United States Environmental Protection Agency

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Response to Peer Review Comments on IWEM 3.0

Final

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Office of Resource Conservation and Recovery
Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency

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1.0 Introduction

The U.S. Environmental Protection Agency (EPA) created the Industrial Waste Management Evaluation Model (IWEM; U.S. EPA, 2002a) as part of the *Guide for Industrial Waste Management* (U.S. EPA, 2002b). This model conducts screening analyses to determine the most appropriate liner design for several types of waste management units (WMUs) that minimize or avoid adverse ground water impacts. IWEM uses a probabilistic (Monte Carlo) approach together with a ground water fate and transport model (EPA's Composite Model for Leachate Migration with Transformation Products [EPACMTP], U.S. EPA, 2003a, b) to model releases from a WMU source into the underlying unsaturated zone, subsequent subsurface transport, and expected ground water concentrations at a downgradient receptor well. IWEM then compares the estimated 90th percentile ground water concentrations to reference ground water concentrations (i.e., constituent- and pathway-specific human health benchmarks) to recommend the minimum liner scenario that is protective for all constituents.

IWEM 2.0 (U.S. EPA, 2010) was created in response to a growing interest in ways to repurpose manufacturing and power generation residuals. This version added a module that simulates an additional source, roadways constructed with beneficially used industrial materials. After an independent external peer review in 2008, IWEM 2.0 was finalized in 2009 to help identify the potential environmental impacts from these beneficial uses.

IWEM 3.0 was developed in response to suggestions made by peer reviewers on IWEM 2.0, to broaden the applicability of the model and to enhance its usability. This version introduced a more rigorous treatment of leaching through the roadway cross section and included ditches, drainage, embankment and surface runoff as optional elements. The beta version of IWEM 3.0 and its documentation, the *IWEM Technical Background Document* (U.S. EPA, 2015a) and the *IWEM User's Guide* (U.S. EPA, 2015b), were submitted for peer review in June 2014. This document summarizes and responds to the peer review comments (U.S. EPA, 2014).

Since the peer review, EPA has developed a newer version of the model, IWEM 3.1, which addresses peer review comments, and contains a new source module that addresses structural fills. The approaches and methodology used for the new source term module are based on the approaches used in the existing landfill source module, which were peer-reviewed as part of IWEM 1.0. The modification made for the structural fills did not depart significantly from the original approaches. Therefore, the EPA determined that another peer review was not necessary for the addition of the structural fill module. References to "IWEM" without a version number in this response to comments document refer to the latest version, IWEM 3.1.

1.1 Reviewers

IWEM 3.0 was reviewed by the following peer reviewers:

- Dr. Mustafa M. Aral, Professor, School of Civil and Environmental Engineering, Georgia Institute of Technology;
- Dr. Charles Harvey, Professor, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology;
- Dr. Lin Li, Associate Professor, Department of Civil and Environmental Engineering, Jackson State University; and
- Dr. Frank W. Schwartz, Professor and Ohio Eminent Scholar, School of Earth Sciences, the Ohio State University.

1.2 Charge Questions

Specifically, EPA asked the reviewers to address the following charge questions:

1. **New Roadway Features.** Comment on whether the new features (e.g., drainage system, gutter, ditch and embankment) added to the roadway module reasonably represent a typical roadway. Are the assumptions and parameters used to represent these components in the model appropriate and adequate? Is there anything significant overlooked in the general road configuration?
2. **Flow Equations.** Are the conceptualizations and derivations of flow equations for surface runoff, discharge from drainage and flow in ditches appropriate and adequate? Are they represented properly in the model? Please also comment on the appropriateness of rates developed for runoff, evaporation, and infiltration using the Hydrologic Evaluation of Landfill Performance (HELP) model. Is the calculation of these rates for the six representative regions on the United States adequate?
3. **Contaminant Flux**. Given that the incorporation of drainage system, runoff, and evaporation can alter the contaminant flux, please provide your comments on the appropriateness of the equations used to calculate the contaminant flux (mass flux, pulse duration, leachate concentration) from a roadway source. Are the results derived from the use of this model reasonably reliable?
4. **Model Simplicity**. With additions made to model, has the EPA appropriately kept the balance between keeping the model simple and easy to use as compared to making it technically more sophisticated?
5. **Documentation.** Does the documentation reasonably explain the assumptions/rationale behind the modeling approach and the conceptualization of the roadway parts? Overall, is it complete and understandable to the reader? Are there any significant omissions that need to be addressed?

The full text of the charge document, which includes background, a general charge, a list of the materials provided for review, and the above charge questions, is included as **Attachment 1.**

1.3 Summary of Conclusions

The reviewers generally provided useful inputs. The two major recurring technical comments were related to: (1) the complexity of the roadway source modeling compared to the simplicity of the WMU source modeling, and the added value of that level of complexity for the roadway source term, given the much more simplified subsurface fate and transport model to which it provides inputs; and (2) the age and accuracy of the underlying databases. Most of the other comments received either reflect a misunderstanding of IWEM or address aspects of the model that are outside the scope of this review. The reviewers generally praised the documentation, but offered a number of specific recommendations for enhancing the clarity of the documentation. Their overall conclusions are summarized in **Table 1**, while the full text of their comments is attached as **Attachment 2**.

1.4 Organization of This Document

Peer reviewers raised the same issues under multiple charge questions. Therefore, this response to comments document is not organized by charge question, but by issue, as follows:

- **Section 2:** Comments on the Roadway Source Module
- **Section 3:** Comments on Ground water Transport
- **Section 4:** Comments on Inputs
- **Section 5:** Comments on Output Metrics
- **Section 6:** Comments on the General Fitness of Software

- **Section 7:** Comments on the Documentation
- **Section 8:** Miscellaneous Comments
- **Attachment 1:** Charge to Peer Reviewers
- **Attachment 2:** Full Text of the Letter Reviews.

The comments are summarized by topic within the above categories, followed by a response.

Table 1. Summary of Peer Review Comments

Question	Dr. Aral	Dr. Harvey	Dr. Li	Dr. Schwartz
General	In general the reference documents are well organized and well written. However, in their current state they are not error free for these documents and the software to be released in public domain.	IWEM appears to be an excellent tool for making simple but useful approximations of the risks of ground water contamination. The code synthesizes a remarkably wide range of databases and predictive models. The authors have reached a good balance of accuracy and efficiency across the different parts.	The new version brings IWEM closer to realistic roadway conditions. However, there are concerns about the add-on functions related to the pavement material property, leaching pattern, ditches and surface runoff. Also, the IWEM interface and icons are too old.	Overall, the design of the code is in keeping the vision of an easy to use package, which is appropriate for the target audience. There are no obvious problems in downloading and running the code. More thought should be given to more descriptive metrics of risk.
New Model Features	The new roadway source model features are a good and very detailed characterization of a typical roadway, with appropriate assumptions and parameters.	The new features of IWEM appear to represent roadways adequately. One aspect that is missing is the case where water from a roadside ditch accumulates in a topographic depression.	Reviewer had a number of very specific comments on various features of the roadway module.	The modular design of the roadway configuration is sufficiently general that it will be able to create common types of roadways that will be encountered in practice. However, it depends on several hard-to-estimate parameters.
Flow Equations	The assumptions and limitations are all standard for screening analysis. The equations used to calculate the steady state Darcy flow velocities or the pore velocities are appropriate, and the adjustment of the Darcy velocities in the saturated flow domain for potential mounding under the WMU is reasonable.	The conceptualization of flow in ditches is nicely formulated, but the explanation can be improved by the use of diagrams and figures. The use of the HELP model, which has been reviewed and described elsewhere, is smart, but additional explanations of the fundamental aspects of HELP would improve the IWEM documents.	Incorporate newer references and international climate data.	IWEM depends on generic databases to provide parameter estimates, which is a weakness because the approaches are dated and without appropriate verification of the data.
Contaminant Flux	Accounting for the drainage, runoff, and evaporation rates is done correctly. The transport equations are incorrect. [In fact, they are correctly implemented but incompletely documented; see Sec 3.3.]	The contaminant flux through the roadway layers is probably a reasonable model, but needs to be better explained.	Either provide detailed documentation for the current pulse source assumption, or adopt a “first flush” and “lagged response” leaching pattern instead.	The approach is generally straightforward and well described with the exception of the “pulse” analogy.
Model Simplicity	The level of detail of the roadway module is inconsistent with the simplicity of the WMU source and unsaturated/ saturated zone model.	Not sure the roadway source module needs to be 3-D.	The model is very complex, with many additional input parameters. Some of the parameters should be merged or removed. Some of the terms are unfamiliar even to experienced ground water flow/transport modeler.	The level of complexity for even simple “roadway” cases is out of proportion to the other flow/transport process modules, e.g., saturated and unsaturated flow.
Documentation	The documentation covers and explains the general assumptions/ rationale behind the modeling approach and the conceptualization of the roadway parts. However, the documentation contains some errors that should be addressed before releasing the software and its documentation in the public domain.	In general, better figures and diagrams would help.	The technical manual and some parts of technical appendix should be combined, because all of equations are shown in appendix. The equations are a key part to understand the technical part.	The documentation is well organized, reasonably well documented, and does an excellent job in facilitating the use of the code. However, the literature cited for the theoretical basis of the approach is thin, mostly of EPA reports and grey literature, rather than primary journal articles.

2.0 Roadway Source Module

2.1 Complexity of Roadway Module

Comment Summary: All four reviewers noted that the complexity of the roadway source module is inconsistent with the simpler WMU source term modules in IWEM, and Drs. Aral and Schwartz questioned the value of that level of complexity given the more simplified approach used to model the unsaturated zone. Drs. Harvey, Li, and Schwartz commented that the complexity of the roadway module is unnecessary, and Dr. Li felt that many of the terms describing the inputs would be unfamiliar to even experienced ground water modelers. Dr. Aral felt that the uncertainty and errors introduced by simplifying the unsaturated and saturated zones are more important than the accuracy gained by the multi-layered roadways source term.

EPA Response: EPA acknowledges the disparity in the level of complexity between the WMU source term modules and the roadway source module and between the roadway source module and the approach used for the unsaturated zone modeling. However, the properties of materials within the complex structure of a roadway are (or should be) known *a priori* as part of a design incorporating beneficially reused materials that are relatively homogeneous within a particular roadway component. The materials in a WMU such as a landfill are more heterogeneous and the properties of those materials are not known by design, nor is it easy to ascertain them. Similarly, the properties of the unsaturated zone are more heterogeneous and more difficult to ascertain. In addition, the added features to roadway module are optional, and the modeler may still consider a simplified roadway design (with monolith layers) to help reduce the level of complexity and additional data requirements. Many of the new features added to IWEM 3.0 were in direct response to peer review comments received on IWEM 2.0 (U.S. EPA, 2009).

2.2 Roadway Module Formulation

2.2.1 Representation of the Ditch

Comment Summary: Dr. Harvey noted, with regard to the representation of the ditch in the roadway module, that the problem is nicely formulated but better explanation is needed. The review raised the following issues:

1. IWEM does not account for water from a roadside ditch accumulating in a topographically depressed area and the potential for contaminants concentrating in that area, subsequently impacting local streams and ground water resources.
2. If there is no net inflow or outflow from a ditch, then the approach is only applicable to the segment that actively receives runoff. Equations C-38a through C-38c in Appendix C appear to allow for different values of Q_{in} and Q_{out}, but it is not clear how the Manning equation is applied when Q_{in} does not equal Q_{out}.
3. The assumption that the depth of the water in the ditch (H_{Str}) is constant over time is an acceptable approximation, but this assumption should be highlighted because the model could be quite inaccurate in places where rain falls in shorter, more intense storms, rather than a constant drizzle.

EPA Response:

1. The model formulation allows the water in the ditch to either move or remain stagnant. Stagnant water can be simulated by setting the slope of the ditch to zero. The chemical concentration in

areas with stagnant water is determined from the mass conservation principle expressed in Equations C-21 through C-23.

2. The approach is based on a steady-state assumption for each segment that $Q_{in} \cong Q_{out}$ as the variation of flow is expected to be small. The Manning equation is applicable when the flow is steady and uniform. Both the velocity and flow rate in the ditch are derived based on an assumption that the flow in each segment represents average flow within the segment. Continuity between two adjacent segments could be estimated by interpolating between segment centroids. However, this approach does not provide an appreciable improvement in the simulation of mass transport for the level of complexity required to account for variations in the ditch cross-sectional area throughout the length of the ditch.
3. The model is designed to handle long-term average steady flow. The user is advised to use a site-specific model for sites better characterized by transient conditions, for example, where precipitation is typically delivered through short-term, high-intensity rainstorm events.

2.2.2 Combining Multiple Layers and Strips

Comment: Drs. Harvey and Li had questions about how the multiple roadway layers and strips interact. Specifically:

1. It is not clear whether aggregating concentrations from multiple roadway strips and layers simply means that the concentrations from multiple strips are summed for the same constituent, or something more complex.
2. It appears that contaminants move from the top layer sequentially downward, never overlapping or diluting, so that all loading to the ground water is from the bottom layer, and contaminants from different layers do not enter the ground water at once. This is a reasonable approximation, but needs to be better explained.
3. The assumption that lateral communication between roadway source strips is insignificant and ignores flows from sloped embankment faces.

EPA Response:

1. IWEM uses Monte Carlo analysis to develop a probability distribution of ground water exposure concentrations for each roadway strip that contains leachable constituent mass. For each constituent, IWEM then sums the 90th percentiles of these distributions from all strips that leach that constituent to obtain the aggregate 90^{th} percentile estimated ground water exposure concentration for comparison to the reference ground water concentration(s). This is explained in the *User's Guide* in Section 5.2; however, the text will be revised for clarity in other sections of the *IWEM User's Guide* (U.S. EPA, 2015b) and *Technical Background Document* where this approach is mentioned more fleetingly (*User's Guide* Section 2.2.2.3 and *Technical Background Document* Sections 1.2.1 and 2.1.3).
2. The reviewer is correct in that all leachate leaves the roadway from the bottom of the lowest layer and that releases are a contiguous series of non-overlapping pulses. The text in Section C.2.2.1 of Appendix C of the *Technical Background Document* has been updated to make the process described mathematically more clear to the reader/user.
3. The objective of IWEM is to provide a screening-level analysis for a roadway design. As such, the decisions as to which processes to incorporate in the model were necessarily balanced against objective, utility and relative significance. The majority of contaminant releases from the roadway not diverted by a collection system will be vertical into underlying ground water.

Comment: Dr. Li wondered how Equations C-8 (contaminant flux), C-9 (infiltration rate), C-12 (pulse duration), and C-13 (concentration of efflux from permeable base) of Appendix C of the *IWEM Technical Background Document* (U.S. EPA, 2015a) were derived.

EPA Response: The equations mentioned were derived as follows:

- Equation C-8 is derived based on the following assumptions:
  - The leachate pulses from the layers in a strip move down through the layers and into the permeable base (the bottom-most layer) without overlapping or leaving gaps between them. As soon as the leachate pulse from one layer completely enters the permeable base, the leachate pulse from the layer above that one begins to enter the permeable base;
  - Any layers that do not contribute to leachate concentrations are ignored; and
  - Water and mass flux are constant for each individual pulse from a layer.
- Equation C-9 represents a weighted average of infiltration rates through each strip above a drain that runs laterally across the roadway.
- Equation C-12 defines the total mass of constituent in the permeable base as the product of the volume of material used in the permeable base and the initial total concentration of leachable constituent in the material.
- Equation C-13 is Equation C-8 (mass flux at any time) divided by the water flux plus the concentration in the permeable base defined by the user.

Text has been added in Section C.2.2.4 of Appendix C of the *IWEM Technical Background Document* to provide a plain language description of the assumptions and formulation of the mathematical statements.

Comment: Dr. Li noted that Equations C-10 and C-11 depend on the assumption of permeable road base and filter reinforcement layer, which needs a careful justification in the typical pavement systems with industrial materials.

EPA Response: Subsurface drainage systems (in the form of a permeable base) were originally included in roadway cross-sections to alleviate moisture-related stress in pavements. The introduction of industrial materials with the potential to release constituents into the environment into the design and construction of new roadways creates additional motivation to consider including controlled diversion of moisture away from the roadway. The rehabilitation of existing roadways designed with a permeable drainage layer with industrial materials is also a reasonable scenario. For these reasons, and to address peer review comments on IWEM 2.0, EPA decided to include the permeable base option. Equation C-11 determines the duration of the pulse of leachate from the permeable base by calculating the total mass divided by the rate at which mass leaves the permeable base. The mass flux is the product of the per-unit-area water flux, the leachate concentration from the permeable base material, and the area through which the mass flux passes.

2.2.3 Infiltration

Comment: Drs. Li and Schwartz raised questions about the assumption that infiltration/runoff is steady state and on the same order of magnitude as regional recharge. Dr. Schwartz cited the scenario of high-intensity rainstorms, which would result in more significant runoff as compared to the hypothetical steady-state case with continuous, low-intensity rainfall. Dr. Li noted that infiltration is time-dependent and may be much higher in the embankment and unpaved shoulder than in the paved median. Dr Li asked whether this assumption can be re-written as the bottom limit of infiltration from the traversing roadway is on the order of magnitude of regional recharge.

