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Rich Adams
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ENBRIDGE

February 13, 2013

Mr. Ralph Dollhopf
Federal On-Scene Coordinator and Incident Commander
United States Environmental Protection Agency
801 Garfield Avenue, #229
Traverse City, MI 49686

RE: In the Matter of Enbridge Energy Partners, L.P., *et al*, *Docket No. CWA 1321-5-10-001*

Dear Mr. Dollhopf:

Enclosed please find a technical memorandum in response to the Technical Review Comments - April 2012 Kalamazoo River Hydrodynamic and Sediment Transport Model Report dated August 22, 2012 received on behalf of the United States Environmental Protection Agency (U.S. EPA) via email by Weston/Start. The comments were written by the United States Geological Survey and Weston/Start.

Enbridge Energy, Limited Partnership (Enbridge) and U.S. EPA met, as requested in the email correspondence, and discussed the comments shortly after receipt of the comments. The enclosed technical memorandum serves as Enbridge's response to the Technical Review Comments - April 2012 Kalamazoo River Hydrodynamic and Sediment Transport Model Report.

Enbridge continues to stand firm in our belief that refinement of the model will not impact operational field activities based on field observations along with the supporting evidence in the technical memorandum.

Please contact myself or Enbridge's Incident Commander, John Sobojinski, if you have any questions.

Sincerely,
ENBRIDGE ENERGY, LIMITED
PARTNERSHIP
By Enbridge Pipelines (Lakehead)
L.L.C.
Its General Partner

Richard Adams
Vice President, U.S. Field Operations

Encl

CC: John Sobojinski, Enbridge
Dave Bareham, Enbridge
Michelle DeLong, MDEQ

TETRA TECH

Technical Memorandum

To: James Snider
Dave Bareham
John Bohrmann
Stacy Frerich

From: Pat McGuire (Tetra Tech)
Dave Richardson (Tetra Tech)
Steven Davie (Tetra Tech)

Date: February 13, 2013

Re: **Hydrodynamic Model**
Enbridge Line 6B MP 608 Marshall, MI Pipeline Release

Introduction

The Consolidated Work Plan (CWP) that was approved by the United States Environmental Protection Agency (USEPA) on December 21, 2011 describes work plan activities to assess transport, containment, and recovery of oil released from the Enbridge Energy, Limited Partnership (Enbridge) Line 6B pipeline. Tasks for the development of a hydrodynamic model were included in the CWP. The objectives for model application(s), as described in the CWP, are as follows:

- Calibrate a three-dimensional (3-D) hydrodynamic model for unsteady, open-channel flow, capable of simulating the spatial and temporal variations in river velocities, bed-shear stresses, and sediment entrainment, transport, and deposition of sediment /oil mixtures,
- Gain an improved understanding of submerged oil transport by simulation of a range of flows including low flows to high flows having a 50-year recurrence interval,
- Simulate scenarios for containment, collection, and recovery of submerged oil-laden sediment and for proposed sediment traps and boom arrangements, and
- Document the post submerged oil recovery findings of the hydrodynamic model to assist in planning, design, implementation, monitoring, and evaluations of management methods.

The Environmental Fluid Dynamics Code (EFDC) was used to model flow and sediment transport within the 40-mile reach of the Kalamazoo River that was impacted by a crude oil release from the Enbridge Line 6B pipeline at Mile Post (MP) 608 in July 2010. Enbridge submitted the report titled 'Kalamazoo River Hydrodynamic and Sediment Transport Model' (model report) to the USEPA on April 20, 2012. The model report describes the base model development, calibration, validation, model scenarios, sensitivity analyses, and base model limitations. The model development and calibration process was a collaborative effort between Enbridge, Enbridge consultants, the USEPA, and the United States Geological Survey (USGS).

The USEPA completed review of the model report on August 22, 2012. The USEPA review comments described the status of model work in terms of CWP objectives and defined additional support work and model development. Following is an overview of the hydrodynamic and transport model work including assumptions, limitations, and results.

