April 20, 2012

Ronald Zelt
USGS
5231 South 19th
Lincoln, NE 68512-1271

Re: Groundwater Modeling Proposal Prepared by the Scientific Support Coordination Group (SSCG) for Biodegradation
Enbridge Line 6B MP608 Release, Marshall, MI

Dear Ron:

I have reviewed the above-referenced Proposal and accompanying Project Statement that were prepared in response to Charge 3 submitted to the SCCG:

a) Provide an evaluation of viable procedures, including benefits and draw backs for each, to assess whether remaining submerged oil will biodegrade over time.
b) Provide a recommendation for the best approach to accomplish this goal.

The group's recommendation was submitted to me with the proposed scope of work contingent upon a positive finding of biodegradability of Line 6B oil by U.S. EPA's Environmental Response Team (ERT). The preliminary findings of that study are now in, and the oil was found to be degradable under the optimal conditions employed. Therefore, I hereby accept the group's recommendation to proceed with a nested-scales approach to groundwater modeling at selected location(s) on the Kalamazoo River. Dr. Michel Boufadel will be the primary SSCG member leading this effort. This study is focused on the potential for groundwater upwelling to enhance the potential for biodegradation of accumulated oil at a proposed sediment trap. Please ensure a close collaboration between this work and the hydrodynamic model under development.

Once again I must extend my since appreciation for the level of professionalism and diligence displayed by the SSCG members. I am grateful for the foresight of its members, as demonstrated by the contingent, flexible nature of approaches that adapt to site conditions and tactical plans for oil recovery.

Sincerely,

Ralph Dollhopf
Federal On-Scene Coordinator and Incident Commander
U.S. EPA, Region 5

cc: L. Kirby-Miles, U.S. EPA, ORC
Sonia Vega, U.S. EPA, Deputy Incident Commander
John Sobojinski, Enbridge
Isaac Aboulafia, START
Mike Alexander, MDEQ
Adriana Bejarano, RPI
Michel Boufadel, Temple University
Jim Chapman, U.S. EPA
Isabelle Cozzarelli, USGS
Mick DeGraeve, GLEC
Linda Dykema, MDCH
Jennifer Gray, MDCH
Steve Hamilton, MSU
Bruce Hollebone, Env. Canada
Alan Humphrey, U.S. EPA – ERT
Neville Kingham, Kingham Consulting Services
Jacqui Michel, RPI
Stephanie Millsap, USFWS
Greg Powell, U.S. EPA – ERT
David Soong, USGS
Mark Sprenger, U.S. EPA – ERT
Bob Steede, Enbridge
Al Uhler, NewFields
Albert Venosa, U.S. EPA
Lisa Williams, USFWS
Robyn Conmy , U.S. EPA – NRMRL

March 22, 2012

Mr. Ralph Dollhopf
Federal OSC and Incident Commander
U.S. EPA, Region 5
Emergency Response Branch
801 Garfield Avenue, #229
Traverse City, MI 49686

Subject: Groundwater Modeling - Enbridge Line 6B MP 608, Marshall, Mich., Pipeline Release

Dear Mr. Dollhopf,

With this memorandum, the Chemistry, Fingerprinting, and Biodegradation Subgroup of the SSCG forwards initial recommendations of its Biodegradation Sub-subgroup, for actions that could be taken already, pending the results of the USEPA-ERT microcosm tests of biodegradability of Line 6B oil under optimal conditions.

Background and FOSC Charge

Groundwater is the principal source of streamflow in the Kalamazoo River (KR) and the impacted area (Neff et al. 2005). Anticipating that high flows will occur during Spring 2012, Enbridge Energy is planning to install sedimentation enhancements at several geomorphically effective sedimentation areas ("traps") along the KR in the late-March to early April period. Both high flows and continuation of oil recovery techniques (toolbox) are likely to remobilize sediment and transport it, along with residual Line 6B oil, into sedimentation areas, where it is expected that maintenance and natural attenuation will combine to remove or degrade submerged oil from the sediment. One of the key environmental controls on natural biodegradation is the oxygenation status of the sediment matrix in which the submerged oil occurs. Groundwater flow through processes generating riparian springs and streambed seepage may be critical for introducing oxygen into otherwise anaerobic zones of fine-sediment deposits. Groundwater also may affect pH and may supply dissolved nutrients in those deposits, and these are other important factors that affect biodegradation (Zhu et al. 2001).

