2.0 Overview of the Tier 1 And Tier 2 Approach

This section provides an overview of the methodology we used to develop the Tier 1 and Tier 2 tools. Section 2.1 discusses the purpose of the tools in terms of waste management scenarios addressed by IWEM. Section 2.2 presents the approach and parameters used for a Tier 1 and Tier 2 evaluation.

2.1 Purpose of The Tier 1 And Tier 2 Tools

IWEM analyzes the potential ground-water impacts of four types of WMU; LF, SI, waste pile (WP), and LAUs; and three liner scenarios: no liner, single clay liner, and composite liner. The purpose of both the Tier 1 and the Tier 2 evaluation is to determine the minimum recommended liner design that is protective of ground water for the waste of concern.

The primary method of controlling the release of waste constituents to the subsurface is to install a low permeability liner at the base of a WMU. A liner generally consists of a layer of clay or other material with a low hydraulic conductivity that is used to prevent or mitigate the flow of liquids from a WMU. However, the type of liner that is appropriate for a specific WMU is highly dependent upon a number of location-specific parameters, such as climate and hydrogeology. In addition, the amount of liquid that migrates into the subsurface from a WMU has been shown to be a highly sensitive parameter in predicting the release of constituents to ground-water. Therefore, one of the main objectives of the tiered modeling approach is to evaluate the appropriateness of a proposed liner design in the context of other location-specific parameters such as precipitation, evaporation, and the hydrogeologic characteristics of the soil and aquifer beneath a facility.

EPA chose to evaluate three types of liner designs, the no-liner, single-liner, and composite-liner designs. The no-liner design (Figure 2.1a) represents a WMU that is relying upon location-specific conditions such as low permeability native soils beneath the unit or low annual precipitation rates to mitigate the release of constituents to ground-water. The single-liner design represents a 3 foot thick clay liner with a low hydraulic conductivity (1×10^{-7} centimeters per second [cm/sec]) beneath a WMU (Figure 2.1b). A composite liner in IWEM consists of a 60 mil (1.5 millimeter) high-density polyethylene (HDPE) layer underlain by either a geosynthetic clay liner with a maximum hydraulic conductivity of 5×10^{-9} cm/sec or a three-fool compacted clay liner with a maximum hydraulic conductivity of 1×10^{-7} cm/sec. (Figure 2.1c).

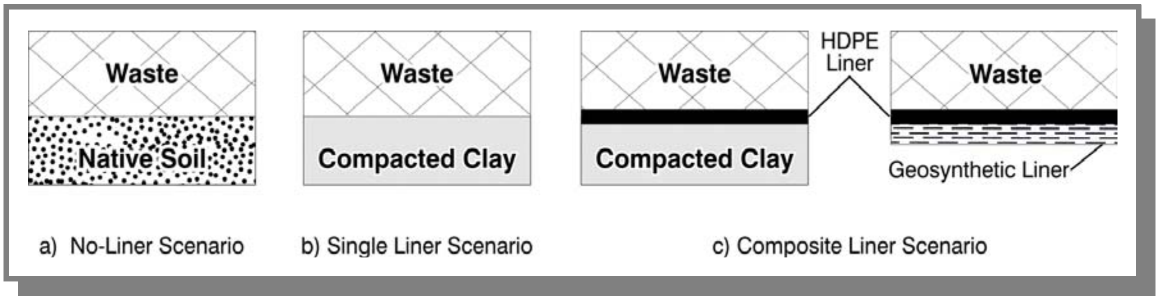

Figure 2.1 Three Liner Scenarios Considered in IWEM.

For a given waste management scenario and waste leachate concentration, IWEM uses ground-water modeling to predict the exposure concentration at a well located downgradient from the WMU, and then compares the predicted exposure concentration to established regulatory or health-based RGCs. The recommended liner design is the minimum liner for which the predicted ground-water concentration of all constituents is less than their RGC. For land application, the model evaluates whether wastes can be protectively land applied, based on leachate constituent concentrations. The Tier 1 and Tier 2 evaluations can be summarized as follows:

Tier 1: Using only expected leachate concentrations of constituents in a waste, generic tables provide design recommendations (liner system or maximum allowable leachate concentrations). If the waste contains several constituents, choose the most protective design indicated for any of the constituents. This tier of analysis uses national data and is designed to be protective for 90% of the possible combinations of waste sites and environmental settings across the United States; Tier 1 results will therefore be protective for the majority of sites.

