Feasibility Study
Former Zephyr Refinery Fire Suppression Ditch
Muskegon Lake Area of Concern,
Muskegon, Michigan

Great Lakes Architect-Engineer Services
Contract: EP-R5-11-10

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U.S. Environmental Protection Agency
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TABLE OF CONTENTS

Page

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

°F	Degrees Fahrenheit
AOC	Area of Concern
AVS	Acid volatile sulfide
BTEX	Benzene, toluene, ethylbenzene, and xylenes
BUI	Beneficial use impairment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COC	Chemical of concern
CSM	Conceptual Site Model
cy	Cubic yard(s)
DRO	Diesel range organics
EA	EA Engineering, Science, and Technology, Inc.
EPA	U.S. Environmental Protection Agency
EVS	Environmental Visualization Software
FS	Feasibility Study
ft	Foot (feet)
HDPE	High density polyethylene
GLNPO	Great Lakes National Program Office
gpm	Gallon(s) per minute
GRO	Gasoline range organics
in.	Inch(es)
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
mg/kg	Milligram(s) per kilogram
MI	Michigan
MNR	Monitored natural recovery
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NREPA	Natural Resources and Environmental Protection Act

ORO	Oil range organics
PCUG	Preliminary clean-up goal
PEC	Probably effects concentration
PPE	Personal protective equipment
RAO	Remedial action objective
RD	Remedial design
SEM	Simultaneously extracted metals
SWAC	Surface-weighted average concentration
TPH	Total petroleum hydrocarbons
TRV	Toxicity reference value
TSS	Total suspended solids
USFWS	U.S. Fish and Wildlife Serves
USACE	U.S. Corps of Engineers

1. INTRODUCTION

EA Science and Technology and its affiliate EA Engineering, Science and Technology, (MI) PLC[1] (EA) has been contracted by the U.S. Environmental Protection Agency (EPA) to perform the Feasibility Study (FS) for the Former Zephyr Refinery Fire Suppression Ditch area (Site) in the Muskegon Lake Area of Concern (AOC) under the Great Lakes Architect-Engineer Services Contract No. EP-R5-11-10. This FS presents an evaluation of remedial and restoration alternatives to address contaminated sediments in the Fire Suppression Ditch area. Development of the FS has been a multi-step process led by the project stakeholders including EPA's Great Lakes National Program Office (GLNPO) and the Michigan Department of Environmental Quality (MDEQ). The purpose of this FS is to document the identification, development, and evaluation of remedial and restoration alternative options for managing contaminated sediments in the Fire Suppression Ditch area of the Former Zephyr Refinery.

1.1 SITE BACKGROUND

The Site is part of the Muskegon Lake AOC and is located approximately 1 mile northeast of Muskegon Lake on a plateau between the Muskegon River and Bear Creek (Figure 1-1). The project site is approximately 16 acres in size and is located in the floodplain/wetland area south of the former Zephyr Refinery. Operations at the refinery from the 1930s to the early 1990s resulted in substantial releases of petroleum hydrocarbons with some single releases exceeding 150,000 gallons. The former Fire Suppression Ditch provided water from the North Branch of the Muskegon River for operation and fire suppression use at the refinery.

In Spring 2012, EPA's GLNPO conducted a site characterization of areas adjacent to the former Zephyr Refinery. The study evaluated the nature and extent of contaminated sediments around the refinery, focusing on the wetlands north and south of the former refinery, as well as Bear Creek and the north branch of the Muskegon River including the Fire Suppression Ditch. Results showed elevated levels of petroleum hydrocarbons, oil and grease, and heavy metals in various offsite lowland areas downgradient of the refinery. Over the past 15 years, remedial actions, including the use of recovery trenches with a groundwater pump and treat system, have been undertaken to hydraulically control the migration of contaminants. Historical contaminant investigations of the refinery and surrounding properties indicated impacted groundwater and light non-aqueous phase liquid have migrated into the Fire Suppression Ditch and adjacent wetlands. Currently, it is assumed the source areas of contamination are controlled and impacts to the Fire Suppression Ditch and adjacent wetlands are no longer occurring from upland source areas. Additional data were collected in October–November 2013 in support of this FS, which further delineated the extent of contaminated sediments within the Fire Suppression Ditch and surrounding wetlands.

[1] EA Engineering, Science, and Technology, Inc. does business as EA Science and Technology in the State of Michigan and EA is affiliated with EA Engineering, Science and Technology, (MI) PLC.

1.2 PURPOSE AND SCOPE

The overall purpose of this project is to address contaminated sediments at the Site that are contributing to beneficial use impairments (BUIs) within the Muskegon Lake AOC. The scope of the project includes both remediation of sediments within the Site and habitat restoration of areas affected by that remediation.

The specific purpose of this FS is to document the identification, development, and evaluation of remediation alternatives and restoration options for managing contaminated sediments in the Fire Suppression Ditch area of the Site. Development of the FS has been a multi-step process and has included preparation of interim documents leading up to the FS that served as an initial focus for review, comment, and revision. These documents have included the Remedial and Restoration Alternatives Screening Technical Memorandum (EA 2013), the Clean-Up Goals Memorandum (EA 2014a) included in Appendix A, and the Remedial and Restoration Alternatives Evaluation Technical Memorandum (EA 2014b). The updated and refined content of these documents has been included in this FS. Additionally, the Site Sampling Technical Memorandum (EA 2014c), included in Appendix B, summarizes sampling activities completed in 2013 in support of this FS. A data usability report, including assessment of the chemical data collected in support of the FS as well as the full analytical data reports, has been provided under separate cover (EA 2014d).

The ultimate goal of the FS is to provide the information necessary to select a remedial alternative and associated restoration options that can be implemented at the Site to achieve remedial objectives. To achieve this goal, the FS includes the following components:

- **<u>Introduction</u>** – Background information is presented in Section 1 to provide a context for the FS and to document the sources of data upon which it is based. This includes the definition of purpose and a description of supporting investigations.

- **<u>Conceptual Site Model (CSM)</u>** – Remedial alternatives for the Fire Suppression Ditch area have been developed based on an understanding of the site gained from past investigations and surveys. This understanding is captured in the CSM, which defines the Site setting, sources of chemicals, and fate and transport pathways. The CSM also discusses the BUIs for the Site and identifies preliminary clean-up goals (PCUGs). It summarizes sampling activities completed in 2013 and includes a discussion of wetland and habitat quality to support the evaluation of restoration options. The CSM is presented in Chapter 2.

- **<u>Screening of Remedial Technologies</u>** – There are many remediation technologies that can be applied to manage contaminated sediments; not all of these technologies are relevant or appropriate for application at the Site. Therefore, technologies are screened in Chapter 3 based on their potential to effectively and efficiently address the remedial action objectives (RAOs). In screening, technologies are retained for consideration or eliminated based on their potential effectiveness, implementability, and cost to implement at the Site.

- **Development of Remedial Alternatives and Restoration Options** – The central focus of the FS is developing and evaluating remedial alternatives. Therefore, Chapter 4 identifies viable alternatives for remediation based on technologies that were retained during screening. The remediation at the Fire Suppression Ditch area includes habitat restoration for areas affected by remediation. Chapter 5 defines the goals of restoration and identifies techniques that can be used to accomplish the restoration goals.

- **Evaluation of Remedial Alternatives and Restoration Options** – Evaluation of remedial alternatives and restoration options begins in Chapter 6, which defines the evaluation criteria. Remedial alternatives were evaluated in two stages. The alternatives for the Site are based on different combinations of two primary technologies: relatively dry excavation and mechanical dredging with hydraulic transport. Therefore, Chapter 7 presents a discussion of how each of these two technologies may be implemented using representative process options, and an independent evaluation of each technology. Chapter 8 presents the evaluation of each alternative, drawing from the discussion in Chapter 7. Options for restoration are evaluated in Chapter 9, which includes a discussion of implementability and range of costs associated with different restoration components.

- **Recommended Alternative** – The FS concludes in Chapter 10 with recommendation of a remedial alternative and restoration options to be selected and implemented at the Site. The recommendation will be carried forward into the remedial design (RD).

It should be noted that the FS utilizes the general framework and terminology presented in guidance for preparing FS documents under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA 1988), with the understanding that the Fire Suppression Ditch area is not a National Priorities List (NPL) site and, thus, is not subject to the requirements of CERCLA. Therefore, some steps and considerations that are specific to CERCLA have been modified to meet the specific needs of the project. Specifically, modifications have been made in association with consideration of restoration alternatives, definition of alternative evaluation criteria, and discussion of permitting requirements.

1.3 INFORMATION SOURCES SUPPORTING THE FEASIBILITY STUDY

The FS for the Fire Suppression Ditch area is based upon numerous sources of information. These include previous investigations, studies, and reports, including the following:

- **Phase 1 Site Characterization:** Information regarding site conditions and chemicals of concern (COCs) at the site are included in the Assessment of Contaminated Sediment Site Characterization Report (EA 2012). Key data from this source include background information, Site setting information, and information regarding the distribution and composition of contaminated sediments in the Fire Suppression Ditch area.

- **Investigation to Support the FS:** Planning for the FS included a field effort to collect additional chemical analytical, lithologic, and sediment thickness data as well as geotechnical data (EA 2014c). A key focus was delineating the extent of contaminated sediments in the Fire Suppression Ditch area and collecting geotechnical data to support development of the FS. Additionally, a habitat evaluation of the Fire Suppression Ditch and its immediately adjacent wetland was conducted to define and evaluate the existing habitats throughout the study area. The findings were used in this FS to determine potential impacts associated with the proposed remedial activities and assess habitat restoration activities that could be conducted in conjunction with the remedial activities.

  A memorandum summarizing field activities and analytical results of the field effort to support the FS is included in Appendix B. The results of the wetland delineation are presented in Appendix C. Methods and results of spatial modeling using chemistry data are presented in Appendix D. A data usability report, including assessment of the chemical data collected in support of the FS as well as the full analytical data reports, has been provided under separate cover (EA 2014d).

Data from the above sources were used to develop the CSM presented in Chapter 2 and form the basis for decisions made in the FS.

2. CONCEPTUAL SITE MODEL

The CSM describes the site setting and habitats, BUIs, PCUGs, sources of chemicals, fate, transport, and exposure pathways for the Site. Based on the results of past site characterization efforts, as well as the investigation conducted in 2013 in conjunction with this FS (Appendix B), the primary chemicals of concern for the Fire Suppression Ditch area are total petroleum hydrocarbons (TPH) and metals.

2.1 SITE SETTING

The former Zephyr Refinery project area is located within the Muskegon Lake AOC, Muskegon, Michigan, and encompasses the North Branch of the Muskegon River, Bear Creek, and the surrounding wetlands. State Highway 120 (Holton Road) separates the northern and southern portions of the Zephyr Site. The former Zephyr Refinery is situated on a groundwater divide where groundwater flow direction is to the north and south. The North Branch of the Muskegon River drains the southern portion of the former refinery while Bear Creek drains the northern portion.

The Zephyr Oil Refinery operated for more than 40 years, and historical releases of petroleum to the Muskegon Lake watershed have contributed to contamination of the sediment, groundwater, and wetlands surrounding the former refinery. Contamination from the former Zephyr Refinery area may potentially be contributing to the BUIs of the Muskegon Lake AOC.

Former waste lagoons and a fire suppression ditch, once part of the Zephyr operations, are located within the southern wetlands approximately 50 to 300 feet (ft) east of the railroad right-of-way. Some of the wetlands located east of the railroad right-of-way on the southern portion of the former Zephyr Refinery were once operated as celery farms and are surrounded by earthen berms that act as a levee system. Portions of these wetlands are actively de-watered by pumping the accumulated surface water from within the earthen berms and discharging the water directly to the North Branch of the Muskegon River.

Since 2000, MDEQ has been operating and maintaining a groundwater extraction remediation system in the upland portion of the Former Zephyr Refinery. Light non-aqueous phase liquids associated with petroleum products have been detected in upland monitoring wells. Currently, it is assumed that all upland source areas of contamination are no longer contributing to contamination in the Fire Suppression Ditch area as a recovery/cut-off trench and groundwater pump and treat system are operated. This CSM addresses the Fire Suppression Ditch area located just south of the upland portion of the former Zephyr Refinery Site.

The CSM for the Site focuses on the ditch itself and associated wetlands to the west and east (Figure 2-1). The ditch is a shallow depression approximately 1,400 ft long and 30 ft wide that contains emergent vegetation and standing water less than 2 ft deep. Flow within the ditch runs from the north, where it receives inputs from the National Pollutant Discharge Elimination System (NPDES) permitted discharge pipe for the existing groundwater pump and treat system, to the south, where it discharges to the Muskegon River through groundwater seeps and a small surface channel. A former waste lagoon (previously remediated and not considered as part of the project area) is located west of the ditch and separated by berms from the ditch and a wetland located to the south. The southern wetland (approximately 4 acres) contains dense emergent vegetation and is part of the project area. East of the ditch lies a wetland of approximately 8 acres containing dense emergent vegetation. Water depths in those wetlands range from 0 to 2 ft deep, with no open water or known direct connection to the river. In many areas, sediments are overlain by significant plant matter. Connectivity between the wetlands and the ditch as well as between the wetlands and the river is unclear. Sediments in the wetlands and ditch include sand, silty sand, silty clay, and silt.

2.1.1 Land Use

The former Zephyr Refinery is located in Muskegon County, Michigan and currently consists of approximately 70 acres located south of M-120 (Holton Road) and west of Wood Road. The upland portion of the former Zephyr Refinery is generally flat with the exception of the south side, which consists of a steep bank which drops to the Muskegon River flats, where the Site (Fire Suppression Ditch area), and focus of this CSM and FS, is located. The property is surrounded by industrial, commercial, and residential land uses. The upland portion of the former Zephyr Refinery is currently utilized for bulk fertilizer storage. Railroad tracks run next to the southern edge of the property and along the western boundary of the Site. The Muskegon River is located adjacent to the Fire Suppression Ditch area to the south. Recreation in the Muskegon River includes boating and fishing.

2.1.2 Climate

Climate data from nearby Muskegon County Airport indicate that average temperatures in the area fluctuate from 18.0 degrees Fahrenheit (°F) in January to 80.0 °F in July. Average temperatures are near or below freezing in December, January, and February. The monthly average amount of precipitation varies from a minimum of 1.7 inches (in.) in February to maximum of 3.3 in. in September, with a yearly average of 33.3 in. Average monthly snowfalls of at least 0.1 in. have been recorded October through April, with the greatest monthly average of 34 in. in January.

2.1.3 Hydrology

Currently, a small surface water channel connects the Fire Suppression Ditch to the adjacent Muskegon River to the south. Groundwater connections between the Fire Suppression Ditch and surrounding wetlands and the Muskegon River are likely as well. Standing water is located within the wetlands on a seasonal basis. Historical aerial photographs indicate a stream channel has been present within the last 50 years, just to the west of the Ditch, flowing from the lagoon at the north end of the Ditch to the River. Flow of the Muskegon River runs from east to west towards Muskegon Lake. Hydrology of the Muskegon River in the vicinity of the Site has historically been controlled by lake levels in Muskegon Lake and Lake Michigan (which is connected to Muskegon Lake by a short channel).

2.1.4 Geology and Sediment Lithology

Muskegon County geology is dominated by deposits of material remaining from past glacial advance and retreat. The lithology of the Site is predominantly sand, with some areas of silt, clay, and organic materials, such as peat. The wetlands are predominantly fine-grained sand, with some silty sand and sandy silt also present.

The Site consists of Tawas and Carlisle muck with a parent material of woody organics over sandy glacial drift. Clay can be found in the Fire Suppression Ditch, except at the southern end, which is mostly sand. In general, the lithology in the wetlands becomes finer grained with depth grading to clayey silt at depths greater than 5 ft and silty clay at depths greater than 8 ft.

Based on the results of the geotechnical sampling completed as part of the 2013 investigation in support of this FS, the Fire Suppression Ditch sediments consist of a combination of fine (66 percent on average) and coarse grained (33 percent on average) material with high organic matter content (20 percent on average) and elevated moisture content. Sediments in the wetlands consisted of a combination of fine grained (56 percent on average) and coarse grained (43 percent on average) material with a high organic matter content (24 percent on average) with an average moisture content of approximately half that of the sediments in the Fire Suppression Ditch. The geotechnical laboratory report is included as an appendix to the Site Sampling Technical Memorandum included as Appendix B of this FS Report.

2.1.5 Habitats

The Site consists of a combination of an open water habitat (Fire Suppression Ditch) and emergent/scrub-shrub wetland habitats as well as an adjacent perennial stream (Muskegon River). As part of the FS field effort, a habitat and wetland survey were completed. The wetland was originally thought to be two individual wetlands, separated by an interior berm and access road. However, during the field review it was determined that the access road and berm does not separate the wetland completely. The delineated wetland covers 16.93 acres of the 19.34 acres of the area of review (88 percent). The wetland is bound on the north, east, and west by existing berms and roads and to the south by the Muskegon River. Additionally, a berm and access road juts into the northwestern portion of the wetland. This wetland consists predominantly of a large emergent wetland dominated by a monotypic stand of narrow-leaf cattail (*Typha angustifolia*). Smaller stands of common reed (*Phragmites australis*) and reed canary grass (*Phalaris arundinacea*) were also identified throughout the wetland although in small patches. Lastly, three small pockets of scrub-shrub wetland were identified along the western and southern boundaries of the onsite wetlands, which appeared to be located on areas of a slight sediment deposition at a stormwater outfall and from typical floodplain hydraulic processes.

In general, the onsite wetland is dominated by invasive species such as common reed, narrow-leaf cattail, and reed canary grass. Additional hydrophytic vegetation identified throughout the wetland included, but was not limited to: sandbar willow (*Salix interior*), broad-leaf cattail (*Typha latifolia*), red maple (*Acer rubrum*), and glossy buckthorn (*Frangula alnus*).

The different wetland areas identified within the area of review are very similar in nature, including the quality of wetland and values that appear to be within the moderate functional value range. The wetland areas delineated for this project appear to have the primary function of providing habitat for wildlife. Additionally, the wetland identified within the area of review appears to function as flood attenuation. However, the wetland predominantly consists of invasive species and therefore the overall quality is diminished, particularly regarding wildlife habitat. The wetland delineation report is included as Appendix C.

Due to its monotypic habitat, characterized by high densities of invasive species such as cattail and common reed, wildlife species most likely utilizing the onsite wetland include those tolerant to degraded habitats. Such species likely present within the area of review include: common waterfowl and songbirds such as the mallard (*Anas platyrhinchos*), Canada goose (*Branta canadensis*), red-winged blackbird (*Agelaius phoeniceus*), and catbird (*Dumetella carolinensis*); amphibians and reptiles not reliant on permanent bodies of water including the Northern spring peeper (*Pseudacris crucifer*), Western chorus frog (*Pseudacris triseriata triseriata*), Northern leopard frog (*Rana pipiens*), Eastern garter snake (*Thamnophis sirtalis*), and potentially the Northern water snake (*Nerodia sipedon*); and mammals such as raccoon (*Procyon lotor*), muskrat (*Ondatra zibethicus*), and white-tailed deer (*Odocoileus virginianus*).

Increased native vegetation diversity and/or reduction in the density of invasive species as well as creation of a variety of habitat types (e.g., permanently inundated marsh/open water) would increase the quality of the onsite wetland, particularly wildlife.

2.2 BENEFICIAL USE IMPAIRMENTS

Contamination from the Site may potentially be contributing to the BUIs of Muskegon Lake AOC. The Muskegon Lake AOC Remedial Action Plan Team has identified the following BUIs for the AOC:

- Beach closings
- Restrictions on fish and wildlife consumption
- Eutrophication or undesirable algae
- Restrictions on drinking water consumption, or taste and odor
- Degradation of fish and wildlife populations
- Degradation of aesthetics
- Degradation of benthos
- Restrictions on dredging activities
- Loss of fish and wildlife habitat.

BUIs are established for the Muskegon Lake AOC as a whole, but not all BUIs apply to every site within the AOC. BUIs specific to the Site are degradation of benthos, degradation of fish and wildlife populations, and loss of fish and wildlife habitat due to heavy metals and petroleum compounds in the sediment.

Degradation of Benthos

The degradation of benthos BUI caused by contaminated sediments will be considered restored for the Muskegon Lake AOC when all remedial actions for known contaminated sediment sites with degraded benthos are completed and monitored according to the approved plan for the sites. Removal of the BUI will not be contingent on full recovery of the benthic community, which may take many years or even decades (MDEQ 2008 and 2011).

Degradation of Fish and Wildlife Populations and Loss of Fish and Wildlife Habitat

The degradation of fish and wildlife populations and loss of fish and wildlife habitat BUIs are considered together in the guidance in the recognition of the integral relationship between them (MDEQ 2008 and 2011). The Site is not expected to currently sustain fish populations. It is possible that remediation and restoration could create open water habitats; therefore, both fish and benthic communities were considered in developing goals associated with this BUI.

The Muskegon Lake Watershed Partnership developed and adopted restoration criteria for the Muskegon Lake AOC for the loss of wildlife habitat and degradation of population in consultation with MDEQ, Michigan Department of Natural Resources (MDNR) Fisheries, EPA, U.S. Fish and Wildlife Service (USFWS), and a team of local experts to address removal of this BUI. The required criteria for removal include:

- A short narrative on historical fish and wildlife habitat or population issues in the AOC
- A description of the impairment(s) and location for each aquatic habitat or population site(s) to address the issues that had been identified in the Remedial Action Plan Updates
- A locally derived restoration target for each impacted habitat or population site
- A list of all other ongoing habitat or population planning processes in the AOC
- A scope of work for restoring each impacted aquatic habitat or population site
- A component for reporting on habitat or population restoration implementation action(s) to MDEQ.

Habitat values and populations need not be fully restored prior to delisting as some may take many years to recover after activities are complete. As such, goal development focused on chemical-specific criteria for clean-up that are expected to reduce impacts within the Site, which will contribute to improvement of conditions throughout the AOC as a whole.

2.3 EXISTING BASIS FOR CLEAN-UP GOALS

The following RAOs have been developed for the Site:

- Remove/manage sediments contributing to the following BUIs within the Muskegon Lake AOC:

  — Degradation of fish and wildlife populations
  — Loss of fish and wildlife habitat
  — Degradation of benthos

- Minimize potential risks to human health and the environment during remedial activities

- Upon completion of remedial activities, restore habitat in the remediated areas.

Inherent to supporting removal of BUIs is controlling or eliminating contaminated sediments which contribute to the degradation of habitat for wildlife and benthos in the Muskegon Lake AOC. The PCUGs have been developed to achieve the objective of removing/managing sediments contributing to BUIs for the AOC. The PCUGs are based primarily on BUIs related to impacts on ecology, as the Site is not heavily used by people, and future land use for the Site is undetermined. Arsenic, copper, lead, mercury, zinc, and TPH are identified as the primary COCs.

PCUGs were developed to be protective of smaller, less mobile organisms such as plants and benthos/aquatic organisms, and larger, more mobile organisms such as wildlife. Guidance and scientific studies were reviewed to compile relevant toxicological data, and candidate benchmarks, referred to as toxicity reference values (TRVs), were calculated as potential goals. For benthos, probable effects concentrations (PECs) from a major consensus-based study (Macdonald et al. 2000) were selected as PCUGs for metals. For TPH, a value was derived by examining the range of values used for screening and assessment of impacts from a range of studies, and selecting a value from the low end of this range. These PCUGs represent point-by-point concentrations as targets for remediation.

Wildlife PCUGs were developed using food web modeling and a range of data from guidance and literature to back-calculate a concentration in sediment that will be protective of wildlife exposures. Because wildlife are highly mobile, these goals represent site-wide averages as opposed to point-by-point targets. No-effect and low-effect concentrations were calculated for four different species (duck, goose, heron, raccoon), and the low effect concentration identified as a PCUG. PCUGs include area use factors because wildlife would be expected to move out of the Site as part of foraging or migration 50 to 75 percent of the time, dependent on species. PCUGs for benthos and wildlife are presented in Table 2-1 below.

PCUGs were not identified for people, but concentrations protective of human health exposures during wading were calculated using EPA guidance (EPA 2013). These were compared to the benthos and wildlife PCUGs, and it was identified that sediment clean-up to meet ecological PCUGs would also protect people from direct contact exposures with sediment.

Table 2-1 Preliminary Clean-Up Goals (PCUGs)

COC	Benthic PCUG (mg/kg)	SWAC-based Wildlife PCUG (mg/kg)
Arsenic	33	38
Cadmium	4.98	44
Chromium	111	96
Copper	149	1,260
Lead	128	134
Mercury	1.06	40
Zinc	459	1,710
Total Petroleum Hydrocarbons	2,000	5,020
Notes: mg/kg = milligrams per kilogram SWAC = surface-weighted average concentration		

Modeling of the extent of contamination requiring remediation was completed based on the benthic PCUGs and back-checked to verify that wildlife PCUGs were also met. The development of the PCUGs is detailed in the Clean-Up Goals Memorandum (EA 2014a) included in Appendix A.

2.4 CHEMICAL SOURCES

The primary chemicals of concern for the Site are TPH and metals. COCs are thought to be derived from historical refinery operations, including the production, storage, and transport or leaded gasoline as well as unidentified historical industrial sources within the project area. Previous investigations have not identified any ongoing sources (i.e., upstream or upland sources) currently contributing additional amounts of TPH or metals to the site beyond what is currently present in onsite sediment deposits. Previous investigations that identified COCs and chemical sources are summarized below.

2012 Phase 1 Site Characterization

The 2012 Phase 1 Site Characterization identified initial COCs at the Site including TPH and metals. In the Fire Suppression Ditch area, diesel range organics (DRO) and oil range organics (ORO) concentrations were highest in the ditch and south of the former waste lagoon located between the railroad right-of-way and the ditch. At ZW12-16, the highest concentrations of DRO and ORO were 36,000 and 19,000 mg/kg, respectively. DRO/ORO concentrations were highest at the surface, decreasing in concentration with depth. At the head of the Fire Suppression Ditch (ZW12-13) concentrations of DRO and ORO increase slightly with depth to a maximum concentration of 1,900 and 2,700 mg/kg, respectively. In general, TPH was detected at higher concentrations within the upper 4 ft of sediment. Only locations ZW12-16 and ZW12-19 had elevated concentrations at depths below 4 ft. Gasoline range organics (GRO) did not appear to be present at elevated concentrations in the Fire Suppression Ditch area.

Metals concentrations were higher in the Fire Suppression Ditch area than other areas investigated during the Phase 1 Site Characterization, with lead being the most frequently detected and having the highest concentrations. The highest concentration for lead (172,000 mg/kg) was detected south of the former waste lagoon (ZW12-16). Elevated concentrations of lead were present in the Fire Suppression Ditch, in the wetlands south of the former waste lagoon, and in the wetlands east of the Fire Suppression Ditch along the earthen berms. Arsenic, copper, lead, and mercury exceeded their respective PEC levels at one of the 18 sampled locations. Generally, the highest concentrations of metals were detected near the surface, except at locations ZW12-16 and ZW12-15, where elevated levels of mercury and lead were found at depths between 4 and 6 ft. In general, higher metal concentrations appeared to correspond to locations with higher concentrations of oil and grease, as well as TPH.

2013 Site Investigation in Support of the FS

The 2013 investigation was completed in order to support development of the FS and further delineate COC impacts noted during the Phase 1 Site Characterization. A summary of the sampling activities, including the presentation of sampling results in tables and figures, is presented in the Site Sampling Technical Memorandum, included as Appendix B of this FS Report. A summary of the results of the investigation activities follows. It should be noted that analytical results were compared to PECs, which were identified in Section 2.3 as the basis for the PCUGs.

A total of 90 sediment samples were collected and submitted for TPH GRO, DRO, and ORO analyses during the 2013 investigation activities (samples were collected by both EA and MDEQ). GRO was detected in 14 of 90 samples with concentrations ranging from 3.3 to 78 mg/kg. The maximum detection occurred in ZW13-32-0001, but the top three intervals from ZW13-25 also had elevated detections relative to other sample concentrations. However, none of the detected concentrations were greater than 100 mg/kg. DRO was detected in 62 of 90 samples with concentration ranging from 8 to 54,000 mg/kg. The maximum detection occurred in ZW13-32-0001, and the detected concentrations in ZW13-30-0001 and ZW13-34-0001 were also greater than 10,000 mg/kg. ORO was detected in 84 of 90 samples with concentrations ranging from 8.3 to 110,000 mg/kg. The maximum detection occurred in ZW13-34-0001. The detected concentrations in the top interval of ZW13-30, ZW13-32, and ZW13-33 and the top two intervals of ZW13-47 were also greater than 10,000 mg/kg. The majority of the maximum detections for petroleum hydrocarbon fractions were located in the wetland west of the Fire Suppression Ditch in areas previously identified as containing elevated TPH detections in sediment.

A total of 90 sediment samples were collected and submitted for metals analysis during the 2013 investigation activities (samples were collected by both EA and MDEQ). The following metals were analyzed: arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel (12 MDEQ samples were not analyzed for nickel), selenium, silver, and zinc. Five of the 8 metals (arsenic, copper, lead, mercury, and zinc) exceeded respective PECs in greater than 5 percent of the samples. For three metals (copper, lead, and zinc) at least one of the detected sample concentrations was greater than 10 times the PEC.

Arsenic was detected in each of the 90 sediment samples. Arsenic concentrations ranged from 0.65 to 52.9 mg/kg. The maximum detection occurred in ZW13-47-0001. Approximately 6.4 percent exceeded the PEC. Each of the detections that exceeded the PEC was located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-31, ZW13-33, ZW13-34, and ZW13-47) or in the ditch itself (ZW13-25-0204).

For barium, selenium and silver, there are no PECs for comparison. Barium was detected in each of the 90 sediment samples. Barium concentrations ranged from 2.3 to 167 mg/kg. The maximum detection occurred in ZW13-25-0204. Selenium was detected in 76 of 90 sediment samples. Selenium concentrations ranged from 0.3 to 13.5 mg/kg. The maximum detection occurred in ZW13-34-0001. Silver was detected in 27 of 90 sediment samples. Silver concentrations ranged from 0.056 to 2 mg/kg. The maximum detection occurred in ZW13-32-0001. The maximum detections are located in the wetland west of the Fire Suppression Ditch or the ditch itself.

Cadmium was detected in 83 of the 90 sediment samples. Cadmium concentrations ranged from 0.023 to 4.6 mg/kg. The maximum detection occurred in ZW13-25-0102. No samples exceeded the PEC.

Chromium was detected in each of the 90 sediment samples. Chromium concentrations ranged from 1.4 to 58 mg/kg. The maximum detection occurred in ZW13-29-0204, which is in the Fire Suppression Ditch. No detections exceeded the PEC.

Copper was detected in 85 of the 90 sediment samples. Copper concentrations ranged from 0.36 to 398 mg/kg. The maximum detection occurred in ZW13-32-0001. Approximately 6.4 percent of the samples exceeded the PEC. Each of the detections that exceeded the PEC was located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-31, ZW13-32, ZW13-33, ZW13-34 and ZW13-47).

Lead was detected in each of the 90 sediment samples. Lead concentrations ranged from 0.51 to 54,200 mg/kg. The maximum detection occurred in ZW13-32-0001. Forty-five percent of the samples exceeded the PEC, and 15 percent exceeded 10 times the PEC. With the exception of the top two intervals of ZW13-41, each of the detections that exceeded 10 times the PEC were located in the wetland west of the Fire Suppression Ditch (top interval of ZW13-30, ZW13-31, ZW13-32, ZW13-33, ZW13-34, and ZW13-35, and the top two intervals of ZW13-47 and ZW13-48).

Mercury was detected in 56 of the 90 sediment samples. Mercury concentrations ranged from 0.0094 to 3.5 mg/kg. The maximum detection occurred in ZW13-33-0001. Approximately 7.3 percent of the samples exceeded the PEC. Each of the detections that exceeded the PEC was located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-32, ZW13-33, ZW13-34, and ZW13-48).

Nickel was detected in each of the 78 sediment samples (MDEQ samples collected were not analyzed for nickel). Nickel concentrations ranged from 0.9 to 48.4 mg/kg. The maximum detection occurred in ZW13-29-0204. No samples exceeded the PEC.

Zinc was detected in each of the 90 sediment samples. Zinc concentrations ranged from 2 to 14,600 mg/kg. The maximum detection occurred in ZW13-25-0102. Five percent of the samples exceeded the PEC. The top three intervals from ZW13-25 exceeded 10 times the PEC. Each of the detections that exceeded the PEC were located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-30, ZW13-31, ZW13-32, ZW13-33, ZW13-34, and ZW13-47) or in the ditch itself (top three intervals of ZW13-25, ZW13-26-0001, ZW13-27-0406, ZW13-29-0102, ZW13-29-0204, and ZW13-29-0406).

A total of eight surface (0 to 0.5 ft) sediment samples and one field duplicate were submitted for simultaneously extracted metals/acid volatile sulfide (SEM/AVS). For samples from the following locations, AVS was not detected, so the SEM/AVS ratio could not be calculated: ZW13-31, ZW13-33, ZW13-38, and ZW13-42. The SEM/AVS ratio for the following locations was greater than one: ZW13-33FD, ZW13-35, and ZW13-41. These results indicate that metals are not bioavailable in a majority of the sampled locations, including locations in the wetlands both east and west of the Fire Suppression Ditch. The SEM/AVS ratio for two samples was less than one, indicating that metals are not bioavailable at ZW13-25 and ZW13-27, which are located in the Fire Suppression Ditch.

Overall, COCs including TPH and metals were detected throughout the Fire Suppression Ditch and surrounding wetlands during the 2013 Site Characterization sampling activities. Figure 2-2 presents detections of lead from the 2013 investigation activities which exceed the PCUG of 128 mg/kg and Figure 2-3 presents detections of TPH from the 2013 investigation activities which exceed the PCUG 0f 2,000 mg/kg in the Fire Suppression Ditch area. Further discussion of detected COCs and the delineation of COC distribution compared to PCUGs are presented below.

2.4.1 Delineation of Chemical Distribution

PCUGs were used to map the area and calculate the volume of sediments requiring remediation. First, the combined data from 2012 and 2013 was mapped in order to evaluate the distribution of the COCs across the Site. The area and associated volume exceeding benthos PCUGs was determined as a target of remediation. The extent of both lead and TPH exceeding PCUGs was found to encompass the extent of all other COCs for the Site, so lead and TPH were used as the primary guide to defining target volumes. Modeling was performed that found that remediating to benthos PCUGs would achieve PCUGs for wildlife, and would achieve concentrations protective of human health under current Site uses. Environmental Visualization Software (EVS) was utilized to determine the extent and volume of sediment contamination using three-dimensional kriging, a spatial statistical interpolation technique. Methodology for the spatial statistical analysis/modeling completed is further described in Appendix D.

The area of sediment remediation based on the benthos PCUGs, and protective of the wildlife PCUGs, is presented in Figure 2-4. Items of note related to the modeling include:

- No overburden requiring handling is present at the Site as each location with exceedances of the benthic PCUG includes a surface sample; and

- The bottom of the contaminated sediment is bounded.

Based on this modeling, approximately 9,704 cubic yards (cy) of contaminated sediment are present in the Fire Suppression Ditch and 20,593 cy of contaminated sediment are present in the surrounding wetlands. The total estimated volume of contaminated sediment to be removed during remedial activities, including contingencies as a result of dredging operations, is 51,217 cy (this volume is calculated *in situ* and is estimated prior to dewatering activities); this value includes the following:

- Contingencies for uncertainties in the volume due to core recovery;

- An estimation of the volume associated with the middle section of the ditch removed due to logistics;

- A 6-in. vertical over-dredge allowance;

- An estimation for presence of vegetation/root mass on top of sediment to be removed; and

- A 1-ft buffer zone horizontally around the perimeter of the wetland removal areas – removed to a depth of 2 ft.

A summary of these volumes is presented in Table 2-2. Table 2-2 also includes estimation of the weight of sediment to be disposed offsite following dewatering activities for each Alternative (2 and 3) as determined following mass balance calculations. The mass balance was performed in order to determine disposal volumes following dewatering activities to reduce the overall volume of material. Based on the high moisture content and organic matter of the material in the Fire Suppression Ditch and wetlands to be remediated, a relatively large volume of water is estimated to be liberated from the sediment during dewatering activities, which leads to sediment disposal volumes that are less than the *in situ* volume removed from the Site.

2.5 FATE, TRANSPORT, AND EXPOSURE MECHANISMS

The primary source of chemicals to the Site is suspected to be historical releases from the upland former Zephyr Refinery. It is suspected that waste was discharged directly to the ditch and some or all of the wetlands. It is also suspected that chemicals in groundwater may have historically discharged to the wetlands and ditch through seeps. Currently, a groundwater cut-off trench is located between the upland source area of contamination and the Site; therefore, it is assumed that upland contaminant sources are no longer contributing to contamination at the Site. The secondary source of chemicals and focus of the FS is the sediment within the Fire Suppression Ditch area. As described in the Clean-Up Goals Technical Memorandum for Remediation of Contaminated Sediment in the Former Zephyr Oil Refinery Fire Suppression Ditch (EA 2014a), the primary COCs for the Site are metals (arsenic, cadmium, chromium, copper, lead, mercury, and zinc) and petroleum-related wastes (TPH). Concentrations of TPH and oil and grease generally decrease with depth of sediment with the majority of impacts in the 0- to 2-ft below ground surface range (EA 2012). In general, higher metal concentrations appeared to correspond to locations with higher concentrations of oil and grease, as well as TPH.

As documented in past investigations (EA 2012), the river does not show signs of contamination from the ditch or wetlands through other pathways. Possible fate and transport pathways include:

- Adsorption of chemicals from groundwater onto surface and subsurface sediment;
- Transport of chemicals in groundwater from upland sources into groundwater below the wetlands and the ditch;
- Transport of chemicals in groundwater from the wetlands into groundwater below the ditch;
- Transport of chemicals in groundwater into surface water through seeps; and
- Mixing within the wetlands and ditch due to porewater movement and bioturbation.

Uptake and bioaccumulation of chemicals is also expected to serve as a fate and transport mechanism. Some metals—specifically methylated metals and some hydrocarbons—may bioaccumulate in plants or animals and, under appropriate conditions, biomagnify through the food chain.

3. IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

This section describes sediment remediation technologies that are applicable to remediation of sediments contaminated with TPH, especially DRO and ORO and heavy metals. The technologies are then screened for their ability to achieve the PCUGs for the Site, based on technical feasibility, implementability, environmental risk, relative cost, and public acceptance. Technologies that are retained as a result of the screening are carried through and utilized to develop remedial alternatives presented in Chapter 4.

Four primary categories of technologies that may be applicable to remediation at the Site are:

- No Action
- Monitored or Enhanced Natural Recovery
- Containment
- Sediment Removal.

These technologies and their associated process options are summarized in Table 3-1.

A screening level evaluation of each technology identified within these categories was performed, using the following criteria.

Technical Feasibility—Technical feasibility is the measure of the applicability of the technology to reduce the concentration of the contaminants present at the Site or to decrease ecological exposure to the contaminants of concern by achieving protectiveness in a limited duration. If the technology is not effective in supporting the removal of BUIs, the proposed technology may be eliminated from further consideration.

Implementability—Implementability is a measure of the availability of the technology and the administrative feasibility of implementing it at the Site. Technologies that are technically or administratively unfeasible or that would require equipment, specialists, or facilities that are not available within a reasonable period may be eliminated from further consideration.

Environmental Risk—Environmental risk is a measure of the potential short-term and long-term impacts of the technology, from an ecological and human health perspective. Technologies that do not substantially decrease ecological risk or do not provide adequate protection of human health may be eliminated from further consideration.

Relative Cost—Qualitative relative costs for implementing the remedy are considered. Technologies that cost more to implement, but that offer no benefit in environmental risk reduction or implementability over other technologies, may be excluded from the alternative development process.

Public Acceptance**—**The likelihood of public acceptance of the remedy is considered. Among technologies with similar effectiveness and implementability, those expected to receive a more favorable response from the public may be given preference.

As part of the screening, each technology is either retained or not retained for further analysis. Table 3-2 summarizes the identified technologies and the results of the screening level evaluation. Screening was performed according to a qualitative "low," "medium," and "high" ranking in which a "high" ranking is deemed more favorable for addressing respective screening criteria. A short summary of the screening process for each of the technologies as well as the associated process options or supporting technologies is provided below.

3.1 NO ACTION

A No Action alternative is typically considered as part of the alternatives screening process and is retained for consideration to allow comparison with the identified technologies. There are no technologies associated with this response action. This alternative includes no institutional controls to prevent exposure to impacted media, nor efforts to contain, remove, treat, or dispose of any media at the Site. A no action response may be appropriate at a site with minimal risks to human health and the environment, but is not acceptable for the Site. It will be carried forward as an alternative because it is standard to evaluate this as a baseline for comparison.

3.2 MONITORED OR ENHANCED NATURAL RECOVERY

Many natural systems have the ability to break down, sequester, or otherwise diminish the availability and toxicity of chemicals. Monitored natural recovery (MNR) is the monitoring of these processes.

3.2.1 Monitored Natural Recovery

MNR is a technology in which contaminant concentrations are monitored with no other actions to assess natural attenuation of contaminants by physical, chemical, and biological processes. Mechanisms by which natural processes could decrease the potential for exposure to contaminants include biodegradation of contaminants and burial of contaminated sediments with clean sediments via natural sedimentation processes, which can reduce exposure levels for aquatic and benthic organisms.

To be accepted as a remedial alternative, MNR must achieve the required reductions in toxicity and risk associated with elevated contaminant concentrations within an acceptable timeframe. Therefore, a key component of MNR is a long-term, comprehensive monitoring program to confirm the expected decreases in risk to human health and the environment.

Conditions contradicting the use of MNR at the Site include a lack of evidence for substantial decreases in contaminant concentrations associated with biodegradation or natural sedimentation processes. As stated above, MNR requires long-term monitoring and, potentially, contingency remedies should it prove ineffective; and there is currently no mechanism of funding these long-term operations at the Site. MNR is also not expected to easily achieve public acceptance due to its failure to achieve removal of BUIs in a reasonable timeframe compared to other technologies. Based on these conditions and the expected feasibility of other technologies, MNR is not retained for further consideration.

3.2.2 Enhanced Monitored Natural Recovery

Enhanced MNR is the placement of a thin layer of clean material at the sediment surface to decrease exposure to contaminants through sediment burial, which is implemented in conjunction with MNR.

Within the Fire Suppression Ditch area, contaminated sediments that contain TPH (DRO/GRO/ORO), oil and grease, and metals could be covered with a layer of clean material (likely stone and/or sand) to decrease the transport and exposure potential of the contaminants. This would effectively enhance the natural attenuation processes that decrease exposure to contaminants by promoting burial of the contaminated sediments with clean material. The costs of cover placement would be low relative to other technologies.

Enhanced MNR with clean cover placement is not expected to be sufficiently effective to support the removal of BUIs because the cover would not be designed to prevent exposure to, or transport of, sediments, but rather to decrease exposure through burial. To be accepted as a stand-alone remedial alternative, enhanced MNR must achieve the required reductions in toxicity and risk associated with elevated contaminant concentrations within an acceptable timeframe. Therefore, a key component of enhanced MNR is a long-term, comprehensive monitoring program to confirm the expected decreases in risk to human health and the environment.

If enhanced MNR is combined with sediment removal technologies, a clean cover could be used in areas where sediment contaminant concentrations are relatively low in order to provide an additional level of protectiveness that could expedite the removal of BUIs in the Muskegon Lake AOC. Placement of a clean cover would be technically feasible and highly implementable; however, the cover may be susceptible to erosion and there may be implications on the type of habitat restoration that can be implemented. Institutional controls would likely be required to prevent exposure and any potential disturbance to the area. Long-term monitoring may be required to demonstrate that enhanced MNR is effectively working to support the removal of BUIs.

Enhanced MNR, as a stand-alone technology is also not expected to easily achieve public acceptance due to its failure to achieve removal of BUIs in a reasonable timeframe compared to other technologies; however, its use in conjunction with other remedial technologies may be more acceptable as the timeframe to achieve removal of BUIs may be reduced.

Enhanced MNR is retained for further evaluation as a technology to be implemented in combination with other remedial technologies.

3.3 CONTAINMENT

Sediment containment would be accomplished through placement of a cap of clean material over the contaminated areas to limit sediment transport and eliminate exposure to contaminants.

3.3.1 Sand Cap

A sand cap is a layer of sand (approximately 3 ft) installed over contaminated sediments as a primary technology intended to largely prevent exposure and transport of contaminated sediments. A sand cap is an accepted technology for remediation of contaminated sediments at a variety of sites. However, the effectiveness of a cap relies on its permanence, which is a function of hydrological conditions, future site uses (e.g., no dredging or other excavation activities), and monitoring and maintenance efforts. Caps located in low-shear-stress areas, with lower surface water flow velocities, require less maintenance and, therefore, are both more effective and more implementable. Release of contaminated sediments is also minimized under low flow conditions and in areas with minimal groundwater seepage. The capped surface could provide high or low quality habitat, depending on the size of stone required. The cap would need to be designed to minimize its impacts on the potential for flooding, associated with increases in the elevation of the wetlands and/or ditch area, and also to minimize flow diversions that could affect the stability of the cap itself. One way to address these concerns would be to remove a layer of sediment equal to the thickness of the cap, prior to construction of the cap, so that the final elevation is at the current, stable grade.

A sand cap may not be particularly effective at isolating or containing dissolved-phase COCs or separate-phase liquids potentially present in the sediments. Thus, contaminant concentrations may not be reduced to acceptable levels at the sediment surface to support the removal of applicable BUIs within the Muskegon Lake AOC. Currently, funding for long-term cap maintenance may not be available and there may be potential concerns from the public regarding leaving the contamination in place.

A sand cap would be implementable from a logistical perspective as capping material is readily available and cap placement in a shallow environment is highly feasible. Following installation, the cap would need to be monitored regularly for thickness, and would require periodic maintenance. With a sand cap, there may be some implications on the type of habitat restoration that can be implemented.

The cost of a sand cap is expected to be moderate, associated mostly with the initial costs during cap installation and also with subsequent monitoring and maintenance.

A sand cap is not retained for further evaluation as part of remedial alternatives due to its potential inability to reduce contaminant concentrations at the sediment surface, long-term monitoring and maintenance requirements, and unlikely acceptance by the public.

3.3.2 Reactive Cap

A cap of reactive material could be placed at the sediment surface to both physically isolate contaminated sediments and chemically treat contaminants transported up through the cap. The selected material would be chosen for its ability to absorb TPH (DRO/GRO/ORO), oil and grease, and metals under site conditions, and would be placed over the existing sediment surface. Contaminants flowing upward through the cap would be removed prior to entering the water column.

A reactive cap would decrease contaminant transport to and exposure at the sediment surface; however, it would not address contamination in sediments at depth and would require monitoring and maintenance for long-term effectiveness. Treatability testing during the design phase could be used to design a cap with the desired lifetime of effectiveness. Following installation, the cap would need to be monitored regularly for thickness, and would require periodic maintenance. As with a sand cap, the cap surface could be of lower habitat quality than the existing sediment surface and there may be some implications related to the type of habitat restoration that can be implemented.

A reactive cap would be more difficult to install than a sand cap due to the technical requirements associated with the reactive material. The cost of a reactive cap is expected to be moderately high due to the relatively expensive capping materials, the requirement of detailed design procedures possibly including treatability testing, and the specialized cap placement procedures required.

A reactive cap is retained for further evaluation due to its potential to contain COCs and limit transport of contaminants to the sediment surface.

3.4 SEDIMENT REMOVAL

Sediment removal is a common technology used to eliminate exposure to and transport of contaminated sediments. Physical removal of contaminated sediment can be conducted by excavation or by mechanical or hydraulic dredging, using standard equipment to remove material from the Site and load it into transport mechanisms (e.g., trucks, barge) for treatment and/or disposal (Section 3.5.4). Regardless of the technology used, removal causes temporary destruction of the benthic habitat. Unlike capping, no maintenance and minimal short-term monitoring are required following sediment removal as the bulk of the contaminated sediment mass is removed and only a small residual fraction of the contaminated sediments remains onsite.

3.4.1 Excavation

Sediment removal by excavation involves dewatering of the targeted area via flow diversion, pumping, or other means, followed by removal of relatively dry contaminated sediment with excavator or long-reach excavator. Sediments would be removed down to a specified depth and backfilled with clean material to form a residual cap.

Sediment removal by excavation would effectively decrease contaminant mass through removal making this technology highly effective at reducing contaminant concentrations and supporting the removal of BUIs. Effectiveness could be slightly limited by the presence of residual contamination following excavation; however, risk associated with these residuals would likely be addressed using a residual backfill cover. As compared to dredging, excavation would not cause mobilization and transport of contaminated sediments by suspension during removal activities.

Implementation of excavation would require a method for diverting the flow of water away from the targeted area and then dewatering the sediments. This is an established sediment removal procedure and it is expected to be implementable in the shallow, relatively low-flow conditions of the Site; however, excavator access to the soft substrate may prove challenging. Temporary facilities would be required for sediment handling and for potential treatment of the water removed from the excavation area. Sediments removed by excavation from a dewatered area are expected to have lower water content than sediments removed by either mechanical or hydraulic dredging and, therefore, would require less effort in dewatering. The costs of excavation are expected to be high, associated with the dewatering, excavation, transport, and disposal activities. No long-term maintenance or monitoring would be required.

Excavation is expected to be highly acceptable to stakeholders and the public as the contaminated sediments are permanently removed from the Site. Excavation will be retained for further evaluation.

3.4.2 Hydraulic Dredging

Hydraulic dredging would entail removal and pumping of the contaminated sediments, in slurry form, from the Site to a temporary facility for processing. Sediments would be removed down to a specified depth via hydraulic dredge, which would require the use of a shallow draft barge. In order to remove sediments via hydraulic dredging in the Fire Suppression Ditch area, the wetlands would need to be flooded in order to provide access for the shallow draft barge. Vegetation in the wetlands may require removal prior to hydraulic dredging.

Sediment removal by hydraulic dredging would effectively decrease contaminant mass through removal. It would require flooding the area to allow for dredge access, which may cause concern from stakeholders and the public, and significant measures would need to be taken to limit sediment suspension and transport during dredging. The water removed from the slurry would likely require treatment prior to disposal, separate from any treatment performed on the sediment. The costs of hydraulic dredging are expected to be higher than the costs of excavation due to costs associated with mobilization of hydraulic dredging equipment, flooding the area, and dewatering of the dredged slurry prior to disposal.

Hydraulic dredging will not be retained for further evaluation as a potential remedial technology based on the difficulty in implementing the technology due to required flooding of the wetland area.

3.4.3 Mechanical Dredging

For mechanical dredging, contaminated sediments would be removed down to a specified depth using equipment such as an environmental dredge bucket or similar equipment, with no or only partial dewatering.

