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PROTECTION

# t e c h n i c a l   u p d a t e

## Weighted Skin-Soil Adherence Factors

Update to: Appendix B of *Guidance for Disposal Site Risk Characterization – In Support of the Massachusetts Contingency Plan* (MADEP, 1995)

### Summary

Based on a review of the recent literature, the Massachusetts Department of Environmental Protection (DEP) is recommending new default skin-soil adherence factors for use in risk assessments at 21E sites. New default adherence factors are recommended for a variety of typical exposure scenarios. The new adherence factors are *weighted* values. That is, the factors have been weighted according to the skin surface area assumed to be exposed to soil. Skin-soil adherence factors are used in risk assessments with other parameters including body weight, exposure frequency and duration to estimate the dermally absorbed dose of a contaminant in soil. The weighted adherence values presented in this supplemental guidance supercede the default value of 0.51 mg/cm<sup>2</sup> previously recommended.

The skin-soil adherence factor describes the amount of soil that adheres to the skin per unit of skin surface area. Soil adherence to the skin is a necessary parameter to estimate the average daily dose to a receptor from dermal contact with oil or hazardous material in soil.

DEP has reviewed data from several recent studies on soil adherence (Kissel *et al.*, 1996; Kissel *et al.*, 1998; Holmes *et al.*, 1999). These studies indicate that adherence of soil to skin varies considerably across different parts of the body and with different activities. Soil properties also influence adherence with skin. The new studies reviewed by DEP provide data on soil adherence by body part, for different activities. Based on this new data, DEP concluded that a change is needed from previous guidance which recommended using a single adherence factor for all body parts and activities.

The weighted adherence values recommended in this supplemental guidance account for the variability in skin-soil adherence that has been reported across different body parts and activities. This supplemental guidance presents default adherence factors for a variety of different receptor groups. Adherence factors are weighted by the body parts assumed to be exposed. This supplemental guidance also summarizes the data reviewed by DEP and provides a detailed rationale for the new default values.

Table 1 below provides the new weighted adherence factors. Adherence factors are provided for 10 different receptor groups and are weighted by the skin surface area assumed to be exposed. Details about how these adherence factors were developed are provided in subsequent sections of this document.

TABLE 1: Weighted soil-skin adherence factors

RECEPTOR GROUP	WEIGHTED SKIN-SOIL ADHERENCE FACTOR (mg/cm <sup>2</sup> )
Adult Resident	0.13
Child Resident/Child Recreational	0.35
Adult Recreational	0.07
Trespasser	0.14
Office Worker	0.004
Industrial/Outdoor Commercial Worker	0.03
Landscaper/Groundskeeper	0.19
Utility Worker/Heavy Construction Worker	0.29
Light Construction Worker	0.18
Exposure to Sediment (swimming/playing/wading)	1.0 *

\* The adherence factor for exposure to sediment is not weighted by skin surface area.

## Using Weighted Dermal Adherence Factors in Risk Characterizations

Dermal absorption of oil or hazardous material is a potentially significant route of exposure whenever direct contact with soil may occur. The skin-soil adherence factor is one of a number of parameters used to estimate the average daily dose to a receptor from dermal contact with oil or hazardous material in soil. Equation 7-15 in DEP's risk characterization guidance (DEP 1995) is the equation recommended for evaluating the average daily dose due to dermal contact with contaminated soil.

When evaluating dermal exposures in a risk characterization, the risk assessor should select the weighted dermal adherence factor from Table 1 for the receptor group being evaluated in the risk characterization. For example, the adherence factor of 0.35 mg/cm<sup>2</sup> (child resident) would be used to evaluate a child resident, aged up to 7 years old. The adult residential adherence factor of 0.13 mg/cm<sup>2</sup> could be used for a resident older than 7 years.

Note that in a risk assessment, the body parts assumed to be exposed to soil should match the body parts inherent in the weighted adherence factor being used. For example, the weighted adherence factor for the child resident assumes soil contact on the face, hands, forearms, lower legs and feet. A risk characterization estimating a dermal dose to a 2 year-old child resident would use the weighted adherence factor of 0.35 mg/cm<sup>2</sup> (child resident) with the appropriate skin surface area for a two year old's face, hands, forearms, lower legs and feet.

## Development of Site-Specific Dermal Adherence Factors

DEP has developed default adherence factors for the receptor groups most commonly evaluated in risk assessments. DEP anticipates that its default values will be used in most risk assessments. However, there may be some situations in which a risk assessor will need to develop a site-specific dermal adherence factor for a receptor group not included in DEP's list of defaults. To do this, DEP recommends that the risk assessor review the soil adherence data from the literature and select an activity which best represents the high-end soil contact activity for the exposure scenario of concern. DEP notes that the list of activity groups in Table 2 is not a comprehensive list of all the

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groups measured in the field studies. The original literature should be consulted for a complete list of the activities for which there is soil adherence data. The site-specific skin-surface area weighted adherence factor should then be calculated using the same equations DEP used to develop its default adherence values.

