PEER REVIEW SUMMARY REPORT

Peer Review of the Industrial Waste Management Evaluation Model Version 3.0

Prepared For:

U.S. Environmental Protection Agency
Office of Resource Conservation and Recovery
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ACKNOWLEDGEMENT

Industrial Economics, Inc. staff, Mark Ewen, organized the independent external peer review and prepared this peer review summary report. Mr. Taetaye Shimeles of the U.S. Environmental Protection Agency, Office of Resource Conservation and Recovery, served as the Work Assignment Manager under Contract No. EP-W-12-013.

SECTION 1: INTRODUCTION

The Industrial Waste Management Evaluation Model (IWEM) software, as developed by EPA, helps determine the most appropriate design for a waste management unit (WMU), or a roadway built of reused industrial materials to minimize or avoid adverse groundwater impacts. IWEM does this by evaluating one or more types of liners (for WMUs) or the material properties and structure of a roadway and the expected leachate concentrations of the anticipated waste or reused industrial material constituents in conjunction with the hydrogeologic conditions of the site. The previous two versions (Versions 1.0 and 2.0) underwent external peer reviews in 2002 and 2008, respectively. For the IWEM Beta Version 3.0, the roadway source module has been enhanced to better simulate the potential for contaminants release from roadways by accounting for engineered systems such as drains, ditches, and embankments.

EPA retained Industrial Economics, Incorporated (IEc) to conduct a peer review of EPA's IWEM model (v. 3.0). This memorandum presents a description of the peer review process and summarizes the results of the peer review. Each of the peer review reports is included as an attachment to this memorandum. A copy of all materials sent to the peer reviewers is provided under separate cover.

SECTION 2: THE PEER REVIEW PROCESS

IEc conducted the review in accordance with the Peer Review Handbook, published by EPA (third edition, June 2006). Our management of the review consisted of the following general activities:

- Independently identified a list of 13 candidate expert peer reviewers, taking into consideration recommendations provided by EPA-ORCR related to targeted areas of expertise.
- Evaluated the expertise and appearance of potential conflict of interest or lack of impartiality of each of the 13 candidate expert peer reviewers.
- Determined the interest and availability of 8 of the 13 of candidate expert peer reviewers.
- Confirmed with each of the 8 candidate peer reviewers his or her area and level of expertise and any potential conflict of interest or lack of impartiality, or the appearance of any potential conflict of interest or lack of impartiality.
- Based on availability and interest, and excluding any candidates with any potential conflict of interest or lack of impartiality, or the appearance of any potential conflict of interest or lack of impartiality, created a short-list of six candidate expert peer reviewers and a preferred panel of four peer reviewers.
- Finalized a team of four expert peer reviewers.

- Initiated the review.
- Coordinated with the peer reviewers to finalize their written reviews.

The review was conducted as a paper review. Each of the reviewers received a packet of review material consisting of the following documents and computer files:

- Charge questions.
- Industrial Waste Evaluation Model Version 3 Beta (IWEM v3.0).
- 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.
- 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.

In seeking candidates to serve as expert peer reviewers, as well as in our selection of the final team of reviewers, we made an effort to include individuals with one or more of the following characteristics:

- Knowledgeable about fate and transport modelling, particularly that of contaminants from waste management units and roadway structures;
- With regard to fate and transport modelling, a special focus in roadway design, roadway hydraulics, and mathematical modelling of runoff from roads;
- Knowledgeable about overland and subsurface hydrology, hydraulics, stormwater and erosion management, water quality, and other related modeling areas (soils, waste management, utility wastes, and drinking water; geology; and geochemistry); and
- Knowledgeable about multidisciplinary areas including groundwater modelling, geotechnical engineering, and general knowledge of risk assessment.

The final panel of expert reviewers included the following individuals. Full *curricula vitae* for the reviewers have been provided under separate cover.

- 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.