The SSCG Biodegradation Sub-Subgroup evaluated and discussed these and additional aspects and benefits of improved understanding of groundwater flow and solute transport along and into the KR that are the basis for our recommendations to undertake numerical groundwater modeling, at nested scales and in close coordination with hydrodynamic modeling now ongoing, in support of the U.S. EPA response to the Enbridge Line 6B Pipeline Release near Marshall, Michigan. These modeling studies and recommendations are responses to the FOSC's Charge No. 3 ([a] Provide an evaluation of viable procedures, including benefits and draw backs for each, to assess whether remaining submerged oil will biodegrade over time. [b] Provide a recommendation for the best approach to accomplish this goal) and the SSCG Concepts framework document (Nov. 17, 2011), which states that "the performance of science related to ecological risk assessment, sediment transport, oil chemistry, weathering, *fate and transport*, temperature effects, and effectiveness of recovery methods will be important in determining the *benefits and consequences of performing, or not performing*, future active oil recovery activities." [italics added] It is the Sub-Subgroup's evaluation that groundwater modeling substantially contributes to the important understanding needed to make those determinations and to establish the final cleanup strategy.

RECOMMENDATIONS:

The Biodegradation Sub-Subgroup recommends that:

1. A nested-scales approach to groundwater modeling should be undertaken immediately to provide initial results within the FOSC's indicated timeline ending April 30, 2012. Objectives and evaluations of modeling approaches are explained in greater detail in the attached document, prepared under the lead authorship of Dr. Michel Boufadel.
2. The groundwater modeling study design should be coordinated with, and results of groundwater-flow simulations should be provided to, the hydrodynamic modeling team presently working on the Enbridge oil spill response to provide improved coverage of and accounting for hydrologic processes and hydraulic mechanisms affecting streamflow and sediment transport in the KR.
3. Interpretations of groundwater simulation results and their implications for the transport and fate of submerged free phase, sediment-associated, or dissolved hydrocarbons should be provided to the FOSC with practical implications for balancing the risks of 2012 oil recovery actions with potential benefits of active versus natural attenuation of submerged oil.

The recommended techniques are well established in the science literature to provide data that can help answer the following questions:

- How much improvement in explaining or predicting the transport and fate of sediment-associated submerged oil with hydrodynamic models is realized by including spatially explicit estimates of groundwater potentiometry along the Kalamazoo River?
- What role in producing or maintaining oxygenated sediment is played by hyporheic exchanges where groundwater flows through the gravel-and-sand framework and into streambed deposits of fine-sediment-associated submerged oil?
- Does the presence of inflowing oxygenated groundwater produce a substantial change in the rate of biodegradation of submerged oil?
- Is groundwater transport of sheen or soluble hydrocarbons from subsurface occurrences in overbank areas of floodplains/islands back into the river important for reaching clean-up endpoints?

Based on subgroup members' experience working on oil spill-related issues for the past 20 years, we recommend the adoption of the attached technical approach in completing the response to the Enbridge Line 6B MP 608 Marshall, Michigan, Pipeline Release.

On behalf of the SSCG sub-group, very sincerely yours,

Ronald B. Zelt, P.HWQ.
Supervisory Hydrologist
U.S. Geological Survey

REFERENCES

Neff, B.P., S.M. Day, A.R. Piggott and L.M. Fuller, 2005, Base Flow in the Great Lakes Basin, Date Posted: November 29, 2005: U.S. Geological Survey Scientific Investigations Report 2005-5217, 23 p. [http://pubs.water.usgs.gov/sir2005-5217/]

Zhu, X., A.D. Venosa, M.T. Suidan, and K. Lee, 2001. Guidelines for the bioremediation of marine shorelines and freshwater wetlands. Cincinnati, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, 156 p.

PROBLEM STATEMENT

Issue 1. HYDRAULICS. Groundwater is the principal source of streamflow in the Kalamazoo River and the impacted area (Neff et al. 2005). For example, mean annual discharge of the river increases by 21% between the USGS gauging stations at Battle Creek and Comstock, after accounting for tributary inputs (Wesley 2005, Table 1). During periods of base flow to moderate flow, the primary mechanism affecting cross-sectional location of the primary zone of downstream transport capacity (and consequently of deposition) could be the transverse hydraulic gradient of groundwater. How much improvement in explaining or predicting the physical transport and fate of sediment-associated submerged oil is realized by including spatially explicit estimates of groundwater potentials along the Kalamazoo River? Are these estimates most efficiently used in hydrodynamic modeling if they are provided from stand-alone GW flow model, an integrated SW-GW flow model, or via hydrogeologic calculations apart from a model?

