UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
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CHICAGO, IL 60604-3590

VIA ELECTRONIC MAIL

November 19, 2021

LU-16

Mr. John Mundell
Mundell & Associates, Inc.
110 South Downey Avenue,
Indianapolis, Indiana 46219-6406

Re: Geophysical Survey and Groundwater Plume Modeling Report Summary
Former Amphenol Facility - IND 044 587 848
980 Hurricane Road, Franklin, Indiana, 46131

Dear Mr. Mundell:

This letter conveys the U.S. Environmental Protection Agency's (EPA) position on the *Geophysical Survey and Groundwater Plume Modeling Report Summary,* dated May 19, 2021, (Report) prepared by Mundell and Associates, Inc. (Mundell). The EPA appreciates the efforts to improve upon the cleanup activities at the site, and the subsequent meetings to go over technical options. In our last meeting on July 26, 2021, there was a productive exchange of information. Based on a recommendation made by you at that meeting, the EPA has consulted with a modeler at another independent agency to review this report. Under an EPA funded inter-agency agreement with the United States Geological Survey (USGS), a USGS groundwater modelling expert assisted EPA in its review of the Report and provided technical comments. In summary, and through consultation with USGS, EPA believes the Report's implied model plume area is based on invalid aquifer and hydrogeologic assumptions and primarily based on unrealistic model parameters. Additionally, the Report does not provide sufficient evidence that the EPA's conceptual site model at the Site is inadequate. Because of this, EPA believes the Report does not provide sufficient evidence to alter the EPA's investigation at the Site and EPA does not anticipate any further action to go beyond EPA's mapped Amphenol plume area as a result of the Report itself.

Background

The EPA, Franklin Power Products Inc., and Amphenol Corp. (Amphenol) entered into a Resource Conservation and Recovery Act (RCRA) Section 3008(h) Administrative Order on Consent (AOC), U.S. EPA Docket No. R8H-5-99-002, on November 24, 1998 to address contamination at the former Amphenol Facility located at 980 Hurricane Road, Franklin Indiana (Site). EPA is ensuring Amphenol, a former operator and one of the Respondents to the AOC, remains in compliance with the AOC as it continues the cleanup process under EPA oversight and review.

If It Was Your Child (IIWYC), a group of residents who live or formerly lived in Franklin, contracted Mundell to develop the Report. The Report's groundwater model was not required or associated with

EPA's AOC for the Site. However, IIWYC released the Report to the public and sent it to EPA on June 1, 2021, and EPA subsequently reviewed the document.

On June 15, 2021, EPA posted an initial response to the Report on the EPA Amphenol web page and has since completed the more thorough review contained in this letter. On July 26, 2021, EPA had a technical meeting that included you, IIWYC and its consultant, Ms. Shannon Lisa, and EPA's contracted facilitator, Ms. Pam Avery, to discuss a series of detailed questions about the Report. The questions were provided to meeting participants in advance. During the call, we were only able to cover a small portion of the questions. At the conclusion of the meeting, Ms. Shannon Lisa stated that written responses to the remaining questions would be provided to EPA and, later in an email, she stated that IIWYC would provide written responses to all questions. To date, EPA has not received any written responses from Ms. Lisa, Mundell and Associates, Inc., or IIWYC.

As the cleanup process continues, EPA anticipates the Statement of Basis document, or proposed cleanup plan, for the Site will be released later in 2021 or early 2022. EPA will also host a virtual public meeting during the 45-day public comment period during which you are welcome to provide questions or comments on the proposed remedy. EPA will select a final remedy that will include a formal response to public comments received during the comment period. For more information, please visit: https://www.epa.gov/in/amphenolfranklin-power-products-franklin-ind.

General Comments

During the July 26, 2021 call, you clarified that the intention of the plume simulation was to produce a "worst-case" scenario. One of EPA's principal concerns with the Report is the single, worst-case simulated plume output map, which predicts high concentrations of TCE spreading into a residential area several thousand feet south of Hurricane Creek. Since groundwater on both sides of the creek flow towards the creek, groundwater in the unconsolidated aquifer would not cross a hydrologic no-flow boundary as defined by the creek. Also, when the Report discusses the *Status of Franklin Investigations,* Section 1.1, it. references Figure 1-B, "Known Groundwater Plumes." The only two plumes depicted on this Figure are the Amphenol Site and the Hougland Cannery Site about three quarters of a mile away; these plumes do not co-mingle and the purpose of introducing the Hougland Site plume is unclear.