Each of the reviewers was allowed four weeks to complete his or her review. Upon receipt of the letter reviews, we reviewed each of them, clarified any inconsistencies with the assistance of the reviewer, and finalized the reviews. We outline the major findings and points of interest from the reviews, and provide short summaries of responses to individual charge questions below. We also include each of the final reviews provided by the peer reviewers as attachments.

SECTION 3: MAJOR FINDINGS AND POINTS OF INTEREST

Each of the reviewers focused on areas of their individual expertise. Taking the reviews together, the reviewers generally commented that the model successfully conceptualized problems at a level appropriate for a screening model, and gave the user an adequate set of options for specifying roadway designs. Several authors also complemented the model on its user friendliness. Dr. Aral noted that "the strength of the application developed can be considered to be the user friendly nature of the computational platform of the software" (p.1). Dr. Schwartz commented that "the beta version has been greatly improved from the initial, in terms of the technical document, user manual, and windows-based data input structure" (p1).

The authors, however, did identify concerns about the quality of data sources, potential errors in the model and documentation, and difficulties understanding or specifying certain model inputs. Each author identified areas where the documentation was unclear, misleading, or potentially incorrect. We summarize key issues identified by more than one reviewer below. Note, however, that any summary such as this necessarily omits important details or nuances concerning the peer reviewers' comments and conclusions. Thus, we encourage the interested reader to examine the full peer review reports attached to this memorandum. Key issues include:

- **Documentation Clarity and Accuracy**. All of the reviewers raised various concerns about the clarity with which the model and model documentation applied and explained certain concepts. For example, both Dr. Schwartz and Dr. Aral noted a lack of conceptual accuracy in the way the documentation defines risk analysis and interprets the 90th percentile exposure concentration. Dr. Schwartz recommends that future versions of the documentation focus on "descriptive metrics of risk and performance" (p.1), while Dr. Aral mentions conceptual errors in the documentation as one of the three major problems with the model. (p.6) All the reviewers recommended including a real-world case study that defines a problem and provides relevant model inputs, model outputs, and an explanation of the results.
- **Quality of Data Sources**. Several reviewers noted a number of areas where the data sources were either outdated or lacked rigor. For example, Dr. Li expressed concern about using a particular source (Apul, et al. 2002) to derive pavement

characteristics, since it is not a peer-reviewed publication, and recommends conducting a "more authoritative literature review" (p.3). Dr. Schwartz agrees that many sources are represented by "grey" literature rather than primary journal articles and writes that the report is "thin in cited literature describing the theoretical basis of the modeling approach" (p. 7). Dr. Schwartz also mentions that many of the subsurface flow parameters are from the DRASTIC model, which has an "obsolete" methodology, and that more modern approaches are available (p.3).

- **Input Parameters**. Two reviewers discussed how some of the input parameters are difficult to define. Dr. Li writes that some terms were "unfamiliar even to [an] experienced groundwater flow/transport modeler" (p.7). Dr. Li also raised the concern that certain data inputs were too complex, misleading or not useful, noting, for example, that "low end and high end pavement materials properties are way off from what is seen in reality" (p.1). Dr. Schwartz agreed that some of the flow/transport parameters were too difficult to estimate. (p.5). Additionally, Dr. Schwartz writes that "there is no possibility that the default values [for subsurface environments] would actually describe a specific site" and that they are "minimally validated and without a transparent basis in science" (p.7). Instead, he proposed that it would be easy for the model to provide users with tools to find the correct input parameters online (p.7).

- **Disproportionate Levels of Complexity**. Several reviewers noted that the complexity of the roadway modules may be out of proportion with the simplicity of the subsurface flow modules and the treatment of other waste sources, such as landfills and ponds. For example, Dr. Aral comments that "it is obvious that the technical development team of one module was not talking to the other team to present a unified picture of both applications" (p. 1-2). Dr. Schwartz commented that the "multiple road segment analysis is far beyond the vision of [a] screening that guided the development of earlier modules (p.5). Dr. Harvey also mentioned that a two-dimensional roadway module "might be sufficient and perhaps better" except for in a few circumstances (p.5).

