Client: **Bechtel**
Project: ALBA Potline (6) and Power Plant (PS 5) Expansion

Environmental and Social Impact Assessment Report

Tebodin

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Abbreviations and Units

Abbreviations

AAQ	Ambient Air Quality
AAQS	Ambient Air Quality Standards
ABF	Anode Baking Furnace
ACC	Air-Cooled Condenser
AE	Anode Effects
ALARP	As low as reasonably possible
Alba	Aluminium Bahrain
AP	Aluminium Pechiney
BAPCO	Bahrain Petroleum Company
BAT	Best Available Technology
BHD	Bahraini dinar
BTEX	Benzene Toluene Ethylbenzene, Xylene
C&D	Construction and Demolition
C2F6	Hexa-fluoroethane
C_6H_6	Benzene
C_7H_8	Toluene
C_8H_{10}	p-xylene
CCGT	Combined Cycle Gas Turbines
CEMS	Continuous Emissions Monitoring System
CF4	Tetra-fluoromethane
CH4	Methane
CN	Cyanide
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPC	Contaminant of Potential Concern
CTG	Combustion Turbine Generator
DC	Direct Current

DCS	Distributed Control System
DLN	dry low NOx
DM	demineralized water
EHS	Environmental, Health, and Safety
EIA	Environmental Impact Assessment
ELVs	End Of Life Vehicles
EPCM	Engineering, Procurement, And Construction Management
ESIA	Environmental and Social Impact Assessment
ESR	Environmental Scoping Report
EWA	Electricity and Water Authority
F^-	Fluoride
FHM	First Hot Metal
FTC	Fume Treatment Centre
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIIP	Good International Industry Practice
GIS	Gas Insulated Switchgear
GLCs	Ground-Level Pollutant Concentrations
GTC	Gas Treatment Centre
GW	Ground Water
H_2S	Hydrogen Sulphide
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
HF	Gaseous Fluoride
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
HVAC	Heating, Ventilating, and Air-Conditioning
ICPD	International Conference on Population and Development
IFC	International Finance Corporation

ISO	International Standard Organization
MOUA	Municipalities and Urban Planning Affairs
MOW	Ministry of Works
MPN	Most Probable Number
MTVs	Metal Transfer Vehicles
NA	Not Available
n-ch4	Non-Methane Hydrocarbons
NH_3	Ammonia
NIOSH	US National Institute for Occupational Safety and Health
NO_2	Nitrogen Dioxide
NOGA	National Oil & Gas Authority
NOx	Nitrous Oxides
NSD	North Sahara Datum
NTP	Notice to Proceed
NTU	Nephelometric Turbidity Unit
O_3	Ozone
PAH	Poly Aromatic Hydrocarbons
PEL	Permissible Exposure Limits
PFC2	Two-perfluorocarbons
PFCs	Perfluorinated compounds
PM	Particulate Matter
PM_{10}	Particulate Matter with a diameter smaller than 10 µg
PPE	Personnel Protection Equipment
PS	Power Station
PTAs	Pot Tending Assemblies
PTM	Pot Tending Machine
R/O	Reverse Osmosis
ROMPE	Regional Organization for the Protection of the Marine Environment
SCE	Supreme Council for Environment
SO_2	Sulphur Dioxide

SoW	Scope of Work
SOx	Sulphur Oxides
SPL	Spent Pot Linings
STG	Steam Turbine Generator
STP	Sewage Treatment Plant
TME	Tebodin Middle East Ltd.
TOC	Total Organic Carbons
TPH	Total Petroleum Hydrocarbons
TSE	Treated Sewage Effluent
TV	Target Values
UAE	United Arab Emirates
UN	United Nations
UPS	Uninterruptible Power Supply
UTM	The Universal Transverse Mercator
VDC	Vertical Direct Chill
VOC	Volatile Organic Carbons
WEEE	Waste Electric and Electronic Equipment
WGS	World Geodetic System
WHO	World Health Organisation
ZLD	Zero Liquid Discharge

Units

$\mu g/ m^3$	Microgram per cubic metre
°C	Degree Celsius
µm	Micrometre
AE/Pot/day	Anode Effect per Pot per Day
Btu/SCF	British Thermal Units (BTU) per standard cubic foot
dB(A)	A-weighted decibels
kA	Kiloampere

kg/t_{Al}	Kilogram per tonne Aluminium
km	Kilometre
km^2	Square kilometres
m/s	Metre per second
m^3/h	Cubic Metre per Hour
mg/kg	Milligram per kilogram
mg/Nm^3	Milligram per Normal Cubic Metre
MJ/m^3	Mega joules per Cubic Metre
mm	Millimetre
MMSCFD	Million Standard Cubic Feet per Day
MW	Megawatt
ppb	Parts per Billion
ppm	Parts per Million
TJ	Tera joule
tpy	Tonnes per year

1 Executive Summary

Aluminium Bahrain (Alba) commenced its operations in 1971 and has operated with increasing success and growing production over 30 years, is planning a further expansion from its current level of production of approximately 884,000 tonnes per annum of Primary Aluminium, to a nominal production capacity of 1,446,321 tonnes of aluminium per annum via an additional Potline and Power Station (the Line 6 (L6) & Power Station 5 (PS5) Project).

Tebodin was commissioned to undertake an Environmental and Social Impact Assessment (ESIA) of the Proposed Line 6 Expansion Plan in accordance with Ministerial Order number 1 of 1998, to determine whether this project should be allowed to proceed from an Environmental and Social perspective.

Based on a detailed study of both Alba's existing and planned operations, as well as an impact analysis and comparison with national and international standards and policies, Tebodin's findings and recommendations are set out in this report and can be summarized as follows:

1. The envisaged expansion meets all current environmental legislative requirements in Bahrain and will utilise what can be regarded as Best Available Technologies

2. Tebodin is accordingly of the opinion that, subject to the qualifications set out in clause 4 below, the plan for the Line 6 (L6) & Power Station 5 (PS5) Project is acceptable with respect to the environmental standards and that unacceptable environmental impacts are not expected related to this expansion. We accordingly recommend that the Project receive Environmental Approval from the concerned authorities.

3. Having analysed both the positive and negative impacts of the project, Tebodin is of the opinion that adverse environmental impacts that we believe could arise from the project can be mitigated satisfactorily, subject to the implementation of the recommended mitigation measures listed below explained in more detail in this report:

    a. Stricter operating practices would be implemented in line with those considered for Potline 6 to reduce the SO_2 and HF emissions for Potline 4 and Potline 5.

    b. Alba proceeds to retire Power Stations 1 and 2;

    c. Alba's environmental monitoring protocol should be expanded to include the monitoring recommendations brought forward in the ESIA report;

    d. The environmental management control in Alba's ISO 14001 certified management system be extended to the Potline 6 expansion;

    e. Efforts to reduce waste and wastewater taking into account the recommendations described in this ESIA, e.g. regarding Spent Pot Lining Wastes and sulphur waste reduction should be continued;

    f. Alba should actively consider the other minor suggestions and recommendations in this report and implement them to the extent that they are relevant, feasible and practicable.

    g. Alba, together with land developers will investigate a revised location of its waste water outfall to sea ensuring proper mixing, taking into account Bahrain's Master Plan 2030.

It is noted that Alba is ISO 14001 certified, and is continuously improving its environmental performance. A concrete example of is that environmental improvement is one of the 5 Key parameters chosen as part of Alba's 5 year Strategic Plan, and involves commitment to reduce unrecycled waste by 25% in the following 5 years, notwithstanding the growth in production and activity from the expansions.

It is also evident that the proposed expansion project will have a number of positive impacts. For example, it is clear that there will be positive socio-economic impacts. A number of positive environmental impacts are also likely; key amongst is the eventual retirement of the old Power Stations 1 and 2 and its replacement by a new more energy efficient power station with low NO_X emissions.

Tebodin also believes, given Alba's continuing commitment to their environmental performance, that the environmental impacts associated with the expansion can be effectively managed and minimised.

2 Introduction

2.1 Background and Overview

Aluminium Bahrain (Alba), located in the Kingdom of Bahrain, commenced its operations in 1971 with an annual capacity of 120,000 tonnes per year (tpy). Over the years additional production facilities were added. The current Alba smelter consists of five (5) Potlines supplied with electrical power by four (4) on-site power stations. Alba's total production was 912,700 tpy in 2013.

Alba's total annual production would be a nominal 924,654 tpy at the crept, future increased production, for Potline 1 through 5. The smelter would consume a nominal average power demand of approximately 1,575 Mega-Watts (MW) including Potlines, smelter and inter-bus power losses

Alba produces a range of aluminium products including; standard and T-ingots extrusion billets, rolling slab, Properzi ingots, molten aluminium, etc. Approximately 50% of the produced aluminium is supplied to Bahrain's downstream aluminium industry, while the rest is exported to other regional and international customers.

Alba is presently considering expanding its smelter operations to include an additional Potline 6 (L6), a Power Station 5 (PS 5), and supporting facilities. Up to 150 MW of power would be sourced from the Electricity and Water Authority (EWA) grid for normal operations. Alba may be able to import up to 400 MW in the winter subject to availability from the grid.

Alba awarded the feasibility study to Bechtel Corporation. Bechtel, with Alba's approval, retained the services of Tebodin Middle East (TME) to conduct an Environmental and Social Impact Assessment (ESIA) study as requested by the General Directorate of Environment & Wildlife Protection.

It is to be noted, an Environmental Impact Assessment (EIA) was prepared by Tebodin in 2003 for the proposed expansion of Potline 5 and Potline 6. However, Potline 6 was never constructed. Alba received approval for the EIA in 2003 from the competent regulatory authorities.

2.2 Project Description

Alba's proposed expansion to include Potline 6 is anticipated to elevate the annual nominal production capacity of liquid aluminium by approximately 514,197 tpy by utilizing DUBAL's DX+ reduction technology operating at 460 kilo Ampere (kA).

The additional Potline 6 liquid metal would be delivered to new Cast House facilities (Vertical Direct Chill (VDC) casting for planned billet production and sow casting for emergency back-up) and/or delivered as liquid metal to downstream industries. The works associated with the addition of the proposed new Potline 6 would either utilize or modify the existing facilities and infrastructure at Alba smelter to support the proposed works while some facilities would be required in the Carbon and Cast House areas. The proposed scope of the expansion project is as follows;

- Expansion of the existing aluminium smelter by the addition of a new potline, Potline 6. This new Potline would include dedicated Gas Treatment Centres (GTCs) for Potline off-gas treatment and a complete material handling and storage facility;

- A new Anode Baking Furnace for baking of the anodes including a Fume Treatment Centre (FTC) for furnace fumes treatment and associated anode handling and storage facilities;

- Expansion of the existing Paste Plant to meet the need for more anodes;

- Modifications to the existing Anode Rodding Shop for rodding of the new baked anodes for the Dubal DX+ technology and their transfer to the new Potline;

- Expansion of the existing Cast House facility for molten aluminium processing;

- A new gas fired combined cycle power plant (PS 5);

- Demolition of some existing buildings within the footprint of the new facilities: these include the Line 5 Carbon area maintenance shop, Line 5 Bath plant maintenance shop and warehouse, two dross treatment facilities, Cast House 2 re-melt facility, and the existing textile factory in the to be acquired Jawed land (south of Potline 6);

- Shutting down of Power Stations (PS) 1 and 2, with the power distribution systems retained;

- New facilities or modifications to existing facilities for auxiliary systems and services, offices and amenities to support the Potline operations ,including a new Fuel Station, Vehicle Maintenance Shop and Sewage Treatment Plant (STP).

- The Potline 6 Project would tie in with the existing utilities network within the Alba smelter complex. A new gas line would be installed by National Oil & Gas Authority (NOGA) external to the Alba fence line to supply gas to the new PS5 and potline. The process and potable water would be supplied from the existing water supply line from Alba's calciner facility at the port.

- The major raw materials for Potline 6 would be imported via the existing dedicated port facilities. The Port Facility would require an additional alumina truck loading station.

A more detailed description of the proposed project will be entailed in Chapter 4.

2.3 Project Location

The existing Alba aluminium smelter is spread across an approximate area of 3.5 square kilometres (km^2) with an existing five (5) Potlines, three (3) Cast Houses, three (3) Paste Plants, a dedicated Carbon Plant, ten (10) Fume Treatment Plants, port facilities, and four (4) power stations. At the port, Alba's facilities include a 550,000 tpy coke calcining plant and a water desalination plant.

Appendix 1 provides the site lay-out, indicating existing and proposed facilities.

The proposed locations for Potline 6, Power Station 5 and Material lay down areas are shown in **Figure 1** below. The proposed material lay down areas are presently awaiting approval from authorities.

Further, an additional truck loading station is proposed to be constructed at the existing port facility for the loading and unloading of additional alumina. The relative distance of the proposed station to the location of the smelter is shown in **Figure 2**.

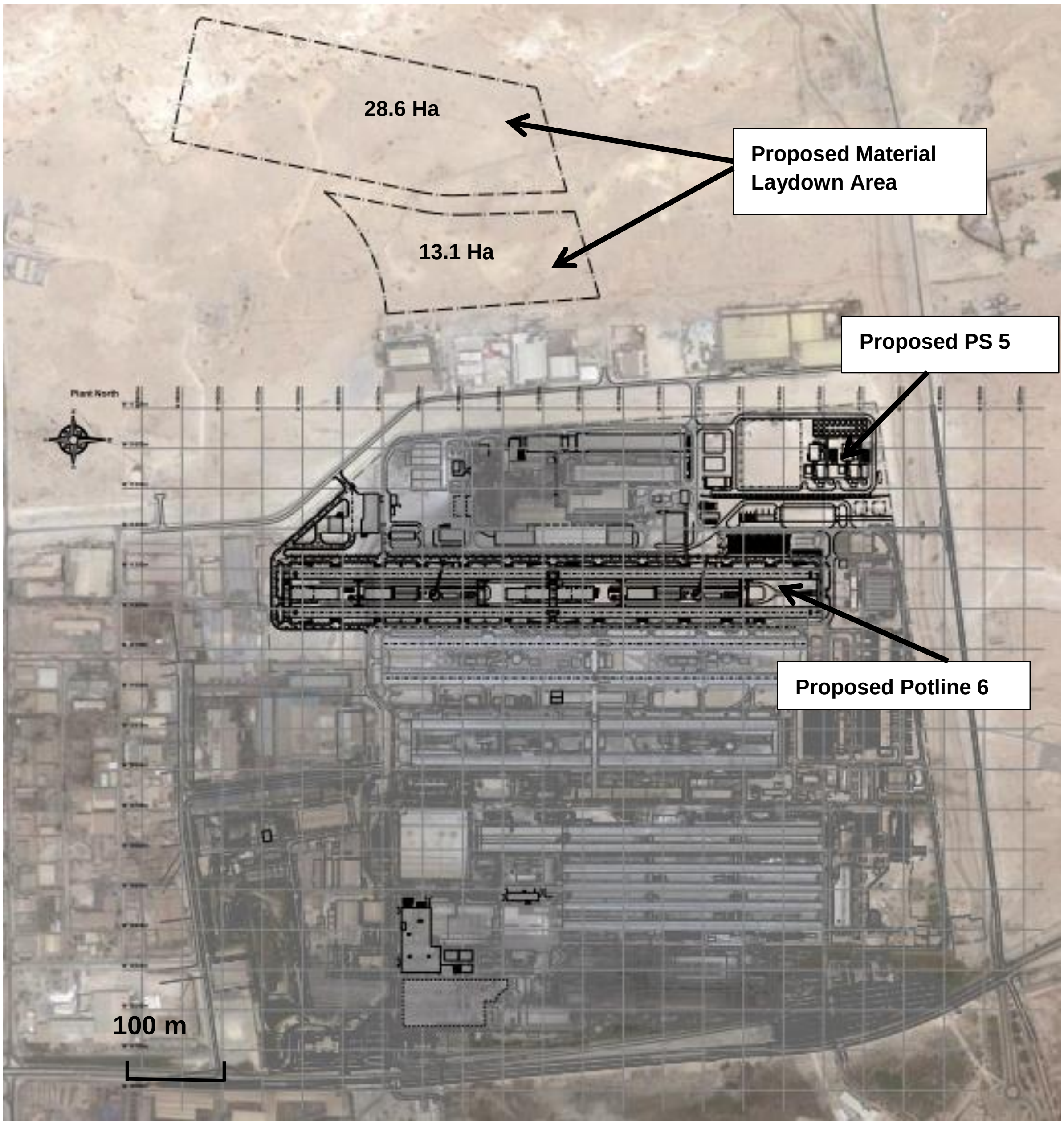

Figure 1: Proposed Location for Potline 6, Power Station 5, and Material Lay-down Area.

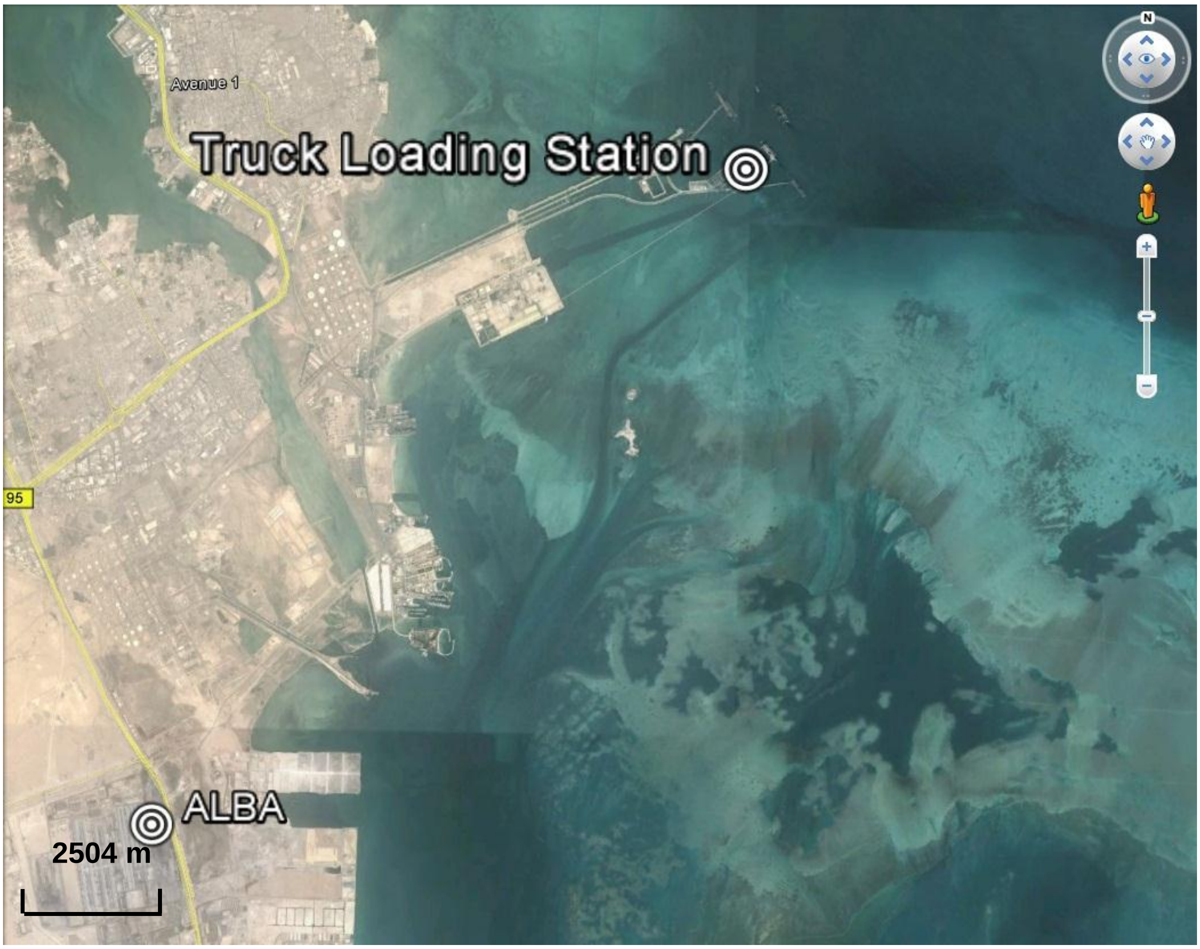

Figure 2: Proposed Location for an Additional Alumina Truck Loading Station at Alba's existing Port facility.

2.4 Project Rationale

The proposed expansion will contribute to Bahrain's economy and will create approximately 547 jobs at Alba and approximately 3,000 jobs at downstream industries. The additional produced aluminium will be used by downstream industries for further development of the Kingdom of Bahrain, Gulf Cooperation Council (GCC) Countries as well as other countries.

The majority of the expansion will be within Alba's fence line with easy access to Alba's existing facilities as to avoid further construction. Additional footprint in Greenfield areas is avoided unless deemed necessary. However, the proposed material lay down areas for the construction phase are located in Greenfield areas outside Alba's fence line as indicated in **Figure 1**.

2.5 Environmental studies

An EIA was prepared by Tebodin in 2003 for the proposed expansion of Potline 5 and Potline 6. However, Potline 6 was never constructed. Alba received approval for the EIA in 2003 from the competent regulatory authorities.

An Environmental Scoping Report (ESR) was prepared by Tebodin and submitted to Supreme Council for Environment (SCE) on 16th January 2014 for the proposed expansion as described in section 2.2 above. The Environmental Scoping

Report described the proposed project, available environmental baseline data, proposed environmental baseline surveys, anticipated environmental impacts and methodology for executing the ESIA for the project.

The ESR was approved by SCE with comments on March 5, 2014. Comments on the ESR were subsequently discussed with the authorities on March 18, 2014. This ESIA report is based on the ESR as approved by SCE. Formal communication received from SCE is included in **Appendix 2**.

2.6 ESIA Report Structure

This report serves to present the findings of the ESIA study that has now been completed for the proposed Alba expansion. The structure of the present ESIA report is as follows:

Executive Summary – this chapter provides an executive summary of the ESIA study findings and conclusions (Chapter 1).

Introduction – this chapter provides a brief description of the project's location, Scope of Work (SoW), and rationale (Chapter 2).

Legal Framework and Standards – this chapter contains a description of the applicable environmental laws and regulations of the Kingdom of Bahrain, including the local and international standards by which the proposed expansion will be assessed (Chapter 3).

Project Description – this chapter contains a description of the aluminium reduction and power generation processes, along with a description of their environmental aspects, followed by a description of the existing Alba plant operations and the proposed expansion project (Chapter 4).

Environmental Baseline Conditions - this chapter contains a description of the existing environmental setting at the project site, highlighting components of the same that may be susceptible to impact or degradation (Chapter 5).

Environmental Impact Assessment – this chapter outlines the impact assessment based on the approved ESIA scoping report (ESR), Taking into account the current state of the environment in which the development will take place and the changes that may arise from the development. The significance of the identified impacts and the mitigation measures to reduce these impacts to as low as reasonably possible (ALARP) are highlighted (Chapter 6).

Alternatives – in this chapter project alternatives and their assessment are described (Chapter 7).

Monitoring Framework – this chapter proposes the monitoring framework of environmental aspects during the construction and operation phases of the expansion project (Chapter 8).

Conclusions and Recommendations – in this chapter, the conclusions of the assessment are presented and recommendations made for maintaining sound environmental management performance during the implementation of the project (Chapter 9).

3 Legal Framework and Standards

3.1 Overview

The following sub-sections highlight the applicable local and international environmental laws which the Kingdom of Bahrain is committed to abide by. The outlined laws and standards shall be reviewed and adhered to during the ESIA study and referenced in recommending mitigation measures to identified significant environmental impacts, if any.

3.2 Legal Framework

3.2.1 International Conventions and Protocols

Bahrain is a signatory of numerous international conventions and protocols covering various environmental aspects, the list of international conventions and protocols ratified by the Kingdom of Bahrain and to be considered when devising the mitigation measures anticipated to arise from the aforementioned project activities are outlined in **Table 1** below.

Table 1: List of International Conventions Ratified by the Kingdom of Bahrain

Title	Description
Framework Convention on Climate Change June 1992	The Framework strives to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.
Kyoto Protocol to the Framework Convention on Climate Change – Ratified January 31, 2006	The Kyoto Protocol, which follows the aforementioned United Nations (UN) Framework Convention on Climate Change, is one of the chief instruments for tackling climate change. It contains the undertakings entered into by the industrialized countries to reduce their emissions of certain greenhouse gases which are responsible for global warming. The total emissions of the developed countries are to be reduced by at least 5 % over the period 2008-2012 compared with 1990 levels.
Convention on Biological Diversity – Ratified in 1996	In response to the growing threat posed by human activity to biodiversity and inspired by the world community's growing commitment to sustainable development, during the 1992 Earth Summit in Rio de Janeiro world leaders adopted the Convention on Biological Diversity (CBD). It is the most important Convention dealing with biodiversity conservation. The Convention has three main objectives: 1. To conserve biological diversity 2. To use biological diversity in a sustainable way 3. To share the benefits of biological diversity fairly and equitably.

Title	Description
Vienna Convention for the Protection of the Ozone Layer – Acceptance on April 27 1990.	The ultimate objective of the Convention is to protect human health and the environment against adverse effects resulting from human activities which modify or likely to modify the ozone layer and urges the Parties to take appropriate measures in accordance with the provisions in the Convention and its Protocols which are in force in the Kingdom of Bahrain. To achieve the aforementioned objectives, the Kingdom of Bahrain, within their capabilities, are expected to: cooperate to better understand and assess the effects of human activities on the ozone layer and the effects of the modification of the ozone layer; adopt appropriate measures and cooperate in harmonizing appropriate policies to control the activities that are causing the modification of the ozone layer; cooperate in the formulation of agreed measures for the implementation of this Convention; and cooperate with competent international bodies to implement effectively this Convention and protocols to which the Kingdom of Bahrain is a party.
Montreal Protocol on Substances that Deplete the Ozone Layer – Acceptance on December 23, 1992.	The Montreal Protocol on Substances that Deplete Ozone Layer is a protocol under the Vienna Convention. The Protocol controls the production and consumption of the most commercially and environmentally significant ozone-depleting substances - those listed in the Annexes to the Protocol. One feature of the Montreal Protocol which makes it unique is Article 6 that requires the control measures to be revised at least every four years (starting 1990), based on the review and assessment of latest available-information on scientific, environmental, technical and economic aspects of the depletion of ozone layer. Based on reports of assessment panels appointed by the Parties and taking into consideration the needs and situation of the developing countries, the Protocol has already been adjusted and amended twice. Further, amendments to the Montreal Protocol were devised by the participating parties.
Stockholm Convention on Persistent Organic Pollutants – January 31, 2006.	The objective of Stockholm Convention is to protect human health and the environment from persistent organic pollutants (POPs). POPs include the Organochlorine pesticides; DDT, Endrin, Dieldrin, Aldrin, chlordane, toxaphene, heptachlor, mirex, hexachlorobenzene; and the industrial chemicals and by-products; PCBs, dioxins and furans.
Convention of the Law of Sea – May 30, 1985.	The UN Convention on the Law of the Sea lays down a comprehensive regime of law and order in the world's oceans and seas establishing rules governing all uses of the oceans and their resources. It enshrines the notion that all problems of ocean space are closely interrelated and need to be addressed as a whole.
Convention to Combat Desertification – Acceptance on July 14, 1997.	It aims at combating desertification or mitigating the effects of drought in arid, semi-arid and dry sub-humid areas through prevention and/or reduction of land degradation, rehabilitation of partly degraded land, or reclamation of desertified land.

Title	Description
	The activity contributes to: • protecting or enhancing dry land ecosystems or remedying existing environmental damage; or • integration of desertification concerns with recipient countries' development objectives through institution building, capacity development, strengthening the regulatory and policy framework, or research; or • developing countries' efforts to meet their obligations under the Convention

3.2.2 Regional Conventions and Protocols

The eight coastal States of the Middle East region comprising of; Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates (UAE) have coordinated a common action to protect the Arabian Gulf and Gulf of Oman. Consequently the Regional Organization for the Protection of the Marine Environment (ROPME) was established on 24th April 1978 to be the governing body to fulfil this goal. Several protocols have been adopted to facilitate coordination between member states to implement the regional programs and activities. Accordingly, Bahrain has signed and ratified the following protocols outlined in **Table 2** below.

Table 2: Regional Co-operation Conventions and Protocols Ratified by the Kingdom of Bahrain

#	Regional Convention
1	Kuwait Regional convention for the co-operation on the protection of marine environment from pollution. Signed in Kuwait on 23rd April, 1978 and ratified on 1 April, 1979.
2	Protocol concerning regional cooperation in combating pollution by oil and other harmful substances in case of emergency, Kuwait on 23rd April, 1978 and ratified on 1 April, 1979.
3	Protocol for the protection of the marine environment against pollution from land based sources, Kuwait, 21st February, 1989 and ratified on 16 May, 1990
4	Protocol concerning marine pollution resulting from exploration and exploitation of the continental shelf, Kuwait 29th March, 1989 and ratified on 16 May, 1990.

3.2.3 Local Legislation for Environmental Protection

For the Kingdom of Bahrain to achieve the goals of the aforementioned international conventions and protocols of which it is a member, numerous local regulations were enacted and implemented. A list of the local environmental legislation relevant to the present ESIA study is outline in **Table 3** below.

Table 3: List of Local Legislation of the Kingdom of Bahrain

#	Local Legislation	Description
1	Legislative Decree No. (21) of the year 1996 in respect to the environment	Concerning protection and development of the environment
2	Ministerial Order No. (1) of 1998 with respect to environmental evaluation projects	Outlines the bases and procedures for the environmental effect evaluation to obtain the

#	Local Legislation	Description
		environmental licenses for a project
3	Ministerial Order No. (1) of the year 1999 with respect to control of the Ozone Layer Depleting Substances	Restricts the use, importation, and exportation of specified ozone depleting substances and the plan to phase-out the aforementioned specified substances in accordance with the provisions of the Montreal Protocol
4	Decision No. (4) of the year 1999 with respect to issuing work permits in maintenance of equipment and buildings containing asbestos and the collection, handling and disposal of asbestos waste	Restricts the maintenance of machinery and buildings containing asbestos except to professionals with the applicable work permits.
5	Resolution No. (10) of 1999 relating to Environment Standards (Air and Water)	Stipulates the standards for water and air pollution sources
6	Resolution number (3) of the year 2001 relating to the modification of some tables attached to decree number (10) of the year 1999 concerning the environmental measurements (air and water) ratified by decree number (2) of the year 2001	Modification of the stipulated water quality and air emission standards
7	Resolution No. (2) of 2001 with respect to amending regulations of resolution No.10 of 1999 with respect to environmental standards (air and water)	Modification to the stipulated waste water quality standards
8	Decision No. (7) of the year 2002 with respect to control of the import and use of chemicals banned and severely restricted	Restricts the importation and use of chemicals banned and severely restricted chemicals, goods, and products containing such chemicals
9	Decision No. (4) of the year 2005 with respect to the management of used oils	Outlines the guidelines to be followed to legally store and dispose of used oils and dictates the laws governing the importation, exportation, and transportation of waste oils via ship vessels.
10	Resolution No. (3) of the year 2005 with respect to work premises conditions and environmental standards	Outlines the environmental conditions related to establishments and the environmental standards for workplace activities
11	Resolution No. (3) of the year 2006 with respect to the management of hazardous materials	This Resolution aims to put in place an appropriate monitoring and control system with a view to control the operations of generating, storing, transporting and treating hazardous waste. It outlines the generator's duties, carrier's duties, hazardous waste treatment units or disposal sites duties.
12	Resolution No. (4) of the year 2006 with respect to the management of hazardous chemicals	This Resolution aims to put in place an appropriate monitoring and management system for the management of hazardous chemical materials listed in Ministerial Order No. 7 of 2002 with respect to the control over the importation and use of banned and strictly restricted chemicals and any other chemicals specified by the General Directorate for the Protection of the Environment and Wildlife under this Regulation,

#	Local Legislation	Description
		with a view to eliminate or limit the spread of its effects that are harmful to human health and the environment (including work environment and external environment). The resolution also outlines the responsibilities of the General Directorate for the Protection of the Environment and Wildlife, packaging of hazardous materials, its transportation, storage method and conditions, production and use, limits of occupational exposure, control and inspection. The resolution also defines the different classifications of hazardous materials into 9 classes.
13	Resolution No. (10) of 2006 with respect to air pollutant emissions	Attached to this resolution is an Air Pollutants Emissions Data Form to be filled by facilities identified by the General Directorate. The ambient air quality of facilities identified by the General Directorate is to be monitored for 8 hours or longer as required, the results are then communicated with the general directorate for comparison of data with their own to determine the accuracy of results. Facilities subject to this resolution are to install units of Continuous Emissions Monitoring System (CEMS) and connect them to a Distributed Control System (DCS) to monitor generated emissions anticipated to pollute the ambient air quality. All facilities are to install CEMS within one year from the issue of this resolution and maintain the data obtained on record for inspection from the general directorate. In case of technical malfunction of the CEMS, the facility is to provide the General Directorate with a maintenance plan outlining the technical difficulty, procedure of maintenance, and the time anticipated. The maintenance period is not to exceed one week from the date of CEMS shutdown

3.3 Environmental Standards

The environmental standards for the concerned environmental aspects relevant to the present project scope are outlined in the upcoming subsections as stipulated by the SCE of the Kingdom of Bahrain and of which this ESIA study shall adhere to. International standards are provided for cases when no local environmental standards are available.

3.3.1 Air Standards

The atmospheric emission standards as stipulated in the Ministerial Order No.3 of 2001 of the Kingdom of Bahrain are outlined in **Table 4** and the Ambient Air Quality Standards (AAQS) are outlined in **Table 5.**

Table 4: Atmospheric Emission Standards

Process	Pollutant	Bahrain Emission Threshold Limit**
Combustion processes – Fuel gas burning*	Nitrogen oxides (as NO_2) (gas fired)	100 mg/Nm^3
	Carbon monoxide	100 mg/Nm^3
	Hydrogen sulphide content in fuel gas	600 ppm (for fuel)
	Particulate matter (PM)	50 mg/Nm3 (Units > 50 MW)
Aluminium smelting – Reduction Lines	Particulate matter	30 mg/Nm^3 3 kg/t Al
	HF	1 mg/Nm^3
	Total Fluorides	2 mg/Nm^3 1.25 kg/t Al
	Sulphur dioxide	32 kg/t Al
	Volatile Organic Compounds	20 mg/Nm^3
Aluminium smelting – Anode baking	Particulate matter	30 mg/Nm^3
	Sulphur dioxide	500 mg/Nm^3
	Nitrogen oxides	400 mg/Nm^3
	Total Fluorides	0.05 kg/t Al
	Volatile Organic Compounds	20 mg/Nm^3

* = *Emission threshold concentration defined for dry conditions at 273 K, 101.3 kPa and an oxygen content of 15%v/v.*

** = *All volumetric values refer to normal conditions, i.e. 101.325 kPa, 273.15 K and dry.*

Table 5: Ambient Air Quality Standards (AAQS)

Pollutant	Averaging Time	Bahrain Ambient Air Quality Standard
Sulphur oxides (as SO_2)	1 hour	350 μg/ m^3 (134 ppb)
	24 hour	125 μg/ m^3 (48 ppb)
	Annual mean	50 μg/ m^3 (19 ppb)
Hydrogen Sulphide	1 hour	30 μg/ m^3
Nitrogen Dioxides (as NO_2)	1 hour	200 μg/ m^3 (106 ppb)
	24 hour	150 μg/ m^3 (80 ppb)
	Annual mean	40 μg/ m^3 (21 ppb)
Carbon monoxide	1 hour	26 ppm
Particulate Matter with a diameter smaller than 10 μg (PM_{10})	24 hour	340 μg/ m^3

Pollutant	Averaging Time	Bahrain Ambient Air Quality Standard
Adopted Ambient Quality Standards, derived from Air Quality Report January – December 2011, June 2012, Bahrain Environmental Assessment & Planning Directorate, Environmental Monitoring Section		
Particulate matter $PM_{2.5}$	24 hour	50 $\mu g/ m^3$
p- Xylene	24 hour	168 ppb
Toluene	24 hour	623 ppb
Benzene	24 hour	4 ppb
Non Methane Hydrocarbons	3 hour	0.24 ppm
Ammonia	1 hour	800 ppb
Ozone	1 hour	100 ppb
ppb – Parts per Billion **ppm – Parts per Million** **$\mu g/ m^3$ – microgram per cubic metre**		

3.3.2 Waste Water

The applicable standards for the discharge of industrial effluent waste water, derived from Resolution No. (3) of 2001, are outlined in **Table 6** below. The following standards are to be adhered to prior to the discharge of industrial waste water effluent into the marine environment.

Table 6: Waste Water Effluent Discharge Standards

Characteristics	Unit	Monthly Average	Maximum Limit
Physiochemical			
Floating Materials		Nothing	
Acidity Rate	pH	6-9	
Total of Hanging Solid Substances	mg / litre	20	**35**
Temperature	Centigrade	(Δ) ± Receiving Waters	**-**
Turbidity Rate	N.T.U	25	**75**
Organic Chemistry			
Oxygen Biochemical Demand	mg / litre	25	**50**
Oxygen Chemical Demand	mg / litre	150	**350**
Total Organic Carbon	mg / litre	50	**-**
Total Nitrogen by Kliegel Method	mg / litre	5	**10**
Oil and Greases	mg / litre	8	**15**
Fluorescent Petroleum Products	mg / litre	0.1	**0.1**
Phenols	mg / litre	0.5	**1**
Inorganic Chemistry			
Ammonia	mg / litre	1	**3**
Residual Chlorine	mg / litre	0.5	**2**
Total Cyanide	mg / litre	0.05	**0.1**
Nitrite	mg / litre	-	**10**
Nitrate	mg / litre	-	**1**
Sulphide	mg / litre	0.5	**1**
Total Phosphate	mg / litre	1	**2**

Characteristics	Unit	Monthly Average	Maximum Limit
Arsenic	mg / litre	0.1	**0.5**
Cadmium	mg / litre	0.01	**0.05**
Total Chrome	mg / litre	0.1	**1**
Copper	mg / litre	0.2	**0.5**
Lead	mg / litre	0.2	**1**
Mercury	mg / litre	0.001	**0.005**
Nickel	mg / litre	0.2	**0.5**
Aluminium	mg / litre	15	**25**
Iron	mg / litre	5	**10**
Zinc	mg / litre	2	**5**
Biological Parameters			
Total Coliform	**MPN/100 ml**	**1000**	**1000**
MPN – Most Probable Number **N.T.U. - Nephelometric Turbidity Unit**			

3.3.3 Noise

The maximum allowable limits related to sound level and exposure from an occupation health perspective as devised in Resolution (3) of the year 2005, Appendix 4 of the Bahraini law are as follows;

Table 7: Allowable limits related to Sound Level and Exposure

Sound Level dB(A)	Exposure Time (Hours)
85	8
88	4
91	2
94	0.5
97	0.5
100	0.125 (7.5 minutes)

3.3.3.1 World Bank Allowable Limits

The World Bank defines allowable noise levels in their ‘General EHS Guidelines’, April 30, 2007. The handbook defines allowable levels on the fence off a plant and at the nearest sensitive receptor outside the plant boundary. Noise impacts should not exceed the levels presented in **Table 8**, or result in a maximum increase in background levels of 3 dB at the nearest receptor location off-site.

Table 8: World Bank Allowable Noise Limits

Receptor	Day-time 07:00-22:00	Night-time 22:00 – 07:00
	One hour L_{Aeq} (dBA)	
Industrial; commercial	70	70
Residential; institutional; educational	55	45

3.3.4 Soil and Groundwater

There are no stipulated standards for soil and groundwater quality in the environmental legislation of the Kingdom of Bahrain. Therefore it is proposed to utilize the Dutch Standards for soil and groundwater quality. The Dutch standards have been utilized as they are widely accepted in past soil and groundwater investigations previously conducted by Tebodin. The Dutch standards for soil and groundwater are enclosed for reference in **Appendix 3**.

3.3.5 Ecology

World Health Organisation (WHO) has provided standards for analysis of the impact to vegetation from atmospheric emissions. The standards for Nitrogen Dioxide (NO_2), Sulphur Dioxide ($SO_{2,}$) and fluoride have been taken from the “Air Quality Guidelines for Europe, 2000”. These norms are used to analyse the impacts of emissions on vegetation.

Table 9: Atmospheric Emission Standards relevant to the impact on Surrounding Vegetation

Pollutant	WHO Standard (Annually)
NO_2	$30\mu g/m^3$
SO_2	$20 - 30\mu g/m^3$
Fluoride	$1\mu g/m^3$

3.3.6 Occupational Health and Safety

Bahrain Resolution No. (3) of 2005 provides requirements with respect to work premises conditions and environmental standards, such as noise levels, lighting, temperature, etc.

For evaluation of the exposure to air pollutants health authorities use in general a separate set of workplace air quality standards. These standards often indicate the permissible workplace concentration for healthy adults working 8 hours/day and 40 hours/week. The Permissible Exposure Limits (PEL) developed by the US National Institute for Occupational Safety and Health (NIOSH[1], September 2007 [**Ref. 15**]) are:

- HF: 2.5 mg/m^3 (3 ppm) time weighted average
- SO_2: 5 mg/m^3 (2 ppm) time weighted average
- NO_2: 1.8 mg/m^3 (1 ppm) short term exposure (15 min)
- Respirable particulate: 5 mg/m^3 (8 hour Time Weighted Average).

3.4 World Bank and IFC Guidelines

As part of the project’s financing process, lenders will require the project to comply with World Bank requirements, Equator Principles III – June 2013 and IFC guidelines (International Finance Corporation).

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[1] NIOSH is the Federal agency responsible for conducting research and making recommendations for the prevention of work-related disease and injury.

Consequently, the following IFC Performance Standards shall be considered and complied with throughout the duration of the ESIA study:

- Assessment and Management of Environmental and Social Risks and Impacts;
- Labour and Working conditions;
- Resource Efficiency and Pollution Prevention;
- Community Health, Safety, and Security;
- Land Acquisition and Involuntary Resettlement;
- Biodiversity Conservation and Sustainable Management of Living Resources;
- Indigenous People; and
- Cultural Heritage.

Further, technical reference documents containing examples of Good International Industry Practice (GIIP) as devised by the World Bank Group shall be reference and utilized in the present ESIA study. They contain general and industry-specific impacts and performance indicators and also, practicable measures that are acceptable and cost-effective. The documents are outlined below;

- Environmental, Health, and Safety (EHS) Guidelines, General EHS Guidelines: Environmental, Waste Management, April 30, 2007;
- Environmental, Health, and Safety (EHS) Guidelines, General EHS Guidelines: Occupational Health And Safety, April 30, 2007;
- IFC Performance Standards on Environmental and Social Sustainability, January 1, 2012;
- Environmental, Health, and Safety Guidelines Base Metal Smelting and Refining, April 30, 2007;
- Environmental, Health, and Safety Guidelines for Thermal Power Plants, December 19, 2008;
- Environmental, Health, and Safety Guidelines for Electric Power Transmission and Distribution, April 30, 2007;
- Environmental, Health, and Safety Guidelines for Ports, Harbours, and Terminals, April 30, 2007; and
- Environmental, Health, and Safety Guidelines for Water and Sanitation, December 10, 2007.

4 Project Description

Prior to describing the existing smelter and the proposed expansion, it is necessary to describe the aluminium production process and to highlight its environmental aspects.

A schematic overview of the major in- and output from primary aluminium production is presented in **Figure 3**. As shown, primary aluminium is produced from aluminium oxide (alumina) in a two stage process starting from bauxite. After alumina is produced from bauxite (stage 1), the alumina is used by Alba for the production of aluminium. A detailed description of the process is presented in subsequent sections.

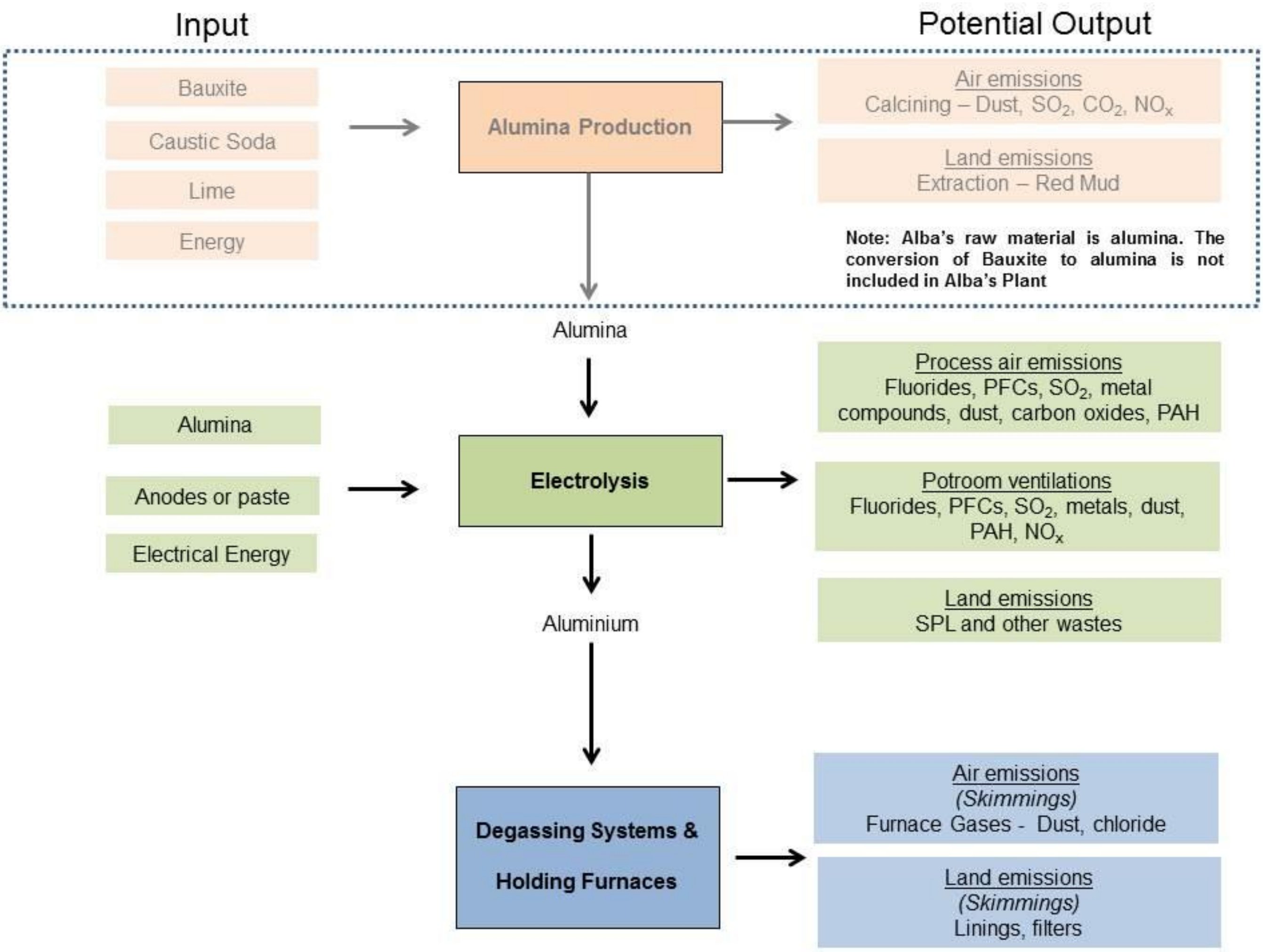

Figure 3: Schematic Overview of the Primary Aluminium Production Process

4.1 The Aluminium Reduction Process

4.1.1 What is Aluminium

Aluminium compounds form eight percent of the earth's crust and are present in most rocks, vegetation and animals. Aluminium is the third most abundant element in the earth's crust after oxygen and silicon, but because of its chemical reactivity, is never found in nature as an element but always in its oxidised form. In its oxidised form, aluminium occurs as one of a selection of about 250 different minerals, of which the most prominent are silicates and clays (essentially weathered silicates). Oxide hydrates are other important compounds and this group includes bauxite, which is the base raw material for primary aluminium production.

Bauxite, or aluminium ore, is a naturally occurring material composed primarily of one or more aluminium hydroxide minerals together with various other minerals including silica and iron oxide. There are numerous bauxite deposits, mainly in the tropical and subtropical regions of the world. Bauxite is generally extracted by open cast mining from layers that are typically some 4-6 metres thick and close to the surface. Before it can be used to produce aluminium the bauxite needs to be refined to form alumina, which is the primary ‘raw’ material input to an aluminium smelter.

4.1.2 Alumina Refining

The bulk of world bauxite production (approximately 85%) is used as feed for the manufacture of alumina via a wet chemical caustic leach method commonly known as the Bayer process. In this process bauxite is washed, ground and dissolved in caustic soda (sodium hydroxide) at high pressure and temperature. The resulting liquor contains a solution of sodium aluminate and un-dissolved bauxite residues containing iron, silicon, and titanium. These residues colloquially referred to as ‘red mud’, sink gradually to the bottom of the tank from where they are removed and disposed of.

The clear sodium aluminate solution is pumped into a tank and fine particles of alumina are added to seed the precipitation of pure alumina particles as the liquor cools. The particles sink to the bottom of the tank, are removed and then passed through a calciner at 1100 degree Celsius (°C) to drive off the chemically combined water. This leaves the pure alumina as a fine, white powder. Approximately two tonnes of bauxite are typically required to produce one tonne of alumina and as a result alumina refineries are typically established close to the source of the bauxite.

4.1.3 Aluminium Smelting

The alumina is then transported to primary aluminium smelters (such as Alba) where the process of aluminium reduction occurs. To some extent the term smelting is a misnomer because although high temperatures are required, the aluminium reduction process is an electrolytic process during which the passage of electricity through the molten alumina reduces the oxide to a metal. Aluminium reduction takes place in a series of pots or electrolytic cells that consist of a metal shell lined with carbon (which forms the cathode) together with a pot superstructure that supports a series of anodes. Electricity is passed through the anode, and then through the electrolytic media (or bath) to the cathode.

The process that is commonly used in the aluminium industry and that is used in all 5 existing potrooms is the HALL-HEROULT process. Alba L1 to L3 are fitted with electrolysis cells developed by Montecatini. L4 and L5 are based on pot technology by Aluminium Pechiney (AP30). L6 would be based on Dubal’s DX+ reduction technology operating at 460 kA.

Pots are arranged in series and connected by aluminium busbars, which conduct the electricity. During pot operations the anodes are gradually consumed and need to be replaced and it is for this reason that aluminium smelters typically have facilities for the production of anodes. The major components of an aluminium smelter are:

- Potlines – these are the electrical circuits connecting the individual pots or cells in series and where the aluminium reduction takes place. This component of the smelter is also referred to as the ‘reduction’ area.

- The Carbon Area - where the anodes are produced and ‘rodded’.

- The Casting Area or Casthouse - where the molten aluminium is cast (cooled) into the various forms such as ingots, extrusion billets, or rolling slabs.

- Utilities – especially the electrical supply (and in Alba’s case generation as well), which requires rectifiers and transformers, water, compressed air and natural gas.

- General Services such as maintenance, logistics, administration and so forth.

Figure 4 provides an overview of the further processes steps and material streams involved in aluminium production. The different areas and process steps are further detailed in subsequent sections.

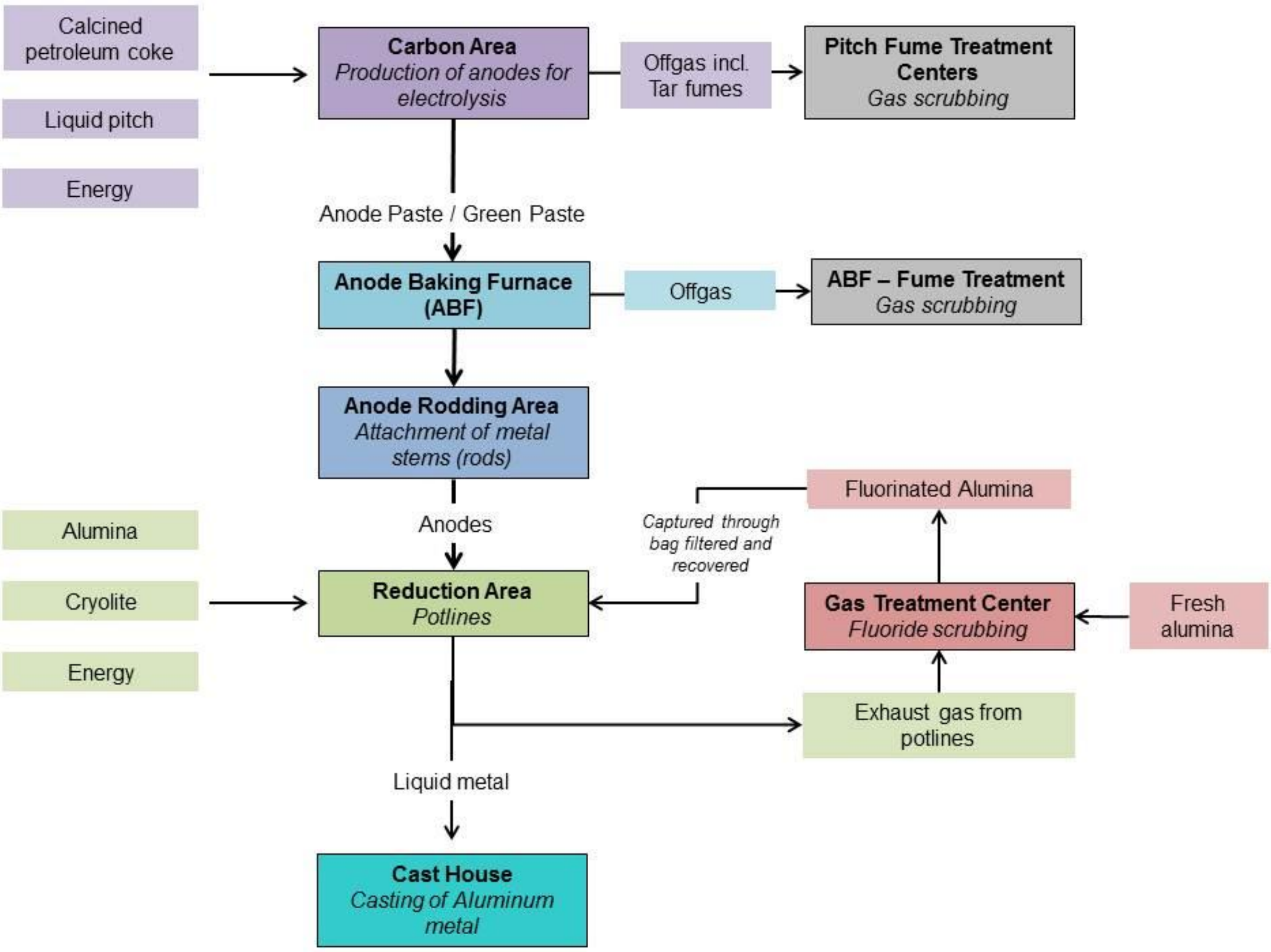

Figure 4: Schematic Overview of Aluminium Smelting Steps

4.1.4 The Carbon Area

As described above, the function of the Carbon Area is to produce anodes for electrolysis. The anodes are produced by crushing calcined petroleum coke and mixing it with liquid pitch to form anode paste. The green paste is then placed in anode moulds, and vibrated to form the green anode. The green anodes then have to be cooled by water for further handling. In order to give the anode the necessary electrical and physical properties, the green anodes have to be calcined, and this is achieved in large Anode Baking Furnaces, where the green anodes are exposed to temperatures of up to 1150 °C over a period of approximately 14 days. Once the baking process has been completed the anodes are allowed to cool and then taken to the anode rodding area where metal stems (rods) are attached. These metal stems provide the conductor necessary to pass electricity through the anodes.

Because the anodes are not completely consumed during electrolysis, the remaining anode butts are recycled. The anode butts are cleaned and removed from the stems, crushed and then reintroduced into the anode production process. The recycling of the anode butts presents an obvious benefit in terms of material recovery and waste minimisation, but during the process of electrolysis, the anodes become impregnated with fluoride and this means that provision has to be made for fluoride scrubbing from the exhaust fumes from the baking process..

4.1.5 Reduction

The principles of aluminium reduction have been explained above, but some additional perspectives are important. As described above, the reduction process takes place in so-called pots and these pots lie in series, in a transverse position throughout the length of the potroom. The pots are serviced (addition of covering alumina, anode changing and tapping of liquid aluminium) by large overhead cranes that are called Pot Tending Assemblies or PTAs. The PTAs move through the length of the potroom progressively adding covering alumina, changing anodes or siphoning of the liquid metal as required.

During electrolysis, gaseous and particulate fluoride emissions, sulphur dioxide and carbon dioxide gases, together with particulate matter (alumina and anode cover material) are liberated. A large proportion of these emissions are captured in the pots by hoods that extend from the pot superstructure to the pot shells. The fumes and dust are extracted and ducted to GTCs where the exhaust gas is scrubbed before being released to atmosphere via a stack. In order to replace the anodes, the pot hoods need to be opened and when this happens, a portion of the fumes and dust that would otherwise have been extracted to the GTC, are released into the potrooms. However, this can be minimized by increasing the exhaust flow during this operation.

To keep the potrooms properly ventilated, they are designed such that there are large openings in the potroom floors combined with gravity ventilators in the roofs. Theheat from the pots provide a through-flow of air. Because of the periodic release of fumes and dust from the pots (when the pots are opened for various necessary operations), the air that is ventilated through the roof vents contains inter alia fluoride, sulphur dioxide and dust.

4.1.6 The Gas Treatment Centre

Of the air pollutants from aluminium reduction, fluoride is probably the most notorious. As a result of fluoride emissions early aluminium smelters typically included a 1-2 kilometre (km) buffer zone around the smelter in which the impact of the fluoride emissions resulted in adverse environmental conditions, particularly to vegetation. Wet scrubbers were then introduced to remove the fluoride but these were not hugely efficient and more importantly, merely moved the fluoride from the air into the water – which was also then subsequently discharged. The currently used far more efficient dry scrubbing methods can substantially eliminate the adverse impacts of fluoride on the environment.

In describing the electrolysis process earlier, mention was made of the electrolytic medium that is required for electrolysis to occur. Although alumina is a necessary component of the electrolytic medium, it is not sufficient on its own and cryolite (Na_3AlF_6) which contains fluoride must be present for efficient electrolysis to occur. In addition, and in order to improve the control of the heat balance of the pot, aluminium fluoride is also added to the pot. What this implies is that fluoride is a direct requirement for the industrial process and this lead to the introduction of a new principle for aluminium smelting namely the recovery and re-use of fluoride.

The GTCs, have the function of both scrubbing the fluoride (where high efficiencies of approximately 99.7% prevail) from the exhaust streams and then reintroducing the captured fluoride back into the process. This happens by passing the exhaust stream from the pots through the incoming fresh alumina injected in a venturi reactor. Because alumina has a very large surface area, it enables the fluoride in the exhaust to be adsorbed onto the alumina. The alumina, which is thus ‘fluorinated’ is captured in a series of bag filters, and recovered before being fed into the pots. As the alumina is fluorinated, the quantity of additional aluminium fluoride required in the pots is dramatically reduced improving not only the environmental impact of the process, but also the cost efficiency.

4.1.7 The Fume Treatment Centre

Earlier it was mentioned that the anode butts that are recycled into the anode production process are impregnated with fluoride. Because of this the fumes that are emitted from the baking furnace also contain fluoride and as a result it is necessary to scrub these fumes. This is achieved through the Fume Treatment Centre, which works on exactly the same principle as the Gas Treatment Centres passing the exhaust gas through the incoming alumina. An important difference between the exhaust stream from anode baking, and that produced during reduction is that exhaust stream from anode baking contains tar fumes. The tar fumes (that come from the pitch in the green anodes) are driven off during the baking process and these are also scrubbed in the Fume Treatment Centre.

4.1.8 The Pitch Fume Treatment System

Due to the generation of pitch fumes in the production of anode paste, the paste plant in which this operation takes place is equipped with a Pitch Fume Treatment System. The principle of operation of the Pitch Fume Treatment System is quite similar to that of the reduction gas and carbon Fume Treatment Centre, with the exception that coke fines are used as the scrubbing reagent. Condensed tars and pitch aerosols adhere to the coke fines and are then captured by a dust collector prior to being reused in the production of anode paste.

4.1.9 The Cast House

The final step in the process of producing primary aluminium is to cast the aluminium metal into the forms that are required by the various customers. These forms include aluminium ingots, slabs and extrusion billets. The major components of the casthouse are holding and melting furnaces, the various casting lines and stations (depending on the cast form in question), cooling facilities, homogenising furnaces and finished product packaging. The casting process begins with the transport of liquid metal from the pots to the casthouse following which the metal is transferred to the holding and melting furnaces, alloyed if required, and then poured into the various casting lines and stations. The cast forms are then cooled so that they can be handled and packaged for shipping to customers.

4.1.10 Utilities

As has been described previously, the principal utility required for aluminium production is large quantities of electricity and in particular to have the electricity as Direct Current (DC) with a low voltage but high current (amperage). This typically requires a large bank of transformers and rectifiers to achieve the voltage and amperage requirements. Most smelters world-wide import their electricity from outside suppliers, (usually National or Regional Utilities) but in Alba’s case, Alba generates its own power through the existing power plant stations.

Additional utilities include compressed air, fuel for firing the various baking and holding and melting furnaces (natural gas in the case of Alba’s on site power generation) and water. The water is required principally for cooling but obviously for potable purposes as well. Power stations are also important water users due to makeup water for feed-water cycle.

4.2 Environmental Aspects of the Aluminium Reduction Process

Environmental aspects are defined as elements of an activity, product or services that interact with the environment. Such aspects include air pollution, waste water and solid waste production and the use of natural resources such as water and energy. Environmental aspects also include socio-economic parameters such as spending and job creation. In the following section the environmental aspects of the aluminium reduction process are briefly described using the categories described above.

4.2.1 Air Pollution Emissions

4.2.1.1 Gaseous and Particulate Fluoride

Fluoride is essential to the electrolysis process and is thus added to the bath in the form of aluminium fluoride. During the electrolysis process, the fluoride is liberated and after most of the fluoride is recovered through scrubbing, some fluoride is released to atmosphere via the Gas Treatment Centres, the potroom roof vents and the Fume Treatment Centre of the bake furnaces as described above.

4.2.1.2 Sulphur Dioxide (SO_2)

The main source of the sulphur is in the petroleum coke that is required for the production of the anodes. As the anodes are consumed during electrolysis, sulphur dioxide is formed. Because SO_2 is one of the gases contained within the pot hoods and ducted to the Gas Treatment Centre, the Gas Treatment Centres are the principal atmospheric SO_2 emission points. SO_2 emissions to atmosphere also occur through the roof vents and are also emitted from the power stations where electricity is generated for the smelter and to a lesser extent from the bake furnaces and holding furnaces.

4.2.1.3 Carbon Dioxide (CO_2)

Carbon dioxide (CO_2) is formed during the combustion of natural gas and also during electrolysis as the anode is consumed and the carbon oxidises to form CO_2. In a similar way to that described for SO_2, the Gas Treatment Centres are the principal emission points for CO_2. Other emission points include the stacks from the remelt/holding furnaces in the casthouse, and the carbon Fume Treatment Centres. CO_2 is also a significant emission from the power stations where electricity is generated for the smelter.

4.2.1.4 Nitrogen Oxides (NO_x)

Nitrous Oxides (NO_x) are generated from a range of sources across the smelter where combustion occurs, including the gas turbines in the power stations, holding and melting furnaces and the Anode Baking Furnaces. NO_X is also generated during electrolysis but in relatively much smaller quantities than from combustion sources.

4.2.1.5 Particulate Matter (PM)

There are several sources of particulate matter across the smelter and these are associated with either the combustion process (typically much finer particulates) or dust that is mechanically generated during raw material (alumina and petroleum coke) handling. Particulate Matter (PM) sources include a number of dust collector (raw materials handling) stacks and dust from the pots. Because of the properties of natural gas, PM emissions are insignificant where natural gas is used as to fuel combustion processes, as in Alba's Power Stations.

A key concern with particulate matter is the Respirable fraction (particle sizes of 10 micrometre (µm) or less) and this fraction is referred to as PM_{10}.

4.2.1.6 Volatile Organic Carbons (VOCs)

Liquid pitch provides the principal source of Volatile Organic Carbons (VOC) emissions. As such VOCs are emitted from the paste plant (green paste and anode production) and in the bake furnace during anode baking operations.

4.2.1.7 Other Pollutants

In addition to the above, there are several other air pollutants that occur in relatively low quantities. The most significant of these are Perfluorocarbons (PFCs). Although emitted in small quantities (they are generated only during anode effects[2]) they have powerful global warming properties. In addition, motor vehicles emissions that include SO_2, Nitrogen Oxide (NO), CO_2 and VOCs are additional source of such pollutants.

4.2.2 Wastewater

The major sources of waste water from an aluminium smelter are the various cooling towers for compressors, cathouses and other systems across the plant. Due to the nature of the cooling systems there is a gradual build-up of dissolved solids in the cooling water, and as a result clean ”make-up” water is added, and water that is high in dissolved salts is discharged or “blown down”. Another important source of waste water is the boiler blow down from the power stations. Additional streams may include wash water and oily water which will be captured in oily water separators (at the fuel station and the rectifiers) and treated sewage (disposed of via Sanivans).

These blow downs are the major waste water streams which will be handled per Alba’s zero discharge philosophy.
An average waste water volume of 1,227 m^3 per day is discharged via the outfall pipeline during normal operations which includes 3 m^3 per day of regeneration waste water from the 2nd pass of the RO-2 plant and 1224 m^3 per day of waste water from the 1st pass of the RO-2 plant. Alba plans to eliminate the discharged 1224 m^3 waste water in the upcoming years.

For the expansion, new calciner water storage tanks will be installed to supply water for the calciner shut-down situation, which will eliminate the need for well water for the L6 expansion.

4.2.3 Waste

A variety of solid and liquid wastes is generated during smelter operations. The liquid wastes include sewage sludges and oils, while the solid wastes include dust, carbon waste, dross, refractory waste, spent pot lining and general waste. Of these wastes, Spent Pot Linings (SPL) are the most significant both in terms of the quantity and the potential hazard of the waste.

4.2.4 Resource Use

4.2.4.1 Electricity

Aluminium smelters are significant users of electricity and a dependable and sustainable source of electricity is an essential requirement for an aluminium smelter. As Alba generates its own electricity, it is a significant consumer of Bahrain’s natural gas resources.

4.2.4.2 Water

As described above aluminium reduction is essentially a dry process, where water is only used for cooling and to a lesser extent, potable purposes. Compared to other industrial processes, aluminium smelters are relatively small users of water. It should be noted that the power generation requirements for aluminium reduction result in a higher use of water.

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[2] Anode effects refer to the build up of bubbles of air underneath the anode during electrolysis.

4.2.4.3 Fuel

Fuel use in an aluminium smelter is limited to the Casthouse holding and melting furnaces and the Anode Baking Furnaces. Gas is the preferred fuel source for such combustion processes because of its cleaner burning properties and is used at Alba for these facilities. Gas is also a fuel source for the power generation requirements of an aluminium smelter as is the case for Alba.

4.3 The Existing Smelter

Aluminium Bahrain was formed under charter from His Highness Sheikh Isa Bin Salman Al Khalifa in 1968. Alba was formed in order to capitalise on the availability of energy resources in Bahrain and with a view to adding value to the resource and generating higher levels of income and employment. In its initial phase the smelter had a capacity of 120,000 tonnes of aluminium per annum with electricity being sourced from a dedicated 360 MW power station that was built at the same time. A series of expansions have seen the power generating capacity of the facility increase to its current capacity of approximately 912,700 tpy of primary aluminium in 2013.

Because aluminium production is a high materials turnover operation (large volumes of raw materials in and large volumes of finished product out) smelters around the world are usually established close to the coast. The Alba smelter is no different and has a dedicated port facility. The port facility provides for the transfer and temporary storage of the three primary raw materials used at the plant: alumina, pitch and petroleum coke. The port facility was upgraded in 2003 to include the addition of a second port jetty that can accommodate larger alumina vessels (60,000 tonnes) and the establishment of a green coke calciner.

The major components of the current Alba Smelter are listed below:

- Five (5) potlines.
- Three (3) carbon plants.
- Two (2) cast houses.
- Four (4) Power Stations (PS).
- Ancillary facilities such as engineering/maintenance workshops, material storage administrative offices and so forth.
- Port facility including coke calciner.

Although Alba currently has four (4) PS in place, PS1 is only occasionally used and Alba does not intent to operate this unit in the future. Operation of PS1 decreased from approximately 60 equivalent-days in 2007 to 10 days in 2012 – with a peak equivalent to 142 days in 2008.

4.3.1 Air Pollution Emissions

As described previously, there are a range of air pollution emissions that are associated with the aluminium reduction process. In terms of Alba, several stand out as being relatively more significant given the emission quantities and their potential impacts. These emissions are summarised in **Table 10** together with their sources, whether smelter and/or power stations, and mass, in tpy.

Note: data based on L1 to L5 producing 884,000 tpy and actual data from Alba for 2007-2013.

Table 10: Summary of Principal Air Pollutants Generated from the Alba Plant Production Process

Pollutant	Source	Emissions (tpy)
Gaseous fluoride	Smelter	725
Particulate fluoride	Smelter	383
Total fluoride	Smelter	1,108
Sulphur dioxide	Smelter/Power station	25,877
Nitrogen oxides	Smelter/Power station	15,566
Carbon dioxide	Smelter/Power station	10,512,099
Carbon monoxide	Smelter/Power station	14,671
Particulate matter	Smelter	1,630
VOCs	Smelter	469
PFCs	Smelter	21.22

4.3.2 Waste

A variety of solid and liquid wastes is generated during smelter operations. The liquid wastes include sewage sludges and oils, while the solid wastes include dust, carbon waste, dross, refractory waste, spent pot lining and general waste. Of these wastes, spent pot linings are the most significant both in terms of the quantity and the potential hazard of the waste.

In this section, all waste streams generated within Alba are described. This includes recycled waste which is re-introduced into the process or sold to other parties. In the subsequent sections, a qualitative description is given regarding various waste streams generated throughout the process.

4.3.2.1 Overview

Current Alba plant facilities produce both general and hazardous solid and liquid waste streams from a variety of sources across the plant. The plant's current waste management activities include segregation, collection and transport, treatment, recycling, storage, and landfill disposal (for appropriate waste types). Waste generated by the plant is classified as presented in **Table 11**.

Table 11: Waste Classification

#	Hazardous / Non-hazardous waste type	Definition
1	Recycled solid wastes	Processed to be reused in the production process or by a third party or recycles by outside party. This includes solidified / frozen bath, dust, scrap steel, wood, pot line spillages, carbon waste, cast iron, some portions of SPL, scrap waste, etc.
2	Un-recycled solid waste	Stored temporarily on-site to be ultimately disposed at appropriate landfills. This includes portions of spent pot linings, dust, construction waste, refractory waste, general rubbish, etc.

#	Hazardous / Non-hazardous waste type	Definition
3	Recycled liquid wastes	Processed to be reused in the irrigation system or recycled by a third party (for example some used oils are collected by a third party for recycling).
4	Un-recycled liquid wastes	Stored temporarily on-site to be ultimately disposed at appropriate landfills or treatment plants. This includes waste oils/water mix and sewage sludges. Waste water that is discharged via outfall pipeline to sea (effluent) is excluded from this definition.

Un-recycled hazardous wastes are transferred to the Hafeera Hazardous Waste Landfill which was funded by Alba and designed and built by SCE to meet international standards including; lined disposal cells, leachate collection and treatment, and groundwater monitoring. General wastes are disposed at Askar Municipal Landfill. Liquid oil wastes are transported to nearby Bahrain Petroleum Company (Bapco) or outside party for recycling. Oil/water mix is transferred to the Askar Municipal Landfill for disposal. Some wastes from the aluminium reduction process are processed on-site and reintroduced in the smelting process. Alba has developed a five-year plan to reduce its total un-recycled waste quantities by 25%.

The waste reduction plan is geared towards significantly reducing Alba's environmental aspects and in so doing reducing the risk of an impact on the environment from the existing smelter (and the proposed expansion). A key element of the plan is reducing SPLs, unused carbon dust, and refractory wastes. The plan also includes reducing the quantities of waste water generated as well as reduction in emissions of sulphur dioxide and nitrogen oxides. Subsequent to the 2003 EIA, a desulfurization system was installed at the calciner facility and PS3 was refurbished with low NO_x burners.

Throughout Alba's production process various waste streams are generated. In order to get more insight into the different wastes, both recyclable and non-recyclable, corresponding waste generating processes are described qualitatively in the subsequent sections.

4.3.2.2 Waste Generation in the Reduction Process

During the reduction process, the solidified or frozen bath is formed on the molten bath. This occurs mainly during anode replacement. The solidified bath is composed of a mix of cryolite and alumina and is removed and transported to the bath processing facility where it is crushed milled and screened, before being re-introduced as a cover material in the reduction cells or sold to outside parties.

In addition, dust is collected from various sources across the reduction area in dust collectors for recycling. Dusts collected from the pot rooms contain cryolite, fluoride and alumina particulate.

Furthermore, the filter bags used in the Gas Treatment Centres periodically fail and need to be replaced. As the bags only retain small traces of alumina and fluoride, they are disposed of at the Askar Municipal Landfill.

During pot room operations material spillages of fluorinated materials occur which includes alumina and bath. Because the spilled materials come into contact with other materials such as sand, stones and wood chips, the material cannot be reintroduced to the process without first being segregated. Spilled material is thus collected, temporarily stored then segregated before being reintroduced to the process. Currently, approximately 3,500 tonnes per annum of spillages are recovered from the existing five (5) potlines. Approximately 2,000 t of additional spillage materials are anticipated due to the expansion.

4.3.2.3 Waste Generated in the Carbon Plants

In the carbon plants, spent anodes (known as butts), are transferred from the pot rooms to the rodding shops for processing. These butts, that contain cryolite and fluoride, are cleaned, crushed, milled, screened, and stored for reuse in green anode production.

Green anode scrap generated from the production of green anodes is recovered and processed for reuse in the green anode paste plant. Approximately 80,000 tonnes of anode butts and 9,000 tonnes of and green anode scrap are currently being recycled per annum for Lines 1 thru 5, which represent a re-introduction into the process of a significant percentage of the required raw materials. For Line 6, an additional 67,000 t of anode butts and 4,600 t of green anode scrap are anticipated.

Carbon dust produced from the cleaning of butts or other carbon processes is collected by the dust collection system and only pure carbon dust reintroduced as a raw material for reuse in the anode manufacturing process. Other carbon dust is collected in bags for disposal in the Askar landfill. Bath dust is also collected at the bath processing facility. These materials, containing cryolite, fluoride and alumina particles, are blended with bath and alumina for use as cell cover in the reduction process. In 2013, 1,136 t of carbon dust was sent to Askar Municipal Landfill along with 635 t of cast iron slag.

In addition, cast iron thimbles which are used to fix the rod to the baked carbon anode are recovered from the anode butts. These are re-melted at a casting carousel and reused for rodding.

During the process, green anodes are cooled by direct water spraying. Thereby the cooling water becomes contaminated with carbon chips from the green paste. These contaminants are removed from the cooling water in the form of a sludge, which is disposed of at the Askar Municipal Landfill.

Moreover, furnace linings from the carbon baking kilns, also known as refractory wastes, are currently disposed at the Askar Municipal Landfill.

These wastes, which are currently sent to landfill, are the subject of a multi-party project aimed at recycling the material for re-use in the process at Alba.

4.3.2.4 Waste Generated in the Casthouse

In the cast house dross is formed by the oxidation of molten aluminium on the surface of the melt and generally occurs in quantities of some 15 to 20 kg per tonne of aluminium produced. The dross is skimmed off the surface of the molten aluminium before casting.

Because dross has an aluminium content of between 30 and 80%, the dross is currently processed using Tardis presses to recover and cool the dross, which is then sent to off-site processors for further recovery of metal. The depleted dross is then either disposed of in landfills for Hazardous materials or exported as secondary raw material.

Moreover, recovered casting oil sludge from the casthouse cooling facilities is taken by external party for treatment. Furthermore, furnace linings from the furnaces at the casting facility are currently disposed at Askar Municipal Waste Landfill but as mentioned above, are likely to be recycled in the near future.

Sulphur wastes from the natural gas desulphurisation at the casthouse are currently sent for disposal at Hafeera Hazardous Waste Landfill (48 t in 2013).

4.3.2.5 Waste Generated in the Pot Lining/Delining Facilities

The lining of a reduction cell, because it is exposed to intense heat and erosion, has a limited operating life. When the cathode fails in a pot, the pot no longer functions. As a result the pot lining needs to be removed and replaced. It is this removed lining that is referred to as spent pot lining (SPL). During reduction the pot linings become impregnated with fluoride and traces of cyanide and this renders the spent pot lining waste hazardous. Components of SPL include carbon, silicon carbide bricks, insulation bricks, refractory bricks, steel collector bars, bath and aluminium flakes. SPL is generally comprised of a hazardous carbon fraction containing cyanide and fluoride (referred to as “first cut”) and the refractory containing portion (referred to as the “second cut”).The first cut is regarded as hazardous waste, whereas the second cut is not currently regulated as a hazardous waste (and is generally disposed of in landfills).

SPL is the major component of Alba’s solid waste. The current method of treatment of SPL has been approved by SCE, and involves the segregation of the SPL into its component parts of steel, carbon, silicon carbide, refractory and insulation and a mixed portion of fine material. The steel, carbon, silicon carbide and refractory and insulation fractions are then recycled by a contractor, with the remaining fines fraction being disposed of at the Hafeera Hazardous Waste Landfill. In 2013, a total of 5024 MT of spent SPL was sent to Hafeera.

Another waste generated in the pot lining area is waste ramming paste from the pot relining. This is disposed of at the Hafeera Hazardous Waste Landfill, along with the SPL fines. Furthermore, the steel collector bars that form part of the cathode are recovered from the SPL and then recycled.

4.3.2.6 Waste Generated in the Power Stations

Normally, the turbine control and lubricating oils will be changed every ten years but may also be changed shortly after commissioning. . The quantity of oil involved on each occasion will be about 30 to 40 m^3 per 400 MW capacity. The collected waste oils are generally sold to Qatar Factory to be processed in their oil recycler. However, oil from designated pits at the power department is transported to Bapco for recycling (881 m^3 in 2013).

Furthermore, liquid hydrocarbons tend to form in the low section of the supply pipeline. These are extracted from the liquid knock-out of the gas handling facility, transferred to drain tanks, then removed and sent to Bapco. Some 168 m^3 was transported in 2013 for recycling.

Last, liquids used to wash the compressors and turbines are synthetic detergents dissolved in water and are used periodically to remove dirt and grease deposits from the blades. The resulting dirty liquids are stored on site then sent for disposal at the Askar Municipal Landfill. The total quantity of these liquids is estimated to be 7 m^3 per unit each time off-line cleaning is performed (usually four times a year).

4.3.2.7 Waste Generated in the Workshops and Maintenance Facilities

In the workshops and maintenance facilities, spent batteries, tires and vehicle radiators are generated and sold for recycling to Crown Metals. Used vehicle batteries are collected in waste skips at the workshops and then sold to Crown Metals for recycling after draining and neutralising the acid.

In addition, waste oils are generated in the workshops during lubrication and oil changes. Waste oils are sold to Qatar Factory which is able to recycle the oil for re-use. Approximately 50 m^3 of waste oil was generated during 2013.

4.3.2.8 Other wastes

In addition to the wastes streams directly related to the production process, construction wastes are generated from various construction activities performed on site. Other wastes, such as domestic wastes, tree cuttings, woods and scrap metal are generated throughout the facilities. An overview of wastes quantities and corresponding disposal strategies are further discussed in section 5.6.2.

4.3.2.9 Summary

Alba has a robust waste management approach, with the necessary steps for segregation and safe disposal of the various solid and liquid wastes that are generated at the plant. The disposal practices include incineration (medical waste only), disposal to the general waste landfill at Askar and to the hazardous waste landfill at Hafeera. Recycling of waste is also evident together with on-going efforts to minimise the amount of waste generated in the first place. As described, and in the spirit of continuous improvement, Alba has set a target for reducing un-recycled waste by some 25% over the next five years with performance against this target being measured continuously in terms of the Company's 5 year Strategic Plan.

The major waste management challenge for Alba (and indeed for smelters around the world) is the safe disposal of SPL. SPL is both the largest waste stream as well as the most hazardous. The current SPL disposal practice has been approved and appears to be working well.

4.4 Energy use

4.4.1 Overall energy use

The Alba plant depends on fossil fuels (natural gas) as a primary source of energy for its operations. Four power stations equipped with gas and steam turbines generate the required electric power for the operation of the reduction lines and their supporting facilities. Natural gas is also used in kilns and furnaces of the carbon plants and cathouses for the production of baked anodes and finished aluminium products, respectively.

Other forms of energy used on-site include diesel oil fuels. The latter are used as backup fuel for power stations 2 and 3, and by all on-site small power generators and mobile service units, such as, trucks, vehicles, forklifts, tankers, etc.

Bapco supplies gas fuel for Alba's power stations. The gas is a mixture of natural gas from Bahrain's Khuff-gas refinery (58%) and residual gas (42%). A heating value of 860 Btu/SCF[3] (32.04 Mega Joules per Cubic Metre (MJ/m^3)) based on Higher Heating Value (HHV) is considered. Currently, the average natural gas consumption at Alba is 375 Million Metric Standard Cubic Feet per Day (MMSCFD) of which 363 MMSCFD is used for Power generation, with the balance used for ancillary smelter facilities.

The other fuel that is used is diesel. It is used for on-site equipment and mobile machineries. Diesel oil is supplied by pipeline from Bapco to a small tank on site. However, diesel consumption for vehicles is currently being replaced by petrol fuel combustion vehicles.

Table 12 gives an overview of fuel use of the current plant operations.

Table 12: Overview of annual fuel use in existing situation

Fuel	Amount	Unit	% of total
Natural gas for power generation	120,012	Tera joule per year (TJ/y)	99.85%
Natural gas for other purposes (carbon plants and cast houses)	88	TJ per year	0.0075%
Diesel (for back-up equipment, and automotive applications)	88	TJ per year	0.075%
Total	**120,187**	**TJ per year**	**100%**
Aluminium production in 2012	890,000	tonne	

It is clear from this **Table 12** that power generation is the major consumer of fuel. More detail about the generation and consumption of electricity and the consumption of fuel is given in the next paragraphs.

4.4.2 Electrical Energy

Four power stations are currently installed at the Alba site. The generated power feeds the Alba facilities. On occasion, there is a swap with the EWA public grid but the net yearly exchange is essentially zero. The overview of the power stations is provided in **Table 13**.

Table 13: Overview of Power Station Capacities at Alba

Power Station	Capacity (MW) Winter at 25 deg C	Capacity (MW) Summer	Efficiency (at 15 deg C)	Efficiency (at 42 deg C)
PS1	278	240	21.20%	20.30%
PS2	158	140	35.60%	34.58%
PS3	794	724	40.36%	39.46%
PS4	888	803	44.78%	44.25%

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[3] British Thermal Units (BTU) per standard cubic foot

4.5 The Proposed Project

The existing Alba smelter consists of five (5) potlines supplied with electrical power by four (4) on-site Alba Power Stations. Alba is currently conducting a program to creep the existing potlines current to produce a nominal total annual production of approximately 924,654 tonnes consuming an average power demand of about 1,575 MW excluding PS auxiliary power needs.

The proposed Project would include a Potline 6 consisting of one (1) Potline with 404 pots, and a nominal annual liquid Aluminium metal production of approximately 514,197 tonnes. Potline 6 would utilize DUBAL's DX+ reduction technology operating at 460 kA.

Alba also intends to shut down the aging Power Stations 1 and 2 due to high maintenance costs and low efficiencies. The Power Station 1 electrical distribution system would be retained.

The Carbon Area, Cast House, Infrastructure and Power Plant 5 facilities would be designed to support the 460 kA operations. At 460 kA amperage, the maximum annual liquid Aluminium metal production would be approximately 521,667 tonnes.

Power Plant 5 would consist of two (2) combined cycle units, installed North-West of the new Potline 6, each nominally 450 MW in a 1x1x1 configuration. Each unit would consist of a natural-gas-fired Class F Combustion Turbine Generator (CTG), one (1) Heat Recovery Steam Generator (HRSG) and one (1) condensing, reheat-type Steam Turbine Generator (STG) and accessory equipment.

Based upon the above assumptions, for Potlines 1 thru 6, with Potline 6 operating at 460 kA, the Smelter would produce, during the approximate first year of the Potline 6 operation, a maximum total annual production of approximately 1,446,321 tonnes consuming an average power demand of about 2,481 MW including Smelter and Power Plant auxiliaries and transformer losses. For the long term mature smelter with six (6) potlines, after approximately 4 years of Potline 6 operation, a nominal production of approximately 1,438,851 tonnes would be produced consuming an average power demand of about 2,485 MW including Smelter and Power Plant auxiliaries and transformer losses.

In general, existing facilities and infrastructure would be used without modification or would be modified to support the new Potline 6. Some new facilities would also be required, specifically in the Carbon and Cast House areas.

For the Carbon Plant, new facilities would include a Potline 6 Paste Plant (in the existing structure constructed as part of Potline 5) and associated cooling tunnel, Anode Storage Building and an Anode Baking Furnace and Anode Handling Systems. The existing Rodding Shop would need to be upgraded to accommodate anodes for both Potline 5 and Potline 6, which are of different dimensions.

For Potline 6, new facilities or modifications to existing facilities for auxiliary systems and services, offices and amenities to support the Potline operations would be required including a Cafeteria/Change-house, Administration building, new Fuel Station, Vehicle Maintenance Shop and a Sewage Treatment Plant.

The additional Potline 6 liquid metal would be delivered to new Cast House facilities (VDC casting for planned billet production and sow casting for emergency back-up) and/or delivered as liquid metal to downstream industries.

The Potline 6 Project would be tied into the existing distribution networks within the ALBA smelter complex, which is connected to the local utility network for natural gas, industrial process water and potable water. The major raw materials for Potline 6 would be imported via the existing port facilities. The Port Facility would require an additional alumina truck loading station with two (2) filling bays.

4.5.1 Site Development

The additional Potline 6 site development would include new facilities or modifications to existing ones including site preparation, roads and paving, and storm water system.

4.5.2 Switch Yard

There would be six (6) identical 1,860 Volt DC, 115 kA rectifier groups provided for Potline 6. Each rectifier group would include a rectifier, regulating transformer, rectifier/transformers, power factor and harmonic filter banks with their associated interconnecting power cables, DC isolating switches and a local control and automation cubicle installed in a weatherproof air conditioned enclosure including all interconnecting control cables.

4.5.3 Reduction

The Smelter would include one DUBAL DX+ technology Potline with a total of four hundred and four (404) pots, and would consist of:

- Two (2) Pot room buildings, each with two hundred and two (202) pots. Each of the two (2) Pot rooms would be subdivided into two (2) sections of hundred and one (101) pots.

- Two (2) gantry passageways (centre and end passageway), at Potline working floor level. The passageways, with embedded floor rails to support a transfer gantry, would connect the two (2) Pot room buildings.

- An emission monitoring system would be provided for the monitoring of roof fluoride emissions for pot tending work practice management and emission compliance testing.

Fresh alumina would be transported to the Potline 6 via tanker trucks from the port to two (2) unloading stations feeding the two main fresh Alumina storage silos (12,500 tonnes capacity each), each located in one (1) of the two (2) Potline courtyards. Alumina consumed in the pots would be processed through the Potline GTC (one per half Potline), where the alumina would absorb the gaseous fluorides from the gases produced by the pots prior to gas emission via the stack. This alumina is referred to as fluorinated alumina which is fed to the pots via a pot feed system.

Crushed Bath would be transferred by truck from a storage silo at the Bath Treatment plant to each of the two (2) six hundred and fifty (650) tonne crushed bath silos located in the courtyards for blending with fluorinated alumina (anode cover material) to feed the pots.

The following additional facilities would be part of the Reduction Facility scope:

- Two lining/delining buildings would house the tools and equipment required to de-line and re-line the pot shells.

- One (1) Pot Tending Machine (PTM) maintenance facility, constructed off the central passageway, in between the two (2) Pot rooms.

- A Potline Equipment Maintenance facility adjacent to and in line with the PTM maintenance facility.

- Potline offices and a control room located off the central passageway. Cool rooms would be provided along the Pot rooms.

- A new facility for storage of 750 tonnes of aluminium fluoride in bulk bags, located South West of Pot room B.

4.5.4 Carbon

The Line 6 Carbon scope would include green anode production facilities, an anode handling and storage area and a rodding shop and supporting infrastructure and is detailed below.

Green Anode production facilities:

- Additions to the existing Potline 5 Coke Receiving and Storage Facility, with a new storage silo and materials handling equipment.

- Additions to the existing Potline 5 Recycle Carbon Products Facility, with new and materials handling equipment.

- A new Coke and Recycle Products Blending Facility, in a new structure.

- Additions to the existing Potline 5 Liquid Pitch Facility.

- A new Paste Preparation and Green Anode Forming process plant and equipment installed in the existing structure adjacent to the Potline 5 Paste Plant building.

- A new Green Anode Cooling Facility, installed in a new building

Anode handling and storage:

- A new Green and Baked Anode Handling and Storage Facility, installed in a new building and other structures.

- A complete Anode Baking Furnace (ABF) Facility, with all required equipment to operate the furnace.

- A new ABF Fume Treatment Facility with all required materials handling and storage plant and equipment.

Rodding shop and supporting infrastructure:

- Modifications to the existing Potline 5 Rodding Shop to process the Potline 6 Dubal DX+ anode assemblies and the Potline 5 anode assemblies. This would include replacement, upgrade or addition of process equipment.

