TOSC Review of Pall Life Sciences
"Final Feasibility Study & Proposed Interim Response Plan for the Unit E Plume"

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Executive Summary

At the request of Ann Arbor and Scio Township community members, the Michigan State University College of Engineering TOSC Program has reviewed the June 1, 2004 "Final Feasibility Study & Proposed Interim Response Plan for the Unit E Plume" prepared by Pall Life Sciences (PLS). This document contains TOSC's comments on the remedial alternative and interim response (IR) options proposed by PLS with additional comments on the Michigan Department of Environmental Quality's (MDEQ's) preferred remedial alternative.

The E Plume, a body of groundwater contaminated by 1,4-dioxane stretching from the PLS facility located on Wagner Road to a location east of Maple Road in western Ann Arbor, is thought to be migrating eastward through a glacial aquifer system. Complex hydrogeologic conditions, gaps in subsurface data, and lack of a comprehensive groundwater model impede the ability to predict the plume's migration path and formulate specific remediation plans. (The area known to be affected by the E Plume is illustrated in Figure 1 at the end of this document.)

For these reasons, TOSC does not concur with the PLS proposal to allow the E Plume to migrate unimpeded toward the Huron River. Rather, TOSC supports the MDEQ's recommended strategy of mass removal at multiple locations within the E Plume, using a combination of interim and leading edge response measures. Such an approach will maximize removal of 1,4-dioxane in the short term, accelerate the reduction of 1,4-dioxane concentrations over the long term, and contribute to a risk reduction for potential downgradient receptors. However, while TOSC supports MDEQ's alternative, the potential benefits of the proposed responses may be compromised by uncertainties associated with a lack of subsurface data in critical locations and a lack of understanding of potential aquifer responses to proposed remedial actions.

Key components of TOSC recommendations for the implementation of leading edge remedies and interim response measures include:

- Acquisition of *additional subsurface data* in four key areas including the area between the present day leading edge of the plume and the Huron River.
- Development of a *stochastic groundwater flow and contaminant transport model*[1] incorporating site specific information and an appropriate level of aquifer complexity. This model will function as an essential planning tool for the evaluation and optimization of remedial alternatives and must be available for public review.
- Implementation of *concurrent activities* including:
    - Permit and construct a pipeline from Maple Village to the Huron River downstream of the city's water supply intake at Barton Pond.
    - Install a groundwater treatment facility at Maple Village.
    - Take interim response measures at Maple Village, but limit them to pumping, treating, and discharging treated water to the city's sewer system (i.e., no reinjection) until the Maple Village – Huron River discharge pipeline is completed.
    - Take interim response measures to remove additional 1,4-dioxane at Wagner Road.

[1] In groundwater modeling, stochastic refers to a dynamic model that considers probabilities and may produce multiple possible outcomes from which decision makers can select.

- Install and operate extraction wells and pipelines at the leading edge of the plume, **but delay this step** until after additional aquifer characterization data are acquired and the number, location, and pumping rates of extraction wells are optimized using a suitable groundwater model.
- Involve residents from neighborhoods located above the plume's leading edge in the planning and optimization process.

Introduction

Pall Life Sciences (PLS) submitted its "Final Feasibility Study & Proposed Interim Response Plan for the Unit E Plume" (FS) to the Michigan Department of Environmental Quality (MDEQ) on June 1, 2004. This document is available for review through the MDEQ website at:

www.michigan.gov/deq/0,1607,7-135-3311_4109_4219_4279-72394--,00.html#PLS_FS.

The FS evaluates a range of alternative final remedies and includes several potential interim response (IR) actions to address 1,4-dioxane contamination in the E plume in portions of Scio Township and the City of Ann Arbor. The E plume includes contamination of the deepest glacial drift aquifer (the E aquifer unit) in the vicinity of the PLS facilities on Wagner Road, as well as contamination of a complex system of aquifer units farther east in the vicinity of the Maple Village Shopping Center and Veterans Park on Maple Road.

The main components of the FS have been summarized in a July 7, 2004 fact sheet published by the MDEQ, which is available at:

www.deq.state.mi.us/documents/deq-rrd-GS-FACTSHEET.pdf.

In addition, at the request of MDEQ, the FS has been reviewed by Weston Solutions of Michigan, Inc. Weston's July 14, 2004 evaluation is available at:

www.deq.state.mi.us/documents/deq-rrd-gs-westonjuly04report.pdf.

TOSC supports the process utilized in the FS to establish and evaluate alternative remedial responses to the E plume contamination. However, TOSC has identified important deficiencies in the FS and disagrees with several of its key conclusions. Rather than restate the contents of the FS or duplicate the assessment provided by Weston, this document is intended to provide: 1) an independent evaluation of the remedial alternative and IR options proposed by PLS in the FS, 2) comments on the MDEQ's preferred remedial alternative, and 3) recommendations for implementation of remedial alternatives and IR measures. TOSC comments focus on the areas of hydrogeology, and groundwater flow and transport modeling. They do not address additional issues of treatment technology, infrastructure installation, or project economics.

Questions about TOSC's comments should be directed to Kirk Riley, TOSC Program Manager, by phone (517-355-7493) or e-mail (rileyk@egr.msu.edu). For additional information on the TOSC Program and the PLS TOSC project, visit:

www.tosc.msu.edu/gelman.