EPA Response: Regarding the magnitude of infiltration for the roadway, EPA believes the reviewers may have misunderstood the nature of the assumptions described in Section 3.3.3 and Appendix C, Section C.2.1, of the *IWEM Technical Background Document*. As noted in Appendix C, EPACMTP (not IWEM) assumes that the general regional ground water flow pattern is not affected by the presence of a source. This assumption implies that infiltration is on the same order of magnitude as recharge, but this is not a condition enforced by EPACMTP or IWEM. That text has been revised to clarify that this is only an implication of the assumption that the regional ground water flow pattern is not significantly altered. Instead, IWEM enforces a practical design limitation that prevents the use of an infiltration rate for each strip that would allow the water table to rise up and make a contact with the roadway. IWEM also limits infiltration through a strip to the lowest material hydraulic conductivity value across all layers in the strip. The model provides default values for roadway infiltration rates, based on the properties of different construction materials and annualized environmental conditions for the selected geographic location. Alternatively, the user may elect to supply rates that are more representative of the specific scenario being modeled. The underlying flow models for the unsaturated and saturated zones are steady-state, so any time-dependent infiltration rate would need to be averaged on an annual basis prior to being entered into IWEM.

Regarding the assumption of steady-state runoff and infiltration, EPA believes this assumption to be an appropriate approach for a screening-level analysis.

Comment: Dr. Schwartz noted that the HELP model is used extensively for parameter estimation, but the documentation assumes that readers are well informed on how this model works and what its limitations are. The reviewer requested a more robust description of the HELP model to support and explain the parameter calculations, including a brief discussion of the method and any papers or reports that describe experiences and any assessments of that material (beyond that in Section E.5). The reviewer added that, rounding what may be highly uncertain parameter estimates (e.g., infiltration rates in Table 6-17) to three significant figures suggests foundational assumptions about the model that require careful reconsideration.

EPA Response: The HELP model has been used exclusively to estimate water infiltration through unlined and clay-lined WMUs, through various pavement and non-pavement surface materials, and for regional infiltration rates (e.g., recharge rates) in the area surrounding the source of contamination. An extensive description of HELP-derived infiltration rates through WMUs are presented in the *Technical Background Document for* EPACMTP. References to that discussion have been added to Appendix D (Infiltration Rate Data for WMUs and Structural Fills) and Appendix E (Infiltration Rates through Pavements) of the *IWEM Technical Background Document*.

Comment: Dr. Harvey approved of the use of the HELP model, but felt that additional explanations of the fundamental aspects of the HELP model would improve the documentation. Specifically, the reviewer wondered

1. What “quasi–two-dimensional model” means?
2. How the HELP model determines evapotranspiration, and whether it is modeled as transient?

EPA Response:
These following points have been clarified in Section 6.4.1 of the *IWEM Technical Background Document*:

1. The HELP model is primarily a vertical flow model (one dimensional – downward), but the model also accounts lateral flow if a permeable drainage layers is specified as part the modeled scenario (hence, quasi–two-dimensional).

2. Potential evapotranspiration is modeled using a modified Penman method (Penman, 1963). The HELP model can calculate transient values. However, both IWEM and EPACMTP calculate transport based on annualized flow and neither can accept these shorter-term, transient inputs.

2.2.4 Pulse Source Assumption

Comment: Dr. Li strongly suggested that EPA either provide a detailed documentation and references for the pulse source assumption (i.e., that leaching occurs at a constant concentration) or adopt the "first flush" (characterized as an initial high leaching rate, followed by a gradual decrease of leachate concentration with time) and "lagged response" (an initial low leaching rate gradually increasing until the source is depleted) leaching patterns instead. Dr. Schwartz agreed that a better description of the pulse analogy should be added, with conceptual description figure(s), rather than only equations, and further explanation of the relevant assumptions.

EPA Response: EPACMTP can model the leachate source as either continuous or finite sources. Furthermore, finite sources can be modeled as a pulse or depleting sources. Both of these modeling options are available for organic constituents. However, for metals that generally exhibit non-linear sorption behavior, the depleting source term modeling option cannot be used as the analytical solution for one-dimensional transport of a solute with non-linear sorption in EPACMTP requires the simplification of the leaching profile to a constant magnitude, finite pulse (i.e., a square pulse). These metals transport capability provided by EPACMTP and its accompanying assumptions have governed the development of the roadway formulation and the primary assumption that leachate profiles are conceptualized as square pulses. More detail discussions of the pulse and depleting leaching scenarios and the underlying assumptions can be found in *Section 2.2 of the EPACTMP Technical Background Document*. In addition, the text in Section C.2.1 of Appendix C of the *IWEM Technical Background Document* has also been updated to reflect how the assumptions of the transport module have influenced the formulation of the roadway module and to improve the presentation of the pulse assumptions and methodology.

2.2.5 Runoff, Leachate from Permeable Base

Comment: Dr. Li raised several questions about the calculation of water fluxes for runoff from pavement and discharge from a permeable base layer (called a drain in IWEM):

1. If no drain is included as part of the roadway are Equations C-19 and C-20 in Appendix C of the *IWEM Technical Background Document* valid?
2. In Equation C-19, how is RO_i calculated? What do the variables w_j and L represent?
3. In Equation C-21, what does the variable $\overline{C_{PB}}$ represent?

EPA Response:

1. IWEM is capable of accounting for surface runoff only when a ditch is included in the roadway cross-section design, as the ditch serves as the primary destination for runoff. If the user does not include a ditch in the roadway cross-section defined in IWEM, then the software does not ask for or permit the entry of a runoff rate, and Equations C-19 and C-20 are not applicable. If a gutter is included, IWEM can be directed to divert some portion of runoff away from the ditch (via the gutter). Additional text has been added in Section C.2.2.4 of Appendix C of the *IWEM Technical Background Document* to provide clarity as to when the equations are applicable or not.
2. In Equation C-19, RO_i, the runoff rate per unit area of strip is an input provided by the user. The variable w_j is the width of a particular strip of road denoted by the subscript j, while L is the

length of the roadway segment. These are initially defined after Equation C-4, but, for clarity, the variable descriptions have been added to the text for Equation C-19 in Section C.2.2.4 of Appendix C of the *IWEM Technical Background Document*.

3. In Equation C-21, $\overline{C_{PB}}$ is the time-averaged leachate concentration released from the bottom of the permeable base, as initially defined in Equations C-13a through C-13c. Again, for clarity, the variable description has been added to the text for Equation C-21 in Section C.2.2.4 of Appendix C of the *IWEM Technical Background Document.*

2.2.6 Roadway Module Features

Comment: Dr. Li made several observations and recommendations about the roadway module features:

1. The current road design options in IWEM do not allow the user to model a scenario that has two parallel highways with a median ditch. Dr. Li also recommended increasing the number of strips from the current maximum of 15 to a maximum of 20, increasing the number of drains and ditches from 2 to more than 3, and adding the number of gutters per unit distance along the segment (rather than whether a gutter is present or not).
2. Gutters should be optional.
3. There are no explicit embankment input parameters (e.g., geometry, elevation, and slope) in the software. Dr. Li also raised the issue of surface runoff and overland transport of contaminants from embankments constructed from industrial waste materials.

EPA Response:

1. EPA acknowledges that there are roadway design scenarios that may not be exactly captured by IWEM. However, the number of components currently allowed in the software was selected to support a divided highway with up to four travel lanes in each direction plus all optional features (shoulders, embankments, and ditches). EPA believes that this is sufficient to cover the majority of highway systems in the United States.
2. Gutters are already optional. If a ditch is specified to be present, the user may choose to specify that there is a gutter.
3. IWEM models embankments as a type of roadway strip. Runoff from any type of roadway strip (including an embankment) can be specified as long as a ditch to receive the runoff water has been defined. The commenter is correct that no additional embankment-specific parameters are included; additional parameters (such as slope) are included only for ditches. To keep the model relatively simple and to maintain the conservative nature of the ground water screening model, overland mass transport is not explicitly considered for embankments or other road components. EPA recognizes that omission of overland transport of contaminants is one of the limitations of IWEM. A modeler can still indirectly account for overland mass transport from a traveled way or embankment and the subsequent down-gradient infiltration outside of IWEM through simple mass balance equations. The resulting leaching information can be used as source term information to model the subsurface migration of contaminants to a receptor well.

2.2.7 Miscellaneous

Comment: Dr. Li requested clarification on how the total concentration is used in the roadway formulation.

EPA Response: Total concentration (or, more properly, total leachable concentration) is used together with the bulk density and volume of the layer to determine the total initial leachable constituent mass in that particular layer of that roadway strip. The total leachable mass is used together with the leachate concentration and infiltration rate, as defined in Equation C-3, to determine the how long it will take to deplete the total leachable mass of each constituent in the layer. The text of the *IWEM Technical Background Document* has been revised to use consistent terminology for this parameter and thus clarify how total concentration is used.

Comment: Dr. Schwartz indicated that little guidance is provided for the user to aid in determining the percentage of runoff and drainage that will reach a ditch prior to infiltration into the underlying aquifer. Dr. Schwartz also noted that it is difficult to associate parameters with the roadway cross-section. The reviewer requested figures that relate the input screens to the roadway geometry.

EPA Response: Text has been added to the Section 3.4.2.3 of the *IWEM User's Guide* (U.S. EPA, 2015b) and Section 6.3.8 of the *Technical Background Document* (U.S. EPA, 2015a) to provide some guidance for specifying the percentage of runoff and drainage that reaches a ditch. Specifically:

- 100% of roadway runoff should reach the ditch if no gutter is present; if a gutter is present, the percentage can be estimated by the ratio of the width of all strips between the gutter and the ditch to the width of all strips that are associated with the ditch.
- The percentage of drainage reaching the ditch should be low if the drain is represented as a continuous layer of highly permeable material; however, if drainage pipe is used only at intervals, then the value could be estimated as a ratio of the area drained by the drainage pipe to the entire area of the roadway underlain by the drain.

Comment: Dr. Schwartz noted that it is difficult to associate parameters with the roadway cross-section and that figures which relate the input screens to the roadway geometry would be helpful.

EPA Response: EPA is considering adding a figure that relates the input screens to the roadway geometry to future versions of the documentation.

3.0 Ground water Transport

3.1 Flow Velocity

Comment: Dr. Harvey noted that two basic features of ground water flow are that (1) it is slower in arid environments and (2) it accelerates from ground water divides toward discharge, usually in rivers. The addition of inputs for the distance from ground water divide and the distance to ground water discharge would improve the estimates of ground water velocity. The reviewer also noted that the description of how the saturated flow problem is formulated and velocities are calculated is confusing i.e., does regional recharge influence the magnitude of the ground water gradient and, thus, velocity?

EPA Response: EPACMTP does have an input for a ground water discharge location that is unique to surface impoundments (SI). Infiltration rates for SIs are determined in the unsaturated flow solution using the height of water in the impoundment and other relevant parameters. The proximity of a discharge point can influence the resulting infiltration rate. Incorporating the inputs for distance from ground water divide and distance to ground water discharge into the current flow solution for WMU sources would require modifications to the numerical solutions in EPACMTP, and the resulting better estimates of velocity would have a greater impact on when maximum concentrations reach a well than on the magnitude of the concentrations (and thus, exposure). Because the primary interest in a screening tool is the magnitude of the exposure, not the timing of that exposure, this does not impact the usefulness of the model. However, the Agency will reconsider these comments during any future work on the model.

3.2 Vertical Dispersion

Comment: Dr. Harvey indicated that the description of how vertical dispersion is conceptualized (e.g., is vertical dispersion only modeled downward?) is unclear.

EPA Response: Text has been added to Section 4.1 of the *IWEM Technical Background Document* to clarify the direction of vertical dispersion and to address any added conservatism resulting from the approach in EPACMTP. EPA considers this level of conservatism appropriate for a screening model.

3.3 Decay Rate

Comment: Dr. Aral indicated that there were major problems with Equations 4-1 and 4-6 [now 4-7] in the *IWEM Technical Background Document* (U.S. EPA, 2015a). Noting that these equations consider two different types of reactions: first-order decay and interactions between the chemical and the environment (e.g., absorption/desorption). Dr. Aral pointed out that the former is a function of the properties of the chemical only and is independent of the ambient environment, while the latter is dependent on the ambient environment, as well as the chemical properties. The reviewer observed that, while this second type of reaction is correctly represented in these equations, decay is not. The reviewer continued that interaction with the ambient environment is represented by the retardation coefficient, R, and if these equations are divided by the retardation factor R, the result is the appropriately reduced velocities and diffusion constants for the interaction with the environment term, as well as a reduced decay constant. This seems to imply that the decay constant of a chemical also reduces under the influence absorption/desorption processes, which is incorrect.

EPA Response: Dr. Aral is correct that the equations for transport in the unsaturated and saturated zone (Equations 4-1 and 4-6 [now 4-7] in the *IWEM Technical Background Document*) are incorrect as presented. The wrong versions of these equations (those reflecting degradation only in the dissolved phase) were incorporated into the IWEM documentation, giving the false impression that IWEM improperly ignores degradation in the sorbed phase. These equations, however, are correctly implemented in EPACMTP (and thus IWEM). The *EPACMTP Technical Background Document* presents these equations for degradation in both dissolved and sorbed phases, and both are codified in the EPACMTP software (and thus IWEM). Equations 4-1 and 4-7 and the accompanying text have been revised to correctly reflect the versions of the equations actually coded in the model, which include the sorbed phase.

3.4 Water Table Boundary Condition

Comment: Dr. Aral indicated that the description of the saturated zone boundary condition at the water table (on page 4-1, first paragraph [second paragraph in the revised text] of the *IWEM Technical Background Document*) is not adequate. Specifically, the reviewer is not clear on whether time dependence is used. The reviewer believed this is an important issue and that needs to be addressed in detail, because the contaminant flux from the unsaturated zone is a function of time and the zone is a boundary to the saturated zone.

Response: EPA acknowledges that details of the mathematical formulation are not presented in the IWEM documentation. The specific paragraph referenced by the commenter is an introductory paragraph intended to give a broad overview of the scope of EPACMTP in the context of subsurface modeling. Thus, additional detail there is not considered appropriate. However, a reference to the *EPACMTP Technical Background Document* (U.S. EPA 2003 a, b), which provides more details on the treatment of boundary conditions for the pseudo-3-D transport solution option(in particular the transfer of mass at the water table) has been added to Section 4.2 (Saturated Zone Module) of the *IWEM Technical Background Document* for the interested reader.

4.0 Inputs

4.1 General Quality and Appropriateness of Supporting Data

Comment: Dr. Schwartz raised concerns about the support databases used by IWEM, stating that these data sources are old and unverified, and that site-based strategies would be preferable. In addition, the reviewer stated that it is inappropriate to provide the user the option to model in the absence of subsurface data (i.e., when the subsurface environment must be classified as “unknown”).

EPA Response: While EPA acknowledges the comment, revising the underlying databases is outside of the scope this project. Additionally, the EPACMTP database and the Hydrogeologic Database for Ground water Modeling that IWEM relies on have been thoroughly peer reviewed and the model output validated extensively using field data. EPACMTP continues to support a number of large-scale Agency risk assessments and the Agency believes that the EPACMTP system provides the most appropriate available tool to conduct the subsurface modeling for IWEM.

Comment: Dr. Li commented that the references cited for formulation of multiple layers with a drainage system (Christopher and McGuffey, 1997; Apul et al., 2002) are too old, and that more recent references are needed. Similarly, the reviewer noted that the pavement material properties in Table 6-16 are also from Apul et al. (2002), which is not an authoritative, peer-reviewed publication. The reviewer added that the properties data should be revised to reflect the latest peer-reviewed publication for the pavement material properties, especially for industrial materials.

EPA Response: EPA acknowledges the age of some of the sources cited. However, this does not mean that the information contained in these sources has become outdated. Both references provide compilations of peer-reviewed literature and have been cited in a numerous other studies and publications. Therefore, in the absence of more contemporary sources identified by the Agency or provided by the commenter, EPA continues to cite to these older sources

Comment: Dr. Aral expressed concern with the random selection of data for certain parameters when the user does not supply values. Dr. Aral felt that this approach reduces the representation of site conditions.

EPA Response: EPA agrees with the reviewer that the reference to random selection of data is misleading and contradicts what is done in IWEM. Optional, site-specific parameters, such as aquifer hydraulic conductivity, that are not supplied by the user are selected probabilistically from nationwide distributions for each model iteration. Therefore, while there is some uncertainty introduced by relying on the national distribution, which may over or under-estimate site-specific conditions in a single model run, the overall magnitude of uncertainty of the aggregated results is likely small.

4.2 Specific Input Issues

4.2.1 Leachate Concentration

Comment: Dr. Schwartz felt that the amount of guidance provided for estimating leachate concentrations is not sufficient in comparison to other inputs and suggested that EPA consider developing a database of information for this input.

EPA Response: EPA has revised Section 6.3.9 of the *IWEM Technical Background Document* (U.S. EPA, 2015a) and Section 3.4.5.2 of the *User's Guide* (U.S. EPA, 2015b) to provide additional references to leaching characterization methods that the Agency has recently developed (such as SW-846 analytical methods 1313, 1314, 1315, and 1316; see http://www.epa.gov/epawaste/hazard/testmethods/sw846/new_meth.htm). These methods specifically allow the evaluation of leaching potential over the range of leaching conditions expected to occur when industrial materials are either disposed or beneficially used. In addition, EPA also provided in Section 6.3.9 two literature sources (Garrabrants, et al., 2013; Kosson et al., 2013) that contain leaching data for some constituents from a fly ash concrete source using Methods 1313 and 1315.

