	5
1988	0	3	3
1989	3	2	5
1990	10	10	20
1991	2	0	2

	Waukegan North			Waukegan South		
Year	Geo. Mean	% >400	CS >500	Geo. Mean	% >400	CS >500
1983	28	4	0	26	3	0
1984	44	8	1	24	7	0
1985	32	6	0	23	1	0
1986	66	18	4	42	8	0
1987	79	13	1	52	4	1
1988	76	8	0	82	10	3
1989	71	12	1	67	9	1
1990	91	20	7	67	10	4
1991	49	9	1	64	10	0

Standards (35 IL Adm Code 302).
Lake Michigan: geometric mean <= 20/100mL.
General Use: geometric mean <= 200/100mL and no more than 10% of samples > 400/100mL.

Criterion for closing beaches (IDPH, 1987).
Consecutive samples >500/100mL.

4.1.12. Added Costs to Agriculture or Industry

According to the IJC (IJC, 1991), additional costs required to treat waters prior to agricultural or industrial use indicate an impaired use. Information on added costs for treatment of water from the Waukegan ESA for industry is not available. There is no agricultural use of water from the Waukegan ESA.

4.1.13. Degradation of Phytoplankton and Zooplankton Populations

Phytoplankton communities in Lake Michigan near Waukegan were monitored by Commonwealth Edison between 1972 and 1974 (CEC, 1972; CEC, 1973; CEC, 1974). Overall, 349 genera representing six algal divisions were identified in samples taken from Lake Michigan between Zion and Waukegan. Dominant phytoplankton by number were Stephanodiscus binderanus and S. hantzchii vel tenuis and by volume was Rhizosolenia eriensis.

Zooplankton populations also were monitored by Commonwealth Edison (CEC, 1972; CEC, 1973; CEC, 1974). Generally, cladocera dominated zooplankton catch and the dominant species observed was Bosmina longirostris.

McNaught et al. (1980) investigated the effects of PCB concentrations on photosynthesis of phytoplankton. Photosynthesis was found to be inhibited 5.7 percent when phytoplankton was exposed to PCB concentrations of 5 ng/L. Likewise, photosynthesis inhibition was determined to be 8.9 percent and 18.9 percent for PCB concentrations of 100 ng/L and 500 ng/L, respectively. PCB concentrations of 5ng/L are comparable to concentrations in open water areas of Lake Michigan and PCB concentrations of 500 ng/L are comparable to those in Waukegan Harbor.

Protozoan community response to Waukegan Harbor sediments was examined by Ross et al. (1988) in-situ and in laboratory tests. Sediment contamination within slip 3 was found to significantly alter the structure of indigenous protozoan communities. This result was confirmed through laboratory test results. Impacts to protozoan communities were found to be greater within lower portions of the water column where suspension of particles which carry toxic chemicals was probably greater.

The studies of Ross et al. (1988) and Risatti et al. (1990) show that the photosynthesis of the green alga *Selenastrum capricornutum* was inhibited by sediment elutriates from several sampling sites within the harbor. Burton et al. (1989) reported toxicity to *Daphnia magna*, *Ceriodaphnia dubia* and *S. capricornutum* when these organisms were exposed to sediments or sediment elutriates from the inner harbor. Also, Marking et al. (1981) observed water flea (probably *Daphnia magna*) mortalities of 100 percent from some sediment suspension samples taken from the Harbor.

The urbanized and industrial nature of the Waukegan lake shore has significantly altered the potential for terrestrial wildlife habitat in the ESA. Development of the ESA is documented as early as 1885 and included two tanneries, two breweries, several mills, and a mattress factory (Sanborn, 1885). Industrial use of the ESA continues presently and provides an important economic base for the Waukegan area. The terrestrial habitat which remains in the Waukegan ESA is predominately located in the portion of the ESA which intersects Illinois State Beach Park. Since the harbor is a man-made structure which was constructed for industrial purposes, its value for wildlife and fish habitat is limited.

In nearshore Lake Michigan areas, both fish and wildlife habitat are impacted through sediment accumulation and contamination. Fish spawning and rearing habitat and avian foraging habitat have been adversely impacted according to the U.S. Department of the Interior Fish and Wildlife Service (Millar, 1991). Sediment accumulation may bury spawning and shelter areas used by small or immature fish. PCB concentrations of 10 ng/L have been associated with a 20 percent increase in the mortality of lake trout fry (Willford, 1980). In addition, Mac (1988) reported decreased hatching of lake trout eggs after exposure to PCBs.

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ILLINOIS ENVIRONMENTAL PROTECTION AGENCY to significantly alter the structure of indigenous protozoan communities. This result was confirmed through laboratory test results. Impacts to protozoan communities were found to be greater within lower portions of the water column where suspension of particles which carry toxic chemicals was probably greater.

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~~Additional study will be required to determine if phytoplankton and zooplankton populations have been degraded in the Waukegan ESA.~~

4.1.14. Loss of Fish and Wildlife Habitat

The urbanized and industrial nature of the Waukegan lake shore has significantly altered the potential for terrestrial wildlife habitat in the ESA. Development of the ESA is documented as early as 1885 and included two tanneries, two breweries, several mills, and a mattress factory (Sanborn, 1885). Industrial use of the ESA continues presently and provides an important economic base for the Waukegan area. The terrestrial habitat which remains in the Waukegan ESA is predominately located in the portion of the ESA which intersects Illinois State Beach Park. Since the harbor is a man-made structure which was constructed for industrial purposes, its value for wildlife and fish habitat is limited.

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4.2. LAKE MICHIGAN WATER QUALITY

The water quality of the Illinois shore of Lake Michigan has improved substantially since the 1970's. In the early 70's total phosphate and ammonia concentrations were routinely above Lake Michigan water quality standards. The trophic status of the Illinois shore has improved from mesotrophic/eutrophic to oligotrophic conditions based on total phosphate. In the open lake, fecal coliform counts have generally been low and uniform since 1970, indicating excellent conditions for swimming. Conductivity measurements and chloride and sulfate levels have fluctuated over the past 11 years but have generally been within water quality standards. Toxic substances including metals and organic compounds have generally been below detection levels and well below water quality standards (IEPA, 1990).

Water samples were collected at seven stations in the Waukegan ESA on November 14, 1990 (Figure 4.3.). Results, presented in Tables 4.6. and 4.7., were compared to appropriate Illinois water quality standards including Lake Michigan, Public Water Supply and General Use Standards (35 IL Adm. Code 302).

Water quality conditions were worse in the upper harbor and tended to improve towards the harbor mouth. A total of 48 standards violations involving 10 parameters were found in the Waukegan Harbor area. The most serious problems were with ammonia, cyanide, phenols and dissolved oxygen.

Upper harbor (QZO01), slip number one (QZP01) and central harbor (QZQ01) each had nine standards violations. Eight violations were found near the boat ramp (QZR01), five each at harbor channel (QZS01) and new harbor (QZT01) and three at North Beach (QZN01). Total phosphorus, total ammonia and sulfate were found to be in violation at all seven stations; dissolved oxygen percent saturation and conductivity at six stations; chloride and phenols at four stations; pH and cyanide at three stations and fecal coliform at one station.

Figure 4.3. Water and Sediment Sampling Locations (Sampling conducted for the Waukegan RAP on November 14, 1990).

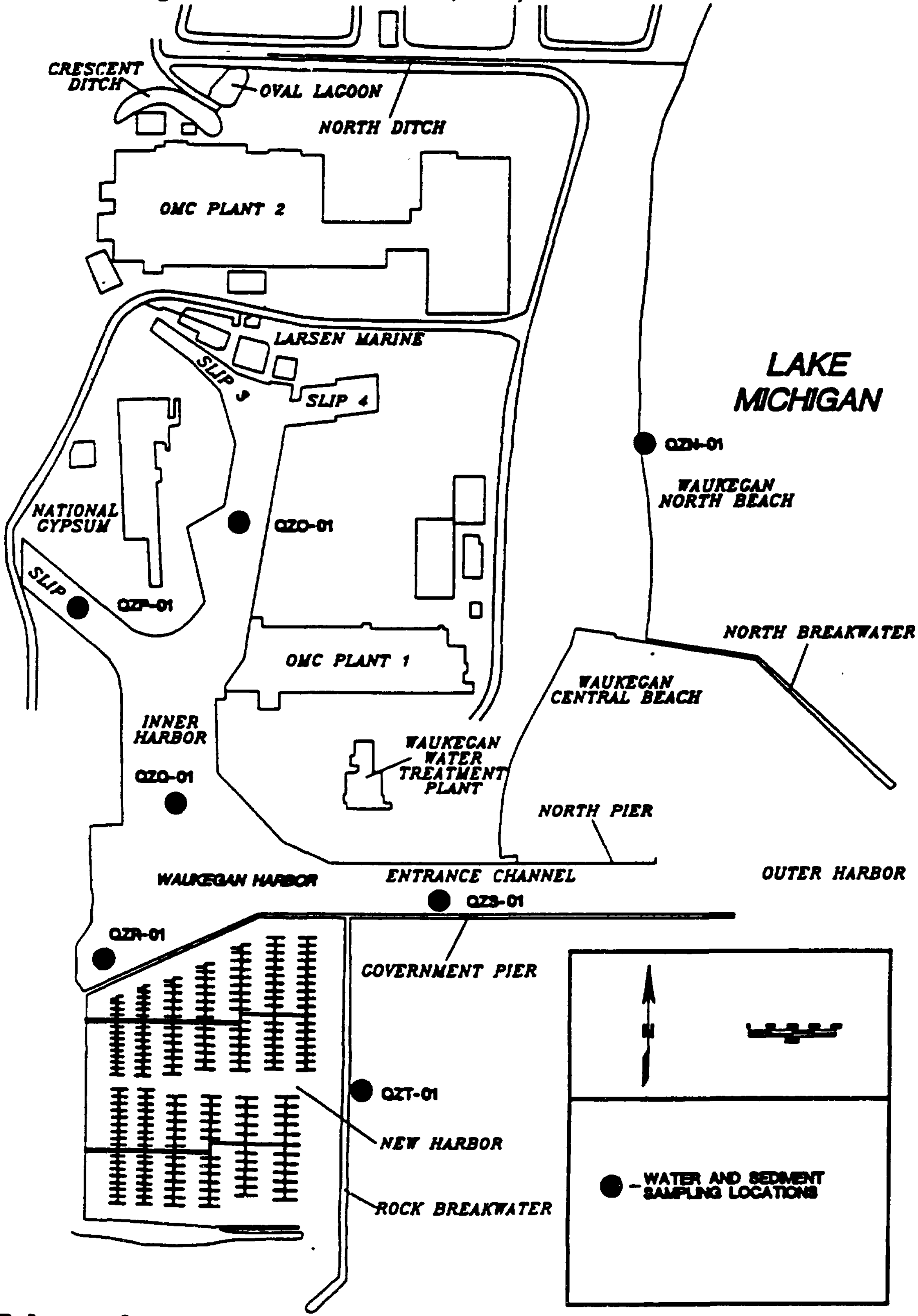

Table 4.6. Water Quality in the Waukegan Harbor Area, November 14, 1990. (Concentrations are in parts per million unless otherwise noted. Samples were collected and analyzed by the Illinois EPA).

Parameter	Standard	North Beach QZN01	Upper Harbor QZO01	Slip No. 1 QZP01	Central Harbor QZQ01	Boat Ramp QZR01	Harbor Channel QZS01	New Harbor QZT01
Water Temperature (C)	--	7.7	7.4	7.3	7.3	6.4	6.8	6.5
pH (units)	7.0 - 9.0 a	7.8	6.7 *	6.6 *	6.7 *	7.0	7.1	7.4
Dissolved Oxygen	5.0 c	11.2	5.9	6.0	6.6	8.7	9.4	10.0
DO Percent Saturation	90 a	96.6	50.9 *	51.7 *	56.9 *	73.1 *	79.7 *	84.0 *
Conductivity (uS/cm) #	300 a	265	349 *	347 *	339 *	339 *	304 *	306 *
Total Phosphorus	0.007 a	0.023 *	0.020 *	0.020 *	0.019 *	0.017 *	0.019 *	0.011 *
Total Ammonia	0.02 a	0.04 *	0.82 *	0.62 *	0.52 *	0.29 *	0.22 *	0.09 *
Un-ionized Ammonia @	0.04 c	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Total Kjeldahl Nitrogen	--	0.3	1.1	0.9	0.8	0.5	0.4	0.3
Nitrite + Nitrate	--	0.26	0.29	0.30	0.30	0.31	0.29	0.31
COD	--	23	16	14	14	12	13	11
Turbidity (NTU)	--	22	8.4	9.1	9.1	7.3	16.4	9.5
Total Suspended Solids	--	34	5	4	6	8	18	6
Volatile Solids	--	6	2	3	3	3	6	4
Chloride	12 a	11	18 *	18 *	16 *	19 *	11	12
Sulfate	24 a	26 *	32 *	32 *	31 *	32 *	28 *	29 *
Cyanide	0.022 c	0.005 K	0.050 *	0.040 *	0.030 *	0.010	0.010	0.005 K
Fluoride	1.4 c	0.09	0.15	0.15	0.15	0.13	0.11	0.10
Phenols (µg/L)	1.0 b	5 K	43 *	26 *	19 *	5 *	5 K	5 K
Fecal Coliform (No./100mL)	20 a	10	18	20	20	60 *	18	50 K

a Lake Michigan Standard (35 IL Adm Code 302)
b Public Water Supply Standard (35 IL Adm Code 302)
c General Use Standard (35 IL Adm Code 302)
K Less than
* Violated Standard
# Conductivity x 0.6 = TDS (mg/L)
@ Calculated

Table 4.7. Water Concentrations of Metals (total) in the Waukegan Harbor Area, November 14, 1990. (Samples were collected and analyzed by the Illinois EPA).

Parameter	Standard	North Beach QZN01	Upper Harbor QZO01	Slip No. 1 QZP01	Central Harbor QZQ01	Boat Ramp QZR01	Harbor Channel QZS01	New Harbor QZT01
Calcium (mg/L)	--	42	45	45	44	45	42	42
Magnesium (mg/L)	--	14	14	14	14	14	14	13
Potassium (mg/L)	--	1.3	2.9	2.7	2.1	2.7	1.2	3.0
Sodium (mg/L)	--	10.0	17.0	17.0	16.0	19.0	12.0	13.0
Hardness (mg/L) c	--	165	169	168	167	170	162	159
Aluminum (µg/L)	--	675	247	312	290	227	494	272
Arsenic (µg/L)	50 a	1 K	7	5	4	2	2	1
Barium (µg/L)	1000 a	25	27	27	27	27	25	24
Beryllium (µg/L)	--	0.5 K	0.5 K	0.5 K	0.5 K	0.5 K	0.5 K	0.5 K
Boron (µg/L)	1000 b	50 K	60	64	54	51	50 K	50 K
Cadmium (µg/L)	10 a	3 K	3 K	3 K	4	3 K	5	3 K
Chromium (µg/L)	50 a	5 K	5 K	5 K	5 K	5 K	5	5 K
Cobalt (µg/L)	--	5 K	5 K	5 K	7	5 K	5 K	5 K
Copper (µg/L)	** b	6	5 K	5	5 K	5 K	5	6
Iron (µg/L)	--	1015	447	486	446	343	691	347
Lead (µg/L)	50 a	50 K	100 K	50 K	100 K	50 K	100 K	50 K
Manganese (µg/L)	150 a	25	42	42	39	22	23	9
Mercury (µg/L)	0.5 b	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Nickel (µg/L)	1000 b	5 K	9	5 K	21	10 K	20	5 K
Silver (µg/L)	5 b	5 K	3 K	5 K	3 K	3 K	3 K	5 K
Strontium (µg/L)	--	129	148	147	145	147	134	134
Vanadium (µg/L)	--	6	5 K	5 K	5 K	5 K	5 K	5 K
Zinc (µg/L)	1000 b	136	50 K	100 K	130	50 K	100 K	50 K

a Public Water Supply Standard (35 IL Adm Code 302)
b General Use Standard (35 IL Adm Code 302)
c Calculated
K Less Than
* Violated Standard
** Depends on Hardness; Acute Copper = $e[0.9422\ln(\text{Hardness})-1.464]$

Water samples were scanned for thirty-eight volatile organic compounds, eighteen organochlorine pesticides, PCBs and pentachlorophenol. A complete list of compounds is presented in Appendix B. Pentachlorophenol and xylenes were the only compounds detected. There are no Illinois water quality standards for these two compounds. The concentrations of pentachlorophenol were at the detection level (0.01 μg/L) and well below USEPA's acute criterion of 55 μg/L (USEPA, 1986). Xylenes were detected in central harbor (39 μg/L), upper harbor (62 μg/L) and slip 1 (64 μg/L). Additional compounds were detected but could not be identified and were reported as aliphatic hydrocarbons (3 μg/L to 64 μg/L) and other organic compounds (4 μg/L to 50 μg/L). Highest levels of these compounds were found in slip 1 and upper harbor.

This recent sampling was compared with results from five Lake Michigan North Shore stations sampled in May and September, 1990 (Tables 4.3. and 4.8.). These stations are located from one to six miles off-shore between Waukegan and Chicago. All of the Lake Michigan mean values were well within standards, while Waukegan Harbor mean values for dissolved oxygen, conductivity, total phosphorus, total ammonia, chloride, sulfate, phenols and fecal coliform were in violation. The most substantial difference was total ammonia which was 37 times higher in Waukegan Harbor than in Lake Michigan. Other parameters which were at least twice as high in Waukegan Harbor than in Lake Michigan were iron, aluminum, TSS, turbidity, manganese, phenols, phosphorus, cyanide, COD, TKN, fecal coliform, sodium, and potassium. Organic compounds were not detected in offshore Lake Michigan.

4.3. SEDIMENT QUALITY

Sediment samples were collected for chemical analyses on November 14, 1990 at seven stations in the Waukegan ESA (Figure 4.3.). Results for metals, cyanide, nutrients, COD, and volatile solids are presented in Table 4.9. Sediment samples were scanned for seventy semi-volatile organic compounds, nineteen organochlorine pesticides, and PCBs. A complete list of organic compounds and the USEPA methods used for their analysis (USEPA, 1990b) is presented in Appendix C. Organic compounds which were detected are

Table 4.8. Comparison of Mean Metals (total) Concentrations in Water from the Waukegan Harbor Area and Lake Michigan, 1990. (Samples were collected and analyzed by the Illinois EPA).

Parameter	Standard	Waukegan Harbor Area (1)	Lake Michigan North Shore (2)
Calcium (mg/L)	--	44	36
Magnesium (mg/L)	--	14	11
Potassium (mg/L)	--	2.3	1.0
Sodium (mg/L)	--	14.8	5.6
Hardness (mg/L) 3	--	166	134
Aluminum (ug/L)	--	360	53
Arsenic (ug/L)	50 a	3	1 K
Barium (ug/L)	1000 a	26	20
Beryllium (ug/L)	--	0.5 K	0.5 K
Boron (ug/L)	1000 b	54	50 K
Cadmium (ug/L)	10 a	3 K	3 K
Chromium (ug/L)	50 a	5 K	5 K
Cobalt (ug/L)	--	5 K	5 K
Copper (ug/L)	** b	5	6 K
Iron (ug/L)	--	539	50 K
Lead (ug/L)	50 a	71 K	50 K
Manganese (ug/L)	150 a	29	5 K
Mercury (ug/L)	0.5 b	0.05 K	0.08 K
Nickel (ug/L)	1000 b	11	8 K
Silver (ug/L)	5 b	4 K	3 K
Strontium (ug/L)	--	140	124
Vanadium (ug/L)	--	5 K	5 K
Zinc (ug/L)	1000 b	88 K	50 K

1 Seven stations, November,1990.
2 Five stations (1N, 3N, 5N, 7N, 9N), May & September, 1990.
3 Calculated
a Public Water Supply Standard (35 IL Adm Code 302)
b General Use Standard (35 IL Adm Code 302)
K Less than
* Violated Standard
** Depends on hardness; acute copper = e[0.9422ln(hardness)-1.464].

Table 4.9. Unsieved Sediment Concentrations in the Waukegan Harbor Area, November 14, 1990. (Concentrations are in parts per million unless otherwise noted. Samples were collected and analyzed by the Illinois EPA).

Parameter	North Beach QZN01	Upper Harbor QZO01	Slip No. 1 QZP01	Central Harbor QZQ01	Boat Ramp QZR01	Harbor Channel QZS01	New Harbor QZT01
Arsenic	1 N	41 H	13 H	23 H	6 M	10 H	4 M
Barium	9 N	52 M	31 M	43 M	27 M	34 M	22 M
Cadmium	1 K	12 H	7 H	12 H	1 K	1 *	1 K
Chromium	4 N	90 H	47 M	88 H	22 N	34 M	15 N
COD	39200 N	117650 H	77648 M	91000 H	24900 N	62600 M	23600 N
Copper	2 N	160 H	53 H	86 H	26 M	50 M	30 M
Cyanide	0.52 K	1.2 K	2.4 K	3.3 K	0.65 K	0.87 K	9.3 H
Iron	3200 N	26000 H	14000 N	20000 M	9000 N	18000 M	12000 N
Kjeldahl Nitrogen	60 K	2500 H	900 N	1700 M	175 N	175 N	450 N
Lead	10 K	140 H	12000 H	120 H	39 N	60 M	10000 H
Manganese	96 N	460 M	91 N	450 M	220 N	480 M	24 N
Mercury	0.1 K	0.40 N	0.19 N	0.34 N	0.1 K	0.13 N	0.1 K
Nickel	5 K	26 M	340 H	21 M	9 N	16 N	400 H
Phosphorus	329 N	826 H	350 N	545 M	202 N	428 M	510 M
Potassium	1000 K	1900	1000	1500	1000 K	1300	1000
Silver	1 K	1 K	13	1 K	1 K	1 K	10
Volatile Solids (%)	2.3 N	9.8 H	7.3 M	8.3 H	4.2 N	4.8 N	2.2 N
Zinc	20 N	280 H	15 N	210 H	100 M	130 M	15 N

Sediment Classifications (USEPA, 1977)
K = Less Than
N = Nonpolluted
M = Moderately Polluted
H = Heavily Polluted
* = Lower limits not established

listed in Table 4.10. This table includes compounds which were detected but could not be identified. These compounds were reported as aliphatic hydrocarbons, aliphatic ketones, or other organic compounds. Results in these tables were compared with guidelines for the pollution classification of Great Lakes harbor sediments (USEPA, 1977) and with sediment results from the Illinois/Indiana area of Lake Michigan.

The upper harbor (Station QZ001) had the highest number of parameters signifying "heavy pollution" with 11 followed by central harbor (QZQ01) with 8, slip 1 (QZP01) with 5, new harbor (QZQ01) with 3 and the harbor channel (QZS01) with 1. The area near the boat ramp (QZR01) had no parameters signifying heavily polluted conditions, but it did have 5 parameters showing moderately polluted conditions. North Beach (QZN01) was classified as nonpolluted for all parameters.

Heavily polluted levels of arsenic and lead were found at four stations; cadmium and copper at three stations; chromium, zinc, nickel, COD and volatile solids at two stations; and cyanide, iron, phosphorus and Kjeldahl nitrogen at one station. Moderately polluted levels of barium were found at six stations; and manganese and PCBs at three stations.

Waukegan Harbor sediment results were compared with results from Lake Michigan, Lake Calumet and five harbors in Illinois and Indiana collected between 1981 and 1990 (Table 4.11.). Only seven parameters (Cd, Cr, Cu, Pb, Mn, Zn, PCBs) were analyzed at all six harbors and Lake Michigan. Waukegan Harbor had samples with the most parameters classified as heavily polluted with six (Cd, Cu, Pb, Mn, Zn, PCBs), followed by Indiana Harbor and Great Lakes Naval Training Center Harbor with four (Cu, Pb, Mn, Zn), Lake Calumet with four (Cr, Cu, Pb, Zn), Calumet Harbor with three (Pb, Mn, Zn), Chicago and Wilmette Harbors with one (Pb and Mn respectively) and none in Lake Michigan. The highest levels of PCBs, lead and cadmium were found in Waukegan Harbor sediments.

Work done in 1985 and 1986 by Ross et al. (1988) found that the highest levels of PCBs in Waukegan Harbor are in slip 3 (maximum = 17,251 ppm), and that concentrations generally decreased towards the harbor mouth. Sampling by IEPA in 1990 also showed this decrease

Table 4.10. Unsieved Sediment Concentrations of Organic Compounds Detected[1] in the Waukegan Harbor Area, November 14, 1990. (Concentrations are in parts per million. Samples were collected and analyzed by the Illinois EPA).

Parameter	North Beach QZN01	Upper Harbor QZO01	Slip No. 1 QZP01	Central Harbor QZQ01	Boat Ramp QZR01	Harbor Channel QZS01	New Harbor QZT01
PCBs	0.010 K	9.000 M	4.600 M	1.900 M	0.200 N	0.260 N	0.037 N
4-Methylphenol	0.5 K	0.5 K	0.5 K	0.62	0.5 K	0.5 K	0.5 K
Bis(2-Ethylhexyl)Phthalate	0.5 K	0.69	0.5 K	0.5 K	0.5 K	1.1	0.5 K
Fluoranthene	0.5 K	0.5 K	0.62	0.5 K	0.66	0.5 K	0.5 K
Pyrene	0.5 K	0.58	0.65	0.5 K	0.63	0.5 K	0.5 K
Aliphatic Hydrocarbon **	ND	70 *	24 *	18 *	1.6 *	1.8 *	ND
Aliphatic Ketone **	ND	ND	ND	ND	0.55 *	ND	ND
C3-Substituted Benzene	ND	0.95 *	ND	ND	ND	ND	ND
C4-Substituted Benzene	ND	6.1 *	3.0 *	1.0 *	ND	ND	ND
C5-Substituted Benzene	ND	2.8 *	1.8 *	ND	ND	ND	ND
Dimethyl Naphthalene #	ND	ND	0.78 *	ND	ND	ND	ND
Methyl Naphthalene #	ND	ND	0.71 *	ND	ND	ND	ND
Ethyl-Dimethyl-Pentane #	ND	1.5 *	ND	ND	ND	ND	ND
Methyl Pentane #	ND	0.60 *	0.59 *	ND	ND	ND	ND
Tetramethyl Pentane #	ND	15 *	7.2 *	ND	ND	ND	ND
Other Organic Compounds **	2.8	16 *	9.1 *	6.9 *	0.63 *	1.3 *	9.6 *

* Approximate Quantitations	Classification Guidelines (USEPA, 1977)
** Could not be identified	N = Nonpolluted
# Tentatively Identified	M = Moderately Polluted
K = Less Than	H = Heavily Polluted
ND = Not Detected	

(1) A priority pollutant scan was done for 90 organic compounds, see Appendix 2 for complete list.

Table 4.11. Comparison of Mean Concentrations of Various Parameters in Unsieved Sediments from the Illinois Area of Lake Michigan. (Concentrations are in parts per million unless otherwise noted.)

Parameter	Waukegan Harbor Area (1)	Waukegan Harbor (2)	Great Lakes Naval Training Center Harbor (3)	Wilmette Harbor (3)	Chicago Harbor (4)	Calumet Harbor (5)	Lake Calumet (6)	Indiana Harbor (7)	Lake Michigan (8)
Volatile Solids (%)	5.6 M	--	4.4 N	4.6 N	4.3 N	8.8 H	--	3.6 N	2.3 N
Kjeldahl Nitrogen	851 N	--	951 N	1060 M	760 N	872 N	--	946 N	592 N
Phosphorus	456 M	--	368 N	229 N	217 N	205 N	20.0 N	678 H	291 N
COD	62371 M	--	46000 M	48850 M	53333 M	72500 M	--	98000 H	47000 M
Arsenic	14 H	--	8 M	6 M	3.6 M	4.7 M	29.8 H	20 H	7.4 M
Barium	31 M	283 H	--	--	--	--	--	--	--
Cadmium	5.0 *	8.0 H	1.2 *	0.4 *	3.0 *	3.0 *	1.8 *	0.5 K	0.5 K
Chromium	43 M	5 N	23 N	13 N	28 M	41 M	76.7 H	58 M	12 N
Copper	58 H	104 H	87 H	30 M	35 M	38 M	57.5 H	110 H	23 N
Lead	3196 H	202 H	134 H	31 N	107 H	132 H	187.0 H	120 H	18 N
Manganese	260 N	531 H	589 H	537 H	490 M	710 H	--	970 H	430 M
Mercury	0.19 N	--	0.32 N	0.18 N	0.34 N	0.38 N	--	0.13 N	0.03 N
Nickel	117 H	18 N	--	--	--	--	23.6 M	--	--
PCBs	2.29 M	2426 H	0.225 N	0.070 N	0.133 N	0.585 N	--	0.400 N	0.017 N

(1) IEPA, 1990, seven samples, includes samples from Waukegan Harbor (except slip no. 3), New Harbor and North Beach.
(2) Metals 23 samples (Risatti et al, 1990); PCBs 18 samples (Ross et al, 1988), (includes samples from slip no. 3).
(3) Three samples (City of Chicago and IEPA, 1985).
(4) Three samples (Stations 15, 16, 17), (U.S.Army Corps of Engineers, 1981).
(5) Four samples (Stations 1, 2, 3, 4), (U.S. Army Corps of Engineers, 1981).
(6) Thirty-seven samples (Ross et al, 1988)
(7) One sample (City of Chicago and IEPA, 1981).
(8) Eight samples (Stations 5A, 5H, 5J, 1N, 7N, 2S, 5S, 7S), (City of Chicago and IEPA, 1981).

Sediment Classification (USEPA, 1977)
N = Nonpolluted
M = Moderately Polluted
H = Heavily Polluted
* Lower limits not established

K = Less Than

in PCB concentrations away from slip 3, although slip 3 was not sampled. A comprehensive discussion of the PCB contamination in Waukegan Harbor can be found in the settlement agreement between the United States of America and the People of the State of Illinois with Outboard Marine Corporation (U.S. District Court, Northern District Eastern Division, Civil Action No. 78-C-1004, April 1989).

A 1987 Waukegan Harbor study by Risatti et al. (1990) found the highest levels of lead (420 ppm) and cadmium (50 ppm) in slip 1. Much higher levels of lead were found in slip 1 (12,200 ppm) and New Harbor (10,000 ppm) by IEPA in 1990. The highest cadmium concentration (12 ppm) in 1990 was found at upper and central harbor stations.

Available information on biological effects of sediments is limited. Present guidelines used for the pollution classification of Great Lakes harbor sediments (USEPA, 1977) are not based on known toxic response but rather on deviations from "normal" concentrations. Sediment classifications in Illinois lakes and streams by Kelly and Hite (1981 and 1984) were developed much the same way. Ross (1991) reviewed a report by Long and Morgan (1990) who compiled data from all available studies that report a minimum sediment concentration of a contaminant required to produce a biological impact. Long and Morgan arranged sediment concentrations in order from lowest to highest and took the 10th percentile and 50th percentile and termed these points the Effects Range - Low (ER-L) and Effects Range-Median (ER-M). The ER-M indicates that adverse biological effects occur over half the time. This procedure was done for zinc, cadmium and lead.