Mechanical dredging would effectively decrease contaminant mass through removal. Effectiveness may be slightly limited by the presence of residual contaminated sediments following dredging activities. However, risks associated with these residuals would likely be addressed using a residual cap.

Low water level and access may preclude use of a barge to implement mechanical dredging to remove contaminated, submerged sediments. However, an amphibious or marsh-type excavator may be used in place of a barge. A nearby staging area for dredged sediments would likely be required. An in-water barrier would be needed to limit suspension and transport of disturbed sediment. Partial dewatering could also be performed prior to dredging within the area confined by the barrier where this is considered advantageous for implementation. The costs of mechanical dredging are expected to be similar in magnitude to the costs of excavation, with some additional costs associated with processing the higher water content dredged material.

Mechanical dredging is expected to be highly acceptable to stakeholders and the public as the contaminated sediments are permanently removed from the Site, and it will be retained for further evaluation.

3.5 ASSOCIATED PROCESS OPTIONS

The following sections described the screening of the process options that may be included as part of the remedial technologies presented above. Table 3-1 presents process options that could be included with each remedial alternative, and Table 3-2 includes screening of these process options based on technical feasibility, implementability, environmental risk, relative cost, and public acceptance.

3.5.1 Sediment Dewatering Technologies

As discussed above, sediments removed from a wetland, lake, or river typically require dewatering prior to disposal. The sediment removal technology determines the water content of the removed material and, thus, also affects the choice of dewatering technologies and the design of the dewatering system. Three dewatering process options were identified for possible application to sediments from the Site and are discussed below. Transport and disposal options are also discussed below.

3.5.1.1 Gravity Settling

A lined settling basin for removed sediments could be established onsite in the upland area. Removed sediments would be trucked to the basin and water would be pumped out as the sediment settles. Technologies such as wick drains could be used to promote separation of water from the sediments.

Dewatering of removed sediments in a settling pond would be expected to achieve the degree of dewatering required for offsite sediment disposal. The timeframe for dewatering would likely be longer than required for other technologies, including dewatering using geotextile tubes or solidification. Therefore, it is most likely to be used for sediments removed by mechanical dredging or excavation, which are expected to have a water content that is too low to allow pumping into geotextile tubes, and too high to allow dewatering by solidification. The water removed would likely require treatment prior to disposal.

Construction of settling basins would require a large area that is available in the upland portion of the Site. Transport of sediments removed by mechanical dredging would likely require trucks that would need to have access to the areas where dredging is performed and to roads leading to the settling pond. Currently, a two-track road exists connecting the upland portion of the former Zephyr Refinery with the Site. Minor improvements may be required to stabilize the road and prevent deterioration during implementation.

Passive dewatering in a settling basin will be considered as a possible dewatering technology, primarily for sediments removed by mechanical dredging or excavation.

3.5.1.2 Geotextile Tubes

Geotextile tubes are constructed of permeable geotextiles that allow passage of water but not sediment. Sediments in slurry form are amended with a thickening, or flocculating, agent to promote settling and drying of the sediment. Sediment, in slurry form, is pumped into the geotextile tubes and the water flows out of the thickened slurry and passes through the geotextile, leaving dewatered sediment within the tube.

The timeframe for dewatering using geotextile tubes is substantially shorter than the timeframe for dewatering in a settling pond. The water that passes through the geotextiles also tends to be of lower turbidity than water pumped out of a pond. This lower turbidity may decrease the need for water treatment prior to disposal, or may decrease the cost of treatment.

Geotextile tubes are typically utilized with hydraulic dredging, but could also be utilized with mechanical dredging or excavation. For use with mechanical dredging or excavation, the excavated sediment would first be made into a slurry and then hydraulically pumped from the slurry pit constructed within the excavation area to the dewatering area. The placement of the dewatering areas would likely be chosen to decrease transport distance through the pipelines. The area required for geotextile tubes would be smaller than that required for a settling basin.

Passive dewatering using geotextile tubes will be considered as a possible dewatering technology for slurried sediments.

3.5.1.3 Solidification

Addition of Portland cement, Calciment®, or similar binding material to the sediment can partially or completely solidify the sediment mass, thus promoting dewatering of moist sediments, and decrease the leachability of contaminants.

Solidification is expected to be highly effective as a fast dewatering solution for sediments removed using dry excavation, which have a relatively low water content following removal. For these sediments, solidification could be used as the primary dewatering technology, and could also improve the chemical properties of the sediment for disposal. Addition of an appropriate percentage of Portland cement to the sediment mixture could be performed within the trucks used for transporting the sediment, and thus would be highly implementable.

Solidification of sediments through addition of cement or similar material is retained as a dewatering and treatment technology, primarily for sediments removed by excavation.

3.5.2 Sediment Transport for Downstream Processing

3.5.2.1 Truck

Transport of sediments by truck to the upland area for dewatering is a technically feasible option with moderate, site-specific implementability. The roads onsite would need minor improvements to allow for the increased two-way traffic between the sediment removal area and the upland area. Truck transport of sediments for downstream processing is retained for further evaluation in remedial alternatives.

3.5.2.2 Hydraulic

Hydraulic transport would require sediments removed by excavation or mechanical dredge to be slurried in a ditch prior to transport. Vegetation removal would also likely be required prior to slurrying. The ditch would be located within the sediment removal area to limit transport distance to the slurry pit. This mode of sediment transport is technically feasible and highly implementable at the Site. Hydraulic transport of sediments for downstream processing is retained for further evaluation in remedial alternatives.

3.5.3 Water Treatment

3.5.3.1 Mobile Wastewater Treatment Plant

Dependent on the treatment necessary to meet discharge requirements, water may be treated by a leased mobile wastewater treatment facility located onsite. This is a technically feasible and highly implementable technology with land available for the mobile unit in the upland area. The cost of utilizing a leased mobile treatment plant is expected to be moderate. Water treatment using a mobile wastewater treatment plant is retained for further evaluation in remedial alternatives.

3.5.3.2 Onsite Treatment Facility

Dependent on the treatment necessary to meet discharge requirements, water may be treated using an existing groundwater extraction treatment facility located in the upland portion of the former Zephyr Refinery. This is technically feasible; however, implementability may be limited by the need to retrofit the facility for effective treatment of contaminants identified at the Site to meet water quality standards required for disposal as well as increased system capacity required during remediation. The cost of utilizing an existing, onsite water treatment plant is expected to be low with the assumption that limited retrofitting will be required. Water treatment using the onsite water treatment facility is retained for further evaluation in remedial alternatives.

3.5.4 Disposal Options

Following removal by excavation or dredging and dewatering, contaminated sediments would require disposal in a manner that prevents future exposure to the contaminants. Options for disposal include offsite disposal in a facility appropriate for the concentration of contaminants present or onsite disposal in a lined, capped disposal area.

3.5.4.1 Offsite Disposal

Offsite disposal is a common disposal option that would permanently remove contaminant mass from the Site. Facilities for disposal of the removed sediments are available nearby. Dewatering and/or amendments would likely need to be used to modify chemical and physical properties of the sediment to facilitate handling and disposal. Offsite disposal can be expensive depending on the location of a site relative to the disposal facility, volume of sediment involved, nature of contamination, and availability of different disposal options in the area. Transport and disposal of contaminated sediment via truck to a nearby municipal solid waste or Subtitle D landfill is highly implementable. Transport by rail was considered as a rail spur is located in the upland portion of the Site; however, due to the handling requirements for transfer from truck to rail car, and potential handling requirements at the disposal facility, it will not be further considered for offsite disposal transport. The overall costs of offsite disposal are expected to be high, associated with transportation and disposal fees.

Offsite disposal is retained for further evaluation in remedial alternatives.

3.5.4.2 Onsite Disposal – Lined, Capped Disposal Area

Contaminated sediments from the Site could also be contained within an onsite capped disposal facility. The upland portion of the former Zephyr Refinery contains space that could be utilized for an onsite disposal facility. An onsite disposal facility would permanently contain contaminated sediments in a lined and capped area onsite, effectively preventing future exposure and transport of the contaminants. The facility would require design and maintenance to prevent any releases of contaminants and would be monitored to ensure containment. Disposal in an onsite facility rather than at an offsite facility would decrease the requirements for transport of sediments and could, therefore, offer cost savings relative to the offsite disposal option. Implementation of an onsite disposal facility would require stakeholder approval, siting, permitting, construction, and monitoring.

Construction of an onsite disposal facility incurs many of the challenges also associated with capping as described in Section 3.3. The maintenance of material onsite requires long-term operations for which there are currently no foreseeable mechanisms and is unlikely to achieve public, stakeholder, and landowner acceptance. For these reasons, construction of an onsite disposal facility is not retained for further evaluation.

3.6 SUPPORTING TECHNOLOGIES

3.6.1 Dredging Residual Cover

A residual cover is a type of clean cover that would be implemented in areas where residual contamination remains following dredging or other removal activities in order to decrease exposure by providing an extra level of protection. Its function is similar to that of the sand cap discussed above. A cover of clean material (likely sand) would be installed up to the original (pre-removal) or another stable grade following the sediment removal action, with design parameters appropriate to decrease contact with and transport of any residual contamination remaining in sediment following the removal action.

A residual cover would be designed to further mitigate any remaining risk associated with residual concentrations of COCs below PCUGs. Such a cover would be more stable than a cover installed above the existing sediment surface, and would not create flow constrictions or increased risk of flooding because it would not be installed above stable grade.

Installation of a residual cover following sediment removal is expected to be highly implementable at the Site. Cover material would need to be transported to the Site and placed in the areas of sediment removal. It would not require excavation beyond the sediment removal action. Follow-up monitoring and maintenance would not be anticipated. Based on these factors, the cost of a residual backfill cover would also be relatively low. Cover placement may not be appropriate for areas where disturbance is planned in the near future.

A residual cover is retained for further evaluation as a technology to further decrease potential exposure following sediment removal activities.

3.6.2 Monitoring

Long-term monitoring is likely to be required only for alternatives that leave sources of contaminants in place. Development of a monitoring plan is anticipated to be required in conjunction with some of the potential remedial technologies to assure that remedial objectives are met. Therefore, this technology is retained.

3.6.3 Institutional Controls

Institutional controls are used to limit risk by controlling exposure to contaminated media. These controls can include deed restrictions limiting the use of properties, fences, or other barriers to limit access to a contaminated site; water use restrictions such as no anchor or no wake zones; limitations on dredging; and maintenance agreements or advisories issued to the public notifying them of the risks associated with contacting contaminated media.

The effectiveness of these advisories depends on the response of the public in terms of a change in behavior to limit exposure, which in turn is dependent on effective communication. However, advisories are a moderately effective, easily implementable, and low-cost option for controlling risks in the short term, before remedial goals are met.

Some potential technologies could require additional restrictions on activities in the area. For example, if contaminated sediments were contained *in situ* using capping technology, restrictions on activities within the Site that would disturb the cap and/or contaminated sediments would likely be necessary. These restrictions would be expected to prevent most potential large-scale disturbances by humans, and would also be easily implementable and relatively low cost.

Institutional controls are retained for incorporation into alternatives because they could be used to prevent unacceptable exposure in the short term and to limit future potential exposure resulting from disturbance of contaminated sediments.

3.7 SHORTLIST OF REMEDIAL ALTERNATIVES

Based on this screening process, the retained remedial technologies were combined into a shortlist of remedial alternatives to be considered during remedial alternative development and evaluation completed as part of this FS. This shortlist of remedial alternatives will be utilized to select three remedial alternatives that will be developed and evaluated further. The following remedial alternatives are included in the shortlist.

Alternative 1: No Action

Alternative 1, in which no remedial actions are taken, is retained for comparison with the other identified remedial alternatives.

Alternative 2: Sediment Removal by Relatively Dry Excavation and Offsite Disposal

Alternative 2 would entail removing sediments containing contamination in excess of clean-up goals from the Site via dry excavation. Dewatering of the removal area to perform dry excavation and subsequent water treatment would be required. Water treatment may apply to some or all of the surface water as well as groundwater recharge and stormwater inputs into the area during construction. Water treatment would be completed either by using a leased mobile wastewater treatment plant or by retrofitting the existing water treatment system at the former Zephyr Refinery as necessary with discharge under the existing permit. Specifications for existing treatment equipment, the system design criteria, and performance requirements will be needed to confirm the effectiveness of using the existing system and its capacity for additional water from the sediment remediation project.

Additional process options required would include sediment dewatering, which could be achieved by either gravity dewatering or the use of amendments to stabilize material. Contaminated sediments would be transported from the removal area to an upland processing area for dewatering via truck utilizing the existing road, which may require minor improvements for use. Following dewatering, contaminated sediments would be transported for offsite disposal via truck. A clean fill cover material, such as sand, would be placed in some or all areas where sediment is removed to decrease exposure to residual contaminants. Habitat restoration would be implemented in the areas remediated, which would be followed by monitoring to demonstrate that the implemented remedies are supporting the removal of BUIs in the Muskegon Lake AOC.

Alternative 3: Sediment Removal and Disposal With Enhanced Monitored Natural Recovery

Alternative 3 would include all the components of Alternative 2, with the addition of cover placement outside the areas targeted for sediment removal, in areas where sediment contaminant concentrations are relatively low but still warrant some protective action, based on the determination of clean-up goals. A clean fill cover material, such as sand, would be placed in these areas to further decrease the transport of, and exposure to, contaminants at the Site. Long-term monitoring may be required to demonstrate that enhanced MNR is supporting the removal of BUIs. Institutional controls would likely be required to prevent exposure and any potential disturbance to the area containing the clean cover. Habitat restoration would be implemented in the areas remediated.

If this alternative is selected, prior to design and costing additional studies would be required to assess contaminant concentrations in the sediment pore water, groundwater flux, and potential contaminant transport mechanisms.

Alternative 4: Sediment Removal and Geotextile Tube Dewatering With Offsite Disposal

Alternative 4 would entail removing sediments containing contamination in excess of clean-up goals from the Site via mechanical dredging with an amphibious or marsh-type excavator with environmental bucket or similar removal equipment. Slurry pits would be utilized to centrally mix sediment and water for hydraulic transport of the contaminated sediment to the upland area for dewatering via geotextile tubes. Hydraulic transport of the sediment slurry to the higher elevation of the upland area is expected to be a generally cost-effective approach to material handling at the Site when combined with use of the ample available space for geotextile tube dewatering. Contaminated sediments would be transported from the removal area to an upland processing/dewatering area via pipeline. If needed, a booster pump or pumps would be included to overcome the elevation change and energy losses in the pipeline.

Water treatment would be completed on the filtrate water collected from the geotextile tubes either by using a leased mobile wastewater treatment plant or by retrofitting the existing water treatment system at the former Zephyr Refinery as necessary with discharge under the existing permit. Specifications for existing treatment equipment, the system design criteria, and performance requirements will be needed to confirm the effectiveness of using the existing system and its capacity for additional water from the sediment remediation project.

A clean fill cover material, such as sand, would be placed in some or all areas where sediment is removed to decrease exposure to residual COCs below PCUGs. Habitat restoration would be implemented in the areas remediated, which would be followed by monitoring to demonstrate that the implemented remedies are supporting the removal of BUIs in the Muskegon Lake AOC.

Alternative 5: Partial Excavation, Partial Reactive Capping, and Partial Enhanced Monitored Natural Recovery

Alternative 5 would entail a combination of excavation, capping using a reactive material, and enhanced MNR. Hotspot areas containing concentrations of COCs in sediments, exceeding the PCUGs, would be removed down to some defined depth followed by a residuals cover or a reactive cap, if necessary. Dewatering of the removal area to perform dry excavation and subsequent water treatment would be required. Water treatment may apply to some or all of the surface water as well as groundwater recharge and stormwater inputs into the area during construction. Water treatment would be completed either by using a leased mobile wastewater treatment plant or by retrofitting the existing water treatment system at the Site as necessary with discharge under the existing permit for the Site. Specifications for existing treatment equipment, the system design criteria, and performance requirements will be needed to confirm the effectiveness of using the existing system and its capacity for additional water from the sediment remediation project. Additional process options required would include sediment dewatering that could be achieved by either gravity dewatering or the use of amendments to stabilize material. Contaminated sediments would be transported from the removal area to an upland processing area for dewatering via truck utilizing the existing road, which may require minor improvements for use. Following dewatering, contaminated sediments would be transported for offsite disposal via truck.

Reactive capping would be utilized in areas outside of the identified hotspots that contain concentrations of COCs that exceed PCUGs. Enhanced MNR would include the placement of a clean cover outside the areas targeted for sediment removal or reactive capping where sediment contaminant concentrations are relatively low but still warrant some protective action. Monitoring and maintenance would be required in capped areas to ensure long-term effectiveness. Institutional controls would likely be required to prevent exposure and any potential disturbance to capped areas. Habitat restoration would be implemented in the areas remediated.

If this alternative is selected and prior to design and costing, additional studies would be required to assess contaminant concentrations in the sediment pore water, groundwater flux, and potential contaminant transport mechanisms. If separate-phase liquid is a potential concern and depending on risk managements decisions, the reactive cap could be engineered to contain this material.

4. REMEDIAL ALTERNATIVES

The retained remedial technologies described in Chapter 3 were combined into a shortlist of remedial alternatives as presented in Section 3.7. The following three remedial alternatives were selected from this shortlist for further evaluation based on technical feasibility, implementability, environmental risk, relative cost, and public acceptance as discussed in Section 3 (Alternatives have been re-numbered for convenience):

- ***Alternative 1: No Action***
  Alternative 1, in which no remedial actions are taken, is retained for comparison with the other identified remedial alternatives.

- ***Alternative 2: Relatively Dry Excavation With Offsite Disposal***
  Alternative 2 would entail removing contaminated sediments via relatively dry excavation. Water levels would be lowered in the ditch and surrounding wetlands (if necessary) to reduce entrainment of water, thereby reducing the amount of dewatering required. The sediments would then be removed and dewatered to the extent required in an upland staging area, utilizing drying agents as required and transported offsite for disposal.

- ***Alternative 3: Mechanical Dredging With Onsite Hydraulic Transport and Offsite Disposal***
  Alternative 3 includes removing contaminated sediment via dredging with fixed arm excavators using marsh excavation equipment or other low ground pressure tracked excavators with engineered access roads for separation from underlying soft sediment. The “dredged” sediment would be mixed with water within a pit to create a slurry, pumped to an upland area containing geotextile dewatering tubes that would be allowed to drain to the extent required, then transported offsite for disposal. Filtrate water from geotextile tubes could be recycled back to the pit for reuse in slurrying to reduce the total water volume required for the alternative. Additional water sources, including the NPDES permitted discharge or water from the Muskegon River could also be utilized for slurrying.

Table 4-1 presents a Remedial Alternatives Assembly Matrix, which identifies each alternative as well as the associated technologies or process options that would be incorporated into that alternative. Table 4-2 presents a brief summary of each remedial alternative and associated processes or technologies which would be employed. A detailed description of each remedial alternative is presented in Chapter 7 prior to further evaluation of the alternative.

5. HABITAT RESTORATION GOALS AND TECHNIQUES

The remediation of contaminated sediments represents but one aspect of restoring habitat to the Site. Impacts from historic uses, the sediment remediation activity itself, and compatibility with future uses must be accounted for in the habitat restoration alternatives approach. Habitat restoration must be compatible with the remedial goals for the project. Habitat restoration must not increase the potential for human or environmental exposure to contaminants or limit the effectiveness of those remedial actions proposed.

The goals of habitat restoration may stem from many sources, including those set forth in watershed implementation plans, local and state goals for biotic integrity, and goals specific to the remediation. The intersection of these competing interests for habitat restoration comes in achieving the following minimum goals:

- Continued use of the Fire Suppression Ditch area following remediation
- Re-establishment of native vegetation to continually improve and maintain the habitats of the Fire Suppression Ditch and surrounding wetlands.

These habitat goals can be refined and achieved by specifying restoration of the Site and re-establishment of native vegetation. The potential habitat restoration options that may coincide with potential remedial alternatives are presented in Table 5-1. The following sections summarize potential restoration options in the Fire Suppression Ditch and surrounding wetlands areas.

5.1 FIRE SUPPRESSION DITCH AREA RESTORATION

The continued use of the Fire Suppression Ditch is a goal for post-remediation and restoration for the property. If remediation of sediments requires disturbance to the existing Fire Suppression Ditch area, several restoration options are available for ensuring its continued use and are dependent on the extent and type of disturbance. For example, if remediation requires placement of a clean cover, the specifications of the clean cover can be defined to include a suitable mix of material for enhanced benthic habitat. Suitable material would likely include grain sizes that currently exist in the adjacent Muskegon River. Clean cover could also include grain sizes that mimic and, therefore, promote spawning for fishes that utilize tributaries and side channels of the Muskegon River. Clean cover placement could also provide suitable planting medium for restoration of an emergent, scrub-shrub, and/or woody riparian corridor.

Options also exist for restoration of the Fire Suppression Ditch area if sediment remediation requires removal and disturbance to the current ditch contours. One option is to restore the Fire Suppression Ditch area to its pre-disturbed contours. Replacement of a suitable substrate would allow for restoration of the riparian corridor, benthic habitat, and surrounding wetlands. Another option is to enhance the existing Fire Suppression Ditch area by increasing or otherwise improving its functional capacity. Creation of a network of open water features, in conjunction with sediment excavation, with hydraulic connections to the Muskegon River could provide water volumes that exceed the current capacity. This network of hydraulically-connected open water features could serve as habitat for fish as well as attract waterfowl.

Implementing restoration of the Fire Suppression Ditch area would not require significant time or effort since the minimum goal is to maintain its current dimensions and functionality. Enhancements to the Fire Suppression Ditch could be implemented concurrent with any sediment removal.

The costs for restoration of the Fire Suppression Ditch area would be low since any sediment disturbance and/or removal could be performed in conjunction with any grading required for the Fire Suppression Ditch area restoration activities.

5.2 WETLAND RESTORATION

Restoration of the wetlands at the Site can complement any of the chosen sediment remediation options and improve the functional capacity of the existing wetlands. Restoration of the vegetation community within the wetlands may address the BUIs by providing diverse and improved wildlife habitats. All vegetation restoration options include invasive species removal and control in order to ensure successful establishment of a native wetland vegetation community. Invasive species management practices include herbiciding, mechanical removal with (e.g., tilling) or without (e.g., hand pulling) soil disturbance, and burning. Vegetation restoration options range from seeding using broadcasting or hydro-seeding, to planting of plugs, containerized shrubs/trees, and submerged/emergent aquatic macrophytes. The type and extent of invasive species management as well as native wetland vegetation re-establishment will be dependent on the chosen remedial alternative. For example, if a clean cover is chosen as the remedial alternative, then vegetation restoration options would be surficial (e.g., herbiciding, hand pulling, and seeding) and would be careful to avoid soil disturbance. If sediment removal is the chosen remedial option, then vegetation restoration could include more extensive invasive species removal (e.g., tilling and removal of invasive root systems) and more intensive planting (e.g., mixing seed with topsoil additions and planting of containerized vegetation).

The implementability of the wetland restoration is dependent on the extent and type of the chosen remedial alternative. The successful establishment of a native wetland community will also depend on the commitment to invasive species management and control following the initial restoration actions completed as part of this project.

The costs of wetland vegetation restoration are typically low compared to the costs of remedial technologies. Cost will be dependent on the extent of native vegetation as well as the extent of invasive species management including not only initial removal but also the duration of annual maintenance activities.

5.3 RESTORATION ALTERNATIVES

Habitat restoration options were presented in the Remedial and Restoration Alternatives Screening Technical Memorandum (EA 2013). The following restoration alternatives were developed from these options for further evaluation:

- ***Alternative 1: No Action***
  Alternative 1, in which no remedial actions are taken, is retained for comparison with the other identified remedial alternatives.

- ***Alternative 2: Limited Restoration of Remediated Areas***
  Alternative 2 includes a combination of open water areas remaining where sediments were removed along with surface preparations, a vegetation plan, and additional site enhancements.

- ***Alternative 3: Restoration of Remediated Areas With Native Species***
  Alternative 3 includes a combination of open water areas along with surface preparation of disturbed areas, a more aggressive native species vegetation plan, landscaping, and additional site enhancements.

- ***Alternative 4: Restoration of Native Habitats in Remediated Areas***
  Alternative 4 includes a combination of new open water habitats/potholes and a variety of wetland flooding regimes incorporating microtopography (diversity of topographic relief such as shallow areas with minor ridges) within remediated areas along with surface preparation, an aggressive native species vegetation plan, and additional site enhancements (i.e., woody debris placements for wildlife cover and perching sites).

- ***Alternative 5: Full Site Restoration***
  Alternative 5 includes a combination of new open water habitats/potholes and a variety of wetland flooding regimes incorporating microtopography (diversity of topographic relief such as shallow areas with minor ridges) within remediated areas, conversion of the Fire Suppression Ditch to a more natural channel and pattern or wetland habitat, as well as providing hydrology to the restored wetlands (i.e., bifurcated open water/channel system created through cut/fill). Additional activities would include surface preparation, an aggressive native species vegetation plan, and additional site enhancements (i.e., woody debris placements for wildlife cover and perching sites).

Table 5-2 presents a brief summary of each habitat restoration alternative. A detailed description of each restoration alternative is presented in Chapter 9 prior to further evaluation.

6. ALTERNATIVES EVALUATION CRITERIA

The remedial and restoration alternatives developed in Chapters 4 and 5 were evaluated using the criteria described below to support selection of a recommended remedy. The criteria fall into three groups: (1) Threshold Criteria, which must be met for any alternative selected as a remedy for the Fire Suppression Ditch area; (2) Balancing Criteria, for which rankings are assigned to each alternative to provide a technical basis for comparing the advantages and disadvantages of the alternatives; and (3) Modifying Criteria, which can be used to distinguish between alternatives that meet the threshold criteria and have similar rankings for the balancing criteria. The evaluation of alternatives according to these criteria are presented in Chapters 7 and 8 (remedial alternatives) and Chapter 9 (restoration alternatives).

6.1 THRESHOLD CRITERIA

Compliance With Permits and Applicable Regulatory Requirements

Compliance with regulatory requirements is the only threshold criterion for this Site. Each alternative is evaluated to determine whether it can perform its intended function and meet the RAOs in accordance with applicable regulatory requirements, with the appropriate permits. Applicable regulatory requirements include requirements for contaminant clean-up levels, waste disposal criteria and regulations, procedures for addressing changes to the wetlands habitat quality, and mitigation for habitat disturbance. The permitting and regulatory requirements identified as potentially associated with each alternative are discussed as part of the evaluation of the alternatives.

6.2 BALANCING CRITERIA

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

This criterion evaluates the adequacy of the alternative to protect human health and the environment while meeting and maintaining compliance with the RAOs over the long term. This includes evaluation of the timeframe to meet RAOs and achieve removal of BUIs in the Fire Suppression Ditch area, the amount of residual contamination anticipated to be left in-place, the reliability of long-term controls, and the potential for transport of contaminated sediment following the remedial action.

Short-Term Effectiveness in Protecting Human Health and the Environment

This criterion evaluates the risks that would be expected to persist or to arise in the short term, during remedy implementation. Potential risks to workers and the community during implementation of the alternative are considered, along with potential negative short-term environmental impacts.

Engineering Implementability, Reliability, Constructability, and Technical Feasibility

This criterion evaluates the implementability of the alternative, including constructability, ease of implementation, availability of materials and workers, and reliability for achieving RAOs.

Cost

This criterion considers engineering and capital costs for each alternative, as appropriate. The cost estimates are based on conventional cost estimating guides, vendor information, and engineering judgment. The preparation of the estimated costs presented in this FS was conducted in sufficient detail to provide costs with an accuracy of plus 50 percent to minus 30 percent for the alternative as described, while identifying the key uncertainties for each alternative. The costs are intended to support comparison of alternatives, and actual costs of implementation of the alternatives are expected to vary based on factors such as actual material and labor costs, additional information regarding site conditions, and technological details as identified during the design process.

6.3 MODIFYING CRITERIA

Stakeholder and Community Acceptance

This criterion considers the extent to which a given alternative is acceptable to the project stakeholders and the local community.

7. EVALUATION OF PRIMARY REMEDIAL ALTERNATIVE TECHNOLOGIES

Chapter 4 describes the three remedial alternatives to be further evaluated as options for meeting RAOs, including the removal of BUIs, for the Muskegon Lake AOC. These alternatives are:

- Alternative 1: No Action
- Alternative 2: Relatively Dry Excavation with Offsite Disposal
- Alternative 3: Mechanical Dredging with Onsite Hydraulic Transport and Offsite Disposal.

This chapter presents detailed descriptions and evaluations of these alternatives and their included technologies, approximately as they would be implemented, including evaluation of each of the alternatives according to the criteria described in Chapter 6.

(Note that Alternative 1, No Action, does not include implementation of any technologies.)

Concept plans showing the site layout for Alternatives 2 and 3 are provided in Appendix E. Evaluation of the three combined alternatives composed of these technologies is presented in Chapter 8.

It is important to note that assumptions regarding application of specific technologies and process options, and their implementation approaches, were determined to allow cost estimating as part of the evaluation of the remedial alternatives. The development of the detailed approach for the preferred remedial alternative will be part of the RD process, while the construction process may have additional differences.

7.1 RELATIVELY DRY EXCAVATION WITH OFFSITE DISPOSAL AND SUPPORTING TECHNOLOGIES

7.1.1 Description

Removal of the contaminated sediment would be accomplished using either standard excavating equipment with low ground pressure or specialized marsh excavation equipment (the latter contains pontoons that allow the equipment to float, though they have limited maneuverability when water depths are sufficient to eliminate traction between track and sediment)—the excavations would occur in a relatively dry condition assuming some dewatering to remove most ponded water to improve visibility and access to the sediment, while reducing water entrainment into sediment as it is excavated. The area to be remediated includes a ditch and shallow wetlands with some standing water; therefore, this alternative would require a temporary structure such as a sheet pile wall to provide a cofferdam along the Muskegon River. Along the Muskegon River, the exterior berms and cofferdam should provide a uniform top elevation (filling in any low or settled areas) to keep flood waters from entering the Site. Additional sheet pile walls would be necessary along sections of the Fire Suppression Ditch where deeper excavation is necessary. All sheet pile walls or cofferdams will be removed upon completion of remedial activities.

Erosion and sediment control measures would be installed, and water would be pumped out to create a relatively dry area. It is assumed initial drawdown of surface water would take approximately 5 days. Depending on groundwater and surface water inflow rates, continuous or intermittent pumping will likely be required to maintain a relatively dry, dewatered area during sediment removal activities. All remediated areas will be dewatered as necessary and haul roads will be improved in areas surrounding wetlands. The discharge point of the existing groundwater extraction remediation system, currently discharging under an NPDES permit at the top of the Fire Suppression Ditch, would be extended to the Muskegon River via temporary hose/pipe. This temporary extension would likely be located along the railroad track berm located to the west of the Site in order to isolate it from the removal areas. It is assumed that access to the railroad right-of-way for temporary treated water transfer will be achievable. In addition to relocation of the existing outfall, an alternate water source for the current Site operations in the upland area will be required as the Site owner currently obtains water from the ditch area. Options to provide this water include water from the existing groundwater treatment system, the previously remediated lagoon located to the northwest of the Site or the Muskegon River.

Access berms and construction access points will be constructed adjacent to dewatering areas to allow for loading of contaminated sediment into haul trucks. Berms will utilize a woven geotextile placed above existing material with fill placed above. Additional construction activities completed prior to sediment removal would include improvements to the existing access road leading to the Site from Wood Road as well as the gravel road located in the upland portion of the former Zephyr Refinery area to utilize as haul roads to and from the dewatering and staging area and for access to offsite transportation routes. Improvements would include the addition of 10 to 12 in. of 2-in.-minus stone to widen and strengthen the road bed as well as the use of a geotextile fabric to improve stability. Additional improvements to the construction entrance at the southern end of Wood Road would be required, including potential widening to allow for haul trucks to turn around and back into the Site if necessary. Additional turn-around areas will be constructed closer to removal areas.

In wetland areas, it is assumed the vegetation and root mass layer will be stripped back in a given area before removing sediment. As sediment is removed in the wetland, if necessary, based on the presence of large-size debris such as logs, a grapple or thumb would be fitted to an excavator to remove, separate, and segregate the large debris. In general, vegetative material and debris would require stockpiling separately from underlying sediment. Later upon drying in stockpiles, the vegetation material would be mixed with sediment to assist in managing the moisture condition and reduce the need for drying agents as part of dewatering prior to transport offsite for disposal. Once removed, excavated material would be placed in standard haul trucks and transported to a large bermed and lined dewatering area located in the upland portion of the former Zephyr Refinery via an onsite haul road.

The bermed dewatering area would be lined with gravel and geotextile fabric which would enclose a filtrate collection system. This system would be made of perforated high density polyethylene (HDPE) pipe which would collect the drained water and direct it to sumps, where it would then be pumped to a package water treatment plant. Following treatment, the wastewater would be discharged under a new NPDES permit.

Prior to transport offsite, sediments will have to pass a paint filter test to verify that no free liquids are present. Depending on the landfill selected, additional requirements related to geotechnical workability and stackability of the material may apply. If necessary, amendments would be added to sediments prior to offsite transport in order to meet moisture and strength requirements. Additional testing to determine potentially hazardous levels of metals in the contaminated sediment may also be required. This sampling would be performed at a frequency to be determined. If contaminated sediment is determined to be hazardous, materials will be handled separately and transported to a separate offsite licensed disposal facility capable of handling the material. The dewatered sediment would then be loaded into larger, lined trucks and transported to an offsite permitted landfill for final disposal.

Following excavation, confirmation sampling of the sediment in the excavated areas would be conducted to confirm that contaminant concentrations in the remaining sediments are below clean-up goals. A post-excavation survey would also be completed.

After proper residuals cover is placed, appropriate restoration would be completed as discussed in Chapter 9. At the completion of the project, staging areas, and temporary haul routes would be properly restored, including any repairs to the asphalt portion of Wood Road to be utilized as part of the haul route.

It is anticipated that for Alternative 2, approximately 51,217 cy of non-hazardous material would be excavated. This volume is an *in situ* estimation. This includes a rough cut estimation of overdredge in the ditch, a 6-in. vertical overdredge allowance in the wetland removal areas, a 1-ft buffer zone horizontally around the perimeter of the wetland removal areas, contingencies for uncertainties in the volume estimate due to core recovery, and an estimation of the volume of vegetation and associated root mass located above the contaminated sediment in wetland areas requiring removal. An estimated 1,376 tons of Portland cement would be added to amend the material (10 percent addition by mass). It is possible the 10 percent by mass amount of Portland cement can be reduced by use of dry vegetation, but this would require additional study to determine. Following dewatering and amendment addition, as necessary, the resulting total estimated disposal weight is 36,500 tons of amended dredged material under Alternative 2.

A concept plan drawing of the implementation for Alternative 2 is included in Appendix E.

7.1.1.1 Sediment Dewatering and Solidification

If sediments removed by dry excavation have an unacceptably high water content, they would be placed on a dewatering pad composed of an area surrounded by berms and lined with geotextile and crushed rock, and graded to facilitate collection of water. Following dewatering, or following excavation if the water content is acceptably low, solidification of the sediments by addition of amendments (e.g., Portland cement or Calciment) would likely be required to meet the disposal facility's moisture and strength requirements. The sediment would be mechanically mixed in the staging/dewatering area. It is estimated that dewatering for Alternative 2 would take approximately 5 months.

The size of the staging/dewatering area would depend on several factors that include the volume of sediment to be removed, sediment amendment cure time, rate of removal versus rate of loading and transport to offsite disposal facilities, required frequency of waste confirmation sampling, and overall project schedule. The area allocated by the property owners in the northeastern corner of the upland portion of the Former Zephyr Refinery, approximately 7 acres, is expected to provide adequate space for both sediment management and water pre-treatment, as well as clean material handling.

7.1.1.2 Water Treatment

Water that may require treatment would be generated from the following sources:

- Water from dewatering prior to/during excavation;
- Dewatering pad drainage from sediment;
- Precipitation into the dewatered ditch during excavation;
- Decontamination water; and
- Precipitation on the dewatering pad.

The components needed to treat the collected water before discharge would be determined during the design. However, to evaluate cost and comparison to other alternatives, it was assumed for this evaluation that water treatment would consist of a packaged leased treatment system which would consist of:

- Oil-water separation;
- pH adjustment (if needed);
- Weir tanks for clarification with coagulant and flocculent addition;
- Sand or Multimedia filtration; and
- Granular activated carbon.

It is assumed that a flow rate of approximately 400 gallons per minute (gpm) would be sufficient for dewatering of the ditch and wetland areas as well as treatment of water generated from dewatering pad drainage.

For the purposes of this FS, it is assumed that a separate NPDES permit will be obtained for the packaged/leased water treatment system. Regular sampling would be conducted to verify that the requirements for discharge are met.

Utilization of the existing groundwater extraction remediation system operated by MDEQ with associated permitted NPDES discharge can be further evaluated during remedial design. If the system were determined to be appropriate for use, a pre-treatment system would likely be required.

The pre-treatment system may consist of the following:

- Oil-water separation;
- pH adjustment (if needed);
- Weir tanks for clarification with coagulant and flocculent addition; and
- Multimedia filtration.

Following pre-treatment, wastewater would be transferred to the existing groundwater extraction treatment system. Water could be transferred in batches or metered depending on needs of the existing treatment system. Additional study is required to determine if flocculent and/or coagulants in pre-treatment water will affect the bioreactor.

The existing groundwater extraction remediation system currently consists of a bioreactor followed by a clarifier. From the clarifier the wastewater is pumped through a knockout tank to the treatment building consisting of bag filtration and two-stage carbon treatment prior to discharge to the top of the Fire Suppression Ditch via an existing NPDES permit. Based on current use, the existing onsite groundwater extraction remediation system operates at an approximate capacity of 200 gpm and can discharge to the NPDES outfall or associated groundwater injection trenches. It should be noted that it is assumed the existing onsite groundwater extraction remediation system removes petroleum-related compounds including benzene, toluene, ethylbenzene, and xylenes (BTEX) as well as whatever lead remains (by removing suspended solids and associated lead) following pre-treatment.

In order to utilize the existing onsite groundwater extraction remediation system, the NPDES permit would likely require modification for flow rate (currently permitted for 150 gpm; could increase to capacity of system of approximately 200 gpm) as well as monitoring requirements due to potential metals content of water collected during dewatering of sediments. Regular sampling would be conducted to verify that the requirements for discharge are met.

7.1.1.3 Offsite Disposal

Trucks used to transport contaminated materials offsite would be covered, and tires and exteriors would be decontaminated after loading and before leaving the Site. Sediments may require additional characterization prior to offsite transportation and disposal. Current analytical data indicate that all contaminated sediments are non-hazardous. Contaminated sediment would be disposed of at a licensed offsite facility. Beneficial use of the sediment is not anticipated, but would be further evaluated during design.

7.1.1.4 Residual Cover

If confirmation sampling indicates concentrations exceeding clean-up goals following excavation, then a thin residual cover consisting of sand would be placed within the ditch, to contain and prevent exposure to residual contamination. For this evaluation, it is assumed that the residual cover would be 3 to 6 in. thick. If the confirmation sampling results identify areas with elevated concentrations near the clean-up goals, a residuals cover would serve to further limit exposures to benthic organisms and wildlife. As an assumption for the alternatives evaluation with dewatering of the excavation to limit sediment resuspension, Alternative 2 includes approximately 500 cy of material for residual cover in the ditch and approximately 2,000 cy of material for residual cover in the wetlands. Areas within the wetland areas with elevated concentrations of metals and TPH near the clean-up goals are assumed to have a cover.

7.1.2 Evaluation of Threshold Criteria

Compliance With Permits and Applicable Regulatory Requirements

Relatively dry excavation and the associated dewatering, water treatment, and offsite disposal would need to be conducted in accordance with federal, state, and local permitting and regulatory requirements, as described below.

7.1.2.1 State

MDEQ Permits and Approvals

The following MDEQ permits and approvals would potentially be required for remedial activities including sediment removal within the Fire Suppression Ditch and adjacent wetlands. The permits would be granted by MDEQ under statutes that may include the following (listed in numerical order):

- Clean Water Act Section 401 Water Quality Certification;
- Coastal Management Program (in conjunction with the U.S. Army Corps of Engineers [USACE] – Detroit District);
- Natural Resources and Environmental Protection Act (NREPA) – Part 303 Wetlands Permit;
- NREPA – Part 323 Shoreline Protection and Management;
- NREPA – Part 111 Hazardous Waste Management;
- NREPA – Part 115 Solid Waste Management;

- NREPA – Part 91 Soil Erosion and Sedimentation Control Plan Approval; and

- National Historic Preservation Act – State Historic Preservation Office (Michigan State Historic Preservation Review Board).

Construction Site Stormwater Discharge Permit

Permit coverage for discharge of dewatering and decontamination water would be required under a new NPDES permit. Compliance with the general permit requires implementation of site erosion control and stormwater management plans. Construction activities performed under this permit would be subject to the following regulations:

- NPDES Permit (Operation);
- NPDES Construction Permit.

If, following remedial design, it is determined that the existing groundwater treatment system can be utilized, discharge of dewatering and decontamination water would likely be covered under the existing NPDES permit (Certificate of Coverage #MIG081127 – *MDEQ-RRD-Zephyr Naph Sol*).

7.1.2.2 Federal

Clean Water Act Section 404 Permit

Section 404 of the Clean Water Act requires permit authorization from USACE for the discharges of dredged or fill material into Waters of the United States. A joint permit application process between USACE – Detroit District and MDEQ exists. USACE will issue a general permit to allow the performance of these activities at the Site that discharge dredged and/or fill material into waters of the United States, according to the provisions of the Clean Water Act (40 Code of Federal Regulations [CFR] 230), Section 404.

Rivers and Harbors Act Permit

Section 10 of the Rivers and Harbors Act states that any work in or affecting navigable waters of the United States (commercially navigable waters) requires a permit from USACE. Such work includes dredging, channelization, excavation, filling, construction of piers, breakwaters, bulkheads, revetments, power transmission lines, aids to navigation, and sewer outfalls over commercially navigable waters.

Additional federal permits or approvals potentially necessary include:

- National Environmental Policy Act Compliance (National Oceanic and Atmospheric Administration[NOAA]);

- Federal Conformity Determination (NOAA) – Muskegon is in non-attainment for 8-hour ozone. Only needed if project exceeds *de minimis* thresholds set by the Clean Air Act;

- Endangered Species Act Coordination (USFWS in conjunction with MDNR);

- Fish and Wildlife Act Coordination (USFWS in conjunction with MDNR);

- Migratory Bird Treaty Act Coordination (USFWS); and

- Bald and Golden Eagle Protection Act Coordination (USFWS).

7.1.2.3 Local

7.1.2.3.1 Muskegon County Permits

Soil Erosion and Sedimentation Control Permit

A permit from the Muskegon County Department of Public Works would be required for disturbances of 1 acre or more of land within 500 ft of a lake or stream.

7.1.2.3.2 City of North Muskegon

No known permits or approvals were identified at this time; however, during remedial design, local stormwater, construction, and noise ordinances should be considered.

7.1.2.4 Tribal

The following permits or approvals associated with tribal groups may be required:

- National Historic Preservation Act – Tribal Historic Preservation Office (Bay Mills Indian Community);

- National Historic Preservation Act – Tribal Historic Preservation Office (Keweenaw Bay Indian Community);

- National Historic Preservation Act – Tribal Historic Preservation Office (Lac Vieux Desert Band of Lake Superior Chippewa Indians); and

- National Historic Preservation Act – Tribal Historic Preservation Office (Pokagon Band of Potawatomi Indians).

7.1.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

Relatively dry excavation offers many advantages for environmental remediation projects, and is expected to be the most effective technology for maximizing removal of sediments exceeding preliminary clean-up goals, with minimal residual contamination, and thus minimal residual risk, remaining after sediment removal. Relatively dry excavation also prevents sediments from becoming suspended during removal activities, and thus prevents both re-deposition of contaminated material on remediated areas following excavation and potential downstream transport of contaminated material during the sediment removal.

By permanently and efficiently removing sediments that exceed preliminary clean-up goals from the contaminated area and allowing disposal in a permitted offsite facility, relatively dry excavation would minimize onsite exposure risks and would be protective of human health and the environment. Excavation would also stop any potential downstream migration of these sediments and thus decrease contaminant exposure throughout the AOC. Relatively dry excavation would therefore support removal of the BUIs identified as associated with the Site.

Confirmation sampling would be used to confirm the effectiveness of the relatively dry excavation. Based on results obtained during such sampling, relatively dry excavation is expected to meet PCUGs without placement of a residual cover over the excavated surface. However, if based on such sampling, a residual cover is deemed necessary, such a cover would be placed to meet PCUGs and to reduce the risk of exposure.

Short-Term Effectiveness in Protecting Human Health and the Environment

Potential short-term risks to human health associated with relatively dry excavation include direct contact of workers with contaminants during sediment excavation, transport, and dewatering operations. These risks would be minimized using safety procedures and appropriate personal protective equipment (PPE). Dust monitoring and control measures may also be necessary, both at the excavation and in the staging/dewatering area, to control inhalation risk among workers and the nearby community. Decontamination of equipment would be conducted before it leaves the excavation area and the staging/dewatering area, to prevent contaminated material from being transported into other nearby properties that are located along sediment transport routes. Sediments in open truckbeds would also be covered prior to leaving the Site to prevent loss of material.

Transporting the sediments by truck from the staging/dewatering area to the disposal facility would cause an increase in heavy truck traffic along the haul route. Construction of onsite temporary haul routes and/or repair of some city streets along the haul route may be necessary to counter the effects of the increased heavy truck traffic.

Relatively dry excavation would cause temporary impacts to the local environment. Dewatering of the contaminated areas and sediment excavation would temporarily eliminate areas of benthic and wildlife habitat. However, these short-term impacts would be followed by long-term benefits associated with the contaminant removal, and reestablishment of benthic and wildlife communities of equal or higher quality would be expected following restoration of the excavated areas. Upland areas would also be disturbed by construction of haul roads, construction access points, and the staging/dewatering area. Areas that are already degraded would be selected for these activities where possible, allowing an improvement in habitat and recreational value following restoration.

Engineering Implementability, Reliability, Constructability, and Technical Feasibility

Relatively dry excavation is most feasible in shallow water areas that can be easily dewatered using temporary cofferdams to redirect water. This technology is therefore expected to be highly implementable throughout the contaminated area, which consists of wetland areas with sporadic standing water and a ditch with shallow water depths. Transport of sediments to a staging/dewatering area would also be highly implementable by truck with improved haul roads.

Onsite treatment of water removed during dewatering, decontamination water, and water that falls as precipitation into the dewatered area would also be highly implementable. Sediments removed by relatively dry excavation are expected to have much lower water content than sediments removed by mechanical dredging; therefore, relatively dry excavation would minimize the amount of wastewater treatment required and would likely reduce required staging/dewatering areas, relative to mechanical dredging with hydraulic transport, due to *in situ* dewatering activities. Addition of sediment amendments would be fast and would serve a dual purpose as both the primary dewatering technology, and also a method to improve the physical properties of the sediment for disposal.

Offsite disposal is a common disposal option that would permanently remove contaminant mass from the Site. Facilities for disposal of non-hazardous sediments are available in the area. As described above, sediment amendments would be used to modify the physical properties of the sediment to meet disposal facility moisture and strength requirements.

Cost

The total average cost for relatively dry excavation and associated technologies is estimated at approximately $204 per *in situ* cubic yard of contaminated sediment. Detailed costing for this technology as incorporated into combined alternatives is provided in Appendix F.

7.1.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

It is anticipated that positive stakeholder and community response to relatively dry excavation and offsite disposal will be received; thus, this remedial option is expected to be accepted.

Community outreach activities would seek to address possible concerns associated with issues such as short-term disturbance of the areas and transport routes for trucks carrying sediment to the processing area and for offsite disposal.

7.2 MECHANICAL DREDGING WITH ONSITE HYDRAULIC TRANSPORTATION AND OFFSITE DISPOSAL AND SUPPORTING TECHNOLOGIES

7.2.1 Description

This alternative assumes dredging would be conducted mechanically via articulated fixed arm excavators as with Alternative 2, potentially including clamshell bucket attachment for the ditch. Low ground pressure tracked excavators or marsh excavation equipment would be used. The excavator(s) would access target areas in the Fire Suppression Ditch from the adjacent wetland, e.g., using a long-reach excavator. Excavators would have a thumb attachment available for removal and management of large or unwieldy debris (i.e., logs, etc.).

This alternative would not require dewatering of the remediation area as water may be usable for a water supply for slurrying. Prior to implementation of this alternative, the discharge point of the existing groundwater treatment system (currently discharging under an NPDES permit) would be extended to the Muskegon River via temporary hose/pipe. This temporary extension would likely be located along the railroad track berm located to the west of the Site in order to isolate it from the area requiring remediation. It is assumed that access to the railroad right-of-way for temporary treated water transfer will be achievable. It is assumed the water from the existing groundwater treatment system is suitable for slurrying activities and can be utilized as necessary.

In addition to relocation of the existing outfall, an alternate water source for the current operations in the upland area will be required as the Site owner currently obtains water from the ditch area. Options to provide this water include water from the existing groundwater treatment system, the previously remediated lagoon located to the northwest of the Site, or the Muskegon River.

Along the Muskegon River, the exterior berms and cofferdam should provide a uniform top elevation (filling in any low or settled areas) to prevent flood waters from entering the Site and any possible transport of sediments to downstream areas of the AOC. Additional sheet pile walls would be necessary along sections of the Fire Suppression Ditch where deeper excavation is necessary. All sheet pile walls or cofferdams would be removed upon completion of remedial activities.

Contaminated sediment would be removed and transferred to a slurry pit, where water would be pumped to continuously feed a specially designed dredged pump called a high solids pump (such as the Toyo high solids pump) for slurrying the sediment. In addition to the water the pump injects to dislodge sediment, supplementary water would be pumped as needed to the pit to assist the slurrying operation. Some water can be supplied from the ditch and recycled (recirculated from the geotextile tubes dewatering in the staging area), though some water may be withdrawn from the river. Vegetation and vegetation root mass would be removed from the wetland first, before sediment is excavated and transferred to the slurry pit—this material would be separately handled and transported to the upland staging area for stockpiling. If necessary depending on time of dewatering within geotextile tubes, some vegetation that has dried can be mixed with higher moisture content sediment from the geotextile tubes, though in general these two separate materials can be disposed of separately.

Pumps would transport the slurry through a pipeline to a manifold system to be directed into geotextile tubes. Due to the sand content in the sediment, the additional step of removing sand in a hydrocyclone tank prior to the geotextile tubes (Particle Separation) may be cost effective if there is a known reuse of the sand applicable for the Site that would reduce the volume of material to be disposed. It should be noted that particle separation is not included in the alternative or cost estimate, but could be explored in the design if this alternative is selected. The geotextile tubes would be placed within a bermed and lined area. Geotextile tubes would be filled in series using a manifold system and polymers would be added to facilitate coagulation and flocculation of solids. The sediment would dewater in the geotextile tubes for an appropriate period of time (cost estimate assumes approximately 5 months) before being dismantled, loaded into larger, watertight trucks and transported offsite for disposal.