Overview: Model Context and Development

Model Context

Actions were initiated to delineate and characterize submerged oil in the Kalamazoo River following the crude oil release that occurred on July 26, 2010. The geomorphology of the Kalamazoo River was evaluated during the emergency response phase in August 2010 using leaf on aerial photographs to determine the river areas that would contain the greatest amount of submerged oil. This evaluation determined that most of the submerged oil would deposit upstream of Ceresco Dam, the Mill ponds, the oxbows like MP 21.50, and the Morrow Lake Delta. The 2010 recovery efforts focused on these areas and were successful until the river froze over.

The 2011 field investigations delineated submerged oil areas and categorized the degree of observed submerged oil. Fluvial geomorphic surface areas were mapped for the 40-mile impacted Kalamazoo River channel in 2011. The geomorphic surface maps were used to evaluate correlation between observed submerged oil from field investigations and mapped erosion and deposition areas. The field investigation sediment core samples and visual observation of submerged oil (poling) were consistent with the fluvial geomorphic setting. Submerged oil was not observed or was considered negligible in high energy areas influenced by erosional processes. Submerged oil was most often observed in low energy, depositional areas with fine-grained surface sediment. The field investigation data and geomorphic interpretations were used to support submerged oil cleanup work that was conducted in 2010 and 2011. The model development was initiated in December 2011 and was completed in April 2012.

Model Development

The modeling process included the development of two base models. The domain for one model included only the river channel (riverine model). The domain for the other model included both the river channel and the floodplain (floodplain model). Both models were developed in two dimensions (2-D). Horizontal grid networks were developed for the base models to provide cells with spatial descriptive data and also to support model numerical finite difference calculations. Inputs for the base models were obtained from USGS gage stations, existing field data collected by Enbridge, or from published literature sources. Discharge and sediment concentration (qualitative) boundary conditions were established based on available data.

The models were calibrated to three parameters: velocity, water surface elevation (field measurements), and discharge, using data from USGS gage stations located on the Kalamazoo River. The models were calibrated to velocity using point and transect data collected by Enbridge on the Kalamazoo River. Model calibration has been an iterative process resulting in model refinement as data gaps were defined and/or additional information became available to improve the model. Model validation was performed by using available flow data for specified time series (historical events) as input to the calibrated model and comparing simulation results for flow and water surface elevations to measured data. Model scenarios or specified historical discharge events were simulated to assess potential sediment transport and also the potential performance of sediment traps in selected geomorphic settings along the Kalamazoo River.

The model simulations provide a basis for characterizing Kalamazoo River hydrodynamics and sediment transport associated with a range of flow conditions. Model simulation results typically agree with quantitative and qualitative field data and fluvial system characteristics. In particular, the model delineation of silt deposition areas corresponds with submerged oil delineation areas developed from 2010 and 2011field data and geomorphic interpretations. Overall, model results have provided insights into fluvial characteristics that are difficult to measure or quantify directly.

Model Assumptions

The primary assumptions related to model development included the following:

- Flow input was obtained from the USGS gaging stations on the Kalamazoo River including stations near Marshall, Battle Creek, and Comstock.
- Flow inputs at dam locations were obtained from the dam rating curves. Equations were developed to obtain the rating curves based on weir flow control structure equations that consider flow as a function of stage. The July 20, 2012 Tetra Tech memorandum to Enbridge provided the April 2012 USEPA comments on the model rating curves and the corresponding Enbridge response.
- Flow inputs from tributaries were based on the flows from the USGS Battle Creek River gaging station. Flows from ungaged tributaries were calculated using a weighted method that considered the drainage area.
- Surface water inputs were assumed to be contributions from surface runoff and groundwater. A USGS document indicates that 60% of the base flow in the Kalamazoo River is from groundwater. Localized groundwater inputs (springs and seeps) were not considered.
- The model with the riverine curvilinear grid was developed to address hydrodynamic and sediment transport for the 40-mile channel model domain. The curvilinear grid size ranged from 10 to 80 meters by 5 to 40 meters.
- The model with the floodplain Cartesian grid was developed to address hydrodynamic and sediment transport for the 40-mile channel and floodplain model domain. The grid size was typically about 15 meters by 15 meters.
- Sediment input was based on suspended sediment data from the USGS station near Albion, Michigan (discontinued in 1976). USGS, on behalf of USEPA, and Enbridge agreed upon a maximum suspended sediment concentration value of 120 milligrams per liter.
- The distribution of sand, silt, and clay particles was based on average values from 109 sediment core samples collected in the Kalamazoo River in 2011.
- Channel and floodplain roughness values were based on estimates since localized data for the 40-mile model domain were not available.