- **Applicability of the Model.** Three of the four reviewers noted key assumption of the model limited the model's ability to characterize and evaluate some environmental situations that commonly occur in reality. Dr. Schwartz and Dr. Harvey noted the steady state assumptions behind IWEM make the model inaccurate under transient conditions, for example, when applied to regions where precipitation is commonly delivered via a high intensity rainfall event (p.4). Dr. Li pointed out that the model cannot evaluate overland transport of contaminants from an above-ground embankment source (p.1). In addition, Dr. Li also noted that climate data incorporated in IWEM is only from the United States, which limits the international use of IWEM (p.2).

SECTION 4: SUMMARY OF PEER REVIEW COMMENTS BY CHARGE QUESTIONS

The majority of reviewers' responses consisted of answers to direct charge questions. Below we repeat individual charge questions, followed by a short summary of reviewer responses.

1) ***New Model 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?

Three of the four reviewers (Dr. Aral, Dr. Schwartz, and Dr. Harvey) agreed that the roadway features and input parameters available allowed the user to reasonably represent a typical roadway. For example, Dr. Aral wrote that the assumptions and parameters used to represent the layers of the system and its components are "appropriate and more than accurate" (p.2). In contrast, Dr. Li suggested a number of areas where the roadway module could be improved in order to better allow the user to characterize a given roadway. For example, Li suggests that the model include an embankment input parameter, and that the number of gutters should be listed as the number of gutters per unit distance rather than fixed units (p.1). Dr. Li, Dr. Schwartz, and Dr. Harvey also commented on ways in which it was often difficult for users to understand and apply the needed model inputs. For example, Dr. Schwartz commented that as roadways can be very complex, modeling specific roadways can be "difficult and speculative because so much site-specific data is required for the roadway source inputs" (p.2).

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?

Three of the four reviewers (Dr. Aral, Dr. Schwartz, and Dr. Harvey) wrote that the formulation of the flow equations were reasonable in their formulation and in their simplicity. Dr. Aral and Dr. Harvey both represented that the use of steady state flow velocities were appropriate for a screening level model. However, two reviewers noted that while assuming steady state is generally correct, it yields incorrect results when the roadway area experiences high-intensity storms rather than a more level rate of precipitation. Dr. Harvey suggested that the model documentation should highlight this assumption (p. 4). Dr. Harvey also noted that the model does not account for the fact that groundwater is slower in arid environments, or that it accelerates when closer to discharge in rivers (p. 3) and writes that the documentation contains several somewhat contradictory explanations concerning how the model calculates groundwater velocity (p.

2). Dr. Li lists a number of instances where equations are not fully explained or validated (p. 3-4).

3) ***Contaminant Flux***. Accounting for the drainage, run-off, and evaporation rates, please provide your comments on the appropriateness of the equations derived and then used to calculate the contaminant flux from roadway source, leachate concentrations in drains and ditches, and the pulse duration. Are the results derived from the use of this model reasonably reliable?

Two reviewers wrote that the approach for modelling drainage, runoff, and evaporation rates was clear and correct. Dr. Schwartz noted that the "approach is generally straightforward and well-described" (p.4), although also added that "the simple evaporation/runoff/infiltration model should be re-examined in the context of a road," especially where precipitation is commonly delivered infrequent through intensity rainstorms (p. 2). Dr. Li and Dr. Aral identified some issues in the contaminant flux equations and on the validity of the pulse leaching assumptions. Specifically, Dr. Aral writes that the chemical decay component of the contaminant transport equations is formulated incorrectly and represents a major problem with the model (p. 4), while Dr. Li simply notes that the reference for the critical assumption [behind pulse leaching] is missing from the technical document" (p. 4). Additionally, Dr. Li recommends replacing the current leaching pattern with mechanisms that account for both physical and geochemical processes (p. 4). Dr. Harvey notes that the model currently only moves solutes through vertical dispersion downward and not upward, which "may be an adequate approximation, but is not clearly explained" (p.3).