Issue 2. SUBSURFACE OIL TRANSPORT. Hydraulic gradients between surface- and groundwater produce potential for oil transport into the subsurface of riparian areas during periods of elevated streamflow, especially via macropore or gravel-matrix flow. Conversely, during periods of base flow in streams, groundwater may transport sheen or soluble fractions of oil from subsurface in riparian areas back into the river, either directly or via short rivulets emerging from riparian seeps or springs. Are these processes important for reaching clean-up endpoints? If so, what are efficient methods for characterizing these processes and quantifying their roles? What existing data are available to assist with these tasks?

Issue 3. OXYGENATION AND BIODEGRADATION. Previous field studies at small scales in pools having fine sediment filling most of the pore spaces within a gravel framework (Ryan and Boufadel, 2006, 2007) found that groundwater composed up to 55% of the water in local areas of a hyporheic zone, and that hyporheic exchange was favored by heterogeneity between upper and lower layers of the bed sediment in terms of hydraulic conductivity. Sediment trapping areas along the Kalamazoo River frequently feature a layer of fine sediment (silt to very fine sand) overlying a gravelly lower layer. What role in producing or maintaining oxygenated sediment is played by hyporheic exchanges where groundwater flows through the gravel framework and into streambed deposits of fine-sediment-associated submerged oil? Does the presence of inflowing oxygenated groundwater produce a substantial change in the rate of biodegradation of submerged oil? Can these questions be addressed best through controlled laboratory studies, field studies, or a combination of both?

RECOMMENDED WORK

A groundwater model would be needed to address the problems stated above. Such a model would need to be coupled to the hydrodynamic model (HDM) of the KR. The most expedient model is MODFLOW (McDonald and Harbaugh, 1988) developed by the USGS. The model has an intrinsic module for rivers, known as the River Package. Although MODFLOW is free, it is best to use it through a Graphical User Interface for ease of entering data and production of results. We propose the use of GMS (www.emsi.com/GMS/gms.html) that costs around $2,000. GMS easily handles irregular geometry and a large number of grid points.

A MODFLOW grid would be developed around the KR. It would extend approximately 150 m (450 feet) beyond the edge of the floodplains, and be 100 to 200 m deep (300 to 600 feet deep). The bottom depth of the domain is a location where the groundwater flow is expected to be negligible. This selection would be re-evaluated once modeling is conducted. The grid spacing along the stream should be 15 m to match with the grid spacing of the hydrodynamic model (HDM). In the lateral direction, the spacing could vary from 15 m to 50 m, depending on the physical information (e.g., topography) and the sought accuracy.

The geometry of the KR along with its bathymetry and the topography of the surrounding aquifer could be readily entered into MODFLOW using the GIS module (as part of the option MODFLOW.2 from GMS). If there is no specific “GIS layer” for the topography, the matrix-type entry through GMS will be pursued, and the existing maps would be used as background figures. Some of the properties of the aquifer-streambed (permeability, leakage coefficient, storage coefficient, porosity, etc.) could be obtained based on the information in USGS map quadrants, and prior studies such as Luukkanen et al. (2005) and the KR RI (Enbridge, 2010).

The MODFLOW model will require the water level in the KR and the regional groundwater levels as boundary conditions. The water level in the KR has been measured by the response at numerous locations, and a HDM model is being calibrated to these measurements. The measured water level will be used as input to MODFLOW along with the output of the HDM at locations where no water level is measured. The regional groundwater table will be obtained from the work of Luukkonen et al. (2004), where they used MODFLOW at the scale of Kalamazoo County and vicinity. The developed stream-aquifer MODFLOW model will incorporate water table data from groundwater wells, and would be used to make recommendation on additional measurements. Note that the developed model can be populated with more data without greatly altering the existing model calibration to the surrounding regions. This is because the flow in the system is mainly the results of local "forcing"; topography, heterogeneity, and river water level. (From a theoretical point of view, the groundwater flow problem is a boundary value problem, and therefore its solution is "non-local". However, from a practical point of view, the local forcing is dominant). In addition, we envisage localized MODFLOW domains for areas of high interest, such as the “sediment trap zones” to complement what is being done by the HDM for these zones.