Tier 2: You can enter site-specific data for up to twenty of the most sensitive WMU and hydrogeologic characteristics to assess whether an alternative design will be protective. In addition, you can modify the default constituent fate parameters, including adding biodegradation. This tier is generally more representative than Tier 1 because it allows the user to incorporate site-specific information in the analysis.

2.2 Approach Used to Develop Tier 1 And Tier 2 Tools

There are several important concepts that are critical to the understanding of how IWEM functions. These concepts include 90th percentile exposure concentration, dilution and attenuations factors (DAFs), reference ground-water concentrations (RGCs), and leachate concentration threshold values (LCTVs). This section presents how we used these concepts in developing IWEM, and the similarities and differences between Tier 1 and Tier 2.

2.2.1 Tier 1

We developed Tier 1 of IWEM around the concept of Leachate Concentration Threshold Values (LCTVs). An LCTV is the maximum leachate concentration that is protective of ground-water. That is, the LCTV will result in a ground-water exposure concentration that does not exceed RGCs. The basic calculation that is performed to develop LCTVs can be summarized as follows:

$$LCTV = DAF \times RGC$$

where:

LCTV	=	Leachate Concentration Threshold Value
DAF	=	Dilution and Attenuation Factor
RGC	=	Reference Ground-water Concentration *(e.g., MCL or HBN)*

In this relationship, DAF represents the reduction in constituent concentration between the point of release at the base of the WMU, and the eventual ground-water exposure concentration at a downgradient well. IWEM uses the EPACMTP ground-water fate and transport model to calculate expected ground-water well concentrations from which the DAFs are determined. EPACMTP and its application under IWEM are discussed in detail in Sections 3 and 4 of this document. The DAF is chemical- and site-specific and is defined as the ratio of the constituent concentration in the waste leachate to the concentration at the monitoring well, or:

$$DAF = \frac{C_L}{C_{RW}}$$

where:

C_L = is the leachate concentration (milligrams per liter [mg/L])
C_{RW} = is the well concentration (mg/L).

The ground-water exposure is evaluated at a well located downgradient from the WMU. The distance between the WMU and the well can vary, but IWEM assumes the well is always located on the centerline of the ground-water plume.

The magnitude of a DAF reflects the combined effect of all dilution and attenuation processes that occur in the unsaturated and saturated zone. The lowest possible value of DAF is one; a DAF value of one means that there is no dilution or attenuation at all; the concentration at the well is the same as that in the waste leachate. High values of DAF on the other hand correspond to a high degree of dilution and attenuation and mean that the expected concentration at the well will be much lower than the concentration in the leachate.

IWEM uses EPACMTP in a probabilistic (Monte Carlo) mode to generate a probability distribution of well concentrations that reflects the variability in the various modeling parameters, for instance the variation of rainfall rate across the United States. IWEM uses the 90th percentile exposure concentration to represent the estimated constituent concentration at a well for a given leachate concentration to determine the DAF that is used in the calculation of LCTVs. The 90th percentile exposure concentration is determined by running EPACMTP in a Monte Carlo mode for 10,000 realizations. For each realization, EPACMTP calculates a maximum time-averaged concentration at a well, depending on the exposure duration of the reference ground-water concentration (RGC) of interest. For example, IWEM assumes a 30-year exposure duration for carcinogens, and therefore, the maximum time-averaged concentration is the highest 30-year average across the modeling horizon. After calculating the maximum time-averaged concentrations across the 10,000 realizations, the concentrations are arrayed from lowest to highest and the 90th percentile of this distribution is selected as the constituent exposure concentration for IWEM. In Tier 1, the EPACMTP modeling used data on WMUs collected throughout the United States. LCTVs used in Tier 1 are therefore designed to be protective with a 90% certainty considering the range of variability associated with waste sites across the United States.

We performed EPACMTP Monte Carlo simulations to determine constituent-specific DAF values for each combination of WMU type and liner listed in Table 1.1. We then multiplied these DAFs with constituent-specific RGCs to obtain the Tier 1 LCTVs. The RGCs included Maximum Contaminant Levels (MCLs) as established under the Safe Drinking Water Act (SDWA) and HBNs, calculated from constituent-specific toxicity data, using standard exposure assumptions for residential receptors (see Section 5.2 of this document). IWEM incorporates HBNs for exposures due to drinking water ingestion and inhalation of volatiles while showering. Constituent-specific HBNs in IWEM correspond to a cancer risk of 10^{-6}, and non-cancer hazard quotient (HQ) of 1, respectively. The relationship shown at the beginning of this section expresses how the LCTV is directly proportional to the RGC and that the LCTV will be lower for constituents with lower MCLs or HBNs even if they have the same fate and transport characteristics (same DAF).

