Appendix 4E
Leaching modelling

1.1 Overview

Preliminary estimates of the impact of contaminated soil on groundwater beneath the contaminated zone have been determined in order to assist with the assessment of the impact of residual soil contamination on groundwater quality (refer Modules 1 and 5 for further details). A conservative approach has been adopted in order to be protective of groundwater quality, however, the leaching modelling presented in this appendix should not be used as a substitute for monitoring groundwater quality where impact on groundwater is suspected.

The modelling has been configured to determine the soil concentration which would give rise to a groundwater concentration equal to the potable water quality criteria (the most stringent, refer Module 5) for a given scenario of soil type, depth to contamination and depth to groundwater.

Combinations of the following factors have been considered in determining the scenarios for leaching modelling:

Soil type:	Six soil types were incorporated in the leaching modelling (fractured basalts and gravel were not considered). The soil type was used to determine an indicative infiltration rate and groundwater throughflow.
Depth to contamination:	Surface (< 1 metres), 1 to 4 metres, > 4 metres (in each case contaminated zone 2 metres thick has been assumed)
Depth to groundwater:	2 to 4 metres, 4 to 8 metres, >8 metres

In practice, the combinations of depth to soil contamination (assuming an arbitrary 2 metres thickness) and depth to groundwater give separations between the base of the contaminated soil layer and the groundwater of 0, 1, 2, 4, 5 and 6 metres.

1.2 Modelling approach

The approach adopted for modelling the leaching of contaminants from soil into groundwater is based on a one dimensional fate and transport equation by van Genuchten and Alves (1982), as used in the RISC model (BP, 1996) to calculate groundwater concentrations as a function of time. The van Genuchten and Alves fate and transport equation results in estimated groundwater concentrations that increase with time as the leaching of contaminants approaches a pseudo-steady state, followed by decreasing contaminant concentrations in groundwater as the source depletes with time.

For each combination of soil type, depth to the contaminated layer and depth to groundwater, an iterative method was used to estimate the maximum groundwater concentration for a given soil concentration, and hence, the maximum value of the leaching factor.

The modelling approach may be summarised as follows:

- an infiltration/recharge rate and hydraulic conductivity were assumed based on a given soil type
- the concentration of contaminants in leachate leaving the contaminated soil zone was determined using normal equilibrium relationships (refer to Appendix 4D, Module 4)
- the pore water velocity (downward infiltration rate) and groundwater velocity were estimated for use in determining the time of travel from the source to the groundwater in order to estimate biodegradation and to estimate dilution of the leachate by groundwater through flow
- source depletion taking into account biodegradation, losses due to leaching to the groundwater and volatilisation to the ambient air
- simple mixing of the leachate entering the groundwater, over an given aquifer thickness, giving an estimate of the contaminant concentration in groundwater at the site or immediately downgradient of the site.

No allowance is made for the biodegradation and attenuation of contaminants in groundwater between the site and any possible point of exposure.

The half-lives for biodegradation for each chemical, and the assumed infiltration rates and the hydraulic conductivities for each soil type are presented in Tables 4E1a, 4E1b and 4E1c respectively.

Table E1a Biodegradation half-life for selected petroleum contaminants

Contaminant	Half-life (yrs)
TPH: C7 to C9	2
TPH: C10 to C14	5
TPH: C15 to C36	10
Benzene	5
Toluene	5
Ethyl benzene	5
Xylene	5
Naphthalene	5
Pyrene	10
Benzo(a)pyrene	10

The biodegradation half-life of a compound is highly dependent on site-specific conditions. The values presented in Table 4E1a are conservative estimates for biodegradation in the unsaturated zone, taking into consideration the impact of aerobic and anaerobic conditions within the bulk and the fringes of the hydrocarbon plume respectively. The adopted half-lives for biodegradation of selected petroleum hydrocarbons are based on professional judgement, giving consideration to the limited range of published information available. The adopted half-lives are expected to be conservative, resulting in an overestimate of the concentrations of petroleum hydrocarbons in leachate entering the groundwater, however, there is limited information available to confirm this expectation. Further research is ongoing in this area.