Ross (1991) compared data from Long and Morgan (1990) with Waukegan Harbor sediment data from Risatti et al. (1990; Appendix D). Results are summarized in Table 4.12. According to Ross (1991) the greatest hazard to aquatic life is from lead. Zinc also presents a clear hazard, while there are possible hazards from cadmium. Ross (1991) also indicated that metals toxicity is additive. In order to approximate the relative additivity of toxic potential at each station, Ross calculated the ratio of zinc, cadmium and lead concentration to the ER-M value for that metal at each of the 23 stations sampled by Risatti et al. These ratios were then summed to give an additive estimate of the hazard to aquatic life from

Table 4.12. Comparison of Lead, Zinc and Cadmium Concentrations in Waukegan Harbor Sediments with Effects Range Levels from Long and Morgan (1990).

	Waukegan Harbor (1) 23 Stations	Waukegan Harbor Area (2) 7 Stations
LEAD (MG/KG)		
Minimum	36	<10
Maximum	420	12000
Mean	202	3196
Number >35 (ER-L)	23	6
Number >110 (ER-M)	18	4
ZINC (MG/KG)		
Minimum	81	15
Maximum	370	280
Mean	214	110
Number >120 (ER-L)	12	3
Number >270 (ER-M)	7	1
CADMIUM (MG/KG)		
Minimum	<1.3	<1.0
Maximum	50.0	12.0
Mean	8.0	5.0
Number >5.0 (ER-L)	7	3
Number >9.0 (ER-M)	4	2

(1) Risatti et al (1990)
(2) IEPA (1990)

ER-L = Effects Range Low (biological effects 10% of the time).
ER-M = Effects Range Median (biological effects 50% of the time).

those three metals. Based on these sums it appears that the most severe metal contamination is in the northern part of Waukegan Harbor and in slip 1. Data collected by IEPA in 1990 also suggests that lead is the greatest problem compared to zinc and cadmium (Table 4.12.), and that slip 1 and New Harbor have severe sediment contamination. A discussion of bioaccumulation of PCBs in fish follows in part 4.4. of this report.

4.4. FISH FLESH CONTAMINATION

On a lakewide basis PCBs and chlordane are the constituents of primary concern. Eighty-nine composite fish samples were collected from the Illinois shore of Lake Michigan from 1986 through 1989. U.S. Food and Drug Administration (USFDA) action levels for PCBs (2.0 ppm) and chlordane (0.3 ppm) were exceeded in 12.4 percent and 11.2 percent of these samples, respectively. Concentrations exceeding action levels were found in lake trout over 23 inches, brown trout over 22 inches, chinook salmon over 36 inches, and carp over 33 inches. PCBs ranged from 0.10 to 18.0 ppm (mean = 1.48) and chlordane ranged from 0.02 to 0.69 ppm (mean = 0.13). Table 4.13. summarizes trout, salmon and perch data for 1986 through 1989 and Tables 4.14., 4.15., 4.16., and 4.17. contain individual sample results for the same period. It should be noted that, while the Waukegan ESA certainly is a source of PCBs in fish flesh, chlordane concentrations are below detection limits throughout the ESA, including Waukegan Harbor.

Advisory information is made available to the public through news releases, pamphlets such as "Guide to Illinois Fishing Regulations" (published by the IDOC and available at the time of purchasing a license) and "Guide to Eating Illinois Sport Fish" (published by the IEPA and available upon request - IEPA, 1991b).

Participating state agencies and departments coordinate Lake Michigan advisories with other states sharing its border as required by the Toxic Substance Control Agreement signed by each of the Great Lake States Governors. Based on data from all the participating states, the Lake Michigan advisory provides uniform recommendations throughout the lake.

Table 4.13. Concentrations of Chlordane and PCBs in Trout, Salmon and Perch Fillets from the Illinois Area of Lake Michigan, 1986 to 1989.

	1986	1987	1988	1989
LAKE TROUT				
Mean Chlordane (mg/kg)	0.17	0.29	0.49 *	0.19
Mean PCBs (mg/kg)	3.81 *	2.58 *	1.76	1.79
Mean Length (inches)	23.7	22.7	24.0	22.8
BROWN TROUT				
Mean Chlordane (mg/kg)	0.05	0.12	0.25	0.12
Mean PCBs (mg/kg)	2.22 *	0.94	1.18	1.63
Mean Length (inches)	20.2	18.0	21.1	21.2
RAINBOW TROUT				
Mean Chlordane (mg/kg)	0.04	0.14	0.14	0.05
Mean PCBs (mg/kg)	0.72	0.96	0.65	0.65
Mean Length (inches)	19.6	19.4	21.0	20.0
CHINOOK SALMON				
Mean Chlordane (mg/kg)	0.22	0.17	0.20	0.09
Mean PCBs (mg/kg)	4.60 *	1.47	1.04	1.04
Mean Length (inches)	30.0	30.0	31.0	23.6
COHO SALMON				
Mean Chlordane (mg/kg)	0.03	0.06	--	0.08
Mean PCBs (mg/kg)	0.69	0.30	--	0.62
Mean Length (inches)	23.4	23.3	--	24.1
YELLOW PERCH				
Mean Chlordane (mg/kg)	--	0.02 K	0.02 K	0.02 K
Mean PCBs (mg/kg)	--	0.10 K	0.10 K	0.11 K
Mean Length (inches)	--	8.9	--	9.4

* Exceeds USFDA Action Level (0.30 mg/kg chlordane; 2.00 mg/kg PCBs)
K = Less than

Table 4.14. Concentration of Organochlorine Compounds in Lake Michigan Fish Fillet Composite Samples From the Illinois Area of Lake Michigan, 1986.

Samples	Date	No. Fish In Sample	Fish Species	Mean Weight (lbs)	Mean Length (inches)	% Fat	Chlordane (mg/kg)	DDT (mg/kg)	Dieldrin (mg/kg)	Heptachlor Epoxide (mg/kg)	PCBs (mg/kg)
1.	10/1	5	LT	4.19	23.36	11.0	0.13	0.70	0.17	0.03	2.60
2.	10/1	5	LT	8.68	28.52	20.0	0.33	3.10	0.29	<0.01	7.90
3.	10/1	3	LT	2.20	19.13	5.2	0.05	0.23	0.06	<0.01	0.93
4.	10/6	1	BT	15.42	29.40	12.0	0.12	1.30	0.19	0.03	6.10
5.	10/6	5	CHO	4.08	22.24	1.7	<0.02	0.15	0.01	<0.01	0.37
6.	10/8	3	BT	2.46	16.87	3.6	<0.02	0.16	<0.01	<0.01	0.94
7.	10/8	5	CHO	1.94	17.04	1.7	<0.02	0.04	<0.01	<0.01	0.15
8.	10/9	2	BT	5.07	22.20	5.0	0.06	0.42	0.07	<0.01	2.70
9.	10/9	5	CHO	20.35	36.61	13.0	0.48	4.70	0.33	0.04	11.00
10.	10/14	5	BT	1.45	14.00	4.5	0.02	0.21	0.03	<0.01	0.65
11.	10/14	3	RBT	1.95	17.73	6.5	<0.02	0.05	0.02	<0.01	0.24
12.	10/14	7	CHN	12.27	33.37	0.9	0.08	0.66	0.02	<0.01	1.60
13.	10/17	5	RBT	6.32	22.39	9.9	0.04	0.10	0.05	<0.01	0.45
14.	10/17	5	CHO	6.85	26.40	1.2	0.03	0.28	0.01	<0.01	0.73
15.	10/21	1	RBT	12.22	27.20	8.4	0.06	0.24	0.08	<0.01	0.76
16.	10/29	3	RBT	0.99	11.00	5.5	0.07	0.58	0.06	<0.01	2.00
17.	10/29	1	CHO	6.94	28.00	1.2	0.06	0.38	0.02	<0.01	1.50
18.	10/29	2	CHN	3.52	20.20	1.3	0.10	0.50	0.03	<0.01	1.20
19.	10/6	3	BT	5.27	22.00	3.6	0.05	0.39	0.06	<0.01	1.30
20.	10/6	2	BT	2.04	16.40	4.3	0.02	0.27	0.03	<0.01	1.60
21.	11/24	1	RBT	3.85	19.80	4.9	<0.02	0.04	0.02	<0.01	0.14
		USFDA action level					0.30	5.00	0.30	0.30	2.00

LI - Lake Trout
BI - Brown Trout
CHO - Coho Salmon
CHN - Chinook Salmon
RBT - Rainbow Trout

Table 4.15. Concentrations of Chlordane and Polychlorinated Biphenyls (PCBs) in Fish Fillet Composite Samples from the Illinois Area of Lake Michigan, 1987.

Date Collected	Fish Species	No. Fish in Sample	Mean Length (inches)	Mean Weight (pounds)	Percent Fat	Total Chlordane (mg/kg)	Total PCBs (mg/kg)
4/87	Alewife	25	6.9	0.1	4.9	0.05	0.46
10/87	Brown Trout	3	12.1	0.6	3.0	0.07	0.65
9/87	Brown Trout	5	18.9	3.3	7.2	0.14	1.20
9/87	Brown Trout	5	23.0	6.7	6.3	0.14	0.96
9/87	Carp	1	33.8	32.6	28.0	0.58	18.00
9/87	Chinook Salmon	6	22.5	4.7	2.5	0.14	0.88
9/87	Chinook Salmon	5	28.6	9.1	1.4	0.13	0.69
9/87	Chinook Salmon	5	32.8	12.0	1.2	0.17	1.70
9/87	Chinook Salmon	6	36.3	16.4	1.9	0.23	2.60
9/87	Coho Salmon	5	16.3	2.1	1.5	0.06	0.35
9/87	Coho Salmon	5	23.3	4.4	3.7	0.04	0.21
9/87	Coho Salmon	5	25.6	5.6	1.7	0.08	0.25
10/87	Coho Salmon	3	28.0	6.8	1.1	0.07	0.38
8/87	Lake Trout	5	15.8	1.5	5.0	0.09	0.55
8/87	Lake Trout	5	23.7	4.6	12.0	0.19	1.60
8/87	Lake Trout	5	28.7	9.7	19.0	0.58	5.60
10/87	Rainbow Trout	3	11.9	0.8	5.1	0.15	1.00
10/87	Rainbow Trout	7	17.8	2.6	7.9	0.13	1.10
9/87	Rainbow Trout	5	21.8	5.3	7.3	0.14	1.10
10/87	Rainbow Trout	5	26.0	7.6	6.0	0.13	0.64
6/87	Yellow Perch	10	8.9	0.3	0.4	<0.02	<0.10
			USFDA Action level			0.30	2.00
			Number above action level			2	3
			Percent above action level			9.5	14.3

Table 4.16. Concentrations of Organochlorine Compounds in Fish Composite Samples from the Illinois Area of Lake Michigan, 1988.

Date Collected	Location	Species	No. Fish in Sample	Mean Length (inch)	Mean Weight (LBS)	Percent Lipid	Total Chlordane (mg/kg)	Dieldrin (mg/kg)	Heptachlor Epoxide (mg/kg)	Total DDT (mg/kg)	Total PCBs (mg/kg)
4/19/88	Waukegan Harbor	Alewife (w)	25	--	0.1	5.4	0.05	0.06	0.01 U	0.19	0.46
9/22/88	Multiple	Brown Trout (f)	5	14.1	1.2	5.7	0.13	0.02	0.01 U	0.30	0.80
10/12/88	Multiple	Brown Trout (f)	5	19.3	3.7	8.5	0.25	0.05	0.01 U	0.52	1.30
9/20/88	GLNTC Harbor	Brown Trout (f)	5	24.0	7.2	6.6	0.31 *	0.05	0.01 K	0.50	1.20
9/22/88	Multiple	Brown Trout (f)	5	27.1	9.2	6.9	0.32 *	0.05	0.01 K	0.71	1.40
9/22/88	Multiple	Chinook Salmon (f)	5	23.2	4.5	2.1	0.10	0.02	0.01 U	0.22	0.65
9/20/88	Multiple	Chinook Salmon (f)	5	30.0	8.4	1.0	0.18	0.01 K	0.01 U	0.50	1.00
9/20/88	Multiple	Chinook Salmon (f)	5	34.0	12.0	1.8	0.18	0.02	0.01 U	0.44	0.83
9/27/88	Multiple	Chinook Salmon (f)	5	36.9	16.5	1.7	0.32 *	0.02	0.01 U	0.71	1.70
8/10/88	Waukegan Harbor	Lake Trout (f)	5	18.7	2.1	6.1	0.17	0.05	0.01 U	0.20	0.59
9/17/88	Waukegan Harbor	Lake Trout (f)	5	24.6	5.4	11.8	0.62 *	0.14	0.04	0.71	1.50
8/12/88	Waukegan Harbor	Lake Trout (f)	5	28.7	8.2	15.7	0.69 *	0.14	0.03	1.10	3.20 *
11/16/88	Diversey Harbor	Rainbow Trout (f)	1	12.2	0.8	4.6	0.10	0.02	0.01 K	0.18	0.40
12/06/88	Diversey Harbor	Rainbow Trout (f)	1	21.0	3.9	6.3	0.18	0.04	0.01 K	0.35	0.81
9/22/88	Multiple	Rainbow Trout (f)	5	23.6	6.7	8.5	0.13	0.05	0.01 K	0.28	0.62
9/22/88	Multiple	Rainbow Trout (f)	5	27.0	8.7	8.3	0.14	0.06	0.01 K	0.29	0.76
6/07/88	Foster Ave.	Yellow Perch (f)	10	--	0.3	0.6	0.02 K	0.01 K	0.01 K	0.02	0.10 K
6/10/88	Lake Bluff	Yellow Perch (f)	10	--	0.4	0.5	0.02 K	0.01 K	0.01 U	0.02	0.10 K
USFDA Action Level (mg/kg)							0.30	0.30	0.30	5.00	2.00
Number above action level							5	0	0	0	1
Percent above action level							27.8	0.0	0.0	0.0	5.6
Mean Concentration (mg/kg)							0.22	0.05	0.01	0.40	0.97
Standard Deviation							0.18	0.04	0.01	0.28	0.72

(f) = Fillets
(w) = Whole
U = Not detected
K = Actual value known to be less than value reported.
* = Value exceeds USFDA Action Level.

Table 4.17. Concentrations of Organochlorine Compounds in Fish Composite Samples from the Illinois Area of Lake Michigan, 1989.

Date Collected	Location	Species	No. Fish in Sample	Mean Length (inch)	Mean Weight (LBS)	Percent Lipid	Total Chlordane (mg/kg)	Dieldrin (mg/kg)	Heptachlor Epoxide (mg/kg)	Total DDT (mg/kg)	Total PCBs (mg/kg)
4/19/89	North Ave, Chicago	Alewife (w)	25	6.8	0.1	10.1	0.05	0.06	0.01K	0.14	0.52
9/01/89	Multiple Sites	Brown Trout (f)	5	14.5	1.2	3.7	0.06	0.01	0.01K	0.15	0.92
9/01/89	Multiple Sites	Brown Trout (f)	4	19.3	5.3	6.7	0.14	0.05	0.01K	0.30	1.40
9/01/89	Multiple Sites	Brown Trout (f)	5	22.8	5.4	9.3	0.16	0.06	0.01K	0.39	1.70
9/01/89	Multiple Sites	Brown Trout (f)	5	28.0	10.1	7.8	0.14	0.06	0.01K	0.41	2.50*
4/01/89	Multiple Sites	Chinook Salmon (f)	1		3.0	5.8	0.09	0.05	0.01K	0.32	0.87
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	20.7	3.1	4.1	0.03	0.02	0.01K	0.17	0.57
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	21.4	3.4	7.6	0.08	0.05	0.01	0.35	1.30
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	21.8	3.4	7.1	0.06	0.04	0.01K	0.25	0.92
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	23.3	5.0	17.7	0.10	0.04	0.01K	0.25	1.10
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	23.8	4.6	9.0	0.18	0.06	0.02	0.70	1.80
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	24.7	4.6	2.8	0.08	0.03	0.01K	0.25	0.74
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	25.1	5.1	4.7	0.04	0.03	0.01K	0.12	0.33
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	25.1	5.0	6.2	0.10	0.05	0.01	0.28	1.10
4/05/89	Michigan City, Ind.	Chinook Salmon (f)	1	26.3	4.8	7.0	0.12	0.03	0.01K	0.33	1.50
4/06/89	Michigan City, Ind.	Chinook Salmon (f)	1		6.8	13.2	0.13	0.08	0.02	0.48	1.60
9/01/89	Multiple Sites	Coho Salmon (f)	5	18.6	2.9	4.1	0.05	0.01	0.01K	0.13	0.39
9/01/89	Multiple Sites	Coho Salmon (f)	5	23.6	4.9	2.8	0.07	0.01	0.01K	0.19	0.66
9/01/89	Multiple Sites	Coho Salmon (f)	5	26.4	6.8	3.4	0.09	0.02	0.01K	0.21	0.66
9/01/89	Multiple Sites	Coho Salmon (f)	5	27.8	6.5	2.7	0.11	0.02	0.01K	0.24	0.78
8/15/89	Waukegan Harbor	Lake Trout (f)	5	19.0	2.3	8.5	0.08	0.04	0.01	0.20	1.30
8/15/89	Waukegan Harbor	Lake Trout (f)	5	21.7	3.2	4.2	0.07	0.02	0.01K	0.18	0.66
8/15/89	Waukegan Harbor	Lake Trout (f)	5	27.7	7.2	14.4	0.43*	0.18	0.02	0.89	3.40*
9/01/89	Multiple Sites	Rainbow Trout (f)	5	12.8	1.0	5.0	0.04	0.01K	0.01K	0.17	0.44
9/19/89	Multiple Sites	Rainbow Trout (f)	1	17.4	2.1	3.7	0.02K	0.01K	0.01K	0.04	0.13
10/02/89	Multiple Sites	Rainbow Trout (f)	5	23.3	5.8	6.9	0.04	0.02	0.01K	0.20	0.44
9/01/89	Multiple Sites	Rainbow Trout (f)	4	26.4	8.0	6.5	0.11	0.03	0.01K	0.49	1.60
6/07/89	Foster Ave.	Yellow Perch (f)	10	9.4	0.3	0.4	0.02K	0.01K	0.01K	0.01K	0.10K
6/08/89	Lake Bluff	Yellow Perch (f)	10	9.5	0.3	0.5	0.02K	0.01K	0.01K	0.02	0.11

	Total Chlordane	Dieldrin	Heptachlor Epoxide	Total DDT	Total PCBs
USFDA Action Level (mg/kg)	0.30	0.30	0.30	5.00	2.00
Number above action level	1	0	0	0	2
Percent above action level	3.4	0.0	0.0	0.0	6.9
Mean Concentration (mg/kg)	0.09	0.04	0.01	0.27	1.02
Standard Deviation	0.08	0.03	0.00	0.19	0.74

(f) = Fillets
(w) = Whole
K = Actual value known to be less than value reported.
* = Value exceeds USFDA Action Level.

By mid-1980, USEPA had completed two types of studies to determine the extent of PCB contamination of fish in Waukegan Harbor. In the first, 16 random samples of fish collected from the harbor averaged 18 ppm PCBs. All but three of these samples exceeded the old 5 ppm USFDA guideline and all but one exceeded 2 ppm, the present guideline. Harbor levels are higher than those found in the lake for the same species.

In a second study, uncontaminated fish were exposed for 30 days to water from slip 3 in the harbor, and then placed in open lake water for an additional 84 days. The 30-day exposure to the harbor water resulted in 20 ppm PCB levels in bluegills and 12 ppm levels in yellow perch. Even after the 84-day exposure to cleaner open lake water, these levels did not drop below 8 ppm (USEPA, 1981).

Although the determination of these concentrations was based upon analysis of the whole fish, and the USFDA guidelines refer only to the edible portions of the fish, the tests strongly indicate that fish caught in Waukegan Harbor should never be eaten, and that fish spending even short periods of time in the harbor should not be eaten except on an infrequent basis (USEPA, 1981).

As a result of these studies the Lake County Health Department has posted signs in the harbor which read "Eating fish caught in the North of Waukegan harbor may be dangerous to your health". The posting continues as of the date of this report (Figure 4.4.).

4.5. THREATENED AND ENDANGERED BIOTA

A total of sixteen plant and animal species are presently on the state endangered or threatened species list in the Waukegan ESA (Table 4.18.). The list includes six bird and nine plant species. All but the Common Tern are found within Illinois Beach State Park, south of the Dead River. Common Terns nest at the Commonwealth Edison Waukegan Plant. This is the only Common Tern nesting colony in Illinois.

Figure 4.4. Posted Fish Consumption Advisory at Waukegan Harbor.

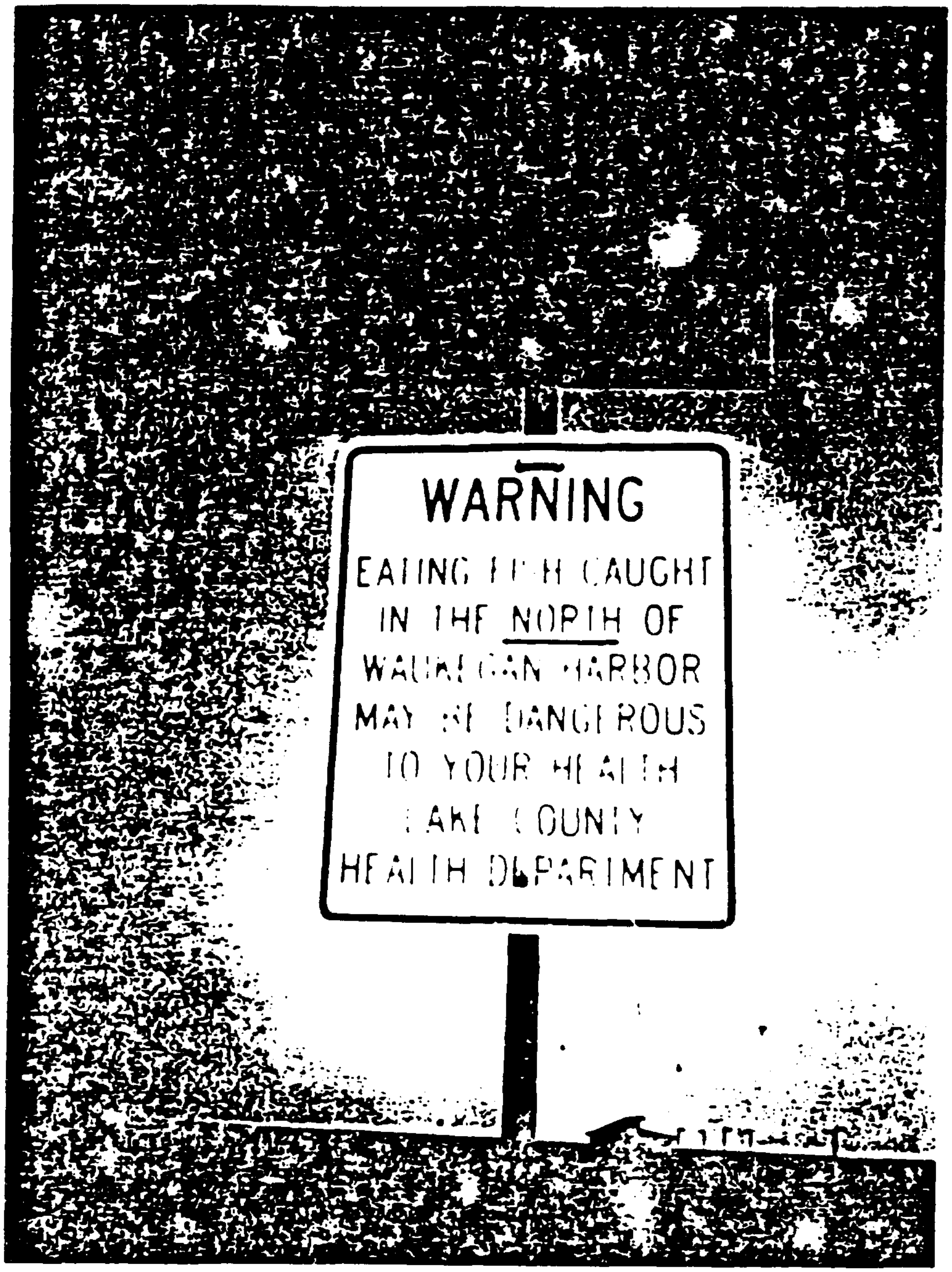

Table 4.18. Listed Species Within the Waukegan ESA.

Scientific Name	Common Name	Last Observed	Status[1]
Euphagus cyanodephalus	Brewer's blackbird	1987	T
Bartramia longicauda	Upland sandpiper	1987	E
Ammodramus henslowii	Henslow's sparrow	1982	T
Podilymbus podiceps	Pied-billed grebe	1982	E
Nycticorax nycticorax	Black-crowned night heron	1983	E
Calopogon tuberosous	Tuberous grass pink	1990	T
Carex garberi	Sedge	1987	E
Carex crawei	Crawe's sedge	1988	T
Eleocharis olivacea	Spikerush	1988	E
Platanthera clavellata	Wood orchid	1977	E
Utricularia cornuta	Horned bladderwort	1990	E
Utricularia minor	Small bladderwort	1970	E
Salix syrticola	Dune willow	1988	E
Ammophila breviligulata	Marram grass	1977	E
Populus balsamifera	Balsam poplar	1990	E
Chamaesyce polygonifolia	Seaside spurge	1977	E
Juncus alpinus	Richardson's rush	1975	E
Carex viridula	Little green sedge	1977	E
Orobanche fasciculata	Clustered broomrape	1988	E
Sterna hirundo	Common tern	1991	E

T = Threatened
E = Endangered

There is no indication that contamination of Waukegan Harbor by PCBs or other chemicals has had an effect on these State-listed species, although no specific studies addressing such effects have been done. Within the Waukegan ESA it is likely that industrial and commercial development of the Lake Michigan shore has reduced the abundance of some of these endangered and threatened species by eliminating suitable habitats. Short of removing such developments from the area, it is unlikely that restoration of those habitats to any significant extent is possible.

Two state threatened fish, the longnose sucker and the lake whitefish, have been found near the Waukegan ESA between Waukegan and Zion (CEC, 1972; CEC, 1973; CEC; 1974). Longnose sucker was collected in 1972 and 1974, and lake whitefish was collected during each of the three years.

4.6. MAJOR POLLUTANTS OF CONCERN (CAUSING THE IMPAIRED USES)

The USEPA recommends that the following yardsticks be used to designate Critical Pollutants for Lake Michigan as additional information becomes available :

1. a pollutant bioaccumulates in fish or wildlife tissue, resulting in a lakewide fish or wildlife health advisory;

2. a pollutant exceeds an enforceable water or sediment quality standard;

3. the trend in a pollutant concentration in fish tissue, sediments, or ambient water suggests that safe concentrations, as established by State or Federal water or sediment quality standards, by the Parties as Specific Objectives under the Great Lakes Water Quality Agreement (GLWQA), or by using accepted risk assessment procedures, will be exceeded; and/or

4. a pollutant is present at sufficient locations and at fish tissue, sediment, or water concentrations capable of violating State narrative quality standards prohibiting the presence of substance in toxic amounts.

Pollutants of concern (Table 4.19.) in Waukegan Harbor include parameters which exceed Illinois water quality standards, are classified as heavily polluted according to USEPA sediment criteria (USEPA, 1977), and exceed USFDA action levels in fish. Those pollutants which have not been directly linked to impaired uses associated with the Waukegan ESA are considered possible potential causes, pending further investigation. For specific information on water, sediment and fish contamination see Sections 4.2., 4.3., and 4.4., respectively. Potential chronic health effects of selected pollutants of concern are presented in Table 4.20.

Table 4.19. Pollutants of Concern in the Waukegan Expanded Study Area.

Water	Sediment	Fish
Total Phosphorus	PCBs[1]	PCBs[1]
Total Ammonia	Arsenic	
Chloride	Barium	
Sulfate	Cadmium	
Total Dissolved Solids	Chromium	
Cyanide	Copper	
Phenols	Iron	
Dissolved Oxygen	Lead	
pH	Manganese	
Fecal Coliform	Nickel	
	Phosphorus	
	Kjeldahl Nitrogen	
	Chemical Oxygen Demand	
	Volatile Solids	
	Cyanide	

[1] Targeted as a lakewide pollutant of concern in the Lake Michigan Lakewide Management Plan, Stage 1 (USEPA, 1991).

Table 4.20. Potential Chronic Health Effects of Selected Pollutants of Concern (Stewart et al., 1988).