4.2.2 Material Properties

Comment: Dr. Li noted that Table 6-16 contains low-end and high-end material properties data for the top/base/subbase courses of Portland cement concrete and asphalt concrete pavements, which seem correct for a single row of data, but which are incorrect and misleading for the entire pavement system from top to bottom layers. The reviewer suggested revising the table to reflect the entire pavement system.

EPA Response: Table 6-16 [Table 6-17 in the revised text] presents material properties used in the HELP model for each layer in a typical roadway component (e.g., an IWEM strip) to derive practical bounding values of infiltration appropriate for a screening model; these values are included in IWEM. Because infiltration is a key sensitive parameter, the HELP model was run for the different layers for which data are presented in the table (top, base, subbase courses) to enable IWEM to evaluate each layer of a strip individually (rather than the whole pavement system at once). This approach captures the reality that the rate of infiltration through different layers is not likely to be the same. Thus, the values that were used to run the HELP model are presented in the table, rather than aggregated values for the entire pavement system that are not actually used in the model.

Comment: Dr. Li asked how the values in Tables 6-17 through 6-20 (infiltration, runoff, evaporation, and pan evaporation rates) were determined, and whether the range of values presented were verified, noting that some appear to be outside of typical ranges. The reviewer also asked whether the presented values represent pavement-related materials or waste materials.

EPA Response: The infiltration rates in Table 6-17 [Table 6-18 in the revised text] were generated using the HELP model and material properties for pavement-related materials, as described in Section 6.4.3.2 of the *IWEM Technical Background Document*. The average precipitation rates were derived from five years of national climate data stored within the HELP model database. The runoff rates in Table 6-18 [Table 6-19 in the revised text] and evaporation rates in Table 6-19 [Table 6-20 in the revised text] were also estimated with the HELP model. EPA has adopted the use of the HELP model, which was subject to both independent external and internal Agency reviews, as the source of infiltration rates for landfills for nearly two decades. EPA acknowledges that there are limitations in using HELP; however, the model has been tested and verified as discussed in the *EPACMTP Parameter/Data Background Document* (U.S. EPA, 2003b).

Comment: Dr. Li asked how the data for pan evaporation is used in the model, and whether there is a more recent source for these data.

EPA Response: The pan evaporation rates (and precipitation rates) are provided as potential default values that define flow in an open ditch. The text in Section 6.4.3.2 has been updated to make that clear. How the high and low values were determined is also described in the text of Section 6.4.3.2 and supplemented by the footnotes attached to the respective tables. The rates presented in the document were taken from NOAA (1982).

4.2.3 Use of K_d Values

Comment: Dr. Aral asked why EPA does not recommend using the Monte Carlo feature of EPACMTP on the soil-water partition coefficient (k_d) value to resolve uncertainty about the effects of the geochemical environment on the mobility of metals. More specifically, the geochemical environment at a site is assumed to be constant and not affected by the presence of the leachate plume. In addition, EPACMTP does not account for colloidal transport or other forms of facilitated transport that may be significant for metals and other constituents that tend to strongly sorb to soil particles.

EPA Response: Although IWEM does not allow the user to supply a distribution for k_d directly for either organic or non-organic constituents, the probabilistic nature of k_d is reflected in other ways:

- For organics, k_d is calculated from K_{oc} and fraction organic carbon. Fraction organic carbon is a probabilistic value based on a nationwide distribution obtained from values of dissolved organic carbon in EPA's STORET water quality database. Thus, k_d calculated from K_{oc} and values drawn from the distribution for fraction organic carbon is also a distribution used in the Monte Carlo analysis.
- For metals, IWEM represents sorption using empirical sorption isotherms selected based on site-based data and national distributions of key variables. Although the user can override this with a single value of k_d, use of the isotherms is the default.

4.2.4 Precipitation Data

Comment: Dr. Li noted that only the minimum and maximum precipitations are provided for each climatic zone (in Table 6-15), and requested the addition of mean precipitations within the climatic zone.

EPA Response: High-end values for the environmental variables in each climatic region were chosen to be consistent with the objective of determining a bounding range of infiltration rates through various material configurations to support a screening level analysis. Mean precipitation can vary considerably within the large climate zones (which encompass numerous meteorological stations), which makes the presentation of a single mean potentially misleading for users who may assume that this value is appropriate for site-specific evaluations anywhere within that climate zone. A high-end value for the climate zone is more appropriately conservative. For roadways with a ditch, users are asked to enter an annual precipitation rate, and may choose whether to enter a high-end or mean value.

5.0 Output Metrics

Comment: Dr. Schwartz recommended that IWEM rely on more descriptive metrics than the comparison of a single high-end percentile to a risk or water quality metric. The comparison of a single percentile to a standard is too simplistic to capture variability of system, and is not a proper procedure of risk analysis. Dr. Aral felt that the probability of exceedance was a more computationally effective way to calculate risk based on an exposure criteria than the use of a 90th percentile.

EPA Response: The use of a high-end (90th percentile) point estimate from a distribution to characterize potential exposures is common and appropriate in screening-level analyses because the use of conservative data and assumptions allows decisions to be made quickly and with greater confidence. The roadway module in IWEM is intended to be a screening-level model for users to quickly determine whether a proposed use of industrial material is an appropriate beneficial use or whether additional site-specific assessment is warranted before making that determination. The *IWEM Technical Background Document* (U.S. EPA, 2015a) and *User's Guide* (U.S. EPA, 2015b) have been revised to clarify this point.

6.0 General Fitness of Software

6.1 Interface

Comment: Dr. Schwartz praised IWEM for performing as expected, being easy to use, and being appropriate for target audience. In general, this reviewer noted that screens are well described and well organized. However, both he and Dr. Li offered several suggestions for improvement:

1. The interface and icons are old and should be modernized
2. The built-in documentation under the "Help" tab is minimal, duplicative of the written documentation, and could be improved.
3. Some labelling could be improved (e.g., "Is Below Drain") on "Layer Properties" tab. The acronyms on some drop menus are unintuitive.
4. On the Source Parameters screen for roadways (Screen 7), it would be helpful to number the five data entry tabs.
5. The EPACMTP console window is distracting, and replace by a less obtrusive status line indicating that the model is running.

EPA Response:

1. IWEM is implemented in Visual Basic 6, an older coding language that was state-of-the-art when IWEM was originally developed in 2002, and the icons and interface are consistent with the age of the coding language. EPA acknowledges that the suggested changes would improve the user interface of IWEM; however, due to the considerable time and resources that would be required to rebuild the model using a more current coding language, the Agency chose to update the model in Visual Basic 6. EPA acknowledges that this decision resulted in a model that may look dated, but this has minimal impact on model utility or ease of use. The Agency will reconsider these comments during any future revisions to IWEM.
2. Unlike the documentation for many commercial software programs, the *IWEM User's Guide* (U.S. EPA, 2015b) and *Technical Background Document* are readily available to the public. These documents are intended to provide all the information needed to understand how to use the model appropriately. Therefore, it is not surprising that the "Help" tab within the model would mirror these texts. The Help is not intended to be a replacement for the documentation, but rather a distillation of the more essential points for the convenience of the user.
3. EPA has reviewed the different input screens for places where space allows for clearer labelling or the full spelling of acronyms and updated the model as appropriate.
4. EPA has numbered the tabbed dialogs for roadway source parameters to minimize confusion.
5. While EPA acknowledges that some users may prefer the ability to minimize the EPACMTP run screen, this is, at most, a minor inconvenience. Thus, EPA focused available resources on areas that would improve model utility and ease of use. The Agency will reconsider this comment during any future revisions to IWEM.

6.2 Scope

Comment: Dr. Li noted that the national scope of climate data contained within IWEM limits the usefulness of the model internationally. This reviewer recommended the addition of data for global climate stations.

EPA Response: The purview of EPA is the United States, and IWEM was initially developed to aid decisions about disposal practices subject to EPA regulations. Even if IWEM were to be updated for a global audience, EPA notes that climate stations are not the only type of data that would need to be updated. Aquifer characteristics and other parameters for which distributions are built into the model were specifically developed for the United States and would need to be recalibrated for international use. Furthermore, the broadening of the scope raises numerous complications, such as how to make the model simultaneously useful for multiple regions around the globe. A screening model that considers a global high-end may become too conservative as to have limited utility for anyone. Therefore, no changes were made in response to this comment.

6.3 Other Software Issues

Comment: Dr. Schwartz noted that he could not find the saved results after running the examples.

EPA Response: EPA has updated Section 3.2.4 (How Do I Save My Work) of the *IWEM User's Guide* to clarify that the user chooses a location to save the files using the standard Windows Save As dialog. EPA has also updated the example problem appendices (Appendices B, C, and D) in the *User's Guide* to identify the default installation location of the data files that correspond to the example problems.

Comment: Dr. Aral commented that the computational times presented on page 2-4 of *IWEM Technical Background Document* (U.S. EPA, 2015a) are not efficient compared to other more complex software.

EPA Response: The computation times presented on page 2-4 in Section 2.2 of the *IWEM Technical Background Document* (45–60 minutes per constituent for all three liner scenarios, or 15–20 minutes per constituent and liner) [now removed from the *Technical Background Document* and revised in Section 3.2.7 *User's Guide*] were outdated and somewhat misleading. For WMUs and structural fills, the runs on a typical computer with a 2.5 GHz processor take about 4 minutes per liner scenario per constituent, not the 15–20 implied by the document. Further, runtimes for all liners is a somewhat misleading metric, given that some sources (land application units, WMUs with a user-defined liner, structural fills) have only one liner scenario and that, for those with three, it may not be necessary to run all three (IWEM runs the liners from least protective to most, and once it finds a liner scenario below the benchmark, no further liners are run). Thus, a more realistic estimate would be 4–12 minutes, depending on the necessary number of liner scenarios. Roadways can take longer, depending on the complexity of the design and the properties of the materials, but typically take 3–12 minutes per constituent per strip. EPA has updated the text with the more current and relevant runtimes noted here in Section 3.2.7 of the *User's Guide*.

7.0 Documentation

7.1 Technical Clarity and Detail

7.1.1 General

Comment: Dr. Harvey suggested adding an upfront roadmap in the *IWEM Technical Background Document* (U.S. EPA, 2015a) that traces the parallel pathways for flow and transport, along with references to the location in the document where detailed discussion of each pathways can be found.

EPA Response: While the suggested revisions may make the IWEM documentation easier to navigate, it will not be a major source of confusion for the reader. After careful review of edits requested by the commenters, EPA made the decision to focus available time and resources on those that would correct errors and improve the clarity of the document. The Agency will reconsider these comments during any future work on the model.

Comment: Dr. Schwartz indicated that it is not clear how concerns and suggestions from the community of users/stakeholders are considered and influence model development.

EPA Response: Information on how to contact EPA for technical support or to provide comments is available via the "Tools" menu (Technical Support) and in the *User's Guide*. Although there is no automated feedback system, user comments are reviewed by the Agency. If the commenter identifies potential errors within the model or points out ways to improve the utility of the model, EPA will work to address these comments at the earliest possible date. If the comments address design or other that topics that do not affect the model utility or ease of use, EPA will address these comments dependent on available funds.

7.1.2 WMU Source (*IWEM Technical Background Document* Section 2.1.1)

Comment: Dr. Aral noted that this section of the text refers to "…location-specific parameters such as precipitation." However, IWEM uses infiltration, not precipitation to model fate and transport.

EPA Response: EPA has revised the text to clarify that inputs, such as infiltration and recharge, are influenced by local rates of precipitation and evaporation. In addition, IWEM does require the user to input an annual precipitation rate for roadway sources with a ditch.

7.1.3 Roadway Source (*IWEM Technical Background Document* Section 6, Appendix C; *User's Guide* Section 2)

Comment: Dr. Harvey indicated that the conceptualization of flow in and out of the ditch would be better supported through an updated version of Figure C-9 and that such a figure would be more helpful if presented earlier in the document.

EPA Response: The figure has been revised in Appendix C. EPA feels it is too detailed to present in the main body of the text, as it illustrates equations presented only in the Appendix.

Comment: Dr. Li noted that the following sentence in Section 6.3.5 is confusing: "Once the mass of leachable constituent is known, the duration of leaching from a material layer is calculated."

EPA Response: The *IWEM Technical Background Document* text has been reviewed and updated to clarify.

Comment: Dr. Li stated that the structure of Table 6-16 should be modified to

1. Eliminate information that will not be used in the model and may be confusing (i.e., air void, texture, field capacity, wilting point, and curve number);
2. Clarify the data source(s);
3. Correct typos; and
4. Include a reference to footnote (8) (not currently referenced in the table) or delete the footnote if it is no longer relevant.

EPA Response:

1. Table 6-16 [Table 6-17 in the revised document] is included to inform the user of the key parameter values used in the HELP model to derive the default infiltration rates provided in IWEM. These values are not intended to be suggested inputs for IWEM. EPA has reviewed and updated the table title and the description of the table in the text to clarify this.
2. Data sources have been added.
3. Typos have been corrected.
4. Reference to footnote (8) has been included in the heading for Layer Thickness.

Comment: Dr. Li asked why Figure C-8 does not depict a subbase.

EPA Response: The subbase is an optional layer that can be included in the model. Figure C-8 is not intended to show all possible layers. Therefore, no changes were made with respect to this figure. However, EPA refers the reader to Figure 2-2 and Appendix E, Figure E-2 in the *IWEM Technical Background Document* to see the depiction of the subbase as part of a roadway layer.

Comment: Dr. Li noted that Figures 2 and 3 in the *IWEM User's Guide* (U.S. EPA, 2015b) are low resolution and difficult to read. The reviewer suggested a better sketch of a ditch, including a gutter, is needed to support the definition of the related inputs.

EPA Response: The EPA assumes that the reviewer is referring to Figures 2-2 and 2-3. After review, EPA finds the resolution of Figure 2-2 to be adequate to communicate the intended information in both the Word and PDF files. In the absence of more specific recommendations on how to improve the figure, EPA made no changes. EPA agrees that Figure 2-3 is low resolution and needlessly complicated. The existing figure has been replaced with a version of Figure C-13 from Appendix C of the *IWEM Technical Background Document*, modified to include gutters. This figure is simpler, higher resolution, and better communicated the intended point.

7.1.4 Saturated Zone Modeling (*IWEM Technical Background Document* Section 4; *User's Guide* Section 2)

Comment: Dr. Aral stated that the text on page 4-4 of the *IWEM Technical Background Document* requires clarification. The last paragraph starts with a definition of steady flow, but then discusses increases in velocity. The reviewer recommended noting that for the case of mounded ground water, velocities are recalculated, not increased (as if it is increasing with the formation time of the mound).

EPA Response: The text on page 4-4 [4-5 in the revised text] of the *IWEM Technical Background Document* has been revised to clarify that ground water mounding beneath the source is represented in the flow system by increased head values at the top of the aquifer. In addition, while EPACMTP calculates the degree of ground water mounding that may occur due to high infiltration rates, the actual saturated flow and transport modules in EPACMTP are based on the assumption of a constant saturated thickness. The only direct effect of ground water mounding in EPACMTP is to increase localized, simulated ground water velocities where the water table has been elevated.

Comment: Dr. Aral stated that the discussion on page 4-1 of the *IWEM Technical Background Document* is misleading because the second paragraph seems to imply that steady-state well concentrations are only influenced by boundary conditions at the source (i.e., whether the source is finite or continuous). Dr. Aral noted that additional factors may influence the nature of steady-state well concentrations, such as distance between the source and the well and the exposure period.

EPA Response: The text on page 4-1 has been revised to clarify that the steady-state well concentrations are estimates, based on several factors not limited to the nature of the source, the distance between the source and the receptor well, constituent fate and transport properties, and the exposure period.

Comment: Dr. Aral indicated that the presentation of the time-averaged concentration calculation in Figure 4-1 is misleading. The reviewer noted that IWEM does not consider exposures that occur before the peak of ground water concentration profile and, as a result, adverse effects that may be experienced by sensitive receptors may be overlooked.

EPA Response: IWEM is designed to return a conservative, maximum time-averaged exposure concentration using an exposure period specified by the user. In addition, the user has the option to provide a screening benchmark that accounts for the potential variability in sensitivity or susceptibility of different receptor groups so that the results of the screening analysis do not underestimate risks to any sensitive receptors.

Comment: Dr. Ara1 indicated that the discussion at the top of page 2-9 of the *IWEM User's Guide* is misleading. This text states: "*These processes decrease constituent concentrations in the ground water as the distance from the source increases.*" However, the processes described decrease the concentration as a function of time, rather than distance. But since the contaminant is being transported over some distance, the concentration decreases as well.

EPA Response: EPA acknowledged the comment, and revised the text on page 2-9 [bottom of the page in the revised text] of the User's Guide.

7.1.5 Miscellaneous

Comment: Dr. Schwartz expressed concern that the report does not provide enough cited literature that describes the theoretical basis of the modeling approach. Specifically:

- What is the basis for Equation 6-5 in the *IWEM Technical Background Document*? Is this equation from Gelhar's Electric Power Research Institute (EPRI) report or did EPA derive this from the data presented in the report?
- What is the basis for Equation 6-14 in the *IWEM Technical Background Document*, and what are the units for the conversion factor?
- No citations are provided that explain where the basis for using non-linear sorption isotherms to characterize metal sorption (Section 6.5.2.2).
- The majority of references in the documents are from EPA. Many sources are represented by "grey" literature, such as Gelhar's EPRI report, which was later published in Water Resources Research, rather than primary journal articles.