PLS Proposed Remedial Alternative

PLS selected Alternative 6 in the FS, which consists of a combination of: a) "Groundwater Pumping – Active Remediation and Treatment Proximate to the Huron River;" along with b) IR measures to remove and treat contaminant mass in two locations. Under this scenario, approximately 200 gallons per minute (gpm) of groundwater pumped from an extraction well in the vicinity of Maple Road would be treated using ozone and hydrogen peroxide and reinjected into the aquifer nearby. On the site of the PLS property on Wagner Road, 200 to 350 gpm pumped from three or more extraction wells would be treated and released into a tributary to Honey Creek under an existing NPDES discharge permit. Under Alternative 6, no attempt would be made to extract groundwater at the present leading edge[2] of the plume, thus "avoiding the disruptions and technical feasibility problems" associated with plume capture. Instead, PLS proposes to install 10 additional observation wells between the leading edge and the Huron River in order to facilitate monitoring and modeling of the plume's behavior. Should future monitoring reveal that contaminated groundwater was approaching drinking water wells at concentrations exceeding 85 ppb or discharging from the aquifer into the Huron River at concentrations exceeding the relevant Groundwater-Surface Water Interface (GWSI) criterion (2,800 ppb), PLS would install extraction wells, pipelines, and treatment facilities at a location near the Huron River. According to PLS, "this combination of approaches best balances the benefits to be gained by quickly attacking the most contaminated portions of the plume and the need for an overall plan that avoids, to the extent possible, disruption of the community, while still being protective of all potential receptors."

MDEQ Preferred Remedial Alternative

The MDEQ review (July 7, 2004 Fact Sheet) of the PLS preferred response determined that Alternative 6 does not meet the criteria established by Part 201 and the Part 201 Rules governing the selection of remedial actions. Because Alternative 6 would result in the expansion of the contaminant plume, it would require a waiver of the applicable rules. MDEQ policy, however, prohibits rule waivers involving expansion of a contaminant plume into an established Wellhead Protection Area[3]. A portion of the E plume has migrated into the approved Wellhead Protection Area for the City of Ann Arbor's Montgomery Wellfield. Low concentrations of 1,4-dioxane detected in the active PW-1 well prompted city officials to discontinue its use. However, the well has not been abandoned and the Wellhead Protection Area therefore remains in force. Furthermore, the MDEQ concluded that Alternative 6 may not adequately protect the welfare of the public based on its failure to provide a reduction in the volume, toxicity, or mobility of 1,4-dioxane and the high degree of uncertainty associated with the complex hydrogeology and contaminant migration predictions.

Consequently, the MDEQ has proposed a remedial alternative combining groundwater extraction at the leading edge of the plume **in combination with** Interim Response measures at Maple Road and Wagner Road. This approach is designed to separate the E plume into three segments and remove 1,4-dioxane at the downgradient edge of each, thus taking advantage of the natural direction of contaminant transport while accelerating the cleanup. Groundwater pumped from Wagner Road extraction wells would be treated on site at PLS and discharged into the Honey Creek tributary under the existing discharge permit. Groundwater extracted from Maple Road would be decontaminated in a treatment system located in the same area and disposed of using surface water

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[2] The FS delineates the "leading edge" on the basis of the 1,4-dioxane concentration contour corresponding to the State of Michigan generic residential and commercial I cleanup criterion (GRCC) for groundwater of 85 parts per billion (ppb). The actual leading edge of the E Plume, as defined by the detectable limit of 1 ppb, extends beyond the 85 ppb concentration contour. For consistency with usage in the FS and the DEQ Fact Sheet, however, the term "leading edge" as applied herein refers to the mapped position of the 85 ppb contour.

[3] A protected surface and subsurface zone surrounding a well or well field that supplies a public water system; it is designed to keep contaminants from reaching the well water.

discharge to the Huron River via a pipeline. Groundwater extracted from the leading edge of the plume would be transported via a double-walled pipeline for treatment at Maple Road with subsequent pipeline transport and discharge to the Huron River. Prior to installation of the pipeline between Maple Village and the Huron River, the MDEQ recommended utilization of excess capacity in Ann Arbor sanitary sewer as an interim disposal method for treated water.

Weston Review of Feasibility Study

Weston Solutions of Michigan, Inc. provided a general evaluation of the FS to the MDEQ on July 14, 2004. Among its major comments on the FS, Weston:

1. Found insufficient information on about future migration of the E Plume to concur that Remedial Alternative 6 would be as protective of human health and the environment as other FS alternatives.
2. Recommended that proposed additional investigation downgradient of the plume be included as a component of any future remediation action.
3. Concurred that IR measures proposed in combination with Alternative 6 would "be a positive step and would make any long-term solution easier to implement."
4. Suggested that "alternate, shorter, less disruptive, and more cost-effective routes" for proposed pipelines may be possible.
5. Recommended that installation of purge wells[4] follow, rather than precede, the completion of infrastructure (i.e., treatment facility and pipelines).

TOSC Comments on PLS Proposed Remedial Alternatives and Interim Response

As summarized above, PLS proposes to implement IR measures on the PLS site and at Maple Road while monitoring the migration of the E Plume toward the Huron River and initiating groundwater pumping and treatment in the vicinity of the Huron River should it prove necessary.

