While this reference is some 10 years old, it remains the current US EPA policy on exposure factors as confirmed by a check of their website in April 2006.

The 95th percentile value has been used for exposure time if statistical data are available. In the absence of statistical data (which is usually the case), reasonable conservative estimates of exposure time have been used. This approach follows the recommendations made by the US EPA (December 1989) *"Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A)"*, which remains current US EPA policy.

The exposure frequencies and durations derived by the analysis have been combined with the exposure concentrations provided in **Section 11.3** to derive the daily intakes for each potential receptor.

11.4.2 Target Receptors

The analysis of exposure concentrations given in **Section 11.3** concluded that present and possible future site conditions have reduced the number of potential migration pathways for contamination at the Former Gasworks site from the seven identified in **Table 22** to two, these being:

- Impacted groundwater that is intercepted by excavations made by construction workers at the Former Gasworks site (**Section 11.3.2**); and
- Contaminant source in surface soils (fill layer) that may be ingested or dermally absorbed by construction workers or site workers at the Former gasworks site (**Section 11.3.4**).

For each of these potential migration pathways, estimates have been made of the contaminant exposure durations for each of the potential receptors. The estimates that are provided in the following sub-sections comprise:

- On-site construction workers exposed to contaminated groundwater (**Section 11.4.3**);
- Off-site construction workers exposed to contaminated groundwater (**Section 11.4.4**);
- Construction workers exposed to contaminated surface soils (**Section 11.4.5**); and
- Site workers exposed to contaminated soils (**Section 11.4.6**).

11.4.3 On-site Construction Workers Exposed to Contaminated Groundwater

The assessment of contaminant exposure durations for a construction worker at the Former Gasworks site has assumed that workers follow good occupational health practices such as washing hands before eating and rest breaks and they minimise unnecessary exposure to contaminants (eg. no drinking of groundwater). The main exposure route for a construction worker would then be in the form of dermal contact as could be experienced by a plumber or labourer working in a trench containing groundwater.

Recommended default exposure values and activity factors are not available in the technical literature for construction workers having dermal exposure to contaminated groundwater. The nearest comparable exposure scenarios where exposure durations are specified are for showering/bathing and swimming, with the exposure values summarised in **Table 25B**.

- Table 25B US EPA Recommended Dermal Exposure Values for Adults

Exposure Parameter	Central Tendency Scenario		RME Scenario (3)	
	Showering/ Bathing (1)	Swimming (2)	Showering/ Bathing (1)	Swimming (2)
Event frequency (events/day)	1	1	1	1
Exposure frequency (days/yr)	350	5	350	150
Event duration (hr/event)	0.25	0.5	0.58	1

Notes:
(1) US EPA (July 2004)
(2) US EPA (January 1992)
(3) RME – Reasonable maximum exposure

It is considered reasonable to assume that the length of time that an adult worker would have their hands immersed in groundwater in a given day should be no more than an adult swimming. On this basis, the event duration for a construction worker dermally exposed to contaminated groundwater at the site has been taken to be 1 hour per day, which corresponds to the RME swimming exposure scenario. It is assumed that the worker would have an exposure frequency of 5 days per week for a sufficiently long period for a TDI to apply.

The organic compounds listed in **Table 23** are the analytes that have been considered in the analysis since dissolved heavy metals have a low dermal absorption potential (US EPA, January 1992) and ammonia is at relatively low concentrations and does not pose a significant health-risk. The maximum concentrations that have been measured in the groundwater investigations have been adopted in this analysis, as previously described in **Section 11.3.2**. These organic contaminants and the exposure concentrations are:

- Benzene = 6370 µg/L
- Toluene = 117 µg/L
- Ethylbenzene = 213 µg/L
- Total Xylene = 417 µg/L
- TPH C_{10}-C_{36} = 18,220 µg/L

- Naphthalene = 3840 µg/L

The daily intake of these organic compounds from dermal contact with groundwater at the Former Gasworks site has been estimated using the US EPA dermal exposure model, which is given in the document *"Dermal Exposure Assessment: Principles and Applications"* US EPA (January 1992).

