5

Generic acceptance criteria for groundwater and surface water

Appendices

Generic acceptance criteria for surface water and groundwater

5.1 Introduction

The derivation of generic surface water and groundwater acceptance criteria is presented in a summary only in this section. Information on the toxicity and dose response factors for contaminants of concern at gasworks sites is presented in Appendix 4A of Module 4 on disk.

This module covers the following:

- ➔ groundwater uses
- ➔ potable use
- ➔ stock watering use
- ➔ irrigation use
- ➔ aquatic ecosystem protection
- ➔ primary contact recreation

Additional information can be found in Section 4 of the Users' Guide, including:

- ▲ potable use (Section 4.3.1.1)
- ▲ stock watering use (Section 4.3.1.2)
- ▲ irrigation use (Section 4.3.1.3)
- ▲ aquatic ecosystem protection (Section 4.3.1.4)
- ▲ primary contact recreation (Section 4.3.1.5)
- ▲ the summary of the generic water acceptance criteria (Section 4.3.2)
- ▲ application of the generic acceptance criteria (Section 4.3.3)
- ▲ developing site specific acceptance criteria (Section 4.4)

5.2 Groundwater uses

The significance of groundwater contamination depends on the uses of the groundwater which require protection. The quality and yield of groundwater can define the range of uses for which it may be suitable. Some uses are dependent on extraction of the groundwater (e.g. potable use, stock watering), and therefore there is no need to protect these uses if groundwater cannot be extracted at a useful rate.

Salinity is used as a primary indicator of groundwater quality and its suitability for various uses. For example, the New Zealand Drinking Water Standards (NZDWS) indicate that a total dissolved solids concentration of 1000 mg/L is an upper limit for drinking water of an acceptable quality.

As the significance of groundwater contamination depends on the uses of the groundwater which are to be protected, defining the potential groundwater uses is an integral step in the assessment of groundwater contamination. These uses will depend on the quality and yield of the aquifer. A range of groundwater uses has been considered in the development of the groundwater acceptance criteria:

- potable use
- stock watering
- irrigation
- aquatic ecosystem support

- primary contact recreation.

5.3 Potable use

Guidelines for the concentration of contaminants in potable water generally consider:

- the protection of public health
- aesthetic considerations including taste and odour, and
- the protection of the water supply assets (e.g. corrosion of pipework).

When assessing the impact of contamination on potable use of the groundwater, reference should be made to the NZDWS 1995, and the New Zealand Drinking Water Guidelines (NZDWG) (Ministry of Health 1995). These guidelines are summarised in Table 5.1.

In the absence of health-based guideline values for gasworks contaminants, health-based acceptance criteria have been derived for the contaminants of concern using the procedures outlined in Module 4.

Health-based acceptance criteria may be summarised as follows:

$$\textbf{Acceptance criterion} = \frac{\textbf{Allowable intake (mg/kg/day) x Body Weight (kg)}}{\textbf{Water Consumption Rate (L/day)}}$$

Where:

Allowable Intake = (Reference Dose (RfD)) x (Proportion of RfD assigned to drinking water)

In accordance with the policies for the derivation of MAVs (Maximum Acceptable Values) in the NZDWS (MoH, 1995), the derivation of health-based acceptance criteria for gasworks contaminants has been based on the following assumptions:

- water consumption rate = 2 L/day
- body weight = 70 kg
- proportion of RfD assigned to drinking water = 0.1 (default assumption)

For details of the reference doses for gasworks contaminants, refer to Appendix 4A of Module 4. The health-based criteria for gasworks contaminants are summarised in Table 5.1 below.

Table 5.1 Summary of potable water quality guidelines (mg/L)

Contaminant	NZDWS MAV[1] (1995)		NZDWG MAV[1] (1995)	NHMRC/ARMCANZ[5] (1996)		Health-Based Acceptance Criteria[5]
	Health-based	Aesthetic	Aesthetic	Health-based	Aesthetic	
PAH	NAD[2]					
Non-carcinogenic PAHs						
Naphthalene						0.01
Acenaphthene						0.2
Anthracene						1.1
Fluorene						0.1
Phenanthrene						0.1
Pyrene						0.1
Fluoranthene						0.1
Acenaphthylene						0.1
Carcinogenic PAHs						
Benzo[a]pyrene	0.0007			0.00001		

BTEX						
Benzene	0.01			0.001		
Toluene	0.8	0.024	0.024-0.17	0.8	0.025	
Ethylbenzene	0.3	0.002	0.002-0.2	0.3		
Xylene	0.6	0.02	0.02-1.8	0.6	0.02	
Phenolics						
Phenol						2.0
Cresol (o,m)						0.2
Cresol (p)						0.02
Inorganic						
Ammonia		1.5	1.5	—[3]	0.5	
Cyanide as CN^-	0.08			0.08		
free[4]						0.1
complexed[4]						0.2
Nitrate	50			50		
Nitrite	3			3		
Sulphate		250	250	500	250	
Sulphide as H_2S		0.05	0.05	-(3)	0.05	

1. MAV - Maximum Acceptable Value
2. NAD - No adequate data to permit recommendation of health-based MAV human health at concentrations normally found in drinking water.
3. Insufficient data to set a guideline value based on health considerations.
4. Proportion of RfD assigned to drinking water = 0.2 consistent with derivation of guideline value for CN^- in the NZDWS.
5. National Health and Medical Research Council/Agricultural and Resource Management Council of New Zealand and Australia "Australian Drinking Water Guidelines", 1996.
6. Nominated where no relevant published guideline is available.

Additional information on potable use can be found in Section 4.3.1.1 of the Users' Guide.

5.4 Stock watering

The derivation of groundwater acceptance criteria for stock water use may include consideration of:

- protection of stock health via the consumption of livestock products
- protection of human health
- palatability of the water for stock.

As there are no stock water quality guidelines in New Zealand for the contaminants of concern, reference is made to guidelines released in other countries, particularly the ANZECC (1992) "Australian Water Quality Guidelines for Fresh and Marine Waters". For most of the organic contaminants of concern at gasworks contaminated sites, these guidelines indicate that the potable use guideline values should be used as a conservative default. In practice the potable use values are expected to be conservative, and less stringent criteria may be justifiable for the protection of stock health and the protection of human health where exposure may occur via the consumption of contaminated livestock products.

5.4.1 Protection of stock health

Acceptance criteria for the protection of stock health may be derived using an approach similar to that used for the derivation of potable use acceptance criteria (refer Module 4). Cattle have been selected as representative of livestock as they exhibit a relatively high water consumption per unit body weight. Acceptance criteria are calculated as follows:

$$\text{Acceptance Criterion} = \frac{\text{Acceptable Intake x Body Weight}}{\text{Water consumption rate}}$$

Assumptions used in the derivation of criteria are as follows:

body weight	=	550 kg for cattle (Shell, 1994)
water consumption rate	=	55 L/day (for lactating cows) (Shell, 1994)

In selecting dose-response factors for determining stock water acceptance criteria, based on those used in the derivation of the potable use acceptance criteria, the following are assumed:

- cancer is not a relevant endpoint for cattle given the relatively short lifespan compared to humans
- full protection of sensitive sub-populations is not required, and therefore the safety factor (of 10) for intraspecies variability, incorporated in Acceptable Daily Intake (ADI) and RfD estimates, need not be applied in determining the Acceptable Intake for stock.

Criteria for the protection of livestock health are presented in Table 5.2. Where the potable use criterion for a contaminant is based on a cancer endpoint assuming a non-threshold dose response relationship, an alternative endpoint has been selected. In particular, the criterion for benzene is based on the most stringent acceptable intake for BTEX and other carcinogenic PAHs.

Table 5.2 Stockwater quality guidelines and groundwater acceptance criteria for stock watering based on livestock health (mg/L)

Contaminant	ANZECC Guideline Stock watering	Acceptable Intake (mg/kg/day)	Acceptance Criteria (mg/L)
PAH (total)		0.3[1]	3
Naphthalene		0.04	0.4
Benzene		1	10
Toluene		2	20
Ethylbenzene		1	10
Xylene		1.8	18
Phenol		6.0	60
Cresol (o,m)		0.5	5
Cresol (p)		0.05	0.5
Ammonia			
Cyanide - free		0.1	1
- complexed		0.25	2.5
Nitrate	30[2]		
Nitrite	10[2]		
Sulphate	1000		

1. Based on pyrene
2. Nitrate, nitrite - as N

5.4.2 Protection of human health

Humans may be exposed to contaminants in groundwater used for stock watering if the contaminants accumulate in edible portions of the animal, particularly in fat. Surface water and groundwater acceptance criteria for stock watering, based on the protection of human health, may be derived based on;

- correlations between the intake and the residue concentrations in cattle, and
- Maximum Residue Levels (MRLs) for specific contaminants in livestock (or in the absence of an MRL, risk-based criteria assuming 100% of animal products are from a contaminated source).

For contaminants to accumulate in livestock to a significant extent, the contaminants must be lipophilic. Contaminants that are lipophilic, however, are generally not present in

groundwater at high concentrations. BTEX, such as benzene, are only moderately lipophilic and are therefore unlikely to accumulate significantly in livestock.