EPA Response: In regards to the comment on Section 6.5.2.2, the Agency believes that the reviewer is referring to section 6.6.2.2. EPA has included more citations to the *EPACMTP Technical Background Document* (U.S. EPA, 2003a, b) where the theoretical basis for many of these equations and parameter distributions are derived. IWEM builds on EPACMTP and does not modify these equations. Therefore, the Agency believes it is redundant to reproduce all of the derivations presented in U.S. EPA (2003a, b).

Comment: Dr. Schwartz stated that the *IWEM Technical Background Document* needs a careful and consistent description of the different types of statistical distributions used in the model. For example, mention is made about Gaussian, lognormal and log ratio distributions in Table 6-24. The model uses cumulative versions of these distributions, as well as other empirical or data-driven cumulative distributions. However, no accompanying discussion of these distributions is provided. The discussion of distributions in the *IWEM Technical Background Document* should include a discussion of typical distributions (e.g., uniform, normal, lognormal) and what they each looks like as cumulative distributions. In addition, when data-driven distributions are developed, each should be explained in its own right. Discussion of the choice of distributions is important because it has some bearing on parameter ranges.

EPA Response: EPA has included more citations, as appropriate, to the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), where the selection of parametric and empirical parameter distributions is supported and described.

Comment: Dr. Schwartz noted that, on page 3-38 of the *User's Guide* (Section 3.4.4.4), it appears that if a single Monte Carlo realization is unrealistic, then it is discarded. If some subset of realizations in a Monte Carlo simulation is not used, there is the potential for bias in the ensemble statistics. It is not clear what constitutes a "sufficient" number of realizations, but a more definitive cutoff should be provided.

EPA Response: EPA has revised the text in Section 3.4.4.4 of the *IWEM User's Guide* to add a footnote cautioning against reducing the number of iterations from the default 10,000, and to provide a cross reference to Section 5.2 of the *IWEM Technical Background Document*, where this subject is discussed in more detail.

7.2 Presentation of Example Problems

Comment: Dr. Harvey thought that users would benefit from example problems that demonstrate how local data may be found, show the inputs and outputs of IWEM, and contain a discussion of how to interpret the results. These examples should span the range of IWEM's capabilities, different WMUs, different contaminants and different geographic areas within the United States. Dr. Schwartz thought the existing discussion of the example problems was cursory, and that including screenshots of the user interface in the examples would be helpful. While some screenshots were provided in Appendix C, Dr. Schwartz felt these were too small.

EPA Response: The IWEM *User's Guide* provides several example problems for WMUs, structural fills and roadways. EPA is providing the IWEM project files for these examples along with the release of IWEM 3.1. EPA will work to improve the specific examples and the resolution of smaller graphics in the documentation.

Comment: Dr. Schwartz suggested additional discussion on parameter uncertainty related to uncertainty in the results.

EPA Response: While EPA acknowledges that an uncertainty analysis based on input parameters may be of interest to readers, the Agency notes that IWEM is intended to be a screening model, with most inputs biased in a known, conservative direction (excluding user-defined inputs that may not be conservative). Therefore, the uncertainties associated the parameters built into the model are unlikely to lead the user to conclude incorrectly that a proposed beneficial use is appropriate.

EPA also points out that the uncertainty associated with parameter variability is accounted for in IWEM through the use of several linked databases of the EPACMTP model, which include: (1) a nationwide database of source term data, (2) a database climate parameters, and (3) a database of subsurface parameters. Through the implementation of EPACMTP's Monte Carlo function, the uncertainty in local conditions are approximated using data that characterize the variability of environmental conditions across the United States.

Comment: Dr. Aral requested that EPA provide files that correspond to each example problems along with the software.

EPA Response: The IWEM project files associated with the example problems are now included as part of the software installation package.

7.3 Editorial Comments

The reviewers provided a number of specific editorial comments, which are summarized in the tables below for the *IWEM Technical Background Document* and the *User's Guide*.

Table 2. Editorial Comments on the *Technical Background Document*

Commenter	Location	Comment	EPA Response
Dr. Schwartz	General	*IWEM Technical Background Document* overuses acronyms	EPA has reviewed the use of acronyms and limit usage to those that are essential and used frequently.
Dr. Schwartz	General	*IWEM Technical Background Document* mixes metric and British units	Revised to metric only, as used by the model.
Dr. Harvey	Figure ES-1	Do not reflect the impact of clean recharge on the elevation of the plume top	Corrected as suggested (also repetitions, Figures 2-3, 6-3)
Dr. Aral	ES, bullet list in right-hand column of page ES-1	Executive Summary refers to applications that IWEM *cannot* be used to analyze: ▪ Protecting air quality in WMU design ▪ Monitoring analysis or help ▪ Corrective action claim (only by repeated iterative analysis, too much effort and too uncertain) ▪ Post closure action claim ▪ Risk based approaches Without an explicit and detailed reference to *Guide* analysis system, the user may get the impression that they can do all these application using IWEM.	The statements regarding these scenarios are made in reference to the Guide for Industrial Waste Management not IWEM. The text has been revised to make that distinction clearer in Section 1.1 of the *IWEM* Technical Background Document. However, the text in the Executive Summary has been removed because it may create confusion without providing appropriate level of context.
Dr. Aral	Sec 2.1.1, First paragraph	"*Controlling the release*" is not the proper terminology; "management" is better.	EPA has revised the text to more appropriate language.
Dr. Aral	Figure 2-2	Figure needs revision. There is vertical flow under the roadway cross-section not the regional flow from left to right.	The figure has been revised to eliminate the reference to regional ground water flow direction in this figure and all repetitions.
Dr. Aral	Page 3-4, Bottom	"…EPACMTP does not account for fluctuations in rainfall rate or degradation of liner systems that may cause the rate of infiltration and release of leachate to vary over time." This is not the correct terminology because the depleting source boundary condition that is used in EPACMTP is a leachate source, which varies over time. This is considered as Boundary Condition in EPACMTP. Thus, this is inconsistent wording of time dependence, needs correction.	The text has been revised to reduce confusion between steady state flow assumptions and contaminant transport boundary conditions.
Dr. Aral	Figure 3-6	Figure needs revision. There is vertical flow under the roadway cross- section not the regional flow from left to right.	The figure has been revised to eliminate the reference to regional ground water flow direction in this figure and all repetitions.
Dr. Aral	Section 4.2, 4.3.2	The use of regional terminology to describe ground water flow inconsistent with inclusion of localized mounding.	EPA has revised the language regarding regional flow.

Table 2. Editorial Comments on the *Technical Background Document*

Commenter	Location	Comment	EPA Response
			(continued)
Dr. Li	Table 6-2 [now 6-3]	Language describing Drain Geometry – Configuration is confusing: ▪ "Ditch strip drain drains to strip number of the ditch for this drain" is confusing ▪ Rename "Layer drain is above" as "layer number underneath the drain", ▪ Rename "Drains what strip" as "which strip need drains".	The table contains a column (Section Reference) that identifies the specific section in the document where each term is defined. EPA revised the labeling of these parameters for clarity.
Dr. Li	Table 6-2 [now 6-3]	Language describing Flow Characteristics is confusing. ▪ Rename "Flow Percentages to Ditch Strips (for relevant strips and drains)" as "Percent of roadway runoff that reaches ditch". ▪ Define "Percent of flow in drain that reaches ditch" and "Ditch strip(s) receiving overland flows" before.	The table contains a column (Section Reference) that identifies the specific section in the document where each term is defined.
Dr. Li	Table 6-2 [now 6-3]	Is it possible to include Flow Percentages to Ditch Strips (for relevant strips and drains)" for Monte Carlo Simulation?	All IWEM roadway source term parameter are deterministic.
Dr. Li	Section 6.4, App A	Clearly define infiltration, percolation, and evaporation and differences among them	EPA has added these terms to the glossary (Appendix A) and highlighted differences between the definitions in Sec. 6.4.
Dr. Li	Appendix C	The term "permeable base" appears in Appendix C but not in main document. The terms "permeable base" and "filter reinforcement layer" are not familiar to common user.	Permeable base and drainage layer are synonymous. IWEM calls both of these a drain, but the formulation in Appendix C is cast in terms of permeable base (which will be used consistently). The main document (Section 3) shows more general layers, including a base layer. The term "filter reinforcement layer" is specific to the appendix and not intended to be a design element to be considered by the common user.
Dr. Li	Appendix C	The term "exfiltration" appears in Appendix C but not in main document.	This term is more specific to the appendix, but also used in the main document to represent water percolating from the bottom of a ditch. The text of the appendix has been modified so that exfiltration is understood to be the rate of water leaving the bottom of the ditch and the term has been added to the Glossary.
Dr. Li	Appendix C	The technical manual and some parts of technical appendix [C] should be combined, because all of equations are shown in appendix. The equations are a key part to understand the technical part.	The segregation of the mathematical formulation from the main text was based on a desire to keep the presentations of each source type similar in the main body of the text.

(continued)

Table 2. Editorial Comments on the *Technical Background Document*

Commenter	Location	Comment	EPA Response
Dr. Li	Figure C-7	The word "section" in the caption is misspelled	The typo in caption has been corrected.
Dr. Li	Figure C-7	Should be updated using AASHTO or FHWA publication	EPA acknowledges the comment; however, the Agency believes the figure is sufficient to illustrate the point made in the preceding paragraph.
Dr. Harvey	Figure 2-6	Does not reflect the impact of clean recharge on the elevation of the plume top.	The figure is revised as suggested
Dr. Aral	Page 2-1, above Table 2.1 [now Table 1.1]	"No liner" is not a liner type	The text has been revised from Liner Type to Liner Scenario, which is also consistent with the *Guide*.

Table 3. Editorial Comments on the *User's Guide*

Commenter	Location	Comment	EPA Response
Dr. Aral	page 2-3, top [now middle of 2-3]	What is a complex site? That definition needs to be introduced here. There are several possible complexities? There are other important complexities that are not mentioned here. Heterogeneity? Fissures? Flow conditions Gradient? Proximity to exposure point? The complexities selected here are not proper.	The text has been revised to state that if site conditions do not reasonably conform to the assumptions fundamental to the formulation of IWEM, then the model is not appropriate for such sites. Also, EPA provided additional examples of site conditions that would be deemed "too complex" for IWEM.
Dr. Schwartz	Figure 3-9	Some graphics are difficult to see in the document (e.g., small roadway inset in Figure 3-9)	EPA improved figures and resolution where possible.

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Attachment 1

Charge to Reviewers

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CHARGE TO REVIEWERS
Peer Review of the Industrial Waste Evaluation Model Version 3.0

BACKGROUND

IWEM v1.0 was the ground water modeling tool developed to support the U.S EPA's Guide for Industrial Waste Management (U.S. EPA, 2002). The model simulates the subsurface migration of chemical constituents from the bottom of a land-based waste management unit (WMU) to down-gradient receptor well. The evaluation is based on a tiered approach analysis that consisted of nationwide distributions (Tier 1) and a location-adjusted probabilistic analysis (Tier 2) with the objective of determining the most appropriate liner design for WMUs that minimize or avoid adverse ground water impacts. Both tiers are designed to assist facility manager, the public, and state regulators a screening-level assessment tool before committing significant resources for a more complex site-specific hydrological investigation and probabilistic modeling.

In 2006, IWEM v2.0 was developed which added a module to simulate fate and transport from a new source type—a roadway constructed by recycling industrial materials (i.e., byproducts). This module provides the user an easy to use tool to determine if the reuse of industrial materials in a roadway setting is environmentally sound. The new source type was restricted to Tier 2 screening-level analyses, in which the user can assign values to a number of key, site-specific parameters, and values for the remaining parameters are selected from predetermined distributions for a Monte Carlo analysis Both IWEM v1.0 and v2.0 were peer reviewed by external independent scientific experts in 2002 and 2008, respectively.

The current version of the model, IWEM v3.0, for which the EPA is seeking an external peer review, introduces a more rigorous treatment of leaching through the roadway cross section by incorporating ditches, drainage, gutter, and embankment/berms into the roadway design. These changes help to simulate fate and transport of contaminants from a roadway by fully accounting flow process through overland as well discharge through drains. Because of these features, the site conditions are better modeled and well concentrations of contaminants are better estimated. Furthermore, the current version restricts all evaluations for the WMUs and roadway sources to Tier 2 analysis option. The Agency opted to remove Tier 1 analysis because the leachate concentration threshold values (LCTVs) stored in the IWEM database and used for Tier 1 analyses were based out-of-dated human health benchmarks (e.g., reference doses and slope factors).

CHARGE TO REVEIWERS

The EPA is seeking an independent scientific peer review of IWEM v3.0 beta, focusing on the changes made to the model since v2.0, which includes: the designs of drainage system, embankment/berm, and ditches; lateral flow through overland, drain systems, and permeable bases; and the subsequent impact of these changes on fate and transport of contaminants. The reviewers are asked to provide comments on the modeling approaches, assumptions made, scientific rationale used to develop the model, and the supporting documentation. In addition, during the review, the reviewers are asked to be mindful that IWEM is designed as a screening level tool, and it is not meant to be used as a final tool in complex site-specific evaluations.

MATERIAL FOR REVIEW

The EPA is providing the following items that include the model and its documentation for review.

1. Industrial Waste Evaluation Model Version 3 Beta (IWEM v3.0)

2. Peer review draft of the *Industrial Waste Evaluation Model Version 3 Beta: Technical Document*.
3. Peer review draft of the *Industrial Waste Evaluation Model Version 3 Beta: User's Guide*

CHARGE QUESTIONS

Based on your knowledge of hydrology and contaminant fate and transport, please provide your comments in response to the following technical questions:

1. **New Roadway Features.** Please comment on whether the new features (e.g., drainage system, gutter, ditch and embankment) added to the roadway module reasonably represent a typical roadway? Are the assumptions and parameters used to represent these components in the model appropriate and adequate? Is there anything significant overlooked in the general road configuration?
2. **Flow Equations.** Are the conceptualizations and derivations of flow equations for surface runoff, discharge from drainage and flow in ditches appropriate and adequate? Are they represented properly in the model? Please also comment on the appropriateness of rates developed for runoff, evaporation, and infiltration using the Hydrologic Evaluation of Landfill Performance (HELP) Model. Is the calculation of these rates for the six representative regions on the United States adequate?
3. **Contaminant Flux**. Given that the incorporation of drainage system, runoff, and evaporation can alter the contaminant flux, please provide your comments on the appropriateness of the equations used to calculate the contaminant flux (mass flux, pulse duration, leachate concentration) from a roadway source. Are the results derived from the use of this model reasonably reliable?
4. **Model Simplicity**. With additions made to model, has the EPA appropriately kept the balance between keeping the model simple and easy to use as compared to making it technically more sophisticated?
5. **Documentation.** Does the documentation reasonably explain the assumptions/rationale behind the modeling approach and the conceptualization of the roadway parts? Overall, is it complete and understandable to the reader? Are there any significant omissions that need to be addressed?

Attachment 2

Full Text of Peer Review Comments

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IWEM 3.0 Peer Review Letter Reports

Draft

June 30, 2014

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Peer Review of the Industrial Waste Evaluation Model (IWEM) Beta Version 3.0

Summary of Conclusions

In this review, I am providing my comments for the following documents that were submitted to me for review:

1. TECHNICAL DOCUMENTATION: IWEM_v3B_TBD_Main_Doc_2-18-2014.pdf
2. APPENDIX for Technical Documentation: IWEM_v3B_TBD_Appendices_2-18-2014.pdf
3. USER'S GUIDE: IWEM_UGv3b_Main_2-18-2014.pdf
4. APPENDIX for User's Guide: IWEM_UGv3b_Appendices_2-18-2014.pdf

The documents listed above constitute the main reference material that were prepared for the model IWEM – Beta Version 3.0. In general the reference documents listed above are well organized and well written. However, in their current state they are not error free for these documents and also the software to be released in public domain. My main points of concern are weaknesses in the review material provided and more importantly I see technical issues with the analysis provided on the subject matter of the model developed. Before addressing these deficiencies I do not recommend the release of this software and its documentation in public domain.

The strength of the application developed can be considered to be the user friendly nature of the computational platform of the software. The GUI provided is adequate for the User to implement the application. However, even with this user friendly platform I would think training sessions will be necessary for the User to fully understand the software, the GUI, the database behind the software and implement the application in their projects successfully. I presume that the necessary support will be provided by the agencies involved. Further, it would have been very useful for the User if the developers have provided several sample input data files of typical projects for the User to open under the GUI of the software and see the general data structure of a typical application and make sample runs and see the outcome. Although I have searched for these sample input data files extensively in the installation folders of the application, I have not found any. Inclusion of these sample input files into the software package would have been very useful for the user. If these files exist somewhere in the installed software folders and I could not find them in the short review time allocated for this task, I apologize.

My specific recommendations can be grouped into three topics as seen below. Before the software and the support documentation is released in public domain the issues addressed in these recommendations should be clarified or corrected:

1. Technical issues identified in this review needs to be addressed and the software computations needs to be revised based on these corrections.
2. Documentation needs to be revised reflecting the recommendations on these technical issues including the conceptual issues that are highlighted in this review.
3. Sample input data files should be included with the software installation package. After installation, these input files should appear in some separate folder in the software

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directory and these files should be accessible through the software by the use of an "OPEN" command under the GUI of the software.