Table 4E1b Summary of infiltration/recharge rates

Soil Type	Infiltration/Recharge Rate (cm/yr)
Sand	10.2
Silty sand	8.2
Silty clay	3.4
Clay	1.4
Pumice	13.6
Peats	1.4

The infiltration/recharge rates were selected as long term average values based on the proportion of rainfall likely to infiltrate for different soil types, based on a rainfall of 700 mm/year and relatively flat topography. Clearly some areas of New Zealand may receive considerably more rainfall and the screening criteria based on leaching of contaminants to groundwater may be revised to account for this. The values presented above (and similar values used in other references such as the ASTM RBCA guidance) refer to infiltration rate, however in practice the groundwater recharge rate is of more interest and may from the infiltration based on site-specific considerations.

The values selected for the hydraulic conductivity and infiltration rate are designed to reflect typical (rather than conservative) values for each soil type. The selection of, for example, a conservative estimate for the hydraulic conductivity and a typical estimate for the infiltration rate would artificially underestimate the dilution of leachate in the aquifer. Hence it is important that the estimates of infiltration and hydraulic conductivity are matched.

Table 4E1c Summary of hydraulic conductivities

Soil Type	Hydraulic Conductivity (m/d)
Sand	10
Silty sand	1
Silty clay	10^{-2}
Clay	10^{-3}
Pumice	10
Peats	1

In considering the expected trend in soil acceptance criteria for the protection of groundwater, the influence of the following should be factors should be evaluated:

- in sands the infiltration rate is reasonably high, however on a relative basis the groundwater flow velocity is higher, and hence, relatively high dilution may be expected (from sand to clay the infiltration rate varies by a factor of 10, whereas the groundwater flow velocity varies by a factor of 10,000). However, in sand the travel time for leachate between the source and the water table is relatively short, and hence, biodegradation is negligible.
- in clay the dilution of infiltration by groundwater through flow is reduced, however the time of travel for leachate from the source to groundwater is increased to the point at which biodegradation becomes important.

These factors act in opposing directions, and therefore, the trend in soil acceptance criteria through the range of soil types reflects the extent to which either of the mechanisms is dominant.

1.3 Model equations

The leaching process is simulated by transport of contaminants in the vadose zone; both volatilisation and leaching. The transport equations are solved using a one-dimensional solute transport equation (van Genuchten and Alves, 1982):

$$R\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial x} - \mu C \qquad \text{(E1)}$$

where:

C = concentration of component in the aqueous phase in the vadose zone (mg/L^3)

D = dispersion coefficient in the unsaturated zone (L^2/T)

V = horizontal pore water velocity (L/T)

μ = first-order decay coefficient (1/T)

x = distance below the source (L])

R = retardation factor

The thickness of contaminated layer is assumed to be 2 metres as for the volatilisation modelling. The depth to the groundwater table is determined from the base of the contaminated layer. The solution to the advection-dispersion equation is given by:

$$C = C_o . B(x,t) . e^{-\beta t} \qquad \text{[E2]}$$

where

$$B(x,t) = \frac{1}{2}\exp\left[\frac{(V-w)x}{2D}\right] erfc\left(\frac{Rx - wt}{2\sqrt{DRt}}\right) + \frac{1}{2}\exp\left[\frac{(V+w)x}{2D}\right] erfc\left(\frac{Rx + wt}{2\sqrt{DRt}}\right) \qquad \text{[E3]}$$

and

$$w = V\sqrt{1 + \frac{4D}{V^2}[\mu - R\beta]} \qquad \text{[E4]}$$

Source Concentration

The initial source concentration is calculated by using an equilibrium phase partitioning equation (refer to Module 4 for greater detail):

$$C_o = \frac{\rho_s C_s}{\rho_s K_{oc} f_{oc} + \theta_w + \theta_a H} \qquad \text{[E5]}$$

where:

C_o = initial water phase concentration (mg/L)

C_s = measured soil concentration (standardised at 1 mg/kg)

ρ_s= soil bulk density (tonnes/m^3)

K_{oc} = organic carbon partition coefficient

f_{oc} = fraction organic carbon

θ_w= water filled porosity

θ_a = air filled porosity

H = Henry coefficient (c/c)

The above expression is limited to estimating the concentration in water phase associated with adsorbed phase hydrocarbons, ie. no separate phase hydrocarbons. As discussed for the volatilisation modelling this is expected to result in an overestimate of leaching.

