Wilcox & Barton INC.
ENVIRONMENTAL AND ENGINEERING SERVICES

June 21, 2012 ***Via Email***

David Wright, Director
Division of Remediation, BRWM
Maine Department of Environmental Protection
17 SHS, Augusta, Maine 04333-0017

Re: Construction Worker Groundwater Remedial Action Guidelines

Dear Mr. Wright,

Attached please find a revised write-up on the calculation of Construction Worker Groundwater Remedial Action Guidelines (RAGs), including the workbook presenting the calculations, addressing your comments of June 1, 2012. Some of the worksheets in the workbook are not intended for inclusion in the final posted file, but were added to perform a check on the RAG calculations. These worksheets can be hidden or deleted prior to posting.

Thank you for the opportunity to work with you. I am available at any time to discuss this project.

Regards,

WILCOX & BARTON, INC.

Cynthia Fuller
Health Risk Assessor

Attachment Development of Construction Worker Groundwater Remedial Action Guidelines (RAGs)

DEVELOPMENT OF
CONSTRUCTION WORKER GROUNDWATER REMEDIAL ACTION GUIDELINES (RAGs)

1.0 INTRODUCTION

A workbook was constructed that calculates the potential human health risks posed to construction workers, or other workers engaged in excavation activities, having contact with groundwater at a site when multiple contaminants of concern (COCs) are present in groundwater. This workbook also presents groundwater Remedial Action Guidelines (RAGs) protective of construction worker exposure to groundwater during typical work conditions.

Construction workers are assessed for exposure to COCs through three exposure pathways: 1) incidental ingestion of groundwater, 2) dermal contact with groundwater, and 3) inhalation of compounds volatilized from the groundwater into outdoor air. Conservative exposure assumptions are applied to calculate groundwater RAGs for individual COCs that are equal to an incremental lifetime cancer risk (ILCR) of one-in-one-hundred thousand ($1x10^{-5}$) or a non-carcinogenic hazard index (HI) of one (1).

The RAG worksheets can also be used to estimate potential human health risks associated with specific concentrations of COCs found at a site. While default values for certain site parameters, such as the excavation trench size and depth to groundwater, have been provided, the option exists for using site-specific information for these parameters. When the workbook is used in this manner, exposure point concentrations (EPCs) of site COCs are entered into the workbook, and the ILCR and/or hazard quotients (HQs) are calculated for each exposure pathway and COC, as appropriate for the COC's potential toxicity. Pathway-specific ILCRs for all carcinogenic COCs and pathway-specific HQs for all non-carcinogenic COCs are summed across all pathways and each target organ or system to derive a total ILCR or target organ/system-specific HI.

A summary table presents the ILCRs and HIs for all exposure pathways combined, and identifies an ILCR of greater than $1x10^{-5}$ (1 in 100,000) or an HI above 1.0 in red.

2.0 REMEDIAL ACTION GUIDELINE CALCULATION

RAGs are based on exposure of construction/utility workers to groundwater through the following exposure pathways:

- Incidental ingestion of groundwater
- Dermal contact with groundwater
- Inhalation of constituents volatilized from groundwater

RAGs were calculated according to the equations discussed in this section.

2.1 RAG Equations

The overall RAGs for carcinogenic and non-carcinogenic constituents are calculated by combining RAGs for individual exposure pathways according to the following equations:

For carcinogenic constituents:

$$RAG_{cw-total-ca} = \frac{1}{\left(\frac{1}{RAG_{cw-ingest-ca}}\right)+\left(\frac{1}{RAG_{cw-dermal-ca}}\right)+\left(\frac{1}{RAG_{cw-inhal-ca}}\right)} \quad \text{Eq 1}$$

For non-carcinogenic constituents:

$$RAG_{cw-total-nc} = \frac{1}{\left(\frac{1}{RAG_{cw-ingest-nc}}\right)+\left(\frac{1}{RAG_{cw-dermal-nc}}\right)+\left(\frac{1}{RAG_{cw-inhal-nc}}\right)} \quad \text{Eq. 2}$$

where:

$RAG_{cw-total-ca}$ = Remedial Action Guideline for construction/utility worker exposure to carcinogens through all three exposure pathways [milligrams per liter (mg/L)];

$RAG_{cw-total-nc}$ = Remedial Action Guideline for construction/utility worker exposure to non-carcinogens through all three exposure pathways (mg/L);

$RAG_{cw-ingest-ca}$ = Remedial Action Guideline for construction/utility worker exposure to carcinogenic constituents through groundwater ingestion (mg/L);

$RAG_{cw-derm-ca}$ = Remedial Action Guideline for construction/utility worker exposure to carcinogenic constituents through groundwater dermal contact (mg/L);

$RAG_{cw-inhal-ca}$ = Remedial Action Guideline for construction/utility worker inhalation exposure to volatile carcinogenic groundwater constituents (mg/L);

$RAG_{cw-ingest-nc}$ = Remedial Action Guideline for construction/utility worker exposure to non-carcinogenic constituents through groundwater ingestion (mg/L);

$RAG_{cw-derm-nc}$ = Remedial Action Guideline for construction/utility worker exposure to non-carcinogenic constituents through groundwater dermal contact (mg/L);

$RAG_{cw-inhal-ca}$ = Remedial Action Guideline for construction/utility worker inhalation exposure to volatile non-carcinogenic groundwater constituents (mg/L).