Proposed IR pumping at the PLS site utilizing existing wells (TW-11, TW-12, and TW-17) offers the advantage of expedient implementation. Unintended consequences of the proposed E aquifer purging in the Core Area (the area on and adjacent to the PLS site on Wagner Road where 1,4-dioxane concentrations in the C3 aquifer exceeded 500 ppb) are poorly understood, however. These include possible accelerated movement of contaminated water from the shallower (C3 and D2) aquifers downward into the E aquifer or, if pumping volumes from C3 and D2 extraction wells are reduced to accommodate E aquifer pumping, potential interference with the hydraulic containment field that is thought to prevent migration of 1,4-dioxane into the Western System (a separate plume migrating northwest of the PLS property). TOSC agrees that short-term removal of 1,4-dioxane mass is beneficial. However, wells TW-11 and TW-17 are poorly situated to take advantage of the general west-to-east natural groundwater flow direction. Additional extraction wells placed along Wagner Road, as proposed by the MDEQ, would be better positioned to capture 1,4-dioxane and prevent its eastward migration. **In addition to optimization of well positions and pumping rates, TOSC recommends that PLS (and thus MDEQ) evaluate the influence of E aquifer pumping on groundwater movement in shallower aquifers using a comprehensive groundwater flow and contaminant transport model.**

[4] *Purge wells* are used for the purpose of extracting and treating water from a contaminated aquifer; to be contrasted with *monitoring wells* that are used to obtain water quality samples or measure groundwater levels.

Proposed IR pumping along Maple Road with reinjection of treated water into contaminated portions of the adjacent aquifer has the advantage of removing mass from a portion of the E Plume with high concentrations, before it can migrate eastward into a more complex aquifer system (where it is likely to be more difficult to recover). Despite the PLS assertion that "it is anticipated that there should be little, if any, distortion of the plume boundaries due to injection at these locations," consequences of the proposed injection into the E aquifer are not predictable. Just as extraction of groundwater from a purge well changes the direction of groundwater flow (diverting it toward the well), injection of treated water into an aquifer will alter the direction of groundwater flow in the vicinity of the injection well. Reinjection within any part of an existing plume may therefore lead to a distortion of the plume that might have detrimental consequences (e.g., if it expands the plume and makes it harder to capture) or beneficial consequences (e.g., if it channels flow toward the extraction well). **Again, TOSC recommends the optimization of well positions and pumping rates, and evaluation of the influence of treated water reinjection on groundwater movement and E plume, using a comprehensive groundwater flow and contaminant transport model incorporating site-specific information and an appropriate degree of aquifer variability, before any reinjection into the aquifer system.**

The PLS proposal to adopt Alternative 6, "Groundwater Pumping – Active Remediation and Treatment Proximate to the Huron River," represents a calculated gamble equivalent to monitored natural attenuation through dispersion and diffusion without additional institutional controls. If it accepts such an approach, the payoff for the community comes in the form of a reduction in potential disturbances associated with the installation and operation of pipelines and extraction wells through neighborhoods situated above the leading edge of the plume. The payoff for PLS comes in the form of a higher regulatory threshold for 1,4-dioxane concentration (2,800 ppb at the Huron River vs. 85 ppb at the leading edge) and the potential to avoid remediation expenses or at least to delay major expenditures into the future, thus lowering the net present value of their costs.

In TOSC's view, adoption of this course of action will likely lead to discharge of 1,4-dioxane-contaminated water into the Huron River at an unknown location somewhere downstream of the City of Ann Arbor's water supply intake at Barton Pond.[5] **Nevertheless, significant gaps remain in subsurface data (test borings and monitoring wells[6]) east of the plume's leading edge, preventing the reliable prediction of the actual location of or the likely contaminant concentration at the ultimate discharge point(s).** Thus, potential downsides of Alternative 6 include the possible need to capture and treat contaminated groundwater at one or more developed locations along the Huron River and potential exposure to downstream receptors (e.g., Ann Arbor Township or University of Michigan central campus wells, or wells east of the Huron River should the plume migrate under the river[7]). Because of these important hydrogeologic uncertainties,

[5] Static water levels in wells near the current leading edge of the E plume are approximately 860 feet above mean sea level. The elevation of the Huron River surface is 799 feet at Barton Pond, 774 feet at the Argo impoundment, and 748-750 feet between Argo and Gallup Park (based on U.S.G.S. 7.5 minute topographic maps of Ann Arbor). Thus, hydraulic gradients, which provide the driving force for groundwater flow, are 1.5 to 2 times greater between the leading edge and the Huron River at downstream locations, suggesting that discharge of the E plume into Barton Pond is less likely than discharge farther downstream. Discharge to Barton Pond cannot be unequivocally ruled out, however, because of the potential for groundwater flow oblique to the direction of the steepest gradient caused by unrecognized anisotropy in the hydraulic conductivity field or as yet undiscovered preferential flow paths between the leading edge and Barton Pond.

[6] A well used to obtain water quality samples or measure groundwater levels.

[7] Although this possibility is unlikely, it cannot be ruled out on the basis of information provided in the FS.

TOSC does not concur that Alternative 6 is protective of the public health, safety, and welfare, and the environment.

TOSC Comments on FS Appendix B – Groundwater Flux Calculations

Appendix B of the FS provides a calculation of the volumetric flux[8] of groundwater contaminated with 1,4-dioxane at concentrations exceeding 85 ppb across control planes[9] located along Maple Road and farther east at the presumed leading edge of the E plume. These calculations form the basis for estimating water volumes necessary for capturing the contaminant plume using extraction wells, sizing treatment facilities, and designing pipeline capacities.