The bermed area would be lined with gravel and geotextile fabric which would enclose a filtrate collection system. This system would be made of perforated HDPE pipe which would collect the drained water and direct it to sumps, where it would then be pumped to storage tanks or a detention basin, where it will be recycled to provide water for slurrying in the removal areas. Water will be recycled to reduce the amount of water in use for slurrying and reduce the total volume of water requiring treatment. Excess filtrate water would be treated via a packaged/leased treatment system. Details regarding water treatment are presented in Section 7.2.1.2.

Similar to Alternative 2, if confirmation sampling indicates concentrations exceeding clean-up goals following excavation, then a thin residual cover consisting of sand would be placed within the ditch, to contain and prevent exposure to residual contamination. For this evaluation, it is assumed that the residual cover would be 3 to 6 in. thick. For Alternative 3, the Contractor may prefer for water to remain in the ditch to use as water supply for slurrying, and resuspension of sediment is more likely to contribute to residuals that may or may not have fully settled at the time of confirmation sampling. Alternative 3 includes approximately 1,000 cy of material for residual cover in the ditch and approximately 2,000 cy of material for residual cover in the wetlands. Areas within the wetland areas with elevated concentrations of metals and TPH near, yet below, the clean-up goals are assumed to have a cover.

After proper cover is placed, appropriate restoration would be completed as discussed in Chapter 9. At the completion of the project, staging areas and temporary haul routes would be properly restored.

It is anticipated that for Alternative 3, approximately 51,217 cy of non-hazardous material would be excavated. This is an *in situ* estimation. This includes a rough cut estimation of overdredge in the ditch, a 6-in. vertical overdredge allowance in the wetland removal areas, a 1-ft buffer zone horizontally around the perimeter of the wetland removal areas, contingencies for uncertainties in the volume estimate due to core recovery, and an estimation of the volume of vegetation and associated root mass located above the contaminated sediment in wetland areas requiring removal. An estimated 342 tons of Portland cement would be added to amend the material (2.5 percent addition by mass). Following dewatering and amendment addition, as necessary, the resulting total estimated disposal weight is 29,700 tons of amended dredged material.

A concept plan drawing of the implementation for Alternative 3 is included in Appendix E.

7.2.1.1 Sediment Dewatering and Solidification

Mechanical dredging with hydraulic transport to the processing area would require a larger area for dewatering per cubic yard of sediment than would dry excavation, due to the large volume of water contained in the sediment slurry that would be created, and a longer timeframe for dewatering slurry within geotextile tubes. Results of bench-scale geotextile testing by RDT test imply this would be a manageable time period, but additional testing was recommended to determine the specifics of geotextile tube performance. Sediment slurry would be conditioned with polymer additives to enhance the passive dewatering. After the geotextile tube dewatering is complete, the sediments would be assessed to determine whether they meet disposal facility moisture and strength requirements—for the feasibility study, it is assumed that the dewatering duration would be selected to reach the point of passing paint filter testing and requiring minimal or no drying agents, for transport offsite. If the dewatered sediments do not meet disposal requirements, soil amendments would be required. For purposes of this evaluation, it was assumed that polymer additives would be mixed into the slurry before it is pumped to the large geotextile tubes and that the passive dewatering would yield material with 50 percent solids by mass that would pass the paint filter test and require minimal additional dewatering or solidification.

The size of the dewatering area would depend on several factors that include the volume of sediment to be removed, sediment amendment cure time, rate of removal versus rate of loading and transport to offsite disposal facilities, required frequency of waste confirmation sampling, and overall project schedule. It is assumed that the area allocated in the upland portion of the former refinery, approximately 7 acres, is sufficient for dewatering and staging. Additional evaluation is required to determine the footprint for geotextile tubes and detention pond for water recycling (recirculation), though given geotextile tubes may be stacked, it is expected this size of staging area will provide suitable space for the required activities of Alternative 3.

7.2.1.2 Water Treatment

Water that may require treatment would be generated from the following sources:

- Water from dewatering prior to/during excavation;
- Dewatering pad drainage from sediment;

- Precipitation into the dewatered ditch during excavation;
- Decontamination water; and
- Precipitation on the dewatering pad.

The components needed to treat the collected water before discharge would be determined during the design. However, to evaluate cost and comparison to other alternatives, it was assumed for this evaluation that water treatment would consist of a packaged leased treatment system which would consist of:

- Oil-water separation;
- pH adjustment (if needed);
- Weir tanks for clarification with coagulant and flocculent addition;
- Sand or Multimedia filtration; and
- Granular activated carbon.

For the purposes of this FS, it is assumed that a separate NPDES permit will be obtained for the packaged/leased water treatment system. Regular sampling would be conducted to verify that the requirements for discharge are met.

Utilization of the existing groundwater extraction remediation system operated by MDEQ with associated permitted NPDES discharge can be further evaluated during remedial design. If the system were determined to be appropriate for use, a pre-treatment system would likely be required. It is assumed that any oil entrained in sediments will be captured by the geotextile tubes and oil/water separation is not required for pre-treatment.

The pre-treatment system may consist of the following:

- pH adjustment (if needed);
- Weir tanks for clarification with coagulant and flocculent addition; and
- Multimedia filtration.

Following pre-treatment, wastewater would be transferred to the existing onsite groundwater extraction treatment system. Water could be transferred in batches or metered depending on needs of the existing treatment system. Additional study is required to determine if flocculent and/or coagulants in pre-treatment water will affect the bioreactor.

The existing groundwater extraction remediation system currently consists of a bioreactor followed by a clarifier. From the clarifier the wastewater is pumped through a knockout tank to the treatment building consisting of bag filtration and two-stage carbon treatment prior to discharge to the top of the Fire Suppression Ditch via an existing NPDES permit. Based on current use, the existing onsite groundwater extraction remediation system operates at an approximate capacity of 200 gpm and can discharge to the NPDES outfall or associated groundwater injection trenches. It should be noted that it is assumed the existing onsite groundwater extraction remediation system removes petroleum-related compounds including

BTEX as well as whatever lead remains (by removing suspended solids and associated lead) following pre-treatment.

In order to utilize the existing groundwater extraction remediation system, the NPDES permit would likely require modification for flow rate (currently permitted for 150 gpm; could increase to capacity of system of approximately 200 gpm) as well as monitoring requirements due to potential metals content of water collected during dewatering of sediments. Regular sampling would be conducted to verify that the requirements for discharge are met.

7.2.1.3 Offsite Disposal

Offsite disposal will be similar to that for dry excavation. Trucks used to transport contaminated materials offsite would be covered, and tires and exteriors decontaminated after loading and before leaving the Site. Sediments would be characterized for disposal before transportation, and would be disposed of at a licensed offsite facility. Beneficial use of the sediment is not anticipated, but would be further evaluated during the remedial design.

7.2.2 Evaluation of Threshold Criteria

Compliance With Permits and Applicable Regulatory Requirements

The permitting and regulatory requirements associated with mechanical dredging with hydraulic transport and associated technologies are consistent with the list presented in Section 7.1.2, for relatively dry excavation.

7.2.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

Mechanical dredging would remove contaminated sediments from the Site, prevent their transport downstream, and thus decrease contaminant exposure throughout the AOC. By permanently and efficiently removing sediments that exceed PCUGs from the area and allowing disposal in a permitted offsite facility, dredging would decrease onsite exposure risks and would be protective of human health and the environment. Mechanical dredging would also prevent potential future downstream migration of these sediments and thus decrease contaminant exposure throughout the AOC. Mechanical dredging would therefore support removal of the BUIs identified as associated with the Site. However, mechanical dredging is expected to be less effective than relatively dry excavation for achieving thorough removal of sediments exceeding the PCUGs.

Mechanical dredging techniques, including using environmental or clamshell buckets, would be used to reduce the amount of re-suspension of contaminated sediments. However, some degree of re-contamination would occur, as fine sediments disturbed during dredging settle back to the wetland or ditch bottom.

Confirmation sampling would be used to assess the effectiveness of the mechanical dredging with hydraulic transport for meeting the remedial objectives. Residuals concentrations exceeding PCUGs associated with the residuals described above, are more likely following dredging than following relatively dry excavation. In cases where contamination exceeding clean-up goals remains, placement of a residuals cover would be used to limit exposure to the remaining contaminated material.

Short-Term Effectiveness in Protecting Human Health and the Environment

Potential short-term risks to human health associated with mechanical dredging and hydraulic transport include direct contact of workers with contaminants during dredging, transport, and dewatering operations. These risks would be minimized using safety procedures and appropriate PPE. Dust monitoring and control measures may also be necessary at the staging/dewatering area, to control inhalation risk among workers and the nearby community. Decontamination of equipment would be conducted before it leaves the staging/dewatering area, to prevent contaminated material from being transported into other nearby properties that are located along sediment transport routes. Sediments in open truckbeds would also be covered prior to leaving the Site to prevent loss of material.

Potential short-term risks to human health associated with particle size segregation are similar to those associated with relatively dry excavation and mechanical dredging.

Dredging would cause temporary impacts to the local environment. During dredging, the benthic habitats within the dredging areas would be dramatically disrupted. Short-term impacts to the aquatic habitats within the ditch would be associated with dredging activities as well as short-term exposure risks associated with resuspension of contaminated sediments into the water column located within the ditch and wetlands. However, these short-term impacts would be followed by long-term benefits associated with the contaminant removal, and reestablishment of aquatic and benthic communities of equal or higher quality would be expected following restoration of the dredged areas. Upland areas would also be disturbed by construction of haul roads, location of hydraulic transport pipeline, construction access points, and the staging/dewatering area. Areas that are already degraded would be selected for these activities where possible, allowing an improvement in habitat and recreational value following restoration.

Engineering Implementability, Reliability, and Constructability, and Technical Feasibility

Mechanical dredging, conducted mechanically via articulated fixed arm excavators with clamshell bucket attachment or crane-mounted environmental or clamshell buckets that would access target areas from the dryer adjacent land, e.g., would be comparable to the dry excavation alternative. This technology is therefore expected to be highly implementable throughout the contaminated area, which consists of wetland areas with sporadic standing water and a ditch with shallow water depths. Pumping the sediment slurry to a staging/dewatering area located in the upland portion of the former Zephyr Refinery would also be highly implementable. Vegetative material located in the wetlands would likely require separate handling, including drying, and would likely be staged near the dewatering sediments and mixed back in with sediment prior to offsite transport and disposal.

Onsite treatment of water removed during dewatering, decontamination water, and water that falls as precipitation into the dewatered area would also be highly implementable. Mechanical dredging with hydraulic transport also produces large amounts of wastewater. The dredged sediment would therefore need to be dewatered, and all wastewater would require treatment. The dewatering in geotextile tubes is expected to be implementable, although it would require an extended timeframe to reach the goal of 50 percent solids by mass, and would therefore require a large staging/dewatering area and possible stacking of the geotextile tubes. Addition of polymers to promote dewatering would facilitate the dewatering; however, the dewatered sediments may also require addition of soil amendments in order to meet disposal facility requirements.

Due to the probability of residual contamination in the ditch, placement of a residual cover after dredging to meet final residual concentration requirements may be necessary. Placement of a residual cover is expected to be highly implementable following sediment removal. Unless provided by particle size segregation, clean cover material would need to be transported to the Site and placed in-water in the location of dredging. Cover placement may not be appropriate for areas where disturbance is planned in the near future.

Offsite disposal is a common disposal option that would permanently remove contaminant mass from the Site. Facilities for disposal of non-hazardous sediments are available within approximately 30 miles of the project area. As described above, sediment amendments would be used to modify the physical properties of the sediment to meet disposal facility moisture and strength requirements.

Cost

The total average cost for mechanical dredging and associated technologies is estimated at approximately $220 per *in situ* cubic yard of contaminated sediment. Detailed costing for this technology as incorporated into combined alternatives is provided in Appendix F.

7.2.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

It is anticipated that positive stakeholder and community response to the mechanical dredging with hydraulic transport and offsite disposal will be received; thus, this remedial option is expected to be accepted. Community outreach activities would seek to address possible concerns associated with issues such as short-term disturbance of the areas and transport routes for trucks carrying sediment for offsite disposal.

7.3 GREEN REMEDIATION CONSIDERATIONS

As discussed in sections above, the RAOs for the project are to address contaminated sediments and to perform restoration for areas affected by the remediation. EPA recognizes that the process of remediation uses energy, water, and other natural materials or resources, and that much can be done to conserve natural resources, minimize waste generation, and reduce energy consumption (EPA 2010). When applied to clean-up, conservation and impact minimization concepts are often referred to as "green remediation." EPA guidance identifies many concepts for making remediation greener. Examples include:

- Conservation of natural resources;
- Re-using materials otherwise considered waste;
- Maximizing energy efficiency;
- Decreasing air emissions;
- Conserving water resources;
- Planning work to include consideration of green practices; and
- Helping to increase the understanding and awareness of green technologies.

These and other green remediation components can produce environmental benefits, if their use is balanced with remedy protectiveness and implementability. Careful consideration must be given to where and how green components can be incorporated, while maintaining compatibility with the RAOs, with regulations, and with project schedule and budget.

The technologies retained as part of remedial alternatives for this FS offer various opportunities for incorporating green remediation principles. The greatest potential for green remediation as part of the Site remediation is associated with conservation of natural resources, minimization of waste, and conserving water resources. Specific opportunities for green remediation will be incorporated into the Remedial Design as appropriate. These may include methods for increasing energy efficiency, decreasing water use (including recycling of water), planning with green concepts in mind, and increasing awareness.

7.3.1 Conservation of Natural Resources

Both of the primary remedial alternative technologies discussed in Sections 7.1 and 7.2 provide opportunities for conservation of natural resources. As discussed in Chapter 5, this project includes goals for restoration in addition to remediation. Thus the overall impact of the project will be to conserve and/or enhance natural resources in any areas affected by remediation using the specific restoration options presented in Chapter 9. While the project will involve some disturbance of natural resources at the site, it will produce overall benefits for fish and wildlife and improve plant communities. Additional consideration of conservation in the design will likely include minimizing the impacts of remedial construction by placing haul roads and staging facilities in existing disturbed or open areas that can be easily restored; the preliminary description of alternatives presented above includes using existing open and disturbed ground to the extent currently considered feasible.

7.3.2 Waste Minimization

Another opportunity for incorporating green remediation concepts into the clean-up at the Site is waste stream segregation and minimization. Minimizing the amount of waste requiring disposal can decrease the amount of space consumed at landfills and reduce the amount of energy used and air emissions produced in excavating and transporting materials. Waste minimization can be conducted by carefully segregating waste so that as little waste as possible requires specialized offsite disposal, and as much as possible can be disposed routinely or even re-used. Waste minimization must be balanced with requirements to meet disposal regulations and to ensure that the RAOs are achieved.

7.3.3 Water Conservation

Opportunities for water conservation vary between the remedial alternatives. All alternatives require transport of water, either water removed from the ditch and wetlands to allow excavation or water entrained by mechanical dredging with hydraulic transport. Opportunities to optimize water conservation for the alternative selected will be assessed in the Remedial Design.

7.3.4 Green Remedy Recommendations

Opportunities for green remediation were considered as part of the Former Zephyr Refinery Fire Suppression Ditch FS. Among the many concepts associated with green remediation, conservation of natural resources, waste minimization, and water conservation were identified as bearing the greatest potential for relevance to alternative development. All alternatives include restoration components that result in conservation of natural resources. All alternatives include measures to conserve water quality. The remedial design for the Fire Suppression Ditch may consider other aspects of green remediation related to energy efficiency, reduced air emissions, planning, and awareness. Green remedy concepts are a part of the FS and thus are part of ongoing efforts to increase awareness and understanding of their application and benefits.

8. EVALUATION OF REMEDIAL ALTERNATIVES

This chapter presents an evaluation of the combined remedial alternatives. With the exception of Alternative 1, No Action, the alternatives evaluated are composed of combinations of the technologies described in Chapters 3 and 7. The evaluation below presents an abbreviated evaluation of the combination alternatives, based on the detailed evaluation of these primary components that is presented in Chapter 7. Table 8-1 provides a summary of the evaluation of the remedial alternatives. This table also provides relative ratings of the alternatives, based on the criteria outlined in Chapter 6, to aid in comparison of the alternatives.

For purposes of the remedial alternatives evaluation, volumes of sediment requiring removal were estimated based on the sediment data from the Phase 1 investigation completed in 2012 (EA 2012) as well as the most recent data collected as part of FS activities summarized in Section 2.4. The volume of contaminated sediment in each deposit was calculated using PCUGs as presented in Section 2.3.

8.1 REMEDIAL ALTERNATIVE 1: NO ACTION

8.1.1 Description

The No Action alternative does not include implementation of any remedial technologies at the Site, and is evaluated to allow comparison of the identified technologies with a no-action scenario.

8.1.2 Evaluation of Threshold Criteria

Compliance With Permits and Applicable Regulatory Requirements

The No Action alternative would not be subject to any permitting or regulatory requirements, because it would not involve any site activities.

8.1.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

The No Action alternative would not be protective of human health and the environment, because it would leave contaminated sediments in place at the Site, and would not impact current exposure pathways for these contaminants. This alternative also would not affect the presence of elevated metals and TPH within the Site, which is recognized as the major contributor to BUIs within the AOC, and thus would not support removal of the BUIs.

Short-Term Effectiveness in Protecting Human Health and the Environment

The No Action alternative would not present additional risks to human health and the environment in the short term, beyond the long-term risks already associated with the presence of the contaminated material.

Engineering Implementability, Reliability, Constructability, and Technical Feasibility

The No Action alternative would be highly implementable from a logistical and technical perspective, because it does not involve any remedial activities at the Site.

Cost

There would be no financial costs associated with implementation of a No Action alternative.

8.1.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

The No Action alternative is not expected to be acceptable to stakeholders and the community, because it would not meet the RAOs for the Site or support the removal of BUIs in the AOC.

8.2 REMEDIAL ALTERNATIVE 2: RELATIVELY DRY EXCAVATION AND OFFSITE DISPOSAL

8.2.1 Alternative 2: Relatively Dry Excavation and Offsite Disposal

8.2.1.1 Description

Alternative 2 would include relatively dry excavation of all sediments exceeding preliminary clean-up goals at the Site, using the processes described in Section 7.1.1. Concept plans for this alternative are provided in Figure 1 in Appendix E. The estimated total volume of sediments excavated would include approximately 51,217 cy of contaminated sediment, with contingencies included. Areas requiring excavation, including both the ditch and wetlands, would be dewatered and the sediments removed and transported by truck to a staging/dewatering area located upland of the excavation area. Sediments would be dewatered in a lined, bermed area and amended with Portland cement, or similar drying agent, to achieve ideal moisture content, and transported by truck for offsite disposal. If confirmation sampling indicates residual contamination exceeding clean-up goals in any areas, a residual cover would be placed to contain and prevent exposure to the contaminated material.

8.2.1.2 Evaluation of Threshold Criteria

Compliance With Permits and Applicable Regulatory Requirements

The anticipated permitting and regulatory requirements associated with this alternative are presented in Section 7.1.2, and include compliance with requirements addressing sediment removal, water quality, erosion control, stormwater control and discharge, construction access, dewatering of the contaminated area, dust control, floodplain and wetland disturbances, and handling and disposal of excavated sediments. Obtaining and complying with the requirements of the necessary permits during implementation of this alternative is expected to be highly feasible.

8.2.1.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

A detailed evaluation of the effectiveness of the relatively dry excavation and the associated technologies that would be used as part of this alternative is presented in Section 7.1.3. Relatively dry excavation would permanently remove contaminated sediments and is expected to be highly effective for removing sediments exceeding preliminary clean-up goals from the area. Relatively dry excavation is also not expected to leave significant amounts of residual contaminated material. Thus, Alternative 2 is expected to be protective of human health and the environment, achieve RAOs, prevent potential downstream transport of contaminated material, and support removal of BUIs.

Short-Term Effectiveness in Protecting Human Health and the Environment

Relatively dry excavation and associated technologies would be associated with various short-term risks to human health and impacts to the local environment, as described in Section 7.1.3. Human health risks would be controlled through use of PPE and appropriate site controls. Short-term environmental impacts during removal including suspension and transportation of contaminants in the ditch would be mitigated with the use of a cofferdam between the end of the ditch and wetland borders and the Muskegon River. Installation and removal of the cofferdams would create short-term impacts to the environment, which would be mitigated during restoration activities. Additional mitigation of resuspension effects would occur with dewatering of the ditch. Disturbance of benthic and wildlife habitats would be outweighed by improved habitat quality following removal of contaminants. Impacts would be focused in degraded areas, where possible, and would be mitigated by restoration of disturbed areas. The short-term risks to human health and the environment are expected to be similar for all sediment removal alternatives.

Engineering Implementability, Reliability, Constructability, and Technical Feasibility

Considerations affecting the implementability, reliability, constructability, and technical feasibility of dry excavation and associated technologies are presented in Section 7.1.3. Overall, relatively dry excavation would be highly implementable in the shallow-water environment of the Fire Suppression Ditch and the surrounding wetlands. It would also produce less water requiring treatment than would Alternative 3, with hydraulic transport, and would require less time for sediment dewatering. Trucking sediment from the excavation areas up to the dewatering facility in the staging area would require considerable trucking as compared to Alternative 3.

Cost

The estimated cost of Alternative 2 is approximately $10,450,000. Details on the derivation of this cost are provided in Appendix F.

8.2.1.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

Relatively dry excavation and offsite disposal is expected to be acceptable to stakeholders and the community based on feedback from a meeting with the Muskegon Lake AOC stakeholders in January 2014.

8.3 REMEDIAL ALTERNATIVE 3: MECHANICAL DREDGING WITH HYDRAULIC TRANSPORT AND OFFSITE DISPOSAL

8.3.1 Alternative 3: Mechanical Dredging With Hydraulic Transport and Offsite Disposal

8.3.1.1 Description

Alternative 3 would include mechanical dredging and hydraulic transport of all sediments exceeding preliminary clean-up goals at the Site, using the processes described in Section 7.2.1. The estimated total volume of sediments excavated would include approximately 51,217 cy of contaminated sediment. Environmental dredging techniques would be used to minimize sediment re-suspension during dredging of the sediment, which would be placed in a slurry pit and mixed with water, then pumped to a staging/dewatering area located upland of the contaminated area. Sediments would be dewatered using geotextile tubes, and transported by truck for offsite disposal. If confirmation sampling indicates residual contamination exceeding clean-up goals in any areas, a residual cover would be placed to contain and prevent exposure to the contaminated material.

8.3.1.2 Evaluation of Threshold Criteria

Compliance with Permits and Applicable Regulatory Requirements

The anticipated permitting and regulatory requirements associated with this alternative are presented in Section 7.2.2, and include compliance with requirements addressing sediment removal, water quality, erosion control, stormwater control and discharge, construction access, dust control, floodplain and wetland disturbances, and handling and disposal of dredged sediments. Obtaining and complying with the requirements of the necessary permits during implementation of this alternative is expected to be highly feasible.

8.3.1.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

A detailed evaluation of the effectiveness of mechanical dredging and the associated technologies that would be used as part of this alternative is presented in Section 7.2.3. Mechanical dredging would permanently remove contaminated sediments from the area. However, it is expected to be less effective than dry excavation for removing sediments exceeding clean-up goals from the ditch due to its tendency for contaminated sediments to become suspended during dredging, both of which lead to residual contamination. Thus, Alternative 3 is expected to be slightly less effective for protecting human health and the environment, achieving RAOs, preventing downstream transport of contaminated material, and supporting removal of BUIs, than alternatives that utilize relatively dry excavation.

Short-Term Effectiveness in Protecting Human Health and the Environment

Mechanical dredging and associated technologies would be associated with various short-term risks to human health and impacts to the local environment, as described in Section 7.2.3. Human health risks would be controlled through use of PPE and appropriate site controls. Short-term environmental impacts during removal including suspension and transportation of contaminants in the ditch would be mitigated with the use of a cofferdam between the end of the ditch and the Muskegon River. Disturbance of aquatic habitats would be outweighed by improved habitat quality following removal of contaminants. Impacts would be focused in degraded areas, where possible, and would be mitigated by restoration of disturbed upland areas. The short-term risks to human health and the environment are expected to be similar for all sediment removal alternatives.

Engineering Implementability, Reliability, Constructability, and Technical Feasibility

Considerations affecting the implementability, reliability, constructability, and technical feasibility of mechanical dredging and associated technologies are presented in Section 7.2.3. Overall, mechanical dredging would be implementable in the Fire Suppression Ditch area. The dredged slurry would require large amounts of area and time for dewatering, and would produce large volumes of water requiring treatment; however, this alternative would produce a smaller volume of material requiring offsite disposal. The greater likelihood of residual contamination following mechanical dredging in the ditch could also necessitate placement of a residual cover.

Cost

The estimated cost of Alternative 3 is approximately $11,290,000. Details on the derivation of this cost are provided in Appendix F.

8.3.1.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

Mechanical dredging with hydraulic transport and offsite disposal is expected to be acceptable to stakeholders and the community based on feedback from a meeting with the Muskegon Lake AOC stakeholders in January 2014.

8.4 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Table 8-1 summarizes the findings of the evaluations presented in Chapter 7 and Sections 8.1 through 8.3, and also presents relative ratings for the three remedial alternatives evaluated, according to the six criteria outlined in Chapter 6. This section provides a narrative summary of the relative attributes of the alternatives.

8.4.1 Threshold Criteria

Compliance with Permits and Applicable Regulatory Requirements

Obtaining and complying with the necessary permits is expected to be highly feasible for all three remedial alternatives evaluated. Alternative 1, No Action, would not be associated with any specific permitting or regulatory requirements. The anticipated permitting and regulatory requirements for the other two alternatives are expected to be similar, and relate to protecting water quality during sediment removal, minimizing erosion and dust and addressing stormwater during sediment transport activities, minimizing and mitigating floodplain and wetland disturbances, and properly handling and disposing of excavated sediments (including Toxic Substances Control Act requirements).

8.4.2 Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

Either relatively dry excavation or mechanical dredging with hydraulic transport would remove contaminated sediments from the Site, prevent their transport downstream, protect human health and the environment by decreasing contaminant exposure throughout the AOC, and thus support removal of the BUIs identified as associated with the Site. Mechanical dredging with hydraulic transport tends to leave more residual contaminated sediment than dry excavation, and is therefore expected to be moderately less effective than dry excavation for removing contaminated sediments in the Fire Suppression Ditch. Residuals left after mechanical dredging with hydraulic transport result from the potential for resuspension and redeposition of contaminated material during subaqueous dredging operations in the ditch. Excavating in a relatively dry environment, which does not involve disturbance of subaqueous material, is expected to cause less sediment to become suspended and thus may result in fewer residuals associated with redeposition.

Based on these considerations, Alternative 2 (which includes relatively dry excavation of some or all sediments requiring removal) is expected to be somewhat more effective in the long term than Alternative 3 (which involves mechanical dredging with hydraulic transport of sediments requiring removal). Alternative 1, No Action, would not protect human health and the environment, prevent downstream transport of contaminants, or support removal of BUIs, and therefore would be the least effective alternative. Overall, the order of rankings for long-term effectiveness is as follows:

Alternative 2 > Alternative 3 >> Alternative 1

Short-Term Effectiveness in Protecting Human Health and the Environment

Short-term risks currently present at the site are associated with elevated concentrations of heavy metals and petroleum-related compounds (TPH) in sediments. Alternative 1, No Action, would not address these risks, and therefore has low short-term effectiveness. The other two alternatives would address these risks, but would also create additional short-term risks associated with sediment removal and related activities. Both would create similar potential short-term risks, resulting from construction activities and contact with contaminated material. These potential risks would be mitigated using design to minimize impacts, PPE, site controls including decontamination of equipment, and restoration activities following completion of the remedial action. Overall, the order of rankings for short-term effectiveness is as follows:

Alternatives 2 and 3 > Alternative 1

Engineering Implementability, Reliability, Constructability, and Technical Feasibility

Alternative 1, No Action, would be highly implementable from a logistical and technical perspective, as it would not require any design or implementation.

Relatively dry excavation is expected to be the most implementable technology for sediment removal in most parts of the Site. Excavation in the dry is easily implemented in a shallow-water environment of the Fire Suppression Ditch, where temporary coffer dams can be used to redirect water and allow dewatering of the ditch. Dry excavation would also produce a smaller volume of removed material than would mechanical dredging with hydraulic transport (due to added water), and the removed material would have a lower water content, therefore requiring smaller staging/dewatering areas and less water treatment. Mechanical dredging with hydraulic transport would also be implementable, but in addition to the larger volumes and higher water content, would be more likely to encounter problems with the higher complexity involved with slurrying sediments for transport. A residual cover is also more likely to be required following mechanical dredging with hydraulic transport, to mitigate residual contamination. Overall, the order of rankings for engineering implementability, reliability, constructability, and technical feasibility is as follows:

Alternative 2 > Alternative 3 > Alternative 1

Cost

Generally, the cost of removing sediments by relatively dry excavation, expressed per cubic yard of contaminated sediment, is somewhat less than the cost of mechanical dredging with hydraulic transport. The marginal cost of added sediment removal volume, if determined to be necessary to achieve remedial goals, would also be lower for relatively dry excavation, as this technology is less costly per cubic yard. The order of rankings for cost (with the highest ranking representing the lowest cost) is as follows:

Alternative 1 > Alternative 2 > Alternative 3

8.4.3 Modifying Criteria

Stakeholder and Community Acceptance

Stakeholder and community acceptance is expected to be primarily contingent upon compliance with permitting and regulatory requirements, achievement of RAOs, protection of human health and the environment, and minimization of short-term impacts. Alternatives 2 and 3 are thought to be the most acceptable, because they would be protective and effective for achieving RAOs, based on the positive response to similar activities implemented in the Fire Suppression Ditch area of the Site. Input received at and after a meeting with the Muskegon Lake AOC stakeholders confirms public support for such an approach. Alternative 1, No Action, is the least acceptable of the alternatives evaluated, because it would not achieve RAOs and would not be protective. The order of rankings for stakeholder and community acceptance, assessed based on overall input received, is as follows:

Alternatives 2 and 3 > Alternative 1

9. EVALUATION OF HABITAT RESTORATION ALTERNATIVES

Chapter 5 described five alternatives for habitat restoration at the Site:

- ***Alternative 1: No Action***
- ***Alternative 2: Limited Restoration of Remediated Areas***
- ***Alternative 3: Restoration of Remediated Areas With Native Species***
- ***Alternative 4: Restoration of Native Habitats in Remediated Areas***
- ***Alternative 5: Full Site Restoration***

This section presents an evaluation of these restoration alternatives, according to the criteria described in Chapter 6.

9.1 EVALUATION OF RESTORATION ALTERNATIVE 1: NO RESTORATION

9.1.1 Description

Alternative 1, in which no remedial actions are taken, is retained for comparison with the other identified remedial alternatives.

In a no-restoration alternative, no actions would be taken to restore habitat, restore grades, or stabilize the Site following remedial action. This alternative may not be feasible given the RAOs and regulations that apply to habitats located in the Muskegon Lake Area AOC.

9.1.2 Evaluation of Threshold Criteria

Compliance with Permits and Applicable Regulatory Requirements

No additional permitting requirements are anticipated for the no-action restoration alternative, beyond the permitting requirements associated with the remedial actions.

9.1.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

A no-action restoration alternative has no significant impacts on human health unless restoration was a critical path in residuals management of the site remediation. No-action alternatives would have a negative impact on existing habitat and the environment; however, in the long term these elements would be anticipated to self-recover to a condition similar to the existing habitat.

Short-Term Effectiveness in Protecting Human Health and the Environment

Under a no-restoration alternative, short-term habitat disruptions associated with the remedial action would persist. Human health effects in the short term would be no different than those already caused by the remedial action.

Engineering Implementability, Reliability, and Constructability, and Technical Feasibility

The no-action alternative is implementable, constructible, and feasible; however, depending on the depths of excavation required through the remedial action, a lack of restoration to existing grades may have stability consequences for banks of surrounding berms and the railroad tracks to the west. This may influence the reliability of the remedial action. Consideration through the design process should evaluate restoration to a minimum of restoring to stable grades if not the existing stable grades on the Site.

Cost

No costs would be incurred with a no-action restoration alternative, other than those incurred through the remedial action and its associated design elements.

9.1.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

The no-action restoration alternative may have negative impacts on aesthetics; however, no recreational, boating, water surface, or other associated impacts are anticipated aside from those which may arise from the remedial action itself. Fire Suppression Ditch usage is not anticipated to be impacted through a no-action restoration alternative.

9.2 EVALUATION OF RESTORATION ALTERNATIVE 2: LIMITED RESTORATION OF REMEDIATED AREAS

9.2.1 Description

Alternative 2, limited restoration of the Site, would include a combination of submergent and emergent marsh where sediments were removed along with surface preparations to restore pre-existing grades along the perimeter of the remedial footprint, using substrate, soil, and other materials in kind with those removed; a vegetation plan to allow natural revegetation from existing seed sources; and additional site enhancements (e.g., educational signage at the main site access point). The goal of this restoration would be to re-establish the biotic integrity of the Site in a limited capacity. The limit of restoration would include only the footprint of the remedial action. A conceptual drawing presenting the implementation of restoration alternative 2 is presented in Appendix E.

9.2.2 Evaluation of Threshold Criteria

Compliance with Permits and Applicable Regulatory Requirements

No additional permitting requirements are anticipated for the this restoration alternative, beyond the permitting requirements associated with the remedial actions.

9.2.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

Restoration to existing conditions has no significant impacts on human health. It is anticipated that the replacement of contaminated substrates with clean substrates may effectively manage residual contamination below the clean-up threshold. Self-recovery would be expedited in a restoration to existing conditions, as compared to a no-action alternative.

Short-Term Effectiveness in Protecting Human Health and the Environment

Short-term impacts of restoration to existing conditions would include disruption in existing available habitat. Human health effects in the short term would be no different than those already caused by the remedial action.

Engineering Implementability, Reliability, and Constructability, and Technical Feasibility

Restoration to existing grades and/or grading stable slopes of open water areas is anticipated to be easily implemented in conjunction with the same perimeter and flow controls which may be utilized as part of a remedial action. No special construction constraints or technical feasibility issues are anticipated. As the geomorphic condition of the wetlands, ditch, and banks of the river is presently stable, no reliability issues are anticipated in the restoration to existing conditions other than any which may presently exist.

Cost

The estimated cost of Alternative 2 is approximately $116,000. Costs of restoring back to existing conditions are associated with cover crops seed, erosion control, and fill materials used to return excavation to existing grade. Fill material may be recycled overburden from the project site, a nearby borrow area, or clean material produced through particle segregation of sediments removed as part of the remedial action. Costs also include educational signage. Costing details are presented in Appendix F.

9.2.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

This restoration alternative may have negative impacts on aesthetics; however, no recreational, boating, water surface, or other associated impacts are anticipated aside from those which may arise from the remedial action itself.

9.3 EVALUATION OF RESTORATION ALTERNATIVE 3: RESTORATION TO PRE-REMEDIAL CONDITIONS WITH NATIVE SPECIES

9.3.1 Description

Alternative 3, restoring the Site to pre-remedial conditions with native species plantings, includes site grading within the remedial footprint to provide a combination of open water, marsh, and wetland habitats. Native species plantings would include a diverse wetland seed mix including aggressively spreading species to reduce the risk of invasive species recolonization, installation of plugs of aquatic and wetland species within the littoral zone of open water areas, and installation of containerized wetland shrubs and trees in restored areas. Maintenance of the native species plantings, including control of invasive species, will be required to some extent in this alternative. Additional site enhancements would include education signage at public access points as well as along constructed access trails (approximately 3-ft-wide footpaths) to the interior of the restoration area. Footpaths would consist of vegetated, mounded earthen material at an elevation slightly above existing wetland elevations, obtained from cut/fill and site grading activities, and would be graded to a stable slope on each side. Brush piles, if available, would be placed within the wetland area to provide cover for wildlife.

Additional enhancements in materials and grading compared to Alternative 1 would improve habitat conditions in those areas. The limit of restoration would be the footprint of the remedial action. A conceptual drawing presenting the implementation of restoration Alternative 3 is presented in Appendix E.

9.3.2 Evaluation of Threshold Criteria

Compliance with Permits and Applicable Regulatory Requirements

No additional permitting requirements are anticipated for this restoration alternative, beyond the permitting requirements associated with the remedial actions.

9.3.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

Restoration with enhancements would have no significant impacts on human health. It is anticipated that the removal of contaminated substrates and/or replacement with clean substrates may effectively manage residual contamination below the clean-up threshold. Self-recovery would be expedited, as compared to a no-action alternative. A goal of this alternative would be a long-term increase in habitat functions and values.

Short-Term Effectiveness in Protecting Human Health and the Environment

Short-term impacts of restoration with enhancements would cause a disruption in existing available habitat. Human health effects in the short term would be no different than those already caused by the remedial action.

Engineering Implementability, Reliability, and Constructability, and Technical Feasibility

Implementability and Constructability: Restoration to existing grades and/or grading stable slopes of open water areas and creation of access trails is anticipated to be easily implemented in conjunction with the same perimeter and flow controls which may be utilized as part of a remedial action. No special construction constraints or technical feasibility issues are anticipated.

Reliability: Long-term success of native species in the restored areas depends heavily on a strong initial seed germination and establishment of root systems of plugs, shrubs, and trees. Environmental conditions such as heat and precipitation will be critical within the first couple years to support strong native species growth and establishment in order to reduce the risk of invasive species recolonization. The reliability of long-term establishment of a native vegetation community within restored areas is, however, still questionable without periodic maintenance. Footpaths would consist of mounded earthen material created from cut/fill and other grading activities as part of the remedial actions. These mounds would be graded to stable slope and therefore there are no reliability concerns.

Cost

The estimated cost of Alternative 3 is approximately $798,000. This includes the cost of native seed, plugs, shrubs and trees, brush and other wildlife cover, erosion control, and educational signage. Brush piles as well as fill material for footpaths may be recycled overburden from the project site, or clearing and grubbing material. Costing details are presented in Appendix F.

9.3.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

This restoration alternative is expected to have positive impacts on aesthetics, and no negative recreational, boating, water surface, or other associated impacts are anticipated aside from those which may arise from the remedial action itself.

9.4 EVALUATION OF RESTORATION ALTERNATIVE 4: RESTORATION OF NATIVE HABITATS IN REMEDIAL AREAS

9.4.1 Description

Alternative 4, restoring the Site with native habitats within the footprint of remedial actions, would involve creation of a variety of open water ponds and channels, marsh, and wetland habitats through incorporation of a variety of topographic relief such as shallow depressions with minor ridges and mounds (i.e., microtopography) using ±0.5-ft elevation changes. Microtopographic relief provides a greater diversity of habitats characterized by the degree of soil saturation and the range of vegetation types adapted to those conditions. Open water channels would be constructed between open water areas (potentially including the Fire Suppression Ditch) to increase connectivity of habitats located within the interior of the restoration area as well as with the Muskegon River.

Revegetation of restoration areas would include a single season application of an herbicide prior to seeding to control re-establishment of invasive species, seeding of an aggressive native wetland seed mix, installation of aquatic and wetland plugs, and installation of containerized wetland shrubs and trees. The application of herbicides may extend the timeframe for establishment of native species as compared to alternatives without herbicide application. This alternative also uses erosion control matting on contoured slopes of ponds and open water channels, creation of footpath access trails, interactive educational signage, and introduction of woody debris and other wildlife cover/perching sites, if available. A conceptual drawing presenting the implementation of restoration alternative 4 is presented in Appendix E.

9.4.2 Evaluation of Threshold Criteria

Compliance with Permits and Applicable Regulatory Requirements

No additional permitting requirements are anticipated for this restoration alternative, beyond the permitting requirements associated with the remedial actions.

9.4.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

Restoration with native habitats would have no significant impacts on human health. It is anticipated that the removal of contaminated substrates and/or replacement with clean substrates may effectively manage residual contamination below the clean-up threshold. Self-recovery would be expedited, as compared to a no-action alternative. A goal of this alternative would be a long-term increase in habitat functions and values.

Short-Term Effectiveness in Protecting Human Health and the Environment

Short-term impacts of restoration with native habitats would cause a disruption in existing available habitat. Human health effects in the short term would be no different than those already caused by the remedial action.

Engineering Implementability, Reliability, and Constructability, and Technical Feasibility

Implementability and Constructability: Restoration to existing grades and/or grading stable slopes of open water areas and creation of access trails is anticipated to be easily implemented in conjunction with the same perimeter and flow controls which may be utilized as part of a remedial action. No special construction constraints or technical feasibility issues are anticipated. Potentially, the need for specialized grading equipment would be required if grading equipment used for remedial actions could not create the microtopographic contours required for the diversity of proposed habitats. Although this equipment is specialized, it is readily available and could be operated by specialized contractors.

Reliability: Long-term success of native species in the restored areas depends heavily on a strong initial seed germination and establishment of root systems of plugs, shrubs, and trees. Environmental conditions such as temperature and precipitation will be critical within the first couple years to support strong native species growth and establishment in order to reduce the risk of invasive species re-colonization. The reliability of long-term establishment of a native vegetation community within restored areas is, however, still questionable without periodic maintenance. Reliability of a native vegetation community within restored areas is greater than the previous alternatives due to the single-season application of an herbicide prior to re-vegetation. Footpaths would consist of mounded earthen material created from cut/fill and other grading activities as part of the remedial actions. These mounds would be graded to stable slope, covered with erosion control matting, and therefore there are no reliability concerns.

Cost

The estimated cost of Alternative 4 is approximately $1,543,000. This includes the cost of herbiciding, and cost for seed, shrubs and trees, erosion control matting, signage, and wildlife cover/perching sites. This material may be recycled overburden from the project site, or clearing and grubbing material. Costing details are presented in Appendix F.

9.4.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

This restoration alternative is expected to have positive impacts on aesthetics, and no negative recreational, boating, water surface, or other associated impacts are anticipated aside from those which may arise from the remedial action itself.

9.5 EVALUATION OF RESTORATION ALTERNATIVE 5: FULL SITE RESTORATION

9.5.1 Description

Alternative 5, full restoration of the Site, includes a combination of new open water habitats, open water channels, and a variety of wetland flooding regimes incorporating microtopography throughout the project site in addition to remediated areas, where feasible. Another major component of this alternative includes restoration of the Fire Suppression Ditch to either a naturalized stream channel or wetland habitat and construction of alternative sources of hydrology for the restored wetlands (e.g., bifurcated open water/channel system created through cut/fill).

Water supply for the current operations in the upland portion of the former Zephyr Refinery would be provided through a newly designed network of open water reservoirs that would increase water capacity as well as improve ecological value. A site-specific invasive species control plan would be developed for the Site that would describe applications of an herbicide prior to seeding as well as seasonally for approximately 5 years and would be used to help control re-establishment of invasive species. Additional site enhancement activities would include interactive educational signage, and creation of footpaths and/or low profile timber boardwalks to open water features and/or other points of interest. Artificial nesting boxes or structures to provide wildlife cover, perching, and nesting sites would be installed to improve wildlife habitat. A conceptual drawing presenting the implementation of restoration alternative 5 is presented in Appendix E.

9.5.2 Evaluation of Threshold Criteria

Compliance with Permits and Applicable Regulatory Requirements

No additional permitting requirements are anticipated for this restoration alternative, beyond the permitting requirements associated with the remedial actions.

9.5.3 Evaluation of Balancing Criteria

Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving Remedial Action Objectives

Full site restoration would have no significant impacts on human health. It is anticipated that the removal of contaminated substrates and/or replacement with clean substrates may effectively manage residual contamination below the clean-up threshold. Self-recovery would be expedited, as compared to a no-action alternative. A goal of this alternative would be a long-term increase in habitat functions and values.

Short-Term Effectiveness in Protecting Human Health and the Environment

Short-term impacts of full site restoration would cause a disruption in existing available habitat. Human health effects in the short term would be no different than those already caused by the remedial action.

Engineering Implementability, Reliability, and Constructability, and Technical Feasibility

Implementability and Constructability: Restoration to existing grades and/or grading stable slopes of open water areas and creation of access trails is anticipated to be easily implemented in conjunction with the same perimeter and flow controls which may be utilized as part of a remedial action. No special construction constraints or technical feasibility issues are anticipated. Potentially, the need for specialized grading equipment would be required if grading equipment used for remedial actions could not create the microtopographic contours required for the diversity of proposed habitats. Although this equipment is specialized, it is readily available and could be operated by specialized contractors.

Reliability: Long-term success of native species in the restored areas depends heavily on a strong initial seed germination and establishment of root systems of plugs, shrubs, and trees. Environmental conditions such as temperature and precipitation will be critical within the first couple years to support strong native species growth and establishment in order to reduce the risk of invasive species re-colonization. A site-specific invasive species control plan to include multiple applications of herbicides will increase the likelihood that a native vegetation community would be established onsite. Footpaths would consist of mounded earthen material created from cut/fill and other grading activities as part of the remedial actions. These mounds would be graded to stable slope, covered with erosion control matting, and therefore there are no reliability concerns. Timbered boardwalks would provide long-term stability and access throughout the Site.

Cost

The estimated cost of Alternative 4 is approximately $2,110,000. This includes the cost of herbiciding, and cost for seed, shrubs and trees, erosion control matting, signage, boardwalks, and wildlife cover/perching sites. Fill and natural cover material may be recycled overburden from the project site, or clearing and grubbing material. Costing details are presented in Appendix F.

9.5.4 Evaluation of Modifying Criteria

Stakeholder and Community Acceptance

This restoration alternative is expected to have positive impacts on aesthetics, and potential positive recreational, boating, water surface, or other associated benefits are anticipated aside from those which may arise from the remedial action itself.

10. RECOMMENDED REMEDIAL ALTERNATIVE AND RESTORATION OPTIONS

The recommended alternative for remediation of the Site is Alternative 2, Relatively Dry Excavation and Disposal of Sediments. This alternative incorporates relatively dry excavation, onsite truck transport of contaminated sediments, dewatering in an upland staging area, and offsite truck transport of sediments.

Alternative 2 will effectively remove sediments with contaminant concentrations exceeding PCUGs from the Site, and thus will protect human health and the environment, further decrease potential downstream transport of contaminated material, and ultimately support removal of BUIs. This alternative will also be highly implementable in the shallow-water environment of the Fire Suppression Ditch and surrounding wetlands. This alternative is recommended rather than Alternative 3, which includes mechanical dredging with onsite hydraulic transport, due to logistical concerns related to the large volume of water treatment required and the ability to utilize the onsite treatment system without pre-treatment. Alternative 2 is therefore the most efficient and effective alternative for meeting the RAOs for the project.

A restoration alternative will be selected during remedial design that will fulfill requirements for permitting and include property owner and stakeholder input.

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Figures

Document Path: L:\GIS\Data\Midwest\Michigan\Zephyr\MXD\Fire Supression Ditch\RAT\Mvatm\Fig 1-1 Site Location.mxd

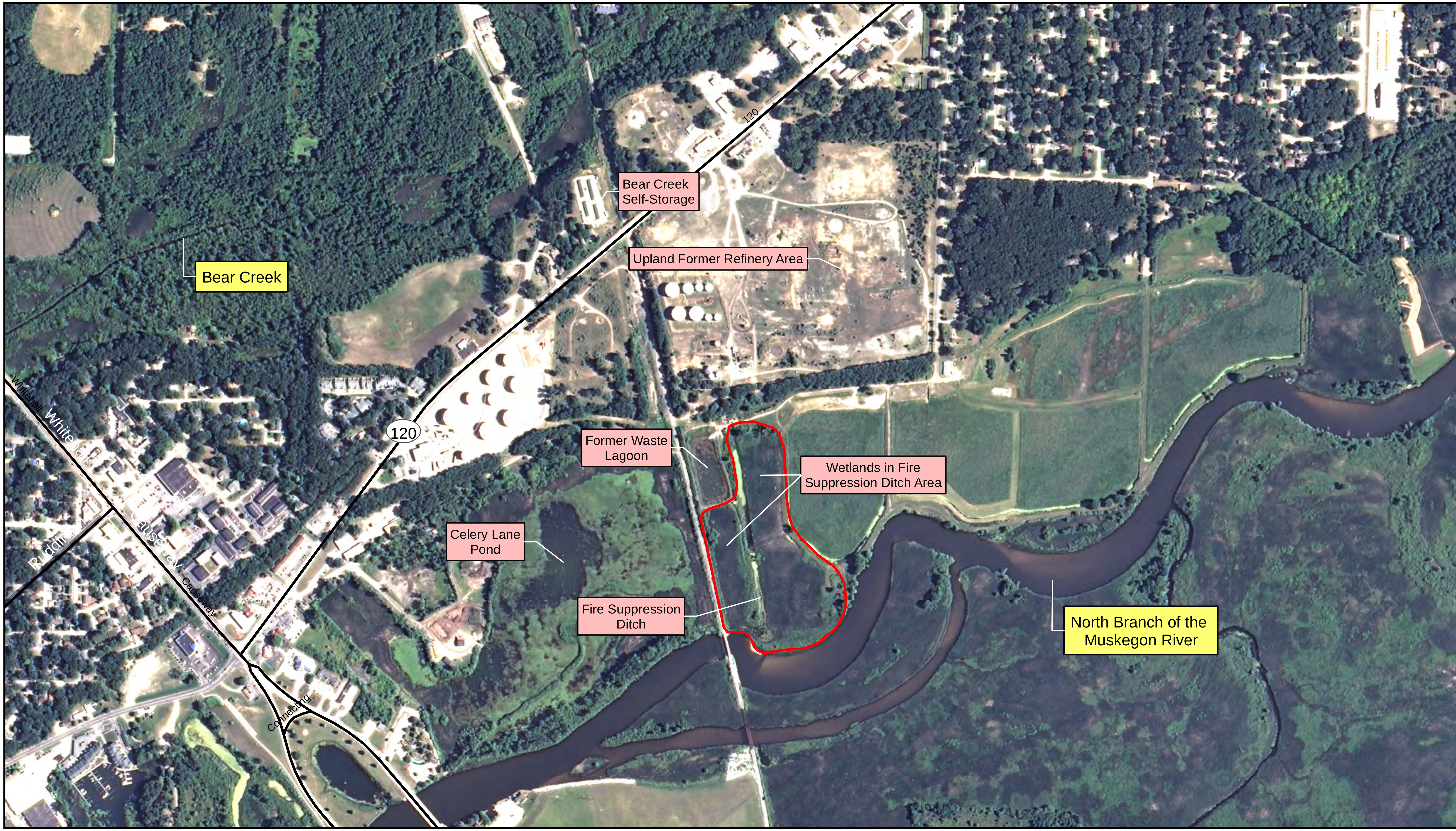
0 2,000 4,000
Feet

N

Feasibility Study
Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: ESRI Bing Maps

Figure 1-1
Site Location Map



Feasibility Study
Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2010 NAIP, USDA/FSA Aerial Photography Field Office, 2010.

