Human Health-Based Screening Levels for Petroleum Products Impacting Gulf Coastal Waters and Beach Sediments

To determine if contaminant levels in environmental samples collected from Florida coastal waters and beach sediments pose a human health risk, screening levels must be adopted. When the Deepwater Horizon Oil Spill occurred, human health risk based screening levels were not available for recreational swimmers or beach goers. The complexities and inherent variability among Gulf States made developing values by Federal Agencies difficult and time consuming. Furthermore, gaps in the fundamental knowledge about some of the carcinogenic constituents of the oil and how they absorb across the skin, made calculations of human health risk uncertain.

Despite the technical difficulties of deriving human health-based screening levels for oil spill contaminants, it was determined that in order to move forward with recovery and long term monitoring of public health risks, Florida would develop them for the Chemicals of Concern associated with the Deepwater Horizon Oil Spill. The Florida Department of Health was directed by Florida Department of Environmental Protection Secretary, Michael Sole, to develop and adopt health protective screening levels for swimmers and beach goers. On July 15, 2010, the State Surgeon General directed the State Toxicologist to derive human health-based screening levels for the Chemicals of Concern. Soon thereafter, work began with Toxicologists and Risk Assessors from the Center for Environmental and Human Toxicology at the University of Florida. The human health-based screening levels provided in Table 1 represent the chemical concentrations in coastal waters and beach sediments determined to not pose a significant human health risk. Exceedance of any screening level does not imply that an imminent health risk exists, but should trigger further evaluation and closer examination by public health officials to determine if any notices or advisories are warranted. The Florida Department of Health recognizes that other sources of these chemicals exist and human exposure to petroleum products is common.

These human health-based screening levels are not regulatory but have been derived using the most current toxicity data and risk assessment procedures. Their primary purpose is to determine if public health advisories or notices should be issued or rescinded, when environmental sampling data are available. If environmental sampling data are not available other criteria, such as visible oil in the water, may be used to issue advisories and notices to protect public health. Using these health-based screening levels in other situations, where the underlying assumptions may be significantly different, could over or under estimate the actual health risk.

The screening levels for coastal waters and sediments presented in Table 1 have been derived for the protection of human health, and are based upon visiting recreational swimmers, visiting beach goers, and long term residential exposures. For this document the term sediments applies to the uppermost 3 inches[1] of beach sediments in the intertidal zone as well as “dry” sand extending above the tidal zone. Two sets of screening levels are provided for sediments. Values labeled as “Visitor” apply to a scenario of short-term, intensive exposure that are intended to reflect a summer vacation with beach visits nearly every day (i.e., 90 out of 120 consecutive days). These

[1] ATSDR Public Health Assessment Guidance Manual, January 2005 (Update). Chapter 5: Exposure Evaluation: Evaluating Environmental Contamination. Page 5-12.

screening levels are intended to trigger the implementation of protective actions to limit the public's exposure to beach sediment on a defined beach extent. The second set of screening levels for beach sediments is for "Unrestricted" use, and is based on long-term exposure. The "Unrestricted" screening levels are intended to guide public health officials when considering whether to rescind restrictions for beach use or public health advisories. A single set of screening levels are presented for water, based upon the short-term, intensive "Visitor" scenario. As with beach sediments, these criteria can be used to trigger actions to mitigate exposure and risk to individuals in contact with oil contaminated water. In conjunction with applicable surface water standards, they may be used to guide decisions for rescinding restrictions or advisories as well.

Table 1. Florida Adopted Screening Levels for Selected Petroleum Products in Coastal Waters and Beach Sediments

		Health–Based Screening Levels			MDL[#]
		Beach Sediments (mg/kg)		Coastal Waters (µg/L)	Coastal Waters (µg/L)
Chemicals of concern	**CAS No.**	**Visitor**	**Unrestricted**	**Visitor**	
Volatile Organic Compounds					
Benzene[c]	71-43-2	200	1.1	380	
Cumene	98-82-8	5,200	2,100	6,600	
Ethylbenzene[c]	100-41-4	1000	5.4	620	
Xylene, m-	108-38-3	9,000	3,400	5,900	
Toluene	108-88-3	43,000	5,000	41,000	
Polycyclic Aromatic Hydrocarbons (PAHs)					
~Acenaphthene	83-32-9	4,400	3,400	840	
~Anthracene	120-12-7	73,000	17,000	7,500	
~Benz[a]anthracene[m]	56-55-3	7.1	0.15	*	0.05
~Benzo[a]pyrene[m]	50-32-8	0.71	0.015	*	0.05
~Benzo[b]fluoranthene[m]	205-99-2	7.1	0.15	*	0.05
~Benzo[k]fluoranthene[m]	207-08-9	71	1.5	*	0.05
~Chrysene[m]	218-01-9	710	15	*	0.05
~Dibenz[a,h]anthracene[m]	53-70-3	0.71	0.015	*	0.05
~Fluoranthene	206-44-0	29,000	2,300	1,200	
~Fluorene	86-73-7	29,000	2,300	4,100	
~Indeno[1,2,3-cd]pyrene[m]	193-39-5	7.1	0.15	*	0.05
~Methylnaphthalene, 1-[c]	90-12-0	730	22	*	0.05
~Methylnaphthalene, 2-	91-57-6	400	310	56	
~Naphthalene[**]	91-20-3	1,200	3.6	580	
~Phenanthrene[a]	85-01-8	73,000	17,000	7,500	
~Pyrene	129-00-0	22,000	1,700	1,400	
Metals					
Nickel Soluble Salts	7440-02-0	2,000	1,500[b]	4,800	
Vanadium and Compounds	NA	500	390[b]	1,800	

Health-based screening levels were developed by the Center for Environmental and Human Toxicology, University of Florida

Minimum Detection Limit for samples reported by laboratory.

