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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION 4

61 Forsyth Street
Atlanta, Georgia 30303-3104

April 5, 2001

4WD-OTS

MEMORANDUM

SUBJECT: Koppers Site, Gainesville, Florida

FROM: William N. O'Steen, Environmental Scientist
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TO: Maher Budeir, Remedial Project Manager
South Site Management Branch

This memorandum report responds to your request for a review of the **Soil Remedial Goals for Ground-Water Protection, Koppers Site, Gainesville, Florida**. If you have any questions about this memorandum or need additional technical assistance on this project, please contact me.

A. Statement of the Problem

Soil remedial goals for ground-water protection were calculated in the Feasibility Study Final Report for the Cabot Carbon/Koppers Site (herein termed the Koppers Site) in Gainesville, Florida. This report is dated May 9, 1990. Since the date of those soil remedial goal determinations, changes have been made to the drinking-water standards in 40 CFR Part 141, Subpart G (National Revised Primary Drinking Water Regulations: Maximum Contaminant Levels and Maximum Residual Disinfectant Levels). Drinking-water standards that have been changed since the completion of the Feasibility Study Final Report are considered in the reevaluation of the soil remedial goals for ground-water protection presented in this memorandum.

There may also be changes to the way that EPA considers both noncarcinogenic and carcinogenic risk in specifying ground-water target protection levels for remedial actions at CERCLA-regulated sites such as Koppers. The effect of changing risk-based ground-water protection levels on the soil remedial goals for ground-water protection is also considered in this memorandum. Risk-based ground-water protection levels were obtained through consultation with Glenn Adams, EPA Region 4 Waste Management Division, Office of Technical Services risk assessor.

Finally, there is a review in this memorandum of the procedure through which soil remedial goals

for ground-water protection were calculated in the Feasibility Study Final Report. Included in this review is consideration of the analytical and modeling approaches, the data which were used in the calculations, and any underlying assumptions about site conditions that were used in the formulation of soil remedial goals for ground-water protection. Where appropriate, revisions to the procedures and input to calculations of the soil remedial goals for ground-water protection have been made.

The result of these changes is a revised set of soil remedial goals for ground-water protection at the Koppers Site. This memorandum report documents the changes that have been made and presents the revised soil remedial goals for ground-water protection.

B. Revised Drinking-Water MCLs and Risk-Based Ground-Water Protection Levels

Considering Table 1.1-5 in the Koppers Site Feasibility Study Final Report, "Soil Remedial Action Objectives (mg/kg) for the Cabot Carbon/Koppers Site", the site contaminants for which different MCLs have been promulgated since the Final Feasibility Study Report was prepared include:

1. pentachlorophenol: 0.001 mg/L MCL effective July 30, 1992 (reference 40 CFR 141.60(a)(2) and 40 CFR 141.61 (c)(16))

2. benzo(a)pyrene: 0.0002 mg/L MCL effective January 17, 1994 (reference 40 CFR 141.60(a)(3) and 40 CFR 141.61(c)(19)

3. chromium: 0.1 mg/L MCL effective July 30, 1992 (reference 40 CFR 141.60(b)(2) and 40 CFR 141.62 (b) (5)).

With the exception of arsenic, risk-based cleanup numbers will apply to the remaining constituents listed in Table 1.1-5 of the Koppers Site Feasibility Study Final Report.

For arsenic, the 0.05 mg/L MCL remains the same as for the date of the Feasibility Study Final Report. However, the proposed arsenic MCL of 0.01 mg/L is a "to be considered" value (per communication from EPA Headquarters, March 2001) and a separate soil remedial goal for ground-water protection is presented, given the potential that a 0.01 mg/L arsenic concentration will become the target ground-water remedial goal.

Ground-water target protection levels that are considered in this memorandum report are presented in Table 1.

Table 1. Revised Ground-Water Target Protection Levels*

Constituent	Ground-Water Target Protection Level	Basis for Ground-Water Goal+
anthracene	0.18 mg/L	R9 PRG-pyrene surrogate
phenanthrene	0.18 mg/L	R9 PRG-pyrene surrogate
acenaphthylene	0.18 mg/L	R9 PRG-pyrene surrogate
acenaphthene	0.37 mg/L	R9 PRG
fluorene	0.24 mg/L	R9 PRG
pyrene	0.18 mg/L	R9 PRG
naphthalene	0.1 mg/L	lifetime health advisory
benz[a] anthracene	0.00009 mg/L (0.0002 mg/L)▲	R9 PRG
benzo[b] fluoranthene	0.00009 mg/L (0.0002 mg/L)▲	R9 PRG
benzo[g, h, i] perylene	0.18 mg/L	R9 PRG
benzo[k] fluoranthene	0.0009 mg/L	R9 PRG
indeno[1,2,3,- c, d] pyrene	0.00009 mg/L (0.0002 mg/L)▲	R9 PRG
benzo[a] pyrene	0.0002 mg/L	Federal and state MCL
pentachlorophenol	0.001 mg/L	Federal and state MCL
arsenic	0.05 mg/L; 0.01 mg/L◆	Federal and state MCL
chromium	0.1 mg/L	Federal and state MCL

* risk assumptions include 10-6 carcinogenic risk for several PAH compounds

+source: Drinking Water Standards and Health Advisories, EPA 822-B-00-001 Summer 2000; Chapter 62-550, Florida Administrative Code, Drinking Water Standards, Monitoring, and Reporting, Florida Department of Environmental Protection, 2000; EPA Region 9 Preliminary Remediation Goal (R9 PRG), October 2000.