Model Limitations

A numerical model, including the hydrodynamic and sediment transport model described in this report, is a tool designed to represent a simplification of field conditions. It is not possible for a numerical hydrodynamic model, or any model designed to replicate a complex system, to precisely replicate actual conditions. Fluvial systems are complex and influenced by many variables. Data to characterize fluvial systems are typically limited. Hydrodynamic numerical models, including EFDC, are used to simulate conditions including flow time series, sediment inputs, and physical changes (e.g., obstructions, channel alteration, etc.) and the corresponding physical response as measured by output variables.

Model limitations included the following:

- The models were developed as 2-D models since limited three dimensional data was available to characterize the 40-mile fluvial system and three dimensional models significantly impact computer run time. The 2-D models therefore are not designed to characterize parameters in more than 2 dimensions (e.g., velocity profile).
- Data that define the sediment concentrations as a function of flow were not available for the Kalamazoo River or tributaries.
- Site-specific data to characterize particle size distribution were collected from 109 sediment cores. The distribution was determined from the average values of core sample sediment surface layers obtained from the Kalamazoo River in 2011, not particle size from surface water samples.
- The models were developed to consider hydrodynamics and sediment transport. The models do not consider submerged oil transport. Literature or field data that provide a basis for characterizing the complex relationships between sediment and submerged oil transport were not available. Therefore the model was not used to estimate submerged oil transport.
- The models were not developed to consider submerged oil biodegradation.

As mentioned previously, no numerical model will precisely replicate the actual conditions of the Kalamazoo River. However, the EFDC-calibrated model simulations that were conducted for a range of Kalamazoo River flow scenarios were consistent with interpretations based on geomorphic surface maps and submerged oil delineations from field data. The model simulations typically provided output that defined erosional and depositional areas in the Kalamazoo River that were comparable to previous and independent fluvial geomorphic interpretations. The fluvial geomorphic interpretations were used in 2010 and 2011 to support submerged oil recovery work.

Model Results and Interpretations

- The model is a useful tool to define erosional and depositional areas within the Kalamazoo River and to evaluate the potential for sediment migration.
- In-channel velocities, at bankfull and below, are highest where the channel narrows and lowest in oxbows, backwaters, and other areas away from the main channel. Areas showing the highest deposition of silts and clays correspond with submerged oil areas. These areas tend to be stable even at simulated high flows (50-year and 100-year events).
- The sediment particle size data from the 109 cores is biased to fine grain depositional areas. These areas were most likely to include submerged oil. The sediment sampling plan was designed to sample fine grained deposits and submerged oil.
- The model shows that significant areas are depositional within the impounded areas (Ceresco, Mill Ponds, and Morrow Lake) even at 100-year flood flows.
- Model output for sediment transport correlated well with the geomorphic surface mapping. Deposition and erosion areas matched similar areas defined in the geomorphic surface mapping. The geomorphic surface mapping was based on multiple lines of evidence including channel width, water depth, sinuosity, water velocity, channel gradient, sediment bed type, bathymetry, and anthropogenic features.
- Model simulations provided significant knowledge regarding river depositional and erosional processes that supported containment and clean-up decision making.

Remediation decisions in 2010 and 2011 were based on field investigations and geomorphic interpretations. The results from model simulations conducted in 2012 were consistent with geomorphic interpretations and do not provide information that would alter submerged oil recovery methods that were generally successful following the oil release.

Consolidated Work Plan Model Tasks

Hydrodynamic modeling tasks defined in the Fall 2011 CWP are grouped by model report topic and discussed.

Boundary Conditions:

1) *Tributary inputs*

Tributary flow was based on a weighted method that considers tributary watershed area and the watershed area and flow from a USGS station. An uncertainty analysis was not possible due to limited flow data from tributaries and USEPA time constraints for model development. Therefore, the model work schedule and only one tributary with a flow record (Battle Creek) did not provide for an uncertainty analysis based on numerical modeling of tributary watersheds or statistical modeling that required tributary flow data.