[a] Toxicity values were not available for phenanthrene. Therefore, toxicity values for anthracene, a structurally related PAH, were used as surrogates.

[b] Florida has unrestricted use soil cleanup target levels for nickel (340 mg/kg) and vanadium (67 mg/kg) based upon potential acute toxicity (Chapter 62-777, F.A.C.). If concentrations exceed these values, further evaluation may be warranted.
[c] Screening levels are based on carcinogenic endpoint.
[m] These chemicals are considered mutagens and the mutagen equations were utilized to derive the screening levels.
*** Due to the large uncertainty in estimated dermal absorbance values (Kp values) for carcinogenic PAHs, a health-based screening level was not set. Florida has chosen to adopt the minimum detection limit as the screening level for these contaminants (e.g., 0.05 μg/L using US EPA Method 8270).**
**Naphthalene is only carcinogenic by the inhalation route and therefore is considered a non-carcinogen for exposure to surface water since inhalation exposure is negligible for this scenario.

The Adopted screening levels presented in Table 1 are based upon a 1×10^{-6} excess lifetime cancer risk for carcinogens, a hazard index of 1 for non-carcinogens, or minimum detection limits for certain chemicals in water samples. Although the current Federal guidance for determining an acceptable level of increased cancer risk allows for a range of 1×10^{-4} to 1×10^{-6}, the State of Florida consistently applies 1×10^{-6} for contaminated water and sediments. For comparison, screening levels based upon 1×10^{-4}, 1×10^{-5} and 1×10^{-6} risk levels and Hazard Quotients of 1 and 3 are provided in Tables 2, 3, and 4.

Health-based screening levels in Table 1 were selected from potential values derived using different target risk levels shown in Tables 2, 3, and 4. The formulas for calculating the screening levels are provided in Tables 5, 6, and 7; toxicity values, other chemical-specific inputs, and exposure assumptions are listed in Tables 8, 9, and 10 respectively.

These screening levels differ somewhat from the Human Health Benchmarks for Chemicals in Water developed by the U.S. EPA (http://www.epa.gov/bpspill/health-benchmarks.html) in response to the BP Spill in the Gulf of Mexico in the following respects: 1) The list of chemicals was modified to reflect petroleum-related contaminants found in Florida waters; 2) screening levels for non-carcinogens were based upon an averaging time of 120 rather than 365 days to better reflect the scenario of a visitor on extended vacation at the beach. This has the effect of reducing the water values for non-carcinogens to approximately 1/3 when compared with those presented in the U.S EPA Human Health Benchmarks; and 3) screening levels for beach sediments were included to facilitate their evaluation.

There are several notes regarding the development and application of these values:

1. The screening levels were derived with the same formulas used by the U.S. EPA to calculate risk-based screening levels. Toxicity values for each of the chemicals were taken from U.S. EPA sources. Assumptions for calculation of "Unrestricted" exposure to beach sediments are consistent with default residential exposure assumptions and models used by the U.S. EPA. (Regional Screening Table – User's Guide, U.S. EPA, May, 2010) These values are intended to be health protective under a scenario with the greatest long-term exposure, i.e., someone who resides on the beach and comes in contact with beach sediments nearly every day over 30 years. The "Visitor" screening levels were calculated using the same model, but with exposure assumptions representing a much shorter, intense period of exposure (i.e., 90 out of 120 days, that could occur during a prolonged summer vacation). This scenario addresses potential health risks in the near term, and although labeled as

"visitor" would be applicable to exposures by Florida residents over the same time period.

2. Screening levels for beach sediments are based upon direct contact, and include incidental ingestion, dermal contact, and inhalation of contaminants bound to dust. Screening levels for water are based upon incidental ingestion of water and dermal contact while swimming.

3. Criteria for carcinogens are based upon a 1 x 10^{-6} excess lifetime cancer risk. Criteria for non-carcinogens are based upon a hazard index of 1.

4. There is significant uncertainty regarding the ability to predict dermal absorption of PAHs through the skin while swimming. Because dermal absorption may be a primary route of exposure while swimming, this uncertainty has resulted in the conclusion that calculating screening levels for the PAHs could create inaccurate values. Furthermore, because some PAHs are known to cause skin cancer through direct action on the skin, using the oral cancer slope factor to calculate health-based screening levels would be inappropriate. As an alternative we recommend basing the screening levels upon the ability to detect PAHs; in other words, if PAHs are detected and measured in water, this would signal the need for further evaluation or actions to warn the public. Detection and quantification levels can vary depending upon the analytical method and instrumentation used. Generally, detection limits of 0.1 or 0.05 µg/L should be attainable with appropriate methods (such as EPA Method 8270). An alternative to using the highest minimum detection limit for relevant samples would be to use the levels measured prior to the oil impact, or pre-impact background levels as a screening level. However in Florida pre-impact background sample results were consistently below detection limits.

