# Enbridge Energy, Limited Partnership

# Line 6B Incident, Marshall, Michigan

# Conceptual Site Model

Prepared: November 30, 2010 Version 0

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## List of Acronyms

| | |
|---|---|
| amsl | above mean sea level |
| API | American Petroleum Institute |
| ATSDR | Agency for Toxic Substances and Disease Registry |
| cfs | cubic feet per second |
| CL | Cold Lake Blend |
| Company | Enbridge Energy, Limited Partnership |
| Consent Order | Voluntary Administrative Consent Order and Partial Settlement Agreement entered into between the MDNRE and Company on November 1, 2010 |
| CSM | Conceptual Site Model |
| Line 6B | The pipeline owned by Company that runs just south of Marshall, Michigan |
| MDEQ | Michigan Department of Environmental Quality (now part of MDNRE) |
| MDNR | Michigan Department of Natural Resources (now part of MDNRE) |
| MDNRE | Michigan Department of Natural Resources and Environment |
| mg/kg | milligrams per kilogram (parts per million) |
| mg/L | milligrams per liter (parts per million) |
| MP | Mile Post |
| Part 201 | Part 201 of Michigan’s Act 451 of 1994 as amended |
| SCAT | Shoreline Cleanup and Assessment Technique |
| ug/L | micrograms per liter (parts per billion) |
| U.S. EPA | United States Environmental Protection Agency |
| WCS | Western Canadian Select |
| WMU | Western Michigan University |

# 1.0 Introduction

On July 26, 2010, Enbridge Energy, Limited Partnership ("Company") discovered a release of crude oil from Line 6B, in the vicinity of its pump station located in Marshall, Michigan. The crude oil spilled out of a break in Line 6B, emerged onto the ground surface, flowed over land, following the natural topography downhill and into Talmadge Creek, and proceeded to flow downstream into the Kalamazoo River and continue down the river. The Company shut down the pipeline and immediately initiated response activities to remove free oil as a first action to protect human health and the environment. Initial response activities to remove free crude oil from the surface waters, to protect human health, and to restore the natural systems were performed under orders from the United States Environmental Protection Agency (U.S. EPA).

On November 1, 2010, Enbridge entered into a voluntary Administrative Consent Order and Partial Settlement Agreement (Consent Order) with Michigan Department of Natural Resources and Environment (MDNRE) in which the Company agrees to perform response and restoration activities at and near the location of the release of crude oil in Marshall, Michigan. This report presents the preliminary Conceptual Site Model (CSM) that will be refined and updated with acquisition of additional data to support decision-making processes for the Company's continued evaluation of the Spill Area as required in Section 7.2 of the Consent Order. A CSM is an understanding of known and suspected sources of contamination, the media potentially affected by source impacts, known and potential routes of migration and known or potential human and environmental receptors. The CSM includes the following components identified in the Consent Order:

- description of nature and extent of contamination and resource impacts from released crude oil and response activities;
- description of contaminant fate and transport, potential receptors, all human and ecological exposure pathways, uncertainties, and restoration and risk reduction strategies; and
- a schedule for regular submittals of CSM updates.

The CSM provides the foundation for site-related decision making which utilizes available historical and current information to:

- Identify and describe the conditions before the spill occurred, including geomorphological system, hydrological characteristics, the human and built environment, and the ecological communities present in the system to allow identification of potential receptors and exposure pathways and description of baseline conditions;

- Describe the crude oil spill event, and the fate and transport of the spilled crude oil in order to estimate where residual contamination is (or might be) located, including spatial patterns and discontinuities, and what is happening to crude oil related residuals in terms of fate and migration within the system;
- Describe the response actions undertaken to remove crude oil, mitigate impacts, and restore affected habitats;
- Describe the existing conditions of the system, as initial response activities are nearing completion; and
- Identify uncertainties, important study questions, and data gaps for follow-up evaluation.

Further definition of these items will be incorporated into the work products generated for this project.

The CSM was prepared by AECOM on behalf of Enbridge with contributions from TetraTech and JFNew. Updates to the CSM will be provided following the schedule in Section 7. Enbridge anticipates working collaboratively with MDNRE on future updates via working group meetings.

# 2.0 Overview of System Information

The crude oil released from Line 6B flowed across an emergent wetland, down Talmadge Creek for appriximately2.2 linear miles to the confluence with the Kalamazoo River (just past MP 2.00) and flowed down the Kalamazoo River, with crude oil related residuals reaching as far down the Kalamazoo River as Morrow Lake (MP 37.75) near Kalamazoo, Michigan. This area is defined as the Study Area for this CSM, as shown in Figure 2-1. To provide sufficient detail, this CSM will describe separately three main areas associated with the spill: (1) the Source Area (i.e. the upland area where the initial pipeline break occurred and where the crude oil flowed toward Talmadge Creek), (2) Talmadge Creek, and (3) the Kalamazoo River (including impoundments along the river as well as Morrow Lake). Under each of these sections, information is presented on:

- the conditions present before the pipeline spill and release,
- the conditions resulting from the affect of the spill event within the system,
- the response to the spill event, and
- the current conditions within each area including description of human health and ecological receptors.

The outcome of the preliminary CSM as described by the current conditions and receptors will be utilized for guiding upcoming remedial investigation and remedial alternative evaluation.

Prior to discussing each area, this section provides an overview of information that applies to the entire system, including:

- a description of the release,
- a summary of the spill response and restoration activities that have taken place to date,
- an overview of the fate and transport of spilled crude oil in this natural system, and
- a description of the regional geographic setting.

Figure 2-2 provides a summary of the issues to be addressed in the remainder of this document.

## 2.1 Description of the Spill Event

On July 26, 2010, the Company notified the National Response Center that a pipeline release of crude oil had occurred near Marshall, Michigan from Line 6B. The spill occurred from a 30-inch diameter oil pipeline, just west of pipeline milepost 608 in the vicinity of its pump station located in Marshall, Calhoun County, Michigan (N1/2, Section 2, T3S, R6W, Latitude: 42.2395273 Longitude: -84.9662018). The Line 6B release point is located in an undeveloped rural area, south of Marshall, Michigan. It is currently

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***Crude Oil Classification System***
***light crude** – API gravity higher than 31.1*
***medium crude** – API gravity between 22.3 and 31.1*
***heavy crude** – API gravity below 22.3*
***extra heavy crude** – API gravity below 10*
*The released crude oil had an API gravity of 11*
*An API gravity above 10 is less dense than water*

Based upon information obtained subsequent to the release and after the pipeline was restarted, it appears that the release may have occurred at or about the time that the latter end of a batch of Western Canadian Select (WCS) was passing through Marshall, Michigan and a batch of Cold Lake Blend (CL) crude had begun. The composition of the crude oil released was approximately 77.5 % CL and 22.5 % WCS. CL is a heavy crude blend of bitumen and condensate, produced by a number of oil companies and originating from the production field at Cold Lake, Alberta, Canada, which is located approximately 185 miles northeast of Edmonton, Alberta, Canada. WCS is a blend of existing Canadian heavy conventional and bitumen crude oils blended with sweet synthetic and condensate diluents, produced by various oil companies in Western Canada. The American Petroleum Institute (API) gravity (or lower the specific gravity) of the crude oil was 11 (referred to subsequently in this CSM as "crude oil"). The released crude oil was therefore slightly less dense than water and would be classified as a "heavy crude".

### 2.1.1 Mile Post Reference System

To provide a consistent reference for activities related to the spill of the crude oil, a reference system was established for the surface waters. Mile Posts (MP) were established every 0.25 mile of the impacted reaches of Talmadge Creek and the Kalamazoo River starting with MP 0.00 at the upstream end of Talmadge Creek which was impacted by crude oil. The impacted area of Talmadge Creek then extends from MP 0.00 to just past MP 2.00 at the confluence with the Kalamazoo River. The MP system continues downstream in the Kalamazoo River from MP 2.00 on to MP 37.75. Additional MP were established downstream of the dam but were not impacted and, therefore, are not discussed or referenced in this CSM. MP references are included throughout the text and are shown on most maps of the system for spatial reference purposes.

### 2.1.2 Rain Event Prior to the Spill Event

Weather conditions prior to and after the spill influenced how the spilled crude oil was transported in the environment. Just prior to the spill event, Marshall, Michigan and much of the watershed for the Kalamazoo River basin upstream from the Ceresco Dam had just received a significant rain event. Over the four days from July 22 to July 25 the town of Ceresco reportedly received 5.70 inches of rain (about 5 miles west of the spill) and Albion received 5.65 inches of rain (about 10 miles east of the spill). In other areas of the Kalamazoo River watershed, rainfall was lower than the area where the spill occurred (USGS, 2010 and Michigan State University, 2010). The subsequent increase in water volume within the Kalamazoo River sub-basin from this significant rainfall event (see Figure 2-3) influenced how the crude oil behaved within the riverine environment and is discussed further in Sections 3 to 5.

## 2.2 Spill Response and Restoration Actions

During and after the spill, the Company performed response and restoration activities to address the impacts from the release. These activities included a very rapid mobilization of people and equipment to immediately initiate removal of the crude oil from the environment. Response and restoration activities in the Source Area, Talmadge Creek and the Kalamazoo River are discussed in the individual sections of the report on these areas. Response activities performed by the Company are presented in the Final Report to U.S. EPA (Enbridge, 2010c) and included, but are not limited to:

- Shut-down of pipeline and closures of pipeline isolation valves;
- Installation and operation of flumes (underflow weirs) down gradient of the release area;
- Installation and operation of oil and water containment and recovery systems;
- Development and implementation of plans for remediation of Source Area [Source Area Response Plan] and downstream impacts [Response Plan for Downstream Impacted Area];
- Development of a Sampling and Analysis Plan and Quality Assurance Project Plan for work under the U.S. EPA;
- Sediment and surface water monitoring from the Source Area all of the way down the Kalamazoo River to Lake Michigan;
- Operations and Maintenance of oil control structures;
- Source Area Response activities that included the excavation of impacted Source Area soils as documented in the Source Area Response Completion Report, and development of a qualitative ecological characterization of the Kalamazoo River and Talmadge Creek;
- Downstream excavation of impacted soil;
- Air monitoring and sampling;
- Sampling and analysis of private and public drinking water wells;

- Shoreline Cleanup and Assessment Technique (SCAT) process;
- Characterization and response activities to address submerged oil: identification of submerged oil priority areas and submerged oil task force actions including dredging at Ceresco dam and aeration and hydraulic recovery of submerged oil in priority areas;
- Stabilizing and/or restoring Kalamazoo River bank erosion sites;
- Soil erosion and sedimentation controls along Talmadge Creek;
- Restoration of wetlands and upland areas within the floodplain of Talmadge Creek and the Kalamazoo River;
- Seeding and stabilizing restored areas;
- Monitoring soil erosion controls and restoration areas along the creek;
- Investigations of groundwater along the Kalamazoo River and of surface soils in public parks; and
- Investigations of the Source Area under the direction of the MDNRE.

## 2.3 Fate and Transport of the Crude Oil

### 2.3.1 Transport of Crude Oil

The released crude oil was initially transported via flow overland from the break towards Talmadge Creek, the nearby topographic low point; and then through advective transport along the surface water in Talmadge Creek and the Kalamazoo River. The pipeline break occurred beneath and emergent wetland. The crude oil was forced from the pipeline under pressure into the surrounding soils and emerged onto the ground surface. The released crude oil was slightly less dense than water and flowed over land through the emergent wetland area, following the natural topography downhill and into Talmadge Creek. Talmadge Creek was flowing with higher than normal flow due to the recent heavy rains. Slicks of crude oil flowed along the surface of the water in Talmadge Creek towards the confluence with the Kalamazoo River, and on into the Kalamazoo River. Due to the elevated water level, the crude oil slick affected overbank areas on both sides of the creek. The crude oil continued downstream along the Kalamazoo River. The river level was high, near its maximum for the rain event and overflowed its banks in many areas. Oil slicks therefore impacted flood plain areas including the shoreline, bank areas, and low-lying overbank floodplain areas. As river levels declines, some crude oil became stranded in low spots of the flooded overbank areas.

*These identified areas of (past and/or current) presence of crude oil are the only potential areas that could require further action and are the focus of the CSM and the Consent Order. All non-oiled areas are not anticipated to be further studied.*

The distribution of observed areas of crude oil impacts were identified and addressed through SCAT. The areas where activities occurred that impacted the land surface were surveyed and are shown on Figure 2-4. The areas where crude oil was observed during SCAT are considered the areas where there is potential for residual impacts to still remain following spill response actions. Overbank areas where no oiling was noted are considered un-impacted. Stranded crude oil on overbank areas (and submerged crude oil in the channel) occurred at discontinuous areas along the river. Stranding was observed associated with low-lying midstream islands and banks where the floodwaters overtopped the bank and sought paths of least obstructed flow, most clearly at meander bends, and where low-lying marshes or backwaters were present along the river. The deposition of crude oil was therefore not continuous throughout the area, but was strongly correlated with geomorphological factors along the river.