Water Velocities

The net infiltration rate, q, for different soil types are presented in Table 4E1b . The vertical pore water velocity, V, in the vadose zone is determined as follows:

$$V = \frac{q}{\theta_w} \quad \text{[E6]}$$

In the saturated zone, Darcy's velocity D_v is calculated as follows:

$$D_v = K \times i \quad \text{[E7]}$$

where

K = hydraulic conductivity (L^2/T)

I = hydraulic gradient (L/L)

An hydraulic gradient of 0.01 m/m has been assumed. This is consistent with typical values assumed for similar modelling, however, it should be acknowledged that lower gradients (potentially resulting in lower dilution ratios) may be expected some sites. The assumed hydraulic conductivities are presented in Table 4E1c.

Dilution

Dilution occurs as the contaminant leaches from the vadose zone into the groundwater. A simple box model is assumed where the length of the contaminated soil zone parallel to the direction of groundwater flow is 15 metres (which is selected as a reasonable value for a service station or small depot site). A groundwater mixing depth of 2 metres is assumed (ie. the depth over which the leached contaminants may be expected to mix with the groundwater within a short distance of the source). The dilution contaminants leaching from the contaminated soil zone, DE, is calculated as:

$$DE = \frac{q \times L}{(q \times L) + (D_v \times d)} \quad \text{[E8]}$$

where

L = length of contamination downgradient (15 metres)

d = mixing depth (2 metres)

Leaching Factor

Leaching factors (LF) are used to relate the predicted contaminant concentrations in groundwater to the measured soil concentrations. The contaminant concentration in the groundwater is calculated using:

$$C_{GW} = C \times DE \quad \text{[E9]}$$

where

C = water phase concentration due to leaching immediately above the groundwater (as a function of time) estimated using equation E2.

DE = dilution effect (from equation E8).

The Leaching Factor may then be determined as follows:

$$LF = \frac{C_{GW}}{C_s} \quad \text{[E10]}$$

For the purposes of deriving the Tier 1 soil acceptance criteria protective of groundwater quality the Leaching Factor was determined using the initial soil concentration and the maximum predicted groundwater concentration.

Source Depletion

Three mechanisms for depletion of source (ie. contaminated soil layer) are considered as follows:

- leaching from source to groundwater
- volatilisation from source to ambient air
- biodegradation.

Source depletion by leaching and volatilisation is accounted for by the ρ term. This may be separated into its components as follows:

$$\beta = \beta_w + \beta_v \quad \text{[E11]}$$

$$\beta_w = \frac{q}{(\rho_s K_{oc} f_{oc} + \theta_w + \theta_a H) L_w} \quad \text{[E12]}$$

$$\beta_v = \frac{D_s^{eff} H}{(\rho_s K_{oc} f_{oc} + \theta_w + \theta_a H) L_d L_w} \quad \text{[E13]}$$

where

L_w = thickness of source contamination layer

L_d = distance from soil surface to centre of source contamination

$$D_s^{eff} = D_{air}\left(\frac{\theta_a^{10/3}}{\theta_T^2}\right) + \frac{D_{wat}}{H}\left(\frac{\theta_w^{10/3}}{\theta_T^2}\right) \quad \text{[E14]}$$

D_{air} = air diffusion coefficient (L^2/T)

D_{wat} = water diffusion coefficient (L^2/T)

θ_T = total porosity $(\theta_a + \theta_w)$

The β term is incorporated in equations E2 to E4.