5. Toxicity from the carcinogenic PAHs are considered additive. To determine whether exposure to combined carcinogenic PAHs in beach sediments exceeds 1 x $10^{-6,}$ use the following formula:

$$Risk = \left[\left(\frac{conc_{PAH1}}{criterion_{PAH1}} \right) + \left(\frac{conc_{PAH2}}{criterion_{PAH2}} \right) + \left(\frac{conc_{PAH3}}{criterion_{PAH3}} \right) + etc \right] \times 10^{-6}$$

6. These screening levels were developed in response to the Deepwater Horizon Gulf Oil Spill to evaluate environmental sample results and their potential impacts on human health. The listed Chemicals of Concern were based on chemicals that were associated with oil product from this spill, but other unrelated sources could contribute to levels found in environmental samples. Before applying these screening levels to situations beyond the MC 252 (Deepwater Horizon) oil spill, users must clearly understand the bases for the inputs and assumptions, as well as the information available when these values were derived. If these screening levels are used for other scenarios, care must be taken to ensure the exposure assumptions and pathways applied to these screening levels are valid.

7. These screening levels are based upon protection of human health. They do not address potential impacts on the environment, such as aquatic and terrestrial species.

8. Screening levels do not include oil dispersants. Information needed to develop human health risk-based screening levels for these chemicals due to environmental exposures is limited.

9. When alkylated PAH homologues are detected in environmental samples they should be treated as their parent compounds due to very limited or no toxicity data. Where sufficient toxicity data are available for certain alkylated homologues of PAHs they should be evaluated individually. The sum of the concentrations of parent and alkylated homologues should be used to compare with screening levels in water and beach sediments.

Table 2. Visitor Screening Levels, Beach Sediments

		Concentration (mg/kg)				
Chemicals of Concern	**CAS No.**	**HQ=1**	**HQ=3**	**Cancer Risk 1E-06**	**Cancer Risk 1E-05**	**Cancer Risk 1E-04**
Volatile Organic Compounds						
Benzene	71-43-2	5.5E+02	1.7E+03	2.0E+02	2.0E+03	2.0E+04
Cumene	98-82-8	5.2E+03	1.6E+04			
Ethylbenzene	100-41-4	4.9E+03	1.5E+04	1.0E+03	1.0E+04	1.0E+05
Xylene, m-	108-38-3	9.0E+03	2.7E+04			
Toluene	108-88-3	4.3E+04	1.3E+05			
Polycyclic Aromatic Hydrocarbons (PAHs)						
~Acenaphthene	83-32-9	4.4E+03	1.3E+04			
~Anthracene	120-12-7	7.3E+04	2.2E+05			
~Benz[a]anthracene	56-55-3			7.1E+00	7.1E+01	7.1E+02
~Benzo[a]pyrene	50-32-8			7.1E-01	7.1E+00	7.1E+01
~Benzo[b]fluoranthene	205-99-2			7.1E+00	7.1E+01	7.1E+02
~Benzo[k]fluoranthene	207-08-9			7.1E+01	7.1E+02	7.1E+03
~Chrysene	218-01-9			7.1E+02	7.1E+03	7.1E+04
~Dibenz[a,h]anthracene	53-70-3			7.1E-01	7.1E+00	7.1E+01
~Fluoranthene	206-44-0	2.9E+04	8.7E+04			
~Fluorene	86-73-7	2.9E+04	8.7E+04			
~Indeno[1,2,3-cd]pyrene	193-39-5			7.1E+00	7.1E+01	7.1E+02
~Methylnaphthalene, 1-	90-12-0	7.0E+03	2.1E+04	7.3E+02	7.3E+03	7.3E+04
~Methylnaphthalene, 2-	91-57-6	4.0E+02	1.2E+03			
~Naphthalene	91-20-3	4.2E+02	1.3E+03	1.2E+03	1.2E+04	1.2E+05
~Phenanthrene[a]	85-01-8	7.3E+04	2.2E+05			
~Pyrene	129-00-0	2.2E+04	6.6E+04			
Metals						
Nickel Soluble Salts	7440-02-0	2.0E+03	6.0E+03			
Vanadium and Compounds	NA	5.0E+02	1.5E+03			

[a] Toxicity values were not available for phenanthrene. Therefore, toxicity values for anthracene, a structurally related PAH, were used as surrogates.

Table 3. Unrestricted Use Screening Levels, Beach Sediments

		Concentration (mg/kg)				
Chemicals of Concern	**CAS No.**	**HQ=1**	**HQ=3**	**Cancer Risk 1E-06**	**Cancer Risk 1E-05**	**Cancer Risk 1E-04**
Volatile Organic Compounds						
Benzene	71-43-2			1.1E+00	1.1E+01	1.1E+02
Cumene	98-82-8	2.1E+03	6.3E+03			
Ethylbenzene	100-41-4			5.4E+00	5.4E+01	5.4E+02
Xylene, m-	108-38-3	3.4E+03	1.0E+04			
Toluene	108-88-3	5.0E+03	1.5E+04			
Polycyclic Aromatic Hydrocarbons (PAHs)						
~Acenaphthene	83-32-9	3.4E+03	1.0E+04			
~Anthracene	120-12-7	1.7E+04	5.1E+04			
~Benz[a]anthracene	56-55-3			1.5E-01	1.5E+00	1.5E+01
~Benzo[a]pyrene	50-32-8			1.5E-02	1.5E-01	1.5E+00
~Benzo[b]fluoranthene	205-99-2			1.5E-01	1.5E+00	1.5E+01
~Benzo[k]fluoranthene	207-08-9			1.5E+00	1.5E+01	1.5E+02
~Chrysene	218-01-9			1.5E+01	1.5E+02	1.5E+03
~Dibenz[a,h]anthracene	53-70-3			1.5E-02	1.5E-01	1.5E+00
~Fluoranthene	206-44-0	2.3E+03	6.9E+03			
~Fluorene	86-73-7	2.3E+03	6.9E+03			
~Indeno[1,2,3-cd]pyrene	193-39-5			1.5E-01	1.5E+00	1.5E+01
~Methylnaphthalene, 1-	90-12-0			2.2E+01	2.2E+02	2.2E+03
~Methylnaphthalene, 2-	91-57-6	3.1E+02	9.3E+02			
~Naphthalene	91-20-3			3.6E+00	3.6E+01	3.6E+02
~Phenanthrene[a]	85-01-8	1.7E+04	5.1E+04			
~Pyrene	129-00-0	1.7E+03	5.1E+03			
Metals						
Nickel Soluble Salts[b]	7440-02-0	1.5E+03	4.5E+03			
Vanadium and Compounds[b]	NA	3.9E+02	1.2E+03			