LEGEND

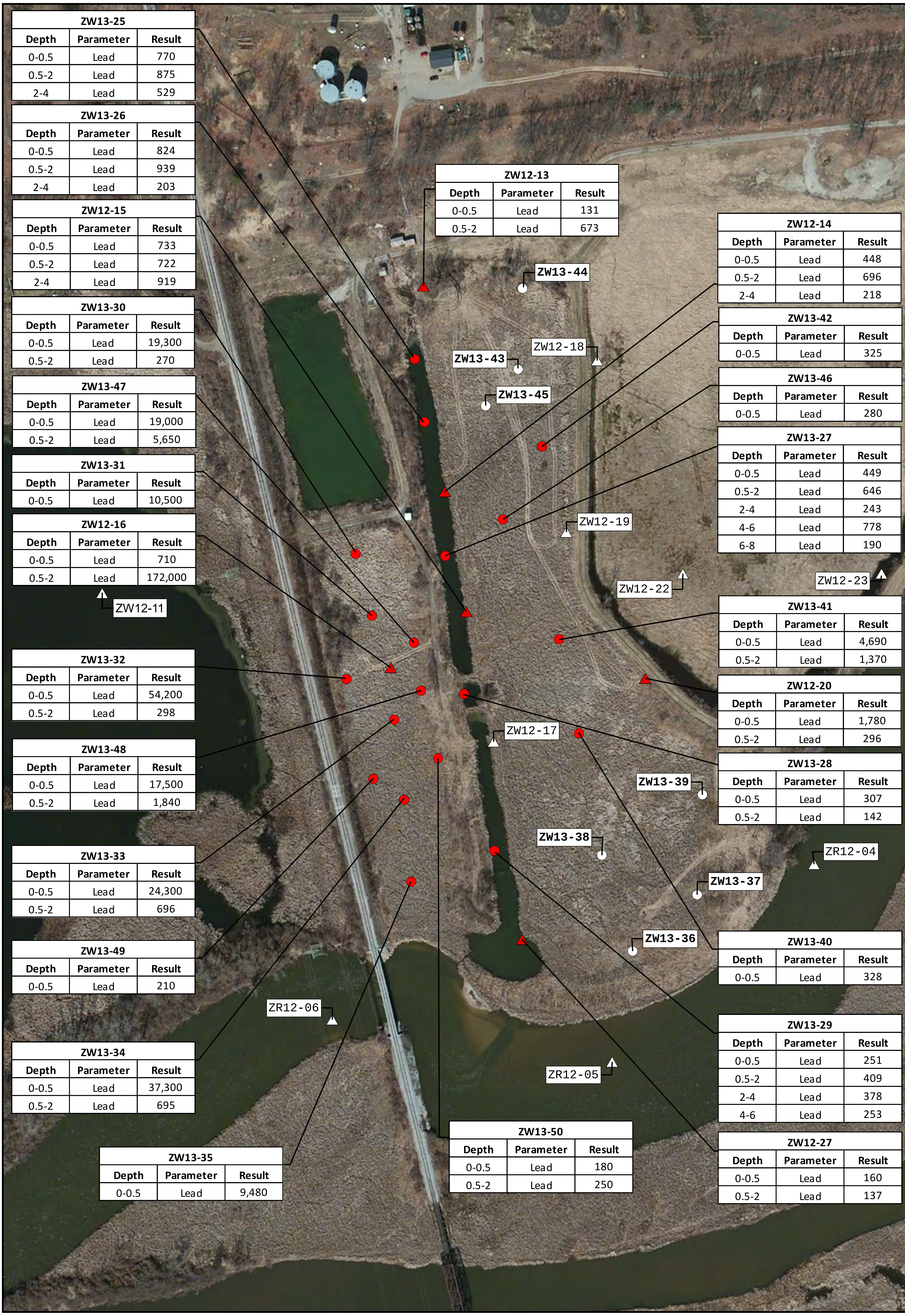
Former Fire Suppression Ditch Area (Site)

0 250 500
Feet

N

Figure 2-1
Site Features

Document Path: L:\GISData\Midwest\Michigan\Zephyr\MXD\Fire Supression Ditch\RATM\ratm\Fig 2-1 Site Features.mxd



ZW13-25

Depth	Parameter	Result
0-0.5	Lead	770
0.5-2	Lead	875
2-4	Lead	529

ZW13-26

Depth	Parameter	Result
0-0.5	Lead	824
0.5-2	Lead	939
2-4	Lead	203

ZW12-15

Depth	Parameter	Result
0-0.5	Lead	733
0.5-2	Lead	722
2-4	Lead	919

ZW13-30

Depth	Parameter	Result
0-0.5	Lead	19,300
0.5-2	Lead	270

ZW13-47

Depth	Parameter	Result
0-0.5	Lead	19,000
0.5-2	Lead	5,650

ZW13-31

Depth	Parameter	Result
0-0.5	Lead	10,500

ZW12-16

Depth	Parameter	Result
0-0.5	Lead	710
0.5-2	Lead	172,000

ZW13-32

Depth	Parameter	Result
0-0.5	Lead	54,200
0.5-2	Lead	298

ZW13-48

Depth	Parameter	Result
0-0.5	Lead	17,500
0.5-2	Lead	1,840

ZW13-33

Depth	Parameter	Result
0-0.5	Lead	24,300
0.5-2	Lead	696

ZW13-49

Depth	Parameter	Result
0-0.5	Lead	210

ZW13-34

Depth	Parameter	Result
0-0.5	Lead	37,300
0.5-2	Lead	695

ZW13-35

Depth	Parameter	Result
0-0.5	Lead	9,480

ZW12-13

Depth	Parameter	Result
0-0.5	Lead	131
0.5-2	Lead	673

ZW12-14

Depth	Parameter	Result
0-0.5	Lead	448
0.5-2	Lead	696
2-4	Lead	218

ZW13-42

Depth	Parameter	Result
0-0.5	Lead	325

ZW13-46

Depth	Parameter	Result
0-0.5	Lead	280

ZW13-27

Depth	Parameter	Result
0-0.5	Lead	449
0.5-2	Lead	646
2-4	Lead	243
4-6	Lead	778
6-8	Lead	190

ZW13-41

Depth	Parameter	Result
0-0.5	Lead	4,690
0.5-2	Lead	1,370

ZW12-20

Depth	Parameter	Result
0-0.5	Lead	1,780
0.5-2	Lead	296

ZW13-28

Depth	Parameter	Result
0-0.5	Lead	307
0.5-2	Lead	142

ZW13-40

Depth	Parameter	Result
0-0.5	Lead	328

ZW13-29

Depth	Parameter	Result
0-0.5	Lead	251
0.5-2	Lead	409
2-4	Lead	378
4-6	Lead	253

ZW13-50

Depth	Parameter	Result
0-0.5	Lead	180
0.5-2	Lead	250

ZW12-27

Depth	Parameter	Result
0-0.5	Lead	160
0.5-2	Lead	137

Figure 2-2
Lead Exceedances of PCUG
Fire Suppression Ditch

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: ESRI
Image Date: 03/13/2012

2013 Sample Results

- Sample Location
- Sample Location Exceeding PCUG

2012 Sample Results

- Sample Location
- Sample Location Exceeding PCUG

Note:
1) All results shown in mg/kg (milligrams per kilogram).
2) Only detected results ≥ PCUG are shown.
3) "PCUG" - preliminary clean up goal
4) PCUG for lead is 128 mg/kg

0 100 200
Feet

N

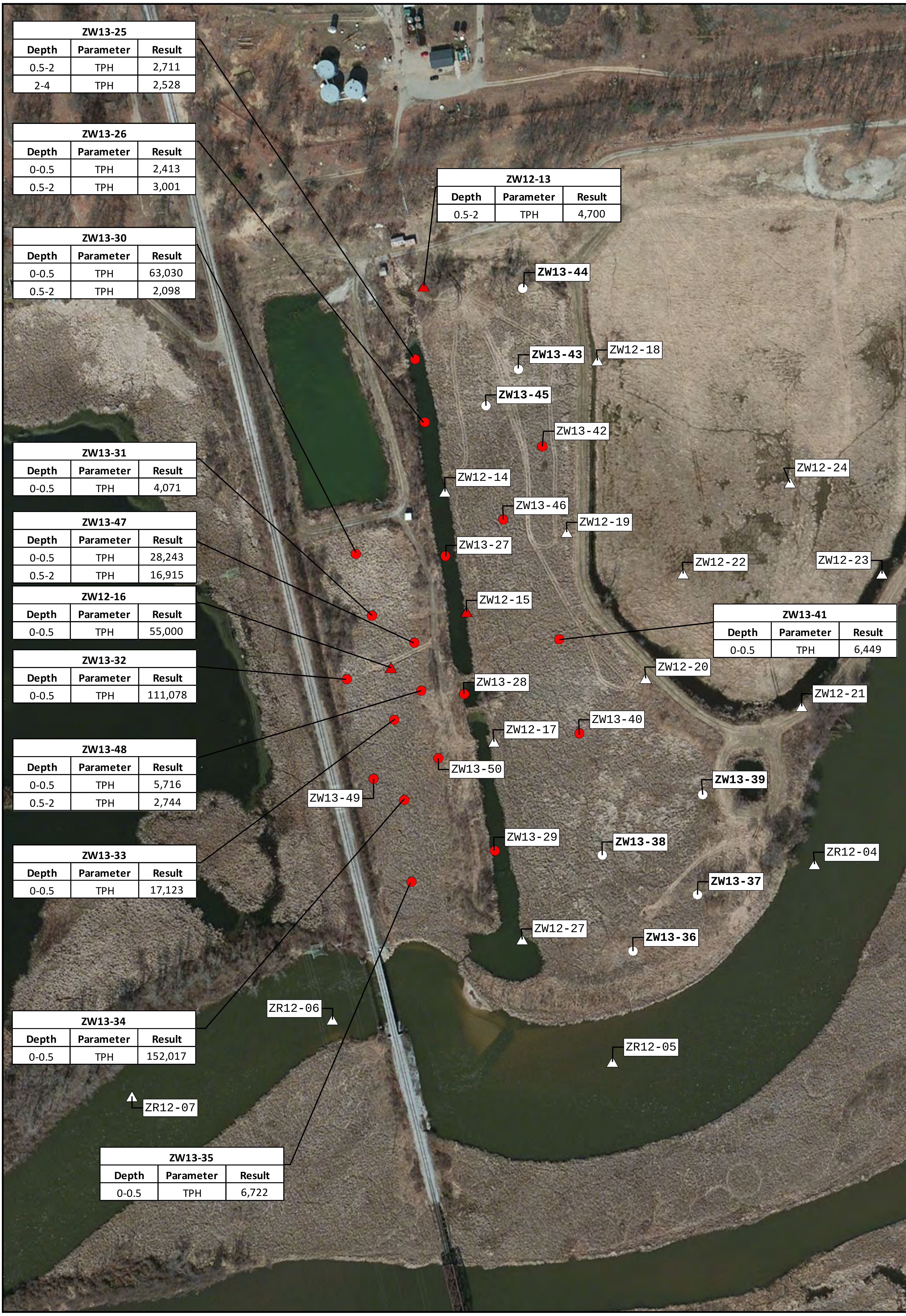


Figure 2-3
TPH Exceeding the PCUG
Fire Suppression Ditch

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: ESRI
Image Date: 03/13/2012

2013 Sample Results

- Sample Location
- Sample Location Exceeding PCUG

2012 Sample Results

- Sample Location
- Sample Location Exceeding PCUG

Note:
1) All results shown in mg/kg (milligrams per kilogram).
2) Only detected results ≥ PCUG are shown.
3) "PCUG" - preliminary clean up goal
4) TPH - Total Petroleum Hydrocarbons
5) PCUG for Total TPH is 2,000 mg/kg

0 100 200
Feet

N

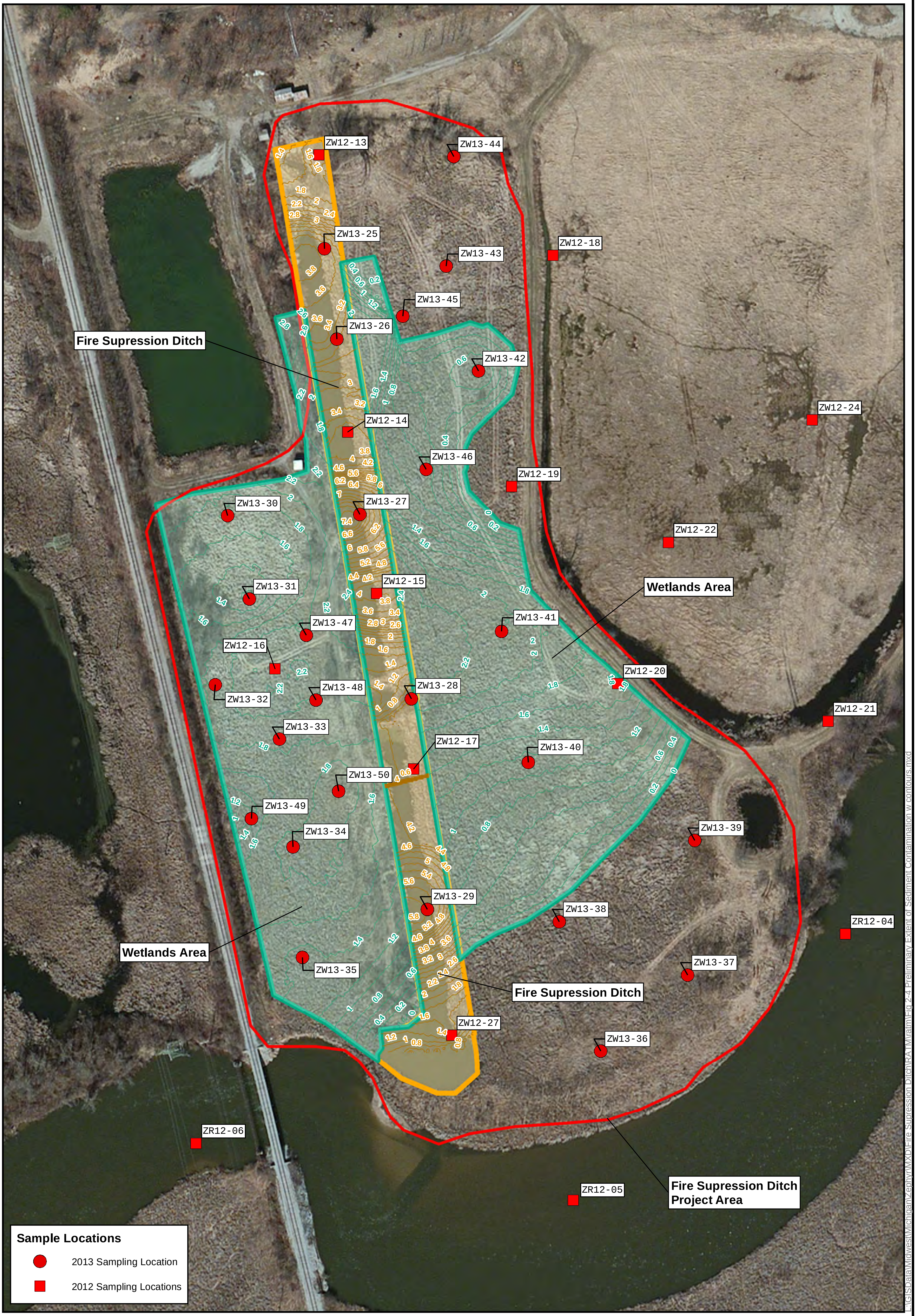


Figure 2-4
Preliminary Extent of Sediment Contamination
Fire Suppression Ditch Project Area

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2010 NAIP, USDA/FSA Aerial Photography Field Office, 2010.

LEGEND

Fire Supression Ditch Project Area

Extent of Contamination - Wetlands Area (Based on Preliminary Clean Up Goals)

Extent of Contamination - Fire Supression Ditch (Based on Preliminary Clean Up Goals)

Fire Supression Ditch Plume Depth Contour

Wetland Plume Depth Contour

0 125 250
Feet

N

Tables

Table 2-2 Estimation of Preliminary Removal Volumes and Disposal Weights
Remedial Alternatives Evaluation, Former Zephyr Refinery, Muskegon, Michigan

Removal Volume Source	Removal Volume Estimate (CY)	Rationale
Fire Suppression Ditch Removal Volumes		
Target Volume	9,704	Modeled using Environmental Visualization Software (EVS) based on lead and total petroleum hydrocarbons (TPH) exceedances of Preliminary Clean-Up Goal (PCUG) for benthos, which encompasses exceedances of other chemicals of concern (COCs).
Overburden Volume (not applicable)		
Contingency Associated with Core Recovery	1,941	Additional 20% of combined target and overburden based on an average of 80% recovery.
Volume Associated with Implementation/Cutline Geometry	1,941	Volume associated with middle section of ditch; material does not exceed PCUGs, but would have to be removed for logistics = ~20%
Vertical Overdredge	1,407	Based on 0.5-foot (ft) overdredge over 76,000 square feet
Horizontal Overdredge	0	Considered included in cutline geometry volume above.
Additional Area in pond (south end of ditch) not included in model	578	Volume associated with pond area at south end of ditch not included in model. Assumed 2-ft depth over 7,798-square-foot area based on result of location ZW12-27
Fire Suppression Ditch Removal Subtotal	**15,570**	**Ditch volume to be excavated, including overburden, target, overdredge, and material removed for logistics.**
Wetlands Removal Volumes		
Target Volume	20,593	Modeled using EVS based on lead and TPH exceedances of PCUG for benthos, which encompasses exceedances of other COCs.
Overburden Volume (not applicable)		
Contingency Associated with Core Recovery	3,089	Additional 15% of combined target and overburden based on an average of 85% recovery.
Volume Associated with vegetation/root mass	4,669	Volume associated with estimated 4 inches of vegetation/root mass over wetland area (382,000 square feet)
Vertical Overdredge	7,074	Based on 0.5-ft overdredge over 382,000 square feet
Horizontal Overdredge	222	Assumes a 1-ft buffer around the perimeter of the target volume (area = 3,000 square feet) to a depth of 2 ft.
Wetland Removal Subtotal	**35,647**	**Wetland volume to be excavated, including overburden, target, overdredge, and material removed for logistics.**
Total Removal Volume	**51,217**	**Combined *in situ* volume to be excavated, including overburden, target, overdredge, and material removed for logistics.**
Disposal Weight Source	**Disposal Weight Estimate (Tons)**	**Rationale**
Alternative 2 Disposal WeightFollowing Dewatering and Amendment Addition	**36,500**	Includes ~4 million gallons of water requiring treatment.
Alternative 3 Disposal Weight Following Dewatering and Amendment Addition	**29,700**	Includes ~35 million gallons of water requiring treatment.

TABLE 3-1 REMEDIAL AND PROCESS OPTIONS

Remedial Option	Technology	Description	Specific Technology/Process Options
No Action	None	No further actions to address contamination in sediment.	No processes associated with a No Action remedial option.
Monitored or Enhanced Natural Recovery	Monitored Natural Recovery	Monitor contaminant concentrations, with no other actions, to assess natural attenuation of contaminants by physical, chemical, and biological processes.	Long-term monitoring and assessment.
	Enhanced Monitored Natural Recovery	Placement of a layer of clean material to decrease exposure to contaminants through sediment burial.	• Direct mechanical placement of capping material. • Long-term monitoring and maintenance of cap integrity including potential institutional controls.
Containment	Sand Cap	Installation of a sand cap at the sediment surface with design parameters appropriate to minimize contact with and transport of contaminated sediments. Fabric could be installed under the cap to provide additional sediment stability.	• Direct mechanical placement of capping material. • Long-term monitoring and maintenance of cap integrity including potential institutional controls.
	Reactive Cap	Installation of a cap of reactive material at the sediment surface to both physically isolate contaminated sediments and chemically treat contaminants transported up through the cap.	• Direct mechanical placement of capping material. • Long-term monitoring and maintenance of cap integrity including potential institutional controls.
Sediment Removal	Excavation	Dewatering of the targeted area of contaminated sediments, likely using temporary barriers, followed by excavation of the sediments to be transported via truck or hydraulically to upland area for downstream processing. Sediments would be excavated down to a specified depth. Hydraulic transport would be facilitated by creating a slurry of the excavated sediment in a temporary central pit within the wetland areas.	• Dewatering of excavated sediment via gravity settling, geotextile tubes, and/or solidification. • Water treatment using a leased mobile wastewater treatment plant or the existing onsite treatment facility. • Transport and disposal of contaminated sediment via truck or rail to nearby municipal solid waste or Subtitle D landfill or in a constructed, upland capped disposal area located onsite. • Some degree of backfill using clean material may be required.
	Hydraulic Dredge	Pumping of contaminated sediments from the river bottom in a slurry and hydraulically transporting the sediment to upland area for downstream processing. Sediments would be dredged down to a specified depth.	• Dewatering of excavated sediment via gravity settling, geotextile tubes, or solidification • Water treatment using a leased mobile wastewater treatment plant or the existing onsite treatment facility • Transport and disposal of contaminated sediment via truck or rail to nearby municipal solid waste or Subtitle D landfill or in a constructed, upland capped disposal area located onsite • Some degree of backfill using clean material may be required
	Mechanical Dredge	Removal of contaminated sediments down to a specified depth using a marsh-type excavator, environmental dredge bucket, or long-reach excavators from perimeter roads and constructed access roads.	• Dewatering of excavated sediment via gravity settling and/or solidification. • Water treatment using a leased mobile wastewater treatment plant or the existing onsite treatment facility. • Transport and disposal of contaminated sediment via truck or rail to nearby municipal solid waste or Subtitle D landfill or in a constructed, upland capped disposal area located onsite. • Some degree of backfill using clean material may be required.

TABLE 3-2 TECHNOLOGY AND PROCESS OPTION SCREENING

Remedial Technology and Process Options	Description	Technical Feasibility	Implementability	Environmental Risk	Relative Cost	Public Acceptance	Screening Comment
Qualitative Ranking: Low = Unfavorable; Medium = Moderately Favorable; High = Favorable							
No Action							
No Action	No further actions to address contaminated sediment.	*High* . No action would be technically feasible as no actions would be completed.	*High* . No action would be implementable from a logistical and technical perspective as no actions would be completed.	*Low* . No action would not create short-term impacts to human health or the environment, but the level of contamination and exposure relative to current conditions would not be reduced and no action would not support the removal of beneficial use impairments.	*High* . No action would not incur any financial costs.	*Low* . No action is not expected to be acceptable to stakeholders and the community as it would not support the removal of beneficial use impairments in the Muskegon Lake Area of Concern.	**Retained for comparative purposes to other remedial technologies.**
Monitored or Enhanced Natural Recovery							
Monitored Natural Recovery (MNR)	Monitor contaminant concentrations, with no other actions, to assess natural attenuation of contaminants by physical, chemical, and biological processes.	*Low* . Additional studies would be required to better understand MNR processes. Biodegradative and burial processes to reduce contaminant exposure may not occur within an acceptable timeframe to support the removal of applicable beneficial use impairments within the Muskegon Lake Area of Concern.	*High* . Would only require the use of institutional controls with long-term monitoring and assessment.	*Low* . Contaminated sediment would remain in place. Would not create short-term impacts to human health or the environment, but the level of contamination and exposure relative to current conditions would not be reduced within an acceptable timeframe.	*High* . Costs would be minimal and would be associated with long-term monitoring and potential institutional controls.	*Low* . Expected to be unfavorable due to the unacceptable timeframe associated with MNR to support the removal of beneficial use impairments as well as required maintenance of potential institutional controls and long-term monitoring.	**Not retained due to unacceptable timeframe required for treatment and required monitoring.**
Enhanced MNR	Placement of a layer of clean material at the sediment surface to decrease exposure to contaminants through sediment burial in conjunction with MNR.	*Medium* . Additional studies would be required to better understand MNR processes. May not effectively reduce contaminant concentrations to acceptable levels to support the removal of applicable beneficial use impairments within the Muskegon Lake Area of Concern. Using a clean cover may have implications on the type of habitat restoration that can be implemented at the site and may be susceptible to erosion.	*High* . Placement of clean material in shallow environment is implementable and materials are readily available.	*Low* . Contaminated sediment would remain in place. Level of contamination and exposure relative to current conditions would not be reduced within an acceptable timeframe. May increase flooding risk.	*High* . Costs would be minimal and would be associated with long-term monitoring and potential institutional controls.	*Low* . Expected to be unfavorable due to the unacceptable timeframe associated with MNR to support the removal of beneficial use impairments as well as required maintenance of potential institutional controls and monitoring.	**Option is not retained as a primary technology; however, it is retained for further evaluation as a supporting technology.**
Containment Technologies							
Sand Cap	Installation of a sand cap at the sediment surface with design parameters appropriate to minimize contact with and transport of contaminated sediments. Fabric could be installed under the cap to provide additional sediment stability.	*Low* . May have limited effectiveness in isolating dissolved phase contaminants of potential concern or separate-phase liquids in the sediments, thus, not effectively reducing contaminant concentrations to acceptable levels to support the removal of applicable beneficial use impairments within the Muskegon Lake Area of Concern. The cap may have restrictions on the type of habitat restoration that can be implemented at the site.	*High* . Capping in shallow environment is implementable. Capping materials are readily available.	*Low* . Contaminated sediments would remain in place. Disturbance of the cap and/or underlying sediments could result in contaminant release. A sand cap may not limit exposure to an acceptable level. Could increase flooding risk.	*High* . Moderate initial costs associated with implementation followed by lower long-term monitoring and maintenance costs.	*Low* . Likely unfavorable due to concerns related to leaving contamination in place, long-term monitoring and maintenance requirements, and increased potential for flooding.	**Not retained due to unacceptable timeframe for removal of beneficial use impairments and long-term monitoring and maintenance requirements.**
Reactive Cap	Installation of a cap of reactive material at the sediment surface to both physically isolate contaminated sediments and chemically treat contaminants transported up through the cap.	*Medium* . The type of cap media would need to be carefully considered regarding the contaminants of interest, transport mechanisms, and local hydrology (groundwater flow) in order to support the removal of applicable beneficial use impairments within the Muskegon Lake Area of Concern. Ensuring long-term effectiveness would require monitoring of cap thickness and periodic maintenance. The cap may have restrictions on the type of habitat restoration that can be implemented at the site.	*Medium* . More difficult to install than a sand cap. Capping in shallow environment is implementable. Capping materials are readily available.	*Medium* . Would provide additional protectiveness relative to a sand cap as the reactive cap could be designed to contain dissolved-phase contaminants and separate-phase liquids, if present. Same deficiencies as the sand cap associated with leaving contaminated material in place, potential contaminant release due to cap disturbance, and risk of flooding.	*Medium* . Moderate to high initial costs associated with relatively expensive capping materials and installation procedures.	*Low* . Likely unfavorable due to concerns related to leaving contamination in place, long-term monitoring and maintenance requirements, and increased potential for flooding.	**Retained for further evaluation.**
Sediment Removal Technologies							

Remedial Technology and Process Options	Description	Technical Feasibility	Implementability	Environmental Risk	Relative Cost	Public Acceptance	Screening Comment
Excavation	Dewatering of the targeted area of contaminated sediments, likely using temporary barriers, followed by excavation of the sediments down to a specified depth.	*High* . Excavation is technically feasible as removal of impacted sediments would reduce contaminant concentrations to acceptable levels and would support the removal of applicable beneficial use impairments within the Muskegon Lake Area of Concern.	*High* . Excavation is implementable due to the shallow nature of the wetlands and fire suppression ditch; however, access to the soft substrate may be challenging. Would require construction of structures to divert water flow from the work area, and use of pumps to remove surface water and infiltrating groundwater. Haul roads are present and could be utilized (with possible improvements) to transport impacted sediments offsite for disposal. Excavation equipment is readily available in the vicinity of the site and the site is accessible to the equipment.	*High* . Would effectively decrease contaminant mass through removal, thus decreasing contaminant exposure throughout the area. Could achieve clean-up goals in a shorter timeframe than other technologies. Not as likely to resuspend contaminated sediments as with dredging; however, excavator equipment may disturb the sediments and mobilize separate-phase liquids (if present). Effectiveness could be slightly limited by the presence of residual contaminated sediments following excavation.	*Medium* . Initial costs associated with implementation, but no long-term monitoring or maintenance costs.	*High* . Due to permanent removal of contaminant material; potential concern regarding short-term disturbances related to increased traffic and noise, and habitat disturbance, all of which can be mitigated during the planning phase of the project.	**Retained for further evaluation.**
Hydraulic Dredge	Pumping of contaminated sediments in a slurry using hydraulic dredging equipment. Sediments would be dredged down to a specified depth.	*High* . Hydraulic dredging is technically feasible as removal of contaminated sediment would reduce contaminant concentrations to acceptable levels and would support the removal of applicable beneficial use impairments within the Muskegon Lake Area of Concern.	*Low* . May be difficult due to low water level limiting barge accessibility and the ability to hydraulically dredge. Area would need to be flooded to allow for dredge access.	*Medium* . Would effectively decrease contaminant mass through removal, thus decreasing contaminant exposure throughout the area. Flooding the area may create significant short-term and long-term risks by connecting the wetland areas to the adjacent river, potentially transporting contaminants downstream.	*Medium* . Initial costs associated with implementation, but no long-term monitoring or maintenance costs.	*Medium* . Due to permanent removal of contaminant material; potential concern regarding contaminant transport related to flooding the area, increased traffic and noise, and habitat disturbance, all of which can be mitigated during the planning phase of the project.	**Not retained for further evaluation based on implementability and potential risks due to implementation of remedy.**
Mechanical Dredge	Removal of contaminated sediments down to a specified depth using a marsh-type excavator, environmental dredge bucket, or long-reach excavators from perimeter roads and constructed access roads.	*Hig* h. Mechanical dredging is technically feasible as removal of contaminated sediment would reduce contaminant concentrations to acceptable levels and would support the removal of applicable beneficial use impairments within the Muskegon Lake Area of Concern.	*Medium* . Dredging may be difficult due to low water level limiting barge accessibility; however, using a marsh-type excavator may be a reasonable alternative and could allow for transfer of material to a barge in the adjacent river or to trucks for land transport and disposal. Marsh-type excavators or other amphibious equipment are readily available in the vicinity of the site and the site is accessible to the equipment.	*High* . Would effectively decrease contaminant mass through removal, thus decreasing contaminant exposure throughout the area. Dredging using a marsh excavator would cause temporary impacts to the local environment. Short-term impacts to the aquatic habitats would be associated with dredging activities and with resuspension of contaminated sediments into the water column.	*Medium* . Initial costs associated with implementation, but no long-term monitoring or maintenance costs.	*High* . Due to permanent removal of contaminant material; potential concern related to increased traffic and noise, and habitat disturbance, all of which can be mitigated during the planning phase of the project.	**Retained for further evaluation.**
Associated Process Options							
Dewatering							
Gravity Settling	Transport of removed sediments to a nearby lined area where dewatering occurs through settling. Water would be pumped out as the sediment settles.	*High* . Gravity settling to remove water from sediment is a feasible process option as it is a proven and effective dewatering option for sediment.	*High* . Will effectively dewater most sediment types assuming sufficient space and dewatering time is provided. Roads are present at the site, which may need minor enhancement to allow for transport of sediments to dewatering location in upland area.	*High* . Limited risk due to required staging/dewatering area which may cause local damage to vegetation. Slight risk to workers exposed to wastewater.	*High* . Gravity settling would likely be the most cost-effective dewatering option.	*High* . Potential concern regarding odor release during the dewatering process, which can be addressed during the planning phase of the project.	**Retained for further evaluation.**
Geotextile Tubes	Pumping of dredged sediment slurry into geotextile tubes, along with flocculant and/or coagulant, to promote dewatering. Water flows out of the thickened slurry, through the geotextile that composes the tube, leaving dewatered sediment within the tube.	*High* . The use of geotextile tubes to remove water from sediment is a feasible process option as it is a proven and effective dewatering option for sediment.	*High* . Will effectively dewater most sediment types assuming sufficient space to allow for this process. Slurry pits could be constructed in the areas being remediated for slurrying sediments for transport to geotextile tube staging area in upland portion of site via pumping.	*High* . Limited risk due to required staging/dewatering area which may cause local damage to vegetation. Slight risk to workers exposed to filtrate water.	*Medium* . Initial costs associated with implementation.	*High* . Potential concern regarding odor release during the dewatering process, which can be addressed during the planning phase of the project.	**Retained for further evaluation.**
Solidification	Addition of Portland cement or similar binding material to the sediment to promote dewatering of moist sediments and decrease the leachability of contaminants.	*High* . Using cement to reduce the water content of sediment is a feasible process option which will effectively dewater sediment if the sediments have relatively low water content.	*High* . Will effectively dewater most sediment types assuming sufficient space to allow for this process. Roads are present at the site, which may need minor improvements to allow for transport of sediments to dewatering/solidification location in upland area.	*High* . Limited risk due to required staging/dewatering area which may cause local damage to vegetation. Workers may be exposed to dust, which can be mitigated using silos and water spray. Solidification decreases the long-term environmental risk and it could improve the chemical properties of the sediment for disposal.	*Medium* . Initial costs associated with implementation.	*High* . Potential concern regarding odor release during the dewatering process, which can be addressed during the planning phase of the project.	**Retained for further evaluation.**
Onsite Sediment Transport for Downstream Processing							

Remedial Technology and Process Options	Description	Technical Feasibility	Implementability	Environmental Risk	Relative Cost	Public Acceptance	Screening Comment
Truck - Onsite	Using a truck to transport the contaminated sediment from the wetland to the upland area for downstream processing.	*High* . Transport of contaminated sediment via truck is a proven process option for sediment transport.	*Medium* . Access to the upland area is limited to a one-lane, unpaved two-track. The road would likely need minor improvements to allow for truck transport.	*Medium* . Would cause temporary impacts to the local environment due to construction of haul roads and truck traffic which may result in fugitive dust, which can be addressed during the planning process.	*High* . Relatively low cost as limited improvements to road onsite may be necessary.	*High* . Truck transport of the sediment from the removal location to the upland area for processing is expected to be favorable to the public.	**Retained for further evaluation.**
Hydraulic - Onsite	Pumping of contaminated sediments from the wetland or ditch bottom in a slurry using hydraulic dredging equipment to the upland area for downstream processing.	*High* . Hydraulic transport of contaminated sediment slurry is a proven process option for sediment transport.	*Medium* . Hydraulic transport would be implementable at the site, as ample space is available in the areas to be removed to allow for slurry pits to be utilized. Would be a more complex process than just trucking the material and would require transfer lines and pumps.	*Medium* . Would cause temporary impacts to the local environment due to potential tree clearing or vegetation disturbance along the pipeline route, but habitat will be restored following remedial activities.	*High* . Hydraulic transport is a cost-effective means to transport sediment.	*High* . Hydraulic transport is expected to be favorable to the public.	**Retained for further evaluation.**
Water Treatment							
Mobile Wastewater Treatment Plant	Recovered water from dewatering would be filtered and pretreated using a leased mobile wastewater treatment facility. The water would then be disposed of at a municipal wastewater treatment facility.	*High* . Mobile wastewater treatment plant is a feasible option to sufficiently remove contaminants and improve water quality to meet standards required for disposal.	*High* . Use of mobile wastewater treatment plant is implementable at the site due to the availability of land in the upland area.	*Medium* . Would cause temporary impacts to the local habitat due to staging and use; however, habitat will be restored following remedial activities.	*Medium* . Capital costs associated with implementation.	*High* . Potential concern regarding odor release during water treatment, which can be addressed during the planning phase of the project.	**Retained for further evaluation.**
Retrofitted, Onsite Treatment Facility	Recovered water from dewatering would be treated at the onsite treatment facility and discharged under the current permit.	*High* . Retrofitted, onsite treatment facility is a feasible option to sufficiently remove contaminants and improve water quality to meet standards required for disposal.	*Medium* . May require retrofitting of existing treatment facility to accommodate for the treatment of specific contaminants.	*High* . Use of the existing water treatment facility should cause very little damage to the surrounding area.	*High* . More cost-effective option assuming the infrastructure is suitable "as-is"—capacity is adequate for the quantity of water that will be produced and no major changes will be needed for additional treatment processes, etc.	*High* . Potential concern regarding odor release during water treatment, which can be addressed during the planning phase of the project.	**Retained for further evaluation.**
Sediment Disposal and Offsite Transport							
Offsite	Disposal of removed (excavated or dredged) sediments at an offsite facility via rail, truck, or barge.	*High* . Feasible disposal option for contaminated materials as multiple disposal facilities are located within reasonable distance of the Site.	*High* . Truck transport highly implementable; however, rail and barge transport are less viable options. Access to the Site via side street and onsite road.	*High* . Would permanently remove contaminant mass from the site. Some short-term disturbance due to construction of haul roads (if necessary) and truck traffic.	*Low* . High costs associated with transportation and disposal fees.	*High* . Due to permanent removal of contaminant mass from the site. Potential concern regarding increase in heavy truck traffic along the haul route(s) to disposal facility.	**Retained for further evaluation.**
Onsite	Disposal of removed (excavated or dredged) sediments in a constructed onsite facility.	*High* . Feasible disposal option for contaminated materials as space is available in the upland area and capping materials would be readily available.	*Medium* . Would require siting, permitting, construction, and monitoring of an onsite disposal facility. Would be dependent upon landowner and stakeholder approval and would require long-term maintenance and monitoring. Would decrease the requirements for transport of sediments to an offsite facility.	*Medium* . Would permanently contain contaminants in a landfill onsite. The facility would be designed to prevent any releases of contaminants and would be monitored to ensure that contaminants remain contained. Short-term disturbances due to construction of disposal facility.	*Medium* . Associated with construction and monitoring of the facility. Expected to be less expensive than offsite disposal due to savings on transportation and disposal fees.	*Low* . Due to keeping the contaminated material onsite for long-term storage. May not be favorable to the landowner.	**Not retained for further evaluation as not likely to be supported by landowner and requirements of long-term monitoring and maintenance not favorable.**
Truck - Offsite	Using a truck to transport the contaminated sediment from the wetland to the upland area for downstream processing.	*High* . Transport of contaminated sediment via truck is a proven process option for sediment transport.	*High.* Truck transport highly implementable	*High* . Would permanently remove contaminant mass from the site.	*High* . Relatively low cost as existing roadways would be used.	*High* . Truck transport of the sediment from the removal location to an offsite disposal facility is expected to be favorable to the public.	**Retained for further evaluation.**
Supporting Technologies							
Dredging Residuals Cover	Placement of a layer of clean material at the sediment surface in areas where residual contamination remains following dredging or removal activities or where other design criteria indicate it is warranted.	*High* . Technically feasible option to provide an extra layer of protectiveness and can be used to restore original grade. Using a residuals cover may have implications on the type of habitat restoration that can be implemented at the site and may be susceptible to erosion.	*High* . Placement of clean material in shallow environment is implementable and materials are readily available.	*High* . Provides extra level of protection following dredging activities. Unlikely to pose flooding risk if used to restore original grade and elevation.	*High* . Low cost relative to the primary remedial technologies.	*High* . Would provide extra level of protection following remedial activities.	**Retained for further evaluation.**

Remedial Technology and Process Options	Description	Technical Feasibility	Implementability	Environmental Risk	Relative Cost	Public Acceptance	Screening Comment
Monitoring	Long-term monitoring of contaminant concentrations in selected media (potentially including fish tissue, sediment, and water).	*Low* . Feasible method to assess changes in contaminant concentrations and exposure over time but does not support reduction of contaminant concentrations over time and would not support removal of beneficial use impairments .	*High* . Requires sample collection and analysis. Site is easily accessible for monitoring purposes.	*High* . Monitoring in conjunction with the primary remedial technologies provides confidence in remedial action selected and does not have any associated short-term or long-term risks.	*High* . Low cost relative to the primary remedial technologies.	*Low* . Long-term monitoring not in concert with a remedial technology would not promote reduction in contaminant concentrations or the removal of beneficial use impairments which would not be favorable.	**Retained for further evaluation.**
Habitat Restoration	Non-engineered instruments, such as administrative and legal controls that help to minimize potential human exposure to contamination. Also used to protect the integrity of a remedy such as a cap.	*High* . Institutional controls such as deed or access restrictions would effectively minimize potential human exposure to contaminants.	*High* . Controls such as deed or land use restrictions are implementable at the site.	*Medium* . Institutional controls would support long-term effectiveness of a remedy by minimizing disturbance of the remedy and contaminated sediments; however, no active remediation of contaminants would be completed.	*High* . Low cost relative to primary remedial technologies.	*Low* . Institutional controls likely in place when contamination not removed from the Site; therefore, likely that beneficial use impairments would remain in place which is not favorable.	**Retained for further evaluation.**
Institutional Controls	Non-engineered instruments, such as administrative and legal controls that help to minimize potential human exposure to contamination. Also used to protect the integrity of a remedy such as a cap.	*High* . Institutional controls such as deed or access restrictions would effectively minimize potential human exposure to contaminants.	*High* . Controls such as deed or land use restrictions are implementable at the site.	*Medium* . Institutional controls would support long-term effectiveness of a remedy by minimizing disturbance of the remedy and contaminated sediments; however, no active remediation of contaminants would be completed.	*High* . Low cost relative to primary remedial technologies.	*Low* . Institutional controls likely in place when contamination not removed from the Site; therefore, likely that beneficial use impairments would remain in place which is not favorable.	**Retained for further evaluation.**

Table 4-1
Remedial Alternatives Assembly Matrix

RA/Major RA Component	Removal				Water Diversion and Management		Sediment and Effluent Management											Transport & Disposal			Capping, and Covers and Monitoring[1]				Habitat Restoration	Institutional Controls
Process	**Excavation**		**Vegetation**	**Mechanical Dredging**	**Hard Structure**	**Water Mgmt.**	**Excavated Material Onsite Placement**		**Onsite Sediment Transport**		**Waste Segregation**		**Dewatering of Sediment**			**Wastewater Treatment**		**Transport Offsite**	**Disposal**		**Reactive Capping**		**Enhanced MNR**	**Residuals Covers**		**IC (Potential)**
Specific Technology/Process Option	**Excavation With Dewatering**	**Debris Removal via Grapple or Thumb Attachments**	**Vegetation Clearing, Grubbing**	**Fixed-Arm Long-Reach Marsh Excavator(s)**	**Hard Structure Such as Coffer dams, Including Inflatable Dams, Temporary Stone Dams, or Sheet Piling**	**Pumping to Control Water Levels and Flow Gradients**	**Placement of Excavated Material in Roll-Off Containers or Trucks**	**Placement of Excavated Material Into Bermed Area**	**Truck Transport or Truck Transport of Roll-Offs via Existing/Improved Roads to Upland Sediment Dewatering Area**	**Hydraulic Slurry Transport via Pump and Pipeline to Upland Sediment Dewatering Area**	**Excavator With Thumb or Grapple or Front-End Loader**	**Particle Segregation via Hydrocyclones, Screens, Tank Aeration**	**Dewatering Using Geotextile Tubes (With Polymer Addition) in a Lined, Bermed Area**	**Gravity Dewatering in Lined Bermed Area/Settling Basin/Roll-Off Box**	**Amendment Addition to Stabilize for Transport**	**Leased Wastewater Treatment Plant (Mobile Units / Processes)**	**Discharge Pretreated Water (From Leased Plant) to Existing MDEQ Wastewater Treatment Plant**	**Truck Transport**	**Landfill Offsite Disposal (Non-Hazardous)**	**Landfill Offsite Disposal (Hazardous: Lead > 5 mg/L TCLP)**	**Subaqueous Reactive Capping**	**Long Term Monitoring and Maintenance of Cap Integrity**	**Enhanced Monitored Natural Recovery**	**Erosion-Resistant Residuals Cover Using Granular Media and/or Other Materials**	**Habitat Restoration**	**Signage, Fencing, Use Restrictions Such as Limiting Acts of Penetrating Ground Cover**
Alternative Name																										
Alternative 1: No Action	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Alternative 2: Relatively Dry Excavation With Offsite Disposal with Residuals Cover	X	X	X	--	X	X	X	--	X	--	X	--	--	X	X	X	X	X	X	--	--	--	--	X	X	--
Alternative 3: Mechanical Dredging With Onsite Hydraulic Transport and Offsite Disposal	--	X	X	X	X	X	--	X	--	X	--	X	X	--	--	X	X	X	X	--	--	--	--	X	X	--

Notes:
1. These technologies are retained as reserved for possible use. Use of these will be based on confirmation sampling.
RA = Remedial Alternative

Table 4-2 Summary of Remedial Alternatives

Alternative 1 No Action	Alternative 2 Dry Excavation with Offsite Disposal	Alternative 3 Mechanical Dredging with Onsite Hydraulic Transport and Offsite Disposal
None	**Site Work** • Vegetation clearing and removal of root masses in wetland (grubbing) • Improve haul roads from excavation area to upland dewatering area. • Improve access areas to wetlands and ditch for removal and transport as necessary	**Site Work** • Vegetation clearing and removal of root masses in wetland (grubbing) • Improve haul roads from excavation area to upland dewatering area. • Improve access areas to wetlands and ditch for removal and transport as necessary
	Removal and Water Management • Dry excavation with long reach excavator • Coffer dam/sheet piling and pumping to control water level and allow for relatively dry excavation • Coffer dam/sheet piling to prevent collapse of banks along ditch during removal	**Removal and Water Management** • Mechanical Dredging via marsh excavator or marsh long-reach excavator, or similar low ground pressure equipment • Coffer dam/sheet piling at end of ditch to prevent downstream migration of contaminated sediment • Coffer dam/sheet piling to prevent collapse of banks along ditch during removal
	Sediment Handling and Processing • Vegetation and large-sized debris removal and segregation using excavator thumb or grapple attachments • Sediment placement into roll-off containers or trucks	**Sediment Handling and Processing** • Vegetation and large-sized debris removal and segregation using excavator thumb or grapple attachments • Construct slurry pit in removal areas, including piping and pumps • Pumps and piping for recycled water from dewatering area to slurry pits • Slurry sediments by mixing with water in slurry pits • Debris and coarse particle screening during slurrying • Sand separation by hydrocyclone, if needed
	Onsite Sediment Transport • Truck sediments (via roll-off or truck) to onsite dewatering area	**Onsite Sediment Transport** • Hydraulic pumping of slurry to onsite dewatering area or geotextile tubes
	Dewatering • Construct upland dewatering and staging area • Gravity dewatering in lined settling basin or within roll-offs • Amendment addition as a supplement to dewatering • Collection and transport of water to a leased pre-packaged treatment system	**Dewatering** • Construct upland dewatering and staging area • Dewatering via geotextile tubes with coagulant and flocculant polymer addition • Collection and transport of water to a leased pre-packaged treatment system
	Wastewater Treatment • Construction of wastewater treatment area and set up of leased pre-packaged treatment system. • Treatment of dewatering effluent, surface water, groundwater recharge water and stormwater via leased WWTP • Discharge of treated water through new National Pollutant Discharge Elimination System (NPDES) permit (may connect with current permitted discharge downstream of sampling points)	**Wastewater Treatment** • Construction of wastewater treatment area and set up of leased pre-packaged treatment system. • Treatment of dewatering effluent, surface water, groundwater recharge water and stormwater via leased WWTP • Discharge of treated water through new National Pollutant Discharge Elimination System (NPDES) permit (may connect with current permitted discharge downstream of sampling points)
	Offsite Transportation and Disposal • Offsite transport of material • Disposal of sediment at an offsite landfill facility	**Offsite Transportation and Disposal** • Offsite transport of material • Disposal of sediment at an offsite landfill facility
	Covers and Capping • Possible residuals cover for ditch sediment; possible backfill for wetland areas	**Covers and Capping** • Possible residuals cover for ditch sediment; possible backfill for wetland areas
	Restoration • Site restoration including haul road areas, disturbed vegetation, etc. • Habitat Restoration Option per Table 5-1	**Restoration** • Site restoration including haul road areas, disturbed vegetation, etc. • Habitat Restoration Option per Table 5-1

TABLE 5-1 HABITAT RESTORATION OPTIONS

Remediation Option	Restoration Option	Description (benefits to land use, habitat, and influence on BUI)	Specific Restoration Actions
No Action	No Action	No further actions to address contamination in sediment.	No processes associated with a No Action remedial option.
Monitored or Enhanced Natural Recovery	Native Vegetation Restoration and Invasive Species Control	• Option 1 (with Monitored Natural Recovery) - Native vegetation restoration/management including invasive species removal, without soil disturbance to increase wildlife habitat quality. Routine monitoring and maintenance to control reestablishment of exotics/invasives will be required. If feasible, species list to promote natural recovery of soils. Benefits include increased aesthetic and functional value of site. • Option 2 (with Enhanced Monitored Natural Recovery - Clean Cover Placement) - Restoration of a native scrub/shrub wetland vegetation community including invasive species removal, seeding and plantings within clean cover to increase wildlife habitat quality. Clean cover would require addition of organic material or other suitable topsoil. Benefits include increased native wetland vegetation diversity and therefore increased functional value and aesthetic value of site.	• Herbicide and mechanical (no soil disturbance) removal of invasive species. • Seeding (broadcast/hydro seeding if no clean cover or drill seeding within clean cover) of native herbaceous wetland species. • Varying degrees of public access (e.g., walking trail along river and through wetland vs. viewing/education outlook).
Containment	Marsh and Scrub/Shrub Restoration	Create microhabitats in conjunction with soil disturbance/capping activities to increase the amount and diversity of wildlife habitat. Removal of invasive species and re-vegetate with native plantings and seeding. Increased topographic relief will allow creation of permanent to ephemeral aquatic habitats, increase diversity of vegetation, and wildlife diversity. Benefits also include increased aesthetics and functional value of site.	• Herbicide and mechanical (e.g., tilling) removal of invasive species. • Planting of plugs and containerized shrubs and seeding of native herbaceous and woody wetland species. • Construction of microhabitats (e.g., vernal pools, uplands, and transition areas) using cut/fill. • Varying degrees of public access (e.g., walking trail along river and through wetland vs. viewing/education outlook).
Sediment Removal	Open Water and Marsh Complex	Creation of an open-water and marsh complex to increase quantity and diversity of wildlife habitat. Construction of additional open water features (e.g., approximately 0.5-1.5 acres each) either with direct (e.g., canal) or indirect (e.g., flood) hydraulic connections to the Muskegon River. Benefits include increased migratory waterfowl use of the site, potential recreational fishing/hunting opportunities, use of open water habitats by fish for spawning habitat. Open water features could serve as a reservoir to increase capacity of the Fire Suppression Ditch. Diversity of open water and marsh habitats will increase the diversity of wildlife and vegetation as well as improve aesthetic value of the site.	• Planting and seeding of native herbaceous and woody wetland species. • Planting submerged and emergent aquatic vegetation in open water habitats. • Include design elements specific for waterfowl viewing and/or hunting and for recreational fishing and boating opportunities. • Creation of microhabitats (e.g., vernal pools, uplands, and transition areas). • Varying degrees of public access (e.g., walking trail along river and through wetland vs. viewing/education outlook).