Initial estimates suggest most contaminants of concern at gasworks are unlikely to accumulate in stock to levels that affect the health of consumers of livestock products. Based on available correlations between contaminant intake and concentrations in livestock products (Travis and Arms, 1988), a relatively low stock water criterion may be predicted for benzo(a)pyrene. The published correlations have generally been developed for pesticides or chlorinated or other persistent compounds which are likely to resist metabolism in mammals. In practice benzo(a)pyrene is readily metabolised in mammals, greatly reducing bioaccumulation. The benzo(a)pyrene concentrations expected in groundwater at gasworks sites are unlikely to result in significant bioaccumulation in livestock.

On this basis, criteria based on the protection of human health and bioaccumulation of contaminants in livestock have not been nominated.

5.4.3 Palatability for stock

No information on the palatability of contaminated groundwater from a gasworks site for stock water use has been identified. Anecdotal information suggests livestock may consume significantly contaminated waters if required.

Additional information on stock watering use can be found in Section 4.3.1.2 of the Users' Guide.

5.5 Irrigation use

The proposed groundwater quality acceptance criteria for irrigation are based principally on the protocol developed by BP (Walden 1996). The protocol has been developed for spray irrigation in a domestic setting, however it is of more general applicability. The following processes have been considered in the development of irrigation water criteria:

- contaminant loss by volatilisation due to spray irrigation
- inhalation of vapours and aerosols by site users
- dermal absorption and ingestion of water by children playing under sprinklers, and
- plant uptake of contaminants applied in irrigation water and consumption of home grown produce (assumption of 100% of produce being home grown would be protective of the general public in the absence of MRLs).

The domestic irrigation scenario was used as the basis of the irrigation water criteria. In this context dermal absorption by children playing with water is estimated to be limiting. In the context of agricultural irrigation higher values may be acceptable.

5.5.1 Derivation of acceptance criteria

A procedure has been developed for the development of irrigation water guidelines based on the work of Walden (1996). The procedure incorporates a number of simplifying assumptions that suggest the derived criteria are likely to be conservative. In particular, the protocol assumes;

- no leaching or volatile losses of contaminants once they have entered the soil. First order biodegradation kinetics are assumed in estimating the steady-state soil concentration resulting from irrigation with contaminated groundwater, and
- no metabolism or degradation of contaminants within the plant.

Surface water and groundwater acceptance criteria for irrigation use have been derived considering both the uptake of contaminants from soil, following accumulation associated with irrigation, and on the uptake of contaminants through direct contact of foliage with irrigation water. The procedures available for estimating the health risk from contaminated

groundwater and surface water for irrigation are subject to uncertainty and therefore the criteria developed should be regarded as preliminary only.

Groundwater criteria based on irrigation use are presented in Table 5.3 (details of the derivation of criteria are presented in Appendix 5B).

Table 5.3 Groundwater criteria based on irrigation use

Contaminant	Generic Acceptance Criteria
Non carcinogenic PAHs	
Naphthalene	0.2
Acenaphthene	2.3
Anthracene	7.9
Fluorene	1.3
Phenanthrene	0.8
Pyrene	0.4
Fluoranthene	0.7
Acenaphthylene	1.0
Carcinogenic PAHs	
Benzo[a]pyrene	0.0002
BTEX	
Benzene	0.3
Toluene	13
Ethylbenzene	5.2
Xylene	8.8
Phenolics	
Phenol	44
Cresol (o,m)	4
(p)	3.3
Cyanide - free	0.5
- complexed	1.2

1. Based on domestic irrigation scenario. Higher values may be acceptable in an agricultural context.

Additional information on irrigation use can be found in Section 4.3.1.3 of the Users' Guide.

5.6 Aquatic ecosystem protection

The Ministry for the Environment is currently developing guidelines for the protection of aquatic ecosystems based on the requirements of the Resource Management Act 1991 (RM Act). These will provide information on both the procedures for deriving acceptable contaminant concentrations in surface water, and guidelines values for a range of common surface water contaminants in New Zealand. The first step in this process is the development of a framework, as outlined in the discussion paper Ministry for the Environment (1995) "A Process for the Development of Guidelines for the Protection of Aquatic Ecosystems".

The provisions of the RM Act require that surface waters be protected so that there is no significant adverse impact on the ecosystem associated with the surface water body. In the absence of definitive New Zealand guidance regarding the protection of ecosystems, guideline values nominated by a number of overseas agencies have been summarised in Table 5.4. Guideline values nominated by the following agencies have been included:

- Australian and New Zealand Environment and Conservation Council (ANZECC)
- United States Environment Protection Agency (USEPA)
- Council of Canadian Ministers for the Environment (CCME).

The guidelines for the protection of aquatic ecosystems are designed to provide effectively full protection to a relatively pristine environment, based on an understanding of "no significant adverse effect". Each of the agencies, however, can define this concept slightly differently. In addition, the data sets underlying each set of guidelines are expected to differ.

Table 5.4 Summary of overseas guidelines for the protection of aquatic ecosystems (mg/L)

	Guideline Values						
	ANZECC (1992)		USEPA[3] (1995)				CCME (1991)
Contaminant	Aquatic Ecosystems (Fresh waters)	Human Consumption of Fish[1]	Freshwater		Marine		Freshwater Aquatic Ecosystems
			Acute	Chronic	Acute	Chronic	
PAHs	0.003	0.00003					ID[2]
Non carcinogenic PAHs							
Naphthalene		0.001					
Acenaphthene		0.00002					
Anthracene					0.3		
Fluorene							
Phenanthrene			0.03	0.0063	0.0077	0.0046	
Pyrene							
Fluoranthene							
Acenaphthylene					0.3		
Carcinogenic PAHs							
Benzo[a]pyrene					0.3		
BTEX							
Benzene	0.3	0.04	5.3[4]		5.1[4]	0.7[4]	0.3
Toluene	0.3	0.00025	17.5		6.3	5.0	0.0003
Ethylbenzene		0.00025	32		0.43		0.7
Xylene			ND	ND	ND	ND	
Phenolics							
Phenol	0.05	0.001-00.01	10.2	2.56	5.8		0.001(total)
Cresol (m)		0.0002					
(o)		0.0004					
(p)		0.0001					
Ammonia							2.2
Cyanide - free	0.005		0.022	0.0052	0.001		0.005
- complexed							
Nitrate							
Nitrite							0.06
Sulphate							
Sulphide as H_2S							

1. Includes consideration of human health and tainting.
2. ID = insufficient data to recommend a guideline.
3. Ambient Water Quality Criteria for Aquatic Organisms (USEPA, 1995)
4. Ambient Water Quality Criteria for Aquatic Organisms (USEPA, 1991)

Additional information on aquatic ecosystem protection can be found in Section 4.3.1.4 of the Users' Guide.

5.7 Primary contact recreation

Limited published information is available on acceptable concentrations of contaminants in water to be used for primary contact recreation, such as swimming. The ANZECC (1992) guidelines indicate that water containing chemicals which are either toxic or irritating to the skin or mucous membrane is unsuitable for primary contact recreation and that the concentration of toxic substances should not exceed levels given for untreated drinking water.

In order to better quantify the potential adverse effects of bodily immersion in water containing contaminants, health risk assessment procedures have been used. The resulting health risk-based acceptance criteria for recreational water are presented in Table 5.5. Details of the procedure used for derivation of criteria for primary contact recreational use are presented in Appendix 5C.

5.7.1 Derivation of acceptance criteria

Primary contact recreational activities, such as bathing, necessarily involve intimate contact between those involved and the potentially contaminated water. Both children and adults are considered in this assessment. The acceptance criteria presented in Table 5.5 are based on a commercial swimming pool scenario assuming regular training, which represents a reasonable worst case scenario. Higher values may be acceptable in the context of recreational bathing in a domestic swimming pool or bathing in surface waters. Criteria based on a typical surface water bathing scenario are presented in Appendix 5C. Both incidental ingestion of water during bathing and dermal absorption have been included in this assessment.

To quantify the health risks associated with exposure to various contaminants, several dose-response factors, such as Reference Dose (RfD) and Slope Factors (SF) by the USEPA and the Acceptable Daily Intake (ADI) or Provisional Tolerable Weekly Intake (PTWI) by the WHO, have been used (refer Appendix 4A of Module 4). These dose-response factors, developed from available human and animal studies, relate the estimated intake of a contaminant to the likelihood of health effects.

For exposure through primary contact recreation, the proposed acceptance criteria have been based on the dose-response factors with a correction for background exposure (default allowance of 50% of the RfD or ADI, refer Appendix 5C).

The assumptions to define the exposure scenario for derivation of the primary contact recreational use criteria are based on a reasonable estimate of the exposure frequency and duration.