- Extension of the Potline 5 Anode Pallet Storage building for storage of both Potline 5 and Potline 6 anode pallets.

- Construction of a new facility for the storage of both Potline 5 and Potline 6 Crust Bath Bins.

4.5.5 Cast House

The new metal production from Potline 6 would either be sold as liquid metal to downstream industries or be sent to a new Cast House. The Line 6 Cast House scope would include:

- The new casting facilities which would contain the furnaces, furnace stacks, launder systems, metal degassing and filtration systems, billet VDC machine (with the capacity to produce slabs) and homogenizing furnaces.
- An air cooled Sow Casting Line as a backup for emergency casting purposes.
- A new metal Treatment (Sodium reduction) and skimming station for liquid metal from Potline 6.
- A new crucible cleaning building for the Potline 6 crucibles.

4.5.6 Utilities

4.5.6.1 Electrical

The auxiliary loads at the smelter would be fed from the 33 kV SH7 and further distributed at 11.5kV including for major loads such as for the compressors and GTC fan motors, similar to the existing distribution scheme. The rectifiers would be fed from 220 kV.

4.5.6.2 Compressed Air

Four (4) new compressors (three (3) operating and one (1) standby) for a total required nominal flow of 48,436 m^3/h and a new Compressor House would be provided. Potline 5 compressors would also be relocated to this new Compressor House.

4.5.6.3 Potable Water System

The additional potable water network would be connected to the existing network tie-in points for the Anode Baking Furnace, Anode Rodding Shop, main Change House and Cafeteria, Administration Building and other amenities.

The existing Potable network would be modified to include:

- All the new users.
- The relocation of the existing main to clear the addition of new facilities and an additional main added to maintain the existing network pressure and flow.

4.5.6.4 Process Water System

The additional Process water network would be connected to the existing network tie-in points for the Green Anode Cooling facility, the ABF Fume Treatment Centre, the cooling tower of the induction furnaces in the anode Rodding Shop as well as for the VDC Cast House. The existing water network services both potable and process water. Two (2) 12,500 m^3 capacity water storage tanks would be installed at the Alba site to provide water for situations when calciner is shut-down which would interrupt the normal supply of water from the existing Alba calciner facility at the Port.

4.5.6.5 Fire Water System

The additional Fire water network would be connected to the existing network tie-in points.

4.5.6.6 Sewage and Sanitary System

A new Sewage Treatment Plant (STP3) would be required for Potline 6 requirements. The treated by-product would be taken off-site via Sanivan-type sewage trucks.

4.5.6.7 Common Services / Infrastructure

The additional Potline 6 common services would include new facilities or modification to existing ones such as:

- Mobile Equipment maintenance facilities.
- Extension of the existing warehouse.
- Main amenities building including change house and laundry for 750 operators, as well as a cafeteria dispensing food for 200 people at a time.
- Administration building.
- Sewage Treatment Plant 3 for Potline 6 requirements of 150m3 per day (sized for 750 people) in the vicinity of the Line 5 STP.
- Service Station for fuel dispensing, including a truck wash facility.
- The site surface-water drainage would be upgraded as required and connected to the existing site drainage circuit which are connected to the existing four outfalls at the Alba fence line. These are connected to the existing municipal drainage system located outside Alba's property lines.
- There would be 2 oily water separators (one at the vehicle maintenance and one at the rectifiers) to ensure capture of oily waters so as not to contaminate the surface water drainage.

4.5.7 Power Plant

The project would consist of two (2) combined cycle units, each nominally 450 MW in a 1x1x1 configuration. For each unit, the major process equipment and support systems would include:

- One (1) natural-gas-fired Class F Combustion Turbine Generator with air inlet filters and auxiliary equipment.
- A by-pass stack so the CTG can be operated in a simple cycle mode.
- One (1) Heat Recovery Steam Generator with three (3) pressure levels, reheat, and outlet stack.
- One (1) condensing, reheat-type Steam Turbine Generator and accessory equipment.
- Two (2) 100% motor-driven feed water pumps.
- One (1) Air-Cooled Condenser (ACC).
- One (1) condensate collection system, including two (2) 100% condensate pumps.
- Closed cooling water system for cooling auxiliary equipment, including two (2) 100% closed cooling water pumps and fin-fan coolers.
- Boiler feed-water chemical injection system.

Systems or equipment common to the two (2) units includes:

- Demineralization water system (Reverse Osmosis).

- Combined Instrument and Service air system.
- Natural gas fuel system including fuel gas pressure control and fuel gas clean up and delivery equipment.
- Domestic (potable) water system.
- Demineralized water storage tank.
- Firewater storage tank.
- Fire protection system, including one diesel pump, one motor-driven pump, and one jockey pump.
- Administration/control building, turbine building, water treatment building, fire water pump module, switchgear enclosure, electrical equipment modules (CTG/HRSG, water treatment and cooling tower).
- Heating, Ventilating, and Air-Conditioning (HVAC) systems for control room, Gas Insulated Switchgear (GIS) building and offices.
- Ventilation for enclosed areas.
- Facility loop and interior roads, parking, and onsite construction access and haul road.
- Storm-water drainage system, as required.

Major electrical equipment and control systems would include:

- Gas Insulated Switchgear (GIS).
- Generator step-up transformers for each of the CTGs and STGs.
- Auxiliary transformers.
- Generator circuit breakers.
- Battery backed Uninterruptible Power Supply (UPS) system.
- Distributed Control System (DCS), and Continuous Emissions Monitoring System (CEMS).
- Lightning, grounding, and cathodic protection systems (if required).
- Electric power distribution system (Medium Voltage Switchgear, Low Voltage load centres, MCCs, and distribution panels).
- In-plant communication systems such as telephone, intercom, or radio.

4.5.8 Raw materials

Water supply for boiler feed water, cooling water and process water would be from Alba’s calciner facility at the Port. Currently an additional consumption of approximately 115 m^3 per hour is considered.

As shown and described earlier (**Figure 4**), the main raw materials used in the aluminium smelter are fresh alumina, calcined coke and liquid pitch. Delivered and consumed quantities of current operations (L1 – 5) and corresponding quantities of the expansion are detailed in **Table 14**.

Table 14: Raw Materials – Current and Future

		Fresh alumina		Calcined coke		Liquid Pitch	
		L 1 to 5 Baseline (2012)	Future [L1-L5 Crept and L6]	L 1 to 5 Baseline (2012)	Future [L1-L5 Crept and L6]	L 1 to 5 Baseline (2012)	Future [L1-L5 Crept and L6]
Yearly consumption	tpy	1,708,800	2,786,687	346,641	559,767	72,743	118,817
	tph	195.07	318	39.57	64	8.30	13.6
Tanker size (truck)	t	33.00	33.00	30.00	30.00	25	25
Number of tankers (roundtrips)	per day	141.87	231	31.66	51.12	7.97	13.1
	per year	51,782	84,315	11,555	18,659	2,910	4,753
Number of ship deliveries	-	33.31	65	-	-	12.12	19.8
Average Parcel Size	t	-	-	-	-	6,000	6,000

4.5.9 Construction phase

The base case for the execution schedule would have construction (site preparation) works commencing in early 2015 for completion in July 2017. An early accelerated scenario (by approximately 6 months) is also under consideration. The base case scenario would have construction (site preparation) works commencing in early 2015 for completion in July 2018. A temporary construction laydown area located west of Alba's property limits would be used during the construction period. This also would house the temporary offices of the Contractors. An area in the to-be acquired property (Jawed land) would be used by the Administration building which would house the Engineering, Procurement, And Construction Management (EPCM) contractor for the construction phase.

The initial construction phase would require earthworks to level the site to rough grade for the future Potline 6, the ABF as well as the Power Station 5 (PS5) areas. Some existing facilities as listed in Section 1.2 above would be demolished. Some of the existing utilities (drainage, electrical and piping) and roads would need to be removed and relocated/rerouted.

The next phase would have the start of the Potline 6, ABF, Casthouse 4, Rectifiers and the PS5 area foundation works. The erection of the structural steel would follow, including the cladding. Installation of major mechanical equipment would follow prior to electrical works. Further details regarding the construction phase are currently not available, and will become available after award of the construction contractor(s). The ESIA will assess the impacts based upon available information. Identified gaps will be highlighted and recommendations will be provided in the ESIA.

Anticipated required craft labour resources during the construction phase are as follows:

- On average 2,600 staff for smelter and 750 staff for Power Station 5;
- Maximum number of working people would be 5,200 staff for smelter and 1,500 staff for Power Station 5.

Labour facilities and accommodation would be provided by the construction contractors. No labour accommodations would be located at the lay-down areas. Therefore no waste water and waste from labour accommodations would be generated at site.

Key construction dates are summarized in the table below.

Table 15: Key Milestones during Construction

Key Milestones	Baseline Date	Months from FHM
Full NTP of EPCM	01-Dec-14	36
Commence Site Preparation and Rock Excavation	01-Aug-15	28
PS5 EPC Contractor Mobilization to Site	01-Aug-15	28
L6 First Concrete	01-May-16	19
L6 First Hot Metal	01-Dec-17	0
PS5 Unit 1 Complete	01-Jan-18	-1
PS5 Unit 2 Complete	01-Apr-18	-4
L6 Last Hot Metal	01-Jun-18	-6
NTP = Notice to Proceed FHM = First Hot Metal		

4.6 Overall Project Schedule

The overall project schedule for the base case is as shown below. Based on a Notice to Proceed of December 1st 2015, First Hot Metal would be on December 1st 2017 with Last Hot Metal on June 1st 2018.

The tentative schedule for the construction of the proposed expansion is presented in **Figure 5** below.

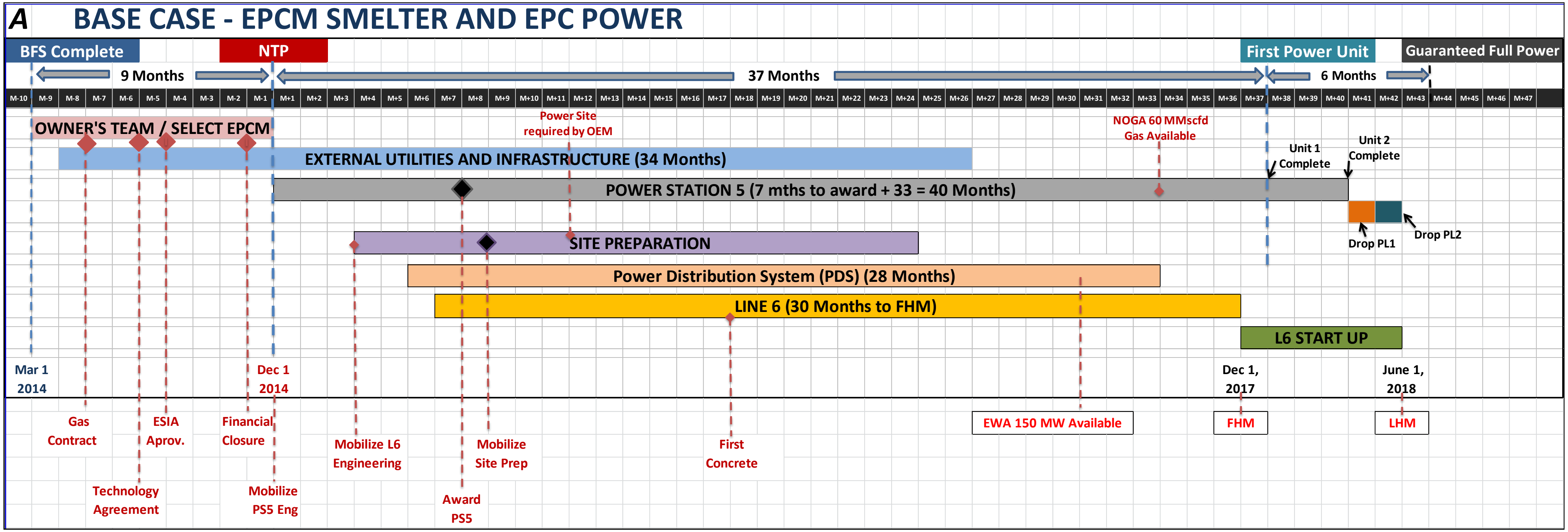


Figure 5: Tentative Construction Schedule

4.7 Performed Consultations

The following consultations have been undertaken by ALBA regarding the proposed expansion:

- A Screening Application was submitted to the SCE in 2010 regarding the potential addition of Potline 6 to the Alba Smelter. SCE's response was received on 18 August 2011, indicating the topics to be considered in the ESIA.

- Discussions were held with the NOGA regarding gas availability to support the proposed Alba Smelter expansion. 60 MMSCFD was requested by Alba for this expansion. No formal commitment has yet been received from NOGA.

- Discussions were held with the EWA regarding power availability from Bahrain grid to support the proposed Alba Smelter expansion. 150MW were said to be available for such an expansion. EWA committed to making the 150MW available from June 2015. Alba and EWA have yet to engineer and scope the construction of 2 x 220kv cable links to support the supply of the 150MW.

- The Ministry of Urban Planning was consulted in 2013 regarding the availability of the land adjacent to Alba located to the west of the Alba Smelter for use as material laydown area and Contractors' offices during the construction phase of the proposed expansion. A request is currently with the Ministry of Industry and Commerce and pending approval.

- The Ministry of Tourism and Culture was consulted in 2013 regarding the importance of archeological and national heritage with respect to the location of the proposed laydown area west of Alba's facilities. In response, The Director of Archaeology & National Heritage indicated in a letter (dated the 30th of March 2014 and attached in **Appendix 16)** that the Ministry of Culture has no archeological concern in the project area.

5 Environmental Baseline Conditions

In this Chapter, the state of the environment in which the proposed expansion will occur is described. The purpose of this description is to highlight key attributes of the environment and particular areas of vulnerability to provide the context for later assessment of potential impacts. At the same time, because the proposed development is an expansion of an existing operation it is necessary to describe the existing operations in terms of on-going environmental performance. The chapter is structured to provide a general statement on the environment followed by descriptions of particular components such as; air, water, ecology, and so forth. It is to be noted that all operational data, including waste quantities, are based on data received from Alba.

5.1 Climate

5.1.1 Temperature and Humidity

The climate in Bahrain is generally characterised as arid with high summer temperatures and scarce rainfall. There are only two distinct seasons namely summer and winter with the former extending from May to October and the latter from November to April with a precipitation range of 22-22.5 millimetre (mm) per year. Relative Humidity ranges from 56% to 75% as shown in **Figure 6** below.

Normally, average temperatures range between 15 °C during the winter season to 32 °C during the summer season with a maximum high of 48 °C and a minimum low of 3 °C, the average annual temperatures in the Kingdom of Bahrain in the year of 2012 are illustrated in **Figure 7**.

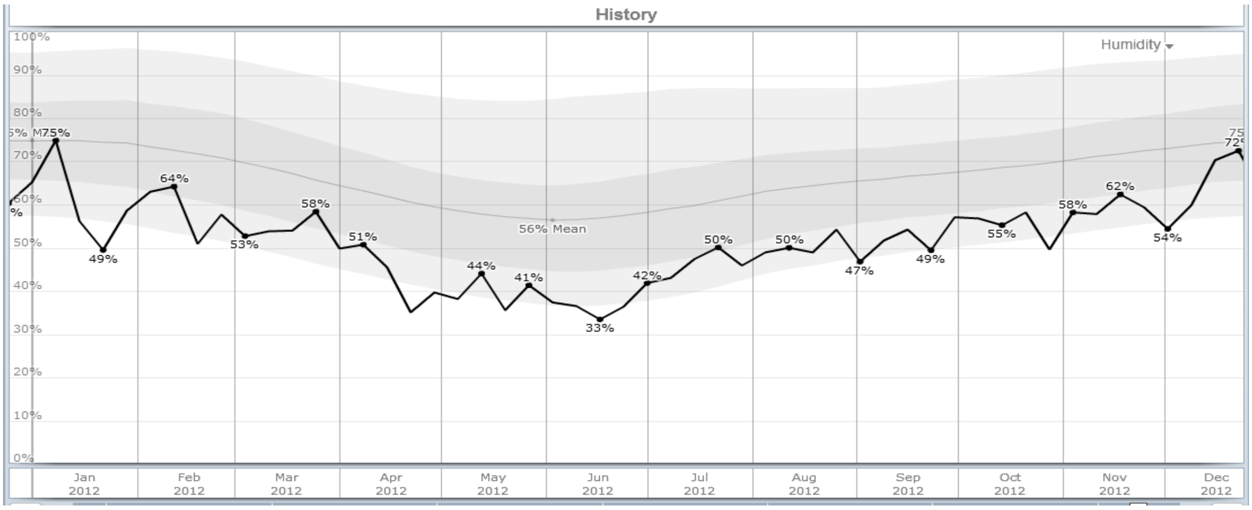


Figure 6: Relative Humidity, Manama- Kingdom of Bahrain (2012)

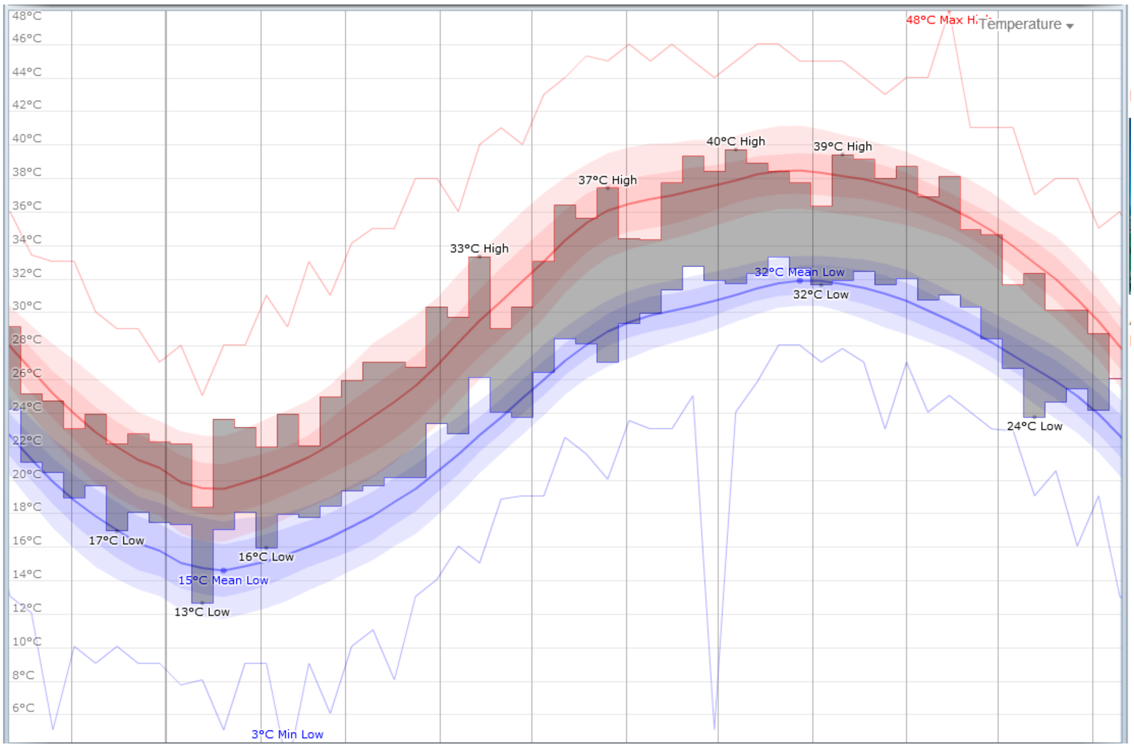


Figure 7: Annual temperatures, Manama- Kingdom of Bahrain (2012)

5.1.2 Wind

The prevailing wind direction in the kingdom of Bahrain is north-westerly with some south-westerly flow as illustrated in **Figure 8**. The averaged wind rose for the years 2008-2012 indicating the prevailing wind direction and wind speed for the aforementioned years is illustrated in **Figure 9** below. Furthermore, an average wind speed of 4.95 metre per second (m/s) was obtained from recordings (2008 – 2012).

Figure 8: Wind Direction, Manama- Kingdom of Bahrain (2012)

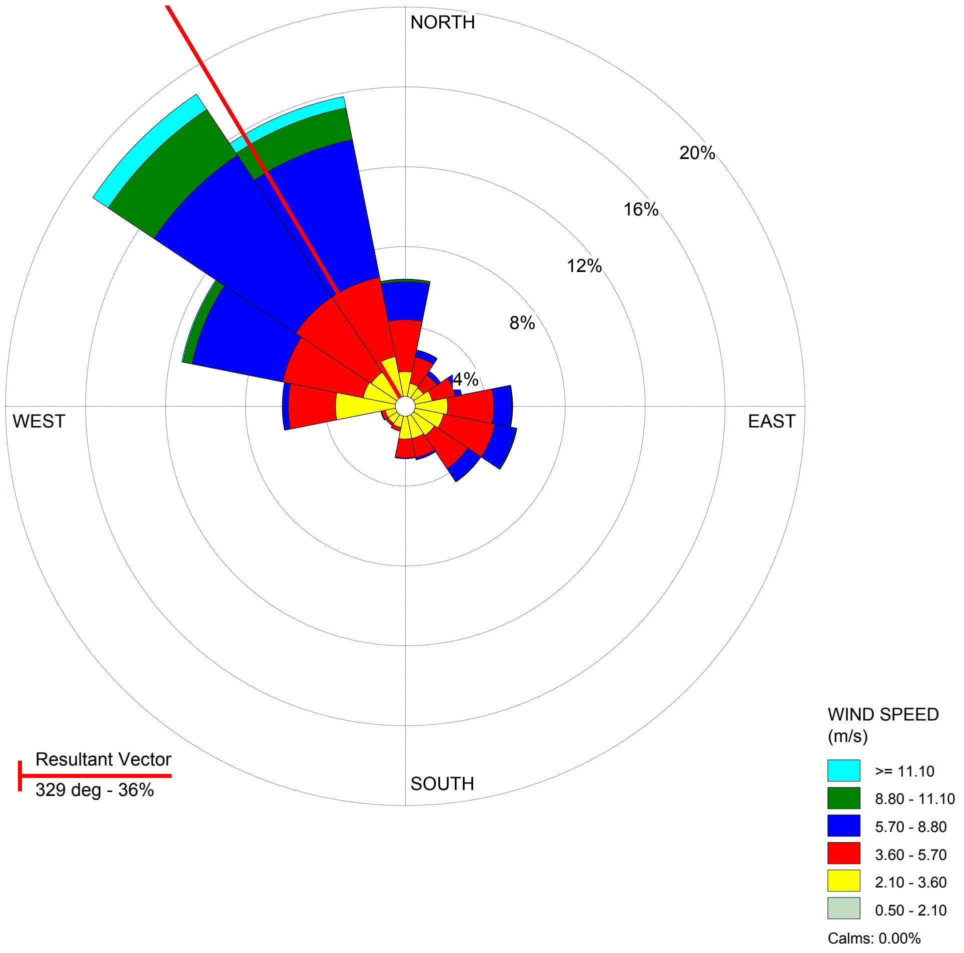
.

WIND ROSE PLOT:

Station #41150 - bahrain international, BH

DISPLAY:

Wind Speed
Direction (blowing from)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2008 - 00:00
End Date: 12/31/2012 - 23:00

COMPANY NAME:

MODELER:

CALM WINDS:

0.00%

TOTAL COUNT:

39865 hrs.

AVG. WIND SPEED:

4.95 m/s

DATE:

4/21/2014

PROJECT NO.:

Figure 9: Wind Rose, 2008-2012

5.2 Air Quality

Bahrain's Public Commission for the Protection of Marine Resources, Environment & Wildlife commissioned five (5) mobile ambient air quality monitoring stations in July of 2006 to monitor twelve air pollutants namely; SO_2, Hydrogen Sulphide (H_2S), NO_2, Carbon Monoxide (CO), Ozone (O_3), Inhalable Particulates (PM_{10} & $PM_{2.5}$), Ammonia (NH_3), Non-Methane Hydrocarbons (n-ch_4), Benzene (C_6H_6), Toluene (C_7H_8), and p-xylene (C_8H_{10}) as well as five meteorological parameters inclusive of wind speed, wind direction, solar radiation, ambient temperature, and relative humidity.

The data obtained from the ambient air quality monitoring stations is annually communicated with the public via an annual air quality report prepared by the Environmental Monitoring Section of the Environmental Assessment and Planning Directorate. For the purpose of assessing the quality of ambient air within the project area and consequently evaluating the impact of the proposed operations on air quality, the annual air quality report for the year 2012 was attained and accordingly evaluated. The locations of the five monitoring stations relative to Alba's location are indicated in red in **Figure 10** below.

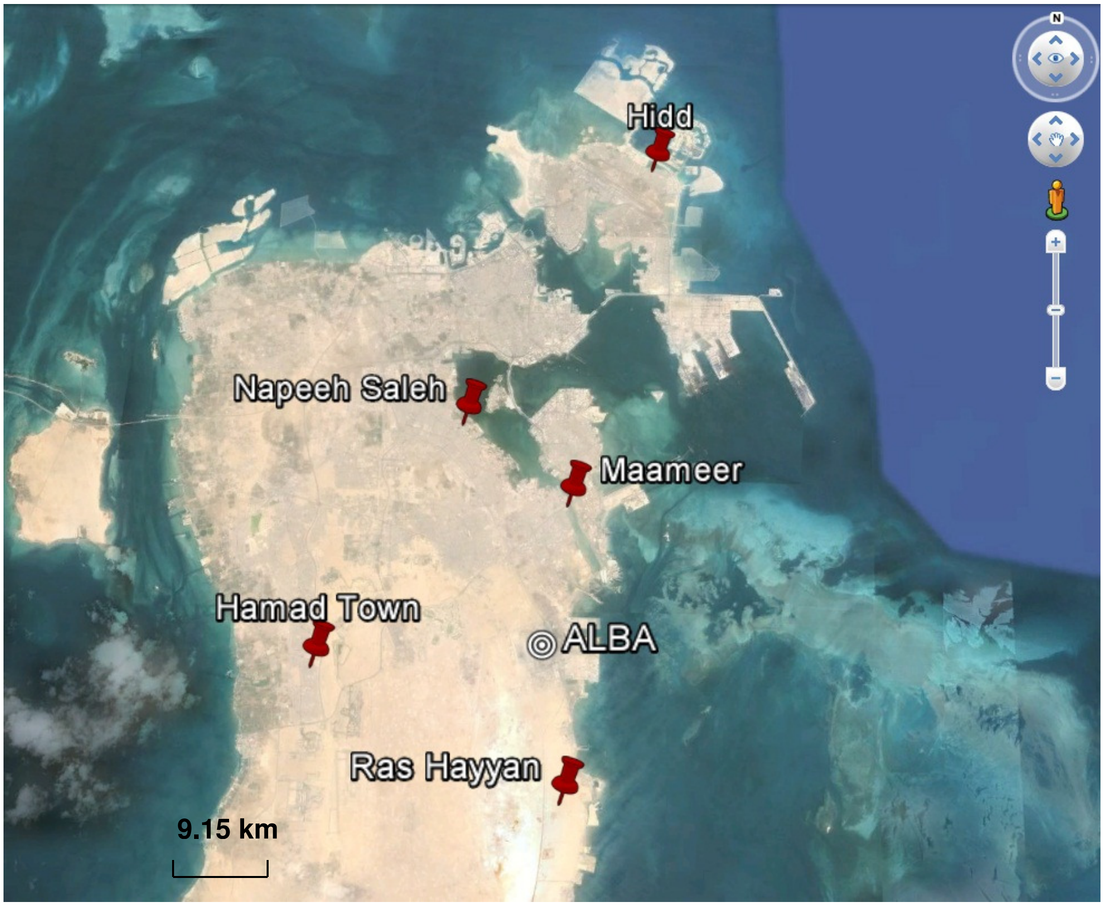


Figure 10: Location of Five Ambient Air Quality Monitoring Station, Kingdom of Bahrain

As indicated in **Figure 10** above, the locations of the five (5) Ambient Air Quality monitoring stations are as follows;

1. The Meteorology Directorate at Hidd area at Muharraq;
2. Club of Bahrain Defence Force at Napeeh Saleh at the Capital;
3. Maamer sport club at the Central Governorate;
4. Ras Hayyan (Askar) at the Southern Governorate; and
5. Hamad Town Southern Police Station at the Northern Governorate.

As previously indicated, the wind direction in the kingdom of Bahrain is north-westerly with some south-westerly flow. Therefore, respective to Alba's location and the prevailing wind direction, the nearest upwind monitoring station is Maamer sport club station at the Central Governorate while the nearest downwind monitoring station coincides at Ras Hayyan (Askar) at Southern Governorate.

To assess the Ambient Air Quality (AAQ) within our study area, the average annual AAQ data from the aforementioned five (5) mobile ambient air quality monitoring stations were obtained from the Environmental Monitoring Section of the Environmental Assessment and Planning Directorate for the years of 2006 – 2012.

The AAQ of criteria pollutants measured in 2012 at the different monitoring stations are shown in **Table 16** along with their respective AAQ standards. As illustrated, concentrations of SO_2, NO_2 and Inhalable Suspended Solids (Particular Matter (PM_{10})) did not exceed the stipulated Bahraini standards. The one exception is the 1-hour NO_2 reading at Maamer, which is a long distance from Alba.

The outlined data will be used to analyse the contribution of Alba's operations to the degradation of ambient air quality of the Kingdom of Bahrain.

Table 16: Ambient Air Quality - Background levels in 2012

Pollutant	Bahrain Ambient Air Quality Standard (µg/m3)		Monitoring Station				
			Ras Hayyan	Hidd	Maamer	Napeeh Saleh	Hamad Town
Sulphur Dioxide (SO_2)	Annual mean	50	6	6	6	6	8
	24-hours	125	29	31	31	31	43
	1-hour	350	71	75	75	76	104
Nitrogen Dioxide (NO_2)	Annual mean	40	1	2	17	3	7
	24-hours	150	6	11	90	15	36
	1-hour	200	15	22	218	35	87
Gaseous Fluoride (HF)	Annual mean	1	NA	NA	NA	NA	NA
Inhalable Suspended Solids (PM10)	24-hours	350	86	295	91	43	28

As demonstrated in **Table 16**, the monitored pollutants are within the maximum allowable limits for Ambient Air Quality as stipulated by the Ministerial Order No.3 of 2001 standard limits stipulated by the Ministry of Environment at all five (5) locations. Furthermore as shown in the table above, a gap is identified with regards to HF air quality monitoring. Nevertheless, in order to assess the impact on air quality. HF dispersion modelling was conducted (section 6.2). As ambient data for this component is currently not available, and therefore no quantitative assessment with regard to ambient concentrations can be established, it is recommended to monitor HF in the future.

Alba is performing monthly HF monitoring at its north and south fenceline and at two locations in the industrial area south of its facilities. The data provided by Alba generally showed HF concentrations of 0.05 to 0.32 $\mu g/m^3$ which is well below the WHO standard of 1 $\mu g/m^3$ (annual). As 24-hour average concentrations are measured once every month, these records are considered as snapshots. Therefore, accuracy of the data can currently not be confirmed since no specific details were made available regarding the meteorological conditions, calibration of equipment etc.

To assess Alba's contribution to the degradation of the ambient air quality, the Ground-Level Pollutant Concentrations (GLCs) for NO_2, SO_2, PM_{10}, and gaseous HF resulting from emission sources were predicted and its dispersions with the use of CALPUFF modelling system for various averaging periods. The input data required to generate the model inclusive of; terrain data, maps, land-use data, and meteorological data were respectively obtained.

5.3 Geology and Hydrology

Generally, the island of Bahrain consists of sedimentary deposits of the Eocene age edged by formations of Pleistocene and Recent age. Geological records [**Ref. 1**] indicate that the Alba site is most likely underlain by Ras Al Aqr formation containing caprock limestone/sandstone, mud flood deposits, and carbon-rich, fine-grained rocks.

The plant is located on relatively flat land, rising at 1.3% towards the western side of the plant. On-site geological investigations conducted in 1989 [**Ref. 2**] revealed rocky limestone deposits under a thin top layer of sand. The moderately strong to strong cryptocrystalline limestone is present close to the surface and tends to reduce in strength with increased depth. Small cavities (30-70 mm) are evident in the rock masses but interconnectedness is not evident. A typical soil profile at the Alba site is shown in **Table 17**.

Table 17: Typical soil profile at the Alba site [**Ref. 2**]

Depth	Description
0 – 0.5 m	Sand and gravel sized fragments from weathered rock head below
0.5 – 2.0 m	Moderately strong to strong limestone
2.0 – 10 m	Slight increase in weathering of limestone and discontinuities in filled with silt and clay

As the plant ground level rises from the east to the west, groundwater levels occur at between 2.5 and 8.5 m (depth below grade) on the eastern side of the plant, but nominally at 18 m or deeper on the western side. Tidal influences are believed not to affect these groundwater levels since the site is sufficiently far from the sea. The Potline 5 Geotechnical study work (Nov 2002) did not encounter groundwater (GW) on the western side but encountered GW at Casthouse 3 (central portion of the site) at a depth of 9.8m below ground (approx. El. +1.2 m plant datum). The recent preliminary Geotechnical study work conducted for the Feasibility Study of Line 6 (2013), did not encounter GW beneath the proposed Line 6 area, but did encounter GW in the newly acquired Jawed land at a depth of about 14.5 m deep (El. +4.2 to 5.2 m North Sahara Datum (NSD)), based on measured levels in two (2) boreholes (24 and 25). These are considered to be deep enough not to present issues during construction or long term.

At the VDC pit location at the proposed site for methane (CH_4), groundwater was detected at a depth of 6.3 meters (El. +1.7 meters NSD), within the 30 meter deep borehole, which would indicate the requirement of dewatering during construction. The pit foundation design would be designed to take into account the buoyancy effects of the groundwater.

5.4 Soil and Groundwater

In this section, the soil and groundwater condition in the study area is described, with particular emphasis on the area in which the proposed expansion will take place. The description is based on ground water information supplied by Alba as well as a dedicated soil investigation conducted as part of the ESIA. Before describing these conditions, it is necessary to briefly address the issue of pollutant mobility in the context of the existing soil and groundwater conditions.

5.4.1 Mobility of Pollutants

Apart from the direct effects of soil contamination, which is problematic in its own right, contaminated soil presents a direct threat to groundwater. The threat posed by contaminated soil is a function of the pollutants and the mobility of those pollutants, i.e. how readily the pollutants may be taken up in the groundwater. For Alba, the pH and organic matter, water and luteum (soil parts smaller than 2 μm) are key determinants of pollutant mobility. For the type of soil present at Alba, mineral oil and PAH can be considered mobile pollutants. However, it is likely that if the concentrations of these pollutants remain relatively small, they will be bound up by the soil, reducing the risk of further dispersion through the soil. Relatively higher concentrations, however, would be more mobile.

A more acidic environment also leads to generally higher mobility of especially heavy metals, but given the abundance of limestone in the area, a decrease in pH is improbable. In addition, there is very little rainfall in Bahrain and penetration of the soil further limited by the low permeability and the high evaporation that occurs. This implies that the soil and the pollutants generally remain in a dry state further reducing the mobility of the pollutants.

5.4.2 Soil Investigation

Soil samples were collected from twelve boreholes as indicated by **Figure 11**. Samples were collected at depths ranging from 0.2 to 0.5 metres by using a fully decontaminated sampling hand auger. The sampling auger was utilized to collect the shallow subsurface soil samples given the previously indicated soil profile of Alba site. It is to be noted that cross contamination during soil sample collection was eliminated through the use of disposable equipment and thorough cleaning of any non-disposable equipment with deionised water. The samples were collected into polyethylene bags provided by the laboratory and stored in a cool box surrounded by ice packs. Subsequently, the collected soil samples were submitted to an approved laboratory for analysis. The Universal Transverse Mercator (UTM) co-ordinates of the installed boreholes are outlined in **Table 18** in the World Geodetic System (WGS-84).

Figure 11: Locations of Soil Sampling Survey

Table 18: UTM Co-ordinates of Borehole Locations (WGS84)

Location No.	Zone	Easting	Northing
1	39 R	459523.23 m E	2885987.76 m N
2	39 R	459461.03 m E	2885852.14 m N
3	39 R	459573.25 m E	2885739.41 m N
4	39 R	459471.16 m E	2885665.12 m N
5	39 R	459827.93 m E	2885955.74 m N
6	39 R	459806.28 m E	2885874.97 m N
7	39 R	459797.53 m E	2885669.05 m N
8	39 R	459904.82 m E	2885546.18 m N

Location No.	Zone	Easting	Northing
9	39 R	459870.06 m E	2885367.49 m N
10	39 R	459959.07 m E	2885223.67 m N
11	39 R	459948.77 m E	2885073.09 m N
12	39 R	460015.07 m E	2884938.10 m N

The collected soil samples from four (4) boreholes were collected into one (1) composite sample[4] with each contributing sample clearly logged to trace back the sample in case of a concentration exceedance of a contaminant. A total of three (3) composite samples were sent to an independent third party laboratory for analysis.

Upon attainment of the data, Dutch soil standards were used to evaluate soil concentrations. However; the Dutch standards lack limits for aluminium, phosphate, magnesium, boron, calcium, acid soluble sulphates, acid soluble chloride, Total Organic Carbons (TOC), and oil & grease. Thus, the Alberta Tier 1 Soil and Groundwater Remediation Guidelines have been used as supplement international standards with the exception of aluminium, due to the lack of a devised standard limit. Accordingly, The Alberta Tier 1 Soil and Groundwater Remediation Guidelines is attached in **Appendix 4** for reference.

Based on the approach in the report ‘Ecological Soil Screening Level for Aluminium’ published by the Office of Solid Waste and Emergency Response department of the United States Environmental Protection Agency (US EPA), potential ecological risks associated with aluminium in soils are identified based on the measurement of the soil pH. Aluminium is identified as a Contaminant of Potential Concern (COPC) only for those soils with a pH less than 5.5. As previously indicated, the soil within Alba’s premises is characterised to be basic (pH of 8.6 on average) due to the abundance of limestone in the area. Therefore, aluminium levels within the soil are deemed to be insignificant. A copy of the aforementioned report is attached in **Appendix 5** for reference.

5.4.2.1 Soil Investigation Results

The three (3) composite samples were analysed in an approved laboratory for heavy metals, Total Petroleum Hydrocarbons (TPH), Benzene Toluene Ethylbenzene, Xylene (BTEX), Poly Aromatic Hydrocarbons (PAH), pH, among others. The results of the analysis for soil samples are enclosed in **Appendix 6** for reference.

Results have shown that Boron (average 5.05 milligram per kilogram (mg/kg)) and Sulphur (average 1965.3 mg/kg) concentrations exceeded the stipulated Dutch Standards for soil quality (see **Section 3.3.4**), 2 mg/kg and 500 mg/kg respectively, in all three composite samples. Moreover, the pH was found to slightly exceed the standard range of 6 – 8.5 in composite samples 1 and 3 which is equivalent to, 8.77 and 8.56 respectively. However, the analysed concentrations for; benzene, naphthalene, anthracene, fluoranthene, and pyrene were below the detection limit in all three composite samples.

5.4.3 Groundwater

Alba operates two (2) active groundwater wells to evaluate the quality of groundwater within the Alba premises via in-house laboratory analyses of samples collected quarterly and reported biannually to the concerned authorities.

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[4] Composite Sample 1: borehole 1,2,3,4; Composite Sample 2: borehole 6,7,9,11; Composite Sample 3: borehole 5,8,10,12

Groundwater Well 1 (GW 1) is located at the metal storage area while Groundwater Well 2 (GW 2) is located west from GW 1 in the proposed area for Potline 6 and in close proximity to the operating potlines. The layout drawing indicating the locations of GW 1 and GW 2 is enclosed in **Appendix 7.**

Analysed parameters include pH, Fluorides, Cyanide (CN), Ammonical Nitrogen, and Oil & Grease. The quarterly groundwater quality data was compiled for the years 2007-2012 by Alba to assess the groundwater quality in the area, a summary of which is enclosed in **Appendix 8**.

5.4.3.1 Groundwater Monitoring

Initially, Alba operated and analysed four (4) groundwater monitoring wells of which the aforementioned two (2) groundwater monitoring wells are presently active. Alba has provided the quarterly groundwater quality data for the years 2007-2012 from the two (2) wells of the following parameters; Oil and Grease, Cyanides (CN), pH, Fluorides (F), and Ammonical Nitrogen. This data was compared to the stipulated Dutch Target Values (TV) for groundwater and supplemented by the UK (ICRL 59/83) standards for parameters not covered by the Dutch standards to assess groundwater quality within Alba’s premises.

The measured concentrations for cyanide comply with the TV of 0.005 ppm as devised by the Dutch soil and groundwater guidelines which sets the target value for cyanide concentration in groundwater at 0.005 ppm and the intervention value at 1.5 ppm. The indicated levels of cyanide have not increased over the monitored 6 years, leading to the deduction that that Alba’s operations do not contribute to the concentrations of cyanide in groundwater. The pH of the monitored groundwater is within the stipulated range.

Further, the monitored Fluoride (F-) concentrations are found to consistently exceed the stipulated Dutch TV of 0.5 mg/l moreover; Fluoride concentrations are higher in Well no. 3 than in Well No. 2 as illustrated in **Figure 12**. Higher fluoride concentrations in groundwater can pose impacts when groundwater is used for other purposes where it can impact flora, fauna or people. The high Fluoride concentrations can be attributed to Alba’s operations as HF is being released into the atmosphere and reaches the surface by fallout of particulate fluorides and percolates during rainfall reaching the groundwater table.

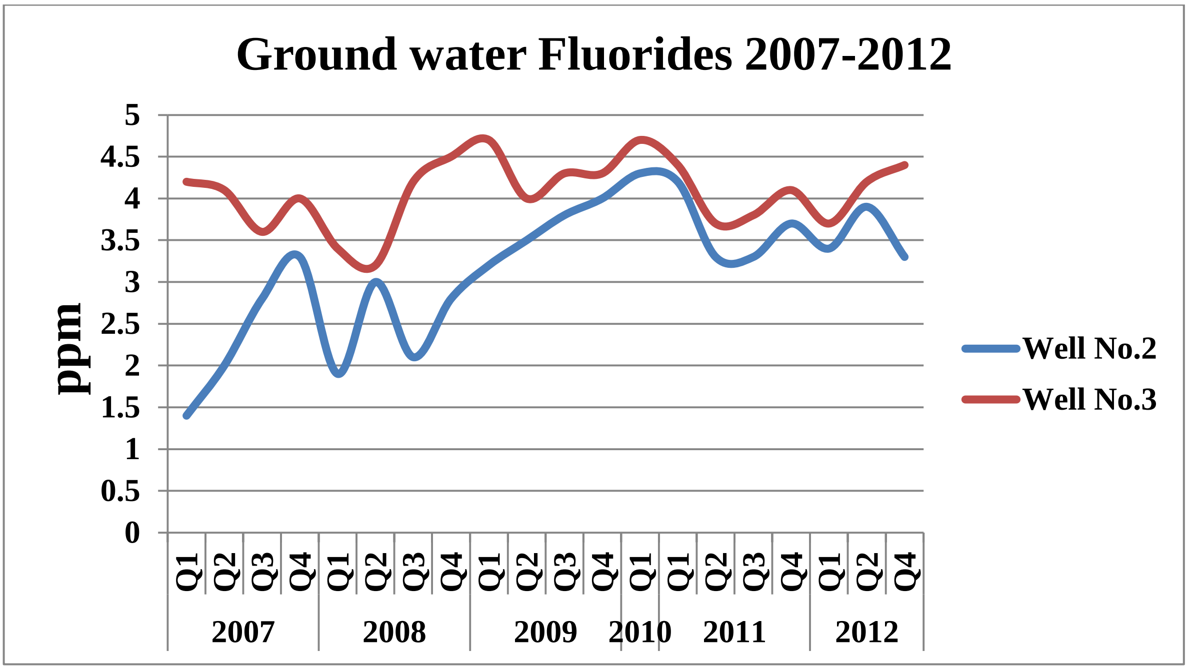


Figure 12: Monitored Fluoride Concentrations, 2007-2012

The Dutch groundwater assessment guidelines or other recognized international standards do not stipulate standard limits for Ammonical N. However, the Ammonical N data received from Alba as shown in **Figure 13** below, shows an increase in the concentrations of Ammonical N between 2007 – 2012. Reasons for increase are not known, but could be caused by seepage of fertilizers in irrigation water or sewage effluent from leaking sewer lines in the area.

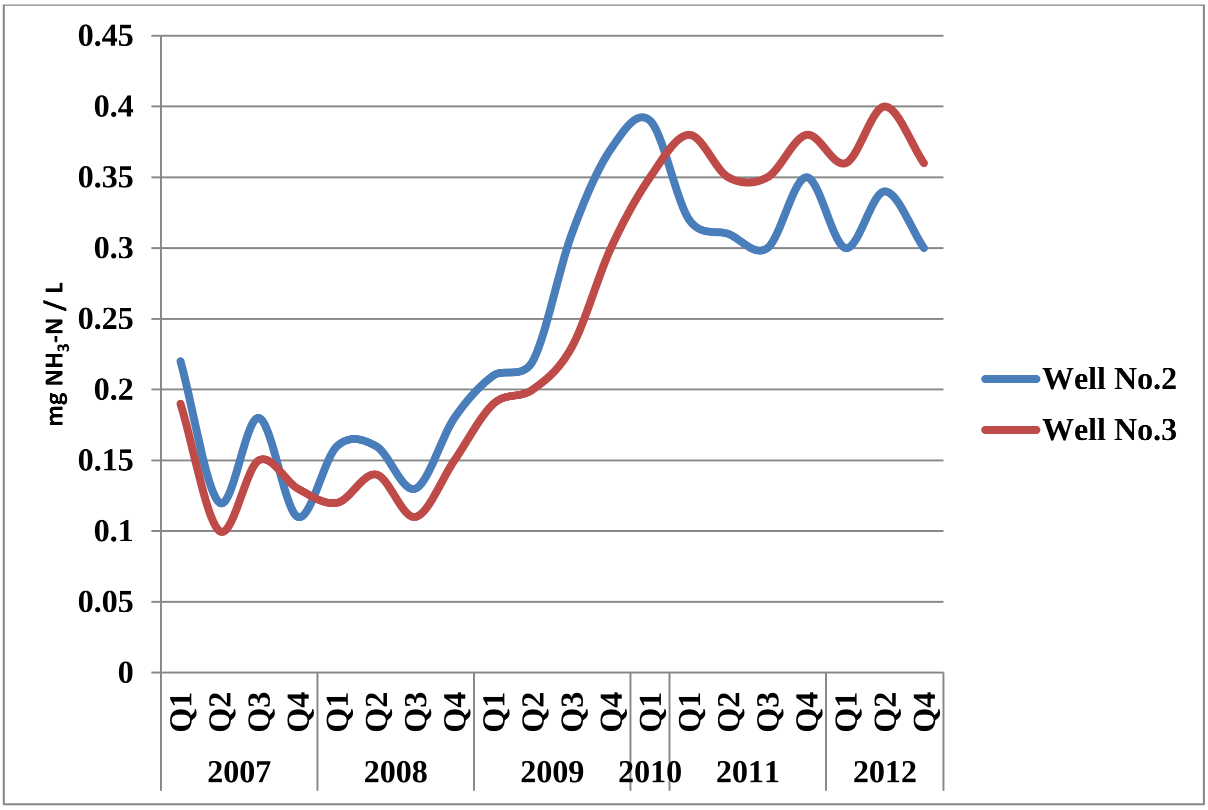


Figure 13: Monitored Ammonical N Concentrations, 2007-2012 [mg NH_3-N / L]

5.5 Ecology

The study area includes two major ecological categories, namely terrestrial and marine ecology. In the section that follows the floral and faunal characteristics of each are presented and described before highlighting zones of particular vulnerability.

5.5.1 Terrestrial ecology

5.5.1.1 Flora

There are approximately 200 terrestrial flora types identified on the island [**Ref. 3**] although vegetation dispersion is thin. There are a few shrubs, scattered grass clumps, and the occasional large shrubby growth such as tamarisk [**Ref. 4**]. Floral diversity is obviously extremely limited given the hot, dry climate and the resultant semi-desert terrain. The most common floral species found in Bahrain are listed in **Table 19** and not surprisingly are all hardy and drought and salinity tolerant. The species as illustrated in **Figure 14** and presented in **Table 19** are those likely to occur within the study area.

Table 19: Listing of common plant species found in Bahrain together with their characteristics.

Plant type	Characteristics
Hammadetea salicornici	In land Sub-Sudanian vegetation
Haloxylotea salicornici	Typical coastal vegetation (likely to found in the region of Alba)
Suaedetea deserti	

Plant type	Characteristics
Rhanterium epapposum	The most widespread shrub species
Hammada elegans	
Calligonum omosum	
Zygophillum qatarense	Low succulent bush
Pancium turgidum	Common grasses
Stipa capensis	
Cyperus conglomerates	Common sedge
Avicennia marina	Mangrove species (considered here as a marine specie)

Figure 14: Photograph showing the typical floral habitat in the vicinity of the Alba facility

5.5.1.2 Fauna

Bahrain is recognised as an important area for avifauna [**Ref. 4, 5, 6, 7**] with at least twenty-six bird species known to breed on the Bahrain archipelago and a total of 265 different species having been recorded in recent years. The island presents an attractive habitat for migrating birds that pass close to Bahrain during their spring and autumn migration. The eastern coast in particular, with its extensive mudflats hosts a large number of migrating birds. The Hawar Islands and Tubli Bay are especially important bird areas and are included on the Ramsar List.

The mudflats provide a habitat for bivalves and worms resulting in a feeding ground for shrimp, crab, waders and shorebirds. Within the study area, the shallows between the Bapco refinery, the Bahrain Yacht Club and the eastern shoreline are known to be important breeding areas. The autumn migration begins in late July [**Ref. 5**] and continues through to early October, with over 40 species being recorded during this time. Flamingos inhabit the eastern shorelines of the study area [**Ref. 5**], while on the western side, the plantations along the road from Awali to Zallaq can hold hundreds of migrating passerines during the spring. Finally, the trees that line the internal road in the plant provide limited roosting for several bird species as illustrated in **Figure 15**. The terrestrial fauna likely to be encountered in the study area is listed in **Table 20**.

Table 20: Terrestrial fauna that may occur in the study area

Fauna
Mammals *Arabian Oryx, Reem Gazelle*
Birds *Desert Lark, Crested Lark, Hoopoe Lark, Flamingos*
Reptiles and Amphibians *Jayakar's agama*
Migrating Birds *Broad-Billed Sandpiper, Curlew Sandpiper, Little and Temnicks Stints, Greater and Lesser Sandplover, Bar-tailed Godwit, Wheatears, White-throated Robin, Redstart, Red-backed, Isabelline, Lesser Gray, Woodchat, Masked Shrike, Bee-eater, Hoopoe, Roller*
Endangered species *Arabian Oryx, Saunders Little Terns, Houbara bustard (Chlamydotis undulata)*

Figure 15: Trees lining the internal plant roads that provide roosting for several bird species.

5.5.1.3 Laydown Areas

During construction, a temporary lay-down area west of the existing Alba facility will be used (**Figure 16**). A brief walk-over survey was conducted to establish the ecological baseline.

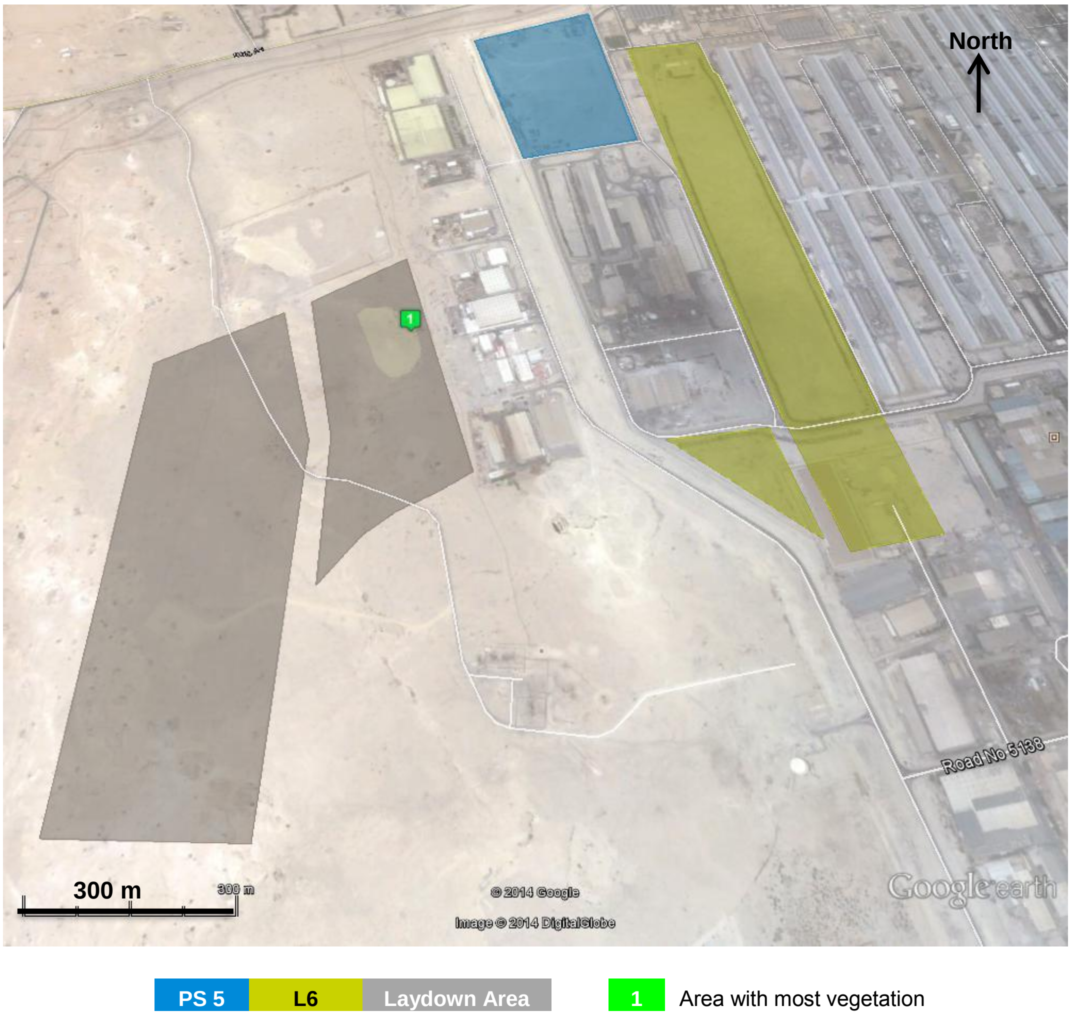
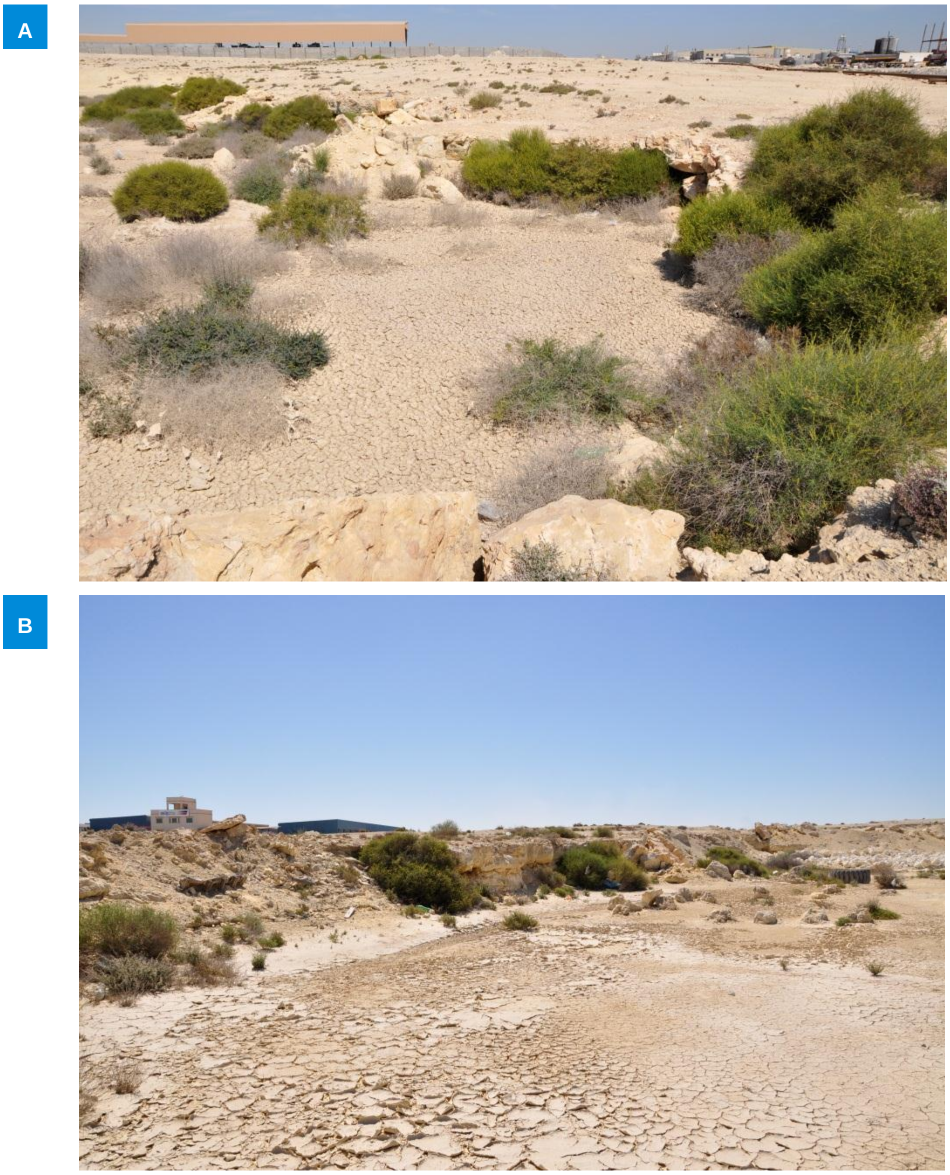


Figure 16: Proposed Laydown Area

The proposed laydown area showed to be an empty sandy stretch with scarce vegetation. Most vegetation was found close to the existing facilities at the north eastern part of the laydown area (indicated with number 1 in **Figure 16** above. This area is approximately 2 metres lower than the surrounding area and showed clear presence of human activities.

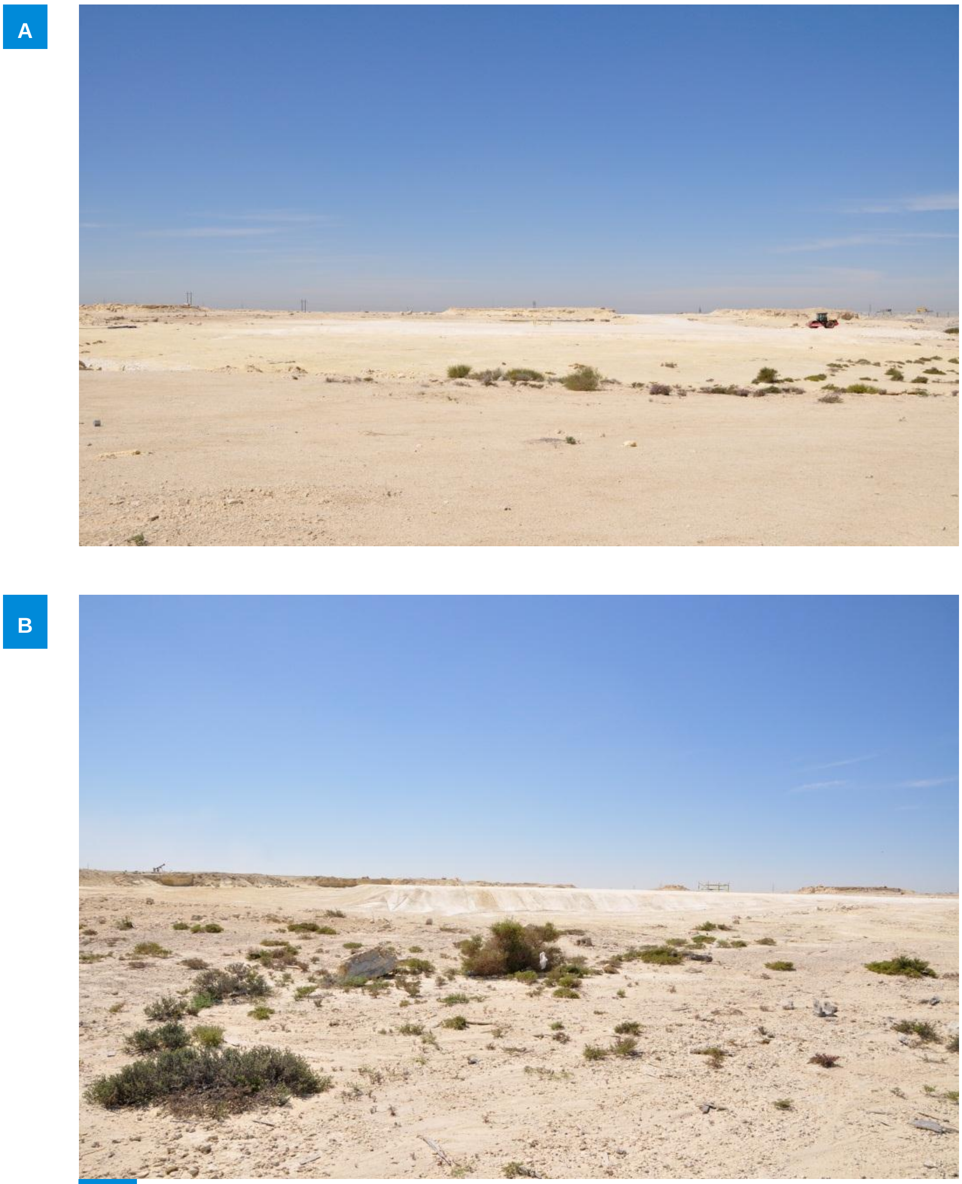
This lower positioned area showed effects from backfilled sand and wind-blown litter and was characterised by deposited rocks. Clear influences from water discharge were visible, which was consistent with a hose found in the area (not in use during the site visit). The presence of discharge water might be the reason for the higher density of vegetation in this part of the proposed laydown area. Photographs taken during the walk-over are presented in **Figure 17**.



A **Photograph taken facing north. Alba's facility is located on the right hand side.**
B **Photograph taken facing east**

Figure 17: Lower Positioned Part of the Laydown Area

The rest of the lay-down area was found to be an empty sandy area (**Figure 18**) with scares vegetation and a few bird species were encountered (laughing dove and sparrow). However, no visual tracks of any species were recorded in the area.



A **Photograph taken facing west**
B **Photograph taken facing south – south-west**

Figure 18: Laydown Area

Based on the above it is concluded that the laydown does not have a significant ecological value.

5.5.2 Marine ecology

5.5.2.1 Flora

The coastal area adjacent to Alba plant contains two main habitats of coral reefs and seagrass beds. The Fasht al Azm Reef is the richest, most diversified and important reef in Bahrain. It stretches eastwards from Sitrah and reaches almost to Qatar covering an area of more than 200 km^2 at a depth of less than 2 m. The northwest edge of the reef is about 2 km away from the Alba port facility and 5 km from the plant site. Only the deeper part of the northern edge of the reef has reasonable cover and species diversity, whereas the shallower parts, the reef flat and the southern edge, are virtually devoid of corals [**Ref. 8, 9**].

Seagrass beds are found to the east and north east of the plant where sediment and light conditions are suitable. The seagrass species in this area include *Halodule uninervis* and *Halophila stipulacea* which is the main food type for threatened species as the Dugong (Dugong dugong), the green turtle (Chelonia midas), and other marine mammals [**Ref. 8, 9, 10**].

A substantial amount of filamentous green algae is supported on the hard substrate of the reef. The reef slopes attract a rich fish fauna and are important commercial fishing grounds. The western part of the reef, 5 km to the east of the plant, has less diversity and cover of live corals which and consists mainly of the dominating *Acrophora* genus. The system in Bahrain is described as "balancing on a knife edge" with "corals existing at the very limits of their tolerance in respect of salinity, temperature, and sediment load" [**Ref. 8, 9**].

In the intertidal areas, the low shore zone has a thin covering of green algae. Further up the shore, barnacles, snails, worms, and small crabs dominate the area. This zone is important for breeding sea birds and other migratory species. At the tide line, the Japanese seaweed *(Sargassum*) occurs with the sub-tidal area mostly composed of sand, silt, and gravel.

5.5.2.2 Fauna

Marine fauna in the study area includes, but is not limited to, shrimps, crabs, reef fish and sizeable turtles, In addition, hump-backed dolphins occur adjacent to the deep-water channel running out from the Bahrain Yacht Club to the port facility. Most of these species, but especially shrimps, are more abundant at Fasht al Azm, Tubli Bay and the northern spawning coastline. The sea cow (*Dugong Dugong*), Omani blind cave fish (*Garra barreimiae*) and the green turtle (*Chelonia midas*) are endangered species that occur in the area [**Ref. 5**]. Flora and fauna that may occur in the study area is listed in **Table 21**. The mudflats also provide an important substrate for nitrogen fixing of blue green algae.

Table 21: Marine fauna and flora that may occur in the study area.

Flora	Fauna
Black Mangrove Avicennia, Phragmites reed beds, *Halodule uninervis, Halophila stipulacea, Sargassum, Hormophysa, Padina* Corals: *Acrophora* Filamentous green algae (*Ulva, Chaetomorpha, Cladophora*)	Sea cow: *Dugong dugong* Green turtle: *Chelonia midas* Sea snakes Shrimps Dolphins (humpbacked, common, bottlenose) Fish

5.5.2.3 Sensitive Areas

Sensitive areas are categorised in Bahrain as a function of their ecological sensitivity. These categories are:

- Priority 1 - full protection status
- Priority 2 - conservation status
- Priority 3 - seasonal management status

Tubli bay, situated 8 km north of the Alba port facility, is categorised a Priority 1 area. It has a unique ecological interaction between mangroves, seagrass and corals and as such provides an important system for spawning coastal fisheries. The only mangrove specie existing in the area is the Black Mangrove (*Avicennia marina*). The most common seagrass in the bay is Halodule uninervis. Fasht Al Azm reef and the Tubli bay fish nursery and feeding areas are categorised as Priority 2 areas. Finally, the eastern coastal strip extending from Sitra to Askar is categorised a priority 3 area due to its importance as a nesting and feeding site for both migratory and resident birds.

Other protected areas in Bahrain include the Hawar Islands (25 km south of Bahrain), and Al-Areen Wildlife Park (20 km to the south-west of Alba). These areas have an important diversity of flora and fauna with the Hawar Islands presenting an important habitat especially for migratory birds.

5.6 Waste Management

In the production process at Alba, a variety of solid and liquid wastes are generated during smelter operations. In order to assess the impact of Alba's expansion on waste generation, the subsequent sections describe the current status of waste management in terms of generation, handling and disposal. In addition to describing the waste management practises within Alba, it is also important to highlight the present-day waste practises in the country as a whole.

Therefore, an overview of the current status of waste generation and waste management in the Kingdom of Bahrain is provided first, followed by a description of waste presently generated at Alba.

5.6.1 Waste in Bahrain

With an average population density of circa 1,461 persons per square kilometre (km^2)[5], Bahrain is one of the highest per capita municipal solid waste generators worldwide. It is estimated that 1.67 to 1.80 kg of solid waste per person is generated daily, which is, despite being the smallest country in the region, the largest amount per person among GCC countries [**Ref. 11**].

1.2 million tons of solid wastes are generated yearly and daily garbage production exceeds 4,500 tons. Municipal waste in Bahrain is characterized by a high percentage of organic material (~ 60%) which is mainly composed of food wastes. Moreover, ~ 24 % of solid waste is recyclable[6] and being processed through informal sectors which are responsible for collection and recycling activities.

In general, waste collection and disposal operation is managed by different private contractors across the five governorates. In the Southern governorate, where Alba is located, waste collection is handled by Sphinx Services. The predominant solid waste management scenario is to collect solid waste and to dispose it at the municipal landfill at Askar (**Figure 19**).

5.6.1.1 Askar Municipal Landfill

Askar, which belongs to the Municipalities and Urban Planning Affairs (MOMUA) Ministry, is the only existing landfill/dumpsite in Bahrain and spread over an area of more than 700 acres or 7 km^2. Askar is operational since 1988 and the site caters to municipal wastes, but also provides to agricultural wastes and non-hazardous industrial wastes.

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[5] Based on a population of ~ 1,100,000 in 2008 – [**Ref. 12**]

[6] 13% paper, 7% plastic, 4% glass

Askar is located approximately 25 km from Manama and 2.2 km from the nearest residential area (Askar Village). The landfill site is located on an impermeable layer of rock and consists of open quarries. Furthermore, the rock and limestone are continuously excavated for the steel industry, construction and other industrial applications [**Ref. 12**].

Landfill is controlled by cellular tipping and compaction of waste. However, there is no leachate drainage layer, lining system, gas collection or monitoring boreholes. Nevertheless it is assumed that the risk of groundwater contamination is low because of the combination of hot climate, low rainfall and low water permeability of the surrounding geology [**Ref. 12**].

Figure 19: Location of Askar Landfill Site

In Askar, approximately 2.4 km^2 of the landfill has been filled to an average waste depth of 15 m. Estimates show that 1.7m^3 of landfill space is required for every tonne of waste. Assuming an annual waste input increase of 5%, the Askar landfill would reach its capacity in 2015 [**Ref. 12**]. A different source indicates that the Askar landfill site might reach its capacity in 2016 [**Ref. 11**].

Therefore, in order to be prepared for future wastes generation, a Public-Private Partnership has been set up, known as the *Askar Waste to Energy Project*, which will comprise of an US $ 480 million waste incineration facility. This facility will treat 390,000 tonnes of solids waste per year, whereby 25 Mega Watt (MW) of power will be generated and fed into the national grid. Currently, this project is put on hold.

In 2012, the global advisory firm KPMG International listed the project in the Top 100 infrastructure projects in the category recycling and waste management [**Ref. 13**]. [7]

5.6.1.2 Non-Hazardous Waste

As part of a systematic analysis of Bahrain's waste management performance, Sabbagh *et al*. (2012) [**Ref. 12**] categorised and quantified non-hazardous wastes disposed at the Asker landfill over the period 2003 to 2009 (**Figure 20**). As shown from the data, a two step-wise increase in waste quantities was observed from 2004 to 2005 and from 2007 to 2009 (indicated in **Figure 20** with arrow 1 and 2 respectively). Within the five years, the overall disposed weight of non-hazardous waste increased almost 2.5 times. Furthermore, during the last two years, Construction and Demolition (C&D) waste was the dominant fraction and increased in absolute quantities as well. As shown in the figure, the domestic waste remained relatively stable until an abrupt increase in 2007 – 2008. It is to be noted that the latter may not indicate actual changes in quantities, but might also be caused by issues with data handling and reporting. In 2009, a total of 1,532,526 tonnes of non-hazardous waste was disposed of at Aska. Furthermore, percentages of 2009 (as provided in the Figure) indicate 37.2% of the annual waste to be related to construction and decommissioning activities in the Kingdom.

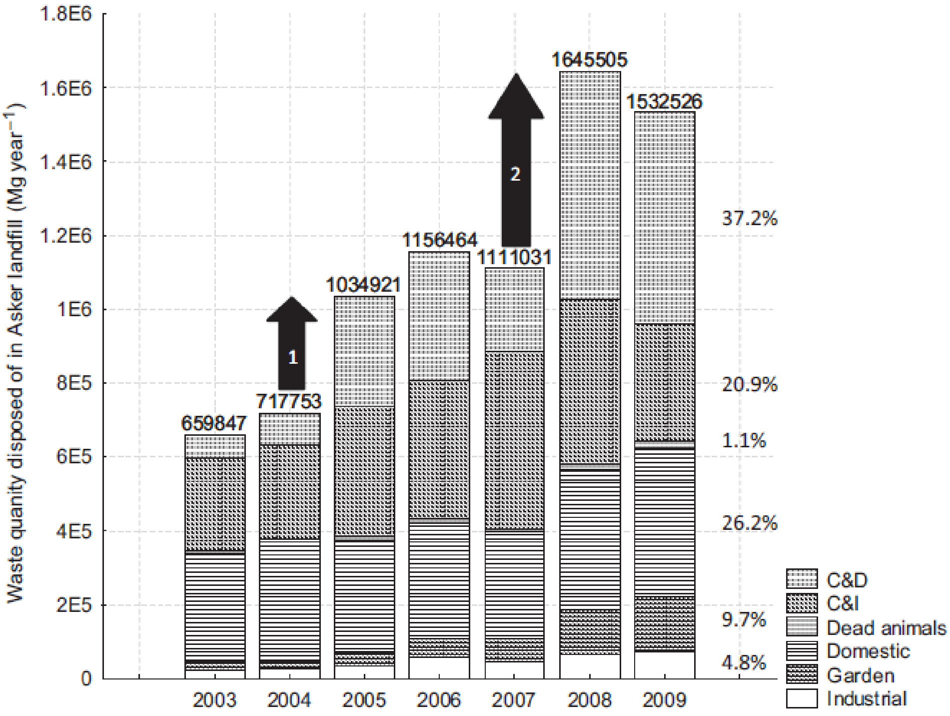

Figure 20: Quantities and Allocations of Non-hazardous Waste - Askar Landfill[8]

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[7] The project was listed number 1 in the Top 10 of waste management projects. Projects were selected by industry experts based on their feasibility, social impact, technical and/or financial complexity, innovation and impact on society.

[8] **Ref. 12**

In addition, a material flow diagram was created by Sabbagh *et al*. (2012) indicating all the key non-hazardous waste system components and flows in the Kingdom of Bahrain (**Figure 21**). Thereby most of the quantities are estimated or extrapolated from the Askar landfill data, and data included for recycling are based on interviews with stakeholders. It is to be noted that the recycling collection points shown in the diagram do not include i) scrap metals obtained from commerce and industry, ii) large Waste Electric and Electronic Equipment (WEEE), and iii) End Of Life Vehicles (ELVs).

The diagram indicates clearly that the majority of waste is used as landfill, with limited collection for recycling. Recycling activities of municipalities are performed by two private waste collection contractors which provide five public recycling points throughout the country. In addition, there are a number of small recycling companies present in Bahrain, of which the largest is Crown Industries which recycles ferrous and non-ferrous metals and plastics.

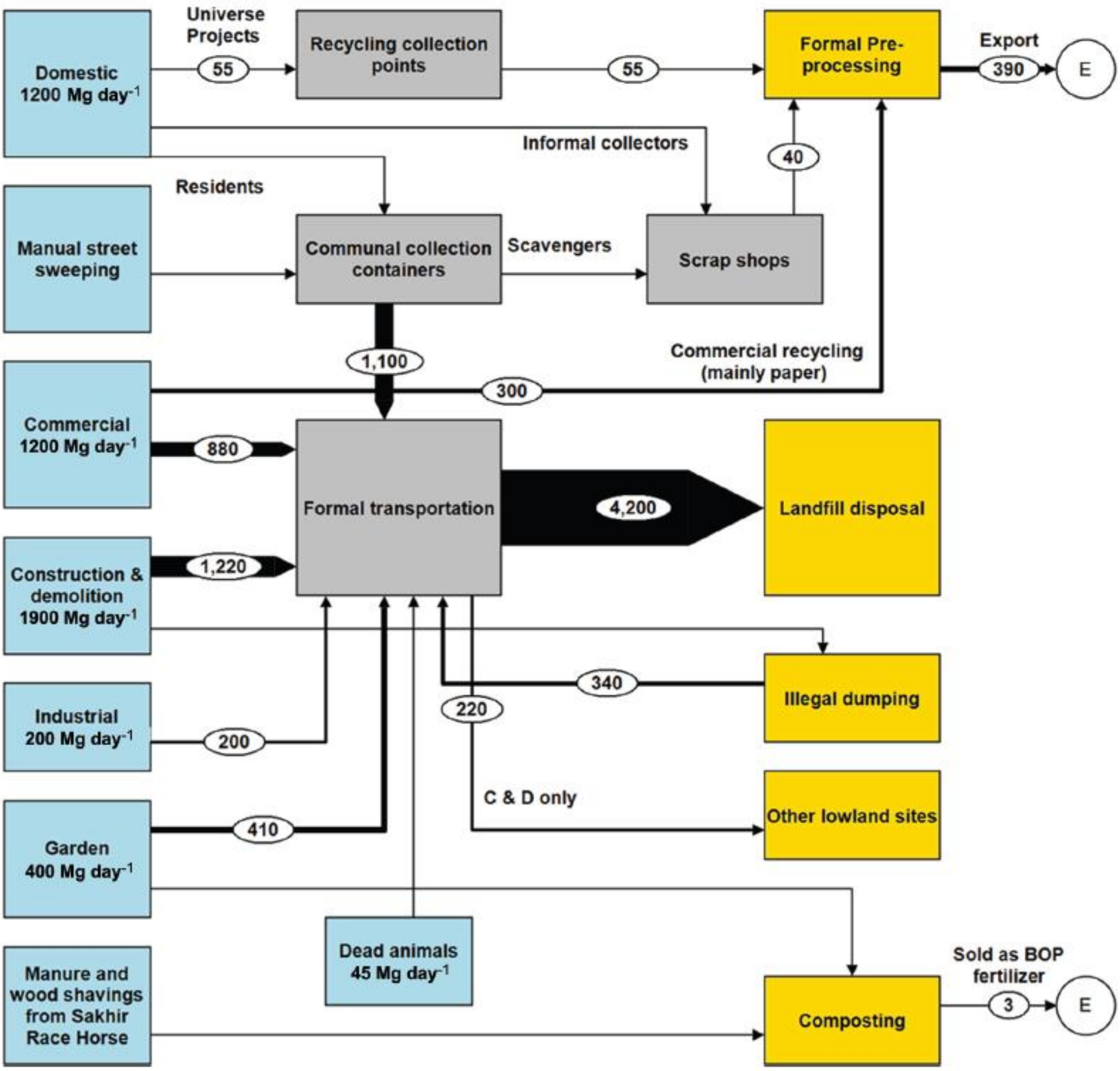

Figure 21: Waste Flow Diagram (Non-hazardous Wastes)[9]

5.6.1.3 Industrial and Hazardous Waste

Whereas MOMUA is the responsible authority for municipal waste, industrial waste is managed by the SCE [**Ref. 14**]. In the Kingdom of Bahrain, 380 tonnes of industrial waste is generated every day [**Ref. 14**].

The industrial hazardous waste is collected by registered hazardous waste collection contractors. In addition, industrial waste is characterized and then disposed at Hafeera Industrial Landfill site, which is located in a quarry area

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[9] **Ref. 12**

approximately 25 km from Manama and was developed by the Public Commission for the Protection of Marine Resources, Environment and Wildlife.

After construction and commissioning in 2001, the Industrial Landfill had the capacity of 746,000 m^3 to accommodate industrial hazardous and semi-hazardous waste generated in the country. The main component of hazardous waste at the landfill site is the spent pot lining from Alba along with other types of industrial wastes including sludges, asbestos and expired medicines. Current available capacity is not known.

5.6.1.4 Medical Waste

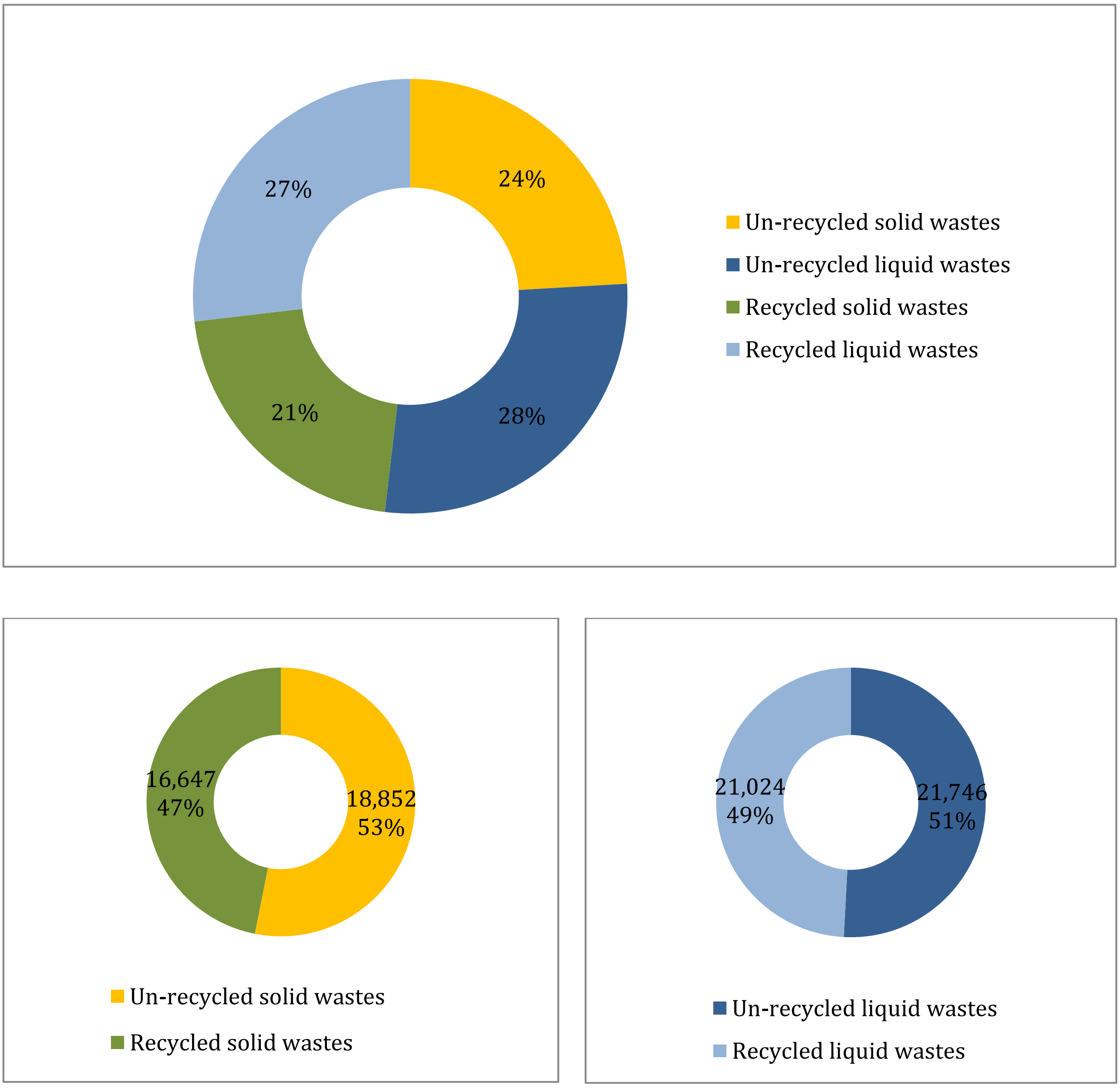
In the Kingdom of Bahrain, medical waste is managed by the Ministry of Health. On a daily basis 7 tonne of health care waste is generated, collected in specialized vehicles and sent to privatised incineration facilities.

5.6.2 Waste Generated at Alba

As indicated earlier in section 4.3.2, a variety of solid and liquid wastes is generated during Alba's operations. These wastes (hazardous and non-hazardous) can be classified as:

- Recycled solid wastes;
- Un-recycled solid wastes;
- Recycled liquid wastes; and
- Un-recycled liquid wastes

An overview of the types of wastes generated in 2013 is presented in **Figure 22**. As shown from the figure, a total of **37,670** t of wastes was recycled, whereas **40,598** t could not be recycled and was sent to landfill (hazardous and non-hazardous). It is to be noted that waste water streams (for example casthouse blow-down water and treated effluent) is not taken into consideration in this section, but is separately discussed in section 8.5 (*Water*).



Recycled Wastes

	Metric Ton / year
Recycled Solid Wastes	16,647
Recycled Liquid Wastes	21,024
Total	**37,670**

Un-recycled Wastes

	Metric Ton / year*
Un-recycled Solid Wastes	18,852
Un-recycled Liquid Wastes	21,746
Total	**40,598**

Figure 22: Overview of Waste Generated in 2013

A summary of the wastes generated in the process (see section 4.3.2) is presented in **Table 22** below.

Table 22: Summary of Waste Currently Generated at Alba

#	Process	Waste Generated	Waste Type	Comments
1	Reduction Area	Solidified Bath	Recyclable	Re-introduced as cover material in reduction cells
		Dust	Recyclable	Re-introduced into the process
		Filter bags	Un-recycled Non-hazardous waste	Askar Municipal Landfill
		Spillages	Recyclable	Spilled alumina and bath is re-introduced into process after segregation
2	Carbon Plant	Carbon Waste	Recyclable	Cleaned, crushed, milled, screened, and stored for reuse in green anode production
		Dust	Recyclable	Reintroduced as a raw material for reuse in the anode manufacturing process
			Un-recycled Non-hazardous waste	Askar Municipal Landfill
		Cast Iron	Recyclable	Re-melted at a casting carousel and the cast iron reused for rodding.
		Slug produced while preparing and casting the iron for road sealing	Un-recycled Non-hazardous waste	Askar Municipal Landfill
		Refractory Waste	Un-recycled Non-hazardous waste	Askar Municipal Landfill – Has the potential to be recycled
3	Cast House	Dross and skimmings	Recyclable	Processed to recover the aluminium
			Un-recycled Hazardous waste	Depleted dross is either sent to Hafeera Hazardous Waste Landfill or exported as secondary raw material
		Refractory wastes	Un-recycled Non-hazardous waste	Askar Municipal Landfill – Has the potential to be recycled
		Sulphur waste	Un-recycled Hazardous waste	Hafeera Hazardous Waste Landfill
		Recoved casting oil - Waste Water	Recycled Hazardous waste	Recently being processed by Osrex[10]
4	Pot Lining / Delining Facilities	Spent Pot linings (SPL)	Partly recyclable	Recycled by contractor
			Un-recycled Hazardous waste	Remaining fines fraction disposed off at Hafeera Hazardous Waste Landfill
		Waste ramming paste	Un-recycled Hazardous waste	Hafeera Hazardous Waste Landfill
		Scrap Steel	Recyclable	Recovered from SPL and then recycled.
5	Power Stations	Used oils	Recyclable	Transported to Bapco and partly sold to the oil recycler (Qatar Factory)

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[10] Osrex is the major waste oil & hydrocarbon residue reprocessing company registered in the kingdom of Bahrain.

#	Process	Waste Generated	Waste Type	Comments
		Hydrocarbon condensates	Recyclable	Extracted from the liquid knock-out of the gas handling and transported to Bapco
		Water/Oil mix	Un-recycled Non-hazardous waste	Askar Municipal Landfill
6	Workshops and Maintenance Facilities	Batteries	Recyclable	Sold to Crown Metals for recycling
		Tires	Recyclable	Sold to Crown Metals for recycling
		Vehicle radiators	Recyclable	Sold to Crown Metals for recycling
		Used oils	Recyclable	Sold to oil recycler (Qatar Factory)
7	Other	Construction wastes	Un-recycled Non-hazardous waste	Askar Municipal Landfill
		Domestic wastes	Un-recycled Non-hazardous waste	Askar Municipal Landfill
		Tree cuttings	Organic Waste	Askar Municipal Landfill
		Sewage sludge	Liquid effluents / waste water	Treatment Plant
		Wood	Recyclable	Sold to Crown Metals for recycling
		Copper	Recyclable	Sold to Crown Metals for recycling
		Drums	Recyclable	Sold to oil recycler (Qatar Factory)
				Other drums sold to Crown Metals for recycling
		Wooden pallets	Recyclable	Sold to Crown Metals for recycling
		PVC	Recyclable	Sold to Crown Metals for recycling
		Medical Wastes	Medical Waste	Incinerated at medical waste incinerator
		Aluminium	Recyclable	Re-introduced into process or sold to Crown Metals.
		General waste	Un-recycled Non-hazardous waste	Askar Municipal Landfill
🟦		Recyclable	🟩	Non-hazardous Waste
🟥		Hazardous-Waste	🟨	Medical Waste

5.6.2.1 Quantities of Non-recyclable Waste

In **Table 23** a quantification of unrecyclable waste streams is provided based on waste generated in 2013.

Table 23: Waste to Landfill

#	Process Area	Waste Generated	Waste Type	Quantities in 2013 (Metric Tons/Year)	Location of Disposal
1	Carbon Plant	Carbon Dust	Non-hazardous	1136.29	Askar Municipal Landfill – Has the potential to be recycled
		Cast Iron Slag	Non-hazardous	635	Askar Municipal Landfill
2	Cast House	Sulphur waste	Hazardous	48.48	Hafeera Hazardous Waste Landfill
		Recovered casting oil – Wet sludge	Hazardous	270 m^3	Hafeera Hazardous Waste Landfill
3	Pot Lining / Delining Facilities	Spent Pot linings (SPL)	Hazardous	5024	Hafeera Hazardous Waste Landfill
		Waste ramming paste	Hazardous	NA	Hafeera Hazardous Waste Landfill
4	Workshop	Oily water	Non-hazardous	245.48	Askar Municipal Landfill
5	Plant Wide / Other	Bag House Ash	Non-hazardous	149.02	Askar Municipal Landfill
		Construction wastes	Non-hazardous	1210.87	Askar Municipal Landfill
		General Waste	Non-hazardous	3831.82	Askar Municipal Landfill
		Office and Cafeteria Waste	Non-hazardous	277.89	Askar Municipal Landfill
		Tree cuttings	Organic Waste	518	Askar Municipal Landfill
		Sewage sludge	Liquid effluents	21,195	Sewage Treatment Plant
		Medical Wastes	Medical Waste	0.39	Incinerated at medical waste incinerator
		Refractory waste (Maintenance)	Non-hazardous	5984	Askar Municipal Landfill
		Calciner Lime Sludge	Non-hazardous	272.76	Askar Municipal Landfill

5.7 Noise

In Alba’s production process, various noise generating sources have an influence on noise levels at the facility. In order to assess the degree to which these noise generating activities may result in a disturbance to surrounding land-users it is necessary to define the activities that are likely to generate noise and to define the commensurate sound power levels.