Appendix B calculations rely on simplified assumptions including uniform hydraulic conductivities, hydraulic gradients[10], and generalized aquifer cross sections based on widely spaced control points. As such, they provide an estimate of contaminated groundwater flux with a high degree of uncertainty. **TOSC believes that these flux estimates do not constitute an appropriate basis for remediation plan assessment or facilities design.** On the one hand, calculated flux values could be grossly underestimated. By design, steady state capture zones for pumping wells remove both contaminated water from the center of a plume as well as uncontaminated water along the plume margins. In most aquifer systems, additional water is extracted from down-gradient portions of an aquifer. On the other hand, calculated flux values could overestimate the extraction volumes needed to hydraulically capture the plume. For example, perceived changes in aquifer quality east of Maple Road (suggested by a marked change in the hydraulic gradient and supported by TW-15 pump test results) may comprise a partial hydraulic barrier that could contribute favorably to the creation of a capture zone using lower pumping rates for extraction wells positioned west of Maple Road. **Three-dimensional groundwater flow modeling, incorporating site-specific information and an appropriate degree of aquifer variability, is required to establish reliable estimates of groundwater pumping volumes necessary to capture the plume.** Until such modeling is completed, a large 'safety factor' should be applied to proposed pipeline and treatment system capacities to mitigate the risk of designing undersized facilities.

TOSC Comments on FS Appendix C – Contaminant Transport Modeling

Appendix C of the FS describes a two-dimensional contaminant transport model constructed to evaluate the fate of the Unit E plume as it migrates hydraulically downgradient, east of the present leading edge toward the Huron River. The model is based on a series of simplifying **assumptions that seriously impair its ability to provide a reliable basis for predicting transport of the E plume.** A listing of problematic assumptions along with *TOSC comments in italics* follows:

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[8] *Volumetric flux* refers to a volume of water per unit time crossing a defined area – essentially a flow rate. Because groundwater flows primarily in the horizontal direction, flux crossing an area defined within a vertical plane is of primary interest.

[9] *Control planes* are vertical surfaces across which the volumetric flux of groundwater can be calculated. In this instance, control planes are defined by geologic cross sections constructed using available monitoring wells and groundwater flux is limited to the cross-sectional area interpreted as aquifer (sand and gravel).

[10] The *hydraulic gradient* is calculated as the difference in static water levels measured at two points, divided by the distance between each point. Thus, the gradient is essentially a slope, with steeper slopes providing greater potential to drive groundwater flow given identical aquifer characteristics.

- Groundwater flow is horizontal – *Vertical hydraulic gradients and vertical migration of 1,4-dioxane are known to occur in the aquifer system.*
- Contaminant concentrations are the same throughout the entire aquifer thickness – *Simulprobe*[11] *sampling of monitoring wells has demonstrated that 1,4-dioxane concentrations can vary more than three orders of magnitude (1000 times or more) vertically in a single well. Use of the highest known concentration throughout the aquifer thickness may be inherently conservative; however, potential for even higher concentrations in preferred contaminant migration pathways that have not been sampled by existing monitoring wells is not addressed.*
- Aquifer hydraulic conductivity is assumed to be isotropic and homogeneous – *Complex spatial variability in aquifer (and aquitard*[12]*) properties are characteristic of the aquifer system, thus providing the potential for preferred contaminant pathways and barriers that could deflect groundwater flow and contaminant transport.*
- All pumping rates, line-sink fluxes…and recharge rates are constant through time – *The model is run in steady state and therefore cannot account for potential changes in pumping rates or boundary conditions over time.*
- All wells are assumed to fully penetrate the aquifer – *To date PLS has selectively screened extraction wells across targeted aquifer zones. It is unlikely that future extraction wells would be fully-screened, except in locations where the aquifer is less than 30 feet thick.*
- Particle traces and streamlines are two-dimensional – *The vertical component of contaminant migration has been neglected.*
- A constant hydraulic gradient (0.00946) was adopted on the basis of the average head gradient between the Maple Village and the Huron River as represented on the Flies & Vandenbrink 2002 potentiometric surface map (included in the FS Appendix A) – *In the area of concern, the head gradient as depicted by Flies & Vandenbrink is constrained only by two wells and the assumption that the Huron River is in direct communication with the aquifer system. In the absence of additional well control to constrain the hydraulic gradient, the use of a uniform average value is an understandable assumption. However, aquifer complexity suggests that a uniform slope (magnitude and direction) along the potentiometric surface is unlikely to persist for extended distances in this aquifer system. The uniform hydraulic gradient assumption, coupled with the uniform and homogeneous hydraulic conductivity assumption, essentially presupposes and controls the predicted contaminant pathway.*
- The longitudinal dispersivity (900 feet) was estimated using the 1/10th rule – *This value is exceedingly large and results in broadening of predicted contaminant breakthrough behavior, thus decreasing the predicted maximum contaminant concentration. Furthermore, the model predicts that detectible levels of 1,4-dioxane will arrive at the Huron River within one to two years. Use of an extraordinarily large longitudinal dispersivity value accelerates the predicted contaminant first arrival time.*

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[11] *Simulprobe* operations are conducted to obtain groundwater samples at different depths as a well is being drilled. After reaching the depth of interest, drilling is suspended while the simulprobe device is driven into the bottom of the well. Upward pressure is then exerted on the device to expose a screen through which a groundwater sample is drawn into a chamber in the tool. The device is then retrieved; the water sample is collected for laboratory analysis; and drilling is resumed.

[12] In contrast to an *aquifer*, where flow of groundwater is readily accommodated, flow of groundwater is impeded or retarded (but not completely eliminated) in an *aquitard.* Poorly-sorted, clay-rich sediments thought to be deposited directly by glaciers without reworking by flowing water commonly form aquitard units in glacial sediments.