Table 5.5 Health-based surface water and groundwater acceptance criteria for primary contact recreational use[1]

Contaminant	Generic Acceptance Criteria
PAHs	
Non carcinogenic PAHs	
Naphthalene	0.3
Acenaphthene	1.8
Anthracene	5.6
Fluorene	1.0
Phenanthrene	0.5
Pyrene	0.4
Fluoranthene	0.3
Acenaphthylene	0.7
Carcinogenic PAHs	
Benzo[a]pyrene	0.00003
BTEX	

Benzene	0.3
Toluene	15
Ethylbenzene	5
Xylene	8
Phenolics	
Phenol	150
Cresol (o,m)	10
(p)	1.0
Inorganic	
Ammonia	
Cyanide - free	1.8
-complexed	5

1. Based on commercial swimming pool scenario assuming regular training. Higher values may be acceptable in the context of domestic swimming pools and bathing in surface waters.

Additional information on primary contact recreation can be found in Section 4.3.1.5 of the Users' Guide.

5.8 References

1. ANZECC 1992 “Australian Water Quality Guidelines for Fresh and Marine Waters”, Australian & New Zealand Environment & Conservation Council , November.
2. CCME (1991) “Canadian Water Quality Guidelines”, Environment Canada, Ottawa.
3. Langley A (1993) “Refining Exposure Assessment” Proc. 2nd Nat. Workshop on the Health Risk Assessment of Contaminated Sites, South Australian Health Commission, Canberra, August.
4. Ministry for the Environment (1995) “A Process for the Development of Guidelines for the Protection of Aquatic Ecosystems”.
5. Ministry of Health (1995). “New Zealand Drinking-Water Standards for New Zealand”, January 1995.
6. Ministry of Health (1995). Drinking-Water Standards for New Zealand.
7. Ministry of Health, “Guidelines for Drinking Water Quality Management in New Zealand”, July.
8. NHMRC/ARMCANZ 1995 “Australian Drinking Water Guidelines” National Health and Medical Research Council/Agricultural and Resource Management Council of Australia and New Zealand.
9. Shell (1994) “The Concepts of HESP, Reference Manual, Human Exposure to Soil Pollutants, Version 2.10a”.
10. Travis C and Arms A (1988) “Bioconcentration of Organics in Beef, Milk, and Vegetation” Environ. Sci. Technol., Vol. 22, No.3, 271-274, American Chemical Society.
11. USEPA 1992 “Dermal Exposure Assessment: Principles and Applications”, EPA/600/8-91/011B.
12. USEPA (1988) “Exposure Assessment Manual”.
13. USEPA (1989) “Risk Assessment Guidance for Superfund, Human Health Evaluation Manual”.
14. USEPA (1990) “Exposure Factors Handbook”.
15. USEPA (1991) “Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual Supplement Guidance, Standard Default Exposure Factors, Interim Final”.
16. USEPA (1992) “Dermal Exposure Assessment : Principles and Applications, Interim Report”.
17. USEPA (1996) “Integrated Risk Information System Database”
18. Walden T and Spence L (1996) “Risk-Based BTEX Clean-up Goals in Groundwater for an Irrigation Scenario” BP Oil internal report.

Appendix 5A
Calculation of criteria for stock water use

Overview

The uptake of contaminants by stock is unlikely to be a limiting consideration where the groundwater is suitable for potable use. It is an important consideration, however, when high salinity limits potable use.

Groundwater acceptance criteria for the protection of stock water use have been set to:

- protect stock health, and
- protect human health where livestock products (e.g. milk and meat) are consumed.

The derivation of stock water criteria is highly uncertain due to inadequate information regarding the accumulation of contaminants in stock and relevant thresholds for the palatability of water for stock. Aesthetic limits for stock water have generally been set a factor of ten higher than the respective limits for potable use.

Uptake model

Summary

The uptake and accumulation of contaminants by stock depends on a range of complex biological processes affecting absorption, distribution, metabolism and elimination of contaminants. Simplified empirical formulae are available which indicate the level of uptake of contaminants by stock. These formulae are presented in numerous research papers. The equations used for the derivation of the groundwater acceptance criteria can be found in the following reference:

- Travis C and Arms A, "Bioconcentration of Organics in Beef, Milk, and Vegetation", Environmental Science and Technology, Vol 22, No 3, 1988.

Pathways

Contaminants are taken up by stock through ingestion of stock water. Contaminants may accumulate within animal tissue or fat reservoirs (e.g. milk) and through the consumption of animal products humans may be exposed to these contaminants. For the purposes of deriving criteria two main pathways, by which humans may ingest contaminants, have been assumed:

- ingestion of meat
- ingestion of milk and dairy products.

Travis and Arms present equations for the uptake of contaminants in beef, which for the purposes of deriving Tier 1 criteria have been assumed to apply to a range of livestock. Equations for the uptake of contaminants in milk are also presented.

Equations

The biotransfer factors for beef (Bb) and milk (Bm) are defined as:

$$Bb = \frac{\text{concentration in beef (mg / kg)}}{\text{daily intake of organic (mg / d)}} \quad \textbf{(A1)}$$

$$Bm = \frac{\text{concentration in milk (mg / kg)}}{\text{daily intake of organic (mg / d)}} \quad \textbf{(A2)}$$

The calculation of the biotransfer factors are calculated as follows:

$$\log Bb = -7.6 + \log K_{ow} \quad \textbf{(A3)}$$

$$\log Bm = -8.1 + \log K_{ow} \quad \textbf{(A4)}$$

where: K_{ow} = Octanol Water Partition Coefficient.

Groundwater criteria calculation

Exposure parameters

Acceptance criteria calculations are made for both meat and milk pathways. The exposure parameters are presented in Table 5A.1.

Table 5A.1 Exposure parameters

Parameter	Value	Reference
Stock		
Stock water ingestion rate	55 L/d	Shell, 1994
Human Reception		
Exposure frequency	365 d/y	
Exposure duration	70 yrs	
Averaging time	70 yrs	
Body weight	70 kg	ANZECC, 1992
Meat ingestion rate	152 g/d	Langley, 1993
Milk ingestion rate	269 g/d	Langley, 1993

Meat and milk concentrations

The contaminant concentrations in the meat and milk corresponding to the acceptable daily intake (e.g. RfD) are calculated using the following equations:

$$Ci = \frac{ADI \times AT \times 365 \times BW}{EF \times IR \times ED} \quad \textbf{(A5)}$$

where:
- Ci = Concentration of contaminant in beef or milk (mg/kg)
- ADI = Average daily intake (mg/kg/d)
- IR = Ingestion rate of beef or milk (kg/d)
- ED = Exposure duration (years)
- AT = Averaging time (70 years for carc., ED for non-carc)
- BW = Body weight (kg)

For carcinogenic contaminants:

$$ADI = \text{Target Risk} / SF \quad \textbf{(A6)}$$

For non-carcinogenic contaminants:

$$ADI = \text{Target Hazard Index} \times RfD \quad \textbf{(A7)}$$

where:
- SF = Slope factor $(mg/kg/d)^{-1}$
- RfD = Reference dose factor (mg/kg/d)

Groundwater concentration

The contaminant concentrations in beef and milk corresponding to the acceptable intake are used to calculate the groundwater acceptance criteria. The beef and milk concentrations are substituted into equations A1 and A2 to calculate the allowable daily intake of contaminants by stock. From this the groundwater concentration is calculated from the equation:

$$\text{Groundwater Concentration (mg / L)} = \frac{\text{Daily intake of contaminants by stock (mg / d)}}{\text{Ingestion rate of stock water (L / d)}} \quad \textbf{(A8)}$$

Groundwater concentrations are calculated for both exposure pathways (i.e. beef and milk consumption), however, risk calculations should combine both sources to determine the groundwater concentration. The combined pathway groundwater acceptance criterion is calculated by:

$$\text{Groundwater Acceptance Criterion (mg / L)} = \frac{1}{\frac{1}{Cb} + \frac{1}{Cm}} \quad \textbf{(A9)}$$

Appendix 5B
Calculation of criteria for irrigation use

Overview

The derivation of groundwater acceptance criteria for the protection of irrigation use has been based on:

- protection of the health of adults and children who may come in contact with contaminated groundwater during irrigation
- protection of the health of residents associated with the inhalation of vapours during use of contaminated groundwater
- protection of the health of residents consuming home grown produce that may have been affected by the use of contaminated groundwater for irrigation
- consideration of aesthetic impacts, including odour.

Walden and Spence (1996) developed a protocol for the development of groundwater acceptance criteria for irrigation use and this has been used as the main basis for the derivation of groundwater acceptance criteria for irrigation. Some modifications have been made to the exposure factors assumed by Walden and Spence in order to retain consistency with exposure factors used in other parts of these guidelines. The protocol developed by Walden and Spence has been modified to account for the adsorption and accumulation of heavier PAHs in the soil.

A general overview of the approach used in derivation of criteria for the protection of irrigation use is presented.

The derivation of irrigation water criteria is discussed in terms of the following:

- shower model (used to estimate volatilisation of contaminants from irrigation water)
- accumulation and loss in soil
- plant uptake
- derivation of Water Criteria based on vegetable consumption
- inhalation of aerosols
- dermal exposure
- odour impact.

Shower model

The shower model is used to estimate the vapour emissions from the sprayed water and the concentration in water hitting the ground. The concentrations in the air are estimated using the following assumptions:

- shower is fully mixed for the entire duration.
- dilution uses a simple box model.
- two film gas-liquid mass transfer.