4) ***Model Simplicity***. With additions made to the model, have we appropriately kept the balance between keeping the model simple and easy to use as compared to making it technically more sophisticated?

This charge question elicited a range of thoughts from the reviewers. Dr. Schwartz noted that "Overall, the design of the code is in keeping [with] the vision of an easy to use package, which is appropriate for the target audience" (p. 6). Dr. Harvey wrote that "IWEM appears to be an excellent tool for making simple but useful approximations of the risks of groundwater contamination," and that the authors had "succeeded pretty well" in building a complex model and keeping the code simple (p. 1). In contrast, Dr. Li considered components of the model as too complex, and that some terms were "unfamiliar even to [an] experienced groundwater flow/transport modeler" (p. 5). Dr. Aral agreed with Dr. Li that the model struggled to maintain an appropriate balance between simplicity and technical sophistication.

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?

All of the reviewers commented on the documentation's need for greater clarity and provided suggestions for editorial refinements. For example, Dr. Aral wrote that the text is "full of conceptual errors, definition errors, errors in example characterizations of certain cases, etc." (p.5). Dr. Schwartz concluded that the technical document is "cumbersome and unwieldy because of the blatant overuse of unintuitive acronyms," and that the mixing of British and metric units is "confusing and makes the information less transparent" (p.2). Drs. Schwartz, Harvey, and Aral each recommended including a real-world case study that explained a problem, model inputs, model outputs, and an explanation of the results. Dr. Schwartz also suggested that the report include an assessment of stakeholder experiences (p.2).

APPENDIX A: CHARGE TO REVEIWERS

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 a 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. As a result 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 documentations. 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. 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.

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 Model 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**. Accounting the drainage, runoff, and evaporation rates, please provide your comments on the appropriateness of the equations derived and then used to calculate the

contaminant flux from roadway source, leachate concentrations in drains and ditches, and the pulse duration. Are the results derived from the use of this model reasonably reliable?

4. **Model Simplicity**. With additions made to model, have we 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?

APPENDIX B: ORIGINAL COMMENTS FROM PEER REVIEWERS

Review by Dr. Mustafa Aral
Review by Dr. Lin Li
Review by Dr. Frank Schwartz
Review by Dr. Charles Harvey

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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.

<u>SECTION A:</u> 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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$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right)-V_x\frac{\partial c}{\partial z}-\varphi\lambda c=\varphi R\frac{\partial c}{\partial t}+Q \qquad (4.6)$$

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 **<u>that would be wrong</u>** 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 **<u>completely wrong</u>** 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)

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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: 90^{th} 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: 90^{th} 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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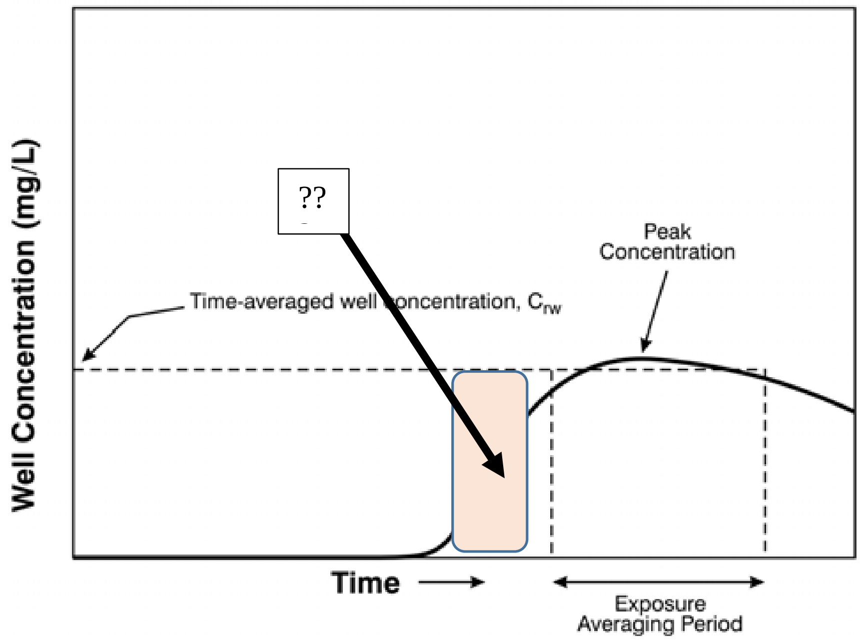