**Enbridge Experience with Crude Oil Resource Impacts in Bemidji Minnesota**

*A similar oil release occurred near Bemidji, Minnesota in 1979, spilling approximately 445,000 gallons of crude oil onto glacial outwash deposits. In contrast to the Marshall Line 6B spill, the oil at Bemidji collected in a wetland and topographic depressions where crude oil infiltrated through the unsaturated zone to a lower water table. After cleanup efforts were completed in 1979 to 1980, about 105,000 gallons of crude oil remained in the subsurface. At the Bemidji site, the trapped oil has been extensively studied to evaluate provided information on processes at work.*

*Subsequent studies of the crude oil source at Bemidji have shown that the oil phase is slowly evolving with time as hydrocarbon components are lost through mass transfer to water and soil gas, and biodegradation. The oil-phase loss of relatively soluble components (e.g., toluene and xylenes) is sensitive to factors controlling dissolution, such as water concentrations and flow rates. Relatively volatile components can be rapidly lost through volatilization. Other constituents are also removed from the crude oil by methanogenic degradation which may be influenced by hydrologic conditions at a site.*

*Although the geochemical processes have changed over time, the plume has not migrated as far as predicted considering the groundwater flow velocities and sorption constants for the crude oil compounds. Research at this site has demonstrated that biodegradation in anaerobic environments can remove substantial amounts of hydrocarbons from groundwater. Solute-transport modeling indicated that 40 percent of total dissolved organic carbon was degraded through aerobic degradation and 60 percent was degraded through anaerobic degradation.*

As discussed in the following section, the crude oil gradually became denser than water, and there may have been emulsified oil driven into the water column at turbulent flows over dam spillways. This material settled in quiescent portions of river channel, becoming submerged oil. Impacts from oil slicks and submerged oil were observed as far down river as Morrow Lake (MP 37.75).

### 2.3.2 Weathering of the Crude Oil through Volatilization and Dissolution

Volatile and semi volatile hazardous substances which have been identified through analysis by the MDNRE in the crude oil are presented in Table 2-1 along with select chemical properties. Most of these compounds have low, but appreciable solubility in water: for example, the solubility of benzene is over 1,000 mg/L (0.1%); the solubility of toluene, ethylbenzene and xylene all exceed 100 mg/L, and the solubility of trimethylbenzenes, cyclohexane, isopropylbenzene, naphthalene, and 2-methyl naphthalene are all over 10 mg/L.

It is predicted that as the crude oil interacted with water and air in the environment, the composition of the crude oil changed in predictable ways. A major change in the crude oil was the preferential removal of compounds that were slightly soluble in water and volatilization of highly volatile constituents. These constituents were ultimately transferred to water or air. The ultimate fate of the lighter fractions that dissolved in the surface waters is ultimately volatilization from the surface water which is often followed by natural degradation in the atmosphere. As an example, the primary route for the removal of cyclohexane from the aquatic environment is volatilization (half-life in a model river, 2 hours) [U.S. EPA, 1994]. Once in the atmosphere, cyclohexane degrades by reaction with photochemically produced hydroxyl radicals with an estimated half-life for this type of reaction of 52 hours (U.S. EPA, 1994).

Similarly, the high volatility of benzene is the controlling physical property for environmental transport and partitioning. Benzene released to waterways is subject to volatilization, photo-oxidation, and biodegradation. Benzene reactions with hydroxyl radicals in the atmosphere "limit the atmospheric residence time of benzene to only a few days, and possibly to only a few hours." (ATSDR, 2007)

Volatilization is also expected to be an important fate for the loss of naphthalene and 2-methylnaphthalene from water. The half-life of naphthalene dissolved in the Rhine River has been measured as 2.3 days (ATSDR, 2005). The vapor pressures water solubility and Henry's law constants for 2-methylnaphthalene are similar to naphthalene, and it is likely that loss of 2-methylnaphthalene from surface water also occurs by volatilization (ATSDR, 2005).

The organic compounds in Table 2-1 are also degraded naturally in surface waters and sediments through photolysis and biological processes. The half-life for photolysis of naphthalene in surface water is estimated to be about 71 hours, with a longer half-life in deeper water (5 m) of 550 days. The half-life for photolysis of 2-methylnaphthalene in surface water has been estimated at 54 hours (ATSDR, 2005). Furthermore, naphthalene biodegradation rates are about 8 to 20 times higher in sediment than in the water column above the sediment. The half-life of naphthalene in sediment is 4.9 hours in oil contaminated sediment and over 88 days in uncontaminated sediment, respectively. 2-Methylnaphthalene biodegrades more slowly, with half-live sediments reported from 14 to 50 weeks (ATSDR, 2005). Degradation is influenced by factors such as temperature and oxidation-reduction state.

As the volatile organic components preferentially volatilize or dissolve into the surface water, the lighter fraction of the crude oil was removed leaving the crude oil heavier, and more viscous. Some of the crude oil

## Table 2-1. Properties of Constituents in the Curde Oil

| | MDNRE Sample 1 | MDNRE Sample 2 | Chemical Abstract Service Number (CAS#) | Log Octanol-Water Partition Coefficient (Log Kow) | Boiling Point | Vapor pressure | Henry's Law Constant at $25^0$C (HLC) | Water Solubility (S) | Soil Organic Carbon-Water Partition Coefficients (Koc) | Molecular Weight (MW) |
|---|---|---|---|---|---|---|---|---|---|---|
| units | mg/kg | mg/kg | | unitless | oF | mmHG | atm-m$^3$/mol | ug/L | L/Kg | g/mol |
| Volatile Organic Compounds (VOCs) | | | | | | | | | | |
| Benzene | 910 | 1100 | 71-43-2 b | 2.13 a | 176 b | 75 b | 0.00555 a | 1,750,000 a | 58 a | 78 a |
| Ethylbenzene | 220 | 260 | 100-41-4 b | 3.14 a | 277 b | 7 b | 0.00788 a | 169,000 a | 367 a | 106 a |
| Xylenes (total) | 1410 | 1650 | mixture | 3.11 a | 281 - 292 b | 7 to 9 b | 0.00604 a | 186,000 a | 348 a | 106 a |
| Toluene | 1700 | 2000 | 108-88-3 b | 2.75 a | 232 | 21 | 0.00664 a | 526,000 a | 180 a | 92 a |
| 1,2,3-Trimethylbenzene | 44 | 58 | 526-73-8 b | | 349 b | 1 @ 62$^o$F b | | | | 120 b |
| 1,2,4-Trimethylbenzene | 340 | 410 | 95-63-6 b | 3.67 a | 337 b | 1 @56$^o$F b | 0.00587 a | 55,890 a | 965 a | 120 a |
| 1,3,5-Trimethylbenzene | 170 | 190 | 108-67-8 b | 3.5 a | 328 b | 2 b | 0.00738 a | 61,150 a | 708 a | 120 a |
| Cyclohexane | 1900 | 2200 | 110-82-7 b | 3.44 e | 177 b | 78 b | 0.195 eC | 55,000 eC | 482 eC | 84 b |
| Isopropylbenzene | 51 | 57 | 98-82-8 b | 3.6 a | 306 b | 8 b | 0.015 a | 56,000 a | 3,460 a | 122 a |
| n-Propylbenzene | 91 | 100 | 103-65-1 a | 3.69 a | | | NA a | NA a | 4,240 a | 120 a |
| p-Isopropyl toluene | 35 | 40 | 99-87-6 | | | | | | | |
| Sec-Butylbenzene | 33 | 35 | 135-98-8 a | 4.57 a | | | NA a | NA a | 31,100 a | 134 a |
| Semivolatile Organics (SVOCs) | | | | | | | | | | |
| 2-Methylnaphthlane | 130 | 150 | 91-57-6 c | 3.9 a | 241 c | 0.068 c | 0.000499 a | 24,600 a | 6,820 a | 142 a |
| Naphthalene | 63 | 72 | 91-20-3 c | 3.36 a | 218 c | 0.087 c | 0.000483 a | 31,000 a | 2,010 a | 128 a |
| Phenanthrene | 82 | 86 | 85-01-8 d | 4.6 a | 340 d | 0.00068 d | 0.000023 a | 1,000 a | 33,300 a | 178 a |

## Table 2-1. Properties of Constituents in the Curde Oil

| | MDNRE Sample 1 | MDNRE Sample 2 | Chemical Abstract Service Number (CAS#) | Log Octanol-Water Partition Coefficient (Log Kow) | Boiling Point | Vapor pressure | Henry's Law Constant at $25^0$C (HLC) | Water Solubility (S) | Soil Organic Carbon-Water Partition Coefficients (Koc) | Molecular Weight (MW) |
|---|---|---|---|---|---|---|---|---|---|---|
| units | mg/kg | mg/kg | | unitless | oF | mmHG | atm-$m^3$/mol | ug/L | L/Kg | g/mol |
| Metals | | | | | | | | | | |
| Beryllium | 0.4 | 0.8 | | Form of metal not specified | | | | | | 9 a |
| Iron | 30 | 7.7 | | Form of metal not specified | | | | | | 56 a |
| Mercury | 0.0003 | 0.0003 | | Form of metal not specified | | | | | | 201 a |
| Molybdenum | ND | 9.3 | | Form of metal not specified | | | | | | 96 a |
| Nickel | 59 | 67 | | Form of metal not specified | | | | | | 59 a |
| Titanium | 2.8 | 3.2 | | Form of metal not specified | | | | | | 48 |
| Vanadium | 130 | 140 | | Form of metal not specified | | | | | | 51 a |

a MDEQ, 2006a.
b NIOSH, 2005.
c ATSDR, 2005.
d ATSDR, 1995.
e US EPA, 1994. eC = calculated

NA Data are not available for this parameter
NR Parameter or property is not relevant for this compound

achieved the same density as water or even a slightly greater density than water and sank in the surface water to the top of the sediment. While loss of volatile organic compounds through volatilization and dissolution are dominant, some volatiles will remain in the submerged material in the sediments. Structures in Talmadge Creek and the Kalamazoo River that caused more mixing, such as dams and flow constructions, enhanced higher energy mixing within the surface water column and increased solubilization and volatilization of some components of the crude oil.

## 2.4 Regional Geological and Hydrogeological Setting

Talmadge Creek and the Kalamazoo River flow through glacial deposits in Michigan that overly bedrock at varying depths. The primary bedrock units are Mississippian and include Marshall Sandstone throughout the Kalamazoo River basin in Calhoun County, and Coldwater Shale in portions of Kalamazoo County (Dorr and Eschman, 1970; WMU, 1981). Depth to bedrock varies within the Study Area from ground surface to approximately 200 feet below ground surface (approximately 700 to 900 feet above mean sea level (amsl)). Within the Kalamazoo River basin, the bedrock topography ranges from approximately 1100 feet amsl near the headwaters to 400 feet amsl near Lake Michigan (WMU, 1981). Erosional terraces of Marshall Sandstone outcrop at various locations along the Kalamazoo River, including at Ceresco Dam. The bedrock units have a slight dip to the northeast (Vanlier, 1966).

*On November 8, 2010, Calhoun County Department of Public Health removed a three-month drinking water well water advisory for those living within 300 feet of the river. The advisory was issued July 29.*

*"We're just satisfied that to date, the groundwater supplies haven't been impacted as a result of the oil spill," said Health Officer Jim Rutherford. "We're satisfied that currently all the wells are free of any contaminants."*

*The decision affected about 200 households within the 300 feet, Rutherford said.*

Overlying the bedrock are an assortment of glacial outwash sands, coarse end-moraine deposits (sands and gravel), fine end-moraine deposits, ice contact material (sorted sands and gravel), clayey till, lake plain deposits, and post-glacial and modern alluvium. The Kalamazoo River basin is dominated by well-drained outwash, coarse end-moraine deposits and ice contact deposits which have higher groundwater yields compared to basins with less permeable deposits (Bent, 1971). In these well-drained soils, a large amount of precipitation and snow-melt percolates to the groundwater and the groundwater flows to the Kalamazoo River, associated tributaries such as Talmadge Creek and sub-basin wetlands (Wesley, 2005). Slug test data collected during the Hydrogeological Assessment measured hydraulic conductivities ranging from approximately 12 feet/day in the finer silt and sand intervals to over 300 feet/day in the fractured sandstone bedrock. These values are within the range of published values for the encountered soils and bedrock (AECOM, 2010).

Groundwater is used as a source of drinking water in the rural areas along Talmadge Creek and the Kalamazoo River. The groundwater is generally of good quality, though naturally occurring metals are locally present and may in some instances exceed aesthetic and health based drinking water criteria (e.g. iron and arsenic) (AECOM, 2010). In addition, known and unknown sites of environmental impact were present prior to the spill along the Kalamazoo River which may have locally impacted groundwater with hazardous constituents such as chlorinated solvents and also gasoline and oil related constituents (AECOM, 2010).