Additionally, the key assumptions required for using the selected model (Domenico model) were not met. Under the Domenico model, the aquifer must be isotropic and homogenous with a steady state invariant flow field (have uniform subsurface horizontal and vertical properties such as 100% sand, and the groundwater flow must remain consistent and unchanged). In fact, the aquifer is heterogenous as acknowledged in the Report. Therefore, the model results are unlikely to represent a credible prediction.

The model was not calibrated or validated for the parameters chosen, which leaves the model parameters unconstrained. Calibration involves using analytical or measured data (much of which is available on the EPA website) to select the best values that will produce outcomes consistent to those data sets. Calibration helps to ensure that the parameters chosen are constrained and that the model will produce validated outputs that correspond to actual field conditions. Because the model parameters are unconstrained, the outcome of the model, in this case the plume footprint, could be considerably different with only small changes in the input values. A detailed discussion of EPA's assessment of the model parameters is included as an enclosure to this letter (source concentration, dispersivities, decay constant, source width and thickness, time, hydraulic conductivity, hydraulic gradient, effective porosity, bulk density, organic carbon partition coefficient, fraction of organic content, and calculated quantities).

All models have inherent uncertainty, and a sensitivity analysis is generally completed to reduce the uncertainty. When a model like the one described in the Report uses assumptions and input parameters that are not based on or calibrated by actual field data, the uncertainty associated with the output increases. To diminish inherent uncertainty, models generally include an array of output simulations based on a range of input parameters, as well as field verification. This Report does not include any of these analyses. Furthermore, the simulated plume is spreading in a direction that would be counter to the natural shallow groundwater flow direction in the unconsolidated aquifer on the south side of the creek. Please see the additional analysis regarding the model's sensitivity included in the enclosure to this letter.

Report Analysis and Comments

The stated purpose of the Report is to persuade EPA and to demonstrate to IIYWC that more data may be necessary to define the off-site plume. The Report suggested sampling locations and well installations between the Site and Hurricane Creek, and in the area south of Hurricane Creek where the plume simulation showed a worst-case possible extent. To support the Report's purpose, it discussed perceived deficiencies in the sampling distribution (both spatial and vertical distribution) and an inadequate spatial definition of the aquifer(s) at the Site. To demonstrate the need for additional sampling, the Report presented the results of a geophysical survey along Hurricane Creek to provide evidence that the aquifer, as defined by the EPA in the study area, was not adequately described. Additionally, the Report presents a hypothetical plume extent, a result of an exploratory modeling study that presumably provided an alternative spatial distribution of the primary constituent of concern, TCE. This simulated plume extent is provided as Figure 4 in Appendix B, Figure C-1 of Appendix C, and is on the cover page of the Report. The details of EPA's position on these aspects of the Report are described in the paragraphs below and in the enclosure to this letter.

<u>Geophysical Survey</u>

The limitations discussion of the geophysical survey section of the Report (Appendix B) states that the results of the survey are only one realization of a group of stratigraphic possibilities that could give a similar resistivity distribution. Additionally, the location of the geophysical survey transects are located along Hurricane Creek in glacial sediments mapped to be within the bounds of the White River and Tributaries Outwash Aquifer System (and subsystem). The glacial materials that make up these systems are dominated by glacial outwash and alluvial processes that filled the river valleys as glaciers retreated and are characterized by thick sequences of sand and gravel with occasional stringers of silt, clayey sand, and clayey gravel. The presence of a clay cap in some areas helps to limit the susceptibility of the aquifer to surface contamination. No clay cap was noted in the geophysical survey cross sections, so the clay cap is likely not present to any great extent.

These sediments along the creek differ from the New Castle Till Aquifer System, which underlies the Site and the EPA-mapped contaminant plume. The New Castle Till Aquifer System is characterized by outwash sands that are 10 to 15 feet thick, generally overlain by clay. There would be no expectation that the geophysical survey of the White River and Tributaries Outwash Aquifer System located along Hurricane Creek would be representative of the New Castle Till Aquifer System located at the Site and the area of the EPA mapped plume. The results of the geophysical survey documented in the Report, done in a different depositional environment that results in many possible stratigraphic interpretations, does not provide sufficient reason to question the Site conceptual model describing the distribution of the sediments that have been interpreted using boring logs.