As part of Alba's hearing conservation programs, noise measurements are periodically undertaken at different locations in the process plant. These measurements are used to assess the employees' daily exposure and to identify high noise level areas.

In 2011 and 2012, measurements were taken with a Sound Level Meter in the following areas:

- Carbon Area 1, 2 & 3 (2011);
- Cast House (2012);
- Pot Line 1 – 3 (2012);
- Power Stations 1 - 5 (2012); and the
- Maintenance and Workshop area (2012).

Major noise generating sources in the carbon area include, but are not limited to, the ball mills, paste coolers, crushers, coke hammer mill, thimble stripper machines, casting and blasting machines. The majority of the readings conducted in the area exceeded Alba's occupational health limit of 85 dB (A) at 1m.

In the cast house area, major noise generating sources are furnaces, hydraulic pumps, compressors, direct casting and metal transfer vehicles. Noise sources within the cast house area ranged from 70 to 100 dB (A).

Noise generated in the potlines range between 70 – 102 dB (A), and is generated by vehicles such as anode changers, point feeders, crushers and air compressors. In the power stations, major noise generating sources are turbines, pumps, compressors, rectifiers and boilers. Noise levels in this area ranged from 70 – 110 dB (A).

Noise generated in the workshop area is mainly related to activities such as fabrications, welding, fitting and vehicle maintenance. Noise levels of 70 – 114 dB (A) were measured in the workshop area.

It is to be noted that the above indicated measurements were conducted as part of industrial hygiene for Alba's employees. Alba's procedures with Personnel Protection Equipment (PPE) for hearing protection apply in zones where noise levels exceed the acceptable limits.

In order to assess the noise impact on surrounding land-users and the contribution to ambient noise levels in these areas, noise monitoring was conducted as part of the current ESIA study.

The ambient noise levels were monitored using a Type-2 Integrated and Logging Sound Level Meter for an approximate duration of fifteen (15) minutes per location.

A total of eleven (11) monitoring locations were selected for noise monitoring during the day-time on a weekend day. Noise monitoring on a weekday was performed at fourteen (14) selected locations during day-time and six (6) locations during night-time. Furthermore, an additional six (6) monitoring locations were selected inside the site premises (weekday, day-time). The monitoring locations and results are presented in Appendix 9. Monitoring results generally showed ambient noise levels (L_{eq} 58.3 dB(A) – 73.5 dB(A)) to be within the applicable limits set by the World Bank for industrial and commercial locations (70 dB (A) for both day- and night-time).

However, noise levels at the South Gate, in close proximity to the emergency clinic, exceeded 70 dB during day-time by 0.5 – 1 dB(A)[11] owing to heavy vehicle movement in the area. In addition, noise levels at the camps off the Alba plot (location number 13, in Appendix 9) reached 73.5 dB(A) due to heavy traffic on the adjacent highway.

The ambient noise levels at the other locations were observed to be within applicable limits.

5.8 Water

Fresh water is extremely scarce in Bahrain and as a result freshwater requirements are met through desalination plants. In general terms there are two water tables, one that is a few metres from the surface and one that occurs at about 150 m below the surface. Because the shallower water table is highly saline, water is sourced from the deeper water table where the water is less saline. This water is pumped from the deeper water table and treated for domestic and industrial use.

5.8.1 Water supply

The water required on the plant is not directly required in the aluminium reduction process, but there are multiple cooling requirements where water is used, including the compressor house, the paste plant, anode rodding, the casthouse and the cooling tower of the Fume Treatment Centre. Main water requirement at the power stations is for boiler feed makeup. The principle source of water at Alba is generated from the desalination plant at the Port calciner facility.

For the generation of demineralized water (DM) for steam generation of PS 2, 3, and 4, the second pass of the R/O plant is used.

For short periods of approximately 1 week every 3 months, water supply for Alba smelter is sourced from three borehole wells feeding three reverse osmosis (R/O) plants via both 1st and 2nd pass ROs.

Moreover, potable water is produced from R/O plants after a single pass as well as from the calciner plant based on the calciner operation described above. The potable water is stored in storage tanks located at the R/O plants for use as a coolant in the cooling tower of compressor station-3 of PS-4, Compressor station-2 at PS-3, and the cooling tower of casthouse-2 and casthouse-3.

5.8.2 Waste water

Waste water generated at Alba follow Alba's zero discharge policy where the water is used directly for irrigation or indirectly by discharging to the Alba lake located within Alba's premises.

The waste water from the power stations (the boiler blowdown), from the cooling towers of the compressor stations as well as from the R/O-2 plant's 2nd pass are used for irrigation. Casthouse 2 and 3 cooling tower waste water is discharged to the Alba lake..

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[11] Measurement Location No. 3 weekend – Leq 71.0 dB (A); Measurement Location No. 3 weekday – Leq 70.5 dB (A)

During normal operations (i.e. water supplied from the calciner facility at the Port), 3 m^3 per day of regeneration waste water (occasional occurrence) associated with the production of demineralized water for the power stations (2nd pass of RO-2 plant) is discharged from the Alba smelter into the nearby marine environment via an outfall pipeline. Moreover, reject brine from the 1st pass of the R/O-2 plant generate an additional 1,224 m^3 per day of waste water effluents. Therefore, a total volume of 1,227 m^3 per day is being discharged into the marine environment via the outfall pipeline during normal operations. However, when the calciner is under upset conditions (calciner shutdown), RO plants 1, 2, and 3 are utilized to supply the required process water. A total volume of 4,539 m^3 per day is being discharged into the marine environment via the outfall pipeline per day during calciner shutdown. The contributing following volumetric flow rates associated with RO plants operations are as follows;

- 984 m^3 per day of waste water from the operations of RO-1 plant;
- 2,448 m^3 per day of waste water from the operations of RO-2 plant;
- 3 m^3 per day of regeneration waste water from the 2nd pass of RO-2 plant; and
- 1,104 m^3 per day from the operations of RO-3 plant.

Effluents from the boiler feed water demineralisation plant (regeneration liquid) have pH-correction and control systems, which render the effluent fit for discharge into the marine environment. The effluent from the coke calcining plant at the Port and the associated desalination plant is discharged into the sea.

Due to the build-up of dissolved solids in the cooling water from cooling towers at compressor stations as it is recycled, it is necessary to periodically supplement the cooling system with fresh water, and to discharge the water in which these dissolved solids have accumulated. This so-called cooling tower ‘blow-down’ water is discharged from the various (semi) closed circuit cooling systems.

In addition to the accumulation of dissolved solids, cooling water used in cooling towers also contains corrosion and fouling inhibitors, typically polyphosphates or phosphonates, and biocides. The biocides are used to prevent algae growth in the cooling water and are typically a chemical mix with either a chlorine or bromine base. Cooling water systems can be dosed in such a way as to ensure that the blow-down water does not contain any of these chemicals in concentrations that exceed specified standards. In a similar way, boiler blow-down water from the power stations can contain low concentrations (typically < 5 ppm) of ammonia.

The existing marine water outfall system used by the smelter consists of a pipeline leaving the site on the eastern side and running towards the sea over a distance of few hundred meters. Although the outfall pipeline originally discharged directly into the sea, land reclamation over the years by other industries has resulted in the pipeline now ending in a stretch of reclaimed land. The water from the discharge pipe is running through a channel to the sea. The marine outfall has been in use for many years. **Figure 23** and **Figure 24** shows the extent of reclaim over time.

Figure 23: Current outfall area - Google Earth imagery 16 May 2013

Figure 24: Outfall area - Google Earth Imagery 23 May 2004

The ‘blow-down’ water from PS 2, 3, 4 as well as compressors’ cooling towers equates to 777 m^3 per day of discharge. To comply with the Zero Liquid Discharge (ZLD) protocol setup by Alba’s management, the ‘blow-down’ water is used for irrigation purposes.

Further, contaminated water from the different plant drains is collected and directed into sumps or tanks for chemical neutralisation treatment before being discharged into the effluent drainage system. Two mechanised oil separator plants remove oil from the cooling water while it is being recycled. In addition, there is another oil separator at the workshop to prevent the risk of a spillage from contaminating the effluent drainage system. Wash down water from areas that may be subject to oil spills or minor leaks join Alba’s effluents pipe line. These processes have the effect of minimising the quantity oil in the effluent discharge to the sea¸ with the result that the effluent that is discharged to the sea, meets all required standards.

As for the sewage that cannot be recycled or that is not fit to be used for irrigation purposes, the plant has sewage treatment plants, STP-1 and STP-2, to treat the domestic sewage that is generated across the plant. The sewage treatment plants are based on an extended aeration activated sludge process and can produce about 19.6 m^3 an hour of treated sewage. The treated sewage from the sewage treatment plants is used to irrigate greenery established throughout the plant, while the generated sludge is transported to the Treatment Plant by road tanker where it is dewatered and dried.

5.8.3 Effluent quality

The effluent that is discharged via the outfall pipeline is sampled and analysed every four weeks and reported every quarter to the MoE. On-going monitoring indicates that the quality of the outfall is well within the limits specified in the regulatory standards (Bahrain Ministerial Order 10/99). An example of the wastewater discharge quality (sample taken in the second quarter of 2011) is enclosed in **Appendix 10.** It can be seen from the table that there was full compliance with the specified standards for all the water quality parameters analysed with the exception of copper. Generally, increased concentrations of copper in waste water could be attributed to several factors such as; corrosion and leaching of plumbing, fungicides (cuprous chloride), pigments, larvicides (copper acetoarsenite), and antifouling paints. Majority of these materials are not being used by Alba.

Moreover, Alba monitors the sea water temperature change at the smelter outfall pipeline half-annually as changes in marine ambient water temperatures can significantly affect the marine environment. The obtained data is enclosed in **Appendix 11**. It can be seen that the reported half-annually monitored temperature changes for the years 2007-2012 are below the stipulated limit of 3°C.

5.9 Traffic

5.9.1 Alba’s Road Use

Alba’s smelter is located at the intersection along King Hamad Highway extending from Alba roundabout to Askar Village on the east coast of the Kingdom of Bahrain and to the south-west of Sitra Island. A fly over road across King Hamad Highway has been constructed leading directly to Alba’s main entrance gate which is further connected to Alba’s Private Road; a layout illustrating the following is enclosed in Appendix 12. Alba’s private road connects the smelter site to the alumina and petroleum coke truck loading stations in Alba’s port facility via Umm Al Saad Avenue in Sitra Island. **Figure**

25 illustrates the above mentioned description as well as the public roads and interchanges supporting the transportation needs of Alba facilities.

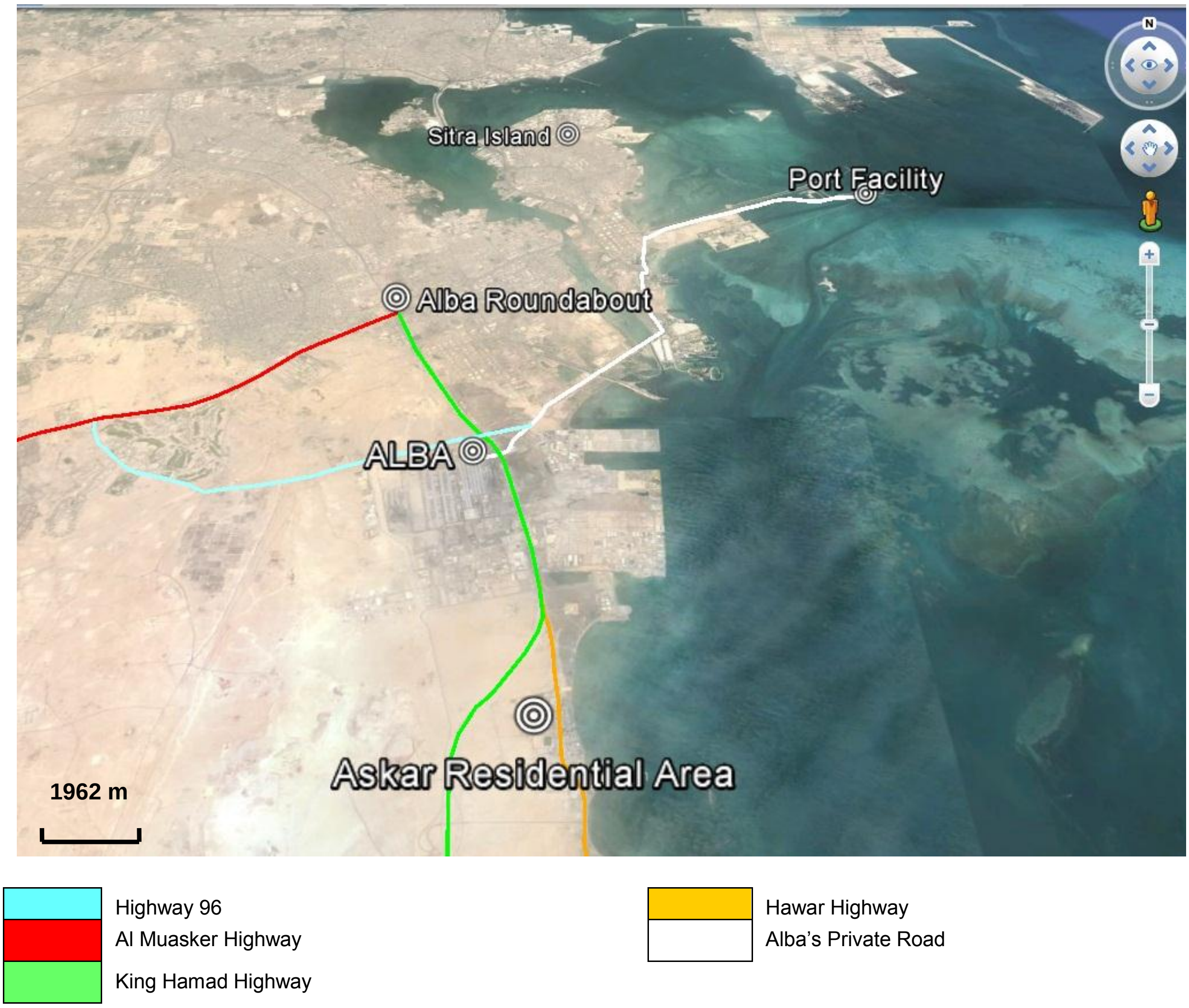

Figure 25: Map showing the various routes that are currently used by Alba

As illustrated above, the smelter is catered to by a number of public roads and intersections which includes;

- Al Muasker Highway;
- Highway 96;
- King Hamad Highway;
- Alba Roundabout;

- Hawar Road; and
- Alba’s private road.

To access Alba smelter site, there are two entrances; the main entrance area, vehicles are directed either through the security gates into the operational plant areas, or onto the old Askar road, which transverses parallel to the Hawar road outside the smelter’s fence, to a second security gate located at the south east corner of the site.

5.9.1.1 Light Vehicle Routes

Light vehicle traffic is made up mainly of employees who drive to and from Alba daily using private vehicles. Alba does provide a comprehensive bus service as a service to employees, and to reduce traffic congestion. The vast majority of employees travel from Manama, Muharraq and from communities to the northwest of Alba. The following roads are utilised for this purpose:

- Al Taawon Highway
- Independence Road (Estiqlal Road)
- Al Muaskar Highway
- Riffa Avenue

Most of this traffic is funnelled through the Alba roundabout on to Hawar road and into the Alba car park.

5.9.1.2 Heavy vehicles

With the exception of the transport of Alba’s end product, much of the heavy vehicle traffic (two thirds) results from the raw material transport between the calciner and the Alba Smelter. The number of tankers involved in the transportation of raw materials inclusive of; fresh alumina, calcined coke, and liquid pitch from the port to the smelter equates to 66,249 tankers in the year of 2012. The 11 km journey starts from Alba gate at the port facility, Alba gate trucks go across first traffic light through Alba causeway and take Umm Al Saad Avenue. After that they pass all the way to Alba private road that they enter through the Boom Gate. They follow this road until they reach the boom gate and traffic lights just outside Alba (Alba entrance intersection). After crossing Hawar road through the traffic light they enter Alba site and are directed through the main gate or along old Askar road to the south gate. Aluminium product is taken to the Mina Salman or North Sitrah Industrial area, via Hawar road and other combinations of routes, for export.

5.9.1.3 Traffic Current Road Use

As part of the environmental baseline data collection, the Roads department of the Ministry of Works (MOW) were approached by Tebodin to attain the latest Traffic count Data for the roads catering Alba facilities with special interest extended to; King Hamad Highway and Highway 96. Sequentially, the MOW supplied Tebodin with the Peak Hour Turning Movement Count Data for the Junction of King Hamad Highway and Highway 96 conducted in July of 2010 and Average Daily Traffic (24-Hour average) on Hawar Highway, near the power station conducted more recently in May, 2013.

The traffic density at the junction of King Hamad Highway and Highway 96 was evaluated based on the count data attained from MOW as conducted on the 15th of July, 2010. A schematic illustrating the aforementioned junction and its relative distance to the Alba site is demonstrated in **Figure 26**.

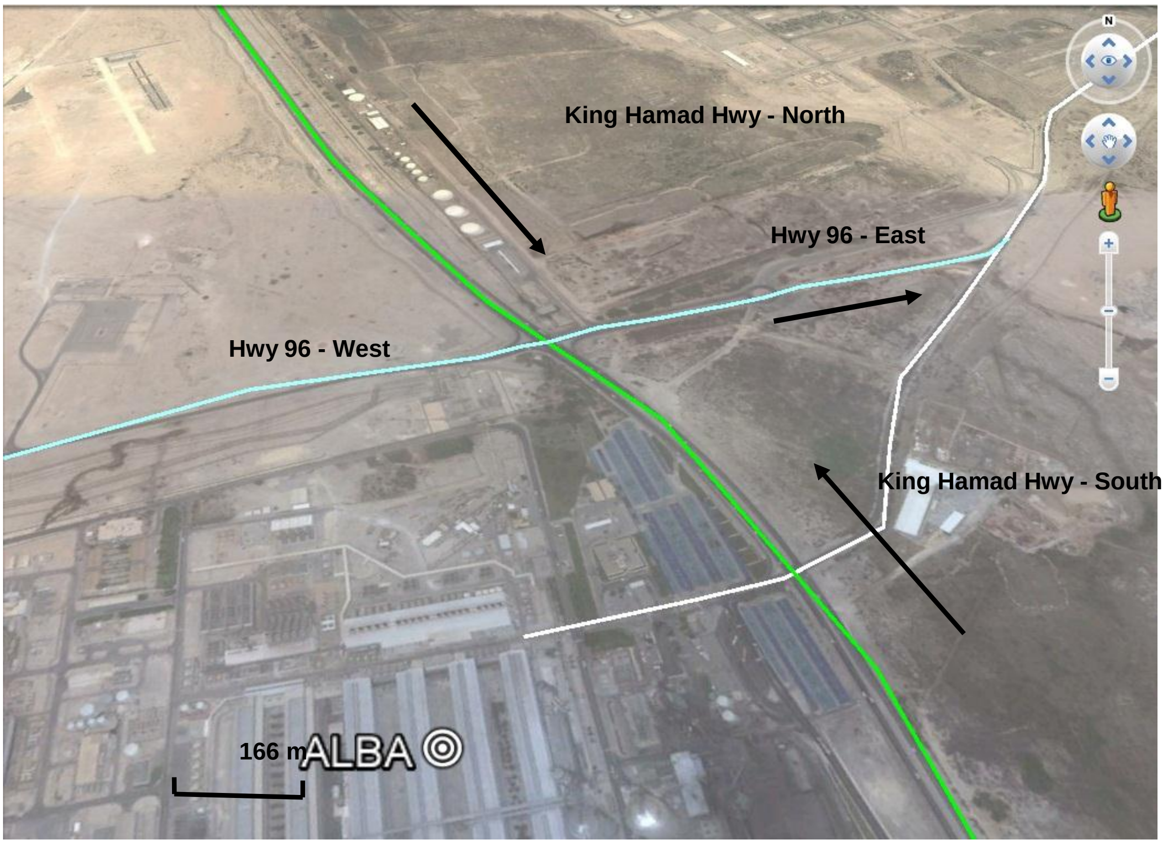

Figure 26: Junction of King Hamad Hwy & Hwy 96 relative to Alba Site

The one-day survey was conducted at two different intervals; AM (between 6:30 and 8:30 AM) and PM (between 12:30 and 15:00 PM), to indicate the peak flows accordingly. The attained data is accordingly communicated in **Appendix 13**. During the survey the numbers of vehicles passing through the Hawar road intersection were counted. It included Alba's contribution to traffic as well as regular traffic coming from the south and west of Alba. First shift leaving Alba is at 2:45 PM which is the end of the day shift.

From the traffic count, it can be deuced that the peak hour during the AM interval coincides with 6:30 – 7:30 AM while the peak hour during the PM interval coincides with 13:45 – 14:45. During the AM peak hour and in reference to average hourly count, the traffic seems to be directed from the north side towards Alba site as well as the south side away from the Alba site on the King Hamad Highway. Further, the traffic seems to be directed to the right on Highway-96 West going towards Alba gate entrance.

During the PM peak hour, same as the AM peak, the traffic seems to be directed from the north side towards Alba site as well as from the south side away from Alba site on King Hamad Highway. However, there is light traffic on the right turn of the south side of King Hamad Highway merging with Highway 96- East and heading towards Sitra Island. As for Highway 96, the traffic seems to be located on the right turn of Highway 96- West which heads to Askar Residential Area.

Given the location of the junction, it can be deduced that the traffic flow is directed either towards Alba site during the AM interval and away from the Alba site during the PM interval or towards the jetty area. Further, the peak hours coincide with Alba's working hours. Therefore, it is safe to conclude that the above mentioned data count is a good representation of the traffic density created by Alba's light and heavy vehicles. However, the survey did not indicate separate counts for heavy and light vehicles therefore, their respective contribution remains unclear.

Further, to estimate the average daily traffic on King Hamad Highway, a more recent traffic survey was conducted on May 20th, 2013 till May 23rd, 2013 on the northbound and southbound directions of King Hamad Highway. The average data of the four-day traffic survey conducted on the northbound and southbound directions of King Hamad Highway were attained from the MOW and accordingly enclosed in **Appendix 14** for reference. Based on the reviewed data, the present traffic density within the road network leading to and from Alba are high in density during their respective peak hours.

5.10 Socio-economic

5.10.1 Introduction

In the present subsection, socio-economic information regarding the Kingdom of Bahrain is outlined to evaluate the current socio-economic status and to further assess impacts of the expansion project on the community's social and economic well-being as summarized in the Project's rationale in **Section 2.4**. Such an assessment requires qualitative and quantitative measures with regards to the community's demographics, employment, personal income, and public services. The presented information has been sourced from the UN Demographic profile of Bahrain.

5.10.2 The Demographic Profile of Bahrain

5.10.2.1 Population

The population size within the Bahrain increased from 358 thousand in 1980 to approximately 1.3 million in 2010. The population size is anticipated to remain on the rise to reach 1.8 million by 2050. The indicated population size and its projections along with the ratio of males to females are illustrated in **Figure 27**. Further, the growth rate in Bahrain decreased from 3.35% to 2.55% during the period of 1985-2005. This was followed by a sharp increase in the growth rate to 11.09% in 2005-2010. Projections show that the growth rate of the Bahraini population will decrease to 2.13% in 2010-2015 and this downward trend will continue and will reach 0.13% in the period 2045-2050.

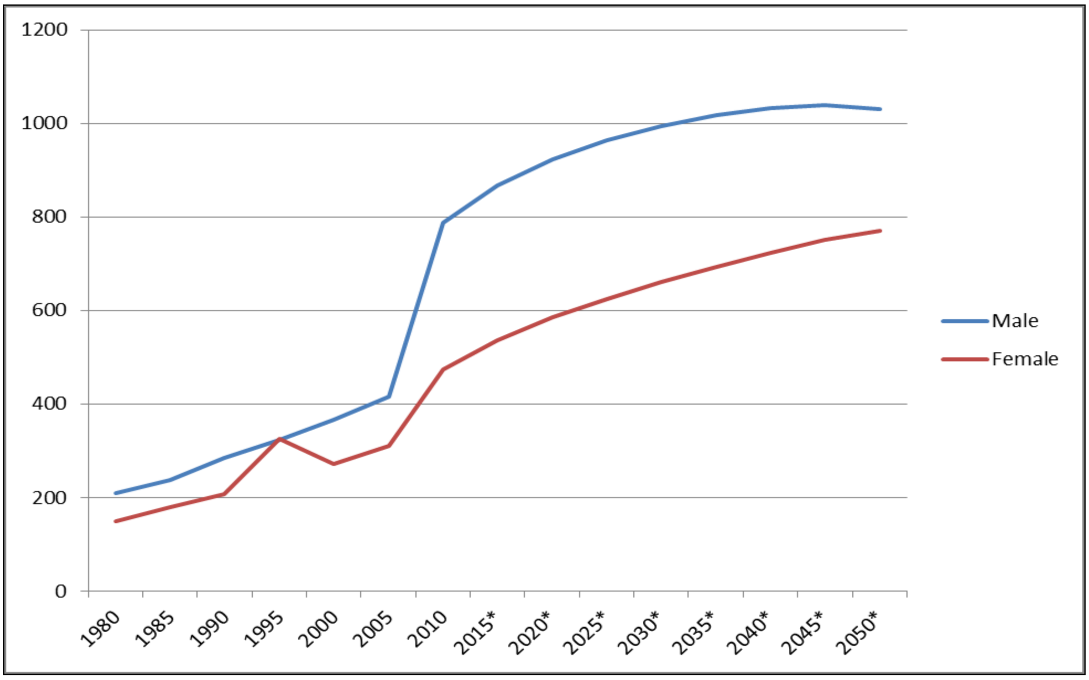

Figure 27: Male and Female Population Size against Time in Bahrain, 1980-2050

5.10.2.2 International Conference on Population and Development

Bahrain is performing very well with regard to meeting the global goals set by the International Conference on Population and Development (ICPD) for life expectancy, infant mortality, under-five mortality, and maternal mortality. With a life expectancy of 74.0 years registered for the period 200-2005, Bahrain has already achieved the ICPD target of greater than 65/70 years set for 2005. Projections show that the country will also meet the global goals of greater than 70/75 years set for 2015 by having a life expectancy of 75.3 years. Further, Bahrain's infant mortality rate for the periods of 1995-2000 and 200-2005 was estimated at 11.5 and 9.1 infant deaths per 1,000 live births, respectively. This indicates that Bahrain has already met the target of 50/70 and of below 50 infants deaths for 2000 and 2005, respectively. The infant mortality rate is projected to remain on decreasing to reach 6.7 infants per 1,000 live births in 2015, which is lower than the target of below 35 deaths per 1,000 live births set for the year of 2015. The following facts have been based on statistics gathered and compiled by the United Nations and consequently enclosed in **Appendix 15.**

The same applies for under-five mortality rate, which was estimated at 14 and 11 deaths per 1,000 live births in the periods of 1995-2000 and 2000-2005, respectively when ICPD targets are 50/70 per 1,000 live births for 2000 and below 60 per 1,000 live births for 2005. The projections also continue to decrease to reach 9 deaths per 1,000 live births in 2015 when ICPD target is below 45 per 1,000 live births for 2015. Further, as to maternal mortality, it stood at 19 maternal deaths per 100,000 live births in 2008, which is already below the goal of 60 to 75 per 100,000 live births set for 2015. The same goes to birth assisted by skilled attendants (quoted as 97% of the deliveries for the period 2000-2010)

5.10.2.3 Socio-economic characteristics of Bahrain

Some key macro-economic figures related to Bahrain from 2012 are listed below;

- Gross Domestic Product (GDP), Current: US $30.4 billion
- Associated Growth: 4.1%

- GDP, Constant: US $27.1 billion
- Associated Growth: 3.4%
- Population: 1,195,020 (2011)
- Currency: Bahraini dinar (BHD) = 1,000 fils
- Inflation: 7%

Today, Bahrain's service industry contributes 41.5 per cent to the GDP. The finance and tourism industry have also been critical elements to Bahrain's economic diversification. The finance industry alone is responsible for nearly 27 per cent of the GDP and 40 per cent of Bahrain's economic growth in 2011. In 2010, Bahrain's GDP grew of 3.955 per cent to US$29.663 billion[12].

5.10.2.4 Manufacturing

With Bahrain's oil reserves anticipated to run out in 10-15 years, the Bahraini government has strived to diversify its economy over the past decade while continuing to grow its oil production to 100,000 barrels per day over the next five years compared to the present 42,000 barrels per day. On the other hand, gas reserves are expected to last for 50 years at the present rates of consumption. However, the rising demand for gas associated with the development boom creates an issue.

Revenues from the export of oil and natural gas currently account for 25% of the GDP however, representing 76% of government income.

Ways of diversifying the economy, include

1. The state owned Bahrain Petroleum Company refinery has a capacity of 260,000 b/d, Saudi Arabia provides the crude oil for refinery operation via a pipeline and by agreement, Bahrain receives half of the net output and revenues from Saudi Arabia's Abu Saafa offshore oilfield.
2. The state-owned Aluminium Bahrain (ALBA) which operates the largest aluminium smelter in the world outside Eastern Europe.
3. Bahrain is a regional financial and business centre

5.10.2.5 Bahrain Balance of Trade

As reported by the Ministry of Finance, Bahrain recorded a trade surplus of 2454.80 Million BHD in 2012 and an average balance of trade of 505.95 Million BHD from 1975 until 2012, reaching an all-time high of 2836.70 Million BHD in 2011 and a record low of -221 Million BHD in 1992. Bahrain has been consistently reporting trade surpluses due to oil and gas exports as well as other exports such as; aluminium, chemical products, transport equipment, electrical equipment and textiles. However, Bahrain's main imports are fuels, electrical equipment, chemical products, transport equipment, metals and plastics. Bahrain's main trading partners are Saudi Arabia, the United States, Australia, the United Arab Emirates

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[12] GDP dollar estimates given are derived from purchasing power parity (PPP) calculations used to used to determine the relative value of different currencies.

and India. The Balance of Trade for the Kingdom of Bahrain between January 2004 and January 2012 is illustrated in **Figure 29**.

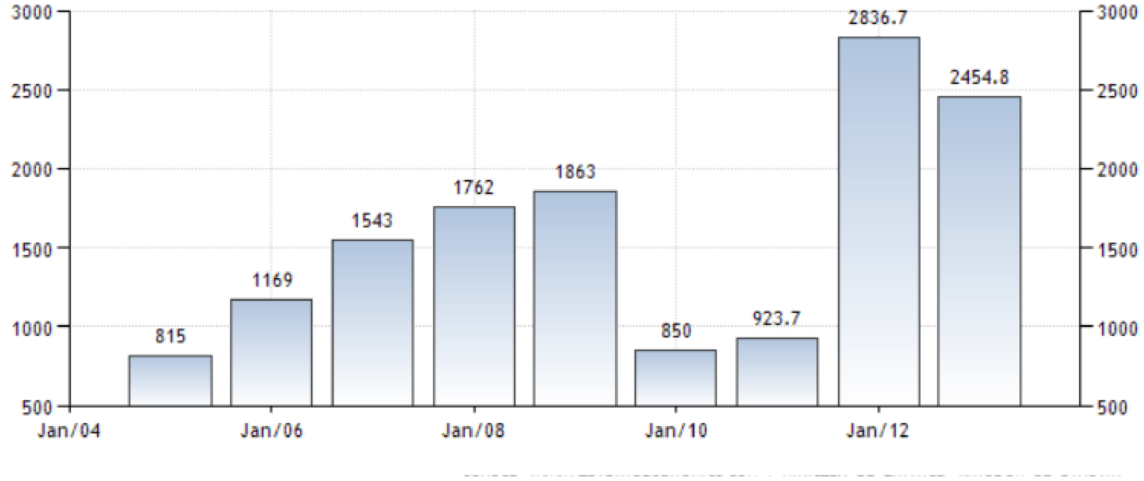

Figure 28: Bahrain Balance of Trade

5.10.2.6 Unemployment

Unemployment Rate in Bahrain is reported by the Central Informatics Organisation - Kingdom of Bahrain. It was reported that the unemployment rate in Bahrain decreased to 3.80 per cent in 2012 from 4 per cent in 2011. From 2008 until 2012, the Bahrain Unemployment Rate averaged 3.8 per cent reaching an all-time high of 4.1 per cent in November of 2009 and a record low of 3.3 per cent in November of 2008. The following unemployment rate includes the number of people actively looking for a job as a percentage of the labour force. Bahrain unemployment rate as reported by the Central Informatics Organisation between July 2009 and January 2013 is illustrated in **Figure 30**

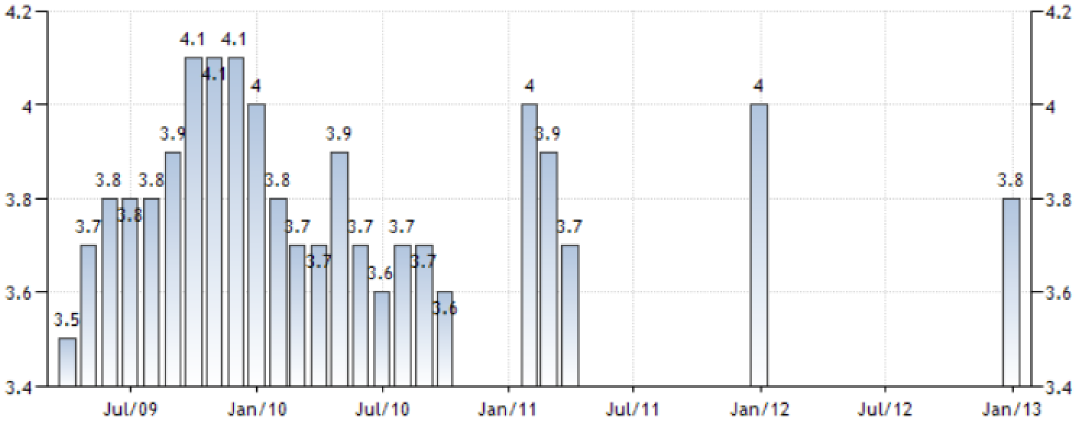

Figure 29: Bahrain Unemployment Rate

As of August 2013, the Bahrain's labour force is made up of 566730.00 employed personals with 44 per cent of them being non-nationals or expatriates. The number of expatriates has declined in recent years since sponsorship for expatriate workers was reduced by the government.

5.11 Archaeology and Cultural Heritage

As previously indicated the material lay down area is located outside Alba's present fence line and is within a designated green field with clear signs of human interaction (asphalt road, backfilling, litter and debris). In order to establish the baseline from an archaeological and cultural heritage point of view, information was sourced from the Kingdom of Bahrain's Ministry of Tourism and Culture. The Director of Archaeology & National Heritage indicated that the Ministry of Culture has no archaeological concern in the project area.[13]

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[13] Letter received on 30th of March 2014, attached in Appendix 16.

6 Impact Assessment

6.1 Introduction and overview

In the previous chapters the environmental aspects of the Alba operation have been described, together with a description of the state of the environment that is currently affected by operations of the existing Alba plant, and that may be affected by the proposed development. Impacts on the environment are a function of these two components, namely the environmental aspects of the operation (existing and proposed) and the state or vulnerability of the existing environment that may be affected by those aspects. In this chapter, the two components are integrated to present possible impacts of the proposed development on the environment together with the significance of those impacts.

The assessment of the impacts includes qualitative and quantitative methods (noise and air) of impact prediction. The impacts are assessed based on assessment matrices with low, medium or high ratings, based on the severity and the duration (for planned / normal aspects) or likelihood (for unplanned aspects) of their occurrence.

Based on the impact assessment results, mitigation measures are included for each environmental aspect and compliance with performance standard from the International Finance Corporation (IFC) is assessed. These performance standards are referred to as Environmental, Health and Safety (EHS) Guidelines that are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP). They contain the performance levels and measures that are normally acceptable to the World Bank Group, and are generally considered to be achievable in new facilities at reasonable costs with existing technology.

The relevant performance standards and their applicability to the different environmental aspects are presented in **Table 24.**

Table 24: Applicable IFC Standards

S. No.	IFC Standard	Content / Aspect	Applicability
1	Environmental, Health, and Safety (EHS) Guidelines, General EHS Guidelines: Environmental, Waste Management, April 30, 2007	Waste Management	Section 6.7, Waste Management
2	Environmental, Health, and Safety (EHS) Guidelines, General EHS Guidelines: Occupational Health And Safety, April 30, 2007	Occupational Health and Safety	Section 6.10, Occupational Health and Safety (OHS)
3	Environmental, Health, and Safety Guidelines Base Metal Smelting and Refining, April 30, 2007	Air Emissions	Section 6.2, Air Quality
		Energy Consumption and Efficiency	Section 6.6, Energy Use
		Waste Water	Section 6.3, Water
		Hazardous Materials	Section 6.4, Soil
		Occupational Health and Safety	Section 6.10, OHS
4	Environmental, Health, and Safety Guidelines for Thermal Power Plants, December 19, 2008	Air Emissions	Section 6.2, Air Quality
		Green House Gas Emissions	Section 6.2, Air Quality
		Water Consumption and Aquatic Habitat Alteration	Section 6.3, Water
		Effluents	Section 6.3, Water
		Noise	Section 6.10, Noise
		Occupational Health and Safety	Section6.10, OHS
5	Environmental, Health, and Safety Guidelines	Collection of effluents	Section 6.3, Water

S. No.	IFC Standard	Content / Aspect	Applicability
	for Water and Sanitation, December 10, 2007		

In addition to the above mentioned IFC Standards, compliance with Best Available Technology (BAT) is assessed for the proposed facility with regards to Best Available Technology Reference Documents (BREF) from the European Commission.

6.2 Air Quality

Both construction and operation of the proposed facility will result in emissions to air. Therefore, in order to determine the possible impact on air quality of the proposed development, it is necessary to:

- Characterise and quantify the air pollution emissions that will occur as a result of the implementation of the project (construction and operations)
- Compare these emissions to specified emissions limits (where these exist)
- Determine the ambient concentrations of these emissions for both, concentrations directly attributable to the development and those of the existing air pollution emissions[14]
- Assess the human health and ecological implications (presented in Section 6.11) of the predicted air pollution concentrations.

The section that follows has been structured to reflect the process described above. Thereby, the construction phase will be discussed first, followed by the operation phase of the proposed facility.

6.2.1 Construction Phase

6.2.1.1 Air Pollution Emissions

Emissions of CO_2, CO, SO_2, NO_X and dust will result from the operation of construction equipment and road vehicles during the construction phase. Emissions will occur over a large area and hence, any worsening in air quality at any one location is unlikely to be significant. In addition, construction emissions are expected to be transient as the construction activities progress over the expansion area.

Although at this stage of the project specific details on the construction activities and construction equipment are not available, the following typical construction activities generate air emissions:

- Clearing of land and related excavation and compaction activities;
- Operation of heavy machinery and related equipment for earthmoving and construction purposes, such as excavators, bulldozers, cranes etc., and the engines associated with such machines;

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[14] An important tool in this process is the air pollution dispersion modelling. Air pollution dispersion models are used to simulate the dispersion of air pollution in the atmosphere and the resultant ambient concentrations.

- Erection of structures using steel, concrete, masonry block, brick, glass, timber and other materials;
- Mechanical activities including grinding, hammering, drilling, grit blasting and demolition;
- Metal joining and finishing including welding, brazing, soldering;
- Transport of materials and supplies onto the site, and transport of wastes off-site;
- Vehicle movement along paved and unpaved roads; and
- Surface coatings using paints and adhesives.

Due to the lack of specific details, the following sections describe the extent of the air emissions in a qualitative manner. Semi-quantitative estimates are provided where possible.

6.2.1.1.1 Dust

Dust emissions are an immediate and obvious outcome of heavy construction. Activities such as land clearing, drilling, ground excavation, cut and fill operations (i.e., earth moving), and vehicle movement on unconsolidated soil all have the potential to generate dust. Dust emissions from construction activities are highly variable both in space and time depending on the activity and its intensity, where the activity occurs and the prevailing meteorological conditions.

Two basic physical processes cause dust generation. The first of these is pulverization and abrasion of surface materials and the second, entrainment of dust particles by the action of turbulent air currents (wind speeds over 19 km/hr). The potential dispersion of dust is governed by the initial injection height of the particle (how high the dust is emitted into the air), the degree of atmospheric turbulence and the terminal settling velocity of the particle. The terminal settling velocity defines how quickly the dust particles settle after they have been emitted into the atmosphere and is a direct function of the size of the particles and wind speed.

For a typical mean wind speed of 16 km/hr, which is similar to the average wind speed in Bahrain, particles larger than about 100 μm are likely to settle within 6 to 9 meters from the source of the emission with particles between 30 and 100 μm in diameter likely to settle within a few hundred meters (depending on atmospheric turbulence). Smaller particles have much slower gravitational settling velocities and will settle further from the source.

In contrast to most other fugitive dust sources, construction emissions are expected to have a clear beginning and end and vary considerably over the different phases of the construction process. At the current stage of the project, details on the construction phase are limited. Therefore, area-wide construction emissions are estimated. Available emissions factors (US EPA-AP42) are based on field measurements of total suspended particulate (TSP) concentrations surrounding heavy construction projects. This resulted in a dust emissions factor for construction activities of 2.44 ton/hectare/month of activity (2.69 ton/hectare/month, US EPA-AP42).

This conservative emission factor was derived using soils with moderate silt contents, a medium activity level and a semi-arid climate and covers all activities such as grading, truck loading, bulldozing, road travel etc. that occur at a construction site. This value will give higher emission estimates than individual activity estimates.

Assuming a construction area of 40 hectares and a construction period of 42 months (3.5 years), the total dust emissions during the construction phase would result in approximately 1,291 tonnes per annum (4,519.2 tonnnes over 3.5 years).

This is an over-estimation given that construction activities are not carried out over the entire project area simultaneously, and that construction emissions vary greatly dependent on the stage of the project.

The major dust generating activities will be limited to the first 8 months of the construction period and a significant portion of the dust generated will settle in close proximity to its source. On this basis, it is concluded that dust emissions from the construction activities, may have an intense localised effect (during intense construction activities and adverse meteorological conditions) but it is unlikely that this effect will be carried much beyond a several hundred metre radius of the source. The main construction roads at the site would use the future permanent roads which would have the base bitumen layer placed, to facilitate vehicle movement and to minimise dust generation.

6.2.1.1.2 Other Emissions to Air

Other emissions from construction sites include those generated from the diesel engines operating vehicles and machinery. This will result in gaseous emissions such as CO_2, CO, sulphur oxides (SO_x), NO_x and organic compounds including PAHs and VOCs.

The extent of exhaust emissions is directly related to the amount of equipment and the operation time. As these details are currently not available these emissions cannot be quantitatively assessed.

As emissions from vehicles and construction equipment will be minimized through controls such as regular maintenance, the impacts from the same are not considered to be significant.

6.2.1.2 Comparison with Emission Limits

No emission limits exist for dust generated during construction activities. However, a practicable dust management strategy, including water spraying and dousing which would be implemented during the project will ensure that construction dust does not lead to any impacts.

6.2.1.3 Mitigation and Control Measures

In addition to the previous section, in order to properly manage construction air emissions, the mitigation and control measures indicated in **Table 25** are to be considered by the Contractor.

Table 25: Sources and Management of Construction Emissions

S. No.	Nature of Source	Applicable Control Options
1	Demolition, earthmoving and excavation	▪ Dust suppression by water spraying and suppression surfactants ▪ Timing of activities with respect to wind direction, and avoiding dust generating construction activities during high wind speeds (>18 km/h)
2	Sanding, grinding and welding	▪ Usage of suitable extraction, ventilation and providing screens to contain dust within working area
3	Waste transfer and storage	▪ Enclosed conveyors and chutes

S. No.	Nature of Source	Applicable Control Options
4	On-site traffic movements (paved and unpaved roads)	▪ Dust suppression by water spraying and suppression surfactants ▪ Introduction of speed limits ▪ Usage of windbreaks ▪ Compacting of soils for temporary roads
5	Diesel exhaust emissions	▪ Proper maintenance and tuning of engines ▪ Efforts to use low-sulphur diesel where available ▪ Limiting idling time ▪ Avoid overloading of trucks ▪ Cover of loads ▪ Appropriate height of discharge above ground level
6	Preparation of concrete, cements etc.	▪ Managing stockpiles by using water sprays (when emptying material bags)
7	Material storage	▪ Stockpile heights and areas should be limited, and removal should take place from the downwind side. ▪ Avoiding dust generating activities during high wind speeds. ▪ Providing screens and/or temporary covers at storage areas to avoid wind erosion

6.2.2 Operation Phase

As indicated previously (section 4.3.1), there is a range of air pollution emissions that are associated with the aluminium reduction process. Given the quantity of emissions and their potential impacts, SO_2, NO_x, HF and PM_{10} emissions are considered to be relatively more significant.

Therefore, Ground Level Concentrations (GLCs) of these components, hereafter referred to as criteria pollutants, were predicted using a CALLPUFF air dispersion model and the results discussed in the forthcoming sections.

In addition to the criteria pollutants, the impacts related to other emissions are discussed separately.

6.2.2.1 Air Pollution Emissions

The subsequent sections provide details on the emissions related to criteria pollutants and other emissions to air.

6.2.2.1.1 Emissions of Criteria Pollutants (SO_2, NO_x, HF and PM_{10})

In order to determine ambient concentrations of the criteria pollutants, emissions to air were determined for the existing and future operations. These emissions were used to predict GLCs (see **section** 6.2.3 and **Appendix 17** for more details).

Plant wide emission factors were established based on figures obtained from current operations as well as from the current operating permit. For pollutants others than criteria pollutants, when data were not readily available, industry accepted general emission factors were used. Applicable emission factors for the different process components used to define current and future maximum conditions are presented in **Table 26**.

Table 26: Applicable Emission Factors

Contaminants	Units	Emission rates	
Sulphur dioxide (SO_2)			
Reduction area	kg/t$_{Al}$	32.0	🟩
Anode baking furnace	mg/Nm^3	500	🟩
Power station	ppm H_2S in natural gas	600	🟩
Total fluoride (TF)			
Reduction area	kg/t$_{Al}$	1.25 for L1 to L5	🟩
		0.60 for L6	🟥
Nitrogen oxides (NO_X)			
Power stations (PS 3, 4 and 5)	mg/Nm^3	100	🟩
Power stations (PS 2)	mg/Nm^3	165	▨
Particulate matters (PM)			
Reduction area	kg/t$_{Al}$	3.0	🟩
🟩 Bahraini Standards	🟥 2010 Saudi Royal Commission	▨ Current Alba Operations	
kg/t$_{Al}$ = kilogram per tonne aluminium			

The emission of criteria pollutants for the project expansion was estimated for operation of Potline 1 through 6 and Power Station 2[15] to 5 for the following scenarios:

- **Scenario 1**: Existing Operations / Baseline (Potline 1 -5, Power Station 2 – 4)
- **Scenario 2**: Future Maximum[16]

  Crept Existing Operations + New L6 and Power Station 5 operating at nameplate production capacity. Maximum SO_2 Emission Limit (Bahraini Standard) for reduction area (32 kg SO_2 / t Al).

- **Scenario 3**: Future Mitigated Operations[17]:

  Crept Existing Operations + New L6 and Power Station 5 operating at nameplate production capacity. SO_2 emissions from all reduction lines are set at 24.7 kg/tAl (maximum emissions recorded between 2007-2012) and total fluoride emissions from the high amperage potlines L4 and L5 are set at 0.6 kg/tAl, as per L6. Moreover, lower NO_x emitting scenario is considered compared to Scenario-2.

As stated above, two different future scenarios were used for modelling purposes.

Scenario-2 is based on the maximum allowable emission limits in the Kingdom of Bahrain for SO_2 and HF, and is considered to be the worst case scenario.

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[15] Power Station 1 is not considered

[16] From hereon referred to as "Future“

[17] From hereon referred to as "Future-1“

Scenario-3 limits the SO_2 emissions from the reduction area to a yearly average value of 24.7 kg/t_{Al} (which represents the highest recorded monthly value from 2007 to 2012) and limits the total fluoride emissions of existing Lines 4 and 5 to a more recent benchmark level of 0.6 kg/t_{Al}. As stated in section 4.2.1.2, the main SO_2 emissions are caused by the sulphur in the petroleum coke during the production of the anodes. The highest recorded SO_2 levels from 2007-2012 are used, since it is anticipated that sulphur levels in petroleum coke will increase in the coming years.

Details on the emissions factors used for the different scenarios are summarised in **Table 27**.

Table 27: Emission Factors of SO_2 and HF used for Modelling

#	Scenario	SO_2 (kg / t Al)	Total Fluoride Emissions (kg/ t Al)				
		All Lines	L1 & 2	L3	L4	L5	L6
1	**Scenario 1**: Existing Operations	20.7[1]	1.25[2]				N/A
2	**Scenario 2**: Future Maximum	32.0[3]	1.25[2]				0.6
3	**Scenario 3**:Future Mitigated Operations	24.7[4]	1.28[5]		0.6[6]		

N/A = Not Applicable
1: Average recorded value from 2007-2012.
2: Bahraini standard for maximum emission limit for the reduction area (Fluoride).
3: Bahraini standard for maximum emission limit for the reduction area (SO_2).
4: Peak value monitored during 2007 – 2012.
5: L1 to 3 - Average performance during January 2007 to October 2013.
6: Target emission value for a high amperage potline.

Emissions from Power Station 2 are taken into account as this unit would be operated as a back-up unit in case of scheduled maintenance or failure of a power group. It is also important to note that emissions from Power Station 2 (a less efficient unit than PS3, 4 and 5) were included in the studied emission scenarios.

Table 28 provides an overview of the analysis of pollutant emissions (in tonnes per day) associated with the various project facilities. These values were used as the basis for the air modelling assessment.

Table 28: Major Emissions to Air – Criteria Pollutants

#	Aspect	Pollutant Emissions (t/day)			
		SO_2	HF	PM_{10}	NO_X
A	**Existing Operations (Scenario 1)**				
A1	Stack Emissions[1]	52.67	0.16	1.03	0.30
A2	Potline Emissions[2]	1.00	1.83	3.44	0.00
A3	Max. Power Station Emissions[3]	11.41	-	-	29.80
	Total Baseline Emissions	***65.08***	***1.99***	***4.47***	***30.1***
B	**Future Operations – Maximum SO_2 Emissions (Scenario 2)**				
B1	Stack Emissions[1]	132.06	0.26	1.72	0.48
B2	Potline Emissions[2]	2.56	2.42	5.69	0.00

#	Aspect	Pollutant Emissions (t/day)			
		SO_2	HF	PM_{10}	NO_X
B3	Max. Power Station Emissions[3]	16.80	-	-	42.34
	Total "Maximum SO_2" Emissions	***151.42***	***2.68***	***7.41***	***42.82***
C	**Future Operations – Normal Operations (Scenario 3)**				
C1	Stack Emissions[1]	103.10	0.26	1.72	0.48
C2	Potline Emissions[2]	1.98	1.67	5.69	0.00
C3	Max. Power Station Emissions[3]	14.35	-	-	37.67
	Total "Normal Operations" Emissions	***119.43***	***1.93***	***7.41***	***38.15***

1. Stack Emissions: include emissions from stack located at Reduction Area, Carbon Area and Casthouses.
2. Potline Emissions: include emission from roof vents of the potlines.
3. Maximum Power Station Emissions: the maximum emissions were calculated based on maximum operation of all stack emission points at the power station (power stations operate intermittently on a monthly basis).

In addition to the emissions used for the air modelling assessment (**Table 28** above), emissions of other fluorides (particulate and total fluoride) are presented in **Table 29**. These emissions are based on monitoring conducted by Alba in 2007 – 2013.

Table 29: Other Fluoride Emissions

S. No	Pollutant	Source	Emissions (tpy)			
			L1 - 5 Baseline*	L1 – 5 Crept	L6	L1 -6 Crept
Production Capacity (tpy)			**884,000**	**924,654**	**521,667**	**1,446,321**
1	Particulate fluoride	Smelter	383	407	108	515
2	Total fluoride	Smelter	1,108	1221	272	1,493

6.2.2.1.2 Other Emissions to Air

In addition to the emissions of criteria pollutants, emissions associated with the proposed development include Greenhouse Gas (GHG) emissions. **Table 30** details the emissions of components not considered in the previous section based on current emissions.

Table 30: Other Emissions to Air

S. No	Pollutant	Source	Emissions (tpy)			
			L1 - 5 Baseline*	L1 – 5 Crept	L6	L1 -6 Crept
Production Capacity (tpy)			**884,000**	**924,654**	**521,667**	**1,446,321**
3	Carbon dioxide	Smelter/Power station	10,508,000	10,992,000	6,201,000	17,193,000
4	Carbon monoxide	Smelter/Power station	90,427	92,587	52,235	144,822
5	VOCs	Smelter	469	491	277	767
6	PFCs	Smelter	21	22	13	35

* Data provided by Alba based on 2007 – 2013

Dioxin emissions are considered to be negligible since these are mostly originated from melting and smelting of secondary aluminium, which is not applied by Alba.

Installation of Combined Cycle Gas Turbines (CCGT) with HRSG will minimise the natural gas burned for power generation and thus reduce emission of greenhouse gas CO_2. Another main GHG emission includes Perfluorinated compounds (PFCs). Two PFCs, namely tetra-fluoromethane (CF4) and hexa fluoroethane (C2F6) are formed during the anode effects (temporary imbalance of raw material feed-in rate and the aluminium production rate) stage of aluminium manufacturing. Once formed, they cannot be removed from the gas stream with existing technology.

Anode effects occur when the alumina content of the electrolyte falls below 1 - 2 per cent which results in the formation of a gas film on the electrode. The formation of the film on the anode results in stoppage of metal production and increases cell voltage from the 4 – 5 volt range to 8 - 50 volts. The generation of PFCs is dependent upon the frequency and duration of the anode effects.[18] Through improved process control and monitoring, Alba's average PFC emissions in 2011/2012 were 0.024 kg/t_{Al} as reported to the Gulf Aluminium Council (GAC).

Implementation of best available technology enables Alba to minimise their air emissions. Based on the same, target emission values for potline 6 are included in **Table 31**.

Table 31: Target Emission Values

	Source	Component	L6 Target Emission Value
1	Potline 6 Roofs and Stack Discharges	PFCs	0.1 AE/Pot/day
2	Anode baking	VOC	20 mg / Nm^3

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[18] Environmental, Health, and Safety Guidelines, BASE METAL SMELTING AND REFINING, IFC, April 30, 2007

	Source	Component	L6 Target Emission Value
3	Anode Paste Plant	VOC	20 mg / Nm^3
4	Cast House	Chlorides	50 mg/Nm^3 (HCl) [1]
		CO	100 mg / Nm^3
5	Power Plant	CO	100 mg / Nm^3

[1] Bahrain Resolution No. 3 of 2001, Non-ferrous metal industries and smelting processes

Note: Target emission values for the criteria pollutants (SO_2, HF, NO_2 and PM) are separately presented in **Table 26**.

In terms of greenhouse gas emissions, most industrialised nations around the world are in the process of setting greenhouse gas emissions limits in order to combat climate change. The primary driver of these emission limits is the Kyoto Protocol. In terms of the Framework Convention, parties are committed to implementing programmes to slow climate change through initially stabilising and then reducing greenhouse gas emissions. Although no direct limits yet exist that would apply to greenhouse gas emissions from Alba, it must be recognised that in future greenhouse gas emitters are likely to come under increasing pressure to reduce their emissions.

Alba is a significant producer of greenhouse gas emissions currently, and will increase those emissions following the proposed expansion. An important control of greenhouse gas emissions lies in optimizing energy efficiency and minimising anode effects.

6.2.2.1.3 Motor Vehicle Emissions

Increases in motor vehicle movements (see section 6.8 for more details) following the expansion will result in increased combustion emissions to air. However, compared with the emissions from the facilities the effect from increased traffic is considered to be negligible. Furthermore, it is worth noting that motor vehicle emission concentrations decrease rapidly from the source, over a distance of about 10 m.

6.2.2.2 Comparison with Emission Limits

The pollution abatement equipment that will be installed as part of the extension of the smelter operation including the Gas and Fume Treatment Centres will ensure that emissions remain within the limits defined earlier.

By implementation of BAT, Alba ensures compliance with the stipulated standards, as shown in **Table 32** below.

In summary, by implementing automatic multiple point feeding of alumina, a boosted suction system connected to the air pollution control equipment and the implementation of an efficient process control system to avoid process excursions that might otherwise lead to increase in fluoride evolution and emissions, Alba reduces its emissions.

The control system would also ensure that operating parameters are maintained within recommended ranges and capable to automatically suppress anode effects, thus reducing the unwanted emission of PFCs.

In addition, a state-of-the-art alumina dry scrubbing system will be implemented in the gas and fume treatment centre followed by a bag filter that would collect the dust particulate and enriched alumina prior to the recycling of the alumina in the electrolysis pots.

For the Alba L6 and PS5 expansion project, the GTC stack emissions for total fluoride would, on a yearly average, be less than 0.8 mg/Nm^3 (IFC Guideline value) but emissions could exceed 1 mg/Nm^3 during summer months. Total particulate emissions obtained by well-maintained state-of the-art system shall emit less than 5 mg/Nm^3 of total particulate (dust).

In the paste mixing and anode forming facility, a coke dry-scrubber followed by a bag filter that would collect dust particulate and charged coke materials (prior to the recycling) will also ensure compliance with the stipulated emission standards.

In regions where SO_2 concentrations in ambient air are relatively high, control of the sulphur content in the anodes is normally implemented as BAT. An emission of 24.7 kg SO_2 per tonne of liquid aluminium produced by future potline 6 is considered, taking into account associated facilities (carbon and casthouse) but excluding PS5 (which emits relatively small quantities of SO_2 compared to the smelter activities).

As summary of the emissions from the expanded Alba operation and the corresponding legal limits are presented in **Table 32**.

Table 32: Compliance with Bahraini Emission Standards

Source	Pollutant	Bahraini Standard	L6 Targeted emission value	Compliance
L6 - Roofs and GTC Stack discharges	Gaseous Fluoride (HF) for Reduction area	1.0 mg/Nm^3[A]	<1.0 mg/Nm^3	**Yes**
	Total Fluoride (TF) for Reduction area	1.25 kg/t$_{Al}$[B]	0.60 kg/t$_{Al}$[C]	**Yes**
	Sulphur dioxide (SO_2)	32 kg/t$_{Al}$	25.4 kg/t$_{Al}$[D]	**Yes**
	Total particulate - Roofs	3.0 kg/t$_{Al}$[B]	3.0 kg/t$_{Al}$ including GTC stack emissions	**Yes**
	Total particulate - stack discharge		5 mg/Nm^3 [E]	**Yes**
	Perfluorocarbons	-	0.1 AE/Pot/day	**Yes**
Anode Baking	Total Fluoride (TF) at FTC Stack	0.05 kg/t$_{Al}$	0.05 kg/t$_{Al}$	**Yes**
	Total particulate - stack discharge	30 mg/Nm^3	5 mg/Nm^3 [E]	**Yes**
	VOC	20 mg/Nm^3	20 mg/Nm^3	**Yes**
	Sulphur dioxide (SO_2)	500 mg/Nm^3	500 mg/Nm^3	**Yes**
	NO_x	400 mg/Nm^3	400 mg/Nm^3	**Yes**
Anode paste plant (mixing and forming)	Total particulate - stack discharge	30 mg/Nm^3	10 mg/Nm^3 [E]	**Yes**
	Hydrocarbon (volatile)	20 mg/Nm^3 VOC	20 mg/Nm^3 VOC	**Yes**
	NO_x	400 mg/Nm^3	400 mg/Nm^3	**Yes**
Casthouse Holding furnaces and degassing system	Total particulate	50 mg/Nm^3	50 mg/Nm^3	**Yes**
	NO_x	100 mg/Nm^3	100 mg/Nm^3	**Yes**
	Carbon monoxide	100 mg/Nm^3	100 mg/Nm^3	**Yes**
Power Plant	NOx	100 mg/Nm^3	100 mg/Nm^3	**Yes**
	Carbon monoxide	100 mg/Nm^3	100 mg/Nm^3	**Yes**
	Sulphur dioxide (SO_2)	600 ppm[G]	600 ppm [F]	**Yes**

[A] At GTC Stacks and potroom roofs;

[B] For reduction area;

Source	Pollutant	Bahraini Standard	L6 Targeted emission value	Compliance
[C] For reduction area as per the Saudi Arabia Royal Commission; [D] Use of coke materials with sulphur concentrations not exceeding on an yearly average 3% elemental sulphur; [E] On yearly average; [F] As H_2S in the Natural Gas				

In addition to the compliance with Bahraini Standards, a comparison with applicable BAT and IFC Guideline Values is presented in **Table 33**. These values are used by the Equator Principles Financial Institutions as part of their assessment and screening process for financing Projects.

Table 33: Comparison with BAT and IFC Guideline Values

Source	Pollutant	BAT Associated Emission Value (IPPC-BREF) Note 1	IFC Emission Guideline Values Note 2	L6 Targeted emission value
L6 - Roofs and GTC Stack discharges	Gaseous Fluoride (HF) at GTC Stacks	0.2 mg/Nm^3	0.5 mg/Nm^3	<1.0 mg/Nm^3
	Particulate Fluoride (PF) at GTC Stacks	-	-	-
	Total Fluoride (TF) at GTC Stacks	0.5 mg/Nm^3	0.8 mg/Nm^3	0.60 kg/t_{Al}[A]
	Sulphur dioxide (SO_2)	-	-	25.4 kg/t_{Al}[B]
	Total particulate - Roofs	-	-	-
	Total particulate - stack discharge	1 – 5 mg/Nm^3	1 – 5 mg/Nm^3	5 mg/Nm^3 [C]
	Perfluorocarbons	< 0.1 AE/Pot/day	0.1 AE/Pot/day	0.1 AE/Pot/day
Anode Baking	Gaseous Fluoride (HF) at FTC Stack	< 0.2 mg/Nm^3	-	0.6 mg/Nm^3
	Particulate Fluoride (PF) at FTC Stack	-	-	0.5 mg/Nm^3
	Total Fluoride (TF) at FTC Stack	< 0.5 mg/Nm^3	-	-
	Total particulate - stack discharge	1 – 5 mg/Nm^3	-	5 mg/Nm^3 [C]
	PAH [OSPAR 11]	<200 µ/Nm^3	-	-
	BaP [PAH indicator]	<0.5 µ/Nm^3	-	-
	VOC	-	-	20 mg/Nm^3
	Sulphur dioxide (SO_2)	-	-	500 mg/Nm^3
	NO_x	-	-	400 mg/Nm^3
Anode paste plant (mixing and forming)	Total particulate - stack discharge	1 – 5 mg/Nm^3	-	10 mg/Nm^3 [E]
	PAH [OSPAR 11]	<200 µg/Nm^3	-	-
	Hydrocarbon (volatile)	< 10 – 50 mg C/Nm^3	-	20 mg/Nm^3 VOC
	Hydrocarbon (condensable)	< 1 – 5 mg C/Nm^3	-	-
	NO_x	-	-	-
Casthouse Holding furnaces and degassing system	Total particulate	1 – 5 mg/Nm^3	1 – 5 mg/Nm^3	-
	Chlorides	< 5 mg/Nm^3	< 5 mg/Nm^3	-
	Fluorides	< 1 mg/Nm^3	-	-
	Sulphur dioxide (SO_2)	< 50-200 mg/Nm^3	< 50-200 mg/Nm^3	-
	NO_x	< 100 mg/Nm^3	100-300 mg/Nm^3	100 mg/Nm^3
	Carbon monoxide	-	-	100 mg/Nm^3

Source	Pollutant	BAT Associated Emission Value (IPPC-BREF) Note 1	IFC Emission Guideline Values Note 2	L6 Targeted emission value
Power Plant	NOx	20-50 mg/Nm³ [D]	51 mg/Nm³ [G]	100 mg/Nm³
	Carbon monoxide	5-100 mg/Nm³ [D]	-	100 mg/Nm³
	Sulphur dioxide (SO_2)	-	-	600 ppm [E]

[A] For reduction area as per the Saudi Arabia Royal Commission. This includes reduction and GTC emissions;
[B] Use of coke materials with sulphur concentrations not exceeding on an yearly average 3% elemental sulphur on a yearly average;
[C] On yearly average;
[D] As H_2S in the Natural Gas
[E] @ 15% O_2

Note 1: The values presented under BAT (IPPC (Integrated Pollution Prevention Control) – BREF (Best Available Technologies Reference)) were compiled by European Organizations operating BAT systems in European facilities and are not regulatory limits. Note: emission levels of temperature dependant BAT processes will be higher in hot and humid countries such as the GCCs. This is particularly true for GTCs and potline emissions.

Note 2: IFC Guideline values are not regulatory emission limits either but “performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs”. IFC Guidelines are based in part on the 2001 - EU BREF (Best Available Technologies Reference document), and hence based on European facilities with the implication that the applicable emissions levels need to be adjusted to take into account the hot and humid environment as stated in Note 1 above.

6.2.3 Predicted Ambient Air Pollutant Concentrations

As described earlier, ambient concentrations for Alba’s contribution alone have been predicted using the CALPUFF air pollution dispersion model for the existing and future operations (scenarios are detailed in **section 6.2.2** and Table 4). Where ambient air quality data was available at selected receptor locations, Alba’s contribution for current operations was established and subsequently extrapolated for the situation after expansion. Results of the air dispersion modelling are presented in subsequent sections. Isopleth contours of the scenarios and standard average time (hourly, daily, yearly average values) are presented in **Appendix 18**.

For benchmarking and validating purposes, it is important to note that the predicted existing SO_2 and NO_2 concentration values for the existing operations (baseline) were higher by approximately 6% and 32% respectively, while comparing with the measurements taken at the air monitoring stations (this data includes all emission sources). Given the lack of existing HF concentrations data from the Ministry, benchmarking of the predicted existing HF concentration was not possible.

The effect on ambient air quality was assessed for the following criteria pollutants:

- change in NO_2 concentrations;
- change in SO_2 concentrations;
- change in gaseous Fluoride (HF) concentrations; and

- change in PM_{10} concentrations.

In order to assess these changes it is important to take the current ambient air quality levels into account. Therefore applicable background concentration data was obtained from Ministry Authorities. However, ambient fluoride concentrations are no longer available by Local Authorities and background fluoride concentrations are not taken into account in the presented results.

Concentration predictions were obtained using one (1) full year of the meteorological simulation. The resulting overall maxima for the different averaging periods (annual mean, 24-hours and 1-hour depending on available air quality standards) are highlighted in subsequent sections.

Accuracy of dispersion model predictions

Generally, models are quoted as having a factor-of-two accuracy. Comparison studies indicate that models can predict the magnitude of highest concentration occurring sometime and somewhere within an area to within ±10 to ±40%. Predictions for a specific site and time are often poorly correlated with observed values. This poor correlation can often be related to errors in wind direction. For more details refer to Appendix 17, section 2.7.

As shown in **Table 34**, maximum predicted concentrations of NO_2 and PM_{10} were found to be within all applicable limits for all scenarios. In addition, maximum predicted ground level concentrations of SO_2 were within applicable limits for the annual mean averaging period.

For SO_2, exceedances (see definition below) were predicted for the 24-hour average concentration Bahraini limit (125 µg SO_2 /m^3) for the future Scenario 2 (196 µg SO_2 /m^3) and for Scenario 3 (162 SO_2 /m^3). Exceedances were also predicted to the applicable one-hour average concentration limit of 350 µg SO_2 /m^3 for all future scenarios.

In addition, all scenarios predicted exceedances of the annual averaging limit (for vegetation, 1 µg HF /m^3) for gaseous fluoride.

It needs to be emphasized that all these exceedances are located within close proximity of the Alba facilities and not at residential areas. **Table 34** below summarises the maximum values of predicted concentrations for the criteria pollutants for the three Scenarios for hourly, daily and yearly values as applicable per regulations.

Exceedances are defined as concentration higher than the value set in the Bahrain Ambient Air Quality Standard (BAAQS) recorded over for consecutive 3 time averaged concentration (hourly, daily and annual).

- Exceedance of hourly value: if a single receptor records three consecutive occurrences over the hourly BAAQS.
- Exceedance of daily value: if a single receptor records 3 exceedances of the hourly BAAQ for 3 consecutive days then it is recorded as exceedance of the daily value.
- Exceedance of annual value: if 3 consecutive daily occurrences were recorded for a single receptor then that particular receptor is assumed to have an exceedance of the annual value.

The extent of the exceedances of SO_2 and HF will be discussed in more detail in subsequent sections. **Table 35** summarises the number of exceedances for the criteria pollutants for the three Scenarios for hourly, daily and yearly values as applicable per regulations.

Table 34: Air Quality Assessment Summary Results – Maximum Predicted Concentrations

Pollutant	Bahrain Air Quality Standard (µg/m^3)		Predicted Maximum Concentration (µg/m^3) Alba alone		
			Scenario 1	Scenario 2	Scenario 3
			Existing	Future	Future-1
Sulphur Dioxide (SO_2)	Annual mean	50	19	31	26
	24 hours	125	123	196	162
	1 hour	350	300	477	430
Nitrogen Dioxide (NO_2)	Annual mean	40	3	4	4
	24 hours	150	17	24	22
	1 hour	200	106	124	119
Gaseous Fluoride (HF)	Annual mean	1	14	16	14
Inhalable Suspended Solids (PM_{10})	24 hours	340	125	221	221

Table 35: Air Quality Assessment Summary Results – Number of Exceedances

Pollutant	Bahrain Air Quality Standard (µg/m^3)		Number of Exceedances Alba alone		
			Scenario 1	Scenario 2	Scenario 3
			Existing	Future	Future-1
Sulphur Dioxide (SO_2)	Annual mean	50	0	0	0
	24 hours	125	0	2	2
	1 hour	350	0	4	4
Nitrogen Dioxide (NO_2)	Annual mean	40	0	0	0
	24 hours	150	0	0	0
	1 hour	200	0	0	0
Gaseous Fluoride (HF)	Annual mean	1	14	15	14
Inhalable Suspended Solids (PM_{10})	24 hours	340	0	0	0

6.2.3.1 Concentrations at Sensitive Receptors

In addition to overall maximum concentrations, concentrations were determined at sixteen sensitive receptors (five air monitoring stations and eleven residential areas). An overview of the respective locations is presented in **Figure 31**.

Maximum concentrations observed at the respective sensitive receptors are presented in **Table 36**. Where available, background concentrations of the four criteria pollutants are indicated. The available background air quality data are available for the five locations indicated in grey in **Figure 31** below.

▨	Air Monitoring Station	🟦	Residential Area

Figure 30: Sensitive Receptors

In **Table 36** below, the values indicated in rows Scenario 1, 2 and 3 indicate the predicted contribution of Alba alone (non-correlated) at those locations, excluding the existing monitored background concentrations. The applicable Bahraini Ambient Air Quality Standards are provided in the table header.

Table 36: Maximum Ground Level Concentrations at Sensitive Receptors[19]

#	Sensitive Receptor		Maximum Actual and Predicted (Alba alone) Scenarios Concentrations (µg/m^3)							
			SO_2			NO_2			HF	PM_{10}
		Bahrain Air Quality Standard (µg/m^3)	Annual mean	24 h	1 h	Annual mean	24 h	1 h	Annual Mean	24 h
			50	125	350	40	150	200	1	340
1	Ras Hayyan	Background [20]	5.6	29.2	71.1	1.2	6.1	14.9	NA	85.9
		Scenario-1 Existing	3.5	21.6	52.5	1.8	8.7	19.6	0.4	5.3
		Scenario-2 Future Max.	6.5	40.5	98.5	2.9	13.4	48.1	0.8	17.7
		Scenario-3 Future-1	6.0	37.3	90.7	2.7	12.3	23.6	0.4	17.7
2	Hidd	Background	5.7	29.7	72.4	NA	NA	NA	NA	294.6
		Scenario-1 Existing	1.5	9.1	22.3	0.1	1.0	8.1	0.0	0.4
		Scenario-2 Future Max.	2.5	15.6	38.0	0.1	1.3	20.4	0.0	0.6
		Scenario-3 Future-1	2.4	14.9	36.3	0.1	1.1	10.9	0.0	0.6
3	Maameer	Background	5.9	30.7	74.7	17.2	89.6	218.2	NA	91.1
		Scenario-1 Existing	2.5	15.6	37.9	0.2	2.7	14.6	0.1	1.6
		Scenario-2 Future Max.	4.6	28.8	70.0	0.3	4.1	35.6	0.1	3.0
		Scenario-3 Future-1	4.3	26.7	65.0	0.3	3.5	18.1	0.1	3.0
4	Napeeh Saleh	Background	6.0	31.2	76.0	2.8	14.5	35.3	NA	43.5
		Scenario-1 Existing	3.0	18.9	45.9	0.5	5.1	18.2	0.1	1.8
		Scenario-2 Future Max.	5.2	32.7	79.6	0.8	8.4	44.6	0.1	3.7
		Scenario-3 Future-1	4.9	30.7	74.7	0.7	6.8	24.2	0.1	3.7
5	Hamad Town	Background	8.19	42.75	104.08	6.83	35.64	86.78	NA	NA
		Scenario-1 Existing	3.2	20.0	48.6	0.7	4.7	16.4	0.1	2.4
		Scenario-2 Future Max.	5.0	31.1	75.7	1.1	6.7	43.2	0.1	4.0
		Scenario-3 Future-1	4.8	29.8	72.6	1.0	6.2	22.7	0.1	4.0
6	Villa 1	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	5.8	36.3	88.4	2.1	12.3	30.0	0.4	7.2
		Scenario-2 Future Max.	10.4	65.3	159.0	3.2	18.3	73.3	0.9	22.0
		Scenario-3 Future-1	9.5	59.4	144.7	3.1	17.6	37.4	0.4	22.0
7	Villa 2	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	5.4	34.1	82.9	1.4	9.5	33.4	0.3	5.9
		Scenario-2 Future Max.	11.0	69.0	167.9	2.3	14.4	93.9	0.3	9.5

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[19] Numbering refers to **Figure 31**, whereby „grey“ indicates an air monitoring station and „blue“ refers to a residential area.

[20] Monitored Background Concentrations

#	Sensitive Receptor		Maximum Actual and Predicted (Alba alone) Scenarios Concentrations (µg/m^3)							
			SO$_2$			NO$_2$			HF	PM$_{10}$
		Bahrain Air Quality Standard (µg/m^3)	Annual mean	24 h	1 h	Annual mean	24 h	1 h	Annual Mean	24 h
			50	125	350	40	150	200	1	340
		Scenario-3 Future-1	10.1	62.9	153.1	2.1	13.1	43.5	0.3	9.5
8	Villa 3	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	7.9	49.1	119.6	1.5	13.6	59.5	0.6	13.6
		Scenario-2 Future Max.	14.0	87.7	213.5	2.4	19.9	159.7	0.2	6.5
		Scenario-3 Future-1	12.9	80.6	196.3	2.2	17.4	76.3	0.6	6.5
9	East Riffa	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	6.3	39.5	96.3	1.0	10.4	39.8	0.2	6.7
		Scenario-2 Future Max.	12.0	74.9	182.4	1.5	14.7	93.8	0.4	12.3
		Scenario-3 Future-1	11.0	68.8	167.5	1.4	14.0	50.6	0.2	12.3
10	Sanabis	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	2.7	17.0	41.3	0.3	3.5	16.2	0.0	1.0
		Scenario-2 Future Max.	5.3	32.9	80.2	0.5	5.1	42.2	0.0	1.7
		Scenario-3 Future-1	5.0	31.1	75.8	0.5	4.5	22.4	0.0	1.7
11	El Eker	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	3.4	21.2	51.5	0.3	3.6	20.3	0.1	2.0
		Scenario-2 Future Max.	6.1	38.0	92.4	0.5	5.5	51.5	0.1	4.1
		Scenario-3 Future-1	5.7	35.8	87.0	0.4	4.8	26.3	0.1	4.1
12	Sitra	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	2.8	17.2	41.9	0.2	2.5	12.2	0.1	1.3
		Scenario-2 Future Max.	4.4	27.7	67.4	0.3	3.3	33.1	0.1	2.5
		Scenario-3 Future-1	4.2	26.4	64.3	0.3	3.4	17.1	0.1	2.5
13	Nuwaidrat	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	3.8	24.0	58.4	0.5	5.3	23.8	0.1	1.9
		Scenario-2 Future Max.	6.7	41.9	102.1	0.7	8.4	59.3	0.1	5.3
		Scenario-3 Future-1	6.2	39.1	95.2	0.6	7.5	29.5	0.1	5.3
14	Sanad	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	3.4	21.1	51.4	0.5	5.5	18.4	0.1	2.4
		Scenario-2 Future Max.	6.4	39.8	96.8	0.8	8.7	47.9	0.1	5.6
		Scenario-3 Future-1	5.8	36.5	89.0	0.8	8.0	25.8	0.1	5.6
15	Ma’ameer Residential	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	2.9	18.4	44.8	0.2	3.0	15.3	0.1	2.0
		Scenario-2 Future Max.	5.2	32.3	78.6	0.3	4.2	36.6	0.1	2.8
		Scenario-3 Future-1	4.8	29.9	72.7	0.3	3.9	19.0	0.1	2.8

#	Sensitive Receptor		Maximum Actual and Predicted (Alba alone) Scenarios Concentrations ($\mu g/m^3$)							
			SO_2			NO_2			HF	PM_{10}
		Bahrain Air Quality Standard ($\mu g/m^3$)	Annual mean	24 h	1 h	Annual mean	24 h	1 h	Annual Mean	24 h
			50	125	350	40	150	200	1	340
16	Labour Camp	Background	NA	NA	NA	NA	NA	NA	NA	NA
		Scenario-1 Existing	7.9	49.2	119.8	0.6	6.2	41.9	0.2	5.8
		Scenario-2 Future Max.	13.7	85.9	209.1	0.9	8.9	97.9	0.6	20.9
		Scenario-3 Future-1	12.4	77.7	189.2	0.6	6.2	41.9	0.2	20.9

The results from the air dispersion modelling as summarised in **Table 36** above show no exceedances of applicable Bahrain Ambient Air Quality Standards at the Sensitive Receptors. This is valid for both Alba's contribution (Scenarios 1, 2 and 3 in **Table 36**) and for the monitored background concentration (with the exception of the NO_2 1-hour monitored background concentration at Maameer which is located about 5.5 km from Alba). Note: any other background values for sensitive receptors 6 to 16 are not accounted for as these are not available.

In order to compare the total correlated predicated concentrations with applicable Bahraini Ambient Air Quality Standards, the available background concentrations were taken into account (in other words, the actual existing and predicted concentrations were correlated). These results are provided in **Table 37** below for the Air Monitoring Stations. **Table 37** states the correlated total maximum predicted concentrations; i.e. it includes the actual background data plus the model predicted data for Alba's contribution alone, where the baseline existing case model data has been adjusted to correlate with the actual data, henceforth stated as "correlated".

Table 37: Predicted Total Correlated Concentrations at Sensitive Receptors

#	Sensitive Receptors[21]		Total Correlated Predicted Concentrations ($\mu g/m^3$)						
			SO_2			NO_2			PM_{10}
		Bahrain Air Quality Standard ($\mu g/m^3$)	Annual mean	24 h	1 h	Annual mean	24 h	1 h	24 h
			50	125	350	40	150	200	340
1	Ras Hayyan	**Scenario-1** Existing	5.6	29.2	71.1	1.2	6.1	14.9	85.9
		Scenario-2 Future Max.	8.6	48.1	117.1	2.2	10.8	43.4	98.4
		Scenario-3 Future-1	8.1	44.9	109.3	2.0	9.8	18.9	98.4
2	Hidd	**Scenario-1** Existing	5.7	29.7	72.4	NA			294.6

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[21] Air Monitoring Station

#	Sensitive Receptors[21]		Total Correlated Predicted Concentrations (µg/m^3)						
			SO_2			NO_2			PM_{10}
		Bahrain Air Quality Standard (µg/m^3)	Annual mean	24 h	1 h	Annual mean	24 h	1 h	24 h
			50	125	350	40	150	200	340
		Scenario-2 Future Max.	6.7	36.2	88.2				294.8
		Scenario-3 Future-1	6.6	35.5	86.4				294.9
3	Maameer	**Scenario-1** Existing	5.9	30.7	74.7	17.2	89.6	218.2	91.1
		Scenario-2 Future Max.	8.0	43.9	106.9	17.3	91.0	239.3	92.5
		Scenario-3 Future-1	7.7	41.8	101.9	17.3	90.5	221.7	92.5
4	Napeeh Saleh	**Scenario-1** Existing	6.0	31.2	76.0	2.8	14.5	35.3	43.5
		Scenario-2 Future Max.	8.2	45.1	109.7	3.0	17.9	61.7	45.5
		Scenario-3 Future-1	7.9	43.1	104.8	3.0	16.3	41.3	45.4
5	Hamad Town	**Scenario-1** Existing	8.2	42.8	104.1	6.8	35.6	86.8	NA
		Scenario-2 Future Maximum	10.0	53.9	131.3	7.2	37.7	113.6	
		Scenario-3 Future-1	9.8	52.6	128.1	7.1	37.2	93.1	

A summary analysis of the data from the above table (**Table 37**) is stated below for the Total Correlated Predicted Concentrations.

6.2.3.2 SO_2 Concentrations

Sulphur dioxide emissions are mainly related to the reduction area of Alba's facilities. As presented **Table 28**, existing emissions from the model indicate approximately 65 tonnes of SO_2 per day (Scenario-1), while the expansion will result in an emission of 151 tonnes SO_2 per day (Scenario-2) based on source emissions per Bahraini emission limits or 119 tonnes per day (Scenario-3), based on Alba operations data of 24.7 kg/t Al.

The above indicates that SO_2 emissions would increase by 132% for the future case (Scenario-2) and approximately 83% for Scenario-3 versus scenario 1 (existing operations).

6.2.3.2.1 1-Hour Average Concentrations

For the baseline (existing facility, Scenario-1), for Alba's contribution alone, the maximum predicted 1-hour average SO_2 concentration at the sensitive receptors is at Ras Hayyan (located downwind of the project site) at 53 µg SO_2 /m^3. The background concentration at this monitoring station is 71 µg SO_2 /m^3. Based on Fractional Bias (FB) analysis comparing monitored data and modelled data, an over-prediction of 6% was estimated. Although CALPUFF is known to over-predict concentrations at near field receptors, the model is generally termed acceptable if Absolute Fractional Bias (AFB) Analysis is less than 0.67 (U.S. EPA 1992), which is the case for the used CALPUFF model.

As shown in **Table 34** presenting the maximum concentrations by Alba alone, future maximum 1-hour average concentrations caused by Alba alone are 477 and 430 µg SO_2/m^3 respectively (Scenario-2 and 3). Thereby, the maximum ground level concentration for maximum operating conditions (Scenario 2) by Alba alone is projected to increase by approximately 59% compared to the existing maximum predicted concentration (Scenario-1). During mitigated future operations (Scenario-3), the increase is predicted to be approximately 43% by Alba.

The maximum concentration is located along the south-western corner of the facility boundary line within one (1) km from the facility boundary line.

The highest predicted total correlated 1-hour SO_2 concentration at any of the monitoring station receptors was at Ras Hayyan which is downwind of the facility. The predicted concentrations for Alba's contribution alone at Ras Hayyan are 98 and 90 µg/m^3 for Scenario 2 and 3 respectively. The predicted maximum concentration at other receptors by Alba alone recorded no exceedance and were within the Bahraini Ambient Air Quality Standards for 1 hour average of 350 µg/m^3.

6.2.3.2.2 24-Hour Average Concentrations

The maximum 24-hour ground level concentration for baseline condition is 123 µg SO_2 /m^3, for Alba's contribution alone, which is below the Bahraini AAQS of 125 µg/m^3. However, the Future Scenarios (2 &3) predicted higher maximum ground level concentration than the Bahraini AAQS.

The 24-hour maximum concentration is predicted to be within 1 km distance from the boundary line, which is consistent with the hourly predicted concentration. SO2 concentrations are predicted to increase by 60 % for Scenario-2 compared to the baseline conditions, and by approximately 30% for Scenario-3.

6.2.3.2.3 Annual Mean Concentrations

As shown in **Table 34**, annual predicated SO_2 concentrations were found to be below the stipulated Bahraini AAQS (50 µg SO_2 /m^3) for Alba's contribution alone. The highest predicted annual SO_2 concentration for the baseline conditions is 19 µg/m^3, 31 µg/m^3 for Scenario 2 and 28 µg/m^3 for Scenario-3.

6.2.3.3 NO_2 Concentrations

It is predicted that Nitrogen Dioxide emissions will be in compliance with the applicable Bahrain Ambient Air Quality Standards. However, monitored background concentrations indicate that hourly values for NO_2 are being exceeded at Maameer (218 µg/m^3 vs standard of 200 µg/m^3).

6.2.3.3.1 1-Hour Average Concentrations

As stated in above **Table 34**, Alba's contribution to the maximum recorded hourly air quality of 218 µg/m^3 at Maameer[22] is only 7% (14.55 µg/m^3). This means that the majority of NO_2 emissions are caused by other activities, such as traffic, power plants, petrochemical industries and other sources. The total correlated hourly NO_2 concentrations will increase by 9.6% at Maameer for Scenario 2 (to a total of 239 µg/m^3), and by 1.6% for Scenario 3 (from 218 to 221 µg/m^3). Overall, the total correlated maximum hourly NO_2 values will increase by 19 % for Scenario 2 and no increase in the ambient air

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[22] 1557 exceedances were recorded from 2007- 2012, indicating that the hourly avaerage maximum concentration is not an one off incident.

concentration for Scenario 3. This is in line with the higher NO_x emissions for Scenario-2 (42.82 t/day) compared with Scenario-3 (38.15 t/day).

6.2.3.3.2 24-Hour Average Concentrations

The maximum 24-hour NO_2 concentration from Alba's existing operations was predicted to be 17 µg/m^3 along the facility fence line. The Future case predicted a maximum concentration caused by Alba of 24 µg/m^3 and 22 µg/m^3 for scenario 2 and 3 respectively. The corresponding 1-hour AAQS is 150 µg/m^3.

6.2.3.3.3 Annual Mean Concentrations

As shown in **Table 34**, annual predicated NO_2 concentrations were found to be below the stipulated Bahraini AAQS (40 µg /m^3). The maximum predicted annual NO_2 concentration by Alba alone for the baseline conditions is 3 µg /m^3, 4 µg /m^3 for Scenario 2 and 4 µg /m^3 for Scenario-3.

6.2.3.4 HF Concentrations

As presented in **Table 34**, exceedances of the maximum annual mean HF concentrations were predicted above the stipulated WHO standard (1 µg /m^3). Note: as stated previously, given the lack of actual data form the ministry for HF concentrations, the HF values are predicted from the model alone without adjustments for actual ground measurements.

These concentrations were predicted to be within the WHO standard beyond 3 km from the facility boundary line (south-west). It is important to note that the specified standard of 1.0 µg/m^3 has been derived to protect vegetation and cattle. It is known that fluoride is extremely phytotoxic (toxic to vegetation) but poses less of a threat to human health. The WHO for example, indicates that no adverse human health effects have been recorded in concentrations of up to 16 µg/m^3. In addition the WHO indicates that indirect human exposure to atmospheric fluoride through soil deposition and groundwater is improbable.

The maximum predicted annual HF concentration caused by Alba's current operations (scenario 1) is 14.4 µg /m^3, 16 µg /m^3 for Scenario-2 and 14 µg /m^3 for Scenario-3. The maximum ground level concentration for Scenario 2 is predicted to increase by 14% compared to the baseline and is predicted to remain unchanged compared to the baseline for Scenario 3.

The overall HF emissions from the Future 2 scenario would have an estimated 35% increase in HF emissions from Alba compared to baseline, while the Future Scenario-3 would have 3% less emissions than the baseline/existing conditions. Thereby, the maximum ground level concentration caused by Alba for maximum operating conditions (Scenario 2) is projected to increase by approximately 14% compared to the existing predicted concentration (Scenario-1). During mitigated future operations (Scenario-3) there will be no impact on HF concentrations from Alba's expansion.

6.2.3.5 PM_{10} Concentrations

As presented in **Table 34**, the maximum daily PM_{10} concentration caused by Alba's current operations is 125 µg/m^3, which is below the Bahrain AAQS of 340 µg/m^3. The emission rates of PM_{10} for Future Scenario 2 and Scenario 3 are equal. The maximum ground level concentration for both Future Scenario 2 and Future Scenario 3 was found to be 221 µg/m^3.

Daily predicated total correlated PM_{10} concentrations were found to be below the stipulated Bahraini AAQS (340 µg/m^3), refer **Table 37**. The monitoring data collected at the ambient air quality stations show higher ambient PM_{10} concentrations which could be due to the arid region of the country. The predicted maximum contribution from Alba of the proposed expansion for the total correlated daily value is 14% and is located at Ras Hayyan ambient air quality monitoring station.

6.2.3.6 Impacts on nearby industrial facilities

The total predicted SO_2 and HF concentrations will be above the ambient air quality standards near the vicinity of Alba. Since these areas are used by industrial facilities where people will be present only during working hours, Ambient Air Quality Standards are not directly applicable. Bahraini AAQS are applicable for locations such as hospitals, schools, and residential areas of continuous exposure.