The Kalamazoo River is the major drainage for this area and groundwater is expected to discharge into the river during most periods. Two expected exceptions are localized groundwater flow at dams and tight bends in the river (AECOM, 2010). At dams in the river where there is a significant and rapid drop in the elevation of the surface water body, groundwater may locally flow out of the river at a higher surface water elevation, parallel the river, and then flow back into the river at the lower surface water elevation. At tight bends in the river, shallow groundwater may parallel the general flow of the river, flow across the tight bend, and then flow back into the river downstream of the bend.

## 2.5 Environmental Stressors

"Stressors" are physical, chemical or biological entities that can induce an adverse response (U.S. EPA, 1997). Non-chemical stressors are environmental stressors present throughout the Study Area of the crude oil release that are relevant to the ecological evaluation and response activities but not associated with crude oil related chemical constituents. Remediation and restoration must consider the integrated manner in which stressors interact so as to degrade habitats and limit restoration. Some non-chemical stressors are directly related to remediation and restoration efforts while others are indirectly related or not related to these efforts. Non-chemical stressors may be physical or biological.

Physical stressors that may influence remediation and restoration may include:

- Substrate limitations strongly influences the species, numbers and diversity of benthic macro-invertebrates that can colonize and persist in river and creek sediments;
- Hydrologic alterations such as buildings and transportation facilities can increase impervious surfaces and alter the drainage and therefore the natural flow of a river;
- Culverts, dams, and flumes can affect movement of fish and other aquatic organisms;
- Pre-existing and new structures such as culverts will alter the hydrology of the creek;
- Dredging and excavation of river and adjacent areas remove plants and destabilize shorelines;
- Soil erosion and sedimentation may adversely affect banks and sediments; and

- Sediment aeration and dredging may temporarily affect sediment and habitat quality for benthic organisms.

Biological Stressors that may influence remediation and restoration may include:

- Invasive species may affect wetland restoration. Important invasive species are reed canary grass, purple loosestrife, *Phragmites* and glossy buckthorn – imported soils may also contain seeds, roots or rhizomes of invasive species;
- Diseases and disease vectors may affect wetland restoration and re-vegetation efforts (e.g. disease carried by the emerald ash borer is stressing and killing ash trees in the area);
- Re-vegetation, if not properly done (correct soil preparation, correct species mix, correct fertilization procedures) may adversely affect the ability of natural plant communities to reemerge in impacted areas (re-vegetation also may have beneficial effects if properly done); and
- Grazing and browsing by deer and rabbits may adversely affect re-vegetation with shrubs and trees.

Other sources of environmental stressors to the river system not associated with the crude oil include releases and impacts resulting from sites regulated under Part 201 of Michigan's Act 451 of 1994, as amended (Part 201) (AECOM, 2010) in the watershed and from NPDES permitted discharges that can affect human health and the environment. These impacts are:

- chemical (e.g. hazardous substances in releases),
- biological (increased oxygen demand, eutrophication, and pathogens from discharges); and
- physical (temperature extremes in cooling water).

# 3.0 Source Area

## 3.1 Baseline Condition in the Source Area

The release from Line 6B occurred in an undeveloped rural area, south of Marshall, Michigan that is adjacent to developed properties used for private residences and light industry. The Source Area where the crude oil came to the surface and flowed to Talmadge Creek was a mixture of emergent, scrub-shrub and forested wetland. Adjacent areas were mostly deciduous forested upland. The crude oil followed a preferential path along the topographic relief overland through the wetland, and did not affect the upland woods. Acute ecological exposure occurred for vegetation and biota in the affected wetland areas, and any wildlife that may have come into contact with the crude oil. Residual exposure may exist from any residual crude oil related constituents still present in the subsurface of the restored wet meadows.

The area was not frequently visited by local residents or recreational users, and no residents are present within 300 feet of the source area.

## 3.2 Release Event

During the release, crude oil impacted the surface and subsurface soils near the pipeline and then flowed overland for about 600 feet to Talmadge Creek. These soils were saturated with water as a result of the recent rains, so the crude oil generally stayed near the top of the soil column between the point of the release and Talmadge Creek and did not penetrate deeply into the ground.

**Insert 3-1 Source Area after re-grading with organic soils**

**Looking west down the pipeline. Note presence of berm extending across Source Area grading in center of picture. Source: U.S. EPA Website. http://www.epa.gov/enbridgespill/photos.html**

## 3.3 Response Actions in the Source Area

The Company shut the pipeline off and immediately initiated the removal of crude oil from the Source Area. The objectives of response actions in the Source Area were to remove crude oil and crude oil impacted soil and vegetation covered with crude oil that could potentially threaten navigable waterways (see Stream and Floodplain Restoration Plans – JFNew, 2010a, b, and c). Response actions in the Source Area near Talmadge Creek include the following:

- Cease pumping in Line 6B and isolation of the leak;
- Repair of Line 6B;

- Installation of a sheet pile trench box around the release site;
- Installation of temporary collection trenches and berms for containment of crude oil and to prevent the flow of crude oil to Talmadge Creek;
- Recovery of crude oil;
- Site clearing and grubbing of trees and vegetation to allow completion of free-phase crude oil removal;
- Generation of laydown areas for equipment and wastes, and eventual restoration of these laydown areas (see Section 6)
- Removal of soil impacted by crude oil, staging and bulking for disposal;
- Backfill of excavated area with organic rich soils to support wetland restoration (see Insert 3-1);
- Reseeding with native plant seed, oats and annual rye;
- Placement of berms after backfill as a precautionary measure to inhibit the flow of any sheen; later removal of the berms when no sheen was being captured;
- Removal and restoration of mat roads and operational areas;
- Seeding of entire area with a mixture of native emergent and scrub-shrub wetland plant species; and
- Storm water management and erosion control.

## 3.4 Current Conditions in the Source Area

Groundwater saturates the filled soils, and water is present at the ground surface in the reconstructed source area wet meadow type wetlands. Oil sheens are not observed in these areas.

*Groundwater flow near Talmadge Creek is expected to be toward the creek with a regional flow toward the Kalamazoo River..*

An investigation has been initiated in the Source Area to document the presence or absence of any crude oil related constituents in the soils extending below the water table. Field screening techniques were used to identify crude oil in the field during the investigation.

Visible oil and visually impacted soil were removed during initial response activities. Groundwater monitoring wells and soil borings were installed and sampled in the Source Area under the supervision of the MDNRE to document the direction of groundwater flow and the groundwater quality. Concentrations of all analytes in groundwater samples from these wells were less than detection limits in the initial samples collected on October 28, 2010. However, it is possible there is residual crude oil related constituents in the Source Area that exceed the applicable Part 201 criteria.

The wet meadow wetlands at the Source Area were re-built and seeded after the excavations. A final restoration plan for this area will be developed to direct and monitor additional restoration as appropriate. These plans will facilitate re-vegetation by preferred native species and will limit the colonization by invasive species.

## 3.5 Principal Study Questions

Uncertainties about the current conditions define the principal study questions associated with the sources area. Addressing these will provide the information necessary to evaluate the nature and extent of hazardous constituents and free crude oil in the Source Area and allow for an evaluation of potential exposure and estimation of risk in this area.

- Is there sufficient r crude oil related constituents remaining in the Source Area and its affected wetland and floodplain habitats to:
    - Leach hazardous constituents from the crude oil into the groundwater and other media at concentrations above generic groundwater criteria under Part 201,
    - Create methane during natural degradation of any remaining crude oil, or
    - Flow into a monitoring well screened across the water table?
- Does the groundwater contain soluble hazardous constituents that were in the crude oil above generic groundwater criteria under Part 201?
- Based upon analytical results from soil and groundwater and the location of observed impacts, what are the human health and ecological exposure pathways warranting further evaluation?
- Based upon analytical results from soil and groundwater, do any human and/or ecological exposure pathways warrant further evaluation?
- Are residual crude oil constituents present at concentrations which would cause adverse impacts to the restored ecological community?

# 4.0 Talmadge Creek

## 4.1 Baseline Conditions in Talmadge Creek

The hydrology of Talmadge creek is influenced by surface water discharges, groundwater discharge and precipitation within its sub-basin. Talmadge Creek receives most of its water from numerous groundwater springs and wetlands present near its banks along most of its length (see Insert 4-1). The creek borders a series of riverine before it discharges into the Kalamazoo River just west of Marshall. In addition to the wetlands, there are also ponds adjacent to the creek. The adjacent and nearby wetlands and ponds are at slightly higher elevations than the creek, demonstrating that the creek is a gaining water through this reach.

**Insert 4-1 Spring-fed wetlands adjacent to Talmadge Creek.**

**Spring fed wetlands are common along length of the creek. Talmadge Creek is located on left side and behind photographer. Source: photo by B.Bjorkman, 18-Nov-2010; looking north near MP 0.50.**

Talmadge Creek flows through culverts under several roads between the Source Area and the confluence with the Kalamazoo River. The longest culvert, which is beneath 16 Mile Road and U.S. Interstate 69, is over 300 feet long.

Natural (e.g. iron bacteria) sources of sheening have been commonly observed along Talmadge, resulting Creek from natural organic materials, particularly near groundwater seeps. These “natural” sheens are visible in wetlands and seeps along the creek in areas that were not impacted by the pipeline release.

Some of the dominant plant species in several areas of the creek were invasive non-native species, which is of importance when considering restoration options (see box below with JFNew observations). The otherwise unstable, muck soils were often bound by a fine network of live and dead roots. Coupled with the apparent dense mats of vegetation these soils appear to have been fairly stable despite an apparent high water table and seeps moving over and through these soils enroute to the creek.

Ecological exposures pathways along Talmadge Creek include:

- In-stream biota. This small creek contains no large fish, but small creek fish (shiners and chub) are present, as are aquatic insects, and benthic macro invertebrates such as crayfish. Following

## TALMADGE CREEK – VEGETATION AND OBSERVATIONS

JFNew viewed a portion of Talmadge Creek and its associated floodplain prior to completion of the excavation activities along the creek corridor. JFNew staff first viewed the creek and its associated floodplains, consisting of both upland and wetland, on August 25, 2010. At that time there were still areas of undisturbed vegetation between the temporary mat roads and the banks of the creek.

Vegetation that was still visible in the upper reaches (east of I-69) included a mixture of native and non-native species commonly associated with wet meadow, emergent and scrub shrub wetlands. Along the edges of the stream still containing vegetation, the areas were dominated by such plant species as reed canary grass (*Phalaris arundinacea*), purple loosestrife (*Lythrum salicaria*), blue joint grass (*Calamagrostis canadensis*), lakebank sedge (*Carex lacustris*), tussock sedge (*Carex stricta*), joe-pye-weed (*Eupatorium maculatum*) and boneset (*E. perfoliatum*). Intermixed with these relatively low height herbaceous/forb species were also scattered shrubs and tree species. Sandbar willow (*Salix exigua*), pussy willow (*S. discolor*), silky dogwood (*Cornus amomum*), and poison sumac (*Rhus vernix*) were the apparent dominant shrub species. Only a few tree species were identified and included bur oak (*Quercus macrocarpa*) and pin oak (*Q. palustris*). Soils identified in these upper reaches consisted primarily of muck and mucky mineral over sands and/or marl encrusted gravel substrates at deeper depths.

Vegetation that was still visible in the lower reaches (west of I-69) included a mixture of native and non-native species commonly associated with emergent, scrub shrub, and forested wetlands. Along the edges of the creek there was a greater diversity of wetland and upland types within the floodplain of the creek. There were emergent and wet meadow wetlands near the creek with scrub-shrub wetland on the outer edges. In areas, apparently not impacted by the release were forested wetlands. Dominant plant species were very similar to those identified in the upper reaches (east of I-69), consisting of reed canary grass, purple loosestrife, lakebank and tussock sedge, blue joint grass, and joe-pye-weed. In the furthest downstream reaches of the creek, there was a change in topography and soils whereas there were fewer wet meadow wetland species and a greater number of forested wetland species along the creek banks. Soils identified in these lower reaches consisted of a mixture of muck, mucky mineral and various loamy soils (e.g. silt, clay and sandy loams).

The final ±100-foot reach of Talmadge Creek, from A Drive to the Kalamazoo River, appeared to have been primarily maintained lawn comprised primarily of grass species (i.e. *Festuca* spp. and *Poa* spp.). In these areas soils were comprised of a mixture of soils, including mostly silty clay loams and historically placed fill.

initial acute impacts from crude oil, recolonization of the creek bed is likely and chronic exposure to residual crude oil should be considered.

- Stream-bank biota. Acute exposures at the time of the spill may have occurred. As part of the restoration effort, most of the habitat was destroyed. Restoration of the riparian and wetland habitat with native species is ongoing, and it is expected that a biota of native wetland vegetation, and animals such as frogs, birds and small mammals will be reestablished. These are complete pathways for exposure to residual crude oil in bank soil or creek media.

Several residences are within 200 feet of the high water mark of Talmadge Creek. Some of these residents use groundwater wells near the creek as their potable water source. The water in these wells is being monitored as part of response activities. Currently, impacts from the crude oil release have not been detected in these wells. Exposure to impacted groundwater is a potentially complete pathway if it is found that the creek at times may be a "losing" stream and crude oil related constituents are available to leach hazardous substances to the groundwater. The creek flows primarily through private property, and following reestablishment of natural vegetation access is difficult (and poison sumac is very common). Recreational use of the creek therefore is minimal, though protection or both residents and recreational users will continue to be a focus of refinements to the CSM (Figure 4-1).