Contaminant	Possible Chronic Health Effect
Arsenic	skin and lung cancer; liver and kidney damage
Asbestos	lung cancer; gastrointestinal cancer when swallowed fibers exceed 10 μm
Barium	hypertension and heart damage
Cadmium	kidney damage
Chromium	liver, kidney, and lung damage
Copper	anemia; digestive disturbances; liver and kidney damage
Lead	brain and nerve damage, especially in children; kidney damage; digestive disturbances; blood disorders; hypertension
Nitrogen	methemoglobinemia in infants
PCBs	cancer; liver damage

4.7. REFERENCES

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APPENDICES

APPENDIX A

Raw and Finished Drinking Water Quality

APR 30

Illinois Environmental Protection Agency • P.O. Box 19276, Springfield, IL 62794-9276

VI N OF PUBLIC WATER SUPPLIES

SAMPLING PROGRAM:
COMPLETE CHEMICAL ANALYSIS

Jun 26 '91
I.E.P.A.
DIV. OF
PUBLIC WATER SUPPLIES

CILITY: 0971900 Waukegan

MPLES SCHEDULED DURING APRIL 1991

MPLE LOCATION: COLLECT FROM RAW SURFACE LAKE MICHIGAN INTAKE

IL REPORT TO:

ME: Frank Chess, Supt
DR: 106 N. Utica St
TY: Waukegan STATE: Ill ZIP: 60085

DATE COLLECTED: May 14, 1991
TIME COLLECTED: 3:05P
SAMPLE COLLECTOR: Ken Sheets
PHONE NUMBER: 360-9000, xt 451

FUNDING CODE: PW30
ENCY ROUTING:
SAMPLE TYPE: RPWS
PURPOSE: 3-REPLACEMENT
PT DICATOR: B
SUBMIT SRCE: 0971900
SMPL PROGRAM: CH - CHEMICAL
PARM GROUP: 21001

SAMPLE TYPE: RAW
FACILITY: Waukegan 0971900
SAMPLE LOCATION:
99901-00

RECEIVED
REGION 2
AUG 2 1991
Div. Public Water Supplies
State of Illinois
Environmental Protection Agency

---LAB USE ONLY---

SAMPLE NUMBER P106755
DATE RECEIVED MAY 16 1991
TIME RECEIVED 11A
RECEIVED BY pd
DATE FORWARDED JUL 11 1991 SPVSR

RECEIVED
JUL 1 2 1991
Environmental Protection Agency
State of Illinois

532-0761 P[illegible] 7-87)-capchem

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

PLE NUMBER : B106755
PLING POINT DESC. : WAUKEGAN 99901-00

MI ING SOURCE # : 0971900 SITE # :
E COLLECTED : 910514 TIME COLLECTED : 1505 SAMPLING PROGRAM : CH

LECTED BY : K SHEETS DELIVERED BY : UPS
MENTS :
ING CODE : PW30 AGENCY ROUTING : 00 UNIT CODE :
TYPE CODE : RPWS SAMPLE PURPOSE CODE : 3 REPORTING INDICATOR : B

E RECEIVED : 910516 TIME RECEIVED : 1100 RECEIVED BY : PMD
OBSERVATIONS : TRIP BL SAM# :
ERVISORS INITIALS : RPF NOTE : K = LESS THAN VALUE 7-31-91

403	PH-LABORATORY	UNITS	8.0	P00095	CONDUCTIVITY	UM/CM	307
300	(ROE) TDS @ 180C	MG/L	181	P00410	ALKALINITY,TOTAL	MG/L	107
900	HARDNESS,EDTATOTAL	MG/L	130	P00951	FLUORIDE,TOTAL	MG/L	0.10
940	CHLORIDE,TOTAL	MG/L	12	P00945	SULFATE,TOTAL	MG/L	15
630	NITRATE&NO2-NTOTAL	MG/L	0.28	P00610	AMMONIA-N,TOTAL	MG/L	0.05
956	SILICA,TOTAL	MG/L	1.0K	P00720	CYANIDE,TOTAL	MG/L	0.005K
002	ARSENIC,TOTAL	UG/L	1	P01051	LEAD,TOT.FURNACE	UG/L	5K
900	MERCURY,TOTAL	UG/L	0.05K	P01147	SELENIUM,TOTAL	UG/L	1K
916	CALCIUM,TOTAL	MG/L	37	P00927	MAGNESIUM,TOTAL	MG/L	12
929	SODIUM,TOTAL	MG/L	6	P00937	POTASSIUM,TOTAL	MG/L	1.4
10	ALUMINUM,TOTAL	UG/L	50K	P01007	BARIUM,TOTAL	UG/L	17
02	BORON,TOTAL	UG/L	50K	P01012	BERYLLIUM,TOTAL	UG/L	0.5K
027	CADMIUM,TOTAL	UG/L	5K	P01034	CHROMIUM,TOTAL	UG/L	5K
042	COPPER,TOTAL	UG/L	5K	P01037	COBALT,TOTAL	UG/L	5K
045	IRON,TOTAL	UG/L	50K	P01055	MANGANESE,TOTAL	UG/L	5K
067	NICKEL,TOTAL	UG/L	7	P01077	SILVER,TOTAL	UG/L	5K
082	STRONTIUM,TOTAL	UG/L	125	P01087	VANADIUM,TOTAL	UG/L	5K
092	ZINC,TOTAL	UG/L	50K	P82394	HARDNESS CALC.	MG/L	141C
700	ANION/CATION BAL	Y/N	Y				

C176121   C176121

Illinois Environmental Protection Agency • 2200 Churchill Road, Springfield, IL 62706

(S) OF PUBLIC WATER SUPPLIES

TRIHALOMETHANE ANALYSIS

RECEIVED
REGION 2
SEP 11 1991
Div. Public Water Supplies
State of Illinois
Environmental Protection Agency

LITY: 0971900 WAUKEGAN

LES SCHEDULED DURING: AUGUST, 1991

REPORT TO:

.: Frank Chess Jr., Supt

: 106 N. Utica St

: Waukegan STATE IL ZIP 60085

DATE COLLECTED Aug 20 1991

SMPL COLLECTOR Ken [illegible]

PHONE NUMBER 708-360-9000 xt 45

ING CODE: [illegible]
ROUTING:
MPLE TYPE: DPWS - DISTRIBUTION
PURPOSE: 1 - ROUTINE
NOTICATION: 3
MIT SRCE: 0971900001
PROGRAM: TH - TRIHALOMETHANE
LAB GROUP:

BLANK SAMPLE USE PURPOSE: B)

COLLECT SAMPLE FROM THE
DISTRIBUTION SYSTEM SERVED BY
WTP E OF SHERIDAN N OF MADISON

WAUKEGAN

BOTTLE 1 1 1A

LOCATION 926 Poplar St

TIME COLLECTED 3:50P PH 7.60

CL RESIDUE .95 TEMP 34 °C

I.E.P.A.
DIV. OF
PUBLIC WATER SUPPLIE
SEP 3 '9

--- LAB USE ONLY ---

SAMPLE NUMBER C176121

DATE RECEIVED AUG 21 1991

TIME RECEIVED 10:30am

RECEIVED BY ZH

```
                   ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

E NUMBER : D196121
ING POINT DESC. : WAUKEGAN/926 POPLAR ST

TT  G SOURCE # : 0971900C01                    SITE # :
COLLECTED : 910820       TIME COLLECTED : 1550    SAMPLING PROGRAM : TH

CTED BY : KEN SHEETS                 DELIVERED BY : UPS
NTS : THMS
NG CODE : PW30          AGENCY ROUTING : --      UNIT CODE :
YPE CODE : DPWS      SAMPLE PURPOSE CODE : 1  REPORTING INDICATOR : B

RECEIVED : 910821       TIME RECEIVED : 1030     RECEIVED BY : L M
BSERVATIONS : 2 THM                        TRIP BL SAM# : D196122
VISORS INITIALS : JTH                        NOTE : K = LESS THAN VALUE


6 CHLOROFORM                           UG/L : 12
1 DICHLOROBROMOMETHANE                 UG/L : 7
5 CHLORODIBROMOMETHANE                 UG/L : 3
4 BROMOFORM                            UG/L : 1.0K
3 METHYLENE CHLORIDE                   UG/L : 1.0K

1 1,1-DICHLOROETHYLENE                 UG/L : 1.0K
6 1,1-DICHLOROETHANE                   UG/L : 1.0K
6 TRANS-1,2-DICHLOROETHYLENE           UG/L : 1.0K
1 1,2-DICHLOROETHANE                   UG/L : 1.0K

6 1,1,1-TRICHLOROETHANE                UG/L : 1.0K
2   RBON TETRACHLORIDE                 UG/L : 1.0K
0 TRICHLOROETHYLENE                    UG/L : 1.0K
5 TETRACHLOROETHYLENE                  UG/L : 1.0K

1 CHLOROBENZENE                        UG/L : 1.0K
6 DICHLOROBENZENE(TOTAL)               UG/L : 1.0K
3 CIS-1,2-DICHLOROETHYLENE             UG/L : 1.0K
```

```
                    ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

PLE NUMBER : D196122
PLING POINT DESC. : BLANK W/96121 WAUKEGAN

MI..ING SOURCE # : 097190C01                        SITE # :
E COLLECTED : 910820     TIME COLLECTED : 1550    SAMPLING PROGRAM : TH

LECTED BY : KEN SHEETS                 DELIVERED BY : UPS
MENTS : THMS
DING CODE : PW30          AGENCY ROUTING : --       UNIT CODE :
 TYPE CODE : DPWS       SAMPLE PURPOSE CODE : 8  REPORTING INDICATOR : B

E RECEIVED : 910821       TIME RECEIVED : 1030     RECEIVED BY : L M
 OBSERVATIONS : 2 BLANKS                   TRIP BL SAM# :
ERVISCRS INITIALS : JTM                     NOTE : K = LESS THAN VALUE


106 CHLOROFORM                              UG/L : 1.0K
101 DICHLOROBROMOMETHANE                    UG/L : 1.0K
105 CHLORODIBROMOMETHANE                    UG/L : 1.0K
104 BROMOFORM                               UG/L : 1.0K
423 METHYLENE CHLORIDE                      UG/L : 1.0K

.501 1,1-DICHLOROETHYLENE                   UG/L : 1.0K
.496 1,1-DICHLOROETHANE                     UG/L : 1.0K
.546 TRANS-1,2-DICHLOROETHYLENE             UG/L : 1.0K
.531 1,2-DICHLOROETHANE                     UG/L : 1.0K

.506 1,1,1-TRICHLOROETHANE                  UG/L : 1.0K
:10  CARBON TETRACHLORIDE                   UG/L : 1.0K
'180 TRICHLOROETHYLENE                      UG/L : 1.0K
.475 TETRACHLOROETHYLENE                    UG/L : 1.0K

.301 CHLOROBENZENE                          UG/L : 1.0K
.716 DICHLOROBENZENE(TOTAL)                 UG/L : 1.0K
 93 CIS-1,2-DICHLOROETHYLENE                UG/L : 1.0K
```

D194543

Illinois Environmental Protection Agency • 2200 Churchill Road, Springfield, IL 62706

.S. ; OF PUBLIC WATER SUPPLIES PESTICIDE ANALYS

.LITY: 0971900 WAUKEGAN

PLES SCHEDULED DURING: JUNE, 1991 Rcvd bottles 7-3-91

. REPORT TO:

:: Frank Chess Jr. Supt DATE COLLECTED July 11, 1991

:: 106 N. Utica St TIME COLLECTED 8:35A

·: Waukegan STATE IL ZIP 60085 SMPL COLLECTOR Ken Sheets

PHONE NUMBER 708-360-9000 x 5

ING CODE: 2030
ROUTING:
PLE TYPE: DPWS - DISTRIBUTION
PURPOSE: 1 - ROUTINE
NDICATOR: B
MIT SRCE: 0971900
PROGRAM: PH - PESTICIDE
.R/ ROUP:

SAMPLE TYPE: DISTRIBUTION

WAUKEGAN

SAMPLE LOCATION: Victory Hospital

RECEIVED
REGION 2
SEP 20 1991
Div. Public Water Supplies
State of Illinois
Environmental Protection Agency

I.E.P.A.
DIV. OF
PUBLIC WATER SUPPLIES
SEP 17 '91

--- LAB USE ONLY ---

SAMPLE NUMBER D194543

DATE RECEIVED JUL 12 1991

TIME RECEIVED 11:00 AM EPA

RECEIVED BY FT.

```
                  ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

LE NUMBER : D194543
LING POINT DESC. : WAUKEGAN/VICTORY HOSPITAL

IT  NG SOURCE # : 0971900                          SITE # :
 COLLECTED : 910711   -  TIME COLLECTED : 0835    SAMPLING PROGRAM : PH

ECTED BY : KEN SHEETS                    DELIVERED BY : EPA
ENTS : PESTICIDE ANALYSIS
ING CODE : PW30        AGENCY ROUTING : --      UNIT CODE :
TYPE CODE : DPWS     SAMPLE PURPOSE CODE : 1  REPORTING INDICATOR : 8

 RECEIVED : 910712       TIME RECEIVED : 1100     RECEIVED BY : F T
OBSERVATIONS : 2 QTS WATER                  TRIP BL SAM# :
RVISORS INITIALS : JTH                        NOTE : K = LESS THAN VALUE

40 GAMMA-BHC (LINDANE)                      UG/L : .01K
10 HEPTACHLOR                               UG/L : .01K
30 ALDRIN                                   UG/L : .01K
20 HEPTACHLOR EPOXIDE                       UG/L : .01K
50 TOTAL CHLORDANE                          UG/L : .01K

80 DIELDRIN                                 UG/L : .01K
90 ENDRIN                                   UG/L : .01K
80 METHOXYCHLOR                             UG/L : .05K
27 O,P'-DDE                                 UG/L : .01K

20  ,P'-DDE                                 UG/L : .01K
15  ,P'-DDD                                 UG/L : .01K
10 P,P'-DDD                                 UG/L : .01K
05 O,P'-DDT                                 UG/L : .01K

00 P,P'-DDT                                 UG/L : .01K
00 TOXAPHENE                                UG/L : 1.0K
 0 2,4-D                                    UG/L : 0.1K
60 SILVEX                                   UG/L : .05K
```

9-18-71

D194530

Illinois Environmental Protection Agency · P.O. Box 19276, Springfield, IL 62794-9276

DIVISION OF PUBLIC WATER SUPPLIES

SAMPLING PROGRAM:
PESTICIDE ANALYSIS

FACILITY: 0971900 Waukegan

Rcvd bottles 7-3-91

SAMPLES SCHEDULED DURING JUNE 1991

MAIL REPORT TO:
NAME: Frank Chess, Jr. Supt
ADDR: 106 N. Utica St
CITY: Waukegan **STATE:** IL **ZIP:** 60045

DATE COLLECTED: July 11, 1991
TIME COLLECTED: 905A
SAMPLE COLLECTOR: Ken Sheets
PHONE NUMBER: 708-360-9000, xt 4

FUNDING CODE: PW30
AGENCY ROUTING:
SAMPLE TYPE: DPWS
PURPOSE: 1-ROUTINE
RPT INDICATOR: B
SUBMIT SRCE: 0971900
SMPL PROGRAM: PH - PESTICIDE
PARM GROUP:

SAMPLE TYPE: DPWS
FACILITY: Waukegan
SAMPLE LOCATION: Raw water

RECEIVED
REGION 2
SEP 20 1991
Div. Public Water Supplies
State of Illinois
Environmental Protection Agency

I.E.P.A.
DIV. OF
PUBLIC WATER SUPPLIES
SEP 17 '91

---LAB USE ONLY---

SAMPLE NUMBER D194530
DATE RECEIVED JUL 12 1991
TIME RECEIVED 9:40Am
RECEIVED BY

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

```
LE NUMBER : D194530
LING POINT DESC. : WAUKEGAN/RAW WATER

I..ING SOURCE # : 0971900                    SITE # :
 COLLECTED : 910711     TIME COLLECTED : 0905    SAMPLING PROGRAM : PM

.ECTED BY : KEN SHEETS                  DELIVERED BY : UPS
IENTS : PESTICIDE ANALYSIS
IING CODE : PW30          AGENCY ROUTING : --       UNIT CODE :
 TYPE CODE : DPWS       SAMPLE PURPOSE CODE : 1  REPORTING INDICATOR : 8

 RECEIVED : 910712        TIME RECEIVED : 0940      RECEIVED BY : F T
 OBSERVATIONS : 2 QTS WATER                 TRIP BL SAM# :
RVISORS INITIALS : JTM                        NOTE : K = LESS THAN VALUE


340 GAMMA-BHC (LINDANE)                    UG/L : .01K
10 HEPTACHLOR                              UG/L : .01K
330 ALDRIN                                 UG/L : .01K
20 HEPTACHLOR EPOXIDE                      UG/L : .01K
50 TOTAL CHLORDANE                         UG/L : .01K

80 DIELDRIN                                UG/L : .01K
90 ENDRIN                                  UG/L : .01K
80 METHOXYCHLOR                            UG/L : .05K
327 O,P'-DDE                               UG/L : .01K

320 P,P'-DDE                               UG/L : .01K
315 O,P'-DDD                               UG/L : .01K
10 P,P'-DDD                                UG/L : .01K
05 O,P'-DDT                                UG/L : .01K

00 P,P'-DDT                                UG/L : .01K
0 TOXAPHENE                                UG/L : 1.0K
30 2,4-D                                   UG/L : 0.1K
60 SILVEX                                  UG/L : .05K

TRAZINE .15 UG/L.
```

9-17-91

D196138 D196138

Illinois Environmental Protection Agency • 2200 Churchill Road, Springfield, IL 62706

IS? 'I OF PUBLIC WATER SUPPLIES VOLATILE ORGANIC CHEMICALS

ILITY: 0971900 WAUKEGAN

'LE AND DEMAND SCHEDULE: AUG 1, 1991 - AUG 31, 1991

.: REPORT TO:

:: Frank Chess Jr., Supt DATE COLLECTED Aug 20, 1991
:: 106 N Utica St SMPL. COLLECTOR Ken Sheets
': Waukegan STATE IL ZIP 60085 PHONE NUMBER 708-360-9000 xt

ING CODE: PW32
IPLE TYPE: FPWS - FINISHED
PURPOSE: 1 - ROUTINE
IMIT SRCE: 097190001
: PROGRAM: VO - VOC
'REQUENCY: QUARTERLY

IL/ SAMPLE USE PURPOSE: 8)

COLLECT WATER FROM THE FINISHED WATER/ENTRY POINT INTO THE DISTRIBUTION SYSTEM SERVED BY 01 WTP E OF SHERIDAN N OF MADISON

BOTTLES: 1 + 1 A
LOCATION: Lab tap
TIME COLLECTED: 3:20P

RECEIVED
REGION 2
SEP ?? 1991
Div. Public Water Supplies
State of Illinois
Environmental Protection Agency

--- LAB USE ONLY ---
SAMPLE NUMBER D196138
DATE RECEIVED AUG 21 1991
TIME RECEIVED 10:30 am
RECEIVED BY
9-3-91

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

MP' - NUMBER : 0196138
MP. NG POINT DESC. : WAUKEGAN/LAB TAP

BMITTING SOURCE # : 097190C01 SITE # :
TE COLLECTED : 910820 TIME COLLECTED : 1520 SAMPLING PROGRAM : VO

LLECTED BY : KEN SHEETS DELIVERED BY : UPS
MMENTS : VOCS
NDING CODE : PW32 AGENCY ROUTING : -- UNIT CODE :
M TYPE CODE : FPWS SAMPLE PURPOSE CODE : 1 REPORTING INDICATOR : B

ATE RECEIVED : 910821 TIME RECEIVED : 1030 RECEIVED BY : L M
AB OBSERVATIONS : 2 VOC TRIP BL SAM# : 0196139
UPERVISORS INITIALS : JTH NOTE : K = LESS THAN VALUE

9-19-91
MB

: .
: .
: .
: .
: TRIHALOMETHANES .

'32106 CHLOROFORM UG/L : 13
'32101 BROMODICHLOROMETHANE UG/L : 6.9
'32105 CHLORODIBROMOMETHANE UG/L : 2.4
P3[illegible]04 BROMOFORM UG/L : 0.5K

: .
: .
: .
: REGULATED VOLATILE ORGANIC COMPOUNDS

P34506 1,1,1-TRICHLOROETHANE UG/L : 0.5K
P34511 1,1,2-TRICHLOROETHANE UG/L : 0.5K
P34501 1,1-DICHLOROETHYLENE UG/L : 0.5K
P34551 1,2,4-TRICHLOROBENZENE UG/L : 0.5K

P34536 1,2-DICHLOROBENZENE UG/L : 0.5K
P32103 1,2-DICHLOROETHANE UG/L : 0.5K
P34541 1,2-DICHLOROPROPANE UG/L : 0.5K
P34571 1,4-DICHLOROBENZENE UG/L : 0.5K

P34030 BENZENE UG/L : 0.5K
P32102 CARBON TETRACHLORIDE UG/L : 0.5K
P34301 CHLOROBENZENE UG/L : 0.5K
P77093 CIS-1,2-DICHLOROETHYLENE UG/L : 0.5K

P34371 ETHYLBENZENE UG/L : 0.5K
P34423 METHYLENE CHLORIDE UG/L : 0.5K
P77128 STYRENE UG/L : 0.5K
[illegible]475 TETRACHLOROETHYLENE UG/L : 0.5K

```
UMBER : 0196138

010 TOLUENE                             UG/L : 0.5K
551 TOTAL XYLENES                       UG/L : 0.5K
54  TRANS-1,2-DICHLOROETHYLENE          UG/L : 0.5K
180 TRICHLOROETHYLENE                   UG/L : 0.5K

175 VINYL CHLORIDE                      UG/L : 0.5K
UNREGULATED VOLATILE ORGANIC COMPOUNDS

562 1,1,1,2-TETRACHLOROETHANE           UG/L : 0.5K

516 1,1,2,2-TETRACHLOROETHANE           UG/L : 0.5K
96 1,1-DICHLOROETHANE                  UG/L : 0.5K
168 1,1-DICHLOROPROPENE                 UG/L : 0.5K
43 1,2,3-TRICHLOROPROPANE              UG/L : 0.5K

66 1,3-DICHLOROBENZENE                 UG/L : 0.5K
173 1,3-DICHLOROPROPANE                 UG/L : 0.5K
170 2,2-DICHLOROPROPANE                 UG/L : 0.5K
55 BROMOBENZENE                        UG/L : 0.5K

13 BROMOMETHANE                        UG/L : 0.5K
11 CHLOROETHANE                        UG/L : 0.5K
18 CHLOROMETHANE                       UG/L : 0.5K
04 CIS-1,3-DICHLOROPROPENE             UG/L : 0.5K

22 DIBROMOMETHANE                      UG/L : 0.5K
70 TOTAL CHLOROTOLUENES                UG/L : 0.5K
95  TRANS-1,3-DICHLOROPROPENE          UG/L : 0.5K
```

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                    ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

 MPLE NUMBER : D196139
 MP' 'NG POINT DESC. : BLANK W/96138 WAUKEGAN

 IBMITTING SOURCE # : 097190C01                     SITE # :
 .TE COLLECTED : 910820       TIME COLLECTED : 1520    SAMPLING PROGRAM : VO

 ILLECTEC BY : KEN SHEETS                  DELIVERED BY : UPS
 IMMENTS : VOCS
 INDING CODE : PW32           AGENCY ROUTING : --      UNIT CODE :
 IM TYPE CODE : FPWS      SAMPLE PURPOSE CODE : 8  REPORTING INDICATOR : 8

 ATE RECEIVED : 910821        TIME RECEIVED : 1030     RECEIVED BY : L H
 AB OBSERVATIONS : 2 BLANKS                     TRIP BL SAM# :
 JPERVISORS INITIALS : JTH                         NOTE : K = LESS THAN VALUE


 : .
 : .
 : .
 : .
 : TRIHALOMETHANES

 32106 CHLOROFORM                          UG/L : 0.5K
 32101 BROMODICHLOROMETHANE                UG/L : 0.5K
 32105 CHLORODIBROMOMETHANE                UG/L : 0.5K
 32104 BROMOFORM                           UG/L : 0.5K

 : .
 : .
 : .
 : REGULATED VOLATILE ORGANIC COMPOUNDS

 34506 1,1,1-TRICHLOROETHANE               UG/L : 0.5K
 34511 1,1,2-TRICHLOROETHANE               UG/L : 0.5K
 34501 1,1-DICHLOROETHYLENE                UG/L : 0.5K
 34551 1,2,4-TRICHLOROBENZENE              UG/L : 0.5K

 34536 1,2-DICHLOROBENZENE                 UG/L : 0.5K
 32103 1,2-DICHLOROETHANE                  UG/L : 0.5K
 34541 1,2-DICHLOROPROPANE                 UG/L : 0.5K
 34571 1,4-DICHLOROBENZENE                 UG/L : 0.5K

 34030 BENZENE                             UG/L : 0.5K
 32102 CARBON TETRACHLORIDE                UG/L : 0.5K
 34301 CHLOROBENZENE                       UG/L : 0.5K
 77093 CIS-1,2-DICHLOROETHYLENE            UG/L : 0.5K

 34371 ETHYLBENZENE                        UG/L : 0.5K
 34423 METHYLENE CHLORIDE                  UG/L : 0.5K
 77128 STYRENE                             UG/L : 0.5K
 34475 TETRACHLOROETHYLENE                 UG/L : 0.5K
```

```
UMBER : 0196139

010 TOLUENE                              UG/L : 0.5K
551 TOTAL XYLENES                        UG/L : 0.5K
54  TRANS-1,2-DICHLOROETHYLENE           UG/L : 0.5K
180 TRICHLOROETHYLENE                    UG/L : 0.5K

175 VINYL CHLORIDE                       UG/L : 0.5K
UNREGULATED VOLATILE ORGANIC COMPOUNDS

562 1,1,1,2-TETRACHLOROETHANE            UG/L : 0.5K

516 1,1,2,2-TETRACHLOROETHANE            UG/L : 0.5K
496 1,1-DICHLOROETHANE                   UG/L : 0.5K
168 1,1-DICHLOROPROPENE                  UG/L : 0.5K
443 1,2,3-TRICHLOROPROPANE               UG/L : 0.5K

566 1,3-DICHLOROBENZENE                  UG/L : 0.5K
173 1,3-DICHLOROPROPANE                  UG/L : 0.5K
170 2,2-DICHLOROPROPANE                  UG/L : 0.5K
55 BROMOBENZENE                          UG/L : 0.5K

13 BROMOMETHANE                          UG/L : 0.5K
11 CHLOROETHANE                          UG/L : 0.5K
18 CHLOROMETHANE                         UG/L : 0.5K
04 CIS-1,3-DICHLOROPROPENE               UG/L : 0.5K