[a] Toxicity values were not available for phenanthrene. Therefore, toxicity values for anthracene, a structurally related PAH, were used as surrogates.

[b] Florida has unrestricted use soil cleanup target levels for nickel (340 mg/kg) and vanadium (67 mg/kg) based upon potential acute toxicity (chapter 62-777, F.A.C.). If concentrations exceed these values, further evaluation may be warranted.

Table 4. Visitor Screening Levels, Coastal Waters

		Concentration (μg/L)				
Chemicals of Concern	**CAS No.**	**HQ=1**	**HQ=3**	**Cancer Risk 1E-06**	**Cancer Risk 1E-05**	**Cancer Risk 1E-04**
Volatile Organic Compounds						
Benzene	71-43-2	9.8E+02	2.9E+03	3.8E+02	3.8E+03	3.8E+04
Cumene	98-82-8	6.6E+03	2.0E+04			
Ethylbenzene	100-41-4	1.6E+03	4.8E+03	6.2E+02	6.2E+03	6.2E+04
Xylene, m-	108-38-3	5.9E+03	1.8E+04			
Toluene	108-88-3	4.1E+04	1.2E+05			
Polycyclic Aromatic Hydrocarbons (PAHs)						
~Acenaphthene	83-32-9	8.4E+02	2.5E+03			
~Anthracene	120-12-7	7.5E+03	2.2E+04			
~Benz[a]anthracene	56-55-3			*	*	*
~Benzo[a]pyrene	50-32-8			*	*	*
~Benzo[b]fluoranthene	205-99-2			*	*	*
~Benzo[k]fluoranthene	207-08-9			*	*	*
~Chrysene	218-01-9			*	*	*
~Dibenz[a,h]anthracene	53-70-3			*	*	*
~Fluoranthene	206-44-0	1.2E+03	3.6E+03			
~Fluorene	86-73-7	4.1E+03	1.2E+04			
~Indeno[1,2,3-cd]pyrene	193-39-5			*	*	*
~Methylnaphthalene, 1-	90-12-0	9.7E+02	1.3E+03	*	*	*
~Methylnaphthalene, 2-	91-57-6	5.6E+01	1.7E+02			
~Naphthalene	91-20-3	5.8E+02	1.7E+03			
~Phenanthrene[a]	85-01-8	7.5E+03	2.2E+04			
~Pyrene	129-00-0	1.4E+03	4.1E+03			
Metals						
Nickel Soluble Salts	7440-02-0	4.8E+03	1.4E+04			
Vanadium and Compounds	NA	1.8E+03	5.4E+03			

[a] Toxicity values were not available for phenanthrene. Therefore, toxicity values for anthracene, a structurally related PAH, were used as surrogates.

*** Due to the large uncertainty in estimated dermal absorbance values (Kp values) for carcinogenic PAHs, a health-based screening level was not set.**

Table 5 – Equations used in deriving the Visitor Beach Sediment Screening Levels (1 of 2):

Cancer Screening Level (SL) Equations:

Ingestion:

$$\frac{(TR \times AT \times LT \times BW_C)}{(EF \times IRS_C \times ED_C \times SFO \times CF1)}$$

Dermal:

$$\frac{(TR \times AT \times LT \times BW_C)}{\left(EF \times ED_C \times SA_C \times AF_C \times \left(\frac{SFO}{GIABS}\right) \times ABS \times CF1\right)}$$

Inhalation:

$$\frac{(TR \times AT \times LT)}{\left(EF \times ED_C \times ET \times CF3 \times IUR \times \left(\left(\frac{1}{VF}\right) + \left(\frac{1}{PEF}\right)\right) \times CF2\right)}$$

Total Cancer Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right) + \left(\frac{1}{Inhalation}\right)\right)}$$

Mutagen SL Equations:

Ingestion:

$$\frac{(TR \times AT \times LT \times BW_C)}{(EF \times IRS_C \times ED_C \times SFO \times ADAF \times CF1)}$$

Dermal:

$$\frac{(TR \times AT \times LT \times BW_C)}{\left(EF \times ED_C \times SA_C \times AF_C \times \left(SFO \times \frac{ADAF}{GIABS}\right) \times ABS \times CF1\right)}$$

Inhalation:

$$\frac{(TR \times AT \times LT)}{\left(EF \times ED_C \times ET \times CF3 \times IUR \times ADAF \times \left(\left(\frac{1}{VF}\right) + \left(\frac{1}{PEF}\right)\right) \times CF2\right)}$$