For these reasons, TOSC regards the contaminant transport model included in Appendix B to be akin to a simplified 'back-of-the-envelope' calculation that cannot provide a reliable basis for assessing downgradient migration of the E Plume. In addition to the development of a more robust three-dimensional model, further efforts to better characterize the hydrogeology of the aquifer system east of the leading edge of the E plume (by installing more monitoring wells) are required before the direction, rate of migration, expansion, and/or dilution of plume can be reliably predicted.

TOSC Comments on MDEQ Proposed Remedial Alternative and Interim Responses

In general, TOSC supports the Remedial Alternative and Interim Responses proposed by the MDEQ as outlined in the July 7, 2004 Fact Sheet. Such an approach will maximize removal of 1,4-dioxane in the short term, accelerate the reduction of 1,4-dioxane concentrations over the long term, and contribute to a risk reduction for potential downgradient receptors. TOSC is concerned, however, that potential benefits of the proposed responses may be compromised by uncertainties in the current understanding of contaminant distribution and aquifer behavior arising from gaps in essential subsurface information and the lack of an appropriate groundwater flow and transport model. Nevertheless, TOSC recognizes the need to arrest further contaminant migration and therefore advocates a staged implementation of the MDEQ Remedial Alternative, concurrent with additional data collection, development of a comprehensive groundwater model, and implementation of interim responses. Specific TOSC recommendations are provided below.

TOSC Recommendations

TOSC recommendations are grouped within the areas of monitoring, modeling, and mass removal:

1. **<u>Monitoring</u>**. Significant gaps remain in the understanding of the distribution of aquifer units, groundwater flow pathways, and 1,4-dioxane distribution. Specific areas of concern include:
    a) Understanding the contaminant migration pathway between the PLS site and the Maple Village area. Are additional migration pathways undetected?
    b) Understanding the connection between the Evergreen Plume and the E Plume. Could a significant portion of the E Plume originate from an uncontained portion of the Evergreen Plume?
    c) Defining the hydrogeology between the leading edge of the E Plume and the Huron River. Where are the preferential flow pathways and barriers to flow? What is the orientation and magnitude of the hydraulic gradient that will drive flow? How much aquifer variability is present and what will its effect be on channeling or dispersing groundwater flow and 1,4-dioxane transport?
    d) Movement of groundwater in the glacial aquifer system once it reaches the Huron River. Does groundwater discharge into or underflow the Huron River? If the latter, does all of the groundwater flow along a course parallel to the Huron River or does some component of flow cross under the Huron River to flow eastward into Ann Arbor Township?

    To address questions involving the E Plume, TOSC recommends that additional monitoring wells be installed in four areas:

a) Between Maple Village and the PLS property
b) Between the current mapped position of the Evergreen and E Plumes

c) Between the leading edge of the E-Plume and the Huron River.
d) Immediately adjacent to the Huron River.

For (a) and (b), additional wells will provide data to evaluate the extent of contaminant movement between the Evergreen and E Plumes, and control points to constrain a three-dimensional aquifer model needed to evaluate remediation alternatives in the vicinity of Maple Road. Wells drilled in these locations will also provide a test of the current level of understanding of aquifer distribution and the validity of the current interpretations of 1,4-dioxane distribution along the inferred migration corridor between PLS and Maple Village. Aquifer unit thicknesses and 1,4-dioxane concentrations in newly drilled wells should be compared to existing maps as a means of assessing the reliability of current interpretations. Reasonable agreement with mapped distributions would support the argument that a suitable level of aquifer and plume characterization has been established. Conversely, unexpected results would suggest the need for additional wells.

For (c), wells drilled between the E Plume and the Huron River will provide the primary basis for establishing aquifer characteristics and hydraulic gradients in the projected pathway of the plume. Information from these wells will provide the basis for constructing and calibrating a groundwater flow model necessary to assess potential 1,4-dioxane migration pathways and concentrations downgradient of the present day E Plume leading edge. Regardless of the Remediation Alternative ultimately selected and implemented, monitoring wells in this position are also needed to establish that applicable cleanup standards are met and potential downstream drinking water wells are not threatened. TOSC recommends that monitoring well data be collected in an iterative fashion, initially on a widely-space (1000-2000 foot) grid with additional infill wells placed in the areas of greatest uncertainty or observed aquifer variability. Each well should be gamma logged[13] and at least one well should be continuously cored from surface to bedrock using rotosonic[14] drilling (see below). Wells should be screened across multiple intervals to allow for the definition of vertical head gradients and to facilitate the detection of 1,4-dioxane at different vertical horizons. At least one pair of closely-spaced wells (50 to 100 feet) should be drilled and gamma logged to assess short-scale horizontal variability in aquifer properties.

For (d), at least two sets of nested monitoring wells should be drilled along the west bank of the Huron River. Information from these wells can establish the degree of hydraulic connection between the river and the glacial aquifer and constrain the piezometric surface of confined or semi-confined aquifers beneath the river. Nested monitoring wells (screened across separate vertical intervals) are necessary to establish the vertical hydraulic gradient and to determine whether groundwater is likely to discharge into the Huron River or to be recharged by the Huron River. Static water levels should also be measured in existing water wells east of the

[13] Gamma logging of a well records the natural gamma radiation generated by sediments penetrated by the well. The gamma ray detection tool (similar to a Geiger counter) is lowered to the bottom of the well on a wireline. It is then pulled out of the well at a constant speed while the number of gamma ray counts per second is recorded. Plots of gamma ray counts as a function of depth thus provide a log of subsurface properties that can be used to infer hydraulic characteristics (sediments containing abundant clays yield high gamma ray counts and are inferred to be aquitards, while well-sorted quartz sands or gravels yield low gamma ray counts and are inferred to be aquifers) or correlate aquifer and aquitard units between wells.
[14] Rotosonic drilling combines downward pressure, pipe rotation, and high frequency vibration to drill through sediments while simultaneously producing a continuous sediment core.