Weighted adherence factors in Table 1 should not be modified by making different assumptions about body parts exposed to soil. For example, a risk assessment evaluating exposures to a trespasser should not modify the trespasser weighted adherence factor in Table 1 using body parts different from the hands, forearms and feet. Site-specific adherence factors should only be developed for a receptor group which is not included in Table 1. Risk assessors may also use DEP's old default adherence factor of 0.51 mg/cm<sup>2</sup> for any scenario except exposures to sediment.

## Evaluating Exposure to Sediment

Soil adherence studies indicate that soil moisture content can affect dermal adherence. Soils with greater moisture content generally adheres more to the skin. One of the field studies reviewed by DEP measured 2 groups of six children each, playing in sediment on the shore of a lake (Kissel *et al.*, 1996). Overall arithmetic mean sediment adherences in these 2 groups of children ("kids-in-the-mud" #1 and #2) ranged from 25.7 mg/cm<sup>2</sup> on the forearms to 60.3 mg/cm<sup>2</sup> on the hands. Geometric means ranged from 11 mg/cm<sup>2</sup> on the forearms to 45 mg/cm<sup>2</sup> on the hands. EPA calculated a weighted adherence factor of 22 mg/cm<sup>2</sup> based on geometric mean measurements of the "kids-in-the-mud" groups.

EPA's weighted adherence factor for "kids-in-the-mud" is two orders of magnitude higher than any of DEP's default values for soil. Use of such a high adherence factor in a risk characterization would lead to a very high estimate of the average daily dose of contaminant received from dermal contact with sediment. DEP recognizes that sediment adherence on the skin can be very high. However, there is evidence that as soil loading on the skin increases above a critical level, the fraction of a contaminant absorbed decreases (EPA 1998 **draft**). The critical level is the monolayer, which is described as a single layer of tightly packed soil particles. The level of soil loading that equals the monolayer has not been well established and is likely to vary according to soil density and particle size. Based on judgement and unpublished experimental observations, DEP has identified a value of 1 mg/cm<sup>2</sup> as a best estimate of the loading that corresponds to a monolayer with most sediment types encountered at hazardous waste sites. Thus, at soil loadings greater than 1 mg/cm<sup>2</sup>, total absorption would not continue to increase.

DEP believes that use of a sediment adherence factor of 22 mg/cm<sup>2</sup> is not reasonable as a default value because it may substantially overestimate the dose of contaminant received from dermal contact with sediment. Instead, DEP recommends using 1 mg/cm<sup>2</sup> as a default adherence factor for sediment. This value is the best estimate of the monolayer, which is in theory, the level at which maximum absorption would occur. This recommended sediment adherence factor of 1 mg/cm<sup>2</sup> is *not* a weighted value and thus, need not be used in combination with specific body part assumptions. Risk assessors should select the body parts appropriate for the receptor group being evaluated.

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## Development of the Default Weighted Dermal Adherence Factors

Several recently published field studies have estimated soil adherence to the skin (Kissel *et al.*, 1996; Kissel *et al.*, 1998, Holmes *et al.*, 1999). In these field studies, soil loading was directly measured from multiple body parts of volunteers engaged in various occupational and recreational activities. Subjects' body surfaces were washed before and after the activity. Mass of soil recovered was converted to loading using allometric models of skin surface area. Skin-soil adherence was reported in the published studies as a geometric mean adherence by body part, for a particular group of subjects engaged in a particular activity. Raw data from each of the field studies are available electronically on the internet. Numbers of subjects measured varied by field study and by activity. Seven was the minimum number of subjects measured for an activity and 29 was the maximum. In several cases, more than one group of subjects engaged in the same activity was measured. For example, three different groups of soccer players were measured. In cases where multiple groups were measured, geometric mean adherences were reported for each group separately (for example, soccer players #1, #2, #3).

With one exception, these studies were not controlled experiments. Volunteers' activities were not staged or scripted. Clothing worn differed among subjects. Activities occurred during different seasons, and in differing soil types. Only one activity "children playing in wet soil," was somewhat staged. In this study, 13 children were given an assortment of toys and allowed to play, undirected, for 20 minutes in a constructed 8 foot by 8 foot soil bed. The soil contained roughly 16 to 18% moisture. Clothing worn by the children was controlled (children wore either short sleeves and short pants or long sleeves and long pants).