Table 5-2 Summary of Habitat Restoration Alternatives

Alternative 1 No Action	Alternative 2 Limited Restoration of Remediated Areas	Alternative 3 Restoration of Remediated Areas With Native Species	Alternative 4 Restoration of Native Habitats in Remediated Areas	Alternative 5 Full Site Restoration
None	**Surface Preparation of Disturbed Areas** • Seeding of temporary cover crop (e.g., fowl bluegrass [*Poa palustris*] and common oat [*Avena sativa*]) to stabilize soil until remaining seedbank and existing adjacent vegetation re-establishes • Application of straw mulch to reduce soil erosion	**Surface Preparation of Disturbed Areas** • Seeding of a native wetland species seed mix consisting of forbs and perennial grasses, sedges, and rushes that includes a temporary cover crop (e.g., fowl bluegrass and common oat) to stabilize soil until perennials/forbs become established after the first year • Application of straw mulch to reduce soil erosion	**Surface Preparation of Disturbed Areas** • Seeding of a native wetland species seed mix consisting of forbs and perennial grasses, sedges, and rushes that includes a temporary cover crop (e.g., fowl bluegrass and common oat) to stabilize soil until perennials/forbs become established after the first year • Application of straw mulch to reduce soil erosion • Installation of erosion control matting on contoured slopes of newly constructed ponds and open water channels	**Surface Preparation of Disturbed Areas** • Seeding of a native wetland species seed mix consisting of forbs and perennial grasses, sedges, and rushes that includes a temporary cover crop (e.g., fowl bluegrass and common oat) to stabilize soil until perennials/forbs become established after the first year • Application of straw mulch to reduce soil erosion • Installation of erosion control matting on contoured slopes of newly constructed ponds and open water channels
	Vegetation Plan • Natural re-establishment of plant species from adjacent undisturbed habitats or from existing seedbank of disturbed areas	**Vegetation Plan** • Wetland seed mix to include aggressively spreading species to reduce risk of invasive species re-colonization • Installation of plugs of native aquatic and obligate wetland species within the littoral zone of open water creation areas • Installation of containerized wetland shrubs (e.g., 2-3 gallon) and trees (e.g., 3-5 gallon) in restored areas (i.e., contoured slopes, open water margins, and trail margins)	**Vegetation Plan** • Single seasonal application of an herbicide prior to seeding to control re-establishment of invasive species • Wetland seed mix to include aggressively spreading species to reduce risk of invasive species re-colonization • Installation of plugs of native aquatic and obligate wetland species within the littoral zone of open water creation areas • Installation of containerized wetland shrubs (e.g., 2-3 gallon) and trees (e.g., 3-5 gallon) in restored areas (i.e., contoured slopes, open water margins, and trail margins)	**Vegetation Plan** • Multiple seasonal applications of an herbicide prior to seeding to control re-establishment of invasive species • Wetland seed mix to include aggressively spreading species to reduce risk of invasive species re-colonization • Installation of plugs of native aquatic and obligate wetland species within the littoral zone of open water creation areas • Installation of containerized wetland shrubs (e.g., 2-3 gallon) and trees (e.g., 3-5 gallon) in restored areas (i.e., contoured slopes, open water margins, and trail margins) • Implementation of a site-specific invasive species control plan for up to 5 years within restored portions of the site

Alternative 1 No Action	Alternative 2 Limited Restoration of Remediated Areas	Alternative 3 Restoration of Remediated Areas With Native Species	Alternative 4 Restoration of Native Habitats in Remediated Areas	Alternative 5 Full Site Restoration
	Landscape • Allow open water areas to remain where remediated soils were excavated (i.e., no fill) • Contour gradual slopes (e.g., 3:1) of excavated pits to promote vegetative growth in littoral zone	**Landscape** • Allow open water areas to remain where remediated soils were excavated (i.e., no fill) • Contour gradual slopes (e.g., 3:1) of excavated pits to promote vegetative growth in littoral zone	**Landscape** • Creation of new open water habitats/potholes and a variety of wetland flooding regimes by incorporating microtopography (e.g., ±0.5-foot [ft] elevation changes) within the footprint of excavated areas • Contour gradual slopes (e.g., 3:1) of excavated pits to promote vegetative growth in littoral zone • Construction of hydraulic connections between open water ponded areas in the form of open water channels that are either directly or indirectly connected with the Muskegon River and/or the existing Fire Suppression Ditch	**Landscape** • Creation of new open water habitats/potholes and a variety of wetland flooding regimes by incorporating microtopography (e.g., ±0.5-ft elevation changes) within and beyond the footprint of excavated areas • Contour gradual slopes (e.g., 3:1) of excavated pits to promote vegetative growth in littoral zone • Construction of hydraulic connections between open water ponded areas in the form of open water channels that are either directly or indirectly connected with the Muskegon River • Conversion of the existing Fire Suppression Ditch to a more natural channel shape and pattern or wetland habitat, and construction of an alternative source(s) for providing hydrology to the restored wetlands at the site (e.g. bifurcated open water/channel system created through cut/fill)
	Site Enhancements • Educational signage	**Site Enhancements** • Educational signage • Creation of 3- to 5-ft wide footpath access trails leading to open water features and/or other points of interest to encourage passive recreational opportunities (e.g., bird and wildlife watching, plant identification) • Introduction of brush piles to provide wildlife cover	**Site Enhancements** • Interactive educational signage • Creation of 3- to 5-ft wide footpath access trails leading to open water features and/or other points of interest to encourage passive recreational opportunities • Introduction of a variety of woody debris including brush piles, placed logs, and snags to provide wildlife cover and perching sites	**Site Enhancements** • Interactive educational signage • Creation of 3- to 5-ft wide footpath access trails and/or low profile timber boardwalks to open water features and/or other points of interest to encourage passive recreational opportunities • Introduction of a variety of woody debris including brush piles, placed logs, and snags, as well as artificial nesting boxes or structures to provide wildlife cover, perching, and nesting sites.

Table 8-1 Evaluation of Remedial Alternatives

Threshold Criteria		Balancing Criteria								Modifying Criteria		
Compliance With Permits and Applicable Regulatory Requirements		Long-Term Effectiveness in Protecting Human Health and the Environment and Achieving RAOs		Short-Term Effectiveness in Protecting Human Health and the Environment		Engineering Implementability, Reliability, Constructability, and Technical Feasibility		Cost		Stakeholder and Community Acceptance		
Rating	Rationale	Rating	Rationale	Rating	Rationale	Rating	Rationale	Rating	Estimate (Million $)	Rating	Rationale	Summary Rating
ALTERNATIVE 1: NO ACTION												
5	No permitting necessary as no actions completed	0	Would not offer additional protection relative to current conditions, would not prevent downstream transport of contaminants, and would not support removal of Beneficial Use Impairments.	4	Would not create short-term impacts to human health or the environment as no actions would be completed.	3	No action would be highly implementable from a logistical and technical perspective as no actions are taken.	5	$0	0	Not acceptable as no action does not achieve Remedial Action Objectives.	17
ALTERNATIVE 2: RELATIVELY DRY EXCAVATION WITH OFFSITE DISPOSAL												
5	Obtaining required permits for this alternative is expected to be highly feasible and would allow remedial activities to be performed in compliance with their requirements. Specific requirements include a joint U.S. Army Corps of Engineers (USACE)/Michigan Department of Environmental Quality (MDEQ) permit for construction activities in wetlands and a National Pollutant Discharge Elimination System (NPDES) permit for a leased water treatment system to allow for treatment of water generated during remedial activities and discharge to the Muskegon River.	5	Dry excavation with offsite disposal is expected to be the most effective technology for complete removal of sediments exceeding preliminary clean-up goals. This alternative would minimize onsite exposure risks and would be protective of human health and the environment by permanently and efficiently removing contaminated sediments for disposal at an offsite permitted facility. If combined with the use of a residuals cover, additional protectiveness would be available by further reducing exposure to benthic organisms and wildlife.	3	Short-term risks to human health and the environment including direct contact of workers with contaminants during sediment excavation, transport, and dewatering operations would be mitigated using personal protective equipment (PPE), site controls, and restoration activities following completion of the remedial action. Short-term environmental impacts during removal including suspension and transportation of contaminants in the ditch would be mitigated with the use of a cofferdam between the end of the ditch and the Muskegon River. Additional mitigation of resuspension effects would occur with dewatering of the ditch.	5	This alternative would be highly implementable in the shallow water environment of the ditch and wetland areas. It would produce a smaller volume of water for treatment with less dewatering time, but potentially larger material volume for offsite disposal than Alternative 3. Trucking some sediment from the excavation areas up to the dewatering facility at the staging area would require considerable trucking as compared to pipeline transport of Alternative 3.	4	$10.45	4	Likely Acceptable	26
ALTERNATIVE 3: MECHANICAL DREDGING WITH HYDRAULIC TRANSPORT AND OFFSITE DISPOSAL												
5	Obtaining required permits for this alternative is expected to be highly feasible and would allow remedial activities to be performed in compliance with their requirements. Specific requirements include a joint U.S. Army Corps of Engineers (USACE)/Michigan Department of Environmental Quality (MDEQ) permit for construction activities in wetlands and a National Pollutant Discharge Elimination System (NPDES) permit for a leased water treatment system to allow for treatment of water generated during remedial activities and discharge to the Muskegon River.	4	The long-term effectiveness of this alternative is expected to be similar to relatively dry excavation for removing sediments exceeding preliminary clean-up goals. Potential resuspension of contaminated materials and presence of residual contamination may occur as water will be left in the ditch during removal activities. If combined with the use of a residuals cover, additional protectiveness would be available by further reducing exposure to benthic organisms and wildlife.	3	Short-term risks to human health and the environment including direct contact of workers with contaminants during sediment excavation, transport, and dewatering operations would be mitigated using PPE, site controls, and restoration activities following completion of the remedial action. Short-term environmental impacts during removal including suspension and transportation of contaminants in the ditch would be mitigated with the use of a cofferdam between the end of the ditch and the Muskegon River. Slightly lower dewatered material volume for handling for disposal will slightly reduce short-term exposure to workers; however, water in the ditch and slurry pits for slurrying activities will increase short-term exposure to workers.	4	This alternative would be highly implementable in the shallow water environment of the ditch and wetland areas. It has greater technical complexity by requiring slurry activities and use of high solids pump with pipeline. Conversely, the large size of staging area available allows use of geotextile tubes for dewatering while larger water volume is addressed by the existing water treatment plant. The water volume would be reduced by recycling (recirculating) filtrate water from geotextile tubes to back to the ditch and slurry pits. This alternative would be expected to produce a smaller volume of material requiring offsite disposal by dewatering sediment within geotextile tubes.	4	$11.29	4	Likely Acceptable, although the more complex approach and greater volume of water for treatment may require additional outreach to the community to address concerns.	24

Note: Ratings are relative and intended to facilitate comparison of alternatives. 0 = worst; 5 = best.

Appendix B

Site Sampling Technical Memorandum

Site Sampling Technical Memorandum
Feasibility Study for
Remediation of Contaminated Sediments in the
Former Zephyr Oil Refinery Fire Suppression Ditch
Muskegon Lake Area of Concern, Muskegon, Michigan

Great Lakes Architect-Engineer Services
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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AOC	Area of Concern
AVS	Acid volatile sulfide
BUI	Beneficial use impairment
COC	Chemical of concern
CPT	Cone penetrometer testing
DRO	Diesel range organics
EA	EA Science and Technology and its affiliate EA Engineering, Science, and Technology, (MI) PLC
EPA	United States Environmental Protection Agency
ft	Foot (feet)
FS	Feasibility Study
FSAP	Field Sampling and Analysis Plan
GLNPO	Great Lakes National Program Office
GRO	Gasoline range organics
in.	Inch(es)
MATECO	MATECO Drilling Company
mg/kg	Milligram(s) per kilogram
MDEQ	Michigan Department of Environmental Quality
ORO	Oil range organics
oz	Ounce(s)
PEC	Probable effect concentration
PID	Photoionization detector
QAPP	Quality Assurance Project Plan
SEM	Simultaneously extracted metals
SQG	Sediment Quality Guideline
SSTM	Site Sampling Technical Memorandum
TCLP	Toxicity Characteristic Leaching Procedure
TEC	Threshold effect concentration
USACE	United States Army Corps of Engineers
USCS	Unified Soil Classification System

1. INTRODUCTION

EA Science and Technology and its affiliate EA Engineering, Science, and Technology, (MI) PLC[1] (EA), on behalf of the U.S. Environmental Protection Agency (EPA) Great Lakes National Program Office (GLNPO), has prepared this Site Sampling Technical Memorandum (SSTM) to describe the Fall 2013 sampling event of the Former Zephyr Oil Refinery Fire Suppression Ditch and adjacent wetlands, located within the Muskegon River Area of Concern (AOC), Muskegon, Michigan (Figure 1-1). This SSTM provides a preliminary assessment of the data that will be used to support the Feasibility Study (FS) for the Remediation of Contaminated Sediments.

1.1 SITE DESCRIPTION AND BACKGROUND

The Former Zephyr Oil Refinery is located in the Muskegon Lake AOC in Muskegon, Michigan (Figure 1-1). The Muskegon Lake AOC encompasses the entire 4,149-acre Muskegon Lake and a portion of its tributaries and watershed. The area was designated as a Great Lakes AOC in 1985 due to water quality and habitat problems linked to historical discharge of pollutants into the area. The entire Zephyr site encompasses the North Branch of the Muskegon River, Bear Creek, and the surrounding wetlands (Figure 1-2). State Highway 120 (Holton Road) separates the northern and southern portions of the Zephyr site. The site is situated on a groundwater divide where groundwater flow direction is to the north and south of the site. The North Branch of the Muskegon River drains the southern portion of the former refinery while Bear Creek drains the northern portion. This FS task order will focus only on the Former Fire Suppression Ditch and adjacent wetlands, located in the southern portion of the Zephyr site.

The Former Zephyr Oil Refinery Fire Suppression Ditch FS project area includes the Fire Suppression Ditch and adjacent wetlands in the area surrounding the Former Zephyr Oil Refinery which operated at this location for more than 40 years. Historical releases of petroleum, at times in excess of 150,000 gallons, to the Muskegon Lake watershed have impacted the sediment, groundwater, and wetlands surrounding the former refinery. The Former Fire Suppression Ditch provided operation water for the refinery that was used to put out fires (EPA 2013).

It is suspected that contamination from the site potentially may be contributing to the beneficial use impairments (BUIs) of Muskegon Lake AOC. The Muskegon Lake AOC Remedial Action Plan Team has identified the following BUIs for the AOC:

- Beach closings
- Restrictions on fish and wildlife consumption
- Eutrophication or undesirable algae
- Restrictions on drinking water consumption, or taste and odor
- Degradation of fish and wildlife populations

1 EA Engineering, Science, and Technology, Inc. does business as EA Science and Technology in the State of Michigan and EA is affiliated with EA Engineering, Science, and Technology (MI), PLC.

- Degradation of aesthetics
- Degradation of benthos
- Restrictions on dredging activities
- Loss of fish and wildlife habitat.

Based on discussion with EPA, BUIs of specific concern in the Former Zephyr Oil Refinery Fire Suppression Ditch FS project area are degradation of benthos, degradation of fish and wildlife populations, and loss of fish and wildlife habitat due to heavy metals and petroleum compounds in the sediment.

GLNPO conducted the Phase 1 site characterization to evaluate the nature and extent of impacts from groundwater to sediment under the Great Lakes Legacy Act in 2012 (EA 2012). The site characterization included a total of 243 sediment samples collected from 49 locations within Bear Creek, the North Branch of the Muskegon River, and the surrounding wetlands. Twenty-seven of the locations were located in the wetlands in the southern portion of the site. In addition, six groundwater monitoring wells were installed and four surface water samples were collected. Results of the initial site characterization are presented in the Assessment of Contaminated Sediments Site Characterization Report (EA 2012).

The initial site characterization report identified oil and grease, oil range organics (ORO), and diesel range organics (DRO) as the primary chemicals of concern (COCs), because they: (1) occurred most frequently, (2) were observed at elevated concentrations, and (3) are generally collocated with other analytes that exceeded the screening levels. Other analytes of concern in the Fire Suppression Ditch and adjacent wetlands included metals and gasoline range organics (GRO). The Fire Suppression Ditch, wetlands south of Bear Creek, and Celery Lane Pond (Figure 1-2) were identified as areas with known impacts that required further assessment.

This project, referred to as the Fire Suppression Ditch FS, will focus on activities discussed in the sections below and was performed in parallel with Phase 2 site characterization activities. Phase 2 activities were completed to further delineate the nature and extent of chemical contaminants in sediments in the wetlands south of Bear Creek and in Celery Lane Pond and adjacent wetlands. The results of the Phase 2 activities will be provided under separate cover.

1.2 PURPOSE AND OBJECTIVES

1.2.1 Project Objectives

Sediments in the Fire Suppression Ditch and adjacent wetlands have elevated concentrations of COCs as documented during the previous site investigation (EA 2012). Additional assessment of the Fire Suppression Ditch and adjacent wetlands was recommended following the Phase 1 investigation. The Phase 1 investigation also identified additional assessment of the Bear Creek Wetlands and Celery Lane Pond; however, assessment of these areas is a part of the Phase 2 activities and is not included in the FS activities.

Additional analytical, geotechnical, habitat survey, and wetland delineation data were collected and will be used in conjunction with data collected during the Phase 1 investigation (EA 2012) in development of the FS. The FS will consider habitat restoration alternatives and evaluate data to examine future remedial work to address impacted sediment.

The primary objective of this field investigation was to collect sufficient data from the Fire Suppression Ditch and adjacent wetlands to support an FS that will evaluate both contaminated sediment remedial alternatives and habitat restoration alternatives. In order to meet these objectives, the following data and samples were collected during the field investigation:

- Sediment samples for chemical and physical analysis;
- Sediment type, thickness, and data for empirical correlations to estimate engineering properties;
- Sediment dewatering evaluation using Calciment®;
- Waste characterization data;
- Aquatic and riparian habitat surveys; and
- Wetland delineation data (i.e., presence or absence of hydrophytic vegetation, wetland hydrology, and hydric soils).

1.2.2 Objectives of the Site Sampling Technical Memorandum

The purpose of the SSTM is to describe the sampling event including the number and location of samples, preliminary chemical and physical analysis unvalidated results, and preliminary maps of the sample locations. The report will also document deviations from the Quality Assurance Project Plan (QAPP) and FSAP (EA 2013a) along with any issues, concerns or problems encountered during data collection and analysis. The SSTM does not include any data interpretation.

2. SAMPLING NARRATIVE

The Fire Suppression Ditch FS sampling was conducted in several phases: core collection, core processing, *in situ* cone penetrometer testing (CPT), and wetland delineation. Work was performed in coordination with EPA and the Michigan Department of Environmental Quality (MDEQ). The investigations, including all sampling activities and analytical testing methods, were carried out in accordance with procedures outlined in the FSAP and QAPP (EA 2013a). Any modifications to the intended procedures are discussed in this section.

2.1 SEDIMENT CORE COLLECTION

Staging for the field effort took place at 1222 Holton Road, Muskegon, Michigan. Mobilization for the Zephyr Fire Suppression Ditch FS sediment sampling commenced on 29 September 2013. The core processing area was staged and sample collection was initiated on 30 September but stopped on 1 October 2013 due to the federal government shutdown. Equipment was stored at Bear Creek Storage for the duration of the shutdown. Demobilization commenced on 2 October 2013. Remobilization to the site was staggered and commenced on 3 through 4 November 2013. Sediment core collection commenced on 4 November 2013 and was completed on 8 November 2013. Core processing began 5 November 2013 and was completed on 9 November 2013. A total of 20 locations were successfully sampled using a Geoprobe® (Figure 2-1). MDEQ sampled 6 locations with a hand auger on 14 November, for a total of 26 sediment sample locations. At least one full core was collected from each location for physical and chemical analysis. More cores were required at some sample locations based on additional sample volume needs. Proposed locations were determined based on a spatial density analysis of the results from the 2012 site characterization (EA 2012). The proposed sample distribution was chosen to delineate horizontal impacts to sediments and provide sufficient data to complete FS objectives discussed in the QAPP (EA 2013a). Target and actual core locations are presented in Table 2-1.

Sample IDs included the location, Former Zephyr Oil Refinery Wetlands (ZW), year of sampling (13), location number, and the interval in feet (ft). Analytical samples were defined at 0 to 0.5 ft (-0001), 0.5 to 2 ft (-0102), and every 2 ft thereafter [2 to 4 ft (-0204), 4 to 6 ft (-0406), etc.] to the end of each core. For example, the analytical sample ZW13-01-0204 is the sample collected at location 01 from 2 to 4 ft.

The targeted sample depth from each location was defined in the QAPP (EA 2013a). Core lengths that extended 6 in. or less into the subsequent defined interval were included in the previous sample. Lengths that extended more than 6 inches (in.) were included in the subsequent interval. Actual core lengths are noted on the core logs included in Appendix A.

Sediment core samples were collected by a subcontractor, MATECO Drilling Company (MATECO), with oversight by EA personnel using a Geoprobe® 420M hydraulic push probe mounted on a Marsh Master®, a fully amphibious unit. The Geoprobe® system on the Marsh Master® consisted of an acetate core liner with an inside diameter of 3 in. and a length of 5 ft fitted into the Geoprobe® unit with a one-way valve at the top to retain sediment during retrieval and a plastic or stainless steel catcher inserted into the bottom of the core. At each location marked by the MATECO surveyor, sediment cores were collected by advancing the Geoprobe® rods through a tube/opening in the floor of the Marsh Master® to the bottom of soft sediment. Upon retrieval of the Geoprobe® rods, the acetate liner was removed from the Macro core sampler and capped at both ends, sealed and measured. Each core was labeled with the location number and direction of top and bottom of core. Multiple lengths of 5-ft-long core liners were advanced in order to attain the sample depth required by the FSAP (EA 2013a). Following collection of the sediment samples, the boreholes were abandoned by allowing the boreholes to naturally collapse.

A log of coring activities, sampling locations, water depths, and core recoveries was recorded in permanently bound logbooks in indelible ink. Personnel names, local weather conditions, and other information that impacted the field sampling program were also recorded. Each page of the logbook was numbered and dated by the personnel entering information. Copies of the field logbooks are provided in Appendix B.

Following collection, sediment cores were transferred to a refrigeration truck (cooled to 4 degrees Celsius) at the staging area. The cores were stored in the secured refrigeration truck until they could be processed.

2.2 CORE PROCESSING

Sediment sample processing was performed in a garage housing an onsite water treatment plant at 1222 Holton Road, Muskegon Michigan. At the processing facility, cores were split, logged, photographed, and target depth intervals were sampled in accordance with the FSAP and QAPP (EA 2013a). Core samples were homogenized by removing all material collected from the designated depth interval in a single core and mixing until consistency was uniform. GRO and simultaneously extracted metals (SEM) to acid volatile sulfide (AVS) ratio samples were collected before homogenization. Sediment samples were packaged and shipped in accordance with EA's standard operating procedures (EA 2013a). Lithologic and photographic logs of sediment cores are included in Appendix A and Appendix C, respectively.

Analysis of samples collected during FS field investigation activities were divided into two groups, the First Analysis Suite and the Second Analysis Suite. First Suite analyses were conducted immediately following collection of samples in the field and include: nature and extent characterization analyses; physical properties analyses; waste characterization; and a Sediment Dewatering Treatability Study. Second Analysis Suite samples were archived in a freezer at TestAmerica until after receipt of First Analysis Suite data. Following receipt of First Analysis Suite data and consultation with EPA and project stakeholders, a subset of frozen samples archived will be analyzed, if necessary. The Second Analysis Suite includes nature and extent characterization analyses and physical properties analyses. More details on which samples were collected for first and second analysis suites can be found in the FSAP (EA 2013a).

2.3 CONE PENETROMETER TESTING (CPT)

The CPT was performed following sediment sampling at four locations co-located with Geoprobe® sediment sampling locations. The CPT does not provide a sample, but includes information on soft sediment thickness. Its instrumentation is comprised of (1) load cells measuring tip resistance and sleeve friction, and (2) a pressure transducer measuring dynamic pore pressure that together provide empirical correlations for sediment type, shear strength, and other parameters.

2.4 WETLAND DELINEATION

Prior to initiating the field survey, a desktop review of relevant site-specific data was completed for the area of review, including available topographic maps, Natural Resources Conservation Service soil survey data, National Wetlands Inventory maps, aerial photographs, and other readily available documentation of the area of review. This information was used to assist in identification of potential wetlands and other waters of the United States within or adjacent to the site. Between 12 and 14 November 2013, EA's wetland scientists conducted onsite investigations of the area of review. Information pertaining to wetland evaluation and delineation was summarized in the Draft Wetland Delineation Report (EA 2013b).

2.5 DEVIATIONS FROM THE QAPP AND FSAP

The FSAP states that sampling locations will be surveyed by EA field personnel. However, through coordination with MATECO, it was determined surveying would be performed by MATECO personnel, in accordance with the same guidance referenced in the QAPP (EA 2013a). For samples located within the Fire Suppression Ditch, several of the target locations were within the banks of the ditch. These sample locations were relocated to the center of the ditch. Actual coordinates are presented in Table 2-1.

Based on coordination with MDEQ and EPA, six additional sample locations were added. MDEQ collected sediment samples from the following locations: ZW13-36, ZW13-37, ZW13-45, ZW13-46, ZW13-49, and ZW13-50 with a hand auger. MDEQ collected samples to 2 ft below ground surface and submitted two sediment samples from each location (0 to 1 ft and 1 to 2 ft) for percent solids, petroleum hydrocarbon fractions, and metal analysis. MDEQ sample results will not be undergoing data validation. In place of collecting samples at ZW13-36 and 37, EA sampled alternative locations ZW13-47 and ZW13-48. Analysis for ZW13-47 and ZW13-48 followed the proposed sampling scheme for ZW13-36 and ZW13-37, respectively.

In the FSAP, it was expected that MATECO would use 2-in.-diameter core liners. However, 3-in.-diameter core liners were used instead. Thus, the number of cores required for sufficient sample volume was less than expected for the analytical samples.

As discussed below in Section 3.1, due to poor sample recovery, the following samples were not collected: ZW13-26-1416, ZW13-25-0810, ZW13-25-1416, ZW13-32-0810, and ZW13-43-0810. In order to evaluate the effect of archiving on sample concentrations (if any), an archive duplicate was submitted for the following samples: ZW13-26-0406, ZW13-26-0608, and ZW13-29-0204.

The jar requirements provided in the FSAP (EA 2013a) were found to be inaccurate based on discussion with Somat Engineering and TestAmerica Laboratories, Inc. The jar requirement for the four geotechnical analyses were two 8-ounce (oz) jars total instead of two 8-oz jars for each of the four analyses. The jar requirement for the Toxicity Characteristic Leaching Procedure (TCLP) analysis was two 16-oz jars instead of the one listed in the FSAP (EA 2013a). In addition, for archived samples, the sample container was only filled two-thirds of the way in order to leave room for expansion during freezing.

GRO sample collection methodology was not described in detail within the FSAP. Samples submitted for GRO analysis were not homogenized. If an elevated photoionization detector (PID) reading was observed during screening of the sediment core, the 3 in. above and 3 in. below the elevated reading were sampled by scooping an equal amount over the 6-in. interval into the sample container, leaving no headspace. If there was no elevated PID reading, the length of the sampled interval was sampled by scooping an equal amount over the entire interval into the sample container, leaving no headspace.

3. RESULTS

This section provides a brief evaluation of the physical site characteristics and the contaminant distribution based on data collected during the Fall 2013 field investigation in the Fire Suppression Ditch and adjacent wetlands. The physical characteristics are based on the results of the grain size analysis and moisture content (percent solids), and on the lithology included in the field logging of the sediment cores. The lithology for each core is summarized on the boring logs located in Appendix A.

Sediment sample results were compared to the consensus-based threshold effect concentrations (TECs) and the probable effect concentrations (PECs) of the Sediment Quality Guidelines (SQGs) (MacDonald 2000), as available. For contaminants without an SQG, such as oil and grease and petroleum hydrocarbons, sample results that exceeded a range of values provided by GLNPO were mapped.

3.1 CORE RECOVERY

When core recovery was not sufficient (60 percent) additional cores were collected at the sample location. A summary of core collection is presented in Table 3-1. Sufficient core recovery was particularly difficult to achieve within the Fire Suppression Ditch. Generally, targeted penetration depths from the FSAP and sufficient recovery were achieved (EA 2013a). However, even with sufficient overall (to depth) core recovery, after several attempts sufficient core recovery in some of the 5-ft core lengths was not achieved and the following samples could not be collected: ZW13-26-1416, ZW13-25-0810, ZW13-25-1416, ZW13-32-0810, and ZW13-43-0810. Each of the samples that were not collected was from the bottom of a 5-ft length of core. Detailed lithographic descriptions of the 20 collected cores are presented in Appendix A.

3.2 ANALYTICAL SEDIMENT RESULTS

The number of samples submitted for analysis was pre-determined by EPA as discussed in the QAPP (EA 2013a). However, due to poor sample recovery, the total number of samples collected was less than the targeted amount (81 for immediate analysis and 45 for archive). A total of 121 sediment samples and 11 field duplicates were submitted for grain size, organic carbon, moisture content, GRO, DRO, ORO, oil and grease, and Michigan 10 metals plus nickel analyses. Only 78 sediment samples and 8 field duplicates were analyzed as part of the First Analysis Suite; 43 sediment samples and 3 field duplicates were archived (plus 3 archive duplicates). Eight samples plus one field duplicate from the top interval were submitted for SEM/AVS analysis; no SEM/AVS samples were archived (Table 3-2). The 12 MDEQ samples and 1 field duplicate were submitted for percent solids, petroleum hydrocarbon, and Michigan 10 metals analysis.

Detected concentrations of constituents were compared to TECs and PECs (MacDonald et al. 2000), as available. Analytical results are presented in Tables 3-3 through 3-6 and are summarized in the following sections by analytical group.

3.2.1 Grain Size, Total Organic Carbon, and Moisture Content

During sediment core processing, cores were split and logged prior to subsampling and homogenization. Photographs were taken of each core and the lithology was recorded on a core log form. Lithology of each core was performed by the same person in order to maintain consistency. Sediment core logs and photographic logs are provided in Appendix A and Appendix C, respectively.

A total of 121 sediment samples (43 for archive) were submitted for grain size, organic carbon, and moisture content analysis, and 12 MDEQ samples were submitted for percent solids. Analytical results are presented in Table 3-3. Half of the sediment samples were composed primarily (greater than 50 percent) of silt and clay and the other half of the sediment samples were composed primarily (greater than 50 percent) of sand. All but one sediment sample (ZW13-34-0001) was less than 5 percent gravel. Total organic carbon in the sediment samples ranged from not detected to 520,000 milligrams per kilogram (mg/kg), with a minimum detected concentration of 1,530 mg/kg. The moisture content in the sediment samples ranged from 16.6 to 1,009 percent. The percent solids ranged from 10.3 to 76.4 percent for MDEQ samples.

3.2.2 Petroleum Hydrocarbons

A total of 121 sediment samples (43 for archive) and 12 MDEQ samples were submitted for GRO, DRO, and ORO petroleum hydrocarbon fraction analyses. Petroleum hydrocarbon fractions results are presented on Figure 3-1 and in Table 3-4. For the Phase 1 site characterization, GLNPO provided the following values for petroleum hydrocarbon fractions to be used to identify spatial distribution and areas of potential concern: 100, 1,000, and 10,000 mg/kg, where exceedance of 10,000 mg/kg indicates a major exceedance. GRO was detected in 14 of 78 samples with concentrations ranging from 3.3 to 78 mg/kg. The maximum detection occurred in ZW13-32-0001, but the top three intervals from ZW13-25 also had elevated detections relative to other sample concentrations. However, none of the detected concentrations were greater than 100 mg/kg. GRO was not detected in any of the 12 MDEQ samples. DRO was detected in 59 of 78 samples with concentration ranging from 8 to 54,000 mg/kg. The maximum detection occurred in ZW13-32-0001, and the detected concentrations in ZW13-30-0001 and ZW13-34-0001 were also greater than 10,000 mg/kg. DRO was detected in 4 of the 12 MDEQ samples. Detected concentrations ranged from 120 to 210 mg/kg. The maximum concentration was detected in the 1 to 2 ft interval from ZW13-49. ORO was detected in 73 of 78 samples with concentrations ranging from 8.3 to 110,000 mg/kg. The maximum detection occurred in ZW13-34-0001. The detected concentrations in the top interval of ZW13-30, ZW13-32, and ZW13-33 and the top two intervals of ZW13-47 were also greater than 10,000 mg/kg. ORO was detected in 11 of the 12 MDEQ samples. Detected concentrations ranged from 160 to 1,600 mg/kg. The maximum concentration was detected in the 1 to 2 ft interval from ZW13-45. Each of the major exceedances for petroleum hydrocarbon fractions was located in the wetland west of the Fire Suppression Ditch.

3.2.3 Oil and Grease

A total of 121 sediment samples (43 for archive) were submitted for oil and grease analysis. Oil and grease results are presented in Figure 3-2 and Table 3-4. For the Phase 1 site characterization, GLNPO provided the following values for oil and grease to be used to identify spatial distribution and areas of potential concern: 1,000, 2,000, and 3,000 mg/kg, where exceedance of 3,000 mg/kg indicates a major exceedance. Oil and grease was detected in 66 of 78 samples with concentrations ranging from 35.5 to 132,000 mg/kg. The maximum detection occurred in ZW13-34-0001. The following samples also had detections exceeding 10,000 mg/kg: the top interval of ZW13-30 (field duplicate only), ZW13-32, and ZW13-33 and the top two intervals of ZW13-47. Each of these sample locations occurs in the wetland west of the Fire Suppression Ditch. The following samples exceeded 3,000 mg/kg (value given by GLNPO during Phase 1 to note major exceedances): the top interval of ZW13-31, ZW13-35, ZW-41, ZW-48, the second interval of ZW13-30, and the top two intervals of ZW-25, ZW13-26, and ZW13-27. Each of these sample locations, with the exception of ZW13-41, occurs in the Fire Suppression Ditch or the wetlands west of the Fire Suppression Ditch.

3.2.4 Metals

A total of 121 sediment samples (43 for archive) and 12 MDEQ samples were submitted for metals analysis. The following metals were analyzed: arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel (MDEQ samples not analyzed for nickel), selenium, silver, and zinc. Metals results are presented on Figure 3-3 and Table 3-5. Each of the metals exceeded the respective TEC (if available) in at least one sample. Five of the 8 metals (arsenic, copper, lead, mercury, and zinc) exceeded respective PECs in greater than 5 percent of the samples. For three metals (copper, lead, and zinc) at least one of the detected sample concentrations was greater than 10 times the PEC, indicating a major exceedance.

Arsenic was detected in each of the 78 sediment samples. Arsenic concentrations ranged from 0.65 to 52.9 mg/kg. The maximum detection occurred in ZW13-47-0001. Thirty-six percent of the arsenic sample concentrations exceeded the TEC and 6.4 percent exceeded the PEC. Each of the detections that exceeded the PEC was located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-31, ZW13-33, ZW13-34, and ZW13-47) or in the ditch itself (ZW13-25-0204). Arsenic was detected in 12 of 12 MDEQ samples. The detected concentrations ranged from 1.8 to 16 mg/kg. The maximum detection occurred in ZW13-45 1'. Five detections exceeded the TEC and no detections exceeded the PEC.

For barium, selenium and silver, there are no TECs or PECs for comparison. Barium was detected in 78 of 78 sediment samples. Barium concentrations ranged from 2.3 to 167 mg/kg. The maximum detection occurred in ZW13-25-0204. Selenium was detected in 66 of 78 sediment samples. Selenium concentrations ranged from 0.49 to 13.5 mg/kg. The maximum detection occurred in ZW13-34-0001. Silver was detected in 26 of 78 sediment samples. Silver concentrations ranged from 0.056 to 2 mg/kg. The maximum detection occurred in ZW13-32-0001. The maximum detections are located in the wetland west of the Fire Suppression Ditch or the ditch itself. Barium was detected in 12 of 12 MDEQ samples ranging from 8.9 to 100 mg/kg. Selenium was detected in 11 of 12 MDEQ samples ranging from 0.3 to 1.6 mg/kg. Silver was detected in 2 of 12 MDEQ samples and both detections were 0.1 mg/kg.

Cadmium was detected in 76 of the 78 sediment samples. Cadmium concentrations ranged from 0.023 to 4.6 mg/kg. The maximum detection occurred in ZW13-25-0102. Five of the cadmium sample concentrations (6.6 percent) exceeded the TEC and none exceeded the PEC. Each of the detections that exceeded the TEC was located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-32 and ZW13-47) or in the ditch itself (top three intervals of ZW13-25). Cadmium was detected in 7 of 12 MDEQ samples ranging from 0.2 to 0.7 mg/kg. Each of the detections fell below the TEC and PEC.

Chromium was detected in each of the 78 sediment samples. Chromium concentrations ranged from 1.4 to 58 mg/kg. The maximum detection occurred in ZW13-29-0204, which is in the Fire Suppression Ditch. The maximum detection was the only detection that exceeded the TEC. No detections exceeded the PEC. Chromium was detected in 12 of 12 MDEQ samples ranging from 3.3 to 28 mg/kg. Each of the detections fell below the TEC and PEC.

Copper was detected in each of the 78 sediment samples. Copper concentrations ranged from 0.36 to 398 mg/kg. The maximum detection occurred in ZW13-32-0001. Twenty-four percent of the copper sample concentrations exceeded the TEC and 6.4 percent exceeded the PEC. Each of the detections that exceeded the PEC was located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-31, ZW13-32, ZW13-33, ZW13-34 and ZW13-47). Copper was detected in 7 of 12 MDEQ samples ranging from 2.1 to 23 mg/kg. Each of the detections fell below the TEC and PEC.

Lead was detected in each of the 78 sediment samples. Lead concentrations ranged from 0.51 to 54,200 mg/kg. The maximum detection occurred in ZW13-32-0001. Fifty-eight percent of the lead sample concentrations exceeded the TEC, 45 percent exceeded the PEC, and 15 percent exceeded 10 times the PEC. With the exception of the top two intervals of ZW13-41, each of the detections that exceeded 10 times the PEC were located in the wetland west of the Fire Suppression Ditch (top interval of ZW13-30, ZW13-31, ZW13-32, ZW13-33, ZW13-34, and ZW13-35 and the top two intervals of ZW13-47 and ZW13-48). Lead was detected in 12 of 12 MDEQ samples ranging from 2.3 to 280 mg/kg. Half of the detections exceeded the TEC and one-third of the detections exceeded the PEC.

Mercury was detected in 56 of the 78 sediment samples. Mercury concentrations ranged from 0.0094 to 3.5 mg/kg. The maximum detection occurred in ZW13-33-0001. Thirty-three percent of the mercury sample concentrations exceeded the TEC and 7.3 percent exceeded the PEC. Each of the detections that exceeded the PEC was located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-32, ZW13-33, ZW13-34, and ZW13-48). Mercury was detected in 1 of 12 MDEQ samples at 0.1 mg/kg, which is less than the TEC.

Nickel was detected in 56 of the 78 sediment samples. Nickel concentrations ranged from 0.9 to 48.4 mg/kg. The maximum detection occurred in ZW13-29-0204. Ten percent of the nickel sample concentrations exceeded the TEC and none exceeded the PEC. Each of the detections that exceeded the TEC, with the exception of the top two intervals of ZW13-39, were located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-30, ZW13-32, ZW13-33, ZW13-34, and ZW13-47) or in the ditch itself (ZW13-29-0204).

Zinc was detected in 69 of the 78 sediment samples. Zinc concentrations ranged from 6.3 to 14,600 mg/kg. The maximum detection occurred in ZW13-25-0102. Eighteen percent of the zinc sample concentrations exceeded the TEC and 5.1 percent exceeded the PEC. The top three intervals from ZW13-25 exceeded 10 times the PEC. Each of the detections that exceeded the PEC were located in the wetland west of the Fire Suppression Ditch (top intervals of ZW13-30, ZW13-31, ZW13-32, ZW13-33, ZW13-34, and ZW13-47) or in the ditch itself (top three intervals of ZW13-25, ZW13-26-0001, ZW13-27-0406, ZW13-29-0102, ZW13-29-0204, and ZW13-29-0406). Zinc was detected in 12 of 12 MDEQ samples ranging from 8.1 to 85 mg/kg. Each of the detections fell below the TEC and PEC.

3.2.5 SEM/AVS

SEM/AVS results are presented in Table 3-6. A total of eight surface (0 to 0.5 ft) sediment samples and one field duplicate were submitted for SEM/AVS. For samples from the following locations, AVS was not detected, so the SEM/AVS ratio could not be calculated: ZW13-31, ZW13-33, ZW13-38, and ZW13-42. The SEM/AVS ratio for the following locations was greater than one: ZW13-33FD, ZW13-35, and ZW13-41. These results indicate that metals are bioavailable in a majority of the sampled locations. The SEM/AVS ratio for two samples was less than one, which indicates metals are not bioavailable at ZW13-25 and ZW13-27.

3.3 GEOTECHNICAL SEDIMENT RESULTS

In addition to the analyses noted above, EA collected sediment for geotechnical analyses for 39 of the sediment intervals following the sampling scheme in the FSAP (EA 2012). As noted in Section 4.1, ZW13-32-0810 was one of five samples not collected due to poor recovery; thus, no sediment was submitted for geotechnical analysis for this sample. The 39 sediment samples from discrete intervals were submitted for the following analyses: Unified Soil Classification System (USCS) classification, Atterberg limits, specific gravity, and organic matter. Two full core composite samples (ZW13-25-COMP and ZW13-31-COMP) were submitted for the same geotechnical analyses plus amendment addition and sediment dewatering testing, bulk density, grain size, moisture content, and waste characterization sampling. All geotechnical laboratory tests were performed in general accordance with applicable ASTM International procedures. For full geotechnical sediment results, see Appendix D.

3.3.1 USCS Classification

Classification per the USCS (ASTM D2487) is based on both the grain size analysis (ASTM D422) test results and Atterberg Limits (ASTM D4318) test results. Those tests were assigned to the two composite sediment samples (ZW13-25-COMP and ZW13-31-COMP) and therefore classification for those two composite samples was performed in accordance with the

USCS. The composite samples were silty sand (ZW13-25-COMP) and silty, clayey sand (ZW13-31-COMP).

For the sediment samples from discrete intervals, grain size analysis was completed by the analytical laboratory. Results of grain size analysis are presented in Section 3.2.1. Since the Geotechnical Laboratory (Somat Engineering, Inc.) did not complete grain size analysis for the discrete sediment samples, the classification was performed visually, per ASTM D2488.

3.3.2 Grain Size

Grain size analysis was performed on the two composite sediment samples. Both samples were approximately 75 percent sand and 25 percent fines. The results of the grain size analysis and the test photographs are presented in Appendix D.

3.3.3 Atterberg Limits

Atterberg Limits analysis was performed on all the sediment samples submitted to Somat Engineering. The results show that 6 of the 41 samples were non plastic while the other 35 samples had a plastic limit ranging between 13 and 323 with an average of 114. The results of the Atterberg Limit analysis tests and the test photographs are presented in Appendix D.

3.3.4 Specific Gravity

Specific gravity tests were performed on all the sediment samples submitted to Somat Engineering. The results show a specific gravity range of 1.50 to 2.73 mass per unit volume and an average of 2.30 mass per unit volume. The results of the specific gravity tests and the test photographs are presented in Appendix D.

3.3.5 Organic Matter

Standard test methods for moisture, ash, and organic matter were performed on all the sediment samples submitted to Somat Engineering. The organic matter ranged between 0.1 and 73.6 percent. The results are presented in Appendix D.

3.3.6 Amendment Addition and Sediment Dewatering

Sediment dewatering was evaluated in order to identify the appropriate amendment dose that achieves stabilized sediment for truck transport to a landfill. Calciment® was added to the two composite samples (ZW13-25-COMP and ZW-31-COMP) at different percentages for several treatments. Each treatment was tested via the Paint Filter Test to evaluate how well the free water is bound. Amendment tests with Calciment® on the ZW13-25-COMP sample required a high dose (32 percent amendment to dry matter ratio) in order to pass the paint filter test. Amendment addition with Calciment® on the ZW13-31-COMP sample was not needed to pass paint filter tests.

The composite sediment samples were tested after conditioning with polymers at a determined dosage using the GeoTube® procedure known as the Rapid Dewatering Test. The recommended polymers for GeoTube® applications are either Solve 9310 or Solve 216B in order to pass a paint filter test for subsequent removal and disposal.

For more information on the amendment addition and sediment dewatering tests and results, see Appendix D.

3.3.7 Bulk Density

The bulk density test was performed in accordance with ASTM D7263 for a re-compacted test specimen on the two composite sediment samples. The test results and test photographs are presented in Appendix D.

3.3.8 Moisture Content

Moisture content determination was performed per ASTM D2216 on the two composite sediment samples. The results of the moisture content tests are presented in Appendix D.

3.3.9 Waste Characterization

The two composite sediment samples were submitted for waste characterization analysis including: cyanide, flashpoint, free liquid, pH, and TCLP. The results are presented in Table 3-7 and were compared to established regulatory levels in 40 Code of Federal Regulations §§ 261.20-24 (2010), as available. There is no current regulatory level for cyanide, but it was not detected. The flashpoints of both sediment samples were greater than 180 degrees Fahrenheit, indicating that the sediment is not flammable. The ZW13-25-COMP sample tested positive for free liquid and the ZW13-31-COMP sample tested negative. The pH of both sediment samples is 7.3, which indicates the sediment is neutral, not corrosive. Each analyte detected in the TCLP was detected at a concentration below the regulatory level. Non-detected analytes had a detection limit less than the regulatory level. The waste characterization testing results indicate that the sediment samples were not hazardous.

3.4 CONE PENETROMETER TESTING RESULTS

The CPT was done at the following sample locations: ZW13-25, ZW13-27, ZW13-32, and ZW13-42, per the FSAP (EA 2013a). The logs for the CPT locations can be found in Appendix E.

3.5 WETLAND DELINEATION RESULTS

For the full results of the wetland delineation, refer to the Wetland Delineation Report (EA 2013b). The investigation found that there is a jurisdictional non-tidal wetland present within the area of review. However, the United States Army Corps of Engineers (USACE) is the federal agency that determines the official jurisdictional status of wetlands/waterways. The Wetland

Delineation Report (EA 2013b), including appendixes, should be submitted to USACE in order to obtain a preliminary or final Jurisdictional Determination. Furthermore, MDEQ, in addition to the federal government, has laws and regulations that govern impact to wetlands that will require authorization from both agencies if proposed remediation activities have the potential to affect these resources.

4. REFERENCES

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Subpart C – Characteristics of Hazardous Waste, 40 Code of Federal Regulations §§ 261.20-24 (2010).