22 DIBROMOMETHANE                        UG/L : 0.5K
70 TOTAL CHLOROTOLUENES                  UG/L : 0.5K
9   RANS-1,3-DICHLOROPROPENE             UG/L : 0.5K
```

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY **PESTICIDE ANALYSIS REPORT FORM**

DIVISION OF PUBLIC WATER SUPPLIES

D054236

R.C.
6-18-87

.AC # 0971900
Waukegan
Howard Peskator
Water Plant
106 North Utica
Waukegan, Illinois 60085

Samples scheduled during: 3/87

Date and time in Laboratory: MAR 12 1987

Received by:

1. Mail Report to: Name: Howard Peskator, Director	2. Date Collected: MARCH 11, 1987
Address: 106 N. Utica St.	3. Sample Collector: Ken Sheets
Post Office: Waukegan State: ILL Zip Code: 60085	4. Sampling Point: 926 Poplar St.
COLLECTOR: *Fill in shaded area only. Type or use black ball point pen. See reverse side for explanations and instructions.*	5. Telephone Number: 312-360-9000 ext 451

All results reported in micrograms per liter (PPB)

Parameter	MCL ug/l	Concentration ug/l
Lindane	4	< 0.01
Heptachlor	0.1	< 0.01
Aldrin	1	< 0.01
Heptachlor Epoxide	0.1	< 0.01
Alpha Chlordane	Total 3	< 0.01
Gamma Chlordane		< 0.01
Dieldrin	1	< 0.01
Endrin	0.2	< 0.01
Methoxychlor	100	< 0.05
PCB.		< 0.1
Herbicide *		

Parameter	MCL ug/l	Concentration ug/l
o,p' - DDE		< 0.01
p,p' - DDE		< 0.01
o,p' - DDD		< 0.01
p,p' - DDD		< 0.01
o,p' - DDT	Total 50	< 0.01
p,p' - DDT		< 0.01
Toxaphene	5	< 1.0
Silvex *	10	< 0.05
2,4-D *	100	< 0.1

APR 14 1987
Environmental Protection Agency
State of Illinois

– Laboratory Use Only –

Laboratory Number: D054236

Date Forwarded: 4-10-87 By: J. Hurley

– DPWS Use Only –

RECEIVED
REGION 2
JUN 25 1987
Div. Public Water Supplies
State of Illinois
Environmental Protection Agency

D054236

This Agency is authorized to require this information under Ill. Rev. Stat., 1979, Chapter 111-1/2, Section 1019. Disclosure of this information is required. Failure to do so may result in a civil penalty up to $10,000.00 and an additional civil penalty up to $1,000.00 for each day the failure continues, a fine up to $1,000.00 and imprisonment up to one year. This form has been approved by the forms Management Center.

APPENDIX B

Organics Scanned in Water Samples

APPENDIX B

ORGANICS SCANNED IN WATER SAMPLES, WAUKEGAN RAP, 1990

(Analytical Methods are Listed According to USEPA, 1990a)

608
ALDRIN
DIELDRIN
TOTAL DDT
O,P-DDE
P,P-DDE
O,P-DDD
P,P-DDD
O,P-DDT
P,P'-DDT
TOTAL CHLORDANE
CHLORDANE, CIS ISOMER
CHLORDANE, TRANS ISOMER
ENDRIN
METHOXYCHLOR
ALPHA-BHC
GAMMA-BHC(LINDANE)
HEXACHLOROBENZENE
TOTAL PCBS
TOXAPHENE

8279/608*
PENTACHLOROPHENOL

8260/624/601/602
CHLOROMETHANE
BROMOMETHANE
VINYL CHLORIDE
CHLOROETHANE
METHYLENE CHLORIDE

8260/624/601/602
ACETONE
TRICHLOROFLUOROMETHANE
BROMOCHLOROMETHANE
CARBON DISULFIDE
1,1-DICHLOROETHYLENE
1,1-DICHLOROETHANE
TRANS-1,2-DICHLOROETHYLENE
CIS-1,2 DICHLOROETHYLENE
CHLOROFORM
1,2 DICHLORETHANE
2 BUTANONE (MEK)
1,1,1-TRICHLOROETHANE
CARBON TETRACHLORIDE
VINYL ACETATE
DICHLOROBROMOMETHANE
1,2-DICHLOROPROPANE
CIS-1,3-DICHLOROPROPENE
TRICHLOROETHYLENE
CHLORODIBROMOMETHANE
1,1,2-TRICHLOROETHANE
BENZENE
TRANS-1,3-DICHLOROPROPENE
2-CHLOROETHYLVINYL ETHER
BROMOFORM
4-METHYL-2 PENTANONE
2-HEXANONE (MBK)
TETRACHLOROETHYLENE
1,2,2,2-TETRACHLOROETHANE
TOLUENE
CHLOROBENZENE
ETHYLBENZENE
STYRENE
XYLENE

* Gas chromatographic analysis preceded by acid extraction and esterification

APPENDIX C

Organics Scanned in Sediment Samples

APPENDIX C

ORGANICS SCANNED IN SEDIMENT SAMPLES, WAUKEGAN RAP, 1990

(Analytical Methods are Listed According to USEPA, 1990b)

8080

TOTAL PCBS
ALDRIN
DIELDRIN
TOTAL DDT
O,P'-DDE
P,P'-DDE
O,P'-DDD
P,P'-DDD
O,P'-DDT
P,P'-DDT
TOTAL CHLORDANE
CHLORDANE,CIS ISOMER
CHLORDANE, TRANS ISOMER
ENDRIN
METHOXYCHLOR
ALPHA-BHC
GAMMA-BHC (LINDANE)
HEXACHLOROBENZENE
HEPTACHLOR
HEPTACHLOR EPOXIDE

8270

PHENOL
BIS(2-CHLOROETHYL)ETHER
2-CHLOROPHENOL
1,3-DICHLOROBENZENE
1,4-DICHLOROBENZENE
BENZL ALCOHOL
1,2-DICHLOROBENZENE
2-METHYLPHENOL
BIS(2-CHLOROISOPROPYL) ETHER
BUTYL BENZYL PHTHALATE
3,3-DICHLORBENZIDINE
BENZO(A)ANTRACENE
BIS(2ETHYHEXYL)PHTHALATE
DI-N-OCTYLPHTHALATE
BENZO(8)FLOUROANTHENE
BENZO(K)FLOUROANTHENE
CHRYSENE
BENZO(A)PYRENE
INDENO(1,2,3-CO) PYRENE
DIBENZO(A)ANTRACENE
DIBENZO(AH)ANTHRACENE
BENZO(GHI)PERYLENE
  :ETHYL-DIMETHYL-PENTANE
  :METHYL PENTANE

8270

  :TETRAMETHYL PENTANE
  :C3-SUBSTITUTED BENZENE
  :C4-SUBSTITUTED BENZENE
  :C5-SUBSTITUTED BENZENE
4-METHYLPHENOL
N-NITROSO-DI-N-PROPYLAMINE
HEXACHLOROETHANE
ISOPHORONE
2-NITROPHENOL
2,4-DIMETHYLPHENOL
BENZOIC ACID
BIS(2-CHLOROETHYOXY)METHANE
2,4-DICHLOROPHENOL
1,2,4-TRICHLOROBENZENE
NAPHTHALENE
4-CHLOROANILINE
HEXACHLOROPHENOL
4 CHLORO-3-METHYLPHENOL
2-METHYLNAPHTHALENE
2-CHLORONAPTHALENE
HEXACHLOROCYCLOPENTADIENE
2,4,6-TRICHLOROPHENOL
2,4,5-TRICHLOROPHENOL
2 CHLORONAPTHALENE
2-NITROANILINE
DIMETHYLPHTHALATE
ACENAPHTHYLENE
2,6-DINITROTOLUENE
3-NITROANILINE
2,4 DINTROPHENOL
4-NITROPHENOL
DIBENZOFURAN
2,4-DINITROTOLUENE
DIETHYLPHTHALATE
4-CHLOROPHENYL PHENYL ETHER
FLUORENE
4-NITROANILINE
4,6 DINITRO-2-METHYLPHENOL
4-BROMOPHENYL ETHER
HEXACHLOROBENZENE
PENTACHLOROPHENOL
PHENTANTHRENE
ANTRACENE
DI-N-BUTYLPHTHALATE
FLOUROANTHENE
PYRENE

APPENDIX C (CONTINUED)

ORGANICS SCANNED IN SEDIMENT SAMPLES

(Analytical Methods are Listed According to USEPA, 1990b)

8270

DIBENZO(AH)ANTHRACENE
BENZO(GHI)PERYLENE
  :ETHYL-DIMETHYL-PENTANE
  :METHYL PENTANE
  :TETRAMEHTHYL PENTANE
  :C3-SUBSTITUTED BENZENE
  :C4-SUBSTITUTED BENZENE
  :C5-SUBSTITUTED BENZENE
ANTHRACENE
DI-N-BUTYLPHTHALATE
FLOUR0ANTHENE
PYRENE

APPENDIX D

Observed Biological Impacts of Sediment Contamination

Table D.1. Effects Range-Low and Effects Range-Median Values for Zinc and 46 Concentrations Used to Determine These Values, in Ascending Order. Waukegan Harbor Concentrations Added (underlined).

Concentration (mg/kg)	Method/Source
51	Sublethal SSB with *R. abronius*
59	Sublethal SSB with *P. affinis*
98	Massachusetts Bay, MA; benthos
117	Massachusetts Bay, MA; benthos
120	**ER-L**
121	Trinity River, TX; bioassay
127	Waukegan Harbor, IL; bioassay
130	San Fransisco Bay, CA; AET
154	Keweenaw Waterway, MI; bioassay
168	Keweenaw Waterway, MI; bioassay
169	Feral Fraser River, BC; *M. balthica* absence
172	San Fransisco Bay, CA, bioassay
172	M. balthica avoidance bioassay
182	Southern California, arthropod abundance
185	Commencement Bay, WA; bioassays
188	Sublethal SSB with *R. abronius*
195	Puget Sound, WA; bioassays
197	Southern California; species richness
205	San Francisco Bay, CA, bioassay
211	Commencement Bay, WA; bioassays
•214	Waukegan Harbor average of 23 stations
223	Los Angeles Harbor, CA; bioassays
230	San Francisco Bay, CA; AET
230	Southern California; echinoderm abundance
260	Puget Sound, WA; AET-benthic
267	Little Grizzly Creek, CA; bioassays
270	**ER-M**
•270	WH-5, WH-9
276	SSB with *R. abronius*; LC-50
•280	WH-8
290	Sheboygan River, WI; bioassays
•290	WH-14
•300	WH-3
310	Torch Lake, MI; bioassays
320	Lake Union, WA; bioassays
327	DuPage River, IL; species richness
•330	WH-7
334	Black Rock Harbor, CT; bioassays
348	Southern California; bioassays

•370	WH-13
387	Commencement Bay, WA; bioassays
410	Puget Sound, WA; AET-benthic
449	Hudson-Raritan Bay, NY; bioassays
570	Phillips Chain of Lakes, WI; bioassays
613	SSB with *R. abronius*
707	Puget Sound, WA; bioassays
739	Palos Verdes, CA; major degradation
760	EP marine chronic threshold @ 4% TOC
870	Puget Sound, WA; AET-amphipod
941	Commencement Bay, WA; bioassays
960	Puget Sound, WA; AET-amphipod
1600	Puget Sound, WA; AET-oyster
1600	Puget Sound, WA; AET-Microtox™
1804	Baltimore Harbor, MD; bioassays
2240	EP marine acute threshold @4% TOC

Table D.2. Effects Range-Low and Effects Range-Median Values for Cadmium and 36 Concentrations used to Determine These Values, in Ascending Order. Waukegan Harbor Concentrations Added (underlined).

Concentration (mg/kg)	Method/Source
4.3	Southern California arthropods COA
4.7	Southern California species richness COA
5.0	**ER-L**
5.1	Puget Sound, Washington, AET-benthic
5.3	Southern California bioassay COA
5.6	SSB with *R. abronius*
5.8	Puget Sound, Washington, AET-benthic
5.8	SSB with *R. abronius*
6.2	Southern California echinoderms COA
6.5	SSB with *R. abronius*
6.7	Puget Sound, Washington AET - amphipod
6.9	SSB with *R. abronius*
•8.0	Waukegan Harbor average of 23 stations
8.2	SSB with *E. sencillus*
8.4	SSB with *R. abronius*
8.5	SSB with *R. abronius*
8.7	SSB with *R. abronius*
8.8	SSB with *R. abronius*
8.9	SSB with *R. abronius*
9.0	**ER-M**
9.1	SSB with *R. abronius*
9.6	Puget Sound, Washington AET - oyster
9.6	Puget Sound, Washington AET - Microtox
9.7	SSB with *R. abronius*
9.8	SSB with *R. abronius*
10.0	SSB with *R. abronius*
10.6	Trinity River, Texas bioassay COA
11.0	SSB with *P. affinis*
11.5	SSB with *R. abronius*
•14.0	WH-17
15.3	Commencement Bay, Washington bioassay COA
18.6	Hudson-Raritan Bay, New York bioassay COA
20.8	SSB with *R. abronius*
22.8	Baltimore Harbor, Maryland bioassay COA
•23.0	WH-12
25.9	SSB with *R. abronius*
28.7	Palos Verdes Shelf, California bioassay COA
28.7	Palos Verdes Shelf, California benthos COA
31.0	EP chronic marine @4% TOC
•38.0	WH-14

41.6	Commencement Bay, Washington bioassay COA
•50.0	WH-13
96.0	EP acute marine @4% TOC

Table D.3. Effects Range-Low and Effects Range-Median Values for Lead and 47 Concentrations used to Determine These Values, in Ascending Order. Waukegan Harbor Concentrations Added (underlined).

Concentration (mg/kg)	Method/Source
26.6	Keweenaw Waterway, Michigan bioassay COA
29.0	Keweenaw Waterway, Michigan bioassay COA
30.6	Kishwaukee River, Illinois benthis COA
32.0	*M. balthica* burrowing ET50 COA
35.0	Norway benthos COA
35.0	**ER-L**
41.3	Los Angeles Harbor, California bioassay COA
42.1	San Francisco Bay, California bioassay COA
42.4	Massachusetts Bay, Massachusetts benthos COA
46.7	Massachusetts Bay, Massachusetts benthos COA
47.8	Southern California arthropods COA
≤50.0	San Francisco, California triad minimum effects
51.0	Southern California species richness COA
53.7	Trinity River, Texas bioassay COA
58.9	San Francisco Bay, California bioassay COA
>60.0	FWPCA Classification: benthos absent COA
63.4	San Francisco Bay, Callifornia bioassay COA
64.4	Southern California echinoderms COA
73.1	Southern California bioassay COA
74.0	*M. Balthica* bioassay avoidance COA
81.7	Fraser River, B.C., Canada benthos COA
89.6	Black Rock Harbor, Connecticut bioassay COA
95.7	San Francisco Bay, California bioassay COA
104.5	San Francisco Bay, California bioassay COA
110.0	**ER-M**
110.0	Torch Lake, Michigan bioassay COA
•110.0	WH-22
113.1	Commencement Bay, Washington bioassay COA
120.0	San Francisco Bay, California AET
•130.0	WH-22
≥130.0	San Francisco Bay, California triad significant effects COA
132.0	EP chronic maine @4% TOC
136.6	Puget Sound, Washington bioassay COA
•140.0	WH-18
140.0	San Francisco Bay, California AET
143.7	DuPage River, Illinois benthos COA
•150.0	WH-3; WH-23
160.0	Phillips Chain of Lakes, Wisconsin bioassay COA
170.8	Commencement Bay, Washington bioassay COA

•190.0	WH-15
•200.0	WH-16
•202.0	Waukegan Harbor average of 23 stations
•210.0	WH-10
•240.0	WH-6
253.0	Sheboygan River, Wisconsin bioassay COA
•260.0	WH-5
•270.0	WH-11
•280.0	WH-9; WH-12; WH-17
•290.0	WH-8
300.0	Puget Sound, Washington AET - benthic
300.0	Lake Union, Washington bioassay COA
312.3	Palos Verdes Shelf, California benthos COA
320.9	Hudson-Raritan Bay, New York bioassay COA
•330.0	WH-7
•370.0	WH-14
•420.0	WH-13
450.0	Puget Sound, Washington AET - benthic
512.0	Baltimore Harbor, Maryland bioassay COA
530.0	Puget Sound, Washington AET - Microtox
570.1	Commencement Bay, Washington AET - amphipod
660.0	Puget Sound, Washington AET - oyster
750.2	Puget Sound, Washington bioassay COA
1613.0	Commencement Bay, Washington bioassay COA
3360.0	EP acute marine @4% TOC

Table D.4. The Ratio of Metal Concentration in Bulk Sediment Samples (Risatti et al., 1990) to the Effects Range-Median (ER-M) value (Long and Morgan, 1990) at 23 stations in Waukegan Harbor. The Sum of These Ratios is Provided in the Rightmost Column (Σ x/ER-M).

Station	$(Zn/ER\text{-}M_{Zn})$	$(Cd/ER\text{-}M_{Cd})$	$(Pb/ER\text{-}M_{Pb})$	Σ X/ER-M
WH-1	0.78	BDL*	0.49	1.27
WH-2	0.48	BDL*	0.33	0.81
WH-3	1.11	BDL*	1.36	2.47
WH-4	0.30	BDL*	0.90	1.20
WH-5	1.00	0.42	2.36	3.78
WH-6	0.96	0.44	2.18	3.58
WH-7	1.22	0.54	3.00	4.76
WH-8	1.04	0.54	2.64	4.22
WH-9	1.00	0.61	2.55	4.16
WH-10	0.78	0.44	1.91	3.13
WH-11	0.78	0.72	2.45	3.95
WH-12	0.74	2.56	2.55	5.85
WH-13	1.37	5.56	3.82	10.75
WH-14	1.07	4.22	3.36	8.65
WH-15	0.74	0.49	1.73	2.96
WH-16	0.74	0.23	1.82	2.79
WH-17	0.89	1.56	2.55	5.00
WH-18	0.41	BDL*	1.27	1.68
WH-19	0.74	0.24	1.18	2.16
WH-20	0.59	0.19	0.91	1.69
WH-21	0.33	BDL*	.55	.88
WH-22	0.36	BDL*	1.00	1.36
WH-23	0.81	0.63	1.36	3.80

---

* Below Detection Limit (1.3 mg/kg) for Cadmium.

Attachment 4

Laboratory Standard Operating Procedures for Cation Exchange Capacity and Weak Acid Dissociable Cyanide

SOP No.: LRD I-0069
Rev No.: 1
Date: 06/11/93

DRAFT

SOIL ANALYSIS
FOR
CATION-EXCHANGE CAPACITY (SODIUM ACETATE)

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SOIL ANALYSIS FOR
CATION-EXCHANGE CAPACITY (SODIUM ACETATE)

Working Linear Range: NA
Reporting Limit: NA
Reporting Units: NA
Matrix: Soil
Holding Time: 180 days from date of collection

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1.0 Scope and Application

1.1 To establish a standard practice for the sodium acetate extraction of most soils, including calcareous and noncalcareous soils for the measurement of the soils cation-exchange capacity. This method is functionally and analytically equivalent to, and meets all quality control requirements of, USEPA Method 9081, CATION-EXCHANGE CAPACITY OF SOILS (SODIUM ACETATE).

2.0 Method Summary

2.1 The soil sample is mixed with an excess of sodium acetate solution, resulting in an exchange of the added sodium cations for the matrix cations. Subsequently, the sample is washed with isopropyl alcohol. An ammonium acetate solution is then added, which replaces the adsorbed sodium with ammonium. The concentration of displaced sodium is then determined by Inductively Coupled Argon Plasma optical emission spectroscopy (ICP), or an equivalent means.

3.0 Interferences

3.1 Interferences can occur during analysis of the extract for sodium content. Thoroughly investigate the chosen analytical method for potential interferences.

4.0 Safety Precautions

4.1 Exercise normal laboratory safety precautions when performing this method.

5.0 Sample collection and Handling

5.1 Sample Collection, Preservation, and Handling: All federal, state, local, customer, or CH2M HILL requirements must be met.

5.2 Sample Size: minimum 25 g.

5.3 Container: glass or plastic

5.4 Preservation: none

6.0 Apparatus

6.1 Centrifuge tube with screw top, 50 mL, plastic, disposable.

6.2 Centrifuge

6.3 Mechanical shaker

6.4 Volumetric flask, 100 mL, glass, ASTM E694 Class A.

6.5 pH Meter

7.0 Routine Preventive Maintenance

7.1 Not applicable.

8.0 Reagents and Calibration Standards

8.1 **Reagent Water:** Reagent water is defined as water in which an interference is not observed at or above the method detection limit of the analyte(s) of interest. Typically dionized water, equivalent to ASTM Type IV water (ASTM D 1193) is used.

8.2 Sodium acetate, ACS reagent grade or better $NaC_2H_3O_2 \cdot 3H_2O$.

8.2.1 Sodium acetate, NaOAc, 1.0N: Dissolve 136 g of $NaC_2H_3O_2 \cdot 3H_2O$ in reagent water and dilute it to 1L. The pH of this solution should be 8.2 ± 0.1. If needed, add a few drops of acetic acid or NaOh solution to bring the pH of the solution to 8.2 ± 0.1.

8.3 Sodium Hydroxide, concentrated, ACS reagent grade or better NaOH.

8.3.1 Sodium Hydroxide, 0.01N: Dissolve 0.4 g

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of NaOH in 1 L of reagent water.

8.4 Ammonium Hydroxide, concentrated, ACS reagent grade or better NH_4OH.

8.5 Acetic Acid, glacial (99.5%), ACS reagent grade or better.

8.6 Ammonium Acetate, ACS reagent grade or better NH_4OAc.

8.6.1 Ammonium Acetate, NH_4OAc, 1.0N: Dissolve 154.2 g of NH_4OAc in reagent water in a 2.0 L volumetric flask and dilute to approximately 1980 mL. Check the pH of the resulting solution, adding additional ammonium hydroxide or glacial acetic acid as needed, to obtain a pH of 7.0 ± 0.1, then dilute the solution to a volume of 2.0 L with reagent water.

8.6.2 Ammonium Acetate, NH_4OAc, 1.0N, Alternate Preparation: Dilute 114 mL of glacial acetic acid with reagent water to a volume of approximately 1 L. Add 138 mL of concentrated ammonium hydroxide, mix, then dilute to approximately 1980 mL with reagent water. Check the pH of the resulting solution, adding additional ammonium hydroxide or glacial acetic acid as needed, to obtain a pH of 7.0 ± 0.1, then dilute the solution to a volume of 2.0 L with reagent water.

8.8 Isopropyl alcohol, ACS reagent grade or better $CH_3CH(OH)CH_3$.

9.0 Calibration Procedure

9.1 The pH meter should be calibrated according to LRD SOP I-0050.

10.0 Sample Preparation

10.1 Mix the sample gently to insure a representative sample.

11.0 Sample Analysis

11.1 Weigh 5.0 g of soil into a 50 mL centrifuge tube.

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11.2 Add 33 mL of 1.0N NaOAc solution, seal the tube, and shake in the shaker for 5 minutes.

11.3 Centrifuge for 5 minutes (until solution is clear) and decant the liquid (into a 100 mL volumetric flask for extractable calcium and magnesium analysis).

> Note: If for CEC only, discard this solution.

11.4 Repeat steps 11.2 and 11.3 two more times. Dilute to 100 mL with reagent water for extractable calcium and magnesium analysis.

11.5 Add 33 mL of 99% isopropyl alcohol, seal the tube and shake it for 5 minutes.

11.6 Centrifuge for 5 minutes (until solution is clear) and decant and discard the liquid.

11.7 Repeat steps 11.5 and 11.6 two more times.

11.8 Add 33 mL of NH_4OAC solution, seal the tube and shake it for 5 minutes.

11.9 Centrifuge for 5 minutes (until solution is clear) and decant the liquid into a 100 mL volumetric flask.

11.10 Repeat steps 11.5 and 11.6 two more times.

11.11 Dilute to volume with NH_4OAC solution and analyze for sodium by ICP.

12.0 Data Treatment

12.1 Calculations:

12.1.1 $$\text{Ca meq/100 g} = \frac{\text{Ca ppm}}{200}$$

12.1.2 $$\text{Mg meq/100 g} = \frac{\text{Mg ppm}}{122}$$

12.1.3 $$\text{CEC meq/100 g} = \text{Na meq/100 g} = \frac{\text{Na ppm}}{230}$$

13.0 Data Package Deliverables

13.1 Refer to the CH2M HILL Redding Quality Analytical Laboratories Quality Assurance Plan and to the specific client contract for a listing of deliverables.

14.0 Quality Control Requirements

14.1 All quality control data should be maintained and available for easy reference or inspection.

14.2 Employ a minimum of one blank per sample batch, or for each 20 samples, to determine if contamination or any memory effects are occurring.

14.3 A material of known cation-exchange capacity must be analyzed with each sample batch, or each group of 20 samples, as a Laboratory Control Sample.

15.0 Method Validation

15.1 Each analyst must make an initial, one-time demonstration of the ability to generate acceptable accuracy and precision with this method. This compliance must be documented by the analytst's supervisor or division manager.

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16.0 References

16.1 USBR Land Classification Techniques and Standards Release No. 514.8.4 and 514.8.6.

16.2 Method 9081, SW-846, TEST METHODS FOR EVALUATING SOLID WASTE, Volume 1A: Laboratory Manual, Physical/Chemical Methods, Third Edition, USEPA Office of Solid Waste and Emergency Response, November 1986.

APPENDIX I

Standard Operating Procedure

SOIL ANALYSIS

FOR

CATION-EXCHANGE CAPACITY (SODIUM ACETATE)

LAB Document Control Number LRD I-0069

Revision 1

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Approved:

LRD Laboratory Manager ______________________

LRD Inorganics Division Manager ______________________

LRD LQAC Officer ______________________

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CH2M HILL
MONTGOMERY LABORATORY
STANDARD OPERATING PROCEDURES
WET CHEMISTRY DEPARTMENT

METHOD WEAK AND DISSOCIABLE CYANIDE ANALYSIS IN WATER

CYANIDE, WEAK AND DISSOCIABLE

Method 335.2 CLP.M* (Titrimetric; Manual Spectrophotometric; Semi-Automated Spectrophotometric)

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1. SCOPE AND APPLICATION

1.1 This method applies to the determination of cyanide in drinking, surface and saline waters, and domestic and industrial wastes

1.2 The titration procedure using silver nitrate with p-dimethylaminobenzalrhodanine indicator is used for measuring concentrations of cyanide exceeding 1 mg/L

1.3 The manual colorimetric procedure is used for concentrations below 1 mg/L of cyanide and is sensitive to about 5 ug/L (Option B, 8.3).

2. SUMMARY OF METHOD

2.1 Hydrogen cyanide (HCN) is liberated from a slightly acidified (pH 4.5 to 6.0) sample under the prescribed distillation conditions. The methods does not cover CN from right complexes that would not be amenable to oxidation by chlorine. The acetate buffer used contains zinc salts to precipitate iron cyanide as a further assurance of the selectivity of the methods.

2.2 In the colorimetric measurement, the cyanide is converted to cyanogen chloride, CNCl, by reaction with chloramine-T at a pH less than 8 without hydrolyzing to the cyanate. After the reaction is complete, color forms upon the addition of pyridinebarbituric acid reagent. The absorbance is read at 578 nm for pyridine-barbituric acid. To obtain colors of comparable intensity, it is essential to have the same salt content in both the sample and the standards.

2.3 The titrimetric measurement uses a standard solution of silver nitrate to titrate cyanide in the presence of a silver sensitive indicator.

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*CLP-M Modified for Weak and Dissociable Cyanide

3. DEFINITIONS

3.1 Weak and Dissociable Cyanide is defined as cyanide ion converted to hydrocyanic acid (HCN) by reaction in a reflux system with slightly acidified sample.

4. SAMPLE HANDLING AND PRESERVATION

4.1 All bottles must be thoroughly cleansed and rinsed to remove soluble material from containers.

4.2 Oxidizing agents such as chlorine decompose most of the cyanides. Test a drop of the sample with potassium iodide-starch test paper (KI-starch paper); a blue color indicates the need for treatment. Add ascorbic acid a few crystals at a time until a drop of sample produces no color on the indicator paper. Then add an additional 0.6 g of ascorbic acid for each liter of sample volume.

4.3 Samples are preserved with 2 ml of 10 N sodium hydroxide per liter of sample (ph > 12) at the time of collection (Exhibit D, Section II).

4.4 Samples must be stored at 4°C (±2°C) and must be analyzed within the holding time specified in Exhibit D, Section II (14 days).

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5. INTERFERENCES

5.1 Interferences are eliminated or reduced by using the distillation procedure described in Procedure 8.1.

5.2 Sulfides adversely affect the colorimetric and titration procedures. If a drop of the distillate on lead acetate test paper shows the presence of sulfides, treat 25 ml more of the sample than that required for the cyanide determination with powdered cadmium carbonate. Yellow cadmium sulfide precipitates if the sample contains sulfide. Repeat this operation until a drop of the treated sample solution does not darken the lead acetate test paper. Filter the solution through a dry filter paper into a dry beaker, and from the filtrate measure the sample to be used for analysis. Avoid a large excess of cadmium carbonate and a long contact time in order to minimize a loss by complexation or occlusion of cyanide on the precipitated material. Sulfides should be removed before the solution is preserved with sodium hydroxide as described in 4.3.

5.3 The presence of surfactants may cause the sample to foam during refluxing. If this occurs, adding an agent such as Dow Corning 544 antifoam agent will prevent the foam from collecting in the condenser. Fatty acids will distill and form soaps under alkaline titration conditions, making the end point almost impossible to detect. When this reaction occurs, one of the spectrophotometric methods should be used.

6. APPARATUS

6.1 Reflux distillation apparatus such as shown in Figure 1. The boiling flask should be 1 liter in size with an inlet tube and provision for a condenser.

6.2 Microburet, 5.0 ml (for titration)

6.3 Spectrophotometer suitable for measurements at 578 nm with a 1.0 cm cell or larger (for manual spectrophotometric method).

6.4 Lachat QuikChem Automated Flow Injection Analyzer which includes:

6.4.1 Automatic Sampler
6.4.2 Proportioning Pump
6.4.3 Injection Valve Module with a 150 cm 0.8 mm i.d. sample loop
6.4.4 Flow Cell, 10 mm, 80 uL
6.4.5 Interference Filter Wavelength, 570 nm
6.4.6 Heater Module
6.4.7 Reaction Module 10-204-00-1-A

7. REAGENTS

7.1 Distillation and Preparation Reagents

7.1.1 Sodium hydroxide solution 0.25N. Dissolve 20 g of NaOH in distilled water, and dilute to 2 liters with distilled water.

7.1.2 Cadmium carbonate: powdered

7.1.3 Ascorbic acid: crystals

7.1.4 Acetic acid, 1 + 9: Mix 1 volume of glacial acetic acid with 9 volumes of water.

7.1.5 Acetate buffer: Dissolve 410 g sodium acetate trihydrate ($NaC_2H_3O_2.3H_2O$) in 500 mL water. Add glacial acetic acid to yield a solution pH of 4.5 (approximately 500 mL)

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Insert Figure 1

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7.1.6 Zinc acetate solution, 100 g/L: Dissolve 100 g Zn $(C_2H_3O_2).H_2O$ in 500 mL water. Dilute to 1 L.

7.1.7 Methyl red indicator.

7.2 Stock Standards and Titration Reagents

7.2.1 Stock cyanide solution: Dissolve 2.51 g of KCN and 2 g KOH in 1 liter of distilled water. Standardize with 0.0192 N $AgNO_3$.

7.2.2 Standard cyanide solution, intermediate: Dilute 50.0 ml of stock (1 ml = 1 mg CN) to 1000 ml with distilled water.

7.2.3 Standard silver nitrate solution, 0.0192 N: Prepare by crushing approximately 5 g $AgNO_3$ crystals and drying to constant weight at 40°C. Weigh out 3.2647 g of dried $AgNO_3$, dissolve it in distilled water, and dilute it to 1,000 ml (1 ml = 1 mg CN).

7.2.4 Rhodanine indicator: Dissolve 20 mg of p-dimethylaminobenzalrhodanine in 100 ml of acetone.

7.3 Manual Spectrophotometric Reagents

7.3.1 Sodium dihydrogenphosphate, 1 M: Dissolve 138 g of NaH_2PO_4 x H_2O in a liter of distilled water. Refrigerate this solution.

7.3.2 Chloramine-T solution: Dissolve 1.0 g of white, water soluble chloramine-T in 100 ml of distilled water and refrigerate until ready to use. Prepare fresh daily.

7.3.3 Color Reagent--One of the following may be used:

7.3.3.1 Pyridine-barbituric acid reagent: Place 15 g of barbituric acid in a 250 ml volumetric flask and add just enough distilled water to wash the sides of the flask and wet the barbituric acid. Add 75 ml of pyridine and mix. Add 15 ml of HCl (sp gr 1.19), mix, and cool to room temperature. Dilute to 250 ml with distilled water and mix. This reagent is stable for approximately 6 months if stored in a cook, dark place.

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7.4 Semi-Automated Spectrophotometric Reagents

7.4.1 Chloramine-T solution: Dissolve 0.40 g of chloramine-T in distilled water and dilute to 100 mL. Prepare fresh daily.

7.4.2 Phosphate buffer: Dissolve 138 g of $NaH_2PO_4 \bullet H_2O$ in distilled water and dilute to 1 liter. Add 0.5 mL of Brij-35 (available from Technicon). Store at 4°C (±2°C).