The U.S. EPA reviewed the same field studies that DEP reviewed (Kissel *et al.*, 1996; Kissel *et al.*, 1998, Holmes *et al.*, 1998). Based on those studies, EPA developed skin surface area-weighted adherence factors for a variety of receptor groups. EPA's adherence factors are published in the Supplemental Guidance for Dermal Risk Assessment (Interim Guidance, November 6, 1998 **draft**). The approach DEP followed to develop its dermal adherence factors is very similar to the approach used by EPA.

### General Approach

DEP has developed adherence factors for receptor groups most commonly evaluated in risk characterizations at hazardous waste sites. For each receptor group, DEP selected an activity from the published adherence factor field data which best represents a "high end" or "full-use" soil contact activity for that receptor group. For example, DEP selected "cleaning and fixing mains, jack-hammering and excavating" to represent "full-use" soil contact activities for utility workers. Selection of a high-end soil contact activity rather than a mid-range activity is consistent with DEP risk characterization regulations and guidance which provide that risk characterizations evaluate "...the full extent of site activities consistent with the identified Site Use." (310 CMR 40.0923(1)(c)). Table 2 summarizes the field study activities DEP selected to represent each receptor group.

For each receptor group, DEP selected body parts which would reasonably be expected to come into contact with soil or have soil deposited on them. It is important to note that based on the recently published adherence data, there is increased evidence that soil particles can be deposited on skin surfaces even when such

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surfaces are covered with clothing. A good example of this is the feet. Field studies reviewed by DEP measured high soil adherence on the feet of individuals who were wearing shoes and socks. Therefore, clothing assumed to be worn by receptor groups is not necessarily assumed to prevent contact with contaminated soil.

Skin surface areas for each body part were taken from DEP guidance (DEP 1995). Table 3 presents, for each receptor group, the body parts assumed to be exposed and skin surface area for each part.

Arithmetic mean soil-skin adherences for each body part were calculated by DEP from the field data published on the internet (John C. Kissel Web Page; <http://depts.washington.edu/jkspage/dermal.html>). Mean adherences calculated by DEP are shown in Table 4. Selection of the arithmetic mean rather than an upper-end estimate of adherence is consistent with DEP risk characterization guidance which provides that risk characterizations should use mid-range estimates of exposure parameters, such as intake rates, contact rates and body weights, which are known to vary among individuals within the specified receptor group. DEP is using the arithmetic mean rather than the geometric mean because it believes the arithmetic mean provides a better estimate of the average adherence an individual would experience over time.

DEP calculated a skin surface area-weighted adherence factor for each receptor group by multiplying the surface area for each body part by its respective mean soil-skin adherence and dividing by the total surface area. The following sections present the equations DEP used to calculate adherence factors.

## Equations and Technical Basis for Default Weighted Dermal Adherence Factors

In the following sections, each adherence value is discussed in detail. Equations are presented to show how the adherence factor was calculated from the field data.

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## Adult Resident

DEP selected “gardeners” as the high-end soil contact activity for adult residents. Residents could come into contact with soil in their yards during such high intensity activities as weeding and digging in gardens. Field studies measured soil adherence on two groups of individuals (Gardeners #1 and #2) performing various activities in a community garden including weeding, pruning, digging small irrigation trenches and picking fruit. Individuals wore long pants, short sleeved shirts and socks and shoes. Some wore gloves.

DEP assumed that soil adheres to the face, hands, forearms, lower legs and feet of adult residents. DEP used skin surface area for females aged 18 to 75 years. DEP used the arithmetic mean adherence for the two groups of gardeners calculated from the raw data.

The following equations were used to calculate the weighted adherence factor for adult residents.

$$\text{Weighted } AF_{\text{adult resident}} = \frac{(AF_{\text{face}})(SA_{\text{face}}) + (AF_{\text{hands}})(SA_{\text{hands}}) + (AF_{\text{forearms}})(SA_{\text{forearms}}) + (AF_{\text{lower legs}})(SA_{\text{lower legs}}) + (AF_{\text{feet}})(SA_{\text{feet}})}{SA_{\text{face}} + SA_{\text{hands}} + SA_{\text{forearms}} + SA_{\text{lower legs}} + SA_{\text{feet}}} \quad (i)$$

$$\text{Weighted } AF_{\text{adult resident}} = \frac{(0.0574 \text{ mg/cm}^2)(370 \text{ cm}^2) + (0.3180 \text{ mg/cm}^2)(817 \text{ cm}^2) + (0.0820 \text{ mg/cm}^2)(1150 \text{ cm}^2) + (0.0419 \text{ mg/cm}^2)(2180 \text{ cm}^2) + (0.2563 \text{ mg/cm}^2)(1140 \text{ cm}^2)}{370 \text{ cm}^2 + 817 \text{ cm}^2 + 1150 \text{ cm}^2 + 2180 \text{ cm}^2 + 1140 \text{ cm}^2} \quad (i.1)$$

$$\text{Weighted } AF_{\text{adult resident}} = 0.13 \text{ mg/cm}^2$$

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## Child Resident and Child Recreational

For both the child resident and the recreational child, DEP selected “children playing in wet soil” as the high-end activity to best represent soil contact a child might have during “full use” of his or her backyard or during “full use” of a recreational resource. Field studies measured soil adherence on 13 children who were given an assortment of toys and allowed to play, undirected, for 20 minutes in a constructed 8 foot by 8 foot soil bed. The soil contained roughly 16 to 18% moisture. Children wore either short sleeves and short pants or long sleeves and long pants. Soil adherence on the feet was not measured (shoes were covered with plastic bags tied at the ankle).