◆ The 0.01 mg/L proposed arsenic MCL is a "to be considered" value, per U.S. EPA, 2001.

▲ based on the 0.0002 mg/L MCL for benzo[a]pyrene (the most carcinogenic of the PAH compounds), the benz[a] anthracene, benzo[b] fluoranthene, and indeno[1,2,3,- c, d] pyrene ground-water protection goals used in the calculation of soil remedial goals for ground-water protection are adjusted to a 0.0002 mg/L value, equal to a somewhat higher carcinogenic risk than the R9 PRG.

C. Review of Feasibility Study Final Report Calculations of Soil Remedial Goals for Ground-Water Protection

This section of the memorandum examines the procedures and model input used to calculate soil remedial goals for ground-water protection. The methods used to calculate those soil remedial goals are presented in Appendix B to the Feasibility Study Final Report, and in part, in the 1990 Risk Assessment for the Koppers Site. Revisions to some of the procedures, model input and calculations are presented in this section of the report and are supported by discussion of EPA policy and references to additional sources of relevant information for the calculations of soil remedial goals for ground-water protection.

1. Overview

The calculations of soil remedial goals for ground-water protection presented in Appendix B to the Feasibility Study Final Report relied on a process that involves several key elements of analysis. These key elements, along with how they are treated in this memorandum report, are presented in Table 2 .

Table 2. Key Elements of Analysis, Calculation of Soil Remedial Goals for Ground-Water Protection

Key Element	Treatment in This Memorandum Report
Selected Model	Modeling of dilution between the downgradient waste disposal area margin and hypothetical receptor well was discarded (see explanation in Section C.3 below). The concentration at the downgradient margin of the waste disposal areas was calculated the same as in the Feasibility Study Report, Appendix B, Section 4.0. The "Summers Model" was retained for the calculation of soil remedial goals for ground-water protection.
Ground-Water Target Protection Level	Modified as per Table 1 above
Conceptual Model of Soil/Source Contamination	Not specified in the Feasibility Study Final Report; see discussion in Section C.2 below
Location of Hypothetical Receptor Well/Dilution Factor	Modified; see explanation in Section C.3 below

Table 2, continued

Key Element	Treatment in This Memorandum Report
Source Area Dimensions	Modified; see explanation in Section C.4 below
Dilution at downgradient margin of the contaminant source	Modified; see explanation in Section C.3 below
Organic carbon partitioning coefficient	Modified, see Section D and Table 4 below
Fraction of Organic Carbon in Soil	Modified; see explanation in Section C.5 below

2. Conceptual Model of the Soil and Source Contamination

After completion of the site Remedial Investigation, subsequent sampling at the Koppers Site identified the presence of dense, non-aqueous phase liquids (DNAPL). The DNAPL has been characterized as being residual-phase DNAPL and a limited amount of free-phase DNAPL, the latter potentially being pooled on top of the clay layer at the base of the surficial aquifer (TRC, 1999; Revised Supplemental Feasibility Study Section 1.3.2.4, Figure 1.7, and Figure 1.13). The areas of DNAPL contamination at the site are surrounded by a much larger volume of contaminated soil with no (or minimal) amounts of DNAPL contamination (compare Figure 1 of this memorandum report to Figure 1.13 of the Revised Supplemental Feasibility Study).

Organic contaminants in the DNAPL phase are considered to be relatively less mobile in the subsurface environment via mass transfer to the aqueous phase, when compared to the environmental mobility of the same contaminants if they are sorbed to the aquifer materials. This difference in environmental mobility is predicted by a comparison of the soil-water partitioning coefficient of a contaminant to the octanol-water partitioning coefficient of that contaminant (the latter being a measure of the affinity of organic substances to partition between an organic phase and an aqueous phase)(Lyman et al, 1990). For example, an approximate partitioning coefficient for naphthalene between DNAPL and water would be predicted to be 1995 (this value is the mode of 72 reported values reported in MacKay et al, 1992). In contrast, an approximate naphthalene partitioning coefficient between Koppers Site soil and water (K_d) would be on the order of 0.6, based on a naphthalene organic carbon partitioning coefficient (K_{OC}) of 1000 (median of 23 reported values; MacKay et al, 1992) and a fraction of organic carbon (f_{OC}) estimated to be 0.0006 (TRC, 1999, Appendix G, Section G.5.2). This comparison indicates a contaminant mobility based on partitioning considerations that is roughly 3000*x* greater for the sorbed naphthalene compared to naphthalene present in a nonaqueous phase. That relative degree of contaminant mobility would apply to numerous organic contaminants of concern at the

Koppers Site. Thus, it can be stated that organic contaminant migration out of the DNAPL at the site would likely be much less than organic contaminant migration due to desorption from soil, given an approximate parity in the DNAPL phase and sorbed phase organic contaminant concentrations.