Flow boundary conditions were based on USGS flow from the USGS station near Marshall and tributary flow as discussed previously. The flow from these sources included contributions from both surface and groundwater flow.

2) *Dam configurations and rating curves*

Model calibration for the river system including the dams considered downstream flow from the USGS Comstock Station. Further explanation of dam rating curves were provided in the July 20, 2012 Tetra Tech memorandum to Enbridge. However, the technical memorandum does not provide a clear explanation of the model representing Ceresco Dam sill width across the channel. The Ceresco Dam width across the channel in the riverine model is represented by three grid cells. Each grid cell has a length of 20 meters so the represented width of the Ceresco Dam in the riverine model is 60 meters.

Discharge data from the Morrow Lake Dam with subsurface draws were not available even though requests were made to the dam operator. The weir rating curve was developed because other data were not available to represent combined weir flow over the dam sill and also flow through turbines. Existing information indicate that turbines are activated (subsurface flow) to satisfy peak energy demand. Despite requests for operational data, the dam operator, STS Hydropower has not provided information on the timing, duration, or frequency of subsurface flow at the dam.

The 2-D model simulations indicate negligible sediment transport potential in Morrow Lake even at high flow events (100-year return frequency). The simulated sediment transport within Morrow Lake is consistent with the characterization of Morrow Lake as a significant depositional area using fluvial geomorphology methods. At the February 2012 modeling development meeting in Atlanta, all participants (USGS and Enbridge) supported the development of a baseline 2-D model instead of the 3-D model required in the CWP to accommodate USEPA schedule demands.

3) *Suspended sediment concentrations and particle sizes*

The sediment particle size distributions used for model development were based on particle size analysis of sediment samples collected from 109 sediment cores from the Kalamazoo River in depositional areas that typically were composed of finer grained sediment (loams not sands). The data from depositional areas were used to determine particle size distribution because field data showed that submerged oil was most associated with the finer grained sediment within depositional areas as indicated in the following table. The sediment core samples included 109 locations throughout the impacted Kalamazoo River. The core samples were obtained from depositional areas with fine grain sediment and were not collected from erosional surfaces with coarser grained sediment. Therefore, the particle distribution results used for model input represent surface fine grain sediment that is most subject to transport. This is biased to fine grain depositional areas and is not representative of the entire river channel.

	Total Focus Areas with Crude Oil	Focus Areas with Crude Oil Deposited with Fine Grain Sediment Only	Focus Areas with Crude Oil Deposited with Fine and Coarse Grain Sediment	Focus Areas with Crude Oil Deposited with Coarse Grain Sediment Only
Number	142	131	8	3
Percent of Total Focus Areas with Submerged Crude Oil	100.0%	92.3%	5.6%	2.1%

Model Inputs

1) *Bathymetry*

Bathymetric data including x, y, and z coordinates using Leica RTK-GPS technology were obtained from more than 1,000 locations in the Morrow Lake Delta (Delta). Collection of bathymetric data using sonar technology from a watercraft was not possible in the Delta due to the shallow water depth. The calibrated model results, based on inputs including bathymetric data, are consistent with mapped fluvial geomorphic features. Generally, the depositional and erosional areas defined with field data and mapping correspond to model simulation results for the 40-mile river model domain. Additional model simulation results will not provide information that would alter submerged oil recovery methods that were generally successful following the crude oil release.

2) *Channel roughness*

The sensitivity analysis indicates that the parameters that most influence model results include flow, velocity, and bathymetry. Bottom roughness and other inputs have varying impact on model results depending on the specific output parameter. Bottom roughness values for the EFDC model represent a friction factor expressed in units of meters. The bottom roughness is similar, but not always equivalent, to a Manning *n* value depending on the specific value. Higher bottom roughness values are less comparable to Manning *n* values. Often in hydrodynamic modeling, the bottom roughness is used as a calibration parameter.