DEP assumed that soil could adhere to the hands, forearms, lower legs and feet of children. Because soil adherence was not measured on the feet of “children playing in wet soil,” DEP used the soil adherence measured on feet of Gardeners #1 and #2 to represent soil adherence on feet of the recreational and resident child. DEP believes that soil adherence measured on the feet of gardeners is unlikely to significantly underestimate soil adherence on the feet of children. Skin surface areas for females aged 1 to 7 years was used in the calculation of a weighted adherence factor for the resident and recreational child.

DEP notes that one of the field studies measured a group of “daycare kids.” DEP did not select “daycare kids” to represent resident or recreational children’s activities because it believes that the “daycare kids” activities do not represent high-end soil contact which would be experienced by the resident or recreational child. “Daycare kids” activities included both inside and outside play. DEP believes that measurements of soil adherence on children playing exclusively in soil for the full duration of the activity is more representative of soil contact a recreational and resident children would receive during “full-use” of the backyard.

The following equations were used to calculate the skin surface area weighted adherence factor for the child resident and the recreational child.

$$AF_{child} = \frac{(AF_{face})(SA_{face}) + (AF_{hands})(SA_{hands}) + (AF_{forearms})(SA_{forearms}) + (AF_{lowerlegs})(SA_{lowerlegs}) + (AF_{feet})(SA_{feet})}{SA_{face} + SA_{hands} + SA_{forearms} + SA_{lowerlegs} + SA_{feet}} \quad (2)$$

$$Weighted AF_{child} = \frac{(0.006 mg/cm^2)(329 cm^2) + (1.5 mg/cm^2)(379 cm^2) + (0.027 mg/cm^2)(472 cm^2) + (0.2 mg/cm^2)(754 cm^2) + (0.2563 mg/cm^2)(500 cm^2)}{329 cm^2 + 379 cm^2 + 472 cm^2 + 754 cm^2 + 500 cm^2} \quad (2.1)$$

$$Weighted AF_{child} = 0.35 mg/cm^2$$

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## Recreational Adult

DEP selected a soccer players scenario (Soccer #2 and #3) to represent high-end soil contact for recreational adults. Two groups of adult women soccer players were measured after playing 90 minute soccer games on all-weather fields composed in part of sand and ground tires. Participants wore shorts, shin guards, high socks and short-sleeves. DEP used the arithmetic mean adherence for the two groups of soccer players calculated from the raw data.

DEP assumed that soil contact could occur on the face, hands, forearms, lower legs and feet of recreational adults. Skin surface area values are for females aged 18 to 75 years. Soil adherence data for the soccer players was available for the entire arms but not the forearms and for the entire legs but not the lower legs. As shown in the equation below, DEP assumed that soil adherence on the arms is the same as the forearms and soil adherence on the legs is the same as the lower legs.

Because soil adherence was not measured on the feet of soccer players #2 and 3, DEP used the soil adherence measured on feet of Gardeners #1 and 2 to represent soil adherence on feet of the recreational adult. DEP believes that soil adherence measured on the feet of gardeners is unlikely to significantly underestimate soil adherence on the feet of recreational adults.

The following equations were used to calculate the skin surface area weighted adherence factor for recreational adults.

$$AF_{adult\ recreational} = \frac{(AF_{face})(SA_{face}) + (AF_{hands})(SA_{hands}) + (AF_{forearms})(SA_{forearms}) + (AF_{lowerlegs})(SA_{lowerlegs}) + (AF_{feet})(SA_{feet})}{SA_{face} + SA_{hands} + SA_{forearms} + SA_{lowerlegs} + SA_{feet}} \quad (3)$$

$$AF_{adult\ recreational} = \frac{\left(0.0154\text{mg/cm}^2\right)\left(370\text{cm}^2\right) + \left(0.0366\text{mg/cm}^2\right)\left(817\text{cm}^2\right) + \left(0.0051\text{mg/cm}^2\right)\left(1150\text{cm}^2\right) + \left(0.0361\text{mg/cm}^2\right)\left(2180\text{cm}^2\right) + \left(0.2563\text{mg/cm}^2\right)\left(1140\text{cm}^2\right)}{370\text{cm}^2 + 817\text{cm}^2 + 1150\text{cm}^2 + 2180\text{cm}^2 + 1140\text{cm}^2} \quad (3.1)$$