For evaluation of the exposure to air pollutants, health authorities in general apply a different set of workplace air quality standards. These standards often state the permissible workplace concentration for healthy adults working 8 hours per day and 40 hours per week. The Permissible Exposure Limits (PEL) developed by the US National Institute for Occupational Safety and Health (NIOSH[23], September 2007 [**Ref. 15**]) are:

- HF: 2.5 mg/m^3 (3 ppm) time weighted average
- SO_2: 5 mg/m^3 (2 ppm) time weighted average
- NO_2: 1.8 mg/m^3 (1 ppm) short term exposure (15 min)
- Respirable particulate: 5 mg/m^3 (8 hour Time Weighted Average).

Since all predicted assessed ambient air quality concentrations for all parameters and all scenarios are in $\mu g/m^3$ which are far below the above workplace air quality standards (expressed in mg/m^3), it can be stated that the proposed expansion will not pose health impacts to the people working at surrounding facilities.

6.2.3.7 Summary of Findings

The air quality analysis was performed in two steps. First, the maximum predicted concentrations resulting from the proposed facility emissions alone were evaluated and compared to the corresponding guideline concentrations. If the predicted maximum concentrations exceeded the guideline limits, then a second step was taken in order to determine the number of averaging periods for which the guideline limit values are exceeded.

The results of the analysis show that the total correlated concentrations for NO_2 and PM_{10} after expansion will be in compliance with the applicable standards and guidelines, with the exception for the Maameer location where existing hourly NO_2 values are currently already being exceeded (218$\mu g/m^3$ versus standard of 200$\mu g/m^3$).

The total correlated SO_2 and HF levels at indicated sensitive receptors are predicted to comply with the applicable standards. However, for Scenario 2, there are predicted to be exceedances of SO_2 and HF levels in the area from Alba's fenceline to several kilometres south to south-west. The maximum ground level concentrations were found to be in the industrial area and would cause less impact on the surroundings. Based on the modelling analysis the contribution of criteria pollutants were found to be temporal in nature, since long term average are well below the Bahraini AAQS, except for HF.

Therefore, for HF, a different scenario based on additional mitigation measures in line with current benchmark operations for similar technology potlines (Scenario 3) was considered to assess the reduction in the predicted impact. The BAT techniques considered in the design of proposed Potline 6 and Power Station 5 limit the emissions from the expansion to

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[23] NIOSH is the Federal agency responsible for conducting research and making recommendations for the prevention of work-related disease and injury.

the extent possible. Scenario 3 therefore limits the source emissions for Potline 4 and Potline 5 via mitigation through stricter operating practices in line with those considered for Potline 6 and industry benchmarks.

The SO_2 source emissions ratio was updated for Scenario 3 as well, to reflect the current Alba operations values versus the less conservative Bahraini standards, with the resultant impact of reduced the number of predicted exceedances.

6.2.4 Possible Adverse Health Effects

Undoubtedly the greatest concern in terms of air pollution and its impact on air quality are the possible adverse effects on human health that are associated with the various pollutants and how these vary in time. In order to assess possible adverse health effects, it is necessary to characterise prevailing air quality in terms of both the pollutants that may be present and the concentrations of these pollutants and how these vary in time. Expected air quality following the implementation of the proposed expansion has been described extensively in this section.

Once prevailing air quality has been characterised, it is necessary to determine exposure, which is defined as who will be exposed to the pollutants and for what period of time / duration. Nonetheless, inhalation is not the only form of exposure given that people can also be affected by dermal absorption and ingestion (via pollutants in crops for example, which are later eaten). On the basis of the exposure, it is also possible to determine the dose that individuals would receive, the organs likely to be affected by the dose and the resultant risk of adverse health effects. Before finalising such an assessment, it is also necessary to define so-called ‘compounding’ factors such as the existing health profile in the population, smoking prevalence and so forth.

In order to try and address all of these components, air quality standards are most often established very conservatively, the most conservative being the WHO. In general terms, WHO’s air quality standards are derived by determining the lowest concentrations of a given pollutant at which adverse health effects *may* occur, and then halving that value to define the standard. As a result, WHO air quality guidelines are widely accepted as providing unambiguous assurance that adverse health risks will be negligible. As the area around Alba is scarcely populated and given that the predicted ambient concentrations are generally within the norms, a full health risk assessment is not required and has not been conducted.

Given the predicted ambient air pollution concentrations, the risk of adverse health effects as a result of the proposed expansion are deemed to be largely negligible. This excludes the short-term exceedances of SO_2 and HF concentrations which are likely to occur. As described in **section 6.2.3.6** above, all predicted air quality levels for SO_2 and HF will be below the workplace air quality standards, indicating that adverse health impacts caused by the emissions are negligible.

Emissions of VOCs from the Alba operation have not been assessed in detail because it is deemed that if any risk of adverse health effects existed, this would be within the occupational, rather than the ambient environment. To this end, recommendations have been included in the occupational health and safety component of this report (**section 6.11**) to ensure that adverse health risks to workers are minimised or prevented.

6.2.5 Mitigation Measures and Compliance with IFC

In order to mitigate and control the impacts to ambient air quality, various techniques have been considered by Alba for the expansion.

The following measures are considered to control emissions to air

- Increase the electrical conversion efficiency – By reducing the global power consumption, associated SO_2, NO_x and CO_2 emissions will be minimised;
- Automatic multiple point feeding of alumina which reduces PFC emissions;
- Boosted suction system connected to the air pollution control equipment reduces untreated gaseous emissions through the potline roof air gravity fans;
- Implementation of an efficient process control system to avoid process excursions that might otherwise lead to increase in fluoride evolution and emissions. This control system would also ensure that operating parameters are maintained within recommended ranges and capable to automatically suppress anode effects, thus reducing the unwanted emission of PFCs.
- Implementation of working practices to minimise time for changing anodes and other activities that require removal of pot side shield covers. This will help to reduce untreated gaseous emissions through the potline roof air gravity fans;

The selected DX+ technology pot with its proprietary control system would ensure an anode effect frequency of less than 0.1 AE/Pot/day which would be in compliance with the IFC guideline value (0.1 AE/Pot/day).

Furthermore, an emission monitoring system would be provided for the monitoring of fluorides roof emissions for pot tending work practice management and emission compliance testing. To achieve this task, two (2) different systems would be installed:

- A continuous optical monitoring system with sample paths over the entire length of each Potroom roof for work practice management. The optical gaseous HF monitoring system would be installed in each of the two (2) potrooms providing coverage and monitoring all pots in operation; four (4) optical monitoring systems in total each covering one half (1/2) of a potroom. The signal would be transmitted to the Potline 6 control room. Access platform would be provided to service the optical monitoring systems.
- A conventional cassette monitoring system, allowing monitoring of both gaseous and particulates fluorides. Sampling coverage would be provided over a total of two (2) half rooms for the potline, with twelve (12) cassettes located in diametrically opposite potrooms. Access walkway would be provided on the roof to service the cassette monitoring system

In addition, exhaust stacks would be fitted with sample ports through which air pollution control equipment and/or emissions can be assessed, and most process bag houses would be fitted with bag leak detection systems warning operators of bag failures.

6.3 Water

To assess the impact of the proposed expansion project on water, it is necessary to define changes in both water usage and effluent discharge associated with the new development for both the construction and operational phases, and to determine whether these will have an impact on the environment.

6.3.1 Construction Phase

The following activities will result in the generation of waste water:

- Washing of vehicle tyres;
- Domestic waste water;
- Water generated during dewatering activities;
- Waste water from concreting and concrete washing; and
- Hydrostatic testing.

Dewatering is anticipated to be required at the VDC pit location as groundwater was detected during a geotechnical survey at a depth of 6.3 meters within a 30 meter deep borehole. The volume of dewatered water generated cannot be presently quantified due to insufficient data however; the volume is expected to be minimal, with disposal to the stormwater drainage system following testing of the water quality.

Moreover, dewatered water is anticipated to be generated at the VDC pit location as groundwater was previously detected during a geotechnical survey at a depth of 6.3 meters within a 30 meter deep borehole. The volume of dewatered water generated cannot be presently quantified due to insufficient data however; the volume is expected to be minimal.

Waste water generated from vehicle washing contains oil, other hydrocarbons, metals, road salt, and grit. If the waste water gets into contact with surface waters, the contaminants can degrade water quality and harm aquatic life. Also, if the waste water is adsorbed into the groundwater, the groundwater would become unfit for consumption. The amount of waste water generated from washing of vehicle tyre depends on the number of vehicles washed and frequency which is presently unknown hence, the amount of waste water cannot be estimated at this phase.

It is assumed that waste water during construction phase will be collected in holding tanks and periodically disposed –off by approved waste collectors. The waste water will not be connected to Alba’s existing waste water systems.

Furthermore, waste water will be generated during the flushing, cleaning and commission activities for piping networks and equipment at Power Station 5 and Potline 6. Details with regards to quantities are currently not available. The hydrotest waste waters will be disposed-off in a manner complaint with the applicable Bahraini regulations and standards.

6.3.2 Operational Phase

6.3.2.1 Water requirements

The additional water requirements of the proposed expansion include potable and process water. As previously described, aluminium reduction is essentially a dry process where the only process water requirements are for cooling. Water will be required for the project for the following activities:

- Casthouse cooling;
- Carbon plant cooling;

- Compressor house cooling;
- Feed water for the waste heat recovery boilers at PS 5;
- Feed "make-up" water in all cooling systems for the gradual removal of build-up dissolved solids;
- Truck washing facility;
- New change house (750 staff) and cafeteria (200 staff) facility; and
- New administration building.

The source of potable quality water at Alba's smelter is from the desalination plant at the calciner which also supplies potable water to Bahrain's Electricity and Water Authority for general consumption in the Kingdom. Potable quality water is also used for process water at Alba. The additional water demand at Alba associated with the expansion will also be sourced from the calciner desalination plant.

The additional process water network would be connected to the existing network tie-in points for the Green Anode Cooling facility, the ABF Fume Treatment Centre, the cooling tower of the induction furnaces in the anode rodding shop as well as for the VDC Cast House and compressor cooling towers. Given that the water for the expansion would be sourced from the calciner or subsequently from the site storage tanks (during calciner shutdown), there would be no impact on the existing groundwater resources.

Similarly, to meet the additional demand for potable water, the additional potable water network would be connected to the existing network tie-in points.

6.3.2.2 Increase in effluent

Additional waste water will be generated due to the additional activities. Waste water generated from the expansion is similar to the existing discharges and mostly consists of blow-down water from RO plants. It is anticipated that the discharges to sea will remain unchanged from the existing normal operation case of 1,227 m^3/day, with the exception of a minimal increase due to the generation of the additional demineralized water for Power Station 5 (average additional 1.2 m^3/day, which relates to $< 0.1\%$ increase compared to current discharge figures).

In the current operation, for the situation where the calciner is down for maintenance, the amount of effluent to the sea is approximately 4,539 m^3/day. This quantity is not anticipated to increase given that for the expansion project, two (2) new 12,500 m^3 tanks will store potable water for utilization during the calciner shut-down, thus eliminating the need for the use of ground water for the L6 expansion (via the R/O plants) and thus avoiding additional discharge into the marine environment. The stored water would meet the requirements for process water for PS-5 and L6 facilities. The stored potable water sourced from the calciner desalination plant would be passed directly to the cooling towers of PS 5 compressor station for cooling purposes.

6.3.2.3 New Power Station (PS 5)

As mentioned above, the additional make-up water demand for PS 5 will be supplied from the Calciner Desalination Plant or from the water storage tanks during the calciner shutdown. A boiler feed water chemical injection system would be added in PS 5 to remove oxygen, carbon dioxide (CO_2), and residual minerals as to avoid the corrosion of the boiler. The system will inject phosphate, sodium hydroxide, and oxygen scavenger such as carbohydrazide, into the feed water. Material Safety Data Sheets of these water treatment chemicals are currently not available.

An additional water consumption of approximately **15** m^3 per hour is anticipated for PS 5 for the boiler feed water as well as for cooling purposes. For mixed bed regeneration, acid and caustic are required. Acid can be Sulphuric acid (H_2SO_4) or Hydrochloric acid (HCl).

6.3.2.4 Sewage Treatment Plant

As part of the proposed expansion, a new Sewage Treatment Plant (STP-3) with a design capacity of **150** m^3 per day (sized for 750 people) will be erected in the vicinity of L5 STP for the treatment of waste water generated from L6, PS 5, and the proposed supporting facilities associated with the expansion project. Sources of waste water received at STP-3 for treatment includes; new cafeteria and change rooms facility as well as the administration building, domestic sewage, etc. Consistent with STP-1 and STP-2, the proposed STP-3 would be based on an extended aeration activated sludge process and will generate Treated Sewage Effluent (TSE) which will be used for irrigation throughout the plant. The discharged effluent will be similar in quality to that being produced currently, and on that basis is not expected to result in impacts of any significance. Arrangements have been made through a contractor who will dispose the associated sludge to Asker landfill.

6.3.2.5 Cafeteria

In accordance with United States Environmental Protection Agency (US EPA) typical waste water flow rates [1], an average of 45 litres of waste water per employee is anticipated to be generated. Given a total number of 547 operators associated with the expansion project, the waste water anticipated to be generated from the proposed cafeteria is equivalent to **22** cubic meters (m^3) of waste water.

6.3.2.6 Laundry

In accordance with US EPA factors [**1**], the typical waste water flow rate from a self-service laundry within an industrial building is 80 litres per unit per day. Under the assumption that the 547 operators will wash their overalls at least once a day with each unit carrying 10 overalls per wash, the generated waste water is equivalent to **4.4** cubic meters (m^3) of waste water per day.

6.3.2.7 Kitchen

US EPA factors state that 26 litres of waste water per meal per day will be generated. Given that one meal will be served for each of the 547 operators, a total daily quantity of waste water equivalent to **14** cubic meters (m^3) of waste water will be generated from the kitchen per day.

6.3.2.8 Truck Wash Facility

A truck wash facility is proposed as part of a service station for fuel dispensing. The waste water generated from the vehicle washing facility will contain cleaning chemicals, oil and grease, dirt, detergents, and debris.

To collect and treat the generated waste water, there would be two oily water separators (one at the vehicle maintenance and one at the rectifiers) to ensure capture of oily waters so as not to contaminate the surface water drainage. The settled dissolved solids will accumulate at the bottom of the oily water separators and will need to be regularly removed to prevent oily water from overflowing into the separated waste water within the oily water separators.

The separated waste water will be transported via tankers to the STP-3 for treatment and discharge for irrigation purposes. Arrangements have been made through a contractor who will dispose the associated sludge to Asker landfill The settled dissolved solids will be disposed-off to Askar Landfill through a contractor, similar to the transport of sludge generated from STP-3. The daily quantity of waste water anticipated to be generated from the truck wash facility is presently unknown.

6.3.2.9 Domestic Waste Water

In reference to US EPA factors [1] for sanitary waste from industrial buildings, the anticipated waste water flow rate is 61 litres per unit per day. Consequently, with a total of 547 operators, a total of approximately **33** m^3 of sanitary waste water is anticipated to be generated per day which will be transferred to the proposed STP-3 for treatment.

6.3.2.10 Storm water drainage

The site surface water drainage is planned to be upgraded and connected to the existing site drainage circuit which are connected to the existing four outfalls at the Alba fence line. These are connected to the existing municipal drainage system located outside Alba’s property lines.

6.3.3 Summary

Additional waste water will be generated due to the additional activities. Waste water generated from the expansion is similar to the existing discharges and mostly consists of blow-down water from RO plants. A minimal additional flow of waste water (1.2 m^3/day, versus 1,227 m^3/day from current operations) is anticipated to be disposed-off via the existing outfall pipeline. All other blowdown water will either be used for irrigation or sent to the Alba lake. Hence, no further impacts on the marine environment are envisaged from the expansion project.

By providing storage of additional water storage tanks on site, the generation of additional blow down water from the expansion for the case of the Calciner being off line will be avoided.

Moreover, the design capacity of STP-3 (150 m^3 per day) is sufficient to withstand the anticipated additional wastewater effluents from the proposed kitchen, laundry, cafeteria, truck washing facility, and domestic waste water as demonstrated in the preceding subsections therefore; no further impacts are envisaged during the operational phase.

6.3.4 Mitigation Measures

Water quality monitoring at the outfall to the sea is obligatory as per government regulations, to monitor compliance with the regulations and standards for 30 water quality parameters. Such monitoring is presently being conducted monthly and the results are presented to the authorities every 3 months. Also, an existing continuous flow integrator is also being used to provide the data for calculating the loads (in kg/day) of pollutants discharged into the sea.

The proposed monitoring framework for waste water generated from the outfall pipeline and the outlet of the STP will be as per the existing monitoring framework. Accordingly, the marine water quality will be sampled and analysed by an accredited laboratory once or twice a year depending on the analysed parameter. Moreover, the variance in sea temperature from discharged waste water streams from the smelter and calciner outlet will also be monitored and analysed via sampling every bi-annually Subsequently, the monitored data will be confirmed by an external environmental laboratory by monitoring all 30 parameters requested by the government half-yearly.

Furthermore, the quality of the waste water at the inlet of STP-3 and the TSE will be analysed by sampling pH, Biochemical Oxygen Demand (BOD), and suspended solids once every four (4) weeks.

It is also recommended that on-line monitoring for free chlorine be implemented to ensure that there is no overdosing. Finally, periodic sampling of effluents from the oil and grease separator during peak flows is recommended, to identify and avoid overloading conditions.

6.4 Soil and Groundwater

Potential impacts on soil and indirectly on groundwater from the proposed expansion lie in the possible contamination of soil by pollutants (i.e. changes in the chemical properties of the soil) and the changes in the soil structure that will be bought about by the construction activities (i.e. changes in the physical properties of the soil). In order to assess these potential impacts, activities that may result in either chemical or physical changes to the soil have been identified and evaluated in terms of whether such effects may result in significant impacts.

6.4.1 Physical changes

6.4.1.1 Construction phase

Physical changes to soil properties during the construction phase will obviously be bought about by a range of construction activities such as excavations, cut and fill activities and compaction. An immediate concern in terms of impacts of excavations is whether or not these will result in an impact on the groundwater. Given the depth of the groundwater (between 15 and 18m) at the proposed facility, and the extent of the excavations, it is unlikely that there will be any direct impact on groundwater as a result of excavations. An exception is VDC pit for CH4 where dewatering is necessary.

6.4.1.2 Operations phase

No changes to the physical properties of soil are expected during operations. SPL will be segregated as per the current practice into hazardous and non-hazardous elements. The non-hazardous SPL elements will be segregated, stored in covered facilities. SPL and solid bath material will be stored in areas similar to the existing facility on L5. These storage areas are covered, open on one side along with three sidewalls. The bulk of the segregation activities will be done in these buildings on a concrete pad and thereby not directly on the soil.

6.4.2 Chemical changes

6.4.2.1 Construction phase

As evident from the baseline investigation of the expansion area, there is limited contamination[24] of the upper soil layer (see Section 5.4). The bulk of this contamination will be removed and remediated by Alba prior to the grading and levelling activities. The stratified nature of the soil tends to retard pollutant mobility and as a result it is expected that deeper soil strata, the limestone and rocky material, are not contaminated.

Although the grading and levelling of the soil will have the effect of removing the contaminated soil it is obviously important to consider where that soil will be placed. If not properly considered, the placement of the soil may result in an impact. It is to be noted that in case of contamination, the top layer will be removed, stored at dedicated areas to avoid cross contamination and, depending on the contamination, treated (internally or externally) or disposed.

In addition, there is a range of construction related activities that could result in changes to the chemical properties of the soil. Foremost amongst these is spillage of various chemical products, fuels and lubricants that will be brought on site and used during the construction phase. Improper methods of storing, transferring and generally handling these products

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[24] Boron and Sulphur concentrations did exceed the standard levels. The source of boron contamination is presently unknown. It is possible taht high levels of boron are „naturally occuring in Alba's area as boron cannot be directly related to Alba's activities. However no data is available to confirm this. Sulphur contamination, on the other hand, could be related to deposition of SO_2 emissions from Alba, traffic and other industrial activities.

can result in spills and resultant soil contamination. Of special concern is the management of waste generated during the construction phase. In case the temporary storage of waste on the construction site is inadequate (before being removed for disposal) the risk exists of contaminating soil. Therefore, mitigation measures are presented in Chapter 9.

There are a number of management measures that can be implemented to reduce the threat of accidental spillage during the construction phase. Nonetheless, if there is a spillage, effective clean-up will be executed. Hence, potential chemical contamination of soil is not deemed to be a significant potential impact, provided that a clear set of management measures are developed and implemented.

Furthermore, during construction a laydown area of approximately 42 hectare will be used. As this is located in a green field area outside Alba's industrial complex, it is recommended to assess the soil and groundwater quality prior to construction to establish a baseline. Suggested locations are provided in **Figure 32** and corresponding coordinates are listed in **Table 38**.

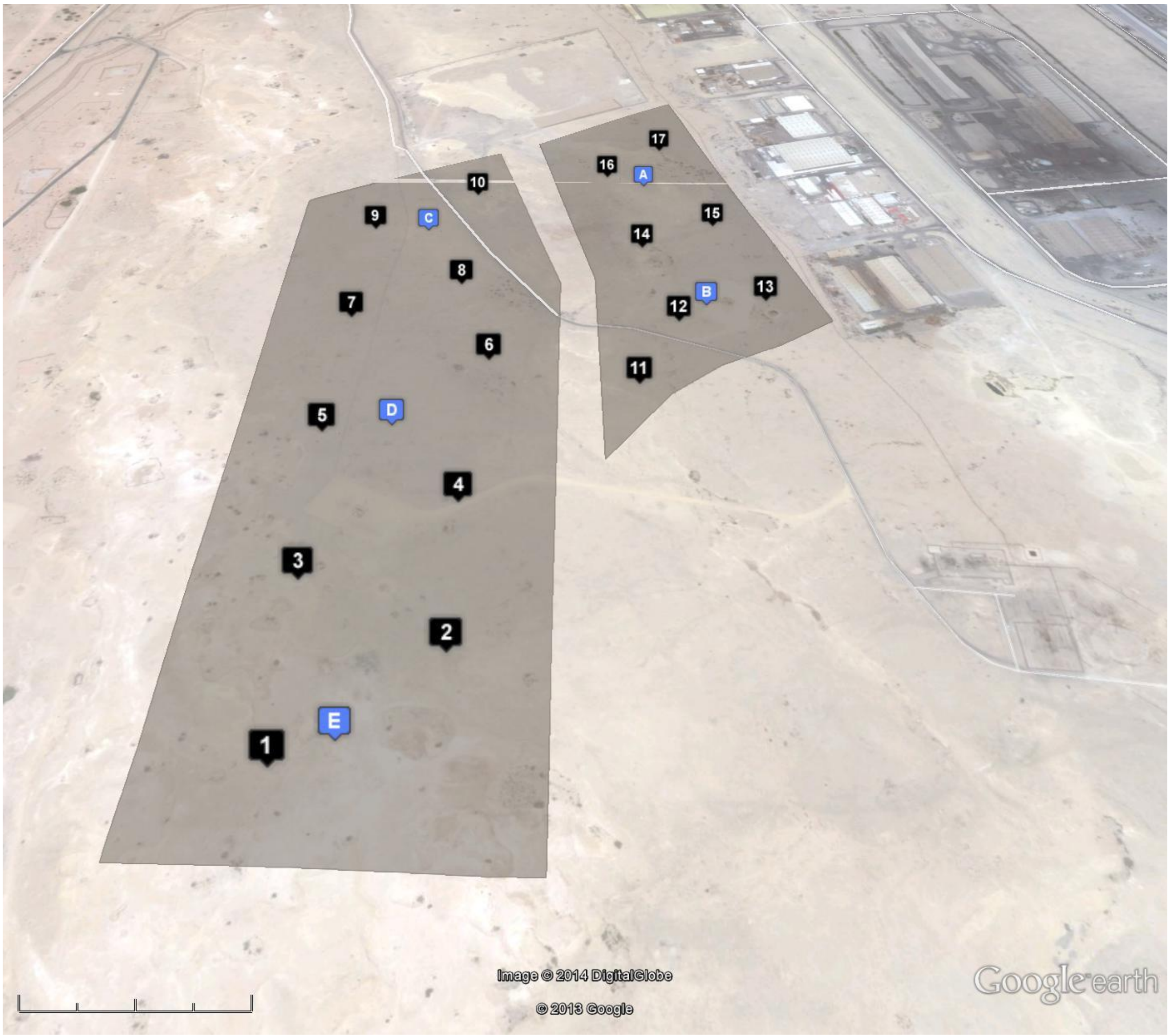

Figure 31: Proposed Locations for Soil (1-17) and Groundwater (A-E) Sampling at the Laydown Area

Table 38: UTM Co-ordinates of Proposed Soil and Groundwater Sampling at the Laydown Area

Location No.	Name	Zone	Easting	Northing
1	Soil 1	39 R	458822.00 m E	2884233.00 m N
2	Soil 2	39 R	458947.00 m E	2884334.00 m N
3	Soil 3	39 R	458812.00 m E	2884410.00 m N
4	Soil 4	39 R	458943.00 m E	2884502.00 m N
5	Soil 5	39 R	458801.00 m E	2884595.00 m N
6	Soil 6	39 R	458959.00 m E	2884707.00 m N
7	Soil 7	39 R	458802.00 m E	2884780.00 m N
8	Soil 8	39 R	458919.00 m E	2884845.00 m N
9	Soil 9	39 R	458805.00 m E	2884957.00 m N
10	Soil 10	39 R	458925.00 m E	2885038.00 m N
11	Soil 11	39 R	459118.00 m E	2884669.00 m N
12	Soil 12	39 R	459166.00 m E	2884775.00 m N
13	Soil 13	39 R	459268.00 m E	2884817.00 m N
14	Soil 14	39 R	459131.00 m E	2884921.00 m N
15	Soil 15	39 R	459221.00 m E	2884973.00 m N
16	Soil 16	39 R	459092.00 m E	2885088.00 m N
17	Soil 17	39 R	459164.00 m E	2885157.00 m N
A	GW 14	39 R	459139.00 m E	2885066.00 m N
B	GW 15	39 R	459199.00 m E	2884805.00 m N
C	GW 16	39 R	458870.00 m E	2884955.00 m N
D	GW 17	39 R	458869.00 m E	2884604.00 m N
E	GW 18	39 R	458869.00 m E	2884255.00 m N

6.4.2.2 Operations

During operations, storage of chemicals and wastes has the potential to impact the quality of the soil. When material is not handled properly, there is a potential for spillage. However, considering Alba's current practises these risks are not considered to result in a major impact.

Furthermore, the following operational phase aspects may result in potential contamination of the soil and would need to be considered in the design, material selection and construction of the expansion.

Table 39: Potential Soil Contamination during Operations

#	Aspect	Potential Threat
1	Sewage System	Where the sewage lines are made from unsound material or when aggressive or soil threatening compounds are drained which can attack the piping. However this is unlikely considering the nature of the soil and Alba's activities
2	Storage of oil products and other chemicals	The risk of soil impacts are present because of the risk of leaks as a result of accidents that may perforate the storage container or knock it over.

3	Waste Storage	The storage of waste material including used oil and other fluids (if stored directly on the soil).
4	Storage of Raw Materials	The key risk here is the potential spillage of fluorinated material.
5	Pipelines	Leakage of materials from the pipelines in the event that they rupture.[25]
6	Activities at the Workshop and Maintenance Facilities	Lubrication, cleaning and oil changes pose a threat of spillage of oil and fuel.
7	Vehicle Washing	If the wash water from these activities is not properly controlled it has the potential to impact on soil.

As is presently the practise in Alba, no waste materials will be allowed to be stored in the open and in contact with the soil. Therefore, materials are segregated and stored directly in concrete pads of the storage areas.

6.4.3 Increased waste

The proposed expansion will result in an increase in the quantities of waste that is generated (see Section 4.3.2 and Section 6.7).

The intermediate storage and handling of waste is likely to pose an increased risk of soil contamination. This risk is also manageable and through the implementation of suitable control measures can be minimised or prevented. Considering waste management practises and storage of wastes in a dedicated area (not directly on the soil), the risk of effects related to contamination of soil through storage of waste are unlikely to be manifested as a result of the future operations related to the expansion.

6.4.4 Mitigation Measures and Compliance with IFC

In order to minimize the impacts on soil and groundwater, proper material and waste handling is of significant importance. Applicable IFC guidelines[26] provide guidance for safe storage and use of hazardous materials. As Alba has a broad set of established HSE procedures for their existing operations, these would also be implemented for the proposed project. Nonetheless, the following control measures are stated as recommendations for implementation.

6.4.4.1 Prevention of spills (construction)

In all areas where liquid chemicals, oils and fuels will be stored, provision must be made for a storage area that is made up of a solid (concrete) base with bund walls that can accommodate the contents of at least one (and preferably two) of the containers that will be stored in the facility. On site refuelling of vehicles should be limited and preferably be effected at dedicated refuelling facilities which would provide for the containment of any spillages during refuelling.

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[25] Possible spillages would be mostly from pipelines and piping transporting liquid (sewage) and hazardous materials (fuels, oil, pitch, HTM, water treatment chemicals, etc.)

[26] Environmental, Health, and Safety Guidelines Base Metal Smelting and Refining, April 30, 2007

6.4.4.2 Immediate remedial action

In case of spillage of liquid chemicals, oils and/or fuels, a mechanism must be in place to immediately remediate the affected area. This could be through the application of spill absorbing materials and the excavation, removal and safe disposal of contaminated soil should that be required.

6.5 Ecology

The expansion will occur within Alba's industrial site which has little ecological value. The proposed off-site construction lay-down areas west of the existing Alba facility were surveyed by a walk-down. The area is sandy with scares vegetation of common species and a few bird species (laughing dove, sparrow). No visual tracks of any species were encountered. The area which has the most vegetation and presence of fauna was the north eastern part of the lay down area, close to the existing industrial facilities. This area consists of a lower lying area, approximately 2 meters lower than the surrounding areas. This area showed clear presence of human activities and impacts due to the existing asphalt road running north-south, deposited rocks, backfilled areas with sand, wind-blown litter and a hose used for discharging water (not in use during site visit). It is possible that the discharges of water that occurred in the area have increased flora and fauna in the area.

Nevertheless neither of the areas is of a high ecological value. Obviously the construction phase impacts will have an impact on existing ecological features. However, it is assumed that after proper site restoration, the site can be restored to conditions similar to current conditions.

Therefore, impacts during the construction phase are considered to be marginal, as long as the sites are restored as much as possible to their original condition.

6.6 Energy Use

6.6.1 Overview

The implementation of the proposed expansion of Potline 6 will increase the energy demand of the existing plant. To account for that increase, an extra power generation facility and additional operational fuels are required. In all calculations it is assumed that the aluminium production after the expansion will be 1,438,851 tonnes per year.

Up to 150 MW of power would be sourced from the Electricity and Water Authority (EWA) grid for normal operations. Alba may be able to import up to 400 MW in the winter subject to availability from the grid.

6.6.2 Electrical power

In **Table 40** the annual energy input and output of power after the expansion of Potline 6 is presented. Below figures exclude import of power.

Table 40: Overview of annual energy input and output for Power Stations after Potline 6 expansion

Power stations	Gas input (TJ)	Average capacity (MW)	Power output (GWh)	Power output (TJ)	Efficiency
Total	159,140	2,481	21,734	78,240	49%

6.6.3 Fuels

Natural gas is also used in the carbon plant, and in the cast house.

Equipment running on diesel are slowly being phased out where possible and replaced by those running on gasoline. Current diesel consumption is approximately 1,900m^3/year, and gasoline consumption is approximately 190m^3/year. Due to phase out of diesel operated equipment these consumption figures will change.

6.6.4 Impact during construction

Extra fuels and electrical power are needed during the construction activities. These demands should cover the machinery, equipment, temporary facilities, and all other components involved during this phase.

Construction power will, in general, be provided from the existing plant distribution system. The peak construction load including temporary site lighting is estimated at 5 MW for the smelter and approximately 2-3 MW for PS5. This figure is insignificant compared to the total installed capacity and will thus have a marginal impact on electrical energy use. The temporary power supplies would be equipped with suitable protection systems, to prevent disturbances on the existing electrical system which might affect plant operations.

The extra fuel quantities (diesel and gasoline), required for onsite machinery, will not have a significant impact on total energy use (TJ). Diesel generators will also be used by on site Contractors. The split between the use of generators and Alba supplied construction power will be finalized during the construction phase.

6.6.5 Impact during operation

Table 41 compares the daily total and specific energy consumption for the production of aluminium of the Alba plant before and after the expansion.

Table 41: Total and specific annual energy consumption

	Baseline (2013)	Expansion (incl. PS 5)	Units
Total electricity production required for aluminium production	50,584	73,164	TJ
of which is attributed to auxiliaries	3,270	5,077	TJ
Production of aluminium	924,654	1,438,851	tpy
Total specific energy use (including all auxiliaries)	15.2	15.1	kWh/kg
Specific electricity use for electrolysis including potline auxiliaries	14.9	14.8	kWh/kg
Specific electricity use for electrolysis excluding auxiliaries	14.2	14.1	kWh/kg

The following conclusions can be derived from this table:

The energy consumption at the Alba plant will increase by 45% due to the proposed expansion, based on total energy input, and by 54% based on total energy consumption attributed to aluminium production. However, by using efficient technologies for power generation and aluminium production, the energy consumption per kg of aluminium will only increase by 0.2% against a total aluminium production increase of 56%.

It is not possible to define an overall impact even if the increase in energy consumption will have an impact on various aspects, such as resource depletion, emissions to air, and other environmental components, etc. Replacing the older power generation units (PS1 and PS2), with modern turbines (PS5) would increase the overall efficiency which would in turn decrease the overall consumption and its effects on the environment per kg of aluminium produced.

The additional energy requirements of the proposed expansion and, more importantly, the environmental aspects of the additional energy supply have been included in the present assessment. The assessment is based on the basis that there will be no electricity export.

6.7 Waste Management

6.7.1 Overview

The proposed expansion will result in a significant increase in the quantities of many of the operational waste streams that are currently generated, while the expansion project itself will generate a variety of construction wastes. In this section the increase in the quantities of waste is predicted and an assessment made of the impacts of these increases.

First, the impact from construction waste is assessed and mitigation measures are proposed to minimise the impact of same. In the second sub-section, the impacts from the operation of the proposed facility are assessed.

6.7.2 Construction Wastes

Construction activities are expected to produce the following waste types:

- Surplus excavated material will be generated during the site preparation activities. However, a large quantity of excavated material from Potline 6 and PS5 locations will be used to level the lay-down areas.
- Other construction wastes would include scrap steel and wood, general rubbish, packaging wastes
- Potential contaminants during demolition work. These areas would need to be surveyed by Alba and if contaminated, would need to be remediated by Alba prior to construction works.
- The increase in workers and machinery capacity will increase the quantities of domestic and workshop wastes (used oils, lubricants, tires, etc.) generated on site.

During the construction period, the contractor will adapt an aggressive recycle program and minimize the waste to the landfills. Scrap/packaging steel, copper, aluminium, paper, plastics, wooden pallets and concrete waste will be recycled.

In general, following solid construction wastes are expected:

- **Approximately 3,000 tonnes recycled solid wastes** - cardboard, plastic, glass & metals, ~ 2,000 tonnes for smelter and ~ 1,000 tonnes for PS5;

- **Approximately 7,000 tonnes un-recycled solid wastes** - construction waste to landfill ~ 5,000 tonnes for smelter plus ~ 2,000 for the PS5 area.

The types and quantities will have to be confirmed by the Contractor.

In addition to the construction wastes, demolition waste is expected to be generated due to the demolition of the following:

- The L5 temporary trailers located south of the existing L5 compressor station;
- Existing buildings within the footprint of the new facilities, including the L5 Carbon area maintenance shop, L5 Bath plant maintenance shop and warehouse, two (2) dross treatment facilities, CH2 re-melt facility; and
- The existing textile factory located at the Jawed land south of L6, which is located outside Alba's Battery limits

The following non-hazardous demolition waste will be generated:

- Plasterboard,
- Concrete, including metal reinforcements,
- Masonry, gypsum blocks
- Tiles, toilet bowls, wash basins
- Metal from reinforcements, ducting, piping, fixtures, cabling, lighting material, door handles, facades, ceiling covers plating
- Wood (structural, doors, cabinets, flooring, furniture, ceiling covers)
- Isolation materials (glass wool, sandwich materials etc.)
- Carpets, linoleum
- Glass

The following hazardous materials will be generated during demolition:

- Equipment containing hazardous materials, such as lubricants, refrigerants
- Tube lights

Any hazardous waste would have to be managed separately. It will have to be disposed of in accordance with the applicable regulations. Hazardous waste in Bahrain can only be disposed of via environmental service providers (waste collecting and recycling companies) mentioned on the two lists available with Directorate of Environmental Assessment & Control:

1. Hazardous waste and oily waste collectors.

2. Oily waste collectors.

Disposal of the excavated material poses two environmental impacts:

- Impacts from disposal of excavated material and contaminated soil; and
- Impacts from general disposal of excavated material.

The soil investigation shows limited amounts of contamination of the upper soil layer from sulphur and boron. Deeper soil strata are not expected to be contaminated, as that contaminate mobility is considered to be low based on the EIA study conducted previously (2003), suggesting that lower soil strata contamination is unlikely.

A significant amount of cut (approximately 800,000 m^3) will be will be hauled off site. Part of the surplus extra excavated material (cut) will be used for as fill for site works. The off-site temporary laydown area would be levelled primarily with this fill material. In addition, waste handling and disposal plans will be developed by the EPC contractor prior to construction.

Removal and land filling of contaminated soil will transfer the environmental risks to human health and environmental quality to the landfill or disposal site. The impact from this will depend on sensitivity of the disposal place. Disposal of this material also poses a potential impact for occupation health and soil. Impacts related to these topics are discussed in their respective chapters (section 6.11 and 6.4 respectively).

Disposal of the non-contaminated soil will also impose environmental impacts. This depends on the manner in how it will be disposed. Disposal to existing landfill sites will put tremendous amount of pressure on capacity of the landfill (see section 5.6.1.1 for a discussion on landfill capacity). The environmental impact that results is the expenditure of limited landfill space. Other environmental impacts can result if the material is deposited in an ecologically sensitive area.

In addition to excavated soil, a range of construction wastes will be generated including, asphalt, concrete, wood scrap, packaging material, oil and other general wastes. For the most part, these wastes are non-hazardous but certain waste types, such as used oils, are hazardous and need to be safely disposed of. The real challenge during construction is to ensure that adequate provision is made to manage the waste effectively and to ensure that the right mechanisms are in place for suitable disposal. The additional waste generated during the construction phase will be an increase over and above the on-going disposal of waste and this will impact negatively on the available airspace of the existing landfills. Finally there will be an increase in the quantity of sewage due to an influx of construction workers and provision will have to be made to manage and dispose of this additional sewage safely and effectively.

To ensure that the risk of environmental impact from waste generated during the construction phase remains low, an effective waste management approach must be developed and implemented. Such a waste management approach should provide for the following:

- Initial segregation of waste on site into recyclable (scrap metal, wood and used oils), general waste (waste food, packaging) and hazardous waste (contaminated soils);
- Sale (or donation) of the recyclable waste stream;
- Disposal of general waste at the general waste landfill;

- Disposal of hazardous waste at the hazardous waste landfill; and
- Compelling contractors to comply with the above requirements.

In line with the above, the EPCM construction team shall provide construction waste management for site wide collection, ensure separation of recyclables and shall dispose of construction waste materials in a safe manner.

6.7.3 Wastes from Operations

The proposed expansion will result in an increase in waste quantities but the properties of these waste streams will be very similar to those generated currently. It has been assumed that the increase in quantity will be proportional to the increase in production capacity (i.e. 57% increase compared with the existing 2013 situation)[27]. In order to address this increase and ensure that it does not become a threat to the environment, Alba has already developed a five-year waste management plan. The waste management plan has as a key objective a 25% reduction in the quantities of waste produced at the existing plant.

An overview of the waste types (hazardous and non-hazardous) is presented in **Table 42**. The corresponding estimated increase in these wastes following the implementation of the proposed expansion is summarised in **Table 43**. As stated previously, SPL is segregated by Alba into Hazardous and Non-Hazardous elements for subsequent processing.

Table 42: Classification of Wastes from Operations

S. No.	Waste Item	Waste Type	S. No.	Waste Item	Waste Type
Un-recycled Solid (MT)					
S1	Carbon Dust to Askar	Non-Hazardous	S9	Construction Waste	Non-Hazardous
S2	Cast Iron Slag	Non-Hazardous	S10	Calciner Bag House Ash	Non-Hazardous
S3	Recovered casting oil – Wet sludge	Hazardous	S11	Laboratory Waste[28]	Hazardous
S4	Sulphur Waste[29]	Hazardous	S12	Medical Waste	Hazardous
S5	SPL to Hafeera[30]	Hazardous	S13	Mixed Rubbish Waste[31]	Non-Hazardous
S6	Office and Cafeteria Waste	Non-Hazardous	S14	Tree Cutting	Non-Hazardous

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[27] Based on production capacity of 2013 and future production capacity of L6 + Crept L1 – 5

[28] Comprises of spilled and depleted chemicals

[29] Sulphur waste is generated in desulphurization process, where sour gas goes through a NALCO solution in a tower and the sulphur is stripped and precipitated at the bottom of the tower. The sulphur is periodically removed in the form of thick slurry dried at Yateem and sent as dry sulphur waste to Hafieera..

[30] Hazardous fraction, the non-hazardous fraction is recycled.

[31] Same composition as general waste and is also sent to Askar landfill, but it was collected from the recycler different skips.

S. No.	Waste Item	Waste Type	S. No.	Waste Item	Waste Type
S7	General Waste[32]	Non-Hazardous	S15	Other Waste[33]	Non-Hazardous
S8	Refractory Waste to Askar	Non-Hazardous			
Un-recycled Liquid (MT)					
L1	CH Cooling Tower Cleaning	Non-Hazardous	L2	Oil/Water to Askar	Non-Hazardous
Recycled Solid (tpy)					
RS 1	SPL Steel to BRAMCO	Non-Hazardous	RS 4	SPL SiC Bricks to BRP	Non-Hazardous
RS 2	SPL Bricks to BRAMCO	Non-Hazardous	RS 5	Tree Cuttings	Non-Hazardous
RS 3	SPL Carbon to BRAMCO	Non-Hazardous	RS 6	Construction Waste	Non-Hazardous
Recycled Liquid (tpy)					
RL 1	Waste Oil to BAPCO	Hazardous	RL 5	Hydrocarbon Condensates	Hazardous
RL 2	Waste Oil to Bapco	Hazardous	RL 6	Waste Water	Semi-Hazardous
RL 3	Waste Oil to Qatar Factory	Hazardous	RL 7	Sewage Sludge Askar	Semi-Hazardous
RL 4	Oil / Water to BAPCO	Hazardous			
Scrap Materials (sold) (tpy)					
Sold 1	Steel (Ferrous)	Non-Hazardous	Sold 9	Wooden Pallets	Non-Hazardous
Sold 2	Timber (Wood)	Non-Hazardous	Sold 10	Filter Elements	Non-Hazardous
Sold 3	Batteries	Hazardous	Sold 11	Vehicle Radiators	Non-Hazardous
Sold 4	Oil Drums	Hazardous	Sold 12	Plastic (PVC)	Non-Hazardous
Sold 5	Cast Iron	Non-Hazardous	Sold 13	AC Condenser	Non-Hazardous
Sold 6	Tires & Belts	Non-Hazardous	Sold 14	Paper & Cartons	Non-Hazardous
Sold 7	Aluminium	Non-Hazardous	Sold 15	Jumbo Bags	Non-Hazardous
Sold 8	Copper	Non-Hazardous			

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[32] Normal wastes collected in blue general waste skips

[33] Mostely construction wastes

The estimates are based on an assumed proportional increase in waste to the increased production capacity. Where applicable, the increase in personnel is also taken into account. Given that there are a number of areas where design modifications and increased efficiencies in the proposed new plant will reduce the waste generated per tonne of aluminium, it is recognised that the projected increase may be an overestimate.

As shown from the table, a total of 28,228 tonnes of non-recyclable solid waste is expected to be generated each year, which corresponds to an increase of 49%. This includes 8,039 tonnes of hazardous waste. Wet sludge from the cast house (S3, Recovered casting oil) is not included in this total, but is presented (in m^3 per year) in the table below. In addition, 389 tonnes of un-recyclable liquid will be generated and comprises oil / water waste to Asker Landfill. This does not include waste water, which is discussed separately in section 6.3.

In addition to the non-recycled waste, 26,677 tpy of recycled solids (an increase of 58%) and 58,528 tpy of recycled liquids (an increase of 38%) will be generated. These quantities indicate that Alba recycles almost half of its solid wastes. An additional 5,016 tpy of scrap metals are expected to be sold each year.

Table 43: Wastes from Operations (tpy)

S. No.	Waste Item	Source	L1 - 5 Baseline (2013)	L1 - 5 Crept	L6	Crept L1 - 6
Production Capacity (tpy)			**912,700**	**924,654**	**521,667**	**1,446,321**
Personnel (Nos)			**2,914**	**2,914**	**547**	**3,461**
Un-recycled Solid (t)						
S1	Carbon Dust to Askar	Carbon	1,136	1,151	649	1,801
S2	Cast Iron Slag	Carbon	635	643	363	1,006
S3	Recovered casting oil – Wet sludge	Casthouse	270 m^3 / year	274 m^3 / year	154 m^3 / year	428 m^3 / year
S4	Sulphur Waste	Casthouse	48	49	28	77
S5*	SPL to Hafeera	Red. Serv.	5,024	5,090	2,872	7,961
S6[1]	Office and Cafeteria Waste	Environment	278	278	52	330
S7[1]	General Waste	Environment	2,599	2,599	488	3,087
S8	Refractory Waste to Askar	Maint.	5,984	6,062	3,420	9,483
S9	Construction Waste	Engg:	1,211	1,227	692	1,919
S10	Calciner Bag House Ash [34]	Calciner	149	149	-	149
S11	Laboratory Waste	Laboratory	3 kg/year	3 kg/year	-	3 kg/year
S12[1]	Medical Waste	Medical	0.39	0.39	0.07	0.46
S13[1]	Mixed Rubbish Waste	Plant Wide	1,233	1,233	231	1,464
S14	Tree Cutting	Plant Wide	518	525	296	821
S15[1]	Other Waste	Plant Wide	36	36	7	43
Total un-recycled solids (tpy)			**18,852**	**19,044**	**9,184**	**28,228**
Un-recycled Liquid (t)						
L1	CH Cooling Tower Cleaning	Casthouse	0	0	0	0
L2	Oil/Water to Askar	W/S (Maint)	245	249	140	389
Total un-recycled liquids(tpy)			**245**	**249**	**140**	**389**

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[34] No increase foreseen as production capacity of the calcining facility is to remain the same

S. No.	Waste Item	Source	L1 - 5 Baseline (2013)	L1 - 5 Crept	L6	Crept L1 - 6
Production Capacity (tpy)			**912,700**	**924,654**	**521,667**	**1,446,321**
Personnel (Nos)			**2,914**	**2,914**	**547**	**3,461**
Recycled Solid (tpy)						
RS 1*	SPL Steel to BRAMCO	Red. Serv.	2,814	2,851	1,608	4,459
RS 2*	SPL Bricks to BRAMCO	Red. Serv.	5,296	5,366	3,027	8,393
RS 3*	SPL Carbon to BRAMCO	Red. Serv.	7,840	7,942	4,481	12,423
RS 4*	SPL SiC Bricks to BRP	Red. Serv.	182	185	104	289
RS 5[2]	Tree Cuttings	Environment	4	4	4	4
RS 6[3]	Construction Waste	Engg	510	517	291	808
Total recycled solids (tpy)			**16,647**	**16,865**	**9,517**	**26,377**
Recycled Liquid (tpy)						
RL 1	Waste Oil to BAPCO	Power	811	822	464	1285
RL 2	Waste Oil to Bapco	Workshop	0	0	0	0
RL 3	Waste Oil to Qatar Factory	Environment	920	932	526	1458
RL 4	Oil / Water to BAPCO	Power	9,582	9,708	5,477	15,184
RL 5	Hydrocarbon Condensates	Power	9,710	9,837	5,550	15,387
RL 6[1]	Waste Water	Plant Wide	33	33	6	39
RL 7[1]	Sewage Sludge to Askar	Plant wide	21,195	2,1195	3,979	25,174
Total recycled liquids(tpy)			**42,252**	**42,527**	**16,001**	**58,528**
Scrap Materials (sold) (tpy)						
Sold 1	Steel (Ferrous)	Plantwide	1941	1966	1109	3075
Sold 2	Timber (Wood)	Plantwide	466	472	267	739
Sold 3	Batteries	Plantwide	86	87	49	136
Sold 4	Oil Drums	Plantwide	46	47	26	73
Sold 5	Cast Iron	Plantwide	293	297	167	464
Sold 6	Tires & Belts	Plantwide	157	159	90	249
Sold 7	Aluminium	Plantwide	12	12	7	18
Sold 8	Copper	Plantwide	2	2	1	3

S. No.	Waste Item	Source	L1 - 5 Baseline (2013)	L1 - 5 Crept	L6	Crept L1 - 6
Production Capacity (tpy)			**912,700**	**924,654**	**521,667**	**1,446,321**
Personnel (Nos)			**2,914**	**2,914**	**547**	**3,461**
Sold 9	Wooden Pallets	Plantwide	0	0	0	0
Sold 10	Filter Elements	Power	45	46	26	72
Sold 11	Vehicles Radiators	Workshop	0	0	0	0
Sold 12	Plastic (PVC)	Plantwide	15	15	9	24
Sold 13	AC Condenser	Workshop	0	0	0	0
Sold 14	Paper & Cartons	Plantwide	68	69	39	108
Sold 15	Jumbo Bags	Reduction	36	36	20	56
Total Sold Scrap Materials (tpy)			**3,166**	**3,207**	**1,809**	**5,016**

NA = Not available

* Note that SPL waste will only be generated from Potline 6 ~ four (4) years after the first aluminium is produced.

1. Quantities based on an increase in personnel as type of waste generated is not related to the increased production capacity.
2. As trees will be removed during the construction of Potline 6 and Power station 5 it is envisioned that the amount of “tree waste” will reduce in the future.
3. Construction waste from maintenance of the new Potline is not expected in the first years of operation. Therefore the waste quantification is considered to be conservative.

As high-lighted previously, non-recyclable wastes are currently disposed of in two landfills (general and hazardous). Although this constitutes an acceptable disposal practice, the impact on the landfill sites especially the gradual use of airspace, needs to be considered an impact in its own right. As a result it is considered necessary for Alba to continue exploring ways of reducing their waste at source. To this end Alba’s five year waste reduction programme is strongly supported especially the target of a 25% reduction in waste from current operations.

In addition to the waste to landfill, Alba recycles their material to the extent possible by re-introducing materials back into their process. For example, alumina used to capture fluoride in the air pollution control equipment is reintroduced as ingredient in the electrolysis pot (charge alumina). An overview of the re-introduced material is provided in **Table 44**.

Table 44: Material Recycled within the Process[35]

S. No.	Process Area / Process	Material		L1 - 5 Baseline (2013)	L1 - 5 Crept	L6	Crept L1 - 6
Production Capacity (tpy)				**921,700**	**924,654**	**521,667**	**1,446,321**
1	Reduction Area	Bath used as cover material		256,430	259,789	146,567	406,356
		Alumina spills	Fresh	3,487	3,533	1,993	5,526
			Enriched	3,487	3,533	1,993	5,526
		Dust[1]		1,743,163	1,765,993	996,330	2,762,324
2	Carbon Plant	Butts and Baked Scrap[2]		121,052	122,637	69,189	191,826
		Green Scraps[2]		8,246	8,354	4,713	13,067
		Cast Iron Content of Butts[3]		938	950	536	1,486
		Spills	Charged alumina	251	254	143	397
			Coke materials[4]	0	0	0	0
		Anode baking furnace packing coke		7,416	7,513	4,239	11,751
		Dust[5]		49,968	50,623	28,560	79,183
3	Aluminium[6]			2,295	2,325	1,312	3,637
4	Dross			13,419	13,595	7,670	21,265
5	SPL[7]		Minimum	12,889	13,058	7,367	20,425
			Maximum	14,655	14,847	8,376	23,223
Total Materials Recycled in the Process				**2,237,696**	**2,267,004**	**1,278,988**	**3,545,992**

1. Alumina used to capture fluoride in the air pollution control equipment is reintroduced as ingredient in the electrolysis pot.
2. Recycled in the anode paste recipe.
3. Recycled in the anode rodding operation.
4. Assumed to be included in the green scraps.
5. Alumina used to capture fluoride in the air pollution control equipment is reintroduced as ingredient in the electrolysis pot (charge alumina).
6. Collected at various locations and would be processed with dross. This includes aluminium in crust bath, in ladle bath, in delined pot bath and in tap bath.
7. Once relining operations are starting on L6 at a steady pace (±4 years after firing the first pot).

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[35] Based on values provided by Alba for a production capacity of 516,971 MTPA (L6 only).

6.7.4 Landfill Capacity

As previously described, un-recycled wastes from Alba are disposed at the Hafeera Hazardous Waste Landfill and the general waste landfill at Askar. The projected increase in waste will put additional pressure on these facilities.

As shown in the preceding section, Alba recycles their material to the extent possible by re-introducing materials back into their process and thereby limiting the pressure on the landfill site. Furthermore, the proposed 25% reduction in wastes from existing operations will ensure that the planned lifetimes of these facilities will be less negatively affected by the proposed expansion.

It is also important to note that Alba funded the construction of the Hafeera Hazardous Waste Landfill to make specific provision for the SPL (hazardous part) disposal. Because SPL is segregated prior to disposal, and the non-hazardous components are recycled, the period for which capacity will exist for SPL disposal has been further extended.

6.7.5 Dross

Dross, formed by the oxidation of molten aluminium on the surface of the melt and produced during primary aluminium production process, is known as “white dross” and has a high metal content[36] ranging from 30% to 80%[37].

Prior to the casting process, the white dross is skimmed off the surface of the molten aluminium and generally occurs in quantities of some 15 to 20 kg per tonne of aluminium produced. The dross produced by the aluminium industry, although a waste, contains aluminium and other valuable elements (aluminium oxides), which can be recovered and reused. Therefore, the dross can be processed using Tardis presses to recover and cool the dross, which is then sent to off-site processors for further recovery of metal.

In the dross press (the most widely used method to cool the dross[38]), liquid placed under pressure will separate from a solid and consequently flow to areas of least pressure. The system rapidly cools the dross and provides high overall dross recoveries (60% - 70%).

A Harsco-controlled joint venture partnership in Bahrain called AluServ is specialized in the processing of dross. AluServ uses the Rotating Tilting Furnace (RTF) technology which focuses on an environmentally-responsive, zero waste solution for recycling of aluminium dross. After processing and subsequent to separation of the metallic units, the residual non-metallic products are recycled into metallurgical additives used in steelmaking.

Previously, Alba used to use presses/ coolers to recover the dross and subsequently it was send for processing. The recovered aluminium was returned from the processing facility as ingots and recycled into Alba’s production process.

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[36] Aluminium dross from secondary aluminium production has a lower metal content and is known as “black dross”. Black dross has a recoverable aluminium content ranging between 12 to 18%, and much higher salt content (typically higher than 40%) than the white dross. However, this is not applicable to Alba’s primary production process.

[37] According to the Organisation for Economic Co-operation and Development (OECD), residues with more than 45% Al are called “skimmings” and materials containing less than 45% Al are called “dross”. In this chapter, „dross“ is used for both definitions.

[38] Other methods include air cooling, rotary cooling, and cooling with Argon.

However, recently, Alba is selling the dross to overseas customers. As it is currently not know how this is processed overseas, the environmental impacts from the dross processing cannot be assessed. Nevertheless, as the dross is sold and transported overseas, this has the added a local benefit of reducing the pressure on the Bahraini hazardous waste landfill capacity.

Aluminium dross contains aluminium nitride (AlN). Upon contact with water or water vapour, AlN hydrolyzes slowly and odorous ammonia is formed[39]. Therefore it is important to apply proper storage and handling practises in regards to dross in order to minimise the effects from ammonia formation.

6.7.6 Spent Pot Linings (SPLs)

As previously described, SPLs is the most significant waste stream in terms of the hazard it presents due to its toxicity and generated quantity. This hazard stems from the presence especially of fluoride and cyanide in SPL.

SPL generation for Potline 6 would start approximately four (4) years after start-up of the Potline when the pot relining sequence is initiated. From that point on, SPL will be generated on a steady basis.

The risk of cyanide (acute toxicity) and fluoride leaching requires SPL to be carefully managed and safely disposed of. Many smelters around the world currently stockpile their SPL in enclosed but well ventilated warehouses, pending the implementation of safe and practicable disposal practice.

Within Alba, the SPL elements are segregated, stored in covered facilities and recycled as soon as possible. The SPL storage areas are covered, open on one side and fitted with walls on three sides. The bulk of the segregation activities are done within these walls on a concrete pad and thereby not directly on the soil.

Although Alba's current disposal practice is in line with that stipulated by the authorities, it is recommended that Alba continue to pursue options for improved disposal and avoiding hazardous waste to landfill. More details on the different options for SPL treatment are included in **Appendix** 19.

6.7.7 Compliance with IFC

In the light of waste management practices, measures considered in Alba's proposed facility were evaluated against the IFC EHS guidelines regarding waste management[40].

Consistent with these guidelines, Alba reviews new waste sources during planning, siting, and design activities, as well as for equipment modifications and process alterations. This enables Alba to identify expected waste generation, pollution prevention opportunities, and necessary treatment, storage, and disposal infrastructure.

Alba also collects data on the types and quantities of the waste streams.

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[39] European Hazardous waste numbers assigned to white dross: 100315 - Skimmings that are flammable or emit, upon contact with water, flammable gases in dangerous quantities. 100304 - Primary smelting slags and white drosses. Furthermore, the United States Occupational Safety and Health Administration (OSHA), have categorized aluminum dross as a class 4.3 hazardous material, "Hazardous When Wet."

[40] Environmental, Health, and Safety (EHS) Guidelines, General EHS Guidelines: Environmental, Waste Management, April 30, 2007

Alba has established a waste management framework to ensure proper waste handling, disposal and treatment. As part of this framework, training is provided to employees on the potential impacts and risks associated with the generated hazardous waste streams.

This, in combination with regular monitoring (visual inspection of waste storage collection and storage areas) exhibits good existing waste management practices.

In addition, the selected DUBAL Technology provides efficient conversion of materials and reduction of the overall waste generated in the process.

Therefore, it is concluded that Alba generally complies with the stipulated IFC guidelines. Further recommendations derived from the IFC guidelines are provided in the section Recommendations (**Chapter 9**).

6.8 Traffic

Both the construction and operations phases of the proposed expansion project will result in increased traffic. Although the increased traffic for the construction phase will be for a fixed period only, the intensity of the increased traffic is likely to be higher than for typical operations and include a considerable number of heavy vehicle deliveries. For operations, the current traffic fleet characteristics will stay the same, but there will be an obvious increase in the frequency of trips and commensurate increased vehicle presence on the roads. In this section the change in traffic as a result of the implementation of the proposed expansion is described and assessed. The impact of shipping is also considered in the assessment. The additional traffic will almost certainly have an impact on existing road users and in the section that follows an attempt is made to define the extent and significance of the impact.

6.8.1 Construction phase road traffic

The planned time frame for the construction phase is approximately 37 months from the date of mobilization to site. The peak construction period is estimated to fall within Month 21 to Month 27 from the date of mobilization and the associated daily traffic density is anticipated to increase during the prescribed period. Moreover, the non-peak period of the project is estimated to fall within Month 8 to Month 21 and from Month 27 to Month 43 of the date of mobilisation to site, where the daily traffic density is anticipated to subside in comparison. A tentative schedule of the construction phase along with a brief indication of the relative key construction activities are illustrated in **Figure 5** (**section 4.5.9**).

Construction traffic will principally use two entrances, namely the existing west gate and a new gate at the south-west side of the site. Using two entrances will relieve pressure at the west gate and therefore on existing roads currently used by adjacent industrial companies west of Alba. For the construction of Casthouse 4, the main south east gate would be used.

Activities performed on the construction site range from Civil, Mechanical and Electrical works. Each phase of construction has different impacts associated with traffic. The construction site will be constantly changing and each contractor will have a different method of carrying out works with different types of machinery and vehicles. Therefore, at this stage of the project quantifying the exact number of vehicles for construction is not feasible. Nonetheless, reference data from previous projects was used to estimate the magnitude of the impact on traffic. 80% of the received material and equipment will be stored and pre-assembled in the Laydown area located offsite to the west of the smelter where all service contractor facilities will also be located in order to minimize interference with the existing operations within the smelter.

6.8.2 Alba's contribution

The transport requirements of the expansion project includes; moving equipment (cranes, bulldozers etc.), soil, building material (cement, building sand, reinforcing steel, shuttering etc.), delivery of fabricated components and equipment (pot shells, pot tending assembly etc.) and the transport of construction workers. The resultant additional traffic fleet will be made up of large trucks (including abnormal load vehicles), buses, mid-sized trucks, light delivery vehicles and private cars. This will cause an increase in traffic density on the public roadways during the construction period of both light and heavy vehicle traffic. An estimate of the daily numbers of heavy vehicles during the construction of PS 5 has been provided by the client based on past experience. The breakdown is shown below;

- 120 buses per day transporting labourers based on morning, lunch, end of first shift, and the same on the second shift;
- 20 light vehicle cars per day for key non-manual personnel and visitors;
- 30 trucks per day for material delivery; and
- 10 trucks per day for subcontractor equipment, cranes, tools, concrete, etc.

Based on the above, an additional **180** vehicles per day will arrive and leave the Alba smelter site for six (6) days a week during the peak construction phase. Most of the heavy and light vehicles entering the smelter will increase traffic density early in the morning at about 6 AM. The traffic density during the construction phase is anticipated to be halved during non-peak period to **90** vehicles per day six (6) days a week.

Similarly, an estimate of the daily increase during the peak periods in light and heavy vehicles traffic associated with the Potline 6 construction works is stated below;

- 235 bus trips carrying craft labour personnel based on morning, lunch, end of first shift, and the same on the second shift;
- 50 shuttle buses (5 shuttle buses per hour) operating between Potline 6 and the laydown area;
- 125 light vehicles (cars, pickups, and SUVs) for key non-manual personnel;
- 100 trucks for material deliveries operating between Potline 6 and laydown area;
- 170 trucks for subcontractor equipment, cranes, tools, concrete, etc.

Based on the above breakdown, an additional **680 vehicles** per day will arrive and leave the Alba smelter six (6) days a week during the peak period of the construction phase for Potline 6. Similar to PS 5, most of the heavy and light vehicles entering the smelter will increase traffic density early in the morning at about 6 AM. Moreover, with a peaking factor of 1.4, an additional **485** vehicles per day will arrive and leave the smelter for six (6) days a week during the construction phase of Potline 6.

In conclusion, a total of additional **860** vehicles per day are anticipated during the peak of the construction phase and a total of **580** vehicles per day for non-peak periods. In summary, the impact on the surrounding road network due to the increased traffic density during the construction period is significant.

6.8.3 Operational phase road traffic

The proposed expansion project will see an increase in both light and heavy vehicles during operations. Estimated increases in these traffic types are described below.

6.8.3.1 Light vehicle traffic

The principal source of light vehicle traffic following the expansion will be increased private car use by the expanded workforce. Alba estimates a workforce of approximately 547 employees will be required to run the expanded operation. Out of the 547 employees, approximately 380 non-management staff will be commuting to the smelter daily. Alba estimates 32% of the non-management staff will utilize the buses for commuting while the remaining 68% will use their private vehicles. Accordingly, an estimated addition of 4 buses and 260 private vehicles is anticipated to utilize the road network per day during the operational phase of the expansion. In addition to the 167 private vehicle utilized by the managerial staff, the total number of private vehicles utilizing the surrounding road network tallies to 427 private cars per day. Therefore, the impact on the surrounding road network due to the increased traffic density during the operational period is significant.

6.8.3.2 Heavy vehicle traffic

6.8.3.2.1 Heavy Vehicle Traffic from the Port Facilities

In reference to **Table 14** of Section 4.5.8, the number of deliveries between the port facility and the smelter is anticipated to increase in order to accommodate the additional yearly consumption (1,077,887 TPA) of raw materials. Accordingly, an additional 89 roundtrips per day (approximately 30 trips per each 8 hour shift) to be carried out by tankers with a capacity of 33 tons will be required to transport fresh alumina from the port facilities to the smelter. As for liquid pitch, an additional 5 roundtrips per day (approximately 2 trips per each 8 hour shift) are to be carried out by tankers with 25 tons capacity to transport liquid pitch from the port facilities to the smelter. Moreover, an additional 18 roundtrips per day (approximately 6 trips per 8 hour shift) for delivery of calcined coke from the port facilities to the smelter by tankers with 30 tons capacity.

Table 45: Estimated Increase in the Number of Heavy Vehicles

Vehicles	Present Operations (Number of Deliveries per Day)*	Present Operations & Expansion Project (Number of Deliveries per Day)
Fresh Alumina Tankers	142 deliveries per day (47 deliveries per shift)	231 deliveries per day (77deliveries per shift)
Calcined Coke Tankers	32 deliveries per day (11 deliveries per shift)	50 deliveries per day (7 deliveries per shift)
Liquid Pitch Tankers	8 deliveries per day (3 deliveries per shift)	13 deliveries per day (88 deliveries per shift)
Total Number of Deliveries per day	182 deliveries per day (61 deliveries per shift)	264 deliveries per day (88 deliveries per shift)

The amount of heavy vehicles transporting raw materials from the port facilities to Alba's smelter via Alba's private road to the south east gate will be increased from 182 roundtrips per day to 294 roundtrips per day which accounts for an approximate increase of **45%**. Consequently, the increase in heavy vehicles commuting from the port facilities to Alba's south east gate will have an impact on traffic density of Alba's private road (Umm Al Saad Avenue), King Hamad Highway, and industrial area truck road (as illustrated in **Figure 25**).

The significance of the impact on Umm Al Saad Avenue is considered to be minimal as the road is already not heavily utilized. The impact on traffic on the industrial area truck road will be limited to companies and employees in surrounding industries. However, the most significant impact on traffic density will take place on the existing King Hamad Highway and Hawar Highway with a risk of congestion at the roads leading to Alba's roundabout and from Alba's roundabout towards Askar.

6.8.3.2.2 Other Heavy Vehicles

Finished products such as extrusion billets and rolling slabs and sows will be transported via trailers to either the metal storage area within the Alba fence line or for shipping. Presently, twenty-five (25) finished products trailers exit the smelter south east gate for shipping. For the expansion, an additional ten (10) finished products trailers are anticipated to carry-out thirteen (13) deliveries per shift and consequently, thirty-nine (39) deliveries per day. In comparison to the existing operations, Alba's portion of the traffic density is anticipated to increase by **40%** on the surrounding road networks. The same gate will be used for shipping of additional finished products.

Moreover, the additional liquid metal will be transported using Metal Transfer Vehicles (MTVs) to downstream industries via the new South west gate using the public road located west of Alba. Within the plant, liquid metal will be transported to the TAC and skimming station prior to shipment off-site to reduce the alkaline earth metals content. Five (5) new MTVs will carry-out forty-five (45) deliveries per 8 hour shift for a total of 135 deliveries per day.

6.8.3.3 Increased shipping

As previously mentioned, the existing port facility accommodates the transfer and temporary storage of the three primary raw materials used at the smelter, namely alumina, pitch and petroleum coke. The port facility was upgraded in 2003 to include the addition of a second jetty to accommodate larger alumina vessels (60,000 tonnes) and the installation of a green coke calciner.

A comparison of the increased shipping as a result of the proposed expansion in relation to the number of ships tallied in 2012 is shown in **Table 46**. The number of ships docking at the port facility to deliver raw materials required for the expansion is increased by approximately **59.6%.**

Table 46: Increase in ship dockings at the Alba port facility

Ship	L1 to L5 Baseline (2012)	Potline 6
Fresh Alumina	33	19
Liquid Pitch	12	7
Calcined Coke	12	8
Total	**57**	**34**

As part of the expansion, an additional truck loading station with two (2) filling bays are to be constructed within the existing port facility to accommodate the increased delivery of fresh alumina from the port facility to the smelter.

6.8.4 Summary

As outlined above, the number of tankers as well as the number of deliveries will increase with approximately 45% in comparison to the existing operations as the consumption rates of raw materials and the production of finished products and liquid metal will increase due to the expansion project. The most significant traffic increase will occur on the King Hamad Highway as it will be utilized by heavy vehicles commuting from the south east gate and port facilities and also, by the heavy vehicles commuting between the new south west gate and downstream industries. As the existing traffic numbers on these roads are already high, especially during rush hours, the increase of traffic will definitely have a moderate to high impact on the existing traffic in the area.

Further, the existing traffic density on the surrounding road network, Alba’s main gate and the parking spaces within the smelter will be considerably impacted by the increase in light vehicles associated with the additional staff during the operational phase of the expansion.

6.8.5 Mitigation Measures

A significant increase in the traffic density is anticipated to occur during the peak of the construction phase as well as for operations of the expansion. To mitigate the impacts associated with the increased traffic volume and likely additional congestion, the following is to be implemented;

- South-west gate to be constructed as part of the expansion project;
- Investigate the options for the addition of parking spaces to accommodate the additional light vehicles for employees and visitors;
- Avoid heavy vehicles from using the King Hamad Highway during peak hours throughout the construction and operational phases of the expansion project; and
- Temporary traffic lights or a traffic controller is to be placed at points where construction heavy vehicles access public roads to further regulate the traffic.

These measures will help in decreasing the anticipated congestion on the surrounding roads, main gate, south east gate, and parking.

6.9 Visual

The Alba plant is located in an industrial area the Bapco Oil Refinery and the MEW's Riffa Power Plant to the north, industrial facilities to the south, and industrial facilities and the sea to the east. The area is thus heavily industrialized and the visual impact of the Alba plant is consistent with such development. At the Alba plant site, measures employed to reduce the visual impact include trees and flowers planted along the internal roads and around the plant buildings.

The general landscape around the Alba plant is flat and typical of the desert environment with few topographic features, little vegetation cover, and complete abundance of sand. There is little agricultural land use in the region and none associated with the smelter expansion. The nearest residential areas are Askar village (2.2km to the south), East Riffa (4 km to the north-west), and the Al Mazrowiah residential area and Golf Course (2.3km to the west).

At the outset it is important to recognise that the proposed expansion will be an extension of the existing visual character of the area given the existing presence of the plant. The facilities that will be developed are very similar in character and shape to the existing facilities, so the visual impact of the expansion will be considerably less severe than a greenfield development. Nonetheless, the plant is visible from a variety of vantage points including Askar and Al Mazrowiah wali – even though these are some distance from the plant (approximately 2.3km). In addition, workers at Alba and surrounding industries may also be affected by the change in the visual character of the area, as well as road users on Hawar road east of the plant.

6.9.1 Visual impact of the construction phase

A number of facets of the construction phase will have a bearing on the prevailing visual character. These include the excavations, stockpiling of materials, temporary construction offices and laydown areas, as well as tall cranes. Potential visual impact will be mitigated by the barrier provided by the existing facilities to road users on Hawar road and the nearby village residents. In addition, the construction activities and facilities are similar in character to the industrial forms that dominate the visual landscape. As a result, it is unlikely that the construction phase will result in a significant visual impact.

6.9.2 Visual impact of the completed expansion

The structures that will be installed for the expansion have a significant visual bearing. Potline 6 will be approximately 1.4km in length, 12.4 m high with large, uniform external surface areas. In addition, the stacks from the Gas Treatment Centres may be as high as 50 m above ground level. Other tall structures include the paste plant, the Fume Treatment Centre with a stack height 55m above ground and the stacks from the Casthouse. The new power station will also be visually dominant and will have a stack of approximately 43 meters above ground level.

When established in an existing industrial area (as in the case of the proposed expansion) the visual character is already strongly defined by similar building forms (i.e. the existing smelter and power stations), the visual impact of such buildings becomes far less significant. In such circumstances the new facilities become an extension of the prevailing visual character. The natural landscape of the area is largely flat, with small isolated patches of shrub type natural vegetation and limited aesthetic appeal. The expansion will be largely shielded from motorists on Hawar road by the existing plant. Given these circumstances it is unlikely that the proposed expansion will result in a significant visual impact in the area. In addition, minor architectural modifications to the buildings, for example patterned cladding, can present a visually attractive industrial form.

The additional lighting of the proposed expansion is unlikely to create a significant additional night-time visual impact because of the extensive existing lighting on the plant and surrounding industries. Again, simple techniques can be used to further minimise the effect by ensuring that lighting does not result in glare beyond the site perimeter.

For the general layout of Alba's existing facilities and the proposed expansion refer to **Appendix 1**.

6.10 Noise

6.10.1 Construction phase noise

During construction, the noise sources are mainly from construction activities and operation of construction equipment. The increased movement of construction vehicles also contributes to noise generation on site. The level of noise varies based on the machine and activity. Noise generated from the movement of heavy vehicles will be higher relative to the background noise levels prevailing in the project area.

The standard sound power levels from typical construction equipment are listed in **Table 47**. Other equipment than those listed below will also contribute to the noise generation from the construction site.

Table 47: Construction Equipment Noise Levels

Equipment	Peak Noise Level (dBA) @ 50 feet from equipment
Cranes	70 – 94
Loaders	77 – 96
Dozers	65 – 95
Graders	72 – 92
Scrapers / excavators	76 – 98
Compressors	70.1 – 92.6

(Source: United States, Department of Transport, Federal Highway Administration)

Elevated noise levels will also be generated at the construction camps, lay-down areas and temporary facilities due to the operation of diesel generators and other equipment. The potential impact to the surrounding environment will be to the workers at the adjacent industrial facilities and Alba personnel.

Noise levels at the construction site are expected to be greater than the stipulated Bahraini noise levels. However, noise levels in general are attenuated by distance and typically reduced by 40 dB(A) at a distance of 100 m based on standard sound wave divergence in homogeneous loss-free environment. Therefore, the noise levels of 90 – 95 dB(A) will reduce to significantly lower levels at 200 - 300 m from the working area. Noise levels will also vary based on the construction activities with high noise from activities such as excavation, piling, drilling, etc.

The results of noise measurements (refer section 5.7) show that ambient noise levels ranged between 58.3 dB(A) – 73.5 dB(A) (L_{eq}) which for most locations is within the applicable limits set by the World Bank for industrial and commercial locations (70 dB(A) for both day- and night-time). However, noise levels at the South Gate, in close proximity to the emergency clinic, exceeded 70 dB(A) during day-time by 0.5 – 1 dB(A) owing to heavy vehicle movement in the area. In addition, noise levels at the camps off the Alba plot reached 73.5 dB(A) due to heavy traffic on the adjacent highway.

In principle, construction activities will be carried out during daytime to reduce the noise levels at night time in the areas affected by the construction activities. However, night-time construction activities may be necessary for schedule and cooler period construction.

Noise levels during the construction phase are considered not to have a significant impact on residential receptors. Some elevated noise levels are anticipated at surrounding industrial facilities.

6.10.2 Operation phase noise

The expansion of ALBA facilities will include a number of noise sources, which will have potential adverse impacts on the workplace and ambient noise levels. Most of the sources are continuous which include the FTC and GTC fans, rectifiers, etc.

A quantitative assessment through noise modelling was conducted as part of the present ESIA study to determine the additional contributions to the ambient noise levels from the proposed PL-6 project.

6.10.2.1 Noise model

The noise modelling for evaluation of noise contributions was conducted using SoundPLAN developed by Braunstein & Berndt GmbH, Germany. The model is based on sound pressure wave divergence. SoundPLAN is a Microsoft Windows based software tool, which can accept multiple stationary noise sources.

6.10.3 Noise Emission Inventory

The various noise generating sources identified and utilised for modelling are as presented in **Appendix 20**.

6.10.4 Noise modelling results Operational phase

Figure 33 below provides the overview of Noise Contributions from Alba (baseline noise levels inclusive of L-6 operations) to the surroundings. The noise contributions include traffic movements to and from the site and on site. The different colours indicate the noise levels in dB(A).

Noise levels close to Alba's fence lines are within the regulatory requirement of 70 dB(A) (limits prescribed for Industries by IFC), as can be seen from the noise maps in **Figure 33** and **Figure 34** below. Based on the above and considering long term impacts, the impacts on noise levels are rated as below.

Table 48: Alba Operations Noise Levels (Current Plus L6 and PS5)

Direction	Baseline Noise Levels (dB(A))	Predicted Noise Levels at Fence Line (dB(A))	Increase in Noise Levels (dB(A))	Remarks
North	61.0	62.0	Negligible	Complies with World Bank Allowable Noise limits
East	71.0	71.0	-	Existing noise levels are slightly non-compliant. This is caused by noise from traffic on King Hamad Highway. Further, noise levels at all areas except at south-east corner (close to PL-6 current office area) are within 70 dB(A)
South	61.0	61.7	Negligible	Complies with World Bank Allowable Noise limits
West	66.5	67.0	0.5	Complies with World Bank Allowable Noise limits

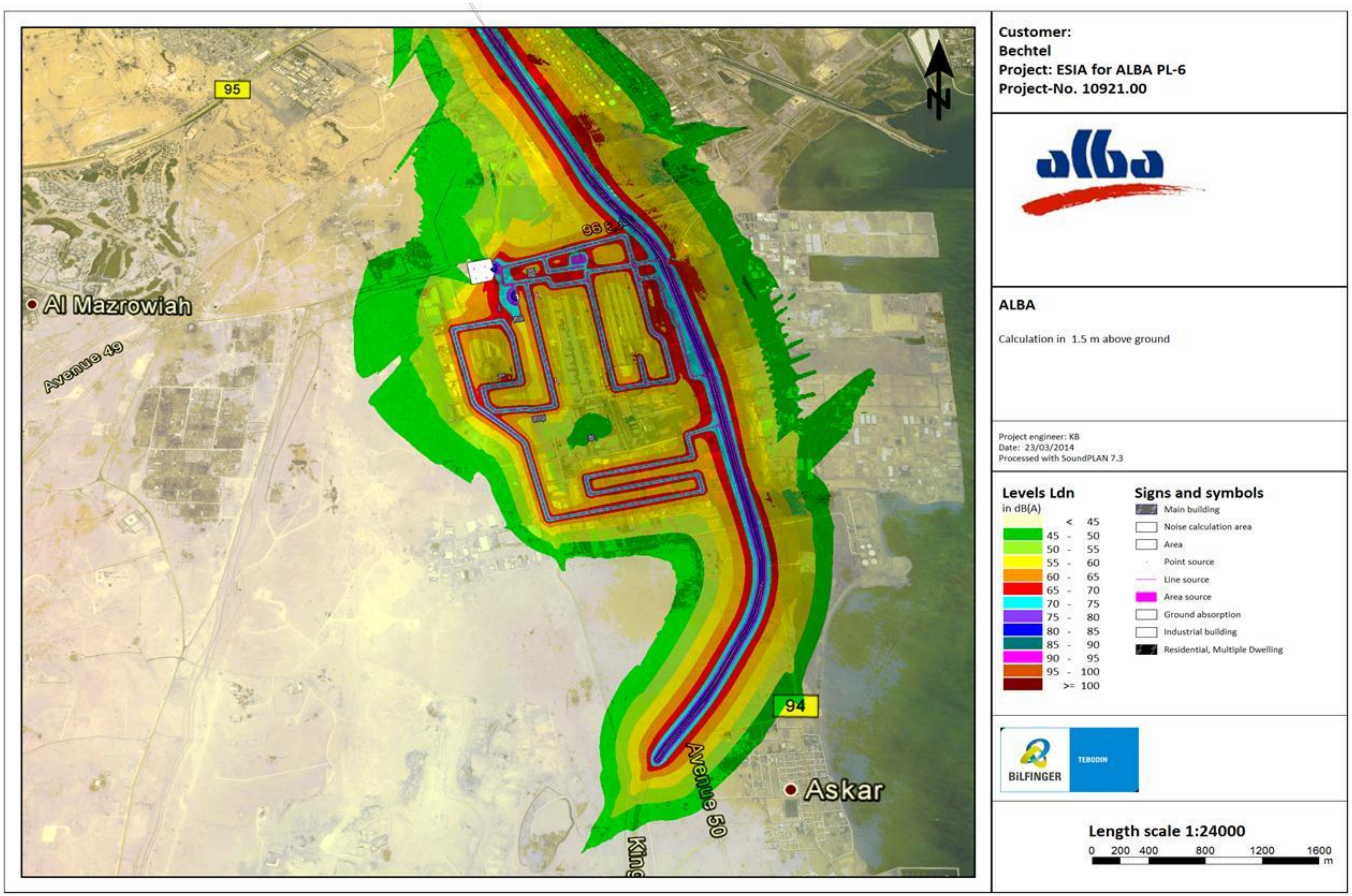

Figure 32: Overview of Noise Contributions from ALBA operations to the surroundings

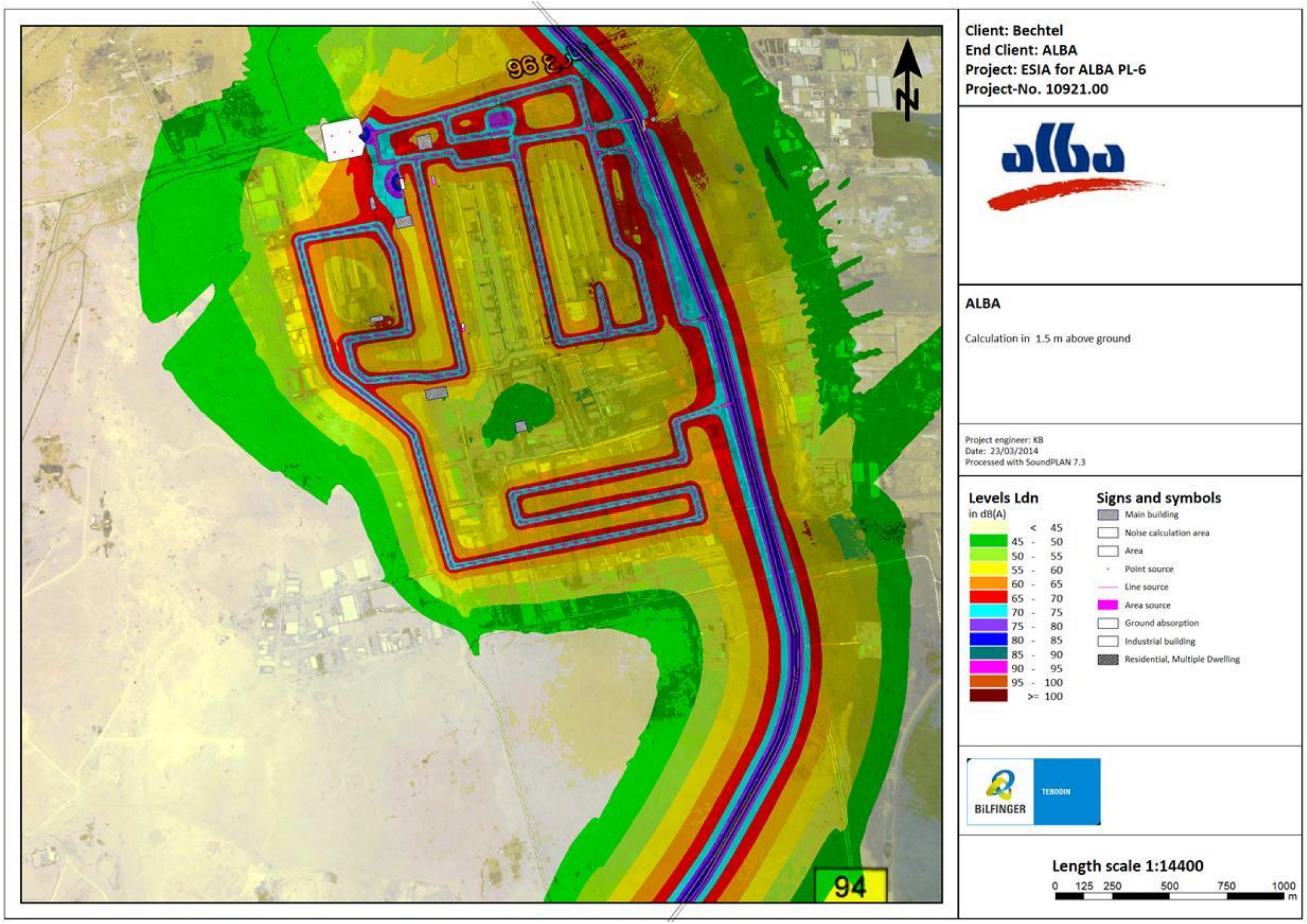

Figure 33: Predicted Noise Levels close to ALBA's fenceline (current operation plus PL6 and PS5)

Based on the results and discussions presented above, it can be seen that the overall noise contributions to the ambient environment from the proposed PL-6 and PS5 is expected to be less than 1 dB(A) at the facility fence lines and hence negligible.

6.10.5 Mitigation measures

As indicated above, noise impacts from the proposed expansion during operational phase are considered negligible. Therefore no additional noise abatement technologies or noise mitigation measures are considered.

In order to minimise noise impacts during the construction phase, the following noise mitigation measures are proposed to be implemented.

Table 49: Alba Operations Noise Levels (Current Plus L6 and PS5)

#	Mitigation Measures Construction Phase
1	Noise from vehicles and powered machinery and equipment used on site will not exceed the manufacturer's specifications, based on the installation of a silencer.
2	Equipment will be regularly serviced with attention given to muffler maintenance and enclosure of noisy equipment.
3	Noisy equipment will be replaced with less noisy alternatives or provide equipment that is specifically designed with noise inhibitors, such as generators and compressors with silencers and muffled jackhammers.
4	Acoustic covers and barriers will be used on all machine engines that generate excessive noise levels.
5	Any machinery which is intermittent in use will be shut off during periods of non-use, or if not practical to be throttled back to a minimum.
6	Where possible, ensure that operation times of noisy equipment, vehicles and activities are carried out during daytime hours. Construction work performed outside these hours (at night) are a possibility and not an exception. Where applicable, contractor to arrange for permission from authorities.
7	Stationery machinery such as generators must be kept in enclosed structures for noise control during the night.
8	Movement of construction trucks will be arranged to avoid residential areas, where possible. Where machines are fitted with engine covers, these must be kept closed. Regular and effective maintenance of stationary and mobile equipment must be conducted.
9	Workers on site will wear adequate PPE (personal protection equipment) when working in close proximity to heavy noise sources.
10	Conduct regular inspection and spot checks of all noise generating equipment.
11	Depending on the outcome of the inspections, suitable noise suppression or abatement measures may be required, such as the provision of sound enclosures and noise screens.
12	Where practical noise generating activities will be scheduled in such a way to avoid impacts on sensitive receivers. Generally and preferably, noisy construction activities will not be carried out between 8 pm and 6 am, if near sensitive receptors.
13	The main contractor will ensure that all subcontractors will comply with these requirements.

6.11 Occupational Health and Safety

6.11.1 Overview

Activities during construction and operations of the proposed expansion present a range of possible occupational health and safety risks. For the most part occupational health and safety issues are best addressed by ensuring that there are appropriate management controls in place, which are continually reviewed and improved.

In the course of the current ESIA, occupational health and safety risk associated with the construction and operation phase of the proposed expansion project were assessed. Thereby the objective was to evaluate whether these risk are so severe as to threaten the acceptability of the project.

In order to assess this issue a brief overview is provided of the major occupational health and safety hazards that could be associated with the construction phase as well as the expanded operation, and the probability and severity of the same.

6.11.2 Construction Hazards

In the section below, occupational health and safety (OHS) hazards that are likely to be significant during the construction phase of the proposed expansion are presented in **Table 50**.

Table 50: OHS Risks - Construction Hazards

S. No.	Aspect	Potential Threat
1	Noise	Virtually all vehicles, machinery and equipment generate noise that can cause nuisance or adverse effects in an occupational setting. However, none of the construction activities would result in noise levels that cannot be mitigated through the use of suitable Personal Protective Equipment (PPE).
2	Climate	High ambient temperatures in Bahrain could lead to heat stress or dehydration. A range of management controls can be implemented to minimize or prevent this risk.
3	Electricity	Risk of electric shock. However, this risk is not greater on the proposed expansion site than on other construction projects.
4	Flammable Substances	There are no specific construction requirements involving flammable materials that render this risk greater than would typically prevail on a construction site.
5	Hazardous Substances	The use of solvents, cleaners and other chemicals pose OHS risks. Of special concern is the ramming paste used for cathode ramming operations, which releases carcinogenic Coal Tar Pitch Volatiles (CTPVs). The use of suitable PPE can lower the risk of adverse health effects.
6	Proximity to Proximity to existi(mix roximity of Brownfield and Greenfield)	As the proposed development is an expansion of an existing facility, construction workers may be exposed to hazards associated with operations.

As shown from **Table 50**, suitable Personal Protective Equipment (PPE) will reduce the OHS risks associated with noise generation and handling of hazardous substances. In addition, the risk of heat stress or dehydration can be minimised by ensuring that each contractor and sub-contractor is responsible to ensure that heat stress is addressed during the work and that adequate water supply is available to all employees during working hours. In particular training shall be provided to employees on how to detect the warnings, signs and symptoms of early heat stress or stroke.

As mentioned in the table above, the risks related to the use of electricity and flammable substances is no greater than on other construction projects. Furthermore, as the construction work will be carried out at an existing facility, all risk associated with operations of the plant are to be considered applicable to the construction phase as well.