Biodegradation is characterised by the following expression:

$$\mu = \frac{t_{1/2}}{\ln 2} \quad \text{[E15]}$$

where

μ = first order biodegradation constant [T^{-1}]

$t_{1/2}$ = contaminant half-life [T]

The half-life of contaminants are presented in Table 4E1a. The degradation term, μ, is then substituted into equation E4.

Adsorption

The retardation factor, R, (accounting for attenuation of contaminant migration by adsorption/desorption processes) is estimated as follows:

$$R = 1 + \frac{\rho_s f_{oc} K_{oc}}{\theta_w} \qquad \text{[E16]}$$

Dispersion

Empirical equations are used to estimate longitudinal dispersivity (Gelhar et al, 1986), as follows:

$$\ln \alpha_L = -4.933 + 3.811 \ln x \qquad 1m \le x \le 2m \qquad \text{[E17]}$$

$$\ln \alpha_L = -2.727 + 0.584 \ln x \qquad x \ge 2m \qquad \text{[E18]}$$

where x is the distance from the bottom of the source.

$$D = \alpha_L V \qquad \text{[E19]}$$

where

D = dispersion coefficient in the unsaturated zone (L^2/T)

V = vertical pore water velocity (L/T).

For a distance less than 1 m, a value of 1 m is used. If equation E4 calculates a negative square root, then a value of 1 x 10^{-6} m^2/d is assumed.

1.4 References

Gelhar, L.W., Gutjahr, A.L., and Naff, R.L., (1979) **Stochastic analysis of macrodispersion in a stratified aquifer**, Water Resources Research 15, no. 6:1387-91

van Genuchten, M. Th. and Alves, W.J. (1982) **Analytical Solutions of the One-Dimensional Convective-Dispersive Solute Transport Equation**, United States Department of Agriculture, Technical Bulletin Number 1661.

Table 4E2a Preliminary Health Risk-Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* SAND Soil Type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

Contaminant	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2 m	4 m	8 m	2 m	4 m	8 m	GW 2 m	GW 4 m	GW 8 m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	4.39E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	5.40E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	1.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				5.99E-02	3.61E-03	1.09E-03	1.28E-02	1.98E-03	7.72E-03
toluene				8.00E-01	8.00E-01	8.00E-01	2.04E-02	1.15E-03	1.33E-04	3.93E-03	6.31E-04	2.47E-03
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	6.05E-03	1.74E-05	2.49E-156	1.06E-03	1.25E-49	3.81E-04
xylene				6.00E-01	6.00E-01	6.00E-01	2.49E-02	1.45E-03	4.40E-04	5.06E-03	7.97E-04	3.11E-03
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	5.22E-03	1.90E-04	6.75E-33	2.73E-03	9.08E-13	5.05E-04
pyrene				1.00E-02	1.00E-02	1.00E-02	1.80E-04	9.55E-96	0.00E+00	2.53E-297	0.00E+00	9.55E-96
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				1.76E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Contaminant	Risk Based Screening Level (mg/kg)											
	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4 m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2 m	GW 4 m	GW 8 m	GW 4 m	GW 8 m	GW 8 m	GW 2 m	GW 4 m	GW 8 m	GW 4m	GW 8m	GW 8m
hexane							4.55E+03	-	-	-	-	-
nonane							7.40E+05	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	1.67E-01	2.77E+00	9.16E+00	7.83E-01	5.06E+00	1.30E+00						
toluene							3.92E+01	6.96E+02	6.00E+03	2.04E+02	1.27E+03	3.24E+02
ethylbenzene							4.96E+01	1.72E+04	1.21E+155	2.84E+02	2.41E+48	7.87E+02
xylene							2.41E+01	4.13E+02	1.36E+03	1.19E+02	7.53E+02	1.93E+02
Aromatics												
naphthalene							1.92E+00	5.26E+01	1.48E+30	3.67E+00	1.10E+10	1.98E+01
pyrene							5.56E+01	1.05E+93	-	3.95E+294	-	1.05E+93
benzo (a)pyrene	3.98E+01	-	-	-	-	-						

