ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF SPILL PREVENTION AND RESPONSE
CONTAMINATED SITES PROGRAM

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Soil-Water Partitioning Equation

PURPOSE:

The purpose of this technical memorandum is to explain the derivation of the revised migration to groundwater cleanup levels for Table B1 contaminants using a soil-water partitioning equation.

The revised equation is presented in the June 9, 2008 *Cleanup Levels Guidance*, which is part of the regulations package that will be effective on October 9, 2008. The reader is advised to reference equations 11 through 14 of the revised guidance while reviewing this technical memorandum. The reader may also wish to review equations 10 through 13 in the *Cleanup Levels Guidance* dated January 30, 2004 to better understand the background discussion.

BACKGROUND:

Contaminants may leach vertically through soil to underlying groundwater. Cleanup levels applicable to migration to groundwater represent maximum contaminant concentrations that may remain in the unsaturated soil zone (vadose zone) without posing an unacceptable risk to the underlying groundwater. A migration to groundwater soil cleanup level is "back-calculated" from the groundwater cleanup level in a linear relationship using a "soil-water partitioning equation." In other words, if a groundwater cleanup level is increased by a factor of 10, the back-calculated soil cleanup level would increase by the same factor.

The equation applies a three-phase partitioning model to determine the migration to groundwater cleanup levels. These contaminant phases are vapor, dissolved, and adsorbed. The equation contains a number of variables, including the groundwater cleanup level, a dilution-attenuation factor (DAF), the soil organic carbon/water partition coefficient, the fraction of organic carbon in the soil (foc), dry soil bulk density, air and water filled soil porosity, and the Henry's Law constant. Of these variables, the equation is most sensitive to changes to the foc and DAF. [1]

The DAF consists of two parts: dilution and attenuation. Dilution results in the spreading and reduction in the maximum concentration of a groundwater contaminant plume downgradient of the source area, but does not reduce the contaminant mass in the aquifer.

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[1] The soil-water partitioning equation for inorganic contaminants does not include foc or the soil organic carbon/water partition coefficient but is otherwise similar to the organics equation.

Contaminant attenuation includes process such as adsorption, volatilization, and chemical or biological degradation. Attenuation reduces contaminant mass.

During the mid-1990s regulations development process, default dilution factors (DF) were determined for the under 40-inch and over 40-inch climate zones based on a number of different factors. [2] Particularly, the infiltration rate for each zone is different, which in turn affects the mixing zone depth. The DF is inversely proportional to the infiltration rate; that is, a higher infiltration rate, which occurs in higher rainfall areas, results in a lower DF. This is because greater infiltration through the soil contaminant source generates more contaminated water relative to the mass of clean groundwater flowing into the site from upgradient. Conversely, a contaminant source located in sub-surface soil in a drier area with low infiltration is relatively immobile. Very little contaminated leachate will enter the groundwater aquifer proportional to the mass of clean groundwater flowing into the site.

The default DF for the under 40-inch zone is 3.3. This means the hypothetical contaminant concentration at a downgradient location of interest is 3.3 times lower than the concentration in the source area as a result of dilution processes. The default DF for the over 40-inch zone is 1.9. This means the hypothetical contaminant concentration at a downgradient location of interest is 1.9 times lower than the concentration in the source area as a result of dilution processes.

DEC then assigned a fixed attenuation factor (AF) of 10 (applicable to both climate zones), and added it to the DF to obtain DAFs applicable to all contaminants. For the under 40-inch zone the default DAF is 13.3 (3.3 + 10). For the over 40-inch zone the DAF is 11.9 (1.9 + 10).

EPA computer probability simulations indicated a DAF of 20 would be protective of drinking water in a thick aquifer 90 to 95% of the time. It is important to note, however, that the EPA soil screening levels were not meant to be definitive cleanup levels. DEC, on the other hand, chose to develop generic cleanup levels using the soil screening level approach, combined with Alaska-specific input parameters and a number of conservative assumptions.

How sensitive is the soil water partitioning equation to DAF changes? Increasing the DAF in the over 40-inch zone from 11.9 to 20, for example, would nearly double the migration to groundwater cleanup level for benzene. What this means is that more benzene could remain in the soil without exceeding the groundwater cleanup level due to

[2] Migration to groundwater is not applicable (under existing regulations) to the Arctic zone due to the presence of permafrost.

increased dilution and attenuation. Site-specific input parameters may be used to modify the default DF. A site-specific AF is not allowed under the existing regulations.

REVISED EQUATION:

The table below summarizes the differences between the former and revised soil-water partitioning equations (11 and 12), dilution factor equation (13), and mixing zone equation (14) in the *Cleanup Levels Guidance.*

Former	Revised
Climate Zones - Applicable to the dilution factor and mixing zone equations	Climate Zones – No longer applicable
Default Mixing Zone Depth - Variable	Mixing Zone Depth – Fixed at 5.5 meters
Default Dilution Factor – May be modified site-specifically; all input parameters are variables	Default Dilution Factor – May be modified site-specifically; mixing zone is a constant
Default Attenuation Factor – Fixed at 10	Default Attenuation Factor - 4.0 - May be modified on a site-specific basis
Dilution Attenuation Factor- Additive	Dilution Attenuation Factor - Multiplicative

To better understand the soil-water partitioning equation in terms of these revisions, two underlying equations must be explored. These are the mixing zone depth equation and the dilution factor equation.