The chemical properties of relevance to the US EPA dermal contact model for water exposure to organic contaminants are:

- Permeability coefficient for the chemical from water through the skin (K_P);
- Partition coefficient between octanol and water (dimensionless) (K_{OW}); and
- The molecular weight of the contaminant (MW).

The US EPA Dermal Exposure Assessment[7] provides values of these chemical properties for the contaminants of concern except TPH C_{10}-C_{36}. For the purposes of the assessment, the naphthalene parameters have been adopted for TPH C_{10}-C_{36}. A summary of these chemical properties is provided in **Table 25C**.

- **Table 25C Summary of Chemical Properties for Organic Contaminants**

Substance	K_p (cm/hr)	Log K_{ow}	MW
Benzene	0.021	2.13	78.1
Toluene	0.045	2.73	92.1
Ethylbenzene	0.074	3.15	106.2
Total Xylenes	0.080	3.20	106.2
TPH C_{10}-C_{36}	0.069	3.30	128.2
Naphthalene	0.069	3.30	128.2

The chemical intake from immersion of a worker's skin in groundwater is estimated from the US EPA model by firstly calculating the dimensionless B parameter given by the equation:

$$B = K_{OW} / 10^4$$

The diffusivity of the contaminant within the skin membrane (D_{SC}) is then calculated using the equation:

$$\log [D_{SC} / l_{SC}] = -2.72 - 0.0061\ MW \quad \text{.....(5)}$$

where:

l_{SC} = Thickness of the stratum corneum = 10^{-3} cm

[7] Refer Table 5-7 in US EPA (January 1992)

Substituting the values for l_{SC} and MW gives:

$$D_{SC} = l_{SC} \times 10^{(-2.72-0.0061MW)} \quad cm^2/hr \quad \text{.....(6)}$$

The time lag for organic contaminants to penetrate the skin is then calculated using the equation:

$$\tau = (l_{SC})^2 / (6D_{SC}) \quad \text{.....(7)}$$

The time it takes for the absorption to reach a steady-state (t*) is then calculated using the equation:

$$t^* = 2.4 \times \tau \quad \text{for the case where } B \leq 0.1 \quad \textbf{.....(8)}$$

For an event time (t_{event}) > t*, the dose absorbed per unit area per event (DA_{event}) is given by the equation:

$$DA_{event} = K_P \cdot C_v \cdot \{t_{event} / (1 + B) + 2\tau [(1 + 3B)/(1 + B)]\} \quad \text{.....(9)}$$

where:

DA_{event}	=	Dose absorbed per unit area per event (mg/cm^2-event)
K_P	=	Permeability coefficient from water (cm/hour)
C_v	=	Concentration of chemical in water ($mg/cm^3 = 1x10^{-6}$ µg/L)
t_{event}	=	Duration of event (hour/event) = 1 hr

If $t_{event} < t^*$, then DA_{event} is given by the equation:

$$DA_{event} = 2 \cdot K_P \cdot C_v \cdot \sqrt{[(6 \cdot \tau \cdot t_{event})/ \pi]} \quad \text{.....} \quad (10)$$

The daily dose (DD) from dermal contact with chemicals in soil or water is estimated from the equation:

$$DD = DA_{event} \times SA \quad \text{.....} \quad (11)$$

where:

DD	=	Daily dose (mg-day)
DA_{event}	=	Dose absorbed per unit area per event (mg/cm^2-event)
SA	=	Skin surface area available for contact (cm^2)

For a worker who immerses his hands in groundwater, the US EPA[8] recommends a skin surface area of $0.084m^2$ ($840cm^2$).

The results of the calculations and the estimated daily doses for on-site construction workers exposed to extracted groundwater at the Former Gasworks site are provided in **Table 26**.