Charge Questions and Responses

NOTE: In the review provided below a critique of the general features of the application and the theory used in the application is discussed first under SECTION A of my review document. Since the documentation provided in support of the application, which I am reviewing, include many misconceptions and misused definitions or misused terminology or miss defined example cases, I had to also include recommended corrections that are identified in terms of page and line positions (approximate) in reference to a paragraph on a page in the document. These review comments are included under SECTION B of my review document.

SECTION A: DISCUSSION OF GENERAL FEATURES OF THE APPLICATION:

1. New Model Features.

The new model features that are included in the IWEM Beta version 3.0 (e.g., drainage system, gutter, ditch and embankment) under the roadway module represents a good and a very detailed characterization of a typical roadway cross-section. The assumptions and parameters used to represent the layered nature of this engineered system and its components are appropriate and more than adequate. There is no need for further sophistication to represent this pathway in the IWEM application.

However, the characterization detail that is included for the roadway module, i.e. representing the layered nature of the vertical cross-section under the roadway, is incompatible with the simplicity considered for the unsaturated/saturated vertical cross-section pathway model that is developed and used for the WMU application for natural environments. In one case several layers with different material properties (heterogeneity) are considered, whereas in the other case natural (layered) heterogeneity that may exist at a typical WMU site is categorically ignored. If a layered system analysis is doable in one application as demonstrated for the roadway model case why is it not possible to do it for the other pathway? If complexity is the issue than the roadway model could have also been simplified to represent the vertical cross-section under the roadway as a single layer using average values as it is done for the unsaturated zone model for WMU. If it is not so complex to represent a vertical cross-section as a layered model as it is done in the roadway model, than the User should also have the option to represent the unsaturated zone under the WMU as a layered system as well if they chose to do so without making drastic simplifications on the unsaturated zone application.

This incompatibility between the two applications is very obvious. In one case the manual goes through an extensive and detailed explanation of the assumptions involved to simplify the application (unsaturated zone model). In the other case the manual again goes into so much detail to describe the characterization and the steps necessary to represent the vertical heterogeneity and the layered roadway application (including the angle of groundwater flow

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direction on segments of the roadway). This is a very unbalanced analysis technique for similar systems within the same software. It is obvious that the technical development teams of one module was not talking to the other team to present a unified picture for both applications. Or one of the modules was developed earlier and the other was tagged on to the software later on. In this case one should also notice that the uncertainty and computational errors introduced to the solution by the use of a simplified unsaturated zone analysis, which should be a zone below the roadway, far exceeds the accuracy gained by the layered analysis of the roadway cross-section. In this sense not much will be gained by the use of a layered roadway module in an application.

In my opinion a balance between the sophistication levels of the two applications needs to be considered. Unnecessarily simplifying one application while unnecessarily complicating the other raises some doubts and concerns.

2. **Flow Equations.**

The IWEM model is basically an interface model which uses another EPA model (EPACMTP) as its computational engine. In this sense the assumptions of the EPACMTP model is directly transferred and used in IWEM software. Accordingly, in the IWEM application, the groundwater flow is defined as steady state both in the unsaturated zone (vertically down) and also in the saturated zone (3D) (horizontal). These assumptions and limitations are all standard for Tier 1 and Tier 2 screening applications which IWEM is another one of these screening family models. Other than the limitations these assumptions introduce, we have to accept them as is since these are simple screening models. In this case there is no problem with the definitions introduced and the equations used to calculate the steady state Darcy flow velocities or the pore velocities in the application domain. In the saturated flow domain the Darcy velocities are also adjusted for the potential of creation of a mound under the WMU which is reasonable. However, in that sense the use of the terminology of “regional” groundwater flow should not have been used since the conditions on the Darcy velocity is no longer regional but local. This is a minor point but needs some attention in the write-up.

Please also refer to recommended corrections under **SECTION B** for line-by-line comments since there are several other similar conceptual errors in the text of the document.

3. Contaminant Flux.

Accounting the drainage, runoff, and evaporation rates, are done correctly but there is a major problem with Equation (4.1) which is also repeated in Equation (4.6). I do not know where this error is originating from. Either EPACMTP definitions is wrong which is a major problem, or the authors of this document has misused (copied) the wrong equation from the EPACMTP documents (I did not check). I hope it is the second case, because if the error is in EPACMTP than both software needs to be corrected and this is a major and a significant issue.

The Equations (4.1) and (4.6) are given as:

$$\frac{\partial}{\partial z}\left(D\frac{\partial c}{\partial z}\right)-V\frac{\partial c}{\partial z}-\theta\lambda c=\theta R\frac{\partial c}{\partial t}+Q \qquad (4.1)$$

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$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right)-V_x\frac{\partial c}{\partial z}-\varphi\lambda c=\varphi R\frac{\partial c}{\partial t}+Q \tag{4.6}$$

where the parameters of these two equations are appropriately defined in the documents. In the above equations two different types of reactions are considered: First the term $(\theta\lambda c)$ in Equation (4.1) or the term $(\varphi\lambda c)$ in Equation (4.6) would define a first order decay or transformation term which represents a homogeneous reaction for the chemical constituent considered in the application. This chemical process is called a homogeneous reaction process because it is a function of the properties of the chemical only and it is independent of the other processes such as the interaction of the chemical with its ambient environment. Thus the first order decay rate of a chemical is constant and it is independent of where the chemical is in the ambient environment. I emphasize, this decay process is independent of other processes the chemical may encounter as it is transported in the pore space of the ambient environment.

The interaction of the chemical with its ambient environment is another chemical process (absorption, desorption etc.) and the retardation coefficient (*R*) which includes some isotherms that is used to define those processes, characterizes those processes. As it is shown in Equations (4.1) and (4.6) this process is also included and correctly represented in terms of the retardation coefficient, *R*. However, the way Equation (4.1) and (4.6) is written and used is wrong in the following sense. If we divide these equations by a constant *R* we appropriately get the reduced velocities and diffusion constants and that is why the parameter *R* is called the retardation coefficient since it gives the impression that velocities and diffusion constants are reduced by the amount of *R* (retarded). However, that division in the case of equations (4.1) and (4.6) will also reduce the decay constant giving the impression that decay constant of a chemical also reduces under the influence absorption desorption etc. processes and **that would be wrong** simply because decay is a property of a chemical and it is independent of the other processes defined in the ambient environment (see ref. 4 or other reliable text books on fate and transport analysis). If the computations and the analysis truly depends on the way these two equations are written than the computations performed by this software and also EPACMTP is **completely wrong** when decay is considered in an application. I hope this is not the case because in this case both software needs to be corrected. I hope this is simply a typo or an error in copying an equation from another text, otherwise it is a major issue. I would also be careful with the definition of the term *Q* in the same sense as well. Same comment applies there as well. This is a major problem which needs further attention by the authors of these documents and also the software and this problem needs to be corrected.

Please also refer to corrections under **SECTION B** for line-by-line comments since there are several other conceptual errors in the text of the document.

4. **Model Simplicity**.

With additions made to model (roadway module), the authors have not kept the balance between keeping the model simple and easy to use as compared to making it technically more sophisticated. On the one hand potential natural heterogeneity is ignored in the unsaturated and saturated zone models, on the other, in order to represent roadway cross section source

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generation term, an extensive layered system is considered. This does not make much sense since the errors made in simplifying the representation of the unsaturated and saturated flow zones is far more important than the error introduced by representing six layer source region as a one layer region with the use of appropriate average conditions in a Tier 2 model. This is an over kill and an unnecessary complication introduced for IWEM application which is a Tier 2 model.

5. Documentation.

The documentation covers and explains the general assumptions/rationale behind the modeling approach and the conceptualization of the roadway parts. However, the text is full of conceptual errors, errors in definitions and errors in example characterizations of certain cases etc. Overall I do not consider this document to be complete. It needs to be revised significantly before it is released in public domain.

Please also refer to corrections under **SECTION B** for line-by-line comments since there are several other conceptual errors in the text of the document.

Other General Comments

This document is technically deficient per my comments on Equation (4.1) and (4.6) above. It is also deficient in terms of definitions and descriptions used in the text of the document. In my opinion this document is not ready for public domain release.

SECTION B: REVIEW OF IMPORTANT POINTS IN THE TEXT OF THE DOCUMENT LINE BY LINE:

NOTE: This section includes cursory and important errors noticed while reading the documents. This list is by no means a complete and full account of all the errors in the text of the document since there are many repetition of similar errors in the document.

Recommended corrections on reference document:

Industrial Waste Evaluation Model (IWEM) Version 3 Beta: Technical Document

ES-1; Right Column first bullet: Protecting AIR QULITY in WMU design is mentioned. I did not see an air quality analysis in this report? (see note below).

ES-1; Right Column second bullet: Monitoring analysis or help is mentioned. I did not see any monitoring analysis in this report? (see note below)

ES-1; Right Column third bullet: Corrective action claim? Misleading. Can only be done by repeated and iterative analysis. This is a lot of effort and given the uncertainty in the current model parameters I would not use this application for corrective action study. (see my note below)

ES-1; Right Column fifth bullet: Post closure action claim? Misleading. Same reason as above. (see my note below)

ES-1; Right Column first paragraph: Risk based approaches? Misleading. (see my note below)

Note: All of the above comments refer to applications that IWEM cannot be used to analyze. Maybe the referenced *GUIDE* system that is mentioned in the document can be used for this purpose, but when one sees these references in IWEM document without an explicit and detailed reference to *GUIDE* analysis system, the user may get the impression that they can do all these application using IWEM. In my opinion, without giving a clear definition of what *GUIDE* is and what it does, the authors are giving the reader a misleading interpretation of the use of IWEM.

ES-2; Right Column: Defining RISK ANALYSIS as comparing a user supplied RGC value with model outcome is a conceptually wrong use of the RISK ANALYSIS techniques. More importantly probability of exceedence analysis should be performed for proper evaluation of RISK when Monte Carlo analysis is used. This is a standard procedure for risk analysis. This would involve the computation of complementary cumulative probability density function which is never mentioned in the document. The current definition is the wrong definition to use in RISK ANALYSIS.

ES-6; Left Column: Statement: "*If site-specific data are not entered, values are drawn randomly.*" This recommendation does not make much sense. Why random data is entered for a site specific case. At least one should recommend the selection of representative values based on **descriptive definitions** of the properties of the site that is provided by the user. Otherwise the application becomes a totally an arbitrary (random) application which would not represent the site conditions and the MC analysis will not provide the uncertainty bounds of such a site specific application since all the initial parameters used are random? This is a wrong recommendation and misleading.

ES-7; Right Column: 90th percentile is not the correct definition for the risk analysis. Probability of exceedence is a more computationally effective way to calculate risk based on an exposure criteria. This is the wrong definition and it is misleading.

Page 1-3: 90th percentile is not the correct definition for the risk analysis. Probability of exceedence is a more computationally effective way to calculate risk based on an exposure criteria. This is the wrong definition and it is misleading.

Page 2-1, First paragraph under 2.1.1: "*Controlling the release*" is not the proper terminology "management" is better. Obviously, we cannot control environmental systems we can only manage them.

Page 2-1, First paragraph under 2.1.1 mid-section: "...*WMUs is to evaluate the appropriateness of a proposed liner design in the context of other location-specific parameters such as precipitation*," IWEM does not use precipitation it uses infiltration?

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Page 2-3 Figure 2.2: Figure needs revision. There is vertical flow under the roadway cross-section not the regional flow from left to right.

Page 2-4 Bottom: This is extensive computation time. Usually this process takes few minutes for 10000 simulations on desk top computers or laptops in a similar software (ACTS) for much more complex applications than the ones used in IWEM? This renders the current application computationally inefficient (maybe a coding issue)?

Page 3-4, Bottom: "…*EPACMTP does not account for fluctuations in rainfall rate or degradation of liner systems that may cause the rate of infiltration and release of leachate to vary over time*." This is not the correct terminology because the depleting source boundary condition that is used in EPACMTP is a leachate source which varies over time. This is considered as Boundary Condition in EPACMTP. Thus, this is inconsistent wording of time dependence, needs correction.

Page 3-7, Figure 3.6: Same problem with flow direction.

Page 4-1, First Paragraph mid-section: Too short a description to introduce the definition for time dependent boundary condition used for the saturated zone model. This needs to be extended for clarity. Or is time dependence truly used here? It is not clear? Since the contaminant flux coming in from unsaturated zone is a function of time and that zone is a boundary to the saturated zone this is an important issue and needs to be addresses in detail.

Page 4-1, Second Paragraph mid-section: This definition or concept is not correct. The steady state nature of the well concentration at a distance from the source is not only a function of Boundary Condition used but it is also a function of the distance between the well and the source and also the exposure period that is considered in the analysis. This statement is conceptually not correct and misleading. It should be further clarified in the document that the well is not operating. Its location is only a reference point for the application as an exposure point.

Page 4-1, Figure 4.1: What if the exposure averaging period belongs to another time range (see the pink domain below?) that only corresponds to (say) the raising part of the concentration breakthrough profile. Assume that the Trimester exposure period of a female is that period? Than what? Here the authors have described an ideal situation which is only one of the many possible cases. This is misleading and not correct.

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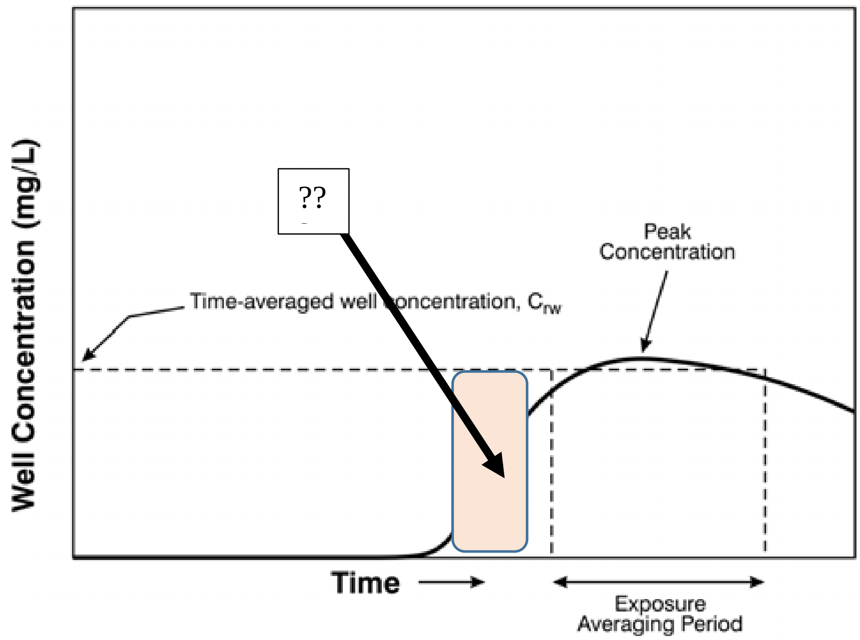

Page 4-2: Equation 4.1 has problems as mentioned earlier.

Page 4.4, Bottom Paragraph: The paragraph starts with steady flow definition, than it is stated that velocity is increased. Needs better wording. Obviously both are steady state. In the mound case velocities are **recalculated** not increased (as if it is increasing with the formation time of the mound).

Page 4-5: Equation 4.6 has problems as mentioned earlier.

Page 5-2: MC section needs revisions with appropriate definition of RISK ANALYSIS. Probability of exceedence calculations using the Complementary Cumulative Probability Density function is the proper definition and evaluation of Risk.

Corrections on reference document:

Industrial Waste Evaluation Model (IWEM) Version 3 Beta: User's Guide

Page 2-1, above Table 2.1: No liner is not a liner type?

Page 2-3, Top: What is a complex site? That definition needs to be introduced here. There are several possible complexities?

Page 2-3, Top: There are other more important complexities that are not mentioned here. Heterogeneity? Fissures? Flow conditions Gradient? Proximity to exposure point? The complexities selected here are not proper.

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Page 2-9. Top: It is stated: "*These processes decrease constituent concentrations in the ground water as the distance from the source increases*" This is misleading, the processes described decrease the concentration as a function of TIME not by distance by their definition. But since the contaminant is being transported over some distance its concentration decreases by distance as well.

Page 2-11, Bottom: It is stated: **"***However given sufficient site-specific data, it is possible to approximate the effect of these transport processes by using a lower value for the kd as a user-input.***"** Why not recommend to use the MC application to resolve the uncertainty in this issue?

General: Step-by-step instructions is good but inclusion of sample input data files will be very beneficial for the user.

References

1. Industrial Waste Evaluation Model Version 3 Beta (IWEM v3.0)

2. U.S. EPA. 2014. Industrial Waste Evaluation Model Version 3 Beta: Technical Background Document. Peer Review Draft. Office of Resource Conservation and Recovery, Washington, DC. Prepared by RTI International and HydroGeoLogic.

3. U.S. EPA. 2014. Industrial Waste Evaluation Model Version 3 Beta: User's Guide. Peer Review Draft. Office of Resource Conservation and Recovery, Washington, DC. Prepared by RTI International and HydroGeoLogic.