2.1.1 Incidental Groundwater Ingestion Component

The RAG components for incidental groundwater ingestion are calculated by the following equations:

For carcinogenic constituents:

$$RAG_{cw-ingest-ca} = \left(\frac{TR \cdot AT \cdot BW \cdot CF_1.}{IR \cdot EF \cdot ED \cdot SF} \right) \quad \text{Eq. 3}$$

For non-carcinogenic constituents:

$$RAG_{cw-ingest-nc} = \left(\frac{THI \cdot AT \cdot BW \cdot CF_1.RfDs}{IR \cdot EF \cdot ED} \right) \quad \text{Eq. 4}$$

Where:

TR =	Target incremental lifetime cancer risk level (unitless)
THI =	Target non-carcinogenic Hazard Index (HI) (unitless)
AT =	Averaging time [years (yr)]
BW =	Body weight [kilograms (kg)]
IR =	Groundwater ingestion rate [liters per day (L/day)]
EF =	Exposure frequency [days per year (dy/yr)]
ED =	Exposure duration (yr)
CF_1 =	Unit conversion factor (dy/yr)
SF =	Oral cancer slope factor [risk per milligram per kilogram per day $(mg/kg\text{-}dy)^{-1}$]
RfDs =	Oral subchronic reference dose (RfDs) (mg/kg-dy)

2.1.2 Dermal Contact Component

The RAG component for dermal contact with groundwater is calculated by the following equations:

For carcinogenic constituents:

$$RAG_{cw-derm-ca} = \left(\frac{TR \cdot AT \cdot BW \cdot CF_1}{SA \cdot DA_{event} \cdot EF \cdot ED \cdot SF} \right) \quad \text{Eq. 5}$$

For non-carcinogenic constituents:

$$RAG_{cw-derm-nc} = \left(\frac{THI \cdot AT \cdot BW \cdot CF_1 \cdot RfDs}{SA \cdot DA_{event} \cdot EF \cdot ED} \right) \quad \text{Eq. 6}$$

where:

SA =	Exposed skin surface area [square centimeters (cm^2)]
DA_{event} =	Dermal absorption per event per mg/cm^3 [$(mg/cm^2\text{-event})/(mg/cm^3)$]

Other parameters were previously defined.

The dermal absorption factor (DA_{event}) for organic constituents is calculated according to the following set of equations obtained from US EPA (2004) *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part E - Guidance for Dermal Risk Assessment) Interim* (EPA/540/R/99/005):

$$DA_{event} = 2 \cdot FA \cdot K_p \cdot C_w \cdot \sqrt{\frac{6 \cdot \tau \cdot t_{event}}{\pi}} \quad \text{Eq. 7}$$

$$\text{Log } K_p = -2.8 + 0.66 \cdot \text{Log } K_{ow} - 0.0056\,MW \quad \text{Eq. 8}$$

$$\tau = 0.105 \cdot 10^{(0.0056MW)} \quad \text{Eq. 9}$$

$$b = \frac{2 \cdot (1+B)^2}{\pi} - c \quad \text{Eq. 10}$$

$$c = \frac{1 + 3B + 3B^2}{3 \cdot (1+B)} \quad \text{Eq. 11}$$

$$B = K_p \frac{\sqrt{MW}}{2.6} \quad \text{Eq. 12}$$

For constituents where $B \leq 0.6$:

$$t^* = 2.4\tau \quad \text{Eq. 13}$$

For constituents where $B > 0.6$:

$$t^* = 6 \cdot \tau \cdot \left(b - \sqrt{b^2 - c^2}\right) \quad \text{Eq. 14}$$

Where the above parameters are defined as shown below:

DA_{event} =	Dermal absorption per event per mg/cm^3 [(mg/cm^2-event)/(mg/cm^3)]
FA =	Fraction of dose absorbed (unitless)
K_p =	Dermal permeability constant [centimeters per hour (cm/hr)] (calculated value)
C_w =	Constituent concentration in water (1 mg/cm^3 assumed)
τ =	Lag time per event [hour per event (hr/event)] (calculated value)
t_{event} =	Event duration (hr/event)
π =	Pi (3.14)
t* =	Time to reach steady state (hr)(calculated value)