7.4.3 Pyridine-barbituric acid solution: Transfer 15 g of barbituric acid into a 1 liter volumetric flask. Add about 100 mL of distilled water and swirl the flask. Add 74 mL of pyridine and mix. Add 15 mL of concentrated HCl and mix. Dilute to about 900 mL with distilled water and mix until the barbituric acid is dissolved. Dilute to 1 liter with distilled water. Store at 4°C (±2°C)

7.4.4 Sampler wash: Dissolve 10 g of NaOH in distilled water and dilute to 1 liter.

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8. PROCEDURE

8.1 Distillation

8.1.1 Place 500 ml of sample, or an aliquot diluted to 500 ml, in the 1 liter boiling flask. Add exactly 100 ml of sodium hydroxide (7.1.1) to the absorbing tube. Connect the boiling flask, condenser, absorber, and trap in the train.

8.1.2 Start a slow stream of air entering the boiling flask by adjusting the vacuum source. Adjust the vacuum so that approximately one bubble of air per second enters the boiling flask through the air inlet tube.

NOTE: The bubble rate will not remain constant after the reagents have been added and while heat is being applied to the flask. It will be necessary to readjust the air rate occasionally to prevent the solution in the boiling flask from backing up into the air inlet tube.

8.1.3 Add 10mL each of the acetate buffer and zinc acetate solutions through air inlet tube. Also add 2 to 3 drops methyl red indicator. Rinse air inlet tube with water and allow air to mix contents. If the solution is not pink, add acetic acid (1 + 9) dropwise through air inlet tube until a pink color persists.

8.1.4 Heat the solution to boiling, taking care to prevent the solution from backing up into and overflowing from the air inlet tube. Reflux for one hour. Turn off heat and continue the airflow for at least 15 minutes. After cooling the boiling flask, disconnect absorber and close off the vacuum source.

8.2 Titrimetric Determination (Option A)

8.2.1 If the sample contains more than 1 mg of CN, transfer the distillate, or a suitable aliquot diluted to 250 ml, to a 500 ml Erlenmeyer flask. Add 10-12 drops of the benzalrhodanine indicator.

8.2.2 Titrate with standard silver nitrate to the first change in color from yellow to brownish-pink. Titrate a distilled water blank using the same amount of sodium hydroxide and indicator as in the sample.

8.2.3 The analyst should familiarize himself with the end point of the titration and the amount of indictor to be used before actually titrating the samples. A 5 or 10 ml microburet may be conveniently used to obtain a more precise titration.

8.3 Manual Spectrophotometric Determination (Option B)

8.3.1 Withdraw 50 ml or less of the solution from the absorbing tube and transfer to a 100 ml volumetric flask. If less than 50 ml is taken, dilute to 50 ml with 0.25 N sodium hydroxide solution. Add 15.0 ml of sodium phosphate solution (7.3.1) and mix.

8.3.1.1 Pyridine-barbituric acid method: Add 2 ml of chloramine-T (7.3.2) and mix., After 1 to 2 minutes, add 5 ml of pyridine-barbituric acid solution (7.3.3.1) and mix. Dilute to mark with distilled water and mix again. Allow 8 minutes for color development, then read absorbance at 578 nm in a 1 cm cell within 15 minutes.

8.3.2 Prepare a minimum of 5 standards and a blank by pipetting suitable volumes of standard solution into 100 ml volumetric flasks. NOTE: One calibration standard must be at the Contract Required Detection Limit (CRDL). To each standard, add 50 ml of 0.25 N sodium hydroxide. Standards must bracket the concentration of the samples. If dilution is required, use the blank solution.

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As an example, standard solutions could be prepared as follows:

ul of Standard Solution 7.2.2	Conc. ug CN
0	Blank
50	5
100	10
250	25
500	50
1,000	100

8.3.2.1 It is not imperative that all standards be distilled in the same manner as the samples. At least one standard (mid-range) must be distilled and compared to similar values on the curve to ensure that the distillation technique is reliable. If the distilled standard does not agree within ±15% of the undistilled standards, the operator should find and correct the cause of the apparent error before proceeding.

8.3.2.2 Prepare a standard curve by plotting absorbance of standard vs. cyanide concentrations.

8.4 Semi-Automatic Spectrophotometric Determination (Option C)

8.4.1 Set up the manifold as shown in manifold diagram. Pump the reagents through the system until a steady baseline is obtained.

8.4.2 Calibration standards: Prepare a blank and at least five calibration standards over the range of the analysis. One calibration standard must be at the CRDL. For a working range of 0-200 ug/L, the following standards may be used:

8.4.2.1 It is not imperative that all standards be distilled in the same manner as the samples. At least one standard (mid-range) must be distilled and compared to similar values on the curve to ensure that the distillation technique is reliable. If the distilled standard does not agree within ±15 percent of the undistilled standards, the operator should find and correct the cause of the apparent error before proceeding.

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uL Standard Solution (7.2.2) diluted to 100 ml	Concentration ug CN/L
0	0
50	2.5
100	5.0
200	10.0
500	25.0
1,000	50.0
2,000	100.0

Add 1.0 g of NaOH to each standard. Store at 4°C (±2°C).

8.4.3 Place calibration standards, blanks, and control standards in the sampler tray, followed by distilled samples, distilled duplicates, distilled standards, distilled spikes, and distilled blanks.

8.4.4 Set Injection Timing With:

8.4.4.1 Pump speed: 35
8.4.4.2 Cycle period: 40 s
8.4.4.3 Sample Loop Length: 150 cm
8.4.4.4 Load period: 20 s
8.4.4.5 Inject period: 20 s
8.4.4.6 Inject to start of peak period: 25 s
8.4.4.7 Inject to end of peak period: 61 s

8.4.5 Set System IV Gain: 340 x 1

8.4.6 System operation

8.4.6.1 Inspect modules for proper connections.

8.4.6.2 Turn on power to all modules. Allow heater to warm up to 60°C.

8.4.6.3 Place reagent transmission lines into proper containers. Rain tension levers on pump tube cassettes.

8.4.6.4 Pump system until a stable baseline is attained.

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8.4.6.5 Set baseline. If necessary, manually inject a high standard to set gain on colorimeter.

8.4.6.6 Program data system to initial parameters or those empirically determined.

8.4.6.7 Place calibration standards and blank in sample tray in descending order of concentration followed by unknowns, and check standards.

8.4.6.8 At end of run, place all transmission lines in water, flush system and pump dry.

8.4.6.9 Turn off pump, all modules, and release pump tube cassettes.

9. CALCULATIONS

9.1 Using the titrimetric procedure, calculate concentration of CN as follows:

$$\text{CN, mg/L} = \frac{(A-B)\ 1{,}000\ \text{ml/L}}{\text{ml orig. sample}} \times \frac{100\ \text{ml}}{\text{ml of aliquot titrated}}$$

where: A = volume of $AgNO_3$ for titration of sample (1 ml = 1 mg Ag)

B = volume of $AgNO_3$ for titration of blank (1 ml = 1 mg Ag)

AND: 100 ml = distillate volume (see 8.1.5)
1,000 ml = conversion ml to L
ml original sample (See 8.1.1)
ml of aliquot titrated (See 8.2.1)

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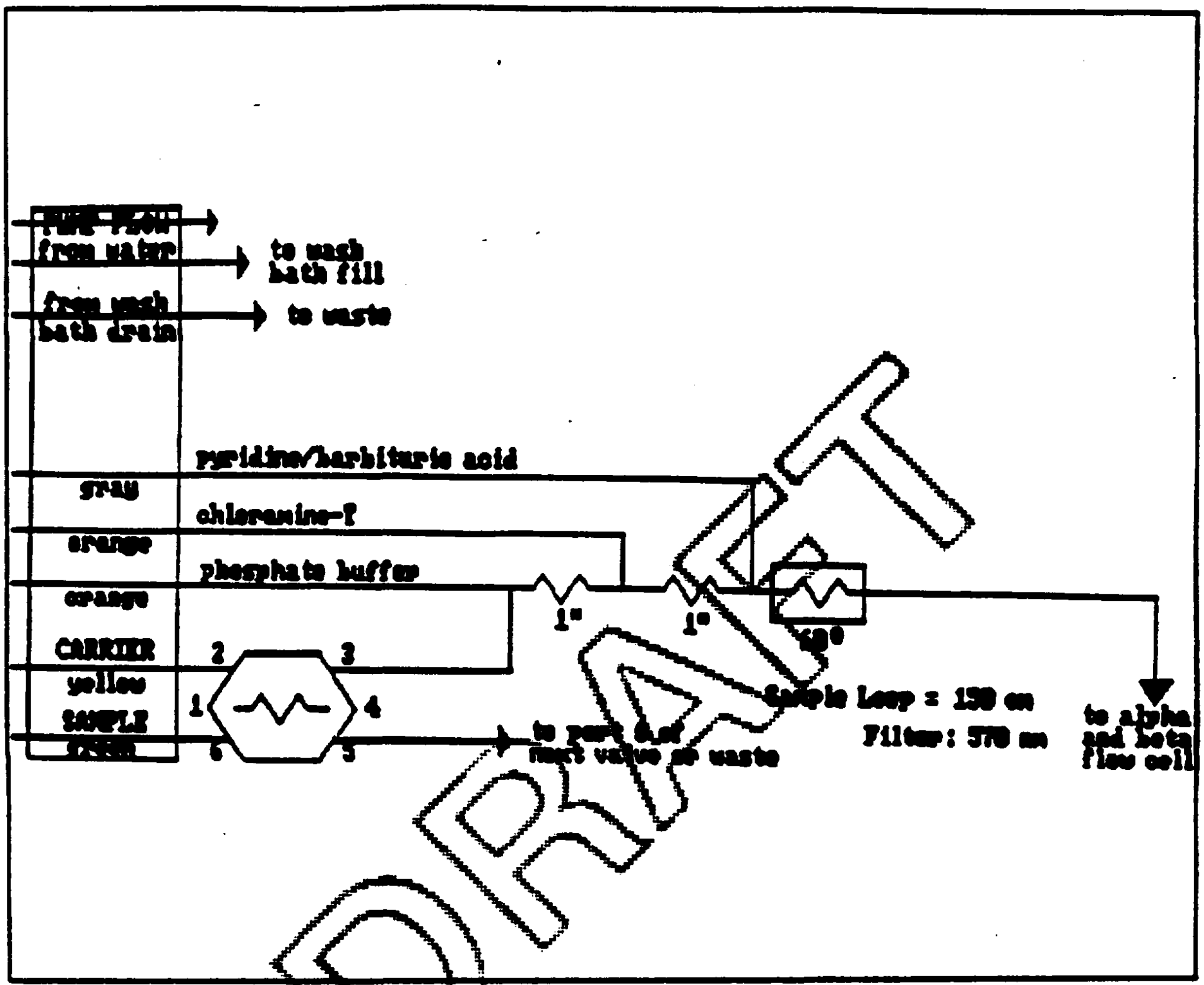
Manifold Diagram



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CARRIER is 0.25 M sodium hydroxide, Reagent 1.

1"	is	70.0	cm of tubing on a 1 in coil support
2"	is	135	cm of tubing on a 2 in coil support
2.5"	is	168	cm of tubing on a 2.5 in coil support
3"	is	202	cm of tubing on a 3 in coil support
4"	is	255	cm of tubing on a 4 in coil support
8"	is	550	cm of tubing on a 8 in coil support

Heated tubing is shown inside a box with the temperature next to the box. heated tubing is 650 cm unless otherwise specified.

All manifold tubing is 0.8 mm (0.032 in) i.d. This is 5.2 uL/cm.

Attachment 5

DNAPL Investigation Guidance

United States
Environmental Protection
Agency

Office of
Research and
Development

Office of Solid Waste
and Emergency
Response

EPA/540/4-91-002
March 1991

EPA Ground Water Issue

DENSE NONAQUEOUS PHASE LIQUIDS

Scott G. Huling* and James W. Weaver**

Background

The Regional Superfund Ground Water Forum is a group of EPA professionals representing EPA's Regional Superfund Offices, committed to the identification and the resolution of ground water issues impacting the remediation of Superfund sites. The Forum is supported by and advises the Superfund Technical Support Project. Dense nonaqueous phase liquids is an issue identified by the Forum as a concern of Superfund decision-makers. For further information contact Scott G. Huling (FTS:743-2313), Jim Weaver (FTS:743-2420), or Randall R. Ross (FTS: 743-2355).

Introduction

Dense nonaqueous phase liquids (DNAPLs) are present at numerous hazardous waste sites and are suspected to exist at many more. Due to the numerous variables influencing DNAPL transport and fate in the subsurface, and consequently, the ensuing complexity, DNAPLs are largely undetected and yet are likely to be a significant limiting factor in site remediation. This issue paper is a literature evaluation focusing on DNAPLs and provides an overview from a conceptual fate and transport point of view of DNAPL phase distribution, monitoring, site characterization, remediation, and modeling.

A nonaqueous phase liquid (NAPL) is a term used to describe the physical and chemical differences between a hydrocarbon liquid and water which result in a physical interface between a mixture of the two liquids. The interface is a physical dividing surface between the bulk phases of the two liquids, but compounds found in the NAPL are not prevented from solubilizing into the ground water. Immiscibility is typically determined based on the visual observation of a physical interface in a water- hydrocarbon mixture. There are numerous methods, however, which are used to quantify the physical and chemical properties of hydrocarbon liquids (31).

Nonaqueous phase liquids have typically been divided into two general categories, dense and light. These terms describe the specific gravity, or the weight of the nonaqueous phase liquid relative to water. Correspondingly, the dense nonaqueous phase liquids have a specific gravity greater than water, and the light nonaqueous phase liquids (LNAPL) have a specific gravity less than water.

Several of the most common compounds associated with DNAPLs found at Superfund sites are included in Table 1. These compounds are a partial list of a larger list identified by a national screening of the most prevalent compounds found at Superfund sites (65). The general chemical categories are halogenated/non-halogenated semi-volatiles and halogenated volatiles. These compounds are typically found in the following wastes and waste-producing processes: solvents, wood preserving wastes (creosote, pentachlorophenol), coal tars, and pesticides. The most frequently cited group of these contaminants to date are the chlorinated solvents.

DNAPL Transport and Fate - Conceptual Approach

Fate and transport of DNAPLs in the subsurface will be presented from a conceptual point of view. Figures have been selected for various spill scenarios which illustrate the general behavior of DNAPL in the subsurface. Following the conceptual approach, detailed information will be presented explaining the specific mechanisms, processes, and variables which influence DNAPL fate and transport. This includes DNAPL characteristics, subsurface media characteristics, and saturation dependent parameters.

Unsaturated Zone

Figure 1 indicates the general scenario of a release of DNAPL into the soil which subsequently migrates vertically under both the forces of gravity and soil capillarity. Soil capillarity is also responsible for the lateral migration of DNAPL. A point is reached at which the DNAPL no longer holds together as a continuous phase, but rather is present as isolated residual globules. The fraction of the hydrocarbon that is retained by capillary forces in the porous media is referred to as residual

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Superfund Technology Support Center for
Ground Water

Robert S. Kerr Environmental
Research Laboratory
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Technology Innovation Office
Office of Solid Waste and Emergency
Response, US EPA, Washington, D.C.

Walter W. Kovalick, Jr., Ph.D.
Director

Table 1. Most prevalent chemical compounds at U.S. Superfund Sites (65) with a specific gravity greater than one.

Compound	Density [1]	Dynamic[2] Viscosity	Kinematic Viscosity[3]	Water[4] Solub.	Henry's Law Constant[5]	Vapor[6] Pressure
Halogenated Semi-volatiles						
1,4-Dichlorobenzene	1.2475	1.2580	1.008	8.0 E+01	1.58 E-03	6 E-01
1,2-Dichlorobenzene	1.3060	1.3020	0.997	1.0 E+02	1.88 E-03	9.6 E-01
Arocior 1242	1.3850			4.5 E-01	3.4 E-04	4.06 E-04
Arocior 1260	1.4400			2.7 E-03	3.4 E-04	4.05 E-05
Arocior 1254	1.5380			1.2 E-02	2.8 E-04	7.71 E-05
Chlordane	1.6	1.1040	0.69	5.6 E-02	2.2 E-04	1 E-05
Dieldrin	1.7500			1.86 E-01	9.7 E-06	1.78 E-07
2,3,4,6-Tetrachlorophenol	1.8390			1.0 E+03		
Pentachlorophenol	1.9780			1.4 E+01	2.8 E-06	1.1 E-04
Halogenated Volatiles						
Chlorobenzene	1.1060	0.7560	0.683	4.9 E+02	3.46 E-03	8.8 E+00
1,2-Dichloropropane	1.1580	0.8400	0.72	2.7 E+03	3.6 E-03	3.95 E+01
1,1-Dichloroethane	1.1750	0.3770	0.321	5.5 E+03	5.45 E-04	1.82 E+02
1,1-Dichloroethylene	1.2140	0.3300	0.27	4.0 E+02	1.49 E-03	5 E+02
1,2-Dichloroethane	1.2530	0.8400	0.67	8.69 E+03	1.1 E-03	6.37 E+01
Trans-1,2-Dichloroethylene	1.2570	0.4040	0.321	6.3 E+03	5.32 E-03	2.65 E+02
Cis-1,2-Dichloroethylene	1.2480	0.4670	0.364	3.5 E+03	7.5 E-03	2 E+02
1,1,1-Trichloroethane	1.3250	0.8580	0.647	9.5 E+02	4.08 E-03	1 E+02
Methylene Chloride	1.3250	0.4300	0.324	1.32 E+04	2.57 E-03	3.5 E+02
1,1,2-Trichloroethane	1.4436	0.1190	0.824	4.5 E+03	1.17 E-03	1.30 E+01
Trichloroethylene	1.4620	0.5700	0.390	1.0 E+03	8.92 E-03	5.87 E+01
Chloroform	1.4850	0.5630	0.379	8.22 E+03	3.75 E-03	1.6 E+02
Carbon Tetrachloride	1.5947	0.9650	0.605	8.0 E+02	2.0 E-02	9.13 E+01
1,1,2,2-Tetrachloroethane	1.6	1.7700	1.10	2.9 E+03	5.0 E-04	4.9 E+00
Tetrachloroethylene	1.6250	0.8900	0.54	1.5 E+02	2.27 E-02	1.4 E+01
Ethylene Dibromide	2.1720	1.6760	0.79	3.4 E+03	3.18 E-04	1.1 E+01
Non-halogenated Semi-volatiles						
2-Methyl Napthalene	1.0058			2.54 E+01	5.06 E-02	6.80 E-02
o-Cresol	1.0273			3.1 E+04	4.7 E-05	2.45 E-01
p-Cresol	1.0347			2.4 E+04	3.5 E-04	1.08 E-01
2,4-Dimethylphenol	1.0360			6.2 E+03	2.5 E-06	9.8 E-02
m-Cresol	1.0380	21.0	20	2.35 E+04	3.8 E-05	1.53 E-01
Phenol	1.0576		3.87	8.4 E+04	7.8 E-07	5.293E-01
Naphthalene	1.1620			3.1 E+01	1.27 E-03	2.336E-01
Benzo(a)Anthracene	1.1740			1.4 E-02	4.5 E-06	1.16 E-09
Flourene	1.2030			1.9 E+00	7.65 E-05	6.67 E-04
Acenaphthene	1.2250			3.88 E+00	1.2 E-03	2.31 E-02
Anthracene	1.2500			7.5 E-02	3.38 E-05	1.08 E-05
Dibenz(a,h)Anthracene	1.2520			2.5 E-03	7.33 E-08	1 E-10
Fluoranthene	1.2520			2.65 E-01	6.5 E-06	E-02 E-06
Pyrene	1.2710			1.48 E-01	1.2 E-05	6.67 E-06
Chrysene	1.2740			6.0 E-03	1.05 E-06	6.3 E-09
2,4-Dinitrophenol	1.6800			6.0 E+03	6.45 E-10	1.49 E-05
Miscellaneous						
Coal Tar	1.028[7]	18.98[7]				
Creosote	1.05	1.08[8]				

---

[1] g/cc

[2] centipoise (cp), water has a dynamic viscosity of 1 cp at 20°C.

[3] centistokes (cst)

[4] mg/l

[5] atm-m³/mol

[6] mm Hg

[7] 45° F (70)

[8] 15.5°C, varies with creosote mix (62)

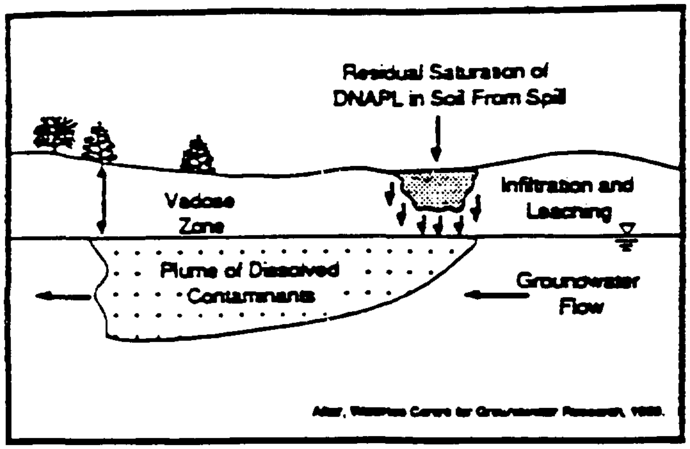

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Figure 1. The entire volume of DNAPL is exhausted by residual saturation in the vadose zone prior to DNAPL reaching the water table. Soluble phase compounds may be leached from the DNAPL residual saturation and contaminate the ground water.

saturation. In this spill scenario, the residual saturation in the unsaturated zone exhausted the volume of DNAPL, preventing it from reaching the water table. This figure also shows the subsequent leaching (solubilization) of the DNAPL residual saturation by water percolating through the unsaturated zone (vadose zone). The leachate reaching the saturated zone results in ground-water contamination by the soluble phase components of the hydrocarbon. Additionally, the residual saturation at or near the water table is also subjected to leaching from the rise and fall of the water table (seasonal, sea level, etc.).

Increasing information is drawing attention to the importance of the possibility that gaseous-phase vapors from NAPL in the unsaturated zone are responsible for contaminating the ground water and soil (18,47). It is reported that the greater "relative vapor density" of gaseous vapors to air will be affected by gravity and will tend to sink. In subsurface systems where lateral spreading is not restricted, spreading of the vapors may occur as indicated in Figure 2. The result is that a greater amount of soils and ground water will be exposed to the DNAPL vapors and may result in further contamination. The extent of contamination will depend largely on the partitioning of the DNAPL vapor phase between the aqueous and solid phases.

DNAPL Phase Distribution - Four Phase System

It is apparent from Figures 1 and 2 that the DNAPL may be present in the subsurface in various physical states or what is referred to as phases. As illustrated in Figure 3, there are four possible phases: gaseous, solid, water, and immiscible hydrocarbon (DNAPL) in the unsaturated zone. Contaminants associated with the release of DNAPL can, therefore, occur in four phases described as follows:

1. Air phase - contaminants may be present as vapors;
2. Solid phase - contaminants may adsorb or partition onto the soil or aquifer material;
3. Water phase - contaminants may dissolve into the water according to their solubility; and

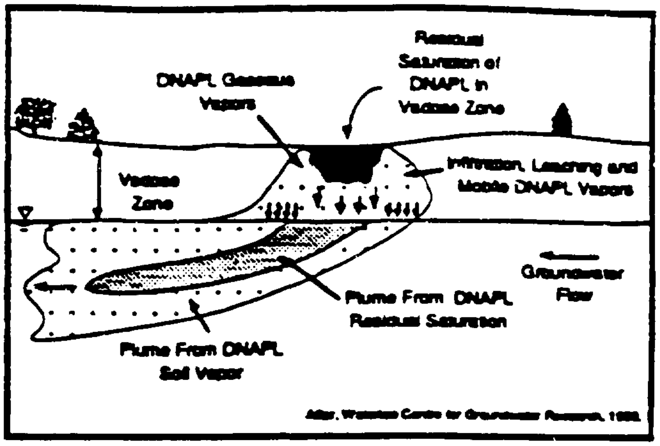

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Figure 2. Migration of DNAPL vapors from the spill area and subsequent contamination of the soils and ground water.

4. Immiscible phase - contaminants may be present as dense nonaqueous phase liquids.

The four phase system is the most complex scenario because there are four phases and the contaminant can partition between any one or all four of these phases, as illustrated in Figure 4. For example, TCE introduced into the subsurface as a DNAPL may partition onto the soil phase, volatilize into the soil gas, and solubilize into the water phase resulting in contamination in all four phases. TCE can also partition between the water and soil, water and air, and between the soil and air. There are six pathways of phase distribution in the unsaturated zone. The distribution of a contaminant between these phases can be represented by empirical relationships referred to as partition coefficients. The partition coefficients, or the distribution of the DNAPL between the four phases, is highly site-specific and highly dependent on the characteristics of both the soil/aquifer matrix and the DNAPL. Therefore, the distribution between phases may change with time and/or location at the same site and during different stages of site remediation.

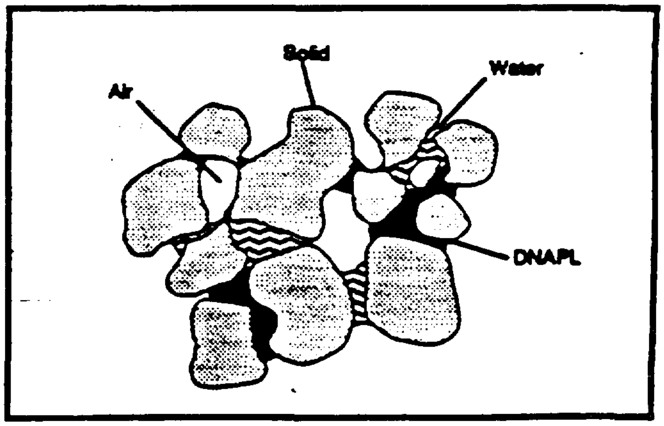


Figure 3. A DNAPL contaminated unsaturated zone has four physical states or phases (air, solid, water, immiscible). The contaminant may be present in any one, or all four phases.

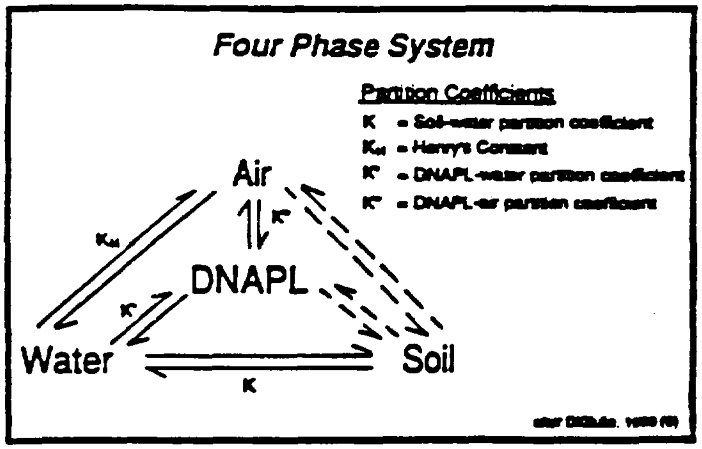


Figure 4. Distribution of DNAPL between the four phases found in the vadose zone.

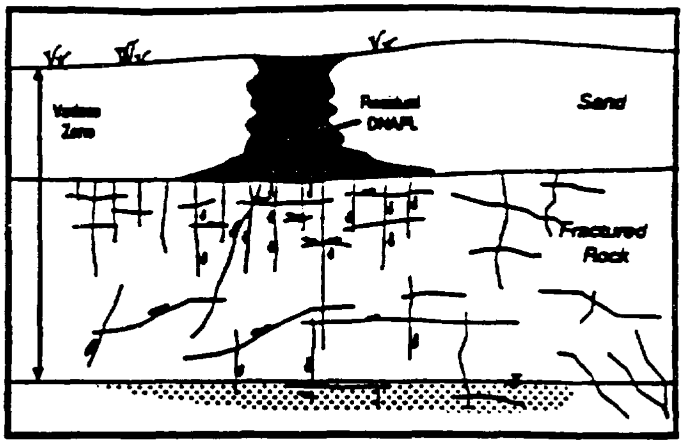


Figure 5. DNAPL spilled into fractured rock systems may follow a complex distribution of the preferential pathways.

The concept of phase distribution is critical in decision-making. Understanding the phase distribution of a DNAPL introduced into the subsurface provides significant insight in determining which tools are viable options with respect to site characterization and remediation.

DNAPL represented by residual saturation in the four phase diagram is largely immobile under the usual subsurface pressure conditions and can migrate further only: 1) in water according to its solubility; or 2) in the gas phase of the unsaturated zone (47). DNAPL components adsorbed onto the soil are also considered immobile. The mobile phases are, therefore, the soluble and volatile components of the DNAPL in the water and air, respectively.

The pore space in the unsaturated zone may be filled with one or all three fluid phases (gaseous, aqueous, immiscible). The presence of DNAPL as a continuous immiscible phase has the potential to be mobile. The mobility of DNAPL in the subsurface must be evaluated on a case by case basis. The maximum number of potentially mobile fluid phases is three. Simultaneous flow of the three phases (air, water, and immiscible) is considerably more complicated than two-phase flow (46). The mobility of three phase flow in a four-phase system is complex, poorly understood, and is beyond the scope of this DNAPL overview. The relative mobility of the two phases, water and DNAPL, in a three-phase system is presented below in the section entitled "Relative Permeability."

Generally, rock aquifers contain a myriad of cracks (fractures) of various lengths, widths, and apertures (32). Fractured rock systems have been described as rock blocks bounded by discrete discontinuities comprised of fractures, joints, and shear zones which may be open, mineral-filled, deformed, or any combination thereof (61). The unsaturated zone overlying these fractured rock systems also contain the myriad of preferential pathways. DNAPL introduced into such formations (Figure 5) follow complex pathways due to the heterogeneous distribution of the cracks, conduits, and fractures', i.e., preferential pathways. Transport of DNAPL may follow non-Darcian flow in the open fractures and/or Darcian flow in the porous media filled fractures. Relatively small volumes of NAPL may move deep, quickly into the rock because the retention capacity offered by the dead-end fractures and the immobile fragments and globules in the larger fractures is so small (32). Currently, the capability to collect the detailed information for a complete description of a contaminated fractured rock system is regarded as neither technically possible nor economically feasible (61).

Low permeability stratigraphic units such as high clay content formations may also contain a heterogeneous distribution of preferential pathways. As illustrated in Figure 6, DNAPL transport in these preferential pathways is correspondingly complex. Typically, it is assumed that high clay content formations are impervious to DNAPL. However, as DNAPL spreads out on low permeable formations it tends to seek out zones of higher permeability. As a result, preferential pathways allow the DNAPL to migrate further into the low permeable formation, or through it to underlying stratigraphic units. It is apparent from Figures 5 and 6 that the complexity of DNAPL transport may be significant prior to reaching the water table.

Saturated Zone

The second general scenario is one in which the volume of DNAPL is sufficient to overcome the fraction depleted by the residual saturation in the vadose zone, as illustrated in Figure 7. Consequently, the DNAPL reaches the water table and contaminates the ground water directly. The specific gravity of DNAPL is greater than water, therefore, the DNAPL migrates into the saturated zone. In this scenario, DNAPL continues the vertical migration through the saturated zone until the volume is eventually exhausted by the residual saturation process or until it is intercepted by a low permeable formation where it begins to migrate laterally.

DNAPL Phase Distribution - Three Phase System

Due to the lack of the gaseous phase, the saturated zone containing DNAPL is considered a three-phase system consisting of the solid, water, and immiscible hydrocarbon (Figure 8). Contaminant distribution in the three-phase system is less complex than the four-phase system. Again, this is highly dependent on the characteristics of both the aquifer

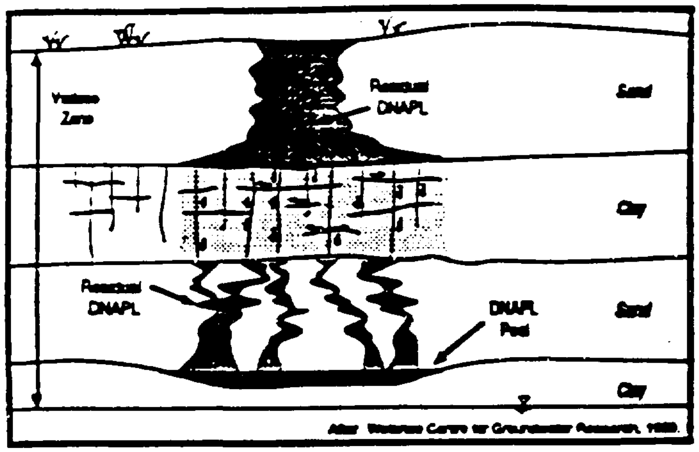


Figure 6. DNAPL spilled into a low permeable formation may follow a complex distribution of preferential pathways. The volume of DNAPL is exhausted in the vadose zone prior to reaching the water table.

matrix and the DNAPL. Figure 9 indicates the three phases and the transfer of the mass of contaminant between the phases. In this scenario, there are only three pathways of phase distribution in the saturated zone.

Note that when the DNAPL is represented by residual saturation in the three-phase system, the mobile phase of the contaminant is the water soluble components of the DNAPL and the immobile phases are the residual saturation and the adsorbed components of the DNAPL associated with the aquifer material. The main mobilization mechanism of the residual saturation is removal of soluble phase components into the ground water. When the DNAPL is present as a continuous immiscible phase, it too is considered one of the mobile phases of the contaminant. While the continuous phase DNAPL has the potential to be mobile, immobile continuous phase DNAPL may also exist in the subsurface. Although the saturated zone is considered a three-phase system, gaseous vapors from DNAPL in the unsaturated zone does have the potential to affect ground-water quality, as was indicated earlier in Figure 2.

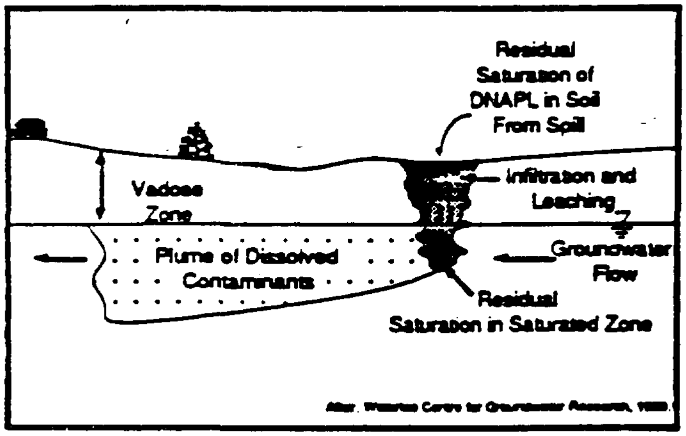


Figure 7. The volume of DNAPL is sufficient to overcome the residual saturation in the vadose zone and consequently penetrates the water table.

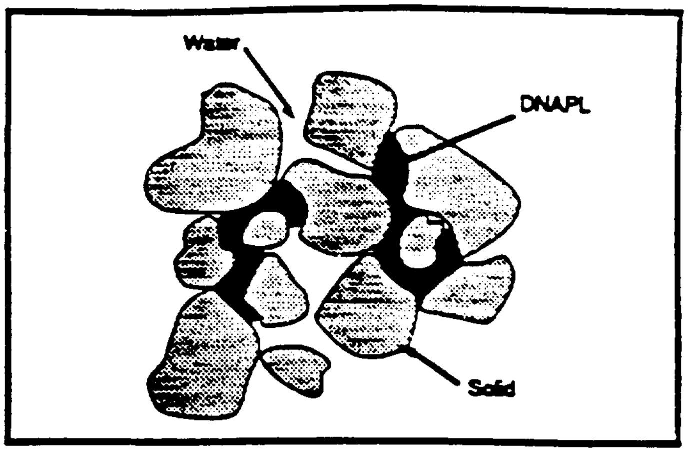
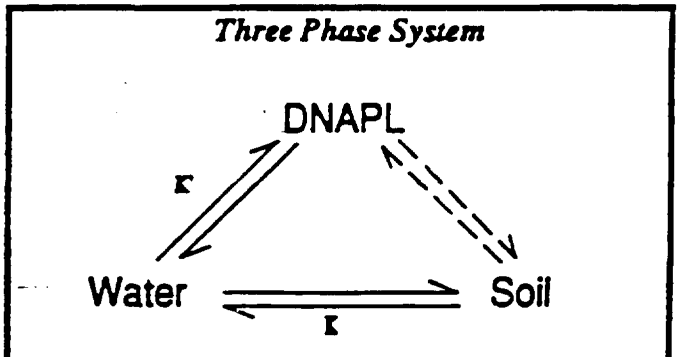


Figure 8. A DNAPL contaminated saturated zone has three phases (solid, water, immiscible). The contaminant may be present in any one, or all three phases.

Assuming the residual saturation in the saturated zone does not deplete the entire volume of the DNAPL, the DNAPL will continue migrating vertically until it encounters a zone or stratigraphic unit of lower permeability. Upon reaching the zone of lower permeability, the DNAPL will begin to migrate laterally. The hydraulic conductivity in the vertical direction is typically less than in the horizontal direction. It is not uncommon to find vertical conductivity that is one-fifth or one-tenth the horizontal value (4). It is expected that DNAPL spilled into the subsurface will have a significant potential to migrate laterally. If the lower permeable boundary is "bowl shaped", the DNAPL will pond as a reservoir (refer to Figure 10). As illustrated in Figure 11, it is not uncommon to observe a perched DNAPL reservoir where a discontinuous impermeable layer; i.e., silt or clay lens, intercepts the vertical migration of DNAPL. When a sufficient volume of DNAPL has been released and multiple discontinuous impermeable layers exist, the DNAPL may be present in several perched reservoirs as well as a deep



K' = DNAPL-water partition coefficient
K = Soil-water partition coefficient

Figure 9. Distribution of DNAPL between the three phases found in the saturated zone.

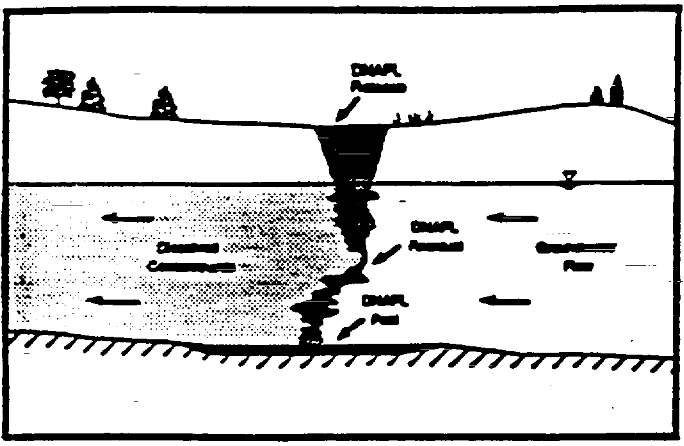


Figure 10. Migration of DNAPL through the vadose zone to an impermeable boundary.

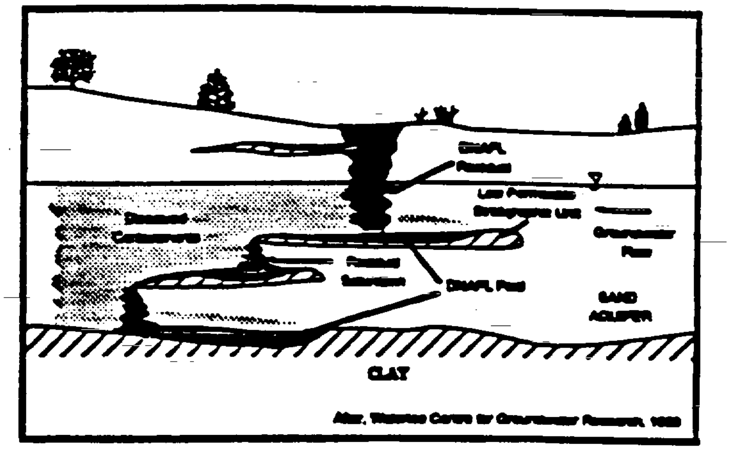


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Figure 12. Perched and deep DNAPL reservoirs.

reservoir (refer to Figure 12). Lateral migration continues until either the residual saturation depletes the DNAPL or an impermeable depression immobilizes the DNAPL in a reservoir type scenario. Soluble-phase components of the DNAPL will partition into the ground water from both the residual saturation or DNAPL pools. The migration of DNAPL vertically through the aquifer results in the release of soluble-phase components of the DNAPL across the entire thickness of the aquifer. Note, that ground water becomes contaminated as it flows through and around, the DNAPL contaminated zone.