6.11.3 Operational hazards

In the section below, occupational health and safety hazards that are likely to be significant during the operations phase of the proposed expansion are listed (**Table 51**) and briefly described.

Table 51: OHS Risks - Operational Hazards

S. No.	Aspect	Potential Threat
1	Noise	A range of noise sources across the plant can result in adverse health effects. These include: compressors, ball mill in the paste plant, rectifiers and turbines in the power stations. Adverse effects can be prevented by treatment at source (acoustical insulation, covers), having dedicated high noise areas and mandatory use of suitable hearing protection.
2	Hot Metal	Handling of hot metal (molten aluminium) poses a potentially lethal hazard. However, the risk of contact with hot metal will be minimised/ prevented through suitable management controls and design.
3	Electromagnetic Forces	The power supplied to electrolytic reduction cells is direct current, and the electromagnetic fields generated in the potrooms are mainly of the static or standing field type. Such fields, in contrast to low frequency electromagnetic fields, are even less readily shown to exert consistent or reproducible biological effects. The flux levels of the magnetic fields measured cell rooms are commonly found to be within threshold limit values for static magnetic, sub-radio frequency and static electric fields. Exposure to ultra-low frequency electromagnetic fields may occur in reduction plants, especially adjacent to rectifier rooms. The flux levels found in the potrooms are minimal and below present standards. EMF exposure may also be associated with electric arc furnaces and other electrical equipment. [Ref. 16]
4	Air Pollution	For anode changing and other pot operations, pot hoods are removed resulting in a release of air pollutants (HF, dust, PFCs) formed during electrolysis.

S. No.	Aspect	Potential Threat
5	Heat stress	High temperatures due to processes and ambient conditions can lead to dehydration, dizziness, lack of concentration and fainting. Therefore, Alba provides training, awareness sessions, monitoring of rehydration as part of their heat stress prevention procedure.

As shown from **Table 51**, OHS risks during operations are associated with noise, hot-metal handling, electromagnetic forces, exposure to air pollutants formed during electrolysis as well as heat stress. Suitable management controls and design specifications will reduce these risks associated with operations. Each electrolysis pot in Potline 6 will be connected to a gas collecting system ensuring gas capture efficiency (hood efficiency) greater than 98%. The gas collection system with dual ventilation mode will ensure a minimum exhaust when all side shields (hoods) of a pot are in the closed position as well as a boosted flow when operation activities are performed on the pot. This dual flow strategy will be operated to minimize the release of untreated gases to the potroom building which will then exhaust through the potroom roof via air gravity static roof ventilators.

These modern potroom designs ensure that the potroom environment is well ventilated reducing the risk related to air pollution - but the occupational health risk of these emissions cannot be discounted completely.

Another factor impacting OHS is related to onsite traffic, which is managed by Alba’s established internal logistics plan. This plan stipulates speed limits and dedicated routes in order to reduce the risks of incidents.

6.11.4 Occupational health and safety impacts

As with any large scale industrial process or construction project, the risk of occupational accident is always existent. Despite the most sophisticated controls, accidents resulting in lost time, disabling injuries or even death are a possibility. However, the implementation of sound health and safety management systems during the construction phase and the extension (and continuous improvement) of the existing operational health and safety management systems to the expanded operations, can ensure that these risks are minimised to the extent that is practicably possible.

Although there are a range of hazards associated with construction and operational activities, there are none that present an inordinate risk that cannot be effectively managed or mitigated. On that basis, it is concluded that the proposed expansion presents no significant additional occupational health and safety impact.

6.11.5 Emergency Plan

Alba has an existing emergency procedure for the current facilities. It will be necessary to update the same to include the new facilities once operational.

For the construction phase, an emergency plan is required to be developed that addresses the need for an on-site medical evacuation response and first aid, fire and assembly point arrangement, hazardous material management and other identified adverse situations. It is mandatory that construction site emergency plans are in place to deal with any contingencies. Responsibility to ensure that the plan is in place and implemented lies with Alba and EPCM Contractor’s environmental, safety and health teams.

6.11.6 Compliance with IFC

Alba's proposed facility was evaluated against the following EHS guidelines:

- Environmental, Health, and Safety (EHS) Guidelines, General EHS Guidelines: Occupational Health And Safety, April 30, 2007
- Environmental, Health, and Safety Guidelines Base Metal Smelting and Refining, April 30, 2007; and
- Environmental, Health, and Safety Guidelines for Thermal Power Plants, December 19, 2008

In order to assess compliance with the above listed IFC standards, Alba's existing management systems with regards to Occupational Health and Safety is reviewed.

Alba has implemented a Health, Safety and Environmental Management System (HSEMS) which is certified per ISO 14001:2004 and OHSAS 108001: 2007. Everyone at Alba is inducted and trained in health and safety practices by OHSAS 18001 certified safety personnel.

The HSEMS covers, but is not limited to, the following:

- Emergency Preparedness Plan
- Planned Safety Inspection
- Environmental Monitoring Plan, including
    - Measurement of Air Pollutants at various locations in the facility (incl. VOCs, Particulates, Fluorides, NO_x, SO_2, CO)

As part of Alba's hearing conservation programs, noise measurements are periodically undertaken at different locations in the process plant. These measurements are used to assess the employees' daily exposure and to identify high noise level areas.

In addition, procedures for the control of personal exposure to HF are in place. Thereby, periodic air monitoring is conducted to evaluate imposed health risks.

Alba is constantly upgrading safety systems through the active involvement of their Risk Assessment Committee, which examines all potential risk situations in the plant and helps enhance safety in the facility.

Alba remains at the forefront of ensuring employees' benefit from a safe work environment, enabling them to be healthy and productive. At the centre of Alba's occupational health initiatives is the Alba Healthcare Centre, which is regarded as one of the most advanced medical facilities available in any industrial organisation in Bahrain.

The Alba Healthcare Centre provides comprehensive range of medical services to all Alba employees, as well as emergency services to residents in the neighbouring areas. Moreover, it regularly conducts various campaigns and health awareness lectures targeting the company's workforce.

In 2006, Alba began providing its employees with medical insurance packages as a joint project between Alba Management and the company's Labour Union. The aim of this project was to further enhance and enrich the quality of medical services being provided to Alba employees. Furthermore, more than 1,000 Alba employees have received official certificates in first-aid as approved by the Bahrain Red Crescent Society. Armed with these certificates, these employees - or first aiders - are deployed at different departments and in all shifts.

Various standard operating procedures covering HSE, such as handling of radioactive material, chemical spill hazard identification, storage of flammable material and working procedures for working at heights are in place and will be used during operations of the new facilities.

Based on the above, it can be concluded that Alba complies with the IFC standards from an OHS point of view. Nonetheless, it is required to ensure that Alba’s existing HSE procedures, training and monitoring systems and emergency response procedures will be updated to cover the new facilities.

6.12 Cultural Heritage

Cultural heritage concerns due to the proposed expansion relate to the possible impact on archaeological or historical sites by physical construction activities, and the possible impact of environmental aspects such as air pollution on existing historical or culturally significant buildings or monuments. Given that there are no archaeological or culturally significant sites in the area proposed for the expansion, the possible impacts of the construction activities on cultural heritage are deemed negligible.

Riffa Fort is an archaeological/historical site that exists close to the study area. It is located on a simple reef in the low desert area lying between East and West Riffa. The fort is about 5 km away from the Alba site on the western side of the plant and as such is too far away from the plant to be impacted upon by either construction or operational activities at Alba. Recreational activities such as the golf course and the Racecourse are within a few kilometres of the site, but are not close enough to be impacted upon by Alba’s activities.

6.13 Social and Economic Environment

Against a background of the potentially negative effects of the proposed expansion project, the investment benefits and job creation aspects are positive outcomes. In the subsequent section, the potential impacts on job creation and local spending will be described and assessed to present the significance of such impacts.

6.13.1 Current labour market

As of August 2013, Bahrain's total labour force was estimated at 566,730 employed persons with 44 percent of them being non-nationals or expatriates. However, since sponsorship has been reduced by the government, the percentage of employed expatriates is on the decline.

Source: *General Organization for Social Insurance, Bahrain [1]*

Figure 34: The Workforce in Bahrain, Jan 2008 - August 2013

6.13.2 Bahrainisation

To reduce the unemployment rate among Bahraini nationals, the Government has introduced a programme of Bahrainisation. This programme is geared towards maximising the employment of Bahrainis and includes quantitative Bahraini employment targets for firms operating in the country. The proposed expansion will present a number of employment opportunities for Bahraini nationals. Alba already has a good track record in employing Bahraini nationals which is at 87%.

6.13.3 Employment

The anticipated required craft labour resources during the construction phase are as follows:

On average 2,600 staff for smelter and 750 staff for Power Station 5;

Maximum number of working people will be 5,200 staff for smelter and 1,500 staff for Power Station 5.

Although this labour demand will be phased during the 37 months construction period, it still presents significant, albeit temporary, employment opportunities and it is likely that Bahraini nationals will take many of these jobs.

During the operational phase, the proposed expansion will create approximately 547 permanent employment opportunities at Alba and approximately 3,000 permanent employment opportunities at downstream industries. Again, it is Alba’s intention to maximise the employment of Bahraini nationals in this expanded labour force.

6.13.4 Impact on GDP, current account and trade balance

As of the 31st of December 2012, the Bahrain Gross Domestic Product (GDP) was US$ 25.86 billion accounting for 0.04 percent of the world economy [3] of which Alba is one of the main contributors as part of the manufacturing industry. In compliance with the Bahrainisation Plan, local hires and resources will be utilized including during the construction phase which implies a short-term increase in Bahrain’s GDP. Alba’s operational activities contribute to Bahrain’s GDP with 25%.

Even though the projected capital cost of the proposed expansion is valued at US$ 3.5 to 4.0 billion for the expansion project, the project is bankable and therefore, no capital outflows will occur during the construction phase of the project affecting the trade balance.

Further, the increased production rate associated with the expansion will contribute to Bahrain's economy given that the additional produced aluminium will be used by downstream industries for the development of Bahrain, the GCC, as well as other countries.

6.13.5 Impact on manufacturing sector

According to the Economic Yearbook of 2013 [2], the industrial sector in the kingdom of Bahrain constitutes 11.6 % of the overall market capitalization of which Alba's contribution is 97.9%. An increase in Alba's contribution to the market is anticipated given the increase in Alba's output and revenues following the expansion.

6.14 Summary of Impact Findings

In order to provide a summary of the possible impacts of the proposed Alba expansion, these are categorised by aspects as shown in **Table 52**. The categories are the extent, duration, intensity and probability of occurrence. Impact significance is presented as either positive (a benefit) or negative (a cost to the environment).

Table 52: Impact Rating Categories

S. No.	Aspect	Definition / Graded in terms of	
1	Extent (E)	On-site	Only within the confines of the construction or operational areas of the site.
		Local	Within approximately 10 km radius of the plant
		Regional	Beyond local but not affecting the country as a whole.
		National	Affecting the whole country.
		Global	The impact has global significance.
2	Duration (D)	Short term	0 to 5 years
		Medium term	5 to 15 years
		Long term	>15 years (with the impact ceasing after the operational lifetime of the development)
		Permanent	The impact once manifested will be permanent.
3	Intensity (I)	Magnitude or size of the impacts and is graded as high, medium, low or negligible.	

S. No.	Aspect	Definition / Graded in terms of	
4	Probability of occurrence (P)	This is the probability of a significant impact being manifest and is graded as improbable, possible, probable and definite.	
5	Significance (S)	Negligible	The impact is unlikely to be manifested.
		Low	The impact will occur but will not result in substantial, detrimental effects.
		Moderate	The impact will occur and may present a risk of substantial, detrimental effect.
		High	The impact will occur and will result in substantial, detrimental effect.

In line with the above categories, the summary of impacts is presented in **Table 53**.

Table 53: Summary of the potential impacts

Nature of the impact	E	D	I	P	S	Comments
Air Quality						
Construction dust emissions	Local	Short-term	Low	Probable	Low	The size and arid nature of the construction area means that dust will be generated.
Greenhouse gas emissions	Global	Long-term	High	Definite	High	Greenhouse gas emissions from Alba are already significant, and these will be further increased following the proposed expansion. That said, there are no limits specified currently on greenhouse gas emissions and as these emissions do not contravene any direct legal requirement.
Human health impacts from ambient SO$_2$ concentrations	Regional	Long-term	Moderate	Improbable	Low	Even though SO$_2$ emissions will increase, impacts on ambient air quality and subsequent human health impacts are considered low.
Human health impacts from ambient NO$_2$ concentrations	Regional	Long-term	Moderate	Improbable	Low	Even though NO$_2$ emissions will increase, impacts on ambient air quality and subsequent human health impacts are considered low.
Human health impacts from ambient HF	Regional	Long-term	Low	Improbable	Low	Predicted ambient fluoride concentrations are well below the standards at which

Nature of the impact	E	D	I	P	S	Comments
concentrations						human health effects may be manifest.
Human health impacts of PM_{10} conc.	Local	Long-term	Low	Improbable	Low	The contribution of the proposed expansion to ambient PM_{10} concentrations is small.
Ecological impacts from ambient HF concentrations	Regional	Long-term	Moderate	Possible	Low	HF concentrations are elevated in near vicinity of Alba. However, since no plantations or crops are in close proximity of Alba, impacts are considered low
Water						
Additional water demand	Regional	Long-term	High	Definite	Low	The additional water use requirements of the proposed expansion will be met through the available reverse osmosis capacity at the Calciner Plant.
Additional wastewater effluent	Local	Long-term	Negligible	Probable	Low	Majority of waste water will be internally recycled, used for irrigation or discharged to Alba's lake. A negligible increase of waste water effluent will be discharged via the existing outfall to sea (< 0.1% increase). Since the current outfall does not enable proper mixing it is recommended to investigate an outfall location providing proper mixing and therefore minimizing impacts. Domestic waste water and waste water from the truck washing facilities will be treated by the proposed STP-3 and further utilized for irrigation purposes or sent to Alba's lake.
Soil and Groundwater						
Soil contamination	Local	Short-term	Low	Possible	Low	The soil contamination is limited and a function of the existing operation. The contaminated soil will be removed and disposed during the construction phase.
Ecology						
Ecological impacts / habitat loss from construction phase	Local	Short term	Medium	Probable	Low	Due to low ecological significance of the lay-down areas, impacts are considered to be low.

Nature of the impact	E	D	I	P	S	Comments
Ecological impacts / habitat loss from operation phase	Local	Long term	Negligible	Probable	Low	Ecological impacts during operational phase are low, since activities will occur at existing industrial facility, within industrial area.
Energy Use						
Consumption of fossil fuels for operations and vehicles	Regional	Long term	High	Definite	High	Increased consumption of fossil fuels (mostly natural gas) will have a high impact on availability of natural gas in Bahrain. Energy efficiency is however considered in selection of production and power generation technologies.
Waste Management						
Construction wastes	Local	Short-term	Medium	Definite	Low	Although the quantities of waste generated during construction will be significant the properties of these wastes allow them to be safely managed.
Spent pot linings	Local	Long-term	Moderate	Possible	Low to moderate	Although the current SPL disposal practice is deemed acceptable, the hazardous nature of SPL dictates improved disposal practise in the medium to long term.
Traffic						
Construction traffic	Local	Short-term	Moderate	Definite	Moderate	The additional vehicles that will be required for the construction phase, will exacerbate congestion.
Elevations in traffic density on King Hamad Highway and surrounding internal roads during operation	Local	Long-term	Moderate	Probable	Low to Moderate	A significant increase in traffic density will occur on King Hamad highway from the heavy traffic commuting back and forth from the south east and new south west gates of Alba's smelter
Visual						
Visual impacts to surroundings	Local	Long-term	Low	Improbable	Low	The prevailing industrial visual character of Alba and its immediate surrounds, will not be dramatically changed by the proposed expansion.

Nature of the impact	E	D	I	P	S	Comments
Noise						
Increase in noise levels due to increased traffic movements and additional noise sources	Local	Long-term	Low	Improbable	Low	The impact assessment indicated an increase of less than 1 dB(A).
Occupational Health and Safety						
Occupational health and safety – construction phase	On-site	Short-term	Moderate	Probable	Moderate	Occupational health and safety risks always prevail on a large construction site and are complicated by the presence of multiple contractors. No extraordinary health and safety risks are presented by the construction requirements.
Occupational health and safety – operations phase	On-site	Long-term	Moderate	Possible	Low to moderate	Occupational health and safety risks always prevail in industrial complexes. The finding presented here is based on the expanded expansion not presenting any extraordinary risks of adverse health effects or injury.
Cultural Heritage						
Impacts to cultural and archaeological features	Local	Long-term	Low	Improbable	Negligible	No cultural heritage sites and/or artefacts occur in close enough proximity to the plant to be directly impacted upon by either the construction or operational activities.
Social Economic						
Job creation	National	Long-term	High	Definite	High, positive impact	The socio-economic impacts associated with the expansion project is manifested as a positive impact on the Kingdom of Bahrain as a whole
Contribution to GDP	National	Long-term	High	Definite	High, positive impact	The expanded operation will increase the contribution to GDP by some US$ 300 million per annum.
Trade balance – construction	National	Short-term	Moderate	Definite	Moderate	During the construction phase there will be net worsening of the trade balance as a result of capital outflows for the purchase of materials and equipment for

Nature of the impact	E	D	I	P	S	Comments
						the expansion.
Trade balance – operations	National	Long-term	High	Definite	High, positive impact	Following the commissioning of the expanded plant, there will be a net improvement in the trade balance. This will be a direct function of the surplus between import costs and the revenue generated through the exported product.

7 Alternatives

Project alternatives are an important component of an EIA, where alternative locations, technologies may hold the key to reduced potential impacts on the environment.

7.1 No development option

The no development option refers to keeping the existing facilities as is and not to implement the proposed expansion. This option has the following implications:

- Alba will become increasingly uncompetitive in terms of its unit cost of production.
- The employment benefits will not be realised and employment will decline as production becomes uncompetitive.
- The economic growth benefits will not be realised.
- The environmental aspects of the current operation will remain unchanged with no additional impact risk.
- An opportunity to increase the efficiency of current operations will be lost (i.e. increased revenues and jobs at a relatively lower environmental cost).

7.2 Location option

The proposed project considers an expansion of an existing facility, using available space within the industrial site. The expansion can thus make use of existing facilities and infrastructure in previously planned and designated areas. Selecting a different location, especially at a green field area is not considered feasible since it would require additional facilities, land and infrastructure and would therefore have a larger environmental impact

7.3 Fuel selection

Apart from a relatively small consumption of diesel, the plant is entirely gas-fired. Natural gas is available in Bahrain. It is the cleanest of the fossil fuels and allows a practically complete combustion in gas turbines. Of the fossil fuels available on the market, gas is by far the cleanest. Alternatives would be coal or oil. Coal is not available indigenously in Bahrain and would have to be imported, resulting in extra emissions due to transport. Moreover, power stations using coal fuels generate more air emissions and solid/liquid wastes, which require further treatment. Oil fuels will generate a larger amount of air emissions than natural gas, and in particular carbon dioxide (CO_2) and sulphur dioxide (SO_2). The use of gas-fired power stations provides many advantages; namely, lower air emissions, lower waste heat, and greater energy efficiency, reduction of the carbon footprint. Moreover, the implementation of a combined cycle gas turbine, for recovery of waste heat through a steam turbine, will increase the electrical output and reduce wasted heat.

7.4 Alternative energy sources

Use of sustainable energy sources for the continuous and high energy demand of aluminium smelters are not considered at Alba for the reasons stated below:

- Hydropower: this resource does not exist in Bahrain due to the absence of flowing water, and cannot be considered as an alternative.

- Tidal: this resource does not exist in Bahrain due to the limited depth of the Arabian Gulf and available 'wave energy', and cannot be considered as an alternative.

- Biomass: wood resources in Bahrain are scarce. Availability of other plant biomass is also limited. This excludes all options using biomass, regardless of conversion technology.

- Geothermal; this resource does not exist in Bahrain, and cannot be considered as an alternative.

- Wind energy: the generally low wind speeds exclude the economically viable application of wind turbines.

- Solar energy: solar electricity generation (photovoltaic) could be considered an option; irradiation is high, even during winter, mainly due to the dry climate. However, available solar systems for electricity generation are still too expensive to be a viable alternative for continuous electrical power generation under the given circumstances. Furthermore, a vast area, multiple square kilometres, for installation of Photovoltaic cells or mirrors would be required. The continuous demand nature of the smelter means that storage of electricity would be required at a level that has not been demonstrated or that a power plant similar to the one proposed for the expansion would still be required for non-daylight operations.

7.5 Power generation technology

Power Station 5 would be a combined cycle electric generating facility. The Combustion Turbine Generators would be Class "F" units with dry low NOx (DLN) combustion systems to control exhaust gas nitrous oxides (NO_x) emissions. Class F Combined cycle units have been selected because of their high efficiency and proven history of reliable operation while balancing environmental and economic benefits, consistent with IFC requirements.

High performance monitoring and process control techniques would be applied to ensure optimum operation.

7.6 Reduction Technology

Alba has requested that the design for L6 be based upon the DX+ technology operating at 460 kA. The technology is being used at two (2) other facilities in the Middle East region, under similar site conditions as would be anticipated at Alba.

The DUBAL DX+ technology design achieves a specific energy consumption averaging approximately13.69 DCkWh per kg of aluminium and a current efficiency averaging about 94.5 per cent. The DX+ reduction technology utilizes efficient conversion materials resulting in an average daily yield of aluminium per pot of around 3.4 tonnes. "The frequency and duration of anode effects (AE) for the DX+ technology are considered very low (Frequency of <0.1 per the Dubal technology package) and meet the IFC guidelines. AE frequency and duration is an industry benchmark linked to perfluorocarbon (PFC) emissions.

In 2011 Alba contracted with a third party engineering and construction firm to undertake a Reduction Technology Selection Study for their future L6. The Technology Selection Study was carried out with the participation of the technology providers in order to supply information to Alba for their respective technologies. The reduction technologies were compared in terms of operating efficiencies, engineering designs, construction features, estimated capital costs, estimated operating costs, project estimated financial return on investment and project implementation differences.

Based upon Alba's evaluation of the Technology Selection Study, the Dubal DX+ technology was selected by Alba as the basis for the FS.

7.7 Conclusion

As valid alternatives do not exist, it is the mitigation of potential impacts that is emphasised in the report as described in previous chapters. The presented mitigations are in addition to the environmental controls such as the Gas and Fume Treatment Plants that would be implemented. Mitigation is presented where such mitigation is technically and economically feasible leading to the best practicable environmental option.

8 Monitoring Framework

In order to monitor the emissions to the environment, a monitoring framework as presented in **Table 54** will be implemented by Alba for the new Potline 6 and Power Station 5.

As describes earlier (section 6.2), roof emissions would be monitored using four (4) continuous optical monitoring systems (1 per half potroom) and two (2) conventional cassette monitoring systems, each covering half a potroom. These systems would be respectively tracking gaseous fluoride and total fluoride emissions (gaseous and particulate).

Table 54: Proposed Monitoring Framework

#	Measurement Location		Measurement Instrument/ Method	Parameters Measured	Testing Frequency	Approx. Sampling Duration	Responsibility
A. Air Emissions							
1	L6 GTCs	A	Continuous online monitoring	Particulates Gaseous Fluorides Temperature	Cont.	N/A	Env. Laboratory
		B	US EPA Method 23 Stack Sampler (Modified) (SOP 75/26)	Particulates Particulate Fluorides Gaseous Fluorides Total Fluorides	4 per year	6h	Env. Laboratory
		C	Gas Analyser (SOP 75/21)	NO_x, SO_2, CO	2 per year	30min	Env. Laboratory
2	L6 FTC	A	Continuous online monitoring	Particulates Temperature	Cont.	N/A	Env. Laboratory
		B	US EPA Method 23 Stack Sampler (Modified) (SOP 75/26)	Particulates Particulate Fluorides Gaseous Fluorides Total Fluorides	4 per year	6h	Env. Laboratory
		C	US EPA Method 23 Stack Sampler (SOP 75/02)	VOCs	4 per year	2-6h	Env. Laboratory
		D	Gas Analyser (SOP 75/21)	NO_x, SO_2, CO	4 per year	30 min	Env. Laboratory
3	L6 Paste Plant (Pitch Fume Treatment)	A	US EPA Method 23 Stack Sampler (SOP 75/02)	VOCs	1 per year	2-6h	Env. Laboratory
		B	Gas Analyser (SOP 75/21)	NO_x, SO_2, CO	4 per year	30 min	Env. Laboratory
4	Casthouse	A	Pechiney Method Stack Sampler (SOP 75/25)	Particulates Particulate Fluorides Gaseous Fluorides Total Fluorides	2 per year	4-6h	Env. Laboratory

#	Measurement Location		Measurement Instrument/ Method	Parameters Measured	Testing Frequency	Approx. Sampling Duration	Responsibility
		B	Gas Analyser (SOP 75/21)	NO_x, SO_2, CO	4 per year	30min	Env. Laboratory
5	Power Station - 5		Continuous online monitoring	NO_x, SO_2, CO, O_2, Dust, Temperature	Cont.	N/A	Power Operations
B. Roof Emissions (Air)							
6	Potline 6	A	Sampling Pump Gas Meters Flow Meters Cassette System (SOP 75/24)	Particulates Particulate Fluorides Gaseous Fluorides Total Fluorides	1 per AP	14 days	Env. Laboratory
		B	Continuous online monitoring	Gaseous Fluorides, Velocity, Temperature	Cont.	N/A	Env. Laboratory
C. Ground Water – As per existing Monitoring Framework							
D. Waste Water – As per existing Monitoring Framework							
E. Wind Data – As per existing Monitoring Framework							

GTC	Gas Treatment Centre
FTC	Fume Treatment Centre
Cont.	Continuous 24h online measurement and recording of emission/air quality parameters.
AP	Accounting Period (4 weeks)

9 Conclusions and Recommendations

9.1 Conclusions

The Environmental Impact Assessment Study Report presented here, contains the findings of an Environmental Impact Assessment (EIA) conducted on the proposed expansion of the Alba plant in Bahrain. The proposed expansion involves the addition of one new potline (Potline 6). In order to provide the power requirements necessary for the operation of the expanded potline, one new combined cycle gas fired power station (Power Station 5) will be built. As a condition to obtain authorisation to proceed with the expansion project it has been mandated by SCE to prepare an ESIA in order to determine the environmental aspects of the current operation, those of the proposed expansion and the exiting state of the environment in which the proposed expansion will take place. This information has been used to determine potential impacts on the environment of the proposed expansion as well as the significance of these impacts.

Of the impacts assessed only two pose a significant risk of impact to the environmental. The first of these is the greenhouse gas emissions that will be generated by the proposed expansion. It is well recognised that aluminium smelters are significant producers of greenhouse gas emissions as is the case for Alba for both the current operations as well as those that will be generated by the proposed expansion.

The second significant impact is that associated with the relatively high SO_2 and HF emissions. The results of the analysis show that the total correlated predicted SO_2 and HF concentrations in the ambient air at indicated sensitive receptors comply with the applicable standards for both the present and future cases. However, there are exceedances of SO_2 and HF levels in the area from Alba’s fenceline to several kilometres south to south-west. Based on the modelling analysis for the maximum allowable Bahraini emissions criteria, the contribution of criteria pollutants were found to be temporal in nature, since long term average are well below the Bahraini AAQS, except for HF. Therefore, a scenario (Scenario 3) with additional mitigation measures was evaluated to reduce the impact of HF. Scenario 3 also incorporated lower SO_2 source emission ratios, in line with current Alba operations. This Scenario 3 is retained as the scenario applied for the proposed expansion project.

The Best Available Technology considered in the design of proposed Potline 6 and Power Station 5 limit the emissions from the expansion to the extent possible. Furthermore, commitments are made to limit the source emissions for existing Potline 4 and Potline 5 via mitigation through stricter operating practices in line with those considered for Potline 6 and as defined for the Scenario 3.

The amount of effluents to sea are expected to remain similar to those of the current operations with the exception of a minimal quantity generated by the Power station. Recommendations with regards to the marine outfall are provided.

Positive impacts include the increased economic growth that will be brought about by the spending on the project as well as the increased revenues that will be generated by the expanded operation. In addition, the construction phase will see some 4,000 temporary jobs with some 500 permanent jobs being created at the expanded plant. The expanded operation will also keep Alba globally competitive in terms of its unit costs of production, and also capitalise on the continued growth in demand for primary aluminium.

The EIA has been concluded by presenting mitigation together with recommendations that should be implemented on the proposed expansion. Implementation of the mitigation and recommendations will ensure that the expanded plant does not result in an impact on the environment, and that it will meet the principles of development that is environmentally, socially and economically sustainable.

9.2 Recommendations

9.2.1 Construction Phase

9.2.1.1 CEMP

Preceding sections discussed the environmental impacts during construction to the extent possible as currently detailed information regarding construction methods and specific activities is not available. SCE requested[41] a Construction Environmental Management Plan (CEMP) to be undertaken prior to the construction works in line with the stipulated guidelines (**Appendix 21**), in order to further assess and mitigate the impacts related to the construction phase.

In addition to this requirement, mitigations measures to be implemented by the EPC contractor are proposed through various control plans as listed below and presented in **Appendix 22**.

- Air Quality Control Plan;
- Erosion and Sediment Control Plan;
- Soil and Groundwater Contamination Control Plan;
- Water Quality Control Plan;
- Noise and Vibrations Control Plan;
- Traffic Control Plan;
- Waste Management Control Plan;
- Chemical and Hazardous Materials Control Plan;
- Contingency Plan;
- Emergency Control Plan; and
- Security Plan

Moreover, it is to be noted that hazardous wastes generated during construction shall be disposed-off through approved contractors as presented in **Appendix 23** and **Appendix 24.**

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[41] See Appendix 2: Formal Communication from SCE

9.2.1.2 Soil and groundwater baseline survey lay-down areas

Since the proposed lay-down areas are greenfield areas, it is proposed to establish the baseline soil quality and to verify if any contamination is present, in order to check if any soil contamination has occurred after demobilization of construction contractors i.e. site restoration.

In order to determine the soil quality on site and to verify if any soil contamination is present, soil samples will be collected from the site for laboratory analysis. Seventeen (17) boreholes will need to be installed and sampled. Soil samples will need to be collected from all boreholes at a depth of 0.2 to 0.5 meters below surface. Below figures provide proposed locations of boreholes and groundwater wells for soil and ground water sampling in the lay-down areas.

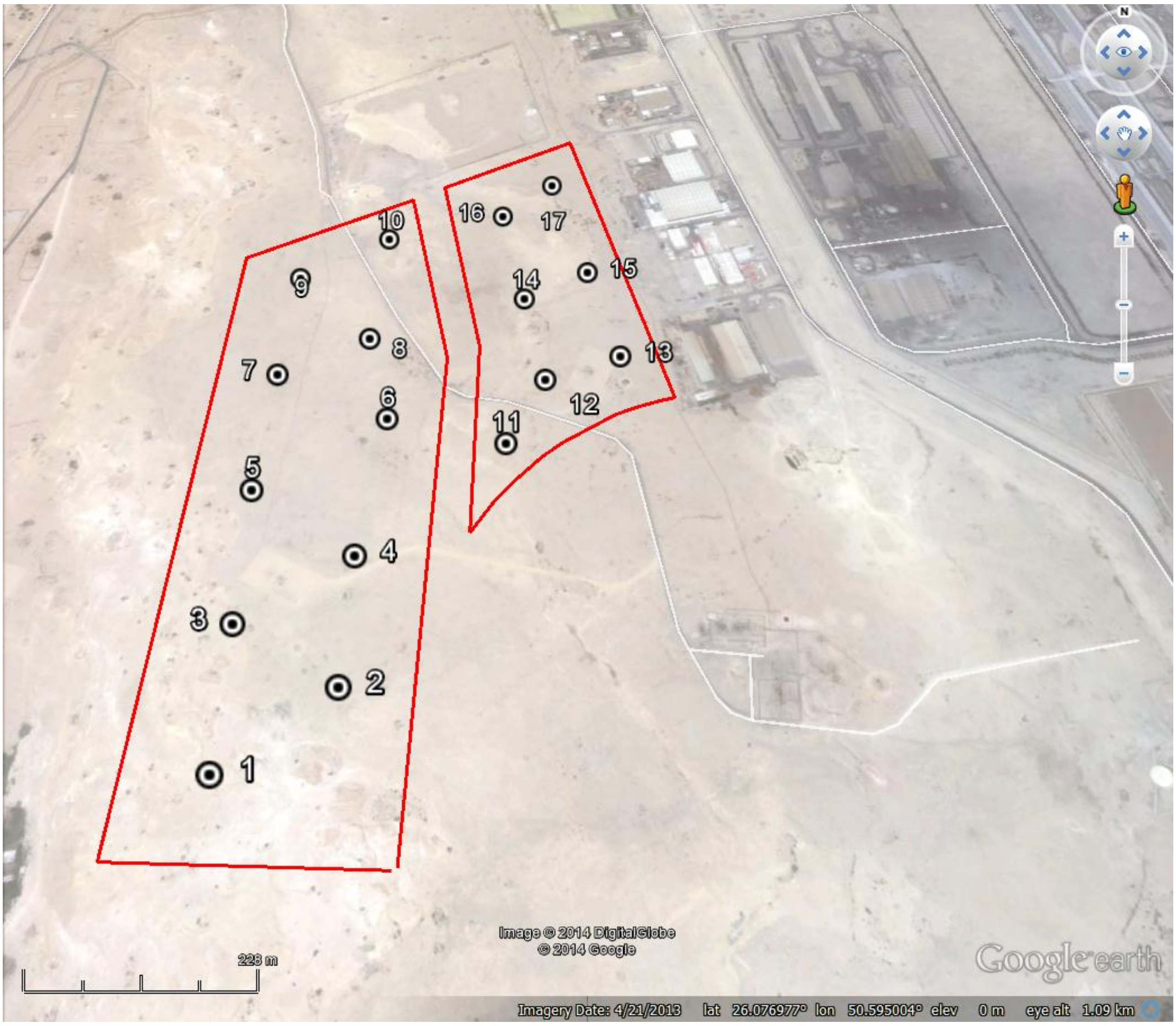

Figure 35 Proposed Soil Sampling Lay-Down Areas

Figure 36 Proposed locations Groundwater Sampling Lay-Down Areas

- Analysis of the soil samples will be carried out by a third party. This party will provide all the necessary sample jars and containers required during field work.

- De-contaminated hand augers will be used wherever possible to carry out the soil sampling.

- During all fieldwork, cross contamination must be avoided by thoroughly cleaning all equipment used from one borehole to the next. This can be achieved by the following procedure: ensure the sampler is cleaned thoroughly in water, and then rinsed in potable water. The sampler is then allowed to air dry before being used again.

- During drilling, no contaminating substances must be introduced into the soil or groundwater.

- The soil profile up to the maximum depth indicated for each borehole must be properly observed, described and reported during the sampling process. For this purpose, soil samples must be taken at each 50 cm depth or when different soil material is observed.

- Clear observations of the bored-out soil must be carried out and reported by investigating the texture, odour, colour and whether the soil is disturbed (presence of debris, metals) or undisturbed.

- All collected soil samples must be stored in de-contaminated laboratory supplied sample containers appropriate to the determinants required for analysis.

- During field storage and transportation, all samples in their appropriate containers must be stored in a cool box containing ice / ice water maintained at 4°C as required by US EPA methods. Samples to be handed over to laboratory on day of sampling.

- QA/QC procedures must be used during all field work, sample storage and transportation. This includes using sterile equipment, use of decontaminated sample containers, cooled storage of samples, and correct labelling of these samples, as described in the conditions above.

- NOCs from utility service providers and other relevant authorities are to be obtained prior to carrying out the drilling works. Inspection pits shall be installed in areas where there is any possibility of the presence of underground services.

- All the members of the team shall undergo a safety induction course in order to be aware hazards involved in the work.

- Workmen shall have all relevant PPE like safety helmet, safety shoe, safety glass and coverall as necessary for the job, in line with ALBA HSE regulations.

- Only experienced technicians / skilled workmen shall be allowed to undertake the job.

9.3 Operations Phase

9.3.1 Waste

9.3.1.1 Dross

As dross is classified as “hazardous when wet” by OSHA safe storage and handling is of major importance from both a safety and environmental point. Therefore, it is recommended to ensure storage in a dry and cool area without direct contact on soil. While transporting the dross, special provision tank containers can use used which should be marked to identify the material. In case containers other than metal or rigid plastic are used, they must be transported in a closed freight container or closed transport vehicle. Bulk containers (roll-off boxes, semi-trailers) can be utilized; however they must be sift-proof, prevent water from reaching hazardous material and provide sufficient venting to preclude accumulation of flammable, corrosive or toxic gases. Last, material must be loaded dry and cool and open top trailers must be covered with a tarp.

9.3.1.2 Spent Pot Linings

As Alba's expansion and increased production capacity will result in an increase in SPL generation, Alba should continue to implement a SPL waste disposal strategy that will be sustainable, without, in the interim, causing any environmental harm. Until recently, SPL could only be partially treated and therefore after being party recycled SPL waste is deposited-off in landfills. However, new technologies for integral waste recovery are emerging in Europe providing major Aluminium producers with a definitive solution.[42] It can be expected that this emerging technology will be established in the Gulf Region in the upcoming years, providing future options for complete SPL recovery in the region.

9.3.1.3 Sulphur Waste

Currently Alba generates sulphur containing slurry from its desulphurization process. This slurry is dried and subsequently sent to landfill. It is recommended to explore alternatives that would enable reuse of sulphur as raw material e.g. for agriculture (fertilizer), chemical production, industrial activities, asphalt, concrete etc. Currently petrochemical industries generate large quantities of sulphur that is being sold and reused.

9.3.2 Waste water

The existing water outfall system consists of a pipeline leaving the site on the eastern side and running towards the sea over a distance of few hundred meters. Although the outfall pipeline originally discharged directly into the sea, land reclamation caused by other developers has resulted in the pipeline now ending in a stretch of reclaimed land. The outfall water now flows from the point where the pipeline ends, along an open trench before discharging into the sea. Given the increased quantities of effluent that will be caused by the proposed expansion, there is a risk of erosion of the open trench and no opportunity presented for enhanced mixing of the outfall where it enters the sea. As a result it is recommended that the outfall pipeline be extended so that it discharges into the open sea, and that a good diffusion facility is installed. The chemical analysis of water streams from main Alba outfall shows that the discharge was well with in the international limits and discharge temperature is ambient.

The location, length, size of the proposed extension of the pipeline and outfall details cannot be detained under the scope of present EIA study. A detailed engineering shall be undertaken to establish the required information. At the same time a proper facility that will allow representative grab samples to be taken should also be established. An access platform to reach the end of the discharge line or a sampling point connected to the line close to the discharge point should be sufficient.

While selecting the new outfall location it is recommended to investigate the location together with land developers while considering Bahrain Master Plan 2030, especially with regards to anticipated land reclamation activities.

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[42] Since 2011 Befesa, an international company specializing in the integral management of industrial wastes, established five SPL recovery plants in Europe (three in Germany, one in Spain and one in the UK). Recently, a memorandum of understanding was signed between Befesa and Senaat (an Abu Dhabi based industrial investment and holding company) to jointly develop a slags and SPL recycling plant in Abu Dhabi Emirate. Further, Befesa aims to be established in the Gulf Region by 2017.

9.3.3 Ambient Air Quality monitoring

As stated in section 5.2, HF monitoring is not being conducted by the Ministry and actual measurements are not available. Air quality HF dispersion modelling was conducted but full quantitative assessment with regard to ambient HF concentrations could be not be established, given the unavailability of ambient air quality data for this component. It is therefore recommended to reinstate monitoring of HF concentrations at sensitive receptor locations and to use this data for further verification of the performed assessment.

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Appendices

The following appendices are included:

Appendix 1: Site Layout – Existing Facilities

Appendix 2: Formal Communication from SCE

Appendix 3: Dutch Standards for Soil and Groundwater

Appendix 4: Alberta Tier 1 Soil and Groundwater Remediation Guidelines

Appendix 5: US EPA Ecological Soil Screening Level for Aluminium

Appendix 6: Results Soil Investigation 2013

Appendix 7: Groundwater Monitoring Locations

Appendix 8: Results Groundwater Monitoring 2007 - 2012

Appendix 9: Noise Monitoring Results 2013

Appendix 10: Waste Water Discharge Quality

Appendix 11: Marine Ambient Water Temperatures

Appendix 12: Road Network

Appendix 13: One-Day Traffic Survey

Appendix 14: Four-day Traffic Survey obtained from MoE

Appendix 15: United Nations Population and Development Statistics

Appendix 16: Ministry of Culture – Letter Regarding Archaeology and Cultural Heritage

Appendix 17: Air Modelling Methodology

Appendix 18: Air Dispersion Isopleths

Appendix 19: SPL Treatment Options

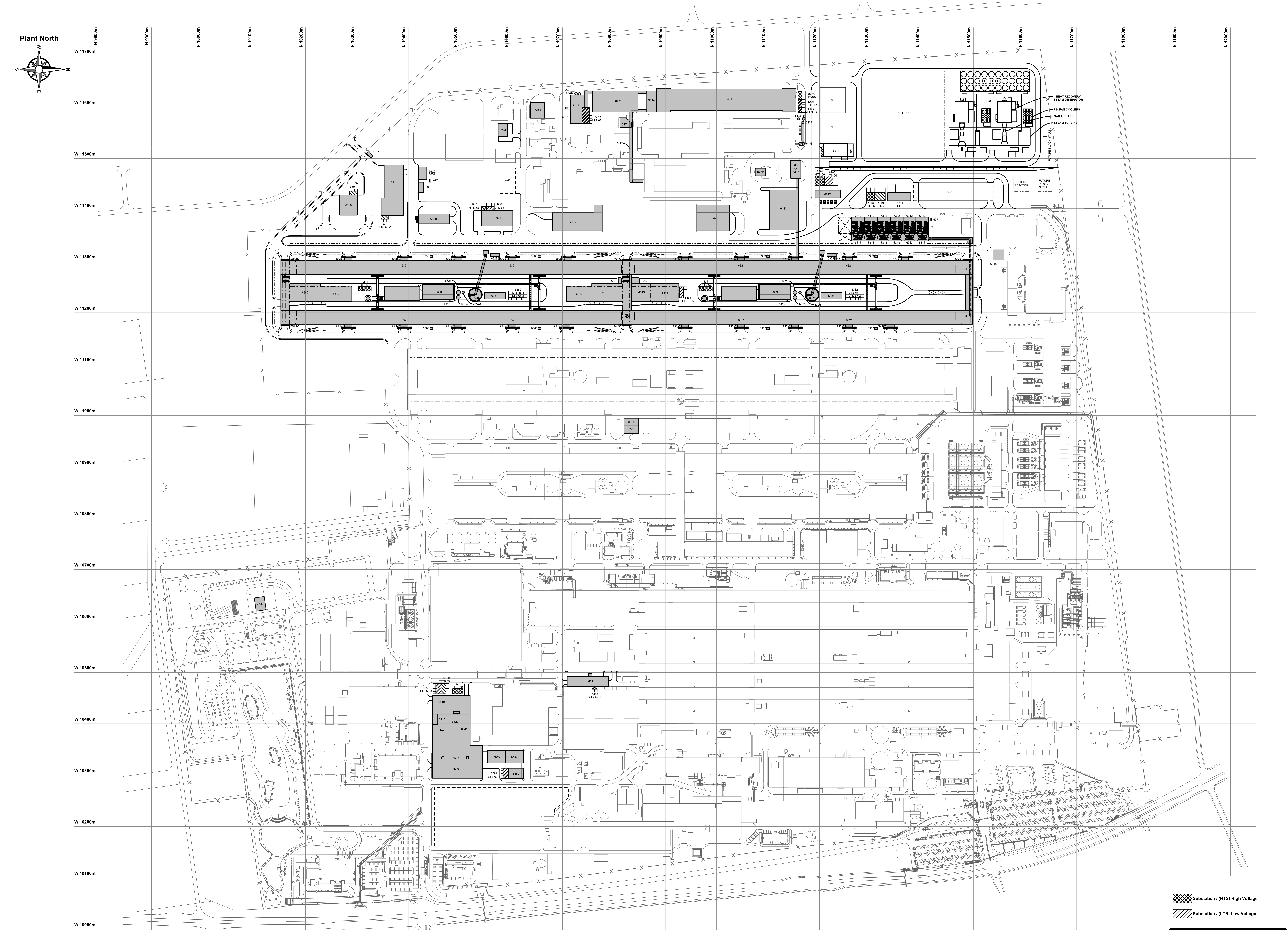
Appendix 20: Noise Modelling

Appendix 21: Mitigation Measures for EPC Contractor

Appendix 23: Approved Waste Transporters

Appendix 24: Approved Oily Waste Transporters

Appendix 1: Site Layout – Existing Facilities



PRELIMINARY DESIGN IN PROGRESS

Alba Line 6 - Facility Descriptions

Fac. Code	Facility Description	Bldg. No.
6000	General Common	-
6100	Site Development	-
6110	Site Preparation (Cleaning, Grubbing, Earthworks, Drainage, Fencing)	-
6120	Roads & Paving	-
6130	Parking Areas	-
6150	Landscaping	-
6160	Storm Water System	-
6180	Fencing	-
6200	Port Facilities	-
6300	Reduction Plant	-
6310	Main Substation & Rectifiers	-
6311	Main Switchyard (GIS) Including Control Bldg. Maintenance & Offices	-
6312	Rectifiers (Including Collector Busbar, DC Current & Voltage Measurement)	-
6313	Harmonic Filters	-
6315	Primary Distribution Voltage Substation (Auxiliaries)	-
6318	Potline Rectifiers Control Room	-
6320	Potline	-
6321	Potline Buildings & Passagways	-
6322	Electrolytic Pots (Including Potshells, Superstructures & Busworks)	-
6323	Pot Tending Equipment	-
6324	Fluorinated Alumina Storage	-
6325	Crushed Bath Storage & Handling	-
6326	Covering Alumina Storage & Handling	-
6327	Pot Control System	-
6328	Fresh Alumina Storage & Handling	-
6329	Mechanical Room (Blower Room) Fresh Alumina and Unloading	-
6330	Potline Gas Treatment Center (GTC)	-
6331	Mechanical Room (Blower Room) Courtyard	-
6340	Potline Services	-
6341	Cathode Sealing	-
6342	Pot Delining / Relining	-
6343	Spent Pot Lining Storage	-
6344	Crucible & Tube Cleaning	-
6345	Pot Tending Machine Maintenance	-
6346	Potline Major Equipment Maintenance	-
6347	Potline Control Room	-
6348	Potline Amenities / Eating / Prayer Rooms	-
6349	Potline Cool Rooms	-
6350	Crucible Lid Preparation Area	-
6351	Crucible De-Lining / Re-Lining Area	-
6360	Potline Offices	-
6380	Reduction Area Substation / Electrical Rooms	-
6381	Reduction Area Substation / Electrical Rooms - HV (GTC)	-
6382	Reduction Area Substation / Electrical Rooms - LV	-
6383	Floating Voltage Electrical Rooms	-
6385	Reduction Area Substation - LV - (PTA)	-
6386	Crucible Cleaning Substation - LV	-
6387	Cathode Sealing Substation - HV	-
6388	Cathode Sealing Substation - LV	-
6390	Aluminium Fluoride Storage & Handling	-
6400	Carbon Area	-
6410	Green Anode Production	-
6411	Anode Paste Plant	-
6412	Pitch Fume Treatment	-
6413	Green Anode Cooling	-
6414	Coke Storage & Handling	-
6415	Plant Site Liquid Pitch Storage	-
6420	Anode Storage & Handling	-
6421	Anode Stacker Crane	-
6422	Anode Handling System (Green / Baked Anodes)	-
6430	Baked Anode Production	-
6431	Anode Baking Furnace	-
6432	Baked Anode Cleaning	-
6434	Coke Fines Handling	-
6435	Baking Furnace Fume Treatment Center (FTC)	-
6436	Furnace Tending Assembly	-
6437	Fume Treatment Center (FTC) Blower Room	-
6438	Charged Alumina	-
6442	Pallet Storage (Anodes, Butts & Bath)	-
6443	Bath Bin Storage	-
6450	Bath Treatment & Storage	-
6460	Anode Butts & Carbon Storage	-
6470	Carbon Services	-
6471	Carbon Area Maintenance Shop 1	-
6472	Carbon Plant Offices & Amenities	-
6473	Carbon Area Maintenance Shop 2	-
6480	Carbon Area Substations / Electrical Rooms	-
6481	Carbon Area Substations / Electrical Rooms - HV (Paste Plant)	-
6482	Carbon Area Substations / Electrical Rooms - LV (Paste Plant)	-
6483	Carbon Area Substations - HV (ABF / FTC)	-
6484	Carbon Area Substations - LV (ABF)	-
6485	Carbon Area Substations - LV (FTC)	-
6500	Casthouse	-
6510	Casthouse 4 Building	-
6514	Casthouse 4 Control Room	-
6515	Casthouse 4 Offices	-
6520	Casthouse 4 Furnace & VDC Casting Area	-
6525	Casthouse 4 Homogenizing Furnace Area	-
6530	Casthouse 4 Metal Product Storage & Handling	-
6540	Casthouse 4 Maintenance	-
6541	Casthouse 4 Mould Shop	-
6550	Casthouse 4 Cooling Water & Treatment	-
6560	Casthouse 4 Dross Processing	-
6570	Sow Casting Facility	-
6571	Sow Caster	-
6572	Sow Caster Product Handling & Storage	-
6573	Sow Caster Cooling Water & Treatment	-
6580	Casthouse 4 Substation - LV - VDC	-
6582	Casthouse 4 Substation - HV	-
6583	Casthouse 4 Substation - LV - Homo Furnace	-
6585	Sow Casting Facility Substation / Electrical Rooms	-
6590	Line 6 Crucible Tac & Skimming Station	-
6594	Tac & Skimming Station Electrical Room	-
6600	General Services	-
6610	Main Gate House & Truck Scales	-
6611	South Gate House & Truck Scales	-
6620	Maintenance Building	-
6621	Central Maintenance Workshop	-
6622	Mobile Equipment Repair & Storage	-
6630	Central Warehouse	-
6631	Gas Bottle Storage	-
6632	By-Product Storage	-
6640	Administration Buildings	-
6641	Main Administration Offices	-
6642	Change House	-
6643	Cafeteria	-
6644	Social & Emergency Services (Medical, Health Center, Musala, etc.)	-
6645	Maintenance & Engineering Offices	-
6650	Service Station & Mobile Equipment	-
6651	Service Station	-
6652	Mobile Equipment	-
6660	Quality Control & Laboratory	-
6680	General Services Area substations / Electrical Rooms	-
6700	Yard Utilities	-
6710	Yard Electrical Utilities	-
6711	Primary Distribution Network (3.3 & 11.5 kV Med. Voltage Distribution)	-
6712	Yard Lighting	-
6713	Emergency Generators	-
6714	Main Auxiliary Substation (33 kV)	-
6715	Main Substation (11 kV) - HV	-
6716	Main Substation (11 kV) - LV	-
6740	Yard Mechanical Utilities	-
6741	Fire Water System	-
6742	Potable Water System	-
6743	Process Water System	-
6744	Sewage & Sanitary System	-
6745	Natural Gas Desulfurization	-
6746	Natural Gas Distribution System	-
6747	Compressed Air System	-
6749	Storm Water System	-
6750	Plant Communication & Information Systems	-
6751	Fiber Optic	-
6752	Plant Wide Communications	-
6753	Fire Protection, Alarm & Detection	-
6754	Access Control & CCTV	-
6755	Manufacturing Execution System (MES)	-
6756	Environmental Monitoring	-
6757	Telephone / Paging Systems	-
6758	Plant Information System Software	-
6759	Computers & Communication Equipment	-
6770	Water Treatment Plant	-
6771	Oily Water Separator	-
6780	Utilies Area Substations / Electrical Rooms	-
6781	Compressor House Substation - HV	-
6782	Compressor House Substation - LV	-
6800	Raw Material Handling & Storage - Plant Site	-
6820	Aluminium Fluoride Handling & Storage	-
6900	Power Station / High Voltage	-
6931	Power Control Room	-
6935	G.I.S.	-
6960	Fuel Gas Area & Fuel Gas Compressors	-
6971	Water Treatment	-

Drawing Number	Title

Reference Documents

No.	Status	Description	Date	By	Chk.	RE	AE	EGS	PEM
00D	IFFS	ISSUED FOR FEASIBILITY STUDY	11.05.2013	JB	-				AE
00C	IFFS	ISSUED FOR FEASIBILITY STUDY	11.01.2013	JB	-				AE
00B	IFR	ISSUED FOR REVIEW	10.23.2013	AG	-				AE
00A	IFR	ISSUED FOR REVIEW	10.18.2013	AG	-				AE

Revisions

Geodetic System:
Vertical Datum:
System of Units: SI (m)
Seal:

Drawn By: AG / JBRADETTE	Date: 08-13-2013
Chk. By: -	Date: -
Rsp. Eng.:	Date:
Area Eng.:	Date:
EGS:	Date:
Eng. Mgr.: -	Date: -

Sheet: A0
Scale: 1 : 2500
0 2500 7500 12500

Bechtel

alba (ألبا)

Client:
Date:
Client:
Date:
Client Drawing Number:
Revision:

Alba
Line 6 Feasibility Study

Line 6 - 404 Pots
General Arrangement
Plot Plan

Bechtel Drawing Number: 25835-6000-P1-6000-0004
Revision: 00D

Appendix 2: Formal Communication from SCE

Kingdom of Bahrain
Supreme Council for Environment

مملكة البحرين
المجلس الأعلى للبيئة

EL-090-14
5th Mar 2014

Mr. Abdulla Yaqoob Senan
Senior Manager S.H.E
ALBA

Fax No.:17830271

Subject: Alba Potline (6) and power Plant (PS 5) Expansion

Dear Mr. Abdulla,

Reference to Alba Potline (6) and power Plant (PS 5) Expansion Project scoping report and its amendments, we are pleased to inform that you may proceed with the implementation of the Environmental Impact Assessment as specified in the ESR considering the following modifications and clarifications:

1. Resources usage and utilization must be highlighted recommending sustainable practices especially with regard to fuel gas requirements.
2. Gas desulphurization units and its impacts are to be assessed based on the quality and quantity of the gas utilized. Any waste generated due to this activity is to be elaborated in terms of storage, treatment, recycling and disposal.
3. Cumulative air quality impacts due to existing emission sources at ALBA power stations in addition to the new proposed Power Station PS-5, considering the shutting down of PS-1 and PS-2. Certain residential areas "north and north east of Alba" must be covered by the dispersion module including "Nuwaidrat, Ma'ameer, AlEkar, Sanad and Sitra".
4. Maintenance plan and schedule including regular required emissions and measures to optimize those bypasses.
5. Demolition of un-wanted existing facilities is to be evaluated.

ص.ب: ١٨٢٣٣ – مجمع البحرين – مملكة البحرين – تليفون: ١٧ ٣٨٦٩٩٩ (+٩٧٣) – فاكس: ١٧ ٣٨٦٥٥٦ (+٩٧٣)
P.O. Box: 18233 - Bahrain Mall - Kingdom of Bahrain - Tel.: (+973) 17386999 - Fax: (+973) 17 386556
E-mail: info@pmew.gov.bh

6. Impact of brine discharge, location of waste water outfall and its presenting issues and recommendations in regard with mixing and flushing.
7. Section 4.1: The impact of utilizing tanker trucks for transportation of fresh alumina and its impact on existing traffic and future expected traffic during construction and operation of Line 6 is to be assessed and mitigated.
8. Section 4.7.7: The details of Sewage treatment plant and processes are to be elaborated with the type, quantity and characteristics/ composition of sludge and its recommended method of disposal.
9. Section 4.9: Details of raw material, chemicals and additives are to be provided in the ESIA.
10. The consultant is required to prepare all the documents and communications for the preparation of the study with government and non-governmental relevant agencies. Data related to those consultations must be presented within the study Indices.
11. The Consultant is required to prepare the Construction Environmental Management Plan and Operational Environmental Management Plan (CEMP and OEMP).

Thank you for your kind cooperation.

Best regards,

Suhad Hussain Al Shehabi
Head of Environmental Licensing Section

CC. Tebodin Middle East LTD

Appendix 3: Dutch Standards for Soil and Groundwater

Dutch Soil Circular 2013 - 10% Organic Carbon and 25% Lutum

Translated from Circulaire bodemsanering per 1 juli 2013

Name of Substance	Target value		Intervention Value	
	Ground water		Soil	Ground water
	Shallow (<10 m-mv) (µg/l)	Deep (>10 m-mv) (µg/l)	(mg/kg d.s.)	(µg/l)
Metals				
Antimony	-	0.15	22	20
Arsenic	10	7.2	76	60
Barium	50	200	-	625
Cadmium	0.4	0.06	13	6
Chrome	1	2.5	-	30
Chromium III	-	-	180	-
Chromium IV	-	-	78	-
Cobalt	20	0.7	190	100
Copper	15	1.3	190	75
Mercury	0.05	0.01	-	0.3
Mercury (inorganic)	-	-	39	-
Mercury (organic)	-	-	4	-
Lead	15	1.7	530	75
Molybdenum	5	3.6	190	300
Nickel	15	2.1	100	75
Zinc	65	24	720	800
Other inorganic substances				
Chloride (mg Cl/l)	100 mg/l		-	-
Cyanide (free)	5		20	1500
Cyanide (complex)	10		50	1500
Thiocyanate	-		20	1500
Aromatic compounds				
Benzene	0.2		1.1	30
Ethyl benzene	4		110	150
Toluene	7		32	1000
Xylenes (sum)	0.2		17	70
Styrene (vinyl benzene)	6		86	300
Phenol	0.2		14	2000
Cresols (sum)	0.2		13	200
Polycyclic Aromatic Hydrocarbons (PAHs)				

Name of Substance	Target value		Intervention Value	
	Ground water		Soil	Ground water
	Shallow (<10 m-mv) (µg/l)	Deep (>10 m-mv) (µg/l)	(mg/kg d.s.)	(µg/l)
Naphthalene	0.01		-	70
Phenanthrene	0.003		-	5
Anthracene	0.0007		-	5
Fluoranthene	0.003		-	1
Chrysene	0.003		-	0.2
Benzo(a)anthracene	0.0001		-	0.5
Benzo(a)pyrene	0.0005		-	0.05
Benzo(a)fluoranthene	0.0004		-	0.05
Indeno(1,2,3cd)pyrene	0.0004		-	0.05
Benzo(ghi)perylene	0.0003		-	0.05
PAHs (total) (sum 10)	-		40	-
Chlorinated Hydrocarbons				
a. (fugitive) hydrocarbons				
Chloroethylene (Vinyl chloride)	0,01		0,1	5
Dichloromethane	0,01		3,9	1
1,1-dichloroethane	7		15	900
1,2-dichloroethane	7		6,4	400
1,1-dichloroethane	0,01		0,3	10
1,2-dichloroethane (sum)	0,01		1	20
dichloropropanes (sum)	0,8		2	80
trichloromethane (chloroform)	6		5,6	400
1,1,1- trichloromethane	0,01		15	300
1,1,2- trichloromethane	0,01		10	130
Trichloroethene (Tri)	24		2,5	500
Tetrachloromethane (Tetra)	0,01		0,7	10
Tetrachlorethene (Per)	0,01		8,8	40
b. chlorobenzenes				
Mono Chlorobenzene	7		15	180
Dichlorobenzenes (sum)	3		19	50
Trichlorobenzenes (sum)	0,01		11	10
Tetrachlorobenzenes (sum)	0,01		2,2	2,5
Penta chlorobenzenes	0,003		6,7	1
hexachlorobenzene	0,00009		2,0	0,5

Name of Substance	Target value		Intervention Value	
	Ground water		Soil	Ground water
	Shallow (<10 m-mv) (µg/l)	Deep (>10 m-mv) (µg/l)	(mg/kg d.s.)	(µg/l)
c. Chlorophenols				
Mono Chlorophenols (sum)	0,3		5,4	100
Dichloro Phenol (sum)	0,2		22	30
Trichlorophenols (sum)	0,03		22	10
Tetra Chlorophenols (sum)	0,01		21	10
Pentachlorophenol	0,04		12	3
d. Polychlorinated biphenyls (PCB's)				
PCB's (sum 7)	0,01*		1	0,01
e. Other chlorinated hydrocarbons				
Monochlooranilinen (sum)	–		50	30
Dioxin (sum TEQ)	–		0,00018	nvt
Chloronaphthalen (sum)	–		23	6
Pesticides				
a. organochlorine pesticides				
Chlordane (sum)	0,02 ng/l		4	0,2
DDT (sum)	–		1,7	–
DDE (sum)	–		2,3	–
DDD (sum)	–		34	–
DDT/DDE/DDD (sum)	0,004 ng/l		–	0,01
Aldrin	0,009 ng/l		0,32	–
Dieldrin	0,1 ng/l		–	–
Endrin	0,04 ng/l		–	–
Drins (sum)	–		4	0,1
α-endosulfan	0,2 ng/l		4	5
α-HCH	33 ng/l		17	–
β-HCH	8 ng/l		1,6	–
γ-HCH (lindane)	9 ng/		1,2	–
HCH-compounds (sum)	0,05		–	1
Heptachlor	0,005 ng/l		4	0,3
Heptachlor epoxide (sum)	0,005 ng/l		4	3
b. Organophosphorus pesticides				
–				
c. Organotin pesticides				

Name of Substance	**Target value**		**Intervention Value**	
	Ground water		**Soil**	**Ground water**
	Shallow (<10 m-mv) (µg/l)	**Deep (>10 m-mv) (µg/l)**	**(mg/kg d.s.)**	**(µg/l)**
Organotin compounds (sum)	0,05 – 16 ng/l		2,5	0,7
d. chloorfenoxy-azijnzuur herbiciden				
MCPA	0,02		4	50
e. other pesticides				
Atrazine	29 ng/l		0,71	150
Carbaryl	2 ng/l		0,45	60
Carbofuran	9 ng/l		0,017	100
Other compounds				
Asbestos	–		100	–
Cyclohexanone	0,5		150	15
Dimethyl phthalate	–		82	–
Diethyl phthalate	–		53	–
Di-isobutyl phthalate	–		17	–
Dibutyl phthalate	–		36	–
Butyl benzyl phthalate	–		48	–
Dihexyl phthalate	–		220	–
Di(2-ethylhexyl)phthalate	–		60	–
Phthalate (sum)	5		–	5
Mineral oil	50		5	600
Pyridine	0,5		11	30
Tetrahydrofuran	0,5		7	300
Tetrahydrothiophene	0,5		8,8	5
Tribromomethane (bromoform)	–		75	630

Appendix 4: Alberta Tier 1 Soil and Groundwater Remediation Guidelines

ALBERTA TIER 1
SOIL AND GROUNDWATER REMEDIATION GUIDELINES

Alberta
Environment

ALBERTA TIER 1
SOIL AND GROUNDWATER
REMEDIATION GUIDELINES

Alberta Environment

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Alberta Tier 1 Soil and Groundwater Remediation Guidelines

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1. INTRODUCTION

1.1 Alberta's Framework for the Management of Contaminated Sites

Alberta's framework for the management of contaminated sites is designed to achieve three policy outcomes:

- **Pollution prevention**: Avoid "impairment of, or damage to, the environment, human health or safety, or property".
- **Health protection**: Take action on contaminated sites that is commensurate with risk to human health and the environment.
- **Productive use**: Encourage remediation and return of contaminated sites to productive use.

Under this framework, three management options are provided: Tier 1, Tier 2, and Exposure Control. Within a given land use, sites will fall into a range of sensitivities because of differences in receptors and site conditions. Tier 1 remediation guidelines are generic; that is, they are developed to protect sites at the more sensitive end of the range and can therefore be used at most sites without modification. The Tier 2 approach allows the consideration of site-specific conditions through the modification of Tier 1 guidelines and/or removing exposure pathways that may not be applicable to the site. Exposure Control involves risk management through exposure barriers or administrative controls based on site-specific risk assessment. These management options are described in more detail in Section 3.

The Tier 1 approach is based on the assumption that all exposure pathways and receptors relevant to a particular land use are actually present. At Tier 1, exposure pathways that are part of the generic scenario for the applicable land use may not be screened out. Under Tier 2 it may be possible to screen out certain exposure pathways and/or modify the Tier 1 guidelines on the basis of site conditions. These options are discussed further in Sections 3 and 5, and in *Alberta Tier 2 Soil and Groundwater Remediation Guidelines* (AENV, 2009a).

1.2 Tier 1 and Tier 2 Levels of Protection

The objective of the Tier 1 and Tier 2 soil and groundwater remediation guidelines is to deliver the same degree of human health and ecological protection, regardless of which option is used. The same protocols are used to develop both Tier 1 and Tier 2 guidelines. The two options differ in the amount of site-specific information used to develop the guidelines.

The Tier 1 remediation guidelines are simple tabular values that require minimal site information for their use. Conservative assumptions about soil and groundwater characteristics have been used to develop the Tier 1 guidelines to protect sites likely to be sensitive to contamination. In this way, less sensitive sites under the applicable land use are also protected. Some site information is needed to ensure that site conditions are adequately represented by the assumptions used to develop the Tier 1 guidelines. Those sites that may be more sensitive than conditions assumed in the Tier 1 guidelines are more appropriately dealt with under the Tier 2 approach.

Applying Tier 2 guidelines typically requires more information from the site than Tier 1 guidelines. This additional information allows the assessor to develop guidelines that are tailored to the particular characteristics of the site. When a site has characteristics that make it more sensitive than the Tier 1 assumptions, the resulting Tier 2 guidelines may be more restrictive than Tier 1 values. Sites which are less sensitive may have Tier 2 guidelines that are less restrictive than Tier 1 values, but which deliver the same level of human and ecological health protection because they are tailored to that specific site.

When adverse effects are evident, contaminants must be managed to alleviate adverse effects, regardless of whether a site meets Tier 1 or 2 remediation guidelines.

1.3 Relationship to Other Guideline Documents

This document focuses on Tier 1 soil and groundwater remediation guidelines, the process used to develop them, and the manner in which they should be applied. The *Alberta Tier 2 Soil and Groundwater Remediation Guidelines* (AENV, 2009a) expands on the Alberta Environment three-tiered system of contaminated site management (summarized in Section 3 of this document) and, in particular, provides the detail needed to make Tier 2 adjustments to the Tier 1 guidelines.

The soil and groundwater guidelines in this document supersede the following guideline documents:

- *Alberta Tier I Criteria for Contaminated Soil Assessment and Remediation* (AEP, 1994)
- *Alberta Soil and Water Quality Guidelines for Hydrocarbons at Upstream Oil and Gas Sites* (AENV, 2001a); and
- *Risk Management Guidelines for Petroleum Storage Tank Sites* (AENV, 2001b).

The following documents contain additional information needed for the application of Tier 1 guidelines and should be used in conjunction with this document:

- *Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes* (AEP, 1996);
- *Surface Water Quality Guidelines for Use in Alberta.* (AENV, 1999);
- *Salt Contamination Assessment and Remediation Guidelines* (AENV, 2001c);
- *Soil Remediation Guidelines for Barite: Environmental Health and Human Health* (AENV, 2009b);
- *Assessing Drilling Waste Disposal Areas: Compliance Options for Reclamation Certification* (AENV, 2009c)

- *Canadian Environmental Quality Guidelines* (CCME, 1999 and updates);
- *Reference Method for the Canada-Wide Standard for Petroleum Hydrocarbons in Soil - Tier 1 Method* (CCME, 2001); and
- *Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM)* (Health Canada, 2000).

Two documents provide the protocols and the primary technical basis for the risk-based guidelines calculated in this volume:

- For all compounds except petroleum hydrocarbons: *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME, 2006); and,
- For petroleum hydrocarbons: *Canada-Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil* (CCME, 2008).

1.4 Ongoing Commitment

The *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* is a living document. Alberta Environment is committed to updating the guidelines as new information and guidelines for new substances become available.

2. ALBERTA ENVIRONMENT POLICY ON CONTAMINATED SITE MANAGEMENT

This section provides an introduction to the guiding principles that underlie Alberta Environment policy on the management of contaminated soil and groundwater. These principles and the associated policy provide a framework for implementing the three contaminated site management options: Tier 1, Tier 2, and Exposure Control.

2.1 Pollution Prevention

Pollution prevention is a critical factor in maintaining a healthy environment. Alberta Environment policy strongly emphasizes the importance of proactive efforts that keep soil and groundwater clean and free of contaminants rather than relying on remediation after contamination has occurred. Remediation programs are often costly and, in the case of large and complex contaminant releases, may not be capable of fully restoring the quality of contaminated land or water, leading to a loss of land or water use options. Soil and groundwater contamination may be prevented or minimized by exercising care and control through:

- proper siting of facilities and chemical storage areas;
- secondary containment of potential contaminants;
- regular inspections and maintenance of tanks and pipelines;
- soil and groundwater monitoring programs;
- early source identification and removal or management; and,
- proper waste disposal and management.

2.2 Legislation

Two key acts, the *Environmental Protection and Enhancement Act* (Government of Alberta, 2006), and the *Water Act* (Government of Alberta, 2000) form the legislative basis of Alberta Environment's policies on the management of contaminated soil and groundwater.

2.2.1 *Environmental Protection and Enhancement Act*

Regulatory requirements related to substance release, remediation and reclamation are found in the *Environmental Protection and Enhancement Act* (EPEA). The purpose of the EPEA (Government of Alberta, 2006) is "to support and promote the protection, enhancement and wise use of the environment". The EPEA allows the Minister to establish guidelines and objectives.

Substance Release Provisions

The EPEA prohibits the release of substances in an amount that causes or may cause a significant adverse effect. "Release", "substance", and "adverse effect" are defined in the EPEA. The release of a substance to the environment can occur rapidly (as in the rupture of a vessel containing the substance) or over a longer period of time (as with a gradual leak from an underground pipe that goes undetected). When a substance is released that causes an adverse effect or, for releases after Sept. 1, 1993, has the potential to cause an adverse effect, the release must be reported. Remedial measures must be implemented whenever a release causes, or has the potential to cause, an adverse effect. Additional guidance on release reporting can be found in *A Guide to Release Reporting* (AENV, 2005) and *Informational Letter 98-1* (ERCB, 1998).

Remediation Certificates

The EPEA authorizes the Director or inspector to issue remediation certificates where contaminated land has been remediated. While encouraging remediation of contaminated land, the remediation certificate also protects the responsible party from future environmental protection orders related to the remediated release.

Conservation and Reclamation

The EPEA includes requirements for the conservation and reclamation of specified land. Specified land is defined in the EPEA and the *Conservation and Reclamation Regulation* (Government of Alberta, 1993; C&R Reg.). The EPEA and the C&R Reg. require reclamation of specified land to equivalent land capability. Equivalent land capability is defined in the C&R Reg. With respect to soil contamination on specified land, the *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* establish generic remediation guidelines for achieving equivalent land capability. Site-specific guidelines for achieving equivalent land capability can be developed using a Tier 2 approach.

2.2.2 *Water Act*

Water is a public resource, and is owned and regulated by the Government of Alberta. Regulatory requirements related to the management of water supplies and water quality (including groundwater quality) are found in the *Water Act* (Government of Alberta, 2000). The purpose of the *Water Act* is "to support and promote the conservation and management of water, including the wise allocation and use of water". The *Water Act* allows the Minister to establish guidelines for water management.

2.3 Principles of Contaminant Management

A contaminant is a substance that is present in an environmental medium in excess of natural background concentration (CCME, 2006). Three key elements of Alberta's framework for the management of contaminated sites are: source control, contamination delineation, and contaminant management, including remediation.

2.3.1 Source Control

A source of contamination is anything that adds contaminant mass to the environment. Source control is a necessary action in support of pollution prevention, a key outcome of Alberta's policy on contaminated site management. If there is evidence of soil or groundwater contamination, the source, if it is still present, must be identified. Sources must be removed or controlled as soon as practicable.

Contaminants can be introduced into the environment in a number of ways. Leaking pipelines and storage tanks are common sources of contamination. Contaminated soil and groundwater may be a source of contamination to other areas of a site if the contaminants are mobile. Removal or management of these sources is a necessary part of contaminated site management. Soil or groundwater with naturally elevated substance concentrations may become a source of contamination if it is redistributed and causes the receiving soil or water to exceed Tier 1 or 2 remediation guidelines. This can be avoided by proper characterization and handling of soil and groundwater prior to redistribution. Failure to control sources allows contaminants to spread, increasing risk and remediation costs, and potentially limiting future land use if remediation to Tier 1 or 2 guidelines is not possible.

Where complete source removal is not feasible, the source must be removed to the extent possible and treatment, control, and/or management measures must be implemented to address the residual source. Treatment measures will assist in the ongoing reduction of source contaminant concentrations. Source control measures must prevent the contaminant from spreading to adjacent areas, causing the soil or groundwater there to exceed Tier 1 or 2 guidelines.

If source control measures are required, they must operate until the source meets Tier 1 or Tier 2 remediation guidelines. Source control must be supported by a monitoring program that demonstrates its efficacy.

Where source control rather than source remediation is implemented, a site is considered to be managed through an Exposure Control approach rather than a Tier 1 or Tier 2 approach.

2.3.2 Delineation

When soil or groundwater is found to contain contaminants in excess of Tier 1 or 2 soil or groundwater remediation guidelines, a delineation program must be implemented (Fig. 3). The delineation program must identify both the horizontal and vertical extent of contaminant concentrations exceeding the Tier 1 guidelines or the Tier 2 guidelines derived by the pathway exclusion approach (Section 5.2 and Table 5 in AENV, 2009a). Adequate delineation provides information needed to support appropriate decisions about contaminant remediation and management. Delineation programs must be extensive enough in both horizontal and vertical directions to allow all applicable exposure pathways and receptors to be properly assessed. Delineation is complete when measured concentrations are less than Tier 1 or 2 remediation guidelines. Complete delineation must be accomplished prior to undertaking remediation. The only exception is for relatively simple sites where contaminants are removed by excavation and compliance with Tier 1 guidelines is shown by post-excavation sampling. When confirmatory samples fail to comply with Tier 1 guidelines after excavation is complete, full delineation of the remaining contamination must be undertaken and used to develop further remediation actions or risk management programs.

2.3.3 Contaminant Management

When the volume of soil or groundwater containing contaminant concentrations that exceed Tier 1 or 2 guidelines is completely delineated, a plan must be developed to remediate or otherwise manage the contaminants in a manner that is consistent with the framework outlined in Section 3. Using dilution to reduce contaminant concentrations is not an acceptable form of management, unless authorized by the appropriate regulatory authority under an operating approval, code of practice, or directive.

2.3.4 Management of Contaminants in Subsoil

In general, Alberta Tier 1 surface soil remediation guidelines apply to all soil and groundwater, regardless of depth. However, subsoil guidelines for salinity and petroleum hydrocarbons may be used at Tier 1 under the following circumstances:

Salinity

Topsoil guidelines for electrical conductivity and sodium adsorption ratio must be applied to the L, F, H, O, and A horizons (Soil Classification Working Group, 1998) or equivalent surficial material where these horizons are not present. Subsoil guidelines may be applied below the A horizon or equivalent in lieu of topsoil guidelines. Further information is available in the *Salt Contamination Assessment and Remediation Guidelines* (AENV, 2001c).

Petroleum Hydrocarbons

Surface soil guidelines for petroleum hydrocarbon fractions F1 to F4, benzene, toluene, ethylbenzene, and xylenes must be applied to a depth of 1.5 metres. Subsurface guidelines may be used as follows:

- Below 1.5 metres in depth within a 5 metre setback from an oilfield wellhead (see Municipal Affairs and Housing Advisory Land Use Planning Notes on Abandoned Wellsites), or
- below 3 metres in depth at any site.

The Tier 1 approach allows the exclusion of the ecological direct contact pathway for soil and groundwater for petroleum hydrocarbon fractions F1 to F4 for any land use below a depth of 3 metres. All other exposure pathways apply. Consistent with the *Canada-Wide Standard for Petroleum Hydrocarbons in Soil* (CCME, 2008), exclusion of the ecological direct soil contact pathway is permitted below 3 metres with the application of "management limits" for petroleum hydrocarbon fractions that represent maximum concentrations that apply at any depth. Management limits for petroleum hydrocarbon fractions F1 to F4 are noted in Appendix A.

2.4 Soil Protection in Alberta

Soil is a resource that supports important ecosystem functions. As a society, we rely on our soil resources to supply food and fibre, purify water, degrade waste materials, maintain healthy forests and grasslands, and provide a structural foundation for urban and rural buildings and infrastructure. As stewards of our soil resource, we have a responsibility to manage our activities in a way that sustains the ecological functions of soil. At sufficient concentrations, soil contamination can impair the ability of soil to support important ecosystem functions as well as pose risks to human health. Care must be taken to prevent soil contamination and, when a substance release occurs, prompt actions must be taken to remediate or otherwise manage the release. Maintenance of good soil quality will ensure that soil fulfills its ecological role and will maintain our land use options as Alberta continues to grow and diversify.

2.4.1 Using Tier 1 Soil Remediation Guidelines

The goal of the Tier 1 soil remediation guidelines is to provide numerical targets for remediation of contaminated soil. To ensure consistency with “pollution prevention”, a key outcome of Alberta’s contaminated sites management framework, the Tier 1 soil remediation guidelines are **not** “pollute-up-to” levels. Sources must not be left uncontrolled until cumulative releases result in an exceedance of Tier 1 or Tier 2 soil remediation guidelines. This results only in further contamination, increased remediation costs, and potential loss of land use options. Source control is a crucial component of pollution prevention.

2.4.2 Background Soil Quality

The background concentration of a substance in soil is the natural concentration of that substance in the absence of any input from anthropogenic activities or sources. In some situations, the background concentration of some substances can be a significant proportion of, or even exceed, the Tier 1 guidelines. In cases were the natural background is demonstrated to be greater than Tier 1 guidelines, the remediation level shall be to natural background or to guidelines developed using Tier 2 procedures.

Background concentrations will vary with soil parent material, soil depth, and hydrologic regime. These factors lead to spatial variations in background concentrations that may or may not be predictable. To gain a good understanding of background conditions at a site, it is necessary to take sufficient representative samples from soils with similar characteristics to the affected site, but which are taken from outside the area affected by contamination. Sample depth and landscape position, soil profile characteristics and parent material should be recorded for all samples.

Care should be taken to distinguish between apparent background concentrations that are the result of diffuse anthropogenic sources, and true, natural background conditions. In comparing against background, emphasis should always be placed on ensuring that anthropogenic sources are not identified as natural background.

2.4.3 Land Use

Potential receptors and their exposure to soil contaminants are affected by land use. For example, workers on an industrial site experience a different exposure than a toddler living on a residential property. Different ecological receptors are found in a forest setting than on an urban commercial property. Tier 1 soil remediation guidelines are calculated for five types of land use: natural areas, agricultural, residential/parkland, commercial, and industrial. These land use types may not correspond exactly to the range of municipal zoning options, but by evaluating the types of receptors and exposure conditions used in calculating the guidelines for each land use scenario, it is possible to identify which land use scenario is protective for a particular municipal zoning requirement. Assessors must determine the full range of uses allowed under the applicable zoning bylaw when determining the appropriate land use for Tier 1 application. Where a municipal zoning decision incorporates more than one land use scenario, the most conservative land use must be applied. More detailed guidance on land use may be found in Section 3.2.

In some cases, a contaminated site may be adjacent to a property with a more sensitive land use. Even though contaminant concentrations may meet appropriate guidelines for the less sensitive land use, mobile substances may migrate to the adjacent property at concentrations that exceed guidelines for the more sensitive land use. This is a particular risk for the vapour inhalation pathway and the groundwater direct ecological contact pathway. When a contaminated site is bordered by a more sensitive land use, the vapour inhalation guidelines (soil and groundwater) and the groundwater direct ecological contact guideline for the more sensitive land use apply to the contaminated site anywhere within 30 m of the more sensitive property boundary (see Figure 1).

2.4.4 Relationship to Air and Water Quality

Soil contamination interacts with air through volatilization and with water through dissolution and leaching to groundwater or runoff to surface water. Mobile soil contamination that is adding contaminant mass to air or water, is automatically considered a source. Therefore it must be remediated, or the contaminant release from the soil must be controlled as noted in Section 2.3.1.

For all land uses except natural areas, the Alberta Tier 1 soil remediation guidelines include soil concentrations that have been developed to protect indoor air quality. When soil contaminant concentrations exceed the soil remediation guideline protective of indoor air, then management of this exposure pathway is required.

The Alberta Tier 1 soil remediation guidelines also include soil concentrations that have been developed to protect groundwater quality. When soil contaminant concentrations exceed the soil remediation guideline protective of any groundwater-governed pathway (e.g., protection of potable groundwater for drinking water, protection of groundwater for freshwater aquatic life, or other groundwater pathways), then an investigation of groundwater quality is required unless the groundwater pathway can be managed under a Tier 2 approach. Tier 2 approaches could include pathway exclusion, site-specific risk assessments, or guideline adjustments based on separation distances between the zone of contamination and the seasonally high saturated zone or the distance to the water body of concern (see AENV, 2009a; Part B, Section 3). A groundwater quality investigation is also strongly recommended when contaminant concentrations in soil are close to the groundwater protection guidelines because the presence of preferential flow paths can result in contaminants reaching groundwater even when general soil conditions appear not to pose a risk. It is also possible that mobile substances have leached out of the vadose zone into groundwater if sufficient time has elapsed since the release event. The purpose of the groundwater quality investigation is to determine if there is groundwater contamination resulting from associated contaminated soil rather than to monitor groundwater quality over time.

2.4.5 Relationship to Land Application of Organic Materials, Industrial By-Products and Pesticides

The *Industrial Release Limits Policy* (AENV, 2000) specifies that substances regulated by Alberta Environment should be managed to prevent soil contamination. Under this policy, Alberta's approach to the management of wastes, industrial byproducts, composts, and other materials is based on the potential to improve soil quality. Wastes that provide no benefits to soil quality must not be applied to land in a manner that causes soil contamination. Industrial byproducts, composts, and other materials that provide a potential benefit to soil quality may be applied to land according to good agronomic or forestry practices and in accordance with any other regulatory requirements. Even when benefits can be shown, any potential contaminants in the byproduct must be managed to prevent their buildup in soil to concentrations that exceed Tier 1 or Tier 2 guidelines. Soil is a biologically active medium and is sometimes used as a treatment medium for soil contaminated by biodegradable substances. Land treatment of soil contaminated by gasoline, diesel fuel, jet fuel and kerosene is allowed if registered in accordance with the *Code of Practice for Land Treatment of Soil Containing Hydrocarbons* (AENV, 2008).

Tier 1 guidelines are used to evaluate chemical concentrations in soil. They can also be used to evaluate chemical concentrations resulting from the mixing of industrial by-products or organic materials into soil. They should not be used to evaluate concentrations in the by-product or organic material itself, unless the material will be placed directly on land without being mixed with soil.

Tier 1 pesticide guidelines have been developed for a limited number of exposure pathways for which sufficient information is available. These values are intended for use in the remediation of pesticide contaminated sites and not for restricting pesticide use in accordance with registered application rates.

Disposal and treatment of wastes generated by the upstream oil and gas industry are regulated by the Alberta Energy Resources Conservation Board in accordance with Directive 50, *Drilling Waste Management* (ERCB, 1996a) and Directive 58, *Oilfield Waste Management Requirements for the Upstream Petroleum Industry* (ERCB, 1996b). Directive 50 Equivalent Salinity Guidelines (AENV, 2009c) can be used to assess and remediate drilling waste disposal areas for reclamation certification.

2.5 Groundwater Protection in Alberta

2.5.1 Alberta's Initiatives to Protect Water Resources

Water is a public resource, and is owned and regulated by the Government of Alberta. Alberta is facing pressures on its water resources as a result of population growth, drought, and agricultural and industrial development. In response to these stresses, the Alberta Government in collaboration with Albertans developed *Water for Life: Alberta's Strategy for Sustainability* (Government of Alberta, 2003). *Water for Life* is a comprehensive strategy for addressing water management concerns for the future that emphasizes knowledge and research, partnerships, and water conservation. The protection of groundwater and surface water quality is a key element in the *Water for Life* approach.

The three primary goals of *Water for Life* are ensuring:

- a safe, secure drinking water supply,
- healthy aquatic ecosystems, and
- reliable, quality water supplies for a sustainable economy.

Groundwater has many beneficial uses and an important role in drinking water, the economy and supporting healthy aquatic ecosystems. Approximately 25 percent of Alberta's population depends on groundwater, and groundwater is used in a wide variety of industrial and commercial activities. Groundwater discharges into surface water bodies, such as rivers and wetlands, supporting aquatic ecosystems. Because groundwater and surface water are integrally connected, groundwater cannot be managed in isolation from surface water and aquatic ecosystems.

A key element of *Water for Life* is the protection of water resources. In the protection of groundwater quality, the strongest emphasis is placed on preventing groundwater resources from becoming contaminated. However, where contamination of this valuable public resource has resulted in an exceedance of Tier 1 or Tier 2 guidelines, it must be remediated or managed to ensure on-going protection of human health and the environment, and the restoration of beneficial uses.

This document provides guidance for managing contaminated groundwater in Alberta, and provides risk-based remediation guidelines to indicate when groundwater quality has been restored to an acceptable level.

2.5.2 Protection of Domestic Use Aquifers

Groundwater for domestic use is a significant current and future resource distributed over large geographic ranges in Alberta. Consequently, there is a need to protect the quality of Domestic Use Aquifers (DUAs).

The definition of a DUA is dependant on the amount of water an aquifer can produce, rather than the quality of the water in the aquifer, recognizing that technological treatment methods exist that can reduce or remove natural background substances.

Furthermore, an aquifer does not have to be currently used for domestic purposes in order to be classified as a DUA, as the intent is to define and protect these aquifers for current and future use. Alberta Environment may consider any body of groundwater above the Base of Groundwater Protection[1] that is capable of a sufficient yield of water to be a DUA.

For the purpose of selecting and applying a groundwater guideline for human health protection by ingestion, a DUA is defined as a geologic unit (either of a single lithology or inter-bedded units) that is above the Base of Groundwater Protection having one or more of the following properties:

- A bulk hydraulic conductivity of 1 x 10^{-6} m/s or greater and sufficient thickness to support a sustained yield of 0.76 L/min or greater; or
- Is currently being used for domestic purposes; or
- Any aquifer determined by Alberta Environment to be a DUA.

While it is possible that peat deposits and muskeg may meet the definition of a DUA, based on hydraulic conductivity and unit thickness, Alberta Environment does not consider peat deposits or muskeg to be a DUA because groundwater in them is unlikely to be used as a domestic source.

The DUA drinking water pathway **cannot** be excluded under the Tier 1 Guideline approach. However, using the Tier 2 Guidelines, it is possible to screen out the DUA drinking water pathway under certain circumstances, such as if an isolating geologic unit meeting specific properties is present, or if the only reason a geologic unit meets the definition of a DUA is the presence of a shallow large diameter well. For more information on the criteria for screening out the DUA drinking water pathway, refer to the *Alberta Tier 2 Soil and Groundwater Remediation Guidelines* (AENV, 2009a).

2.5.3 Using Tier 1 Groundwater Remediation Guidelines

The goal of the Alberta groundwater remediation guidelines is to provide numerical targets for the remediation of contaminated groundwater. To ensure consistency with “pollution prevention”, a key outcome of Alberta’s framework for contaminated sites management, the Tier 1 groundwater remediation guidelines are **not** “pollute-up-to” levels. Sources must not be left uncontrolled until cumulative releases result in an exceedance of Tier 1 or Tier 2 groundwater remediation guidelines. This results only in further contamination, increased remediation costs, and potential loss of water use options. Source control is a crucial component of pollution prevention.

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[1] The Base of Groundwater Protection is the depth above which groundwater is naturally non-saline, having a natural concentration of total dissolved solids that is less than or equal to 4000 milligrams per litre. Information on the Base of Groundwater Protection is available from the Alberta Geological Survey.

2.5.4 Background Groundwater Quality

The background concentration of a substance in groundwater is the natural concentration of that substance in a particular groundwater zone in the absence of any input from anthropogenic activities or sources. In some situations, the background concentration of some substances can be a significant proportion of, or even exceed the Tier 1 remediation guideline. Remediation of groundwater to below background conditions is not feasible and is not required. Accordingly, it is important to have a good understanding of background groundwater conditions at a site.

Background concentrations will be specific to the groundwater zone being considered, and will vary both spatially and temporally. To gain a good understanding of background conditions at a site it is necessary to consider groundwater quality data from several monitoring wells installed in the zone of interest, located up- or cross- gradient from any contaminant sources. The more time-series data that are available, the better the understanding of background conditions will be.

Care should be taken to distinguish between apparent background concentrations that are the result of diffuse anthropogenic sources, and true, natural background conditions. In comparing against background, emphasis should always be placed on ensuring that anthropogenic sources are not identified as natural background.

2.5.5 Relationship to Soil, Air and Surface Water

Environmental media are interconnected. Contaminants in soil may leach into pore water or groundwater. Volatile compounds in groundwater may volatilize at the water table and can migrate through the soil into the interior space of buildings above. Soluble contaminants in groundwater can be transported laterally with the groundwater flow, and potentially enter a surface water body (creek, slough, lake, etc.) at the point of groundwater discharge.

Alberta Tier 1 groundwater remediation guidelines are developed to protect indoor air quality, plants and soil invertebrates, and water quality for a range of uses. Guidelines to protect a particular water use are calculated based on the corresponding water quality guideline (drinking water, aquatic life, irrigation, or livestock or wildlife watering).