It is presumed that because of potential difficulties in identifying and remediating DNAPL contamination, along with other site-specific concerns, the subsurface contamination that needs to be considered here is strictly the sorbed or solid-phase contamination. Thus, soil remedial goals for ground-water protection presented in this memorandum report should not be taken as having applicability to DNAPL contamination.

3. Location of the Receptor Well/Dilution Factor

Appendix B to the Koppers Site Feasibility Study Final Report presents distances from the source areas to hypothetical receptor wells of 150 feet (cooling pond/treatment plant to well ITW-5), 900 feet (southern lagoon to M-17, now identified as MW-17) and 1,125 feet (northern lagoon to monitoring well ITW-23). A review of the locations of these monitoring wells indicates they are either at or in close proximity to the Koppers Site boundary, downgradient of any areas where contaminated soils are present to any significant degree.

EPA has defined the area over which ground-water cleanup levels apply as the area of attainment (U.S. EPA, 1988). Without some special provisions that allow for ground-water contamination to indefinitely persist in areas outside of a location where waste is managed in place, EPA considers the "area of attainment" to encompass "...the area outside the boundary of any waste remaining in place and up to the boundary of the contaminant plume" (U.S. EPA, 1988). Thus, a hypothetical receptor well would conceivably be located at the downgradient margin of the area of attainment, or more generally, drinking-water maximum contaminant levels would have to be met at the downgradient margin of the waste disposal management area. This position is consistent with the application in CERCLA, as being relevant and appropriate, of the regulations that apply to RCRA-regulated hazardous waste treatment, storage, and disposal facilities (specifically 40 CFR Part 264, Subpart F, Section 264.95, point of compliance). Thus, the allowable dilution of contamination reaching the ground-water through soil contaminant leaching is generally only that which occurs by the ground water moving beneath the waste disposal area (presumably, this ground water is either uncontaminated as it moves into the area below the waste disposal or waste management area or is less contaminated than the soil water recharge). The issue of the boundaries of the waste management area as defining the area of ground-water dilution also has applicability to the determination of the source area dimensions, which influence the vertical plume mixing, as detailed in Section C.4 below.

Where there is a close proximity of several waste disposal areas/areas of soil contamination, it is the practice of EPA to define such a cluster of waste disposal areas as representing an entire waste management area, rather than being considered as individual waste disposal areas. This

interpretation is of considerable practical significance when applied to calculations of soil remedial goals for ground-water protection, since those calculations either consider that ground-water flow entering the area beneath a waste disposal or waste management area is uncontaminated, or there must be an adjustment to the calculations to account for a background level of a contaminant of concern. Where there are multiple contaminant inputs along a ground-water flow path, the more downgradient of the contaminant sources would necessarily have a lower soil remedial goal for ground-water protection, since the upgradient input of contaminants must be accounted for. In fact, since the soil remedial goal calculations define a soil contaminant concentration at which the appropriate ground-water target concentration is the exact result, a waste disposal area downgradient of a second waste disposal area at a site would have no allowable contaminant concentration in the recharge. The issue of definition of the waste disposal or waste management areas at the Koppers Site is addressed in more detail in Section C.4 of this memorandum report.

The dilution factor is determined in a simplified analysis of soil contaminant leaching to ground water through use of the following equation (U.S. EPA, 1996a page 43, "Option 2"):

$$\text{dilution factor} = (Q_p + Q_A)/Q_p \qquad (1)$$

where
Q_p is the percolation flow rate (m^3/year)
Q_A is the ground-water flow rate (m^3/year)

To calculate the percolation flow rate, use

$$Q_p = IA \qquad (2)$$

where I is the recharge through the
waste disposal area (m/year)
and A is the waste management area (m^2)

To calculate the ground-water flow rate, use

$$Q_A = WdKi \qquad (3)$$

where W is the width of the waste disposal area
perpendicular to the direction of ground-water flow (m^2)
d is the mixing zone depth (calculated as per
equation (4) below)
K is the aquifer hydraulic conductivity (m/d)
i is the hydraulic gradient (unitless)

The mixing zone depth is calculated using the following equation:

$$d = (2\,\alpha_v L)^{0.5} + B(1-\exp(-LI/V_s n_e B)) \qquad (4)$$

where d = mixing zone thickness

I = recharge rate (m/year)
α_V = vertical dispersivity (m)
L = length of waste disposal area parallel to
the ground-water flow direction (m)
B = the aquifer thickness (m)
V_s = the ground-water seepage velocity (m/year)
n_e = the effective porosity (unitless)

In Appendix B to the Feasibility Study Final Report, the recharge through the waste management areas was determined by subtracting a reported lake evaporation of 45 inches from an annual average rainfall of 53 inches per year. This is a crude approach for estimating recharge, since lake evaporation is not equivalent to actual evapotranspiration, the process that would actually be occurring at the Koppers Site. Therefore, an alternative to this Feasibility Study Final Report method for estimating recharge is needed.

Two alternative approaches were used to estimate the recharge through the areas of concern at the Koppers Site. In the first method, hydrologic budget data from a published report (C.W. Thornthwaite Associates, 1964) were used to estimate recharge as follows:

P-AE=R
where P is precipitation in mm/y
AE is actual evapotranspiration in mm/y
R is recharge in mm/y.