Huron River to investigate whether hydraulic gradients will drive groundwater flow toward the Huron River or allow groundwater flow to pass under the Huron River.

In addition, TOSC recommends the following:

1. Gamma ray logging of PW-1 and PW-2 in the Montgomery Wellfield to facilitate their correlation with the aquifer system and incorporation into an E Plume groundwater model.
2. Gamma ray logging of the in situ chemical oxidation (ISCO) observation well grid located in the vicinity of MW-85 at Maple Village. Gamma ray logs of a grid of closely spaced wells will provide the opportunity to construct geostatistical variograms of lateral aquifer spatial variability while minimizing uncertainty arising from widely spaced control points. The data will also be useful in providing a measure of how much confidence to place in the ability of more widely spaced monitoring wells to detect plume movement.
3. Quality control of future gamma ray logs should be assured by re-logging a minimum of 100 feet of each hole to demonstrate repeatability in log measurements.
4. All future extraction wells should be gamma ray logged to facilitate their incorporation into aquifer cross sections and numerical groundwater models.
5. Use of rotosonic drilling and multiple petrophysical well logging techniques (e.g., natural gamma ray, induction resistivity, and sonic logs) as recommended by David Westjohn, the U.S. Geological Survey representative on the Technical Work Group advising the MDEQ on PLS remediation efforts. Rotosonic drilling will provide continuous sediment cores that can be described and correlated with log responses. Calibration of sediment properties with gamma ray logs will facilitate the use of existing logs from the extensive monitoring well network to develop geostatistical models (recommended below) of the three-dimensional distribution of aquifer properties. Rotosonic drilling is not required on all wells but would best be implemented for a minimum of three wells, ideally drilled to bedrock, in the areas of the PLS property, Maple Village, and the leading edge of the E Plume.

2. **Modeling**. Mathematical models of aquifer systems are commonly employed to support decision-making in the selection and optimization of remediation alternatives for contaminated aquifers. Such models attempt to capture the most important hydrogeologic features and incorporate relevant flow and transport phenomena. A wide variety of modeling software and tools has been developed to facilitate the modeling process. However, the inherent complexity of glacial aquifer systems poses significant challenges for geologists and engineers striving to characterize the subsurface and predict groundwater flow and dissolved contaminant transport through glacial sediments.

   In eastern Scio Township and western Ann Arbor, interpretation of the aquifer system has been further complicated by perturbation of the natural system through many years of installing and operating purge wells that have extracted groundwater at nonuniform rates and irregular operating intervals. Hence, groundwater tables and piezometric surfaces have been altered so that static water level measurements in monitoring wells can no longer be assumed to represent steady state conditions. Documented characteristics of the system, including significant vertical head gradients and contaminant migration through progressively deeper confined aquifer layers, indicate that individual aquifers are often separated by effective aquitards but are also connected locally so that groundwater extraction from one aquifer horizon may perceptibly influence other aquifer zones.

TOSC believes that the development of a comprehensive numerical flow and transport model is essential for the evaluation of the remedial actions and interim responses proposed by PLS and the MDEQ. Conventional deterministic models based on idealized aquifer geometries (e.g., layer cake stratigraphy) and other simplified assumptions can be used to effectively answer narrowly defined questions. They are not, however, a substitute for more detailed models built using site-specific information that are required to evaluate more complex system interactions. Although complex models are more difficult, time consuming, and expensive to build, they offer the potential to incorporate important details of aquifer features that can significantly affect or control system behavior. Without such a model, interim responses such as the Maple Road groundwater extraction and reinjection proposed by PLS or the leading edge remediation alternative proposed by the MDEQ will remain risky – implemented without the benefit of optimization or an analysis of the risks of unintended consequences (e.g., plume disruption, incomplete capture, etc.).

Specifically, TOSC recommends that a *stochastic* approach be adopted for modeling the glacial aquifer system. Use of additional deterministic models (i.e. layered models with one layer for each perceived aquifer or aquitard interval) should be avoided. A stochastic approach will rely upon geostatistical methods to generate multiple realizations of aquifer configurations that can be used to quantify the uncertainty in aquifer responses to remediation alternatives. Each of the realizations should honor the distribution of known aquifer properties at the position of monitoring wells and also honor the statistical description of spatial variability of aquifer properties (variograms). However, each realization will also include a random component to incorporate uncertainty derived from aquifer variability between control points.

The proposed modeling effort is likely to require many months to complete. TOSC recommends that the modeling effort be contracted to a nationally recognized environmental consulting firm specializing in groundwater flow and transport modeling (e.g., S.S. Papadopulos & Associates, GeoTrans, Inc., Waterloo Hydrogeologic, Inc.). The model could be built in an incremental fashion and refined over time. Initial emphasis should be placed on modeling the E Plume east of Wagner Road with later refinement of the model to incorporate the aquifer system west of Wagner Road.