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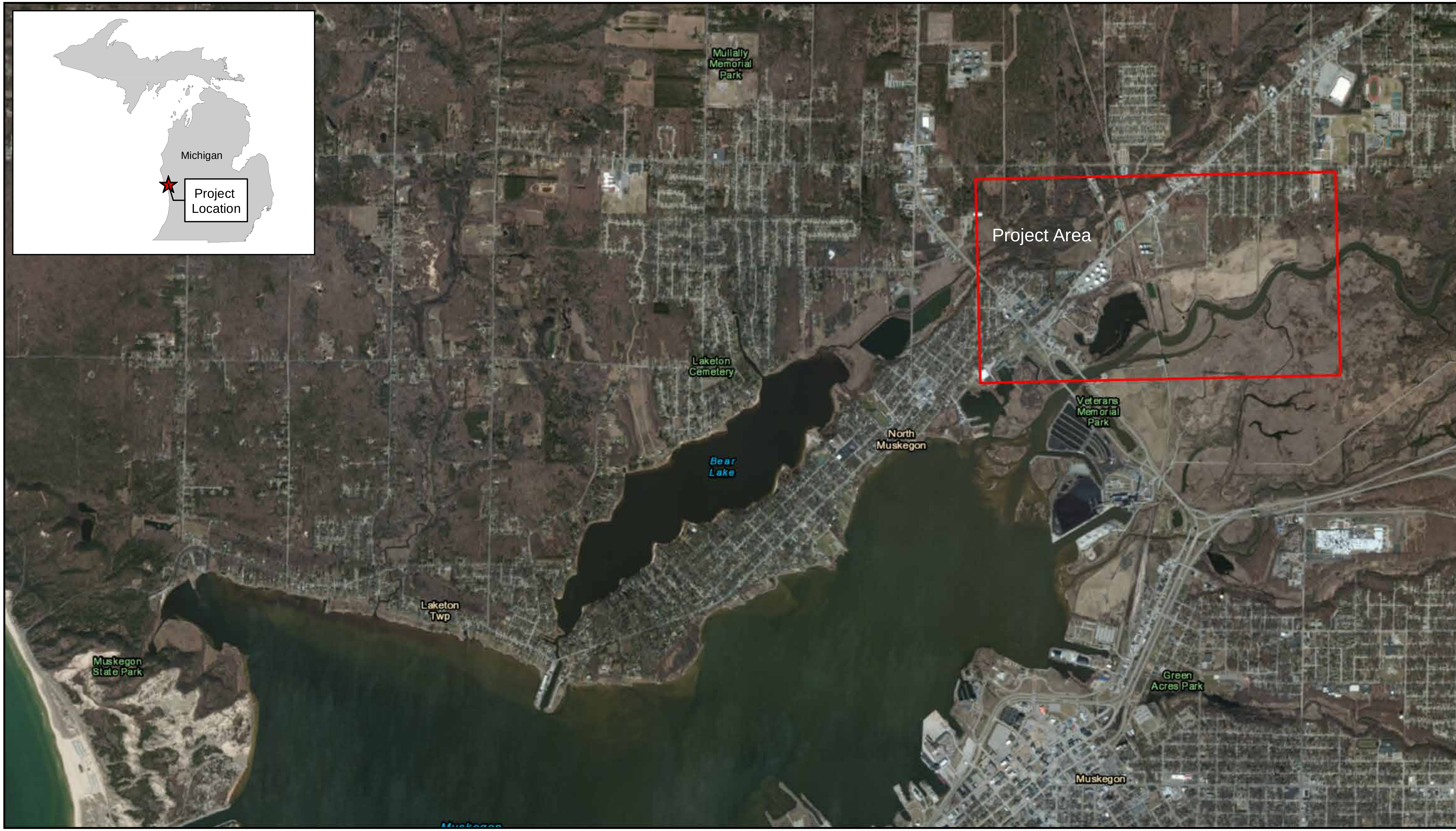
Figures



Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

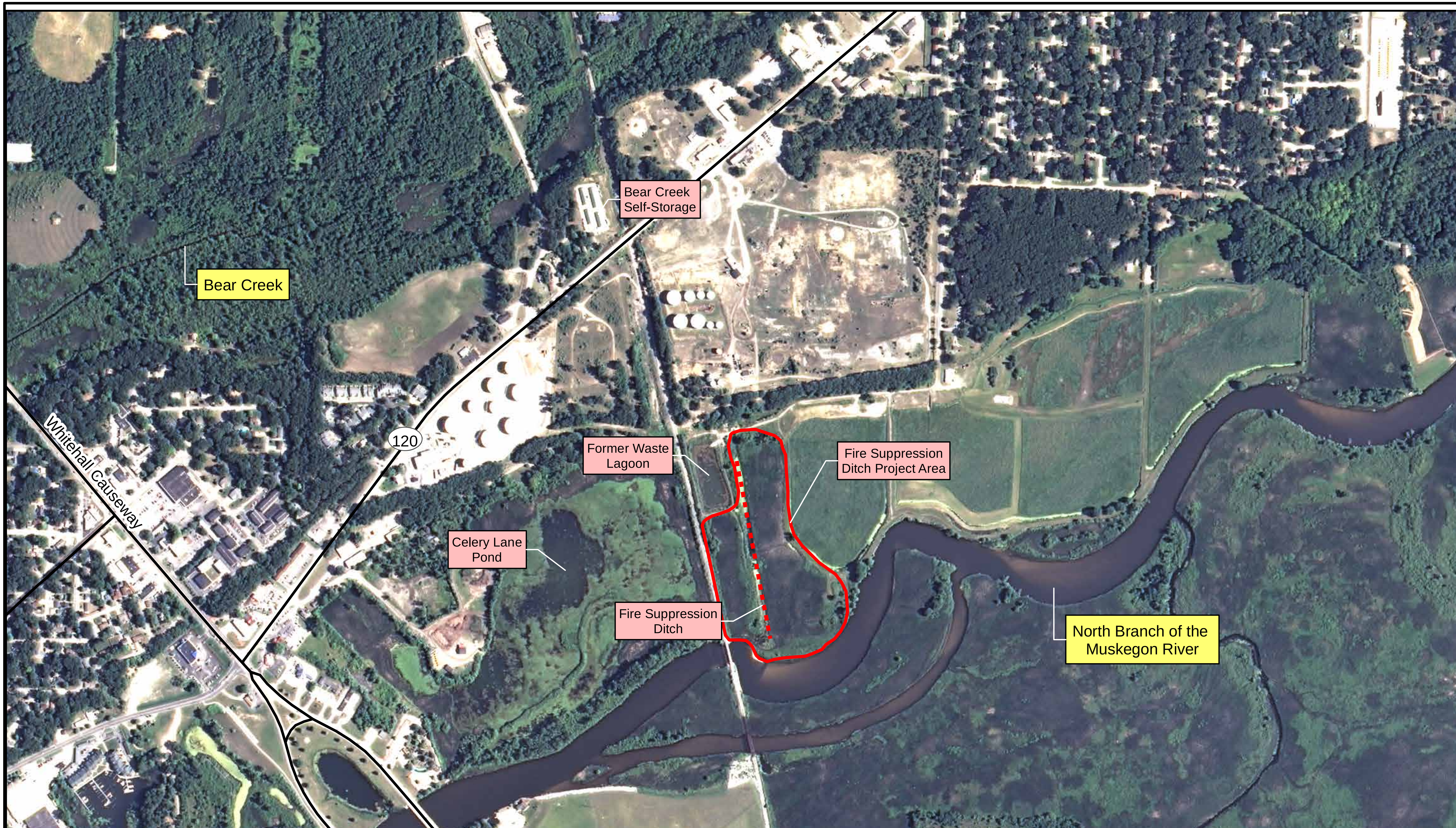
Image Source: ESRI Bing Maps

0 2,000 4,000
Feet

N

Figure 1-1
Site Location Map

\\Lovetonfederal\agencies\Non DoD\USEPA Region V GLAES\6256101 Zephyr Oil Refinery\GIS\MXD\Fig1_Site_Location.mxd



Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2010 NAIP, USDA/FSA Aerial Photography Field Office, 2010.

0 250 500
Feet

N

Figure 1-2
Site Features
Fire Suppression Ditch Project Area

Figure 2-1
Sampling Location Overview
Fire Suppression Ditch

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

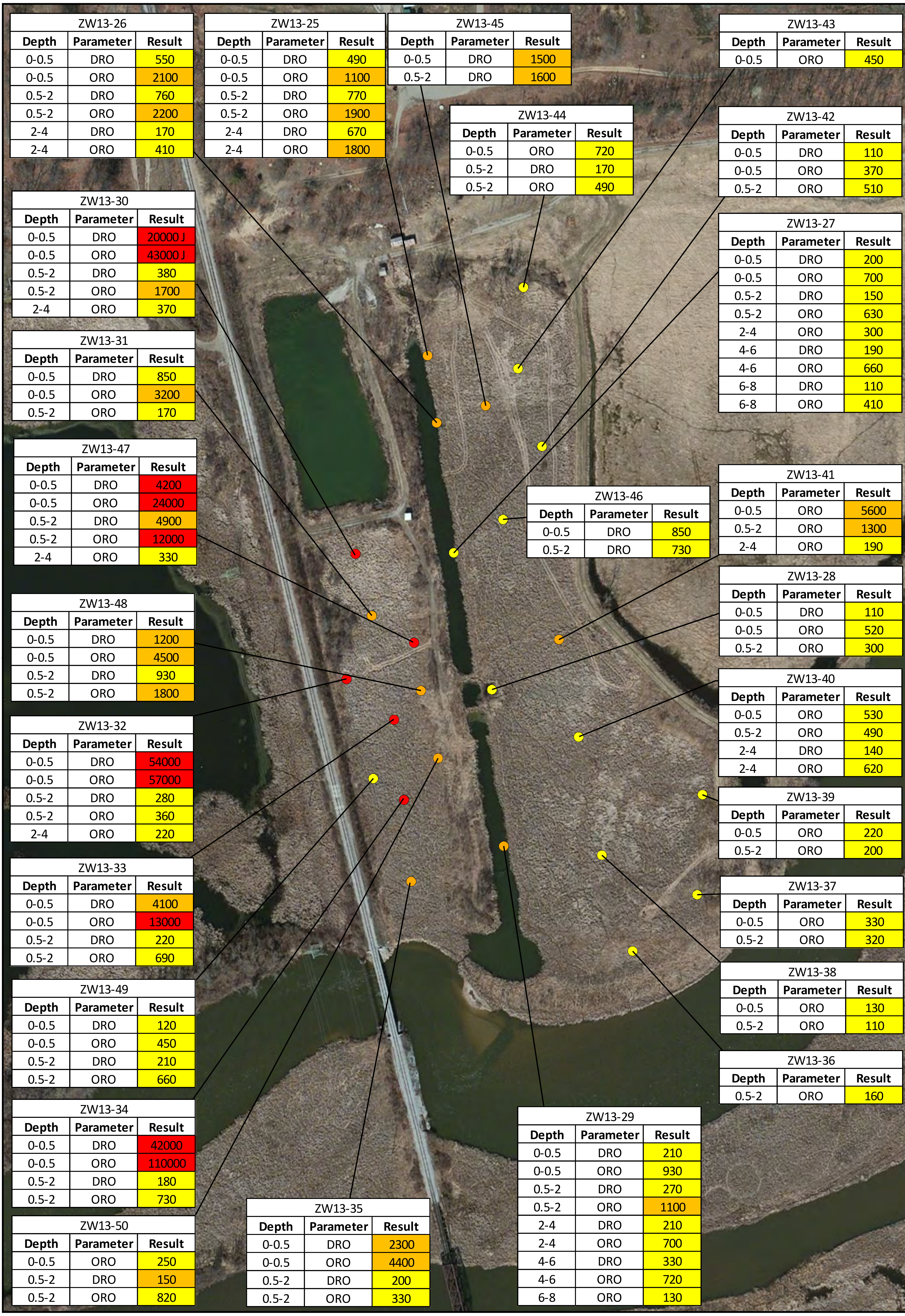
Image Source: 2012 Microsoft
Image Date: 03/13/2012

2013 Sample Locations
Sampling Location in Ditch
Sampling Location in Wetland

Major Sediment Exceedances in Previously Sampled Locations (2012)
No Major Exceedances
Major Exceedances (See Notes)

0 100 200
Feet
N

Notes:
1) Major exceedances means metals > 10x PEC or TPH > 1,000 mg/kg or O & G > 3,000 mg/kg
2) No major exceedances were noted for TPAH



ZW13-26

Depth	Parameter	Result
0-0.5	DRO	550
0-0.5	ORO	2100
0.5-2	DRO	760
0.5-2	ORO	2200
2-4	DRO	170
2-4	ORO	410

ZW13-25

Depth	Parameter	Result
0-0.5	DRO	490
0-0.5	ORO	1100
0.5-2	DRO	770
0.5-2	ORO	1900
2-4	DRO	670
2-4	ORO	1800

ZW13-45

Depth	Parameter	Result
0-0.5	DRO	1500
0.5-2	DRO	1600

ZW13-43

Depth	Parameter	Result
0-0.5	ORO	450

ZW13-44

Depth	Parameter	Result
0-0.5	ORO	720
0.5-2	DRO	170
0.5-2	ORO	490

ZW13-42

Depth	Parameter	Result
0-0.5	DRO	110
0-0.5	ORO	370
0.5-2	ORO	510

ZW13-30

Depth	Parameter	Result
0-0.5	DRO	20000 J
0-0.5	ORO	43000 J
0.5-2	DRO	380
0.5-2	ORO	1700
2-4	ORO	370

ZW13-27

Depth	Parameter	Result
0-0.5	DRO	200
0-0.5	ORO	700
0.5-2	DRO	150
0.5-2	ORO	630
2-4	ORO	300
4-6	DRO	190
4-6	ORO	660
6-8	DRO	110
6-8	ORO	410

ZW13-31

Depth	Parameter	Result
0-0.5	DRO	850
0-0.5	ORO	3200
0.5-2	ORO	170

ZW13-47

Depth	Parameter	Result
0-0.5	DRO	4200
0-0.5	ORO	24000
0.5-2	DRO	4900
0.5-2	ORO	12000
2-4	ORO	330

ZW13-41

Depth	Parameter	Result
0-0.5	ORO	5600
0.5-2	ORO	1300
2-4	ORO	190

ZW13-46

Depth	Parameter	Result
0-0.5	DRO	850
0.5-2	DRO	730

ZW13-28

Depth	Parameter	Result
0-0.5	DRO	110
0-0.5	ORO	520
0.5-2	ORO	300

ZW13-48

Depth	Parameter	Result
0-0.5	DRO	1200
0-0.5	ORO	4500
0.5-2	DRO	930
0.5-2	ORO	1800

ZW13-40

Depth	Parameter	Result
0-0.5	ORO	530
0.5-2	ORO	490
2-4	DRO	140
2-4	ORO	620

ZW13-32

Depth	Parameter	Result
0-0.5	DRO	54000
0-0.5	ORO	57000
0.5-2	DRO	280
0.5-2	ORO	360
2-4	ORO	220

ZW13-39

Depth	Parameter	Result
0-0.5	ORO	220
0.5-2	ORO	200

ZW13-33

Depth	Parameter	Result
0-0.5	DRO	4100
0-0.5	ORO	13000
0.5-2	DRO	220
0.5-2	ORO	690

ZW13-37

Depth	Parameter	Result
0-0.5	ORO	330
0.5-2	ORO	320

ZW13-49

Depth	Parameter	Result
0-0.5	DRO	120
0-0.5	ORO	450
0.5-2	DRO	210
0.5-2	ORO	660

ZW13-38

Depth	Parameter	Result
0-0.5	ORO	130
0.5-2	ORO	110

ZW13-36

Depth	Parameter	Result
0.5-2	ORO	160

ZW13-34

Depth	Parameter	Result
0-0.5	DRO	42000
0-0.5	ORO	110000
0.5-2	DRO	180
0.5-2	ORO	730

ZW13-29

Depth	Parameter	Result
0-0.5	DRO	210
0-0.5	ORO	930
0.5-2	DRO	270
0.5-2	ORO	1100
2-4	DRO	210
2-4	ORO	700
4-6	DRO	330
4-6	ORO	720
6-8	ORO	130

ZW13-35

Depth	Parameter	Result
0-0.5	DRO	2300
0-0.5	ORO	4400
0.5-2	DRO	200
0.5-2	ORO	330

ZW13-50

Depth	Parameter	Result
0-0.5	ORO	250
0.5-2	DRO	150
0.5-2	ORO	820

Figure 3-1
Sediment Sampling Results – Petroleum Hydrocarbon Fractions - Fire Suppression Ditch

Sample Results

- Sample Location ≥ 100 mg/kg
- Sample Location ≥ 1,000 mg/kg
- Sample Location ≥ 10,000 mg/kg

Notes:
1. Field Duplicates only shown when their result is greater than the parent sample.
2. All samples shown are mg/kg (milligrams per kilogram)
3. DRO - Diesel Range Organics
4. ORO - Oil Range Organics

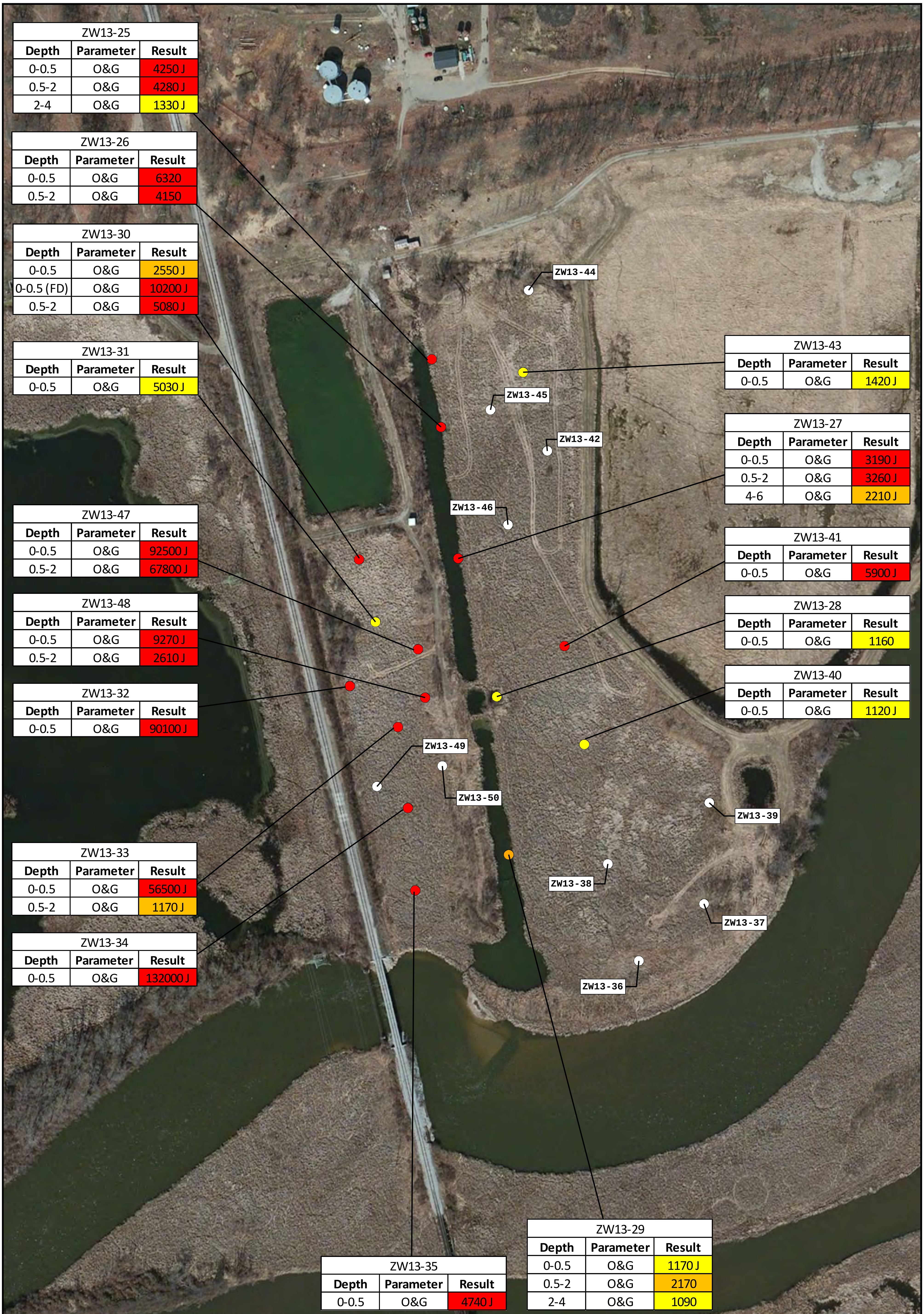
N

0 100 200
Feet

March 2014

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2012 Microsoft
Image Date: 03/13/2012



ZW13-25		
Depth	Parameter	Result
0-0.5	O&G	4250 J
0.5-2	O&G	4280 J
2-4	O&G	1330 J

ZW13-26		
Depth	Parameter	Result
0-0.5	O&G	6320
0.5-2	O&G	4150

ZW13-30		
Depth	Parameter	Result
0-0.5	O&G	2550 J
0-0.5 (FD)	O&G	10200 J
0.5-2	O&G	5080 J

ZW13-31		
Depth	Parameter	Result
0-0.5	O&G	5030 J

ZW13-47		
Depth	Parameter	Result
0-0.5	O&G	92500 J
0.5-2	O&G	67800 J

ZW13-48		
Depth	Parameter	Result
0-0.5	O&G	9270 J
0.5-2	O&G	2610 J

ZW13-32		
Depth	Parameter	Result
0-0.5	O&G	90100 J

ZW13-33		
Depth	Parameter	Result
0-0.5	O&G	56500 J
0.5-2	O&G	1170 J

ZW13-34		
Depth	Parameter	Result
0-0.5	O&G	132000 J

ZW13-43		
Depth	Parameter	Result
0-0.5	O&G	1420 J

ZW13-27		
Depth	Parameter	Result
0-0.5	O&G	3190 J
0.5-2	O&G	3260 J
4-6	O&G	2210 J

ZW13-41		
Depth	Parameter	Result
0-0.5	O&G	5900 J

ZW13-28		
Depth	Parameter	Result
0-0.5	O&G	1160

ZW13-40		
Depth	Parameter	Result
0-0.5	O&G	1120 J

ZW13-35		
Depth	Parameter	Result
0-0.5	O&G	4740 J

ZW13-29		
Depth	Parameter	Result
0-0.5	O&G	1170 J
0.5-2	O&G	2170
2-4	O&G	1090

Figure 3-2
Sediment Sampling Results – Oil & Grease
Fire Suppression Ditch

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2012 Microsoft
Image Date: 03/13/2012

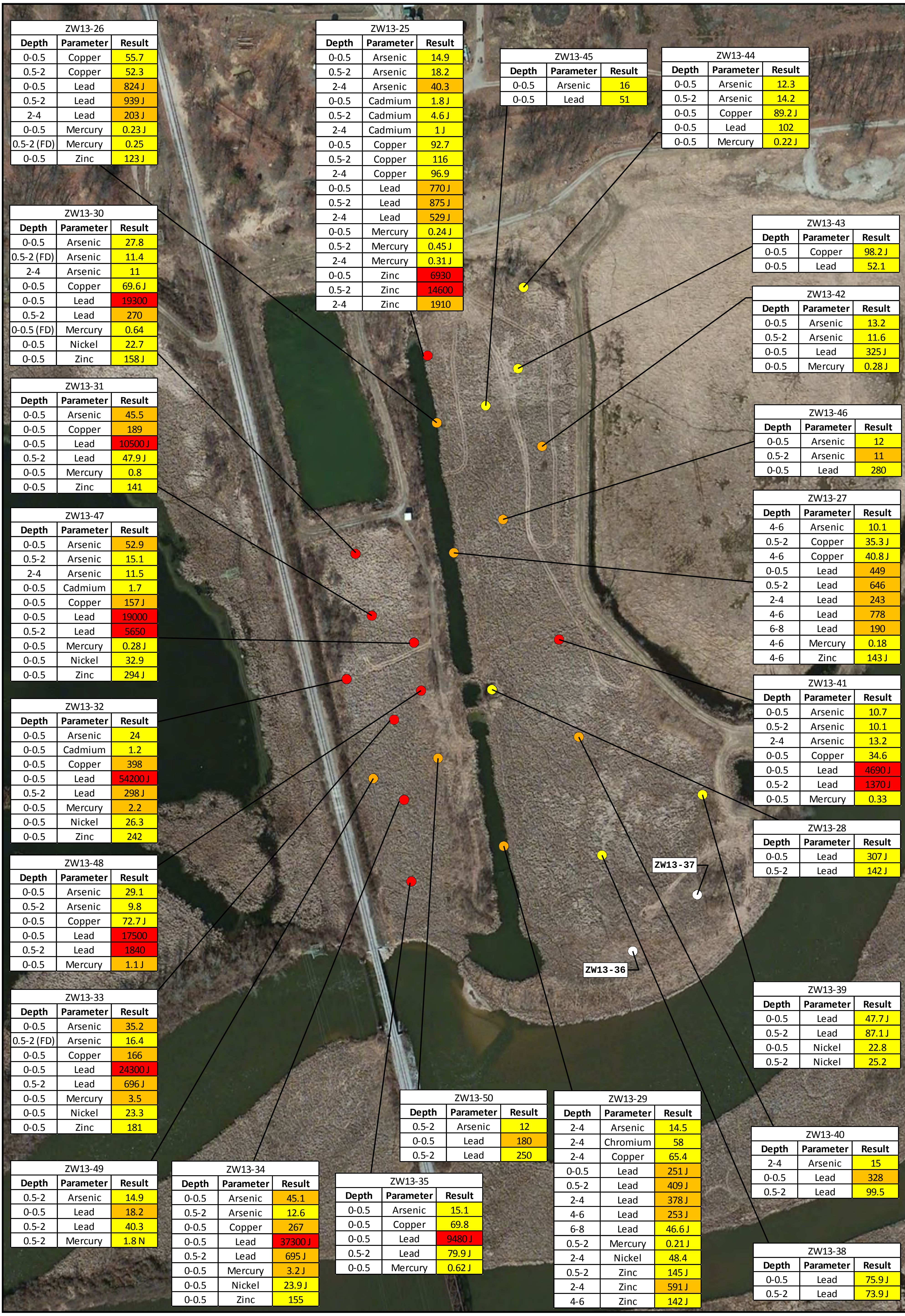
Sample Results

- Sample Location < 1,000 mg/kg
- Sample Location ≥ 1,000 mg/kg
- Sample Location ≥ 2,000 mg/kg
- Sample Location ≥ 3,000 mg/kg

Notes:
1. Field Duplicates only shown when their result is greater than the parent sample.
2. All samples shown are mg/kg (milligrams per kilogram)
3. O&G - Oil and Grease

0 100 200
Feet
N

March 2014



ZW13-26		
Depth	**Parameter**	**Result**
0-0.5	Copper	55.7
0.5-2	Copper	52.3
0-0.5	Lead	824 J
0.5-2	Lead	939 J
2-4	Lead	203 J
0-0.5	Mercury	0.23 J
0.5-2 (FD)	Mercury	0.25
0-0.5	Zinc	123 J

ZW13-25		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	14.9
0.5-2	Arsenic	18.2
2-4	Arsenic	40.3
0-0.5	Cadmium	1.8 J
0.5-2	Cadmium	4.6 J
2-4	Cadmium	1 J
0-0.5	Copper	92.7
0.5-2	Copper	116
2-4	Copper	96.9
0-0.5	Lead	770 J
0.5-2	Lead	875 J
2-4	Lead	529 J
0-0.5	Mercury	0.24 J
0.5-2	Mercury	0.45 J
2-4	Mercury	0.31 J
0-0.5	Zinc	6930
0.5-2	Zinc	14600
2-4	Zinc	1910

ZW13-45		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	16
0-0.5	Lead	51

ZW13-44		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	12.3
0.5-2	Arsenic	14.2
0-0.5	Copper	89.2 J
0-0.5	Lead	102
0-0.5	Mercury	0.22 J

ZW13-30		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	27.8
0.5-2 (FD)	Arsenic	11.4
2-4	Arsenic	11
0-0.5	Copper	69.6 J
0-0.5	Lead	19300
0.5-2	Lead	270
0-0.5 (FD)	Mercury	0.64
0-0.5	Nickel	22.7
0-0.5	Zinc	158 J

ZW13-43		
Depth	**Parameter**	**Result**
0-0.5	Copper	98.2 J
0-0.5	Lead	52.1

ZW13-42		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	13.2
0.5-2	Arsenic	11.6
0-0.5	Lead	325 J
0-0.5	Mercury	0.28 J

ZW13-31		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	45.5
0-0.5	Copper	189
0-0.5	Lead	10500 J
0.5-2	Lead	47.9 J
0-0.5	Mercury	0.8
0-0.5	Zinc	141

ZW13-46		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	12
0.5-2	Arsenic	11
0-0.5	Lead	280

ZW13-47		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	52.9
0.5-2	Arsenic	15.1
2-4	Arsenic	11.5
0-0.5	Cadmium	1.7
0-0.5	Copper	157 J
0-0.5	Lead	19000
0.5-2	Lead	5650
0-0.5	Mercury	0.28 J
0-0.5	Nickel	32.9
0-0.5	Zinc	294 J

ZW13-27		
Depth	**Parameter**	**Result**
4-6	Arsenic	10.1
0.5-2	Copper	35.3 J
4-6	Copper	40.8 J
0-0.5	Lead	449
0.5-2	Lead	646
2-4	Lead	243
4-6	Lead	778
6-8	Lead	190
4-6	Mercury	0.18
4-6	Zinc	143 J

ZW13-32		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	24
0-0.5	Cadmium	1.2
0-0.5	Copper	398
0-0.5	Lead	54200 J
0.5-2	Lead	298 J
0-0.5	Mercury	2.2
0-0.5	Nickel	26.3
0-0.5	Zinc	242

ZW13-41		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	10.7
0.5-2	Arsenic	10.1
2-4	Arsenic	13.2
0-0.5	Copper	34.6
0-0.5	Lead	4690 J
0.5-2	Lead	1370 J
0-0.5	Mercury	0.33

ZW13-28		
Depth	**Parameter**	**Result**
0-0.5	Lead	307 J
0.5-2	Lead	142 J

ZW13-48		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	29.1
0.5-2	Arsenic	9.8
0-0.5	Copper	72.7 J
0-0.5	Lead	17500
0.5-2	Lead	1840
0-0.5	Mercury	1.1 J

ZW13-33		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	35.2
0.5-2 (FD)	Arsenic	16.4
0-0.5	Copper	166
0-0.5	Lead	24300 J
0.5-2	Lead	696 J
0-0.5	Mercury	3.5
0-0.5	Nickel	23.3
0-0.5	Zinc	181

ZW13-39		
Depth	**Parameter**	**Result**
0-0.5	Lead	47.7 J
0.5-2	Lead	87.1 J
0-0.5	Nickel	22.8
0.5-2	Nickel	25.2

ZW13-50		
Depth	**Parameter**	**Result**
0.5-2	Arsenic	12
0-0.5	Lead	180
0.5-2	Lead	250

ZW13-29		
Depth	**Parameter**	**Result**
2-4	Arsenic	14.5
2-4	Chromium	58
2-4	Copper	65.4
0-0.5	Lead	251 J
0.5-2	Lead	409 J
2-4	Lead	378 J
4-6	Lead	253 J
6-8	Lead	46.6 J
0.5-2	Mercury	0.21 J
2-4	Nickel	48.4
0.5-2	Zinc	145 J
2-4	Zinc	591 J
4-6	Zinc	142 J

ZW13-40		
Depth	**Parameter**	**Result**
2-4	Arsenic	15
0-0.5	Lead	328
0.5-2	Lead	99.5

ZW13-49		
Depth	**Parameter**	**Result**
0.5-2	Arsenic	14.9
0-0.5	Lead	18.2
0.5-2	Lead	40.3
0.5-2	Mercury	1.8 N

ZW13-34		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	45.1
0.5-2	Arsenic	12.6
0-0.5	Copper	267
0-0.5	Lead	37300 J
0.5-2	Lead	695 J
0-0.5	Mercury	3.2 J
0-0.5	Nickel	23.9 J
0-0.5	Zinc	155

ZW13-35		
Depth	**Parameter**	**Result**
0-0.5	Arsenic	15.1
0-0.5	Copper	69.8
0-0.5	Lead	9480 J
0.5-2	Lead	79.9 J
0-0.5	Mercury	0.62 J

ZW13-38		
Depth	**Parameter**	**Result**
0-0.5	Lead	75.9 J
0.5-2	Lead	73.9 J

Figure 3-3
Sediment Sampling Results – Metals
Fire Suppression Ditch

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2012 Microsoft
Image Date: 03/13/2012

Sample Results

- Sample Location < TEC
- Sample Location ≥ TEC
- Sample Location ≥ PEC
- Sample Location ≥ 10x PEC

Exceedance Criteria for Metals (mg/kg)			
Parameter	**TEC**	**PEC**	**10x PEC**
Arsenic	9.79	33	330
Cadmium	0.99	4.98	49.8
Chromium	43.4	111	1110
Copper	31.6	149	1490
Lead	35.8	128	1280
Mercury	0.18	1.06	10.6
Nickel	22.7	48.6	486
Zinc	121	459	4590

Notes:
1. Field Duplicates only shown when their result is greater than the parent sample.
2. All samples shown are mg/kg (milligrams per kilogram)

N

0 100 200
Feet

March 2014

Tables

TABLE 2-1 PROPOSED AND ACTUAL SAMPLE LOCATIONS

Exposure Area	Sample Location	Proposed Coordinates		Actual Coordinates	
		Northing	Easting	Northing	Easting
Fire Suppression Ditch	ZW13-25	650379.07	12625001.87	650372.91	12624977.49
	ZW13-26	650251.27	12625019.41	650252.06	12624996.09
	ZW13-27	650003.20	12625051.98	649997.39	12625035.53
	ZW13-28	649742.60	12625124.65	649734.68	12625071.16
	ZW13-29	649444.42	12625147.20	649435.62	12625129.40
Fire Suppression Ditch Adjacent Wetlands	ZW13-30	650001.40	12624864.71	650001.48	12624864.72
	ZW13-31	649883.80	12624895.55	649883.73	12624895.59
	ZW13-32	649762.62	12624847.37	649762.67	12624847.35
	ZW13-33	649685.22	12624937.97	649685.13	12624937.99
	ZW13-34	649532.91	12624957.25	649532.88	12624957.28
	ZW13-35	649376.75	12624970.74	649376.73	12624970.71
	ZW13-36	649243.96	12625392.77	649243.93	12625392.84
	ZW13-37	649351.71	12625515.55	649351.69	12625515.54
	ZW13-38	649427.12	12625334.05	649427.07	12625334.06
	ZW13-39	649542.14	12625525.57	649542.10	12625525.53
	ZW13-40	649652.40	12625290.03	649659.53	12625290.61
	ZW13-41	649837.82	12625252.44	649838.39	12625252.49
	ZW13-42	650206.17	12625219.87	650206.08	12625219.88
	ZW13-43	650354.57	12625174.00	650353.13	12625174.69
	ZW13-44	650509.37	12625184.79	650507.40	12625182.77
	ZW13-45	650283.71	12625112.59	650283.71	12625112.59
	ZW13-46	650067.14	12625145.40	650067.14	12625145.40
	ZW13-47	649832.28	12624976.16	649832.28	12624976.16
	ZW13-48	649740.87	12624989.61	649740.87	12624989.61
	ZW13-49	649572.95	12624898.50	649572.95	12624898.50
	ZW13-50	649611.57	12625021.69	649611.57	12625021.69

NOTE:
Coordinates in Michigan State Plane South Coordinate System (North American Datum of 1983, in units of survey feet)

TABLE 3-1 CORE COLLECTION SUMMARY

Sampling Location	Date Collected	Time Collected	Water Depth (ft)	Sediment Surface Elevation (ft, NAD 83)	Penetration Depth (ft)	Sediment Recovery (ft)	Percent Recovery (%)
ZW13-25	11/5/2013	8:40	2	576.129	16	12.8	80.2
ZW13-26	11/8/2013	8:52	2	576.078	16	9.7	60.4
ZW13-27	11/7/2013	12:05	2	576.018	10	8.8	88.3
ZW13-28	11/8/2013	14:20	2	576.1	10	8.3	82.5
ZW13-29	11/8/2013	15:48	3	575.171	10	9.2	91.7
ZW13-30	11/7/2013	13:43	1.65	578.819	10	7.1	70.8
ZW13-31	11/7/2013	10:32	2.8	577.604	10	8.5	85.0
ZW13-32	11/7/2013	8:35	2.5	576.92	10	6.5	65.0
ZW13-33	11/6/2013	16:36	4.9	574.862	10	8.3	82.5
ZW13-34	11/6/2013	15:22	1.35	577.974	10	7.9	79.2
ZW13-35	11/6/2013	12:20	5	574.134	10	7.4	74.2
ZW13-38	11/6/2013	9:31	3.8	575.763	10	8.3	83.3
ZW13-39	11/6/2013	8:55	5.25	573.782	10	8.4	84.2
ZW13-40	9/30/2013	16:07	1.4	577.517	10	9.0	90.0
ZW13-41	11/4/2013	11:40	4.9	573.743	10	8.2	81.7
ZW13-42	11/4/2013	9:57	5	574.618	10	9.3	92.5
ZW13-43	9/30/2013	14:46	3	579.065	10	8.5	85.0
ZW13-44	9/30/2013	12:50	3	579.63	10	8.3	83.3
ZW13-47	11/7/2013	15:30	1	578.107	10	7.5	75.0
ZW13-48	11/7/2013	14:45	4	575.873	10	8.8	87.5

Table 3-2 Former Zephyr Oil Refinery Fire Suppression Ditch Sample Count

	Maximum Number of Samples Targeted for Collection for First Analysis Suite				Maximum Number of Samples Targeted for Collection for Second Analysis Suite (Archive)				Number of Samples Submitted for First Analysis Suite				Number of Samples Submitted for Second Analysis Suite (Archive)					MDEQ Samples			
Analysis	**Investigatory Samples**	**Field Duplicates**	**MS/MSD**	**Total**	**Investigatory Samples**	**Field Duplicates**	**MS/MSD**	**Total**	**Investigatory Samples**	**Field Duplicates**	**MS/MSD**	**Total**	**Investigatory Samples**	**Field Duplicates**	**Archive Duplicates**	**MS/MSD**	**Total**	**Investigatory Samples**	**Field Duplicates**	**MS/MSD**	**Total**
Grain Size	81	9	0	90	45	3	0	48	78	8	0	86	43	3	3	0	49	0	0	0	0
Moisture Content	81	9	0	90	45	3	0	48	78	8	0	86	43	3	3	0	49	12	1	0	13
GRO	81	9	5	95	45	3	2	50	78	8	4	90	43	3	3	2	51	12	1	NA	13
DRO	81	9	5	95	45	3	2	50	78	8	4	90	43	3	3	2	51	12	1	NA	13
ORO	81	9	5	95	45	3	2	50	78	8	4	90	43	3	3	2	51	12	1	NA	13
Oil and Grease - HEM	81	9	5	95	45	3	2	50	78	8	4	90	43	3	3	2	51	0	0	0	0
Michigan 10 Metals	81	9	5	95	45	3	2	50	78	8	4	90	43	3	3	2	51	12	1	NA	13
Nickel	81	9	5	95	45	3	2	50	78	8	4	90	43	3	3	2	51	0	0	0	0
TOC	81	9	5	95	45	3	2	50	78	8	4	90	43	3	3	2	51	0	0	0	0
SEM/AVS	8	1	1	10	0	0	0	0	8	1	1	10	0	0	0	0	0	0	0	0	0
Percent Solids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1	0	13

Notes:
DRO - Diesel range organics
GRO - Gasoline range organics
HEM - n-Hexane Extractable Material
MS/MSD - Matrix spike/matrix spike duplicate
NA - This information is not available. For the 12 hand auger locations, it is not known whether or not MDEQ submitted MS/MSD samples.
ORO - Oil range organics
SEM/AVS - Simultaneously extracted metals/acid volatile sulfide
TOC - Total organic carbon