4. Charbeneau, R. J. 2000. Groundwater Hydraulics and Pollutant Transport, Waveland Press Inc., 593p.

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Peer review of: Industrial Waste Evaluation Model (IWEM)Version 3.0
Prepared for: Industrial Economics, 2076 Mass. Ave, Cambridge, MA 02140
June 29, 2014

IWEM appears to be an excellent tool for making simple but useful approximations of the risks of groundwater contamination. The challenge in developing this tool was to find a way to efficiently move from "soup to nuts," to link a sequence of calculations all the way from the specific geometry of contaminant sources to finally generate Monte-Carlo predictions of downstream concentrations. I agree that the Monte-Carlo approach is necessary because of the large uncertainties. But, how to build this model without creating an incomprehensible monster code? My impression is that authors have succeeded pretty well. The code synthesizes a remarkably wide range of databases and predictive models. I am particular impressed with how a variety of data bases of parameters have been built into the Monte Carlo framework. I can't easily point to any particular aspect of the model as the weakest link – I can (and will) quibble with individual links in the chain, but I can't name the weak link. I believe this indicates that the authors have reached a good balance of accuracy and efficiency across the different parts. They do not load any one step with too much detail. Below, I list questions, concerns and suggestions and then provide specific responses to the charge questions.

(1) The authors should consider adding an early section that diagrams, with reference to detailed future sections, the water and chemical flows that the code simulates. This section would separate the flow calculations (water fluxes and velocities from the source through the aquifer), from the simulations of chemical transport and transformation. This separation would help users understand the rest of the document because the model is coupled in only one direction. Flow drives all the chemical transport but there are no modeled processes by which chemistry can affect flow. The sequential approach of to chemistry is natural to follow. As it is, I find it a bit confusing that the model input and report jump between the flow and chemical components. Such a "master diagram" would be very helpful if flow arrows were annotated to show to show which sections of the document describe the calculation of each component.

(2) I am confused about a number of related aspects of the groundwater flow calculations and list these here as four separate items.

i. A set of figures (2-6 in Users Guide, ES-1, 2-3, 6-3 in the Technical Document) show a cross section through a plume emanating from a source. All of the figures show the contaminated water filling the area below the water table down to what appears to be a flow line emanating from the upstream edge of the source. Is this really what the simulated plumes look like? Does the model neglect clean recharge entering above the plume and displacing the plume downward in the aquifer? This appears inconsistent with the description of recharge (section 6.3.3 in Technical Document). In the figure below, I show what the plume should look like. Contaminant plumes can pass beneath shallow well screens. The figures in the report appear to show that this can never happen.

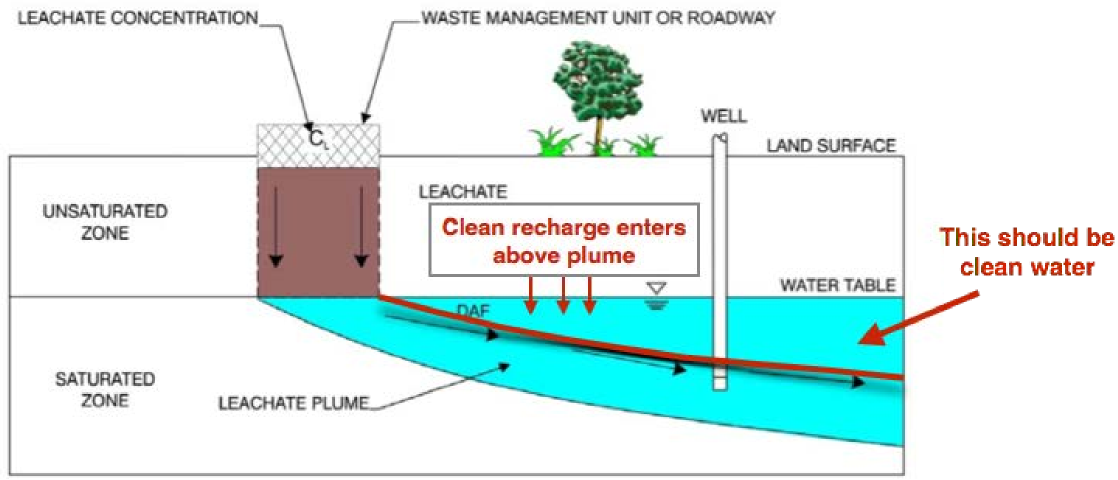


Figure ES-1 Conceptual cross-section view of the subsurface system simulated by EPACMTP.

ii. I am confused by how groundwater velocities are calculated. The program accepts input of the saturated thickness, hydraulic conductivity, hydraulic gradient and effective porosity. I gather that, if all of these are entered, then the velocity is calculated by Darcy's law. If none, or only some, of these parameters are entered, then the other needed parameters are generated randomly from the HGDB database taking into account correlations between the parameters found in the 400 sites sampled for the data base. With this approach, the calculated velocity is independent of the recharge (entered or randomly generated) or the distance from a groundwater divide or discharge location (not discussed). However, the report also talks about simulating hydraulic heads and flow. On page 4-5, the technical document states that the "The pseudo-3-D module simulates groundwater flow using a 1-D steady state model for predicting hydraulic head…" This leaves the impression that Darcy fluxes are calculated after solving the differential equation for head – such a calculation would include recharge and would need boundary conditions.

The best approach would be to use the simple solution for the 2-D, cross-sectional, flow field in homogeneous aquifer with constant recharge: horizontal velocity that is uniform with depth but increases linearly with distance from the divide; downward vertical velocity that decreases linearly from the water table, where it matches recharge, to the aquifer base where it is zero. This simple model captures the basic flow pattern of layered groundwater flow with flow paths entering at the surface and becoming more horizontal with depth.

This approach would also link to an important aspect of IWEM. IWEM considers recharge calculated for different regions of the US to calculated the infiltration through WMUs. This same approach could be used to determine the top boundary flux for the groundwater model.

iii. It appears that the current model only moves solutes to depth through vertical dispersion. This may be an adequate approximation, but it is not clearly explained. It is a conservative "protective" approximation. In reality, the flowtube extending downgradient from a surface source looses solute by vertical dispersion both downward and upward into underlying and overlying flow tubes. The model here, only allows for dispersion downward. Consequentially, it models about half of the dilution that would really occur.

iv. Two basic features of groundwater flow are that: (1) it is slower in arid environments and; (2) It accelerates from groundwater divides toward discharge, usually in rivers. I believe IWEM neglects both of these features.

The first feature, faster groundwater flow in wetter regions, should relatively easily be incorporated in IWEM through the regional recharge map – where recharge is large, the hydraulic gradient is large and hence groundwater flow is fast. Is this part of the model? Or is the hydraulic gradient generated without consideration of the local recharge? It is clear that regional recharge rates are used to calculate the infiltration form WMUs, but are they also used to estimate the groundwater velocity.

The second feature, position of the well in a flow tube, appears to be absent. I would encourage EPA to consider adding an input for distance from groundwater divide and distance to groundwater discharge, then using the recharge to calculate the velocity along the flow tube. This would be an easy addition that would improve the estimate of groundwater velocity, a key control on the ultimate Monte Carlo results.

CHARGE QUESTIONS

1. **New Model Features.**

The new features of IWEM appear to adequately represent roadways, although I am not a roadway expert. One aspect that I can see missing is the case where water from a roadside ditch accumulates in a topographic depression. In this case, contamination from the road would be concentrated in one location, then either contaminate a stream or infiltrate locally to produce to produce a larger groundwater contamination plume. I don't believe the model can currently represent this situation, and in some landscapes it may be the primary mechanism by which roadway contamination enters the environment.

2. **Flow Equations.**

Ditches. I only understood the modeled flow in and out of ditches after working through the equations in appendix section C.2.2.5. In other words, the conceptualization is only fully explained through its mathematical formulation. The water balance and contaminant balance for the ditch should be better explained by adding an improved version of figures C-9 and C-16 into an earlier section of the document.

If I understand the model correctly, the crux of the approach is that the depth of water in the ditch H_{Str} is constant along the ditch and is determined by the model. The depth of water in the ditch H_{Str} links the infiltration out the bottom of the channel to the upstream inflow and down stream outflow because H_{Str} is a variable in both Darcy's law for infiltration and in Manning's equation (C-19) for flow through the ditch (it is found in the calculation of the hydraulic radius R which is in Manning's equation). H_{Str} is set by the balance of inflow from the local road segment and outflow by infiltration, then it is used to calculated the flow down the ditch. Inflow along the ditch from upstream of a segment equals out flow to downstream of the segment (e.g. equation C-13), – no net inflow or outflow through the ditch to other segments. Is this correct? If, so it is a nice approach when only considering one segment, and I think it should be clarified earlier in the description.

However, I am confused about how this formulation can be used for multiple ditch segments. Equations 38a-c appear to allow for different inflow Q_{in} and outflow Q_{out}. This seems physically reasonable -- steeper segments have faster flow through the ditch allowing the water to be shallower (smaller $H_{Str)}$ and diminishing infiltration so that there would be more discharge out the downstream end of the ditch. I see how the recursive equations C-38 and C-39 provide an elegant way to link both the flow and the concentrations in the segments. But, I am confused about how Manning's equation is applied to a ditch segment if Q_{in} does not equal Q_{out}. (Could be as simple as using the average Q.)

My overall feeling is that this problem is nicely formulated, but the explanation could be better and that use of diagrams and figures could be much better. A better explaination should address my specific questions, but also help any reader understand both the IWEM code and the underlying physics of infiltration, flow, and contaminant transport from roadways.

One simplification that should be highlighted is that the depth of water in the ditch is constant over both time (steady flow assumption) and the length of the ditch (see above). This is important because Manning's equation is nonlinear with H_{Str} so the steady-state value of H_{Str} for the average rainfall is not the time average of varying H_{Str} for transient flows driven by storms. I think this is an acceptable approximation, and trying to model the transient effects of rainstorms would be very expensive! But this assumption should be highlighted because the model could be quite inaccurate in places where rain falls in few big storms instead of a constant drizzle. In big storm, most of the flow may flush through the ditch quickly, whereas in a constant drizzle there may be much more infiltration through the ditch.

HELP model. It was smart of the developers to employ the HELP model, a standalone model that has been reviewed and described elsewhere. However, some additional explanations of the fundamental aspects of HELP would improve the IWEM documents.

What is meant by "The HELP model is a quasi-two-dimensional model" (6-16)? I would have guessed it's one dimensional – where's the quasi-second dimension? How does HELP calculate evapotranspiration? The best approach would be if HELP took into account the seasonal climate and specific weather of each location to calculate transient evapotranspiration. This would supply good estimates of the annual average to be used in IWEM. Was HELP employed for these transient simulations?

3. **Contaminant Flux**.

The superposition of solute input from different roadway strips and layers should be clarified. What is meant by **"**Aggregating" concentrations from multiple strips and layers? (Top of page 2-3, "IWEM aggregates…") Does aggregate mean that the concentrations from different strips of the same constituent are summed? Or does aggregate mean something more complex?

Furthermore, how are inputs from the different layers handled within a strip? The formulation in Appendix C.2.2.1 appears to model solute input to groundwater from the layers as sequential – all of the contaminant enters from the bottom layer, followed by transport downward of a pulse of contaminants from the next higher layer, and then sequentially up to the top. Solutes do not mix across layers. Does this mean that different layers in the same strip can never contribute chemical input to the aquifer at the same time? This may be a reasonable approximation, but it should be explained. It may be a reasonable model because, for any particular contaminant, a linear adsorption model constrains the solutes to all move down in sequence never overlapping each other or diluting. This is an interesting idea, but needs to be much better explained.

4. **Model Simplicity**.

I am unconvinced that the roadway addition to IWEM must be three-dimensional. A two-dimensional cross-section through a road segment might be sufficient and perhaps better in certain circumstances. For a long straight road, the contaminant input may be approximately the same along the entire road. In this case, there is no reason to include the lateral dimensional along the direction of the road. I can see two cases where the third dimension is needed: (1) If the distance to the receptor road is great and the road takes a sharp curve; (2) If the transport of contaminants by flow in a ditch is significant. (See my comments above.) If neither of these cases is true, then the model is unnecessarily complex by including the third dimension. Unless a road has sharp bends, it could reasonably be approximated as laterally infinite line source. So, the question is: are there a significant number of cases where the third dimension is necessary? It seems that the documentation should prove that there is a real advantage to the third-dimension before adding it. The simpler 2-D approach could still work when groundwater flow is not perpendicular to the road.

For the other WMU's, such as landfills, the lateral extend may be short relative to the distance to the receptor well, so they could no be simplified to a line source. Roads are, in fact, simpler in this regard.

5. **Documentation.**

In general, better figures and diagrams would help. I see several categories of useful figures that could be added:

i. Diagrams of flow and then solute transport processes. These would include variable names as used in equations, as well as the equations themselves or references to equation numbers. These figures should emphasize water and solute balances – inflow and outflows and changes in storage. They could pair pictures of the true processes in the real world, with its heterogeneity, with diagrams of the model processes. These pairings could be used to illustrate model simplification and assumptions.

ii. Where the model shift its calculations. There are several parts of IWEM where calculations are made differently based specific cases. For example, the code decides if a ditch is dry or overflowing before calculating flow in the ditch. It would be particularly useful to develop diagrams of the internal decision trees for these cases.

iii. Better illustrations of databases. This would include histograms of the hydrogeological parameters from HGDB from which realizations are drawn for the Monte Carlo simulations and maps of the national databases.

iv. Case studies. Users would greatly benefit from example problems. Actual, real world, case studies are a very useful mechanism for making a complex package like IWEM accessible. These case studies would begin with data collection, giving examples of how local data may be found, then show the input and output of IWEM, and finally contain a discussion of the results. Users could then approach IWEM by first studying the case-study that most resembles their site. I strongly recommend the addition of a section of example cases that span the range of IWEM's capabilities, different WMUs different, different contaminants and different areas of the US.

Peer Review of the Industrial Waste Evaluation Model (IWEM) Beta Version 3.0

Dr. Lin Li
June 15, 2014

Summary of Conclusions

Compared to IWEM 2.0 version, the IWEM 3.0 (beta) adds leaching through the roadway cross section with ditches, drainage, and surface runoff as optional elements. The additional function can be used for the leaching impact study for the roadway system with ditch, gutter, embankment and surface runoff consideration. The new version makes the IWEM closer to realistic roadway condition. During the technical review, there are major concerns about the add-on functions related to the pavement material property, leaching pattern, ditches and surface runoff.

Table 6-16 of Technical Documentation needs major revision. It contains unnecessary information, such as “Wilting point” and “Curve Number”. The low-end and high-end of pavement materials properties are far off from the practical data range. If the user has incorrect information from the Table 6-16, the following simulation is also incorrect. The following Table 6-17, 6-18, 6-19 and 6-20 of Technical Documentation needs much clear explanation about how to get these data and how to verify these data, because some of these data are out of typical ranges. The pulse source assumption is suggested to revise. The “first flush” and “lagged response” leaching pattern should be considered.

The detailed comments are shown in the following section. A major revision is strongly suggested.

Charge Questions and Responses

1. New Model Features.

The current version of IWEM 3.0 (Beta) setup the maximum value of 15 of roadway strips, 5 layers of per strip, 2 of drains, 2 of ditches, and 2 of gutters. The assumption may not be validated for two parallel highways separated with median ditch (such as northbound and southbound highway). It is suggested to increase the maximum number of roadway strip to 20, number of drains (more than 3), number of ditches (more than 3) and number of gutters. The number of gutters should be as a number of gutters per unit distance along the roadway.

There is no embankment input parameters in this beta version. The embankment should be illustrated in the roadway stretch. Embankment input parameters can include the geometry of the embankment, and elevation of the embankment. Since embankment is higher than ground surface, the elevation of the roadway should be included in the input parameters. Another issue about the embankment surface runoff consideration. In case the industrial materials are used in subbase layer in the embankment which can be above ground surface, the runoff may contain metal contaminants. Can the IWEM consider this scenario?

IWEM assumes that infiltration from the traversing roadway is on the order of regional recharge. However, infiltration may be much higher in the unpaved shoulder than the paved median. The infiltration may be much higher in the embankment. The regional recharge is time-average estimation, but the infiltration is time-dependent. Can this assumption be re-written as the bottom limit of infiltration from the traversing roadway is on the order of regional recharge?

IWEM assumes that lateral communication between roadway-source strips is insignificant. This assumption has limitation for embankment. When the base layer has slope, most of infiltrated water flows out of the roadway horizontal instead of vertical.

Including gutters in the roadway system should be optional, because a highway typically does not have gutters.

Figure 2 and Figure 3 in the user manual are unclear to read. A better resolution should be included for the two figures. There is a need for a better sketch of ditch to define the slope, water depth in ditch, and thickness. The gutter shape is also needed in the sketch.

The infiltration/percolation/evaporation is used in the manual. The definition should be provided, since the three terms are easily confused to the user.

Table 6-2, Term “Ditch strip drain drains to→strip number of the ditch for this drain” is confusing. Suggest rename “Layer drain is above” as “layer number underneath the drain”, suggest rename “Drains what strip”as “which strip need drains”.

Table 6-2, it is difficult for user to provide “Flow Percentages to Ditch Strips (for relevant strips and drains)”. Suggest rename as “Percent of roadway runoff that reaches ditch”. Is it possible to include it for Monte Carlo Simulation?

Table 6-2, it is confusing “Percent of flow in drain that reaches ditch”. Need definition first. It is confusing for “Ditch strip(s) receiving overland flows”.

Page 6-11, it is confusing “Once the mass of leachable constituent is known, the duration of leaching from a material layer is calculated”. Please revise it.