Volatilisation is limited by mass transfer rates. The overall mass transfer coefficient is calculated as:

$$K_L = \left[\frac{1}{k_l} + \frac{RT}{Hk_g} \right]^{-1} \qquad \textbf{(B1)}$$

where: K_L = overall mass transfer coefficient (cm/hr)
H = Henry's Law constant for contaminant (atm.m^3 / mol)
R = gas constant (assumed to be 8.2E-5) (atm.m^3 / mol.K)
T = absolute temperature (assumed to be 293) (K)
k_g = gas phase mass transfer coefficient (cm/hr)

k_l = liquid phase mass transfer coefficient (cm/hr)

The gas and liquid phase mass transfer coefficients for contaminants may be estimated from measure values for CO_2 and H_2O and the following correlations:

$$k_{g(VOC)} = k_{g(H_20)}\left[\frac{18}{MW_{VOC}}\right]^{0.5} \quad \textbf{(B2)}$$

$$k_{l(VOC)} = k_{l(CO_2)}\left[\frac{44}{MW_{VOC}}\right]^{0.5} \quad \textbf{(B3)}$$

where: $k_{g(H20)}$ = gas phase mass transfer coefficient for water (cm/hr)
= 3000 cm/hr
$k_{l(CO2)}$ = liquid phase mass transfer coefficient for carbon dioxide (cm/hr)
= 20 cm/hr
18 = molecular weight of water
44 = molecular weight of carbon dioxide
MW_{VOC} = molecular weight of contaminant

The overall mass transfer coefficient must be adjusted for shower temperature and the viscosity of water at the slower temperature.

$$K'_{L(Ts)} = K_L\left[\frac{T_l \mu_S}{T_S \mu_l}\right]^{-0.5} \quad \textbf{(B4)}$$

where: $K'_{L(Ts)}$ = adjusted overall mass transfer coefficient (cm/hr)
T_l = calibration water temperature of K_L (K)
T_S = shower water temperature (K)
μ_l = water viscosity at T_l (g/m.s)
μ_S = water viscosity at T_S (g/m.s)

Water viscosity may be estimated from the following relationships (T in ^oC):

If $T \leq 20\ ^oC$: $\mu = 100 \,.\, 10^y$

where: $$y = \frac{1301}{998.33 + 8.1855(T-20) + 0.00585(T-20)^2} - 3.30233 \quad \textbf{(B5)}$$

If $T > 20\ ^oC$: $\mu = 1.002 \,.\, 10^y$

where: $$y = \frac{-1.37272(T-20) - 0.001053(T-20)^2}{T + 105} \quad \textbf{(B6)}$$

Volatilisation is assumed to be a first order process:

$$C_{sh} = C_o e^{-K'_L t/600d} \quad \textbf{(B7)}$$

where: C_{sh} = concentration of contaminant in shower droplet after time t (mg/L)
C_o = concentration of contaminant in shower water (mg/L)
d = shower droplet diameter (cm)
= 0.2 cm
t = shower droplet drop time (s)
= 10 s

C_{sh} is the concentration of the shower drop which enters the soil.

The total amount of contaminant that volatilises is given by:

$M_{sh} = f_v \,.\, Q \,.\, time_{sh} \,.\, C_o$ **(B8)**

where: M_{sh} = mass of contaminant volatilised (mg)
f_v = the fraction of contaminant volatilised $(1 - e^{-K_L' t/600d})$ (mg/mg)
Q = the volumetric flow rate of water (L/min)
$time_{sh}$ = the duration for which the shower water is flowing (min)
C_o = the concentration of contaminant in the shower water (mg/L)

The concentration of the shower air can be estimated from:

$$C_{sh} = \frac{M_{sh}}{V_{sh}} \quad \textbf{(B9)}$$

where: C_{sh} = air concentration in the shower (mg/m^3)
V_{sh} = volume of air in the shower (m^3)

Accumulation and loss in soil

In order to calculate a produce contaminant concentration it is required to know at what concentration the contaminant exists in the soil, which depends on the following parameters:

- garden area of concern
- volume and mass of soil affected by watering
- rate of water flow
- frequency of watering
- concentration of contaminant in droplets (after volatilisation) and
- half-life of contaminants in soil.

The first step is to calculate the total amount of contaminants sprayed onto the soil for any one event. To determine this the following assumptions are used:

- the concentration of the irrigation water is after volatilisation has occurred, calculated by the shower model
- 100 L of water is used for every 10 m^2 of garden to be watered
- 1 % of the water is lost as aerosol during watering, leaving 99 L of water to enter the soil.

Since events do not occur every day the 100 L per event is changed to L/day by averaging the watering frequency over a year. This is to account for the degradation of the contaminants in the soil.

The next step is to calculate the total addition of contaminant per watering (based on the yearly day average) per unit mass of soil. The assumptions used here are:

- total volume of soil is 3 m^3 (2m x 5m x 0.3m);
- using a bulk density of 2.0 t/m^3 the soil weight is 6000 kg; and
- contaminant disperses uniformly throughout entire soil mass.

The final consideration is contaminant degradation. It is assumed that the concentration of a contaminant in the soil is at steady state. i.e. sufficient time has elapsed such that the rate of degradation and accumulation are equal. This soil concentration is given by the following:

$$Cs = D \ / \ k \quad \textbf{(B10)}$$

where: Cs = Steady state soil concentration (mg/kg)
D = Daily (averaged) addition of contaminant (mg/kg/day)
k = Degradation constant (day^{-1})

and: $k = (Ln\ 2) / t_{1/2}$ **(B11)**

where: Ln 2 = Natural log of 2
$t_{1/2}$ = Half life of contaminant (day)

Plant uptake

The uptake of contaminants by plants is a complex biological process. There is no accurate, theoretically robust model for predicting the concentration of a contaminant in plant material, however, empirical formula have been derived by numerous sources to simulate contaminant uptake by plants.

The following reference is used for modeling the uptake of contaminants by plants:

- C.C. Travis and A.D. Arms, *Bioconcentration of Organics in Beef, Milk and Vegetation*, Environ. Sci. Technol., Vol. 22, No. 3, 1988, pp271-274.

Travis and Arms have developed correlations for the uptake of contaminants in beef, milk and vegetation. The primary contaminants of concern are pesticides, although information is included for benzo(a)pyrene uptake by plants and the same methodology may be used for other contaminants.

Travis and Arms make use of a concept known as the Biotransfer Factor. In the case of plants this may also be known as the uptake factor. This is defined as:

$$B_v = \frac{\text{concentration in vegetation (mg / kg)}}{\text{soil contaminant concentration (mg / kg)}} \qquad \textbf{(B12)}$$

The biotransfer factor of an organic compound is directly proportional to its octanol-water partition coefficient. Based on review studies involving various chemicals the following correlation was derived:

$$\log B_v = 1.588 - 0.578 \log K_{ow} \qquad \textbf{(B13)}$$

The above is the biotransfer for plants. This may be considered to be the uptake factor.

Deposited water

As part of the ingestion pathway, residual water on plants is a consideration given in SAHC. The amount of water deposited on the plant surface is considered to be 1 % of the weight of the vegetable and 50% is removed by peeling/washing processes leaving a residual of 0.5% of the weight of the vegetable.

The concentration of this water is that calculated in the shower model left in the water droplet after spraying. Knowing the consumption rate, the total intake of contaminants may be calculated. A factor of 5 is allowed for accumulation following deposition and removal processes such as precipitation, photolysis and photooxidation.

Inhalation of aerosols

As well as inhalation of volatilised contaminants through the shower model, the receptors inhale water mist. It has been assumed that 1 percent of water sprayed on the garden forms an aerosol. Of this 0.1 % is inhaled by the receptors. This inhalation pathway is added to the volatilised contaminants inhaled by the receptors during gardening.

Dermal exposure

Children are subjected to dermal contact when playing under the sprinkler. It is assumed that the child's entire body is exposed to the contaminated water and the concentration of the water is that of the groundwater C_o.

The average daily dose (mg/kg.d) is calculated by the equation:

$$ADD = \frac{10^{-3} C_w \times SA \times ET \times PC \times EF \times ED}{365\ AT \times BW} \qquad \textbf{(B14)}$$

where: C_w = concentration of contaminant in groundwater (mg/L)
SA = total skin surface area (cm^2)
ET = activity duration (hr/day)
PC = chemical specific skin permeability coefficient (cm/hr)
EF = exposure frequency for playing/gardening (d/yr)

ED = exposure duration (yrs)
AT = averaging time (yrs)
= 70 yrs for carcinogenic contaminants
= ED for non-carcinogenic contaminants
BW = body weight

The USEPA (Dermal Exposure Assessment: Principles and Applications, 1992) have estimates of permeability coefficients. These are estimated by the following equation:

$$\text{Log } K_p = -2.72 + 0.71 \text{ Log } K_{ow} - 0.0061 \text{ MW} \quad \textbf{(B15)}$$

where: K_p = permeability coefficient (cm/hr)
K_{ow} = Octanol Water Partition Coefficient
MW = Molecular weight (g/mol)

Table 5B.1 shows the permeability coefficients used in the model.