$$\text{Weighted } AF_{adult\ recreational} = 0.07\text{ mg/cm}^2$$

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## Trespasser

For the youth trespasser receptor group, DEP selected youth soccer players (Soccer #1) to represent high-end soil contact. Trespassers could come into contact with soil while sitting, walking and other low to medium intensity activities. Field measurements on soil adherence were made on a group of teenaged children while they were practicing soccer players. Some individuals wore long pants and some wore short pants. Most wore long sleeved shirts and some wore shin guards. Participants played soccer on a field of half grass and half bare earth.

DEP assumed that soil contact could occur on trespassers' hands, forearms and feet. Skin surface area values were used for children aged 11 to 18 years.

Because soil adherence was not measured on the feet of soccer players #1, DEP used the soil adherence measured on feet of Gardeners #1 and #2 to represent soil adherence on feet of trespassers. DEP believes that soil adherence measured on the feet of gardeners is unlikely to significantly underestimate soil adherence on the feet of trespassers.

The following equations were used to calculate the skin surface area weighted adherence factor for trespassers.

$$\text{Weighted } AF_{\text{trespasser}} = \frac{(AF_{\text{hands}})(SA_{\text{hands}}) + (AF_{\text{forearms}})(SA_{\text{forearms}}) + (AF_{\text{feet}})(SA_{\text{feet}})}{SA_{\text{hands}} + SA_{\text{forearms}} + SA_{\text{feet}}} \quad (4)$$

$$\text{Weighted } AF_{\text{trespasser}} = \frac{(0.1259 \text{ mg/cm}^2)(791 \text{ cm}^2) + (0.0130 \text{ mg/cm}^2)(1002 \text{ cm}^2) + (0.2563 \text{ mg/cm}^2)(1135 \text{ cm}^2)}{791 \text{ cm}^2 + 1002 \text{ cm}^2 + 1135 \text{ cm}^2} \quad (4.1)$$

$$\text{Weighted } AF_{\text{trespasser}} = 0.14 \text{ mg/cm}^2$$

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## Office Worker

DEP selected “practicing tae kwon do” as the high-end activity to represent adult office workers. Office workers could be exposed to soil at their workplace during such very low intensity activities as walking and eating lunch outside. Field studies measured soil adherence on 6 teenagers and one adult practicing tae kwon do, a martial arts activity, indoors on a carpeted surface. All were barefoot and wore loose fitting long-sleeved and long-legged martial arts clothing.

DEP assumed that soil could adhere to workers’ hands, forearms and feet. DEP used skin surface area for females, aged 18 to 75 years. Soil adherence data for the tae kwon do subjects was available for the entire arms but not the forearms. As shown in the equation below, DEP assumed that soil adherence on the forearms is the same as was measured on the arms of the field subjects.

The following equations were used to calculate the skin surface area weighted adherence factor for office workers.

$$\text{Weighted } AF_{\text{office worker}} = \frac{(AF_{\text{hands}})(SA_{\text{hands}}) + (AF_{\text{forearms}})(SA_{\text{forearms}}) + (AF_{\text{feet}})(SA_{\text{feet}})}{SA_{\text{hands}} + SA_{\text{forearms}} + SA_{\text{feet}}} \quad (5)$$

$$\text{Weighted } AF_{\text{office worker}} = \frac{(0.0071 \text{ mg/cm}^2)(817 \text{ cm}^2) + (0.0034 \text{ mg/cm}^2)(1150 \text{ cm}^2) + (0.0030 \text{ mg/cm}^2)(1140 \text{ cm}^2)}{817 \text{ cm}^2 + 1150 \text{ cm}^2 + 1140 \text{ cm}^2} \quad (5.1)$$

$$\text{Weighted } AF_{\text{office worker}} = 0.0004 \text{ mg/cm}^2$$

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## Industrial/Outdoor Commercial Worker

Commercial workers could come into contact with soil during light to moderately intense activities such as working around truck loading/unloading areas or using outdoor dumpster areas or tool/machine areas. Digging or extensive soil contact is not assumed. DEP selected a group of groundskeepers (Groundskeepers #1-5) as the field study group to represent high-end soil contact for the commercial worker receptor group. Soil adherence was measured on five field study groups of groundskeepers. Groundskeeper participants were engaged in groundskeeping activities at campus grounds, an urban horticulture center and an arboretum. All participants wore long pants and some used gloves. Most wore short sleeves. DEP used arithmetic mean for all five groups of groundskeepers calculated from the raw data.

For the commercial worker receptor group, DEP assumed that soil contact could occur on the face, hands, forearms and feet. Skin surface areas used in the equations below are from females aged 18 to 75 years.