Page 4-2: Equation 4.1 has problems as mentioned earlier.

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.

Dr. Mustafa Aral (PhD, PE)

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.

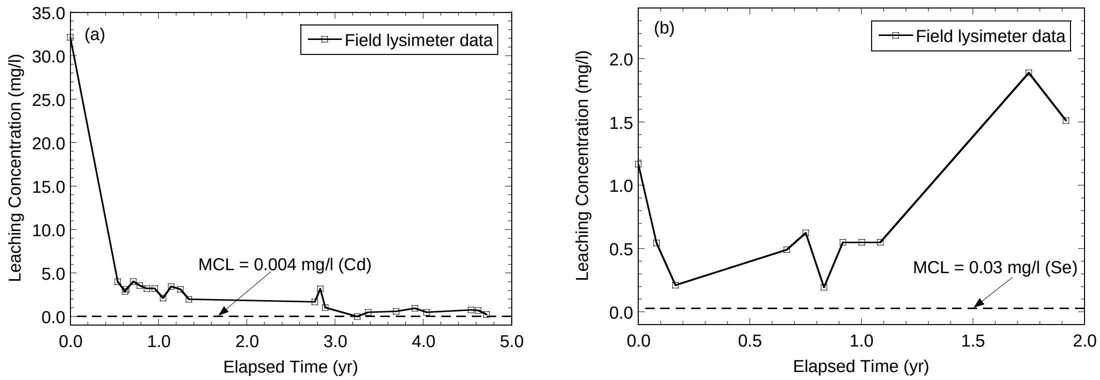


Figure 1. Example of leaching pattern from the CCP application in roadways construction: (a) first flush elution pattern measured from the fly ash subbase stabilization at STH 60 (Edil et al. 2002); and (b) lagged response elution patterns measured from the fly ash embankment at the Colebrook, NH (Gardner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

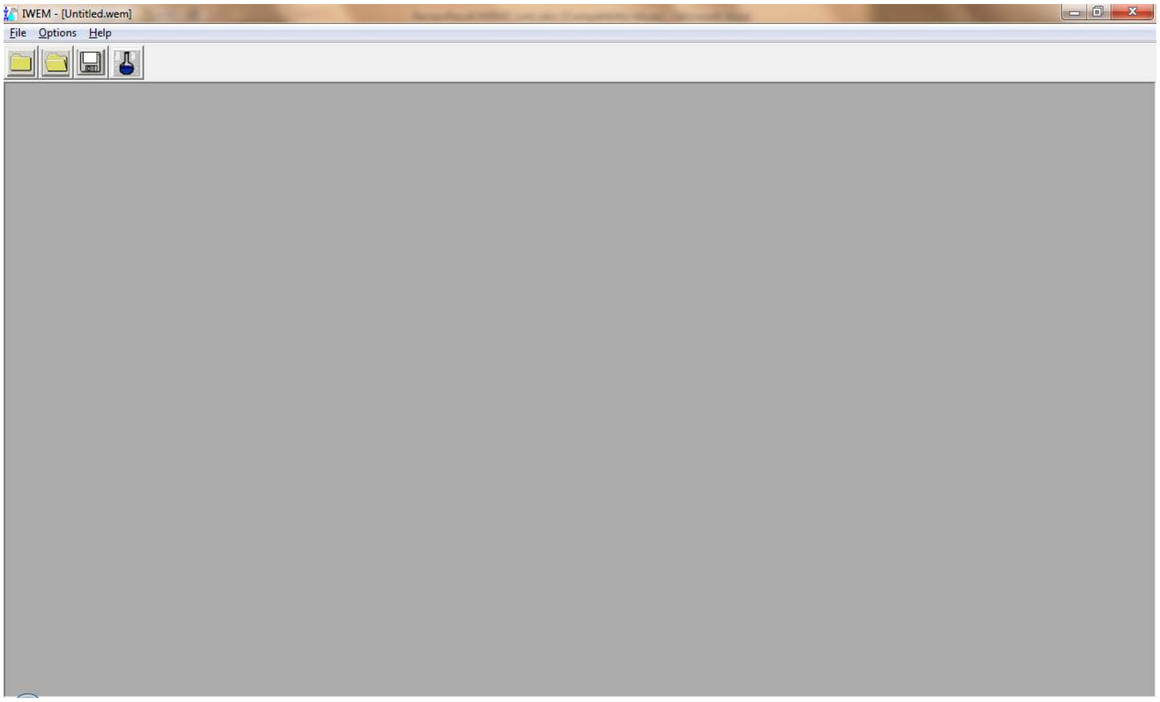
The IWEM 3.0 (Beta) makes the model complex, with so much additional input parameters compared to version 2.0. Some of the parameters should be merged, or removed. Some of the terms are unfamiliar even to experienced groundwater flow/transport modeler.