Total Mutagen Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right) + \left(\frac{1}{Inhalation}\right)\right)}$$

Table 5 – Equations used in deriving the Visitor Beach Sediment Screening Levels (2 of 2):

Noncancer SL Equations:

Ingestion:

$$\frac{(THQ \times AT \times ED_C \times BW_C)}{\left(EF \times ED_C \times IRS_C \times \left(\frac{1}{RfD}\right) \times CF1\right)}$$

Dermal:

$$\frac{(THQ \times AT \times ED_C \times BW_C)}{\left(EF \times ED_C \times SA_C \times AF_C \times ABS \times CF1 \times \left(\left(\frac{1}{RfD}\right) \times GIABS\right)\right)}$$

Inhalation:

$$\frac{(THQ \times AT \times ED_C)}{\left(EF \times ED_C \times ET \times CF2 \times \left(\frac{1}{RfC}\right) \times \left(\left(\frac{1}{VF}\right) + \left(\frac{1}{PEF}\right)\right)\right)}$$

Total Noncancer Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right) + \left(\frac{1}{Inhalation}\right)\right)}$$

Table 6 – Equations used in deriving the Visitor Water Screening Levels (1 of 3):

Cancer SL Equations:

Ingestion:

$$\frac{(TR \times AT \times LT \times BW_C \times CF3)}{EF \times IRW_C \times ED_C \times ET \times EV_{swim} \times SFO}$$

Dermal:

$$DA_{Event} = \frac{\left(\left(\frac{TR \times GIABS}{SFO}\right) \times BW_C \times LT \times AT\right)}{(EV_{swim} \times ED \times EF \times SA_C)}$$

For Organic Compounds:

IF ET > t* Then $C_W = \frac{DA_{Event}}{\left(FA \times K_p \times \left(\left(\frac{ET}{(1+B)}\right) + 2 \times \tau \times \left(\frac{(1+3B+3B^2)}{(1+B)^2}\right)\right)\right)}$

Or

IF ET < t* Then $Cw = \frac{DA_{Event}}{\left(2 \times FA \times K_p \times \left(\frac{6 \times \tau \times ET}{\pi}\right)^{0.5}\right)}$

SL Dermal = $C_W \times CF4$

For Inorganic Compounds:

SL Dermal = $\frac{DA_{Event} \times CF4}{K_p \times ET}$

Total Cancer Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right)\right)}$$

Table 6 – Equations used in deriving the Visitor Water Screening Levels (2 of 3):

Mutagen SL Equations:

Ingestion:

$$\frac{TR \times AT \times LT \times BW_C \times CF3}{EF \times IRW_{SWIM} \times ED_C \times ET \times EV_{SWIM} \times SFO \times ADAF}$$

Dermal:

DA_{Event} =

$$\frac{\left(\left(\frac{TR \times GIABS}{SFO \times ADAF}\right) \times BW_C \times LT \times AT\right)}{(EV_{swim} \times ED \times EF \times SA_C)}$$

For Organic Compounds:

IF ET > t* Then C_W =

$$\frac{DA_{Event}}{\left(FA \times K_p \times \left(\left(\frac{ET}{(1+B)}\right) + 2 \times \tau \times \left(\frac{(1+3B+3B^2)}{(1+B)^2}\right)\right)\right)}$$

Or

IF ET_< t* Then Cw =

$$\frac{DA_{Event}}{\left(2 \times FA \times K_p \times \left(\frac{6 \times \tau \times ET}{\pi}\right)^{0.5}\right)}$$

SL Dermal = $C_W \times CF4$

For Inorganic Compounds:

SL Dermal = $\frac{DA_{Event} \times CF4}{K_p \times ET}$

Total Mutagen Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right)\right)}$$

Table 6 – Equations used in deriving the visitor Water Screening Levels (3 of 3):

Noncancer SL Equations:

Ingestion:

$$\frac{THQ \times AT \times ED \times BW_C \times CF3}{EF \times IRW_{SWIM} \times ED \times ET \times EV \times \frac{1}{SRfD}}$$

Dermal:

$$DA_{Event} = \frac{(THQ \times GIABS \times SRfD) \times BW_C \times ED_C \times AT}{EV_{SWIM} \times ED_C \times EF \times SA_C}$$

For Organic Compounds:

IF ET > t* Then $C_W = \frac{DA_{Event}}{\left(FA \times K_P \times \left(\left(\frac{ET}{(1+B)}\right) + 2 \times \tau \times \left(\frac{(1+3B+3B^2)}{(1+B)^2}\right)\right)\right)}$

Or

IF ET ≤ t* Then $Cw = \frac{DA_{Event}}{\left(2 \times FA \times K_P \times \left(\frac{6 \times \tau \times ET}{\pi}\right)^{0.5}\right)}$

SL Dermal = $C_W \times CF4$

For Inorganic Compounds:

SL Dermal = $\frac{DA_{Event} \times CF4}{K_P \times ET}$

Total Noncancer Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right)\right)}$$

Table 7 – Equations used in deriving the Unrestricted Beach Sediment Screening Levels (1 of 2):

Cancer Screening Level (SL) Equations:

Ingestion:

$$\frac{(TR \times AT_C \times LT)}{\left(SFO \times EF \times CF1 \times \left((ED_C \times IRS_C \div BW_C) + (ED_A \times IRS_A \div BW_A)\right)\right)}$$