Table 5B.1 Permeability coefficients for dermal exposure

Contaminant	Permeability Coefficient, Kp (cm/hr)
Naphthalene	0.07
Acenaphthalene	0.13
Anthracene	0.23
Fluorine	0.17
Phenanthrene	0.23
Pyrene	0.46
Fluoranthene	0.36
Acenaphthylene	0.17
Benzo(a)pyrene	1.2
Phenols	0.0055
Cresol(o,m)	0.01
2,4-Dimethylphenol	0.015
Benzene	0.021
Toluene	0.045
Ethylbenzene	0.074
Xylene	0.080
Cyanide (free & complex)	0.001

Table 5B.2 Exposure parameters for irrigation model

Parameter	Child	Adult
Water ingestion rate (L/day)	0.25	-
Vapour inhalation rate (m^3/hr)	0.83	0.83
Gardening/play activity duration (hr/d)	0.5	2
Gardening/play exposure frequency (d/yr)	100	100
Gardening exposure duration (yrs)	6	30
Vegetable ingestion exposure frequency (d/y)	350	350
Vegetable ingestion. exposure duration (yrs)	6	30
Vegetable ingestion rate (g/day)	130	450
Fraction of vegetables home grown	0.10	0.10
Vegetable water retention (%)	80	80
Skin surface area (cm^2)	6800	-
Wind speed (m/s)	2	2
Inhalation “box” volume (m^3)	21,600	86,400
Sprinkler flow rate (L/min)	30	30
Water temperature (^oC)	25	25
Lifetime (yrs)	70	70
Body weight (kg)	15	70

Odour based criteria

Odour based criteria were determined using threshold values obtained from literature and air concentration values calculated from the shower model. Shower air concentrations were

calculate for a water concentration of 1 mg/L. A proportional relationship allows the calculation of the water concentration, which would produce a shower concentration equal to the odour threshold.

Odour threshold air concentrations were obtained from in the following references:

- T. Walden and L. Spence, *Risk-Based BTEX Cleanup Goals in Groundwater for Irrigation Scenarios,* 1996.
- *Odor Thresholds for Chemicals with Established Occupational Health Standard,* American Industrial Hygiene Association, 1989.

Table 5B.3 Groundwater acceptance criteria Irrigation use

Site Use	Residential	Exposure duration (child)	6 yrs	Garden duration (child)	0.5 hr/d	Produce ingestion (child)	0.13kg/d
Receptor	Children resident on site for up to 30 yrs	Exposure duration (adult)	30 yrs	Garden duration (adult)	2 hr/d	Produce ingestion (adult)	0.45 kg/d
		Exposure duration (ad,com)	24 yrs	Garden exp frequency	100 d/yr	Proportion home grown	0.1
Target Risk	0.00001	Ave time (carc)	70 yrs	Inhale rate (child)	20 m3/d	Produce exposure frequnecy	350 d/yr
Target HI	1	(non-carc, child)	6 yrs	Inhale rate (adult)	20 m3/d	Skin area (child)	6800cm2
		(non-carc, adult)	30 yrs	Water ingestion (child)	0.25 L/d		
		Body weight (child)	15 kg	Water ingestion (adult)	0 L/d		
		Body weight (adult)	70 kg				

Contaminant	Skin Absorption Factor	SF (1/(mg/kg/d)) Oral	RfD (mg/kg/d) Oral	SF (1/(mg/kg/d)) Inhalation	RfD (mg/kg/d) Inhalation	Acceptable CDI (mg/kg/d)						Acceptable Criteria (mg/L-H2O)		
						Carcinogenic			Non-carcinogenic			Child	Adult	Child-> Adult
						Oral	Dermal	Inhalation	Oral	Dermal	Inhalation			
PAHs									2.00E-03	2.00E-03	2.00E-03	2.12E-01	4.93E+00	
napthalene	7.00E-02		2.00E-03		2.00E-03				3.00E-02	3.00E-02	3.00E-02	2.29E+00	9.10E+01	
acenaphthene	1.30E-01		3.00E-02		3.00E-02				1.50E-01	1.50E-01	1.50E-01	7.85E+00	7.59E+02	
anthracene	2.30E-01		1.50E-01		1.50E-01				2.00E-02	2.00E-02	2.00E-02	1.29E+00	7.66E+01	
fluorene	1.70E-01		2.00E-02		2.00E-02				1.50E-02	1.50E-02	1.50E-02	7.85E+00	7.83E+01	
phenanthrene	2.30E-01		1.50E-02		1.50E-02				1.50E-02	1.50E-02	1.50E-02	4.50E-01	1.31E+02	
pyrene	4.60E-01		1.50E-02		1.50E-02				2.00E-02	2.00E-02	2.00E-02	7.36E-01	1.07E+02	
fluoroanthene	3.60E-01		2.00E-02		2.00E-02				1.50E-02	1.50E-02	1.50E-02	9.68E-01	5.25E+01	
acenaphthylene	1.70E-01		1.50E-02		1.50E-02							2.02E-04	6.78E-02	2.02E-04
benzo(a)pyrene	1.20E+00	7.30E+00		7.30E+00		1.37E-06	1.37E-06	1.37E-06						

Contaminant	Pathway contribution to risk											
	Child				Adult				Child->Adult			
	Inhalation	Produce ingestion	Water ingestion	Skin absorption	Inhalation	Produce ingestion	Water ingestion	Skin absorption	Inhalation	Produce ingestion	Water ingestion	Skin absorption
PAHs	%	%	%	%	%	%	%	%	%	%	%	%
napthalene	1.62	4.01	48.34	46.02	30.80	69.20	0.00	0.00	-	-	-	-
acenaphthene	0.83	2.52	34.92	61.73	25.70	74.30	0.00	0.00	-	-	-	-
anthracene	0.33	1.09	23.88	74.70	21.97	78.03	0.00	0.00	-	-	-	-
fluorene	0.71	1.53	29.52	68.25	32.91	67.09	0.00	0.00	-	-	-	-
phenanthrene	0.25	1.14	23.89	74.72	15.90	84.10	0.00	0.00	-	-	-	-
pyrene	0.08	0.41	13.71	85.79	10.48	89.52	0.00	0.00	-	-	-	-
fluoroanthene	0.63	0.23	16.81	82.33	75.27	24.73	0.00	0.00	-	-	-	-
acenaphthylene	0.81	1.62	29.46	68.11	34.84	65.18	0.00	0.00	-	-	-	-
benzo(a)pyrene	0.03	0.07	5.77	94.14	11.23	88.77	0.00	0.00	0.05	0.22	5.76	93.97

Table 5B.4 Irrigation criteria calculation
Shower model

Water conc		1 mg/L							
Viscosity	T	25C	Drop diameter	0.2cm	Gardening exposure time			Area of soil	10m2
	if T<20		Drop time	10s		adult	2hr	Weight of soil	6000kg
		y -2.050650852				child	0.5hr	Total flow for A	27.4L (ave over year)
		u 0.889916272	Wind speed	2 m/s				Total flow	100
	if T>20		Sprinkler dis.	4 m	Box volume	adult	86400m3	fr aerosol inh	0.01
		y -0.051248654	Receptor height	1.5 m		child	21600m3	fr aerosol on pla	0.005
		u 0.890469539	Flowrate	30 L/min				fr aerosol inhal	0.001
	u	0.890469539 g/m.s							

Chemical	MW g/mol	H @ 20C L-H2O/L-air	H atm.m3/mol	kg cm/hr	kl cm/hr	KI cm/hr	KF cm/hr	Cspray mg/L
Naphthalene	128		4.83E-04	1125	11.7260394	7.722214783	7.248437956	0.547969037
Acenaphthene	154.2		1.90E-04	1024.979833	10.68351458	4.608868287	4.308197935	0.696362832
Anthracene	178		6.50E-05	953.998092	9.943661524	2.049092199	1.915414855	0.852469451
Fluorene	166.2		2.10E-04	987.2837697	10.29060301	4.693532169	4.387338569	0.693772246
Phenanthrene	178.2		3.90E-05	953.4625892	9.9380799	1.3390483641	1.251786132	0.900940996
Pyrene	202.3		1.10E-05	894.8692109	9.327352555	0.392465471	0.366862084	0.969890754
Fluoranthene	202.3		1.69E-02	894.8692109	9.327352555	9.191156739	8.591550032	0.48872149
Acenaphthylene	152.2		2.80E-04	1030.692281	10.75347941	5676515375	5.306194556	0.6426321
Benxo(a)pyrene	252.3		2.00E-06	801.3068992	8.352138908	0.66174816	0.061857746	0.994858451