The following equations were used to calculate skin surface area weighted soil adherence value for commercial workers.

$$\text{Weighted } AF_{\text{commercial}} = \frac{(AF_{\text{face}})(SA_{\text{face}}) + (AF_{\text{hands}})(SA_{\text{hands}}) + (AF_{\text{forearms}})(SA_{\text{forearms}}) + (AF_{\text{feet}})(SA_{\text{feet}})}{SA_{\text{face}} + SA_{\text{hands}} + SA_{\text{forearms}} + SA_{\text{feet}}} \quad (6)$$

$$\text{Weighted } AF_{\text{commercial}} = \frac{(0.0058 \text{ mg/cm}^2)(370 \text{ cm}^2) + (0.0697 \text{ mg/cm}^2)(817 \text{ cm}^2) + (0.0133 \text{ mg/cm}^2)(1150 \text{ cm}^2) + (0.0149 \text{ mg/cm}^2)(1140 \text{ cm}^2)}{370 \text{ cm}^2 + 817 \text{ cm}^2 + 1150 \text{ cm}^2 + 1140 \text{ cm}^2} \quad (6.1)$$

$$\text{Weighted } AF_{\text{commercial}} = 0.03 \text{ mg/cm}^2$$

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## Landscaper/Groundskeeper

Landscaper/groundskeepers could come into contact with soil during yardwork activities such as weeding, lawnmowing, pruning and planting. DEP selected a group of gardeners (Gardeners #1 and #2) as the field study group to represent high-end soil contact for the landscaper/groundskeeper receptor group. Field studies measured soil adherence on two groups of individuals (Gardeners #1 and #2) performing various activities in a community garden including weeding, pruning, digging small irrigation trenches and picking fruit. Individuals wore long pants, short sleeved shirts and socks and shoes. Some wore gloves.

DEP assumed that soil adheres to the face, hands, forearms and feet of landscapers/groundskeepers. DEP used skin surface area for females aged 18 to 75 years. DEP calculated the arithmetic mean adherence for the two groups of gardeners from the raw data.

The following equations were used to calculate skin surface area weighted soil adherence value for landscapers/groundskeepers.

$$\text{Weighted } AF_{\text{land/groundskeepers}} = \frac{(AF_{\text{face}})(SA_{\text{face}}) + (AF_{\text{hands}})(SA_{\text{hands}}) + (AF_{\text{forearms}})(SA_{\text{forearms}}) + (AF_{\text{feet}})(SA_{\text{feet}})}{SA_{\text{face}} + SA_{\text{hands}} + SA_{\text{forearms}} + SA_{\text{feet}}} \quad (7)$$

$$\text{Weighted } AF_{\text{land/groundskeepers}} = \frac{(0.0574 \text{ mg/cm}^2)(370 \text{ cm}^2) + (0.3180 \text{ mg/cm}^2)(817 \text{ cm}^2) + (0.0820 \text{ mg/cm}^2)(1150 \text{ cm}^2) + (0.2563 \text{ mg/cm}^2)(1140 \text{ cm}^2)}{370 \text{ cm}^2 + 817 \text{ cm}^2 + 1150 \text{ cm}^2 + 1140 \text{ cm}^2} \quad (7.1)$$

$$\text{Weighted } AF_{\text{land/groundskeepers}} = 0.19 \text{ mg/cm}^2$$

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## Utility/Heavy Construction Worker

This receptor group could come into contact with soil during very high intensity activities such as construction in and around foundations of buildings and excavation work. For the utility/heavy construction worker receptor group, DEP selected field study measurements made on two groups of utility workers (utility workers #1 and #2). Utility worker participants engaged in various activities including cleaning and fixing mains, connecting water pipes, jack-hammering and excavating trenches with a back hoe and with a shovel. All wore long pants, short sleeves, leather boots and a hat. Some wore gloves part of the time. Soil adherence was measured on the utility workers' face, hands and forearms.

DEP assumed that utility/heavy construction workers could have soil adhered to the face, hands, forearms and feet. Because soil adherence for the feet was not measured in the field study of utility workers, DEP used soil adherence measured for the feet of the gardeners #1 and #2 groups. DEP believes that soil adherence measured on the feet of gardeners is unlikely to significantly underestimate soil adherence on the feet of utility/heavy construction workers. DEP used skin surface area values for an 18 to 75 year old female.