As indicated earlier, DNAPL will migrate laterally upon reaching a stratigraphic unit of lower permeability. Transport of DNAPL will therefore be largely dependent on the gradient of the stratigraphy. Occasionally, the directional gradient of an impermeable stratigraphic unit may be different than the direction of ground-water flow as illustrated in Figure 13a. This may result in the migration of the continuous phase DNAPL in a direction different from the ground-water flow. Nonhorizontal stratigraphic units with varying hydraulic conductivity may also convey DNAPL in a different direction than ground-water flow, and at different rates (refer to Figure 13b). Determination of the direction of impermeable stratigraphic units will therefore provide useful information concerning the direction of DNAPL transport.

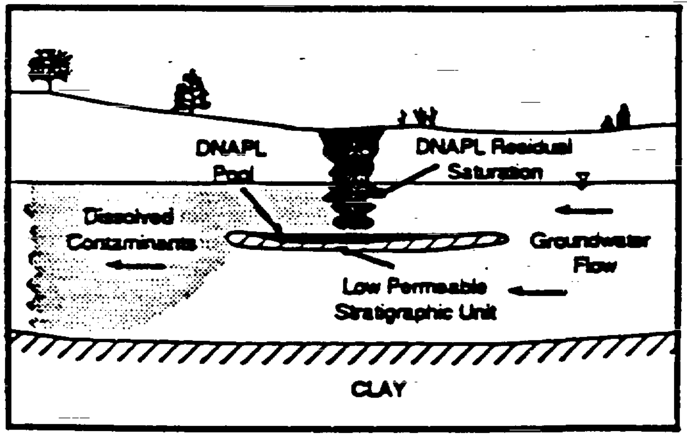

Figure 11. Perched DNAPL reservoir.

Similar to the unsaturated zone, the saturated zone also contains a complex distribution of preferential pathways from cracks, fractures, joints, etc. DNAPL introduced into such formations correspondingly follow the complex network of pathways through an otherwise relatively impermeable rock material. Other pathways which may behave as vertical conduits for DNAPL include root holes, stratigraphic windows, disposal wells, unsealed geotechnical boreholes, improperly sealed hydrogeological investigation sampling holes and monitoring wells, and old uncased/unsealed water supply wells (72). Transport of the DNAPL may migrate very rapidly in these open conduits or follow Darcian flow in the surrounding porous media or porous media filled fractures. A relatively small volume of DNAPL can move deep into a fractured system due to the low retentive capacity of the fractured system. Consequently, fractured clay or rock stratigraphic units, which are often considered lower DNAPL boundary conditions, may have preferential pathways leading to lower formations, as depicted in Figure 14. Careful inspection of soil cores at one Superfund site indicated that DNAPL flow mainly occurred through preferential pathways and was not uniformly distributed throughout the soil mass (8). Due to the complex

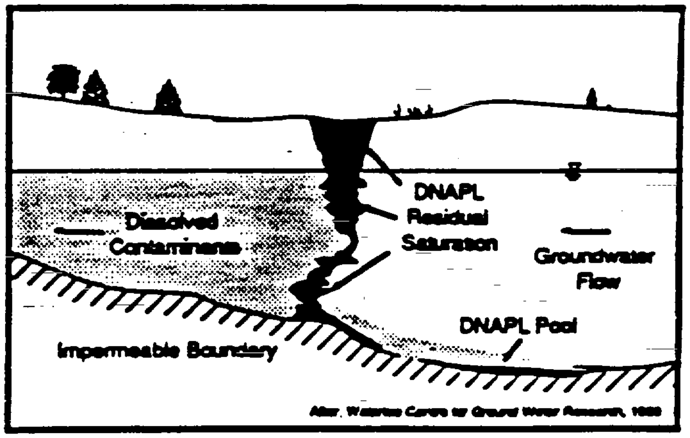

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Figure 13a. Stratigraphic gradient different from ground water gradient results in a different direction of flow of the ground water and continuous phase DNAPL.

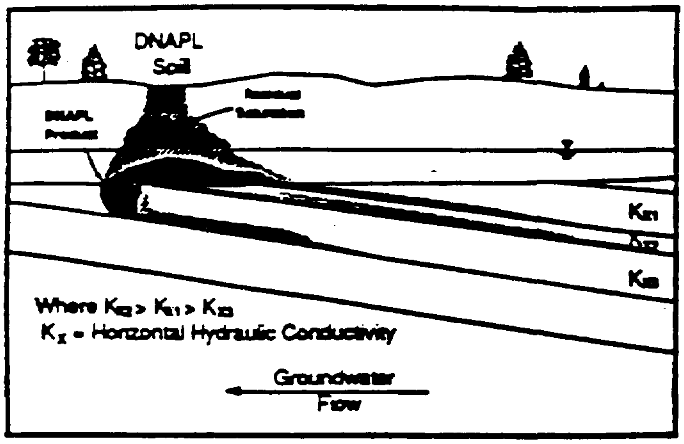

Figure 13b. Non-horizontal stratigraphic units with variable hydraulic conductivity may convey DNAPL in a different direction than the ground water flow direction.

distribution of preferential pathways, characterization of the volume distribution of the DNAPL is difficult.

Important DNAPL Transport and Fate Parameters

There are several characteristics associated with both the subsurface media and the DNAPL which largely determine the fate and transport of the DNAPL. A brief discussion of these parameters is included to help identify the specific details of DNAPL transport mechanisms. Several of the distinctive DNAPL phenomena observed on the field-scale relates back to phenomena at the pore-scale. Therefore, it is important to understand the principles from the pore-scale level to develop an understanding of field-scale observations, which is the scale at which much of the Superfund work occurs. A more complete and comprehensive review of these parameters is available (2,36,71).

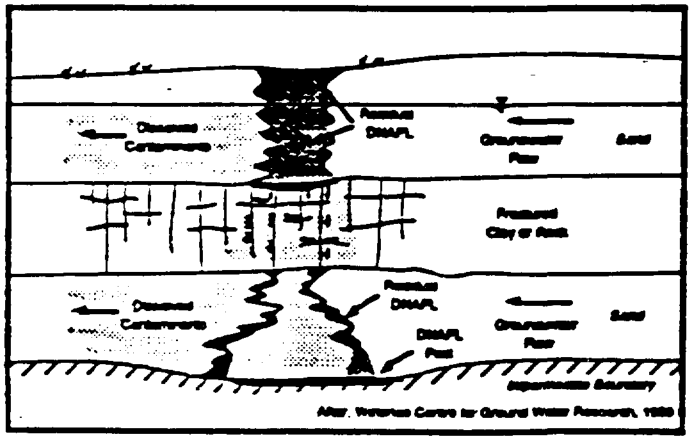

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Figure 14. DNAPL transport in fracture and porous media stratigraphic units.

DNAPL Characteristics

Density

Fluid density is defined as the mass of fluid per unit volume, i.e. g/cm^3. Density of an immiscible hydrocarbon fluid is the parameter which delineates LNAPL's from DNAPL's. The property varies not only with molecular weight but also molecular interaction and structure. In general, the density varies with temperature and pressure (2). Equivalent methods of expressing density are specific weight and specific gravity. The specific weight is defined as the weight of fluid per unit volume, i.e. lb/ft^3. The specific gravity (S.G.) or the relative density of a fluid is defined as the ratio of the weight of a given volume of substance at a specified temperature to the weight of the same volume of water at a given temperature (31). The S.G. is a relative indicator which ultimately determines whether the fluid will float (S.G.$<$ 1.0) on, or penetrate into (S.G.$\geq$1.0) the water table. Table 1 contains a list of compounds with a density greater than one that are considered DNAPL's. Note, however, that while the specific gravity of pentachlorophenol and the non-halogenated semi-volatiles is greater than 1.00, these compounds are a solid at room temperature and would not be expected to be found as an immiscible phase liquid at wood preserving sites but are commonly found as contaminants. Pentachlorophenol is commonly used as a wood preservant and is typically dissolved (4-7%) in No. 2 or 3 fuel oil.

Viscosity

The viscosity of a fluid is a measure of its resistance to flow. Molecular cohesion is the main cause of viscosity. As the temperature increases in a liquid, the cohesive forces decrease and the absolute viscosity decreases. The lower the viscosity, the more readily a fluid will penetrate a porous media. The hydraulic conductivity of porous media is a function of both the density and viscosity of the fluid as indicated in equation [1]. It is apparent from this equation that fluids with either a viscosity less than water or fluids with a density greater than water have the potential to be more mobile in the subsurface, than water.

$$K = \frac{k \rho g}{\mu} \quad \text{where,} \tag{1}$$

K = hydraulic conductivity
k = intrinsic permeability
ρ = fluid mass density
g = gravity
μ = dynamic (absolute) viscosity

Results from laboratory experiments indicated that several chlorinated hydrocarbons which have low viscosity (methylene chloride, perchloroethylene, 1,1,1-TCA, TCE) will infiltrate into soil notably faster than will water (47). The relative value of NAPL viscosity and density, to water, indicates how fast it will flow in porous media (100% saturated) with respect to water. For example, several low viscosity chlorinated hydrocarbons (TCE, tetrachloroethylene, 1,1,1-TCA, Methylene Chloride, Chloroform, Carbon Tetrachloride, refer to Table 1) will flow 1.5-3.0 times as fast as water and higher viscosity compounds including light heating oil, diesel fuel, jet fuel, and crude oil (i.e. LNAPL's) will flow 2-10 times slower than water (45). Both coal tar and creosote typically have a specific gravity greater than one and a viscosity greater than water. It is interesting to note that the viscosity of NAPL may change with time (36). As fresh crude oils lose the lighter volatile components from evaporation, the oils become more viscous as the heavier components compose a larger fraction of the oily mixture resulting in an increase in viscosity.

Solubility

When an organic chemical is in physical contact with water, the organic chemical will partition into the aqueous phase. The equilibrium concentration of the organic chemical in the aqueous phase is referred to as its solubility. Table 1 presents the solubility of several of the most commonly found DNAPL's at EPA Superfund Sites. The solubility of organic compounds varies considerably from the infinitely miscible compounds, including alcohols (ethanol, methanol) to extremely low solubility compounds such as polynuclear aromatic compounds.

Numerous variables influence the solubility of organic compounds. The pH may affect the solubility of some organic compounds. Organic acids may be expected to increase in solubility with increasing pH, while organic bases may act in the opposite way (31). For example, pentachlorophenol is an acid which is ionized at higher pH's. In the ionized form, pentachlorophenol would be more soluble in water (59). Solubility in water is a function of the temperature, but the strength and direction of this function varies. The presence of dissolved salts or minerals in water leads to moderate decreases in solubility (31). In a mixed solvent system, consisting of water and one or more water-miscible compounds, as the fraction of the cosolvent in the mixture increases, the solubility of the organic chemical increases exponentially (12). In general, the greater the molecular weight and structural complexity of the organic compound, the lower the solubility.

Organic compounds are only rarely found in ground water at concentrations approaching their solubility limits, even when organic liquid phases are known or suspected to be present. The observed concentrations are usually more than a factor of 10 lower than the solubility presumably due to diffusional limitations of dissolution and the dilution of the dissolved organic contaminants by dispersion (74). This has also been attributed to: reduced solubility due to the presence of other soluble compounds, the heterogeneous distribution of DNAPL in the subsurface, and dilution from monitoring wells with long intake lengths (10). Detection of DNAPL components in the subsurface below the solubility should clearly not be interpreted as a negative indicator for the presence of DNAPL.

In a DNAPL spill scenario where the DNAPL or its vapors are in contact with the ground water, the concentration of the soluble phase components may range from non-detectable up to the solubility of the compound. The rate of dissolution has been expressed as a function of the properties of the DNAPL components (solubility), ground water flow conditions, differential between the actual and solubility concentration, and the contact area between the DNAPL and the ground water (10). The contact area is expected to be heterogeneous and difficult to quantify. Additionally, as the time of contact increases between the DNAPL and the water, the concentration in the aqueous phase increases.

Vapor Pressure

The vapor pressure is that characteristic of the organic chemical which determines how readily vapors volatilize or evaporate from the pure phase liquid. Specifically, the partial pressure exerted at the surface by these free molecules is known as the vapor pressure (30). Molecular activity in a liquid tends to free some surface molecules and this tendency towards vaporization is mainly dependent on temperature. The vapor pressure of DNAPL's can actually be greater than the vapor pressure of volatile organic compounds. For example, at 20 C, the ratio of the vapor pressures of TCE and benzene is 1.4 (1).

Volatility

The volatility of a compound is a measure of the transfer of the compound from the aqueous phase to the gaseous phase. The transfer process from the water to the atmosphere is dependent on the chemical and physical properties of the compound, the presence of other compounds, and the physical properties (velocity, turbulence, depth) of the water body and atmosphere above it. The factors that control volatilization are the solubility, molecular weight, vapor pressure, and the nature of the air-water interface through which it must pass (31). The Henry's constant is a valuable parameter which can be used to help evaluate the propensity of an organic compound to volatilize from the water. The Henry's law constant is defined as the vapor pressure divided by the aqueous solubility. Therefore, the greater the Henry's law constant, the greater the tendency to volatilize from the aqueous phase, refer to Table 1.

Interfacial Tension

The unique behavior of DNAPLs in porous media is largely attributed to the interfacial tension which exists between DNAPL and water, and between DNAPL and air. These interfacial tensions, result in distinct interfaces between these fluids at the pore-scale. When two immiscible liquids are in contact, there is an interfacial energy which exists between the fluids resulting in a physical interface. The interfacial energy arises from the difference between the inward attraction of the molecules in the interior of each phase and those at the surface of contact (2). The greater the interfacial tension between two immiscible liquids; the less likely emulsions will form; emulsions will be more stable if formed, and the better the phase separation after mixing. The magnitude of the interfacial tension is less than the larger of the surface tension values for the pure liquids, because the mutual attraction of unlike molecules at the interface reduces the large imbalance of forces (31). Interfacial tension decreases with increasing temperature, and may be affected by pH, surfactants, and gases in solution (36). When this force is encountered between a liquid and a gaseous phase, the same force is called the surface tension (66).

The displacement of water by DNAPL and the displacement of DNAPL by water in porous media often involves a phenomena referred to as immiscible fingering. The lower the interfacial tension between immiscible fluids, the greater the instability of the water:DNAPL interface and thus the greater the immiscible fingering (27). The distribution of the fingering effects in porous media has been reported to be a function of the density, viscosity, surface tension (27) and the displacement velocity

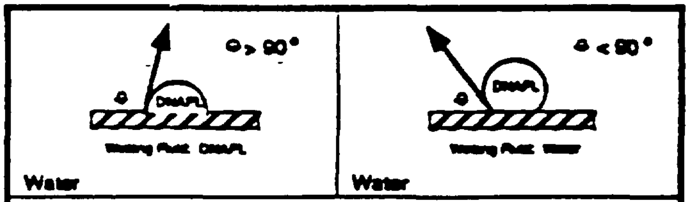
(13) of the fluids involved as well as the porous media heterogeneity (28).

Wettability

Wettability refers to the relative affinity of the soil for the various fluids - water, air, and the organic phase. On a solid surface, exposed to two different fluids, the wettability can be inferred from the contact angle (66), also referred to as the wetting angle, refer to Figure 15. In general, if the wetting angle is less than 90 degrees, the fluid is said to be the wetting fluid. In this scenario, water will preferentially occupy the smaller pores and will be found on solid surfaces (14). When the wetting angle is near 90 degrees, neither fluid is preferentially attracted to the solid surfaces. If the wetting angle is greater than 90 degrees, the DNAPL is said to be the wetting fluid. The wetting angle is an indicator used to determine whether the porous material will be preferentially wetted by either the hydrocarbon or the aqueous phase (71). Wettability, therefore, describes the preferential spreading of one fluid over solid surfaces in a two-fluid system. The wetting angle, which is a measure of wettability, is a solid-liquid interaction and can actually be defined in terms of interfacial tensions (71). Several methods have been developed to measure the wetting angle (36,71). In most natural systems, water is the wetting fluid, and the immiscible fluid is the non-wetting fluid. Coal tar may be the exception (i.e. contact angle greater than 90 degrees), which is mainly attributed to the presence of surfactants (70). The wetting fluid will tend to coat the surface of grains and occupy smaller spaces (i.e. pore throats) in porous media, the non-wetting fluid will tend to be restricted to the largest openings (47).

The wetting angle depends on the character of the solid surface on which the test is conducted. The test is conducted on flat plates composed of minerals which are believed representative of the media, or on glass. Contact angle measurements for crude oil indicates that the wetting angles vary widely depending on the mineral surface (53). Soil and aquifer material are not composed of homogeneous mineral composition nor flat surfaces. The measured wetting angle can only be viewed as a qualitative indicator of wetting behavior.

The reader is recommended to refer to reference No. 82 for review of the basic principles and for various techniques to measure the following DNAPL parameters: density, viscosity, interfacial tension, solubility, vapor pressure, and volatility.



Fluid Relationships:

System	Wetting Fluid	Non-Wetting Fluid
air:water	water	air
air: DNAPL	DNAPL	air
water:DNAPL	water	DNAPL
air:DNAPL:water	water>organic>air (1)	

(1) Wetting fluid order

After: Waterloo Centre for Groundwater Research, 1989.

Figure 15. Wetting angle and typical wetting fluid relationships.

Subsurface Media Characteristics

Capillary Force/Pressure

Capillary pressure is important in DNAPL transport because it largely determines the magnitude of the residual saturation that is left behind after a spill incident. The greater the capillary pressure, the greater the potential for residual saturation. In general, the capillary force increases in the following order; sand, silt, clay. Correspondingly, the residual saturation increases in the same order. Capillary pressure is a measure of the tendency of a porous medium to suck in the wetting fluid phase or to repel the nonwetting phase (2). Capillary forces are closely related to the wettability of the porous media. The preferential attraction of the wetting fluid to the solid surfaces cause that fluid to be drawn into the porous media. Capillary forces are due to both adhesion forces (the attractive force of liquid for the solids on the walls of the channels through which it moves) and cohesion forces (the attraction forces between the molecules of the liquid) (32). The capillary pressure depends on the geometry of the void space, the nature of solids and liquids, the degree of saturation (2) and in general, in-creases with a decrease in the wetting angle and in pore size, and with an increase in the interfacial tension (71). All pores have some value of capillary pressure. Before a nonwetting fluid can enter porous media, the capillary pressure of the largest pores (smallest capillary pressure) must be exceeded. This minimum capillary pressure is called the entry pressure.

In the unsaturated zone, pore space may be occupied by water, air (vapors), or immiscible hydrocarbon. In this scenario, capillary pressure retains the water (wetting phase) mainly in the smaller pores where the capillary pressure is greatest. This restricts the migration of the DNAPL (non-wetting phase) through the larger pores unoccupied by water. Typically, DNAPL does not displace the pore water from the smaller pores. It is interesting to note that the migration of DNAPL through fine material (high capillary pressure) will be impeded upon reaching coarser material (low capillary pressure).

The capillary fringe will obstruct the entry of the DNAPL into the saturated zone. When a sufficient volume of DNAPL has been released and the "DNAPL pressure head" exceeds the water capillary pressure at the capillary fringe (entry pressure), the DNAPL will penetrate the water table. This is why DNAPL is sometimes observed to temporarily flatten out on top of the water table. Similarly, laboratory experiments have been conducted in which DNAPL (tetrachloroethylene) infiltrating through porous media was found to flow laterally and cascade off lenses too fine to penetrate (28), (refer to Figure 11). This was attributed to the inability of the DNAPL to overcome the high capillary pressure associated with the lenses. Logically, when "DNAPL pressure head" exceeds the capillary pressure, the DNAPL will penetrate into the smaller pores. These laboratory experiments are important because they illustrate that small differences in the capillary characteristics of porous media can induce significant lateral flow of non-wetting fluids.

A comprehensive investigation of capillary trapping and multiphase flow of organic liquids in unconsolidated porous media revealed many intricacies of this process in the vadose and saturated zone (66). An important note is that while capillary pressure is rarely measured at hazardous waste sites, the soil texture (sand, silt, clay) is usually recorded during drilling operations and soil surveys. This information, along with soil core analyses will help to delineate the stratigraphy and the volume distribution of NAPL.

Pore Size Distribution/Initial Moisture Content

In natural porous media, the geometry of the pore space is extremely irregular and complex (2). The heterogeneity of the subsurface environment i.e. the variability of the pore size distribution, directly affects the distribution of the capillary pressures along the interfaces between the aqueous and immiscible phases (50). In saturated column experiments, it was observed that NAPL preferentially traveled through strings of macropores, almost completely by-passing the water filled micropores (66). In the same study, a heterogeneous distribution of coarse and fine porous material was simulated. Most of the incoming organic liquid preferentially traveled through the coarse lens material.

In short term column drainage experiments, results indicated that the particle grain size is of primary importance in controlling the residual saturation of a gasoline hydrocarbon (19). Fine and coarse sands (dry) were found to have 55% and 14% residual saturation, respectively. The finer the sand, the greater the residual saturation. During these experiments, the residual saturation was reduced 20-30% in a medium sand and 60% in a fine sand when the sands were initially wet. Soil pore water held tightly by capillary forces in the small pores will limit the NAPL to the larger pores, and thus, result in lower residual saturation. In a similar laboratory (unsaturated) column study, the smaller the grain size used in the experiment, the greater the residual saturation of the NAPL (74). The residual saturation in the saturated column experiments was found to be greater than the unsaturated columns and was independent of the particle size distribution.

These observations follow traditional capillary force theory. Residual saturation resulting from a DNAPL spill in the unsaturated zone is highly dependent on the antecedent moisture content in the porous media. When the moisture content is low, the strong capillary forces in the smaller pores tenaciously draw in and hold the DNAPL. When the moisture content is high, the capillary forces in the smaller pores will retain the soil pore water, and DNAPL residual saturation will mainly occur in the larger pores. Therefore, greater residual saturation can be expected in dryer soils. Correspondingly, NAPL will migrate further in a wetter soil, and displacement of NAPL from small pores is expected to be more difficult than from large pores.

Stratigraphic Gradient

DNAPL migrating vertically will likely encounter a zone or stratigraphic unit of lower vertical permeability. A reduction in the vertical permeability of the porous media will induce lateral flow of the DNAPL. The gradient of the lower permeable stratigraphic unit will largely determine the direction in which the DNAPL will flow. This is applicable to both the saturated and unsaturated zones. As depicted in Figures 13a and 13b, the lateral direction of DNAPL flow may be in a different direction than ground-water flow.

Ground Water Flow Velocity

The ground water flow velocity is a dynamic stress parameter which tends to mobilize the hydrocarbon (39). As the ground water velocity increases, the dynamic pressure and viscous forces increase. Mobilization of DNAPL occurs when the viscous forces of the ground water acting on the DNAPL exceeds the porous media capillary forces retaining the DNAPL.

Saturation Dependent Functions

Residual Saturation

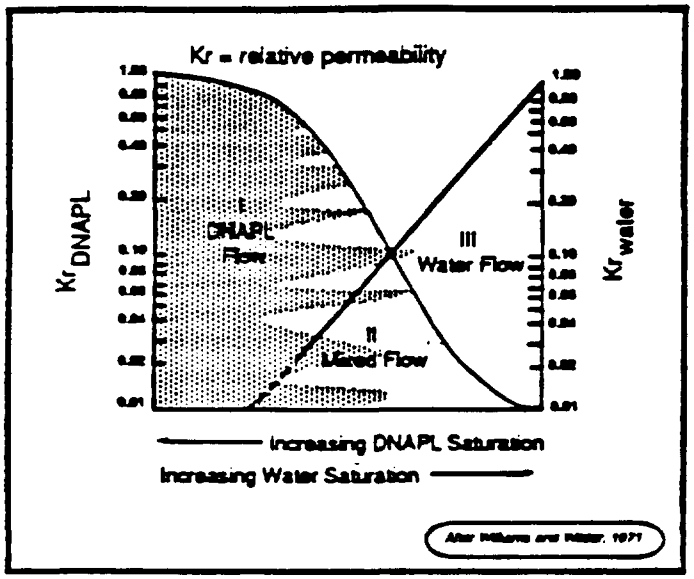
Residual saturation is defined as the volume of hydrocarbon trapped in the pores relative to the total volume of pores (38) and therefore is measured as such (74). Residual saturation has also been described as the saturation at which NAPL becomes discontinuous and is immobilized by capillary forces (36). The values of residual saturation vary from as low as 0.75 - 1.25% for light oil in highly permeable media to as much as 20% for heavy oil (50). Residual saturation values have also been reported to range from 10% to 50% of the total pore space (39,74). Other researchers reported that residual saturation values appear to be relatively insensitive to fluid properties and very sensitive to soil properties (and heterogeneities) (66). Laboratory studies conducted to predict the residual saturation in soils with similar texture and grain size distribution yielded significantly different values. It was concluded that minor amounts of clay or silt in a soil may play a significant role in the observed values.

In the unsaturated zone during low moisture conditions, the DNAPL residual saturation will wet the grains in a pendular state (a ring of liquid wrapped around the contact point of a pair of adjacent grains). During high moisture conditions, the wetting fluid, which is typically water, will preferentially occupy the pendular area of adjacent grains and the hydrocarbon will occupy other available pore space, possibly as isolated droplets. In the saturated zone, the DNAPL residual saturation will be present as isolated drops in the open pores (47). Furthermore, results of laboratory experimentation indicated that residual saturation increased with decreasing hydraulic conductivity in both the saturated and unsaturated zones and that the residual saturation is greatest in the saturated zone. Laboratory experiments indicated that vadose zone residual saturation was roughly one third of the residual saturation in the saturated zone (66). The increase in residual saturation in the saturated zone is due to the following: [1] the fluid density ratio (DNAPL:air versus DNAPL:water above and below the water table, respectively) favors greater drainage in the vadose zone; [2] as the non-wetting fluid in most saturated media, NAPL is trapped in the larger pores; and, [3] as the wetting fluid in the vadose zone, NAPL tends to spread into adjacent pores and leave a lower residual content behind, a process that is inhibited in the saturated zone (36). Thus, the capacity for retention of DNAPLs in the unsaturated zone is less than the saturated zone.

Relative Permeability

Relative permeability is defined as the ratio of the permeability of a fluid at a given saturation to its permeability at 100% saturation. Thus it can have a value between 0 and 1 (71).

Figure 16 illustrates a relative permeability graph for a two fluid phase system showing the relationship between the observed permeability of each fluid for various saturations to that of the observed permeability if the sample were 100% saturated with that fluid (73). The three regions of this graph are explained as follows (71): Region I has a high saturation of DNAPL and is considered a continuous phase while the water is a discontinuous phase, therefore, water permeability is low. Assuming the DNAPL is the non-wetting fluid, water would fill the smaller capillaries and flow through small irregular pores. In Region II, both water and DNAPL are continuous phases although not necessarily in the same pores. Both water and NAPL flow simultaneously. However, as saturation of either phase increases, the relative permeability of the other phase correspondingly decreases. Region III exhibits a high saturation of water while the DNAPL phase is mainly discontinuous. Water flow dominates this region and there is little or no flow of DNAPL.

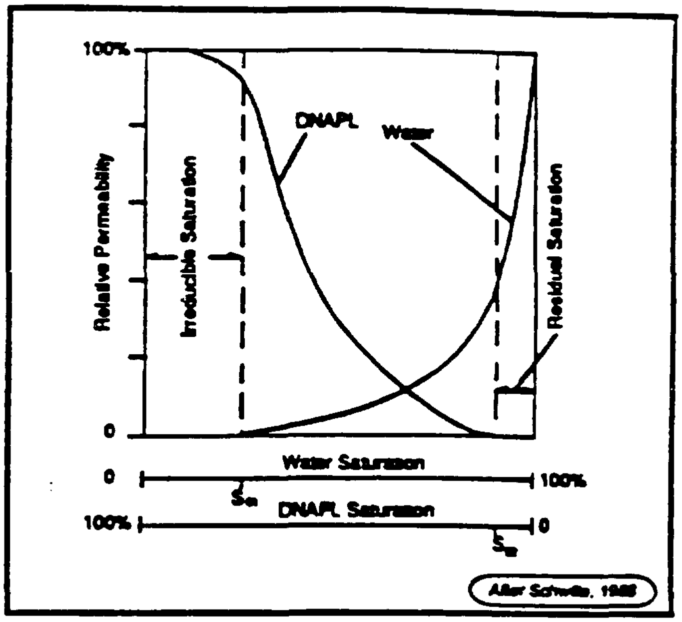


After Williams and Wilder, 1971

Figure 16. Relative permeability graph.

Both fluids flow through only a part of the pore space and thus only a part of the cross section under consideration is available for flow of each fluid. Therefore, the discharge of each fluid must be lower corresponding to its proportion of the cross sectional area (46).