Inhalation:

$$\frac{(TR \times AT_C \times LT)}{\left(IUR \times CF3 \times EF \times ED_R \times ET \times CF2 \left(\left(\frac{1}{VF}\right) + \left(\frac{1}{PEF}\right)\right)\right)}$$

Dermal:

$$\frac{(TR \times AT \times LT)}{\left(\left(\frac{SFO}{GIABS}\right) \times EF \times \left((ED_C \times SA_C \times AF_C \div BW_C) + (ED_A \times SA_A \times AF_A \div BW_A)\right) \times ABS \times CF1\right)}$$

Total Cancer Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right) + \left(\frac{1}{Inhalation}\right)\right)}$$

Mutagen SL Equations:

Ingestion:

$$\frac{(TR \times AT \times LT)}{(SFO \times EF \times IFSM_{ADJ} \times CF1)}$$

Where $IFSM_{ADJ}$ = $(ED_{0-2} \times IRS_C \times 10 \div BW_C) + (ED_{2-6} \times IRS_C \times 3 \div BW_C) + (ED_{6-16} \times IRS_A \times 3 \div BW_A) + (ED_{16-30} \times IRS_A \times 1 \div BW_A)$

Inhalation:

$$\frac{(TR \times AT \times LT)}{\left(EF \times ET \times CF3 \times \left((ED_{0-2} \times IUR \times 10) + (ED_{2-6} \times IUR \times 3) + (ED_{6-16} \times IUR \times 3) + (ED_{16-30} \times IUR \times 1)\right) \times \left(\left(\frac{1}{VF}\right) + \left(\frac{1}{PEF}\right)\right) \times CF2\right)}$$

Table 7 – Equations used in deriving the Unrestricted Beach Sediment Screening Levels (2 of 2):

Mutagen SL Equations - Continued:

Dermal:

$$\frac{(TR \times AT \times LT)}{\left(\left(\frac{SFO}{GIABS}\right) \times EF \times DFSM_{ADJ} \times ABS \times CF1\right)}$$

Where $DFSM_{adj}$ =

$$(ED_{0-2} \times AF_C \times SA_C \times 10 \div BW_C) + (ED_{2-6} \times AF_C \times SA_C \times 3 \div BW_C) + (ED_{6-16} \times AF_A \times SA_A \times 3 \div BW_A) + (ED_{16-30} \times AF_A \times SA_A \times 1 \div BW_A)$$

Total Mutagen Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right) + \left(\frac{1}{Inhalation}\right)\right)}$$

Noncancer SL Equations:

Ingestion:

$$\frac{(THQ \times AT \times ED_C \times BW_C)}{\left(EF \times ED_C \times IRS_C \times \left(\frac{1}{RfD}\right) \times CF1\right)}$$

Dermal:

$$\frac{(THQ \times AT \times ED_C \times BW_C)}{\left(EF \times ED_C \times SA_C \times AF_C \times ABS \times CF1 \times \left(\left(\frac{1}{RfD}\right) \times GIABS\right)\right)}$$

Inhalation:

$$\frac{(THQ \times AT \times ED_C)}{\left(EF \times ED_C \times ET \times CF3 \times \frac{1}{RfC} \times \left(\left(\frac{1}{VF}\right) + \left(\frac{1}{PEF}\right)\right) \times CF2\right)}$$

Total Noncancer Screening Level:

$$\frac{1}{\left(\left(\frac{1}{Ingestion}\right) + \left(\frac{1}{Dermal}\right) + \left(\frac{1}{Inhalation}\right)\right)}$$

Table 8. Toxicity Values

Chemical of Concern	CAS No.	SFO (mg/kg-day)$^{-1}$	IUR ($\mu g/m^3$)$^{-1}$	RfDo (mg/kg-day)	$SRfD_o$ (mg/kg-day)	RfC_i (mg/m^3)	$SRfC_i$ (mg/m^3)
Volatile Organic Compounds							
Benzene	71-43-2	5.5E-02[I]	7.8E-06[I]	4.0E-03[I]	1.0E-02[P]	3.0E-02[I]	8.0E-02[P]
Cumene	98-82-8			1.0E-01[I]	4.0E-01[H]	4.0E-01[I]	**
Ethylbenzene	100-41-4	1.1E-02[C]	2.5E-06[C]	1.0E-01[I]	**	1.0E+00[I]	9.0E+00[P]
Xylene, m-	108-38-3			2.0E-01[I]		7.0E-01[I]	
Toluene	108-88-3			8.0E-02[I]	8.0E-01[P]	5.0E+00[I]	5.0E+00[P]
Polycyclic Aromatic Hydrocarbons (PAHs)							
~Acenaphthene	83-32-9			6.0E-02[I]			
~Anthracene	120-12-7			3.0E-01[I]	1.0E+00[P]		
~Benz[a]anthracene	56-55-3	7.3E-01[E]	1.1E-04[C]				
~Benzo[a]pyrene	50-32-8	7.3E+00[I]	1.1E-03[C]				
~Benzo[b]fluoranthene	205-99-2	7.3E-01[E]	1.1E-04[C]				
~Benzo[k]fluoranthene	207-08-9	7.3E-02[E]	1.1E-04[C]				
~Chrysene	218-01-9	7.3E-03[E]	1.1E-05[C]				
~Dibenz[a,h]anthracene	53-70-3	7.3E+00[E]	1.2E-03[C]				
~Fluoranthene	206-44-0			4.0E-02[I]	4.0E-01[H]		
~Fluorene	86-73-7			4.0E-02[I]	4.0E-01[H]		
~Indeno[1,2,3-cd]pyrene	193-39-5	7.3E-01[E]	1.1E-04[C]				
~Methylnaphthalene, 1-	90-12-0	2.9E-02[P]		7.0E-02[I]			
~Methylnaphthalene, 2-	91-57-6			4.0E-03[I]	4.0E-03[P]		
~Naphthalene	91-20-3		3.4E-05[C]	2.0E-02[I]		3.0E-03[I]	
~Phenanthrene[a]	85-01-8			3.0E-01[I]	1.0E+00[P]		
~Pyrene	129-00-0			3.0E-02[I]	3.0E-01[P]		
Metals							
Nickel Soluble Salts	7440-02-0		2.6E-04[C]	2.0E-02[P]	2.0E-02[P]	9.0E-05[A]	
Vanadium and Compounds	NA			5.0E-03[p]			