The equations below were used to calculate skin surface area weighted soil adherence value for utility/heavy construction workers.

$$\text{Weighted } AF_{\text{utility/heavy construction}} = \frac{(AF_{\text{face}})(SA_{\text{face}}) + (AF_{\text{hands}})(SA_{\text{hands}}) + (AF_{\text{forearms}})(SA_{\text{forearms}}) + (AF_{\text{feet}})(SA_{\text{feet}})}{SA_{\text{face}} + SA_{\text{hands}} + SA_{\text{forearms}} + SA_{\text{feet}}} \quad (8)$$

$$\text{Weighted } AF_{\text{utility/heavy construction}} = \frac{(0.1102 \text{ mg/cm}^2)(370 \text{ cm}^2) + (0.3487 \text{ mg/cm}^2)(817 \text{ cm}^2) + (0.3279 \text{ mg/cm}^2)(1150 \text{ cm}^2) + (0.2563 \text{ mg/cm}^2)(1140 \text{ cm}^2)}{370 \text{ cm}^2 + 817 \text{ cm}^2 + 1150 \text{ cm}^2 + 1140 \text{ cm}^2} \quad (8.1)$$

$$\text{Weighted } AF_{\text{utility/heavy construction}} = 0.29 \text{ mg/cm}^2$$

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## Light Construction Worker

Light construction workers would be expected to have moderate intensity soil contact during such activities as finish construction work and other activities involving a minor amount of digging in soil. For the construction worker receptor group, DEP selected field study measurements made on one group of 8 construction workers. Participants worked for an 8-hour day erecting corrugated metal walls for a public storage facility. Most wore short pants and short sleeved shirts. All wore low socks. Soil adherence was measured on the utility workers' face, hands, forearms and lower legs.

DEP assumed that its group of light construction workers could have soil adhered to the face, hands, forearms and feet. Because soil adherence for the feet was not measured in the field study of construction workers, DEP used soil adherence measured for the feet of the gardeners #1 and #2 groups. DEP believes that soil adherence measured on the feet of gardeners is unlikely to significantly underestimate soil adherence on the feet of construction workers. DEP used skin surface area values for an 18 to 75 year old female.

The equations below were used to calculate skin surface area weighted soil adherence value for light construction workers.

$$\text{Weighted } AF_{\text{light construction}} = \frac{(AF_{\text{face}})(SA_{\text{face}}) + (AF_{\text{hands}})(SA_{\text{hands}}) + (AF_{\text{forearms}})(SA_{\text{forearms}}) + (AF_{\text{feet}})(SA_{\text{feet}})}{SA_{\text{face}} + SA_{\text{hands}} + SA_{\text{forearms}} + SA_{\text{feet}}} \quad (9)$$

$$\text{Weighted } AF_{\text{light construction}} = \frac{(0.0316 \text{ mg/cm}^2)(370 \text{ cm}^2) + (0.26 \text{ mg/cm}^2)(817 \text{ cm}^2) + (0.1040 \text{ mg/cm}^2)(1150 \text{ cm}^2) + (0.2563 \text{ mg/cm}^2)(1140 \text{ cm}^2)}{370 \text{ cm}^2 + 817 \text{ cm}^2 + 1150 \text{ cm}^2 + 1140 \text{ cm}^2} \quad (7.1)$$

$$\text{Weighted } AF_{\text{light construction}} = 0.18 \text{ mg/cm}^2$$

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## References

DEP 1995. Guidance for Disposal Site Risk Characterization in Support of the Massachusetts Contingency Plan, Interim Final Policy #WSC/ORS-95-141, July 1995.

John C. Kissel Web Page, Post-Activity Soil Loadings,  
<http://depts.washington.edu/jkspage/dermal.html>.

Kissel *et al.*, 1996. Kissel, J.C.; K.Y. Richter and R.A. Fenske, Field Measurement of Dermal Soil Loading Attributable to Various Activities: Implications for Exposure Assessment, *Risk Analysis* 16:115-125, 1996.

Kissel *et al.*, 1998. Kissel, J.C.; J.H. Shirai, K.Y. Richter and R.A. Fenske, "Investigation of Dermal Contact with Soil in Controlled Trials", *J. Soil Contamination* 7(6):737:752.

Holmes *et al.* 1999. Holmes, K.K.; J.H. Shirai, K.Y. Richter and J.C. Kissel, "Field Measurement of Dermal Loadings in Occupational and Recreational Activities", **Environ. Res.** 80:148-157.

U.S. EPA 1992. Dermal Exposure Assessment: Principles and Applications, Office of Research and Development, EPA/600/8-91/011B, January 1992.