5. Documentation.

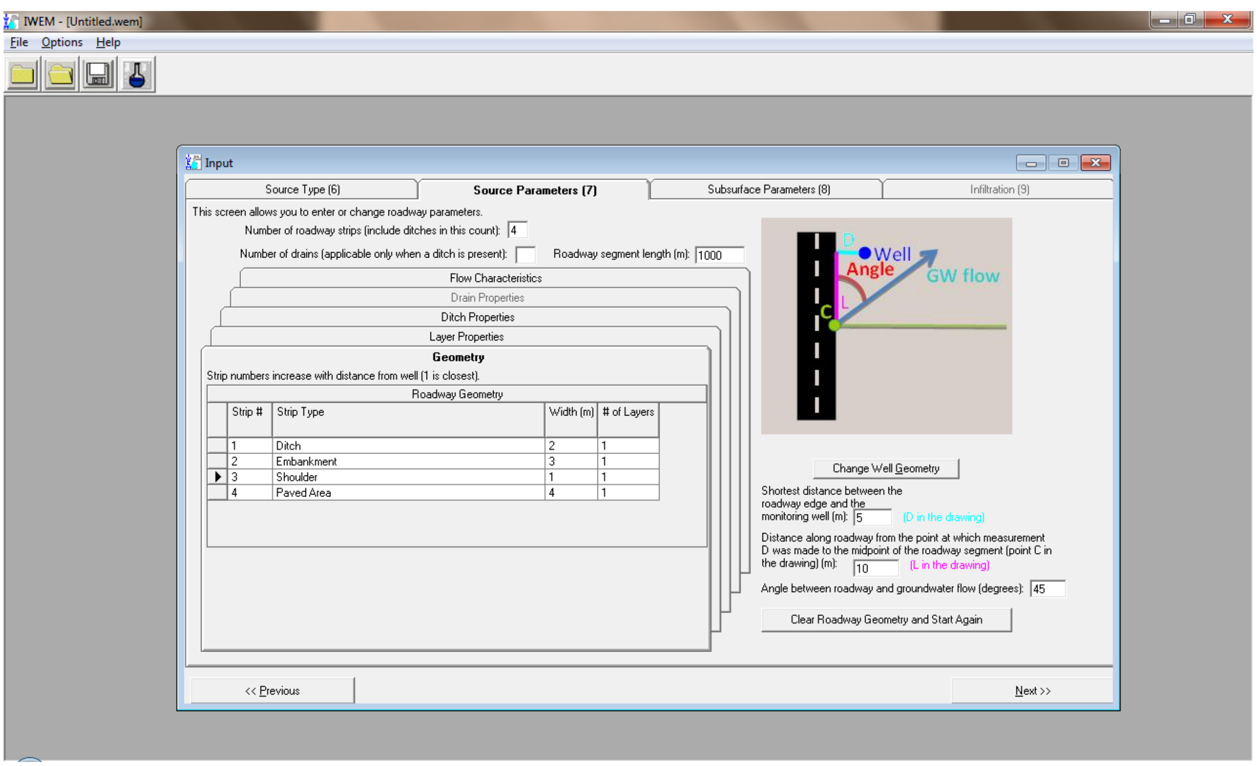
The technical manual and some parts of technical appendix should be combined, because all of equations are shown in appendix in the beta version. The equations are a key part to understand the technical part. After the literature are updated (see above comments), and the tables are revised (see above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