2.5.6 Points of Compliance

For the purpose of this document, a point of compliance is the spatial location in an aquifer at which a groundwater quality guideline must be achieved to protect human and ecological receptors, to protect a groundwater resource, or to meet other conditions such as industrial use or groundwater management guidelines.

At one extreme, the compliance point could be established at the point of exposure such as a drinking water well (human-ingestion) or a river (ecological-aquatic life). However, this would imply that there could be deterioration in the quality of the groundwater between the contaminant source and the receptor, which could be judged unacceptable in terms of legislative requirements and/or restriction of potential future use of a groundwater resource. At the other extreme, a precautionary approach could set the groundwater compliance point directly beneath the contaminant source. This is likely to result in a more stringent remedial target concentration and may be unnecessary, as certain exposure pathways may be irrelevant at that particular location, the contaminated groundwater may never reach a receptor, or contaminants may be significantly attenuated in groundwater prior to reaching the exposure point.

To address both conditions, some fundamental principles are used to guide decisions for setting groundwater remediation guidelines and compliance points on individual sites in Alberta.

A DUA, as defined in Section 2.5.2, is an important current and future groundwater resource and must be protected to the maximum extent possible. The compliance point for the human health water ingestion pathway is everywhere within a DUA.

Groundwater aquifers can be an important current or potential future agricultural groundwater resource used for livestock watering and irrigation. For livestock watering, the compliance point is everywhere within the relevant livestock watering aquifer existing below agricultural or other grazing land. For irrigation, the compliance point is everywhere within the irrigation-use aquifer, where applicable.

Ecological receptors must be protected at key exposure points. For aquatic life or wildlife receptors, the minimum point of compliance is at the point of groundwater discharge into a surface water body that is capable of supporting an aquatic ecosystem. Groundwater guidelines are calculated to achieve this. Therefore, the groundwater at all points of groundwater discharge immediately adjacent to the aquatic water body must meet the aquatic surface water quality guideline. For terrestrial receptors (plants and soil invertebrates), the point of compliance is everywhere within the shallow groundwater zone (i.e. the extent of groundwater less than 3 m below ground surface) and at the point of ground surface discharge.

3. ALBERTA FRAMEWORK FOR THE MANAGEMENT OF CONTAMINATED SITES

3.1 Implementation Framework and Management Levels

The general framework for the management of contaminated sites in Alberta has three options and is illustrated by the flowchart presented in Figure 2. A more detailed framework specific to site management under the Tier 1 approach is presented in Figure 3. A brief description of the framework is provided below; a detailed discussion of the management and technical aspects of the Tier 1 guidelines is presented in subsequent sections of the document.

Under the Alberta framework, three options are provided for the management of contaminated sites as the proponent proceeds from initial site assessment to regulatory closure. The three options are:

- Tier 1 - generic remediation guidelines.
- Tier 2 - site-specific remediation guidelines based on the modification of Tier 1 guidelines.
- Exposure Control - risk management through exposure barriers or administrative controls based on site-specific risk assessment.

Regardless of the option chosen, the target level of human health and ecological protection afforded by Tier 1, Tier 2, or Exposure Control is the same.

As discussed below, regulatory closure is available for sites managed to achieve Tier 1 and Tier 2 remediation guidelines. This means that no conditions are imposed on future use of the site, within a given land use. The three management options are briefly described in the following paragraphs:

Tier 1 – Generic Remediation Guidelines

Generic guidelines are based on identification of the receptors to be protected under various land uses, the applicable exposure pathways, and a corresponding set of parameters that allow reasonably conservative predictions of risk at sites throughout Alberta. Whenever possible, models that incorporate toxicity information, receptor characteristics, and fate and transport mechanisms are used to derive Tier 1 guidelines. Risk-based assessments have not been completed for fluoride, sulphur, antimony, beryllium, boron, cobalt, molybdenum, silver, and tin. The Tier 1 guidelines for these compounds are based on professional judgment. Other compounds have been evaluated for only a limited number of exposure pathways. Where site assessments identify the presence of other influential exposure pathways related to these substances, Tier 2 guidelines may need to be developed.

Tier 1 guidelines are expected to be applicable to the majority of contaminated sites in Alberta, although site managers may choose a Tier 2 approach to incorporate more site information in the development of remediation guidelines. There may be some situations where site conditions result in a *more* sensitive scenario than is captured by the conservative generic scenarios (e.g., a site underlain by very coarse sand and gravel with a high hydraulic conductivity). Information on situations where Tier 1 is not applicable is provided in Section 5.1.6. In such cases, a Tier 2 or Exposure Control approach will be required. Where the Tier 2 approach is required under section 5.1.6, it can be restricted to the specific pathway/receptor relationships that are in question. Even at sites that eventually use a Tier 2 or Exposure Control approach, Tier 1 guidelines are normally used for an initial screening as the first step in a phased site assessment.

The Tier 1 process comprises an initial site assessment and characterization followed by the selection of the applicable Tier 1 guidelines. If feasible and appropriate, remediation management to Tier 1 guidelines will be undertaken. When a proponent believes Tier 1 remediation management is not feasible and/or appropriate, the proponent may proceed to the Tier 2 process or, in some cases, to Exposure Control. The use of Tier 1 guidelines is described further in Section 5.

Tier 2 - Modified Generic Remediation Guidelines

There may be circumstances where site-specific conditions modify potential human and ecological exposure, relative to the generic conditions used to derive Tier 1 guidelines, such that the generic guidelines are unnecessarily conservative. Alternatively, site-specific conditions may increase risks to a level that renders a Tier 1 approach unacceptable. Accordingly, guidance is provided in the companion Tier 2 document (AENV, 2009a) on ways in which Tier 2 guidelines can be developed. The Tier 2 guidelines will normally be determined by screening out exposure pathways that are not present or by adjusting the Tier 1 models using site-specific values for certain parameters. In either case a more detailed site assessment will be required. Other approaches to calculating Tier 2 guidelines may be allowable, as long as they do not require any form of engineered, administrative, or other exposure control.

Sites where major adjustments to parameters or models are needed may require site-specific ecological risk assessment and/or human health risk assessment to develop appropriate remediation objectives. Quantitative risk assessment is a complex process with intensive data requirements. Complex risk assessments that do not require restrictions to the typical activities considered under a given land use and do not require ongoing risk management may be acceptable for regulatory closure under the Tier 2 process. However, these sites may have additional assessment, monitoring, and/or regulatory requirements that are beyond the scope of this guidance document.

Exposure Control - Risk Management

Exposure Control relies on ongoing risk management to control risks to human health and the environment. This management option is used for sites that require restrictions to the typical activities considered under a given land use or require ongoing risk management.

3.2 Land Use Definitions

For the purpose of developing and implementing soil and groundwater remediation guidelines in Alberta, five generic land uses have been defined – natural areas, agricultural, residential/ parkland, commercial and industrial. A generic land use scenario is envisioned for each category based on typical activities on these lands. The five land uses are defined for the purpose of this document only. Where allowable land uses, as defined by a given jurisdictional authority, differ from those noted here, an assessment of allowable receptors and potential exposure pathways must be made to ensure consistency with assumptions based on definitions here. Where a more sensitive receptor or exposure pathway is allowed, the more sensitive land use description must be used in selecting the appropriate Tier 1 guidelines. Assessors must determine the full range of uses allowed under the applicable zoning bylaw when determining the appropriate land use for Tier 1 application. For most sites in Alberta, one of the five generic land use scenarios should be applicable. If none of the generic land uses are applicable, a site-specific Tier 2 approach will be required. The five land uses are defined as follows:

Natural Areas

Natural areas are defined as being away from human habitation and activities, where the primary concern is the protection of ecological receptors. Accordingly, human exposure pathways are not considered, with the exception of the protection of groundwater for drinking water pathway that, based on the definition of a DUA (Section 2.5.2), applies in all land uses. Much of Alberta's forested land will fall into natural areas land use. Forested lands that are specified as grazing leases represent a special case that requires an amendment to the normal exposure scenario for natural areas. On such grazing leases, the livestock soil ingestion and protection of groundwater for livestock pathways must be addressed in addition to the regular pathways considered under natural areas land use. Natural areas land use must not be applied to areas that may reasonably be expected to be developed, such as those near municipalities and permanent dwellings.

Agricultural Lands

On agricultural land the primary land use is growing crops or tending livestock as well as human residence. This also includes agricultural lands that provide habitat for resident and transitory wildlife and native flora. To allow unrestricted future use of the land, a farm residence is assumed to be present anywhere on agricultural land.

Residential/Parkland

The primary activity on residential/parkland is residential or recreational activity. This land use includes campground areas and urban parks, but not wildlands in provincial parks, which are considered natural areas. Where urban parks are frequented by wildlife, wildlife exposure pathways should be addressed.

Commercial Land Use

On commercial land, the primary activity is commercial (e.g., shopping mall) and all members of the public, including children, have unrestricted access. Commercial land use includes day-care centres, buildings for religious services, hospitals, and medical centres. Commercial land does not include operations where food is grown directly in impacted soil on the site. Such operations would fall under agricultural land use.

Industrial Land Use

Industrial land is land where the primary activity is the production, manufacture or construction of goods. Public access is restricted and children are not permitted continuous access or occupancy.

3.3 Groundwater and Surface Water Use Definitions

Soils are hydrologically linked to groundwater and surface water systems. One of the objectives of Alberta's soil remediation guidelines is to manage soil-to-groundwater pathways to prevent unacceptable transfer of contaminants from the soil, which may ultimately affect groundwater and surface water use. Alberta's groundwater and surface water quality guidelines are representative of allowable chemical concentrations in groundwater or surface water at the point of compliance (see Section 2.5.6).

Alberta guidelines have been developed for four generic uses of groundwater or surface water affected by groundwater discharge:

- human consumption (potable water);
- aquatic life;
- livestock and wildlife watering; and,
- irrigation

These water uses are linked to land uses through the definitions of the generic land use categories. Other water use categories, for example recreation, as well as variations in water use within a defined land use category, may be addressed using the Tier 2 process.

3.4 Conditions and Restrictions Associated with Tier 2 and Exposure Control

The Alberta soil and groundwater remediation guidelines and implementation framework are intended to provide the same high level of protection of human health and the environment at all levels or tiers of site management. For Tier 1, this is ensured by the use of relatively conservative assumptions in the derivation of the risk-based numerical guidelines, such that the values can be applied to the large majority of sites within a land use category without condition or restriction. In other words, the normal activities associated with a particular land use are protected without the need for ongoing management of the site or of contaminants which may be present. Alberta Environment will provide regulatory closure for a site complying with the Tier 1 guidelines, unless site conditions are unsuitable for their application (see section 5.1.6).

Management under Tier 2 guidelines delivers the same level of health and environmental protection by incorporating site-specific data into the development of appropriate remediation guidelines. Sites remediated to Tier 2 guidelines are eligible for regulatory closure.

Certain types of site-specific data or assumptions dictate the need for ongoing site management to ensure that the assumptions used to assess human and ecological risks or to develop site-specific objectives remain valid. Ongoing management of a site, or of the contaminants present, will generally invoke a land use restriction or condition that will preclude regulatory closure. Therefore site-specific adjustments or assumptions that would trigger ongoing management requirements can only be implemented under the Exposure Control option.

To avoid the need for ongoing management and, hence, possible conditions and land use restrictions, Tier 2 adjustments are usually limited to parameters that are measurable and stable, such as soil properties, geological conditions, hydrogeology and distances to natural surface water bodies. Tier 2 assessments that involve full site-specific risk assessment using models and assumptions that may differ from those used in the calculation of the Tier 1 guidelines may be accepted provided they do not require any form of ongoing risk management. Parameters that are unique to current site use, an existing development or the location of a receptor, such as the characteristics of a site building or the distance to a water well, may change in the future thereby invalidating the site-specific assumptions. Adjustments of such parameters are not allowed at Tier 2. In some cases exposure pathways may be inoperative under a particular site use (e.g. direct human or ecological contact with contaminated soil at a commercial site that is paved or capped) or the frequency of exposure may differ from the generic assumptions. Preservation of these conditions would require ongoing management; therefore these adjustments cannot be made at Tier 2. Further guidance on parameters and assumptions eligible for adjustment at Tier 2 is provided in the companion Tier 2 document (AENV, 2009a).

4. SCIENTIFIC BASIS FOR DEVELOPING TIER 1 REMEDIATION GUIDELINES

4.1 Risk-Based Guidelines

Risk-based guidelines are developed with the understanding that for risk from chemical contamination to exist, all of the following elements must be present:

- the substance must possess toxic properties;
- the substance must be present in the environmental medium of concern (soil or groundwater);
- a receptor must be present (human, livestock, crop, or ecological receptor); and,
- there must be an exposure pathway through which the substance can reach the receptor and be taken in to the receptor's body.

Risk-based guidelines are then calculated by first determining the amount (dose or concentration) of substance to which a receptor can be safely exposed. Next, for each exposure pathway, a conservative estimate is made of a concentration of the substance in soil or groundwater that will protect the receptor from exposure exceeding the safe amount. These substance concentrations are referred to as risk-based guidelines and represent remediation objectives for the protection of human and ecological health on contaminated sites.

4.1.1 Steps in the Development of Tier 1 Risk-Based Guidelines

The steps in the development of the risk-based guidelines in Tables 1, 2 and 3 are as follows.

1. Identification of the potential receptors and the potential exposure pathways through which contaminants can come into contact with receptors (e.g., humans or ecological receptors such as livestock, crops, and wildlife).
2. Identification of appropriate protection endpoints for each exposure pathway/receptor combination.
3. Calculation of a substance concentration in soil and/or groundwater (guideline) for each exposure pathway that offers a safe level of protection.
4. Determination of an overall Tier 1 risk-based guideline for soil and/or groundwater by selecting the lowest of the guidelines calculated for all relevant exposure pathways.

The remainder of Section 4 describes how these four steps were implemented in the development of the Tier 1 soil and groundwater remediation guidelines. The details of the calculations used in Step 3 are provided in Appendix C.

4.2 Protection of Human Health

4.2.1 Human Receptors and Exposure Pathways

In establishing appropriate risk-based guidelines, the most sensitive user of a contaminated site must be considered and protected. The most sensitive receptor is normally a function of the degree of potential exposure, the exposure pathway(s) and the substance(s) of concern. For the application of Tier 1 and Tier 2 guidelines, the land use and contaminant characteristics will dictate the critical receptor. When developing Tier 1 and Tier 2 guidelines, people of all ages are assumed to be present on agricultural, residential/parkland and commercial land. At industrial sites, only employees are assumed to be routinely present, which precludes the exposure of children. Human receptors are assumed to be absent in natural areas, although underlying groundwater is considered to be a potential source of drinking water.

The following human exposure pathways are considered when developing and implementing Tier 1 and Tier 2 remediation guidelines (based on CCME, 2006). The exposure pathways are applicable to all land uses, except where noted below.

Direct Contact

Humans coming into direct contact with contaminated soil via incidental ingestion, dermal contact, or inhalation of air-born soil particles. Applicable to all land uses except natural areas.

Drinking Water

Humans drinking from and showering or bathing in water that is sourced from groundwater. Applicable to all land uses.

Inhalation

Volatile contaminants being released from soil and/or groundwater and migrating upwards into living or working spaces where humans are exposed via inhalation. Applicable to all land uses except natural areas.

Off-Site Surface Migration by Wind or Water Erosion

The soil quality guideline for commercial and industrial land use may be greater than the corresponding guideline for more sensitive land uses. Wind or water transport of contaminated soil from a commercial or industrial site onto an adjacent site with a more sensitive land use could potentially result in contaminant concentrations that exceed the human direct contact soil quality guideline applicable to the more sensitive land use. The off-site migration check is calculated to ensure that the commercial or industrial guidelines set are protective of this exposure pathway.

4.2.2 Human Health Protection Endpoints

The human health protection endpoint is the same at all tiers of management, and is expressed in terms of an allowable exposure level at which the likelihood of a receptor experiencing adverse health effects is essentially negligible. Specifically, the level of human exposure to a threshold chemical (i.e., non-carcinogen) must not exceed the tolerable daily intake specified by Health Canada or other appropriate regulatory agency, including background exposure to the chemical. For a non-threshold chemical (i.e., carcinogen), the incremental lifetime cancer risk must not exceed 1 in 100,000 (1×10^{-5}), the value considered by Health Canada to be essentially negligible (Health Canada, 2004).

4.3 Ecological Protection

4.3.1 Ecological Receptors and Exposure Pathways

Risk-based guidelines fulfill two main goals from the ecological standpoint: protection of ecological receptors expected to be present at a site based on land use, and preservation of an appropriate level of ecological function of the site and its ecosystem components.

Ecological receptors at a typical contaminated site, within the range of generic land uses considered in the development of the Alberta guidelines, span a range of trophic levels including soil-dependent organisms (plants, including crops, and soil invertebrates) and higher order consumers (terrestrial and avian wildlife and livestock). In addition, based on the potential for groundwater underlying a site to discharge to a surface water body that is capable of supporting an aquatic ecosystem, aquatic receptors including invertebrates, fish, and aquatic plants are considered. Receptors assigned to each land use for the purpose of guideline derivation must be both ecologically relevant to a site and sufficiently sensitive to be representative of the range of receptors normally present. In addition to the protection of ecological receptors *per se*, ecologically based guidelines must be protective of other processes such as nutrient cycling and related microbial activities.

The following ecological exposure pathways are considered in the determination and implementation of Tier 1 remediation guidelines where appropriate to the defined land uses (based on CCME, 2006).

Direct Contact

Plants and soil invertebrates coming into direct contact with contaminants in soil or shallow groundwater. Direct contact is applicable to all land uses. This pathway may be eliminated below 3 m for petroleum hydrocarbon fractions 1 to 4 only.

Nutrient and Energy Cycling

This exposure pathway examines the microbial functioning of the soil, including carbon and nitrogen cycling. Applicable to all land uses.

Livestock/Wildlife Soil and Food Ingestion

Livestock or wildlife ingesting contaminants via the incidental ingestion of soil and ingesting contaminants that have bioaccumulated from soil into fodder. Applicable to agricultural and natural area land use only.

Aquatic Life

Aquatic life, including fish, aquatic invertebrates and aquatic plants, being exposed to contaminants when groundwater discharges to a surface water body that is capable of supporting an aquatic ecosystem. Applicable to all land uses.

Irrigation

Crops being exposed to contaminants when groundwater is used for irrigation. Applicable to agricultural land use only.

Livestock/Wildlife Watering

Livestock or wildlife being exposed to contaminants when groundwater is used for livestock watering, or groundwater discharges to a surface water body where wildlife may drink. Applicable to agricultural and natural area land use only.

4.4 Calculation of Guidelines

Soil remediation guidelines were calculated for each land use and soil texture using models consistent with the latest CCME (2006) protocols. In some cases, more recent deliberations of the Sub-Groups supporting the 2007 revision of the Petroleum Hydrocarbon Canada-Wide Standard (PHC CWS; CCME, 2008) have resulted in revisions to parameter values, and these revisions have been adopted in the current document. Parameter values were adapted for Alberta conditions and policies where appropriate. Groundwater remediation guidelines were calculated for each water use by adapting the models from the soil remediation guideline calculations, as appropriate. Details of all models and parameters used are provided in Appendix C.

4.5 Determination of Overall Guideline

Tier 1 guidelines are intended to be a conservative screening tool. The lowest of the guidelines (tabulated in Appendix A and B) calculated for applicable exposure pathways and the appropriate land use and soil texture is the overall Tier 1 remediation guideline (Tables 1, 2, and 3). At some sites, it may be possible to demonstrate that certain exposure pathway(s) are not relevant, and exclude the corresponding objective for those pathway(s) using a Tier 2 approach. Conditions for excluding particular exposure pathways are provided in the companion document describing Tier 2 procedures (AENV, 2009a).

4.6 Integration of New and Existing Guidelines

New risk-based guidelines were calculated for a wide range of organic compounds in this document using the latest CCME (2006) protocols (in some cases modified based on the 2007 revisions to the PHC CWS) and adapted for Alberta conditions and policies (Tables 1, 2, and 3). Guidelines were not recalculated for inorganic compounds, except arsenic; existing risk-based guidelines were retained from Canadian Environmental Quality Guidelines (CCME, 1999 and updates). Existing guidelines for the soil ecological contact pathway and the soil and food ingestion pathway were also retained where they existed, or were recalculated in the case of soil ingestion guidelines for certain hydrocarbons. Soil remediation guidelines based on professional judgment were retained from previous guideline documents for antimony, beryllium, boron, cobalt, fluoride, molybdenum, silver, elemental sulphur, and tin because risk-based Alberta Tier 1 guidelines have not yet been developed for these substances. Guidelines for these substances were adopted from the *Alberta Tier 1 Criteria for Contaminated Soil Assessment and Remediation* (AEP, 1994) for natural areas, agricultural, and residential/parkland land uses. For commercial and industrial land uses, and for all uses if the substance was not included in AEP (1994), guidelines were adopted from the *Interim Canadian Environmental Quality Criteria for Contaminated Sites* (CCME, 1991). Soil remediation guidelines for electrical conductivity and sodium adsorption ratio (Table 4) were adopted from the *Salt Contamination Assessment and Remediation Guidelines* (AENV 2001c).

5. USER GUIDANCE FOR TIER 1 MANAGEMENT

The process for implementing the Alberta Tier 1 soil and groundwater remediation guidelines is illustrated schematically by the flow diagrams presented in Figures 2 and 3. Detailed guidance for Tier 2 is provided in a companion document (AENV, 2009a) and is summarized herein.

As illustrated in Figures 2 and 3, Tier 1 management is divided into three stages: assessment, evaluation, and decision/management. These three stages are discussed in the following sections.

5.1 Information Requirements for Tier 1 (Tier 1 Assessment)

5.1.1 Overview of Requirements

A preliminary site characterization is required for all Tier 1 assessments. Site characterization must be comprehensive enough to adequately describe site conditions and address all assessment and management options within the scope of Tier 1.

The Tier 1 assessment may be more comprehensive and detailed, at the discretion of the proponent, providing additional information for potential use in developing Tier 2 guidelines. While there are advantages associated with a phased approach to site assessment, there may also be economies in combining data collection activities into a single investigation, particularly at locations where mobilization and demobilization costs are significant.

The minimum data requirements for a Tier 1 site assessment include:

Land Use and Sensitivity Factors

- site description;
- land use, including the full range of uses allowed under the applicable zoning bylaw;
- proximity of the site to surface water and drinking water supplies;
- actual and potential uses of groundwater;
- human receptors; and,
- ecological receptors.

Physical Conditions

- soil particle size;
- stratigraphy and properties of surficial materials;
- depth to groundwater; and,
- presence and types of buildings and other structures.

Contaminant Characteristics and Distribution

- contamination characterization; and,
- horizontal and vertical extent of contamination.

The above information is generally required at all tiers, to a level of detail appropriate for the requirements of the evaluation and decision stages of each tier.

5.1.2 Land Use and Sensitivity Factors

One of the objectives of the Tier 1 site assessment is to determine whether the site broadly fits any of the five generic land use categories. In this regard, the minimum data requirements for a Tier 1 assessment are as follows:

Site Description

The site description must include basic identifying data such as location and legal description, site dimensions, registered owner(s) etc., as well as a description of the physical surface expression of the site (surface topography), vegetative cover, nature of site development and, where applicable, site history.

Land Use

In determining land use, consideration must be given not only to present land use but also to historic and potential future land uses. Land use on private land is normally prescribed by the current and/or future zoning of the land and local development trends. Land use for public land is determined by the land manager who will use resource based input and tools such as land reservations and integrated plans as guidance. Attention must be given to all uses allowed under the applicable zoning bylaws and land use decisions.

Sufficient descriptive and legal or administrative information must be obtained to determine the generic land use category (natural areas, agricultural, residential/parkland, commercial, industrial) and whether the land use may be considered typical for the assigned category. The five generic land uses are defined and described in Section 3.2.

Land uses of adjacent or nearby properties must also be documented, as the presence of more sensitive off-site land uses may drive the site management requirements. Where a contaminated site on a less sensitive land use borders, or lies within 30m, of a more sensitive land use, the vapour inhalation guidelines (soil and groundwater) and the groundwater direct ecological contact guidelines for the more sensitive land use must be applied to the contaminated site within 30 m of the more sensitive land use boundary (see Figure 1).

Proximity of Site to Surface Water and Drinking Water Supplies

The assessment must document all existing and potential uses of groundwater and surface water, including their locations. The distance beyond which water uses are not significant or relevant depends on site-specific conditions but, as a minimum for Tier 1, water uses within 300 m should be identified. If the direction of groundwater flow has been reliably determined by site-specific groundwater monitoring, documentation of water uses can be limited to 100 m upgradient and 300 m down gradient of the site. Flood risk areas should be taken into account when considering distance to surface water receptors. For more information see the companion Tier 2 document (AENV, 2009a).

The distance of 300 m was selected as being greater than the length of the majority of groundwater plumes of dissolved petroleum hydrocarbon. This value is based on studies of hydrocarbon plumes in the upstream oil and gas industry in western Canada undertaken by the Consortium of Research on Natural Attenuation (CAPP, 2002). The value of 300 m is also consistent with a compilation of 647 petroleum hydrocarbon plumes presented in Wiedemeier *et al.* (1999), in which it was determined that 98.1% of the plumes were less than 900 feet (274 m) long.

Water uses at greater distances must be considered on a case-by-case basis when subsurface conditions are such that adverse impact may be possible. For example, plumes of conservative soluble compounds that do not interact with the soil matrix, such as chloride, may travel farther than dissolved hydrocarbons (CAPP, 2002). Municipal water supply wells located more than 300 m from a site might be expected to be at risk from a contaminant source located anywhere within the zone of capture of the wells.

The assessment must recognize that, while the locations of most natural surface water bodies are essentially fixed, seasonal water bodies may exist at other locations, and anthropogenic groundwater uses could be initiated at any location relative to the site, in areas of usable groundwater.

Human and Ecological Receptors

In general, the presence of human receptors will be directly related to the land uses. However, sufficient information must be obtained to determine whether the land use is typical of the respective category, or whether receptors are present that would warrant a variation from the defined generic land use categories.

5.1.3 Physical Conditions

Certain physical conditions and parameters must be determined to permit the implementation of Tier 1 management. The minimum physical data requirements are discussed below.

Soil Particle Size

As a minimum, since Tier 1 guidelines are prescribed for coarse-grained and fine-grained soils, sufficient particle size information should be obtained to permit classification of the soils as either coarse or fine. Fine-grained soils are defined as having a median grain size of less than or equal to 75 µm; coarse-grained soils have a median grain size of greater than 75 µm. The absence of sufficient particle size information will result in the default application of the more conservative Tier 1 guideline for each substance. Where both fine and coarse grained strata are present, the dominant soil particle size is determined by the stratum governing horizontal and vertical migration to a receptor.

Soil Stratigraphy and Physical Properties

Information on soil stratigraphy and physical properties is normally obtained by means of an intrusive subsurface investigation, although preliminary, qualitative information can often be obtained from other sources including published surficial geological information or the results of other subsurface investigations conducted in the area. In certain circumstances, it may be possible to apply the Tier 1 guidelines without a prior subsurface investigation. For example, the decision could be made to manage a spill of limited extent by removing all materials containing contaminant concentrations in excess of Tier 1 guidelines. Confirmation of the degree and extent of impact, as well as the subsurface conditions, could be obtained at the time of soil excavation. However, subsurface investigations are commonly conducted to support the application of Tier 1 guidelines, in part for the purpose of contaminant characterization and site management planning.

The Tier 1 assessment must provide an overall description of the subsurface soil conditions and their vertical and lateral variability. Of particular importance is the uniformity of the soil particle size and the presence of any depositional or structural features, such as lenses or fissures, that could influence the fate and transport of certain chemicals in the subsurface. Where there are multiple geological deposits falling into both the coarse and fine definition such that the particle size dominating transport cannot be determined, the Tier 1 guidelines must default to the most stringent option.

Hydrogeological Conditions

A hydrogeological investigation will normally form part of any subsurface investigation. Although soil guidelines have been developed to protect groundwater for various uses, care must be taken in using them to assess risk to groundwater at contaminated sites. Soils are heterogeneous. Variations in contaminant concentration and soil lithology and the presence of preferential flow paths can result in contaminants reaching groundwater even when general soil conditions appear not to pose a risk. It is also possible that mobile substances have leached out of the vadose zone into groundwater if sufficient time has elapsed since the release event. Alberta Environment strongly recommends that groundwater quality be investigated when contaminant concentrations in soil are close to the groundwater protection guidelines. The cost of installing groundwater monitoring wells can be minimized if they are installed when soil boreholes are drilled.

Information must be collected on depth to groundwater table, groundwater flow direction, hydraulic gradient and, with the appropriate field tests, hydraulic conductivity. While all of these parameters are influential, their quantitative determination is not required for the basic implementation of Tier 1, and qualitative information may be available from other sources. However, as with soil parameters, they can facilitate the decision between managing to Tier 1 guidelines or developing Tier 2 remediation guidelines or Exposure Control options.

For some substances, groundwater chemical characteristics are required for the development of a groundwater guideline. Where this applies, Table 2 references the

Surface Water Quality Guidelines for Use in Alberta (AENV, 1999) for further information on the chemical data required.

Buildings and Other Structures

When volatile substances are present, the site assessment must identify presence of buildings. When a building is not present, but the municipal zoning allows one to be built, its presence must be assumed. Site assessments must also consider the presence of structures, such as utility corridors and dirt basements, that may require a Tier 2 approach.

5.1.4 Contaminant Characteristics and Distribution

Requirements for site characterization to address all aspects for regulatory requirements or to characterize contaminants that are not included in the Tier 1 guideline process are beyond the scope of this document. It is the responsibility of the proponent to ensure that sufficient site characterization is carried out to address relevant regulatory requirements and to address any potential contaminants of concern not included in the Tier 1 soil and groundwater remediation guidelines. However, for the purposes of applying the Tier 1 guideline tables, the following general guidance can be given.

Sufficient characterization of the contamination must be conducted for the purpose of comparing contaminant concentrations with Tier 1 guidelines. This will normally comprise the collection and laboratory analysis of sufficient soil or groundwater samples to determine representative concentrations. As part of the Tier 1 assessment, the proponent must conduct sufficient sampling to delineate the lateral and vertical extent of impacted soil and groundwater (Fig. 3). An exception is allowed where the contaminated soil is completely removed and confirmatory samples show compliance with Tier 1 guidelines. When confirmatory samples fail to comply with Tier 1 guidelines after excavation is deemed complete, full delineation of the remaining contamination must be undertaken and used to develop further remediation actions or risk management programs. Whether delineating contamination or confirming remediation success, the data collected must be sufficient to support regulatory closure.

5.1.5 Conditions Where Additional Exposure Pathways May Be Applicable

There may be conditions where certain exposure pathways are applicable that would not normally be considered under a given land use. An example of this is a grazing lease within a natural area. In the case of such grazing leases, the livestock soil and food ingestion and protection of groundwater for livestock watering pathways apply in addition to the regular exposure pathways considered for that land use. Adding additional pathways to those typically considered for a land use may be done under the Tier 1 approach, provided no additional site information is needed for the additional pathway. Note that *removing* pathways that may not be applicable for a given land use from the pathways specified for the Tier 1 guidelines is *not* permitted, and may only be done under the Tier 2 approach.

5.1.6 Conditions Where Tier 1 Guidelines Are Not Applicable

Tier 1 guidelines are derived using relatively conservative default parameters and assumptions corresponding to the defined generic exposure scenarios and land use categories. As such, they are intended and expected to be protective of human health and the environment in the large majority of cases. However, there may be situations in which Tier 1 guidelines are not applicable, either where conditions violate one or more assumptions essential to the validity of the modelling used in the Tier 1 derivation, or where actual exposure conditions or receptors at a site are more sensitive than in the generic exposure scenario.

Some examples of situations where Tier 1 guidelines are not applicable are highlighted below. These situations must be addressed through the Tier 2 process. The companion Tier 2 document (AENV, 2009a) should be consulted for further details.

Source of Volatile Contaminants Present Within 30 cm of a Building Foundation

Within this distance, the model used to assess vapour intrusion to buildings is not reliable, and Tier 1 guidelines are not applicable.

Unusual Structural Features

Building features such as earthen floors or unusually low air exchange rates are not considered in the Tier 1 model, and a Tier 2 approach is required. Where very coarse textured materials (see below) are found within utility corridors that are controlling contaminant migration, a Tier 2 approach is required.

Groundwater Flow to Stagnant Water Bodies

Additional consideration is required if groundwater at a site has the potential to discharge to a stagnant water body. A stagnant water body is defined as a water body without significant outflow, and where the main pathway of water loss is via evaporation. Stagnant water bodies will tend to concentrate discharging persistent groundwater contaminants through evaporation. Water bodies with no obvious or known outflow should be considered stagnant. If outflow is suspected via groundwater and no obvious surface outflow is present, a groundwater investigation will be needed to provide confirmation.

In the assessment of whether soil or groundwater contaminants are likely to have an adverse effect on a stagnant surface water body, the current concentrations of contaminants in groundwater are less important than the long-term effect on contaminant concentrations in the stagnant water body. Accordingly, when there is the potential for a contaminant in groundwater to discharge to a stagnant surface water body, a Tier 2 mass balance assessment of the likely concentrations of that contaminant in the stagnant water body over the anticipated lifetime of the groundwater discharge is required. The assessment should take into consideration, in a qualitative sense, the likelihood of other potential future contaminant releases to the stagnant surface water body. Unless the effect on contaminant concentrations in the stagnant surface water body can be shown to be insignificant, remedial action will be required.

Groundwater Within 10 m of a Surface Water Body

Tier 1 soil and groundwater remediation guidelines for the protection of aquatic life assume a minimum separation of 10 m between the point that the soil or groundwater concentration is measured, and the discharge point. Accordingly, Tier 1 guidelines only apply to soil or groundwater located at least 10 m from the nearest surface water body that is capable of supporting an aquatic ecosystem. Within this distance, a Tier 2 approach is required, or in the case of groundwater guidelines, the corresponding surface water freshwater aquatic life guideline may be applied directly to groundwater quality. The 10 m offset distance must take into account potential for seasonal fluctuations in the water level. This may require information on the flood risk area. For more information, see the companion Tier 2 document (AENV, 2009a).

Very Coarse Textured Materials Enhancing Groundwater or Vapour Transport

Groundwater velocity is a function of both hydraulic conductivity and hydraulic gradient and assumed to be $1x10^{-5}$ m/s and 0.028 m/m, respectively, for Tier 1 guideline derivation. The resulting Darcy groundwater velocity is 3×10^{-7} m/s.

The rate of vapour transport through coarse soil is largely governed by vapour permeability which is assumed to be $6x10^{-8}$ cm^2 for Tier 1 guideline derivation.

If the Darcy groundwater velocity exceeds $3x10^{-7}$ m/s, or vapour permeability is greater than $6x10^{-8}$ cm^2 at a site, a Tier 2 approach is required. In these cases, the Tier 2 guideline must incorporate groundwater or vapour inhalation as potentially dominant exposure pathway(s).

Fractured Bedrock

The Tier 1 remediation guidelines were developed for unconsolidated soil material, therefore the presence of bedrock may require a Tier 2 re-evaluation. However, the guidelines may be applied to contaminants in contact with bedrock if the bedrock is likely to behave conservatively as one of the two soil textures. The actual texture of the bedrock material will often be less influential on contaminant movement than the degree of bedrock weathering and fracturing. Professional judgment must be applied in determining whether coarse or fine soil guidelines are the most appropriate, given the expected contaminant mobility within the bedrock. For instance, a weathered shale material may not automatically require a Tier 2 re-evaluation but it may require use of a coarse soil guideline due to the presence of minor fractures within the matrix.

Tier 2 re-evaluation is required where flow paths in the fractured bedrock cannot reasonably be expected to behave similarly to those in an aggregated soil medium. When the fracture length exceeds approximately 2 cm, flow paths in the fractured bedrock may be different than those in an aggregated soil medium. Under such conditions, groundwater transport in fractured bedrock is outside the scope of the calculations for Tier 1 guidelines and a Tier 2 or Exposure Control approach must be taken.

Source Length Greater than 10 m

The model used to develop Tier 1 guidelines for groundwater remediation and protection assumes a source of groundwater contamination that is 3m deep and 10m wide with a length of 10 m parallel to the direction of groundwater flow. Sources are discussed in Section 2.3.1 and include anything that adds contaminant mass to the environment. For the purposes of the groundwater transport model used to develop Tier 1 guidelines, the source length is relevant to sources that are releasing contaminants to groundwater. Source length is determined by soil concentrations that exceed soil guidelines for the protection of groundwater pathways (see Appendix A). When the length of such a source is greater than 10 m parallel to the direction of groundwater flow, Tier 1 guidelines may be applied to the site if contaminant delineation shows that the source volume is less than 300 m^3. Alternatively, if source and site characteristics indicate no potential for groundwater contamination and remediation of the site to Tier 1 guidelines will result in a source length less than 10 m or volume less than 300 m^3, then remediation to Tier 1 objectives may proceed. In all other cases a Tier 2 approach is required. When the contaminated soil is not in contact with the seasonally high saturated zone, a Tier 2 guideline adjustment (AENV 2009a, Part B, Section 3) provides the assessor with an approach for estimating contaminant attenuation between the contaminated zone and the saturated zone.

Organic Soils

When inorganic contaminants occur in organic soils, a Tier 2 approach is required. Organic soils are defined in *The Canadian System of Soil Classification* (Soil Classification Working Group, 1998). Coarse textured soil and groundwater remediation guidelines may be used for organic contaminants in organic soil.

5.2 Identification of Appropriate Tier 1 Guidelines (Tier 1 Evaluation)

5.2.1 Land Use and Water Use Conditions and Primary Soil Type

Land use and water use conditions are established on the basis of the information compiled for the Tier 1 assessment. Land use conditions are compared with the descriptions of the generic land use categories (natural area, agricultural, residential/parkland, commercial, industrial) to assign the site to the most sensitive applicable category. In some instances municipalities or public land managers may allow a range of uses in accordance with zoning bylaws and other land use decisions. These uses must be evaluated with respect to the five land uses described for Tier 1 guidelines. The most sensitive land use will determine Tier 1 guidelines.

Groundwater and surface water use conditions are assigned, if applicable, to one or more of the generic categories of potable water, surface water that is sustaining an aquatic ecosystem, water used for livestock or wildlife watering, and irrigation.

Exceptions to the above categories are discussed in the following section.

5.2.2 Conformity with Generic Land and Water Use Categories

The principal criterion for the application of the Tier 1 guidelines is conformity with the generic land and water use scenarios and exposure conditions assumed in the development of the Tier 1 guidelines, and discussed in Section 3 of this document. It is the responsibility of the proponent to identify and respond to any site or receptor factors that could unduly accentuate exposure or risk beyond that envisioned in the Tier 1 exposure scenarios and, where necessary, move to the Tier 2 approach.

First, the land and water use must normally be encompassed by one or more of the defined generic categories. Examples of land uses not addressed in the development of the Tier 1 guidelines include wetlands and riparian zones. Examples of water uses not directly addressed by Tier 1 include: water used in the food processing industry (although this may be represented by the potable water scenario); and surface water used for swimming or similar recreational activity. In the absence of an applicable Tier 1 standard for the actual land or water use, a Tier 2 approach must be followed.

Second, the exposure conditions associated with the identified land and water use must not be more sensitive or critical than those assumed in the determination of the Tier 1 guidelines. Examples of factors giving rise to greater sensitivity are: a greater frequency or intensity of human or ecological exposure beyond that associated with typical use of the land or water; or, variations in physical site conditions resulting in greater exposure than that assumed (discussed in Section 5.1.6). The human and ecological exposure factors and physical parameters used for the Tier 1 guidelines are presented in Appendix C. These values should be used as the basis for assessing whether site-specific factors are indicative of more frequent or intense exposure.

Ingestion of produce, milk, and meat produced on the site is not included in Tier 1 human exposure estimates because of its site-specific nature. Where a significant portion of an individual's diet is obtained from areas contaminated by substances that bioconcentrate, this exposure pathway must be evaluated with the Tier 2 approach.

5.2.3 Identification of Applicable Tier 1 Guidelines

Tier 1 guidelines for soil and groundwater are presented in Tables 1 through 4. Guidelines in Tables 1 through 3 are presented for coarse-grained and fine-grained soils; selection of the appropriate set of values is based on the texture of the dominant soil type as determined in the Tier 1 assessment. The dominant soil type is that which governs fate and transport via the various transport and exposure pathways. For example, a continuous layer of coarse-grained soil beneath the water table will often govern groundwater flow in the saturated zone, even though its thickness may be small in relation to the total thickness of saturated fine-grained soils. Similarly, a thin layer of fine-grained soil in the unsaturated zone may be a more significant control on the migration of vapours than a thicker layer of coarse-grained soil. Professional judgment should be exercised in establishing the dominant soil type.

The use of subsoil guidelines for petroleum hydrocarbons (Table 3) and salinity (Table 4) may be used at Tier 1 under the following circumstances:

Petroleum Hydrocarbons

Surface soil guidelines for petroleum hydrocarbon fractions F1 to F4, benzene, toluene, ethylbenzene, and xylenes must be applied to a depth of 1.5 m. Subsurface guidelines may be used as follows:

- below 1.5 m in depth within a 5 m setback from an oilfield wellhead (see Municipal Affairs and Housing Advisory Land Use Planning Notes on Abandoned Wellsites) , or
- below 3 m in depth at any site.

Exclusion of the soil and groundwater direct ecological contact pathway is permissible under the Tier 1 approach at any site below a depth of 3 m for petroleum hydrocarbon fractions F1 to F4 only.

Salinity

Topsoil guidelines for electrical conductivity and sodium adsorption ratio must be applied to the L, F, H, O, and A horizons (Soil Classification Working Group, 1998) or equivalent surficial material where these horizons are not present. Subsoil guidelines may be applied below the A horizon or equivalent in lieu of topsoil guidelines. Further information is available in the *Salt Contamination Assessment and Remediation Guidelines* (AENV, 2001c).

For each contaminant, the lowest guideline tabulated in Appendix A and B for the established soil type and identified land use defines the governing exposure pathway/receptor and, hence, becomes the governing Tier 1 guideline. At Tier 1, all exposure pathways for which generic guidelines have been calculated must be considered. If the governing guideline is based on a soil to groundwater or surface water pathway that is not applicable to the site, based on the prior identification of water uses, a Tier 2 approach may be possible, and the companion Tier 2 document (AENV, 2009a) should be consulted.

5.2.4 Additional Guidance for Specific Substances

Salinity

Electrical conductivity (EC) and sodium adsorption ratio (SAR) guidelines are found in Table 4 for topsoil and subsoil. At Tier 1, the objective for salt contaminated site remediation is to return the site to the same rating category as non-contaminated soils of the same type. To apply the guidelines, background samples are needed from uncontaminated soils that are representative of the same type, depth, and landscape position as the contaminated soil on the site. The background samples are used to establish the appropriate rating categories for the site. The range of EC and SAR values for the appropriate rating categories become the remediation objectives for the site.

Further guidance is provided in the *Salt Contamination Assessment and Remediation Guidelines* (AENV, 2001c).

Barite-Barium

Guidelines are provided for both barium (non-barite) and barite-barium. The barium guidelines are intended to apply to all barium sources, and therefore assume that the source is relatively soluble. Barite, a commonly used weighting agent in drilling fluids, is relatively insoluble and therefore guidelines have been developed specifically for this form of barium. To confirm that barium measured in soil samples meets the conditions of low solubility assumed for the barite-barium guidelines, the sample must pass a $CaCl_2$ extraction test. True total barium concentrations from samples that pass the $CaCl_2$ extraction test may be compared to the barite-barium guidelines. True total barium must be measured by fusion-XRF or fusion-ICP methods. Further information on applying the barite-barium guidelines, including the $CaCl_2$ test, is provided in *Soil Remediation Guidelines for Barite: Environmental and Human Health* (AENV, 2009b).

Elemental Sulphur

Tier 1 soil remediation guidelines are provided for elemental sulphur. If these values are exceeded, management options include the application of calcium carbonate to control the acidity generated by the oxidation of elemental sulphur. Elemental sulphur can be managed in this way up to a total sulphur concentration of 4%. Further guidance is provided in *Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes* (AEP, 1996).

Drilling Waste Disposal Areas

Drilling waste disposal falls under the jurisdiction of the Energy Resources Conservation Board. Management and disposal options are provided by Directive 50 (ERCB, 1996). Alberta Environment has developed D50 Equivalent Salinity Guidelines for assessing and remediating drilling waste disposal areas for reclamation certification. Further information is provided in *Assessing Drilling Waste Disposal Areas: Compliance Options for Reclamation Certification* (AENV, 2009c).

Polycyclic Aromatic Hydrocarbons (PAH)

Non-carcinogenic PAHs (naphthalene, acenapthene, fluorene, fluoranthene, anthracene, pyrene) have been included as components of petroleum hydrocarbon Fractions 1 to 4. When the sources of hydrocarbon contamination are crude petroleum or refined fuels, separate analysis of non-carcinogenic PAHs is not necessary. Analysis of these PAHs is necessary when dealing with non-petroleum hydrocarbons such as creosote or products such as solvents where individual compounds may be present at a much greater concentration than in crude products or fuels.

5.3 Tier 1 Decision and Management

The Tier 1 decision process is illustrated schematically by the lower part of the flow diagram presented in Figure 3. The process consists of a number of decision nodes. The decision process and criteria at each node are discussed in the following paragraphs.

5.3.1 Comparison of Conditions with Identified Tier 1 Guidelines

If no exceedances are found in the Tier 1 assessment, relative to the identified Tier 1 guidelines, any sources have been removed, and site conditions are consistent with application of Tier 1 process (see Section 5.1), the site can be considered to be in compliance with Tier 1 and no further action is necessary.

If exceedances are found, the proponent enters a decision process whereby the option of managing to Tier 1 guidelines is weighed against the option of proceeding to the Tier 2 approaches. If site conditions preclude application of Tier 1 guidelines (see Section 5.1.6) then the proponent must use the Tier 2 process.

Verification of remediation to Tier 1 or Tier 2 guidelines can achieve regulatory closure.

5.3.2 Assessment of Opportunity for Tier 2

If the default assumptions used in the derivation of the governing Tier 1 guidelines are conservative relative to actual site-specific conditions, the replacement of default assumptions with site-specific data for certain influential parameters may permit the development and implementation of less stringent remediation guidelines without compromising health and environmental protection goals. Furthermore, point-of-exposure measurements, if less than those predicted using the relatively conservative modeling procedures employed to derive the Tier 1 guidelines, may also permit the implementation of less stringent guidelines. In such cases, proceeding to Tier 2 would generally be advantageous, and the companion Tier 2 document (AENV, 2009a) should be consulted.

6. REFERENCES

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TABLES

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Soil Type	Fine					Coarse					Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	
General and Inorganic Parameters											
pH (in 0.01M $CaCl_2$)	6-8.5	6-8.5	6-8.5	6-8.5	6-8.5	6-8.5	6-8.5	6-8.5	6-8.5	6-8.5	1
Cyanide (free)	0.9	0.9	0.9	8	8	0.9	0.9	0.9	8	8	2
Fluoride	200	200	200	2,000	2,000	200	200	200	2,000	2,000	1
Sulphur (elemental)	500	500	500	500	500	500	500	500	500	500	3
Metals											
Antimony	20	20	20	40	40	20	20	20	40	40	1
Arsenic (inorganic)	17	17	17	26	26	17	17	17	26	26	
Barium (non-barite)	750	750	500	2,000	2,000	750	750	500	2,000	2,000	2
Barite-barium	10,000	10,000	10,000	15,000	140,000	10,000	10,000	10,000	15,000	140,000	4
Beryllium	5	5	5	8	8	5	5	5	8	8	1
Boron (hot water soluble)	2	2	2	2	2	2	2	2	2	2	1
Cadmium	3.8	1.4	10	22	22	3.8	1.4	10	22	22	2
Chromium (hexavalent)	0.4	0.4	0.4	1.4	1.4	0.4	0.4	0.4	1.4	1.4	2
Chromium (total)	64	64	64	87	87	64	64	64	87	87	2
Cobalt	20	20	20	300	300	20	20	20	300	300	1
Copper	63	63	63	91	91	63	63	63	91	91	2
Lead	70	70	140	260	600	70	70	140	260	600	2
Mercury (inorganic)	12	6.6	6.6	24	50	12	6.6	6.6	24	50	2
Molybdenum	4	4	4	40	40	4	4	4	40	40	1
Nickel	50	50	50	50	50	50	50	50	50	50	2
Selenium	1	1	1	2.9	2.9	1	1	1	2.9	2.9	2
Silver	20	20	20	40	40	20	20	20	40	40	1
Thallium	1	1	1	1	1	1	1	1	1	1	2
Tin	5	5	5	300	300	5	5	5	300	300	1
Uranium	33	23	23	33	300	33	23	23	33	300	
Vanadium	130	130	130	130	130	130	130	130	130	130	2
Zinc	200	200	200	360	360	200	200	200	360	360	2
Hydrocarbons											
Benzene	0.046	0.046	0.046	0.046	0.046	0.078	0.073	0.073	0.078	0.078	5
Toluene	0.52	0.52	0.52	0.52	0.52	0.49	0.49	0.49	0.49	0.49	5
Ethylbenzene	0.11	0.11	0.11	0.11	0.11	0.21	0.21	0.21	0.21	0.21	5

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Soil Type	Fine					Coarse					Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	
Xylenes	15	15	15	15	15	28	12	12	28	28	5
Styrene	0.68	0.68	0.68	0.68	0.68	0.80	0.80	0.80	0.80	0.80	
F1	210	210	210	320	320	210	24	24	270	270	6
F2	150	150	150	260	260	150	130	130	260	260	6
F3	1,300	1,300	1,300	2,500	2,500	300	300	300	1,700	1,700	6
F4	5,600	5,600	5,600	6,600	6,600	2,800	2,800	2,800	3,300	3,300	6
Acenapthene	0.32	0.32	0.32	0.32	0.32	0.38	0.38	0.38	0.38	0.38	
Acenaphthylene	5.0	5.0	5.0	5.0	5.0	6.0	6.0	6.0	6.0	6.0	
Anthracene	0.0046	0.0046	0.0046	0.0046	0.0046	0.0056	0.0056	0.0056	0.0056	0.0056	
Fluoranthene	0.032	0.032	0.032	0.032	0.032	0.039	0.039	0.039	0.039	0.039	
Fluorene	0.29	0.29	0.29	0.29	0.29	0.34	0.34	0.34	0.34	0.34	
Naphthalene	0.016	0.016	0.016	0.016	0.016	0.018	0.018	0.018	0.018	0.018	
Phenanthrene	0.051	0.051	0.051	0.051	0.051	0.061	0.061	0.061	0.061	0.061	
Pyrene	0.034	0.034	0.034	0.034	0.034	0.040	0.040	0.040	0.040	0.040	
Carcinogenic PAHs	IARC<1.0	IARC<1.0	IARC<1.0	IARC<1.0	IARC<1.0	IARC<1.0	5.3; IARC<1.0	5.3; IARC<1.0	8.0; IARC<1.0	8.0; IARC<1.0	7
Benz[a]anthracene	0.070	0.070	0.070	0.070	0.070	0.083	0.083	0.083	0.083	0.083	8
Benzo[b+j]fluoranthene	6.2	6.2	-	-	-	6.2	6.2	-	-	-	8
Benzo[k]fluoranthene	6.2	6.2	-	-	-	6.2	6.2	-	-	-	8
Benzo[g,h,i]perylene	-	-	-	-	-	-	-	-	-	-	
Benzo[a]pyrene	0.60	0.60	0.70	0.70	0.70	0.60	0.60	0.77	0.77	0.77	8
Chrysene	6.2	6.2	-	-	-	6.2	6.2	-	-	-	8
Dibenz[a,h]anthracene	7.4	7.4	7.4	7.4	7.4	8.4	8.4	8.4	8.4	8.4	8
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	-	-	-	-	-	
Halogenated Aliphatics											
Vinyl chloride	0.014	0.0083	0.0083	0.014	0.014	0.020	0.00034	0.00034	0.0043	0.0043	
1,1-Dichloroethene	0.15	0.15	0.15	0.15	0.15	0.24	0.021	0.021	0.24	0.24	
Trichloroethene (Trichloroethylene, TCE)	0.054	0.054	0.054	0.054	0.054	0.081	0.012	0.012	0.081	0.081	5, 11
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.69	0.69	0.69	0.69	0.69	0.77	0.16	0.16	0.77	0.77	
1,2-Dichloroethane	0.025	0.0062	0.025	0.025	0.025	0.041	0.0027	0.0027	0.033	0.033	
Dichloromethane (Methylene chloride)	0.10	0.052	0.10	0.10	0.10	0.095	0.048	0.095	0.095	0.095	
Trichloromethane (Chloroform)	0.0029	0.0029	0.0029	0.0029	0.0029	0.0030	0.0010	0.0010	0.0030	0.0030	
Tetrachloromethane (Carbon tetrachloride)	0.059	0.013	0.013	0.059	0.059	0.062	0.00056	0.00056	0.0068	0.0068	

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Soil Type	Fine					Coarse					Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	
Dibromochloromethane	0.91	0.12	0.91	0.91	0.91	1.5	0.12	0.27	1.5	1.5	
Chlorinated Aromatics											
Chlorobenzene	0.61	0.39	0.39	0.61	0.61	1.1	0.018	0.018	0.22	0.22	12
1,2-Dichlorobenzene	0.097	0.097	0.097	0.097	0.097	0.18	0.18	0.18	0.18	0.18	12
1,4-Dichlorobenzene	0.051	0.051	0.051	0.051	0.051	0.098	0.098	0.098	0.098	0.098	
1,2,3-Trichlorobenzene	0.26	0.26	0.26	0.26	0.26	0.31	0.26	0.26	0.31	0.31	
1,2,4-Trichlorobenzene	0.78	0.78	0.78	0.78	0.78	0.93	0.23	0.23	0.93	0.93	
1,3,5-Trichlorobenzene	1.9	1.9	1.9	1.9	1.9	3.6	0.13	0.13	1.3	1.3	
1,2,3,4-Tetrachlorobenzene	0.042	0.042	0.042	0.042	0.042	0.050	0.050	0.050	0.050	0.050	
1,2,3,5-Tetrachlorobenzene	0.37	0.37	0.37	0.37	0.37	0.70	0.10	0.10	0.70	0.70	
1,2,4,5-Tetrachlorobenzene	0.19	0.19	0.19	0.19	0.19	0.37	0.052	0.052	0.37	0.37	
Pentachlorobenzene	3.7	3.7	3.7	3.7	3.7	4.5	4.5	4.5	4.5	4.5	
Hexachlorobenzene	3.6	0.80	3.6	3.6	3.6	7.0	0.50	0.50	6.0	6.0	
2,4-Dichlorophenol	0.0029	0.0029	0.0029	0.0029	0.0029	0.0034	0.0034	0.0034	0.0034	0.0034	
2,4,6-Trichlorophenol	0.19	0.19	0.19	0.19	0.19	0.37	0.37	0.37	0.37	0.37	
2,3,4,6-Tetrachlorophenol	0.039	0.039	0.039	0.039	0.039	0.047	0.047	0.047	0.047	0.047	
Pentachlorophenol	0.024	0.024	0.024	0.024	0.024	0.029	0.029	0.029	0.029	0.029	5
Dioxins & Furans	0.00025	0.000004	0.000004	0.000004	0.000004	0.00025	0.000004	0.000004	0.000004	0.000004	9
PCBs	1.3	1.3	22	33	33	1.3	1.3	22	33	33	5
Pesticides											
Aldicarb	0.041	0.012	0.041	0.041	0.041	0.065	0.012	0.065	0.065	0.065	12
Aldrin	5.9	3.4	3.4	5.1	5.9	7.4	3.4	3.4	5.1	7.4	
Atrazine and metabolites	0.0088	0.0088	0.0088	0.0088	0.0088	0.010	0.010	0.010	0.010	0.010	
Azniphos-methyl	0.41	0.41	0.41	0.41	0.41	0.75	0.75	0.75	0.75	0.75	
Bendiocarb	0.14	0.14	0.14	0.14	0.14	0.21	0.21	0.21	0.21	0.21	
Bromoxynil	0.044	0.044	0.044	0.044	0.044	0.052	0.052	0.052	0.052	0.052	13
Carbaryl	1.9	1.9	1.9	1.9	1.9	3.6	3.6	3.6	3.6	3.6	12
Carbofuran	0.68	0.082	0.68	0.68	0.68	1.2	0.089	1.2	1.2	1.2	12
Chlorothalonil	0.0084	0.0084	0.0084	0.0084	0.0084	0.010	0.010	0.010	0.010	0.010	
Chlorpyrifos	49	3.2	49	49	49	95	3.8	95	95	95	12
Cyanazine	0.12	0.029	0.12	0.12	0.12	0.21	0.032	0.21	0.21	0.21	12, 13
2,4-D	0.43	0.10	0.43	0.43	0.43	0.67	0.10	0.67	0.67	0.67	12

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Soil Type	**Fine**					**Coarse**					**Notes**
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	
DDT	0.015	0.015	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.018	5
Diazinon	2.2	2.2	2.2	2.2	2.2	4.2	4.2	4.2	4.2	4.2	
Dicamba	0.50	0.12	0.50	0.50	0.50	0.79	0.12	0.79	0.79	0.79	12,13
Dichlofop-methyl	2.0	0.059	2.0	2.0	2.0	2.4	0.071	2.4	2.4	2.4	
Dieldrin	0.011	0.011	0.011	0.011	0.011	0.014	0.014	0.014	0.014	0.014	
Dimethoate	0.0058	0.0028	0.0058	0.0058	0.0058	0.0055	0.0027	0.0055	0.0055	0.0055	
Dinoseb	2.8	1.1	2.8	2.8	2.8	5.5	1.3	5.5	5.5	5.5	12
Diquat	11	11	11	11	11	21	21	21	21	21	
Diuron	1.9	1.9	1.9	1.9	1.9	3.5	3.5	3.5	3.5	3.5	
Endosulfan	0.0085	0.0085	0.0085	0.0085	0.0085	0.010	0.010	0.010	0.010	0.010	
Endrin	0.0075	0.0075	0.0075	0.0075	0.0075	0.0090	0.0090	0.0090	0.0090	0.0090	
Glyphosate	0.054	0.054	0.054	0.054	0.054	0.049	0.049	0.049	0.049	0.049	
Heptachlor epoxide	0.039	0.039	0.039	0.039	0.039	0.076	0.010	0.010	0.076	0.076	12
Lindane	0.31	0.11	0.31	0.31	0.31	0.60	0.13	0.60	0.60	0.60	12
Linuron	0.051	0.051	0.051	0.051	0.051	0.059	0.059	0.059	0.059	0.059	13
Malathion	0.82	0.82	0.82	0.82	0.82	1.3	1.3	1.3	1.3	1.3	12
MCPA	0.020	0.020	0.020	0.020	0.020	0.032	0.025	0.032	0.032	0.032	12,13
Methoxychlor	0.046	0.046	0.046	0.046	0.046	0.056	0.056	0.056	0.056	0.056	
Metolachlor	0.048	0.048	0.048	0.048	0.048	0.055	0.055	0.055	0.055	0.055	
Metribuzin	0.024	0.012	0.024	0.024	0.024	0.028	0.014	0.028	0.028	0.028	
Paraquat (as dichloride)	1.1	1.1	1.1	1.1	1.1	2.2	2.2	2.2	2.2	2.2	
Parathion	7.2	7.2	7.2	7.2	7.2	14	14	14	14	14	12
Phorate	0.075	0.075	0.075	0.075	0.075	0.14	0.14	0.14	0.14	0.14	
Picloram	0.024	0.024	0.024	0.024	0.024	0.022	0.022	0.022	0.022	0.022	
Simazine	0.033	0.033	0.033	0.033	0.033	0.038	0.038	0.038	0.038	0.038	13
Tebuthiuron	2.5	0.12	2.5	2.5	2.5	3.7	0.11	3.7	3.7	3.7	12,13
Terbufos	0.080	0.080	0.080	0.080	0.080	0.15	0.15	0.15	0.15	0.15	
Toxaphene	3.3	3.3	3.3	3.3	3.3	6.3	4.8	4.8	6.3	6.3	12
Triallate	0.0077	0.0077	0.0077	0.0077	0.0077	0.0092	0.0092	0.0092	0.0092	0.0092	
Trifluarin	0.038	0.038	0.038	0.038	0.038	0.045	0.045	0.045	0.045	0.045	
Other Organics											
Aniline	0.36	0.36	0.36	0.36	0.36	0.60	0.60	0.60	0.60	0.60	12
Bis(2-ethyl-hexyl)phthalate	34	34	34	34	34	41	41	41	41	41	

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Soil Type	Fine					Coarse					Notes
Land Use	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	
Unit	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
Dibutyl phthalate	0.54	0.54	0.54	0.54	0.54	0.65	0.65	0.65	0.65	0.65	
Dichlorobenzidine	4.2	4.2	4.2	4.2	4.2	8.1	8.1	8.1	8.1	8.1	
Diisopropanolamine	14	14	14	14	14	17	17	17	17	17	5
Ethylene glycol	60	60	60	60	60	62	62	62	62	62	5
Hexachlorobutadiene	0.026	0.026	0.026	0.026	0.026	0.031	0.0067	0.0067	0.031	0.031	
Methylmethacrylate	1.3	1.3	1.3	1.3	1.3	1.8	0.10	0.10	1.3	1.3	
MTBE	0.044	0.044	0.044	0.044	0.044	0.062	0.046	0.046	0.062	0.062	
Nonylphenol + ethoxylates	2.7	2.7	2.7	2.7	2.7	3.3	3.3	3.3	3.3	3.3	5
Phenol	0.0028	0.0014	0.0028	0.0028	0.0028	0.0024	0.0012	0.0024	0.0024	0.0024	5
Sulfolane	0.18	0.18	0.18	0.18	0.18	0.21	0.18	0.21	0.21	0.21	5

Soil Type	Fine					Coarse					Notes
Land Use	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	
Unit	(Bq/g)	(Bq/g)	(Bq/g)	(Bq/g)	(Bq/g)	(Bq/g)	(Bq/g)	(Bq/g)	(Bq/g)	(Bq/g)	
Radionuclides											
Uranium-238 Series (all progeny)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	10
Uranium-238 (^{238}U, ^{234}Th, ^{234}mPa, ^{234}U)	10	10	10	10	10	10	10	10	10	10	10
Thorium-230	10	10	10	10	10	10	10	10	10	10	10
Radium-226 (in equilibrium with its progeny)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	10
Lead-210 (in equilibrium with ^{210}Bi and ^{210}Po)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	10
Thorium-232 Series (all progeny)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	10
Thorium-232	10	10	10	10	10	10	10	10	10	10	10
Radium-228 (in equilibrium with ^{228}Ac)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	10
Thorium-228 (in equilibrium with its progeny)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	10
Potassium-40	17	17	17	17	17	17	17	17	17	17	10

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Notes:

Guideline values calculated for this document using latest available CCME protocols except where noted.

1. *Value adopted from AEP (1994) and/or CCME 1991*
2. *Value adopted from CCME (1999)*
3. *For more information see Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes (AEP, 1996)*
4. *True total barium as measured by fusion-XRF or fusion-ICP. For more information see Soil Remediation Guidelines for Barite: Environmental Health and Human Health (AENV, 2009b)*
5. *Ecological direct contact values from CCME (1999), other values calculated in this document*
6. *Ecological direct contact values from CCME (2007), other values calculated in this document*
7. *Carcinogenic PAH concentrations in coarse textured soil under all land uses except natural areas must meet both the Human Direct Contact guideline (5.3 mg/kg or 8.0 mg/kg as B(a)P TPE) and the Index of Additive Cancer Risk (IACR) <1 guideline. Individual PAH compounds must also meet guidelines for ecological receptors where specified in Table 1 with footnote 8.*

B[a]P TPE (Total Potency Equivalents) are calculated by multiplying the soil concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the estimates of carcinogenic potential and are based on the World Health Organization (1999) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

The IACR is calculated by dividing the soil concentration of each carcinogenic PAH by its Protection of Domestic Use Aquifer guideline value to calculate a hazard index for each PAH and subsequently summing the hazard indexes for the entire PAH mixture, as follows:

Fine Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{1.6\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{0.74\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.16\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{32\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{1.7\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{10\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{1.1\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{13\ \mathrm{mg\cdot kg^{-1}}}$$

Coarse Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{3.1\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{1.4\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.31\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{63\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{3.4\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{19\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{2.1\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{24\ \mathrm{mg\cdot kg^{-1}}}$$

Table 1. Alberta Tier 1 Soil Remediation Guidelines

8. *For ecological receptors only*
9. *Expressed as toxic equivalents (TEQs) based on 2,3,7,8-TCDD (See CCME, 1999 and updates)*
10. *When two or more radiounuclides are found, the following relationship should be satisfied:*

$$\frac{[\text{Radionuclide}]_1}{\text{Guideline}_1} + \frac{[\text{Radionuclide}]_2}{\text{Guideline}_2} + \ldots \frac{[\text{Radionuclide}]_i}{\text{Guideline}_i} \leq 1$$

For more information see Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM) (Health Canada, 2000)

11. *If trichloroethene is found in soil, its degradation product vinyl chloride must also be measured and compared to guideline values*
12. *Guideline for protection of aquatic life is below detection limit and has not been included in the Tier 1 derivation. Groundwater monitoring is required for all land uses if the Tier 1 guideline is exceeded.*
13. *Guideline for protection of irrigation water is below detection limit and has not been included in the Tier 1 derivation. Groundwater monitoring is required for agricultural land use if the Tier 1 guideline is exceeded.*

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Soil Type	**Fine**				**Coarse**				**Notes**
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	
General and Inorganic Parameters									
pH	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	
Ammonia	see note 1	see note 1	see note 1	see note 1	see note 1	see note 1	see note 1	see note 1	1
Chloride	230	100	230	230	230	100	230	230	
Cyanide	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Fluoride	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	
Nitrate	13	13	13	13	13	13	13	13	
Nitrate + Nitrite (as nitrogen)	-	100	-	-	-	100	-	-	
Nitrite (as nitrogen)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	
Sodium	200	200	200	200	200	200	200	200	
Sulphate	500	500	500	500	500	500	500	500	
Sulphide (as H_2S)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
Total Dissolved Solids (TDS)	500	500	500	500	500	500	500	500	
Metals									
Aluminum	see note 1	see note 2	see note 1	see note 1	see note 1	see note 2	see note 1	see note 1	1
Antimony	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	
Arsenic	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Barium	1	1	1	1	1	1	1	1	
Boron	5	0.5	5	5	5	0.5	5	5	
Bromate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Cadmium	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	2
Chromium	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	2
Copper	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	2
Iron	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Lead	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	2
Manganese	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Mercury	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	see note 2	2
Nickel	see note 1	see note 2	see note 1	see note 1	see note 1	see note 2	see note 1	see note 1	1,2
Selenium	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Silver	see note 1	see note 2	see note 1	see note 1	see note 1	see note 2	see note 1	see note 1	1,2
Uranium	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	
Zinc	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Soil Type	**Fine**				**Coarse**				**Notes**
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	
Hydrocarbons									
Benzene	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Toluene	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	
Ethylbenzene	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	
Xylenes	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Styrene	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	
F1	2.2	2.2	2.2	2.2	2.2	0.81	0.81	2.2	
F2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
Acenapthene	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	
Acenaphthylene	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	
Anthracene	0.000012	0.000012	0.000012	0.000012	0.000012	0.000012	0.000012	0.000012	
Fluoranthene	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	
Fluorene	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
Naphthalene	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	
Phenanthrene	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	
Pyrene	0.000025	0.000025	0.000025	0.000025	0.000025	0.000025	0.000025	0.000025	
Carcinogenic PAHs (as B(a)P TPE)	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	3
Benz[a]anthracene	0.000018	0.000018	0.000018	0.000018	0.000018	0.000018	0.000018	0.000018	4
Benzo[b+j]fluoranthene	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	4
Benzo[k]fluoranthene	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	4
Benzo[g,h,i]perylene	0.00021	0.00021	0.00021	0.00021	0.00017	0.00017	0.00017	0.00017	4
Benzo[a]pyrene	0.000017	0.000017	0.000017	0.000017	0.000015	0.000015	0.000015	0.000015	4
Chrysene	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	4
Dibenz[a,h]anthracene	0.00028	0.00028	0.00028	0.00028	0.00026	0.00026	0.00026	0.00026	4
Indeno[1,2,3-c,d]pyrene	0.00023	0.00023	0.00023	0.00023	0.00021	0.00021	0.00021	0.00021	4
Halogenated Aliphatics									
Vinyl chloride	0.002	0.002	0.002	0.002	0.002	0.0011	0.0011	0.002	
1,1-Dichloroethene	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	
Trichloroethene (Trichloroethylene, TCE)	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	5
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	
1,2-Dichloroethane	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Soil Type	Fine				Coarse				Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	
Dichloromethane (Methylene chloride)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Trichloromethane (Chloroform)	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	
Tetrachloromethane (Carbon tetrachloride)	0.005	0.005	0.005	0.005	0.005	0.00056	0.00056	0.005	
Dibromochloromethane	0.19	0.1	0.19	0.19	0.19	0.1	0.19	0.19	
Chlorinated Aromatics									
Chlorobenzene	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	
1,2-Dichlorobenzene	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	
1,4-Dichlorobenzene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
1,2,3-Trichlorobenzene	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	
1,2,4-Trichlorobenzene	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
1,3,5-Trichlorobenzene	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	
1,2,3,4-Tetrachlorobenzene	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	
1,2,3,5-Tetrachlorobenzene	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	
1,2,4,5-Tetrachlorobenzene	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
Pentachlorobenzene	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	
Hexachlorobenzene	0.00057	0.00052	0.00057	0.00057	0.00057	0.00052	0.00057	0.00057	
2,4-Dichlorophenol	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
2,4,6-Trichlorophenol	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
2,3,4,6-Tetrachlorophenol	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Pentachlorophenol	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	
Dioxins & Furans	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	
PCBs	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	
Pesticides									
Aldicarb	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Aldrin and dieldrin	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	
Atrazine and metabolites	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	
Azniphos-methyl	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	
Bendiocarb	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	
Bromoxynil	0.005	0.00033	0.005	0.005	0.005	0.00033	0.005	0.005	
Carbaryl	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Carbofuran	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	
Chlorothalonil	0.00018	0.00018	0.00018	0.00018	0.00018	0.00018	0.00018	0.00018	

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Soil Type	Fine				Coarse				Notes
Land Use	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	
Unit	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
Chlorpyrifos	0.0000035	0.0000035	0.0000035	0.0000035	0.0000035	0.0000035	0.0000035	0.0000035	
Cyanazine	0.002	0.0005	0.002	0.002	0.002	0.0005	0.002	0.002	
2,4-D	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	
DDT	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	
Diazinon	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Dicamba	0.01	0.000006	0.01	0.01	0.01	0.000006	0.01	0.01	
Dichlofop-methyl	0.0061	0.00018	0.0061	0.0061	0.0061	0.00018	0.0061	0.0061	
Dieldrin	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056	
Dimethoate	0.0062	0.003	0.0062	0.0062	0.0062	0.003	0.0062	0.0062	
Dinoseb	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	
Diquat	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	
Diuron	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	
Endosulfan	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	
Endrin	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036	
Glyphosate	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	
Heptachlor epoxide	0.0000038	0.0000038	0.0000038	0.0000038	0.0000038	0.0000038	0.0000038	0.0000038	
Lindane	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	
Linuron	0.007	0.000071	0.007	0.007	0.007	0.000071	0.007	0.007	
Malathion	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
MCPA	0.0026	0.000025	0.0026	0.0026	0.0026	0.000025	0.0026	0.0026	
Methoxychlor	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	
Metolachlor	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	
Metribuzin	0.001	0.0005	0.001	0.001	0.001	0.0005	0.001	0.001	
Paraquat (as dichloride)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Parathion	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	
Phorate	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
Picloram	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	
Simazine	0.01	0.0005	0.01	0.01	0.01	0.0005	0.01	0.01	
Tebuthiuron	0.0016	0.00027	0.0016	0.0016	0.0016	0.00027	0.0016	0.0016	
Terbufos	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Toxaphene	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	
Triallate	0.00024	0.00024	0.00024	0.00024	0.00024	0.00024	0.00024	0.00024	

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Soil Type	Fine				Coarse				Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	
Trifluarin	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Other Organics									
Aniline	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	
Bis(2-ethyl-hexyl)phthalate	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	
Dibutyl phthalate	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	
Dichlorobenzidine	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	
Diisopropanolamine	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
Ethylene glycol	31	31	31	31	31	31	31	31	
Hexachlorobutadiene	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	
Methylmethacrylate	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	
MTBE	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
Nitrilotriacetic acid	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
Nonylphenol + ethoxylates	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Phenol	0.004	0.002	0.004	0.004	0.004	0.002	0.004	0.004	
Sulfolane	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	
Trihalomethanes - total (THMs)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	

Soil Type	Fine				Coarse				Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	
Unit	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	
Naturally Occurring Radionuclides									
Beryllium-7	4000	4000	4000	4000	4000	4000	4000	4000	6
Bismuth-210	70	70	70	70	70	70	70	70	6
Lead-210	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	6
Polonium-210	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	6
Radium -224	2	2	2	2	2	2	2	2	6
Radium-226	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	6
Radium-228	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6
Thorium-228	2	2	2	2	2	2	2	2	6
Thorium-230	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	6
Thorium-232	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	6

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Soil Type	Fine				Coarse				Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	
Unit	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	
Thorium-234	20	20	20	20	20	20	20	20	6
Uranium-234	4	4	4	4	4	4	4	4	6
Uranium-235	4	4	4	4	4	4	4	4	6
Uranium-238	4	4	4	4	4	4	4	4	6
Other Radionuclides									
Americium-241	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	6
Antimony-122	50	50	50	50	50	50	50	50	6
Antimony-124	40	40	40	40	40	40	40	40	6
Antimony-125	100	100	100	100	100	100	100	100	6
Barium-140	40	40	40	40	40	40	40	40	6
Bromine-82	300	300	300	300	300	300	300	300	6
Calcium-45	200	200	200	200	200	200	200	200	6
Calcium-47	60	60	60	60	60	60	60	60	6
Carbon-14a	200	200	200	200	200	200	200	200	6
Cerium-141	100	100	100	100	100	100	100	100	6
Cerium-144	20	20	20	20	20	20	20	20	6
Cesium-131	2000	2000	2000	2000	2000	2000	2000	2000	6
Cesium-136	50	50	50	50	50	50	50	50	6
Chromium-51	3000	3000	3000	3000	3000	3000	3000	3000	6
Cobalt-57	40	40	40	40	40	40	40	40	6
Cobalt-58	20	20	20	20	20	20	20	20	6
Cobalt-60	2	2	2	2	2	2	2	2	6
Gallium-67	500	500	500	500	500	500	500	500	6
Gold-198	90	90	90	90	90	90	90	90	6
Indium-111	400	400	400	400	400	400	400	400	6
Iodine-129	1	1	1	1	1	1	1	1	6
Iron-55	300	300	300	300	300	300	300	300	6
Iron-59	40	40	40	40	40	40	40	40	6
Manganese-54	200	200	200	200	200	200	200	200	6
Mercury-197	400	400	400	400	400	400	400	400	6
Mercury-203	80	80	80	80	80	80	80	80	6
Neptunium-239	100	100	100	100	100	100	100	100	6

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Soil Type	**Fine**				**Coarse**				**Notes**
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial/ Industrial**	
Unit	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	**(Bq/L)**	
Niobium-95	200	200	200	200	200	200	200	200	6
Phosphorus-32	50	50	50	50	50	50	50	50	6
Plutonium-238	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	6
Plutonium-239	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	6
Plutonium-240	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	6
Plutonium-241	10	10	10	10	10	10	10	10	6
Rhodium-105	300	300	300	300	300	300	300	300	6
Rubidium-81	3000	3000	3000	3000	3000	3000	3000	3000	6
Rubidium-86	50	50	50	50	50	50	50	50	6
Ruthenium-103	100	100	100	100	100	100	100	100	6
Ruthenium-106	10	10	10	10	10	10	10	10	6
Selenium-75	70	70	70	70	70	70	70	70	6
Silver-108m	70	70	70	70	70	70	70	70	6
Silver-110m	50	50	50	50	50	50	50	50	6
Silver-111	70	70	70	70	70	70	70	70	6
Sodium-22	50	50	50	50	50	50	50	50	6
Strontium-85	300	300	300	300	300	300	300	300	6
Strontium-89	40	40	40	40	40	40	40	40	6
Sulphur-35	500	500	500	500	500	500	500	500	6
Technetium-99	200	200	200	200	200	200	200	200	6
Technetium-99m	7000	7000	7000	7000	7000	7000	7000	7000	6
Tellurium-129m	40	40	40	40	40	40	40	40	6
Tellurium-131m	40	40	40	40	40	40	40	40	6
Tellurium-132	40	40	40	40	40	40	40	40	6
Thallium-201	2000	2000	2000	2000	2000	2000	2000	2000	6
Ytterbium-169	100	100	100	100	100	100	100	100	6
Yttrium-90	30	30	30	30	30	30	30	30	6
Yttrium-91	30	30	30	30	30	30	30	30	6
Zinc-65	40	40	40	40	40	40	40	40	6
Zirconium-95	100	100	100	100	100	100	100	100	6

Table 2. Alberta Tier 1 Groundwater Remediation Guidelines

Notes:

1. *See Surface Water Quality Guidelines for Use in Alberta (AENV, 1999) for further guidance on aquatic life pathway.*
2. *Tier 1 guideline = lowest of aquatic life guideline and all other guidelines (See Appendix B).*
3. *B[a]P TPE (Total Potency Equivalents) are calculated by multiplying the groundwater concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the estimates of carcinogenic potential and are based on the World Health Organization (1999) scheme, as follows:*

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

4. *For ecological receptors only*
5. *If trichloroethene is found in groundwater, its degradation product vinyl chloride must also be measured and compared to guideline values*
6. *When two or more radiounuclides are found, the following relationship should be satisfied:*

$$\frac{[\text{Radionucli de}]_1}{\text{Guideline}_1} + \frac{[\text{Radionucli de}]_2}{\text{Guideline}_2} + \ldots \frac{[\text{Radionucli de}]_i}{\text{Guideline}_i} \leq 1$$

NGR = no guideline required - values for all exposure pathways that could be calculated are above compound solubility

Table 3. Alberta Tier 1 Subsoil Remediation Guidelines (BTEX and PHCs Only)

Soil Type	Fine					Coarse					Notes
Land Use	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	**Natural Area**	**Agricultural**	**Residential/ Parkland**	**Commercial**	**Industrial**	
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	
Benzene	0.046	0.046	0.046	0.046	0.046	0.078	0.078	0.078	0.078	0.078	2
Toluene	0.52	0.52	0.52	0.52	0.52	0.49	0.49	0.49	0.49	0.49	2
Ethylbenzene	0.11	0.11	0.11	0.11	0.11	0.21	0.21	0.21	0.21	0.21	2
Xylenes	15	15	15	15	15	28	16	16	28	28	2
F1	420	420	420	640	640	420	30	30	440	440	1, 3
F2	300	300	300	520	520	300	160	160	520	520	1, 3
F3	2,600	2,600	2,600	3,500	3,500	600	600	600	2,500	2,500	1, 3
F4	10,000	10,000	10,000	10,000	10,000	5,600	5,600	5,600	6,600	6,600	1, 3

Notes:

Guideline values calculated for this document using latest available CCME protocols except where noted.

1. Ecological direct contact pathway may be eliminated below 3 metres in depth for F1 to F4 only; the next lowest guideline value applies.

2. Ecological direct contact values from CCME (1999), other values calculated in this document

3. All values calculated in this document

Table 4. Alberta Tier 1 Salt Remediation Guidelines

Rating Categories	Good	Fair	Poor	Unsuitable	Commercial/Industrial
Topsoil[e]					
EC[a] (dS/m)	<2[c]	2 to 4	4 to 8	>8	4
SAR[b]	<4	4 to 8	8 to 12	>12[d]	12
Subsoil[e]					
EC[a] (dS/m)	<3	3 to 5	5 to 10	>10	4
SAR[b]	<4	4 to 8	8 to 12	>12	12

Notes:

a. Electrical conductivity

b. Sodium Adsorption Ratio

c. Some plants are sensitive to salts at EC < 2 dS/m (e.g., flax, clover, beans, some wheat varieties, peas, some garden crops).

d. Material characterized by SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.

e. Topsoil: surface A, L, F, H, and O horizons on the control area, or the equivalent surface soil where these horizons are not present.

Subsoil: B and C horizons and the upper portion of the parent material.

FIGURES

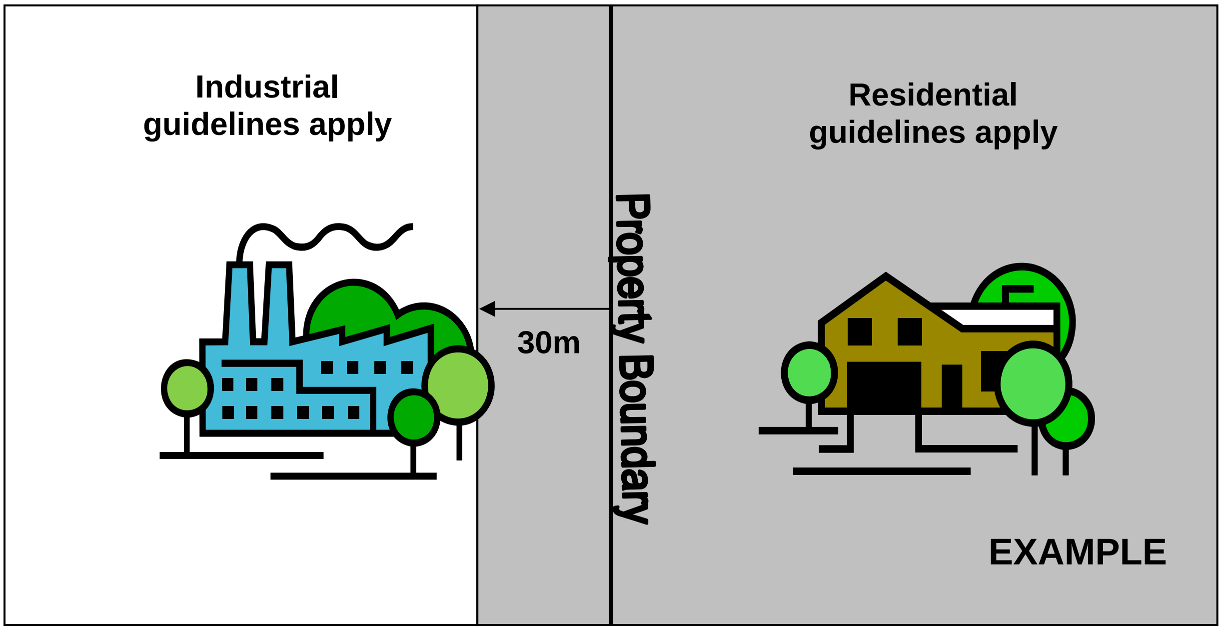

Figure 1: Example of the 30 m buffer zone for the more sensitive land use. The diagram is for illustration purposes and can be applied for any land use scenario where a more sensitive land use is adjacent to a less sensitive land use.

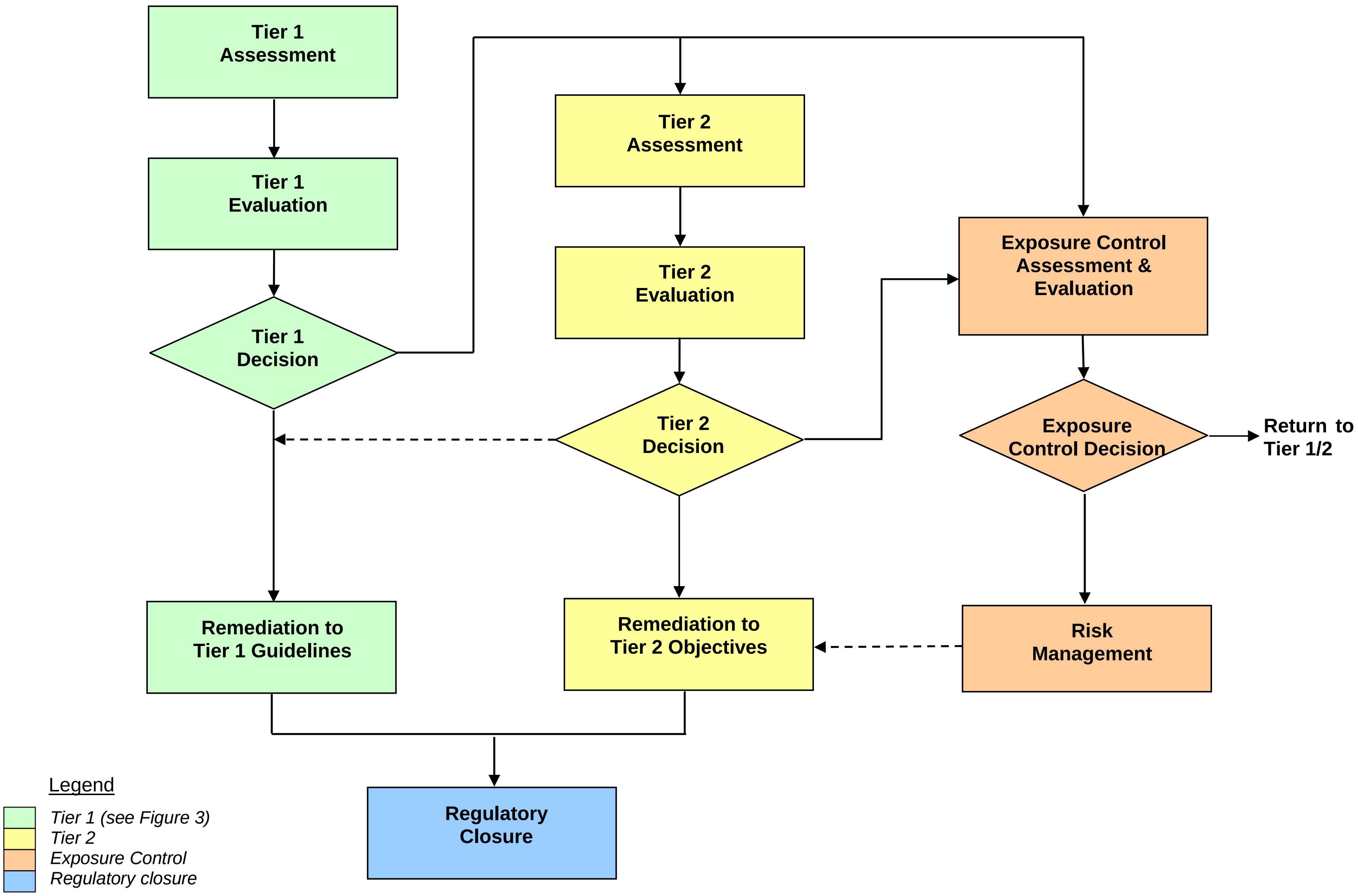

Figure 2: Implementation Framework for Tier 1, Tier 2 and Exposure Control Guidelines

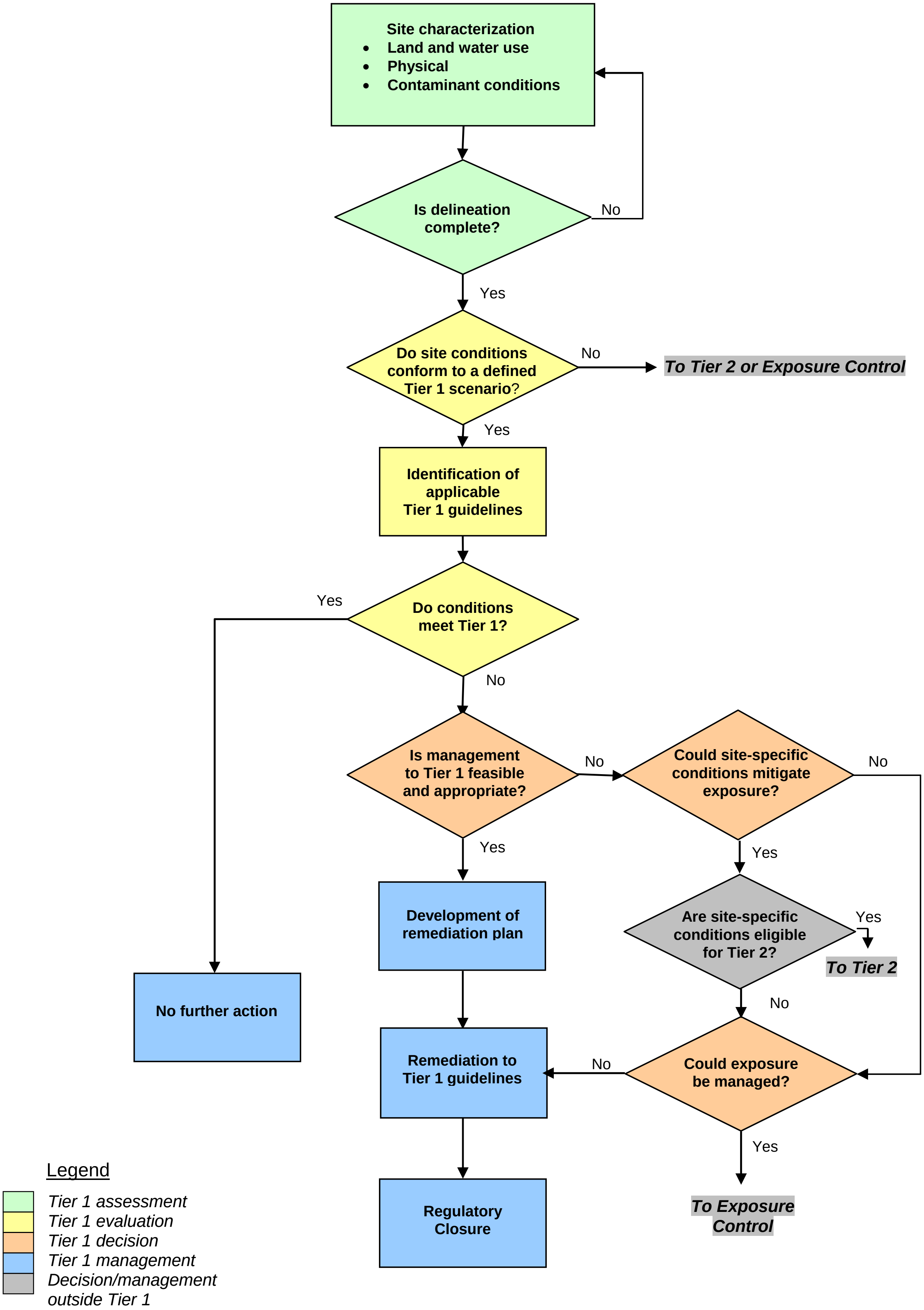

Figure 3: Expanded Flow Diagram – Tier 1

APPENDIX A
SOIL REMEDIATION GUIDELINES ALL EXPOSURE PATHWAYS

Appendix A consists of ten tables, comprised of surface soil and subsoil tables for each of the land uses. Each table provides the soil remediation guideline for each exposure pathway, where available. **Tier 1 guidelines must be chosen from Tables 1 to 4, not from Appendix A or B.** The only exception occurs when a more sensitive land use borders on, or is less than 30m from, the site of interest. Under this condition guidelines for specific exposure pathways on the more sensitive land use must be evaluated and if they are lower than the Tier 1 guideline, they must be applied to the site of interest (See Section 5.1.2 and Figure 1).