## 4.2 Release Event

The crude oil reached Talmadge Creek by overland flow and flowed down the creek and into the Kalamazoo River (Insert 4-2). The water level in the creek was elevated at the time of the release from recent rains, with the adjoining wetlands already inundated prior to the release. The crude oil migrated down the main path of the creek, coating the banks and vegetation with crude oil. In the overbank, most of the vegetation was not completely submerged at the time of the release, and the undersides of vegetation were coated with crude oil. The crude oil mixed with water and was exposed to air as it spread out on the surface of the creek and flowed through the vegetation.

Constrictions in the flow path of Talmadge Creek such as the culverts at Division Street, 16 Mile Road and I-69, 15 ½ Mile Road, and A Drive caused crude oil to back up on the water surface upstream of the constriction and increased mixing as the water and crude oil flowed out of the culverts at a higher velocity.

**Insert 4-2 Talmadge Creek west of I-96, with visible sheen on July 28, 2010.**

**This photo shows impacted overbank areas where vegetation was coated below the tops of the plants. Source: U.S. EPA Website. http://www.epa.gov/enbridgespill/photos.html**

The crude oil had a density of less than 1 and floated on the high water in the creek. But as the crude oil interacted with the water and atmosphere, volatile and soluble fractions were gradually removed from the crude oil or some crude oil entrained in suspended solids and the water column. Some of the crude oil may have reached or exceeded the density of water and sank in the creek.

As the flow receded, crude oil was trapped in overbank areas and became stranded. The crude oil is likely to have had acute impact to aquatic biota including vegetation, benthic invertebrates, and fish.

## 4.3 Response Actions in Talmadge Creek

The Company immediately initiated response actions to remove crude oil and eliminate the discharge of crude oil onto surface waters. These activities included actions to block or control the flow of crude oil and activities to capture and remove crude oil. Following these response activities, restoration activities have been initiated throughout the areas impacted by the spill and the response actions (Insert 4-3).

**Insert 4-3 Oiled soils during initial response actions.**

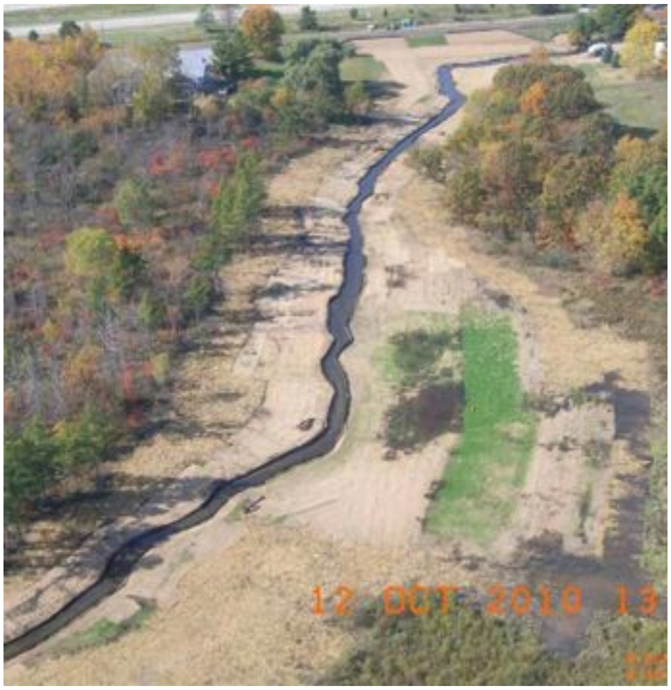
**Note the abundance of Purple Loosestrife on both banks.**
**Source: U.S. EPA Website.**
**http://www.epa.gov/enbridgespill/photos.html**

Control structures were used in Talmadge Creek to reduce the flow of crude oil further downstream and into the Kalamazoo River. These structures included absorbent booms and also flume structures with an underflow drain to eliminate the migration of floating crude oil. In addition, a sediment trap was created near the confluence with the Kalamazoo River to capture sediments mobilized as a result of Talmadge Creek restoration actions.

The overbank areas that contained observable free crude oil were excavated. Under supervision by the U.S. EPA, excavations were classified as; (Method A) surface excavation where free crude oil was only present at the ground surface, (Method B) deeper excavations that extended to the water table, (Method C) excavations that extended below the water table. Excavated soils were removed, staged, bulked, and disposed of off-site. The overbank area was divided into a series of clearance areas shown in Figure 2-4, and the U.S. EPA signed off documenting the removal of free crude oil in each clearance area prior to restoration (Enbridge, 2010a). During the clearance of the excavation areas, soil samples were collected from the clearance areas in coordination with the MDNRE.

During the overbank excavations, the creek channel was left in place through most of the length of the creek, and excavated in some areas at the direction of the U.S. EPA. After the soil excavations, the creek bottom was raked and locally aerated to remove crude oil from the bottom of the creek, with concurrent capture of the crude oil that was liberated by these processes. Raking and aerating the subsurface sediments caused free crude oil to float to the surface and also provided further mixing with water and increased the removal of soluble components from any remaining materials.

Mat roads were constructed along the entire length of Talmadge Creek to support the excavation activities from the release area (MP 0.00) down to the confluence with the Kalamazoo River just after MP 2.00. The mat roads were removed at the completion of backfill operations. As the mat roads were being removed, soils that were exposed under the mats were inspected and oiled soils were removed.



**Insert 4-4 Talmadge Creek shortly after mat roads were removed near MP 1.00.**

**Source: U.S. EPA Website. http://www.epa.gov/enbridgespill/photos.html**

In general, restoration consisted of replacing excavated soil with clean organic soil, placing 12-inch coir logs along both banks of the stream as necessary, seeding disturbed areas with native wetland seed mixes and placing biodegradable erosion control blankets over the seeded areas (Insert 4-4). In only a few areas was field stone used to restore, but moreover to stabilize affected and/or erosion prone banks.

*Planting of native shrubs and trees is planned for the spring of 2011. The length of the creek is monitored weekly both for restoration and soil erosion .*

All of the flumes in the creek have been removed except the flume closest to the Kalamazoo River. This flume is still in place with an associated sediment trap to collect sediments transported downstream by the creek before the sediment reaches the Kalamazoo River. Removal of this flume is currently under review with the agencies with an anticipated schedule for removal in early November, 2010.

The specific response actions and locations in Talmadge Creek are identified in ten *Pipeline Release Source Contamination Removal and Verification Summary Reports* (Enbridge, 2010a). Sediment raking is detailed in the *Submerged Oil Recovery Summary Report* (Enbridge, 2010b). Interim restoration of Talmadge Creek is documented in three interim restoration plans (JFNew, 2010a, b and c).

## 4.4 Current Conditions in Talmadge Creek

### 4.4.1 Residual Impacts

Visible crude oil has been removed from Talmadge Creek and the adjacent overbank areas. Results from the confirmation soil samples in the clearance areas document that the hazardous constituents from the crude oil are not detected in most of the remaining soils. Residual contaminants may be present in places along the creek banks, and concentrations of some chemicals in soil, sediment and groundwater may exceed applicable Part 201 criteria.

Residual crude oil constituents may be present in some soils and creek sediments where the creek channel and the bank material along Talmadge Creek were left in place, even after raking and aerating. The limited amount of crude oil residuals remaining is expected to be in the high organic or peaty soils along the creek where it may be held by the organic matrix.

Groundwater along the creek appears to flow toward the creek. Seeps can be observed draining groundwater into the creek. The hydraulic gradient toward the creek was large enough that restoration activities were modified to ensure that the groundwater gradient toward the creek did not create bank instability. With the gradient toward the creek, there is very limited potential for groundwater to be impacted by any residual material that may remain in soils adjacent to the creek. However, there is ongoing monitoring of groundwater wells adjacent to Talmadge Creek, current and future residential use of groundwater will continue to be a primary focus of the CSM.

Because the restoration activities did not remove all bank material immediately adjacent to the stream, flowing surface water or bank erosion in Talmadge Creek may liberate sheens from residual crude oil constituents in bank soils, or from accumulations of recent sediment deposition within the water column.

Confirmation soil samples were collected following the closure of the clearance areas. Furthermore, continuing surface water and sediment monitoring has been conducted in Talmadge Creek at SW-107. Since August 26, 2010, there have been limited detections of crude oil related contaminants in surface water. The two detections of toluene and seven vanadium detections in validated data (through October 14, 2010), below Michigan Rule 57 Surface Water values.

There were limited detections of crude oil related contaminants in sediment at SW-107. Volatile organic compounds such as benzene, ethylbenzene, toluene, and xylenes were not detected. Polynuclear aromatic hydrocarbons were frequently detected with total PAH concentrations below a 22.8 mg/kg, a commonly applied U.S. EPA “consensus” probable effect level for benthic biota (MDEQ, 2006b).

Metals such as nickel, vanadium, and mercury were frequently detected, as were other naturally-occurring metals commonly found in regional soil (e.g. arsenic, iron, magnesium).

Aesthetic impacts may exist due to small oil sheens in stranded overbank water or staining on tree trunks and structures that abut Talmadge Creek.

The overbank area of Talmadge Creek was re-built after the excavations of visible crude oil. A final restoration plan for this area will be developed to direct and monitor the restoration as appropriate. These plans will facilitate re-vegetation by preferred native species and will limit the colonization by invasive species. In addition, restoration activities, already begun, will ensure that appropriate habitat is present for wildlife along Talmadge Creek.

### 4.4.2 Exposure Pathways

Figure 4-1 includes likely exposure pathways. The crude oil spill and subsequent removal actions had an acute impact on biota that utilize the creek and banks, and response activities have significantly reduced long term exposure pathways to the crude oil through direct removal activities. Residual materials present in the sediment and coating rocks, gravel, and objects in the creek and along the shores may continue releasing contaminants to water and also may cause direct effects on human and/ or ecological receptors contacting the residual material.

It is expected that diversity and species abundance along the creek was reduced as a result of the initial spill and associated response actions. The residual material may continue to inhibit re-growth and re-colonization, and therefore to slow natural recovery. Residual material in soil, water and sediment may also pose a risk to wildlife ingesting or coming into contact with coated objects or affected media or ingesting dietary organisms during normal feeding habits.

Talmadge Creek is a small and shallow water body and lacks the habitat for larger fish. Exposures, therefore, are focused on the benthic invertebrate community, and small (such as shiners) fish populations. These aquatic animals are important resources for predators such as raccoons, kingfishers, and herons.

Human health receptors include recreational users (including hunter) and streamside residents with access to the creek, or who use impacted groundwater extracted near the creek as shown in Figure 4-1.

## 4.5 Principal Study Questions

- Is there sufficient crude oil remaining along Talmadge Creek to:
    - ➢ Leach hazardous constituents from the crude oil to groundwater that would migrate into the surface water or a residential well at concentrations above generic criteria under Part 201,

  - Flow into a monitoring well screened across the water table, or
  - Create sheen on the creek during special events such as high water or freeze-thaw cycles?
- Based upon analytical results from environmental media, do any human and/or ecological exposure pathways warrant further evaluation?
- Is the implemented restoration confirming vegetation, soil biota, and wetland biota recovery following the exposure to crude oil?
- Is there adverse impact from residual crude oil on the local ecological community in the creek and adjacent overbank habitats?

# 5.0 Kalamazoo River

## 5.1 Baseline Condition in the Kalamazoo River

This section presents an overview of the environmental conditions of the Kalamazoo River before the crude oil spill and the receptors that were potentially impacted by the spill. This evaluation is based upon site observations and published literature to present information related to the transport and fate of crude oil in the Kalamazoo River and potential exposure to residual crude oil remaining in the system. A baseline description of the Kalamazoo River is provided in the Michigan Department of Natural Resources detailed study on the basin from 2005 that includes comprehensive information about the natural history of the basin, stream flows, channel morphology, water quality, and biological communities (Wesley, 2005).

### 5.1.1 Watershed Information

The Kalamazoo River basin consists of a 2,020 square mile drainage system that flows northwest and ultimately discharges an average of 1,925 cubic feet per second (cfs) to Lake Michigan. The basin contains 175 miles of mainstem drainage (Kalamazoo River), 899 miles of tributary streams and 287 lakes ranging between 10 and 2,661 acres (Wesley, 2005). Watershed valley segments are defined by Wesley (2005) based upon the concept of a natural ecological unit as determined by fluvial and biological processes (shown on Figure 2-3). Valley segments are characterized by similar hydrologic, limnologic, channel morphology, and riparian dynamics and serve as the initial divisional units of the Kalamazoo CSM area. Geospatial and attribute data for the valley segments are available from the Michigan Surface Water Information System (http://www.mcgi.state.mi.us/miswims).