Chemical	Cshower mg/L	Mass vol (mg) adult	Csh (mg/m3) adult	Half life days	Soil Conc mg/kg	Kow	Uptake Factor	Cplant g/g	Odour threshold mg/m3	Odour based criteria (mg/L)
Naphthalene	0.452030963	1627.311469	0.018834623	258	0.922114329	1995	0.479328226	4.41995E-07	0.2	10.6
Acenaphthene	0.301637168	1085.893805	0.012588215	397	1.808342421	8317	0.210019319	3.797897E-07	-	-
Anthracene	0.147530549	531.1099749	0.006147106	397	2.207386477	28180	0.103737101	2.28988E-07	-	-
Fluorene	0.306227754	1102.419913	0.01275949	397	1.796455547	15140	0.14855499	2.66872E-07	4.5	352.7
Phenanthrene	0.099059004	356.6124153	0.004127459	397	2.332898812	28840	0.102358224	2.38791E-07	8	1938.2
Pyrene	0.030109246	108.393286	0.001254552	506	3.200975735	123000	0.044262388	1.41683E-07	8.7	6934.7
Fluoranthene	0.51127851	1840.602637	0.021303271	530	1.689453922	166000	0.037220099	6.28816E-08	0.35	16.43
Acenaphthylene	0.3573679	1286.524439	0.014890329	397	1.664033128	11750	0.171995907	2.86207E-07	0.20	13.43
Benxo(a)pyrene	0.005141549	18.50957627	0.000214231	530	3.439111126	1096000	0.012502288	4.29968E-08	-	-

Adult	Risk/HI inhalation	Risk/HI produce	Risk/HI total	Child	Risk/HI inhalation	Risk/HI vegetation	Risk/HI water ing	Risk/HI dermal	Risk/HI total
Naphthalene	6.25E-02	1.40E-01	2.03E-01	Naphthalene	7.67E-02	1.89E-01	2.28E+00	2.17E+00	4.72E+00
Acenaphthene	2.82E-03	8.16E-03	1.10E-02	Acenaphthene	3.61E-03	1.10E-02	1.52E-01	2.69E-01	4.36E-01
Anthracene	2.90E-04	1.03E-03	1.32E-03	Anthracene	4.16E-04	1.39E-03	3.04E-02	9.52E-02	1.27E-01
Fluorene	4.30E-03	8.76E-03	1.31E-02	Fluorene	5.49E-03	1.18E-02	2.28E-01	5.28E-02	7.73E-01
Phenanthrene	2.03E-03	1.07E-02	1.28E-02	Phenanthrene	3.19E-03	1.45E-02	3.04E-01	9.52E-01	1.27E+00
Pyrene	7.99E-04	6.82E-03	7.62E-03	Pyrene	1.82E-03	9.19E-03	3.04E-01	1.90E+00	2.22E+00
Fluoranthene	7.04E-03	2.31E-03	9.36E-03	Fluoranthene	8.55E-03	3.12E-03	2.28E-01	1.12E+00	1.36E+00
Acenaphthylene	6.64E-03	1.24E-02	1.91E-02	Acenaphthylene	8.34E-03	1.67E-02	3.04E-01	7.04E-01	1.03E+00
Benxo(a)pyrene	1.68E-05	1.31E-04	1.47E-04	Benxo(a)pyrene	1.24E-05	3.53E-05	2.86E-03	4.66E-02	4.95E-02

Adult (com)	Risk/HI inhalation	Risk/HI produce	Child->Adult	Risk/HI inhalation	Risk/HI vegetation	Risk/HI water ing	Risk/HI dermal	Risk/HI total
Naphthalene			Naphthalene					
Acenaphthene			Acenaphthene					
Anthracene			Anthracene					
Fluorene			Fluorene					
Phenanthrene			Phenanthrene					
Pyrene			Pyrene					
Fluoranthene			Fluoranthene					
Acenaphthylene			Acenaphthylene					
Benxo(a)pyrene	1.32E-05	7.40E-05	Benxo(a)pyrene	2.56E-05	1.09E-04	2.86E-03	4.66E-02	4.96E-02

Table 5B.5 Groundwater acceptance criteria
Irrigation use

Site Use	Residential	Exposure duration (child)	6 yrs	Garden duration (child)	0.5 hr/d	Produce ingestion (child)	0.13kg/d
Receptor	Children resident on site	Exposure duration (adult)	30 yrs	Garden duration (adult)	2 hr/d	Produce ingestion (adult)	0.45 kg/d
	for up to 30 yrs	Exposure duration (ad,com)	24 yrs	Garden exp frequency	100 d/yr	Proportion home grown	0.1
Target Risk	0.00001	Ave time (carc)	70 yrs	Inhale rate (child)	20 m3/d	Produce exposure frequnecy	350 d/yr
Target HI	1	(non-carc, child)	6 yrs	Inhale rate (adult)	20 m3/d	Skin area (child)	6800cm2
		(non-carc, adult)	30 yrs	Water ingestion (child)	0.25 L/d		
		Body weight (child)	15 kg	Water ingestion (adult)	0 L/d		
		Body weight (adult)	70 kg				

Contaminant	Skin Absorption Factor	SF (1/(mg/kg/d)) Oral	RfD (mg/kg/d) Oral	SF (1/(mg/kg/d)) Inhalation	RfD (mg/kg/d) Inhalation	Acceptable CDI (mg/kg/d)						Acceptable Criteria (mg/L-H2O)		
						Carcinogenic			Non-carcinogenic			Child	Adult	Child-> Adult
						Oral	Dermal	Inhalation	Oral	Dermal	Inhalation			
Phenolics														
Phenol	5.50E-02		3.00E-01		3.00E-01				3.00E-01	3.00E-01	3.00E-01	4.39E+01	2.11E+02	
Cresol (o,m)	1.00E-02		2.50E-02		2.50E-02				2.50E-02	2.50E-02	2.50E-02	4.04E+00	3.42E+01	
Dimethylphenol	1.50E-02		2.00E-02		2.00E-02				2.00E-02	2.00E-02	2.00E-02	3.25E+00	4.19E+01	
BTEX														
Benzene	2.10E-02	2.90E-02		2.90E-02		3.45E-04	3.45E-04	3.45E-04				5.32E-01	6.29E-01	3.18E-01
Toluene	4.50E-02		1.00E-01		1.00E-01				1.00E-01	1.00E-01	1.00E-01	1.30E+01	3.65E+02	
Ethylbenzene	7.40E-02		5.00E-02		5.00E-02				5.00E-02	5.00E-02	5.00E-02	5.19E+00	1.33E+02	
Xylene	8.00E-02		9.00E-02		9.00E-02				9.00E-02	9.00E-02	9.00E-02	8.84E+00	1.80E+02	
Inorganics														
Cyanide -free	1.00E-03		2.50E-03		2.50E-03				2.50E-03	2.50E-03	2.50E-03	4.69E+01	4.88E+00	
Complexed	1.00E-03		6.25E-03		6.25E-03				6.25E-03	6.25E-03	6.25E-03	1.17E+00	1.22E+01	

Contaminant	Pathway contribution to risk											
	Child				Adult				Child->Adult			
%	Inhalation	Produce ingestion	Water ingestion	Skin absorption	Inhalation	Produce ingestion	Water ingestion	Skin absorption	Inhalation	Produce ingestion	Water ingestion	Skin absorption
Phenolics												
Phenol	0.27	27.97	66.77	4.99	0.30	99.70	0.00	0.00	-	-	-	-
Cresol (o,m)	0.31	15.81	73.83	10.04	0.68	99.32	0.00	0.00	-	-	-	-
Dimethylphenol	0.33	10.33	74.20	15.14	1.23	98.77	0.00	0.00	-	-	-	-
BTEX												
Benzene	2.90	19.52	60.34	17.23	14.39	85.61	0.00	0.00	7.51	46.14	36.05	10.30
Toluene	2.74	1.70	59.28	36.28	64.53	35.47	0.00	0.00	-	-	-	-
Ethylbenzene	2.15	2.83	47.36	47.66	48.19	53.81	0.00	0.00	-	-	-	-
Xylene	2.00	4.38	44.84	48.78	34.00	66.00	0.00	0.00	-	-	-	-
Inorganics												
Cyanide -free	0.34	12.86	85.63	1.16	0.76	99.24	0.00	0.00	-	-	-	-
Complexed	0.34	12.86	85.63	1.16	0.76	99.24	0.00	0.00	-	-	-	-

Table 5B.6 Irrigation criteria calculation
Shower model

Water conc		1 mg/L							
Viscosity	T	25C	Drop diameter	0.2cm	Gardening exposure time			Area of soil	10m2
	if T<20		Drop time	10s		adult	2hr	Weight of soil	6000kg
		y -2.050850852				child	0.5hr	Total flow for A	27.4L (ave over year)
		u 0.889916272	Wind speed	2 m/s				Total flow	100
	if T>20		Sprinkler dis.	4 m	Box time	adult	86400m3	fr aerosol inh	0.01
		y -0.051248654	Receptor height	1.5 m		child	21600m3	fr aerosol on pla	0.005
		u 0.890469539	Flowrate	30 L/min					
	u	0.890469539 g/m.s							