General steps anticipated in the modeling process are:

1. Data gathering, QC, and coding.
2. Analysis of variance (ANOVA) to create semi-variogram models.
3. Geostatistical simulation of conditional aquifer models using classic or indicator methods. A hybrid approach is recommended, with indicator geostatistics used to model the distribution of aquifer and aquitard units followed by conventional Gaussian geostatistics to populate cells with appropriate aquifer property values. Simulation cell sizes should be on the order of 1-5 feet x 50-200 feet x 50-200 feet. All realizations should be conditioned to honor existing control points.
4. Population of a groundwater flow model (e.g., MODFLOW) with geostatistical values. The model should be pixel-based and have as many layers as the vertical distribution of

cells in the geostatistical simulations so that the geostatistical grid can be directly imported without upscaling or downscaling.

5. Incorporation of appropriate regional boundary conditions (Huron River, Groundwater Divides, and general head boundary conditions as necessary).
6. Grid refinement around pumping or monitoring wells, as needed.
7. Model calibration and sensitivity analysis.
8. History matching (e.g., comparison of model predictions with known contaminant migration pathways, drawdown responses to purge wells, etc.) if time permits.
9. Screening of models using simple advective transport code (e.g., particle tracking with MODPATH) to identify realizations exhibiting extreme transport behavior (e.g., realizations with the quickest or longest contaminant arrival times at a given observation point). Such end-member models are useful in demonstrating that proposed remediation activities can be effective under 'best case' and 'worst case' modeled conditions.
10. Monte Carlo analysis of multiple realizations to quantify uncertainty in key aquifer responses (e.g., the probability that a given configuration of extraction wells will fail to hydraulically capture the plume, the estimated contaminant transport times to reach the Huron River, the range of expected 1,4-dioxane concentrations at any specified observation point, the range in expected arrival points at Huron River, etc.) using an advective-dispersive transport modeling code (e.g., MT3D).

Finally, in concert with National Research Council recommendations on groundwater models[15], *the model must be available to the public* so that it can undergo public comment and review by those who may be affected by regulatory decisions stemming from the model's use.

3. **Mass Removal**. At present, significant uncertainties exist in the known distribution of aquifer units and 1,4-dioxane concentrations, in predicted future migration pathways of the E Plume, and in expected aquifer responses to proposed pumping and/or reinjection. TOSC's recommendations for *Monitoring* and *Modeling* are intended to help reduce some of that uncertainty; however, it is unacceptable to wait until the problem can be defined with greater confidence before taking action to halt the continued migration of 1,4-dioxane in the E plume. Based upon information that is available today, TOSC believes that concrete steps can be taken toward implementation of a comprehensive remedial action for the E plume. **These steps should be taken concurrently with the implementation of interim response measures, the acquisition of additional data, and the development of an appropriate groundwater flow and contaminant transport model.**

   In preparation for remediation actions at the leading edge of the E plume, several activities should be initiated. First, permitting and installation of the proposed pipeline intended to transport treated water from the Maple Village area to the Huron River downstream of Barton Pond should commence immediately. Required rights-of-way should be established with the appropriate city, county, and residential entities. Application for required discharge permits should also proceed without delay. Pipeline capacity and discharge volumes should be estimated conservatively so as to accommodate future expansion of cleanup efforts if necessary. Second, selection of a treatment technology (ultra violet light and hydrogen peroxide as currently employed at the PLS site or ozone + hydrogen peroxide if approved by the MDEQ) and installation of water treatment facilities at Maple Village should be completed. In the

[15] Ground Water Models: Scientific and Regulatory Applications, National Academy Press, 1990, p. 12

absence of a firm estimate of extraction well volumes, it is recommended that excess capacity be engineered into the treatment system – ideally in a modular fashion to provide redundancy in treatment operations and the ability to add capacity to treat additional volumes of purged groundwater should it become necessary.

Concurrent with the activities described above, TOSC recommends implementation of interim response measures. At the PLS site along Wagner Road, pumping from the E aquifer via existing wells TW-11, TW-12, and the recently installed TW-17 should continue while preparations for the installation of substitute extraction wells along Wagner Road are completed. Optimization of the number, location, and pumping volumes of new wells along Wagner Road should be based on sensitivities explored using the stochastic groundwater model recommended above. After installation of the new wells, pumping from existing E aquifer wells (with the possible exception of TW-12, which is located along Wagner Road) should be discontinued unless modeling results can demonstrate that their continued use is consistent with optimization of other Core Area extraction well operation. Operation of Wagner Road E unit extraction wells should continue until reduction in 1,4-dioxane concentrations below the applicable regulatory threshold can be demonstrated.

In addition to IR responses at Wagner Road, TOSC concurs with PLS's statement that "the value of the proposed interim response at Maple Village is that it can … reduce the threat to drinking water supplies and to the Huron River by reducing mass in the aquifer and accelerating the rate at which the aquifer will meet the target criteria." Interim response measures at Maple Village can commence once the initial treatment system is installed at Maple Village and groundwater modeling is completed to optimize the number, location, and pumping volumes of new wells required to capture the E Plume segment along Maple Road. If Maple Village treatment facilities are installed prior to completion of the Maple Village – Huron River discharge pipeline, TOSC concurs with the MDEQ suggestion that excess capacity in the City of Ann Arbor sewer system (sanitary or storm) be used for interim water disposal. Operation of Maple Road extraction wells should continue until reduction in 1,4-dioxane concentrations below the applicable regulatory threshold can be demonstrated.