Mixing Zone Depth (Equation 14)
The mixing zone depth is a characterization of the maximum depth of contaminant migration at the downgradient edge of the source area. Variables that can be changed in the current mixing zone depth calculation to develop an alternative migration to groundwater soil cleanup level are infiltration rate, hydraulic conductivity, hydraulic gradient, and the source length parallel to groundwater flow. For the current climate zones, infiltration rate is a critical variable: as the infiltration rate increases with precipitation, the mixing zone depth also increases.

As a result of Statement of Cooperation (SOC) working group findings, the soil-water partitioning equation for Table B1 contaminants now uses a 5.5 meter (18 feet) fixed mixing zone depth rather than a variable mixing zone depth that would potentially allow a deep aquifer to be contaminated.[3]

Variables in the mixing zone depth equation that may no longer be modified site-specifically are infiltration rate, hydraulic conductivity, hydraulic gradient, and the source length parallel to groundwater flow. The infiltration rate has been fixed at 0.13 meters per year statewide (current under 40-inch zone infiltration rate). The under 40-inch zone infiltration rate was adopted as the default because it covers the greatest surface area of the state. The other default values in the equation have not changed.

<u>Dilution Factor (Equation 13)</u>
The fixed mixing zone depth is a constant in the revised DF calculation, the next equation underlying the main soil-water partitioning equation. All other input parameters may still be modified site-specifically. These include the infiltration rate, hydraulic gradient, hydraulic conductivity, and source length parallel to groundwater flow.

This final technical modification increases flexibility when calculating an alternative migration to groundwater soil cleanup level. The CSP had initially proposed a fixed DF when the revised regulations and *Cleanup Levels Guidance* were released for public comment in the fall of 2007.

If a site-specific DF is calculated for the purpose of developing an alternative migration to groundwater soil cleanup level, a calculated mixing zone depth (equation 14) can be generated as well. This is possible because the input parameters in both equations are identical, thereby allowing site-specific information to be used for a dual purpose. If soil contaminant concentrations exceed the calculated alternative cleanup level, the calculated mixing zone depth may prove useful to: 1) understand the depth of contaminant penetration into the saturated zone and groundwater aquifer; and 2) help determine well placement depth and well screen intervals for the purpose of characterizing the extent of dissolved contamination in groundwater. It is important to note, however, that this calculated mixing zone depth cannot be used in place of the fixed mixing zone depth in equation 13.

<u>Attenuation Factor</u>
The revised soil-water partitioning equation incorporates a default AF of 4.0 based on Visual Modflow modeling results (Geosphere and CH2MHill, 2005). For petroleum compounds, within a fixed mixing zone of 18 feet, modeling showed that a 105-foot-long source area has an AF of about 2.7, while a 300-foot-long source area has an AF of about 7.5. Although degradation rates do vary by chemical, a default AF of 4.0 is both

[3] The SOC papers are available for staff reference on the Contaminated Sites web page at the following link: http://www.dec.state.ak.us/spar/csp/soc.htm

reasonable and conservative for generic application to all contaminated sites in Alaska. With an AF of 4.0, the modeled source length is slightly higher than the source length for an AF of 2.7.

Unlike the fixed AF of 10 under current regulation, the default AF can now be modified for an individual chemical on a site-specific basis at the request of the responsible person. It will be incumbent upon CSP project managers to ensure proposed modifications to the default AF are technically defensible.

Dilution-Attenuation Factor

The final revision to the soil-water partitioning equation is the modification to the DAF calculation. The DAF, formerly calculated additively (DF + AF), is now calculated multiplicatively (DF x AF). This modification corrects a mathematical flaw that has been present in the equation since the regulations became effective in 1999.

Summary and Conclusions

In practice, the revised Table B1 migration to groundwater cleanup levels are nearly the same as the current under 40-inch zone cleanup levels because the default dilution-attenuation factor has not significantly changed (DAF of 13.2 statewide versus 13.3 for the current under 40-inch zone). However, the proposed modifications to the soil-water partitioning equation strengthen the technical defensibility of the regulations while retaining flexibility when calculating an alternative migration to groundwater cleanup level. In summary:

1. a default AF that can be modified site-specifically can adjust for more recalcitrant compounds;
2. a fixed mixing zone depth protects deep aquifers by ensuring that thick mixing zones do not occur as a result of increased contaminant source length;
3. a default DF that can be modified site-specifically parallels the current approach, with the exception of a fixed rather than variable mixing zone depth in the equation; and
4. the DAF has been corrected to calculate multiplicatively rather than additively.

In addition to the three contaminant partitioning phases the equation incorporates, petroleum hydrocarbons exist as non-aqueous phase liquid (NAPL, or free product). For this reason we will continue to explore a more technically robust equation for Table B2 contaminants. The SOC's recommendations will be taken into consideration during future revisions to the site cleanup rules.