Table 6-4, how user to provide: “Infiltration rate through a strip (m/yr)”, “Runoff rate (m/yr)”. “Precipitation rate (m/yr)”, and “Evaporation rate (m/yr)” for roadway module. It is too complex for common user.

Figure 6-6 divides the US into 12 climatic zones. It is acceptable for a screening model used in US. But IWEM model is an international widely used screening model. The climatic zones in US will limit the IWEM model as domestic code only. In my personal opinion, it will significantly reduce the international usage of the new IWEM function. It is suggested to consider global climatic zones. In each climatic zone, the two climate stations located within the zone from the HELP climate database, with minimum and maximum 5-year ave precipitations, are selected (Table 6-15). The minimum and maximum precipitations only cover the range of the precipitations within the climatic zone. Is it possible to add mean precipitations within the climatic zone?

Since IWEM model is screen-level model, the Table 6-16 of Technical Documentation is too complex. It involves so many uncertainties. The user may not select correct material properties for each layer. The Table 6-16 should be much more condensed. For example, the “Median (unpaved) is same as shoulder (unpaved)”. Most of users do not know the definition and usage of “Air void”, “Total porosity”, “Field capacity”, “Wilting point”, and “Curve Number”. There is no “ML” or “GP” for the US Department of Agriculture soil classification system. It is suggested to add AASHTO soil classification system in the Table, because all of DOT contractor/officers are familiar with AASHTO soil classification system. The "subbase course" is one layer of "optional" layer. Sometimes it is non-existent in the pavement system. The data source of Table 6-16 is unclear. There is no subscript of 8 in the Table. A typo of "Eqation" is found in subscript of 4. If we only look at the low-end and high-end, the data is far off from the practical data range. The Table 6-16 is strongly suggested to revise. If the user has incorrect information from the Table 6-16, the following simulation is also incorrect.

Table 6-16 used Apul et al. (2002) for the pavement material properties. The Apul et al. (2002) is a report, which is not a peer-reviewed authoritative publication. The adoption of using this report by IWEM model (EPA) is not suitable. **A more authoritative literature review should be conducted for the latest peer-reviewed publication for the pavement material properties, especially for industrial waste materials.** I am willing to help in this part. It takes more times, but it is definitely needed. The pavement material properties will decide the infiltration rate through the pavement system. The Table 6-16 contains too much information that will not be used in the model, such as "Air void", "Texture", "Field capacity", "Wilting point", and "Curve number". All of these terms are confusing and non-familiar to ground water flow modeler. The Table 6-16 contains low-end and high-end data for top/base/subbase course. If we only consider the single row of data, it seems correct. But when we look at the entire pavement from top to bottom layers, the data of this table are incorrect and misleading. The structure of this table is suggested to modify to reflect the entire payment system.

In Table 6-17 of Technical Documentation, how to get the infiltration rates? Is it verified with authoritative published results? It is so high of an infiltration rate for embankment at Annette, AK. The data is out of typical ranges. In Table 6-18 of Technical Documentation, how to get the runoff rates? Is it verified with authoritative published results? The data is out of typical ranges. In Table 6-19 of Technical Documentation, how to get the evaporation rates? Is it verified with authoritative published results? Is it for HIGH and LOW? In Table 6-20 of Technical Documentation, how to get the pan evaporation rates? Is it verified with authoritative published results? Is it for HIGH and LOW?

Table 6-17 to Table 6-20 depends on Table 6-16. How to get the data in these tables? It is unclear in the technical documentation. Are they for general pavement materials or for industrial waste materials? What are the reference/equations for the calculation? What is pan evaporation used for? Is the reference NOAA (1982) too old? Can we consider the latest reference?

2. Flow Equations.

Figure C-7 of Appendix has typo. The Figure is from Apul et al. (2002). It is suggested to update it from the AASHTO standard or FHWA publication for the pavement section. The "permeable base" is the first time used here, but it is not discussed in the technical documentation. Where is the subbase in the Figure C-8? The term of "Exfiltration" is the first time used here, but it is not discussed in the technical documentation. The permeable base is referred from Van Sambeek (1989), and filter reinforcement layer is referred from Christopher (1998). Both terms are not familiar to the common user. Suggest more authoritative references to revise this part. The Equation (C-8) and (C-9) are in question. How to derive these equations? Equation (C-10) and (C-11) depends on the assumption of permeable base and filter reinforcement layer, which needs more careful justification in the typical pavement systems with industrial materials. Equation (C-12) and (C-13) are in question. How to derive these equations?

The section of “C.2.2.3 Multiple Material Layers with a Drainage System” is based on (Christopher and McGuffey, 1997; Apul et al., 2002). It is unacceptable for these old references for the 2014 IWEM Model. It has been updated to the current references.

The section of “C.2.2.4 Runoff from Top of Pavement and Discharge from Permeable Base” is based on permeable base for the runoff estimation. If there is no permeable base, are Equation (C-19) and (C-20) validated? In the Equation (C-19), how to calculate RO_i, and what is w_L and L? What is C_{PB} in Equation (C-21) and how to get it?

Figure 6-6 divides the US into 12 climatic zones. It is acceptable for a screen model used in US. But IWEM model is an international widely used screening model. The climatic zones in US will limit the IWEM model as domestic code only. In my personal opinion, it will significantly reduce the international usage of the new IWEM function. It is suggested to consider global climatic zones.

3. Contaminant Flux.

IWEM defines contaminant flux as infiltration rate multiplied by initial leachate concentration. The pulse source is assumed based on screen-level analysis and a pulse source is assumed appropriate for metals. The reference for this critical assumption is missing from the technical document. Creek and Shackelford (1992) and Sauer et al. (2012) indicate that leaching patterns for coal combustion products (CCPs) and highway materials stabilized with CCPs generally can be grouped into two classes referred to as “first flush” and “lagged response” leaching. As shown in Fig. 1, the “first flush” pattern is characterized by monotonically decreasing concentrations as water percolates through the CCPs (Bin-Shafique et al. 2006), whereas the “lagged response” pattern is characterized by decreasing concentration followed by increasing concentration. First-flush leaching patterns from CCPs generally correspond to adsorption-controlled release and can be described mathematically by advection-dispersion-reaction equation with instantaneous, linear, and reversible sorption (Bin-Shafique et al. 2006). Lagged response leaching can be attributed to a variety of geochemical processes and generally cannot be described using a single mathematical function used in WiscLEACH (Li et al. 2006). WiscLEACH was originally developed by Li et al. (2006) for assessing potential groundwater impacts associated with fly ash stabilization in roadway construction. Based on three analytical solutions for the advection-dispersion-reaction process in the subsurface, Li et al. (2006) only evaluated the “first flush” leaching pattern in the two-dimension application of fly ash stabilization. WiscLEACH was revised to extend the capacity of original WiscLEACH from a two-dimensional application of fly ash stabilization to a three dimensional application of embankment and structural fills in roadway construction. The “lagged response ”and“ first flush leaching patterns are both included in this revised WiscLEACH (Li et al. 2011). The WiscLEACH has been used in several studies of industrial materials in embankments (Cetin et al. 2013ab, Li et al. 2014).

Since the contaminant flux is critical for the IWEM prediction, it is strongly suggested to consider either to provide more detailed documentation for the current assumption, or to adopt the “first flush” and “lagged response” leaching pattern instead of pulse source.

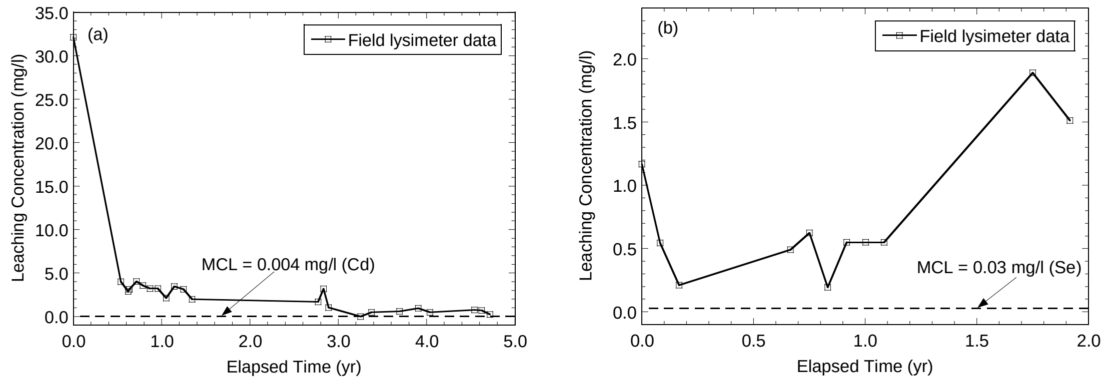


Figure 1. Example of leaching pattern from the CCP application in roadways construction: (a) first flush elution pattern measured from the fly ash subbase stabilization at STH 60 (Edil et al. 2002); and (b) lagged response elution patterns measured from the fly ash embankment at the Colebrook, NH (Gardner et al. 2009).

IWEM needs Constituent-specific initial leachate concentrations and total concentrations in layers containing reused materials. How to use total concentration in the model?

4. Model Simplicity.

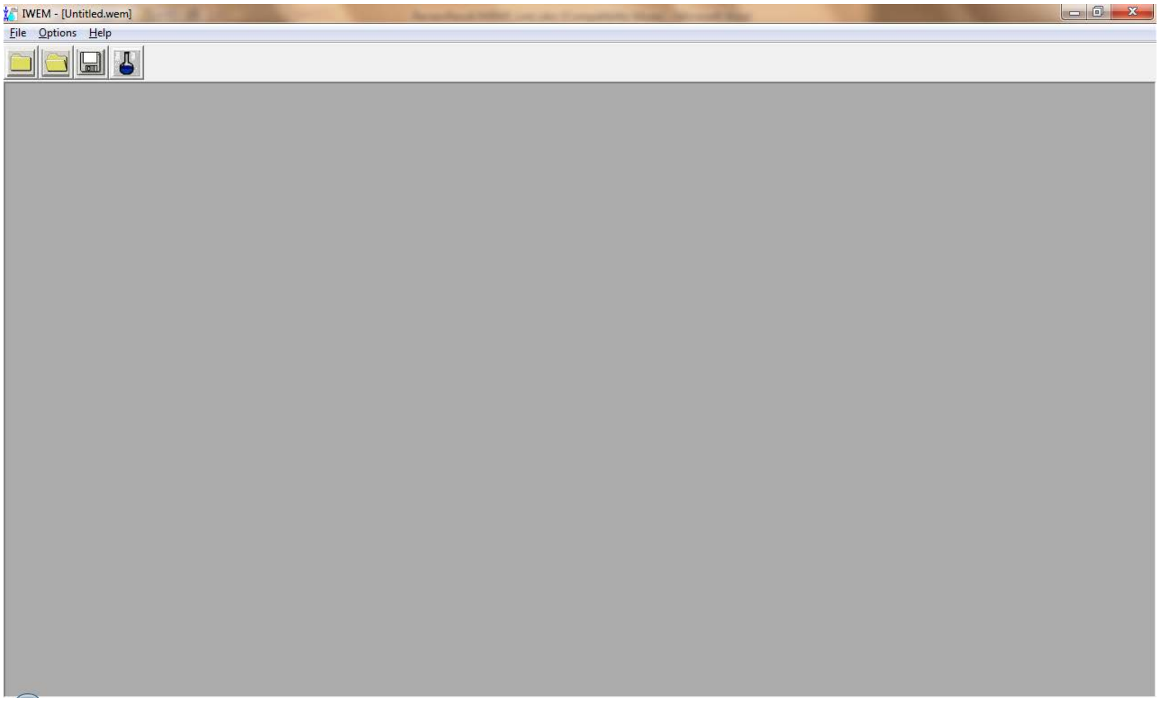
The IWEM 3.0 (Beta) makes the model complex, with so much additional input parameters compared to version 2.0. Some of the parameters should be merged, or removed. Some of the terms are unfamiliar even to experienced groundwater flow/transport modeler.

5. Documentation.

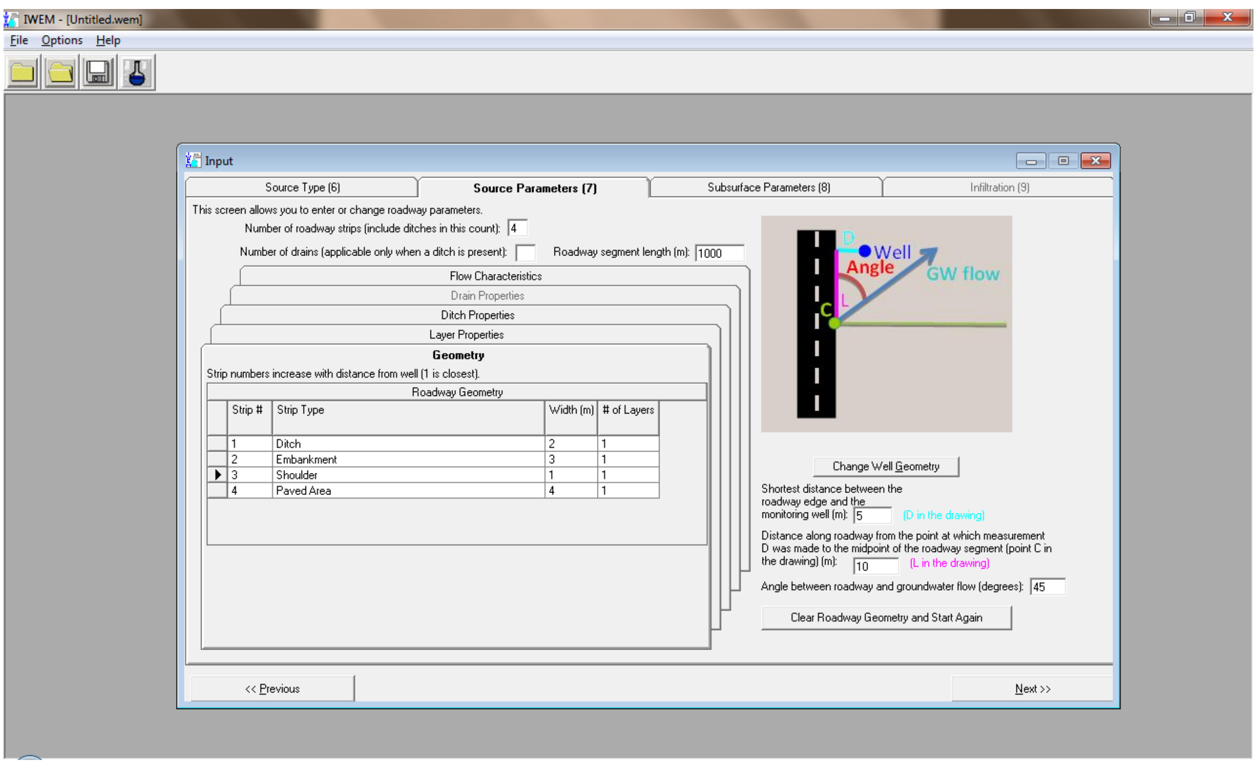
The technical manual and some parts of technical appendix should be combined, because all of equations are shown in appendix in the beta version. The equations are a key part to understand the technical part. After the literature are updated (see above comments), and the tables are revised (see above comments), the technical manual can be more readable to user.

Other General Comments

The IWEM interfaces are too old. When the user opens the IWEM, the icons of first screen are Windows 95 icons (shown in next Figure). Is it possible to change to at least Windows 7?



The “Source Parameters” with “Flow Characteristics”, “Drain Properties”, “Ditch Properties”, Layer Properties” and “Geometry” are flying and confusing to the user when user inputs the source parameters. Is it possible to fix their sequence or give labels with “1, 2, 3, 4, 5, …” to make a sequence for input of these source parameters. The flying interface does not help the user to input.



When the user finishes the input and clicks the run, a DOS window is popping up and shows the simulation in process. In the Windows 8 environment, is it possible to remove this pop up and only in IWEM interface to show a status line "Simulation is on, please wait"?

References

Please fully cite any documents or literature that you reference in the letter review.

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Peer Review of the Industrial Waste Evaluation Model (IWM) Beta Version 3.0

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Summary of Conclusions

(i) I reviewed earlier versions of the modeling package, specifically focused on EPACMTP. Beta Version 3.0, including the Technical Document, User's Guide and software package has been improved in many different ways. In particular, the Windows-based data input structure has significantly improved the usability of the code. The modular design of the new roadway module is sufficiently general that it will be able to facilitate the analysis of common types of roadways that will be encountered in practice.

(ii) There are no obvious problems in downloading and running the code. I ran two test cases from Appendix C of the User's Guide (B.1 and C.2) without difficulty, yielding the answers and reports presented in the User's Guide. My audit of the software shows that the data entry works fine and the transport module provides correct answers. Overall, the design of the code is in keeping the vision of an easy to use package, which is appropriate for the target user group.

(iii) The Technical Document and User's Guide are well organized, reasonably well documented, and overall do an excellent job in facilitating the use of the code. They are written for a sophisticated reader with good background knowledge of groundwater flow and transport. I think that this level of presentation is appropriate, given that the model although billed as a screening tool does require background hydrogeological knowledge.