#### 5.1.1.1 Hydrology

The hydrology of the Kalamazoo River watershed is influenced by the Pleistocene glacial deposits that cover most of the surface of the watershed. The soils in the upper portions of the Kalamazoo River are moderately fine textured to moderately coarse textured soils with moderate infiltration rates when thoroughly wet (Fongers, 2008). The permeable soil allows rainwater to infiltrate and provide a base flow to the Kalamazoo River through the study area. This base flow contributes to a relatively stable watershed system in terms of both water flow and stream temperature. Stream flows in the Kalamazoo watershed are also influenced by climatic factors, which vary over the watershed area, and by engineered structures.

#### 5.1.1.2 Climate

Annual precipitation generally increases from 32 to 36 inches between the headwaters and mouth of the watershed and temperatures are more seasonally moderated closer to Lake Michigan due to lake effects (Wesley, 2005). The highest stream flows are typically in March and April due to snowmelt and storm water runoff flowing over frozen soils. The wettest months with the highest rainfall are June and July. Lower stream flows typically occur in August through October (base flow).

#### 5.1.1.3 Channel Gradient

Channel gradients of the Kalamazoo River gradually decrease downstream, averaging 3 feet per mile. The channel gradient typically ranges from 4 to 10 feet per mile between the town of Marshall and Morrow Lake (Michigan Geographic Data Library, 2010), with higher channel gradient reaches being impounded. There are twelve dams along the mainstem of the river between the river's headwaters and Lake Michigan. According to Wesley (2005), the characteristics of the impoundments in the Study Area are:

- Ceresco Dam- 15 ft head; surface area of 367 acres (ac); storage capacity of 2200 acre-feet (ac-ft); average depth of 6.0 ft,
- Mill Pond Dam- 2 ft head; surface area of 4 ac; storage capacity of 3 ac-ft; average depth of 0.8 ft, and
- Morrow Dam- 14 ft head; surface area of 1000 ac; storage of 6000 ac-ft; average depth of 6.0 ft.

#### 5.1.1.4 Water Quality

Water quality throughout much of the Kalamazoo River watershed has historically been degraded as a result of municipal and industrial discharges, most of which are now regulated. However, water quality in the Study Area is generally considered good, based on macro-invertebrate surveys conducted by the MDNR as referenced by Wesley (2005). Additional information on historical water quality indicators can be found through the Water Quality Data Access System (http://www.gis.iwr.msu.edu/storet/), USGS Water-Quality Data for the Nation (http://waterdata.usgs.gov/nwis/qw), and Michigan Geographic Data Library (2010).

The Kalamazoo River downstream of Morrow Lake and the Study Area was designated as an Area of Concern (AOC) by the International Joint Commission (Great Lakes Information Network, accessed at http://www.great-lakes.net). A 1994-1995 mass balance study of polychlorinated biphenyls (PCBs), atrazine, mercury, and nutrient discharges to Lake Michigan found the Kalamazoo River to be within the top five contributors of the various pollutants to the lake (U.S. EPA, 2003). The AOC's Remedial Action Plan was written by the Michigan Department of Environmental Quality (MDEQ, now part of the MDNRE) in 1998 and revised and rereleased in 2000 in collaboration with the Kalamazoo River Watershed Council (KRWC). The Remedial Action Plan now serves as the watershed management plan.

Contributors to water quality degradation in the watershed from the Study Area are residential lawn clippings and nutrients, commercial petroleum, and erosion caused by damming (MDEQ and KRWC, 2000). Chlorine, heavy metal, cyanide, and oily sludge deposits were also identified in sediment upstream of the Study Area and high levels of copper and zinc were detected in sediments downstream of the Marshall Waste Water Treatment Plant prior to the 2010 spill (Wesley, 2005). Urban and agricultural non-point sources are probably also significant.

#### 5.1.1.5 Environmental Stressors

There are existing stressors and habitat modifiers on the Kalamazoo River which do not relate to crude oil related constituents from the spill to the system. Environmental stressors were discussed briefly in Section 2.5 for the entire system, and pre-existing stressors related to the Kalamazoo River discussed further here. The following additional environmental stressors were present prior to the spill:

- Three dams are present in the Study Area: Ceresco Dam near MP 5.8; Mill Pond Dam near MP 15.7; and the Morrow Lake Dam near MP 39.8;
- Bridge abutments which restrict flow;
- NPDES permitted discharges which may add chemical and thermal loads to the river;
- Non-point sources consisting of sediments, nutrients, bacteria, organic chemicals, or metals – sources of these pollutants include agricultural fields, surface runoff from construction sites, parking lots, urban streets, uncontrolled septic seepage, groundwater contamination and industrial sites (Wesley, 2005);
- Channelized flow with stabilized banks – particularly from MP 15.8 to MP 16.5 but also including other sections such as MP 16.5 to MP 18;
- Substrate limitations that may limit species diversity of benthic macro-invertebrates, particularly around urban areas and in impounded water behind dams;
- Increased run-off in urban areas such as Battle Creek;
- Invasive species which include reed canary grass, purple loosestrife, *Phragmites* and glossy buckthorn; and
- Diseases and disease vectors such as the emerald ash borer.

### 5.1.2 Geomorphological Divisions

The distribution of species, ecotypes and community diversity along a river primarily reflects the nature of the functional process zones rather than the geographic position along the river (Thorp et al., 2006). Therefore, the river segments can be refined into functional segments (Figures 5-1 through 5-4) that can be identified (mapped) and discussed based on distinguishing characteristics determined by:

- Stream bed material,
- Bank definition and slope,
- Flood zone width
- Flow regime
- Overbank flow characteristics during flooding

Key fluvial geomorporhologic features have been defined by Rosgen (1994). The Rosgen scheme classifies rivers according to key characteristics such as entrenchment ratio (i.e. a measure of how "well defined" the riverbed and how steep the banks are), the width-to-depth ratio, the sinuosity and the channel material. The Kalamazoo River does not exhibit a very wide variation in Rosgen type in the stretches considered here. The river has been divided into four fairly distinct functional zones that form a continuum (i.e., zones alternate or grade into each other). The divisions serve to classify the most significant chemical fate and transport and receptor exposure processes expected to dominate in each segment and receptors are predicted to be more similar within a functional zone than between functional zones. Table 5-1 below presents a comparison of the geographic, valley segments, and functional reaches. The classification of functional segments may change as the CSM is refined.

Four preliminary functional process zones have been identified in the Study Area as likely to have a strong influence on determining the (ecological) receptors and the exposure pathways potentially affected by the spill.

1. **Low Sinuosity Channel Segments**: Reaches with low sinuosity with fewer backwaters, eddies, and fringing marshes. These segments typically have well defined, steeper banked channel, with narrower flood zones (Figure 5-1).
2. **High Sinuosity Channel Segments**: These reaches often are meandering (sinuous), with abundant backwaters, islands, oxbow lakes, fringing wetlands, swampy depressions, and relict channels. Overbank flow is not parallel to the main channel during flood events increasing transport from the main channel into the overbank. Reaches typically have a wider flood zone with shallow banks (Figure 5-2).
3. **Anthropogenic Channel Segments**: Channelized reaches, where the channel has been completely re-designed and modified. In this segment the Kalamazoo River flows in concrete channels or rip-rapped straightened channel (Figure 5-3).
4. **Impounded Segments**: Impounded reaches, where dams constructed across the rivers create a lake-like environment and the river flows over a dam. These impoundments are river like in the

upper part and lake like at the lower end often with delta-like deposits in the headwaters (Figure 5-4).

Table 5-1 Kalamazoo River functional Divisions

| MP (approx.) | Functional Division | Geographic Zone | Valley Segment (MDNRE) | Notes |
|---|---|---|---|---|
| 0.00 – 2.00 | Small Stream | Talmadge Creek (TC) | 1092 | See Section 4 |
| 2.00 – 4.50 | Low sinuosity | TC to Ceresco Dam<br>▪ 2.5 miles low sinuosity<br>▪ 1.25 miles impounded | 3039 | Residential lots, farmland close to river bank |
| 4.50 – 5.75 | Impoundment | | 3040 (to MP 6.0) | Narrow, river-like impoundment |
| 5.75 – 9.25 | Low Sinuosity | Ceresco Dam to Mill Pond Dam<br>▪ 3.5 miles low sinuosity<br>▪ 4.75 miles high sinuosity<br>▪ 1.5 mile impounded | 3041 | Some backwaters are present, frequent islands. Generally undeveloped shores. |
| 9.25 – 14.00 | High Sinuosity | | | Flood zone wider, sinuous river, undeveloped shores |
| 14.00 – 14.50 | Low Sinuosity | | | Residential riverside lots |
| 14.50 – 15.50 | Impounded (Mill Pond) | | 3042 | Narrow, river-like impoundment. |
| 15.50 – 16.50 | Channelized | Mill Pond Dam to Morrow Lake<br>▪ 1 mile channelized<br>▪ 3 miles partly channelized<br>▪ 16.5 miles high sinuosity | 3043 | 15.5 to 16.5 concrete channel through city, |
| 16.50 – 19.5 | Channelized (in part) /low sinuosity | | 347 | Straight and steep banked, with rip-rap banks. More natural towards lower end. |
| 19.50 – 36.75 | High Sinuosity | | | Wide flood zone, meanders and oxbows present indicates slow flowing low entrenchment river. |
| 36.75 – 39.75 | Impoundment, including delta | Morrow Lake<br>3 miles impounded | 1072 | Morrow lake and delta – large, lake-like impoundment. Well developed delta. |

#### 5.1.2.1 Low Sinuosity Segments

This zone includes:

- 2.5 miles of river between Talmadge Creek and Ceresco Dam pool;
- two segments of 3.5 miles and 0.5 miles, respectively, of river between Ceresco Dam and Mill Pond Dam;
- 3.75 miles in the Battle Creek area, which may be partly channelized, based on a preliminary evaluation of the affected stretch of the Kalamazoo River.

These segments of the river, as shown on Figure 5-1, are characterized by gentler curves, low sinuosity, well defined and relatively steep banks, with a narrower flood zone (i.e. rising water levels do not inundate large areas, and the storm surge is more contained in the main channel). Backwater marshes are present where meander bends are present and where tributary streams or groundwater seeps are present. Terrestrial vegetation (trees) grows right next to the river, and strictly riparian vegetation is not as dominant. In these areas, residential property or farmland are more likely to be located close to the channel because of the somewhat higher banks that are less susceptible to flooding.

The river bed consists largely of coarse sediments (cobble, gravel, and sand). Water depth is generally shallow, but the riverbed is well established and forms no rapids and few riffles.

Midstream gravel bars and narrow vegetated islands are common. The higher bars have acquired a soil layer and a permanent riparian vegetation similar to those seen at point bars in the more sinuous stretches (see Insert 5-1). Backwaters and eddies are not frequent, but are present in small areas of increased sinuosity, where conditions are akin to those in the high sinuosity segments.

**Insert 5-1 Midstream Island in low sinuosity segment.**

**Shows a vegetated soil layer over alluvial gravel and cobble base. Other islands have thicker loam/silt soil layer. Source: B.Bjorkman 11/14/2010**

#### 5.1.2.2 High Sinuosity Segments

These segments of the river, as shown on Figure 5-2, are characterized by high sinuosity and have lower banks except where the river reaches the edge of the flood plain. The flood zone is wide to very wide. When bank-full conditions are reached, large areas or riparian area are easily and frequently flooded.

Point bars are formed at the inner sides of meander bends and erosion occurs at the outer sides of bends. These meander bends are often overtopped during floods and flow may wash across the land area. In some cases, the erosion may carve a new river channel across the point bar, and the old channel becomes a cut-off backwater that may become an oxbow lake. Examples of these features occur in the affected reaches of the Kalamazoo River.

**Insert 5-2 High sinuosity segment at MP 21-22.**

**Meandering segment with numerous backwaters and oxbow lakes and low banks. Source; U.S. EPA Website. http://www.epa.gov/enbridgespill/photos.html**

The bank material tends to be fine (silt or sand) and easily erodible. The flood zone is flat, with frequent relict channels, hollows, and topographic low spots. Large, fringing palustrine marshes, wooded swamps, and backwater ponds may be present. Below Battle Creek the river exhibits a well developed meander system, with numerous backwaters and oxbow lakes (see Insert 5-2). Vegetation is riparian, with a dominance of species adapted to frequent flooding and wet conditions. Dense macrophytes (e.g., reeds and cattails, submerged macrophytes such as milfoil and pond weed, and floating plants such as water lilies and duckweed) are common in backwaters.

The river bed consists of finer sediments, consisting of sand and silt, with smaller areas of gravel than in more energetic portions of the river above Mill Pond Dam than in the straight segments. Downstream of the City of Battle Creek, the river bed is dominated by silt and sand, with clay admixture in the bank areas. Water depth is variable, having areas of very shallow riffles alternating with deeper pools and deeply excavated channels on the outside of meander bends. Water flow is usually somewhat less turbulent, especially the lower part of the river.

Sunken logs and snags are very common, as the lower energy in these areas (and abundant riverside sources) cause objects carried by the current to be trapped. During flood events silt and sediment are carried into the riparian flats where they deposit out as fresh silt.