<u>Contaminant Plume Model</u>

The Report's contaminant plume model relies on some key assumptions. The Report assumes:

1) Transport of groundwater occurs in an isotropic aquifer (meaning the aquifer properties are the same in all directions)
2) An aquifer with homogeneous properties (meaning the sediments are uniform throughout), and
3) The groundwater flow field is unidirectional and at steady state.

However, EPA has documented through on-site borings that the aquifer is not isotropic or homogeneous, but predominantly heterogenous being composed of multiple sediments (clay, sand, gravel) in layers and pockets. The Report itself demonstrates that the aquifer in the area of the geophysical survey area is not uniform and would not meet the definition for an isotropic homogeneous aquifer. The groundwater flow field likely varies in direction over time (perhaps associated with recharge events and height of water in Hurricane Creek), and is not in a steady state condition. This is apparent when comparing multiple synoptically measured potentiometric surfaces over time and maps of the groundwater surface over different seasons and years which showed varied amounts of groundwater flow. Ultimately, the primary assumptions of the transport model are not met, therefore the results from the model are unlikely to represent a credible prediction for a site that deviates substantially from the key assumptions. Additionally, modeling this area as an isotropic homogeneous aquifer would tend to exaggerate the model results relative to actual conditions.

Model results were shown to cross Hurricane Creek and progress thousands of feet beyond the creek in a direction that would be counter to the natural shallow groundwater flow direction in the unconsolidated aquifer on the south side of the creek. Two general conditions have to be met to allow groundwater to move across a hydrologic no-flow boundary defined by the location of the creek:

1) The flow has to be confined such that flow in the aquifer is physically separated from flow in the creek.
2) A groundwater discharge zone that is capable of receiving the groundwater discharge on the south side of the creek has to exist.

The geophysical survey demonstrates that the aquifer at the creek is not confined and there is no impediment for flow in the aquifer to discharge to the creek. Also, a discharge zone on the south side of the creek in the direction of flow depicted on the Report's plume extent map (Figure C-1) does not exist. The natural shallow groundwater flow in the unconsolidated aquifer on the south side of the creek would be to the north, toward the creek. Therefore, it is very unlikely that the groundwater plume depicted on Figures 4 and C-1 would cross the creek as shown.

Moreover, since the contaminant plume model was not calibrated (as the software manual advises), the parameters that the model is highly and moderately sensitive to (including dispersivity, source concentration, TCE decay constant, hydraulic conductivity, source width, time, and hydraulic gradient) are unconstrained in the model. Small variation in the above parameters could cause large changes in the model outcome.

Finally, the contaminant transport was modeled as three separate models that were combined to create a final composite result. The Report states that the model results were summed where the models overlapped. However, chemical constituents in solution interact with each other by mixing. Assuming no other chemical reactions are taking place that would affect the final solution concentration, the final concentration of two interacting plumes would be an average of two or more values where the modeled plumes overlap (not the sum).

Parameter Values Used in the Transport Modeling Study

EPA examined the parameter assumptions used in the model (see letter enclosure) and considered them against what would be realistic or site-specific, in contrast with the Report's objective to produce a worst-case outcome in the simulation of the potential contaminant plume distribution. Each model input parameter was examined to see if it represented a realistic assumption and value in the domain of possible assumptions. Throughout the Report, the author(s) uses the phrase that the model is using "conservative" values of the input parameters and that the results are conservatively predicting the outcome of the contaminant plume. During the July 26, 2021 technical meeting, it was clarified that by "conservative," the Report meant parameters that would result in a *worst-case* outcome. In the enclosure, these input parameters are discussed.

The model software that was employed for the model simulation in the Report requires a separate model to be constructed independently at each source area location. As stated in the Report, the model output for the three independent models was combined to produce a composite modeling result for the three source areas. The key assumptions (isotropic homogeneous aquifer with a steady state invariant flow field) required for the model were not met, so the model results are less likely to represent a credible prediction. Because the model parameters are unconstrained, as detailed below, the outcome of the model could deviate considerably from what was reported with only small changes in the model parameters. Please see the enclosed review of individual parameters used in the model and a discussion of their sensitivity on the model outcome.