The ten tables are as follows:

- Table A-1. Surface Soil Remediation Guidelines for Natural Area Land Use
- Table A-2. Surface Soil Remediation Guidelines for Agricultural Land Use
- Table A-3. Surface Soil Remediation Guidelines for Residential/Parkland Use
- Table A-4. Surface Soil Remediation Guidelines for Commercial Land Use
- Table A-5. Surface Soil Remediation Guidelines for Industrial Land Use
- Table A-6. Subsoil Remediation Guidelines for Natural Area Land Use
- Table A-7. Subsoil Remediation Guidelines for Agricultural Land Use
- Table A-8. Subsoil Remediation Guidelines for Residential/Parkland Use
- Table A-9. Subsoil Remediation Guidelines for Commercial Land Use
- Table A-10. Subsoil Remediation Guidelines for Industrial Land Use

In some cases, there is a value for the overall guideline, but no values for individual exposure pathways. This situation corresponds to non-risk-based guidelines that have been adopted from previous guideline documents, as explained in the main text.

All exposure pathways are applicable at Tier 1. However, it may be possible to exclude or modify certain pathways at Tier 2. The companion Tier 2 document (AENV, 2009a) should be consulted for further information. The information in the tables in this appendix will assist in determining whether a Tier 2 approach for soil is likely to be useful at a given site.

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**		**Ecological**									**Other**	
Pathway			**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Wildlife Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
General and Inorganic Parameters															
pH (in 0.01M $CaCl_2$)	6-8.5	6-8.5	-	-	6-8.5	6-8.5	-	-	-	-	-	-	-	-	-
Cyanide (free)	0.9	0.9	-	-	0.9	0.9	-	11	-	-	-	-	-	-	-
Fluoride	200	200	-	-	200	200	-	-	-	-	-	-	-	-	-
Sulphur (elemental) [a]	500	500	-	-	500	500	-	-	-	-	-	-	-	-	-
Metals															
Antimony	20	20	-	-	20	20	-	-	-	-	-	-	-	-	-
Arsenic (inorganic)	17	17	-	-	17	17	-	380	-	-	-	-	-	-	-
Barium (non-barite)	750	750	-	-	750	750	-	-	-	-	-	-	-	-	-
Barite-barium [b]	10,000	10,000	-	-	200,000	200,000	-	30,000	10,000	-	-	-	-	-	-
Beryllium	5	5	-	-	5	5	-	-	-	-	-	-	-	-	-
Boron (hot water soluble)	2	2	-	-	2	2	-	-	-	-	-	-	-	-	-
Cadmium	3.8	3.8	-	-	10	10	54	3.8	-	-	-	-	-	-	-
Chromium (hexavalent)	0.4	0.4	-	-	0.4	0.4	-	-	-	-	-	-	-	-	-
Chromium (total)	64	64	-	-	64	64	52	-	-	-	-	-	-	-	-
Cobalt	20	20	-	-	20	20	-	-	-	-	-	-	-	-	-
Copper	63	63	-	-	63	63	350	300	-	-	-	-	-	-	-
Lead	70	70	-	-	300	300	723	70	-	-	-	-	-	-	-
Mercury (inorganic)	12	12	-	-	12	12	20	-	-	-	-	-	-	-	-
Molybdenum	4	4	-	-	4	4	-	-	-	-	-	-	-	-	-
Nickel	50	50	-	-	50	50	146	355	-	-	-	-	-	-	-
Selenium	1	1	-	-	1	1	-	4.5	-	-	-	-	-	-	-
Silver	20	20	-	-	20	20	-	-	-	-	-	-	-	-	-
Thallium	1	1	-	-	1.4	1.4	-	1.0	-	-	-	-	-	-	-

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**		**Ecological**									**Other**	
Pathway			**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Wildlife Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Tin	5	5	-	-	5	5	-	-	-	-	-	-	-	-	-
Uranium	33	33	-	-	500	500	-	33	-	-	-	-	-	-	-
Vanadium	130	130	-	-	130	130	255	-	-	-	-	-	-	-	-
Zinc	200	200	-	-	200	200	200	640	-	-	-	-	-	-	-
Hydrocarbons															
Benzene	0.046	0.078	0.046	0.078	60	31	-	44	18	73	1.6	15	0.33	-	-
Toluene	0.52	0.49	0.52	0.95	110	75	-	2,500	980	250,000	0.49	NGR	1,000	-	-
Ethylbenzene	0.11	0.21	0.11	0.21	120	55	-	1,600	640	NGR	540	NGR	17,000	-	-
Xylenes	15	28	15	28	65	95	-	6,600	2,600	NGR	250	NGR	16,000	-	-
Styrene	0.68	0.8	110	210	-	-	-	-	-	0.68	0.8	-	-	-	-
F1	210	210	1,100	2,200	210	210	-	27,000	11,000	30,000	1,300	30,000	30,000	800	700
F2	150	150	1,500	2,900	150	150	-	25,000	9,800	30,000	520	30,000	30,000	1,000	1,000
F3	1,300	300	-	-	1,300	300	-	30,000	16,000	-	-	-	-	3,500	2,500
F4	5,600	2,800	-	-	5,600	2,800	-	21,000	8,400	-	-	-	-	10,000	10,000
Acenapthene	0.32	0.38	NGR	NGR	-	-	-	21.5	21.5	0.32	0.38	NGR	NGR	-	-
Acenaphthylene	5.0	6.0	-	-	-	-	-	-	-	5.0	6.0	-	-	-	-
Anthracene	0.0046	0.0056	NGR	NGR	2.5	2.5	-	61.5	61.5	0.0046	0.0056	NGR	NGR	-	-
Fluoranthene	0.032	0.039	NGR	NGR	50	50	-	15.4	15.4	0.032	0.039	NGR	NGR	-	-
Fluorene	0.29	0.34	NGR	NGR	-	-	-	15.4	15.4	0.29	0.34	NGR	NGR	-	-
Naphthalene	0.016	0.018	28	53	-	-	-	8.8	8.8	0.016	0.018	NGR	NGR	-	-
Phenanthrene	0.051	0.061	-	-	-	-	-	43	43	0.051	0.061	NGR	NGR	-	-
Pyrene	0.034	0.040	NGR	NGR	-	-	-	7.7	7.7	0.034	0.040	NGR	NGR	-	-
Carcinogenic PAHs	IARC<1.0 ^{c}	IARC<1.0 ^{c}	IARC<1.0 ^{c}	IARC<1.0 ^{c}	-	-	-	-	-	-	-	-	-	-	-
Benz[a]anthracene ^{d}	0.070	0.083	1.6	3.1	-	-	-	6.2	6.2	0.070	0.083	NGR	NGR	-	-

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**		**Ecological**									**Other**	
Pathway			**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Wildlife Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Benzo[b+j]fluoranthene [d]	6.2	6.2	0.74	1.4	-	-	-	6.2	6.2	NGR	NGR	NGR	NGR	-	-
Benzo[k]fluoranthene [d]	6.2	6.2	0.16	0.31	-	-	-	6.2	6.2	NGR	NGR	NGR	NGR	-	-
Benzo[g,h,i]perylene	-	-	32	63	-	-	-	-	-	NGR	NGR	-	-	-	-
Benzo[a]pyrene [d]	0.6	0.6	1.7	3.4	20	20	-	0.6	0.6	0.70	0.77	NGR	NGR	-	-
Chrysene [d]	6.2	6.2	10	19	-	-	-	6.2	6.2	NGR	NGR	NGR	NGR	-	-
Dibenz[a,h]anthracene [d]	7.4	8.4	1.1	2.1	-	-	-	-	-	7.4	8.4	-	-	-	-
Indeno[1,2,3-c,d]pyrene	-	-	13	24	-	-	-	-	-	NGR	NGR	-	-	-	-
Chlorinated Aliphatics															
Vinyl chloride	0.014	0.02	0.014	0.02	-	-	-	-	-	-	-	-	-	-	-
1,1-Dichloroethene	0.15	0.24	0.15	0.24	-	-	-	-	-	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.054	0.081	0.054	0.093	3	3	-	-	-	0.72	0.081	-	-	-	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.69	0.77	0.77	1.4	-	-	-	-	-	0.69	0.77	-	-	-	-
1,2-Dichloroethane	0.025	0.041	0.025	0.041	-	-	-	-	-	0.12	0.12	-	-	-	-
Dichloromethane (Methylene chloride)	0.1	0.095	0.21	0.32	-	-	-	-	-	0.1	0.095	-	-	-	-
Trichloromethane (Chloroform)	0.0029	0.003	0.62	1.0	-	-`	-	-	-	0.0029	0.003	-	-	-	-
Tetrachloromethane (Carbon tetrachloride)	0.059	0.062	0.092	0.16	-	-	-	-	-	0.059	0.062	-	-	-	-
Dibromochloromethane	0.91	1.5	0.91	1.5	-	-	-	-	-	-	-	-	-	-	-
Chlorinated Aromatics															
Chlorobenzene [e]	0.61	1.1	0.61	1.1	-	-	-	-	-	BDL	BDL	-	-	-	-
1,2-Dichlorobenzene [e]	0.097	0.18	0.097	0.18	-	-	-	-	-	BDL	BDL	-	-	-	-
1,4-Dichlorobenzene	0.051	0.098	0.051	0.098	-	-	-	-	-	0.32	0.38	-	-	-	-
1,2,3-Trichlorobenzene	0.26	0.31	1.9	3.6	-	-	-	-	-	0.26	0.31	-	-	-	-
1,2,4-Trichlorobenzene	0.78	0.93	2.0	3.9	-	-	-	-	-	0.78	0.93	-	-	-	-

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) **.**

Receptor	**Overall Guideline**		**Human**		**Ecological**									**Other**	
Pathway			**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Wildlife Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
1,3,5-Trichlorobenzene	1.9	3.6	1.9	3.6	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.042	0.05	3.1	5.9	-	-	-	-	-	0.042	0.05	-	-	-	-
1,2,3,5-Tetrachlorobenzene	0.37	0.70	0.37	0.70	-	-	-	-	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.19	0.37	0.19	0.37	-	-	-	-	-	-	-	-	-	-	-
Pentachlorobenzene	3.7	4.5	24	47	-	-	-	-	-	3.7	4.5	-	-	-	-
Hexachlorobenzene	3.6	7	3.6	7	-	-	-	-	-	-	-	-	-	-	-
2,4-Dichlorophenol	0.0029	0.0034	0.018	0.034	-	-	-	-	-	0.0029	0.0034	-	-	-	-
2,4,6-Trichlorophenol	0.19	0.37	0.19	0.37	-	-	-	-	-	0.42	0.5	-	-	-	-
2,3,4,6-Tetrachlorophenol	0.039	0.047	0.16	0.31	-	-	-	-	-	0.039	0.047	-	-	-	-
Pentachlorophenol	0.024	0.029	6	12	11	11	-	-	-	0.024	0.029	-	-	-	-
Dioxins & Furans ^{f,g}	0.00025	0.00025	-	-	-	-	-	0.00025	0.00025	-	-	-	-	-	-
PCBs	1.3	1.3	-	-	33	33	-	1.3	1.3	-	-	-	-	-	-
Pesticides															
Aldicarb ^{e}	0.041	0.065	0.041	0.065	-	-	-	-	-	BDL	BDL	-	-	-	-
Aldrin	5.9	7.4	5.9	11	-	-	-	-	-	6.1	7.4	-	-	-	-
Atrazine and metabolites	0.0088	0.01	0.10	0.19	-	-	-	-	-	0.0088	0.01	-	-	-	-
Azniphos-methyl	0.41	0.75	0.41	0.75	-	-	-	-	-	-	-	-	-	-	-
Bendiocarb	0.14	0.21	0.14	0.21	-	-	-	-	-	-	-	-	-	-	-
Bromoxynil	0.044	0.052	0.18	0.35	-	-	-	-	-	0.044	0.052	-	-	-	-
Carbaryl ^{e}	1.9	3.6	1.9	3.6	-	-	-	-	-	BDL	BDL	-	-	-	-
Carbofuran ^{e}	0.68	1.2	0.68	1.2	-	-	-	-	-	BDL	BDL	-	-	-	-
Chlorothalonil	0.0084	0.01	27	53	-	-	-	-	-	0.0084	0.01	-	-	-	-
Chlorpyrifos ^{e}	49	95	49	95	-	-	-	-	-	BDL	BDL	-	-	-	-
Cyanazine ^{e}	0.12	0.21	0.12	0.21	-	-	-	-	-	BDL	BDL	-	-	-	-

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) **.**

Receptor	Overall Guideline		Human		Ecological									Other	
Pathway			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient Energy Cycling Check	Livestock Soil and Food Ingestion	Wildlife Soil and Food Ingestion	Protection of Freshwater Aquatic Life		Protection of Wildlife Water		Management Limit	
Soil Type	Fine	Coarse	Fine	Coarse	Fine	Coarse		-	-	Fine	Coarse	Fine	Coarse	Fine	Coarse
Building Type			-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
2,4-D ^{e}	0.43	0.67	0.43	0.67	-	-	-	-	-	BDL	BDL	-	-	-	-
DDT	0.015	0.018	5,900	11,000	12	12	547	0.7	0.7	0.015	0.018	-	-	-	-
Diazinon	2.2	4.2	2.2	4.2	-	-	-	-	-	-	-	-	-	-	-
Dicamba ^{e}	0.5	0.79	0.5	0.79	-	-	-	-	-	BDL	BDL	-	-	-	-
Dichlofop-methyl	2	2.4	12	24	-	-	-	-	-	2	2.4	-	-	-	-
Dieldrin	0.011	0.014	0.59	1.1	-	-	-	-	-	0.011	0.014	-	-	-	-
Dimethoate	0.0058	0.0055	0.077	0.12	-	-	-	-	-	0.0058	0.0055	-	-	-	-
Dinoseb ^{e}	2.8	5.5	2.8	5.5	-	-	-	-	-	BDL	BDL	-	-	-	-
Diquat	11	21	11	21	-	-	-	-	-	-	-	-	-	-	-
Diuron	1.9	3.5	1.9	3.5	-	-	-	-	-	-	-	-	-	-	-
Endosulfan	0.0085	0.01	99	190	-	-	-	-	-	0.0085	0.01	-	-	-	-
Endrin	0.0075	0.009	2.4	4.7	-	-	-	-	-	0.0075	0.009	-	-	-	-
Glyphosate	0.054	0.049	0.95	1.4	-	-	-	-	-	0.054	0.049	-	-	-	-
Heptachlor epoxide ^{e}	0.039	0.076	0.039	0.076	-	-	-	-	-	BDL	BDL	-	-	-	-
Lindane ^{e}	0.31	0.6	0.31	0.6	-	-	-	-	-	BDL	BDL	-	-	-	-
Linuron	0.051	0.059	0.56	1.1	-	-	-	-	-	0.051	0.059	-	-	-	-
Malathion ^{e}	0.82	1.3	0.82	1.3	-	-	-	-	-	BDL	BDL	-	-	-	-
MCPA ^{e}	0.02	0.032	0.02	0.032	-	-	-	-	-	BDL	BDL	-	-	-	-
Methoxychlor	0.046	0.056	5700	11000	-	-	-	-	-	0.046	0.056	-	-	-	-
Metolachlor	0.048	0.055	1.3	2.4	-	-	-	-	-	0.048	0.055	-	-	-	-
Metribuzin	0.024	0.028	7.8	15	-	-	-	-	-	0.024	0.028	-	-	-	-
Paraquat (as dichloride)	1.1	2.2	1.1	2.2	-	-	-	-	-	-	-	-	-	-	-
Parathion ^{e}	7.2	14	7.2	14	-	-	-	-	-	BDL	BDL	-	-	-	-
Phorate	0.075	0.14	0.075	0.14	-	-	-	-	-	-	-	-	-	-	-

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) **.**

Receptor	**Overall Guideline**		**Human**		**Ecological**									**Other**	
Pathway			**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Wildlife Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Picloram	0.024	0.022	0.64	0.94	-	-	-	-	-	0.024	0.022	-	-	-	-
Simazine	0.033	0.038	0.14	0.25	-	-	-	-	-	0.033	0.038	-	-	-	-
Tebuthiuron [e]	2.5	3.7	2.5	3.7	-	-	-	-	-	BDL	BDL	-	-	-	-
Terbufos	0.08	0.15	0.08	0.15	-	-	-	-	-	-	-	-	-	-	-
Toxaphene [e]	3.3	6.3	3.3	6.3	-	-	-	-	-	BDL	BDL	-	-	-	-
Triallate	0.0077	0.0092	16	31	-	-	-	-	-	0.0077	0.0092	-	-	-	-
Trifluarin	0.038	0.045	35	67	-	-	-	-	-	0.038	0.045	-	-	-	-
Other Organics															
Aniline [e]	0.36	0.6	0.36	0.6	-	-	-	-	-	BDL	BDL	-	-	-	-
Bis(2-ethyl-hexyl)phthalate	34	41	3,600	7,000	-	-	-	-	-	34	41	-	-	-	-
Dibutyl phthalate	0.54	0.65	70	130	-	-	-	-	-	0.54	0.65	-	-	-	-
Dichlorobenzidine	4.2	8.1	4.2	8.1	-	-	-	-	-	-	-	-	-	-	-
Diisopropanolamine	14	17	130	250	360	360	-	-	-	14	17	-	-	-	-
Ethylene glycol	60	62	60	68	1,100	1,100	1,700	-	-	89	62	-	-	-	-
Hexachlorobutadiene	0.026	0.031	0.5	0.95	-	-	-	-	-	0.026	0.031	-	-	-	-
Methylmethacrylate	1.3	1.8	1.3	1.8	-	-	-	-	-	-	-	-	-	-	-
MTBE	0.044	0.062	0.044	0.062	-	-	-	-	-	7.1	6.1	-	-	-	-
Nonylphenol + ethoxylates	2.7	3.3	-	-	5.7	5.7	-	-	-	2.7	3.3	-	-	-	-
Phenol	0.0028	0.0024	1.6	2.3	20	20	-	-	-	0.0028	0.0024	-	-	-	-
Sulfolane	0.18	0.21	0.18	0.21	210	210	-	-	-	24	18	-	-	-	-

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Notes:

a. For more information see Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes (AEP, 1996)

b. True total barium as measured by fusion-XRF or fusion-ICP. For more information see Soil Remediation Guidelines for Barite: Environmental Health and Human Health (AENV, 2009b)

c. The Index of Additive Cancer Risk (IACR) is calculated by dividing the soil concentration of each carcinogenic PAH by its Protection of Domestic Use Aquifer guideline value to calculate a hazard index for each PAH and subsequently summing the hazard indexes for the entire PAH mixture, as follows:

Fine Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{1.6\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{0.74\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.16\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{32\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{1.7\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{10\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{1.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{13\ \mathrm{mg \cdot kg^{-1}}}$$

Coarse Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{3.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{1.4\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.31\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{63\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{3.4\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{19\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{2.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{24\ \mathrm{mg \cdot kg^{-1}}}$$

d. Overall guideline value for ecological receptors only.

e. Guideline for protection of aquatic life is below detection limit, groundwater monitoring is required.

f. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

g. Guideline values adopted directly from CCME (1999 and updates) without change.

BDL - Below detection limit
NGR - no guideline required, calculated value >1,000,000 mg/kg; or for PAH groundwater protection, calculated value results in groundwater concentration greater than solubility

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
General and Inorganic Parameters																								
pH (in 0.01M $CaCl_2$)	6-8.5	6-8.5	-	-	-	-	-	-	-	6-8.5	6-8.5	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyanide (free)	0.9	0.9	29	-	-	-	-	-	-	0.9	0.9	-	11	-	-	-	-	-	-	-	-	-	-	-
Fluoride	200	200	-	-	-	-	-	-	-	200	200	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulphur (elemental) [a]	500	500	-	-	-	-	-	-	-	500	500	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals																								
Antimony	20	20	-	-	-	-	-	-	-	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (inorganic)	17	17	21	-	-	-	-	-	-	17	17	-	380	-	-	-	-	-	-	-	-	-	-	-
Barium (non-barite)	750	750	-	-	-	-	-	-	-	750	750	-	-	-	-	-	-	-	-	-	-	-	-	-
Barite-barium [b]	10,000	10,000	10,000	-	-	-	-	-	-	200,000	200,000	-	30,000	10,000	-	-	-	-	-	-	-	-	-	-
Beryllium	5	5	-	-	-	-	-	-	-	5	5	-	-	-	-	-	-	-	-	-	-	-	-	-
Boron (hot water soluble)	2	2	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Cadmium	1.4	1.4	1.4	-	-	-	-	-	-	10	10	54	3.8	-	-	-	-	-	-	-	-	-	-	-
Chromium (hexavalent)	0.4	0.4	-	-	-	-	-	-	-	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (total)	64	64	220	-	-	-	-	-	-	64	64	52	-	-	-	-	-	-	-	-	-	-	-	-
Cobalt	20	20	-	-	-	-	-	-	-	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper	63	63	1,100	-	-	-	-	-	-	63	63	350	300	-	-	-	-	-	-	-	-	-	-	-
Lead	70	70	140	-	-	-	-	-	-	300	300	723	70	-	-	-	-	-	-	-	-	-	-	-
Mercury (inorganic)	6.6	6.6	6.6	-	-	-	-	-	-	12	12	20	-	-	-	-	-	-	-	-	-	-	-	-
Molybdenum	4	4	-	-	-	-	-	-	-	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel	50	50	-	-	-	-	-	-	-	50	50	146	355	-	-	-	-	-	-	-	-	-	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Selenium	1	1	80	-	-	-	-	-	-	1	1	-	4.5	-	-	-	-	-	-	-	-	-	-	-
Silver	20	20	-	-	-	-	-	-	-	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-
Thallium	1	1	1	-	-	-	-	-	-	1.4	1.4	-	1.0	-	-	-	-	-	-	-	-	-	-	-
Tin	5	5	-	-	-	-	-	-	-	5	5	-	-	-	-	-	-	-	-	-	-	-	-	-
Uranium	23	23	23	-	-	-	-	-	-	33	33	-	500	-	-	-	-	-	-	-	-	-	-	-
Vanadium	130	130	-	-	-	-	-	-	-	130	130	255	-	-	-	-	-	-	-	-	-	-	-	-
Zinc	200	200	-	-	-	-	-	-	-	200	200	200	640	-	-	-	-	-	-	-	-	-	-	-
Hydrocarbons																								
Benzene	0.046	0.073	78	1.7	1.6	0.1	0.073	0.046	0.078	60	31	-	44	18	73	1.6	0.2	0.21	15	0.33	-	-	-	-
Toluene	0.52	0.49	20,000	2,100	1,900	130	95	0.52	0.95	110	75	-	2,500	980	250,000	0.49	26	29	NGR	1,000	-	-	-	-
Ethylbenzene	0.11	0.21	8,500	1,000	930	60	44	0.11	0.21	120	55	-	1,600	640	NGR	540	36	42	NGR	17,000	-	-	-	-
Xylenes	15	12	140,000	280	250	16	12	15	28	65	95	-	6,600	2,600	NGR	250	160	180	NGR	16,000	-	-	-	-
Styrene	0.68	0.8	10,000	250	220	14	10	110	210	-	-	-	-	-	0.68	0.8	-	-	-	-	-	-	-	-
F1	210	24	12,000	710	610	30	24	1,100	2,200	210	210	-	27,000	11,000	30,000	1,300	6,600	7,400	30,000	30,000	-	-	800	700
F2	150	130	6,800	3,600	3,100	160	130	1,500	2,900	150	150	-	25,000	9,800	30,000	520	16,000	19,000	30,000	30,000	-	-	1,000	1,000
F3	1,300	300	15,000	-	-	-	-	-	-	1,300	300	-	30,000	16,000	-	-	-	-	-	-	-	-	3,500	2,500
F4	5,600	2,800	21,000	-	-	-	-	-	-	5,600	2,800	-	21,000	8,400	-	-	-	-	-	-	-	-	10,000	10,000
Acenapthene	0.32	0.38	5,300	120,000	99,000	4,800	3,900	NGR	NGR	-	-	-	21.5	21.5	0.32	0.38	NGR	NGR	NGR	NGR	-	-	-	-
Acenaphthylene	5.0	6.0	-	-	-	-	-	-	-	-	-	-	-	-	5.0	6.0	-	-	-	-	-	-	-	-
Anthracene	0.0046	0.0056	24,000	NGR	NGR	780,000	670,000	NGR	NGR	2.5	2.5	-	61.5	61.5	0.0046	0.0056	NGR	NGR	NGR	NGR	-	-	-	-
Fluoranthene	0.032	0.039	3,500	NGR	NGR	550,000	480,000	NGR	NGR	50	50	-	15.4	15.4	0.032	0.039	NGR	NGR	NGR	NGR	-	-	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Fluorene	0.29	0.34	2,700	270,000	220,000	10,000	8,600	NGR	NGR	-	-	-	15.4	15.4	0.29	0.34	NGR	NGR	NGR	NGR	-	-	-	-
Naphthalene	0.016	0.018	1,800	58	51	2.9	2.2	28	53	-	-	-	8.8	8.8	0.016	0.018	NGR	NGR	NGR	NGR	-	-	-	-
Phenanthrene	0.051	0.061	-	-	-	-	-	-	-	-	-	-	43	43	0.051	0.061	NGR	NGR	NGR	NGR	-	-	-	-
Pyrene	0.034	0.040	2100	NGR	NGR	810,000	730,000	NGR	NGR	-	-	-	7.7	7.7	0.034	0.040	NGR	NGR	NGR	NGR	-	-	-	-
Carcinogenic PAHs (as B(a)P TPE) [e]	IARC<1.0 [e]	IARC<1.0 [e]	5.3[d]	NGR	NGR	NGR	NGR	IARC<1.0 [e]	IARC<1.0 [e]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Benz[a]anthracene [f]	0.070	0.083	-	-	-	-	-	1.6	3.1	-	-	-	6.2	6.2	0.070	0.083	NGR	NGR	NGR	NGR	-	-	-	-
Benzo[b+j]fluoranthene [f]	6.2	6.2	-	-	-	-	-	0.74	1.4	-	-	-	6.2	6.2	NGR	NGR	NGR	NGR	NGR	NGR	-	-	-	-
Benzo[k]fluoranthene [f]	6.2	6.2	-	-	-	-	-	0.16	0.31	-	-	-	6.2	6.2	NGR	NGR	NGR	NGR	NGR	NGR	-	-	-	-
Benzo[g,h,i]perylene	-	-	-	-	-	-	-	32	63	-	-	-	-	-	NGR	NGR	-	-	-	-	-	-	-	-
Benzo[a]pyrene [f]	0.6	0.6	-	-	-	-	-	1.7	3.4	20	20	-	0.6	0.6	0.70	0.77	NGR	NGR	NGR	NGR	-	-	-	-
Chrysene [f]	6.2	6.2	-	-	-	-	-	10	19	-	-	-	6.2	6.2	NGR	NGR	NGR	NGR	NGR	NGR	-	-	-	-
Dibenz[a,h]anthracene [f]	7.4	8.4	-	-	-	-	-	1.1	2.1	-	-	-	-	-	7.4	8.4	-	-	-	-	-	-	-	-
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	-	-	13	24	-	-	-	-	-	NGR	NGR	-	-	-	-	-	-	-	-
Chlorinated Aliphatics																								
Vinyl chloride	0.0083	0.00034	71	0.009	0.0083	0.00049	0.00034	0.014	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,1-Dichloroethene	0.15	0.021	1,900	0.5	0.46	0.03	0.021	0.15	0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.054	0.012	35	0.31	0.28	0.017	0.012	0.054	0.093	3	3	-	-	-	0.72	0.081	0.13	0.14	-	-	-	-	-	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.69	0.16	530	4.1	3.7	0.22	0.16	0.77	1.4	-	-	-	-	-	0.69	0.77	-	-	-	-	-	-	-	-
1,2-Dichloroethane	0.0062	0.0027	2,800	0.06	0.055	0.0038	0.0027	0.025	0.041	-	-	-	-	-	0.12	0.12	0.0062	0.0062	-	-	-	-	-	-
Dichloromethane	0.052	0.048	990	18	16	1.0	0.71	0.21	0.32	-	-	-	-	-	0.1	0.095	0.052	0.048	-	-	-	-	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) **.**

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
(Methylene chloride)																								
Trichloromethane (Chloroform)	0.0029	0.001	220	0.024	0.022	0.002	0.001	0.62	1.0	-	-	-	-	-	0.0029	0.003	0.16	0.17	-	-	-	-	-	-
Tetrachloromethane (Carbon tetrachloride)	0.013	0.00056	27	0.014	0.013	0.00077	0.00056	0.092	0.16	-	-	-	-	-	0.059	0.062	0.022	0.023	-	-	-	-	-	-
Dibromochloromethane	0.12	0.12	760	11	7.8	0.28	0.27	0.91	1.5	-	-	-	-	-	-	-	0.12	0.12	-	-	-	-	-	-
Chlorinated Aromatics																								
Chlorobenzene [g]	0.39	0.018	16,000	0.44	0.39	0.024	0.018	0.61	1.1	-	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-
1,2-Dichlorobenzene [g]	0.097	0.18	16,000	260	230	14	10	0.097	0.18	-	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-
1,4-Dichlorobenzene	0.051	0.098	4,200	17	14	0.91	0.67	0.051	0.098	-	-	-	-	-	0.32	0.38	-	-	-	-	-	-	-	-
1,2,3-Trichlorobenzene	0.26	0.26	49	8.8	6.8	0.30	0.26	1.9	3.6	-	-	-	-	-	0.26	0.31	-	-	-	-	-	-	-	-
1,2,4-Trichlorobenzene	0.78	0.23	38	7.6	6	0.26	0.23	2.0	3.9	-	-	-	-	-	0.78	0.93	-	-	-	-	-	-	-	-
1,3,5-Trichlorobenzene	1.9	0.13	46	4.1	3.2	0.14	0.13	1.9	3.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.042	0.05	75	27	20	0.88	0.84	3.1	5.9	-	-	-	-	-	0.042	0.05	-	-	-	-	-	-	-	-
1,2,3,5-Tetrachlorobenzene	0.37	0.1	8.8	3.3	2.5	0.1	0.1	0.37	0.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.19	0.052	4.6	1.7	1.3	0.054	0.052	0.19	0.37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pentachlorobenzene	3.7	4.5	22	160	140	7.9	6.1	24	47	-	-	-	-	-	3.7	4.5	-	-	-	-	-	-	-	-
Hexachlorobenzene	0.8	0.5	18	13	12	0.64	0.5	3.6	7	-	-	-	-	-	-	-	0.8	0.97	-	-	-	-	-	-
2,4-Dichlorophenol	0.0029	0.0034	2,200	170,000	140,000	6,300	5,400	0.018	0.034	-	-	-	-	-	0.0029	0.0034	-	-	-	-	-	-	-	-
2,4,6-Trichlorophenol	0.19	0.37	260	11,000	8,200	360	320	0.19	0.37	-	-	-	-	-	0.42	0.5	-	-	-	-	-	-	-	-
2,3,4,6-Tetrachlorophenol	0.039	0.047	220	15,000	11,000	480	460	0.16	0.31	-	-	-	-	-	0.039	0.047	-	-	-	-	-	-	-	-
Pentachlorophenol	0.024	0.029	230	NGR	NGR	110,000	83,000	6	12	11	11	-	-	-	0.024	0.029	-	-	-	-	-	-	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Dioxins & Furans [h,i]	0.000004	0.000004	0.000004	-	-	-	-	-	-	-	-	-	0.00025	0.00025	-	-	-	-	-	-	-	-	-	-
PCBs	1.3	1.3	22	-	-	-	-	-	-	33	33	-	1.3	1.3	-	-	-	-	-	-	-	-	-	-
Pesticides																								
Aldicarb [g]	0.012	0.012	22	-	-	-	-	0.041	0.065	-	-	-	-	-	BDL	BDL	0.012	0.012	-	-	0.06	0.059	-	-
Aldrin	3.4	3.4	3.4	-	-	-	-	5.9	11	-	-	-	-	-	6.1	7.4	-	-	-	-	-	-	-	-
Atrazine and metabolites	0.0088	0.01	11	-	-	-	-	0.10	0.19	-	-	-	-	-	0.0088	0.01	0.025	0.028	-	-	0.049	0.057	-	-
Azniphos-methyl	0.41	0.75	55	-	-	-	-	0.41	0.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bendiocarb	0.14	0.21	89	-	-	-	-	0.14	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bromoxynil [g]	0.044	0.052	11	-	-	-	-	0.18	0.35	-	-	-	-	-	0.044	0.052	0.097	0.11	-	-	BDL	BDL	-	-
Carbaryl [g]	1.9	3.6	220	-	-	-	-	1.9	3.6	-	-	-	-	-	BDL	BDL	5.7	6.5	-	-	-	-	-	-
Carbofuran [g]	0.082	0.089	220	-	-	-	-	0.68	1.2	-	-	-	-	-	BDL	BDL	0.082	0.089	-	-	-	-	-	-
Chlorothalonil	0.0084	0.01	330	-	-	-	-	27	53	-	-	-	-	-	0.0084	0.01	7.9	9.5	-	-	0.27	0.32	-	-
Chlorpyrifos [g]	3.2	3.8	220	-	-	-	-	49	95	-	-	-	-	-	BDL	BDL	3.2	3.8	-	-	-	-	-	-
Cyanazine [g]	0.029	0.032	29	-	-	-	-	0.12	0.21	-	-	-	-	-	BDL	BDL	0.029	0.032	-	-	BDL	BDL	-	-
2,4-D [g]	0.1	0.1	220	-	-	-	-	0.43	0.67	-	-	-	-	-	BDL	BDL	0.1	0.1	-	-	-	-	-	-
DDT	0.015	0.018	220	-	-	-	-	5,900	11,000	12	12	547	0.7	0.7	0.015	0.018	1500	1800	-	-	-	-	-	-
Diazinon	2.2	4.2	44	-	-	-	-	2.2	4.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dicamba [g]	0.12	0.12	280	-	-	-	-	0.5	0.79	-	-	-	-	-	BDL	BDL	0.12	0.12	-	-	BDL	BDL	-	-
Dichlofop-methyl	0.059	0.071	22	-	-	-	-	12	24	-	-	-	-	-	2	2.4	3	3.6	-	-	0.059	0.071	-	-
Dieldrin	0.011	0.014	3.4	-	-	-	-	0.59	1.1	-	-	-	-	-	0.011	0.014	-	-	-	-	-	-	-	-
Dimethoate	0.0028	0.0027	44	-	-	-	-	0.077	0.12	-	-	-	-	-	0.0058	0.0055	0.0028	0.0027	-	-	-	-	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

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This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Dinoseb [g]	1.1	1.3	22	-	-	-	-	2.8	5.5	-	-	-	-	-	BDL	BDL	10	12	-	-	1.1	1.3	-	-
Diquat	11	21	180	-	-	-	-	11	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diuron	1.9	3.5	350	-	-	-	-	1.9	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Endosulfan	0.0085	0.01	210	-	-	-	-	99	190	-	-	-	-	-	0.0085	0.01	-	-	-	-	-	-	-	-
Endrin	0.0075	0.009	10	-	-	-	-	2.4	4.7	-	-	-	-	-	0.0075	0.009	-	-	-	-	-	-	-	-
Glyphosate	0.054	0.049	670	-	-	-	-	0.95	1.4	-	-	-	-	-	0.054	0.049	0.23	0.21	-	-	-	-	-	-
Heptachlor epoxide [g]	0.039	0.010	0.46	0.31	0.21	0.010	0.012	0.039	0.076	-	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-
Lindane [g]	0.11	0.13	6.7	-	-	-	-	0.31	0.6	-	-	-	-	-	BDL	BDL	0.11	0.13	-	-	-	-	-	-
Linuron [g]	0.051	0.059	44	-	-	-	-	0.56	1.1	-	-	-	-	-	0.051	0.059	-	-	-	-	BDL	BDL	-	-
Malathion [g]	0.82	1.3	440	-	-	-	-	0.82	1.3	-	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-
MCPA [g]	0.02	0.025	11	-	-	-	-	0.02	0.032	-	-	-	-	-	BDL	BDL	0.026	0.025	-	-	BDL	BDL	-	-
Methoxychlor	0.046	0.056	3500	-	-	-	-	0.046	0.056	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metolachlor	0.048	0.055	110	-	-	-	-	1.3	2.4	-	-	-	-	-	0.048	0.055	0.3	0.35	-	-	0.17	0.2	-	-
Metribuzin	0.012	0.014	180	-	-	-	-	7.8	15	-	-	-	-	-	0.024	0.028	1.9	2.2	-	-	0.012	0.014	-	-
Paraquat (as dichloride)	1.1	2.2	22	-	-	-	-	1.1	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parathion [g]	7.2	14	110	-	-	-	-	7.2	14	-	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-
Phorate	0.075	0.14	4.4	-	-	-	-	0.075	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Picloram	0.024	0.022	440	-	-	-	-	0.64	0.94	-	-	-	-	-	0.024	0.022	0.15	0.14	-	-	-	-	-	-
Simazine [g]	0.033	0.038	29	-	-	-	-	0.14	0.25	-	-	-	-	-	0.033	0.038	0.033	0.038	-	-	BDL	BDL	-	-
Tebuthiuron [g]	0.12	0.11	1600	-	-	-	-	2.5	3.7	-	-	-	-	-	BDL	BDL	0.12	0.11	-	-	BDL	BDL	-	-
Terbufos	0.08	0.15	1.1	-	-	-	-	0.08	0.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

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This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Toxaphene [g]	3.3	4.8	4.8	4,600	3,100	150	170	3.3	6.3	-	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-
Triallate	0.0077	0.0092	290	-	-	-	-	16	31	-	-	-	-	-	0.0077	0.0092	7.4	8.8	-	-	-	-	-	-
Trifluarin	0.038	0.045	110	-	-	-	-	35	67	-	-	-	-	-	0.038	0.045	8.4	10	-	-	-	-	-	-
Other Organics																								
Aniline [g]	0.36	0.6	160	720	640	34	26	0.36	0.6	-	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-
Bis(2-ethyl-hexyl)phthalate	34	41	1,000	NGR	NGR	NGR	NGR	3,600	7,000	-	-	-	-	-	34	41	-	-	-	-	-	-	-	-
Dibutyl phthalate	0.54	0.65	1,300	22,0000	18,0000	9,200	7,400	70	130	-	-	-	-	-	0.54	0.65	-	-	-	-	-	-	-	-
Dichlorobenzidine	4.2	8.1	130	NGR	NGR	NGR	NGR	4.2	8.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diisopropanolamine	14	17	22,000	-	-	-	-	130	250	360	360	-	-	-	14	17	-	-	-	-	16	18	-	-
Ethylene glycol	60	62	73,000	NGR	NGR	120,000	86,000	60	68	1,100	1,100	1,700	-	-	89	62	-	-	-	-	-	-	-	-
Hexachlorobutadiene	0.026	0.0067	210	0.18	0.16	0.0087	0.0067	0.5	0.95	-	-	-	-	-	0.026	0.031	-	-	-	-	-	-	-	-
Methylmethacrylate	1.3	0.10	1,100	3.4	3.0	0.14	0.10	1.3	1.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MTBE	0.044	0.046	380	1.2	1.1	0.065	0.046	0.044	0.062	-	-	-	-	-	7.1	6.1	-	-	-	-	-	-	-	-
Nonylphenol + ethoxylates	2.7	3.3	-	-	-	-	-	-	-	5.7	5.7	-	-	-	2.7	3.3	-	-	-	-	-	-	-	-
Phenol	0.0014	0.0012	2,000	14,000	13,000	660	480	1.6	2.3	20	20	-	-	-	0.0028	0.0024	0.0014	0.0012	-	-	-	-	-	-
Sulfolane	0.18	0.18	350	-	-	-	-	0.18	0.21	210	210	-	-	-	24	18	-	-	-	-	0.24	0.18	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Notes:

a. *For more information see Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes (AEP, 1996)*

b. *True total barium as measured by fusion-XRF or fusion-ICP. For more information see Soil Remediation Guidelines for Barite: Environmental Health and Human Health (AENV, 2009b)*

c. *Human health direct soil contact guidelines for carcinogenic PAHs are based on B[a]P Total Potency Equivalents (TPE). TPEs are calculated by multiplying the soil concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (WHO/IPCS, 1998) scheme, as follows:*

Carcinogenic PAH Compound	**PEF**
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

d. *The B[a]P Total Potency Equivalents (TPEs) calculated for specific soil samples using Potency Equivalency Factors (PEFs) should be multiplied by an Uncertainty Factor of 3 when evaluating PAH mixtures associated with creosote or coal tar-type environmental releases, prior to evaluating against the human health direct contact soil remediation guideline.*

e. *The Index of Additive Cancer Risk (IACR) is calculated by dividing the soil concentration of each carcinogenic PAH by its Protection of Domestic Use Aquifer guideline value to calculate a hazard index for each PAH and subsequently summing the hazard indexes for the entire PAH mixture, as follows:*

Fine Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{1.6\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{0.74\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.16\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{32\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(a)pyrene}]}{1.7\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Chrysene}]}{10\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{1.1\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{13\ \mathrm{mg}\cdot\mathrm{kg}^{-1}}$$

Coarse Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{3.1\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{1.4\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.31\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{63\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Benzo(a)pyrene}]}{3.4\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Chrysene}]}{19\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{2.1\ \mathrm{mg}\cdot\mathrm{kg}^{-1}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{24\ \mathrm{mg}\cdot\mathrm{kg}^{-1}}$$

f . *Overall guideline value for ecological receptors only.*

g. *Guideline for protection of aquatic life or irrigation water is below detection limit, groundwater monitoring is required.*

h. *Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)*

i. *Guideline values adopted directly from CCME (1999 and updates) without change.*

BDL - Below detection limit

NGR - no guideline required, calculated value >1,000,000 mg/kg; or for PAH groundwater protection, calculated value results in groundwater concentration greater than solubility

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	Overall Guideline		Human							Ecological					Other	
Pathway			Direct Soil Contact	Vapour Inhalation				Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/ Energy Cycling Check	Protection of Freshwater Aquatic Life		Management Limit	
Soil Type	Fine	Coarse	-	Fine	Fine	Coarse	Coarse	Fine	Coarse	Fine	Coarse		Fine	Coarse	Fine	Coarse
Building Type			-	Basement	Slab	Basement	Slab	-	-	-	-	-	-	-	-	-
Unit	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
General and Inorganic Parameters																
pH (in 0.01M $CaCl_2$)	6-8.5	6-8.5	-	-	-	-	-	-	-	6-8.5	6-8.5	-	-	-	-	-
Cyanide (free)	0.9	0.9	29	-	-	-	-	-	-	0.9	0.9	-	-	-	-	-
Fluoride	200	200	-	-	-	-	-	-	-	200	200	-	-	-	-	-
Sulphur (elemental) [a]	500	500	-	-	-	-	-	-	-	500	500	-	-	-	-	-
Metals																
Antimony	20	20	-	-	-	-	-	-	-	20	20	-	-	-	-	-
Arsenic (inorganic)	17	17	21	-	-	-	-	-	-	17	17	-	-	-	-	-
Barium (non-barite)	500	500	-	-	-	-	-	-	-	500	500	-	-	-	-	-
Barite-barium [b]	10,000	10,000	10,000	-	-	-	-	-	-	200,000	200,000	-	-	-	-	-
Beryllium	5	5	-	-	-	-	-	-	-	5	5	-	-	-	-	-
Boron (hot water soluble)	2	2	-	-	-	-	-	-	-	2	2	-	-	-	-	-
Cadmium	10	10	14	-	-	-	-	-	-	10	10	54	-	-	-	-
Chromium (hexavalent)	0.4	0.4	-	-	-	-	-	-	-	0.4	0.4	-	-	-	-	-
Chromium (total)	64	64	220	-	-	-	-	-	-	64	64	52	-	-	-	-
Cobalt	20	20	-	-	-	-	-	-	-	20	20	-	-	-	-	-
Copper	63	63	1,100	-	-	-	-	-	-	63	63	350	-	-	-	-
Lead	140	140	140	-	-	-	-	-	-	300	300	723	-	-	-	-

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Mercury (inorganic)	6.6	6.6	6.6	-	-	-	-	-	-	12	12	20	-	-	-	-
Molybdenum	4	4	-	-	-	-	-	-	-	4	4	-	-	-	-	-
Nickel	50	50	-	-	-	-	-	-	-	50	50	146	-	-	-	-
Selenium	1	1	80	-	-	-	-	-	-	1	1	-	-	-	-	-
Silver	20	20	-	-	-	-	-	-	-	20	20	-	-	-	-	-
Thallium	1	1	1	-	-	-	-	-	-	1.4	1.4	-	-	-	-	-
Tin	5	5	-	-	-	-	-	-	-	5	5	-	-	-	-	-
Uranium	23	23	23	-	-	-	-	-	-	500	500	-	-	-	-	-
Vanadium	130	130	-	-	-	-	-	-	-	130	130	255	-	-	-	-
Zinc	200	200	-	-	-	-	-	-	-	200	200	200	-	-	-	-
Hydrocarbons																
Benzene	0.046	0.073	78	1.7	1.6	0.1	0.073	0.046	0.078	60	31	-	73	1.6	-	-
Toluene	0.52	0.49	20,000	2,100	1,900	130	95	0.52	0.95	110	75	-	250,000	0.49	-	-
Ethylbenzene	0.11	0.21	8,500	1,000	930	60	44	0.11	0.21	120	55	-	NGR	540	-	-
Xylenes	15	12	140,000	280	250	16	12	15	28	65	95	-	NGR	250	-	-
Styrene	0.68	0.8	10,000	250	220	14	10	110	210	-	-	-	0.68	0.8	-	-
F1	210	24	12,000	710	610	30	24	1,100	2,200	210	210	-	30,000	1,300	800	700
F2	150	130	6,800	3,600	3,100	160	130	1,500	2,900	150	150	-	30,000	520	1,000	1,000

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
F3	1,300	300	15,000	-	-	-	-	-	-	1,300	300	-	-	-	3,500	2,500
F4	5,600	2,800	21,000	-	-	-	-	-	-	5,600	2,800	-	-	-	10,000	10,000
Acenapthene	0.32	0.38	5,300	120,000	99,000	4,800	3,900	NGR	NGR	-	-	-	0.32	0.38	-	-
Acenaphthylene	5.0	6.0	-	-	-	-	-	-	-	-	-	-	5.0	6.0	-	-
Anthracene	0.0046	0.0056	24,000	NGR	NGR	780,000	670,000	NGR	NGR	2.5	2.5	-	0.0046	0.0056	-	-
Fluoranthene	0.032	0.039	3,500	NGR	NGR	550,000	480,000	NGR	NGR	50	50	-	0.032	0.039	-	-
Fluorene	0.29	0.34	2,700	270,000	220,000	10,000	8,600	NGR	NGR	-	-	-	0.29	0.34	-	-
Naphthalene	0.016	0.018	1800	58	51	2.9	2.2	28	53	-	-	-	0.016	0.018	-	-
Phenanthrene	0.051	0.061	-	-	-	-	-	-	-	-	-	-	0.051	0.061	-	-
Pyrene	0.034	0.040	2,100	NGR	NGR	810,000	730,000	NGR	NGR	-	-	-	0.034	0.040	-	-
Carcinogenic PAHs (as B(a)P TPE)^{c}	IARC<1.0 ^{e}	IARC<1.0 ^{e}	5.3 ^{d}	NGR	NGR	NGR	NGR	IARC<1.0 ^{e}	IARC<1.0 ^{e}	-	-	-	-	-	-	-
Benz[a]anthracene ^{f}	0.070	0.083	-	-	-	-	-	1.6	3.1	-	-	-	0.070	0.083	-	-
Benzo[b+j]fluoranthene	-	-	-	-	-	-	-	0.74	1.4	-	-	-	NGR	NGR	-	-
Benzo[k]fluoranthene	-	-	-	-	-	-	-	0.16	0.31	-	-	-	NGR	NGR	-	-
Benzo[g,h,i]perylene	-	-	-	-	-	-	-	32	63	-	-	-	NGR	NGR	-	-
Benzo[a]pyrene ^{f}	0.7	0.77	-	-	-	-	-	1.7	3.4	20	20	-	0.70	0.77	-	-
Chrysene	-	-	-	-	-	-	-	10	19	-	-	-	NGR	NGR	-	-
Dibenz[a,h]anthracene ^{f}	7.4	8.4	-	-	-	-	-	1.1	2.1	-	-	-	7.4	8.4	-	-

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) **.**

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	-	-	13	24	-	-	-	NGR	NGR	-	-
Chlorinated Aliphatics																
Vinyl chloride	0.0083	0.00034	71	0.009	0.0083	0.00049	0.00034	0.014	0.02	-	-	-	-	-	-	-
1,1-Dichloroethene	0.15	0.021	1,900	0.5	0.46	0.03	0.021	0.15	0.24	-	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.054	0.012	35	0.31	0.28	0.017	0.012	0.054	0.093	3	3	-	0.72	0.081	-	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.69	0.16	530	4.1	3.7	0.22	0.16	0.77	1.4	-	-	-	0.69	0.77	-	-
1,2-Dichloroethane	0.025	0.0027	2,800	0.06	0.055	0.0038	0.0027	0.025	0.041	-	-	-	0.12	0.12	-	-
Dichloromethane (Methylene chloride)	0.1	0.095	990	18	16	1.0	0.71	0.21	0.32	-	-	-	0.1	0.095	-	-
Trichloromethane (Chloroform)	0.0029	0.001	220	0.024	0.022	0.002	0.001	0.62	1.0	-	-	-	0.0029	0.003	-	-
Tetrachloromethane (Carbon tetrachloride)	0.013	0.00056	27	0.014	0.013	0.00077	0.00056	0.092	0.16	-	-	-	0.059	0.062	-	-
Dibromochloromethane	0.91	0.27	760	11	7.8	0.28	0.27	0.91	1.5	-	-	-	-	-	-	-
Chlorinated Aromatics																
Chlorobenzene ^{g}	0.39	0.018	16,000	0.44	0.39	0.024	0.018	0.61	1.1	-	-	-	BDL	BDL	-	-
1,2-Dichlorobenzene ^{g}	0.097	0.18	16,000	260	230	14	10	0.097	0.18	-	-	-	BDL	BDL	-	-
1,4-Dichlorobenzene	0.051	0.098	4,200	17	14	0.91	0.67	0.051	0.098	-	-	-	0.32	0.38	-	-
1,2,3-Trichlorobenzene	0.26	0.26	49	8.8	6.8	0.30	0.26	1.9	3.6	-	-	-	0.26	0.31	-	-

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
1,2,4-Trichlorobenzene	0.78	0.23	38	7.6	6	0.26	0.23	2.0	3.9	-	-	-	0.78	0.93	-	-
1,3,5-Trichlorobenzene	1.9	0.13	46	4.1	3.2	0.14	0.13	1.9	3.6	-	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.042	0.05	75	27	20	0.88	0.84	3.1	5.9	-	-	-	0.042	0.05	-	-
1,2,3,5-Tetrachlorobenzene	0.37	0.10	8.8	3.3	2.5	0.10	0.10	0.37	0.70	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.19	0.052	4.6	1.7	1.3	0.054	0.052	0.19	0.37	-	-	-	-	-	-	-
Pentachlorobenzene	3.7	4.5	22	160	140	7.9	6.1	24	47	-	-	-	3.7	4.5	-	-
Hexachlorobenzene	3.6	0.5	18	13	12	0.64	0.50	3.6	7	-	-	-	-	-	-	-
2,4-Dichlorophenol	0.0029	0.0034	2,200	170,000	140,000	6,300	5,400	0.018	0.034	-	-	-	0.0029	0.0034	-	-
2,4,6-Trichlorophenol	0.19	0.37	260	11,000	8,200	360	320	0.19	0.37	-	-	-	0.42	0.5	-	-
2,3,4,6-Tetrachlorophenol	0.039	0.047	220	15,000	11,000	480	460	0.16	0.31	-	-	-	0.039	0.047	-	-
Pentachlorophenol	0.024	0.029	230	NGR	NGR	110,000	83,000	6	12	11	11	-	0.024	0.029	-	-
Dioxins & Furans [h,i]	0.000004	0.000004	0.000004	-	-	-	-	-	-	-	-	-	-	-	-	-
PCBs	22	22	22	-	-	-	-	-	-	33	33	-	-	-	-	-
Pesticides																
Aldicarb [g]	0.041	0.065	22	-	-	-	-	0.041	0.065	-	-	-	BDL	BDL	-	-
Aldrin	3.4	3.4	3.4	-	-	-	-	5.9	11	-	-	-	6.1	7.4	-	-
Atrazine and metabolites	0.0088	0.01	11	-	-	-	-	0.10	0.19	-	-	-	0.0088	0.01	-	-
Azniphos-methyl	0.41	0.75	55	-	-	-	-	0.41	0.75	-	-	-	-	-	-	-

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Bendiocarb	0.14	0.21	89	-	-	-	-	0.14	0.21	-	-	-	-	-	-	-
Bromoxynil	0.044	0.052	11	-	-	-	-	0.18	0.35	-	-	-	0.044	0.052	-	-
Carbaryl ^{g}	1.9	3.6	220	-	-	-	-	1.9	3.6	-	-	-	BDL	BDL	-	-
Carbofuran ^{g}	0.68	1.2	220	-	-	-	-	0.68	1.2	-	-	-	BDL	BDL	-	-
Chlorothalonil	0.0084	0.01	330	-	-	-	-	27	53	-	-	-	0.0084	0.01	-	-
Chlorpyrifos ^{g}	49	95	220	-	-	-	-	49	95	-	-	-	BDL	BDL	-	-
Cyanazine ^{g}	0.12	0.21	29	-	-	-	-	0.12	0.21	-	-	-	BDL	BDL	-	-
2,4-D ^{g}	0.43	0.67	220	-	-	-	-	0.43	0.67	-	-	-	BDL	BDL	-	-
DDT	0.015	0.018	220	-	-	-	-	5,900	11,000	12	12	547	0.015	0.018	-	-
Diazinon	2.2	4.2	44	-	-	-	-	2.2	4.2	-	-	-	-	-	-	-
Dicamba ^{g}	0.5	0.79	280	-	-	-	-	0.5	0.79	-	-	-	BDL	BDL	-	-
Dichlofop-methyl	2	2.4	22	-	-	-	-	12	24	-	-	-	2	2.4	-	-
Dieldrin	0.011	0.014	3.4	-	-	-	-	0.59	1.1	-	-	-	0.011	0.014	-	-
Dimethoate	0.0058	0.0055	44	-	-	-	-	0.077	0.12	-	-	-	0.0058	0.0055	-	-
Dinoseb ^{g}	2.8	5.5	22	-	-	-	-	2.8	5.5	-	-	-	BDL	BDL	-	-
Diquat	11	21	180	-	-	-	-	11	21	-	-	-	-	-	-	-
Diuron	1.9	3.5	350	-	-	-	-	1.9	3.5	-	-	-	-	-	-	-
Endosulfan	0.0085	0.01	210	-	-	-	-	99	190	-	-	-	0.0085	0.01	-	-

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Endrin	0.0075	0.009	10	-	-	-	-	2.4	4.7	-	-	-	0.0075	0.009	-	-
Glyphosate	0.054	0.049	670	-	-	-	-	0.95	1.4	-	-	-	0.054	0.049	-	-
Heptachlor epoxide [g]	0.039	0.010	0.46	0.31	0.21	0.010	0.012	0.039	0.076	-	-	-	BDL	BDL	-	-
Lindane [g]	0.31	0.6	6.7	-	-	-	-	0.31	0.6	-	-	-	BDL	BDL	-	-
Linuron	0.051	0.059	44	-	-	-	-	0.56	1.1	-	-	-	0.051	0.059	-	-
Malathion [g]	0.82	1.3	440	-	-	-	-	0.82	1.3	-	-	-	BDL	BDL	-	-
MCPA [g]	0.02	0.032	11	-	-	-	-	0.02	0.032	-	-	-	BDL	BDL	-	-
Methoxychlor	0.046	0.056	3,500	-	-	-	-	0.046	0.056	-	-	-	-	-	-	-
Metolachlor	0.048	0.055	110	-	-	-	-	1.3	2.4	-	-	-	0.048	0.055	-	-
Metribuzin	0.024	0.028	180	-	-	-	-	7.8	15	-	-	-	0.024	0.028	-	-
Paraquat (as dichloride)	1.1	2.2	22	-	-	-	-	1.1	2.2	-	-	-	-	-	-	-
Parathion [g]	7.2	14	110	-	-	-	-	7.2	14	-	-	-	BDL	BDL	-	-
Phorate	0.075	0.14	4.4	-	-	-	-	0.075	0.14	-	-	-	-	-	-	-
Picloram	0.024	0.022	440	-	-	-	-	0.64	0.94	-	-	-	0.024	0.022	-	-
Simazine	0.033	0.038	29	-	-	-	-	0.14	0.25	-	-	-	0.033	0.038	-	-
Tebuthiuron [g]	2.5	3.7	1,600	-	-	-	-	2.5	3.7	-	-	-	BDL	BDL	-	-
Terbufos	0.08	0.15	1.1	-	-	-	-	0.08	0.15	-	-	-	-	-	-	-
Toxaphene [g]	3.3	4.8	4.8	4,600	3,100	150	170	3.3	6.3	-	-	-	BDL	BDL	-	-

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Triallate	0.0077	0.0092	290	-	-	-	-	16	31	-	-	-	0.0077	0.0092	-	-
Trifluarin	0.038	0.045	110	-	-	-	-	35	67	-	-	-	0.038	0.045	-	-
Other Organics																
Aniline [g]	0.36	0.6	160	720	640	34	26	0.36	0.6	-	-	-	BDL	BDL	-	-
Bis(2-ethyl-hexyl)phthalate	34	41	1,000	NGR	NGR	NGR	NGR	3,600	7,000	-	-	-	34	41	-	-
Dibutyl phthalate	0.54	0.65	1,300	22,0000	18,0000	9,200	7,400	70	130	-	-	-	0.54	0.65	-	-
Dichlorobenzidine	4.2	8.1	130	NGR	NGR	NGR	NGR	4.2	8.1	-	-	-	-	-	-	-
Diisopropanolamine	14	17	22,000	-	-	-	-	130	250	360	360	-	14	17	-	-
Ethylene glycol	60	62	73,000	NGR	NGR	120,000	86,000	60	68	1,100	1,100	1,700	89	62	-	-
Hexachlorobutadiene	0.026	0.0067	210	0.18	0.16	0.0087	0.0067	0.5	0.95	-	-	-	0.026	0.031	-	-
Methylmethacrylate	1.3	0.10	1,100	3.4	3.0	0.14	0.10	1.3	1.8	-	-	-	-	-	-	-
MTBE	0.044	0.046	380	1.2	1.1	0.065	0.046	0.044	0.062	-	-	-	7.1	6.1	-	-
Nonylphenol + ethoxylates	2.7	3.3	-	-	-	-	-	-	-	5.7	5.7	-	2.7	3.3	-	-
Phenol	0.0028	0.0024	2,000	14,000	13,000	660	480	1.6	2.3	20	20	-	0.0028	0.0024	-	-
Sulfolane	0.18	0.21	350	-	-	-	-	0.18	0.21	210	210	-	24	18	-	-

Table A-3. Surface Soil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Notes:

a. For more information see Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes (AEP, 1996)

b. True total barium as measured by fusion-XRF or fusion-ICP. For more information see Soil Remediation Guidelines for Barite: Environmental Health and Human Health (AENV, 2009b)

c. Human health direct soil contact guidelines for carcinogenic PAHs are based on B[a]P Total Potency Equivalents (TPE). TPEs are calculated by multiplying the soil concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (WHO/IPCS, 1998) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

d. The B[a]P Total Potency Equivalents (TPEs) calculated for specific soil samples using Potency Equivalency Factors (PEFs) should be multiplied by an Uncertainty Factor of 3 when evaluating PAH mixtures associated with creosote or coal tar-type environmental releases, prior to evaluating against the human health direct contact soil remediation guideline.

e. The Index of Additive Cancer Risk (IACR) is calculated by dividing the soil concentration of each carcinogenic PAH by its Protection of Domestic Use Aquifer guideline value to calculate a hazard index for each PAH and subsequently summing the hazard indexes for the entire PAH mixture. For example, the IARC for coarse textured soil would be calculated as follows:

Fine Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{1.6\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{0.74\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.16\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{32\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{1.7\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{10\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{1.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{13\ \mathrm{mg \cdot kg^{-1}}}$$

Coarse Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{3.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{1.4\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.31\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{63\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{3.4\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{19\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{2.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{24\ \mathrm{mg \cdot kg^{-1}}}$$

f. Overall guideline value for ecological receptors only.

g. Guideline for protection of aquatic life is below detection limit, groundwater monitoring is required.

h. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

i. Guideline values adopted directly from CCME (1999 and updates) without change.

BDL - Below detection limit

NGR - no guideline required, calculated value >1,000,000 mg/kg; or for PAH groundwater protection, calculated value results in groundwater concentration greater than solubility

Table A-4. Surface Soil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
General and Inorganic Parameters																
pH (in 0.01M $CaCl_2$)	6-8.5	6-8.5	-	-	-	-	-	-	6-8.5	6-8.5	-	-	-	-	-	-
Cyanide (free)	8	8	110	-	-	-	-	-	8	8	-	-	-	-	-	-
Fluoride	2,000	2,000	-	-	-	-	-	-	2,000	2,000	-	-	-	-	-	-
Sulphur (elemental) [a]	500	500	-	-	-	-	-	-	500	500	-	-	-	-	-	-
Metals																
Antimony	40	40	-	-	-	-	-	-	40	40	-	-	-	-	-	-
Arsenic (inorganic)	26	26	26	-	-	-	-	-	26	26	-	-	-	-	-	-
Barium (non-barite)	2,000	2,000	-	-	-	-	-	-	2,000	2,000	-	-	-	-	-	-
Barite-barium [b]	15,000	15,000	15,000	-	-	-	-	140,000	200,000	200,000	-	-	-	140,000	-	-
Beryllium	8	8	-	-	-	-	-	-	8	8	-	-	-	-	-	-
Boron (hot water soluble)	2	2	-	-	-	-	-	-	2	2	-	-	-	-	-	-
Cadmium	22	22	49	-	-	-	-	-	22	22	195	-	-	-	-	-
Chromium (hexavalent)	1.4	1.4	-	-	-	-	-	-	1.4	1.4	-	-	-	-	-	-
Chromium (total)	87	87	630	-	-	-	-	-	87	87	-	-	-	-	-	-
Cobalt	300	300	-	-	-	-	-	-	300	300	-	-	-	-	-	-
Copper	91	91	4,000	-	-	-	-	-	91	91	350	-	-	-	-	-
Lead	260	260	260	-	-	-	-	-	600	600	834	-	-	-	-	-
Mercury (inorganic)	24	24	24	-	-	-	-	-	50	50	52	-	-	-	-	-
Molybdenum	40	40	-	-	-	-	-	-	40	40	-	-	-	-	-	-
Nickel	50	50	-	-	-	-	-	-	50	50	182	-	-	-	-	-
Selenium	2.9	2.9	300	-	-	-	-	1,135	2.9	2.9	-	-	-	5	-	-
Silver	40	40	-	-	-	-	-	-	40	40	-	-	-	-	-	-
Thallium	1	1	1	-	-	-	-	-	3.6	3.6	-	-	-	-	-	-

Table A-4. Surface Soil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Tin	300	300	-	-	-	-	-	-	300	300	-	-	-	-	-	-
Uranium	33	33	33	-	-	-	-	-	2000	2000	-	-	-	-	-	-
Vanadium	130	130	-	-	-	-	-	-	130	130	255	-	-	-	-	-
Zinc	360	360	-	-	-	-	-	-	360	360	320	-	-	-	-	-
Hydrocarbons																
Benzene	0.046	0.078	120	11	0.9	0.046	0.078	1,100	310	180	-	73	1.6	440	-	-
Toluene	0.52	0.49	31,000	13,000	1,200	0.52	0.95	290,000	330	250	-	250,000	0.49	1,100	-	-
Ethylbenzene	0.11	0.21	13,000	6,500	530	0.11	0.21	120,000	430	300	-	NGR	540	790	-	-
Xylenes	15	28	210,000	1,700	140	15	28	NGR	230	350	-	NGR	250	930	-	-
Styrene	0.68	0.8	16,000	1,600	120	110	210	150,000	-	-	-	0.68	0.8	-	-	-
F1	320	270	19,000	4,500	270	1,100	2,200	30,000	320	320	-	30,000	1,300	3,000	800	700
F2	260	260	10,000	23,000	1,500	1,500	2,900	30,000	260	260	-	30,000	520	2,100	1,000	1,000
F3	2,500	1,700	23,000	-	-	-	-	30,000	2,500	1,700	-	-	-	4,300	3,500	2,500
F4	6,600	3,300	30,000	-	-	-	-	30,000	6,600	3,300	-	-	-	30,000	10,000	10,000
Acenapthene	0.32	0.38	8,000	770,000	43,000	NGR	NGR	75,000	-	-	-	0.32	0.38	-	-	-
Acenaphthylene	5.0	6.0	-	-	-	-	-	-	-	-	-	5.0	6.0	-	-	-
Anthracene	0.0046	0.0056	37,000	NGR	NGR	NGR	NGR	350,000	32	32	-	0.0046	0.0056	36	-	-
Fluoranthene	0.032	0.039	5,300	NGR	NGR	NGR	NGR	50,000	180	180	-	0.032	0.039	720	-	-
Fluorene	0.29	0.34	4,100	NGR	91,000	NGR	NGR	39,000	-	-	-	0.29	0.34	-	-	-
Naphthalene	0.016	0.018	2,800	370	25	28	53	26,000	-	-	-	0.016	0.018	-	-	-
Phenanthrene	0.051	0.061	-	-	-	-	-	-	-	-	-	0.051	0.061	-	-	-
Pyrene	0.034	0.040	3,200	NGR	NGR	NGR	NGR	30,000	-	-	-	0.034	0.040	-	-	-
Carcinogenic PAHs (as B(a)P TPE) [c]	IARC<1.0 [e]	IARC<1.0 [e]	8.0 [d]	NGR	NGR	IARC<1.0 [e]	IARC<1.0 [e]	75	-	-	-	-	-	-	-	-
Benz[a]anthracene [f]	0.070	0.083	-	-	-	1.6	3.1	-	-	-	-	0.070	0.083	-	-	-

Table A-4. Surface Soil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Benzo[b+j]fluoranthene	-	-	-	-	-	0.74	1.4	-	-	-	-	NGR	NGR	-	-	-
Benzo[k]fluoranthene	-	-	-	-	-	0.16	0.31	-	-	-	-	NGR	NGR	-	-	-
Benzo[g,h,i]perylene	-	-	-	-	-	32	63	-	-	-	-	NGR	NGR	-	-	-
Benzo[a]pyrene [f]	0.70	0.77	-	-	-	1.7	3.4	-	72	72	-	0.70	0.77	290	-	-
Chrysene	-	-	-	-	-	10	19	-	-	-	-	NGR	NGR	-	-	-
Dibenz[a,h]anthracene [f]	7.4	8.4	-	-	-	1.1	2.1	-	-	-	-	7.4	8.4	-	-	-
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	13	24	-	-	-	-	NGR	NGR	-	-	-
Chlorinated Aliphatics																
Vinyl chloride	0.014	0.0043	110	0.055	0.0043	0.014	0.02	1,000	-	-	-	-	-	-	-	-
1,1-Dichloroethene	0.15	0.24	2,900	3.1	0.27	0.15	0.24	27,000	-	-	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.054	0.081	54	1.9	0.15	0.054	0.093	630	50	50	-	0.72	0.081	43	-	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.69	0.77	810	26	2	0.77	1.4	7,600	-	-	-	0.69	0.77	-	-	-
1,2-Dichloroethane	0.025	0.033	4,200	0.37	0.033	0.025	0.041	40,000	-	-	-	0.12	0.12	-	-	-
Dichloromethane (Methylene chloride)	0.1	0.095	1,500	110	9.0	0.21	0.32	14,000	-	-	-	0.1	0.095	-	-	-
Trichloromethane (Chloroform)	0.0029	0.003	330	0.15	0.014	0.62	1.0	3,100	-	-	-	0.0029	0.003	-	-	-
Tetrachloromethane (Carbon tetrachloride)	0.059	0.0068	40	0.09	0.0068	0.092	0.16	380	-	-	-	0.059	0.062	-	-	-
Dibromochloromethane	0.91	1.5	1,200	76	2.5	0.91	1.5	11,000	-	-	-	-	-	-	-	-
Chlorinated Aromatics																
Chlorobenzene [g]	0.61	0.22	25,000	2.7	0.22	0.61	1.1	230,000	-	-	-	BDL	BDL	-	-	-
1,2-Dichlorobenzene [g]	0.097	0.18	25,000	1,700	130	0.097	0.18	230,000	-	-	-	BDL	BDL	-	-	-
1,4-Dichlorobenzene	0.051	0.098	6,200	100	8	0.051	0.098	59,000	-	-	-	0.32	0.38	-	-	-

Table A-4. Surface Soil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
1,2,3-Trichlorobenzene	0.26	0.31	74	58	2.7	1.9	3.6	700	-	-	-	0.26	0.31	-	-	-
1,2,4-Trichlorobenzene	0.78	0.93	58	51	2.4	2.0	3.9	540	-	-	-	0.78	0.93	-	-	-
1,3,5-Trichlorobenzene	1.9	1.3	69	27	1.3	1.9	3.6	660	-	-	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.042	0.05	110	190	7.9	3.1	5.9	1,100	-	-	-	0.042	0.05	-	-	-
1,2,3,5-Tetrachlorobenzene	0.37	0.70	14	23	1	0.37	0.70	130	-	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.19	0.37	7	12	0.49	0.19	0.37	66	-	-	-	-	-	-	-	-
Pentachlorobenzene	3.7	4.5	34	1000	70	24	47	320	-	-	-	3.7	4.5	-	-	-
Hexachlorobenzene	3.6	6	27	85	6	3.6	7	260	-	-	-	-	-	-	-	-
2,4-Dichlorophenol	0.0029	0.0034	3,300	NGR	57,000	0.018	0.034	31,000	-	-	-	0.0029	0.0034	-	-	-
2,4,6-Trichlorophenol	0.19	0.37	400	71,000	3,300	0.19	0.37	3,700	-	-	-	0.42	0.5	-	-	-
2,3,4,6-Tetrachlorophenol	0.039	0.047	340	110,000	4,400	0.16	0.31	3,000	-	-	-	0.039	0.047	-	-	-
Pentachlorophenol	0.024	0.029	340	NGR	950,000	6	12	3,200	28	28	-	0.024	0.029	160	-	-
Dioxins & Furans ^{h,i}	0.000004	0.000004	0.000004	-	-	-	-	0.000004	-	-	-	-	-	-	-	-
PCBs	33	33	33	-	-	-	-	310	33	33	-	-	-	470	-	-
Pesticides																
Aldicarb ^{g}	0.041	0.065	34	-	-	0.041	0.065	320	-	-	-	BDL	BDL	-	-	-
Aldrin	5.1	5.1	5.1	-	-	5.9	11	49	-	-	-	6.1	7.4	-	-	-
Atrazine and metabolites	0.0088	0.01	17	-	-	0.10	0.19	160	-	-	-	0.0088	0.01	-	-	-
Azniphos-methyl	0.41	0.75	84	-	-	0.41	0.75	790	-	-	-	-	-	-	-	-
Bendiocarb	0.14	0.21	130	-	-	0.14	0.21	1,300	-	-	-	-	-	-	-	-
Bromoxynil	0.044	0.052	17	-	-	0.18	0.35	160	-	-	-	0.044	0.052	-	-	-
Carbaryl ^{g}	1.9	3.6	340	-	-	1.9	3.6	3,200	-	-	-	BDL	BDL	-	-	-
Carbofuran ^{g}	0.68	1.2	340	-	-	0.68	1.2	3,200	-	-	-	BDL	BDL	-	-	-
Chlorothalonil	0.0084	0.01	500	-	-	27	53	4,800	-	-	-	0.0084	0.01	-	-	-

Table A-4. Surface Soil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Chlorpyrifos [g]	49	95	340	-	-	49	95	3,200	-	-	-	BDL	BDL	-	-	-
Cyanazine [g]	0.12	0.21	44	-	-	0.12	0.21	410	-	-	-	BDL	BDL	-	-	-
2,4-D [g]	0.43	0.67	340	-	-	0.43	0.67	3,200	-	-	-	BDL	BDL	-	-	-
DDT	0.015	0.018	340	-	-	5,900	11,000	3,200	12	12	547	0.015	0.018	170	-	-
Diazinon	2.2	4.2	67	-	-	2.2	4.2	630	-	-	-	-	-	-	-	-
Dicamba [g]	0.5	0.79	420	-	-	0.5	0.79	4,000	-	-	-	BDL	BDL	-	-	-
Dichlofop-methyl	2	2.4	34	-	-	12	24	320	-	-	-	2	2.4	-	-	-
Dieldrin	0.011	0.014	5.1	-	-	0.59	1.1	49	-	-	-	0.011	0.014	-	-	-
Dimethoate	0.0058	0.0055	67	-	-	0.077	0.12	630	-	-	-	0.0058	0.0055	-	-	-
Dinoseb [g]	2.8	5.5	34	-	-	2.8	5.5	320	-	-	-	BDL	BDL	-	-	-
Diquat	11	21	270	-	-	11	21	2,500	-	-	-	-	-	-	-	-
Diuron	1.9	3.5	520	-	-	1.9	3.5	4,900	-	-	-	-	-	-	-	-
Endosulfan	0.0085	0.01	320	-	-	99	190	3,000	-	-	-	0.0085	0.01	-	-	-
Endrin	0.0075	0.009	15	-	-	2.4	4.7	150	-	-	-	0.0075	0.009	-	-	-
Glyphosate	0.054	0.049	1,000	-	-	0.95	1.4	9,500	-	-	-	0.054	0.049	-	-	-
Heptachlor epoxide [g]	0.039	0.076	0.69	2.4	0.094	0.039	0.076	6.5	-	-	-	BDL	BDL	-	-	-
Lindane [g]	0.31	0.6	10	-	-	0.31	0.6	95	-	-	-	BDL	BDL	-	-	-
Linuron	0.051	0.059	67	-	-	0.56	1.1	630	-	-	-	0.051	0.059	-	-	-
Malathion [g]	0.82	1.3	670	-	-	0.82	1.3	6,300	-	-	-	BDL	BDL	-	-	-
MCPA [g]	0.02	0.032	17	-	-	0.02	0.032	160	-	-	-	BDL	BDL	-	-	-
Methoxychlor	0.046	0.056	5,300	-	-	5,700	11,000	50,000	-	-	-	0.046	0.056	-	-	-
Metolachlor	0.048	0.055	170	-	-	1.3	2.4	1,600	-	-	-	0.048	0.055	-	-	-
Metribuzin	0.024	0.028	280	-	-	7.8	15	2,600	-	-	-	0.024	0.028	-	-	-
Paraquat (as dichloride)	1.1	2.2	34	-	-	1.1	2.2	320	-	-	-	-	-	-	-	-

Table A-4. Surface Soil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways

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Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Parathion ^{g}	7.2	14	170	-	-	7.2	14	1,600	-	-	-	BDL	BDL	-	-	-
Phorate	0.075	0.14	6.7	-	-	0.075	0.14	63	-	-	-	-	-	-	-	-
Picloram	0.024	0.022	670	-	-	0.64	0.94	6,300	-	-	-	0.024	0.022	-	-	-
Simazine	0.033	0.038	44	-	-	0.14	0.25	410	-	-	-	0.033	0.038	-	-	-
Tebuthiuron ^{g}	2.5	3.7	2,400	-	-	2.5	3.7	22,000	-	-	-	BDL	BDL	-	-	-
Terbufos	0.08	0.15	1.7	-	-	0.08	0.15	16	-	-	-	-	-	-	-	-
Toxaphene ^{g}	3.3	6.3	7.3	36,000	1,400	3.3	6.3	69	-	-	-	BDL	BDL	-	-	-
Triallate	0.0077	0.0092	440	-	-	16	31	4,100	-	-	-	0.0077	0.0092	-	-	-
Trifluarin	0.038	0.045	160	-	-	35	67	1,500	-	-	-	0.038	0.045	-	-	-
Other Organics																
Aniline ^{g}	0.36	0.6	240	4500	300	0.36	0.6	2,200	-	-	-	BDL	BDL	-	-	-
Bis(2-ethyl-hexyl)phthalate	34	41	1,500	NGR	NGR	3,600	7,000	14,000	-	-	-	34	41	-	-	-
Dibutyl phthalate	0.54	0.65	1,900	NGR	82,000	70	130	19,000	-	-	-	0.54	0.65	-	-	-
Dichlorobenzidine	4.2	8.1	190	NGR	NGR	4.2	8.1	1,800	-	-	-	-	-	-	-	-
Diisopropanolamine	14	17	33,000	-	-	130	250	310,000	750	750	-	14	17	5,100	-	-
Ethylene glycol	60	62	110,000	NGR	NGR	60	68	NGR	1,800	1,800	2,000	89	62	16,000	-	-
Hexachlorobutadiene	0.026	0.031	320	1.2	0.078	0.5	0.95	3,000	-	-	-	0.026	0.031	-	-	-
Methylmethacrylate	1.3	1.3	1,700	20	1.3	1.3	1.8	16,000	-	-	-	-	-	-	-	-
MTBE	0.044	0.062	580	7.4	0.57	0.044	0.062	5,400	-	-	-	7.1	6.1	-	-	-
Nonylphenol + ethoxylates	2.7	3.3	-	-	-	-	-	-	14	14	-	2.7	3.3	82	-	-
Phenol	0.0028	0.0024	3,100	90,000	5,800	1.6	2.3	29,000	130	130	-	0.0028	0.0024	290	-	-
Sulfolane	0.18	0.21	540	-	-	0.18	0.21	5,000	430	430	-	24	18	3,000	-	-

Table A-4. Surface Soil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Notes:

a. For more information see Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes (AEP, 1996)

b. True total barium as measured by fusion-XRF or fusion-ICP. For more information see Soil Remediation Guidelines for Barite: Environmental Health and Human Health (AENV, 2009b)

c. Human health direct soil contact guidelines for carcinogenic PAHs are based on B[a]P Total Potency Equivalents (TPE). TPEs are calculated by multiplying the soil concentration of individual carcinogenic PAHs by a the standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (WHO/IPCS, 1998) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

d. The B[a]P Total Potency Equivalents (TPEs) calculated for specific soil samples using Potency Equivalency Factors (PEFs) should be multiplied by an Uncertainty Factor of 3 when evaluating PAH mixtures associated with creosote or coal tar-type environmental releases, prior to evaluating against the human health direct contact soil remediation guideline.

e. The Index of Additive Cancer Risk (IACR) is calculated by dividing the soil concentration of each carcinogenic PAH by its Protection of Domestic Use Aquifer guideline value to calculate a hazard a hazard index for each PAH and subsequently summing the hazard indexes for the entire PAH mixture, as follows:

Fine Soils:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{1.6\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{0.74\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.16\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{32\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{1.7\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{10\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{1.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{13\ \mathrm{mg \cdot kg^{-1}}}$$

Coarse Soils:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{3.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{1.4\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.31\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{63\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{3.4\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{19\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{2.1\ \mathrm{mg \cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{24\ \mathrm{mg \cdot kg^{-1}}}$$

f. Overall guideline value for ecological receptors only.

g. Guideline for protection of aquatic life is below detection limit, groundwater monitoring is required.

h. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

i. Guideline values adopted directly from CCME (1999 and updates) without change.