Table 4E2b Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* SILTY SAND Soil Type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
Hexane				2.00E+00	2.00E+00	2.00E+00	3.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nonane				4.00E+00	4.00E+00	4.00E+00	3.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eicosane				-	-	-	9.59E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				3.50E-01	2.18E-02	2.08E-03	1.19E-01	4.93E-03	4.83E-02
toluene				8.00E-01	8.00E-01	8.00E-01	1.34E-01	7.97E-03	5.98E-06	4.38E-02	1.48E-03	1.76E-02
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	4.17E-02	1.14E-04	7.69E-60	1.29E-02	4.36E-20	1.73E-03
xylene				6.00E-01	6.00E-01	6.00E-01	1.62E-01	9.89E-03	4.26E-04	5.43E-02	2.40E-03	2.19E-02
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	3.60E-02	6.09E-04	1.36E-16	1.61E-02	1.14E-12	1.94E-75
pyrene				1.00E-02	1.00E-02	1.00E-02	1.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a)pyrene	7.00E-04	7.00E-04	7.00E-04				1.24E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							5.76E+02	-	-	-	-	-
nonane							1.05E+05	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	2.86E-02	4.60E-01	4.82E+00	8.39E-02	2.03E+00	2.07E-01						
toluene							5.95E+00	1.00E+02	1.34E+05	1.83E+01	5.40E+02	4.54E+01
ethylbenzene							7.20E+00	2.62E+03	3.90E+58	2.32E+01	6.88E+18	1.74E+02
xylene							3.70E+00	6.06E+01	1.41E+03	1.11E+01	2.50E+02	2.73E+01
Aromatics												
naphthalene							2.78E-01	1.64E+01	7.33E+13	6.20E-01	8.75E+09	5.16E+72
pyrene							7.92E+00	-	-	-	-	-
benzo (a) pyrene	5.67E+00	-	-	-	-	-						

Table 4E2c Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* SILTY CLAY Soil Type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	2.55E-02	0.00E+00	0.00E+00	7.26E-286	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	2.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	5.82E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				1.75E+00	1.52E-02	3.19E-33	9.08E-02	7.13E-13	2.96E-02
toluene				8.00E-01	8.00E-01	8.00E-01	7.55E-01	9.02E-05	5.32E-270	9.67E-02	8.35E-162	9.13E-05
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	2.47E-01	1.23E-95	0.00E+00	3.56E-12	0.00E+00	1.23E-95
xylene				6.00E-01	6.00E-01	6.00E-01	8.98E-01	1.17E-02	7.19E-196	1.02E-01	1.41E-112	1.21E-02
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	2.13E-01	5.19E-122	0.00E+00	1.52E-17	0.00E+00	5.19E-122
pyrene				1.00E-02	1.00E-02	1.00E-02	7.65E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				7.49E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							7.83E+01	-	-	-	-	-
nonane							1.73E+04	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	5.72E-03	6.57E-01	3.14E+30	1.10E-01	1.40E+10	3.38E-01						
toluene							1.06E+00	8.87E+03	1.50E+269	8.28E+00	9.59E+160	8.76E+03
ethylbenzene							1.22E+00	2.43E+94	-	8.42E+10	-	2.43E+94
xylene							6.68E-01	5.13E+01	8.34E+194	5.87E+00	4.25E+111	4.96E+01
Aromatics												
naphthalene							4.70E-02	1.93E+119	-	6.59E+14	-	1.93E+119
pyrene							1.31E+00	-	-	-	-	-
benzo (a) pyrene	9.34E-01	-	-	-	-	-						

Table 4E2d Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* CLAY soil type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