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[8] Section 6.2.5 in US EPA (August 1997)

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- Table 26 Estimates of Dermal Intake for On-site Construction Workers Exposed to Intercepted Groundwater from the Former Gasworks Site

Substance	B	Dsc (cm^2/hr)	τ (hr)	t* (hr)	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	0.013	6.362E-07	0.262	0.629	2.039E-04	1.713E-01
Toluene	0.054	5.226E-07	0.319	0.765	8.697E-06	7.305E-03
Ethylbenzene	0.141	4.287E-07	0.389	0.933	2.910E-05	2.444E-02
Total Xylenes	0.158	4.287E-07	0.389	0.933	6.183E-05	5.194E-02
TPH (C10-C36)	0.200	3.148E-07	0.530	1.271	2.528E-03	2.124E+00
Naphthalene	0.200	3.148E-07	0.530	1.271	5.329E-04	4.476E-01

11.4.4 Off-Site Construction Workers Exposed to Contaminated Groundwater

The daily contaminant intakes for off-site construction workers exposed to contaminated groundwater have been calculated using the average groundwater concentrations presented in **Table 23** in **Section 11.3.2** and the methodology described in **Section 11.4.3**. The results of the calculations and the estimated daily doses for off-site construction workers exposed to extracted groundwater at an adjoining residential property are provided in **Table 26B**.

- Table 26B Estimates of Dermal Intake for Off-site Construction Workers Exposed to Intercepted Groundwater from the Former Gasworks Site

Substance	B	Dsc (cm^2/hr)	τ (hr)	t* (hr)	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	0.013	6.362E-07	0.262	0.629	2.042E-05	1.716E-02
Toluene	0.054	5.226E-07	0.319	0.765	1.026E-06	8.617E-04
Ethylbenzene	0.141	4.287E-07	0.389	0.933	4.003E-06	3.362E-03
Total Xylenes	0.158	4.287E-07	0.389	0.933	9.875E-06	8.295E-03
TPH (C10-C36)	0.200	3.148E-07	0.530	1.271	3.116E-04	2.618E-01
Naphthalene	0.200	3.148E-07	0.530	1.271	5.020E-05	4.216E-02

11.4.5 Construction Workers Exposed to Contaminated Surface Soils

The two exposure routes for construction workers in contact with contaminated soil are listed in **Table 22** as ingestion and dermal adsorption.

Ingestion

The amount of soil ingestion for an adult is given in Australian guidelines (ANZECC/NHMRC, 1992; NEPC, 1999a) as 25 mg soil/day. The contaminant concentrations for construction/ maintenance workers exposed to surface soils at the Former Gasworks site are those given in **Table 24** in **Section 11.3.4**, these being total PAHs 3953mg/kg, benzo(a)pyrene 220mg/kg, TPH C_{10}-C_{36} 38,400mg/kg, benzene 7mg/kg and total xylenes 210mg/kg. The estimated exposure intakes by ingestion for a construction/maintenance worker are calculated to be:

Total PAHs	= 98.8 µg / day
Benzo(a)pyrene	= 5.50 µg / day
TPH C_{10}-C_{36}	= 960 µg / day
Benzene	= 0.175 µg / day
Total Xylenes	= 5.25 µg / day

Dermal Adsorption

The dermal absorption of contaminants from the soil by construction workers has been calculated using the US EPA dermal exposure model given in the document *"Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment"* (US EPA, July 2004).

The dose absorbed per unit area per event (DA_{event}) is given by the equation:

$$DA_{event} = C_{soil} \cdot CF \cdot AF \cdot ABS_d \quad \text{.....(12)}$$

where:

DA_{event}	=	Dose absorbed per unit area per event (mg/cm^2-event)
C_{soil}	=	Chemical concentration in soil (mg/kg)
CF	=	Conversion factor (10^{-6} kg/mg)
AF	=	Adherence factor of soil to skin (mg/cm^2-event)
ABS_d	=	Dermal absorption fraction

The daily dose (DD) from dermal contact with chemicals in soil or water is estimated using Equation (11).