Figure 17 is another relative permeability graph which demonstrates several points. Small increases in DNAPL saturation results in a significant reduction in the relative permeability of water. However, a small increase in water saturation does not result in a significant reduction in DNAPL relative permeability. This figure identifies two points, SO1 and SO2, where the saturation of the DNAPL and the water are greater than 0 before there is a relative permeability for this fluid. The two fluids hinder the movement of the other to different degrees and both must reach a minimum saturation before they achieve any mobility at all (47). These minimum saturations, for the water and DNAPL are identified as irreducible and residual saturation, respectively.



After Schwille, 1988

Figure 17. The relative permeability curves for water and a DNAPL in a porous medium as a function of the pore space saturation.

Site Characterization for DNAPL

Characterization of the subsurface environment at hazardous waste sites containing DNAPL is complex and will likely be expensive. Specific details associated with the volume and timing of the DNAPL release are usually poor or are not available and subsurface heterogeneity is responsible for the complicated and unpredictable migration pathway of subsurface DNAPL transport. As discussed previously, slight changes in vertical permeability may induce a significant horizontal component to DNAPL migration.

Site characterization typically involves a significant investment in ground-water analyses. Although analysis of ground water provides useful information on the distribution of the soluble components of the DNAPL, the presence of other phases of the DNAPL may go unrecognized. The investigation must, therefore, be more detailed to obtain information concerning the phase distribution of the DNAPL at a site. Site characterization may require analyses on all four phases (aqueous, gaseous, solid, immiscible) to yield the appropriate information (refer to Table 2). In brief, data collected on the various phases must be compiled, evaluated and used to help identify: where the contaminant is presently located; where it has been; what phases it occurs in; and what direction the mobile phases may be going. A comprehensive review of site characterization for subsurface investigations is available (68). Development of monitoring and remediation strategies can be focused more effectively and efficiently after a clear definition of the phase distribution has been completed.

Ground Water

Ground water analyses for organic compounds, in conjunction with ground water flow direction data, has repeatedly been used to: delineate the extent of ground water contamination from DNAPL; determine the direction of plume migration; and

Table 2 - Phase Distribution of DNAPL in the Subsurface

	MATRIX	PHASE
1.	ground water	aqueous - soluble components of DNAPL
2.	soil/aquifer material	solid - adsorbed components of DNAPL on solid phase material
3.	DNAPL	immiscible - continuous phase (mobile), residual saturation (immobile)
4.	soil gas	gaseous - volatile components

to identify probable DNAPL source area(s). While this approach has been used successfully to characterize the distribution of contaminants in the subsurface, there are limitations. For example, since DNAPL and ground water may flow in different directions, as indicated in Figures 13a and 13b, ground water analyses may not necessarily identify the direction of DNAPL migration.

Ground water analyses may be useful to identify probable DNAPL source areas, but, estimating the volume of DNAPL in the subsurface is limited using this approach. Soluble phase components of DNAPL are rarely found in excess of 10% of the solubility even when organic liquids are known or suspected to be present. The concentration of soluble DNAPL components in the ground water is not only a function of the amount of DNAPL present, but also the chemical and physical characteristics of the DNAPL, the contact area and time between the ground water and DNAPL, and numerous transport and fate parameters (retardation, biodegradation, dispersion, etc.). One technique has been developed using chemical ratios in the ground water as a means of source identification and contaminant fate prediction (18).

Soil/Aquifer Material

Exploratory Borings

Physical and chemical analyses of soil and aquifer material (drill cuttings, cores) from exploratory borings will provide useful information in the delineation of the horizontal and vertical mass distribution of DNAPL. While simple visual examination for physical presence or absence of contamination might seem like a worthwhile technique, it can be deceiving and does nothing to sort out the various liquid phases and their relationship to each other (71). A quantitative approach is necessary to determine DNAPL distribution.

Drill cuttings or core material brought to the surface from exploratory borings can be screened initially to help delineate the depth at which volatile components from the various phases of the hydrocarbon exists. The organic vapor analyzer and the HNU are small portable instruments that can detect certain volatile compounds in the air. These methods are used to initially screen subsurface materials for volatile components of DNAPL. Identification of individual compounds and their concentrations may be confirmed by other, more precise, analyses.

Analysis of the soil or aquifer material by more accurate means, such as gas chromatography or high pressure liquid chromatography, will take longer but will provide more specific information on a larger group of organic compounds, i.e., volatile/non-volatile, and on specific compounds. This information is necessary to help fix the horizontal and vertical mass distribution of the contaminant and to help delineate the phase distribution. These analyses do not distinguish between soluble, sorbed or free-phase hydrocarbon, however; a low relative concentration indicates that the contaminant may mainly be present in the gaseous or aqueous phases; and a high relative concentration indicates the presence of sorbed contaminant or free phase liquid either as continuous-phase or residual saturation. A more rigorous set of analyses is required to distinguish between the various phases.

Additional tests to identify the presence of NAPL in soil or aquifer core sample are currently undeveloped and research in this area is warranted. Squeezing and immiscible displacement techniques have been used to obtain the pore water from cores (40). Other methods of phase separation involving vacuum or centrifugation may also be developed for this use. A paint filter test was proposed in one Superfund DNAPL field investigation where aquifer cores were placed in a filter/funnel apparatus, water was added, and the filtrate was examined for separate phases. These core analysis techniques have potential to provide valuable field data to characterize NAPL distribution.

Cone Penetrometer

The cone penetrometer (ASTM D3441-86)(69) has been used for some time to supply data on the engineering properties of soils. Recently, the application of this technology has made the leap to the hazardous waste arena. The resistance of the formation is measured by the cone penetrometer as it is driven vertically into the subsurface. The resistance is interpreted as a measure of pore pressure, and thus provides information on the relative stratigraphic nature of the subsurface. Petroleum and chlorinated hydrocarbon plumes can be detected most effectively when the cone penetrometer is used in conjunction with in-situ sensing technologies (48). Features of the cone penetrometer include: a continuous reading of the stratigraphy/permeability; in-situ measurement; immediate results are available; time requirements are minimal; vertical accuracy of stratigraphic composition is high; ground-water samples can be collected in-situ; and the cost is relatively low.

Data from the cone penetrometer can be used to delineate probable pathways of DNAPL transport. This is accomplished by identifying permeability profiles in the subsurface. A zone of low permeability underlying a more permeable stratigraphic unit will likely impede vertical transport of the DNAPL. Where such a scenario is found, a collection of DNAPL is probable and further steps can be implemented to more accurately and economically investigate and confirm such an occurrence. This general approach has successfully been implemented at one Superfund site (8).

DNAPL

Well Level Measurements

In an effort to delineate the horizontal and vertical extent of the DNAPL at a spill site, it is important to determine the elevation of DNAPL in the subsurface. Monitoring DNAPL elevation over time will indicate the mobility of the DNAPL. There are several methods that can be used to determine the presence of DNAPL in a monitoring well. One method relies on the difference in electrical conductivity between the DNAPL and water. A conductivity or resistivity sensor is lowered into the well and a profile is measured. The interface of the DNAPL is accurately determined when the difference in conductivity is detected between the two fluids. This instrument may also be used to delineate LNAPL. A transparent, bottom-loading bailer can also be used to measure the thickness (and to sample) of DNAPL in a well (36). The transparent bailer is raised to the surface and the thickness of the DNAPL is made by visual measurement.

Several laboratory and field studies have been performed which investigate the anomaly between the actual and measured LNAPL levels in ground-water wells (15,16,24,25). The anomaly between actual and measured NAPL thickness in the subsurface is also applicable to DNAPL, but for different reasons. The location of the screening interval is the key to understanding both scenarios. First, if the well screen interval is situated entirely in the DNAPL layer, and the hydrostatic head (water) in the well is reduced by pumping or bailing, then to maintain hydrostatic equilibrium, the DNAPL will rise in the well (36,44,71) (refer to Figure 18). Secondly, if the well screen extends into the barrier layer, the DNAPL measured thickness will exceed that in the formation by the length of the well below the barrier surface (36) (refer to Figure 19). Both of these scenarios will result in a greater DNAPL thickness in the well and thus a false indication (overestimate) of the actual DNAPL thickness will result. One of the main purposes of the monitoring well in a DNAPL investigation is to provide information on the thickness of the DNAPL in the aquifer. Therefore, construction of the well screen should intercept the ground water:DNAPL interface and the lower end of the screen should be placed as close as possible to the impermeable stratigraphic unit.

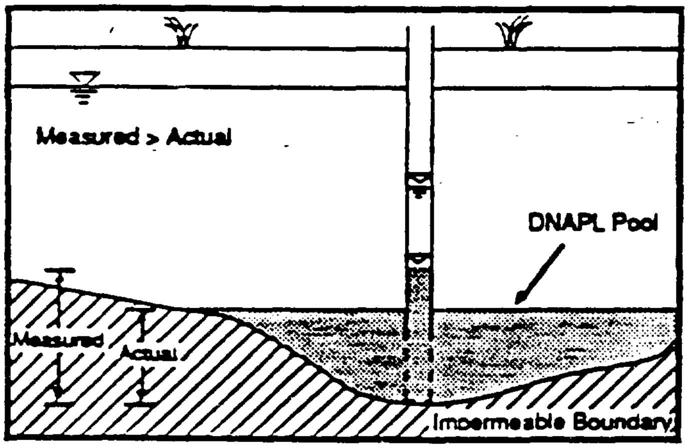


Figure 18. A well screened only in the DNAPL in conjunction with lower hydrostatic head (i.e. water) in the well may result in an overestimation of DNAPL thickness.

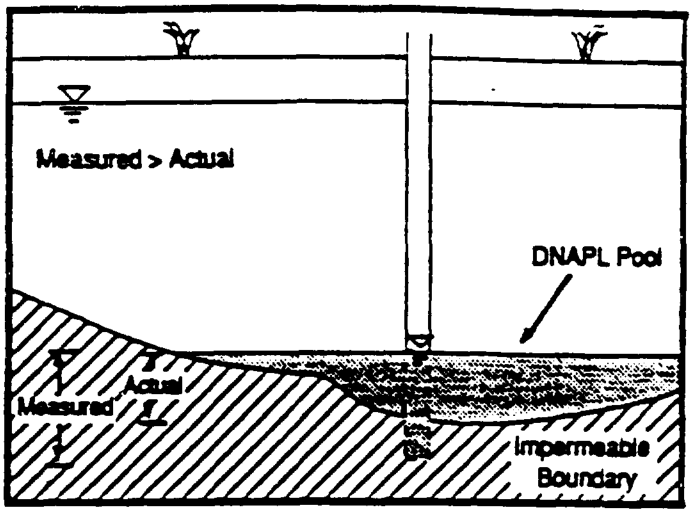


Figure 19. A well screened into an impermeable boundary may result in an over-estimation of the DNAPL thickness.

DNAPL Sampling

Sampling of DNAPL from a well is necessary to perform chemical and physical analyses on the sample. Two of the most common methods used to retrieve a DNAPL sample from a monitoring well are the peristaltic pump and the bailer. A peristaltic pump can be used to collect a sample if the DNAPL is not beyond the effective reach of the pump, which is typically less than 25 feet. The best method to sample DNAPL is to use a double check valve bailer. The key to sample collection is controlled, slow lowering (and raising) of the bailer to the bottom of the well (57). The dense phase should be collected prior to purging activities.

Soil-Gas Surveys

A soil-gas survey refers to the analysis of the soil air phase as a means to delineate underground contamination from volatile organic chemicals and several techniques have been developed (34,52). This investigative tool is mainly used as a preliminary screening procedure to delineate the areal extent of volatile organic compounds in the soil and ground water. This method is quick, less expensive than drilling wells and can provide greater plume resolution (33).

Data from a soil-gas survey is a valuable aid in the development of a more detailed subsurface investigation where ground water monitoring wells and exploratory borings are strategically located for further site characterization. There are limitations to soil-gas surveys (26,52) and data interpretation must be performed carefully (35,49). Soil-gas investigations have mainly been conducted to identify the location of the organic contaminants in ground water. At the time of this publication, the scientific literature did not contain information specifically applicable to the delineation of DNAPL from soil-gas survey data. However, it is surmisable that soil-gas surveys can be used to help delineate DNAPL residual saturation in the unsaturated zone or the location of perched DNAPL reservoirs.

Miscellaneous

The vertical migration of DNAPL in the saturated zone will eventually be challenged by a low permeability stratigraphic unit. According to the principles of capillary pressure, the lower permeability unit will exhibit a greater capillary pressure. Displacement of water by DNAPL requires that the hydrostatic force from the mounding DNAPL exceed the capillary force of the low permeability unit. The Hobson formula is used to compute the critical height calculation to overcome the capillary pressure under different pore size conditions (70).

In an effort to minimize further DNAPL contamination as a result of drilling investigations, precautionary steps should be taken. Penetration of DNAPL reservoirs in the subsurface during drilling activities offers a conduit for the DNAPL to migrate vertically into previously uncontaminated areas. It is very easy to unknowingly drill through a DNAPL pool and the bed it sits on, causing the pool to drain down the hole into a deeper part of the aquifer or into a different aquifer (32). Special attention to grouting and sealing details during and *after drilling operations will help prevent cross-contamination.*

Precautionary efforts should also be considered when a DNAPL reservoir is encountered during drilling operations. The recommended approach is to cease drilling operations and install a well screen over the DNAPL zone and cease further drilling activities in the well. If it is necessary to drill deeper, construction of an adjacent well is recommended. Alternatively, if it is not necessary to screen off that interval, it is recommended to carefully seal off the DNAPL zone prior to drilling deeper.

Well construction material compatibility with DNAPL should be investigated to minimize downhole material failure. A construction material compatibility review and possible testing will prevent the costly failure of well construction material. The *manufacturers of well construction material are likely to have* the most extensive compatibility data and information available.

Remediation

Remediation of DNAPL mainly involves physical removal by either pumping or trench-drainline systems. Removal of DNAPL early in the remediation process will eliminate the main source of contaminants. This step will substantially improve the overall recovery efficiency of the various DNAPL phases including the long term pump and treat remediation efforts for soluble components. Remediation technologies such as vacuum extraction, biodegradation, ground water pumping, and soil flushing is mainly directed at the immobile DNAPL and the various phases in which its components occur. Physical barriers can be used in an effort to minimize further migration of the DNAPL.

Clean-up of DNAPL can involve sizable expenditures: they are difficult to extract and the technology for their removal is just evolving (43). Historically, field recovery efforts usually proceed with a poor understanding of the volume distribution of the DNAPL. This reflects the difficulties involved in adequate site characterization, poor documentation of the release, and the complexity associated with the DNAPL transport in the subsurface.

Pumping Systems

Pumping represents an important measure to stop the mobile DNAPL from migrating as a separate phase by creating a hydraulic containment and by removal of DNAPL (44). Very simply, DNAPL recovery is highly dependent on whether the DNAPL can be located in the subsurface. The best recovery scenario is one in which the DNAPL is continuous and has collected as a reservoir in a shallow, impermeable subsurface depression. Once the DNAPL has been located and recovery wells are properly installed, pumping of pure phase DNAPL is a possible option but depends largely on site specific conditions which include, but are not limited to: DNAPL thickness, viscosity, and permeability.

Many DNAPL reservoirs in the subsurface are of limited volume and areal extent. Therefore, it can be expected that both the level of DNAPL (saturated thickness) in the well will decline from the prepumping position and the percentage of DNAPL in the DNAPL:water mixture will decrease rather rapidly. Correspondingly, DNAPL recovery efficiency decreases. *Field results indicate that recovery wells screened* only in the DNAPL layer will maintain maximum DNAPL:water ratios (102). Well diameter was not found to influence long term DNAPL recovery; however, large diameter wells allow high volume pumping for short durations; and small diameter wells result in lower DNAPL:water mixtures and greater drawdown.

An enhanced DNAPL recovery scheme may be used to improve recovery efficiency. An additional well is constructed with a screen interval in the ground water zone located vertically upward from the DNAPL screen intake. Ground water is withdrawn from the upper screen which results in an upwelling of the DNAPL (70), *refer to* Figure 20. The upwelling of the DNAPL, coal tar in this case, improved the rate (twofold) at which the coal tar was recovered resulting in a more efficient operation. *The ground water withdrawal rate must be carefully* determined; too much will result in the coal tar from rising excessively and being either mixed (emulsions) with or *suppressed by the higher water velocity above; too low will not*

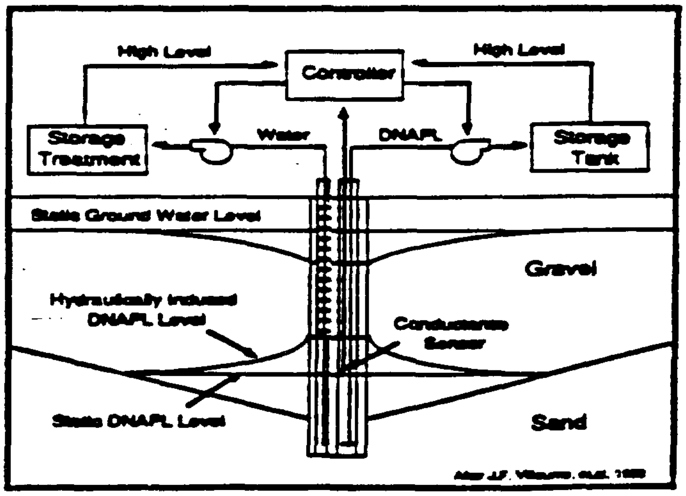


Figure 20. A DNAPL recovery system where deliberate upwelling of the static coal-tar surface is used to increase the flow of product into the recovery wells.

caused upwelling. An estimate of this upwelling can be calculated using the simplified Ghyben-Herzberg Principle under ideal conditions (4). Laboratory studies indicated that dimethyl phthalate (1.19 g/cc) recovery rate was doubled or tripled over the conventional, non-upconing, recovery scheme (75). A similar application of this technique was used to increase the level of DNAPL (solvents) in a sandstone bedrock formation (11). Other enhanced DNAPL recovery techniques were implemented utilizing both water flooding and wellbore vacuum. Essentially, this minimized drawdown, allowing a maximum pumping rate of the DNAPL-water mixture. Both techniques offered significant advantages in terms of the rate and potential degree of DNAPL removal (8).

The highly corrosive nature of some DNAPL's may increase maintenance problems associated with the recovery system. A design consideration during any DNAPL recovery program should include a material compatibility review to minimize downhole failures. This is applicable to the well construction material and the various appurtenances of the recovery system. Manufacturers of the construction material would most likely have the best compatibility information available.

While most scientists agree that the residual saturation of immiscible hydrocarbon droplets in porous media are immobile, researchers have investigated the mobility of residual saturation in porous media for enhanced oil recovery and for NAPL remediation at spill sites. Specifically, this includes a complex interplay between four forces (viscous, gravity, capillary, buoyancy). These forces are dependent on both the chemical and physical characteristics of the DNAPL and porous media. The mobilization of residual saturation mainly hinges on either increasing the ground water velocity which increases the viscous forces between the residual saturation and the ground water, or decreasing the interfacial tension between the residual saturation and the ground water which decreases the capillary forces.

The capillary number is an empirical relationship which measures the ratio between the controlling dynamic stresses (absolute viscosity and ground water velocity) and static stresses (interfacial tension) of the residual saturation (39). The former are the viscous stresses and the dynamic pressure in the water which tend to move the oil. The latter are the capillary stresses in the curved water/oil interfaces which tend to hold the oil in place. As the capillary number is increased, the mobility of the residual saturation increases. In a laboratory column study, the capillary number had to be increased two orders of magnitude from when motion was initiated to complete displacement of the hydrocarbon in a sandstone core (74). In a glass bead packed column, only one order of magnitude increase was required. However, a higher capillary number was required to initiate mobility. The difference in mobility between the two columns was attributed to the pore geometry, i.e. size, shape.

There are limitations to residual saturation mobilization. The ground water gradient (dh/dl) necessary to obtain the critical capillary number to initiate blob mobilization would be 0.24. To obtain complete NAPL removal would require a gradient of 18 (3). Ground water gradients of this magnitude are unrealistic. Another estimate of the gradient necessary to mobilize carbon tetrachloride in a fine gravel and medium sand was 0.09 and 9.0 respectively (74). The former gradient is steep but not unreasonable and the latter gradient is very steep and impractical to achieve in the field. The same researchers concluded from more recent, comprehensive studies, that the earlier predictions were optimistic, and that the gradient necessary to mobilize residual organic liquid is clearly impractical (66). Another limitation is that along with residual saturation mobilization, the NAPL blobs disperse into smaller blobs and that the blob distribution was dependent on the resulting capillary number (6). Recovery of the NAPL residual saturation by pumping ground water may be more feasible where the porous media is coarse and capillary forces are low, i.e. coarse sands and gravel. However, even in this scenario, it is expected that the radius of residual saturation mobilization would be narrow.

It is held in petroleum engineering theory that the only practical means of raising the capillary number dramatically is by lowering the interfacial tension (39) and that this can be achieved by using surfactants (66). Surfactants reduce the interfacial tension between two liquids, and therefore, are injected into the subsurface for enhanced recovery of immiscible hydrocarbons. In laboratory experiments, surfactant flushing solutions produced dramatic gains in flushing even after substantial water flushing had taken place (54). Unfortunately, surfactants can be quite expensive and cost prohibitive in NAPL recovery operations. Surfactants are usually polymeric in nature and a surfactant residue may be left behind in the porous media which may not be environmentally acceptable. Additionally, surfactants may be alkaline and thus affect the pH of the subsurface environment. It has been suggested that such a surfactant may inhibit bacterial metabolism and thus preclude subsequent use of biological technologies at the site. Significant research in this area is currently underway which may uncover information improving the economics and feasibility of this promising technology.

In summary, practical considerations and recommendations concerning the mobilization and recovery of residual saturation include the following: greater effectiveness in very coarse porous media i.e. coarse sands and gravel; recovery wells should be installed close to the source to minimize flow path distance; a large volume of water will require treatment/disposal at the surface; compounds with high interfacial tension or viscosity will be difficult to mobilize; and implementation of linear one-dimensional sweeps through the zones of residual saturation (74) and surfactants will optimize recovery.

Pumping the soluble components (aqueous phase) of DNAPL from the immiscible (continuous and residual saturation), solid (sorbed), and gaseous phases has been perhaps one of the most effective means to date to both recover DNAPL from the subsurface and to prevent plume migration. Recovery of soluble components quite often has been the only remediation means available. This is largely attributed to the inability to locate DNAPL pools and due to low, DNAPL yielding formations. The basic principles and theory of pump and treat technology and the successes and failures have been summarized in other publications (64,67) and is beyond the scope of this publication.

Pumping solubilized DNAPL components from fractured rock aquifers historically has been plagued with a poor recovery efficiency. Although the rock matrix has a relatively small intergranular porosity, it is commonly large enough to allow dissolved contaminants from the fractures to enter the matrix

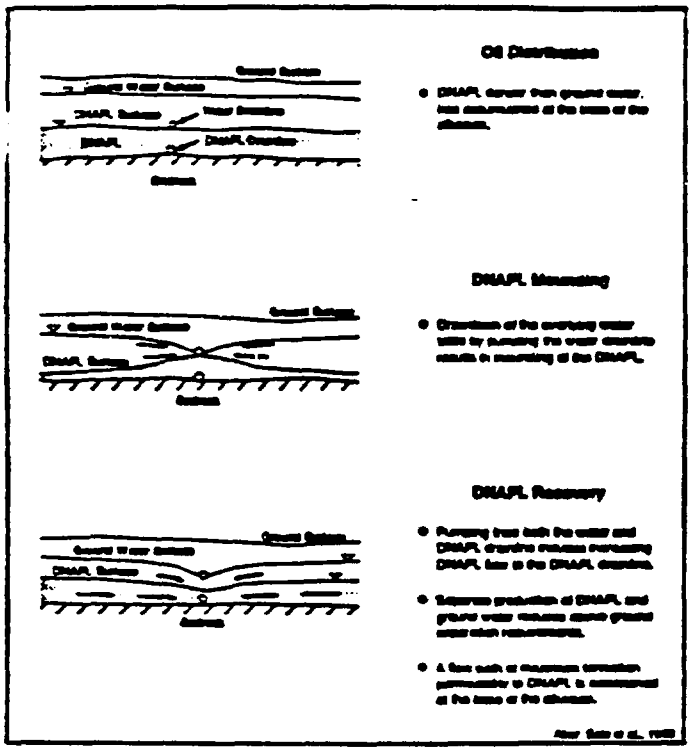


Figure 21. Trench recovery system of DNAPL utilizing the dual drainline concept.

by diffusion and be stored there by adsorption (32). The release of these components is expected to be a slow diffusion dominated process. This is because little or no water flushes through dead-end fracture segments or through the porous, impervious rock matrix. Therefore, clean-up potential is estimated to be less than that expected for sand and gravel aquifers.

Trench Systems

Trench systems have also been used successfully to recover DNAPL and are used when the reservoir is located near the ground surface. Trench systems are also effective when the DNAPL is of limited thickness. Recovery lines are placed horizontally on top of the impermeable stratigraphic unit. DNAPL flows into the collection trenches and seep into the recovery lines. The lines usually drain to a collection sump where the DNAPL is pumped to the surface. Similar to the pumping system, an enhanced DNAPL recovery scheme may be implemented using drain lines to improve recovery efficiency. This "dual drain line system" (41) utilizes a drain line located in the ground water vertically upward from the DNAPL line. Ground water is withdrawn from the upper screen which results in an upwelling of the DNAPL which is collected in the lower line, refer to Figure 21. This increases the hydrostatic head of the DNAPL. Excessive pumping of either single or dual drain line systems may result in the ground water "pinching off" the flow of DNAPL to the drain line. An advantage of the dual drain system is that the oil:water separation requirements at the surface are reduced.

Vacuum Extraction