MW = Constituent molecular weight [grams per gram-mole (g/mole)]

K_{ow} = Constituent octanol/water partition coefficient [cubic centimeters per gram (cm^3/g)]

B = Ratio of constituent permeability constant through the stratum corneum relative to its permeability constant across viable epidermis (unitless) (calculated value)

b = Empirical correlation coefficient (unitless) (calculated value)

c = Empirical correlation coefficient (unitless) (calculated value)

For inorganic constituents, DA_{event} is calculated according to the following equation,

$$DA_{event} = K_p \cdot C_w \cdot t_{event} \qquad \text{Eq. 15}$$

where K_p is a tabulated, experimentally-derived value presented in the EPA guidance (EPA 2004).

2.1.3 Inhalation Component

The RAG components for inhalation of volatile constituents in groundwater are calculated by the following equations:

For carcinogenic constituents:

$$RAG_{cw-inhal-ca} = \left(\frac{TR \cdot AT \cdot CF_2}{VF \cdot ET \cdot EF \cdot ED \cdot UR \cdot CF_3} \right) \qquad \text{Eq. 16}$$

For non-carcinogenic constituents:

$$RAG_{cw-inhal-nc} = \left(\frac{THI \cdot AT \cdot CF_2 \cdot RfCs}{VF \cdot ET \cdot EF \cdot ED} \right) \qquad \text{Eq. 17}$$

where:

VF = Volatilization factor [liters per cubic meter (L/m^3)]

ET = Exposure time [hours per day (hr/day)]

CF_2 = Unit conversion factor (hr/yr)

CF_3 = Unit conversion factor [micrograms per milligram (µg/mg)]

UR = Inhalation cancer unit risk [risk per microgram per cubic meter $(\mu g/m^3)^{-1}$]

RfCs = Subchronic inhalation reference concentration [milligrams per cubic meter (mg/m^3)].

Other parameters were previously defined.

The method for calculating a volatilization factor was adopted from the method developed by the Virginia Department of Environmental Quality (VDEQ) for groundwater within 15 feet of the ground surface. The volatilization factor, VF, is calculated by the following equations:

$$VF = \frac{K_i \cdot A \cdot F \cdot CF_4 \cdot CF_5 \cdot CF_6}{ACH \cdot V} \quad \text{Eq. 18}$$

$$K_i = 1/\left(\left(\frac{1}{k_{iL}}\right) + \left[\frac{(RT)}{(H_i \cdot k_{iG})}\right]\right) \quad \text{Eq. 19}$$

$$k_{iL} = \left(\frac{MW_{O_2}}{MW_i}\right)^{0.5} \cdot \left(\frac{T}{298}\right) \cdot k_{LO_2} \quad \text{Eq. 20}$$

$$k_{iG} = \left(\frac{MW_{H_20}}{MW_i}\right)^{0.335} \cdot \left(\frac{T}{298}\right)^{1.005} \cdot k_{G,H_20} \quad \text{Eq. 21}$$

where:

$H_{i=}$	Henry's Law Constant for constituent (atm-m^3/mol)
Ki =	Overall mass transfer coefficient of the constituent (cm/s) (calculated value)
k_{iL} =	Liquid phase mass transfer coefficient of constituent (cm/s) (calculated value)
k_{iG} =-	Gas phase mass transfer coefficient of constituent (cm/s) (calculated value)
A =	Area of trench (m^2)
F =	Fraction of trench floor through which contaminant can enter (unitless)
R =	Ideal gas constant (atm-m^3/mol-ºK)
T =	Average system absolute temperature (ºK)
ACH =	Air changes per hour (hr^{-1})
V =	Volume of trench (m^3)
CF_4 =	Conversion factor (10^{-3} L/cm^3)
CF_5 =	Conversion factor (10^4 cm^2/m^2)
CF_6 =	Conversion factor (3600 sec/hr)
$k_{iL,O2}$ =	Liquid phase mass transfer coefficient of oxygen (0.002 cm/s)
$k_{iG,H2O}$ =	Gas phase mass transfer coefficient of water (0.833 cm/s)

2.2 Modeling Assumptions

The following values were applied to calculate DA_{event} and VF:

MODELING ASSUMPTIONS APPLIED TO GROUNDWATER MAXIMUM EXPOSURE GUIDELINES FOR CONSTRUCTION/UTILITY WORKERS		
Parameter	**Value Applied**	**Reference**
Dermal permeability constant (K_p)	Constituent-specific (cm/hr)	Calculated for organic constituents; tabled values for inorganic constituents (US EPA 2004).
Constituent concentration in groundwater (C_w)	1 mg/cm^3	Assumed value for calculational purposes.
Fraction of dose absorbed (FA)	1	Assumed value.
Event duration (t_{event})	0.33 hr	20 minutes; assumed value.
Molecular weight (MW)	Constituent-specific (g/mole)	ChemID (2012); MassDEP (2009).
Octanol/water partition coefficient (K_{ow})	Constituent-specific (cm^3/g)	ChemID (2012); MassDEP (2009).
Henry's Law Constant ($H_{i\,)}$	Constituent-specific (atm-m^3/mol)	ChemID (2012); MassDEP (2009).
Area of trench (A)	2.2 m^2	Trench of areal dimensions of 8 feet by 3 feet assumed.
Fraction of trench floor through which contaminant can enter (F)	1	Assumed value.
Ideal gas constant (R)	$8.5x10^{-5}$ atm-m^3/mol-ºK	Constant.
Average system absolute temperature (T)	298 ºK	77ºF.
Air changes per hour (ACH)	2 hr^{-1}	Assumed value.
Volume of trench (V)	5.4 m^3	An 8-foot trench depth assumed.
Liquid phase mass transfer coefficient of oxygen ($k_{iL,O2}$)	0.002 cm/s	Constant.
Gas phase mass transfer coefficient of water ($k_{iG,H2O}$)	0.833 cm/s	Constant.
Unit conversion factor (CF_4)	10^{-3} L/cm^3	Unit conversion.
Unit conversion factor (CF_5)	10^4 cm^2/m^2	Unit conversion.
Unit conversion factor (CF_6)	3600 sec/hr	Unit conversion.

ChemIDplus Advanced (US National Library of Medicine) (http://chem.sis.nlm.nih.gov/chemidplus/)
USEPA (2004) Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) (July) (EPA/540/R/99/005.
MassDEP (2009) Method 1 Numerical Standards and supporting documentation (MCP Toxicity.xls).

2.3 Exposure Factors

The following exposure factors were applied to calculate RAGs:

EXPOSURE FACTORS APPLIED TO CONSTRUCTION WORKER GROUNDWATER REMEDIAL ACTION GUIDELINES (RAGS)		
Parameter	**Value Applied**	**Reference**
Target incremental lifetime cancer risk level (TR)	$1x10^{-5}$	MEDEP (2012).
Target Hazard Index (HI)	1.0	MEDEP (2012).
Groundwater ingestion rate (IR)	0.05 L/day	MEDEP (2009).
Exposed skin surface area (SA)	3,300 cm^2	MEDEP (2009). Represents the 50^{th} percentile surface area for head, hands, and forearms in adults
Exposure time (ET)	8 hr/day	Conventional workday duration.
Exposure frequency (EF)	26 days/year	One day a week for 6 months
Exposure duration (ED)	1 yr	Exposure to occur over a one-year period (MEDEP)
Averaging time (AT)	Carcinogens: 70 years Non-carcinogens: 0.5 years	MEDEP (2009). A conventional lifetime of 70 years for carcinogens; and a 6-month period for non-carcinogens.
Body weight (BW)	70 kilograms	MEDEP (2009)
Oral cancer slope factor (SF)	Constituent-specific	MEDEP (2012); US EPA (2012); US EPA (2011)
Inhalation cancer unit (UR)	Constituent-specific	MEDEP (2012); US EPA (2012); US EPA (2011)
Subchronic Inhalation Reference Concentration (RfCs)	Constituent-specific	MEDEP (2012); US EPA (2012); US EPA (2011)
Subchronic oral Reference Dose (RfDs)	Constituent-specific	MEDEP (2012); US EPA (2012); US EPA (2011)
Unit conversion factor (CF_1)	365 days/year	Unit conversion
Unit conversion factor (CF_2)	8,760 hours/year	Unit conversion
Unit conversion factor (CF_3)	1000 µg/mg	Unit conversion

MEDEP (2009) Guidance for Human Health Risk Assessments for Hazardous Substance Sites in Maine (draft) (DEP-BRWM 2B 2009)

MEDEP (2012) Maine Remedial Action Guidelines (RAGS) for Sites Contaminated with Hazardous Substances (Draft).

US EPA (2012) Integrated Risk Information System (IRIS).

US EPA (2011) Regional Screening Level tables (November).

2.4 Toxicity Values

Toxicity values used to develop RAGs were obtained from the values used in the Maine DEP draft Remedial Action Guidelines (RAGS) for Sites Contaminated with Hazardous Substances (MEDEP 2012), as provided in table Tox-info-RAGS-October-2011-v2.xlsx.

3.0 PRESENTATION OF RAGs

The RAG workbook is presented in Appendix A, the resultant RAGs, equal to an ILCR of $1x10^{-5}$ and/or a HI of 1.0 are shown on Table 1. For constituents that had RAGs derived for both the non-carcinogenic and carcinogenic endpoints, the lower RAG is adopted.

TABLE

ATTACHMENT A