TOSC recommends delaying the design and installation of leading edge extraction wells and pipelines until additional aquifer characterization (drilling of monitoring wells between the leading edge and Huron River) and construction of a detailed groundwater model are completed. TOSC concurs with the Weston Solutions conclusion that "the timing of the installation of extraction wells follow the completion of infrastructure rather than precede it." TOSC also maintains that optimization of the number, location, pumping volumes, and pipeline routes for extraction wells must be based on adequate subsurface characterization and defensible modeling results. Furthermore, TOSC believes that active community involvement will be required before neighborhood residents will agree to support leading edge remediation actions. At a minimum, this involvement should include meetings with neighborhood representatives to explore ways to incorporate community concerns into the optimization process. Participation of one or two citizen representatives on the Technical Work Group advising the MDEQ on PLS remediation efforts may also be appropriate. Knowledgeable community members must also have access to and the opportunity to review the groundwater model employed.

Finally, TOSC recommends that several nested monitoring wells be installed down-gradient of the Wagner Road, Maple Road, and Leading Edge extraction wells. These wells are needed to establish the effectiveness of implemented remedies (i.e., capture of the segmented plume at each downgradient location) and to provide an early indication of system failure so that modifications of pumping rates or other necessary adjustments can be made.

TOSC Recommendations (continued)

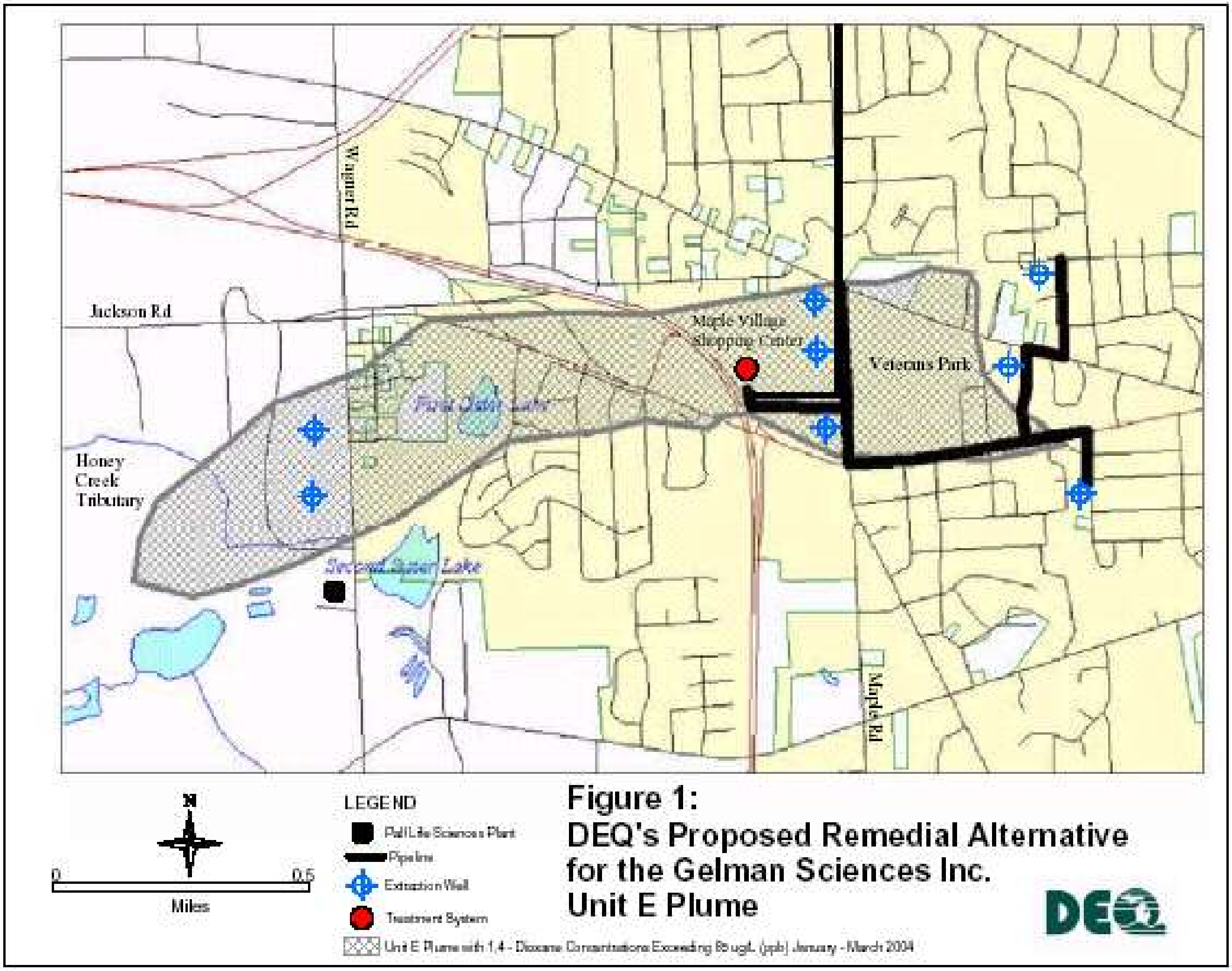

Figure 1: Conceptual diagram illustrating MDEQ's Proposed Remedial Alternative. Key components of the proposal include extraction wells along Wagner Road, Maple Road, and the leading edge of the E Plume; a treatment facility located in the vicinity of the Maple Village shopping center; and pipelines to transport extracted water to the treatment facility and treated water to the Huron River for discharge downstream of Barton Pond. Well and pipeline locations are conjectural and are shown solely to illustrate one potential distribution of remediation plan components. Map source: MDEQ Fact Sheet on Proposed Remedial Alternative (http://www.deq.state.mi.us/documents/deq-rrd-GS-FACTSHEET.pdf)