From that reference, P is 1253 mm/y and AE is 1091 mm/y for Gainesville, Florida. These values yield an estimated recharge value of 162 mm/y (6.38 in/y)

In the second method, modeling of the site using EPA's Hydrologic Evaluation of Landfill Performance (HELP) model was considered. This modeling was done in the Revised Supplemental Feasibility Study (TRC, 1999) and is documented in Appendix G to that document. From that site-specific analysis, a recharge rate for the existing ground surface of 5.8 inches per year was estimated. This value closely approximates the 6.38 inches per year recharge rate that is estimated from the reference. As a reasonable approximation, a recharge of 6 inches per year is considered to be appropriate for the Koppers Site evaluation of soil remedial goals for ground-water protection.

4. Source Area Dimensions

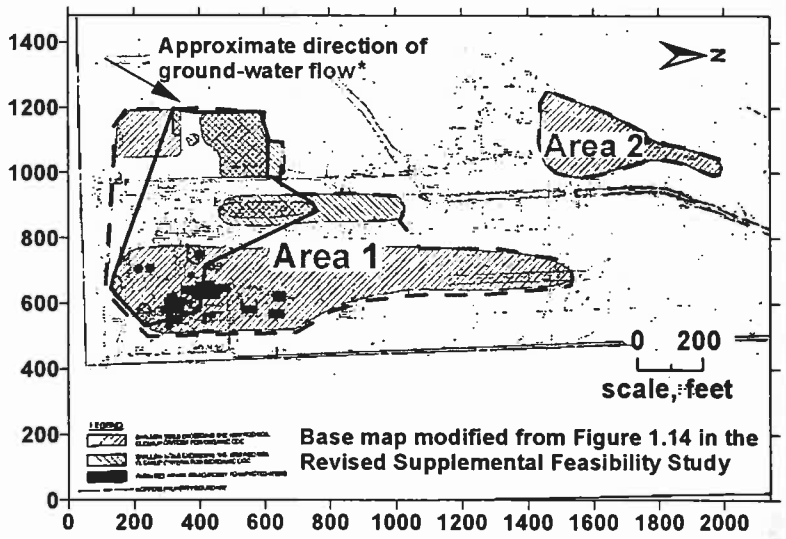
The dimensions of the source area are important for defining the dilution factor used to calculate the soil remedial goals for ground-water protection. The source area dimensions are presented in Table 1 of Appendix B to the Feasibility Study Final Report. These dimensions are herein

revised, based upon the results of soil sampling and other site investigations completed after 1990.

In order to avoid complex calculations of incremental leachate contributions from numerous smaller contaminant source areas, clusters of smaller areas of contamination at the Koppers Site that are in close proximity are considered as one area. Figure 1.14, "Areas with Shallow Soil Exceeding 1990 ROD Soil Cleanup Criteria" (TRC , 1999) is used to define two subareas of the site where there is organic soil contamination of significance and a separate subarea of the site where there is inorganic contamination of significance. Figure 1 of this memorandum reproduces a part of that referenced figure as a base map, along with showing the organic and inorganic soil contamination subareas of the site that are defined in this analysis.

Figure 1 shows the dimensions of the different soil contamination/source areas identified at the Koppers Site. Of importance are the overall dimensions of the waste disposal areas, which are used to estimate the recharge volume, and the dimensions of the waste disposal areas parallel and perpendicular to the ground-water flow direction, which enter into the calculations of ground-water flow available for dilution and the mixing zone depth, applied in equations (3) and (4) above. Table 3 presents the estimate areas of waste disposal and contaminant source dimensions parallel and perpendicular to ground-water flow. These areas and dimensions are used to calculate recharge, ground-water flow, and the mixing zone, as shown below Table 3.

Figure 1. Estimated Areas of Soil Contamination, Koppers Site



Area Calculations

Approximated Organic Soil Contamination Areas

Area 1: 506,880 square feet

Area 2: 73,680 square feet

Approximated Inorganic Soil Contamination Area

Area: 222,720 square feet

***Based on Figure 1.4 in the Revised Supplemental Feasibility Study**

Table 3. Waste Areas and Dimensions

Waste Area (reference Figure 1)	Overall Dimension	Width Perpendicular to Ground-Water Flow	Length Parallel to Ground-Water Flow
Organic Contamination Area 1	506,880 square feet = 47,091 square meters	757 feet = 231 meters	1100 feet = 335 meters
Organic Contamination Area 2	73,680 square feet = 6845 square meters	218 feet = 66 meters	396 feet = 121 meters
Inorganic Contamination Area	222,720 square feet = 67,885 square meters	736 feet = 224 meters	460 feet = 140 meters

Calculations:

1. Annual recharge through the waste disposal areas calculated using equation (2):

Organic contamination area 1: 506,880 square feet • 0.5 feet of recharge per year = 253,440 cubic feet/year = 7,177 cubic meters of recharge per year

Organic contamination area 2: 73,680 square feet • 0.5 feet of recharge per year = 36,840 cubic feet of recharge per year = 1,043 cubic meters of recharge per year

Inorganic contamination area: 222,720 square feet • 0.5 feet of recharge per year = 111,360 cubic feet/year = 3,153 cubic meters of recharge per year