The meandering results in frequent eddies, island formation, and creation of backwaters and oxbow lakes. Due to the lower flow energy these areas are depositional sinks for silt and tend to have muddy banks and beds.

#### 5.1.2.3 Anthropogenic Channelized Segments

These segments of the river, as shown on Figure 5-3, are characterized by man-made channelized reaches where the channel has been re-designed and/or modified. The segments of the river in the City of Battle Creek largely have been channelized. A 1-mile section below the Mill Pond Dam is fully channelized in a concrete lined ditch, and retains no natural features (Insert 5-3). Channelization is intended for rapid and efficient drainage.

**Insert 5-3 Channelized Section in Battle Creek.**

**Source: photo by Glenn Hendrix, AECOM, 2010 near MP 16.25.**

The 3 mile stretch downstream of this ditch, after the confluence with the Battle Creek River, is straightened and constrained within rip-rap banks, with a cobble gravel bed. This stretch is considered anthropogenic although it presents some characteristics of a low sinuosity river segment.

#### 5.1.2.4 Impounded Segments

Based on a preliminary evaluation of the affected stretch of the Kalamazoo River, this zone includes three impoundments (Figure 5-4):

- Ceresco Dam impoundment (MP 4.5 to 5.75). This is a narrow, river-like impoundment;
- Mill Pond impoundment (MP 14.5 to 15.5). This is a narrow, river-like impoundment with associated emergent wetlands; and
- Morrow Lake (MP 36.75 to 39.75). This is the only large impoundment, with a clearly developed "delta" at the inlet, and a large lake-like open water surface.

Impounded areas are characterized by lake-like conditions. Water trapped behind a weir or dam forms a pool, where water flow velocity drops substantially. Depending on the size relative to the river flow, the impoundment can function as a lake. In general the conditions are more lake-like at the downstream end of the impoundment. At the upper end the inflowing river may deposit sediment as the flow energy drops, forming a delta (Insert 5-4). The turbulence where the outflow drops over the dam may significantly alter oxygenation and mixing of the waters.

The impoundments at Ceresco Dam and Mill Pond pool are heavily silted in, with over 5 feet of accumulation, and shallow water depths (<0.5 to 1 foot) (TetraTech, 2010). Sediments are unconsolidated

Insert 5-4 Simplified example of lake-like and river-like conditions in a typical impounded lake

organic mucks, silts and sands, and in part are anoxic. Backwater depositional areas typically have circulation only during high water conditions. Deeper conditions are present in the main river channel (1.5 to 2 feet). These smaller impoundments do not have lake-like characteristics, and are more akin to riverine backwaters.

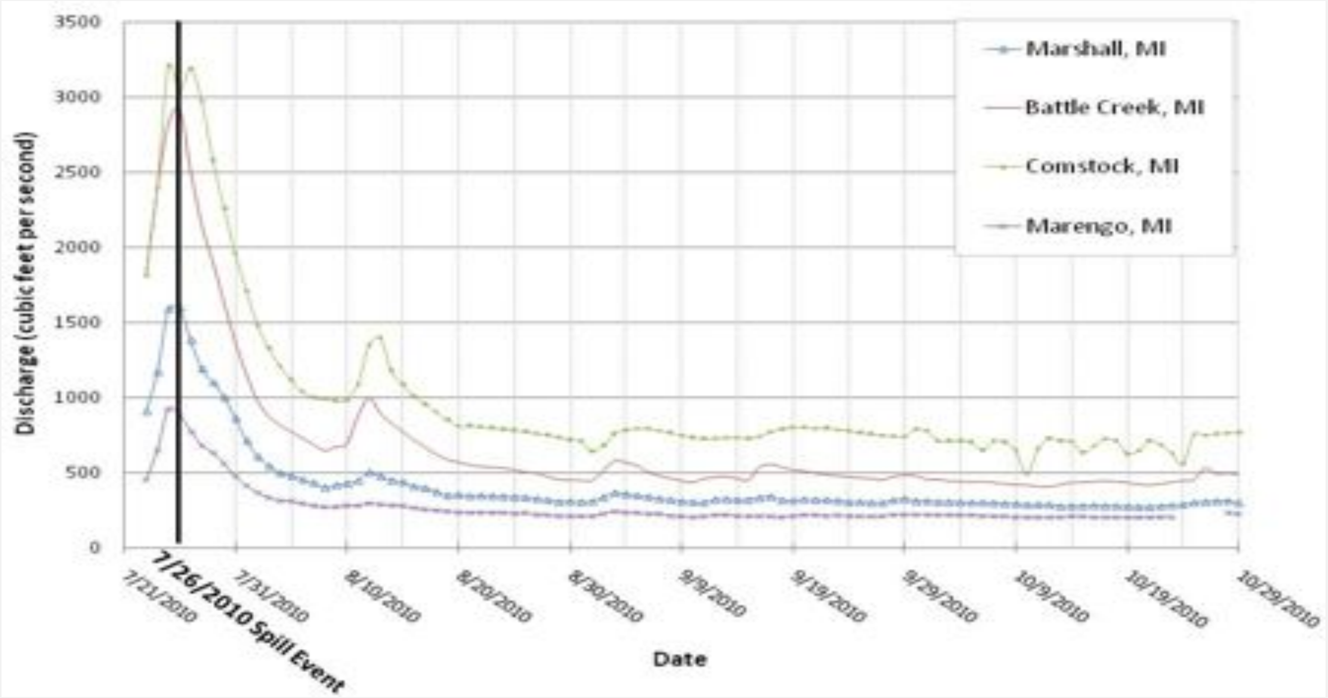
The large storage capacity of an impoundment results in a smaller footprint of the flood zone. Banks are variable, but in general are steep as impoundments are built where the impounded water can be easily confined. The water depth in the Morrow Lake delta ranged from 1.1 to 2.4 feet and the lower energy mudflats and sand flat areas had depths of 0 to 0.5 feet (TetraTech, 2010). These mud and sand flats are sinks for sediment deposition.

## 5.2 Release Event

Crude oil entered the Kalamazoo River where Talmadge Creek enters the river on the left descending bank. The crude oil was dominantly less dense than water, and floated down the river. The release happened after a period of high rain, and the flow in the river had already increased. Details on the rain event is presented in Section 2.1.2. At the time of the release, the river had already inundated adjoining low overbank areas d. More rain was received in the upper reaches of the Kalamazoo River near the source area, so the high water mark represented a larger storm event in the upper reaches than in the lower reaches of the study area (Hoard, et al., 2010). Insert 5-4 presents the hydrographs of river stations showing that at the time when the crude oil slicks flowed through the river stage was at or near its peak, and extensive overbank inundation was ongoing.

On July 25, 2010 the Kalamazoo River reached flood stages at stream gage 4103500 in Marshall that are estimated by Hoard, et al. (2010) to be between the 4-percent to 10-percent annual exceedance probabilities. The flood inundation zone as modeled by USGS for the July 25th event is shown on Figure 2-4. The peak discharge at the Marshall stream gage reported by Hoard, et al. (2010) was 1,770 cubic feet per second (cfs). The peak discharge at the Battle Creek stream gage 04105500 was below the 10-percent annual exceedance discharge of 4,350 cfs. The hydrograph on the Battle Creek River, a tributary to the Kalamazoo River, decreased at the same time, illustrating the variability of the storm event throughout the watershed (Hoard, et al., 2010). The storm event hydrographs for stream gages of the Kalamazoo River and the Battle Creek River generated from provisional data available at USGS's Real Time Water Data for Michigan webpage <http://waterdata.usgs.gov/mi/nwis/rt > are shown on Figure 2-3 and summarized on one graph on Insert 5-5.

Overbank deposition occurred primarily between MP 2.0 and 15.75. In-channel deposition occurred



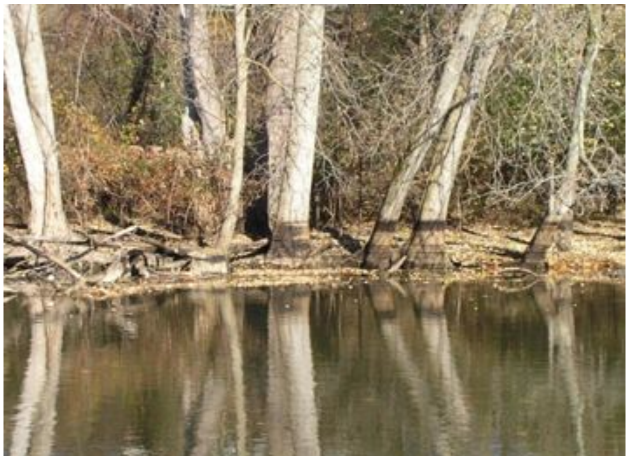
**Insert 5-5 Kalamazoo River Discharge Hydrographs for July 23, 2010 to October 29, 2010.**

**Data source: provisional USGS Real-time data.** http://waterdata.usgs.gov/mi/nwis/rt behind Ceresco Dam forming submerged oil deposits, which was also predominant downstream of MP 21.25 due to re-entrainment of sediment, transport and deposition. The areas of overbank (SCAT areas) and in-channel submerged oil tracking points are shown on Figure 2-4.

### 5.2.1 Release Event in the Low Sinuosity Segments

When the release occurred, the river had already inundated adjoining wetland. Crude oil floated on the top of the river and moved in slicks parallel to the main river channel. Floating crude oil moving down the river was carried through the low sinuosity segments.

Oiling of overbank areas was dominantly along the edges of the straight section of the river and into backwater areas where eddy currents could direct flow. The flood zone was narrow (and deep), and floating crude oil tended to form distinct and clearly delimited bands on shores and tree trunks (see Insert 5-6). Floating crude oil tended to be washed away and did not get extensively stranded. Since the spill occurred during high water, oiling of cobbles and gravel beds in the river did not occur.



**Insert 5-6. Example of tree trunk staining, indicating level of overbank flow during event.**

**Source: G. Hendrix, AECOM, 2010**

There are relatively few inlets, eddies and backwaters. However, to the extent these are present, accumulations of crude oil may be stranded and result in sinking crude oil and consequent sediment impacts.

There are frequent bar islands and banks in the river. The lower (un-vegetated) gravel bars were generally well underwater during the release and slicks flowed over with low impact. The islands, which possess a soil layer and developed vegetation would have been overtopped by oil slicks. Impacts would result from overbank flow through the vegetation and stranded crude oil. Because of often thin soil layers, crude oil may have entered air spaces in gravel and cobble alluvial substrate, from where it is a potential source for releases of sheens.

### 5.2.2 Release Event in the High Sinuosity Segments

In the high sinuosity segments, overbank flow flowed into and out of the overbank areas as the main channel bends and moves away from and then toward the edges of the floodway following the path of least resistance. As surface water moved out of the main channel, the crude oil was directed into the overbank in predictable locations as the bends turned away from the edge of the floodway. Crude oil moved into the overbank throughout the flood event and were held up by vegetation. As the river receded, overbank pools of crude oil became stranded in places (Insert 5-7). The areas where SCAT activities removed vegetation are shown in Figure 2-4, along with the inundation predicted by the USGS for the river up to the confluence with the Battle Creek River. The presence of oiled areas (SCAT areas) can be seen on the upriver portion of the overbank areas at MP 10.00 (left descending bank) and then at MP10.25 (right descending bank).

**Insert 5-7 Typical low spot on relict channel in high sinuosity area.**

**Oil stranding occurred when water retreated following overbank flow. Source: B. Bjorkman, AECOM, 2010 Nov 18.**

The fate and transport of crude oil in this river segment was strongly influenced by the velocity of the water. Slower flow encouraged sinking of heavier components of the crude oil, and collection of slicks in backwaters and eddies. Low-lying marshy areas and inlets accumulated crude oil trapped by lower flow rates and by friction with vegetation (with consequent widespread oiling). Crude oil was frequently stranded in low and flat spots, and settled into hollows and burrows. Impact to wetlands covered relatively wide areas due to flat topography.

Crude oil trapped in inlets, backwaters and eddies will partly evaporate and partly sink, leaving these areas susceptible to submerged oil and sediment impacts. Oxygenation is low in these sediments and anaerobic conditions may be present.

### 5.2.3 Release Event in the Anthropogenic Segments

The channelized segments are designed for rapid and efficient drainage. There are few obstructions or vegetation to trap crude oil. Even during the elevated flows during the spill, the river was contained in the channel. The crude oil flowed through these areas quickly and did not form extensive slicks. Impacts are limited to staining in a “bathtub ring” pattern on rip-rapped or concrete banks and urban features such as intake or point-source discharge pipes. Limited crude oil may be trapped in the rip-rap.

### 5.2.4 Release Event in the Impounded Segments

As crude oil weathered, residual crude oil became more dense (see Section 2.3), and may have become entrained in the water column as submerged oil. The impoundments were the major sinks for the submerged oil.

In Morrow Lake, the submerged oil was settled on the silt and mud flats of the delta at the eastern end of the lake. In the organic muds found there, oxygen may be low and residuals may contribute to the oxygen demand. Therefore, crude oil may affect water chemistry and therefore the trophic state and productivity of the impoundment.