3) *Riverine sediment physical characteristics (bulk density, particle size)*

Core samples (109) were collected in 2011 from depositional areas to support the EFDC model. The minimum, average, and maximum wet bulk density values were 0.86, 1.24, and 1.95 grams per cubic centimeter (g/cm^3), respectively. The wet bulk density analysis was a weight to volume laboratory measurement that included sediment mineral and organic fraction. These values are comparable to wet bulk density values reported in the literature. McNeil and Lick (J. Great Lakes Res. 30(3):407-418, 2004) reported average sediment wet bulk densities for a portion of the Kalamazoo River near Plainwell (downstream from investigation). The reported average values for 15 centimeter (cm) intervals for 35 core samples ranged from 1.05 to 1.99 g/cm^3. The average minimum and maximum values for the 15 cm core samples were 1.05 and 1.97 g/cm^3, respectively.

Sediment cores were collected during 2012 quantification of submerged oil field activities for bulk density analysis. The cores were collected from 37 locations within geomorphic settings along the Kalamazoo River. The minimum, average, and maximum wet bulk densities values were 0.88, 1.35, and 2.08 g/cm^3, respectively. Kalamazoo River sediment wet bulk density measurements collected in 2011 and 2012 for quantification of submerged oil activities are consistent between datasets. In addition, bulk density measurements on Kalamazoo River sediment samples are within the range of values reported in the literature for wet bulk densities.

4) *Water Velocity Profiling*

The model was calibrated using measured Acoustic Doppler Current Profiler (ADCP) data obtained in November 2011. Acoustic Doppler Velocimeter data were not collected in 2011. The calibrated model results, based on inputs including ADCP velocity data, are consistent with fluvial geomorphology based mapped areas. Generally, the depositional and erosional areas defined with field data and mapping correspond to model simulation results for the 40-mile river model domain. The model simulation results do not provide information that would alter submerged oil recovery methods that were generally successful following the oil release.

The calibration process was reviewed and supported by USGS staff that represented USEPA at the model development meetings in Atlanta on February 22, 2012 and Marshall on March 14, 21, and 23, 2012. The model design was presented by Tetra Tech at the Scientific Support Coordination Group (SSCG) Meeting at Marshall on March 29, 2012. At the time of the SSCG meeting, USGS staff that represented USEPA supported model calibration and authorized Enbridge to proceed with validation and model scenarios.

5) Agitation techniques

The EFDC sediment settling velocity function is dependent on variables including water temperature, particle size and distribution, particle density, turbulence, and velocity. Existing data was used to develop inputs that influence sediment settling velocity. An SSCG agitation study, conducted in 2012, has experimental results which have not been provided to Enbridge. The methods to obtain the data and the validity of the data are presently unsubstantiated.

6) *Critical shear stress for deposition*

There is a distinction between critical shear stress for deposition (model input) and shear stress (model output). The shear stress parameter is an output value and not an input value for the EFDC model. Therefore, critical shear stress data for jet test or sedflume tests would not be used as model input unless related to critical shear stress for deposition.

The model inputs were based on background literature, field measurements, or other site specific data sources. The best available data were used to develop the model. Additional data collection and model refinement may result in a more robust hydrodynamic model but the understanding of the river geomorphology or submerged oil occurrence in depositional areas will not be significantly improved by additional modeling.

Model Scenarios and Sensitivity Analyses:

1) *1.5-year flood (2000 cubic feet per second (cfs)), 2-year flood (2500 cfs), 25-year flood (4600 cfs) flow scenarios were not simulated.*

Flow scenarios that were simulated between <600 cfs and >6000 cfs, which encompass the flows mentioned in the CWP, include the following:

- September 2010 (Low Flow) <600 cfs
- October/November 2011 640 cfs
- April 2011 (bankfull) 1200 cfs
- Memorial Day 2011 2000 cfs
- July 2010 3000 cfs
- 50 Year flood 5500 cfs
- 100 Year flood 6500 cfs

2) *Sensitivity increments and analysis*

Sensitivity analysis was conducted at ±50% of the base model values, which encompass and are more conservative than the increments defined in the CWP. The sensitivity analysis showed that model results were most influenced by bathymetry, velocity, and discharge parameter data.