While EPA appreciates this submittal, we have many concerns with the Report that are detailed in this letter. The Report does not provide sufficient evidence to alter the EPA's investigation at the Site because the Report's implied model plume area is based on invalid aquifer and hydrogeologic assumptions and primarily based on unrealistic model parameters. Additionally, the Report does not provide sufficient evidence that the EPA's interpretation of the Site plume is inadequate. Because of this, EPA does not anticipate any further action to go beyond EPA's mapped Amphenol plume area as a result of the Report. The limits of the plume have been defined and will be re-defined following remedy implementation using performance monitoring data. EPA is working under the AOC issued to Amphenol Corp to arrive at a proposed remedy and all stakeholders will be invited to comment on the *Statement of Basis* document when it is posted for public comment.

For any questions regarding this letter, please contact me at (312) 886-1451 or at black.christopher@epa.gov.

Sincerely,

11/19/2021

X Christopher Black

Christopher Black
RCRA Corrective Action Project Manager
Signed by: CHRISTOPHER BLACK

Christopher Black
Project Manager
Land and Chemicals Division
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Corrective Action Section 2

Enclosure

Ecc: Shannon Lisa, IIWYC
Stacie Davidson, IIWYC
Kari Reinhart, IIWYC
Gillian Asque, EPA-ORC
Kevin Davis, IDEM

Enclosure: Domenico Model Parameter Analysis and Sensitivity Discussion

The model input parameters discussed below are also described in the software manual for the Domenico spreadsheet model used in the Report, in the link below: http://files.dep.state.pa.us/EnvironmentalCleanupBrownfields/LandRecyclingProgram/LandRecyclingProgramPortalFiles/GuidanceTechTools/QD_manual_v3b%2002-28-2014.pdf.

3.1. Source Concentration

Symbol: C_0	Units: mg/L	Sensitivity: High

1. The Report states: "Given TCE has a solubility of about 1000 mg/L, if we assume the source area concentration is 1/100 to 1/10 of the solubility, the source concentration, Co, ranges between 5,000 to 50,000 ug/L."

   If one divides 1,000 mg/L by 100 and 10 as the Report implies, the resultant concentrations would be 10 and 100 mg/L which would convert to 10,000 and 100,000 ug/L not 5,000 to 50,000 ug/L. The Report should verify the method of calculating the estimated source area concentrations.

   The Report states the concentration at the three separate source areas are estimated at 5,000 ug/ml. Additional justification should be presented that the selection of the source area concentration represents a reasonable estimate at the Site and justification should relate that estimate to the values obtained by sampling near the source areas. The model is highly sensitive to the initial concentration at the source. Without further explanation in the Report, the value of source area concentrations does not seem to be realistic when looking at the sampled concentrations near the source areas defined in the study nor does the assumption that all three would be the same value.

3.2. Dispersivities

Symbol: α	Units: ft	Sensitivity: High

2. The Report states the longitudinal, transverse, and vertical hydrodynamic dispersivity values as 30 ft, 3 ft, 0.3 ft, respectively. The justification of these values is not provided.

   The model manual states that the model is highly sensitive to these dispersivity values (particularly the longitudinal value) and that the values are usually initially estimated based on the distance between the source and the receptor (a downgradient well with a known concentration value). The values are then varied (along with other parameters) by up to an order of magnitude in an attempt to match the concentration at the receptor. Because no receptor wells were used as a guide to refine (calibrate) the dispersivity values (as well as other highly sensitive parameters), these values are unconstrained and there is little chance that they represent the 'true' dispersivity values at the Site. Because the dispersivity values are unconstrained, it is unknown if they represent realistic values appropriate for modeling contaminant transport in this area.

3.3. Decay Constant

Symbol: λ	Units: day^{-1}	Sensitivity: High

3. The Report states TCE half-life was assumed and simulated as 10,000 years. The model is highly sensitive to the decay constant. Additional justification should be made as to why the value used in the model should be considered reasonable and realistic. Published values state the abiotic

degradation half-life of TCE to be as much as 108 years.[1] The decay constant used in the model is orders of magnitude greater than what is published in the literature and thus does not represent a realistic value. Additionally, the Domenico-Robbins 1985 Model is unable to approximate the degradation of chlorinated volatile organic compounds (VOC's) into their daughter products. BIOCHLOR is a similar program in that it uses the same analytical solute transport model but would be able to approximate the first-order degradation products (i.e., TCE degradation to cis-1,2, DCE).