**Insert 5-8 Oil slick overtops Ceresco Dam.**

Increased evaporation and aerobic stripping, and emulsification into water column. Photo source: US EPA http://epa.gov/enbridgespill/photos.html

In the two smaller impoundments (Ceresco Dam and Mill Pond Dam), there was sufficient crude oil and sufficient flow to carry free crude oil across the spillways of the dams (see Insert 5-8). As the water and crude oil flowed over the spill way, the water and crude oil were aerated and also aggressively mixed. This action caused more soluble components to partition into the surface water and more volatile compounds to partition into the air. In addition to stripping components from the crude oil, turbulence at the dams may have emulsified the crude oil.

There was significantly less overbank staining and stranding of crude oil in overbank areas of the Kalamazoo River below Battle Creek. In Morrow Lake, fewer surface slicks entered the lake than at the impoundments behind Ceresco Dam and Mill Pond Dam; in addition, Morrow Lake is much larger with a much lower gradient. Wind friction is expected to be more important than surface water flow for driving the transport of materials floating on Morrow Lake to the downwind side of the lake. Floating crude oil was not observed to go over Morrow Lake Dam.

## 5.3 Response Actions and Restoration

Response actions were selected to optimize the removal of crude oil depending on the nature of the deposits and impacted media. In-channel deposits were mapped and prioritized by the Submerged Oil Task Force (SOTF). In-channel deposits that were of highest priority were raked and aerated to promote the dispersion and further weathering. Deposits contained by dams were removed by skimming and dredging (TetraTech, Oct. 29, 2010 Submerged Oil Report). Overbank deposits were mapped by SCAT teams and oiled soil was removed by excavation, and sheen-producing surface oil (e.g. on vegetation or oiled debris, as in Insert 5-9) was collected and removed or washed (SCAT reports available on line at http://epa.gov/enbridgespill/data/scat.html).

**Insert 5-9 Vegetation trapped oil stranded on overbank areas as water levels waned.**

Oiled vegetation was removed during SCAT process. Photo source: US EPA http://epa.gov/enbridgespill/photos.html

Evaluations performed through the SCAT process and through evaluations of river sediments, documented the conditions along the river. The SCAT process included manual removal of oiled soil and debris, including vegetation such as shown in Insert 5-9. SCAT also removed pooled crude oil through low-pressure/high-volume flushing; absorption methods with downstream snare and boom capture; and bulk excavation under the direction of the U.S. EPA. The results of the SCAT process are documented in the "Oil Recovery Report - Kalamazoo River" dated September 20, 2010 (Enbridge, 2010d). Figure 2-4 provides the SCAT profile of the creek and river area.

### 5.3.1 Response Actions

Some access roads and boat launch facilities were constructed to provide access to the river. Others were already in place and were dedicated to recovery operations. Some clearing of log jams in the river was done to facilitate boat traffic necessary for remedial and maintenance activities. An extensive system of booms, absorbent materials and oil recovery systems were installed and maintained to remove floating crude oil from the river.

*The nature and extent of oil deposits and the type of response and restoration performed dictates where there are residual impacts and the extent to which any receptor exposure remains. Each functional segment will be assessed to identify the nature and extent of residual impacts, potentially complete exposure pathways, and potential receptors. The influence of other potential stressors will also be examined.*

Different response actions were implemented in different habitat types and to respond to different degrees of impact. Response actions are discussed in Enbridge 2010d and Enbridge, 2010e and summarized in Table 5-2.

## Table 5-2 Summary of Response Actions by Habitat

| Habitat Type or feature | Cleanup Actions |
|---|---|
| Shoreline | • Cut low hanging limbs extending over and into the water 2" above oiling level.<br>• Removed oiled vegetation leaving roots intact up to 10' from waterline.<br>• Did not remove woody plants greater than 2" diameter (as measured one foot above ground surface).<br>• Minimize scraping. |
| Floodplain, Oxbows, and mud areas | • Did not remove woody plants greater than 2" diameter (as measured one foot above ground surface).<br>• Minimized ingress and egress to the least amount necessary to remove pooled crude oil and used planks were necessary to avoid leaving deep footprints that may drive crude oil into soils.<br>• In areas categorized as pooled crude oil, removed crude oil using portable vacuum or absorption techniques (e.g. snare/pom-poms, sorbent pads). Cut and removed vegetation from around these crude oil pools to up to 10 ft. as needed to detect other pools of crude oil.<br>• In areas with pooled crude oil where persistent crude oil occurred in moderate to heavy amounts or when crude oil formed semi-solid to solid masses, manually removed crude oil and contaminated soil by scooping with flat shovels, rags, sorbent pads, gentle raking, gloved hands, hand tools, or similar manual methods.<br>• In areas where absorption and/or manual removal techniques were ineffective, more mechanized approaches or other countermeasures were utilized.<br>• Did not replace removed soil with new fill.<br>• Overbank areas greater than 100 feet from the river shoreline or an oxbow lake/pond were be addressed through natural attenuation when oil staining was minimal, or existed only as small patches or oiled deadfall. |
| Emergent Wetlands | • Minimized entry (to prevent unnecessary substrate contamination).<br>• SCAT Team provided cleanup recommendations on a case by case basis in areas used by sensitive wildlife.<br>• Passive sorbents used to minimize disturbance of substrate and vegetation and to prevent excess waste generation. |
| Oiled debris | • Mobilized and captured crude oil with boom or sorbent material before and during moving debris.<br>• Manually removed oiled debris. |
| Oiled Manmade Structures and larger rocks | • Manually removed (scraping or wiping with sorbents on oil < 0.1 cm)<br>• High pressure, cold water wash on oil covers (oil > 0.1cm to <1 cm thick)<br>• Visible residual crude oil that could not be scraped off was left in place. |
| Large Woody Debris | • Oiled woody debris larger than 4" diameter left, unless it poses a safety hazard.<br>• Mobilized and captured crude oil with boom or sorbent material before and during moving debris.<br>• Removed smaller oiled branches that were not anchored to riverbank or bottom |
| Aquatic vegetation holding floating crude oil<br>[water lilies, grasses, etc.] | • Cut vegetation when the risk of oiled vegetation contaminating wildlife was greater than the value of the vegetation and there was no less destructive method to remove or reduce risk to acceptable levels. Cut below low water's surface, leaving roots to allow re-growth.<br>• Used snares to collect released crude oil.<br>• Bagged vegetation for disposal.<br>• Operations monitored to minimize effect of root destruction and mixing of crude oil deeper into the sediment. |
| Oiled mixed sand and gravel | • Booms placed prior to treatment.<br>• Manually removed when significant crude oil presence observed.<br>• Low pressure, cold water flushing if practical and crude oil could be captured. |

**Table 5-2 Summary of Response Actions by Habitat**

| Habitat Type or feature | Cleanup Actions |
|---|---|
| Turf<br>(private/public lawns) | • Booms placed prior to treatment.<br>• Low pressure, cold water flushing if practical and crude oil could be captured.<br>• Removed sod (top 2”) and replaced with new sod (or add soil and reseed) in areas with high oil adhesion.<br>• Layers of solid oil, tar material, and tar mats removed using manual methods (gentle raking, removal by hand, and hand tools. |
| Islands | • Categorized each island based on habitat type or feature.<br>• Used cleanup recommendations for that category.<br>• Island flushed to facilitate capture of crude oil.<br>• Layers of solid oil, tar material, and tar mats removed using manual methods (gentle raking, removal by hand and hand tools). |

#### 5.3.1.1 Low Sinuosity Segment Response Actions

In low sinuosity segments, the impacts tended to be associated with shoreline vegetation, debris, structures and rocks and along the shore. If there was a small sharp bend, these bends often behaved similar to a bend in a high sinuosity segment. Submerged oil occurred less frequently, we cut-off channels were uncommon.

In general, the common remedial actions in low sinuosity units included:

- Removal of low hanging limbs extending over and into the water 2” above oiling level,
- Removed oiled vegetation leaving roots intact up to 10’ from waterline,
- Woody plants greater than 2” diameter and soils were not removed or scraped,
- Removal of oiled debris,
- Cleaning of man-made structures and larger rocks, and
- Low pressure cold water flushing of sand and gravel.

#### 5.3.1.2 High Sinuosity Segment Response Actions

In high sinuosity segments the impacts tended to be associated with floodplains, oxbows, islands, mud flats, overbank areas, emergent wetlands and large woody debris. Submerged oil occurred in some areas, especially in oxbows, overflow channels, and backwater areas.

In general, the common remedial actions in shallow entrenched units included:

- Removal of pooled crude oil by pumping, absorbents or soil removal,
- Use of passive absorbents in fragile habitats such as emergent wetlands,

- Favored natural attenuation if impacts were minor,
- Removal of oiled branches,
- Cleaning of larger woody debris, and
- Sediment flushing, aeration and raking.

#### 5.3.1.3 Anthropogenic Channelized Segment Response Actions

In channelized units in Battle Creek, Michigan, the impacts tended to be associated with structures and banks. In general, the common remedial actions in channelized units included:

- Removal of oiled vegetation less than 2 inches in diameter
- Removal of oiled debris
- Wash oiled sand and gravel

#### 5.3.1.4 Impounded Segment Response Actions

In the impoundments, (Ceresco, Mill Pond Dam and Morrow Lake) impacts generally were associated with submerged aquatic vegetation (lily pads, etc) and submerged oil on sediments. Submerged aquatic vegetation was removed as necessary and areas with submerged oil were raked and aerated, and floating oil was collected by surface booms. In addition, portions of the impoundment at Ceresco were dredged with hydraulic dredging equipment or skimmers for surface crude oil. Gabion baskets filled with sorbent material and X-Tex curtains were used to capture residual entrained crude oil.

### 5.3.2 Restoration Actions

Restoration actions along the river are similar to those for Talmadge Creek and generally included:

- The removal of contaminated soils, backfilling, seeding and blanketing in most areas. In areas of high erosion potential and/or where excavations have created a diversity of wetland habitats/types no backfill was used. These areas were then seeded with appropriate native wetland seed mixes and blanketed to reduce erosion potential and aide with vegetative establishment.
- Removal of equipment, containers and supplies from access areas;
- Removal and decommissioning of access roads and boat launches (some areas remain in use);
- Erosion controls; and
- Clean topsoil fill in limited locations and re-vegetation of all disturbed areas with a quick-sprouting grass and seeds of native vegetation.

### 5.3.3 Identification of human receptors and exposure pathways

The potentially impacted areas of the Kalamazoo River run through diverse land use areas and include many potential human land uses and receptor groups. Exposure pathways and receptors related to human health and the environment are addressed for the affected reaches of the Kalamazoo River as a whole. Human exposures are not as strongly tied to geomorphological zones as ecological receptors are, and in the context of these reaches of the Kalamazoo River it makes sense to consider human health receptors and pathways for the river as a whole.

Residential communities including small clusters of homes along the river and cities are present in specific areas of the river. Industry is present along the river, primarily in the stretch of the Kalamazoo River that flows through Battle Creek, Michigan. According to aerial photo review, these areas occur at the areas identified in Table 5-3.

**Table 5-3 Land use along the Kalamazoo River**

| MP (approximate) | Type of Land Use on Shoreline |
|---|---|
| 2.50 – 3.10 | suburban/rural residents with waterfront lots and presumed contact with river |
| 5.70 – 6.00 (Ceresco Dam Area) | clearly urban waterfront with mix of residential and commercial /industrial land use |
| 7.20 – 8.50 | suburban/rural residents with bigger setbacks and presence of undeveloped riparian zone with presumed occasional contact with river |
| 9.25 – 10.50 | suburban/rural residents with waterfront lots and presumed contact with river |
| 12.00 -18.5 (Battle Creek Area) | clearly urban waterfront with mix of residential and commercial /industrial land use (13.25 – 13.50 and 14.50) |
| 20.50- 20.75 | Commercial/ industrial |
| 22.50 – 23.25 | clearly urban waterfront with mix of residential and commercial /industrial land use |
| 24.50 | rural residents with waterfront lots and presumed contact with river [confirm] |
| 28.50-29.50 (Augusta Area) | clearly urban waterfront with mix of residential and commercial /industrial land use |
| 32.25 – 33.75 | suburban/rural residents with bigger setbacks and presence of undeveloped riparian zone with presumed occasional contact with river |
| 36.00 -36.25 | suburban/rural residents with bigger setbacks and presence of undeveloped riparian zone with presumed occasional contact with river |
| Morrow Lake | suburban/rural residents with bigger setbacks and presence of undeveloped riparian zone with presumed occasional contact with river |

The remainder of the shoreline of the Kalamazoo River is comprised of heavily wooded land, undeveloped land, agricultural land as well as a number of public parks and river access.