2. Mixing zone depth calculated using equation (4):

a. α_V = vertical dispersivity (m) is estimated based on an approximate average hydraulic conductivity of 23.5 feet per day (average of 4 values reported in Section G.3, Volume 2, of the Revised Supplemental Feasibility Study; TRC, 1999) and the relationships between scale and longitudinal dispersivity and longitudinal and vertical dispersivity as presented in Xu and Eckstein (1995) and ASTM (1995). Because different contaminant source areas have different scales (lengths parallel to ground-water flow), a separate vertical dispersivity value is estimated for each area. For organic contamination area 1, the vertical dispersivity is estimated to be 0.73 meters. For organic contamination area 2, the vertical dispersivity is estimated to be 0.4 meters. For the inorganic contamination area, the vertical dispersivity was estimated based on a larger length than that shown in Table 3 above. This adjustment was made because it would be illogical to specify a ground-water compliance point for the inorganic contamination within the soil organic contamination waste management area. The length used to estimate the vertical dispersivity for the area of inorganic soil contamination was therefore determined based on the length of the area of inorganic contamination parallel to ground-water flow (140 meters, per Table 3 above), plus an additional 130 meters distance where the organic ground-water concentration standards or risk-based remedial goals would not need to be met. Based on this

total 270-meter length parallel to ground-water flow, the vertical dispersivity for the inorganic contaminant source area is approximated as 0.65 meters.

b. The term B in equation (4), the aquifer thickness, is estimated based on Figure 1-4 and Figure G-2 in the Revised Supplemental Feasibility Study. These figures indicate that across the site, the difference between the water table elevation (under static conditions) and the base of the surficial aquifer ranges from approximately 16 to 24 feet. As an approximate average, the aquifer thickness is assumed to be 20 feet (6.1 meters).

c. The combined terms $V_s n_e$ in equation (4) are equivalent to the product of the aquifer hydraulic conductivity, K, and the aquifer hydraulic gradient, i. As noted above, the average aquifer hydraulic conductivity at the Koppers Site is estimated to be 23.5 feet per day (7.16 meters/day). A slightly higher hydraulic conductivity value is reported in Section 1.3.1.4 of the Revised Supplemental Feasibility Study; either value is approximately correct. The hydraulic gradient, i, is reported as 0.005 in Section 1.3.1.4 of the Revised Supplemental Feasibility Study. These two values combined indicate a daily value of 0.0358 m/d ($K \bullet i = 0.0358$ m/d). This 0.0358 m/d value equals an annual value of 13.07 m/y.

d. The terms I and L in equation (4) are, as per Table 3, item a. and calculation 1 above, defined as I = 0.5 feet/year $\doteq$ 0.1524 m/y; L for organic contamination area 1 = 335 m, L for organic contamination area 2 = 121 m and L for the inorganic contamination area = 270 m..

Calculated mixing zone depths are as follows:

For organic contamination area 1, the calculated mixing zone thickness using equation (4) is 25 meters. The mixing zone equation predicts the plume will likely mix across the full saturated thickness of the surficial aquifer by the time the plume reaches the downgradient margin of the waste disposal or waste management area.

For organic contamination area 2, the calculated mixing zone thickness using equation (4) is 11 meters. The mixing zone equation predicts the plume will likely mix across the full saturated thickness of the surficial aquifer at the downgradient margin of this waste disposal or waste management area.

For the area of inorganic contamination, the calculated mixing zone thickness using equation (4) is 21 meters. The mixing zone equation predicts the plume will likely mix across the full saturated thickness of the surficial aquifer at the downgradient margin of this waste disposal or waste management area.

3. Ground-water flow beneath waste disposal areas calculated using equation (3):
Organic contamination area 1: The annual ground-water flow beneath organic contamination area 1 is calculated using equation 3 as:

$Q_A = 231 \text{ m} \bullet 6.1 \text{ m} \bullet 7.16 \text{ m/d} \bullet 365 \text{ days/y} \bullet 0.005 = 18{,}412 \text{ m}^3\text{/y}.$

Organic contamination area 2: The annual ground-water flow beneath organic contamination area 2 is calculated using equation 3 as:

$Q_A = 66\ m \bullet 6.1\ m \bullet 7.16\ m/d \bullet 365\ days/y \bullet 0.005 = 5{,}261\ m^3/y.$

Inorganic contamination area: The annual ground-water flow beneath the area of inorganic contamination is calculated using equation 3 as:

$Q_A = 224\ m \bullet 6.1\ m \bullet 7.16\ m/d \bullet 365\ days/y \bullet 0.005 = 17{,}855\ m^3/y.$

4. Dilution factor calculated using equation (1):

Using the dilution factor equation (1), the following dilution factors are calculated:

For organic contamination area 1, the dilution factor is calculated as:
$(18{,}412\ m^3/y + 7{,}177\ m^3/y)/\ 7{,}177\ m^3/y = 3.565.$

For organic contamination area 2, the dilution factor is calculated as:
$(5{,}261\ m^3/y + 1{,}043\ m^3/y)/1{,}043\ m^3/y = 6.044.$

For the area of inorganic contamination, the dilution factor is calculated as:
$(17{,}855\ m^3/y + 3{,}153\ m^3/y)/\ 3{,}153\ m^3/y = 6.663.$