Bin-Shafique, S., Benson C. H., Edil T. B. and Hwang K., 2006, Leachate Concentrations from Water Leach and Column Leach Tests on Fly-ash Stabilized Soils. Environmental Engineering Science, 23(1): 53-67.

Cetin, B., Adyilek, A. H., and Li, L., 2013a, Leaching Behavior of Aluminum, Arsenic, and Chromium from Highway Structural Fills Amended with High-Carbon Fly Ash, Journal of Transportation Research Board, 2349:72-80.

Cetin, B., Adyilek, A. H., and Li, L., 2013b, Trace Metal Leaching from Embankment Soils Amended with High Carbon Fly Ash, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 140(1): 1-13.

Creek D.N. and Shackelford C.D., 1992, Permeability and Leaching Characteristics of Fly Ash Liner Materials. Transportation Research Record, 1345: 74-83.

Edil, T.B. et al., 2002, Field Evaluation of Construction Alternatives for Roadways over Soft Subgrade. Transportation Research Record, 1786: 36-48.

Gardner, K. 2009, National Green Highway Activities and Resources to Support Recycling and Reuse. Resource Conservation Challenge (RCC) 2009 Workshop, Hyatt Regency Crystal City, DC, March 25 - 27, 2009.

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Li, L., Peng, B., Santos, F., Li, Y., and Amini, F., 2011, Groundwater Impacts from Leaching of Coal Combustion Products in Roadways Embankment Constructions, Journal of ASTM International, 8(8): 1-12.

Li, Y., Li, L., Cordero-Zayas, S., Santo, F., and Yaeger, J. H., 2014, Environmental Impact of Fly Ash Utilization in Roadway Embankments, Journal of Material Cycles and Waste Management, DOI 10.1007/s10163-014-0266-6.

Sauer, J., Benson, C., Aydilek, A., and Edil, T. 2012, Trace Elements Leaching from Organic Soils Stabilized with High Carbon Fly Ash, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 138(8): 968-980.

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

Dr. Frank W. Schwartz
June 6, 2014

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 <u>initial leachate concentrations</u>. 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.