The C_{soil} contaminant concentrations used in the analysis are those given in **Table 24** in **Section 11.3.4** for "construction/maintenance workers'. An AF value of 0.3 has been adopted, which corresponds to the 95th percentile default value recommended by the US EPA[9] for construction workers. The ABS_d values provided for PAHs and semivolatile organic compounds have also been adopted from the US EPA guideline[10], the values being:

- Benzo(a)pyrene and other PAHs = 0.13
- Semivolatile organic compounds = 0.10

The skin surface area (SA) used in the analysis was 4860cm^2, which is the sum of the 50th percentile areas recommended by the US EPA[11] for adult male hands (990cm^2), forearms (1310cm^2) and lower legs (2560cm^2).

The results of the calculations and the estimated daily doses for construction workers dermally exposed to contaminated surface soils at the Former Gasworks site are provided in **Table 27**.

- Table 27 Estimates of Dermal Intake for Construction Workers Exposed to Contaminated Surface Soils at the Former Gasworks Site

Substance	Csoil (mg/kg)	CF (kg/mg)	AF (mg/cm^2)	ABSd	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	7	1.00E-06	0.30	0.1	2.100E-07	1.021E-03
Total Xylenes	210	1.00E-06	0.30	0.1	6.300E-06	3.062E-02
TPH (C10-C36)	38400	1.00E-06	0.30	0.1	1.152E-03	5.599E+00
Total PAHs	3953	1.00E-06	0.30	0.13	1.542E-04	7.493E-01
Benzo(a)pyrene	220	1.00E-06	0.30	0.1	8.580E-06	4.170E-02

11.4.6 Site Workers Exposed to Contaminated Soils

The two exposure routes for construction workers in contact with contaminated soil are listed in **Table 22** as ingestion and dermal adsorption.

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[9] Refer Exhibit 3-3 in US EPA (July 2004)
[10] Refer Exhibit 3-4 in US EPA (July 2004)
[11] Refer Exhibit C-1 in US EPA (July 2004)

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Ingestion

The amount of soil ingestion for an adult is given in Australian guidelines (ANZECC/NHMRC, 1992; NEPC, 1999a) as 25 mg soil/day. The contaminant concentrations for Site Workers exposed to surface soils at the Former Gasworks site are those given in **Table 24** in **Section 11.3.4**, these being total PAHs 586mg/kg, benzo(a)pyrene 39mg/kg, TPH C_{10}-C_{36} 8,010mg/kg, benzene 0.8mg/kg and total xylenes 21mg/kg. The estimated exposure intakes by ingestion for a Site Worker are calculated to be:

Total PAHs	= 14.7 µg / day
Benzo(a)pyrene	= 0.975 µg / day
TPH C_{10}-C_{36}	= 200 µg / day
Benzene	= 0.020 µg / day
Total Xylenes	= 0.525 µg / day

Dermal Adsorption

The daily intake by long-term site workers from dermal contact with surface soils at the Former Gasworks site has been estimated using the same methodology as used in **Section 11.4.5**. The C_{soil} contaminant concentrations used in the analysis are those given in **Table 24** in **Section 11.3.4** for "site workers'. The AF, ABS_d and SA values remain the same as used in the previous analysis.

The results of the calculations and the estimated daily doses for site workers dermally exposed to contaminated surface soils at the Former Gasworks site are provided in **Table 28.**

- **Table 28 Estimates of Dermal Intake for Site Workers Exposed to Contaminated Surface Soils at the Former Gasworks Site**

Substance	Csoil (mg/kg)	CF (kg/mg)	AF (mg/cm^2)	ABSd	DA_{event} (mg/cm^2-event)	DD (mg/day)
Benzene	1	1.00E-06	0.30	0.1	2.400E-08	1.166E-04
Total Xylenes	21	1.00E-06	0.30	0.1	6.300E-07	3.062E-03
TPH (C10-C36)	8010	1.00E-06	0.30	0.1	2.403E-04	1.168E+00
Total PAHs	586	1.00E-06	0.30	0.13	2.285E-05	1.111E-01
Benzo(a)pyrene	39	1.00E-06	0.30	0.1	1.521E-06	7.392E-03