Chemical	MW g/mol	H @ 20C L-H2O/L-air	H atm.m3/mol	kg cm/hr	kl cm/hr	KI cm/hr	KF cm/hr	Cspray mg/L
Phenol	94	-	3.30E-07	1312.784923	13.6833491	0.018007529	0.016832766	0.998598253
Cresol (o,m)	108	-	1.00E-06	1224.744871	12.76569477	0.050773066	0.047460766	0.996052747
Dimethylphenol	122	-	2.00E-06	1152.331919	12.01092399	0.095163729	0.0889555	0.99261445
Benzene	78.11	-	5.50E-03	1440.13826	15.01077153	14.35706435	13.42044752	0.326811859
Toluene	92	-	6.64E-03	1326.977605	13.8312815	13.3285957	14.45907344	0.354071602
Ethylbenzene	106	-	8.43E+00	1236.245076	12.88556308	12.8851803	12.04458529	0.366515143
Xylene	106	-	7.60E-03	1236.245076	12.88556308	12.47451706	11.66071263	0.378429285
Cyanide - free	-	-	-	-	-	-	-	1
Complexed	-	-	-	-	-	-	-	1

Chemical	Cshower mg/L	Mass vol (mg) adult	Csh (mg/m3) adult	Half life days	Soil Conc mg/kg	Kow	Uptake Factor	Cplant g/g	Odour threshold mg/m3	Odour based criteria (mg/L)
Phenol	0.001401747	5.046289648	5.84061E-05	63	0.410336734	28.84	5.547824856	2.27648E-06	0.23	3937.9
Cresol (o,m)	0.003947523	14.21011029	0.000164489	63	0.409290753	93.3	2.814546382	1.15197E-06	0.0027	16.4
Dimethylphenol	0.00738555	26.4879804	0.000307731	63	0.407877913	199.5	1.813982127	7.39883E-07	-	-
Benzene	0.673188141	2423.477306	0.028049506	365	0.778036407	134.9	2.274327974	1.76951E-06	4.5	160.4
Toluene	0.645928398	2325.342232	0.026913683	63	0.145492529	537	1.023469401	1.48907E-07	8	297.2
Ethylbenzene	0.633484857	2280.545485	0.026395202	228	0.545049337	1413	0.585083473	3.18899E-07	8.7	329.6
Xylene	0.621570715	2237.654573	0.02589878	365	0.900920871	1413	0.585083473	5.27114E-07	0.35	13.51
Cyanide - free	0	0	0	-	-	-		0.0000008	-	-
Complexed	0	0	0	-	-	-		0.0000008	-	-

Adult	Risk/HI inhalation	Risk/HI produce	Risk/HI total	Child	Risk/HI inhalation	Risk/HI vegetation	Risk/HI water ing	Risk/HI dermal	Risk/HI total
Phenol	1.43E-05	4.73E-03	4.74E-03	Phenol	6.23E-05	6.38E-03	1.52E-02	1.14E-03	2.28E-02
Cresol (o,m)	1.99E-04	2.90E-02	2.92E-02	Cresol (o,m)	7.78E-04	3.91E-02	1.83E-01	2.48E-02	2.47E-01
Dimethylphenol	2.95E-04	2.36E-02	2.39E-02	Dimethylphenol	1.02E-03	3.18E-02	2.28E-01	4.66E-02	3.08E-01
Benzene	2.29E-06	1.36E-05	1.59E-05	Benzene	5.45E-07	3.67E-06	1.14E-05	3.24E-06	1.88E-05
Toluene	1.77E-03	9.72E-04	2.74E-03	Toluene	2.11E-03	1.31E-03	4.57E-02	2.79E-02	7.70E-02
Ethylbenzene	3.47E-03	4.04E-03	7.52E-03	Ethylbenzene	4.15E-03	5.45E-03	9.13E-02	9.19E-02	1.93E-01
Xylene	1.89E-03	3.68E-03	5.57E-03	Xylene	2.27E-03	4.95E-03	5.07E-02	5.52E-02	1.13E-01
Cyanide - free	1.57E-03	2.03E-01	2.05E-01	Cyanide - free	7.31E-03	2.74E-01	1.83E+00	2.48E-02	2.13E+00
Complexed	6.26E-04	8.14E-02	8.20E-02	Complexed	2.92E-03	1.10E-01	7.31E-01	9.94E-03	8.53E-01

Adult (com)	Risk/HI	Risk/HI	Child->Adult	Risk/HI	Risk/HI	Risk/HI	Risk/HI	risk/HI

	inhalation	produce		inhalation	vegetation	water ing	dermal	total
Phenol			Phenol					
Cresol (o,m)			Cresol (o,m)					
Dimethylphenol			Dimethylphenol					
Benzene	1.82E-06	1.09E-05	Benzene	2.36E-06	1.45E-05	1.14E-05	3.24E-06	3.15E-05
Toluene			Toluene					
Ethylbenzene			Ethylbenzene					
Xylene			Xylene					
Cyanide - free			Cyanide - free					
Complexed			Complexed					

Appendix 5C

Calculation of criteria for primary contact recreation

Ingestion of contaminated water

The Chronic Daily Intake (CDI) may be determined by the following expression:

$$\mathbf{CDI} = \frac{\mathbf{C_i \times IR_{adj} \times EF \times MF}}{\mathbf{AT}}$$

where: C_i = concentration of species "i" in the water (mg/L)
EF = exposure frequency(events/yr)
AT = averaging time
= (ED x 365) days for non-carcinogens by convention or (70 years x 365) days for carcinogens, a lifetime, by convention
IR_{adj} = age adjusted ingestion rate (L/d)
MF = matrix factor, accounts for reduced bioavailability of contaminant due to binding to the soil matrix. In the absence of necessary information, MF usually taken as 1.0.

$$\mathbf{IR_{adj}} = \sum \frac{\mathbf{ED \times IR \times CF}}{\mathbf{BW}}$$

where: ED = exposure duration (yr)
IR = ingestion rate (mL/d)
CF = conversion factor
= 0.001 L/mL
BW = body weight (kg)

Dermal absorption from contaminated water

The Chronic Daily Intake (CDI) for dermal absorption from contaminated water may be determined by the following expression (USEPA, 1989)[1]:

$$\mathbf{CDI} = \frac{\mathbf{t \times AV_{adj} \times C \times PC \times EF \times CF}}{\mathbf{AT}}$$

where: t = duration of exposure (hours/event)
AV_{adj} = age adjusted skin surface area (cm^2)
C = contaminant concentration in water (mg/L)
PC = dermal permeability constant (cm/hr)
EF = exposure frequency (event/yr)
AT = averaging time (days)
CF = conversion factor
= 10^{-3} L/cm^3

$$\mathbf{AV_{adj}} = \sum \frac{\mathbf{AV} \times \mathbf{ED}}{\mathbf{BW}}$$

where: AV = skin surface area (cm^2)
ED = exposure duration (yr)
BW = body weight (kg)

Note, for the purposes of developing human health-based acceptance criteria for non-carcinogenic health effects only, the most sensitive receptor, i.e. children, is considered in the

[1] Based on steady state model dermal absorption, subject to review.

assessment of primary contact recreational exposure. In the case of carcinogenic health effects it is necessary to consider an age weighted exposure.

Primary contact recreation

Health based acceptance criteria have been developed for both the ingestion and dermal absorption exposure routes, employing plausible or reasonable worst case assumptions. The major exposure assumptions are summarised as follows:

• exposure duration	=	Child (4-10 yrs): 6 yrs Adult: 24 yrs	
• water ingestion rate	=	100 mL/event	(ANZECC, 1992)
• skin surface area	=	Child (4-10 yrs): 8290 cm^2 Adult: 18000 cm^2	(USEPA, 1989)
• body weight	=	Child (4-10 yrs): 30 kg Adult: 70 kg	(USEPA, 1989)
• exposure frequency	=	150 event/yr	(USEPA, 1992)
• event duration	=	1 hr/ event	(USEPA, 1992)

For recreational bathing in surface water bodies, an exposure frequency of 7 events/yr and an event duration of 2.6 hrs/event may be used.