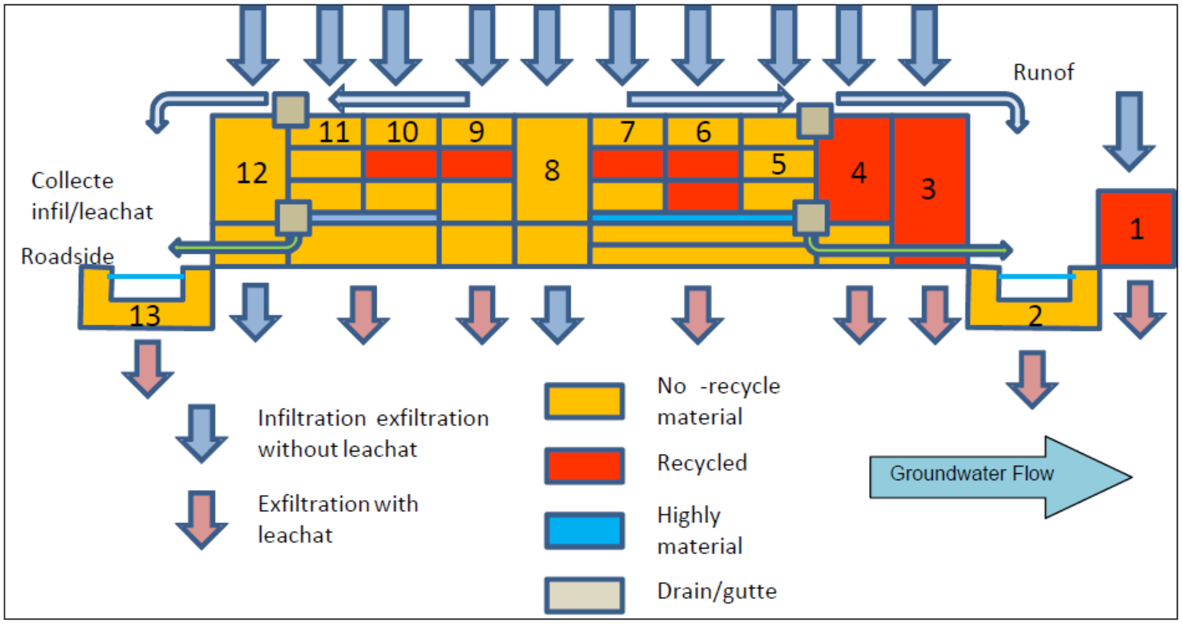

Figure 1: Example of a complex roadway from the report Appendix.

(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 detailed analysis 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 essentially unpredictable. 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 unknown. 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

References

McClymont, G.L. and F.W. Schwartz, 1991. Embedded knowledge in software: 1. Description of a system for transport modeling. Ground Water, 29(5), 648-654.

McClymont, G.L. and F.W. Schwartz, 1991. Embedded knowledge in software: 2. Demonstration and preliminary evaluation. Ground Water, 29(6), 878-884.

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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.

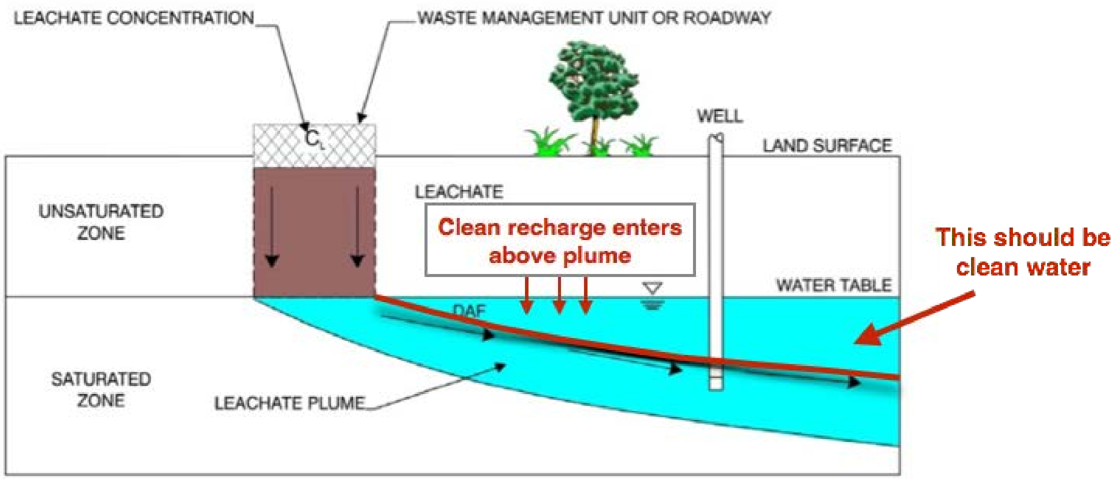

Figure ES-1 Conceptual cross-section view of the subsurface system simulated by EPACMTP.

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.