[I]IRIS, [C]Cal EPA, [E] Environmental Criteria and Assessment Office, U.S. EPA, [P]Provisional Peer Reviewed Toxicity Values (PPRTV), [H]Health Effect Assessment Summary Tables (HEAST), [A]Agency for Toxic Substances and Disease Registry (ATSDR).

[a] No toxicity values were available for phenanthrene. Therefore, values for a structurally related PAH, anthracene, were used as surrogates.

** - Subchronic reference values are available for these chemicals. However, the subchronic toxicity values are lower than the chronic values. Because this is counterintuitive, we have utilized the more conservative chronic toxicity values for the visitor scenarios.

Table 9. Chemical Specific Information (1 of 2)

Chemical of Concern	CAS No.	Kp (cm/hr)	VF (m^3/kg)	PEF (m^3/kg)	ABS	GIABS (RAGSe) (unitless)
Volatile Organic Compounds						
Benzene	71-43-2	1.5E-02	3.8E+03	1.4E+09	*	1
Cumene	98-82-8	9.0E-02	6.7E+03	1.4E+09	*	1
Ethylbenzene	100-41-4	4.9E-02	6.1E+03	1.4E+09	*	1
Xylene, m-	108-38-3	5.3E-02	5.9E+03	1.4E+09	*	1
Toluene	108-88-3	3.1E-02	4.6E+03	1.4E+09	*	1
Polycyclic Aromatic Hydrocarbons (PAHs)						
~Acenaphthene	83-32-9	8.6E-02	1.5E+05	1.4E+09	0.13	1
~Anthracene	120-12-7	1.4E-01	5.6E+05	1.4E+09	0.13	1
~Benz[a]anthracene	56-55-3	5.5E-01	*	1.4E+09	0.13	1
~Benzo[a]pyrene	50-32-8	7.1E-01	*	1.4E+09	0.13	1
~Benzo[b]fluoranthene	205-99-2	4.2E-01	*	1.4E+09	0.13	1
~Benzo[k]fluoranthene	207-08-9	6.9E-01	*	1.4E+09	0.13	1
~Chrysene	218-01-9	6.0E-01	*	1.4E+09	0.13	1
~Dibenz[a,h]anthracene	53-70-3	9.5E-01	*	1.4E+09	0.13	1
~Fluoranthene	206-44-0	3.1E-01	*	1.4E+09	0.13	1
~Fluorene	86-73-7	1.1E-01	3.0E+05	1.4E+09	0.13	1
~Indeno[1,2,3-cd]pyrene	193-39-5	1.2E+00	*	1.4E+09	0.13	1
~Methylnaphthalene, 1-	90-12-0	9.3E-02	6.3E+04	1.4E+09	*	1
~Methylnaphthalene, 2-	91-57-6	9.2E-02	6.2E+04	1.4E+09	*	1
~Naphthalene	91-20-3	4.7E-02	5.0E+04	1.4E+09	0.13	1
~Phenanthrene[a]	85-01-8	1.4E-01	6.9E+05	1.4E+09	0.13	1
~Pyrene	129-00-0	2.0E-01	2.6E+06	1.4E+09	0.13	1
Metals						
Nickel Soluble Salts	7440-02-0	2.0E-04	*	1.4E+09	*	0.04
Vanadium and Compounds	NA	1.0E-03	*	1.4E+09	*	1

[a] No toxicity value was available for phenanthrene. Therefore, values for a structurally related PAH, anthracene, was used as a surrogate.
* The value is assumed to be zero.

Table 9. Chemical Specific Information (2 of 2)

Chemicals of Concern	CAS No	B	tau (τ)	t*	FA
Volatile Organic Compounds					
Benzene	71-43-2	0.05	0.29	0.70	1
Cumene	98-82-8	0.38	0.50	1.21	1
Ethylbenzene	100-41-4	0.20	0.42	1.01	1
Xylene, m-	108-38-3	0.21	0.42	1.01	1
Toluene	108-88-3	0.11	0.35	0.84	1
Polycyclic Aromatic Hydrocarbons (PAHs)					
~Acenaphthene	83-32-9	0.41	0.78	1.87	1
~Anthracene	120-12-7	0.73	1.06	2.55	1
~Benzo[a]anthracene	56-55-3	3.21	2.03	4.88	1
~Benzo[a]pyrene	50-32-8	4.36	2.77	6.65	1
~Benzo[b]fluoranthene	205-99-2	2.55	2.77	6.65	1
~Benzo[k]fluoranthene	207-08-9	4.22	2.77	6.65	1
~Chrysene	218-01-9	3.46	2.03	4.88	1
~Dibenz[a,h]anthracene	53-70-3	6.12	3.88	9.32	0.6
~Fluoranthene	206-44-0	1.68	1.45	3.48	1
~Fluorene	86-73-7	0.55	0.91	2.19	1
~Indeno[1,2,3-cd]pyrene	193-39-5	7.93	3.78	9.08	0.6
~Methylnaphthalene, 1-	90-12-0	0.42	0.67	1.60	1
~Methylnaphthalene, 2-	91-57-6	0.42	0.67	1.60	1
~Naphthalene	91-20-3	0.20	0.56	1.34	1
~Phenanthrene[a]	85-01-8	0.70	1.06	4.11	1
~Pyrene	129-00-0	1.10	1.45	3.48	1
Metals					
Nickel Soluble Salts	7440-02-0	0.00	0.23	0.55	1
Vanadium and Compounds	NA	0.00	0.21	0.49	1