Table 5C.1 Health-based acceptance criteria
Primary recreational use of surface water
Typical

Receptor	Children and adults resident on site up to 30 yrs	Target risk	0.00001
		Target HI	1
Exposure frequency	7 d/yr	Body weight (4-10 yrs)	30 kg
Averaging time (carc)	70 yrs	Body weight (adult)	70 kg
(non-carc)	6 yrs	Exposure duration (4-10 yrs)	6 yrs
Ingestion rate	100 mL/event	Exposure duration (adult)	24 yrs
Event duration (t)	2.6 hr/d (av.)	Surface area (4-10 yrs)	8290 sq.cm 50% CI
		Surface area (adult)	18000sq.cm 50% DI

Contaminant	ADI		Permeability[2]	Water Quality Criteria (mg/L)[3]		
	Oral	Dermal	Constant (cm/h)	Oral	Dermal	Combined
Phenolics						
phenol	3.00E-01	3.00E-01	5.54E-03	4.69E+03	3.93E+03	2.14E+03
cresol (o)	2.50E-02	2.50E-02	1.01E-02	3.91E+02	1.79E+02	1.23E+02
cresol (m)	2.50E-02	2.50E-02	1.03E-02	3.91E+02	1.76E+02	1.21E+02
cresol (p)	2.50E-03	2.50E-03	9.97E-03	3.91E+01	1.82E+01	1.24E+01
BTEX						
benzene	3.45E-04	3.45E-04	2.04E-02	2.32E+01	3.03E+00	2.68E+00
toluene	1.00E-01	1.00E-01	4.45E-02	1.56E+03	1.60E+02	1.45E+02
ethylbenzene	5.00E-02	5.00E-02	7.41E-02	7.82E+02	4.90E+01	4.61E+01
xylene	9.00E-02	9.00E-02	8.87E-02	1.41E+03	7.36E+01	7.00E+01
Non-carcinogenic PAHs						
napthalene	2.00E-03	2.00E-03	4.33E-02	3.13E+01	3.35E+00	3.03E+00
acenaphthene	3.00E-02	3.00E-02	1.33E-01	4.69E+02	1.64E+01	1.59E+01
anthracene	1.50E-01	1.50E-01	2.26E-01	2.35E+03	4.82E+01	4.72E+01
fluorene	2.00E-02	2.00E-02	1.71E-01	3.13E+02	8.47E+00	8.24E+00
phenanthrene	1.50E-02	1.50E-02	2.29E-01	2.35E+02	4.76E+00	4.66E+00
pyrene	1.50E-02	1.50E-02	3.24E-01	2.35E+02	3.36E+00	3.31E+00
fluoroanthene	2.00E-02	2.00E-02	5.65E-01	3.13E+02	2.57E+00	2.55E+00
acenaphthylene	1.50E-02	1.50E-02	1.74E-01	2.35E+02	6.25E+00	6.08E+00
Carcinogenic PAHs						
benzo(a)pyrene	1.37E-06	1.37E-06	9.70E-01	9.20E-02	2.53E-04	2.52E-04
Inorganics						
cyanide (free)	2.50E-03	2.50E-03	NA	3.91E+01	NA	3.91E+01
cyanide (complex)	6.25E-03	6.25E-03	NA	9.78E+01	NA	9.78E+01

$$\log K_p = -2.72 + 0.71 \log K_{ow} - 0.00610\ MW$$

Contaminant	MW	K_{ow}	$\log K_{ow}$	$\log K_p$	K_p
Phenolics					
phenol	94	28.84	1.459995256	-2.25680337	0.00553601
cresol (o)	108	89.13	1.950023907	-1.99428303	0.01013251
cresol (m)	108	91.20	1.959994838	-1.98720366	0.01029903
cresol (p)	108	87.10	1.940018155	-2.00138711	0.00996811
BTEX					
benzene	78.11	132.00	2.120573931	-1.69086351	0.02037682
toluene	92	537.00	2.729974286	-1.32491826	0.04540271
ethylbenzene	106	1413.00	3.150142162	-1.12999907	0.07413118
xylene	106	1820.00	3.260071388	-1.05194931	0.08872596
Non-carcinogenic PAHs					
napthalene	128	1203.00	3.009875634	-1.3637883	0.04327427
acenaphthene	154.2	8317.00	3.919966701	-0.87744364	0.13260392
anthracene	178	28180.00	4.449940989	-0.6463419	0.22576577
fluorene	166.2	15140.00	4.180125875	-0.76593063	0.17142311
phenanthrene	178.2	28840.00	4.459995256	-0.64042337	0.22886355
pyrene	202.3	75858.00	4.880001388	-0.48922901	0.32416863
fluoroanthene	202.3	166000.00	5.220108088	-0.24775326	0.56525803
acenaphthylene	152.2	11750.00	4.070037867	-0.75869311	0.17430381
Carcinogenic PAHs					
benzo(a)pyrene	252.3	954993.00	5.980000188	-0.01322987	0.96999643
Inorganics					
cyanide (free)	26.02				
cyanide (complex)	26.02				

[2] Permeability constant data (Kp) from Dermal Exposure Assessment Interim Report USEPA/600/8-91/011B
[3] Water quality criteria for carcinogens are based on entire 30 yrs. For non-carcinogens based on most critical 6 yrs.

Table 5C.2 Health-based acceptance criteria Primary recreational use of surface water Reasonable maximum

Receptor	Children and adults resident on site up to 30 yrs	Target risk	0.00001
		Target HI	1
Exposure frequency	7 d/yr	Body weight (4-10 yrs)	30 kg
Averaging time (carc)	70 yrs	Body weight (adult)	70 kg
(non-carc)	6 yrs	Exposure duration (4-10 yrs)	6 yrs
Ingestion rate	100 mL/event	Exposure duration (adult)	24 yrs
Event duration (t)	2.6 hr/d (av.)	Surface area (4-10 yrs)	8290 sq.cm 50% CI
		Surface area (adult)	18000sq.cm 50% DI

Contaminant	ADI		Permeability[4]	Water Quality Criteria (mg/L)[5]		
	Oral	Dermal	Constant (cm/h)	Oral	Dermal	Combined
Phenolics						
phenol	3.00E-01	3.00E-01	5.54E-03	2.19E+02	4.77E+02	1.50E+02
cresol (o)	2.50E-02	2.50E-02	1.01E-02	1.83E+01	2.17E+01	9.92E+00
cresol (m)	2.50E-02	2.50E-02	1.03E-02	1.83E+01	2.14E+01	9.84E+00
cresol (p)	2.50E-03	2.50E-03	9.97E-03	1.83E+00	2.21E+00	9.99E-01
BTEX						
benzene	3.45E-04	3.45E-04	2.04E-02	1.08E+00	3.68E-01	2.75E-01
toluene	1.00E-01	1.00E-01	4.45E-02	7.30E+01	1.94E+01	1.53E+01
ethylbenzene	5.00E-02	5.00E-02	7.41E-02	3.65E+01	5.94E+00	5.11E+00
xylene	9.00E-02	9.00E-02	8.87E-02	6.75E+01	8.93E+00	7.86E+00
Non-carcinogenic PAHs						
napthalene	2.00E-03	2.00E-03	4.33E-02	1.46E+00	4.07E-01	3.18E-01
acenaphthene	3.00E-02	3.00E-02	1.33E-01	2.19E+01	1.99E+00	1.83E+00
anthracene	1.50E-01	1.50E-01	2.26E-01	1.10E+02	5.85E+00	5.55E+00
fluorene	2.00E-02	2.00E-02	1.71E-01	1.46E+01	1.03E+00	9.60E-01
phenanthrene	1.50E-02	1.50E-02	2.29E-01	1.10E+01	5.77E-01	5.48E-01
pyrene	1.50E-02	1.50E-02	3.24E-01	1.10E+01	4.07E-01	3.93E+01
fluoroanthene	2.00E-02	2.00E-02	5.65E-01	1.46E+01	3.12E-01	3.05E-01
acenaphthylene	1.50E-02	1.50E-02	1.74E-01	1.10E+01	7.58E-01	7.09E-01
Carcinogenic PAHs						
benzo(a)pyrene	1.37E-06	1.37E-06	9.70E-01	4.30E-03	3.07E-05	3.05E-05
Inorganics						
cyanide (free)	2.50E-03	2.50E-03	NA	1.83E+00	NA	1.83E+00
cyanide (complex)	6.25E-03	6.25E-03	NA	4.56E+00	NA	4.56E+00

$$\log K_p = -2.72 + 0.71 \log K_{ow} - 0.00610\ MW$$

Contaminant	MW	K_{ow}	$\log K_{ow}$	$\log K_p$	K_p
Phenolics					
phenol	94	28.84	1.459995256	-2.25680337	0.00553601
cresol (o)	108	89.13	1.950023907	-1.99428303	0.01013251
cresol (m)	108	91.20	1.959994838	-1.98720366	0.01029903
cresol (p)	108	87.10	1.940018155	-2.00138711	0.00996811
BTEX					
benzene	78.11	132.00	2.120573931	-1.69086351	0.02037682
toluene	92	537.00	2.729974286	-1.32491826	0.04540271
ethylbenzene	106	1413.00	3.150142162	-1.12999907	0.07413118
xylene	106	1820.00	3.260071388	-1.05194931	0.08872596
Non-carcinogenic PAHs					
napthalene	128	1203.00	3.009875634	-1.3637883	0.04327427
acenaphthene	154.2	8317.00	3.919966701	-0.87744364	0.13260392
anthracene	178	28180.00	4.449940989	-0.6463419	0.22576577
fluorene	166.2	15140.00	4.180125875	-0.76593063	0.17142311
phenanthrene	178.2	28840.00	4.459995256	-0.64042337	0.22886355
pyrene	202.3	75858.00	4.880001388	-0.48922901	0.32416863
fluoroanthene	202.3	166000.00	5.220108088	-0.24775326	0.56525803
acenaphthylene	152.2	11750.00	4.070037867	-0.75869311	0.17430381
Carcinogenic PAHs					
benzo(a)pyrene	252.3	954993.00	5.980000188	-0.01322987	0.96999643
Inorganics					
cyanide (free)	26.02				
cyanide (complex)	26.02				

[4] Permeability constant data (Kp) from Dermal Exposure Assessment Interim Report USEPA/600/8-91/011B

[5] Water quality criteria for carcinogens are based on entire 30 yrs. For non-carcinogens based on most critical 6 yrs.