U.S. EPA 1998 Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance, Dermal Risk Assessment Interim Guidance, **peer consultation workshop draft**

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TABLE 2: Summary of field studies used to develop weighted adherence factors

DEP RECEPTOR GROUP	FIELD STUDY GROUP	SOURCE OF FIELD DATA	FIELD ACTIVITY DESCRIPTION	CLOTHING WORN	BODY PARTS MEASURED	AGE (yrs)	TOTAL # SUBJ MEASURED
<b>Adult Resident</b>	Gardeners # 1 & 2	Holmes <i>et al.</i> 1999	Weeding, pruning, digging	Mostly long pants and short sleeves, socks & shoes, some gloves	face, forearms, hands, lowerlegs, feet	16-52	15
Child Resident and Child Recreational	Children Playing (wet soil)	Kissel <i>et al.</i> 1998	“Staged” children playing in 8’ x 8’ soil bed	Mostly shorts and short sleeves, some long pants and long sleeves	face, forearms, hands, lower legs	8-12	13
Adult Recreational	Soccer #2	Kissel <i>et al.</i> 1996	Playing soccer on an all weather field of sand and ground tires.	Short pants, short sleeves, shin guards, high socks	hands, arms, legs, face	24-34	8
Trespasser	Soccer #1	Kissel <i>et al.</i> 1996	Playing soccer on a field of half grass and half bare earth	Long and short pants, mostly long sleeves, some shin guards	face, forearms, hands, lower legs	13-15	8
Office Worker	Tae kwon do	Kissel <i>et al.</i> 1996	Practicing tae kwon do indoors	Loose fitting long pants, long sleeves, barefoot	face, forearms, hands, lower legs	8-42	7
Industrial/Outdoor Commercial Worker	Groundskeepers # 1-5	Kissel <i>et al.</i> 1996	Campus grounds, urban horticulture center, arboretum	Long pants, mostly short sleeves, some gloves	face, forearms, hands, lower legs	19-64	29
Landscaper/ Groundskeeper	Gardeners # 1 & 2	Holmes <i>et al.</i> 1999	Weeding, pruning, digging	Mostly long pants and short sleeves, socks & shoes, some gloves	face, forearms, hands, lowerlegs, feet	16-52	15
Utility Worker/Heavy Construction Worker	Utility Worker # 1 & 2	Holmes <i>et al.</i> 1999	Cleaning, fixing mains, jack-hammering, excavating trenches	Long pants, short sleeves, boots, hat, some gloves	face, forearms, hands	23-44	11
Light Construction Worker	Construction Worker	Holmes <i>et al.</i> 1999	Erecting corrugated metal walls for a public storage facility	Half long pants, most short sleeves	Face, forearms, hands	21-30	8



TABLE 3. Skin Surface Area by Body Part

DEP Receptor Group	Field Study Group	Skin Surface Area (cm <sup>2</sup> )					Source (all surface area values from DEP 1995)
		Face*	Hands	Forearms	Lower Legs	Feet	
Adult Resident	Gardeners #1 and 2	370	817	1150	2180	1140	Median, 18<76 year-old female
Child Resident and Child Recreational	Children playing (wet soil)	329	379	472	754	500	Median, 1<8 year-old female
Adult Recreational	Soccer #2 - #3	370	817	1150	2180	1140	Median, 18<76 year-old female
Trespasser	Soccer #1	---	791	1002	---	1135	Median, 11<18 year-old female
Office Worker	Tae kwon do	---	817	1150	---	1140	Median, 18<76 year-old female
Industrial/Outdoor Commercial Worker	Groundskeepers #1-5	370	817	1150	---	1140	Median, 18<76 year-old female
Landscaper/Groundskeeper	Gardeners #1 and 2	370	817	1150	---	1140	Median, 18<76 year-old female
Utility Worker/Heavy Construction	Utility Workers #1 and 2	370	817	1150	---	1140	Median, 18<76 year-old female
Light Construction Worker	Construction Worker	370	817	1150	---	1140	Median, 18<76 year-old female

\* Face was assumed to be 1/3 the surface area of the head.

---DEP assumed that the body part is not exposed to soil.

TABLE 4. Arithmetic Mean Skin-Soil Adherence by Body Part

Field Study Group	Arithmetic Mean Soil-Skin Adherence (mg/cm <sup>2</sup> )						
	Face	Hands	Arms	Forearms	Legs	Lower Legs	Feet
Gardeners #1 and #2 *	0.0574	0.3180	NM	0.0820	NM	0.0419	0.2563
Tae kwon do	NM	0.0071	0.0034	NM	0.0023	NM	0.0030
Children playing (wet soil)	0.006	1.5	NM	0.027	NM	0.2	NM
Soccer #1	0.0124	0.1259	0.0130	NM	0.0625	NM	NM
Soccer #2 - #3 *	0.0154	0.0366	0.0051	NM	0.0361	NM	NM
Groundskeeper #1- #5 *	0.0058	0.0697	NM	0.0133	NM	0.0011	0.0149
Utility Workers #1 and #2 *	0.1102	0.3487	NM	0.3279	NM	NM	NM
Construction Worker	0.0316	0.2600	NM	0.1040	NM	0.0697	NM

\* Adherence value is an overall arithmetic mean value for multiple groups.

NM = not measured