Abiotic degradation of chloroethenes occurs slowly under conditions commonly found in aquifers (Vogel, 1994).[2] Although considerable variability exists, reported half-lives for abiotic degradation of TCE and DCE are as long as 108 years (Jeffers and others, 1989).[3] Abiotic degradation half-lives for TCE can be as short as minutes or a few days in systems amended with an abundance of zero-valent iron (Gillham and O'Hannesin, 1994)[4], but abundant zero-valent iron is uncommon in natural settings." - U.S. GEOLOGICAL SURVEY; Scientific Investigations Report 2006-5056.

3.4. Source Width

Symbol: *Y*	Units: ft	Sensitivity: Medium

and

3.5. Source Thickness

Symbol: *Z*	Units: ft	Sensitivity: Low

4. The Report states the source width and height are 10 x10 ft. Additional information should be included to justify that the shape and size of this assumption is reasonable and applies equally to all three source areas in the model. No justification was given to explain the source width and height used in the model so without further explanation these parameters are speculative and don't necessarily represent a realistic value.

   Essentially, the source width and thickness in the model is a plane of constant concentration that the groundwater passes through, and its size can influence the height, width, and depth of the modeled plume. The source thickness is more important when looking at the vertical dispersion of the modeled plume and has less of an effect on the horizontal centerline concentrations of the modeled plume.

[1] The quoted excerpt is from page 12 of: Dinicola, R.S., 2006, Continued biodegradation of chloroethene compounds in ground water at Operable Unit 1, Naval Undersea Warfare Center, Division Keyport, Washington: U.S. Geological Survey Scientific Investigations Report 2006-5056, 42 p.
[2] Vogel, T.M., 1994, Natural bioremediation of chlorinated solvents: in Norris, R.D., and others, Handbook of Bioremediation: Boca Raton, Lewis Publishers, p. 201-225.
[3] Jeffers, P.M., Ward, L.M., Woytowitch, L.M., and Wolfe, N.L., 1989, Homogeneous hydrolysis rate constants for selected chlorinated methanes, ethanes, ethenes, and propanes: Environmental Science and Technology, v. 23, no. 8, p. 965-969.
[4] Gillham, R.W., and O'Hannesin, S.F., 1994, Enhanced degradation of halogenated aliphatics by zero-valent iron: Ground Water, v. 32, no. 6, p. 959-967.

3.6. Time

Symbol: *t*	Units: days	Sensitivity: Medium

5. The Report states the model period = 55 years, representing the period 1963-2018. This duration appears to be a worst-case selection and does not take into account the expected date of operational failure of the sewer system.

   The beginning of the model period seems to be based, in part, on a realistic assumption since the Site began operation in 1963. The introduction of the COCs at the Site probably could realistically be assumed to have begun when the Site began operation. Introduction of the COCs to the sewer system could have begun then as well. Sewer systems have finite operational life spans just like any other infrastructure system, and this span is likely related to the construction methods and materials used. However, we do not know if the sewer system was leaking in 1963 or when in its operational life span it began leaking. To better define a realistic period when the leaks may have begun in the sewer system, we would need to know what the expected useful life of the sewer system was and when it was built. For example, if the sewer system was installed in the early 60's and the useful life was 20 years (all made up numbers) one could realistically assume that the leaking would not have started until the early 80's when it exceeded its operational life span. Therefore, a more realistic assumption for the period of modeling for the two simulations originating in the sewer system would be the expected date of operational failure of the sewer system.

   Conceivably, after the leaking began in the sewer system, some COCs could accumulate in the sediment surrounding the leaking areas of the sewer pipe and could effectively provide a source of contamination to the groundwater system even after the Site ceased operation in 1983. Additionally, COCs in the sediments at the Site would likely remain a source of contamination to the groundwater system. These potential source areas would remain a concern to groundwater contamination until remediated (by source removal, groundwater containment, or both).

   A pump-and-treat system at the Site has been in place since 1995. This system provides containment for the groundwater that would have interacted with the COCs at the Site. A more realistic period of modeling for the COCs at the Site (northern source area) would likely be from 1963-1995 (approximately 32 years).

   A more realistic period of modeling for the COCs at the leaking sewer system would be from the time of operational failure to the removal of the source materials associated with the sediments surrounding the leaking sewer line; 2018 is a realistic end time for the modeling period.