5. Soil Fraction of Organic Carbon

As presented above, the average fraction of organic carbon for the Koppers Site has been determined to be 0.0006. This value is considered representative of soils below the water table (average of three samples from depths of 8 feet to 15 feet below ground surface; TRC, 1999, Appendix G, Attachment G.4). This average omits a relatively high fraction of organic carbon value of 0.0045 (TRC, 1999). It also likely underestimates the fraction of organic carbon in shallower subsurface soils, based on the work of O'Steen (1994). The calculations of soil remedial goals for ground-water protection that were presented in the 1990 Feasibility Study assumed a soil fraction of organic carbon of 0.005. Based on O'Steen, 1994, this 0.005 value of the f_{OC} approximates the average organic carbon content for Florida sandy soils at depths less than approximately 20 centimeters below ground surface, but exceeds the soil organic carbon contents of most sandy soils below a 20 cm depth. For those deeper soils, the mean f_{OC} for 387 sandy soil samples is estimated to be 0.004 (O'Steen, 1994, utilizing data from U.S. Department of Agriculture Soil Conservation Service Soils Surveys across Florida). The median f_{OC} for these 387 samples of deeper sandy soils is somewhat lower, approximately 0.0015. Based on samples of Millhopper Sand (the soil series present in most of the Koppers Site) from Alachua County, Florida (U.S. Department of Agriculture, 1985) the average soil organic carbon for the depth range of 23 to 224 cm below ground surface is 0.0006 (this average was calculated for this memorandum report using an approach analogous to the calculation of the mean vertical hydraulic conductivity of a series of layers with variable hydraulic conductivities; reference

Freeze and Cherry, 1979). The organic carbon content of these Millhopper Sand soil samples varies from a high of 0.0018 for the 23 to 53 cm depth interval to only 0.0003 for soil samples deeper than 162 cm.

Given all of the information on the fraction of organic carbon in soils, a reasonable estimated soil organic carbon to be used in the calculations of soil remedial goals for ground-water protection at the Koppers Site is 0.001.

D. Calculation of Soil Remedial Goals for Ground-Water Protection

Section 4.0 of Appendix B to the Feasibility Study Final Report for the Cabot Carbon/Koppers Site (Environmental Science and Engineering Inc., 1990) presents an equation which is known as the Summers Model (U.S. EPA, 1996a; reference Section 2.5.5). The soil remedial goals for ground-water protection calculated in this memorandum report are determined using that soil contaminant leaching model. A simplified expression for the Summers Model is presented as equation (5):

$$SCL = DF \bullet K_d \bullet GWPS \qquad (5)$$

where:
SCL is the soil target cleanup level
DF is the dilution factor
K_d is the soil-water partitioning coefficient
GWPS is the ground-water protection level

The dilution factors applicable to the three identified areas of soil contamination are presented in Section C. 4 above. Ground-water protection standards are presented in Table 1 of this memorandum report. The soil-water partitioning coefficient for organic contaminants is the product of the K_{OC} and the f_{OC}. The f_{OC} is considered to be 0.001 for purposes of these calculations (see discussion above). The K_{OC} is contaminant-specific. A comprehensive summary of K_{OC} values for most of the site organic contaminants of concern is presented in the reference by MacKay et al (1992). For pentachlorophenol, the K_{OC} is determined based on an analysis in Section 5.3.2 of U.S. EPA, 1996a.

Table 4 presents K_{OC} mean and median values from the references cited above.

For inorganic contaminants, the soil-water partitioning coefficient, K_d, is a measure of the composite capacity of the soil to retain inorganic contaminants. A number of different processes contribute to this capacity. Ideally, the soil-water partitioning coefficient for inorganic contaminants is determined from site-specific investigations, typically using a contaminant leaching test such as the U.S. EPA's Synthetic Precipitation Leaching Procedure. Such a site - specific evaluation of the mobility of arsenic and chromium in the site soils has apparently either not been done, or is very poorly documented in the available Koppers Site record and is therefore considered as unusable. Complicating the evaluation of the environmental mobility of these

metals is the fact they are potentially present in the environment at difference valence states and the species of arsenic and chromium may change across the site, depending on the specific subsurface environmental conditions.

Table 4. Organic Carbon Partition Coefficient Values for Koppers Organic Contaminants*

Contaminant of Concern	Median Koc	Mean Koc	Number of Samples
anthracene	20,417	63,455	27
phenanthrene	19,055	86,499	19
acenaphthylene	4,757	4,697	4
acenaphthene	4,677	51,838	5
fluorene	14,125	69,068	6
pyrene	66,069	247,366	39
naphthalene	1,000	5,668	23
benz[a] anthracene	118,340	3,704,613	6
benzo[b] fluoranthene	525,364	525,364	2
benzo[g, h, i] perylene	1,702,297	1,702,297	2
benzo[k] fluoranthene	831,764	2,473,708	5
indeno[1,2,3,- c, d] pyrene		3,467,368◆	NA
benzo[a] pyrene	3,195,291	35,287,370	6
pentachlorophenol		7,440+	NA

* unless otherwise stated, the K_{OC} values reported in this table are taken from MacKay et al. 1992.