Fifteen parks/access points have been identified and were recently evaluated for impacts (shown on Figure 5-5):

Public Parks

- Historic Bridge Park
- Jackson Street Linear Park
- River Oaks County Park

Access Locations

- 15 Mile Rd bridge
- Squaw Creek subdivision
- Ceresco Dam
- Raymond Road bridge
- Baker Mobile Home Park at Beadle Lake Road (evaluating during CSM preparation)
- Dirt road to landscape business
- Riverside Country Club
- Burnham Bridge
- Corner of Hayes and Parrish
- Custer Bridge
- Legacy Wildlife Preserve (not evaluated)
- MDNRE Boat Launch on Morrow Lake

Farmland in the flood zone is present; however, crops are not grown in the area of the river bank that was impacted by crude oil via flooding. Therefore, it is not expected that there will be risk for human associated with agricultural lands.

Hunters (deer, waterfowl and others) and recreational users are present in the heavily wooded lands that abut the Kalamazoo River in many places. The hunters would potentially come into contact with impacted overbank soil and river media and exposure for this receptor group will be considered in the CSM.

Lastly, fisherman on the Kalamazoo River may potentially be exposed to impacted surface water, sediment and /or contaminated fish. This exposure pathway will be considered in the CSM as complete

Therefore, the following potential land uses and human receptors have been identified for the Kalamazoo River: residents, industrial/ commercial workers, recreational park users, and fishing and hunting on the Kalamazoo River and shorelines.

## 5.4 Current Conditions – Kalamazoo River

The current understanding of the Kalamazoo River include consideration of the following primary site conditions:

- Groundwater studies indicate that groundwater flow is towards the Kalamazoo River under most conditions except near tight bends and dams (AECOM, 2010). At dams, some local river water recharge to groundwater occurs and this groundwater then flows back toward the river that is at a lower elevation below the dam. This investigative finding indicates that groundwater impacts adjacent to the river are expected to be minimal.
- Residents using local groundwater as their drinking water source have been and may continue to be voluntarily tested to ensure water quality is consistent with pre-release condition. Data analyzed to date does not indicate that potable water has been impacted by the spill.
- The composition of the heavy crude oil limits its transport in groundwater and surface water, which is supported by analytical data summarized in the Final report (Enbridge, 2010c).
- Aesthetic impacts exist due to small oil sheens and stained tree trunks and structures.

Visible crude oil and visually impacted soil was removed during initial response activities. Primary areas of submerged oil were also addressed during initial response activities or are on-going. It is possible there is residual contamination present along the river and that concentrations of some chemicals in soil, sediment and groundwater exceed applicable Part 201 criteria. There is also potential for oil sheens to form on the river, which is an aesthetic impact. Some staining of structures, logs and trees remain. The stain is tar-like, weathered crude oil that is difficult to remove and is not mobile. These stains are an aesthetic impact with little expected hazard.

### 5.4.1 Identification of Ecological Receptors and Exposure Pathways

TetraTech (2010) conducted qualitative surveys in September and October, 2010 along the Kalamazoo River. Observations of wildlife are summarized in Table 5-4 below.

**Table 5-4 Wildlife Species and Aquatic Biota Observed Along the Kalamazoo River. Source: TertraTech (2010) qualitative survey**

| | Natural River Reaches (high and low sinuosity) | Impoundments | | | |
|---|---|---|---|---|---|
| **Wildlife and Aquatic Biota Observed** | | **Ceresco Dam pool** | **Mill Creek pool** | **Morrow Lake Delta** | **Morrow Lake** |
| **Mammals** | | | | | |
| Muskrat | ✓ | ✓ | ✓ | ✓ | ✓ |
| Raccoon | ✓ | ✓ | ✓ | ✓ | ✓ |
| White-tailed Deer | ✓ | | | | ✓ |
| Meadow Vole | ✓ | | | | |
| Short-tailed Shrew | ✓ | | | | |
| Mink | ✓ | | | | |
| Gray squirrel | ✓ | ✓ | | | |
| **Birds** | | | | | |
| Belted Kingfisher | ✓ | | ✓ | ✓ | ✓ |
| Great Blue Heron | ✓ | ✓ | ✓ | ✓ | ✓ |
| Wood Duck | ✓ | | | | |
| Mallard | ✓ | ✓ | ✓ | ✓ | ✓ |
| Black Duck | ✓ | | ✓ | | |
| Osprey | | | | | ✓ |
| Red-tailed Hawk | ✓ | | | | ✓ |
| Canada Goose | ✓ | | | ✓ | ✓ |
| Ring-billed Gull | | | | ✓ | ✓ |
| **Amphibians** | | | | | |
| Green frog | ✓ | | | | |
| Ranid sp. | ✓ | | | | |
| **Reptile** | | | | | |
| Map turtle* | ✓ | | | | |
| Spotted turtle* | ✓ | | | | |
| Snapping Turtle* | ✓ | | | | |
| Blandings Turtle* | ✓ | | | | |
| Mud Turtle | ✓ | | | | |
| **Aquatic Invertebrates** | | | | | |
| Freshwater Mussels** | ✓ | | | | ✓ |
| Crayfish | ✓ | | | | ✓ |
| Misc. Aquatic Invertebrates | ✓ | ✓ | ✓ | ✓ | ✓ |

*Observed from wildlife recovery effort staff

** Several freshwater mussel species of special concern have been documented from the Kalamazoo River basin.

Fish assemblages in the riverine segments are dominated by rosyface shiners, small-mouth bass, and rock bass (Michigan Geographic Data Library, 2005).

#### 5.4.1.1 Low Sinuosity Segment Ecology

Steep-banked, straight river segments include sensitive and valuable habitat, especially where the water is shallow. The coarse and well oxygenated substrate is rich in particulate organic matter (e.g. leaf pack) providing a food source for insect juveniles (the so-called "EPT" taxa: Ephemeroptera [mayflies], Plecoptera (stone flies), and Trichoptera (caddis flies)). These in turn are a major food resource for open water, strong swimmer fish species of major economic value such as bass.

Phytoplankton is uncommon, and primary productivity is driven by periphyton and rooted plants. Secondary productivity (fish and invertebrate biomass) may be high. Aquatic vegetation (floating and submerged) is limited, although encrusting mosses and algae (periphyton) and submerged snags are common. The food web is based on particulate organic material entering the river from banks and upstream, providing resources to the filtering, grazing and shredding benthic groups. Insert 5-10 shows an idealized typical aquatic food web in riverine systems. Filtering aquatic mussels also can be found in these segments.

**Insert 5-10 A typical riverine aquatic food web [Orange-Senqurak, 2010]**

Quieter and protected areas may be important nursery areas for fish species, and populations of frogs and turtles may be expected. Frogs and turtles also frequent shorelines along the main river channel.

There is relatively limited riparian habitat, except in localized areas of inlets or fringing marsh, where conditions similar to those described for meandering segments. Terrestrial upland habitat and vegetation may reach to the bank. Terrestrial animals may use the river as a drinking water source and (e.g. raccoons, kingfishers) as a source of food.

#### 5.4.1.2 High Sinuosity Segment Ecology

These segments can be distinguished from the well entrenched segments by the more extensive riparian ecosystem, containing a rich biodiversity of wetland, riparian and aquatic plants and animals. These include semi-aquatic birds and mammals (mink, muskrats, herons, and many other species that use the river and the riparian zone for food and shelter). Backwater marsh areas have a diverse wetland vegetation and fauna. Oxbow lakes and marshes support populations of turtles, amphibians and insects.

The river itself is likely to have a benthic fauna with fewer EPT-taxa insects and more sediment dwelling infauna due to relative absence of coarse grained riffle areas. The silty conditions favor burrowing benthic organisms such as Annelids and Chironomids. These areas may also be home to species of freshwater mussels. The fish fauna is rich, with many smaller fish (and juvenile fish) in the inlets and backwaters, and larger fish in the open water.

Bird and mammal use is extensive. Quiet areas may be resting and feeding areas for migratory birds. Many of the species shown for riverine areas observed during qualitative surveys along the Kalamazoo River (TetraTech, 2010) and listed in Table 5-4 are likely to be more common in this type of functional unit of the river.

Primary production in these stretches of river is somewhat higher than in swifter flowing segments, as macrophytes provide productivity, in addition to algae and phytoplankton in quiescent areas, and dense riparian vegetation on land and wetlands.

### 5.4.1.3 Anthropogenic Channelized Segment Ecology

The channelized sections of the river support limited ecological habitat value. The concrete ditch portion has no ecological habitat, but may have an ecological role as migration pathway for fish and other aquatic organisms.

### 5.4.1.4 Impounded Segment Ecology

Lake-like impoundments will have lake-like ecology. This includes a system dominated by primary production by phytoplankton (and also macrophytes), and food web including zooplankton and planktivorous and grazing fish (e.g. carp, shad, sunfish). The sediment is low in biota and may be almost devoid of biota if deep and anoxic. The littoral zone may support a varied fauna including turtles and amphibians. Insert 5-11 shows a typical lake food web, descriptive of larger impoundments such as Morrow Lake.

**Insert 5-11 A typical lake aquatic food web [FEN, 2010]**

Impoundments are important resting and feeding areas for migratory fowl and shorebirds. Piscivorous birds (e.g. osprey) may be present. Although the crude oil residual constituents are not bioaccumulative compounds of concern (BCC), these substances can still be a complete exposure pathway for piscivores in impoundments.

The delta areas of larger impoundments often contain extensive mudflats for use by migratory birds. Morrow Lake, the larger impoundment, supports dense stands of submerged aquatic vegetation throughout the lake (water milfoil, coontail and curly leaf pondweed) The shoreline supports a complex mix of lacustrine emergent and palustrine emergent wetlands. Lacustrine emergent wetlands are dominated by white water lily, arrow arum pickerel weed. The palustrine emergent wetlands are dominated by purple loosestrife, black willow, common reed and alder (TetraTech, 2010).

The Morrow Lake Delta area contains a large continuous area (approximately 40 acres) of emergent wetlands that reduce velocity of the river discharge to Morrow Lake. Emergent wetlands in the delta are dominated by white water lily, arrow arum and pickerel weed. Scattered islands of non-submerged, accreted sediments in the delta support purple loosestrife and scattered mature black willow trees. Fish were observed to be relatively abundant in the delta and this area appears to represent a good fish nursery and refuge area. Numerous bird species (gulls, waterfowl, herons) were observed in the delta area.

Wetland areas found in backwater areas likely provide important refuge and habitat for fish. Submerged snags are abundant in the backwaters and provide additional habitat structure.

The smaller impoundments contain mudflats with sparse vegetation of algae and coontail. Elsewhere the shallow impoundments support purple loosestrife, water lilies, arrow arum and pickerel weed. Dense stands of submerged macrophytes (sago pond weed, coontail, and water milfoil) and floating macrophytes (water lilies and duckweed) are present. The extensive water lily/arrow arum macrophytes beds provide habitat for smaller fish. Shallow depths preclude larger fish. The Mill Pond pool mudflats are unvegetated or sparsely vegetated with coontail and filamentous algae. Narrow fringes of purple loosestrife, as well as water-lily, arrow arum, and pickerel weed are found along the channels and edges of the Mill Pond Dam impoundment. Near the Mill Pond dam, dense stands of submergent macrophytes (sago pond weed, curly leaf pond weed, coontail, water milfoil) and floating macrophytes (white water lily and duckweed) provide habitat for largemouth bass and sunfish, which were observed in the open water areas within the basin.

## 5.5 Principal Study Questions

- Is there sufficient crude oil remaining in the overbank along the Kalamazoo River to:
    - Leach hazardous constituents from the crude oil to groundwater that would migrate into the surface water at concentrations above appropriate surface water criteria under Part 201,
    - Flow into a monitoring well screened across the water table, or
    - Release a sheen to the river (including during special events such as high water or freeze-thaw cycles)?
- Is there sufficient crude oil remaining in the channel of the Kalamazoo River to
    - Release a sheen to the river?
    - Impact the aquatic community?
    - Impact sediment or surface water quality above standards?
- Have the limited areas where the conditions of the Kalamazoo River are a losing stream as defined via conditions described in the Hydrogeology Report been defined?
- Based upon analytical results from soil and groundwater, do any human and/ or ecological exposure pathways warrant further evaluation?
- Is there adverse impact from residual crude oil on the local ecological community?
- Are vegetation, soil biota, and wetland biota recovering following acute exposure to the crude oil release?
- Is there adverse impact to the edible fish community?
- Do non- chemical stressors impact the ability to implement the effectiveness of response or restoration activities?
- What is the ultimate fate of residual crude oil in the system?

# 6.0 Laydown and Access Areas

Site operations required the use of property that was not impacted by the crude oil spill. Examples of areas used for site operations include:

- boat access along the Kalamazoo River;
- roadways to move equipment, soils, and water;
- staging areas for wastes; and
- laydown area for equipment.

As lay down areas were no longer used, the areas were restored. Areas that managed waste were inspected and sampled if necessary to assure that residual impacts were addressed.

It is not currently anticipated that the use of these areas adversely impacted human health or ecological receptors. Assessment (qualitative or quantitative) of these areas will be utilized to test this assumption and update conditions if necessary.

# 7.0 Schedule of CSM Updates

The CSM will be updated quarterly and presented verbally to the MDNRE in teaming meetings. Written meeting notes will be captured and shared as an attachment to document updates to the CSM.

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