3.7. Hydraulic Conductivity

Symbol: *K*	Units: ft/day	Sensitivity: High

6. The Report states a "conservative" (worst-case) value of hydraulic conductivity was used but does not state what source was used to obtain the range of values mentioned in the Report. Additional justification for the hydraulic conductivity range stated in the Report should be provided. While the range of 20-100 feet/day is likely within the range of hydraulic conductivity values one might expect for various grain sizes of unconsolidated material that might be present at the Site, the Report does not state what value applies to this grain size. Choosing a value from the lower end of the range is probably the most realistic value of the range presented, however, it is unclear from the text if the range represents hydraulic conductivity values that exist at the Site.

Because the aquifer materials are nonhomogeneous, the hydraulic properties are anisotropic and the groundwater flow is most likely dominantly controlled by interconnected zones of preferential flow, modeling contaminant transport using a single value of hydraulic conductivity to represent the system oversimplifies the natural complexity of the aquifers in this area, which could lead to substantial inaccuracies in the outcome of the model.

Hydraulic conductivity was measured at some locations during a survey using a combined Membrane Interface Probe (MIP) and Hydraulic Profiling Tool (HPT) at 28 locations south of the Site along the old sewer line.

Values ranged from too low to measure to at least over 50 ft/day with some measurements of over 75 ft/day at the sampling points. However, the values described here included all the units encountered while estimating K. It is likely that the very low values are in the confining units.

3.8. Hydraulic Gradient

Symbol: i	**Units:** ft/ft	**Sensitivity:** Medium

7. The Report states the hydraulic gradient to be 0.01 ft/ft and suggests this value is the same as the topographic gradient in the area. It is unclear if the Report is using the topographic gradient to estimate the hydraulic gradient. In an unconfined aquifer, the groundwater table generally follows topography, but the gradient doesn't necessarily mimic the topographic gradient. If the Report is using the topographic gradient as a proxy for the hydraulic gradient, justification should be provided why the gradient of the groundwater system is equivalent to the topographic gradient in the area. After review of some water-level data and potentiometric surfaces prepared for the Site, the value of 0.01 ft/ft appears to be too large by a factor of about 2.

   Because the model is moderately sensitive to the hydraulic gradient (it is used in the calculation of groundwater velocity) changes in the value can have moderate effects on the length and shape of the simulated plume.

   A more realistic hydraulic gradient could be computed from an average of at least one pair of wells (representing the predominant groundwater flow direction) measured multiple times in various seasons.

3.9. Effective Porosity

Symbol: n_e	**Units:** —	**Sensitivity:** Low

8. The Report states the effective porosity used in the model is 30%. No justification was given for this value. The value does fall into the range of porosity that is expected for the sediments that are found at the Site. It is unknown if the porosity stated in the model is realistic. For a homogeneous sand aquifer, a value of 30% would probably be a good estimate. However, the aquifer is not homogeneous, and the value likely overestimates the effective porosity.

3.10. Bulk Density

Symbol: ρ_b	**Units:** g/cm^3	**Sensitivity:** Low

9. The Report states the bulk density is 1.65 grams per cubic centimeter. There was no justification presented in the report for this value. The value of bulk density is within the range of values for the unconsolidated sediment at the Site.

3.11. Organic Carbon Partition Coefficient

Symbol:	K_{oc}	Units:	L/kg	Sensitivity:	Low

10. The Report states organic carbon partition coefficient is 2.42 L/kg which is consistent with the value for TCE given in https://www.epa.gov/sites/default/files/2015-06/documents/tce.pdf

3.12. Fraction of Organic Carbon

Symbol:	f_{oc}	Units:	—	Sensitivity:	Low

11. The Report states that the modeled value of the organic carbon content of the aquifer was 2%. The value was not justified in the Report. The fraction of organic carbon in the aquifer does affect the calculated retardation factor used in the model, though its effect on the overall shape of the plume is low.

3.16. Calculated Quantities

12. Several quantities are calculated in the model and depend on some of the other chosen model parameters. They include the groundwater velocity and the retardation factor. The groundwater velocity depends on the hydraulic conductivity, hydraulic gradient, and the effective porosity of the aquifer material. The retardation factor depends on the organic carbon partition coefficient, the fraction of organic carbon in the aquifer, the bulk density of the aquifer, and the effective porosity of the aquifer.

    The calculated quantities are dependent on several highly or moderately sensitive model parameters and small changes in these parameters could have an effect on the overall size and shape of the modeled plume outcome. Because the model parameters are unconstrained, the resultant calculated quantities are also unconstrained.