Soil vacuum extraction (SVE) is a remediation technology which involves applying a vacuum to unsaturated subsurface strata to induce air flow. Figure 22 illustrates that the volatile contaminants present in the contaminated strata will evaporate and the vapors are recovered at the surface and treated. Common methods of treatment include granular activated carbon, catalytic oxidation, and direct combustion. SVE can effectively remove DNAPL present as residual saturation or its soluble phase components in the unsaturated zone. In general, vacuum extraction is expected to be more applicable for the chlorinated solvents (PCE, TCE, DCE) than the polycyclic aromatic compounds (wood preserving wastes, coal tars, etc.). When DNAPL is present in perched pools (Figure 12) it is more effective to remove the continuous phase DNAPL prior to the implementation of SVE. The same strategy is applicable in the saturated zone where DNAPL removal by SVE is attempted concomitantly with lowering the water table. Upon lowering the water table, SVE can be used to remove the remnant volatile wastes not previously recovered. Often, the precise location of the DNAPL is unknown; therefore, SVE can be used to remediate the general areas where the presence of DNAPL is suspected. Removal of DNAPL by SVE is not expected to be as rapid as direct removal of the pure phase compound. One advantage of SVE however, is that the precise location of the DNAPL need not be known.

Important parameters influencing the efficacy of SVE concern both the DNAPL and porous media. Porous media specific parameters include: soil permeability, porosity, organic carbon, moisture, structure, and particle size distribution. DNAPL specific parameters include: vapor pressure, Henry's constant, solubility, adsorption equilibrium, density, and viscosity (20). These parameters and their relationships must be evaluated on a site specific basis when considering the feasibility of vacuum extraction and a practical approach to the design, construction, and operation of venting systems (22). Additionally, soil gas surveys which delineate vapor concentration as a function of depth is critical in locating the contaminant source and designing an SVE system.

Historically, SVE has been used to remove volatile compounds from the soil. Recently it has been observed that SVE enhances the biodegradation of volatile and semivolatile organic compounds in the subsurface. While SVE removes volatile components from the subsurface, it also aids in supplying oxygen to biological degradation processes in the unsaturated zone. Prior to soil venting, it was believed that biodegradation in the unsaturated zone was limited due to inadequate concentrations of oxygen (17). In a field study where soil venting was used to recover jet fuel, it was observed that approximately 15% of the contaminant removal was from the result of microbial degradation. Enhanced aerobic biodegradation during SVE increases the cost effectiveness of the technology due to the reduction in the required above ground treatment.

Vacuum extraction is one form of pump and treat which occurs in the saturated zone where the fluid is a gas mixture. Therefore, many of the same limitations to ground water pump and treat are also applicable to vacuum extraction. While the application of vacuum extraction is conceptually simple, its success depends on understanding complex subsurface

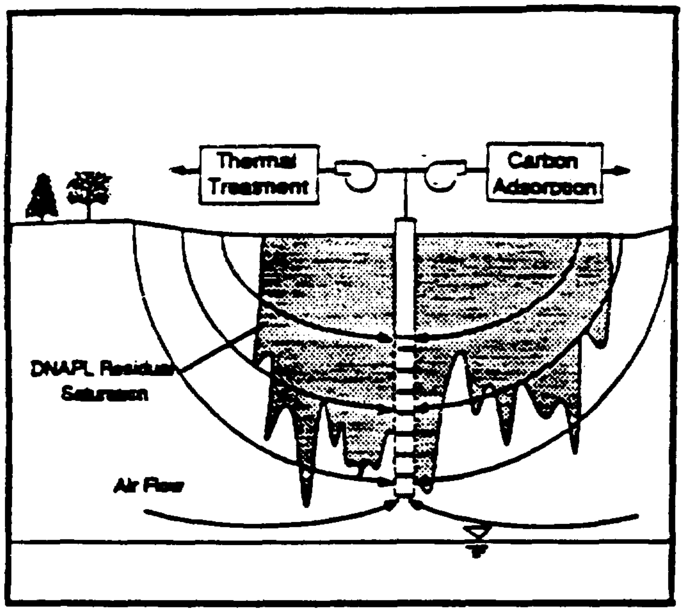


Figure 22. Vacuum extraction of DNAPL volatile components in the unsaturated zone. As shown here, vapors are treated by thermal combustion or carbon adsorption and the air is discharged to the atmosphere.

chemical, physical, and biological processes which provide insight into factors limiting its performance (9).

Biodegradation

The potential for biodegradation of immiscible hydrocarbon is highly limited for several reasons. First, pure phase hydrocarbon liquid is a highly hostile environment to the survival of most microorganisms. Secondly, the basic requirements for microbiological proliferation (nutrients, electron acceptor, pH, moisture, osmotic potential, etc.) is difficult if not impossible to deliver or maintain in the DNAPL. A major limitation to aerobic bioremediation of high concentrations of hydrocarbon is the inability to deliver sufficient oxygen. A feasible remediation approach at sites where immiscible hydrocarbon is present is a phased technology approach. Initial efforts should focus on pure phase hydrocarbon recovery to minimize further migration and to decrease the volume of NAPL requiring remediation. Following NAPL recovery, other technologies could be phased into the remediation effort. Bioremediation may be one such technology that could be utilized to further reduce the mass of contaminants at the site. NAPL recovery preceding bioremediation will improve bioremediation feasibility by reducing the toxicity, time, resources, and labor.

Similar to other remediation technologies, a comprehensive feasibility study evaluating the potential effectiveness of bioremediation is critical and must be evaluated on a site specific basis. A comprehensive review of biodegradation of surface soils, ground water, and subsoils of wood preserving wastes, i.e. PAH's (29,37,51,62,63) are available. A comprehensive review of microbial decomposition of chlorinated aromatic compounds is also available (58).

Soil Flushing

Soil flushing utilizing surfactants is a technology that was developed years ago as a method to enhance oil recovery in the petroleum industry. This technology is new to the hazardous waste arena and available information has mainly been generated from laboratory studies. Surfactant soil flushing can proceed on two distinctly different mechanistic levels: enhanced dissolution of adsorbed and dissolved phase contaminants, and displacement of free-phase nonaqueous contaminants. These two mechanisms may occur simultaneously during soil flushing (42).

Surfactants, alkalis, and polymers are chemicals used to modify the pore-level physical forces responsible for immobilizing DNAPL. In brief, surfactants and alkalis reduce the surface tension between the DNAPL and water which increases the mobility. Polymers are added to increase the viscosity of the flushing fluid to minimize the fingering effects and to maintain hydraulic control and improve flushing efficiency. Based on successful laboratory optimization studies where an alkali-polymer-surfactant mixture was used, field studies were conducted on DNAPL (creosote) which resulted in recovery of 94% of the original DNAPL (42). Laboratory research has also been conducted which indicated that aqueous surfactants resulted in orders of magnitude greater removal efficiency of adsorbed and dissolved phase contaminants than water flushing (55).

Depth to contamination, DNAPL distribution, permeability, heterogeneities, soil/water incompatibility, permeability reduction, and chemical retention are important factors when considering soil flushing (42). Prior to this technology being cost effective in the field, surfactant recycling will be necessary to optimize surfactant use (55). Soil flushing is complex from a physical and chemical point of view; is relatively untested in the field; and will likely be challenged regulatorily. Considerable research currently being conducted in this area may result in the increased use of this technology to improve DNAPL recovery in the future.

Thermal methods of soil flushing involve injecting hot water or steam in an effort to mobilize the NAPL. The elevated temperature increases volatilization and solubilization and decreases viscosity and density. A cold-water cap is used to prevent volatilization. The mobile phases of the DNAPL are then recovered using a secondary approach, i.e. pumping, vacuum extraction etc. This approach (Contained Recovery of Oily Wastes) to enhance recovery of DNAPL is currently under EPA's Superfund Innovative Technology Evaluation Program and a pilot-scale demonstration is forthcoming (21). A limitation in the use of thermal methods is that the DNAPL may be converted to LNAPL due to density changes (36). The adverse effects from this are that the DNAPL, existing as a thin layer, becomes buoyant and mobilizes vertically resulting in a wider dispersal of the contaminant. Other limitations involve the high energy costs associated with the elevated water temperature and the heat loss in the formation (36).

Physical Barriers

Physical barriers may be used to prevent the migration of DNAPL's in the subsurface and are typically used in conjunction with other recovery means. One feature of physical barriers is the hydraulic control it offers providing the opportunity to focus remediation strategies in treatment cells. Unfortunately, physical barriers, while satisfactory in terms of ground water control and containment of dissolved-phase plumes, may contain small gaps or discontinuities which could permit escape of DNAPL (7). Chemical compatibility between physical barriers and construction material must agree to insure the physical integrity of the barrier. The history of the performance of these containment technologies is poorly documented and is mainly offered here for completeness of review. A more complete review of these physical barriers is available (5,56).

Sheet piling involves driving lengths of steel that connect together into the ground to form an impermeable barrier to lateral migration of DNAPL. Ideally, the bottom of the sheet pile should be partially driven into an impermeable layer to complete the seal. Slurry walls involve construction of a trench which is backfilled with an impermeable slurry (bentonite) mixture. Grouting is a process where an impermeable mixture is either injected into the ground or is pumped into a series of interconnected boreholes which together form an impermeable boundary. Again, the main feature of these techniques is to physically isolate the DNAPL.

In summary, site characterization and remediation options for sites containing DNAPL are limited. Field data from site characterization and remediation efforts are also limited. This is largely due to the complexity of DNAPL transport and fate in the subsurface, poorly developed techniques currently available to observe and predict DNAPL in the subsurface, and to the fact that this issue has not been widely recognized until recently. Clearly, there is a growing realization within the scientific and regulatory community that DNAPL is a significant factor in limiting site remediation. Correspondingly, current research efforts within the private, industrial, and public sectors are focusing on both the fundamentals and applications aspects of DNAPL behavior in subsurface systems. Additionally, the number of field investigations reflecting an increased awareness of DNAPLs, is growing.

DNAPL Modeling

A modeling overview report identified nineteen (numeric and analytic) multiphase flow models which are currently available (60). Most of these models were developed for salt water intrusion, LNAPL transport, and heat flow. Four models are qualitatively described as immiscible flow models but do not specifically indicate DNAPL. A more recent model has been developed which simulates density driven, three phase flow, that is capable of modeling DNAPL transport (23). Presently, very little information is available on DNAPL modeling in the scientific literature.

Multiphase flow modeling involves modeling systems where more than one continuous fluid phase (NAPL, water, gaseous) is present. Modeling any subsurface system requires a conceptual understanding of the chemical, physical, and biological processes occurring at the site. Modeling of simultaneous flow of more than one fluid phase requires a conceptual understanding of the fluids and the relationship between the fluid phases. The significance of multiphase flow over single phase flow is the increased complexity of fluid flow and the additional data requirements necessary for modeling.

As presented earlier, numerous variables strongly influence DNAPL transport and fate, and consequently, the mathematical relationship of these variables is complex. Therefore, it follows that DNAPL modeling presents paramount technical challenges.

Presently, it is exceedingly difficult to obtain accurate field data which quantitatively describes DNAPL transport and fate variables within reasonable economic constraints. DNAPL transport is highly sensitive to subsurface heterogeneities (8,27,28) which compounds the complexity of modeling. Heterogeneities are, by nature, difficult to identify and quantify and models are not well equipped to accommodate the influence of heterogeneities. Additionally, relative permeability and capillary pressure functions must be quantified to identify the relationship between fluids and between the fluids and the porous media. Unfortunately, these parameters are very difficult to measure, particularly in three phase systems. Prior to an investment of time and money to model a given site, a careful evaluation of the specific objectives and the confidence of the input and anticipated output data should be performed. This will help illuminate the costs, benefits, and therefore, the relative value of modeling in the Superfund decision making process.

In summary, DNAPL modeling at Superfund sites is presently of limited use. This is mainly due to: the fact that very little information is available in the scientific literature to evaluate previous work; accurate and quantitative input data is expected to be costly; the sensitivity of DNAPL transport to subsurface heterogeneities; and, the difficulty in defining the heterogeneities in the field and reflecting those in a model. However, multiphase flow models are valuable as learning tools.

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Attachment 6

Project Health and Safety Plan Amendments

PROJECT HEALTH AND SAFETY PLAN AMENDMENT

AMENDMENT #: 1

PROJECT NAME: Waukegan Manufactured Gas and Coke Plant Site, Phase II Remedial Investigation

PROJECT NUMBER: 13/49-003 JSL 51

DATE: 04/03/93

REASON FOR AMENDMENT:

This amendment updates the work zones, personal protective equipment, and air monitoring instrumentation to be used for Phase II activities at the Waukegan Manufactured Gas and Coke Plant Site. It also includes the most recent data available on chemical substances of concern.

AMENDMENT:

A. TASKS

The following is a revised list of activities Barr personnel will perform on-site:

- Measure water levels in monitoring wells and at harbor well
- Survey boring and well locations
- Observe soil boring operations
- Observe monitoring well installations
- Observe monitoring well development
- Collect soil samples
- Collect water samples from monitoring wells
- Perform headspace screening
- Conduct slug and pumping tests
- Collect water samples from surface water bodies
- Collect water samples from the water treatment unit

B. WORK ZONES

Safety work zones will be established at each soil boring/monitoring well installation. The hot zone will be the area within an approximate three-foot radius of the borehole. The exclusion zone will be approximately equal to the height of the equipment boom plus ten feet. The contamination reduction zone will be located upwind of activities whenever possible. Entrance and exit from the exclusion zone will be done only through the contamination reduction zone. FIGURE A-1-WORK AND EXCLUSION ZONES FOR DRILLING ACTIVITIES illustrates site work zones.

C. POTENTIAL CHEMICAL HAZARDS ON-SITE

Tables A-1A through A-1D lists chemical substances of concern that have been found on-site.

TABLE A-1A

VOLATILE ORGANIC COMPOUNDS OF CONCERN ON-SITE

VOLATILE ORGANIC COMPOUNDS	MAXIMUM CONCENTRATION IN GROUNDWATER AND SAMPLE LOCATION (mg/L)	MAXIMUM CONCENTRATION IN SOIL AND SAMPLE LOCATION (mg/kg)
Benzene	1.5 (MW6D)	62 (T03W02)
Toluene	0.4 (MW6D)	140 (TT2303)
Ethylbenzene	0.1 (MW6D)	64 (TT2303)
Xylene	0.2 (MW6D)	370 (TT2303)

TABLE A-1B

SEMIVOLATILE ORGANIC COMPOUNDS OF CONCERN ON-SITE

SEMIVOLATILE ORGANIC COMPOUNDS (vapor pressures greater than naphthalene's)	MAXIMUM CONCENTRATION IN SOIL AND SAMPLE LOCATION (mg/kg)	MAXIMUM CONCENTRATION IN GROUNDWATER AND SAMPLE LOCATION (mg/L)
2-Methylphenol	29 (T03W02)	210 (MW3D)
4-Methylphenol	71 (T03W02)	730 (MW3D)
2,4-Dimethylphenol	32 (T03W02)	41 (MW4D)
Phenol	41 (T03W02)	1500 (MW4D)
Naphthalene	3500 (T03W01)	NA

TABLE A-1C

LOW VAPOR PRESSURE PAH COMPOUNDS OF CONCERN ON-SITE

PAHs WITH VERY LOW VAPOR PRESSURES (less than naphthalene's)	MAXIMUM CONCENTRATION IN SOIL AND SAMPLE LOCATION (mg/kg)
Acenaphthylene	300 (T03W02)
Acenaphthene	180 (TT0602)
Fluorene	280 (T03W02)
Phenanthrene	3701 (X-101S)
Anthracene	200 (T03W02)
Fluoranthene	370 (X-101S)
Pyrene	260 (X-101S)
Chrysene	160 (X-101S)
Benzo(b)Fluoranthene	73 (T03W02)
Benzo(k)Fluoranthene	90 (T03W02)
Benzo(a)Pyrene	90 (T03W02)
Benzo(a)Anthracene	150 (T03W02)
Indeno(1,2,3-c,d)Pyrene	35 (T03W02)
Benzo(g,h,i)Perylene	24 (T03W02)
Total cPAHs	700 (X-101S)
Total PAHs	5,000 (TT03W02)

TABLE A-1D

METALS OF CONCERN ON-SITE

METALS	MAXIMUM CONCENTRATION IN SOIL AND SAMPLE LOCATION (μg/g)	MAXIMUM CONCENTRATION IN GROUNDWATER AND SAMPLE LOCATION (mg/L)
Arsenic	1,820 (TT0701)	27.1 MW4D
Aluminum	12,500 (SS09)	NA
Antimony	73.5 (TT0701)	NA
Cadmium	4.4 (TT1402)	0.051 MW4D
Chromium	25.5 (SS15)	0.040 MW1D
Cyanide	956 (TT03W03)	0.71 MW4D
Lead	160 (X-105)	0.016 MW1D
Mercury	58 (X-107)	NA

NA = Information not available
X-105 = Illinois EPA sample June 14, 1989. 3.5-4.5 feet
X-107 = Illinois EPA sample June 14, 1989. 1-5 feet
MW1D = Barr Engineering Co. (BEC) sample, April 9, 1992
MW3D = BEC sample, April 7, 1992
MW4D = BEC sample, April 7, 1992
MW6D = BEC sample, April 8, 1992
T03W01 = BEC sample, March 13, 1992, 4 feet
T03W02 = BEC sample, March 13, 1992, 3.5 feet
TT0602 = BEC sample, March 9, 1992, 4.5 feet
TT0701 = BEC sample, March 19, 1992, 4.5 feet
TT1402 = BEC sample, March 18, 1992, 4 feet
TT2303 = BEC sample, March 19, 1992, 4 feet
SS09 = BEC sample, March 11, 1992, 2-4 feet
SS15 = BEC sample, March 7, 1992, 2-4 feet

D. PERSONAL PROTECTION LEVELS

The potential routes of exposure to chemical substances are expected to be the following:

- Inhalation of gases
- Inhalation of contaminated dust
- Skin contact with contaminated soil or liquid
- Ingestion by transmitting contaminants to the mouth after skin contact with contaminated solids and liquids

Personal protective equipment has been selected to protect against these hazards and is described in TABLE A-2 - HAZARD GROUPS FOR PROJECT TASKS and TABLE A-3 - PERSONAL PROTECTION LEVELS. These levels may be modified by the Barr Project Health and Safety Team Leader depending on specific site conditions, equipment configuration, air monitoring and results and previous experience. Tables A-2 and A-3 supersede Tables 2-3 and 2-5 in the February 1992 PHASP.

TABLE A-2

HAZARD GROUPS FOR PROJECT TASKS

	HAZARD GROUP				
TASK	0	1	2	3	4
NONINTRUSIVE ACTIVITIES					
Site Preparation ▪ Reconnaissance ▪ Perform geophysical survey ▪ Perform topographical survey	✓	D1			
INTRUSIVE ACTIVITIES					
Drilling ▪ Observe soil boring operations ▪ Observe monitoring well installation ▪ Observe monitoring well development			D2	D3	D4
Soil Sampling • Collect soil samples from soil borings • Perform headspace screening			D2	D3	
Water Sampling • Collect water samples from monitoring wells • Conduct hydraulic conductivity tests • Measure water levels in wells • Collect surface water samples*			D2	D3	D4
DECONTAMINATION ACTIVITIES					
Equipment DECON Operations • Observe steam cleaning of equipment					

✓ - Normal Work Clothes

* - Special situation, see Amendment Section F.

TABLE A-3

PERSONAL PROTECTION LEVELS

	D1	D2	D3	D4	C1	C2	C3	C4
GENERAL SAFETY EQUIPMENT								
Hard Hat(1)	R	R	R	R	R	R	R	R
Safety Glasses	R	R	R	R	R	R	-	-
Chemical Goggles/Face Shield	O	O	O	O	O	O	-	-
Hearing Protection(2)	R	R	R	R	R	R	R	R
BOOTS								
Steel-Toed Boots/Insulated Steel-Toed Boots	R	R	R	R	R	R	R	R
Chemical Resistant Steel-Toed Boots(3)	-	O	O	O	-	O	O	O
Boot Covers(4)	-	R	R	R	-	R	R	R
CLOTHING								
Cotton Coveralls	-	O	-	-	-	O	-	-
Kleengard	-	R	-	-	-	R	-	-
Tyvek	-	O	R	-	-	O	R	-
Poly-Coated Tyvek (taped)	-	O	O	R	-	O	O	R
RESPIRATORS								
½ Mask Respirator with HEPA/OVAG cartridges	-	-	-	-	R	R	-	-
Full Face - with GMC-H cartridge	-	-	-	-	O	O	R	R
ELSA	-	O	O	O	-	O	O	O
GLOVES								
Inner Glove (Surgical)	-	R	R	R	-	R	R	R
Outer Glove (Nitrile, neoprene, monkey grip)	-	R	R	R	-	R	R	R

R = Required   O = Optional   - = Not Required

SPECIAL CONSIDERATIONS

(1) Hard hat not required in the absence of construction activities or overhead physical hazards, unless required by the client.

(2) Hearing protection is required during soil boring and monitoring well installation.

(3) Chemical resistant steel-toed boots may be used instead of steel-toed leather boots and boot covers, if water is available for boot decontamination.

(4) Boot covers or chemical resistant steel-toed boots not required when walking does not involve contact with contamination.

E. AIR MONITORING PROCEDURES

Air monitoring instrumentation that should be used for Phase II activities, and the intervals of use are specified in TABLE A-3 - AIR MONITORING INSTRUMENTATION REQUIRED ON-SITE. Air monitoring will be conducted in the breathing zone, and upwind and downwind for comparison purposes.

TABLE 1-3

AIR MONITORING INSTRUMENTATION REQUIRED ON-SITE

Monitoring Equipment[1]	Task	Action Levels	Frequency	Record Data
Organic Vapor Analyzer	Monitoring Well Installations Soil Boring Soil Sampling Water Sampling Surveying	<3 ppm above background → Level D >3 ppm above background (for 10 min.) → Level C >50 ppm → Leave site and reassess	Periodic	Every hour (indicate range of values)
Detector tubes for benzene, phenol	Monitoring Well Installations Soil Boring Soil Sampling	None. Use data to modify organic vapor action level	Hourly when OVA levels >3 ppm	Each tube
Thermo-Luminescent Badge	Worn continuously while on site	NA	NA	NA

F. WATER SAFETY

Several surface water samples will be collected from Lake Michigan offshore of the site and the city beach. Samples will be collected in a small boat. There are no chemical hazards associated with the sample collection. The city beach has from time to time been closed to swimming due to elevated coliform count.

When operating a boat, the following rules will apply:

- All personnel in the boat will wear DOT approved personal floatation devices (PFD)
- There will be two people in the boat at all times
- If the boat is motor-powered, a set of paddles or oars shall also be kept in the boat
- The maximum weight and occupancy capacity of the boat will not be exceeded
- On-the-water operations will stop during inclement weather or high wind conditions

Since there is some probability that there may be an elevated coliform concentration in the water, personnel should avoid contacting water with their bare hand. Personnel should wash their hands thoroughly before eating or drinking and when they return to the shore.

G. APPENDICES

The attached Appendices document supersedes any previous Appendices issued for this project.

H. FIGURES

The attached figures supersede any figures referenced in the February 1992 PHASP.

___ Amendment discussed with Project Manager on ______________ and approved.

_X_ Amendment discussed with Project Industrial Hygienist on 04/12/93 and approved.

______________________________ __________________
Preparer of Amendment Date

______________________________ __________________
Barr Project Health and Safety Team Leader Date

NOTE: This Amendment form is to be used when there is a change in site tasks not considered in this PHASP.

c: Project Safety File
Project Manager
Barr Health and Safety Manager
Project Industrial Hygienist
Barr Project Health & Safety Team Leader

PROJECT HEALTH AND SAFETY PLAN AMENDMENT

AMENDMENT #: 2

PROJECT NAME: Waukegan Manufactured Gas and Coke Plant Site, Phase II Remedial Investigation

PROJECT NUMBER: 13/49-003 JSL 51

DATE: 05/12/93

AMENDMENT SECTION: 1.3 Organization and Coordination

REASON FOR AMENDMENT: Change in project personnel.

AMENDMENT:

Project Manager: James R. Langseth

Project Health and Safety Team Leader: Karlene French

Alternate Project Health and Safety Team Leader: John Fox

Project Industrial Hygienist: Colin S. Brownlow

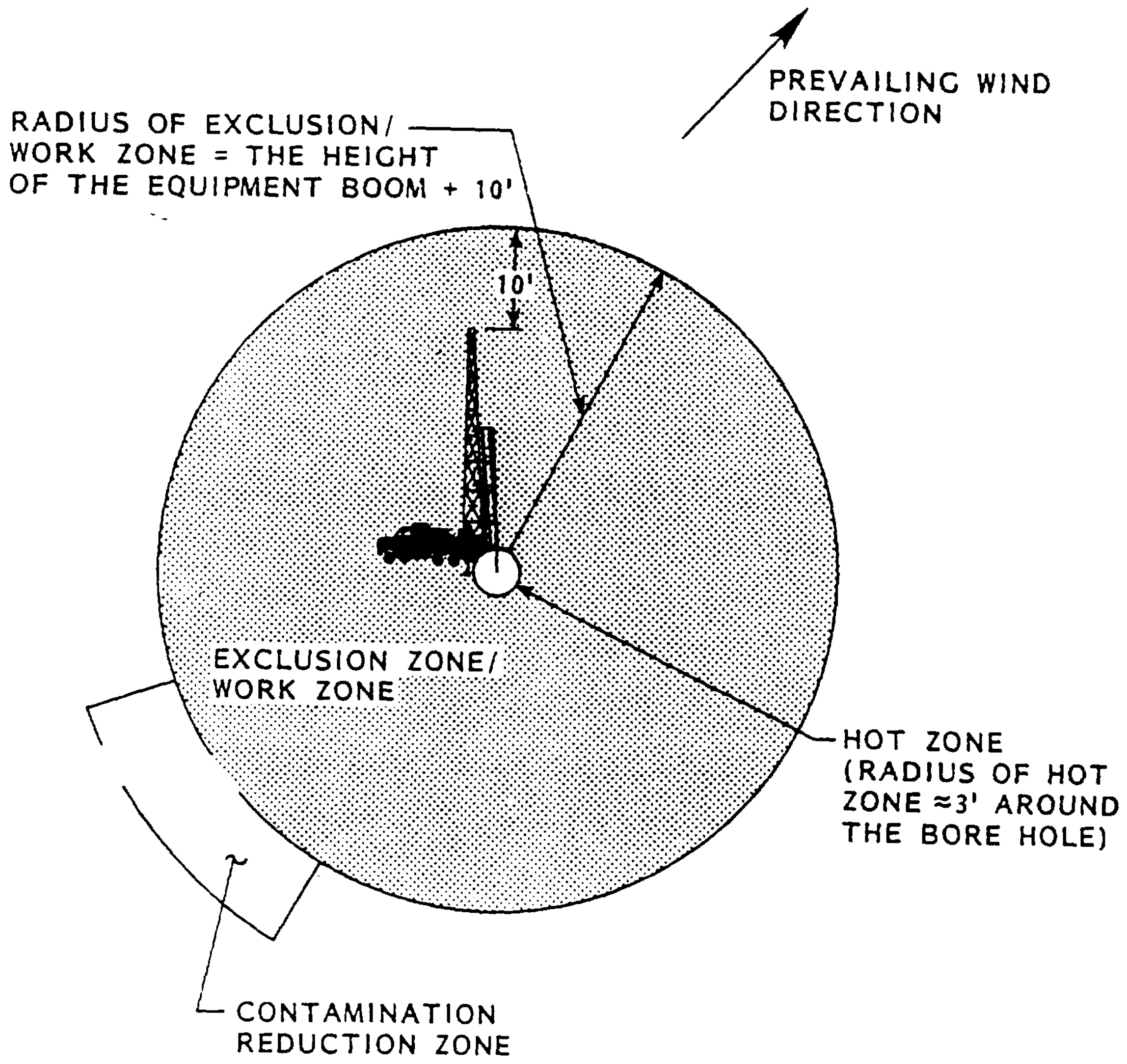
___ Amendment discussed with Project Manager on ______________ and approved.

___ Amendment discussed with Project Industrial Hygienist on ______________ and approved.

Preparer of Amendment	Date
Barr Project Health and Safety Team Leader	Date

NOTE: This Amendment form is to be used when there is a change in site tasks not considered in this PHASP.

c: Project Safety File
Project Manager
Barr Health and Safety Manager
Project Industrial Hygienist
Barr Project Health & Safety Team Leader



Safety Work Zones to be Established at Each Boring/Monitoring Well Installation.

Enter and Exit Exclusion Zone Only Through Contamination Reduction Zone.

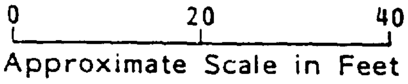
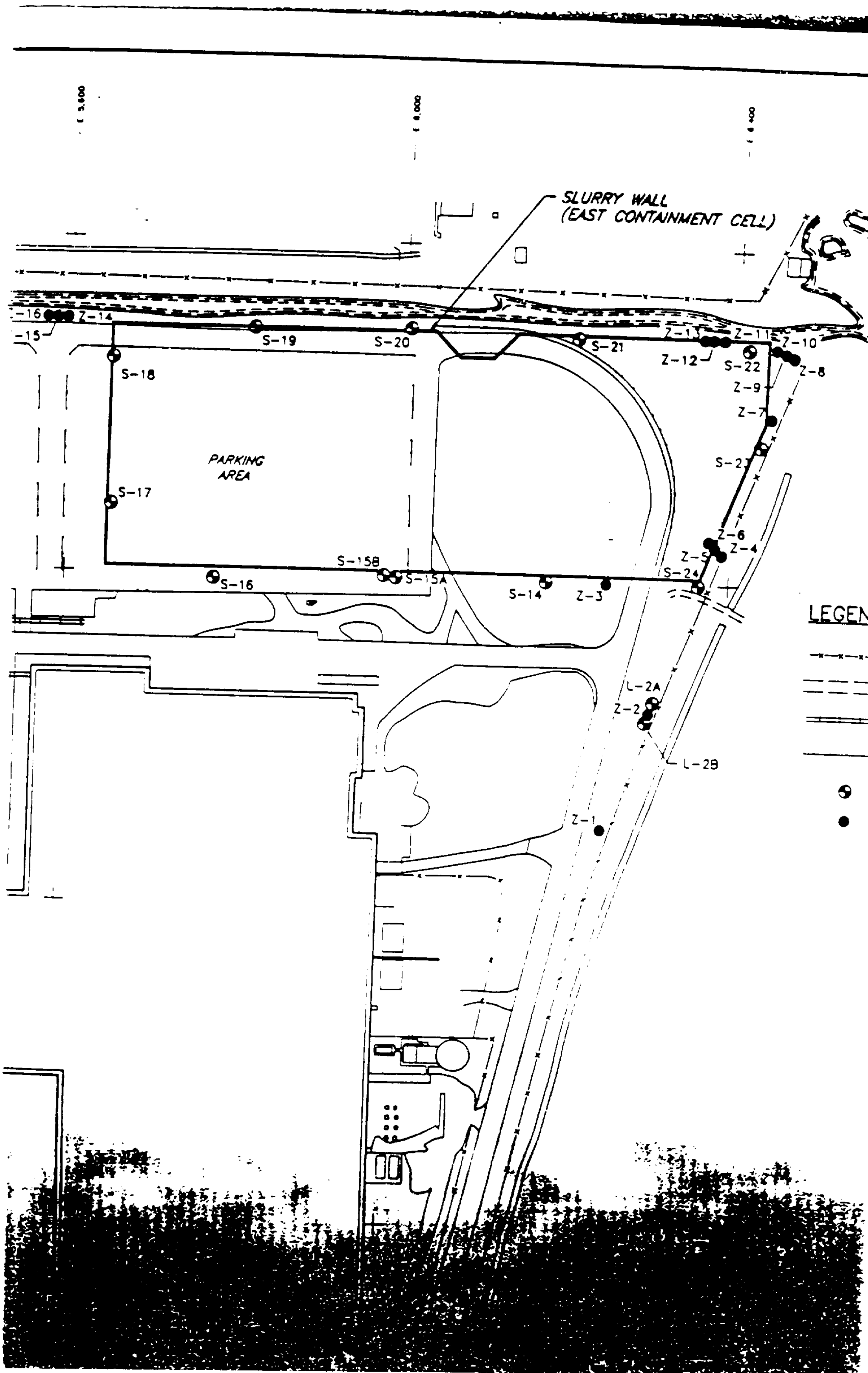


Figure A-1

WORK AND EXCLUSION ZONES FOR DRILLING ACTIVITIES

Attachment 7

OMC Piezometer Location Map


E 3,800
E 4,000
E 4,200
SLURRY WALL
(EAST CONTAINMENT CELL)
PARKING AREA
-16
-15
Z-14
S-19
S-20
S-21
Z-13
Z-12
Z-11
Z-10
S-22
Z-8
Z-9
Z-7
S-18
S-17
S-23
Z-6
Z-4
Z-5
S-24
S-15B
S-15A
S-16
S-14
Z-3
L-2A
Z-2
L-2B
Z-1
LEGEN

ATTACHMENT 8

PHASE II ANALYTICAL PARAMETERS FOR GROUNDWATER

Polynuclear Aromatic Hydrocarbons

Naphthalene
2-Methylnaphthalene
Acenaphthylene
Acenaphthene
Dibenzofuran
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo(a)anthracene
Chrysene
Benzo(b+k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-cd)pyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene
Carbazole

Phenolic Compounds

Phenol
2-Chlorophenol
o-Cresol
p-Cresol
2-Nitrophenol
2,4-Dimethylphenol
4-Chloro-3-methylphenol
2,4,6-Trichlorophenol
2,4,5-Trichlorophenol
2,4-Dinitrophenol
4-Nitrophenol
2-Methyl-4,6-dinitrophenol
Pentachlorophenol

Inorganics

Arsenic (total, +III, +V)
Cadmium
Lead
Mercury
Selenium
Total ammonia
Total cyanide
Thiocyanate
Weak acid dissociable cyanide
Amenable cyanide

Volatile Organic Compounds

Chloromethane
Bromomethane
Vinyl chloride
Chloroethane
Methylene chloride
Acetone
Carbon disulfide
1,1-Dichloroethylene
1,1-dichloroethane
1,2-Dichloroethylene
Chloroform
1,2-Dichloroethane
Methyl ethyl ketone
1,1,1-Trichloroethane
Carbon tetrachloride
Bromodichloromethane
1,2-Dichloropropane
cis-1,3-Dichloro-1-propene
Trichloroethylene
Chlorodibromomethane
1,1,2-Trichloroethane
trans-1,3-Dichloro-1-propene
Bromoform
Methyl isobutyl ketone
2-Hexanone
Tetrachloroethylene
1,1,2,2-Tetrachloroethane
Chlorobenzene
Styrene
Benzene
Ethyl benzene
Toluene
Xylenes

Attachment 9

Revised Attachment 4a-
Standard Operating Procedure for the Field Measurement of Soil pH

ATTACHMENT 9

REVISED ATTACHMENT 4A
(Revised June 14, 1993)

STANDARD OPERATING PROCEDURE FOR THE FIELD MEASUREMENT OF SOIL pH

PURPOSE: The purpose is to describe the method by which pH measurements on soil samples will be made and documented in the field.

RESPONSIBILITIES: The soil samplers are responsible for making and documenting the field soil pH measurements.

EQUIPMENT/MATERIALS:
Orion Research Model 407A pH meter or equivalent pH meter
Paper cups (unwaxed)
Wooden tongue depressors
Distilled water

PROCEDURES:

1. The pH meter will be calibrated according to manufacturer's recommendations using pH standard solutions. (See Attachment 5A of the October 1991 Field Sampling Plan.)
2. As soon as possible after sampler retrieval, place a tablespoon of soil in a clean paper cup.
3. Add an equal amount of distilled water to the soil.
4. Stir the suspension several times with the wooden tongue depressor.
5. Place pH meter probe into the suspension.
6. Wait for meter reading to stabilize as directed by the manufacturer of the meter.
7. Rinse probe with a trisodium phosphate and water solution and then with deionized water.

DOCUMENTATION: pH values of samples will be written down on the field data sheet for the samples from each boring. The results will be reported as "soil pH measured in water."