After calculating the Tier 1 LCTVs as outlined above, we applied a series of caps that:

- Restrict LCTVs to not exceed 1,000 mg/L,
- Restrict LCTVs to not exceed Toxicity Characteristic (TC) Rule leachate levels (for the 39 constituents identified in the TC Rule), and
- Account for transformation of leachate constituents into toxic hydrolysis daughter products.

Section 6 discusses these caps in more detail. The final result is a set of nationwide leachate screening values. The final Tier 1 LCTVs are listed in Appendix F of this document. They are also incorporated as a series of lookup tables in the IWEM software.

To perform a Tier 1 evaluation only the following information is needed:

- WMU type;
- Constituents present in the leachate; and
- Expected leachate concentration of each constituent.

The IWEM software will compare expected leachate concentrations with LCTVs for each constituent, and determine a minimum recommended liner design that is protective for all waste constituents.

2.2.2 Tier 2

A Tier 2 evaluation is also based on a 90^{th} percentile ground-water protection level, but takes into account site-specific factors. If appropriate for site conditions (for example, an arid climate), it may be possible to avoid unnecessarily costly WMU designs. It may also provide an additional level of certainty that liner designs are protective of sites in vulnerable settings, such as high rainfall and shallow ground-water. In Tier 2, EPACMTP uses site-specific information to determine the expected 90^{th} percentile exposure concentration for each waste constituent and liner scenario. IWEM then directly compares these exposure concentrations to RGCs to determine whether a particular liner scenario is protective or not. If the ground-water exposure concentration of each constituent is less than its RGC, then the liner scenario being evaluated is protective. If the exposure concentration of any waste constituent exceeds its RGC, then the liner scenario is not protective. In the Tier 2 analysis, IWEM also calculates LCTVs. These are provided to help users determine whether waste minimization may be appropriate to meet a specific liner design. For example, a facility may find it more cost effective to reduce the concentration of constituents in waste and design a clay-lined LF than to dispose of the current waste in a LF with a composite liner. The LCTVs calculated for the Tier 2 analysis is based on the expected exposure concentration for a specific site, and LCTVs from this analysis are not applicable to other sites. The trade-off in performing a Tier 2 evaluation is that although a more site-specific result is generated, the fate and transport simulations which are performed inside the IWEM software are computationally very demanding and can take hours to complete, even on high-speed desk top computers.

For Tier 2, the same inputs as Tier 1 are required. In addition, there are several more required site-specific parameters, as well as other optional parameters. The required additional site-specific parameters that a user must input for Tier 2 are:

- Geographic location of the WMU;
- Footprint area of the WMU, and
- Depth of the WMU (LF or SI)

If sufficient site-specific data is available, the user may also provide the following optional Tier 2 site-specific characteristics:

- Distance to the nearest surface waterbody (SI)
- Depth of the base of the WMU below ground surface (LF, SI, and WP)
- Operational life of the WMU (SI, WP and LAU)
- Sludge thickness (SI)
- Waste type (WP)
- Leakage (infiltration) rate from the WMU
- Distance to the nearest down-gradient well
- Unsaturated zone soil type
- Subsurface environment type, and/or individual of values of:
    - Depth from ground surface to the water table
    - Saturated thickness of the upper aquifer
    - Hydraulic conductivity in the saturated zone
    - Regional hydraulic gradient
    - Ground water pH
- Constituent fate parameters:
    - Sorption coefficient (k_d)
    - (Bio-) degradation rate
- Constituent-specific RGC values and corresponding exposure durations

As in Tier 1, liner recommendations and LCTVs are based not only on toxicity and DAFs, but also incorporate other criteria to cap the model-calculated values. IWEM caps leachate concentrations from an industrial solid WMU at a level no higher than 1000 mg/L for any single constituent. The 39 constituents covered by the TC Rule are capped at their TC levels because concentrations above those levels mean that the waste is classified as hazardous waste. The final liner recommendations and LCTVs accommodate both the parent constituent as well as any toxic daughter products. For instance, if a parent waste constituent rapidly hydrolyzes into a persistent daughter product, the ground-water exposure caused by the parent itself may be minimal (for example, it has already degraded before it reaches the ground-water well), but the final liner recommendation and LCTV generated by IWEM would be based on the exposure caused by the daughter product.