The physical information of the river-aquifer system would be entered into the model, and different permeability will be assigned to different regions. In particular, we envisage that the lower layers of the aquifer have higher permeability. As there is uncertainty in aquifer properties, one could also report the results as normalized to a given value (e.g., flow in the stream), such that one could understand the relative role of each aquifer unit without knowing the exact aquifer property.

As groundwater flow is much slower than river flow, the time step used in MODFLOW can be much larger than that used in the hydrodynamic model (say, 100 times larger) without a loss in the relative accuracy. In addition, MODFLOW would run in a matter of minutes (or less) whereas any hydrodynamic model would take hours, and sometimes might not converge without judicious selection of parameters. Therefore, the additional burden of using MODFLOW is negligible.

Using a physically-based groundwater model that is calibrated to the field at each location of interest is generally superior to relying on simple models such as a direct application of Darcy's law. A good illustration is in Figure 1 taken from Harvey and Bencala (1993). The figure shows that groundwater flows are very convoluted around "steps" (i.e., change in topography of the aquifer). Therefore, relying on two points to compute the hydraulic gradient between the KR and the surrounding aquifer is not correct, and one would need to account for the gradient in different directions, which is done automatically in MODFLOW.

The final stage of the calibration of any model is conducting a sensitivity analysis, and fortunately GMS has such modules. In addition, a sensitivity analysis could be also used to evaluate groundwater flows after excavation and replacement of soil.

OBJECTIVES

This work will address the challenges raised in the first section "Problem Statement" in particular Issues 1 and 3, as we suspect that dissolved oil components (Issue 2) are negligible in pore water. The added benefits of the model are:

1- The present model would allow one to avoid incorrect characterization of groundwater pathways and incorrect quantification of these flows, which would result from the over-simplification of applying Darcy's law across the stream bank.
2- The model provides the advantage of producing all results in normalized form, which would allow one to evaluate the effect of topography and heterogeneity without actually knowing the exact value of the aquifer permeability. For example, the permeability of silt is much smaller than that of sand. So even if the individual values are not known the comparison could still provide valuable insights on the relative role of each formation. This allows one to locate "control sections".
3- The model would allow one to quantify groundwater flows that occur in regions that were subjected to major cleanup work, such as excavation and/or soil re-emplacement.
4- As the lower layer of the aquifer is more permeable, the application of Darcy's law across the stream bank is fraught with uncertainty. A groundwater model such as the one proposed herein incorporates the heterogeneity implicitly.