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25
	Sample Name:	ZW13-25-0001	ZW13-25-0102	ZW13-25-0204	ZW13-25-0406	ZW13-25-0608	ZW13-25-0810	ZW13-25-1012
	Sample Depth (ft):	0-0.5	0.5-2	2-4	4-6	6-8	8-10	10-12
	Date Sampled:	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13
Analyte	**Unit**							
Gravel	%	0.9	3.6	0.6	0	0	0	0
Sand	%	26.4	17.8	23.1	53.3	51	69.3	26.3
Coarse Sand	%	1.5	1.4	1.1	0	0	0	0
Medium Sand	%	4.1	1.3	2.3	0.6	0	0.1	0
Fine Sand	%	20.8	15.1	19.7	52.7	51	69.2	26.3
Silt	%	56.5	52.1	50.4	32.9	34.5	28.5	57
Clay	%	16.2	26.5	25.9	13.8	14.5	2.2	16.7
Silt + Clay	%	72.7	78.6	76.3	46.7	49	30.7	73.7
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	97.2	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	99.1	96.4	99.4	100	100	100	100
Sieve Size #10 - Percent Finer	% passed	97.6	95	98.3	100	100	100	100
Sieve Size #20 - Percent Finer	% passed	95.7	94.5	98.1	99.8	100	100	100
Sieve Size #40 - Percent Finer	% passed	93.5	93.7	96	99.4	100	99.9	100
Sieve Size #60 - Percent Finer	% passed	89.9	90.6	92.5	90.9	91.7	93.7	98.9
Sieve Size #80 - Percent Finer	% passed	86.4	88.1	88.9	75.4	78.7	77.8	96.3
Sieve Size #100 - Percent Finer	% passed	83.1	86.3	86.2	65.6	69.3	64.1	93
Sieve Size #200 - Percent Finer	% passed	72.7	78.6	76.3	46.7	49	30.7	73.7
Hydrometer Reading 1 - Percent Finer	% passed	61.8	74.7	51.2	27	29.3	9	44
Hydrometer Reading 2 - Percent Finer	% passed	25.3	40.7	46.9	24	25	5.9	36
Hydrometer Reading 3 - Percent Finer	% passed	22.3	29.3	38.5	19.1	21.7	3.5	24.6
Hydrometer Reading 4 - Percent Finer	% passed	19.3	29.3	30.1	16	16.6	2.8	20.1
Hydrometer Reading 5 - Percent Finer	% passed	16.2	26.5	25.9	13.8	14.5	2.2	16.7
Hydrometer Reading 6 - Percent Finer	% passed	16.2	23.2	19.3	9.5	9.9	1.8	10.6
Hydrometer Reading 7 - Percent Finer	% passed	15.7	20.3	17.2	6.9	6.7	1.4	7.2
Total Organic Carbon	%	16.5 J	17.5 J	13.3 J	0.742 J	1.91 J	0.655 J	1.39 J
Moisture Content	%	669.8	589.4	291.9	20.1	17	18.6	17.7
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-25	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26
	Sample Name:	ZW13-25-1214	ZW13-26-0001	ZW13-26-0102	ZW13-26-0102FD	ZW13-26-0204	ZW13-26-0204FD	ZW13-26-0406
	Sample Depth (ft):	12-14	0-0.5	0.5-2	0.5-2	2-4	4-6	6-8
	Date Sampled:	11/5/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13
Analyte	**Unit**							
Gravel	%	0	0	0	0	0	0	0
Sand	%	19.7	30.9	22.7	20.4	58.8	56.9	92.4
Coarse Sand	%	0	1.6	3.7	1	1	0.3	0
Medium Sand	%	0	6.3	1.3	4.2	5	6.1	0.2
Fine Sand	%	19.7	23	17.7	15.2	52.8	50.5	92.2
Silt	%	45.9	37.9	49	48.3	30.4	29.5	3.2
Clay	%	34.4	31.2	28.3	31.3	10.8	13.6	4.4
Silt + Clay	%	80.3	69.1	77.3	79.6	41.2	43.1	7.6
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #10 - Percent Finer	% passed	100	98.4	96.3	99	99	99.7	100
Sieve Size #20 - Percent Finer	% passed	100	95.8	96.2	97.7	96	96.8	100
Sieve Size #40 - Percent Finer	% passed	100	92.1	95	94.8	94	93.6	99.8
Sieve Size #60 - Percent Finer	% passed	99.7	86.8	87.9	90.8	81.9	83.2	81.7
Sieve Size #80 - Percent Finer	% passed	98	82.7	85.5	88	66.9	68.5	51
Sieve Size #100 - Percent Finer	% passed	95.2	79.5	83.8	86	57.7	59.4	31
Sieve Size #200 - Percent Finer	% passed	80.3	69.1	77.3	79.6	41.2	43.1	7.6
Hydrometer Reading 1 - Percent Finer	% passed	61.4	42	73.4	77.9	22.7	27.3	5
Hydrometer Reading 2 - Percent Finer	% passed	56.7	42	42.8	47.2	16.9	19.4	5
Hydrometer Reading 3 - Percent Finer	% passed	48.5	42	36.7	43.6	14.5	18.3	5
Hydrometer Reading 4 - Percent Finer	% passed	40.3	31.2	31.1	40.5	11	14.7	4.4
Hydrometer Reading 5 - Percent Finer	% passed	34.4	31.2	28.3	31.3	10.8	13.6	4.4
Hydrometer Reading 6 - Percent Finer	% passed	26	27.8	22.8	28.2	8.4	11.4	4.4
Hydrometer Reading 7 - Percent Finer	% passed	19	27.8	20	25.1	8.4	10.3	3.9
Total Organic Carbon	%	1.09 J	20.3	19.9	18	8.14	9.48	0.1 U
Moisture Content	%	17.9	906.9	581.5	574.6	180.4	169.7	19.8
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-26	ZW13-26	ZW13-26	ZW13-27	ZW13-27	ZW13-27	ZW13-27
	Sample Name:	ZW13-26-0608	ZW13-26-1012	ZW13-26-1214	ZW13-27-0001	ZW13-27-0102	ZW13-27-0204	ZW13-27-0406
	Sample Depth (ft):	8-10	10-12	12-14	0-0.5	0.5-2	2-4	4-6
	Date Sampled:	11/9/13	11/9/13	11/9/13	11/8/13	11/8/13	11/8/13	11/8/13
Analyte	**Unit**							
Gravel	%	0	0	0	0.4	0.6	0	0.1
Sand	%	59.1	11.4	14.3	27.7	23.4	65.9	24.2
Coarse Sand	%	0	0	0	1.2	1.8	0.4	0.8
Medium Sand	%	0.4	0	0.1	5.5	2.6	10.7	5.9
Fine Sand	%	58.7	11.4	14.2	21	19	54.8	17.5
Silt	%	32.6	40.4	31.3	65.5	69.6	27.5	56.5
Clay	%	8.3	48.2	54.4	6.4	6.4	6.6	19.2
Silt + Clay	%	40.9	88.6	85.7	71.9	76	34.1	75.7
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	100	100	100	99.6	99.4	100	99.9
Sieve Size #10 - Percent Finer	% passed	100	100	100	98.4	97.6	99.6	99.1
Sieve Size #20 - Percent Finer	% passed	100	100	100	96.4	96.3	98.5	97.1
Sieve Size #40 - Percent Finer	% passed	99.6	100	99.9	92.9	95	88.9	93.2
Sieve Size #60 - Percent Finer	% passed	94.6	99.6	99.4	86.7	87.8	65.4	85.5
Sieve Size #80 - Percent Finer	% passed	85.2	98.7	98.2	82.9	85.1	51.1	83.2
Sieve Size #100 - Percent Finer	% passed	74.4	97.4	96.4	80.4	83.5	43.4	81.7
Sieve Size #200 - Percent Finer	% passed	40.9	88.6	85.7	71.9	76	34.1	75.7
Hydrometer Reading 1 - Percent Finer	% passed	20.4	77.5	76.7	27.6	50.1	33.4	68.7
Hydrometer Reading 2 - Percent Finer	% passed	14.9	70.8	72	14.9	15.7	14.5	33.8
Hydrometer Reading 3 - Percent Finer	% passed	11.6	62.8	65.6	14.9	15.7	12.6	30.3
Hydrometer Reading 4 - Percent Finer	% passed	9.4	56.2	60.8	6.4	7.2	10.7	23.3
Hydrometer Reading 5 - Percent Finer	% passed	8.3	48.2	54.4	6.4	6.4	6.6	19.2
Hydrometer Reading 6 - Percent Finer	% passed	7.2	37.5	41.7	5.7	5.7	4.4	11.6
Hydrometer Reading 7 - Percent Finer	% passed	6.1	28.2	30.5	5	5	2.2	7.6
Total Organic Carbon	%	1.45	1.46	2.06	17.9 J	21.9 J	19.1 J	17.9 J
Moisture Content	%	16.6	18.3	22	935.6	1008.9	330.4	564
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-27	ZW13-27	ZW13-28	ZW13-28	ZW13-28	ZW13-28	ZW13-28
	Sample Name:	ZW13-27-0608	ZW13-27-0810	ZW13-28-0001	ZW13-28-0102	ZW13-28-0204	ZW13-28-0406	ZW13-28-0608
	Sample Depth (ft):	6-8	8-10	0-0.5	0.5-2	2-4	4-6	6-8
	Date Sampled:	11/8/13	11/8/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13
Analyte	**Unit**							
Gravel	%	0.3	0	0.4	4.6	0.6	0.5	1.2
Sand	%	31	18.9	28.8	71.7	96.8	96	95.8
Coarse Sand	%	0.3	0	0.8	2.5	0.3	0.3	0.7
Medium Sand	%	3.2	0	0.6	10.9	4.6	11.7	3.5
Fine Sand	%	27.5	18.9	27.4	58.3	91.9	84	91.6
Silt	%	56	54.9	48	14.3	1	2.3	1.9
Clay	%	12.7	26.2	22.8	9.4	1.7	1.1	1.1
Silt + Clay	%	68.7	81.1	70.8	23.7	2.7	3.4	3
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	98.6	100	100	99.3
Sieve Size #4 - Percent Finer	% passed	99.7	100	99.6	95.4	99.4	99.5	98.8
Sieve Size #10 - Percent Finer	% passed	99.4	100	98.8	92.9	99.1	99.2	98.1
Sieve Size #20 - Percent Finer	% passed	98.1	100	98.6	91.5	97.8	97.9	96.2
Sieve Size #40 - Percent Finer	% passed	96.2	100	98.2	82	94.5	87.5	94.6
Sieve Size #60 - Percent Finer	% passed	88.1	99.4	92.8	56.4	56.1	48.3	41.1
Sieve Size #80 - Percent Finer	% passed	81.6	97.6	88	43.4	36.6	30.8	16.1
Sieve Size #100 - Percent Finer	% passed	77.2	95	84	35.8	25.1	22.5	8.5
Sieve Size #200 - Percent Finer	% passed	68.7	81.1	70.8	23.7	2.7	3.5	3
Hydrometer Reading 1 - Percent Finer	% passed	39.8	55.7	47	17.8	2.2	1.6	1.1
Hydrometer Reading 2 - Percent Finer	% passed	34.4	49.6	40	16	1.7	1.6	1.1
Hydrometer Reading 3 - Percent Finer	% passed	23.7	38.5	34.3	13	1.7	1.6	1.1
Hydrometer Reading 4 - Percent Finer	% passed	18.1	32.4	27	10.3	1.7	1.1	1.1
Hydrometer Reading 5 - Percent Finer	% passed	12.7	26.2	22.8	9.4	1.7	1.1	1.1
Hydrometer Reading 6 - Percent Finer	% passed	8.5	17.6	17.2	7.5	1.1	1.1	1
Hydrometer Reading 7 - Percent Finer	% passed	5.6	11.5	11.5	5.7	1	0.6	0.5
Total Organic Carbon	%	10.6 J	1.56 J	5.13	2.79	0.1 U	0.1 U	0.1 U
Moisture Content	%	150.8	20.7	198.4	82.4	18.3	18.9	16.7
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-28	ZW13-29	ZW13-29	ZW13-29	ZW13-29	ZW13-29	ZW13-29
	Sample Name:	ZW13-28-0810	ZW13-29-0001	ZW13-29-0102	ZW13-29-0204	ZW13-29-0406	ZW13-29-0608	ZW13-29-0810
	Sample Depth (ft):	8-10	0-0.5	0.5-2	2-4	4-6	6-8	8-10
	Date Sampled:	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13
Analyte	**Unit**							
Gravel	%	0	0.3	0	0	0	0.7	0.5
Sand	%	12.7	44.9	26.3	27.6	41.6	74.9	95.7
Coarse Sand	%	0	3.5	2.8	1.4	1.1	0.4	0.2
Medium Sand	%	1.1	2.4	6.1	3.1	3.2	2.3	8.1
Fine Sand	%	11.6	39	17.4	23.1	37.3	72.2	87.4
Silt	%	31.5	44.8	58.7	50.3	43.8	18.8	2.7
Clay	%	55.8	10	15	22.1	14.6	5.7	1.1
Silt + Clay	%	87.3	54.8	73.7	72.4	58.4	24.5	3.8
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	99.7	100
Sieve Size #4 - Percent Finer	% passed	100	99.7	100	100	100	99.3	99.5
Sieve Size #10 - Percent Finer	% passed	100	96.2	97.2	98.6	98.9	98.9	99.3
Sieve Size #20 - Percent Finer	% passed	100	94.7	93.5	96.5	98.5	97.6	98.6
Sieve Size #40 - Percent Finer	% passed	98.9	93.8	91.1	95.5	95.7	96.6	91.2
Sieve Size #60 - Percent Finer	% passed	94.3	85.9	87.5	89.3	87.3	63.8	61.5
Sieve Size #80 - Percent Finer	% passed	91.1	75.3	83.9	85	77.5	44	35.5
Sieve Size #100 - Percent Finer	% passed	89.7	67.2	80.9	81.5	70.2	32.5	17.2
Sieve Size #200 - Percent Finer	% passed	87.3	54.8	73.7	72.4	58.4	24.4	3.8
Hydrometer Reading 1 - Percent Finer	% passed	82.5	45.9	65.5	58.4	39.7	10.6	2.7
Hydrometer Reading 2 - Percent Finer	% passed	77.5	19	23.4	37	24	8.5	2.7
Hydrometer Reading 3 - Percent Finer	% passed	70.8	16	20.6	30.6	19.3	7.9	2.2
Hydrometer Reading 4 - Percent Finer	% passed	64.1	13	15	24.2	17.8	6.5	1.7
Hydrometer Reading 5 - Percent Finer	% passed	55.8	10	15	22.1	14.6	5.7	1.1
Hydrometer Reading 6 - Percent Finer	% passed	42.4	7	9.4	15.7	11.5	4.4	1.1
Hydrometer Reading 7 - Percent Finer	% passed	28.7	6.5	8.9	11	8.1	3.6	1.1
Total Organic Carbon	%	0.724	12.9	16.1	12.8	8.63	1.25	0.176
Moisture Content	%	25	746.8	582	301.9	226.4	54	18.6
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-30	ZW13-30	ZW13-30	ZW13-30	ZW13-30	ZW13-30	ZW13-31
	Sample Name:	ZW13-30-0001	ZW13-30-0001FD	ZW13-30-0102	ZW13-30-0102FD	ZW13-30-0204	ZW13-30-0204FD	ZW13-31-0001
	Sample Depth (ft):	0-0.5	0-0.5	0.5-2	0.5-2	2-4	2-4	0-0.5
	Date Sampled:	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/7/13
Analyte	**Unit**							
Gravel	%	0.9	0.4	0	0	1.9	0	0.3
Sand	%	39.5	49.5	36.1	32	31.9	16.4	57.9
Coarse Sand	%	0.9	1.5	0	0	0.4	0	0.5
Medium Sand	%	26	29.7	22	15.5	2.4	2	14.3
Fine Sand	%	12.6	18.3	14.1	16.5	29.1	14.4	43.1
Silt	%	52	45.5	55.1	45.6	56	71	27.3
Clay	%	7.7	4.6	8.8	22.4	10.2	12.6	14.5
Silt + Clay	%	59.7	50.1	63.9	68	66.2	83.6	41.8
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	99.1	99.6	100	100	98.1	100	99.7
Sieve Size #10 - Percent Finer	% passed	98.2	98.1	100	100	97.7	100	99.2
Sieve Size #20 - Percent Finer	% passed	78.4	77.5	83.4	91.5	97.1	98.7	87.9
Sieve Size #40 - Percent Finer	% passed	72.2	68.4	78	84.5	95.3	98	84.9
Sieve Size #60 - Percent Finer	% passed	65.8	60.7	72.6	78.7	90.5	95.2	70.2
Sieve Size #80 - Percent Finer	% passed	63.6	56.9	70.2	75.8	87.3	93.6	48.4
Sieve Size #100 - Percent Finer	% passed	62.5	54.5	68.7	73.8	82.9	91.8	46.3
Sieve Size #200 - Percent Finer	% passed	59.6	50.1	63.9	68	66.2	83.6	41.8
Hydrometer Reading 1 - Percent Finer	% passed	30.6	18.5	35.1	65.1	37.1	45.8	31.9
Hydrometer Reading 2 - Percent Finer	% passed	17.5	11.6	14	34.6	17.9	22.1	18
Hydrometer Reading 3 - Percent Finer	% passed	14.2	11.6	11.4	28.5	14.1	17.4	18
Hydrometer Reading 4 - Percent Finer	% passed	10.9	4.6	8.8	22.4	12.2	15	18
Hydrometer Reading 5 - Percent Finer	% passed	7.7	4.6	8.8	22.4	10.2	12.6	14.5
Hydrometer Reading 6 - Percent Finer	% passed	4.4	4.6	3.5	16.3	6.4	7.9	14.5
Hydrometer Reading 7 - Percent Finer	% passed	4.4	1.2	0.9	10.2	4.5	3.2	10.4
Total Organic Carbon	%	40.6 J	40.8 J	14.3 J	14.7 J	9.36 J	12.4 J	23.7
Moisture Content	%	355.4	348.9	300.5	395.4	183.2	256.3	324.4
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-31	ZW13-31	ZW13-32	ZW13-32	ZW13-32	ZW13-33	ZW13-33
	Sample Name:	ZW13-31-0102	ZW13-31-0204	ZW13-32-0001	ZW13-32-0102	ZW13-32-0204	ZW13-33-0001	ZW13-33-0102
	Sample Depth (ft):	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5	0.5-2
	Date Sampled:	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13
Analyte	**Unit**							
Gravel	%	0.3	0	0.4	0	0	2.4	0
Sand	%	88	86.4	23	69.7	44.1	36.3	25.3
Coarse Sand	%	0.3	0	1.5	0.4	0	4.7	0
Medium Sand	%	10.8	1.1	4.2	2.4	1.5	8.7	6.8
Fine Sand	%	76.9	85.3	17.3	66.9	42.6	22.9	18.5
Silt	%	9.5	12.5	70.2	30.1	54	60.7	74.1
Clay	%	2.3	1.1	6.4	0.2	2	0.6	0.6
Silt + Clay	%	11.8	13.6	76.6	30.3	56	61.3	74.7
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	99.7	100	99.6	100	100	97.6	100
Sieve Size #10 - Percent Finer	% passed	99.4	100	98.1	99.6	100	92.9	100
Sieve Size #20 - Percent Finer	% passed	93.9	99.4	97.4	97.9	99.1	87.8	96.6
Sieve Size #40 - Percent Finer	% passed	88.6	98.9	93.9	97.2	98.5	84.2	93.2
Sieve Size #60 - Percent Finer	% passed	46.6	82.3	87.4	84.4	94	73.8	87
Sieve Size #80 - Percent Finer	% passed	26.7	57	83.5	67.3	79	70.1	83.1
Sieve Size #100 - Percent Finer	% passed	20.3	36.5	81.1	52.5	66.6	67.7	81
Sieve Size #200 - Percent Finer	% passed	11.7	13.6	76.6	30.3	55.9	61.3	74.7
Hydrometer Reading 1 - Percent Finer	% passed	10	3.9	18.5	8.8	13.6	11.8	17.7
Hydrometer Reading 2 - Percent Finer	% passed	6.1	2	14.5	7.3	8.6	4.4	10.8
Hydrometer Reading 3 - Percent Finer	% passed	2.3	2	14.5	3.1	3.6	4.4	7.4
Hydrometer Reading 4 - Percent Finer	% passed	2.3	1.1	8.4	1.7	2	0.6	4
Hydrometer Reading 5 - Percent Finer	% passed	2.3	1.1	6.4	0.2	2	0.6	0.6
Hydrometer Reading 6 - Percent Finer	% passed	0.3	0.2	0.3	0.2	0.3	0.6	0.6
Hydrometer Reading 7 - Percent Finer	% passed	0	0	0	0	0	0	0
Total Organic Carbon	%	5.73	5.25	19.2	3.18	6.04	39.2	12
Moisture Content	%	145.7	51.3	168.7	104.2	153.1	307.3	299.3
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-33	ZW13-33	ZW13-33	ZW13-34	ZW13-34	ZW13-34	ZW13-35
	Sample Name:	ZW13-33-0102FD	ZW13-33-0204	ZW13-33-0204FD	ZW13-34-0001	ZW13-34-0102	ZW13-34-0204	ZW13-35-0001
	Sample Depth (ft):	2-4	4-6	6-8	0-0.5	0.5-2	2-4	0-0.5
	Date Sampled:	11/7/13	11/7/13	11/7/13	11/6/13	11/6/13	11/6/13	11/6/13
Analyte	**Unit**							
Gravel	%	0	0	0	12.7	0.8	0.1	2.7
Sand	%	27.8	70.1	65.7	53	43.2	85.7	32.9
Coarse Sand	%	0	0	0.5	22.8	2.2	0.2	11.3
Medium Sand	%	3.9	9	2	13.2	22.7	7.7	6.2
Fine Sand	%	23.9	61.1	63.2	17	18.3	77.8	15.4
Silt	%	69.3	29.7	25.6	26.2	43.9	12.3	58.3
Clay	%	2.9	0.2	8.7	8.1	12.1	1.9	6.1
Silt + Clay	%	72.2	29.9	34.3	34.3	56	14.2	64.4
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	100	100	100	87.3	99.2	99.9	97.3
Sieve Size #10 - Percent Finer	% passed	100	100	99.5	64.5	97	99.7	86
Sieve Size #20 - Percent Finer	% passed	97.2	99	98.8	59.9	87.9	99.3	82.5
Sieve Size #40 - Percent Finer	% passed	96.1	91	97.5	51.3	74.3	92	79.8
Sieve Size #60 - Percent Finer	% passed	86.8	66.5	68.9	43	66.3	57.8	73.6
Sieve Size #80 - Percent Finer	% passed	82.8	56.1	58.2	40.4	62.8	35.1	70.7
Sieve Size #100 - Percent Finer	% passed	80.4	49.7	51.3	38.7	61	24.3	68.8
Sieve Size #200 - Percent Finer	% passed	72.2	29.9	34.3	34.3	56	14.2	64.4
Hydrometer Reading 1 - Percent Finer	% passed	27.5	6.2	14.6	20.2	49.9	3.8	19.9
Hydrometer Reading 2 - Percent Finer	% passed	12.7	3.8	13.2	12.9	24.2	3.2	14.2
Hydrometer Reading 3 - Percent Finer	% passed	7.8	2.6	13.2	12.9	21.9	2.6	12.2
Hydrometer Reading 4 - Percent Finer	% passed	5.3	1.4	11.6	8.1	17.2	2.6	10.3
Hydrometer Reading 5 - Percent Finer	% passed	2.9	0.2	8.7	8.1	12.1	1.9	6.1
Hydrometer Reading 6 - Percent Finer	% passed	0.4	0.2	7.3	5.2	9.8	1.3	4.2
Hydrometer Reading 7 - Percent Finer	% passed	0	0	7.3	5.2	5.1	0.7	2.3
Total Organic Carbon	%	17.7	2.3	3.41	26.7 J	17.5 J	0.153 J	26.7 J
Moisture Content	%	267.1	47.9	64.9	330.4	280.8	33.9	354.3
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-35	ZW13-36*	ZW13-36*	ZW13-37*	ZW13-37*	ZW13-37*	ZW13-35
	Sample Name:	ZW13-35-0102	ZW13-36 1'	ZW13-36 2'	ZW13-37 1'	ZW13-37 2'-DUP	ZW13-37 2'	ZW13-35-0204
	Sample Depth (ft):	0.5-2	0-1	1-2	0-1	1-2	1-2	2-4
	Date Sampled:	11/6/13	11/14/13	11/14/13	11/14/13	11/14/13	11/14/13	11/6/13
Analyte	**Unit**							
Gravel	%	0.3	--	--	--	--	--	0
Sand	%	82.3	--	--	--	--	--	96
Coarse Sand	%	0.5	--	--	--	--	--	0.2
Medium Sand	%	4.3	--	--	--	--	--	13.8
Fine Sand	%	77.5	--	--	--	--	--	82
Silt	%	16.7	--	--	--	--	--	3.4
Clay	%	0.7	--	--	--	--	--	0.6
Silt + Clay	%	17.4	--	--	--	--	--	4
Sieve Size 3 inch - Percent Finer	% passed	100	--	--	--	--	--	100
Sieve Size 2 inch - Percent Finer	% passed	100	--	--	--	--	--	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	--	--	--	--	--	100
Sieve Size 1 inch - Percent Finer	% passed	100	--	--	--	--	--	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	--	--	--	--	--	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	--	--	--	--	--	100
Sieve Size #4 - Percent Finer	% passed	99.7	--	--	--	--	--	100
Sieve Size #10 - Percent Finer	% passed	99.2	--	--	--	--	--	99.8
Sieve Size #20 - Percent Finer	% passed	98.7	--	--	--	--	--	97.6
Sieve Size #40 - Percent Finer	% passed	94.9	--	--	--	--	--	86
Sieve Size #60 - Percent Finer	% passed	63	--	--	--	--	--	62.8
Sieve Size #80 - Percent Finer	% passed	32.6	--	--	--	--	--	41.9
Sieve Size #100 - Percent Finer	% passed	22.7	--	--	--	--	--	24.2
Sieve Size #200 - Percent Finer	% passed	17.4	--	--	--	--	--	4
Hydrometer Reading 1 - Percent Finer	% passed	2.3	--	--	--	--	--	2.3
Hydrometer Reading 2 - Percent Finer	% passed	1.7	--	--	--	--	--	1.8
Hydrometer Reading 3 - Percent Finer	% passed	1.2	--	--	--	--	--	1.2
Hydrometer Reading 4 - Percent Finer	% passed	0.7	--	--	--	--	--	0.7
Hydrometer Reading 5 - Percent Finer	% passed	0.7	--	--	--	--	--	0.6
Hydrometer Reading 6 - Percent Finer	% passed	0.09	--	--	--	--	--	0.5
Hydrometer Reading 7 - Percent Finer	% passed	0.09	--	--	--	--	--	0.5
Total Organic Carbon	%	0.8 J	--	--	--	--	--	0.218 J
Moisture Content	%	32.2	--	--	--	--	--	21.4
Percent Solids	%	--	76.4	68.2	51.7	44.5	45.7	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-38	ZW13-38	ZW13-38	ZW13-39	ZW13-39	ZW13-39	ZW13-40
	Sample Name:	ZW13-38-0001	ZW13-38-0102	ZW13-38-0204	ZW13-39-0001	ZW13-39-0102	ZW13-39-0204	ZW13-40-0001
	Sample Depth (ft):	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5
	Date Sampled:	11/6/13	11/6/13	11/6/13	11/6/13	11/6/13	11/6/13	9/30/13
Analyte	**Unit**							
Gravel	%	0.5	1.3	0	1	0	0	1.3
Sand	%	63.6	41.7	93.1	20.6	20.8	97.3	19.8
Coarse Sand	%	1.5	1.4	0.5	1.1	0	0	1
Medium Sand	%	9.8	8.7	1.2	4.4	0.5	8.1	11
Fine Sand	%	52.3	31.6	91.4	15.1	20.3	89.2	7.8
Silt	%	24.1	32.4	2.7	63.3	72.4	2.8	50.7
Clay	%	11.8	24.6	4.2	15.1	6.8	0	28.2
Silt + Clay	%	35.9	57	6.9	78.4	79.2	2.8	78.9
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	99.5	98.7	100	99	100	100	98.7
Sieve Size #10 - Percent Finer	% passed	98	97.3	99.5	97.9	100	100	97.7
Sieve Size #20 - Percent Finer	% passed	95.4	97.1	99.3	97.1	99.7	99.4	91
Sieve Size #40 - Percent Finer	% passed	88.2	88.6	98.3	93.5	99.5	91.9	86.7
Sieve Size #60 - Percent Finer	% passed	47.5	67.8	71.2	88.2	94.1	41.9	83.9
Sieve Size #80 - Percent Finer	% passed	42.1	63.3	41.1	85.7	91.5	20.3	82.5
Sieve Size #100 - Percent Finer	% passed	40.5	61.5	23.6	84.1	88.9	11.8	81.2
Sieve Size #200 - Percent Finer	% passed	35.9	57	6.9	78.4	79.2	2.8	78.9
Hydrometer Reading 1 - Percent Finer	% passed	24.2	44.9	7.7	33.7	20.4	0	45.3
Hydrometer Reading 2 - Percent Finer	% passed	18.5	33.5	6.3	29	17.7	0	38.6
Hydrometer Reading 3 - Percent Finer	% passed	16.6	30.6	5.6	24.4	15	0	35.2
Hydrometer Reading 4 - Percent Finer	% passed	14.6	27.7	4.9	17.4	12.2	0	31.9
Hydrometer Reading 5 - Percent Finer	% passed	11.8	24.6	4.2	15.1	6.8	0	28.2
Hydrometer Reading 6 - Percent Finer	% passed	8.6	18.6	2.8	5.4	3.6	0	19.6
Hydrometer Reading 7 - Percent Finer	% passed	4.8	11.5	1.4	3.1	3.6	0	14
Total Organic Carbon	%	11.8 J	5.63 J	1.9 J	11.8	10.4	0.709	17.2
Moisture Content	%	82	144.9	57.9	153.5	186.6	22.2	151.7
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-40	ZW13-40	ZW13-40	ZW13-41	ZW13-41	ZW13-41	ZW13-42
	Sample Name:	ZW13-40-0001FI	ZW13-40-0102	ZW13-40-0204	ZW13-41-0001	ZW13-41-0102	ZW13-41-0204	ZW13-42-0001
	Sample Depth (ft):	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5
	Date Sampled:	9/30/13	9/30/13	9/30/13	11/6/13	11/6/13	11/6/13	11/5/13
Analyte	**Unit**							
Gravel	%	0.5	0.2	0.2	0.3	2.7	0.1	0.9
Sand	%	23	16.1	30.1	25.6	32.2	83.2	51.6
Coarse Sand	%	0.7	0.2	0.1	0.3	1.1	2.4	2.3
Medium Sand	%	14.5	9	13	5	1.6	28.8	35.3
Fine Sand	%	7.8	6.9	17	20.3	29.5	52	14
Silt	%	46.4	61	48.6	65.1	49.2	15.6	31.1
Clay	%	30.1	22.7	21.1	9	15.9	1.1	16.4
Silt + Clay	%	76.5	83.7	69.7	74.1	65.1	16.7	47.5
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	98.6	100	100
Sieve Size #4 - Percent Finer	% passed	99.5	99.8	99.8	99.7	97.3	99.9	99.1
Sieve Size #10 - Percent Finer	% passed	98.8	99.6	99.7	99.4	96.2	97.5	96.8
Sieve Size #20 - Percent Finer	% passed	89.3	94.9	92.5	95.9	95.8	84.5	68.6
Sieve Size #40 - Percent Finer	% passed	84.3	90.6	86.7	94.4	94.6	68.7	61.5
Sieve Size #60 - Percent Finer	% passed	81.2	87.9	81.6	88.1	88.2	35.2	53.7
Sieve Size #80 - Percent Finer	% passed	79.8	86.8	79.3	85.1	82.2	25.2	51.3
Sieve Size #100 - Percent Finer	% passed	78.9	86	77.8	82.9	77.8	20.9	50.2
Sieve Size #200 - Percent Finer	% passed	76.5	83.7	69.7	74.1	65.1	16.7	47.5
Hydrometer Reading 1 - Percent Finer	% passed	46.4	46.3	69.1	24.5	35.1	6.7	39.4
Hydrometer Reading 2 - Percent Finer	% passed	40	33.5	36.4	19.4	30.8	4.8	30.5
Hydrometer Reading 3 - Percent Finer	% passed	36.8	28.3	27.6	16.8	26.6	3	21.6
Hydrometer Reading 4 - Percent Finer	% passed	33.6	28.3	23.3	11.6	20.2	2	17.1
Hydrometer Reading 5 - Percent Finer	% passed	30.1	22.7	21.1	9	15.9	1.1	16.4
Hydrometer Reading 6 - Percent Finer	% passed	21.9	17.2	14.2	3.4	7.1	-0.8	14.9
Hydrometer Reading 7 - Percent Finer	% passed	16.5	13.7	9.8	3.4	2.8	-0.9	14.9
Total Organic Carbon	%	16	17.9	18	20.7	11.7	13	34.8 J
Moisture Content	%	154	259.1	307.5	256.1	215.1	79.3	378.3
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-42	ZW13-42	ZW13-43	ZW13-43	ZW13-43	ZW13-44	ZW13-44
	Sample Name:	ZW13-42-0102	ZW13-42-0204	ZW13-43-0001	ZW13-43-0102	ZW13-43-0204	ZW13-44-0001	ZW13-44-0102
	Sample Depth (ft):	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5	0.5-2
	Date Sampled:	11/5/13	11/5/13	9/30/13	9/30/13	9/30/13	9/30/13	9/30/13
Analyte	**Unit**							
Gravel	%	1.6	0	0.3	0.6	0	0.7	0
Sand	%	26.9	87.7	76	89.6	93	52.5	60.7
Coarse Sand	%	7.2	0.4	2.7	1.6	1.3	1.2	0.2
Medium Sand	%	14.3	4.4	18.7	12.9	1.9	14.9	32.2
Fine Sand	%	5.4	82.9	54.6	75.1	89.8	36.4	28.3
Silt	%	65.1	10.4	21.9	8.4	5.8	34.8	36.3
Clay	%	6.4	1.9	1.8	1.4	1.2	12	3
Silt + Clay	%	71.5	12.3	23.7	9.8	7	46.8	39.3
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	100	100	100
Sieve Size #4 - Percent Finer	% passed	98.4	100	99.7	99.4	100	99.3	100
Sieve Size #10 - Percent Finer	% passed	91.2	99.6	97	97.8	98.7	98.1	99.8
Sieve Size #20 - Percent Finer	% passed	80.9	98.6	89.1	93.9	98.6	88.5	73.7
Sieve Size #40 - Percent Finer	% passed	76.9	95.2	78.3	84.9	96.8	83.2	67.6
Sieve Size #60 - Percent Finer	% passed	74.6	63.7	51.8	59.7	69.1	70.3	60.7
Sieve Size #80 - Percent Finer	% passed	73.4	35.3	40.1	41.3	29.9	62.1	53.6
Sieve Size #100 - Percent Finer	% passed	72.8	20.7	34.4	30.4	15.2	57.7	48.4
Sieve Size #200 - Percent Finer	% passed	71.5	12.3	23.7	9.8	7	46.8	39.3
Hydrometer Reading 1 - Percent Finer	% passed	18.5	4	10	3.2	1.8	36	24.6
Hydrometer Reading 2 - Percent Finer	% passed	10.8	3	5	3.2	1.2	26	10.2
Hydrometer Reading 3 - Percent Finer	% passed	7	3	4	3.2	1.2	18	3
Hydrometer Reading 4 - Percent Finer	% passed	7	3	3	1.6	1.2	14	3
Hydrometer Reading 5 - Percent Finer	% passed	6.4	1.9	1.8	1.4	1.2	12	3
Hydrometer Reading 6 - Percent Finer	% passed	5.1	0.7	1.7	1.3	1.1	9.4	2.4
Hydrometer Reading 7 - Percent Finer	% passed	5.1	0.7	1.3	1.1	0.8	4.7	1.2
Total Organic Carbon	%	18.4 J	1.56 J	9.86	12.1	1.37	23.2	52
Moisture Content	%	486.6	49.5	93.4	64.3	42.4	216.7	561.6
Percent Solids	%	--	--	--	--	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-45*	ZW13-45*	ZW13-46*	ZW13-46*	ZW13-44	ZW13-47	ZW13-47
	Sample Name:	ZW13-45 1'	ZW13-45 2'	ZW13-46 1'	ZW13-46 2'	ZW13-44-0204	ZW13-47-0001	ZW13-47-0102
	Sample Depth (ft):	0-1	1-2	0-1	1-2	2-4	0-0.5	0.5-2
	Date Sampled:	11/14/13	11/14/13	11/14/13	11/14/13	9/30/13	11/8/13	11/8/13
Analyte	**Unit**							
Gravel	%	--	--	--	--	0	3	0.3
Sand	%	--	--	--	--	93.7	29.1	68.2
Coarse Sand	%	--	--	--	--	0.6	2.8	0.5
Medium Sand	%	--	--	--	--	2	8.7	3.1
Fine Sand	%	--	--	--	--	91.1	17.6	64.6
Silt	%	--	--	--	--	5.6	59.2	27.5
Clay	%	--	--	--	--	0.8	8.7	4
Silt + Clay	%	--	--	--	--	6.4	67.9	31.5
Sieve Size 3 inch - Percent Finer	% passed	--	--	--	--	100	100	100
Sieve Size 2 inch - Percent Finer	% passed	--	--	--	--	100	100	100
Sieve Size 1.5 inch - Percent Finer	% passed	--	--	--	--	100	100	100
Sieve Size 1 inch - Percent Finer	% passed	--	--	--	--	100	100	100
Sieve Size 0.75 inch - Percent Finer	% passed	--	--	--	--	100	100	100
Sieve Size 0.375 inch - Percent Finer	% passed	--	--	--	--	100	100	100
Sieve Size #4 - Percent Finer	% passed	--	--	--	--	100	97	99.7
Sieve Size #10 - Percent Finer	% passed	--	--	--	--	99.4	94.2	99.2
Sieve Size #20 - Percent Finer	% passed	--	--	--	--	97.8	90.1	97.6
Sieve Size #40 - Percent Finer	% passed	--	--	--	--	97.4	85.5	96.1
Sieve Size #60 - Percent Finer	% passed	--	--	--	--	83.6	79.1	77.3
Sieve Size #80 - Percent Finer	% passed	--	--	--	--	55.6	76.2	56.1
Sieve Size #100 - Percent Finer	% passed	--	--	--	--	32.5	74.2	44.4
Sieve Size #200 - Percent Finer	% passed	--	--	--	--	6.3	67.9	31.5
Hydrometer Reading 1 - Percent Finer	% passed	--	--	--	--	0.8	34.7	8.6
Hydrometer Reading 2 - Percent Finer	% passed	--	--	--	--	0.8	19.8	5.6
Hydrometer Reading 3 - Percent Finer	% passed	--	--	--	--	0.8	12.4	5.6
Hydrometer Reading 4 - Percent Finer	% passed	--	--	--	--	0.8	8.7	4
Hydrometer Reading 5 - Percent Finer	% passed	--	--	--	--	0.8	8.7	4
Hydrometer Reading 6 - Percent Finer	% passed	--	--	--	--	0.5	5	2.5
Hydrometer Reading 7 - Percent Finer	% passed	--	--	--	--	0.3	5	1.8
Total Organic Carbon	%	--	--	--	--	3.82	38.2 J	5.56 J
Moisture Content	%	--	--	--	--	53.2	637.8	48.5
Percent Solids	%	13	10.3	17.1	21.6	--	--	--

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-3 SEDIMENT RESULTS FOR GRAIN SIZE

	Sample Location:	ZW13-47	ZW13-48	ZW13-48	ZW13-48	ZW13-49*	ZW13-49*	ZW13-50 1'	ZW13-50*
	Sample Name:	ZW13-47-0204	ZW13-48-0001	ZW13-48-0102	ZW13-48-020	ZW13-49 1'	ZW13-49 2'	ZW13-50 1'	ZW13-50 2'
	Sample Depth (ft):	2-4	0-0.5	0.5-2	2-4	0-1	1-2	0-1	1-2
	Date Sampled:	11/8/13	11/8/13	11/8/13	11/8/13	11/14/13	11/14/13	11/14/13	11/14/13
Analyte	**Unit**								
Gravel	%	0	0	0	0	--	--	--	--
Sand	%	30.4	57	40.6	81.4	--	--	--	--
Coarse Sand	%	0	0	0	1	--	--	--	--
Medium Sand	%	2.8	14.3	6.9	7.1	--	--	--	--
Fine Sand	%	27.6	42.7	33.7	73.3	--	--	--	--
Silt	%	55.2	33.4	40.2	14.2	--	--	--	--
Clay	%	14.4	9.6	19.2	4.4	--	--	--	--
Silt + Clay	%	69.6	43	59.4	18.6	--	--	--	--
Sieve Size 3 inch - Percent Finer	% passed	100	100	100	100	--	--	--	--
Sieve Size 2 inch - Percent Finer	% passed	100	100	100	100	--	--	--	--
Sieve Size 1.5 inch - Percent Finer	% passed	100	100	100	100	--	--	--	--
Sieve Size 1 inch - Percent Finer	% passed	100	100	100	100	--	--	--	--
Sieve Size 0.75 inch - Percent Finer	% passed	100	100	100	100	--	--	--	--
Sieve Size 0.375 inch - Percent Finer	% passed	100	100	100	100	--	--	--	--
Sieve Size #4 - Percent Finer	% passed	100	100	100	100	--	--	--	--
Sieve Size #10 - Percent Finer	% passed	100	100	100	99	--	--	--	--
Sieve Size #20 - Percent Finer	% passed	98.1	93.1	96.6	95.5	--	--	--	--
Sieve Size #40 - Percent Finer	% passed	97.2	85.7	93.1	91.9	--	--	--	--
Sieve Size #60 - Percent Finer	% passed	89.7	72	79.4	56.2	--	--	--	--
Sieve Size #80 - Percent Finer	% passed	83.6	63.7	73	46.1	--	--	--	--
Sieve Size #100 - Percent Finer	% passed	79.9	57.3	68.6	38	--	--	--	--
Sieve Size #200 - Percent Finer	% passed	69.6	43	59.4	18.6	--	--	--	--
Hydrometer Reading 1 - Percent Finer	% passed	34.8	35.6	39.7	8.1	--	--	--	--
Hydrometer Reading 2 - Percent Finer	% passed	25.7	15.4	24.8	6.9	--	--	--	--
Hydrometer Reading 3 - Percent Finer	% passed	21.2	9.6	21.1	5.7	--	--	--	--
Hydrometer Reading 4 - Percent Finer	% passed	16.6	9.6	21.1	5	--	--	--	--
Hydrometer Reading 5 - Percent Finer	% passed	14.4	9.6	19.2	4.4	--	--	--	--
Hydrometer Reading 6 - Percent Finer	% passed	7.6	6.7	13.6	2.6	--	--	--	--
Hydrometer Reading 7 - Percent Finer	% passed	3	3.9	9.9	1.9	--	--	--	--
Total Organic Carbon	%	9.4 J	34.3 J	13.1 J	6.05 J	--	--	--	--
Moisture Content	%	202.7	238.6	185.6	47.4	--	--	--	--
Percent Solids	%	--	--	--	--	37.8	29.7	58.9	29.7

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected

TABLE 3-4 SEDIMENT RESULTS FOR OIL AND GREASE AND PETROLEUM HYDROCARBON FRACTIONS

	Sample Location:	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25
	Sample Name:	ZW13-25-0001	ZW13-25-0102	ZW13-25-0204	ZW13-25-0406	ZW13-25-0608	ZW13-25-0810	ZW13-25-1012	ZW13-25-1214
	Sample Depth (ft):	0-0.5	0.5-2	2-4	4-6	6-8	8-10	10-12	12-14
	Date Sampled:	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13
Analyte	**Unit**								
Oil and Grease	mg/kg	4250 J	4280 J	1330 J	203 UJ	193 UJ	198 UJ	194 UJ	205 UJ
Petroleum Hydrocarbon Fractions									
Gasoline Range Organics (C6-C10)	mg/kg	69	41	58	20	3.3 J	5.6 U	5.4 U	5.9 U
Diesel Range Organics (C10-C20)	mg/kg	490	770	670	19	15	8.1 U	16	17
Oil Range Organics (C20-C36)	mg/kg	1100	1900	1800	33	10	8.1 U	14	28

	Sample Location:	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26
	Sample Name:	ZW13-26-0001	ZW13-26-0102	ZW13-26-0102FD	ZW13-26-0204	ZW13-26-0204FD	ZW13-26-0406	ZW13-26-0608	ZW13-26-1012
	Sample Depth (ft):	0-0.5	0.5-2	0.5-2	2-4	2-4	4-6	6-8	10-12
	Date Sampled:	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13
Analyte	**Unit**								
Oil and Grease	mg/kg	6320	4150	3740	568	525	43.5 J	38.2 J	195 U
Petroleum Hydrocarbon Fractions									
Gasoline Range Organics (C6-C10)	mg/kg	63 U	41 U	40 U	14 U	13 U	5.7 U	5.7 U	5.8 U
Diesel Range Organics (C10-C20)	mg/kg	550	760	630	170	160	8	7.7 U	12
Oil Range Organics (C20-C36)	mg/kg	2100	2200	1800	410	400	8 U	7.7 U	26

	Sample Location:	ZW13-26	ZW13-27	ZW13-27	ZW13-27	ZW13-27	ZW13-27	ZW13-27	ZW13-28
	Sample Name:	ZW13-26-1214	ZW13-27-0001	ZW13-27-0102	ZW13-27-0204	ZW13-27-0406	ZW13-27-0608	ZW13-27-0810	ZW13-28-0001
	Sample Depth (ft):	12-14	0-0.5	0.5-2	2-4	4-6	6-8	8-10	0-0.5
	Date Sampled:	11/9/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/9/13
Analyte	**Unit**								
Oil and Grease	mg/kg	35.5 J	3190 J	3260 J	709 UJ	2210 J	804 J	203 UJ	1160
Petroleum Hydrocarbon Fractions									
Gasoline Range Organics (C6-C10)	mg/kg	5.9 U	47 U	40 J	16 J	14 J	5.3 J	5.9 U	15 U
Diesel Range Organics (C10-C20)	mg/kg	9.7	200	150	86	190	110	8.2 U	110
Oil Range Organics (C20-C36)	mg/kg	15	700	630	300	660	410	10	520

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected
J = Result is less than the Reporting Limit (RL), but greater than or equal to the Method Detection Limit and the concentration is an approximate value
B = Method blank contamination
mg/kg = milligrams per kilogram

TABLE 3-4 SEDIMENT RESULTS FOR OIL AND GREASE AND PETROLEUM HYDROCARBON FRACTIONS

	Sample Location:	ZW13-28	ZW13-28	ZW13-28	ZW13-28	ZW13-28	ZW13-29	ZW13-29	ZW13-29
	Sample Name:	ZW13-28-0102	ZW13-28-0204	ZW13-28-0406	ZW13-28-0608	ZW13-28-0810	ZW13-29-0001	ZW13-29-0102	ZW13-29-0204
	Sample Depth (ft):	0.5-2	2-4	4-6	6-8	8-10	0-0.5	0.5-2	2-4
	Date Sampled:	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13
Analyte	**Unit**								
Oil and Grease	mg/kg	783	194 U	195 U	192 U	208 U	1170 J	2170	1090
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	8.9 U	5.6 U	5.5 U	5.4 U	6.1 U	43 U	37 U	19 U
Diesel Range Organics (C10-C20)	mg/kg	62	7.8 U	7.9 U	7.6 U	9.7	210	270	210
Oil Range Organics (C20-C36)	mg/kg	300	8.3	10	7.6 U	18	930	1100	700

	Sample Location:	ZW13-29	ZW13-29	ZW13-29	ZW13-30	ZW13-30	ZW13-30	ZW13-30	ZW13-30
	Sample Name:	ZW13-29-0406	ZW13-29-0608	ZW13-29-0810	ZW13-30-0001	ZW13-30-0001FD	ZW13-30-0102	ZW13-30-0102FD	ZW13-30-0204
	Sample Depth (ft):	4-6	6-8	8-10	0-0.5	0-0.5	0.5-2	0.5-2	2-4
	Date Sampled:	11/9/13	11/9/13	11/9/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13
Analyte	**Unit**								
Oil and Grease	mg/kg	272 J	230 J	201 U	2550 J	10200 J	5080 J	674 UJ	550 UJ
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	16 U	7.1 U	6 U	30 U	28 U	18 U	20 U	7.8 J
Diesel Range Organics (C10-C20)	mg/kg	330	35	8 U	20000 J	970 J	380	190	92
Oil Range Organics (C20-C36)	mg/kg	720	130	8 U	43000 J	4500 J	1700	890	370

	Sample Location:	ZW13-30	ZW13-31	ZW13-31	ZW13-31	ZW13-32	ZW13-32	ZW13-32	ZW13-33
	Sample Name:	ZW13-30-0204FD	ZW13-31-0001	ZW13-31-0102	ZW13-31-0204	ZW13-32-0001	ZW13-32-0102	ZW13-32-0204	ZW13-33-0001
	Sample Depth (ft):	2-4	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5
	Date Sampled:	11/8/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13
Analyte	**Unit**								
Oil and Grease	mg/kg	585 UJ	5030 J	353 UJ	315 UJ	90100 J	482 J	395 UJ	56500 J
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	17 U	21 U	12 U	6.9 U	78	16	11 U	23 U
Diesel Range Organics (C10-C20)	mg/kg	110 U	850	37	26 U	54000	280	95	4100
Oil Range Organics (C20-C36)	mg/kg	330	3200	170	94	57000	360	220	13000

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected
J = Result is less than the Reporting Limit (RL), but greater than or equal to the Method Detection Limit and the concentration is an approximate value
B = Method blank contamination
mg/kg = milligrams per kilogram

TABLE 3-4 SEDIMENT RESULTS FOR OIL AND GREASE AND PETROLEUM HYDROCARBON FRACTIONS

	Sample Location:	ZW13-33	ZW13-33	ZW13-33	ZW13-33	ZW13-34	ZW13-34	ZW13-34	ZW13-35
	Sample Name:	ZW13-33-0102	ZW13-33-0102FD	ZW13-33-0204	ZW13-33-0204FD	ZW13-34-0001	ZW13-34-0102	ZW13-34-0204	ZW13-35-0001
	Sample Depth (ft):	0.5-2	0.5-2	2-4	2-4	0-0.5	0.5-2	2-4	0-0.5
	Date Sampled:	11/7/13	11/7/13	11/7/13	11/7/13	11/6/13	11/6/13	11/6/13	11/6/13
Analyte	**Unit**								
Oil and Grease	mg/kg	1170 J	744 J	250 UJ	276 UJ	132000 J	850 J	212 UJ	4740 J
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	17 U	19 U	7.1 U	7.7 U	17 U	19 U	6.1 U	22 U
Diesel Range Organics (C10-C20)	mg/kg	220	150	16	18	42000	180	8.4 U	2300
Oil Range Organics (C20-C36)	mg/kg	690	530	46	53	110000	730	18	4400

	Sample Location:	ZW13-35	ZW13-35	ZW13-36*	ZW13-36*	ZW13-37*	ZW13-37*	ZW13-37*	ZW13-38
	Sample Name:	ZW13-35-0102	ZW13-35-0204	ZW13-36 1'	ZW13-36 2'	ZW13-37 1'	ZW13-37 2'	ZW13-37 2'-DUP	ZW13-38-0001
	Sample Depth (ft):	0.5-2	2-4	0-1	1-2	0-1	1-2	1-2	0-0.5
	Date Sampled:	11/6/13	11/6/13	11/14/13	11/14/13	11/14/13	11/14/13	11/14/13	11/6/13
Analyte	**Unit**								
Oil and Grease	mg/kg	217 UJ	202 UJ	--	--	--	--	--	295 UJ
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	6.4 U	6 U	7.4 U	8.7 U	12 U	16 U	18 U	8.5 U
Diesel Range Organics (C10-C20)	mg/kg	200	8.1 U	33 U	37 U	48 U	55 U	56 U	25
Oil Range Organics (C20-C36)	mg/kg	330	17	130 U	160	330	320	310	130

	Sample Location:	ZW13-38	ZW13-38	ZW13-39	ZW13-39	ZW13-39	ZW13-40	ZW13-40	ZW13-40
	Sample Name:	ZW13-38-0102	ZW13-38-0204	ZW13-39-0001	ZW13-39-0102	ZW13-39-0204	ZW13-40-0001	ZW13-40-0001FD	ZW13-40-0102
	Sample Depth (ft):	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5	0-0.5	0.5-2
	Date Sampled:	11/6/13	11/6/13	11/6/13	11/6/13	11/6/13	9/30/13	9/30/13	9/30/13
Analyte	**Unit**								
Oil and Grease	mg/kg	375 UJ	248 UJ	617 J	459 J	225 UJ	1120 J	978 J	397 J
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	11 U	7.4 U	13 U	11 U	6.4 U	12 U	12 U	17 U
Diesel Range Organics (C10-C20)	mg/kg	20	12	53	43	9.5	82 U	83	94 U
Oil Range Organics (C20-C36)	mg/kg	110	70	220	200	22	530	510	490

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected
J = Result is less than the Reporting Limit (RL), but greater than or equal to the Method Detection Limit and the concentration is an approximate value
B = Method blank contamination
mg/kg = milligrams per kilogram

TABLE 3-4 SEDIMENT RESULTS FOR OIL AND GREASE AND PETROLEUM HYDROCARBON FRACTIONS

	Sample Location:	ZW13-40	ZW13-41	ZW13-41	ZW13-41	ZW13-42	ZW13-42	ZW13-42	ZW13-43
	Sample Name:	ZW13-40-0204	ZW13-41-0001	ZW13-41-0102	ZW13-41-0204	ZW13-42-0001	ZW13-42-0102	ZW13-42-0204	ZW13-43-0001
	Sample Depth (ft):	2-4	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5
	Date Sampled:	9/30/13	11/6/13	11/6/13	11/6/13	11/5/13	11/5/13	11/5/13	9/30/13
Analyte	**Unit**								
Oil and Grease	mg/kg	107 J	5900 J	530 J	567 UJ	897 UJ	926 UJ	253 UJ	1420 J
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	20 U	19 U	15 U	17 U	27 U	28 U	7.4 U	8.8 U
Diesel Range Organics (C10-C20)	mg/kg	140	830 U	250 U	54 U	110	230 U	21 U	120 U
Oil Range Organics (C20-C36)	mg/kg	620	5600	1300	190	370	510	56	450

	Sample Location:	ZW13-43	ZW13-43	ZW13-44	ZW13-44	ZW13-44	ZW13-45*	ZW13-45*	ZW13-46*
	Sample Name:	ZW13-43-0102	ZW13-43-0204	ZW13-44-0001	ZW13-44-0102	ZW13-44-0204	ZW13-45 1'	ZW13-45 2'	ZW 13 - 46 1'
	Sample Depth (ft):	0.5-2	2-4	0-0.5	0.5-2	2-4	0-1	1-2	0-1
	Date Sampled:	9/30/13	9/30/13	9/30/13	9/30/13	9/30/13	11/14/13	11/14/13	11/14/13
Analyte	**Unit**								
Oil and Grease	mg/kg	115 J	274 UJ	311 J	1050 UJ	208 UJ	--	--	--
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	8.6 U	7.7 U	13 U	32 U	8.3	67 U	89 U	54 U
Diesel Range Organics (C10-C20)	mg/kg	15	16	170 U	170	16	190 U	240 U	150 U
Oil Range Organics (C20-C36)	mg/kg	80	65	720	490	35	1500	1600	850

	Sample Location:	ZW13-46*	ZW13-47	ZW13-47	ZW13-47	ZW13-48	ZW13-48	ZW13-48	ZW13-49*
	Sample Name:	ZW 13 - 46 2'	ZW13-47-0001	ZW13-47-0102	ZW13-47-0204	ZW13-48-0001	ZW13-48-0102	ZW13-48-0204	ZW13-49 1'
	Sample Depth (ft):	1-2	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-1
	Date Sampled:	11/14/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/14/13
Analyte	**Unit**								
Oil and Grease	mg/kg	--	92500 J	67800 J	616 J	9270 J	2610 J	369 J	--
Total Petroleum Hydrocarbons									
Gasoline Range Organics (C6-C10)	mg/kg	38 U	43 U	15	17 U	16 U	14 U	9.8 U	20 U
Diesel Range Organics (C10-C20)	mg/kg	120	4200	4900	140 U	1200	930	33	120
Oil Range Organics (C20-C36)	mg/kg	730	24000	12000	330	4500	1800	85	450

Notes:
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J = Result is less than the Reporting Limit (RL), but greater than or equal to the Method Detection Limit and the concentration is an approximate value
B = Method blank contamination
mg/kg = milligrams per kilogram

TABLE 3-4 SEDIMENT RESULTS FOR OIL AND GREASE AND PETROLEUM HYDROCARBON FRACTIONS

	Sample Location:	ZW13-49*	ZW13-50*	ZW13-50*
	Sample Name:	ZW13-49 2'	ZW13-50 1'	ZW13-50 2'
	Sample Depth (ft):	1-2	0-1	1-2
	Date Sampled:	11/14/13	11/14/13	11/14/13
Analyte	**Unit**			
Oil and Grease	mg/kg	--	--	--
Total Petroleum Hydrocarbons				
Gasoline Range Organics (C6-C10)	mg/kg	28 U	12 U	28 U
Diesel Range Organics (C10-C20)	mg/kg	210	42 U	150
Oil Range Organics (C20-C36)	mg/kg	660	250	820

Notes:
* Locations sampled by MDEQ
U = Indicates the analyte was analyzed for but not detected
J = Result is less than the Reporting Limit (RL), but greater than or equal to the Method Detection Limit and the concentration is an approximate value
B = Method blank contamination
mg/kg = milligrams per kilogram

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25	ZW13-25
			Sample Name:	ZW13-25-0001	ZW13-25-0102	ZW13-25-0204	ZW13-25-0406	ZW13-25-0608	ZW13-25-0810	ZW13-25-1012	ZW13-25-1214
			Sample Depth (ft):	0-0.5	0.5-2	2-4	4-6	6-8	8-10	10-12	12-14
			Date Sampled:	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13	11/5/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	**14.9**	**18.2**	**40.3**	2.8	1.1	0.93 J	3.3	4.3
Barium	NSL	NSL	mg/kg	143 J	112 J	167 J	21.6 J	16.9 J	10.5 J	31.5 J	58.9 J
Cadmium	0.99	4.98	mg/kg	**1.8 J**	**4.6 J**	**1 J**	0.12 J	0.11 J	0.11 J	0.18 J	0.23 J
Chromium	43.4	111	mg/kg	10.5 J	11.6 J	9.4 J	5.3 J	4.5 J	3.3 J	9 J	17.4 J
Copper	31.6	149	mg/kg	**92.7**	**116**	**96.9**	4.2	2.8	2.2 J	6.7	13.5
Lead	35.8	128	mg/kg	**770 J**	**875 J**	**529 J**	17.8 J	2.5 J	1.8 J	5.1 J	9.3 J
Mercury	0.18	1.06	mg/kg	**0.24 J**	**0.45 J**	**0.31 J**	0.43 UJ	0.39 UJ	0.45 UJ	0.43 UJ	0.033 J
Nickel	22.7	48.6	mg/kg	11.4 J	12 J	10 J	5.3 J	4.2 J	2.9 J	8.7 J	17.4 J
Selenium	NSL	NSL	mg/kg	2.9 J	2.4 J	1.6 J	0.61 J	0.54 J	3.5 U	0.83 J	1.1 J
Silver	NSL	NSL	mg/kg	0.22 J	0.28 J	0.13 J	0.95 U	0.94 U	0.99 U	0.93 U	0.08 J
Zinc	121	459	mg/kg	**6930**	**14600**	**1910**	12	9.4	6.8	19.6	37.1

Notes:
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N = Spiked sample recovery not within control limits.
U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
TEC = Threshold effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
PEC = Probable effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26	ZW13-26
			Sample Name:	ZW13-26-0001	ZW13-26-0102	ZW13-26-0102FD	ZW13-26-0204	ZW13-26-0204FD	ZW13-26-0406	ZW13-26-0608	ZW13-26-1012
			Sample Depth (ft):	0-0.5	0.5-2	0.5-2	2-4	2-4	4-6	6-8	10-12
			Date Sampled:	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	9.3	7.8	6.7	5.2	4.8	0.78 J	0.81 J	3.2
Barium	NSL	NSL	mg/kg	101	76.9	62.3	47.3	42	6.5 J	11 J	50.6
Cadmium	0.99	4.98	mg/kg	0.55	0.63	0.53	0.28 J	0.26 J	0.07 J	0.11 J	0.19 J
Chromium	43.4	111	mg/kg	12.6 J	9.2 J	7.3 J	6.3 J	5 J	1.8 J	3.1 J	16.2 J
Copper	31.6	149	mg/kg	**55.7**	**52.3**	**40.2**	12.2	11	1.3 J	4.6	13.1
Lead	35.8	128	mg/kg	**824 J**	**939 J**	**789 J**	**203 J**	**174 J**	4.6 J	1.8 J	8.9 J
Mercury	0.18	1.06	mg/kg	**0.23 J**	**0.24**	**0.25**	0.05 J	0.051 J	0.1 U	0.097 U	0.0094 J
Nickel	22.7	48.6	mg/kg	12.1	9.6	7.6	6 J	5.1 J	1.7 J	2.7 J	15.7
Selenium	NSL	NSL	mg/kg	1.2 J	2.1 J	1.6 J	7 U	1.1 J	2.8 U	2.9 U	1.1 J
Silver	NSL	NSL	mg/kg	0.15 J	0.06 J	0.1 J	2 U	1.9 U	0.79 U	0.82 U	0.8 U
Zinc	121	459	mg/kg	**123 J**	116 J	97.3 J	22.9 J	19.3 J	4.7 U	8.7 J	33.9 J

Notes:
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NSL = No screening level
mg/kg = Milligrams per kilogram.
TEC = Threshold effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
PEC = Probable effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-26	ZW13-27	ZW13-27	ZW13-27	ZW13-27	ZW13-27	ZW13-27	ZW13-28
			Sample Name:	ZW13-26-1214	ZW13-27-0001	ZW13-27-0102	ZW13-27-0204	ZW13-27-0406	ZW13-27-0608	ZW13-27-0810	ZW13-28-0001
			Sample Depth (ft):	12-14	0-0.5	0.5-2	2-4	4-6	6-8	8-10	0-0.5
			Date Sampled:	11/9/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/9/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	2.6	8.7	9.5	7.2	**10.1**	5.4	2.5	5.1
Barium	NSL	NSL	mg/kg	31.6	82.8	73.2	49.8	83.8	37.7 J	61.7	64.2
Cadmium	0.99	4.98	mg/kg	0.16 J	0.55	0.7	0.23 J	0.73	0.26 J	0.19 J	0.45 J
Chromium	43.4	111	mg/kg	7.8 J	12.9	15.4	10	18.4	7.9	13.7	14.1 J
Copper	31.6	149	mg/kg	6.2	28.7 J	**35.3 J**	10.2 J	**40.8 J**	7.5 J	10.8 J	16.3
Lead	35.8	128	mg/kg	4.4 J	**449**	**646**	**243**	**778**	**190**	7.9	**307 J**
Mercury	0.18	1.06	mg/kg	0.11 U	0.061 J	0.091 J	0.033 J	0.18	0.047 J	0.018 J	0.054 J
Nickel	22.7	48.6	mg/kg	7.8	13.2	14.9	7.7	17	6.7 J	12.5	13.3
Selenium	NSL	NSL	mg/kg	0.59 J	3	3.4	1.6 J	2.9 J	1.5 J	1.2 J	1.5 J
Silver	NSL	NSL	mg/kg	0.79 U	0.15 J	0.16 J	0.83 U	0.15 J	2.3 U	0.93 U	2.2 U
Zinc	121	459	mg/kg	17.4 J	83.3 J	109 J	25.7 J	**143 J**	22.1 J	28.5 J	67.6 J

Notes:
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NSL = No screening level
mg/kg = Milligrams per kilogram.
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Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-28	ZW13-28	ZW13-28	ZW13-28	ZW13-28	ZW13-29	ZW13-29	ZW13-29
			Sample Name:	ZW13-28-0102	ZW13-28-0204	ZW13-28-0406	ZW13-28-0608	ZW13-28-0810	ZW13-29-0001	ZW13-29-0102	ZW13-29-0204
			Sample Depth (ft):	0.5-2	2-4	4-6	6-8	8-10	0-0.5	0.5-2	2-4
			Date Sampled:	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13	11/9/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	3.2	1.7	1.4	0.65 J	3	6.5	9.5	**14.5**
Barium	NSL	NSL	mg/kg	18.9 J	2.6 J	2.7 J	2.3 J	64.7	82.3	98.4	72.1
Cadmium	0.99	4.98	mg/kg	0.21 J	0.049 J	0.053 J	0.023 J	0.21 J	0.54	0.94	0.74
Chromium	43.4	111	mg/kg	6.4 J	1.7 J	1.8 J	1.6 J	16.7 J	16.1 J	22.3 J	**58 J**
Copper	31.6	149	mg/kg	6.9	0.6 J	0.72 J	0.76 J	13.2	21.3	28.5	**65.4**
Lead	35.8	128	mg/kg	**142 J**	0.97 J	2.9 J	0.74 J	9.8 J	**251 J**	**409 J**	**378 J**
Mercury	0.18	1.06	mg/kg	0.024 J	0.11 U	0.1 U	0.1 U	0.011 J	0.089 J	**0.21 J**	0.12 J
Nickel	22.7	48.6	mg/kg	5.8	1.2 J	1.3 J	1.2 J	15.9	12.6	16.6	**48.4**
Selenium	NSL	NSL	mg/kg	0.79 J	2.7 U	2.9 U	2.7 U	1 J	2.4 J	3.1	3 J
Silver	NSL	NSL	mg/kg	1.4 U	0.78 U	0.84 U	0.77 U	0.069 J	0.11 J	0.15 J	0.18 J
Zinc	121	459	mg/kg	28.1 J	4.7 U	5 U	4.6 U	39 J	78.7 J	**145 J**	**591 J**

Notes:
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U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
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PEC = Probable effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-29	ZW13-29	ZW13-29	ZW13-30	ZW13-30	ZW13-30	ZW13-30	ZW13-30
			Sample Name:	ZW13-29-0406	ZW13-29-0608	ZW13-29-0810	ZW13-30-0001	ZW13-30-0001FD	ZW13-30-0102	ZW13-30-0102FD	ZW13-30-0204
			Sample Depth (ft):	4-6	6-8	8-10	0-0.5	0-0.5	0.5-2	0.5-2	2-4
			Date Sampled:	11/9/13	11/9/13	11/9/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	7.3	2.8	0.97	**27.8**	**23.5**	9.2	**11.4**	**11**
Barium	NSL	NSL	mg/kg	75.4	18.4 J	3.9 J	64.1	44	50.4	49.3	67.2
Cadmium	0.99	4.98	mg/kg	0.65 J	0.17 J	0.45 U	0.47	0.34 J	0.32 J	0.34 J	0.4 J
Chromium	43.4	111	mg/kg	16.9 J	5 J	1.7 J	16.6	11	19	17.3	17.5
Copper	31.6	149	mg/kg	20	4.2	0.36 J	**69.6 J**	**52.4 J**	13.9 J	13.3 J	11.6 J
Lead	35.8	128	mg/kg	**253 J**	**46.6 J**	0.51 J	**19300**	**7090**	**270**	**143**	7.6
Mercury	0.18	1.06	mg/kg	0.13 J	0.024 J	0.11 U	**0.26 J**	**0.64**	0.039 J	0.052 J	1.2 U
Nickel	22.7	48.6	mg/kg	12.7	3.7 J	1.1 J	22.7	22.1	15.9	14.1	13.3
Selenium	NSL	NSL	mg/kg	1.9 J	0.73 J	3.1 U	7.8	6.6	2 J	1.8 J	2.5 J
Silver	NSL	NSL	mg/kg	2.2 U	1 U	0.89 U	0.34 J	0.16 J	0.88 U	0.81 U	2.7 U
Zinc	121	459	mg/kg	**142 J**	22.5 J	5.4 U	**158 J**	121 J	51.3 J	42.1 J	44 J

Notes:
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U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
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PEC = Probable effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-30	ZW13-31	ZW13-31	ZW13-31	ZW13-32	ZW13-32	ZW13-32	ZW13-33
			Sample Name:	ZW13-30-0204FD	ZW13-31-0001	ZW13-31-0102	ZW13-31-0204	ZW13-32-0001	ZW13-32-0102	ZW13-32-0204	ZW13-33-0001
			Sample Depth (ft):	2-4	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5
			Date Sampled:	11/8/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13	11/7/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	**10.6**	**45.5**	2.7	8.6	**24**	4.4	8.1	**35.2**
Barium	NSL	NSL	mg/kg	59.3	53	33.6	25 J	70.1	20 J	25.9 J	77
Cadmium	0.99	4.98	mg/kg	0.33 J	0.57	0.21 J	0.69 U	**1.2**	0.18 J	0.24 J	0.83
Chromium	43.4	111	mg/kg	15.9	11.9	8	8.9	18.1	8.6	9.7	24.2
Copper	31.6	149	mg/kg	10.8 J	**189**	7.2	6.6	**398**	7	8.5	**166**
Lead	35.8	128	mg/kg	8.6	**10500 J**	**47.9 J**	2.1 J	**54200 J**	**298 J**	19.9 J	**24300 J**
Mercury	0.18	1.06	mg/kg	0.034 J	**0.8**	0.038 J	0.014 J	**2.2**	0.033 J	0.024 J	**3.5**
Nickel	22.7	48.6	mg/kg	11.6	18.1	7.6	7.8	**26.3**	6.8	8.3	**23.3**
Selenium	NSL	NSL	mg/kg	1.9 J	13.2	0.95 J	1.6 J	8.7	1.7 J	1.9 J	9.5
Silver	NSL	NSL	mg/kg	0.056 J	0.44 J	1.6 U	1.4 U	2	1.4 U	2 U	0.42 J
Zinc	121	459	mg/kg	39.9 J	**141**	30.7	24.6	**242**	24.2	29.8	**181**

Notes:
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N = Spiked sample recovery not within control limits.
U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
TEC = Threshold effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
PEC = Probable effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-33	ZW13-33	ZW13-33	ZW13-33	ZW13-34	ZW13-34	ZW13-34	ZW13-35
			Sample Name:	ZW13-33-0102	ZW13-33-0102FD	ZW13-33-0204	ZW13-33-0204FD	ZW13-34-0001	ZW13-34-0102	ZW13-34-0204	ZW13-35-0001
			Sample Depth (ft):	0.5-2	0.5-2	2-4	2-4	0-0.5	0.5-2	2-4	0-0.5
			Date Sampled:	11/7/13	11/7/13	11/7/13	11/7/13	11/6/13	11/6/13	11/6/13	11/6/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	**10.9**	**16.4**	4	4.6	**45.1**	**12.6**	1.2	**15.1**
Barium	NSL	NSL	mg/kg	67.6	65.9	17 J	19.8 J	63.6 J	96.7 J	3.7 J	49.5 J
Cadmium	0.99	4.98	mg/kg	0.5	0.76	0.13 J	0.16 J	0.56 J	0.5 J	0.042 J	0.38 J
Chromium	43.4	111	mg/kg	16.2	14.1	4.6	4.9	25.9 J	21.6 J	1.7 J	22.6 J
Copper	31.6	149	mg/kg	18.1	18	3.1	3.7	**267**	18.5	0.58 J	**69.8**
Lead	35.8	128	mg/kg	**696 J**	**158 J**	5 J	4.4 J	**37300 J**	**695 J**	4.6 J	**9480 J**
Mercury	0.18	1.06	mg/kg	0.066 J	0.1	0.016 J	0.019 J	**3.2 J**	0.12 J	0.45 UJ	**0.62 J**
Nickel	22.7	48.6	mg/kg	15.4	17.5	4.3 U	4.5 U	**23.9 J**	17.6 J	1.2 J	16.4 J
Selenium	NSL	NSL	mg/kg	2.9	2.9	1.3 J	1.4 J	13.5	2.3 J	3.2 U	4.4
Silver	NSL	NSL	mg/kg	0.77 U	0.81 U	1.1 U	1.1 U	0.94	0.064 J	0.91 U	0.19 J
Zinc	121	459	mg/kg	65.6	115	12.9	14.2	**155**	60.9	5.5 U	87.6

Notes:

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N = Spiked sample recovery not within control limits.