Contaminant	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	3.06E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	2.56E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	6.43E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				1.87E+00	1.17E-05	2.87E-121	1.33E-02	3.20E-75	1.20E-05
toluene				8.00E-01	8.00E-01	8.00E-01	8.22E-01	8.29E-27	0.00E+00	1.31E-05	4.95E-250	8.31E-27
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	2.72E-01	3.81E-129	0.00E+00	3.80E-45	0.00E+00	3.81E-129
xylene				6.00E-01	6.00E-01	6.00E-01	9.76E-01	1.04E-19	3.21E-303	7.12E-04	2.31E-199	1.05E-19
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	2.34E-01	1.25E-154	0.00E+00	6.75E-56	0.00E+00	1.25E-154
pyrene				1.00E-02	1.00E-02	1.00E-02	8.45E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				8.28E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Contaminant	Risk Based Screening Level (mg/kg)											
	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							6.54E+01	-	-	-	-	-
nonane							1.56E+04	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	5.36E-03	8.53E+02	3.49E+118	7.54E-01	3.12E+72	8.34E+02						
toluene							9.73E-01	9.65E+25	-	6.11E+04	1.62E+249	9.63E+25
ethylbenzene							1.10E+00	7.88E+127	-	7.90E+43	-	7.88E+127
xylene							6.15E-01	5.75E+18	1.87E+302	8.43E+02	2.60E+198	5.74E+18
Aromatics												
naphthalene							4.27E-02	8.02E+151	-	1.48E+53	-	8.02E+151
pyrene							1.18E+00	-	-	-	-	-
benzo (a) pyrene	8.46E-01	-	-	-	-	-						

Table 4E2e Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* PUMICE Soil Type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

Contaminant	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	4.22E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	4.31E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	1.08E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				4.20E-02	4.06E-03	5.86E-04	1.92E-02	1.23E-03	9.07E-03
toluene				8.00E-01	8.00E-01	8.00E-01	1.56E-02	1.44E-03	7.55E-05	6.88E-03	5.05E-04	3.23E-03
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	4.75E-03	1.64E-04	3.41E-31	2.03E-03	6.67E-12	4.13E-04
xylene				6.00E-01	6.00E-01	6.00E-01	1.89E-02	1.80E-03	2.78E-04	8.52E-03	5.45E-04	4.01E-03
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	4.09E-03	1.66E-04	1.67E-15	2.49E-03	4.69E-12	7.93E-66
pyrene				1.00E-02	1.00E-02	1.00E-02	1.43E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				1.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Contaminant	Risk Based Screening Level (mg/kg)											
	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							4.74E+03	-	-	-	-	-
nonane							9.29E+05	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	2.38E-01	2.46E+00	1.71E+01	5.22E-01	8.11E+00	1.10E+00						
toluene							5.14E+01	5.56E+02	1.06E+04	1.16E+02	1.58E+03	2.47E+02
ethylbenzene							6.32E+01	1.83E+03	8.80E+29	1.48E+02	4.50E+10	7.27E+02
xylene							3.18E+01	3.34E+02	2.16E+03	7.04E+01	1.10E+03	1.50E+02
Aromatics												
naphthalene							2.45E+00	6.01E+01	5.99E+12	4.02E+00	2.13E+09	1.26E+63
pyrene							7.00E+01	-	-	-	-	-
benzo (a) pyrene	5.01E+01	-	-	-	-	-						

Table 4E2f Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and agricultural site use* PEATS and HIGHLY ORGANIC Soil Type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	2.30E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	1.85E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	4.65E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				2.70E-03	0.00E+00	0.00E+00	5.32E-154	0.00E+00	1.01E-52
toluene				8.00E-01	8.00E-01	8.00E-01	7.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E-186
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	2.12E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
xylene				6.00E-01	6.00E-01	6.00E-01	9.58E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E-148
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	1.80E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
pyrene				1.00E-02	1.00E-02	1.00E-02	6.13E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				5.99E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							8.71E+04	-	-	-	-	-
nonane							2.16E+07	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	3.70E+00	-	-	1.88E+151	-	9.86E+49						
toluene							1.05E+03	-	-	-	-	4.41E+185
ethylbenzene							1.42E+03	-	-	-	-	-
xylene							6.27E+02	-	-	-	-	5.02E+147
Aromatics												
naphthalene							5.54E+01	-	-	-	-	-
pyrene							1.63E+03	-	-	-	-	-
benzo (a) pyrene	1.17E+03	-	-	-	-	-						