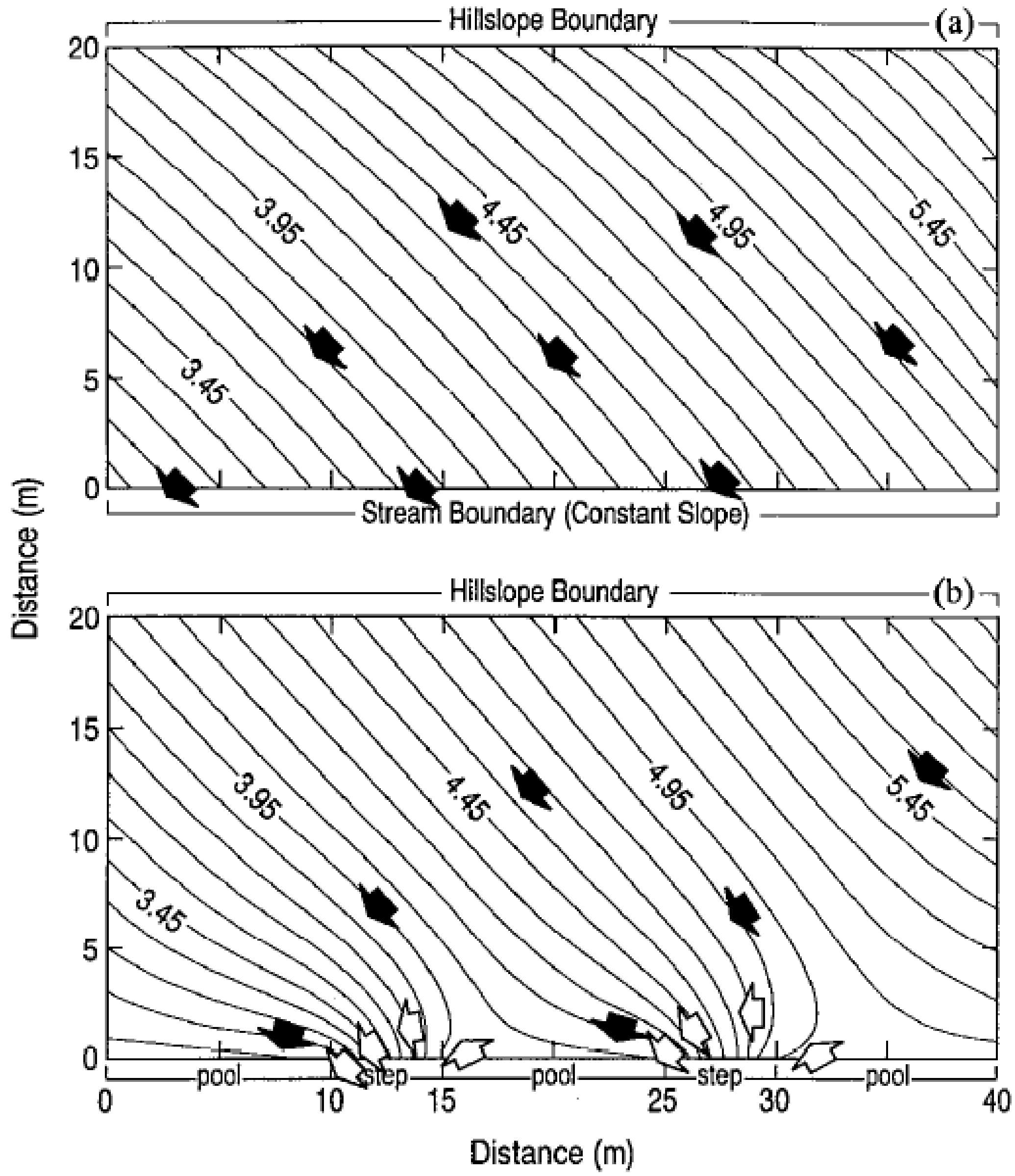

Figure 1: Interaction of groundwater with a stream. (a) Idealized case when the slope of the stream is constant (i.e., profile decreases linearly downstream), the groundwater flows are unaffected by the stream. (b) Convoluted groundwater flows that emerge at locations of relatively rapid change in stream topography. The configuration in (b) is more representative of natural environments. Figure from Harvey and Bencala (1993).

REFERENCES

Harvey, J., and K. Bencala, The effect of stream topography on surface-subsurface water exchange in mountain catchment: Water Resources Research, Vol 29, (1), 89-98, 1993.

Luukkonen, C.L., S.P. Blumer, T.L. Weaver, and Julie Jean, 2004, Simulation of the Ground-Water-Flow System in the Kalamazoo County area, Michigan: U.S. Geological Survey Scientific Investigations Report 2004-5054, 65 p., available athttp://pubs.usgs.gov/sir/2004/5054/

McDonald MG, Harbaugh AW, A modular three dimensional finite-difference ground-water flow model. U.S. Geol. Surv. Techniques of water resources investigations, book 6, chap A1, Washington, DC, 1988.

Neff, B.P., S.M. Day, A.R. Piggott and L.M. Fuller, 2005, Base Flow in the Great Lakes Basin, Date Posted: November 29, 2005: U.S. Geological Survey Scientific Investigations Report 2005-5217, 23 p. [http://pubs.water.usgs.gov/sir2005-5217/]

Enbridge Energy, Hydrogeological evaluation report for Enbridge Line 6B MP 608 Release Marshall, MI. Evaluation of Potential Impact of Released Oil on Groundwater used for Drinking Water, October 30, 2010

Ryan, R.J., and M.C. Boufadel, 2006. Influence of streambed hydraulic conductivity on solute exchange with the hyporheic zone. Environ. Geology 51: 203-210, DOI 10.1007/s00254-006-0319-9

Ryan, R.J., and M.C. Boufadel, 2007. Lateral and longitudinal variation of hyporheic exchange in a piedmont stream pool. Environ. Science and Technology 41:4221-4226, doi:10.1021/es061603z.

Wesley, J.K., 2005. Kalamazoo River assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report 35, Ann Arbor.