U = Indicates the analyte was analyzed for but not detected.

NSL = No screening level

mg/kg = Milligrams per kilogram.

TEC = Threshold effect concentration.

Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).

PEC = Probable effect concentration.

Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).

Bold = Above or equal to TEC value.

Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-35	ZW13-35	ZW13-36*	ZW13-36*	ZW13-37*	ZW13-37*	ZW13-37*	ZW13-38
			Sample Name:	ZW13-35-0102	ZW13-35-0204	ZW13-36 1'	ZW13-36 2'	ZW13-37 1'	ZW13-37 2'	ZW13-37 2'-DUP	ZW13-38-0001
			Sample Depth (ft):	0.5-2	2-4	0-1	1-2	0-1	1-2	1-2	0-0.5
			Date Sampled:	11/6/13	11/6/13	11/14/13	11/14/13	11/14/13	11/14/13	11/14/13	11/6/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	1.5	1.2	2.1	1.8	8.2	5.2	5.9	6.6
Barium	NSL	NSL	mg/kg	3.7 J	3.5 J	8.9	18	97	100	99	68.3 J
Cadmium	0.99	4.98	mg/kg	0.037 J	0.058 J	0.2 U	0.2 U	0.2 U	0.3	0.2	0.47 J
Chromium	43.4	111	mg/kg	1.8 J	2.1 J	3.3	6.1	27	28	27	17.6 J
Copper	31.6	149	mg/kg	0.96 J	0.74 J	2.1	4.3	19	17	15	13.9
Lead	35.8	128	mg/kg	**79.9 J**	3.7 J	2.3	4.8	20	8.4	7.2	**75.9 J**
Mercury	0.18	1.06	mg/kg	0.47 UJ	0.44 UJ	0.07 U	0.07 U	0.1	0.1 U	0.1 U	0.11 J
Nickel	22.7	48.6	mg/kg	1.4 J	1.4 J	--	--	--	--	--	13.3 J
Selenium	NSL	NSL	mg/kg	3.5 U	3.4 U	0.2 U	0.3	1	1	1	1.9 J
Silver	NSL	NSL	mg/kg	0.99 U	0.97 U	0.1 U	0.1 U	0.1	0.1 U	0.1 U	1.4 U
Zinc	121	459	mg/kg	6.9	5.8 U	8.1	15	46	45	44	53.4

Notes:
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U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
TEC = Threshold effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
PEC = Probable effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-38	ZW13-38	ZW13-39	ZW13-39	ZW13-39	ZW13-40	ZW13-40	ZW13-40
			Sample Name:	ZW13-38-0102	ZW13-38-0204	ZW13-39-0001	ZW13-39-0102	ZW13-39-0204	ZW13-40-0001	ZW13-40-0001FD	ZW13-40-0102
			Sample Depth (ft):	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5	0-0.5	0.5-2
			Date Sampled:	11/6/13	11/6/13	11/6/13	11/6/13	11/6/13	9/30/13	9/30/13	9/30/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	7.5	3.1	9.1	9	4.3	7.8	7.3	7.6
Barium	NSL	NSL	mg/kg	88.5 J	9.9 J	156	139	7.9 J	102 J	97 J	83.1 J
Cadmium	0.99	4.98	mg/kg	0.46 J	0.11 J	0.65 J	0.63 J	0.049 J	0.74 J	0.75 J	0.5 J
Chromium	43.4	111	mg/kg	21.8 J	3.9 J	28.6	29.8	2.9	25.3 J	24.2 J	20.4 J
Copper	31.6	149	mg/kg	15.9	2 J	21.6	21.8	1.4 J	24.7 J	23.5 J	15.5 J
Lead	35.8	128	mg/kg	**73.9 J**	1.4 J	**47.7 J**	**87.1 J**	3.3 J	**328**	**311**	**99.5**
Mercury	0.18	1.06	mg/kg	0.15 J	0.039 J	0.048 J	0.067 J	0.13 U	0.16 J	0.15 J	0.07 J
Nickel	22.7	48.6	mg/kg	16.3 J	2.8 J	**22.8**	**25.2**	4.3 U	18.5 J	17.8 J	15.1 J
Selenium	NSL	NSL	mg/kg	2.2 J	0.82 J	4 J	4 J	0.56 J	3.3 J	3.4 J	1.5 J
Silver	NSL	NSL	mg/kg	1.9 U	1.2 U	2.3 U	1.8 U	1.1 U	2 UJ	2 UJ	0.94 UJ
Zinc	121	459	mg/kg	57.1	9.4	83.9	105	7.8	87.7 J	85.8 J	52.2 J

Notes:
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U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
TEC = Threshold effect concentration.
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Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-40	ZW13-41	ZW13-41	ZW13-41	ZW13-42	ZW13-42	ZW13-42	ZW13-43
			Sample Name:	ZW13-40-0204	ZW13-41-0001	ZW13-41-0102	ZW13-41-0204	ZW13-42-0001	ZW13-42-0102	ZW13-42-0204	ZW13-43-0001
			Sample Depth (ft):	2-4	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-0.5
			Date Sampled:	9/30/13	11/6/13	11/6/13	11/6/13	11/5/13	11/5/13	11/5/13	9/30/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	**15**	**10.7**	**10.1**	**13.2**	**13.2**	**11.6**	3	4.6
Barium	NSL	NSL	mg/kg	40 J	61.4	57	41.2	55.2 J	31.5 J	6.2 J	34.1 J
Cadmium	0.99	4.98	mg/kg	0.46 J	0.52	0.47 J	0.29 J	0.78 J	0.29 J	0.041 J	0.35 J
Chromium	43.4	111	mg/kg	14.1 J	14.7	20.4	12.5	11.3 J	11.4 J	3.2 J	5.4 J
Copper	31.6	149	mg/kg	10.1 J	**34.6**	20.9	10.9	26.1	10.6	1.5 J	**98.2 J**
Lead	35.8	128	mg/kg	4.9	**4690 J**	**1370 J**	24.2 J	**325 J**	5.9 J	0.85 J	**52.1**
Mercury	0.18	1.06	mg/kg	0.37 U	**0.33**	0.1 J	0.034 J	**0.28 J**	0.037 J	0.57 UJ	0.094 J
Nickel	22.7	48.6	mg/kg	11.4 J	15.5	17.9	10.3	11.4 J	8.7 J	2.3 J	3.3 J
Selenium	NSL	NSL	mg/kg	1.5 J	3	4.1 J	3.1	2.7 J	1.9 J	0.49 J	1.4 J
Silver	NSL	NSL	mg/kg	0.85 UJ	0.13 J	2.4 U	0.063 J	0.12 J	0.69 U	1.1 U	1.4 UJ
Zinc	121	459	mg/kg	35.6 J	75.5	65.9	36	81.6	29	6.9	38.4 J

Notes:
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U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
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Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-43	ZW13-43	ZW13-44	ZW13-44	ZW13-44	ZW13-45*	ZW13-45*	ZW13-46*
			Sample Name:	ZW13-43-0102	ZW13-43-0204	ZW13-44-0001	ZW13-44-0102	ZW13-44-0204	ZW 13 - 45 1'	ZW 13 - 45 2'	ZW 13 - 46 1'
			Sample Depth (ft):	0.5-2	2-4	0-0.5	0.5-2	2-4	0-1	1-2	0-1
			Date Sampled:	9/30/13	9/30/13	9/30/13	9/30/13	9/30/13	11/14/13	11/14/13	11/14/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	2.4	1.1	**12.3**	**14.2**	1.3	**16**	8.1	**12**
Barium	NSL	NSL	mg/kg	21.3 J	4.3 J	46 J	23.1 J	2.9 J	31	38	60
Cadmium	0.99	4.98	mg/kg	0.17 J	0.041 J	0.47 J	0.39 J	0.034 J	0.2 U	0.2 U	0.5
Chromium	43.4	111	mg/kg	3.6 J	1.4 J	33.7 J	4.4 J	1.4 J	5.2	9	15
Copper	31.6	149	mg/kg	31.3 J	1 J	**89.2 J**	10 J	0.65 J	11	12	20
Lead	35.8	128	mg/kg	12.1	1.5	**102**	9.8	0.79 J	**51**	32	**280**
Mercury	0.18	1.06	mg/kg	0.033 J	0.15 U	**0.22 J**	0.6 U	0.12 U	**0.4 U**	**0.5 U**	**0.3 U**
Nickel	22.7	48.6	mg/kg	2.5 J	0.9 J	12.8 J	3.8 J	0.99 J	--	--	--
Selenium	NSL	NSL	mg/kg	0.72 J	3.9 UJ	3 J	0.87 J	3.2 UJ	1	1.2	1.6
Silver	NSL	NSL	mg/kg	1.3 UJ	1.3 UJ	2 UJ	0.88 UJ	0.93 UJ	0.1 U	0.1 U	0.1 U
Zinc	121	459	mg/kg	14.3 J	6.7 UJ	47.9 J	6.3 J	5.4 UJ	15	15	38

Notes:

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N = Spiked sample recovery not within control limits.

U = Indicates the analyte was analyzed for but not detected.

NSL = No screening level

mg/kg = Milligrams per kilogram.

TEC = Threshold effect concentration.

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PEC = Probable effect concentration.

Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).

Bold = Above or equal to TEC value.

Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-46*	ZW13-47	ZW13-47	ZW13-47	ZW13-48	ZW13-48	ZW13-48	ZW13-49*
			Sample Name:	ZW 13 - 46 2'	ZW13-47-0001	ZW13-47-0102	ZW13-47-0204	ZW13-48-0001	ZW13-48-0102	ZW13-48-0204	ZW 13 - 49 1'
			Sample Depth (ft):	1-2	0-0.5	0.5-2	2-4	0-0.5	0.5-2	2-4	0-1
			Date Sampled:	11/14/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/8/13	11/14/13
Analyte	**TEC**	**PEC**	**Unit**								
Arsenic	9.79	33	mg/kg	**11**	**52.9**	**15.1**	**11.5**	**29.1**	**9.8**	5.7	5.9
Barium	NSL	NSL	mg/kg	56	53.9	13.2 J	39.6	48.9	54.2	31.9 J	45
Cadmium	0.99	4.98	mg/kg	0.4	**1.7**	0.35 J	0.27 J	0.59 J	0.46 J	0.28 J	0.5
Chromium	43.4	111	mg/kg	20	16.2	5.1	12.5	16.7	17.3	12.9	14
Copper	31.6	149	mg/kg	16	**157 J**	24.4 J	9.8 J	**72.7 J**	22.6 J	18.7 J	15
Lead	35.8	128	mg/kg	23	**19000**	**5650**	10.6	**17500**	**1840**	9.6	**210**
Mercury	0.18	1.06	mg/kg	**0.2 U**	**0.28 J**	0.051 J	0.35 U	**1.1 J**	0.15 J	0.79 U	0.1 U
Nickel	22.7	48.6	mg/kg	--	**32.9**	6.7	9.5	13.9	16.2	8.9	--
Selenium	NSL	NSL	mg/kg	1.3	8.3	1.6 J	2 J	7.3 J	2.7 J	1.7 J	0.9
Silver	NSL	NSL	mg/kg	0.1 U	0.29 J	0.22 J	0.86 U	2.4 U	2.2 U	1.7 U	0.1 U
Zinc	121	459	mg/kg	35	**294 J**	44.2 J	30.4 J	68.1 J	87.4 J	36.6 J	85

Notes:
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U = Indicates the analyte was analyzed for but not detected.
NSL = No screening level
mg/kg = Milligrams per kilogram.
TEC = Threshold effect concentration.
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PEC = Probable effect concentration.
Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).
Bold = Above or equal to TEC value.
Bold & Shaded = Above or equal to PEC value.

TABLE 3-5 SEDIMENT RESULTS FOR METALS

			Sample Location:	ZW13-49*	ZW13-50*	ZW13-50*
			Sample Name:	ZW 13 - 49 2'	ZW 13 - 50 1'	ZW 13 - 50 2'
			Sample Depth (ft):	1-2	0-1	1-2
			Date Sampled:	11/14/13	11/14/13	11/14/13
Analyte	**TEC**	**PEC**	**Unit**			
Arsenic	9.79	33	mg/kg	**13**	4.5	**12**
Barium	NSL	NSL	mg/kg	51	30	79
Cadmium	0.99	4.98	mg/kg	0.4	0.2	0.7
Chromium	43.4	111	mg/kg	22	9.9	27
Copper	31.6	149	mg/kg	15	10	23
Lead	35.8	128	mg/kg	**110**	**180**	**250**
Mercury	0.18	1.06	mg/kg	**0.2 U**	0.08 U	**0.2 U**
Nickel	22.7	48.6	mg/kg	--	--	--
Selenium	NSL	NSL	mg/kg	1.3	0.7	1.3
Silver	NSL	NSL	mg/kg	0.1 U	0.1 U	0.1
Zinc	121	459	mg/kg	44	39	68

Notes:

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N = Spiked sample recovery not within control limits.

U = Indicates the analyte was analyzed for but not detected.

NSL = No screening level

mg/kg = Milligrams per kilogram.

TEC = Threshold effect concentration.

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PEC = Probable effect concentration.

Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al. 2000).

Bold = Above or equal to TEC value.

Bold & Shaded = Above or equal to PEC value.

TABLE 3-6 SEDIMENT RESULTS FOR SEM/AVS

	Sample Location:	ZW13-25	ZW13-27	ZW13-31	ZW13-33	ZW13-33	ZW13-35	ZW13-38	ZW13-41	ZW13-42
	Sample Name:	ZW13-25-0001	ZW13-27-0001	ZW13-31-0001	ZW13-33-0001	ZW13-33-0001FD	ZW13-35-0001	ZW13-38-0001	ZW13-41-0001	ZW13-42-0001
	Sample Depth (ft):	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5
	Date Sampled:	11/5/13	11/8/13	11/7/13	11/7/13	11/7/13	11/6/13	11/6/13	11/6/13	11/5/13
Analyte	**Unit**									
Cadmium	umole/g	0.049 J	ND	ND	ND	ND	ND	ND	0.011 J	ND
Copper	umole/g	1.2	ND	1	ND	0.64	0.59	0.082 J	ND	0.15 J
Lead	umole/g	4.1	1.6	14.4	11.8	23.5	25.1	0.095	10.8	0.58
Mercury	umole/g	ND	ND	0.00064	0.000094 J	0.00031	0.000065 J	0.000032 J	ND	0.00013 J
Nickel	umole/g	0.15 J	ND	0.25 J	0.078 J	0.14 J	0.17 J	0.066 J	0.15 J	0.074 J
Zinc	umole/g	250	1	1.9	0.86	1.3	0.94	0.36	1.3	0.67
∑ SEM	none	255.499	2.600	17.551	12.738	25.580	26.800	0.603	12.261	1.474
Acid Volatile Sulfides (AVS)	umole/g	283	34.5	ND	ND	2.5	6.6	ND	2	ND
∑ SEM/AVS	none	0.903	0.075	NC	NC	10.232	4.061	NC	6.131	NC

NOTES:
Σ = Sum
umole/g = Micro mole per gram
NC = Not calculated.
ND = Not detected.

TABLE 3-7 SEDIMENT RESULTS FOR WASTE CHARACTERIZATION

		Sample Location:	ZW13-25	ZW13-31
		Sample Name:	ZW13-25-COMP	ZW13-31-COMP
		Sample Depth (ft):	--	--
		Date Sampled:	11/5/13	11/7/13
Analyte	**Unit**	**Regulatory Level**		
Waste Characteristics				
Cyanide, Total	mg/kg	NA	0.97 U	0.93 U
Flashpoint	deg f	≤ 140	> 180	> 180
Free Liquid	none	NA	POS	NEG
pH	pH units	≤ 2 or ≥ 12.5	7.29	7.32
TCLP Metals				
Arsenic	mg/l	5	0.0085 J	0.006 J
Barium	mg/l	100	10 U	10 U
Cadmium	mg/l	1	0.1 U	0.1 U
Chromium	mg/l	5	0.5 U	0.5 U
Lead	mg/l	5	0.054 J	0.5 U
Mercury	mg/l	0.2	0.002 U	0.002 U
Selenium	mg/l	1	0.25 U	0.25 U
Silver	mg/l	5	0.5 U	0.5 U
Pesticides				
Chlordane (technical)	mg/l	0.03	0.005 UJ	0.005 U
Endrin	mg/l	0.02	0.0005 UJ	0.0005 U
gamma-BHC (Lindane)	mg/l	0.4	0.0005 UJ	0.0005 U
Heptachlor	mg/l	0.008	0.0005 UJ	0.0005 U
Heptachlor epoxide	mg/l	0.008	0.0005 UJ	0.0005 U
Methoxychlor	mg/l	10	0.001 UJ	0.001 UJ
Toxaphene	mg/l	0.5	0.02 UJ	0.02 U
Herbicides				
2,4-D	mg/l	10	0.002 UJ	0.002 U
Silvex (2,4,5-TP)	mg/l	1	0.0005 UJ	0.0005 U
SVOCs				
1,4-Dichlorobenzene	mg/l	7.5	0.004 U	0.004 U
2,4,5-Trichlorophenol	mg/l	400	0.02 U	0.02 U
2,4,6-Trichlorophenol	mg/l	2	0.02 U	0.02 U
2,4-Dinitrotoluene	mg/l	0.13	0.02 U	0.02 U
2-Methylphenol	mg/l	200	0.004 U	0.004 U
3 & 4 Methylphenol	mg/l	200	0.04 U	0.04 U
Hexachlorobenzene	mg/l	0.13	0.02 U	0.02 U
Hexachlorobutadiene	mg/l	0.5	0.02 U	0.02 U
Hexachloroethane	mg/l	3	0.02 U	0.02 U
Nitrobenzene	mg/l	2	0.004 U	0.004 U
Pentachlorophenol	mg/l	100	0.04 U	0.04 U
Pyridine	mg/l	5	0.02 U	0.02 U
VOCs				
1,1-Dichloroethene	mg/l	0.7	0.025 U	0.025 U
1,2-Dichloroethane	mg/l	0.5	0.025 U	0.025 U
2-Butanone (MEK)	mg/l	200	0.25 U	0.25 U
Benzene	mg/l	0.5	0.025 U	0.025 U
Carbon tetrachloride	mg/l	0.5	0.025 U	0.025 U
Chlorobenzene	mg/l	100	0.025 U	0.025 U
Chloroform	mg/l	6	0.025 U	0.025 U
Tetrachloroethene	mg/l	0.7	0.025 U	0.025 U
Trichloroethene	mg/l	0.5	0.025 U	0.025 U
Vinyl chloride	mg/l	0.2	0.025 U	0.025 U

NOTES:
Regulatory Levels from 40 CFR 261, Subpart C - Characteristics of Hazardous Waste
mg/kg = milligrams per kilogram
deg f = degrees Fahrenheit
mg/l = milligrams per liter

Appendix E

Conceptual Site Layouts for Remedial and Restoration Alternatives

Remedial Alternative 2
Relatively Dry Excavation Concept
Fire Supression Ditch Project Area

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2010 NAIP, USDA/FSA Aerial Photography Field Office, 2010.

Legend

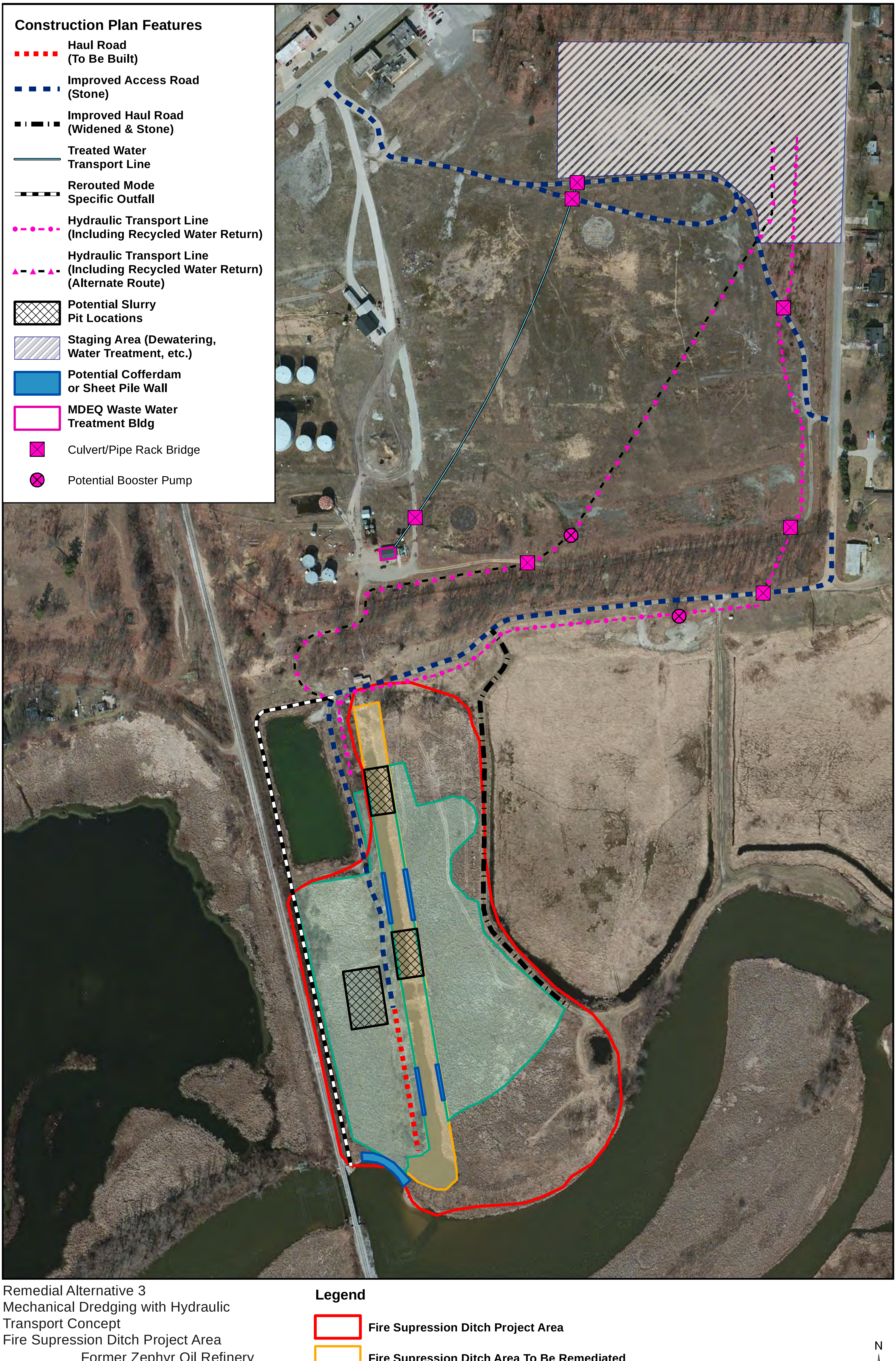
Fire Supression Ditch Project Area

Fire Supression Ditch Area To Be Remediated

Wetlands Area To Be Remediated

0 200 400
Feet

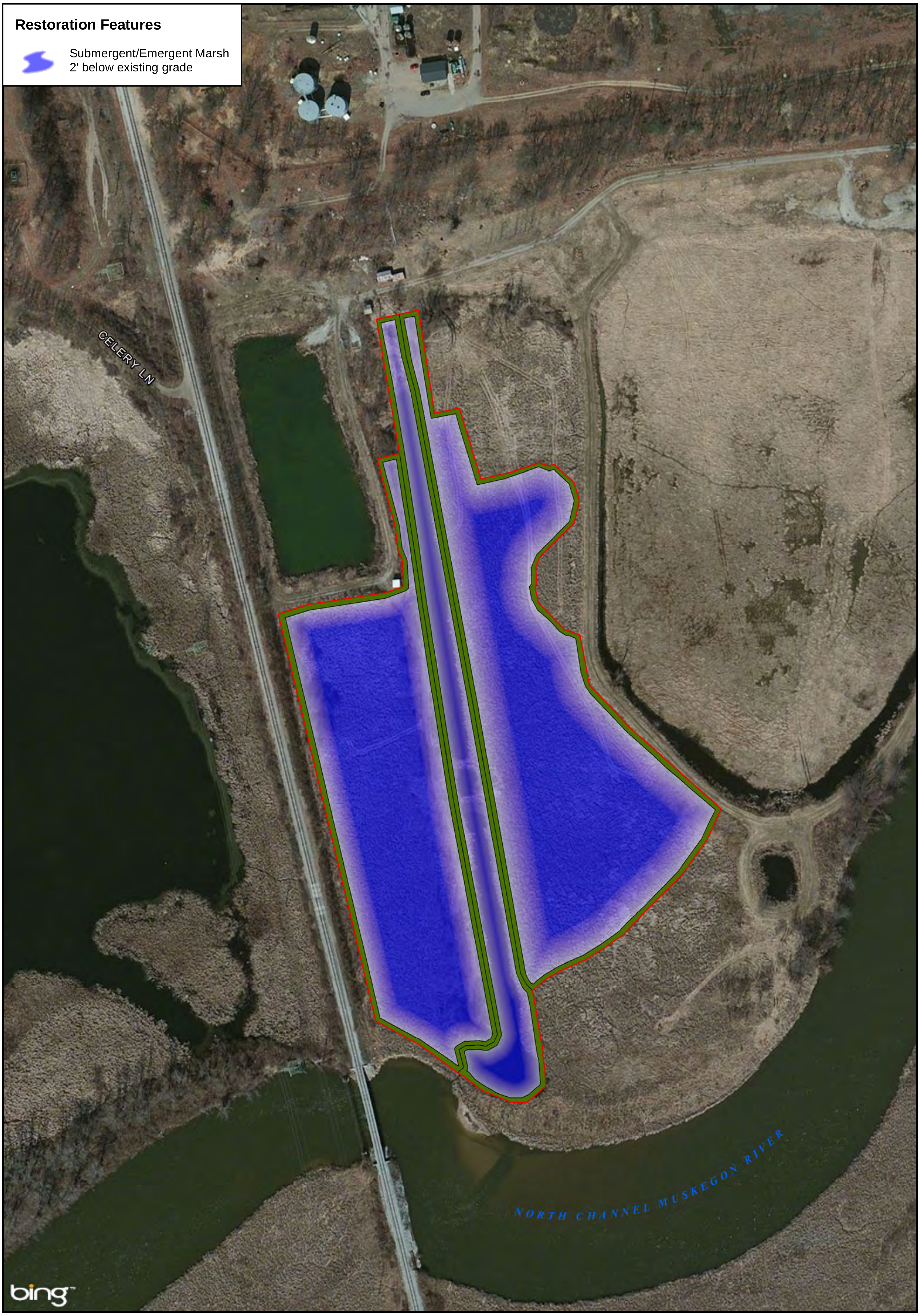
N



Remedial Alternative 3
Mechanical Dredging with Hydraulic Transport Concept
Fire Supression Ditch Project Area

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: 2010 NAIP, USDA/FSA Aerial Photography Field Office, 2010.



Restoration Alternative 2
Limited Restoration of Remediated Areas Concept
Fire Supression Ditch Project Area

Legend

Remedial Action Footprint

0 150 300
Feet

N

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Restoration Alternative 3
Restoration with Native Species Concept
Fire Supression Ditch Project Area

Legend

Remedial Action Footprint

0 150 300
Feet

N

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Restoration Alternative 4
Restoration of Native Habitats Concept
Fire Supression Ditch Project Area

Legend

Remedial Action Footprint

N

0 150 300
Feet

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Image Source: Bing Maps ©2010 Microsoft Corporation and its data suppliers.

Restoration Alternative 5
Full Site Restoration Concept
Fire Supression Ditch Project Area

Legend

Remedial Action Footprint

0 150 300
Feet

N

Former Zephyr Oil Refinery
Muskegon Lake AOC
Muskegon, Michigan

Appendix F

Costing Details for Remedial and Restoration Alternatives

Table F-1 Summarized Cost Estimate for Alternative 2: Dry Excavation with Offsite Disposal and Residuals Cover				
Cost Item	**Quantity**	**Units**	**Unit Price**	**Total Cost**
A. Mobilization/Demobilization				
Mobilization/Demobilization	10%	% Items B-G	NA	$640,730
B. Site Preparation, Support Facilities, and Access Control				
Site trailer, Temporary Facilities	5.0	Month	$3,158	$15,800
Site Manager & Health and Safety Officer	5.0	Month	$29,200	$146,000
Rough Grading	7.0	Acres	$6,453	$45,180
Site clearing and grubbing	0.25	Acres	$975	$250
Decon pad and material staging areas (graded compacted gravel pads)	45000	SF	$2	$98,750
Onsite Haul Roads - new	500	LF	$34	$16,990
Onsite Haul Roads - improvement to existing	8070	LF	$26	$213,100
Expand Existing Access Road	1200	LF	$73	$87,080
200' x 200' paved area for amendment mixing	4444	SY	$30	$133,340
Erosion control	2000	LF	$3	$5,000
Gated security fencing (installation & demolition)	2500	LF	$30	$76,000
Facilities maintenance (Erosion controls, staging areas)	5%	%	NA	$41,880
Electrical	1	LS	$34,200	$34,200
Wastewater Treatment Plant Setup and breakdown	1	LS	$97,540	$97,540
C. Removal				
Sediment Removal in Wetland (Alt 2)	35647	CY	$30	$1,069,410
Sediment Removal in Wetland (includes all slurrying activity) (Alt 3)	0	CY	$25	$0
Sediment Removal in Ditch (long-reach crawler excavator)	15570	CY	$40	$622,800
Cofferdam / Sheetpiling lease and installation along river	6000	SF	$30	$180,000
Cofferdam/Sheetpiling Removal along river	6000	SF	$20	$120,000
Sheetpiling in ditch installation and removal to 30' depth (includes reinstalling at second location)	300	LF	$1,200	$360,000
Backfill for Sheetpiling in ditch	1667	CY	$9	$15,000
Drawdown with pump to Relatively Dry	5	DAY	$11,807	$59,040
D. Dredged Material Handling				
Gravity Dewatering basin (graded, lined, bermed area with leachate coll system for water removal)	45000	SF	$5	$209,920
Gravity Dewatering basin (pumps and tank)	1	LS	$14,900	$14,900
Pipeline and pumps for discharge point extension	1400	LF	$31	$43,400
Pipeline and pumps for fertilizer operation	1400	LF	$31	$43,400
Geotube Dewatering Material	0	LF	$38	$0
Geotube Dewatering Labor and Equipment	0	DAY	$7,888	$0
Geotube Dewatering Pond	0	AC	$15,101	$0
Portland Cement Material for Sediment Amendment	1500	TON	$158	$237,060
Portland Cement Amendment Addition Acivities	71	DAY	$3,692	$263,250
Wastewater Management & Treatment (package treatment plant)	5	MO	$72,325	$361,630
Existing Water Treatment System Use	0	MO	$15,000.00	$0
E. Off-site Transportation and Disposal				
Offsite Truck Transport	36500	Ton	$15	$560,640
Offsite Landfill Disposal	36500	Ton	$17	$620,500
F. Capping and Covers				
Residuals cover (sand)	2500	CY	$50	$125,000
G. Sampling and Surveys				
Pre-Design sampling	1	LS	$48,500	$48,500
Pre-Design survey	1	LS	$15,569	$15,570
Pre-construction baseline sampling	1	LS	$15,375	$15,380
Confirmatory sampling during and after excav.	1	LS	$151,500	$151,500
Post-construction sampling to compare to baseline	1	LS	$15,375	$15,380
Post-Construction Survey	1	LS	$15,569	$15,570
Water Testing	1	LS	$33,040	$33,040
Site Restoration				
Remove/dispose of fill used to expand access roads	3067	TON	$47	$145,240
Grading and erosion control pending habitat restoration (placeholder)	1	LS	$50,000	$50,000
H. Administrative Costs and Bonding				
Design and Engineering	7.5%	% Items A-G	NA	$513,960
Permitting, Environmental Assessment & Supporting Studies	1	Each	$150,000	$150,000
Treatability/Pilot/Proof of Concept Studies	0	Each	$75,000	$0
Insurance	5%	% Items A-G	NA	$342,640
Bonding	5%	% Items A-G	NA	$342,640
I. Contingency				
Contingency	30%	% Items A-G	NA	$2,055,820
TOTAL COST				$10,453,030

Table F-2 Summarized Cost Estimate for Alternative 3: Dredging, Hydraulic Onsite Transport, Trucked Landfill Disposal				
Cost Item	**Quantity**	**Units**	**Unit Price**	**Total Cost**
A. Mobilization/Demobilization				
Mobilization/Demobilization	10%	% Items B-G	NA	$675,500
B. Site Preparation, Support Facilities, and Access Control				
Site trailer, Temporary Facilities	5	Month	$3,158	$15,800
Site Manager & Health and Safety Officer	5	Month	$29,200	$146,000
Rough Grading	7	Acres	$6,453	$45,180
Site clearing and grubbing	0.25	Acres	$975	$250
Decon pad and material staging areas (graded compacted gravel pads)	20,000	SF	$2	$43,890
Onsite Haul Roads - new	500	LF	$34	$16,990
Onsite Haul Roads - improvement to existing	6,570	LF	$26	$173,490
Expand Existing Access Road	1,200	LF	$73	$87,080
Erosion control	2,000	LF	$3	$5,000
Gated security fencing (installation & demolition)	2,500	LF	$30	$76,000
Facilities maintenance (Erosion controls, staging areas)	5%	%	NA	$30,490
Electrical	1	LS	$34,200	$34,200
Wastewater Treatment Plant Setup and breakdown	1	LS	$97,540	$97,540
C. Removal				
Sediment Removal in Wetland (Alt 2)	0	CY	$30	$0
Sediment Removal in Wetland (includes all slurrying activity) (Alt 3)	30978	CY	$25	$774,450
Sediment Removal in Ditch (long-reach crawler excavator)	15570	CY	$40	$622,800
Vegetation and debris segregation & Sediment Transport to Staging Area	4669	CY	$30	$140,070
Cofferdam / Sheetpiling lease and installation along river	6000	SF	$30	$180,000
Cofferdam/Sheetpiling Removal along river	6000	SF	$20	$120,000
Sheetpiling in ditch installation and removal to 30' depth (includes reinstalling at second location)	300	SF	$1,200	$360,000
Backfill for Sheetpiling in ditch	1667	CY	$9	$15,000
Drawdown with pump to Relatively Dry	0	CY	$11,807	$0
D. Dredged Material Handling				
Gravity Dewatering basin (graded, lined, bermed area with leachate coll system for water removal)	80000	SF	$5	$373,200
Gravity Dewatering basin (pumps and tank)	1	LS	$14,900	$14,900
Pipeline and pumps for discharge point extension	1400	LF	$31	$43,400
Pipeline and pumps for fertilizer operation	1400	LF	$31	$43,400
Geotube Dewatering Material	11000	LF	$38	$418,000
Geotube Dewatering Labor and Equipment	96	DAY	$7,888	$754,490
Geotube Dewatering Pond	0.5	Acre	$15,101	$7,560
Portland Cement Material for Sediment Amendment	500	TON	$158	$79,020
Portland Cement Amendment Addition Acivities	20	DAY	$3,692	$73,850
Wastewater Management & Treatment (package treatment plant)	5	MO	$72,325	$361,630
Existing Water Treatment System Use	0	MO	$15,000.00	$0
E. Off-site Transportation and Disposal				
Offsite Truck Transport	29700	Ton	$15	$456,200
Offsite Landfill Disposal	29700	Ton	$17	$504,900
F. Capping and Covers				
Residuals cover (sand)	3000	CY	$50	$150,000
Site Restoration				
Remove/dispose of fill used to expand access roads	3067	TON	$47	$145,240
Grading and erosion control pending habitat restoration (placeholder)	1	LS	$50,000	$50,000
G. Sampling and Surveys				
Pre-Design sampling	1	LS	$48,500	$48,500
Pre-Design survey	1	LS	$15,569	$15,570
Pre-construction baseline sampling	1	LS	$15,375	$15,380
Confirmatory sampling during and after excav.	1	LS	$151,500	$151,500
Post-construction sampling to compare to baseline	1	LS	$15,375	$15,380
Post-Construction Survey	1	LS	$15,569	$15,570
Water Testing	1	LS	$33,040	$33,040
H. Administrative Costs and Bonding				
Design and Engineering	10%	% Items A-G	NA	$743,050
Permitting, Environmental Assessment & Supporting Studies	1	Each	$150,000	$150,000
Treatability/Pilot/Proof of Concept Studies	0	Each	$75,000	$0
Insurance	5%	% Items A-G	NA	$371,530
Bonding	5%	% Items A-G	NA	$368,330
I. Contingency				
Contingency	30%	% Items A-G	NA	$2,229,140
TOTAL COST				$11,292,510

Table F-3
Summarized Cost Estimate for Alternative 2: Limited Restoration of Remediated Areas

Cost Item	Quantity	Units	Unit Price	Total Cost
A. Mobilization/Demobilization				
Mobilization/Demobilization	1	LS	$2,714	$2,714
B. Surface Preparation of Disturbed Areas				
Temporary cover crop (e.g. fowl bluegrass and common oat)	0.3	Acres	$1,000	$300
Erosion control - straw mulch	0.3	Acres	$1,500	$450
C. Vegetation Plan				
Natural Re-establishmennt of plant species	0	Acres	$0	$0
D. Landscape - Grading, Cut/Fill				
Finish Grading - contour to stable slope (3:1)	7,300	SY	$4	$29,200
Borrow excavation to create slope margins	3,000	CY	$20	$60,000
Fill - wetland topsoil	0	CY	$26	$0
E. Site Enhancements				
Educational Signage	1	Each	$500	$500
Subtotal				**$93,164**
Contingency			**15%**	**$13,975**
Bond			**1.5%**	**$1,397**
Construction Management			**7.5%**	**$6,987**
TOTAL COST				**$115,523**

Table F-4
Summarized Cost Estimate for Alternative 3: Restoration of Remediated Areas with Native Species

Cost Item	Quantity	Units	Unit Price	Total Cost
A. Mobilization/Demobilization				
Mobilization/Demobilization	1	LS	$18,738	$18,738
B. Surface Preparation of Disturbed Areas				
Temporary cover crop (e.g. fowl bluegrass and common oat)	3.5	Acres	$1,000	$3,500
Erosion control - straw mulch	3.5	Acres	$1,500	$5,250
C. Vegetation Plan				
Native wetland species seed mix	3.5	Acres	$4,500	$15,750
Aquatic and obligate wetland plugs	1.8	Acres	$55,000	$99,000
Containerized wetland shrubs (e.g. 2-3 gallon)	0.33	Acres	$950	$314
Containerized wetland trees (e.g. 3-5 gallon)	0.67	Acres	$3,125	$2,094
D. Landscape - Grading. Cut/Fill				
Finishg Grading - contour to stable slope (3:1)	23,400	SY	$4	$93,600
Borrow excavation to create slope margins	3,400	CY	$20	$68,000
Fill - wetland topsoil	12,400	CY	$26	$322,400
Fill - footpath construction	733	CY	$8	$5,864
E. Site Enhancements				
Brush Piles	0.5	Day	$1,500	$750
Educational signage	3	Each	$500	$1,500
Footpaths (5' wide) - grading	1,642	SY	$4	$6,568
Subtotal				**$643,328**
Contingency			**15%**	**$96,499**
Bond			**1.5%**	**$9,650**
Construction Management			**7.5%**	**$48,250**
TOTAL COST				**$797,727**

Table F-5
Summarized Cost Estimate for Alternative 4: Restoration of Native Habitats in Remediated Areas

Cost Item	Quantity	Units	Unit Price	Total Cost
A. Mobilization/Demobilization				
Mobilization/Demobilization	1	LS	$36,246	$36,246
B. Surface Preparation of Disturbed Areas				
Temporary cover crop (e.g. fowl bluegrass and common oat)	7.4	Acres	$325	$2,405
Erosion control - straw mulch	7.4	Acres	$1,500	$11,100
Erosion control - matting on contoured slopes	6,873	SY	$3	$20,619
C. Vegetation Plan				
Native wetland species seed mix	7.4	Acres	$4,500	$33,300
Herbicide application - single season prior to seeding (e.g. glyphosate)	10.99	Acres	$70	$769
Aquatic and obligate wetland plugs	2.1	Acres	$55,000	$115,500
Containerized wetland shrubs (e.g. 2-3 gallon)	0.73	Acres	$950	$694
Containerized wetland trees (e.g. 3-5 gallon)	1.47	Acres	$3,125	$4,594
D. Landscape - Grading, Cut/Fill				
Finishg Grading - contour to stable slope (3:1)	36,000	SY	$4	$144,000
Borrow excavation to create marsh and FSD slope margins	2,400	CY	$20	$48,000
Fill - wetland topsoil	30,200	CY	$26	$785,200
Fill - footpath construction	1,630	CY	$8	$13,040
E. Site Enhancements				
Educational signage	5	Each	$500	$2,500
Footpaths (5' wide) - grading	2,807	SY	$4	$11,228
Brush Piles	1	Day	$1,500	$1,500
Bridge/Boardwalk across ditch	75	Linear Feet	$150	$11,250
Wildlife habitat (perching sites, nesting boxes, etc.)	5	Each	$500	$2,500
Subtotal				**$1,244,445**
Contingency			**15%**	**$186,667**
Bond			**1.5%**	**$18,667**
Construction Management			**7.5%**	**$93,333**
TOTAL COST				**$1,543,112**

Table F-6
Summarized Cost Estimate for Alternative 5: Full Site Restoration

Cost Item	Quantity	Units	Unit Price	Total Cost
A. Mobilization/Demobilization				
Mobilization/Demobilization	1	LS	$49,552	$49,552
B. Surface Preparation of Disturbed Areas				
Temporary cover crop (e.g. fowl bluegrass and common oat)	8.1	Acres	$325	$2,633
Erosion control - straw mulch	8.1	Acres	$1,500	$12,150
Erosion control - matting on contoured slopes	8,650	SY	$3	$25,950
C. Vegetation Plan				
Clearing and grubbing (wetlands outside footprint)	2.4	Acres	$600	$1,440
Native wetland species seed mix	8.1	Acres	$4,500	$36,450
5yr Herbicide - Spring & Fall application (e.g. glyphosate)	8.1	Acres	$700	$5,670
Aquatic and obligate wetland plugs	4.4	Acres	$55,000	$242,000
Containerized wetland shrubs (e.g. 2-3 gallon)	0.6	Acres	$950	$542
Containerized wetland trees (e.g. 3-5 gallon)	1.1	Acres	$3,125	$3,531
Site-specific invasive species control plan	1.0	LS	$5,000	$5,000
D. Landscape - Grading, Cut/Fill				
Finishg Grading - contour to stable slope (3:1)	39,300	SY	$4	$157,200
Borrow excavation to create marsh slope margins	23,900	CY	$20	$478,000
Fill - wetland topsoil	6,000	CY	$26	$156,000
Fill - footpath construction	0	CY	$8	$0
E. Site Enhancements				
Engineering - Fire suppression ditch conversion	1	LS	$118,680	$118,680
Educational signage	5	Each	$500	$2,500
Footpaths (5' wide) - grading	0	SY	$4	$0
Timber boardwalks	2,000	Linear Feet	$200	$400,000
Brush Piles	1	Day	$1,500	$1,500
Wildlife habitat (perching sites, nesting boxes, etc.)	5	Each	$500	$2,500
Subtotal				**$1,701,298**
Contingency			**15%**	**$255,195**
Bond			**1.5%**	**$25,519**
Construction Management			**7.5%**	**$127,597**
TOTAL COST				**$2,109,610**