+ the K_{OC} for pentachlorophenol is a function of the pH of the environment. An estimate of the site average pH was made based on ground-water pH values shown on Figure 4.2-12 of the Remedial Investigation Report. The mean ground-water pH at the site is approximately 5 (the reported pH range is from 4.6 to 6.3). For a pH of 5, the K_{OC} for pentachlorophenol is approximately 7440, based on the relationships between pH and the K_{OC} for pentachlorophenol presented in Table 43 of U.S. EPA, 1996a.

◆ the Koc for indeno[1.2.3- c.d] pyrene is derived from Table 39 of U.S. EPA, 1996a.

A qualitative evaluation of the subsurface environmental mobility of arsenic and chromium can be made by reviewing soil and ground-water concentration data that have been obtained from the Koppers Site. Considering the information presented in Figure 1.8 and the last paragraph of

Section 1.5.1 of the Supplemental Feasibility Study (TRC, 1999), the ground-water arsenic concentrations in the general area of the most significant inorganic soil contamination suggest that for a soil arsenic concentration of roughly 200 mg/Kg, the corresponding, resultant ground-water concentrations probably are in the range of 0.31 to 3 mg/L. The 200 mg/Kg soil concentration is the mean concentration of all soil arsenic concentrations reported on Figure 1.8 of the Supplemental Feasibility Study (TRC, 1999) for the South Lagoon area soils that exceed than the 1990 Record of Decision (ROD)-specified soil arsenic remedial goal of 27 mg/Kg. The 0.31 to 3 mg/L ground-water concentrations apply to two ground-water samples obtained from the part of the Koppers Site just downgradient of the South Lagoon area (reference TRC, 1999, Figure 1.5 and Figure 1.8). Taking these points together, an order of magnitude approximate soil-water partitioning coefficient for arsenic at the Koppers Site is probably on the order of 67 to 645 (this range is calculated as the above-referenced 200 mg/Kg average soil arsenic concentration divided by the two ground-water arsenic concentrations).

A second approach for qualitatively assessing the mobility of contaminants in the soil is to consider soil concentration versus soil depth. Assuming a surface or near-surface contaminant source, a low mobility contaminant would be expected to have a limited depth of penetration into the subsurface, while higher mobility contaminants would be expected to extend more deeply into the subsurface. Figure 4.3-4 of the Koppers Site Remedial Investigation Report (Environmental Science and Engineering, Inc., 1990) provides a usable depiction of soil arsenic and chromium concentrations versus depth for Remedial Investigation samples obtained from the South Lagoon area of the Koppers Site. This figure shows that soil arsenic concentrations above the ROD-specified soil remedial goal of 27 mg/Kg extend to depths of 10 feet or more, but there is a general decrease in concentration with increasing depth. Variable depth-concentration profiles from this area are consistent with a range in arsenic mobility in the subsurface (as suggested by the range in the observed ground-water concentrations of arsenic immediately downgradient of the South Lagoon area, as note above).

Figure 4.34 from the Remedial Investigation Report also shows the concentrations of chromium versus sample depth. The plots of soil chromium concentrations versus sample depth also suggest a range in chromium mobility in the subsurface. Chromium appears to be somewhat less mobile in the subsurface compared to arsenic. This observation is based on the ratios of shallowest to deepest soil concentrations of the two metals. Using the Remedial Investigation Report Figure 4.3-4 data, for a set of 9 samples with both chromium and arsenic measurements, the median shallowest to deepest concentration ratio was 3.93:1 for arsenic (indicating the shallow soil arsenic concentration averaged 3.93*x* the deepest paired soil arsenic concentration), whereas the median ratio of shallowest to deepest chromium for the same nine sample pairs was 10.59:1.

The mobility of the inorganic contaminants of concern relates to both the type of metals present and to the soil chemical environment. For the Koppers wood preserving site, the type of arsenic present is arsenate (As_2O_5), the form of arsenic used in wood preservative (ATSDR, 2000). Arsenate is relatively less toxic than arsenite (AsO_2^-), the reduced form of arsenic (McLean and Bledsoe, 1992). The adsorption of arsenate is pH dependent, with increasing pH associated with decreasing arsenic adsorption (McLean and Bledsoe, 1992). As a generalization,

the arsenite (As^{+3}) form of arsenic is more mobile than arsenate (U.S. EPA, 1996a). This higher mobility of arsenite compared to arsenate is partly due to solubility of arsenate and arsenite compounds; arsenite compounds are reported to be 4 to 10 times more soluble than arsenate compounds (McLean and Bledsoe, 1992). Arsenate adsorption is likely to be most important at a pH of approximately 5, based on the research by Griffin and Shimp (1978).

Considering the geochemical environment likely applicable to the Koppers Site, measured shallow ground-water pH obtained during the RI had a median value of 4.8, and the reported soil pH for the Millhopper Sand is between 4.5 and 6.5 (U.S. Department of Agriculture, 1985). These pH data suggest that arsenate mobility will be relatively low in the Koppers Site environment.

Published soil-water partitioning coefficients for arsenic and chromium are presented in Table 43 of U.S. EPA, 1996a. For arsenic, the K_d values reported in this table are as high as 200, but are reported to range from 5.86 to 19.4 for arsenic in general and from 1.9 to 18, with a geometric mean value of 6.7, for As^{+5}. A more recent reference (U.S. EPA, 1999) presents twenty one K_d values for As^{+5}. These values are more consistent with the geometric mean value of 200 reported in Table 43 of U.S. EPA (1996a). The 1999 EPA reference indicates that for As^{+5}, the median K_d reported was 2520, while the lowest K_d reported was 67.