[a] No toxicity value was available for phenanthrene. Therefore, values for a structurally related PAH, anthracene, was used as a surrogate

Table 10. Exposure Assumptions (1 of 2)

	Beach Sediments		Water
Parameter	**Visitor**	**Unrestricted**	**Visitor**
TR (target cancer risk) unitless	1E-06, 1E-05, 1E-04	1E-06, 1E-05, 1E-04	1E-06, 1E-05, 1E-04
THQ (target hazard quotient) unitless	1 and 3	1 and 3	1 and 3
AT_{nc} (non-carcinogenic averaging time) days/year	120	365	120
AT_c (carcinogenic averaging time) days/year	365	365	365
EF (exposure frequency) days/year	90	350	90
ED_c (exposure duration - child) years	1	6	1
ED_a (exposure duration - adult) years	NA	24	NA
ED_r (exposure duration - resident) years	NA	30	NA
$ED_{0\text{-}2}$ (exposure duration 0-2 years old) years	NA	2	NA
$ED_{2\text{-}6}$ (exposure duration 2-6 years old) years	NA	4	NA
$ED_{6\text{-}16}$ (exposure duration 6-16 years old) years	NA	10	NA
$ED_{16\text{-}30}$ (exposure duration 16-30 years old) years	NA	14	NA
LT (lifetime) yr	70	70	70
ET (exposure time) hours/event	8	24	1
EV_{swim} (event frequency - child) events/day	NA	NA	1
BW_c (body weight - child) kg	15	15	15
BW_a (body weight - adult) kg	NA	70	NA
IRS_c (soil intake rate - child) mg/day	200	200	NA
IRS_a (soil intake rate - adult) mg/day	NA	100	NA
IRW_{swim} (water intake rate) L/hour	NA	NA	0.05
SA_c (skin surface area - child) cm^2	2800	2800	6600
SA_a (skin surface area - adult) cm^2	NA	5700	NA
Skin thickness cm	NA	NA	0.001
AF_c (skin adherence factor - child) mg/cm^2	0.2	0.2	NA
AF_a (skin adherence factor - adult) mg/cm^2	NA	0.07	NA
ADAF (Mutagenic adjustment factor)	3	NA	3
CF1 (conversion factor kg/mg)	1.0E-06	1.0E-06	1.0E-06
CF2 (conversion factor days/hr)	4.17E-02	4.17E-02	4.17E-02
CF3 (conversion factor μg/mg)	1.0E+03	1.0E+03	1.0E+03
CF4 (conversion factor $\mu g\text{-}cm^3/mg\text{-}L$)	1.0E+06	1.0E+06	1.0E+06

Table 10. Exposure Assumptions (2 of 2)

	Beach Sediments		Water
Parameter	**Visitor**	**Unrestricted**	**Visitor**
SFO (oral slope factor) $(mg/kg\text{-}d)^{-1}$	Chemical-specific	Chemical-specific	Chemical-specific
GIABS (gastrointestinal absorption) unitless	Chemical-specific	Chemical-specific	Chemical-specific
ABS (dermal absorption) unitless	Chemical-specific	Chemical-specific	Chemical-specific
IUR (inhalation unit risk) $(\mu g/m^3)^{-1}$	Chemical-specific	Chemical-specific	Chemical-specific
VF (volatilization factor) m^3/kg	Chemical-specific	Chemical-specific	Chemical-specific
PEF (particulate emission factor) m^3/kg	Chemical-specific	Chemical-specific	Chemical-specific
RfD (oral reference dose) mg/kg-d	Chemical-specific	Chemical-specific	Chemical-specific
RfC (reference concentration) mg/m^3	Chemical-specific	Chemical-specific	Chemical-specific
t* (time to reach steady-state) hr	Chemical-specific	Chemical-specific	Chemical-specific
C_w (chemical concentration in water) mg/cm^3	Chemical-specific	Chemical-specific	Chemical-specific
FA (fraction absorbed) unitless	Chemical-specific	Chemical-specific	Chemical-specific
Kp (dermal permeability coefficient) cm/hr	Chemical-specific	Chemical-specific	Chemical-specific
tau (τ) (lag time) hr/event	Chemical-specific	Chemical-specific	Chemical-specific
B (permeability ratio) unitless	Chemical-specific	Chemical-specific	Chemical-specific
SRfDo (subchronic oral reference dose) mg/kg-d	Chemical-specific	Chemical-specific	Chemical-specific
SRfCi (subchronic reference concentration) mg/m^3	Chemical-specific	Chemical-specific	Chemical-specific

NA – Not applicable for this scenario