(iv) Beta Version 3.0 has opportunities for improvement. First, the level of complexity for even simple "roadway" cases is out of proportion to the other flow/transport process modules, e.g., saturated and unsaturated flow. In particular, the multiple roadway segment is unusually complex and relies on calculations outside of the code. I can expect that a typical user would not be able to understand how to do such an analysis. Overall, the roadway modules are obviously much more complicated than the other types of waste sources (landfills, ponds) and push the "screening" paradigm that has guide the development of the package.

Second, the usefulness of IWEN depends on generic databases to provide parameter estimates. I consider this to be a weakness because the approaches are dated and without appropriate verification of the data. My review here suggests alternative, site-based strategies.

(v) Following are three key recommendations. First, the simple evaporation/runoff/infiltration model should be re-examined in the context of a road. If precipitation is commonly delivered via high intensity rainstorms, I expect runoff to be much more significant as compared to the steady-state case with continuous, low intensity rains.

This version of the software and report appears to have focused on new modules. Going forward, I would secondly recommend that much more thought be given to more descriptive metrics of risk and performance that are more than just a comparison of a probability distribution number to some water quality metric.

Finally, I recommend improvements to the various written materials. The present Technical Document is cumbersome and unwieldy because of the blatant overuse of unintuitive acronyms. The mixing of metric and British units within the reports and appendices is confusing and makes the information less transparent. The report would benefit from an assessment of accumulated experience (concerns and suggestions) from users/stakeholders.

Charge Questions and Responses

1. New Model Features

The modular design of the roadway configuration is sufficiently general that it will be able to create common types of roadways that will be encountered in practice. Roadways are sufficiently complex in terms of components and design features (e.g., internal drains) that they appear to require many parameters to describe their behavior. My opinion in reading the reports is that routine application of the roadways module will be difficult and speculative because so much site specific data is required for the roadway source inputs.

(a) There are many implicit assumptions in the development of the roadway module. The most obvious is that infiltration through the roadway is steady state. This assumption of 1-D steady-state flow has been present in all the previous versions of EPAMCT models and probably reasonable for those applications.

Overall, the simple evaporation/runoff/infiltration model needs to be much more carefully examined in the context of a road. If precipitation is commonly delivered via high intensity rainstorms then runoff would be much more significant as compared to the hypothetical steady-state case with continuous low intensity rain. The HELP model is used extensively for parameter estimation, assuming readers are well informed as to how it works and what its limitation might be. The report and appendices contain tabulations, but little in the way of material (beyond E4.2) to support and explain the parameter calculations.

(b) The usefulness of IWEN product depends in many ways on national databases to provide parameter estimates. I consider this to be a weakness because the approaches are dated and without no verification of the accuracy of the guidance. A following section here suggests alternative, strategies.

Given the maturity of the product, I was expecting a more robust description of the HELP methodology, including a brief discussion of the method, and papers or reports describing experiences and any assessments of that material (beyond Section E.5). In many cases, reading what are likely highly uncertain parameter estimates (e.g., infiltration Table 6-17) to three significant figures suggests foundational assumptions about the model will require careful reconsideration.

Along the same lines, the subsurface parameters come from an old DRASTIC-based classification of hydrogeological settings. The DRASTIC methodology is obsolete as is for example Dr. Newell's 1989 assessment of subsurface settings (used pg. 6-45,46). I was a reviewer of that work back in the late 1980s but more modern approaches are available.

(c) Any estimate of concentration at a receptor well will require a good estimate of initial leachate concentrations. The report is weak in terms of guidance provided as to how these values will be estimated, one long paragraph on 6-13,14. The small size of this piece is out of proportion to treatment given to other parameters, e.g., infiltration rates.

The Recycled Materials Resource Center (RMRC) website is not particularly user friendly and would require work in extracting usable numbers for simulation purposes. I feel that it is a stretch to assume that users can develop appropriate numbers from testing data or field data (pg. 6-13). A suggestion would be to conduct a MINTEQ style analysis for some typical concentrations for type materials as a future work.

My concerns in this respect stem from the problem that the state-of-technology in industry for conducting leaching experiments is not particularly good. Examples I have seen are often plagued by experimental errors, problems in sample handling and other things.

2./3. Flow Equations/Contaminant Flux

Appendix C.2 to the Technical Document describes the development of equations for the calculation and timing of loading due to a roadway. The approach generally uses mass balance concepts to provide loading to the footprints of the various strips. The approach is generally straightforward and well described. This Appendix also summarizes key assumptions. I did not check the equations in detail.

Individual sections are used to describe relevant process details. For example, Appendix C 2.2.4 describes the calculation of runoff from the top of the pavement and along with discharge from a permeable base. Again, this piece is well described along with assumptions.

(a) There are opportunities for improvement of the write up. The "pulse" analogy is poorly described, assuming that a set of relatively complex equations provide a concept that is understandable by stakeholders. Section C.2.2.1 (page C-7) should begin with a conceptual model explaining the pulse modeling concept in words and with a picture. The pulse concept comes with inherent assumptions that are not fully explained.

(b) With the roadway module, the level of complexity for even simple cases is out of proportion to the other process modules, e.g., saturated and unsaturated flow. The details and complexity of the hydrogeological setting greatly influence concentration distributions. Yet, this part of the model has been simplified given the "screening" purpose for the modeling system. Moreover, the roadway modules are noticeably more complicated than the other types of waste sources (landfills, ponds).

Transport in the saturated zone is simulated by about 10 parameters, e.g., advective velocity, 3 dispersivity values, and sorption/decay processes. Compare this for example with the description of the complex roadway shown in Figure 1. This kind of roadway might require 100 to 150 parameters to represent the various components. Many of the necessary parameters will not be known for sites and end up as guestimates.

In the case of the landfill and waste rock pile etc. the model would seem to provide recommendations about design features, liner, cover etc. The road design could be so complex that it may not be obvious as to what parameters are driving the risk.

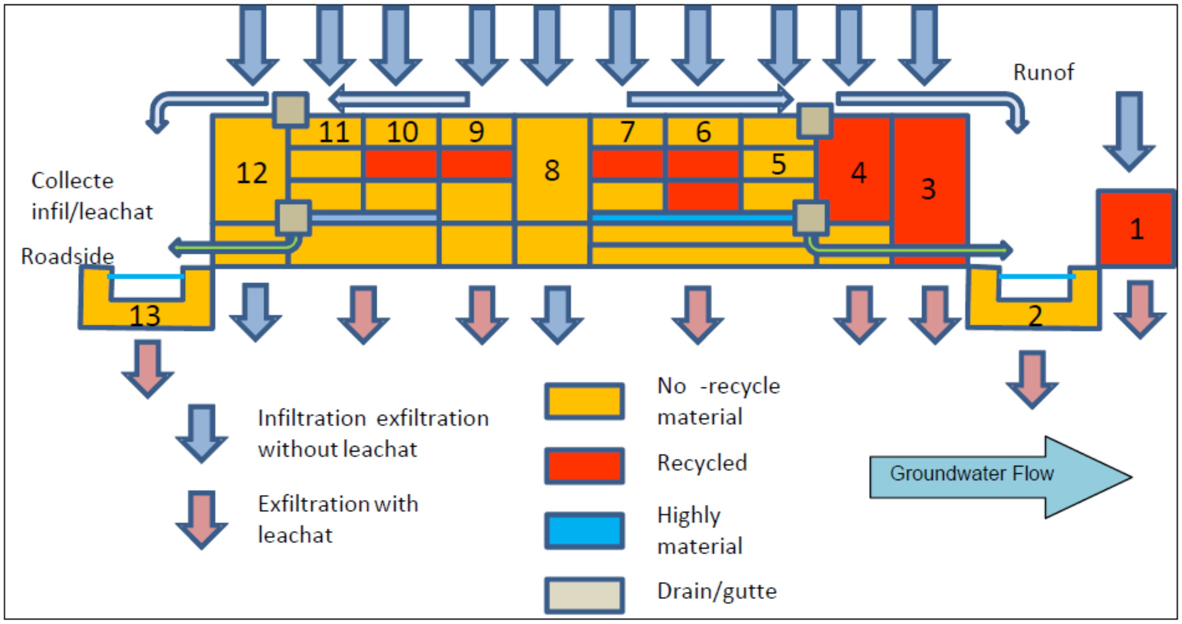

Figure 1: Example of a complex roadway from the report Appendix.

(c) Given the comments in 2 (b), I would like to comment on the development of equations for multiple road segments. If I interpret this short piece C.2.2.6 (Appendix pg. 20-22) correctly, the user needs a set of standalone tools that would take output from a sequence of IWEM runs and superimpose solutions and route mass along the ditch. I can expect that a typical user would not understand how to do such an analysis. If such a capability is desirable, then a simple worked example needs to be presented as a conceptual model, including steps explaining ditch routing and superposition of mass transport calculations.

My view is that the multiple road segment analysis is far beyond the vision of screening that guided the development of earlier modules. In addition, given the complexity and large number of uncertain parameters, it is questionable whether doing this kind of analysis would be credible in a regulatory sense.

(d) In terms of flow associated with the roadway, the analysis depends on several hard-to-estimate parameters. For example, the User's Guide on pg. 3-28 explains how users should provide a value e.g., "a percentage of Overland Flow to Each Ditch not Captured by Gutter". This number is totally empirical with no help to help determine the value. Similarly, on pg. 3-29, values for parameters as B. and C. are not well explained and could end up just being guesses. The User's Guide should contain more figures that make it clear what road geometry is being described in Figures 3-8 to 3-14. Otherwise, the parameter associations are very difficult to follow.

4. Model Simplicity

As part of my evaluation of the code itself, I ran two test cases from Appendix C of the User's Guide. The first was B.1, an example of land application of foundry sand in home gardens. The second was C.2 – Example Problem 1 for a roadway, in this case Wisconsin State Highway 60.

Running the two cases was straightforward, and the code yielded the answers provided in the User's Guide. I printed both reports without a problem. Thus, my limited audit shows that the data entry works fine and the transport module provides correct answers. Overall, the design of the code is in keeping the vision of an easy to use package, which is appropriate for the target audience.

(a) My expectation is that the model developers, as part of the model development, could have provided an illustrative example with a <u>detailed analysis</u> of the output. The examples in the Appendix to the User's Guide are helpful but cursory. One purpose would be to understand how uncertainty in input parameters provides uncertainty in ensemble statistics for a roadway setting. Such an analysis could serve as a starting point for a complete re-examination of what other kinds of output could be provided to the model user.

As the report discusses, a cumulative probability distribution with the Monte Carlo module can be interpreted to provide the probability that some standard will be exceeded. In the Technical Document example (Figure 5-1) shows concentrations varying over 7 orders of magnitude. Simply providing the concentration associated with a 90% probability of occurrence glosses over the fact that this system is very uncertain and <u>essentially unpredictable</u>. Every realization has an equal likelihood of occurrence and for this example concentration changes by about one order of magnitude for every 10% in probability.

This version of the software and report appears to have focused on new modules. Going forward, I would recommend that much more thought be given to more descriptive metrics of risk and performance that are more than just a probability distribution number, which are not known with much confidence.

(b) The software and databases go out of their way to provide numbers to users who have little in the way of site specific information. I think that the authors of the report at a minimum need to rethink their approach in dealing with sites for which the subsurface environments are <u>unknown</u>. For example, the User's Guide on page 4-19 shows how "national average" values are applied when a user selects the subsurface environment as unknown. There is no possibility that the default values of Table 4-4 would actually describe a specific site. I think that it is inappropriate to provide users a capability of creating results in absence of subsurface data – the result is meaningless.

(c) The so-called national databases need to be de-emphasized because as a practical matter they are old assessments, minimally validated and without a transparent basis in science. This was mentioned previously in section 1a.

Another possible solution would be to provide users with a series of online tools that would take specific qualitative/easily discoverable geologic observations about the site and translate them into model parameters. Such an approach was used in an expert system by McClymont and Schwartz (1991a; 1991b). The notion that a three word description of a site could yield a complete quantitative description of hydrogeologic setting is quite a stretch in my opinion. The scientific basis for the choice of parameters would be much more transparent to the users and evaluators alike.

(d) There is a real divergence in the roadway module with how parameters are chosen. On the one hand for the groundwater system, one can specify “unknown” and receive a default collection of parameters. On the other hand, as stated on pg. 3-20 of the User’s Guide all of the source parameters for the roadway are site specific and actual values must be provided. The parameter treatment in the total package, thus, is rather inconsistent and unbalanced.

5. Documentation

The Technical Document is well organized, reasonably well documented, and does an excellent job in facilitating the use of the code. It is written for a sophisticated reader with good background knowledge of groundwater flow and transport. I think that this level of presentation is appropriate, given that the model although billed as a screening tool will be require background hydrogeological knowledge.

I have reviewed earlier versions of this software specifically focused on EPACMTP. The present package including the Technical Document, User’s Guide and software package have been improved in many different ways. In particular, the Windows-based data input structure has significantly improved the usability of the code.

Future versions of the Technical Document have opportunities for improvement.

(a) The report is thin in cited literature describing the theoretical basis of the modeling approach. There is only about 1.5 pages of non-EPA references. Many sources are represented by "grey" literature rather than primary journal articles. A good example is Gelhar's EPRI report which was later published in Water Resources Research.

Here are particular examples. Where did equation 6-14 come from, and what units are buried in the so called conversion factor? Where did equation 6-5 come from? Is this Gelhar's equation or did the authors construct this from data presented in the report?

Another example is the whole concept of sorption of metals that are treated using non-linear sorption isotherms (Section 6.5.2.2). I have never seen this approach used and tested in models. I couldn't find one citation that explained where this approach was developed and how it was tested.

(b) The report omits a careful and consistent description of the different types of statistical distributions used in the model. For example, with Table 6-24 mention is made about Gaussian, log normal and log ratio distributions. Yet, I cannot find a discussion of these distributions. The obvious place for such a discussion is in Section 5.1. As far as I can see, the modeling uses cumulative versions of these as well as empirical or data-driven cumulative distributions. The discussion of distributions in the Technical Document should include a discussion of typical distributions – uniform, normal, lognormal etc., what they look like as cumulative distributions. Also, when data-driven distributions are developed, they should be explained in their own right.

The choice of distribution has some bearing on parameter ranges. For example, in Table 6-24, why is the lower limit of hydraulic conductivity 0 for lognormal distributions?

(c) The mixing of metric and British units within the reports and appendices is confusing and makes the information less transparent. For example, climate data from Table 6-9 is in inches, leading to infiltration rates in in/yr in Table 6-17. In the code (see Figure 3-18), apparently infiltration rates are needed in m/yr.

Hydraulic conductivity values are sometimes in cm/s or m/yr. In the future, consistency of units should be a priority.

(d) In my earlier reviews of versions of this material, I criticized the use of acronyms. The present Technical Document has approximately 50 acronyms of all kind. Often the acronyms are unintuitive. When a reader needs to constantly refer to page of acronyms, the report becomes cumbersome and unwieldy to deal with. This feature of the report is a substantial negative in the overall presentation.

The User's Guide with related appendices provides an understanding of how the code is used. As part of my evaluation, I downloaded a version of the code to my PC, and set it up according to the introductory material in Chapter 3 of the User's Guide. The set-up went smoothly with no problems, providing a code ready to go. The IWEM icon appeared on the desktop as indicated on page 3-1. As an aside, the icon has a rough and amateurish look.

(e) The various screens provided to the code users are well described in the User's Guide. I particularly liked the blue arrows added [A], [B], etc. along with the more detailed descriptions. In the code itself, the screens are well organized and laid out. Where necessary, the units assigned to numbers that are entered as data are indicated. There are a few places where labelling could be improved. One example is Figure 3-11, with the notation "Is Below Drain". The acronyms on some of the drop-down menus are also unintuitive in a few cases.

The drafted figures that sometimes turn up as part of a screen are sometimes rough looking. A good example is Figure 3-9 on page 3-22. The colors and detail of the small roadway figure are difficult to view.

(f) Both Appendices B and C provided a useful step-by-step description of how to do run the test cases. My only complaint was that case B.1 would have been helped by presenting actual screens, although the example was obviously simple. For Problem 1 in Appendix C, it would be better to associate Tables C-1 to C-3 with the actual screens. The actual screen shots in Appendix C (e.g., Figure C-5b and C-6) are too small and required a magnifying glass to read the numbers etc. on the figures.

(g) My only problem in running the code was in saving the final output. It could be my inexperience, but in both the examples run, I don't know where that information was saved.

(h) I examined the Built-in-Help available as part of the code. I think that what is there is helpful, but in its present form is rather barebones, mostly repeating things in the written manual. There is room for improvement here

Other General Comments

(a) Reading the documentation, it is not exactly clear how concerns and suggestions from the community of users/stakeholders actually percolate down to the code developers. Is the community happy with the model and do they use it?

(b) A quick search of Google also indicates that this modeling approach has not gained traction in the scientific/academic community. There are a few papers by the model developers but otherwise just a few others. To some extent, information on actual use in site investigations and other metrics (e.g., number of code downloads) could be interpreted in terms of its overall usefulness. Future advances in this modeling approach could be better related to wishes and needs of the user community. I would have liked to see this to help justify various directions taken in the future.

(c) On page 3-38 of the User's Guide, it appears that if a single Monte Carlo realization is unrealistic then it is discarded. If a subset of realizations in a Monte Carlo simulation is not used, there can be issues of bias in the ensemble statistics. It is not clear what a "sufficient" number of realizations is, but, the code developers perhaps should have a more definitive cutoff. Or, perhaps this cutoff exists and is just not written down

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