Given the information regarding the arsenic K_d and the type of arsenic expected to be present in the Koppers Site subsurface environment, a conservative K_d value used in calculations of the soil remedial goals for ground-water protection is 67. This value is at the low end of the K_d values reported in U.S. EPA(1999) and is at the low end of the range of K_d values that appear to be applicable to the Koppers Site, based on a comparison of contaminated soil concentrations to nearby shallow ground-water concentrations. Table 5 presents the calculated soil remedial goals for the area of significant soil arsenic contamination at the Koppers Site using this K_d value of 67.

For chromium, the type of chromium present in wood treating preservative is Cr^{+3} (ATSDR, 2000). Cr^{+3} is the less toxic form of chromium. In the conditions in the subsurface at the Koppers Site, Cr^{+3} is not expected to oxidize to the more toxic form of chromium. Cr^{+3} is readily adsorbed by soils, and was found to be relatively less mobile than arsenic species at a soil pH of 5 (McLean and Bledsoe, 1992; Griffin and Shimp, 1978). A lower Koppers Site soil mobility of chromium compared to arsenic is suggested by the soil concentration versus depth analysis presented above.

U.S. EPA (1996a) presents a range of chromium K_d values of 168 to 3,600. For these values, the valence state of chromium is unspecified. U.S. EPA (1999) presents thirty five Cr^{+3} K_d values. These thirty five observations indicate a median Cr^{+3} K_d of 8910, with a minimum K_d of 298. A nonparametric sign confidence interval on the median K_d of these thirty five data points is 5,129 to 15,065 (C.I.. = 0.95), indicating that the average K_d for Cr^{+3} is probably greater than 5,129. The lower quartile for the thirty five Cr^{+3} K_d values is 3800, indicating that 75% of the referenced Cr^{+3} K_d values exceed this value.

Because there are no site-specific Cr^{+3} K_d data for the Koppers Site, the lowest reported literature K_d value specific to Cr^{+3} (presented in U.S. EPA, 1999) is used to calculate a soil remedial goal

Table 5, continued

for ground-water protection. This K_d value is 298. Table 5 presents the calculated chromium soil remedial goal for ground-water protection.

Considering the ground-water protection standards of Table 1, the calculated dilution factors in Section C. 4, the fraction of organic carbon in Section C.5, the selected K_d values for arsenic and chromium, as discussed above, and the organic carbon partitioning coefficients of Table 4, the soil remedial goals for ground-water protection are calculated. Table 5 presents those calculated soil remedial goals. Two values are presented in Table 5 for most of the modeled scenarios. The first value is calculated using the median K_{OC} for the organic contaminants. The second soil remedial goal for ground-water protection is calculated using the mean K_{OC} for the organic contaminant.

Table 5. Soil Remedial Goals for Ground-Water Protection*

Contaminant of Concern	Organic Contamination Area 1	Organic Contamination Area 2	Inorganic Contamination Area
anthracene	13.1 mg/Kg 40.7 mg/Kg	22.2 mg/Kg 69 mg/Kg	
phenanthrene	12.2 mg/Kg 55.5 mg/Kg	20.7 mg/Kg 94.1 mg/Kg	
acenaphthylene	3.1 mg/Kg 3 mg/Kg	5.3 mg/Kg 5.2 mg/Kg	
acenaphthene	6.2 mg/Kg 68.4 mg/Kg	10.5 mg/Kg 116 mg/Kg	
fluorene	17.5 mg/Kg 85.4 mg/Kg	29.7 mg/Kg 145 mg/Kg	
pyrene	42.4 mg/Kg 159 mg/Kg	71.9 mg/Kg 270 mg/Kg	
naphthalene	0.4 mg/Kg 2.20 mg/Kg	0.6 mg/Kg 3.4 mg/Kg	
benz[a] anthracene	0.1 mg/Kg 2.6 mg/Kg	0.1 mg/Kg 4.5 mg/Kg	
benzo[b] fluoranthene	0.4 mg/Kg	0.6 mg/Kg	
benzo[g, h, i] perylene	1092 mg/Kg	1852 mg/Kg	

Contaminant of Concern	Organic Contamination Area 1	Organic Contamination Area 2	Inorganic Contamination Area
benzo[k] fluoranthene	2.68 mg/Kg 8 mg/Kg	4.5 mg/Kg 13.6 mg/Kg	
indeno[1,2,3,- c, d] pyrene	2.5 mg/Kg	4.2 mg/Kg	
benzo[a] pyrene	2.3 mg/Kg 25.2 mg/Kg	3.9 mg/Kg 42.7 mg/Kg	
pentachlorophenol	0.03 mg/Kg	0.04 mg/Kg	
arsenic			22.3 mg/Kg; 4.5 mg/Kg[+]
chromium			199 mg/Kg

[*] remedial goals are rounded to the nearest 0.1 mg/Kg for concentrations between 0.05 mg/Kg and 100 mg/Kg; and are rounded to the nearest mg/Kg for concentrations above 100 mg/Kg

[+] calculated using the proposed arsenic MCL of 0.01 mg/L (a "to be considered" concentration, as of 4/01).

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