Model Objectives

1) *Successfully calibrate a 3-D model for unsteady, open-channel flow, capable of simulating with useful accuracy the spatial and temporal variations in the river velocities, bed-shear stresses, and consequent sediment entrainment, transport, and deposition of sediment-oil mixtures*

   The calibrated 2-D model simulations indicate negligible sediment transport potential in Morrow Lake even at high flow events (100-year return frequency). The negligible model simulated sediment transport within Morrow Lake is consistent with the characterization of Morrow Lake as a significant depositional area using fluvial geomorphology methods. Therefore, available information does not suggest that a 3-D model would provide results that are considerably different from the 2-D simulations for Morrow Lake. In addition, the subsurface draws occur intermittently due to the peaker operation of the dam. Despite requests, the dam operator, STS Hydropower, has not provided data regarding the frequency, duration, or turbine release rates. The effects of the intermittent subsurface draws on velocity and sediment transport are presumably localized. The model simulated Morrow Lake flow is influenced by the close proximity to the established downriver model flow boundary, which is based on data from the USGS Comstock gage station.

2) *Gain improved understanding of the transport of submerged oil; specifically, by simulation of the variables in Objective 1, resulting from various regimes of stream flow conditions that include flows ranging from low to 50-year recurrence interval (e.g., submerged oil transport as a subset of sediment transport)*

   The EFDC model calibration was based on inputs from data that were available for model development beginning December 2011 and ending on April 2012. During model development, the relationships between submerged oil, sediment particle size, and transport were not available through published literature or site field investigations. Therefore, the transport model did not simulate submerged oil transport. The transport model did simulate fine grain sediment transport, which possibly included the submerged oil. This was a conservative approach because all fine grained sediment did not contain submerged oil but the submerged oil was predominately present in fine grained deposition areas. The model assumptions and limitations were described previously. A range of flows, from low flow to a 100-year flow return frequency, were simulated.

3) *Simulate a variety of scenarios for containment, collection, and recovery of submerged oil-laden sediment, and proposed sediment collection structures and future boom arrangements*

Finite Difference numerical models including the EFDC model are scale dependent. The model that was developed was scaled (e.g., grid size) to simulate processes throughout the 40-mile Kalamazoo River domain and was not designed to focus on localized areas. The EFDC model calibration and validation were based on data that were available for model development beginning December 2011 and ending on April 2012.

The sediment trap locations were selected based on the fluvial geomorphology of the Kalamazoo River. The understanding of geomorphic processes, the results of the poling investigation, and sediment core profiles were used to select the sediment trap locations. The hydrodynamic model scale was not designed to model areas less than 40 meters by 10 meters (riverine grid size). The model was used to simulate barriers to create a sediment trap, however, based on scale, was marginally successful.

The amount of sediment collected in the cylindrical sampling devices (CSDs) do not represent reasonable sedimentation rates for the sediment traps since existing rates would result in traps that were completely full by now, which has not been observed. The USEPA and USGS, in a focus meeting agreed that the sediment rates collected in the CSDs do not represent actual trap sedimentation rates.

4) *Document the post submerged oil recovery findings of this hydrodynamic model to assist in the long term planning, design, implementation, monitoring, and evaluation of future river management methods.*

The calibrated model results are consistent with the fluvial geomorphology mapped areas. Generally, the depositional and erosional areas defined with field data and mapping correspond to model simulation results for the 40-mile river model domain. The calibrated model has been used to support selection of sediment traps. The model simulation results do not provide information that would alter submerged oil recovery methods that were generally successful following the crude oil release.

Summary

The EFDC hydrodynamic model for the Kalamazoo River was calibrated, validated, and a number of model scenarios were simulated. The model development, capabilities/limitations, scenario simulations, and results are provided in the Kalamazoo River Hydrodynamic and Sediment Transport Model Report submitted to the USEPA on April 20, 2012. The modeling results were consistent with interpretations made previously and independently of the model based on field characterization of submerged oil occurrence and geomorphic surface mapping. Additional data collection and model refinement may result in a more robust hydrodynamic model but the understanding of the river geomorphology or submerged oil occurrence in depositional areas will not be significantly improved by additional modeling.