BDL - Below detection limit

NGR - no guideline required, calculated value >1,000,000 mg/kg; or for PAH groundwater protection, calculated value results in groundwater concentration greater than solubility

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
General and Inorganic Parameters																
pH (in 0.01M $CaCl_2$)	6-8.5	6-8.5	-	-	-	-	-	-	6-8.5	6-8.5	-	-	-	-	-	-
Cyanide (free)	8	8	420	-	-	-	-	-	8	8	-	-	-	-	-	-
Fluoride	2,000	2,000	-	-	-	-	-	-	2,000	2,000	-	-	-	-	-	-
Sulphur (elemental) [a]	500	500	-	-	-	-	-	-	500	500	-	-	-	-	-	-
Metals																
Antimony	40	40	-	-	-	-	-	-	40	40	-	-	-	-	-	-
Arsenic (inorganic)	26	26	26	-	-	-	-	-	26	26	-	-	-	-	-	-
Barium (non-barite)	2,000	2,000	-	-	-	-	-	-	2,000	2,000	-	-	-	-	-	-
Barite-barium [b]	140,000	140,000	140,000	-	-	-	-	140,000	200,000	200,000	-	-	-	140,000	-	-
Beryllium	8	8	-	-	-	-	-	-	8	8	-	-	-	-	-	-
Boron (hot water soluble)	2	2	-	-	-	-	-	-	2	2	-	-	-	-	-	-
Cadmium	22	22	2,090	-	-	-	-	-	22	22	195	-	-	-	-	-
Chromium (hexavalent)	1.4	1.4	-	-	-	-	-	-	1.4	1.4	-	-	-	-	-	-
Chromium (total)	87	87	2,300	-	-	-	-	-	87	87	-	-	-	-	-	-
Cobalt	300	300	-	-	-	-	-	-	300	300	-	-	-	-	-	-
Copper	91	91	16,000	-	-	-	-	-	91	91	350	-	-	-	-	-
Lead	600	600	8,200	-	-	-	-	-	600	600	834	-	-	-	-	-
Mercury (inorganic)	50	50	99	-	-	-	-	-	50	50	52	-	-	-	-	-
Molybdenum	40	40	-	-	-	-	-	-	40	40	-	-	-	-	-	-
Nickel	50	50	-	-	-	-	-	-	50	50	182	-	-	-	-	-

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Selenium	2.9	2.9	1,135	-	-	-	-	1,135	2.9	2.9	-	-	-	5	-	-
Silver	40	40	-	-	-	-	-	-	40	40	-	-	-	-	-	-
Thallium	1	1	1	-	-	-	-	-	3.6	3.6	-	-	-	-	-	-
Tin	300	300	-	-	-	-	-	-	300	300	-	-	-	-	-	-
Uranium	300	300	510	-	-	-	-	300	2,000	2,000	-	-	-	7,100	-	-
Vanadium	130	130	-	-	-	-	-	-	130	130	255	-	-	-	-	-
Zinc	360	360	-	-	-	-	-	-	360	360	320	-	-	-	-	-
Hydrocarbons																
Benzene	0.046	0.078	120	11	0.9	0.046	0.078	1,100	310	180	-	73	1.6	440	-	-
Toluene	0.52	0.49	350,000	13,000	1,200	0.52	0.95	290,000	330	250	-	250,000	0.49	1,100	-	-
Ethylbenzene	0.11	0.21	120,000	6,500	530	0.11	0.21	120,000	430	300	-	NGR	540	790	-	-
Xylenes	15	28	NGR	1,700	140	15	28	NGR	230	350	-	NGR	250	930	-	-
Styrene	0.68	0.8	150,000	1,600	120	110	210	150,000	-	-	-	0.68	0.8	-	-	-
F1	320	270	30,000	4,500	270	1,100	2,200	30,000	320	320	-	30,000	1,300	3,000	800	700
F2	260	260	30,000	23,000	1,500	1,500	2,900	30,000	260	260	-	30,000	520	2,100	1,000	1,000
F3	2,500	1,700	30,000	-	-	-	-	30,000	2,500	1,700	-	-	-	4,300	3,500	2,500
F4	6,600	3,300	30,000	-	-	-	-	30,000	6,600	3,300	-	-	-	30,000	10,000	10,000
Acenapthene	0.32	0.38	75,000	770,000	43,000	NGR	NGR	75,000	-	-	-	0.32	0.38	-	-	-
Acenaphthylene	5.0	6.0	-	-	-	-	-	-	-	-	-	5.0	6.0	-	-	-
Anthracene	0.0046	0.0056	300,000	NGR	NGR	NGR	NGR	350,000	32	32	-	0.0046	0.0056	36	-	-
Fluoranthene	0.032	0.039	50,000	NGR	NGR	NGR	NGR	50,000	180	180	-	0.032	0.039	720	-	-

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Fluorene	0.29	0.34	46,000	NGR	91,000	NGR	NGR	39,000	-	-	-	0.29	0.34	-	-	-
Naphthalene	0.016	0.018	34,000	370	25	28	53	26,000	-	-	-	0.016	0.018	-	-	-
Phenanthrene	0.051	0.061	-	-	-	-	-	-	-	-	-	0.051	0.061	-	-	-
Pyrene	0.034	0.040	34,000	NGR	NGR	NGR	NGR	30,000	-	-	-	0.034	0.040	-	-	-
Carcinogenic PAHs (as B(a)P TPE)^{c}	IARC<1.0^{e}	IARC<1.0^{e}	8^{d}	NGR	NGR	IARC<1.0^{e}	IARC<1.0^{e}	75	-	-	-	-	-	-	-	-
Benz[a]anthracene^{f}	0.070	0.083	-	-	-	1.6	3.1	-	-	-	-	0.070	0.083	-	-	-
Benzo[b+j]fluoranthene	-	-	-	-	-	0.74	1.4	-	-	-	-	NGR	NGR	-	-	-
Benzo[k]fluoranthene	-	-	-	-	-	0.16	0.31	-	-	-	-	NGR	NGR	-	-	-
Benzo[g,h,i]perylene	-	-	-	-	-	32	63	-	-	-	-	NGR	NGR	-	-	-
Benzo[a]pyrene^{f}	0.70	0.77	-	-	-	1.7	3.4	-	72	72	-	0.70	0.77	290	-	-
Chrysene	-	-	-	-	-	10	19	-	-	-	-	NGR	NGR	-	-	-
Dibenz[a,h]anthracene^{f}	7.4	8.4	-	-	-	1.1	2.1	-	-	-	-	7.4	8.4	-	-	-
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	13	24	-	-	-	-	NGR	NGR	-	-	-
Chlorinated Aliphatics																
Vinyl chloride	0.014	0.0043	110	0.055	0.0043	0.014	0.02	1,000	-	-	-	-	-	-	-	-
1,1-Dichloroethene	0.15	0.24	34,000	3.1	0.27	0.15	0.24	27,000	-	-	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.054	0.081	720	1.9	0.15	0.054	0.093	630	50	50	-	0.72	0.081	43	-	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.69	0.77	9,600	26	2	0.77	1.4	7,600	-	-	-	0.69	0.77	-	-	-
1,2-Dichloroethane	0.025	0.033	4,200	0.37	0.033	0.025	0.041	40,000	-	-	-	0.12	0.12	-	-	-
Dichloromethane	0.1	0.095	7,300	110	9.0	0.21	0.32	14,000	-	-	-	0.1	0.095	-	-	-

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
(Methylene chloride)																
Trichloromethane (Chloroform)	0.0029	0.003	4,400	0.15	0.014	0.62	1.0	3,100	-	-	-	0.0029	0.003	-	-	-
Tetrachloromethane (Carbon tetrachloride)	0.059	0.0068	260	0.09	0.0068	0.092	0.16	380	-	-	-	0.059	0.062	-	-	-
Dibromochloromethane	0.91	1.5	14,000	76	2.5	0.91	1.5	11,000	-	-	-	-	-	-	-	-
Chlorinated Aromatics																
Chlorobenzene [g]	0.61	0.22	300,000	2.7	0.22	0.61	1.1	230,000	-	-	-	BDL	BDL	-	-	-
1,2-Dichlorobenzene [g]	0.097	0.18	300,000	1700	130	0.097	0.18	230,000	-	-	-	BDL	BDL	-	-	-
1,4-Dichlorobenzene	0.051	0.098	74,000	100	8	0.051	0.098	59,000	-	-	-	0.32	0.38	-	-	-
1,2,3-Trichlorobenzene	0.26	0.31	930	58	2.7	1.9	3.6	700	-	-	-	0.26	0.31	-	-	-
1,2,4-Trichlorobenzene	0.78	0.93	850	51	2.4	2.0	3.9	540	-	-	-	0.78	0.93	-	-	-
1,3,5-Trichlorobenzene	1.9	1.3	920	27	1.3	1.9	3.6	660	-	-	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.042	0.05	540	190	7.9	3.1	5.9	1,100	-	-	-	0.042	0.05	-	-	-
1,2,3,5-Tetrachlorobenzene	0.37	0.70	66	23	0.96	0.37	0.70	130	-	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.19	0.37	34	12	0.49	0.19	0.37	66	-	-	-	-	-	-	-	-
Pentachlorobenzene	3.7	4.5	160	1000	70	24	47	320	-	-	-	3.7	4.5	-	-	-
Hexachlorobenzene	3.6	6	30	85	6	3.6	7	260	-	-	-	-	-	-	-	-
2,4-Dichlorophenol	0.0029	0.0034	16,000	NGR	57,000	0.018	0.034	31,000	-	-	-	0.0029	0.0034	-	-	-
2,4,6-Trichlorophenol	0.19	0.37	400	71,000	3,300	0.19	0.37	3,700	-	-	-	0.42	0.5	-	-	-
2,3,4,6-Tetrachlorophenol	0.039	0.047	1,500	110,000	4,400	0.16	0.31	3,000	-	-	-	0.039	0.047	-	-	-
Pentachlorophenol	0.024	0.029	4,000	NGR	950,000	6	12	3,200	28	28	-	0.024	0.029	160	-	-

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

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Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Dioxins & Furans [h,i]	0.000004	0.000004	-	-	-	-	-	0.000004	-	-	-	-	-	-	-	-
PCBs	33	33	160	-	-	-	-	310	33	33	-	-	-	470	-	-
Pesticides																
Aldicarb [g]	0.041	0.065	160	-	-	0.041	0.065	320	-	-	-	BDL	BDL	-	-	-
Aldrin	5.9	7.4	44	-	-	5.9	11	49	-	-	-	6.1	7.4	-	-	-
Atrazine and metabolites	0.0088	0.01	80	-	-	0.10	0.19	160	-	-	-	0.0088	0.01	-	-	-
Azniphos-methyl	0.41	0.75	400	-	-	0.41	0.75	790	-	-	-	-	-	-	-	-
Bendiocarb	0.14	0.21	640	-	-	0.14	0.21	1,300	-	-	-	-	-	-	-	-
Bromoxynil	0.044	0.052	80	-	-	0.18	0.35	160	-	-	-	0.044	0.052	-	-	-
Carbaryl [g]	1.9	3.6	1,600	-	-	1.9	3.6	3,200	-	-	-	BDL	BDL	-	-	-
Carbofuran [g]	0.68	1.2	1,600	-	-	0.68	1.2	3,200	-	-	-	BDL	BDL	-	-	-
Chlorothalonil	0.0084	0.01	2,400	-	-	27	53	4,800	-	-	-	0.0084	0.01	-	-	-
Chlorpyrifos [g]	49	95	1,600	-	-	49	95	3,200	-	-	-	BDL	BDL	-	-	-
Cyanazine [g]	0.12	0.21	210	-	-	0.12	0.21	410	-	-	-	BDL	BDL	-	-	-
2,4-D [g]	0.43	0.67	1,600	-	-	0.43	0.67	3,200	-	-	-	BDL	BDL	-	-	-
DDT	0.015	0.018	1,600	-	-	5,900	11,000	3,200	12	12	547	0.015	0.018	170	-	-
Diazinon	2.2	4.2	320	-	-	2.2	4.2	630	-	-	-	-	-	-	-	-
Dicamba [g]	0.5	0.79	2,000	-	-	0.5	0.79	4,000	-	-	-	BDL	BDL	-	-	-
Dichlofop-methyl	2	2.4	160	-	-	12	24	320	-	-	-	2	2.4	-	-	-
Dieldrin	0.011	0.014	44	-	-	0.59	1.1	49	-	-	-	0.011	0.014	-	-	-
Dimethoate	0.0058	0.0055	320	-	-	0.077	0.12	630	-	-	-	0.0058	0.0055	-	-	-

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

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This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Dinoseb [g]	2.8	5.5	160	-	-	2.8	5.5	320	-	-	-	BDL	BDL	-	-	-
Diquat	11	21	1,300	-	-	11	21	2,500	-	-	-	-	-	-	-	-
Diuron	1.9	3.5	2,500	-	-	1.9	3.5	4,900	-	-	-	-	-	-	-	-
Endosulfan	0.0085	0.01	3,000	-	-	99	190	3,000	-	-	-	0.0085	0.01	-	-	-
Endrin	0.0075	0.009	130	-	-	2.4	4.7	150	-	-	-	0.0075	0.009	-	-	-
Glyphosate	0.054	0.049	4,800	-	-	0.95	1.4	9,500	-	-	-	0.054	0.049	-	-	-
Heptachlor epoxide [g]	0.039	0.076	2.8	2.4	0.094	0.039	0.076	6.5	-	-	-	BDL	BDL	-	-	-
Lindane [g]	0.31	0.6	48	-	-	0.31	0.6	95	-	-	-	BDL	BDL	-	-	-
Linuron	0.051	0.059	320	-	-	0.56	1.1	630	-	-	-	0.051	0.059	-	-	-
Malathion [g]	0.82	1.3	3,200	-	-	0.82	1.3	6,300	-	-	-	BDL	BDL	-	-	-
MCPA [g]	0.02	0.032	80	-	-	0.02	0.032	160	-	-	-	BDL	BDL	-	-	-
Methoxychlor	0.046	0.056	50,000	-	-	5,700	11,000	50,000	-	-	-	0.046	0.056	-	-	-
Metolachlor	0.048	0.055	800	-	-	1.3	2.4	1,600	-	-	-	0.048	0.055	-	-	-
Metribuzin	0.024	0.028	1,300	-	-	7.8	15	2,600	-	-	-	0.024	0.028	-	-	-
Paraquat (as dichloride)	1.1	2.2	160	-	-	1.1	2.2	320	-	-	-	-	-	-	-	-
Parathion [g]	7.2	14	800	-	-	7.2	14	1,600	-	-	-	BDL	BDL	-	-	-
Phorate	0.075	0.14	32	-	-	0.075	0.14	63	-	-	-	-	-	-	-	-
Picloram	0.024	0.022	3,200	-	-	0.64	0.94	6,300	-	-	-	0.024	0.022	-	-	-
Simazine	0.033	0.038	210	-	-	0.14	0.25	410	-	-	-	0.033	0.038	-	-	-
Tebuthiuron [g]	2.5	3.7	11,000	-	-	2.5	3.7	22,000	-	-	-	BDL	BDL	-	-	-
Terbufos	0.08	0.15	8	-	-	0.08	0.15	16	-	-	-	-	-	-	-	-

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

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This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Toxaphene [g]	3.3	6.3	7.3	36,000	1,400	3.3	6.3	69	-	-	-	BDL	BDL	-	-	-
Triallate	0.0077	0.0092	2,100	-	-	16	31	4,100	-	-	-	0.0077	0.0092	-	-	-
Trifluarin	0.038	0.045	770	-	-	35	67	1,500	-	-	-	0.038	0.045	-	-	-
Other Organics																
Aniline [g]	0.36	0.6	1,100	4,500	300	0.36	0.6	2,200	-	-	-	BDL	BDL	-	-	-
Bis(2-ethyl-hexyl)phthalate	34	41	37,000	NGR	NGR	3,600	7,000	14,000	-	-	-	34	41	-	-	-
Dibutyl phthalate	0.54	0.65	9,600	NGR	82,000	70	130	19,000	-	-	-	0.54	0.65	-	-	-
Dichlorobenzidine	4.2	8.1	190	NGR	NGR	4.2	8.1	1,800	-	-	-	-	-	-	-	-
Diisopropanolamine	14	17	280,000	-	-	130	250	310,000	750	750	-	14	17	5,100	-	-
Ethylene glycol	60	62	530,000	NGR	NGR	60	68	NGR	1,800	1,800	2,000	89	62	16,000	-	-
Hexachlorobutadiene	0.026	0.031	320	1.2	0.078	0.5	0.95	3,000	-	-	-	0.026	0.031	-	-	-
Methylmethacrylate	1.3	1.3	8,000	21	1.3	1.3	1.8	16,000	-	-	-	-	-	-	-	-
MTBE	0.044	0.062	6,800	7.4	0.57	0.044	0.062	5,400	-	-	-	7.1	6.1	-	-	-
Nonylphenol + ethoxylates	2.7	3.3	-	-	-	-	-	-	14	14	-	2.7	3.3	82	-	-
Phenol	0.0028	0.0024	26,000	90,000	5,800	1.6	2.3	29,000	130	130	-	0.0028	0.0024	290	-	-
Sulfolane	0.18	0.21	2,600	-	-	0.18	0.21	5,000	430	430	-	24	18	3,000	-	-

Table A-5. Surface Soil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a) .

Notes:

a. For more information see Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes (AEP, 1996)

b. True total barium as measured by fusion-XRF or fusion-ICP. For more information see Soil Remediation Guidelines for Barite: Environmental Health and Human Health (AENV, 2009b)

c. Human health direct soil contact guidelines for carcinogenic PAHs are based on B[a]P Total Potency Equivalents (TPE). TPEs are calculated by multiplying the soil concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (WHO/IPCS, 1998) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

d. The B[a]P Total Potency Equivalents (TPEs) calculated for specific soil samples using Potency Equivalency Factors (PEFs) should be multiplied by an Uncertainty Factor of 3 when evaluating PAH mixtures associated with creosote or coal tar-type environmental releases, prior to evaluating against the human health direct contact soil remediation guideline.

e. The Index of Additive Cancer Risk (IACR) is calculated by dividing the soil concentration of each carcinogenic PAH by its Protection of Domestic Use Aquifer guideline value to calculate a hazard index for each PAH and subsequently summing the hazard indexes for the entire PAH mixture. For example, the IARC for coarse textured soil would be calculated as follows:

Fine Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{1.6\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{0.74\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.16\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{32\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{1.7\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{10\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{1.1\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{13\ \mathrm{mg\cdot kg^{-1}}}$$

Coarse Soil:

$$\mathrm{IACR} = \frac{[\mathrm{Benz(a)anthracene}]}{3.1\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(b+j)fluoranthene}]}{1.4\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(k)fluoranthene}]}{0.31\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(g,h,i)perylene}]}{63\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Benzo(a)pyrene}]}{3.4\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Chrysene}]}{19\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Dibenz(a,h)anthracene}]}{2.1\ \mathrm{mg\cdot kg^{-1}}} + \frac{[\mathrm{Indeno(1,2,3-c,d)pyrene}]}{24\ \mathrm{mg\cdot kg^{-1}}}$$

f. Overall guideline value for ecological receptors only.

g. Guideline for protection of aquatic life is below detection limit, groundwater monitoring is required.

h. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

i. Guideline values adopted directly from CCME (1999 and updates) without change.

BDL - Below detection limit

NGR - no guideline required, calculated value >1,000,000 mg/kg; or for PAH groundwater protection, calculated value results in groundwater concentration greater than solubility

Table A-6. Subsoil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathways (BTEX and PHC Only)

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2009a).

Receptor	**Overall Guideline**		**Human**		**Ecological**									**Other**	
Pathway			**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Wildlife Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Benzene	0.046	0.078	0.046	0.078	120	62	-	na	na	73	1.6	15	0.33	-	-
Toluene	0.52	0.49	0.52	0.95	220	150	-	na	na	250,000	0.49	NGR	1,000	-	-
Ethylbenzene	0.11	0.21	0.11	0.21	240	110	-	na	na	NGR	540	NGR	17,000	-	-
Xylenes	15	28	15	28	130	190	-	na	na	NGR	250	NGR	16,000	-	-
F1	420	420	1,100	2,200	420	420	-	na	na	30,000	1,300	NGR	30,000	800	700
F2	300	300	1,500	2,900	300	300	-	na	na	30,000	520	NGR	30,000	1,000	1,000
F3	2,600	600	-	-	2,600	600	-	na	na	-	-	-	-	3,500	2,500
F4	10,000	5,600	-	-	11,200	5,600	-	na	na	-	-	-	-	10,000	10,000

Notes:

na = exposure pathway not applicable to subsoil

NGR - no guideline required, calculated value >1,000,000 mg/kg

Table A-7. Subsoil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways (BTEX and PHC Only)

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2009a).

Receptor	**Overall Guideline**		**Human**							**Ecological**													**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Livestock Soil and Food Ingestion**	**Wildlife Soil and Food Ingestion**	**Protection of Freshwater Aquatic Life**		**Protection of Livestock Water**		**Protection of Wildlife Water**		**Protection of Irrigation Water**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		-	-	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Benzene	0.046	0.078	78	1.7	1.6	0.10	0.14	0.046	0.078	120	62	-	na	na	73	1.6	0.2	0.21	15	0.33	-	-	-	-
Toluene	0.52	0.49	20,000	2,100	2,000	130	180	0.52	0.95	220	150	-	na	na	250,000	0.49	26	29	NGR	1,000	-	-	-	-
Ethylbenzene	0.11	0.21	8,500	1,000	970	60	86	0.11	0.21	240	110	-	na	na	NGR	540	36	42	NGR	17,000	-	-	-	-
Xylenes	15	16	140,000	280	260	16	23	15	28	130	190	-	na	na	NGR	250	160	180	NGR	16,000	-	-	-	-
F1	420	30	12,000	710	630	30	55	1,100	2,200	420	420	-	na	na	30,000	1,300	6,600	7,300	NGR	30,000	-	-	800	700
F2	300	160	6,800	3,600	3,300	160	290	1,500	2,900	300	300	-	na	na	30,000	520	16,000	19,000	NGR	30,000	-	-	1,000	1,000
F3	2,600	600	15,000	-	-	-	-	-	-	2,600	600	-	na	na	-	-	-	-	-	-	-	-	3,500	2,500
F4	10,000	5,600	21,000	-	-	-	-	-	-	11,200	5,600	-	na	na	-	-	-	-	-	-	-	-	10,000	10,000

Notes:

na = exposure pathway not applicable to subsoil

NGR - no guideline required, calculated value >1,000,000 mg/kg

Table A-8. Subsoil Remediation Guideline Values for Residential/Parkland Land Use - All Exposure Pathways (BTEX and PHC Only)

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4.
This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2009a).

Receptor	**Overall Guideline**		**Human**							**Ecological**					**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**				**Protection of Domestic Use Aquifer**		**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Fine**	**Coarse**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**		**Fine**	**Coarse**	**Fine**	**Coarse**
Building Type			-	**Basement**	**Slab**	**Basement**	**Slab**	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Benzene	0.046	0.078	78	1.7	1.6	0.10	0.14	0.046	0.078	120	62	-	73	1.6	-	-
Toluene	0.52	0.49	20,000	2,100	2,000	130	180	0.52	0.95	220	150	-	250,000	0.49	-	-
Ethylbenzene	0.11	0.21	8,500	1,000	970	60	86	0.11	0.21	240	110	-	NGR	540	-	-
Xylenes	15	16	140,000	280	260	16	23	15	28	130	190	-	NGR	250	-	-
F1	420	30	12,000	710	630	30	55	1,100	2,200	420	420	-	30,000	1300	800	700
F2	300	160	6,800	3,600	3,300	160	290	1,500	2,900	300	300	-	30,000	520	1,000	1,000
F3	2,600	600	15,000	-	-	-	-	-	-	2,600	600	-	-	-	3,500	2,500
F4	10,000	5,600	21,000	-	-	-	-	-	-	11,200	5,600	-	-	-	10,000	10,000

Notes:
na = exposure pathway not applicable to subsoil
NGR - no guideline required, calculated value >1,000,000 mg/kg

Table A-9. Subsoil Remediation Guideline Values for Commercial Land Use - All Exposure Pathways (BTEX and PHC Only)

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2009a).

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Benzene	0.046	0.078	120	11	1.2	0.046	0.078	1,100	620	360	-	73	1.6	890	-	-
Toluene	0.52	0.49	31,000	14,000	1,600	0.52	0.95	290,000	660	500	-	250,000	0.49	2,100	-	-
Ethylbenzene	0.11	0.21	13,000	6,700	760	0.11	0.21	120,000	860	600	-	NGR	540	1,600	-	-
Xylenes	15	28	210,000	1,800	210	15	28	NGR	460	700	-	NGR	250	930	-	-
F1	640	440	19,000	4,700	440	1,100	2,200	180,000	640	640	-	30,000	1300	3,000	800	700
F2	520	520	10,000	24,000	2,400	1,500	2,900	97,000	520	520	-	30,000	520	2,100	1,000	1,000
F3	3,500	2,500	23,000	-	-	-	-	210,000	5,000	3,400	-	-	-	4,300	3,500	2,500
F4	10,000	6,600	32,000	-	-	-	-	300,000	13,200	6,600	-	-	-	40,000	10,000	10,000

Notes:

na = exposure pathway not applicable to subsoil

NGR - no guideline required, calculated value >1,000,000 mg/kg

Table A-10. Subsoil Remediation Guideline Values for Industrial Land Use - All Exposure Pathways (BTEX and PHC Only)

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Tables 1, 3 and 4. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2009a).

Receptor	**Overall Guideline**		**Human**						**Ecological**						**Other**	
Pathway			**Direct Soil Contact**	**Vapour Inhalation**		**Protection of Domestic Use Aquifer**		**Off-Site Migration**	**Direct Soil Contact**		**Nutrient/ Energy Cycling Check**	**Protection of Freshwater Aquatic Life**		**Off-Site Migration**	**Management Limit**	
Soil Type	**Fine**	**Coarse**	-	**Fine**	**Coarse**	**Fine**	**Coarse**	-	**Fine**	**Coarse**		**Fine**	**Coarse**	-	**Fine**	**Coarse**
Building Type			-	**Slab**	**Slab**	-	-	-	-	-	-	-	-	-	-	-
Unit	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**mg/kg**	**mg/kg**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Benzene	0.046	0.078	120	11	1.2	0.046	0.078	1,100	620	360	-	73	1.6	890	-	-
Toluene	0.52	0.49	350,000	14,000	1,600	0.52	0.95	290,000	660	500	-	250,000	0.49	2,100	-	-
Ethylbenzene	0.11	0.21	120,000	6,700	760	0.11	0.21	120,000	860	600	-	NGR	540	1,600	-	-
Xylenes	15	28	NGR	1,800	210	15	28	NGR	460	700	-	NGR	250	930	-	-
F1	640	440	180,000	4,700	440	1,100	2,200	180,000	640	640	-	30,000	1300	3,000	800	700
F2	520	520	96,000	24,000	2,400	1,500	2,900	97,000	520	520	-	30,000	520	2,100	1,000	1,000
F3	3,500	2,500	210,000	-	-	-	-	210,000	5,000	3,400	-	-	-	4,300	3,500	2,500
F4	10,000	6,600	300,000	-	-	-	-	300,000	13,200	6,600	-	-	-	40,000	10,000	10,000

Notes:

na = exposure pathway not applicable to subsoil

NGR - no guideline required, calculated value >1,000,000 mg/kg

APPENDIX B
GROUNDWATER REMEDIATION GUIDELINES ALL WATER USES

Appendix B consists of four tables, one for each of the land uses, except that commercial and industrial groundwater guidelines are identical, and separate tables are not required. Each table provides the groundwater remediation guideline for each applicable water use, where available. **Tier 1 guidelines must be chosen from Tables 1 to 4, not from Appendix A or B.** The only exception occurs when a more sensitive land use borders on, or is less than 30m from, the site of interest. Under this condition guidelines for specific exposure pathways on the more sensitive land use must be evaluated and if they are lower than the Tier 1 guideline, they must be applied to the site of interest (See Section 5.1.2 and Figure 1).

The four tables are as follows:

- Table B-1. Groundwater Remediation Guideline Values for Natural Area Land Use
- Table B-2. Groundwater Remediation Guideline Values for Agricultural Land Use
- Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland Use
- Table B-4. Groundwater Remediation Guideline Values for Commercial/Industrial Land Use

Note that the groundwater guidelines protective of inhalation under agricultural or residential/parkland use are based on a building with slab-on-grade construction. These values are protective in all cases of both slab-on-grade and basement construction.

All water uses are applicable at Tier 1. However, it may be possible to exclude or modify certain water uses at Tier 2. The companion Tier 2 document (AENV, 2009a) should be consulted for further information. The information in the tables in this appendix will assist in determining whether a Tier 2 approach for groundwater is likely to be useful at a given site.

Table B-1. Groundwater Remediation Guideline Values for Natural Areas - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable GW**	**Eco Soil Contact**		**Aquatic Life**		**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
General and Inorganic Parameters									
pH	6.5-8.5	6.5-8.5	6.5-8.5	-	-	6.5-9	6.5-9	-	-
Ammonia	see note d	see note d	-	-	-	see note d	see note d	-	-
Chloride	230	230	250	-	-	230	230	-	-
Cyanide	0.005	0.005	0.2	-	-	0.005	0.005	-	-
Fluoride	0.12	0.12	1.5	-	-	0.12	0.12	-	-
Nitrate	13	13	45	-	-	13	13	-	-
Nitrite (as nitrogen)	0.06	0.06	1.0	-	-	0.06	0.06	-	-
Sodium	200	200	200	-	-	-	-	-	-
Sulphate	500	500	500	-	-	-	-	-	-
Sulphide (as H_2S)	0.002	0.002	0.05	-	-	0.002	0.002	-	-
Total Dissolved Solids (TDS)	500	500	500	-	-	-	-	-	-
Metals									
Aluminum	see note d	see note d	-	-	-	see note d	see note d	-	-
Antimony	0.006	0.006	0.006	-	-	-	-	-	-
Arsenic	0.005	0.005	0.01	-	-	0.005	0.005	-	-
Barium	1	1	1	-	-	-	-	-	-
Boron	5	5	5	-	-	-	-	-	-
Bromate	0.01	0.01	0.01	-	-	-	-	-	-
Cadmium	See note e	See note e	0.005	-	-	see note d	see note d	-	-
Chromium (Total)	See note e	See note e	0.05	-	-	see note d	see note d	-	-
Copper	See note e	See note e	1	-	-	see note d	see note d	-	-
Iron	0.3	0.3	0.3	-	-	0.3	0.3	-	-
Lead	See note e	See note e	0.01	-	-	see note d	see note d	-	-
Manganese	0.05	0.05	0.05	-	-	-	-	-	-
Mercury	See note e	See note e	0.001	-	-	see note d	see note d	-	-
Nickel	see note d	see note d				see note d	see note d		
Selenium	0.001	0.001	0.01	-	-	0.001	0.001	-	-

Table B-1. Groundwater Remediation Guideline Values for Natural Areas - All Water Uses

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable GW**	**Eco Soil Contact**		**Aquatic Life**		**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Silver	see note d	see note d	-	-	-	see note d	see note d	-	-
Uranium	0.02	0.02	0.02	-	-	-	-	-	-
Zinc	0.03	0.03	5	-	-	0.03	0.03	-	-
Hydrocarbons									
Benzene	0.005	0.005	0.005	100	61	33	0.69	6.8	0.14
Toluene	0.024	0.024	0.024	82	59	NGR	0.083	NGR	180
Ethylbenzene	0.0024	0.0024	0.0024	42	20	NGR	41	NGR	NGR
Xylenes	0.3	0.3	0.3	21	31	NGR	18	NGR	NGR
Styrene	0.072	0.072	2.8	-	-	0.072	0.072	-	-
F1	2.2	2.2	2.2	6.5	7.1	NGR	9.8	NGR	NGR
F2	1.1	1.1	1.1	1.8	1.8	NGR	1.3	NGR	NGR
Acenapthene	0.0058	0.0058	1.4	-	-	0.0058	0.0058	NGR	NGR
Acenaphthylene	0.046	0.046	-	-	-	0.046	0.046	-	-
Anthracene	0.000012	0.000012	NGR	0.025	0.025	0.000012	0.000012	NGR	NGR
Fluoranthene	0.00004	0.00004	NGR	0.24	0.24	0.00004	0.00004	NGR	NGR
Fluorene	0.003	0.003	0.94	-	-	0.003	0.003	NGR	NGR
Naphthalene	0.0011	0.0011	0.47	-	-	0.0011	0.0011	NGR	NGR
Phenanthrene	0.0004	0.0004	-	-	-	0.0004	0.0004	NGR	NGR
Pyrene	0.000025	0.000025	0.71	-	-	0.000025	0.000025	NGR	NGR
Carcinogenic PAHs (as B(a)P TPE) [a]	0.00001	0.00001	0.00001	-	-	-	-	-	-
Benz[a]anthracene [b]	0.000018	0.000018	-	-	-	0.000018	0.000018	NGR	NGR
Benzo[b+j]fluoranthene [b]	0.00048	0.00048	-	-	-	0.00048	0.00048	NGR	NGR
Benzo[k]fluoranthene [b]	0.00048	0.00048	-	-	-	0.00048	0.00048	NGR	NGR
Benzo[g,h,i]perylene [b]	0.00021	0.00017	-	-	-	0.00021	0.00017	-	-
Benzo[a]pyrene [b]	0.000017	0.000015	-	0.0018	0.0018	0.000017	0.000015	NGR	NGR
Chrysene [b]	0.0014	0.0014	-	-	-	0.0014	0.0014	NGR	NGR
Dibenz[a,h]anthracene [b]	0.00028	0.00026	-	-	-	0.00028	0.00026	NGR	NGR
Indeno[1,2,3-c,d]pyrene [b]	0.00023	0.00021	-	-	-	0.00023	0.00021	-	-

Table B-1. Groundwater Remediation Guideline Values for Natural Areas - All Water Uses

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable GW**	**Eco Soil Contact**		**Aquatic Life**		**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Halogenated Aliphatics									
Vinyl chloride	0.002	0.002	0.002	-	-	-	-	-	-
1,1-Dichloroethene	0.014	0.014	0.014	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.005	0.005	0.005	4.4	5	0.27	0.029	-	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.03	0.03	0.03	-	-	0.11	0.11	-	-
1,2-Dichloroethane	0.005	0.005	0.005	-	-	0.1	0.1	-	-
Dichloromethane (Methylene chloride)	0.05	0.05	0.05	-	-	0.098	0.098	-	-
Trichloromethane (Chloroform)	0.0018	0.0018	0.093	-	-	0.0018	0.0018	-	-
Tetrachloromethane (Carbon tetrachloride)	0.005	0.005	0.005	-	-	0.013	0.013	-	-
Dibromochloromethane	0.19	0.19	0.19	-	-	-	-	-	-
Chlorinated Aromatics									
Chlorobenzene	0.0013	0.0013	0.03	-	-	0.0013	0.0013	-	-
1,2-Dichlorobenzene	0.0007	0.0007	0.003	-	-	0.0007	0.0007	-	-
1,4-Dichlorobenzene	0.001	0.001	0.001	-	-	0.026	0.026	-	-
1,2,3-Trichlorobenzene	0.008	0.008	0.014	-	-	0.008	0.008	-	-
1,2,4-Trichlorobenzene	0.015	0.015	0.015	-	-	0.024	0.024	-	-
1,3,5-Trichlorobenzene	0.014	0.014	0.014	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.0018	0.0018	0.032	-	-	0.0018	0.0018	-	-
1,2,3,5-Tetrachlorobenzene	0.0038	0.0038	0.0038	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.002	0.002	0.002	-	-	-	-	-	-
Pentachlorobenzene	0.006	0.006	0.0094	-	-	0.006	0.006	-	-
Hexachlorobenzene	0.00057	0.00057	0.00057	-	-	-	-	-	-
2,4-Dichlorophenol	0.0002	0.0002	0.0003	-	-	0.0002	0.0002	-	-
2,4,6-Trichlorophenol	0.002	0.002	0.002	-	-	0.018	0.018	-	-
2,3,4,6-Tetrachlorophenol	0.001	0.001	0.001	-	-	0.001	0.001	-	-
Pentachlorophenol	0.0005	0.0005	0.03	0.87	0.88	0.0005	0.0005	-	-
Dioxins & Furans[c]	0.00000012	0.00000012	0.00000012	-	-	-	-	-	-

Table B-1. Groundwater Remediation Guideline Values for Natural Areas - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable GW**	**Eco Soil Contact**		**Aquatic Life**		**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
PCBs	0.0094	0.0094	0.0094	-	-	-	-	-	-
Pesticides									
Aldicarb	0.001	0.001	0.009	-	-	0.001	0.001	-	-
Aldrin	0.0007	0.0007	0.0007	-	-	0.003	0.003	-	-
Atrazine and metabolites	0.0018	0.0018	0.005	-	-	0.0018	0.0018	-	-
Azniphos-methyl	0.00001	0.00001	0.02	-	-	0.00001	0.00001	-	-
Bendiocarb	0.04	0.04	0.04	-	-	-	-	-	-
Bromoxynil	0.005	0.005	0.005	-	-	0.005	0.005	-	-
Carbaryl	0.0002	0.0002	0.09	-	-	0.0002	0.0002	-	-
Carbofuran	0.0018	0.0018	0.09	-	-	0.0018	0.0018	-	-
Chlorothalonil	0.00018	0.00018	0.14	-	-	0.00018	0.00018	-	-
Chlorpyrifos	0.0000035	0.0000035	0.09	-	-	0.0000035	0.0000035	-	-
Cyanazine	0.002	0.002	0.01	-	-	0.002	0.002	-	-
2,4-D	0.004	0.004	0.1	-	-	0.004	0.004	-	-
DDT	0.000001	0.000001	0.093	-	-	0.000001	0.000001	-	-
Diazinon	0.02	0.02	0.02	-	-	-	-	-	-
Dicamba	0.01	0.01	0.12	-	-	0.01	0.01	-	-
Dichlofop-methyl	0.0061	0.0061	0.009	-	-	0.0061	0.0061	-	-
Dieldrin	0.000056	0.000056	0.0007	-	-	0.000056	0.000056	-	-
Dimethoate	0.0062	0.0062	0.02	-	-	0.0062	0.0062	-	-
Dinoseb	0.00005	0.00005	0.01	-	-	0.00005	0.00005	-	-
Diquat	0.07	0.07	0.07	-	-	-	-	-	-
Diuron	0.15	0.15	0.15	-	-	-	-	-	-
Endosulfan	0.00002	0.00002	0.057	-	-	0.00002	0.00002	-	-
Endrin	0.000036	0.000036	0.0028	-	-	0.000036	0.000036	-	-
Glyphosate	0.065	0.065	0.28	-	-	0.065	0.065	-	-
Heptachlor epoxide	0.0000038	0.0000038	0.000052	-	-	0.0000038	0.0000038	-	-
Lindane	0.00001	0.00001	0.0028	-	-	0.00001	0.00001	-	-

Table B-1. Groundwater Remediation Guideline Values for Natural Areas - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable GW**	**Eco Soil Contact**		**Aquatic Life**		**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Linuron	0.007	0.007	0.019	-	-	0.007	0.007	-	-
Malathion	0.0001	0.0001	0.19	-	-	0.0001	0.0001	-	-
MCPA	0.0026	0.0026	0.0047	-	-	0.0026	0.0026	-	-
Methoxychlor	0.00003	0.00003	0.9	-	-	0.00003	0.00003	-	-
Metolachlor	0.0078	0.0078	0.05	-	-	0.0078	0.0078	-	-
Metribuzin	0.001	0.001	0.08	-	-	0.001	0.001	-	-
Paraquat (as dichloride)	0.01	0.01	0.01	-	-	-	-	-	-
Parathion	0.000013	0.000013	0.05	-	-	0.000013	0.000013	-	-
Phorate	0.002	0.002	0.002	-	-	-	-	-	-
Picloram	0.029	0.029	0.19	-	-	0.029	0.029	-	-
Simazine	0.01	0.01	0.01	-	-	0.01	0.01	-	-
Tebuthiuron	0.0016	0.0016	0.66	-	-	0.0016	0.0016	-	-
Terbufos	0.001	0.001	0.001	-	-	-	-	-	-
Toxaphene	0.0000002	0.0000002	0.00043	-	-	0.0000002	0.0000002	-	-
Triallate	0.00024	0.00024	0.12	-	-	0.00024	0.00024	-	-
Trifluarin	0.0002	0.0002	0.045	-	-	0.0002	0.0002	-	-
Other Organics									
Aniline	0.0022	0.0022	0.066	-	-	0.0022	0.0022	-	-
Bis(2-ethyl-hexyl)phthalate	0.016	0.016	0.41	-	-	0.016	0.016	-	-
Dibutyl phthalate	0.019	0.019	0.59	-	-	0.019	0.019	-	-
Dichlorobenzidine	0.007	0.007	0.007	-	-	-	-	-	-
Diisopropanolamine	1.6	1.6	3.6	160	160	1.6	1.6	-	-
Ethylene glycol	31	31	31	9,200	16,000	190	190	-	-
Hexachlorobutadiene	0.0013	0.0013	0.006	-	-	0.0013	0.0013	-	-
Methylmethacrylate	0.47	0.47	0.47	-	-	-	-	-	-
MTBE	0.015	0.015	0.015	-	-	10	10	-	-
Nitrilotriacetic acid	0.4	0.4	0.4	-	-	-	-	-	-
Nonylphenol + ethoxylates	0.001	0.001	-	0.0081	0.0081	0.001	0.001	-	-

Table B-1. Groundwater Remediation Guideline Values for Natural Areas - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable GW**	**Eco Soil Contact**		**Aquatic Life**		**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Phenol	0.004	0.004	0.57	110	150	0.004	0.004	-	-
Sulfolane	0.09	0.09	0.09	1,700	2,800	50	50	-	-
Trihalomethanes - total (THMs)	0.1	0.1	0.1	-	-	-	-	-	-

Notes:

a. B[a]P TPE (Total Potency Equivalents) are calculated by multiplying the groundwater concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (1999) scheme, as follows:

Carcinogenic PAH Compound	**PEF**
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

b. For ecological receptors only.

c. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

d. See Surface Water Quality Guidelines for Use in Alberta (AENV, 1999) for further guidance on aquatic life pathway.

e. Tier 1 guideline = lowest of aquatic life guideline and potable GW guideline.

NGR - no guideline required, calculated value > solubility or >1,000,000 mg/L

Potable GW = protection of groundwater for potable drinking water

Eco Soil Contact = protection of terrestrial plants and soil invertebrates in areas with shallow groundwater

Aquatic Life = protection of groundwater discharging to a surface water body hosting aquatic life

Wildlife Watering = protection of groundwater discharging to a surface water body from which wildlife may drink

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**		**Irrigation**	**Livestock**	**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**All**	**All**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
General and Inorganic Parameters													
pH	6.5-8.5	6.5-8.5	6.5-8.5	-	-	-	-	6.5-9	6.5-9	-	-	-	-
Ammonia	see note d	see note d	-	-	-	-	-	see note d	see note d	-	-	-	-
Chloride	100	100	250	-	-	-	-	230	230	100	-	-	-
Cyanide	0.005	0.005	0.2	-	-	-	-	0.005	0.005	-	-	-	-
Fluoride	0.12	0.12	1.5	-	-	-	-	0.12	0.12	1	1	-	-
Nitrate	13	13	45	-	-	-	-	13	13	-	-	-	-
Nitrate + Nitrite (as nitrogen)	100	100	-	-	-	-	-	-	-	-	100	-	-
Nitrite (as nitrogen)	0.06	0.06	1.0	-	-	-	-	0.06	0.06	-	10	-	-
Sodium	200	200	200	-	-	-	-	-	-	-	-	-	-
Sulphate	500	500	500	-	-	-	-	-	-	-	1000	-	-
Sulphide (as H_2S)	0.002	0.002	0.05	-	-	-	-	0.002	0.002	-	-	-	-
Total Dissolved Solids (TDS)	500	500	500	-	-	-	-	-	-	-	3000	-	-
Metals													
Aluminum	See note e	See note e	-	-	-	-	-	see note d	see note d	5	5	-	-
Antimony	0.006	0.006	0.006	-	-	-	-	-	-	-	-	-	-
Arsenic	0.005	0.005	0.01	-	-	-	-	0.005	0.005	0.1	0.025	-	-
Barium	1	1	1	-	-	-	-	-	-	-	-	-	-
Boron	0.5	0.5	5	-	-	-	-	-	-	0.5	5	-	-
Bromate	0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-
Cadmium	See note e	See note e	0.005	-	-	-	-	see note d	see note d	0.0051	0.08	-	-
Chromium (Total)	See note e	See note e	0.05	-	-	-	-	see note d	see note d	-	0.05	-	-
Copper	See note e	See note e	1	-	-	-	-	see note d	see note d	0.2	0.5	-	-
Iron	0.3	0.3	0.3	-	-	-	-	0.3	0.3	5	-	-	-
Lead	See note e	See note e	0.01	-	-	-	-	see note d	see note d	0.2	0.1	-	-

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**		**Irrigation**	**Livestock**	**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**All**	**All**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Manganese	0.05	0.05	0.05	-	-	-	-	-	-	0.2	-	-	-
Mercury	See note e	See note e	0.001	-	-	-	-	see note d	see note d	-	0.003	-	-
Nickel	See note e	See note e	-	-	-	-	-	see note d	see note d	0.2	1	-	-
Selenium	0.001	0.001	0.01	-	-	-	-	0.001	0.001	0.02	0.05	-	-
Silver	See note e	See note e	-	-	-	-	-	see note d	see note d	0.02	0.05	-	-
Uranium	0.01	0.01	0.02	-	-	-	-	-	-	0.01	0.2	-	-
Zinc	0.03	0.03	5	-	-	-	-	0.03	0.03	1	50	-	-
Hydrocarbons													
Benzene	0.005	0.005	0.005	2.8	0.14	100	61	33	0.69	-	0.088	6.8	0.14
Toluene	0.024	0.024	0.024	NGR	74	82	59	NGR	0.083	-	4.9	NGR	180
Ethylbenzene	0.0024	0.0024	0.0024	NGR	16	42	20	NGR	41	-	3.2	NGR	NGR
Xylenes	0.3	0.3	0.3	80	3.9	21	31	NGR	18	-	13	NGR	NGR
Styrene	0.072	0.072	2.8	90	4.3	-	-	0.072	0.072	-	-	-	-
F1	2.2	0.81	2.2	19	0.81	6.5	7.1	NGR	9.8	-	53	NGR	NGR
F2	1.1	1.1	1.1	NGR	1.5	1.8	1.8	NGR	1.3	-	NGR	NGR	NGR
Acenapthene	0.0058	0.0058	1.4	NGR	NGR	-	-	0.0058	0.0058	-	NGR	NGR	NGR
Acenaphthylene	0.046	0.046	-	-	-	-	-	0.046	0.046	-	-	-	-
Anthracene	0.000012	0.000012	NGR	NGR	NGR	0.025	0.025	0.000012	0.000012	-	NGR	NGR	NGR
Fluoranthene	0.00004	0.00004	NGR	NGR	NGR	0.24	0.24	0.00004	0.00004	-	NGR	NGR	NGR
Fluorene	0.003	0.003	0.94	NGR	NGR	-	-	0.003	0.003	-	NGR	NGR	NGR
Naphthalene	0.0011	0.0011	0.47	14	0.6	-	-	0.0011	0.0011	-	NGR	NGR	NGR
Phenanthrene	0.0004	0.0004	-	-	-	-	-	0.0004	0.0004	-	NGR	NGR	NGR
Pyrene	0.000025	0.000025	0.71	NGR	NGR	-	-	0.000025	0.000025	-	NGR	NGR	NGR
Carcinogenic PAHs (as B(a)P TPE) [a]	0.00001	0.00001	0.00001	-	-	-	-	-	-	-	-	-	-
Benz[a]anthracene [b]	0.000018	0.000018	-	-	-	-	-	0.000018	0.000018	-	NGR	NGR	NGR

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**		**Irrigation**	**Livestock**	**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**All**	**All**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Benzo[b+j]fluoranthene [b]	0.00048	0.00048	-	-	-	-	-	0.00048	0.00048	-	NGR	NGR	NGR
Benzo[k]fluoranthene [b]	0.00048	0.00048	-	-	-	-	-	0.00048	0.00048	-	NGR	NGR	NGR
Benzo[g,h,i]perylene [b]	0.00021	0.00017	-	-	-	-	-	0.00021	0.00017	-	-	-	-
Benzo[a]pyrene [b]	0.000017	0.000015	-	-	-	0.0018	0.0018	0.000017	0.000015	-	NGR	NGR	NGR
Chrysene [b]	0.0014	0.0014	-	-	-	-	-	0.0014	0.0014	-	NGR	NGR	NGR
Dibenz[a,h]anthracene [b]	0.00028	0.00026	-	-	-	-	-	0.00028	0.00026	-	NGR	NGR	NGR
Indeno[1,2,3-c,d]pyrene [b]	0.00023	0.00021	-	-	-	-	-	0.00023	0.00021	-	-	-	-
Halogenated Aliphatics													
Vinyl chloride	0.002	0.0011	0.002	0.018	0.0011	-	-	-	-	-	-	-	-
1,1-Dichloroethene	0.014	0.014	0.014	0.68	0.039	-	-	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.005	0.005	0.005	0.41	0.02	4.4	5	0.27	0.029	-	0.05	-	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.03	0.03	0.03	2.3	0.11	-	-	0.11	0.11	-	-	-	-
1,2-Dichloroethane	0.005	0.005	0.005	0.17	0.01	-	-	0.1	0.1	-	0.005	-	-
Dichloromethane (Methylene chloride)	0.05	0.05	0.05	61	3.4	-	-	0.098	0.098	-	0.05	-	-
Trichloromethane (Chloroform)	0.0018	0.0018	0.093	0.05	0.003	-	-	0.0018	0.0018	-	0.1	-	-
Tetrachloromethane (Carbon tetrachloride)	0.005	0.00056	0.005	0.011	0.00056	-	-	0.013	0.013	-	0.005	-	-
Dibromochloromethane	0.1	0.1	0.19	26	1.1	-	-	-	-	-	0.1	-	-
Chlorinated Aromatics													
Chlorobenzene	0.0013	0.0013	0.03	0.3	0.014	-	-	0.0013	0.0013	-	-	-	-
1,2-Dichlorobenzene	0.0007	0.0007	0.003	116	5.4	-	-	0.0007	0.0007	-	-	-	-
1,4-Dichlorobenzene	0.001	0.001	0.001	4.6	0.22	-	-	0.026	0.026	-	-	-	-
1,2,3-Trichlorobenzene	0.008	0.008	0.014	0.8	0.032	-	-	0.008	0.008	-	-	-	-

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**		**Irrigation**	**Livestock**	**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**All**	**All**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
1,2,4-Trichlorobenzene	0.015	0.015	0.015	0.71	0.028	-	-	0.024	0.024	-	-	-	-
1,3,5-Trichlorobenzene	0.014	0.014	0.014	0.38	0.015	-	-	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.0018	0.0018	0.032	NGR	0.14	-	-	0.0018	0.0018	-	-	-	-
1,2,3,5-Tetrachlorobenzene	0.0038	0.0038	0.0038	0.41	0.017	-	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.002	0.002	0.002	0.21	0.0088	-	-	-	-	-	-	-	-
Pentachlorobenzene	0.006	0.006	0.0094	NGR	0.038	-	-	0.006	0.006	-	-	-	-
Hexachlorobenzene	0.00052	0.00052	0.00057	0.029	0.0012	-	-	-	-	-	0.00052	-	-
2,4-Dichlorophenol	0.0002	0.0002	0.0003	NGR	1500	-	-	0.0002	0.0002	-	-	-	-
2,4,6-Trichlorophenol	0.002	0.002	0.002	NGR	54	-	-	0.018	0.018	-	-	-	-
2,3,4,6-Tetrachlorophenol	0.001	0.001	0.001	NGR	NGR	-	-	0.001	0.001	-	-	-	-
Pentachlorophenol	0.0005	0.0005	0.03	NGR	NGR	0.87	0.88	0.0005	0.0005	-	-	-	-
Dioxins & Furans [c]	0.00000012	0.00000012	1.2E-07	-	-	-	-	-	-	-	-	-	-
PCBs	0.0094	0.0094	0.0094	-	-	-	-	-	-	-	-	-	-
Pesticides													
Aldicarb	0.001	0.001	0.009	-	-	-	-	0.001	0.001	0.055	0.011	-	-
Aldrin	0.0007	0.0007	0.0007	-	-	-	-	0.003	0.003	-	-	-	-
Atrazine and metabolites	0.0018	0.0018	0.005	-	-	-	-	0.0018	0.0018	0.01	0.005	-	-
Azniphos-methyl	0.00001	0.00001	0.02	-	-	-	-	0.00001	0.00001	-	-	-	-
Bendiocarb	0.04	0.04	0.04	-	-	-	-	-	-	-	-	-	-
Bromoxynil	0.00033	0.00033	0.005	-	-	-	-	0.005	0.005	0.00033	0.011	-	-
Carbaryl	0.0002	0.0002	0.09	-	-	-	-	0.0002	0.0002	-	1.1	-	-
Carbofuran	0.0018	0.0018	0.09	-	-	-	-	0.0018	0.0018	-	0.045	-	-
Chlorothalonil	0.00018	0.00018	0.14	-	-	-	-	0.00018	0.00018	0.0058	0.17	-	-
Chlorpyrifos	0.0000035	0.0000035	0.09	-	-	-	-	0.0000035	0.0000035	-	0.024	-	-
Cyanazine	0.0005	0.0005	0.01	-	-	-	-	0.002	0.002	0.0005	0.01	-	-

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**		**Irrigation**	**Livestock**	**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**All**	**All**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
2,4-D	0.004	0.004	0.1	-	-	-	-	0.004	0.004	-	0.1	-	-
DDT	0.000001	0.000001	0.093	-	-	-	-	0.000001	0.000001	-	0.1	-	-
Diazinon	0.02	0.02	0.02	-	-	-	-	-	-	-	-	-	-
Dicamba	0.000006	0.000006	0.12	-	-	-	-	0.01	0.01	0.000006	0.12	-	-
Dichlofop-methyl	0.00018	0.00018	0.009	-	-	-	-	0.0061	0.0061	0.00018	0.009	-	-
Dieldrin	0.000056	0.000056	0.0007	-	-	-	-	0.000056	0.000056	-	-	-	-
Dimethoate	0.003	0.003	0.02	-	-	-	-	0.0062	0.0062	-	0.003	-	-
Dinoseb	0.00005	0.00005	0.01	-	-	-	-	0.00005	0.00005	0.016	0.15	-	-
Diquat	0.07	0.07	0.07	-	-	-	-	-	-	-	-	-	-
Diuron	0.15	0.15	0.15	-	-	-	-	-	-	-	-	-	-
Endosulfan	0.00002	0.00002	0.057	-	-	-	-	0.00002	0.00002	-	-	-	-
Endrin	0.000036	0.000036	0.0028	-	-	-	-	0.000036	0.000036	-	-	-	-
Glyphosate	0.065	0.065	0.28	-	-	-	-	0.065	0.065	-	0.28	-	-
Heptachlor epoxide	0.0000038	0.0000038	0.000052	0.0043	0.00024	-	-	0.0000038	0.0000038	-	-	-	-
Lindane	0.00001	0.00001	0.0028	-	-	-	-	0.00001	0.00001	-	0.004	-	-
Linuron	0.000071	0.000071	0.019	-	-	-	-	0.007	0.007	0.000071	-	-	-
Malathion	0.0001	0.0001	0.19	-	-	-	-	0.0001	0.0001	-	-	-	-
MCPA	0.000025	0.000025	0.0047	-	-	-	-	0.0026	0.0026	0.000025	0.025	-	-
Methoxychlor	0.00003	0.00003	0.9	-	-	-	-	0.00003	0.00003	-	-	-	-
Metolachlor	0.0078	0.0078	0.05	-	-	-	-	0.0078	0.0078	0.028	0.05	-	-
Metribuzin	0.0005	0.0005	0.08	-	-	-	-	0.001	0.001	0.0005	0.08	-	-
Paraquat (as dichloride)	0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-
Parathion	0.000013	0.000013	0.05	-	-	-	-	0.000013	0.000013	-	-	-	-
Phorate	0.002	0.002	0.002	-	-	-	-	-	-	-	-	-	-
Picloram	0.029	0.029	0.19	-	-	-	-	0.029	0.029	-	0.19	-	-

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**		**Irrigation**	**Livestock**	**Wildlife Watering**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**All**	**All**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Simazine	0.0005	0.0005	0.01	-	-	-	-	0.01	0.01	0.0005	0.01	-	-
Tebuthiuron	0.00027	0.00027	0.66	-	-	-	-	0.0016	0.0016	0.00027	0.13	-	-
Terbufos	0.001	0.001	0.001	-	-	-	-	-	-	-	-	-	-
Toxaphene	0.0000002	0.0000002	0.00043	6.4	0.31	-	-	0.0000002	0.0000002	-	-	-	-
Triallate	0.00024	0.00024	0.12	-	-	-	-	0.00024	0.00024	-	0.23	-	-
Trifluarin	0.0002	0.0002	0.045	-	-	-	-	0.0002	0.0002	-	0.045	-	-
Other Organics													
Aniline	0.0022	0.0022	0.066	1,900	87	-	-	0.0022	0.0022	-	-	-	-
Bis(2-ethyl-hexyl)phthalate	0.016	0.016	0.41	NGR	NGR	-	-	0.016	0.016	-	-	-	-
Dibutyl phthalate	0.019	0.019	0.59	NGR	NGR	-	-	0.019	0.019	-	-	-	-
Dichlorobenzidine	0.007	0.007	0.007	NGR	NGR	-	-	-	-	-	-	-	-
Diisopropanolamine	1.6	1.6	3.6	-	-	160	160	1.6	1.6	2	-	-	-
Ethylene glycol	31	31	31	NGR	NGR	9,200	16,000	190	190	-	-	-	-
Hexachlorobutadiene	0.0013	0.0013	0.006	0.031	0.0013	-	-	0.0013	0.0013	-	-	-	-
Methylmethacrylate	0.47	0.47	0.47	17	0.84	-	-	-	-	-	-	-	-
MTBE	0.015	0.015	0.015	6.1	0.34	-	-	10	10	-	-	-	-
Nitrilotriacetic acid	0.4	0.4	0.4	-	-	-	-	-	-	-	-	-	-
Nonylphenol + ethoxylates	0.001	0.001	-	-	-	0.0081	0.0081	0.001	0.001	-	-	-	-
Phenol	0.002	0.002	0.57	73,000	3,700	110	150	0.004	0.004	-	0.002	-	-
Sulfolane	0.09	0.09	0.09	-	-	1,700	2,800	50	50	0.5	-	-	-
Trihalomethanes - total (THMs)	0.1	0.1	0.1	-	-	-	-	-	-	-	-	-	-

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Notes:

a. *B[a]P TPE (Total Potency Equivalents) are calculated by multiplying the groundwater concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence Factor (PEF) to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (1999) scheme, as follow:*

Carcinogenic PAH Compound	**PEF**
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

b. For ecological receptors only.

c. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

d. See Surface Water Quality Guidelines for Use in Alberta (AENV, 1999) for further guidance on aquatic life pathway.

e. Tier 1 guideline = lowest of aquatic life guideline and all other guidelines.

NGR - no guideline required, calculated value > solubility or >1,000,000 mg/L
Potable GW = protection of groundwater for potable drinking water
Inhalation = protection of volatilization from groundwater and migration into indoor air
Eco Soil Contact = protection of terrestrial plants and soil invertebrates in areas with shallow groundwater
Aquatic Life = protection of groundwater discharging to a surface water body hosting aquatic life
Irrigation = protection of a potential irrigation groundwater source
Livestock Watering = protection of a potential livestock watering groundwater resource
Wildlife Watering = protection of groundwater discharging to a surface water body from which wildlife may drink

Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
General and Inorganic Parameters									
pH	6.5-8.5	6.5-8.5	6.5-8.5	-	-	-	-	6.5-9	6.5-9
Ammonia	see note d	see note d	-	-	-	-	-	see note d	see note d
Chloride	230	230	250	-	-	-	-	230	230
Cyanide	0.005	0.005	0.2	-	-	-	-	0.005	0.005
Fluoride	0.12	0.12	1.5	-	-	-	-	0.12	0.12
Nitrate	13	13	45	-	-	-	-	13	13
Nitrite (as nitrogen)	0.06	0.06	1.0	-	-	-	-	0.06	0.06
Sodium	200	200	200	-	-	-	-	-	-
Sulphate	500	500	500	-	-	-	-	-	-
Sulphide (as H_2S)	0.002	0.002	0.05	-	-	-	-	0.002	0.002
Total Dissolved Solids (TDS)	500	500	500	-	-	-	-	-	-
Metals									
Aluminum	see note d	see note d	-	-	-	-	-	see note d	see note d
Antimony	0.006	0.006	0.006	-	-	-	-	-	-
Arsenic	0.005	0.005	0.01	-	-	-	-	0.005	0.005
Barium	1	1	1	-	-	-	-	-	-
Boron	5	5	5	-	-	-	-	-	-
Bromate	0.01	0.01	0.01	-	-	-	-	-	-
Cadmium	See note e	See note e	0.005	-	-	-	-	see note d	see note d
Chromium (Total)	See note e	See note e	0.05	-	-	-	-	see note d	see note d
Copper	See note e	See note e	1	-	-	-	-	see note d	see note d
Iron	0.3	0.3	0.3	-	-	-	-	0.3	0.3
Lead	See note e	See note e	0.01	-	-	-	-	see note d	see note d
Manganese	0.05	0.05	0.05	-	-	-	-	-	-

Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Mercury	See note e	See note e	0.001	-	-	-	-	see note d	see note d
Nickel	see note d	see note d	-	-	-	-	-	see note d	see note d
Selenium	0.001	0.001	0.01	-	-	-	-	0.001	0.001
Silver	see note d	see note d	-	-	-	-	-	see note d	see note d
Uranium	0.02	0.02	0.02	-	-	-	-	-	-
Zinc	0.03	0.03	5	-	-	-	-	0.03	0.03
Hydrocarbons									
Benzene	0.005	0.005	0.005	2.8	0.14	100	61	33	0.69
Toluene	0.024	0.024	0.024	NGR	74	82	59	NGR	0.083
Ethylbenzene	0.0024	0.0024	0.0024	NGR	16	42	20	NGR	41
Xylenes	0.3	0.3	0.3	80	3.9	21	31	NGR	18
Styrene	0.072	0.072	2.8	90	4.3	-	-	0.072	0.072
F1	2.2	0.81	2.2	19	0.81	6.5	7.1	NGR	9.8
F2	1.1	1.1	1.1	NGR	1.5	1.8	1.8	NGR	1.3
Acenapthene	0.0058	0.0058	1.4	NGR	NGR	-	-	0.0058	0.0058
Acenaphthylene	0.046	0.046	-	-	-	-	-	0.046	0.046
Anthracene	0.000012	0.000012	NGR	NGR	NGR	0.025	0.025	0.000012	0.000012
Fluoranthene	0.00004	0.00004	NGR	NGR	NGR	0.24	0.24	0.00004	0.00004
Fluorene	0.003	0.003	0.94	NGR	NGR	-	-	0.003	0.003
Naphthalene	0.0011	0.0011	0.47	14	0.6	-	-	0.0011	0.0011
Phenanthrene	0.0004	0.0004	-	-	-	-	-	0.0004	0.0004
Pyrene	0.000025	0.000025	0.71	NGR	NGR	-	-	0.000025	0.000025
Carcinogenic PAHs (as B(a)P TPE) [a]	0.00001	0.00001	0.00001	-	-	-	-	-	-
Benz[a]anthracene [b]	0.000018	0.000018	-	-	-	-	-	0.000018	0.000018
Benzo[b+j]fluoranthene [b]	0.00048	0.00048	-	-	-	-	-	0.00048	0.00048

Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland - All Water Uses

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Benzo[k]fluoranthene [b]	0.00048	0.00048	-	-	-	-	-	0.00048	0.00048
Benzo[g,h,i]perylene [b]	0.00021	0.00017	-	-	-	-	-	0.00021	0.00017
Benzo[a]pyrene [b]	0.000017	0.000015	-	-	-	0.0018	0.0018	0.000017	0.000015
Chrysene [b]	0.0014	0.0014	-	-	-	-	-	0.0014	0.0014
Dibenz[a,h]anthracene [b]	0.00028	0.00026	-	-	-	-	-	0.00028	0.00026
Indeno[1,2,3-c,d]pyrene [b]	0.00023	0.00021	-	-	-	-	-	0.00023	0.00021
Halogenated Aliphatics									
Vinyl chloride	0.002	0.0011	0.002	0.018	0.0011	-	-	-	-
1,1-Dichloroethene	0.014	0.014	0.014	0.68	0.039	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.005	0.005	0.005	0.41	0.02	4.4	5	0.27	0.029
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.03	0.03	0.03	2.3	0.11	-	-	0.11	0.11
1,2-Dichloroethane	0.005	0.005	0.005	0.17	0.01	-	-	0.1	0.1
Dichloromethane (Methylene chloride)	0.05	0.05	0.05	61	3.4	-	-	0.098	0.098
Trichloromethane (Chloroform)	0.0018	0.0018	0.093	0.05	0.003	-	-	0.0018	0.0018
Tetrachloromethane (Carbon tetrachloride)	0.005	0.00056	0.005	0.011	0.00056	-	-	0.013	0.013
Dibromochloromethane	0.19	0.19	0.19	26	1.1	-	-	-	-
Chlorinated Aromatics									
Chlorobenzene	0.0013	0.0013	0.03	0.3	0.014	-	-	0.0013	0.0013
1,2-Dichlorobenzene	0.0007	0.0007	0.003	116	5.4	-	-	0.0007	0.0007
1,4-Dichlorobenzene	0.001	0.001	0.001	4.6	0.22	-	-	0.026	0.026
1,2,3-Trichlorobenzene	0.008	0.008	0.014	0.8	0.032	-	-	0.008	0.008
1,2,4-Trichlorobenzene	0.015	0.015	0.015	0.71	0.028	-	-	0.024	0.024
1,3,5-Trichlorobenzene	0.014	0.014	0.014	0.38	0.015	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.0018	0.0018	0.032	NGR	0.14	-	-	0.0018	0.0018

Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
1,2,3,5-Tetrachlorobenzene	0.0038	0.0038	0.0038	0.41	0.017	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.002	0.002	0.002	0.21	0.0088	-	-	-	-
Pentachlorobenzene	0.006	0.006	0.0094	NGR	0.038	-	-	0.006	0.006
Hexachlorobenzene	0.00057	0.00057	0.00057	0.029	0.0012	-	-	-	-
2,4-Dichlorophenol	0.0002	0.0002	0.0003	NGR	1500	-	-	0.0002	0.0002
2,4,6-Trichlorophenol	0.002	0.002	0.002	NGR	54	-	-	0.018	0.018
2,3,4,6-Tetrachlorophenol	0.001	0.001	0.001	NGR	NGR	-	-	0.001	0.001
Pentachlorophenol	0.0005	0.0005	0.03	NGR	NGR	0.87	0.88	0.0005	0.0005
Dioxins & Furans [c]	0.00000012	0.00000012	0.00000012	-	-	-	-	-	-
PCBs	0.0094	0.0094	0.0094	-	-	-	-	-	-
Pesticides									
Aldicarb	0.001	0.001	0.009	-	-	-	-	0.001	0.001
Aldrin	0.0007	0.0007	0.0007	-	-	-	-	0.003	0.003
Atrazine and metabolites	0.0018	0.0018	0.005	-	-	-	-	0.0018	0.0018
Azniphos-methyl	0.00001	0.00001	0.02	-	-	-	-	0.00001	0.00001
Bendiocarb	0.04	0.04	0.04	-	-	-	-	-	-
Bromoxynil	0.005	0.005	0.005	-	-	-	-	0.005	0.005
Carbaryl	0.0002	0.0002	0.09	-	-	-	-	0.0002	0.0002
Carbofuran	0.0018	0.0018	0.09	-	-	-	-	0.0018	0.0018
Chlorothalonil	0.00018	0.00018	0.14	-	-	-	-	0.00018	0.00018
Chlorpyrifos	0.0000035	0.0000035	0.09	-	-	-	-	0.0000035	0.0000035
Cyanazine	0.002	0.002	0.01	-	-	-	-	0.002	0.002
2,4-D	0.004	0.004	0.1	-	-	-	-	0.004	0.004
DDT	0.000001	0.000001	0.093	-	-	-	-	0.000001	0.000001
Diazinon	0.02	0.02	0.02	-	-	-	-	-	-

Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Dicamba	0.01	0.01	0.12	-	-	-	-	0.01	0.01
Dichlofop-methyl	0.0061	0.0061	0.009	-	-	-	-	0.0061	0.0061
Dieldrin	0.000056	0.000056	0.0007	-	-	-	-	0.000056	0.000056
Dimethoate	0.0062	0.0062	0.02	-	-	-	-	0.0062	0.0062
Dinoseb	0.00005	0.00005	0.01	-	-	-	-	0.00005	0.00005
Diquat	0.07	0.07	0.07	-	-	-	-	-	-
Diuron	0.15	0.15	0.15	-	-	-	-	-	-
Endosulfan	0.00002	0.00002	0.057	-	-	-	-	0.00002	0.00002
Endrin	0.000036	0.000036	0.0028	-	-	-	-	0.000036	0.000036
Glyphosate	0.065	0.065	0.28	-	-	-	-	0.065	0.065
Heptachlor epoxide	0.0000038	0.0000038	0.000052	0.0043	0.00024	-	-	0.0000038	0.0000038
Lindane	0.00001	0.00001	0.0028	-	-	-	-	0.00001	0.00001
Linuron	0.007	0.007	0.019	-	-	-	-	0.007	0.007
Malathion	0.0001	0.0001	0.19	-	-	-	-	0.0001	0.0001
MCPA	0.0026	0.0026	0.0047	-	-	-	-	0.0026	0.0026
Methoxychlor	0.00003	0.00003	0.9	-	-	-	-	0.00003	0.00003
Metolachlor	0.0078	0.0078	0.05	-	-	-	-	0.0078	0.0078
Metribuzin	0.001	0.001	0.08	-	-	-	-	0.001	0.001
Paraquat (as dichloride)	0.01	0.01	0.01	-	-	-	-	-	-
Parathion	0.000013	0.000013	0.05	-	-	-	-	0.000013	0.000013
Phorate	0.002	0.002	0.002	-	-	-	-	-	-
Picloram	0.029	0.029	0.19	-	-	-	-	0.029	0.029
Simazine	0.01	0.01	0.01	-	-	-	-	0.01	0.01
Tebuthiuron	0.0016	0.0016	0.66	-	-	-	-	0.0016	0.0016
Terbufos	0.001	0.001	0.001	-	-	-	-	-	-

Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland - All Water Uses

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Water Use	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Toxaphene	0.0000002	0.0000002	0.00043	6.4	0.31	-	-	0.0000002	0.0000002
Triallate	0.00024	0.00024	0.12	-	-	-	-	0.00024	0.00024
Trifluarin	0.0002	0.0002	0.045	-	-	-	-	0.0002	0.0002
Other Organics									
Aniline	0.0022	0.0022	0.066	1,900	87	-	-	0.0022	0.0022
Bis(2-ethyl-hexyl)phthalate	0.016	0.016	0.41	NGR	NGR	-	-	0.016	0.016
Dibutyl phthalate	0.019	0.019	0.59	NGR	NGR	-	-	0.019	0.019
Dichlorobenzidine	0.007	0.007	0.007	NGR	NGR	-	-	-	-
Diisopropanolamine	1.6	1.6	3.6	-	-	160	160	1.6	1.6
Ethylene glycol	31	31	31	NGR	NGR	9,200	16,000	190	190
Hexachlorobutadiene	0.0013	0.0013	0.006	0.031	0.0013	-	-	0.0013	0.0013
Methylmethacrylate	0.47	0.47	0.47	17	0.84	-	-	-	-
MTBE	0.015	0.015	0.015	6.1	0.34	-	-	10	10
Nitrilotriacetic acid	0.4	0.4	0.4	-	-	-	-	-	-
Nonylphenol + ethoxylates	0.001	0.001	-	-	-	0.0081	0.0081	0.001	0.001
Phenol	0.004	0.004	0.57	73,000	3,700	110	150	0.004	0.004
Sulfolane	0.09	0.09	0.09	-	-	1,700	2,800	50	50
Trihalomethanes - total (THMs)	0.1	0.1	0.1	-	-	-	-	-	-

Table B-3. Groundwater Remediation Guideline Values for Residential/Parkland - All Water Uses

This table must not be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Notes:

a. B[a]P TPE (Total Potency Equivalents) are calculated by multiplying the groundwater concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (1999) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

b. For ecological receptors only.

c. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

d. See Surface Water Quality Guidelines for Use in Alberta (AENV, 1999) for further guidance on aquatic life pathway.

e. Tier 1 guideline = lowest of aquatic life guideline and potable GW guideline.

NGR - no guideline required, calculated value > solubility or >1,000,000 mg/L
Potable GW = protection of groundwater for potable drinking water
Inhalation = protection of volatilization from groundwater and migration into indoor air
Eco Soil Contact = protection of terrestrial plants and soil invertebrates in areas with shallow groundwater
Aquatic Life = protection of groundwater discharging to a surface water body hosting aquatic life

Table B-4. Groundwater Remediation Guideline Values for Commercial/Industrial - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Pathway	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
General and Inorganic Parameters									
pH	6.5-8.5	6.5-8.5	6.5-8.5	-	-	-	-	6.5-9	6.5-9
Ammonia	see note d	see note d	-	-	-	-	-	see note d	see note d
Chloride	230	230	250	-	-	-	-	230	230
Cyanide	0.005	0.005	0.2	-	-	-	-	0.005	0.005
Fluoride	0.12	0.12	1.5	-	-	-	-	0.12	0.12
Nitrate	13	13	45	-	-	-	-	13	13
Nitrite (as nitrogen)	0.06	0.06	1.0	-	-	-	-	0.06	0.06
Sodium	200	200	200	-	-	-	-	-	-
Sulphate	500	500	500	-	-	-	-	-	-
Sulphide (as H_2S)	0.002	0.002	0.05	-	-	-	-	0.002	0.002
Total Dissolved Solids (TDS)	500	500	500	-	-	-	-	-	-
Metals									
Aluminum	see note d	see note d	-	-	-	-	-	see note d	see note d
Antimony	0.006	0.006	0.006	-	-	-	-	-	-
Arsenic	0.005	0.005	0.01	-	-	-	-	0.005	0.005
Barium	1	1	1	-	-	-	-	-	-
Boron	5	5	5	-	-	-	-	-	-
Bromate	0.01	0.01	0.01	-	-	-	-	-	-
Cadmium	See note e	See note e	0.005	-	-	-	-	see note d	see note d
Chromium (Total)	See note e	See note	0.05	-	-	-	-	see note d	see note d
Copper	See note e	See note e	1	-	-	-	-	see note d	see note d
Iron	0.3	0.3	0.3	-	-	-	-	0.3	0.3
Lead	See note e	See note e	0.01	-	-	-	-	see note d	see note d
Manganese	0.05	0.05	0.05	-	-	-	-	-	-
Mercury	See note e	See note e	0.001	-	-	-	-	see note d	see note d
Nickel	see note d	see note d	-	-	-	-	-	see note d	see note d
Selenium	0.001	0.001	0.01	-	-	-	-	0.001	0.001

Table B-4. Groundwater Remediation Guideline Values for Commercial/Industrial - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Pathway	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Silver	see note d	see note d	-	-	-	-	-	see note d	see note d
Uranium	0.02	0.02	0.02	-	-	-	-	-	-
Zinc	0.03	0.03	5	-	-	-	-	0.03	0.03
Hydrocarbons									
Benzene	0.005	0.005	0.005	19	1.8	540	350	33	0.69
Toluene	0.024	0.024	0.024	NGR	NGR	240	200	NGR	0.083
Ethylbenzene	0.0024	0.0024	0.0024	NGR	NGR	150	110	NGR	41
Xylenes	0.3	0.3	0.3	NGR	48	74	120	NGR	18
Styrene	0.072	0.072	2.8	NGR	51	-	-	0.072	0.072
F1	2.2	2.2	2.2	NGR	9.1	9.9	11	NGR	9.8
F2	1.1	1.1	1.1	NGR	17	3.1	3.1	NGR	1.3
Acenapthene	0.0058	0.0058	1.4	NGR	NGR	-	-	0.0058	0.0058
Acenaphthylene	0.046	0.046	-	-	-	-	-	0.046	0.046
Anthracene	0.000012	0.000012	NGR	NGR	NGR	0.32	0.32	0.000012	0.000012
Fluoranthene	0.00004	0.00004	NGR	NGR	NGR	0.86	0.86	0.00004	0.00004
Fluorene	0.003	0.003	0.94	NGR	NGR	-	-	0.003	0.003
Naphthalene	0.0011	0.0011	0.47	NGR	7	-	-	0.0011	0.0011
Phenanthrene	0.0004	0.0004	-	-	-	-	-	0.0004	0.0004
Pyrene	0.000025	0.000025	0.71	NGR	NGR	-	-	0.000025	0.000025
Carcinogenic PAHs (as B(a)P TPE) [a]	0.00001	0.00001	0.00001	-	-	-	-	-	-
Benz[a]anthracene [b]	0.000018	0.000018	-	-	-	-	-	0.000018	0.000018
Benzo[b+j]fluoranthene [b]	0.00048	0.00048	-	-	-	-	-	0.00048	0.00048
Benzo[k]fluoranthene [b]	0.00048	0.00048	-	-	-	-	-	0.00048	0.00048
Benzo[g,h,i]perylene [b]	0.00021	0.00017	-	-	-	-	-	0.00021	0.00017
Benzo[a]pyrene [b]	0.000017	0.000015	-	-	-	0.0066	0.0066	0.000017	0.000015
Chrysene [b]	0.0014	0.0014	-	-	-	-	-	0.0014	0.0014
Dibenz[a,h]anthracene [b]	0.00028	0.00026	-	-	-	-	-	0.00028	0.00026
Indeno[1,2,3-c,d]pyrene [b]	0.00023	0.00021	-	-	-	-	-	0.00023	0.00021

Table B-4. Groundwater Remediation Guideline Values for Commercial/Industrial - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Pathway	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Halogenated Aliphatics									
Vinyl chloride	0.002	0.002	0.002	0.12	0.013	-	-	-	-
1,1-Dichloroethene	0.014	0.014	0.014	4.5	0.49	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.005	0.005	0.005	2.8	0.25	73	83	0.27	0.029
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.03	0.03	0.03	16	1.3	-	-	0.11	0.11
1,2-Dichloroethane	0.005	0.005	0.005	1.2	0.13	-	-	0.1	0.1
Dichloromethane (Methylene chloride)	0.05	0.05	0.05	410	43	-	-	0.098	0.098
Trichloromethane (Chloroform)	0.0018	0.0018	0.093	0.35	0.04	-	-	0.0018	0.0018
Tetrachloromethane (Carbon tetrachloride)	0.005	0.005	0.005	0.078	0.0068	-	-	0.013	0.013
Dibromochloromethane	0.19	0.19	0.19	250	10	-	-	-	-
Chlorinated Aromatics									
Chlorobenzene	0.0013	0.0013	0.03	2.2	0.18	-	-	0.0013	0.0013
1,2-Dichlorobenzene	0.0007	0.0007	0.003	NGR	64	-	-	0.0007	0.0007
1,4-Dichlorobenzene	0.001	0.001	0.001	32	2.6	-	-	0.026	0.026
1,2,3-Trichlorobenzene	0.008	0.008	0.014	6.9	0.33	-	-	0.008	0.008
1,2,4-Trichlorobenzene	0.015	0.015	0.015	6.1	0.29	-	-	0.024	0.024
1,3,5-Trichlorobenzene	0.014	0.014	0.014	3.3	0.15	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.0018	0.0018	0.032	NGR	NGR	-	-	0.0018	0.0018
1,2,3,5-Tetrachlorobenzene	0.0038	0.0038	0.0038	NGR	0.16	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.002	0.002	0.002	NGR	0.08	-	-	-	-
Pentachlorobenzene	0.006	0.006	0.0094	NGR	0.44	-	-	0.006	0.006
Hexachlorobenzene	0.00057	0.00057	0.00057	0.21	0.014	-	-	-	-
2,4-Dichlorophenol	0.0002	0.0002	0.0003	NGR	NGR	-	-	0.0002	0.0002
2,4,6-Trichlorophenol	0.002	0.002	0.002	NGR	540	-	-	0.018	0.018
2,3,4,6-Tetrachlorophenol	0.001	0.001	0.001	NGR	NGR	-	-	0.001	0.001
Pentachlorophenol	0.0005	0.0005	0.03	NGR	NGR	2.2	2.2	0.0005	0.0005
Dioxins & Furans [c]	0.00000012	0.00000012	0.00000012	-	-	-	-	-	-

Table B-4. Groundwater Remediation Guideline Values for Commercial/Industrial - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Pathway	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
PCBs	0.0094	0.0094	0.0094	-	-	-	-	-	-
Pesticides									
Aldicarb	0.001	0.001	0.009	-	-	-	-	0.001	0.001
Aldrin	0.0007	0.0007	0.0007	-	-	-	-	0.003	0.003
Atrazine and metabolites	0.0018	0.0018	0.005	-	-	-	-	0.0018	0.0018
Azniphos-methyl	0.00001	0.00001	0.02	-	-	-	-	0.00001	0.00001
Bendiocarb	0.04	0.04	0.04	-	-	-	-	-	-
Bromoxynil	0.005	0.005	0.005	-	-	-	-	0.005	0.005
Carbaryl	0.0002	0.0002	0.09	-	-	-	-	0.0002	0.0002
Carbofuran	0.0018	0.0018	0.09	-	-	-	-	0.0018	0.0018
Chlorothalonil	0.00018	0.00018	0.14	-	-	-	-	0.00018	0.00018
Chlorpyrifos	0.0000035	0.0000035	0.09	-	-	-	-	0.0000035	0.0000035
Cyanazine	0.002	0.002	0.01	-	-	-	-	0.002	0.002
2,4-D	0.004	0.004	0.1	-	-	-	-	0.004	0.004
DDT	0.000001	0.000001	0.093	-	-	-	-	0.000001	0.000001
Diazinon	0.02	0.02	0.02	-	-	-	-	-	-
Dicamba	0.01	0.01	0.12	-	-	-	-	0.01	0.01
Dichlofop-methyl	0.0061	0.0061	0.009	-	-	-	-	0.0061	0.0061
Dieldrin	0.000056	0.000056	0.0007	-	-	-	-	0.000056	0.000056
Dimethoate	0.0062	0.0062	0.02	-	-	-	-	0.0062	0.0062
Dinoseb	0.00005	0.00005	0.01	-	-	-	-	0.00005	0.00005
Diquat	0.07	0.07	0.07	-	-	-	-	-	-
Diuron	0.15	0.15	0.15	-	-	-	-	-	-
Endosulfan	0.00002	0.00002	0.057	-	-	-	-	0.00002	0.00002
Endrin	0.000036	0.000036	0.0028	-	-	-	-	0.000036	0.000036
Glyphosate	0.065	0.065	0.28	-	-	-	-	0.065	0.065
Heptachlor epoxide	0.0000038	0.0000038	0.000052	0.051	0.002	-	-	0.0000038	0.0000038
Lindane	0.00001	0.00001	0.0028	-	-	-	-	0.00001	0.00001

Table B-4. Groundwater Remediation Guideline Values for Commercial/Industrial - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Pathway	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Linuron	0.007	0.007	0.019	-	-	-	-	0.007	0.007
Malathion	0.0001	0.0001	0.19	-	-	-	-	0.0001	0.0001
MCPA	0.0026	0.0026	0.0047	-	-	-	-	0.0026	0.0026
Methoxychlor	0.00003	0.00003	0.9	-	-	-	-	0.00003	0.00003
Metolachlor	0.0078	0.0078	0.05	-	-	-	-	0.0078	0.0078
Metribuzin	0.001	0.001	0.08	-	-	-	-	0.001	0.001
Paraquat (as dichloride)	0.01	0.01	0.01	-	-	-	-	-	-
Parathion	0.000013	0.000013	0.05	-	-	-	-	0.000013	0.000013
Phorate	0.002	0.002	0.002	-	-	-	-	-	-
Picloram	0.029	0.029	0.19	-	-	-	-	0.029	0.029
Simazine	0.01	0.01	0.01	-	-	-	-	0.01	0.01
Tebuthiuron	0.0016	0.0016	0.66	-	-	-	-	0.0016	0.0016
Terbufos	0.001	0.001	0.001	-	-	-	-	-	-
Toxaphene	0.0000002	0.0000002	0.00043	75	2.9	-	-	0.0000002	0.0000002
Triallate	0.00024	0.00024	0.12	-	-	-	-	0.00024	0.00024
Trifluarin	0.0002	0.0002	0.045	-	-	-	-	0.0002	0.0002
Other Organics									
Aniline	0.0022	0.0022	0.066	13,000	1,000	-	-	0.0022	0.0022
Bis(2-ethyl-hexyl)phthalate	0.016	0.016	0.41	NGR	NGR	-	-	0.016	0.016
Dibutyl phthalate	0.019	0.019	0.59	NGR	NGR	-	-	0.019	0.019
Dichlorobenzidine	0.007	0.007	0.007	NGR	NGR	-	-	-	-
Diisopropanolamine	1.6	1.6	3.6	-	-	320	320	1.6	1.6
Ethylene glycol	31	31	31	NGR	NGR	15,000	26,000	190	190
Hexachlorobutadiene	0.0013	0.0013	0.006	0.22	0.015	-	-	0.0013	0.0013
Methylmethacrylate	0.47	0.47	0.47	120	10	-	-	-	-
MTBE	0.015	0.015	0.015	40	4.3	-	-	10	10
Nitrilotriacetic acid	0.4	0.4	0.4	-	-	-	-	-	-
Nonylphenol + ethoxylates	0.001	0.001	-	-	-	0.02	0.02	0.001	0.001

Table B-4. Groundwater Remediation Guideline Values for Commercial/Industrial - All Water Uses

This table must <u>not</u> be used for Tier 1 assessment and remediation, unless directed by Section 5.1.2. Tier 1 guidelines are found in Table 2. This table is provided to assist Tier 2 guideline development, using the procedures outlined in the companion Tier 2 document (AENV 2008a).

Pathway	**Lowest Guideline**		**Potable**	**Inhalation**		**Eco Soil Contact**		**Aquatic Life**	
Soil Type	**Fine**	**Coarse**	**All**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**
Unit	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Phenol	0.004	0.004	0.57	NGR	45,000	730	1000	0.004	0.004
Sulfolane	0.09	0.09	0.09	-	-	3,400	5,700	50	50
Trihalomethanes - total (THMs)	0.1	0.1	0.1	-	-	-	-	-	-

Notes:

a B[a]P TPE (Total Potency Equivalents) are calculated by multiplying the groundwater concentration of individual carcinogenic PAHs by a standardized Benzo[a]pyrene Potency Equivalence to produce a Benzo[a]pyrene relative potency concentration, and by subsequently summing the relative potency concentrations for the entire PAH mixture. B[a]P PEFs are order of magnitude estimates of carcinogenic potential and are based on the World Health Organization (1999) scheme, as follows:

Carcinogenic PAH Compound	**PEF**
Benz[a]anthracene	0.1
Benzo(b+j)fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[ghi]perylene	0.01
Benzo[a]pyrene	1
Chrysene	0.01
Dibenz[a,h]anthracene	1
Indeno[1,2,3-c,d]pyrene	0.1

b. For ecological receptors only.

c. Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)

d. See Surface Water Quality Guidelines for Use in Alberta (AENV, 1999) for further guidance on aquatic life pathway.

e. Tier 1 guideline = lowest of aquatic life guideline and potable GW guideline.

NGR - no guideline required, calculated value > solubility or >1,000,000 mg/L

Potable GW = protection of groundwater for potable drinking water

Inhalation = protection of volatilization from groundwater and migration into indoor air

Eco Soil Contact = protection of terrestrial plants and soil invertebrates in areas with shallow groundwater

Aquatic Life = protection of groundwater discharging to a surface water body hosting aquatic life

APPENDIX C - PROTOCOLS FOR CALCULATING ALBERTA TIER 1 SOIL AND GROUNDWATER REMEDIATION GUIDELINES

LIST OF TABLES

1. INTRODUCTION

This Appendix provides the protocols, parameter values, and equations used to determine the numerical values for Alberta Tier 1 Soil and Groundwater Remediation Guidelines for each of the exposure pathways described in the main text.

1.1 Approach

A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines (CCME, 2006a) was used as a starting point for developing the soil remediation guidelines. The protocol was adapted as appropriate.

Since the Canadian Council of Ministers of the Environment (CCME) issued their protocol for deriving soil quality guidelines (CCME, 2006a), the deliberations associated with the 2006 review of the Petroleum Hydrocarbon Canada-Wide Standard (PHC CWS; CCME, 2008a) have resulted in changes to a few additional parameters. Most of these parameter changes have been adopted here. Additionally, where appropriate, parameters have been adjusted to reflect the differences between conditions in Alberta and the assumptions in the CCME guidance that reflect conditions in the whole of Canada.

No CCME protocols are currently available for calculating groundwater guidelines. Accordingly, for each exposure pathway, the corresponding CCME protocol for the soil guideline was adapted to calculate a groundwater guideline. Where calculated groundwater values are greater than the solubility of the chemical in question, the guideline value is replaced in the appropriate table with “NGR” for “no guideline required”.

2. PARAMETER VALUES

Parameter values used in the models that calculate the Alberta Tier 1 Soil and Groundwater Remediation Guidelines fall into two main groups: i) parameters relating to receptor exposure and properties of the site, referred to as "non-chemical-specific parameters"; and, ii) parameters that relate to the chemical properties, toxicity, or background exposure to chemicals, referred to as "chemical-specific parameters". These two groups of parameters are discussed below.

2.1 Non-Chemical-Specific Parameters

Parameter values used in the models in this section relating to human receptor characteristics, soil and hydrogeological parameters, site characteristics, building parameters, and livestock and wildlife receptor characteristics are summarized in Tables C-1 to C-5, respectively. All parameters are adopted directly from CCME (2006a) except where noted below.

In Table C-2, the saturated hydraulic conductivity for fine soils is 32 m/year for all exposure pathways, the lateral hydraulic gradient is 0.028, and the soil permeability to vapour flow is 10^{-9} cm^2 for fine soil and $6x10^{-8}$ cm^2 for coarse soil. These changes from parameter values in CCME (2006a) are based on the latest decisions made by the Soil Quality Guidelines Task Group of the CCME, and reflect the deliberations that took place during the process of revising the PHC CWS (CCME, 2008a). The groundwater recharge rate is 0.012 m/year in fine soil and 0.06 m/year in coarse soil. Groundwater recharge rates are based on extensive research by Atomic Energy of Canada Limited (AECL, 1990, 1991, 1992, and 1995) and hydrogeological literature for the prairies (*e.g.*, Trudell, 1994; Keller *et al.,* 1986; Woo and Rowsell, 1993). This work is consistent with groundwater recharge being less than 10% of precipitation in Coarse soils and less than 2% of precipitation in Fine soils. Taking these values together with precipitation data for the wettest of the Alberta locations for which climate normals are available (Edson: precipitation = 568 mm/year, based on 1961 to 1990 Canadian Climate Normals, Environment Canada, 2001) and rounding up, gives recharge values of 60 mm/year, and 12 mm/year for Coarse and Fine soils, respectively.

In Table C-4, the height for a residential building is 360 cm, and the air exchange rates for residential and commercial buildings are 0.5 and 0.9 exchanges/hour, respectively. Again, these changes from parameter values in CCME (2006a) are based on the latest decisions made by the Soil Quality Guidelines Task Group of the CCME, and reflect the deliberations that took place during the process of revising the PHC CWS (CCME, 2008a). In addition, for petroleum hydrocarbons only, there is an adjustment factor of 10 applied in the calculation of the indoor infiltration and inhalation guideline, reflecting empirical evidence that concentrations of petroleum hydrocarbon vapours in buildings are typically less than predicted values by this factor or more due to biodegradation in the subsurface and conservatism in the partitioning relationship as it applies to these substances. No adjustment factor is used for non-petroleum hydrocarbons, since no empirical evidence is available to support such a factor.

In Table C-5, the cattle body weight and water ingestion rate are the same as were used in CCME (2006a), and the soil ingestion rate is taken from NRC (1996). The meadow vole was selected as the surrogate ecological receptor that would be protective of the majority of wildlife species, based on its small home range and high soil and water ingestion rates relative to its bodyweight. Meadow vole body weight and water ingestion rate were taken from USEPA (1993). Meadow vole soil ingestion rate was calculated from data and equations provided in USEPA (1993) as follows:

$$SIR = FIR \cdot PSID$$

and

$$FIR = 0.0687 \cdot BW^{0.822} \cdot 1{,}000$$

Where: SIR = soil ingestion rate for meadow voles (g/day);
PSID = proportion of soil in diet for meadow voles (0.024 – USEPA, 1993);
FIR = food ingestion rate for meadow voles (2.41 g dry weight/day; calculated below);
BW = meadow vole body weight (0.017 kg – minimum value from the range given in USEPA, 1993); and,
1,000 = conversion factor from kg to g.

Substituting these values in the above equation yields value for FIR of 2.41 g dry weight/day and for SIR of 0.058 g day (Table C-5).

2.2 Chemical-Specific Parameters

2.2.1 Physical Parameters

Physical parameters for the Alberta Tier 1 substances are summarized in Table C-6, together with an indication of the source for each. The parameters K_{oc} (organic carbon partition coefficient), H′ (dimensionless Henry's Law constant), and D_{air} (diffusion coefficient in air) are used in the soil and groundwater guideline models. Solubility was also included, to enable groundwater guideline values greater than solubility to be identified. References for each source are provided at the end of this appendix.

2.2.2 Toxicological Parameters

Human toxicity reference values (TRVs) for the Alberta Tier 1 substances are summarized in Table C-7, together with an indication of the source for each. For non-carcinogenic substances, the applicable TRVs are the tolerable daily intake (TDI) for oral exposure and the tolerable concentration (TC) for inhalation exposure. For carcinogens, the oral slope factor and the inhalation unit risk are provided in Table C-7. Where needed in the guideline calculations, the risk-specific dose and the risk-specific concentration were calculated as follows:

$$RsD = \frac{ARL}{SF}$$

$$RsC = \frac{ARL}{UR}$$

Where:

RsD = risk-specific dose (mg/kg bw per day);
ARL = acceptable risk level (10^{-5}, see below); and,
SF = slope factor (Table C-7); (mg/kg bw per day)$^{-1}$;
RsC = risk-specific concentration (mg/m^3);
UR = unit risk (Table C-7); (mg/m^3)$^{-1}$.

The acceptable risk level was set at 10^{-5} based on guidance in Health Canada (Health Canada, 2004a) and precedent from Alberta Environment.

TRVs were taken from the following sources, in order of preference:

- Health Canada;
- CCME guideline documents;
- The United States Environmental Protection Agency (IRIS database); and,
- The United States Oak Ridge National Laboratory toxicological database.

For volatile chemicals, if an inhalation tolerable concentration or unit risk was not available, one was estimated from the oral tolerable daily intake or the oral slope factor, using the adult body weight and inhalation rate provided in Table C-1. References for each source are provided at the end of this appendix.

2.2.3 Human Exposure Parameters

Human absorption factors are summarized in Table C-8.

Human background exposure parameters for the Alberta Tier 1 substances are summarized in Table C-9, together with an indication of the source for each. Note that background exposure rates are not required in the case of carcinogenic chemicals. Parameter values include toddler and adult estimated daily intake (EDI), which is the daily dose of chemical that an individual might receive from all non-site-related sources (assumed to be soil, water, air, food, and consumer products for Tier 1 guideline derivation), background air concentration (C_a), and soil allocation factor (SAF). The following sources of background exposure information were used, in order of preference:

- CCME guideline documents;
- Assessments carried out as part of the priority substance list (PSL) program under the Canadian Environmental Protection Act (CEPA); and,

- Information in the United States Agency for Toxic Substances and Disease Registry toxicological profiles.

Recognizing that a receptor might be exposed to contaminants from other sources than site-related soil, a soil allocation factor is used to ensure that exposure to contaminated soil represents only a portion of the overall allowable exposure. For the purposes of guideline calculation, exposure is assumed to be possible from five environmental compartments: soil, water, air, food, and consumer products (CCME, 2006a). Values for the soil allocation factor (SAF) were selected based on the following logic:

1. If a value of SAF other than the default value of 0.2 had previously been used in a guideline document, then that value was retained (e.g., hydrocarbon compounds, sulfolane, diisopropanolamine).
2. If the substance could exist in all five of the environmental compartments, then the default SAF of 0.2 was used.
3. If background exposure information was available and it was unlikely that the substance would appear in one of the five environmental compartments because of its chemical or physical properties, then an SAF of 0.25 was used to reflect exposure divided between the remaining four compartments.

References for each source are provided at the end of this appendix.

2.2.4 Petroleum Hydrocarbon Fractions

Petroleum hydrocarbons are a complex mixture of substances. To facilitate the calculation of risk-based soil and groundwater remediation guidelines, each fraction has been divided into several sub-fractions on the basis of chemical structure (aliphatic vs. aromatic) and carbon chain length.

Soil or groundwater remediation guidelines for each PHC fraction were developed by combining guidelines for each individual sub-fraction according to the proportion (by mass) of each sub-fraction within the fraction, according to the equation below:

$$SGRG\ (mg/kg-bw/day)=\frac{1}{\sum_i \frac{F_i}{SGRG_i}}$$

Where:

SGRG = soil (mg/kg) or groundwater (mg/L) remediation guideline;
F_i = the assumed proportion of the fraction in soil or groundwater made up of sub-fraction i (dimensionless, see below; values in Table C-10); and,
$SGRG_i$ = soil (mg/kg) or groundwater (mg/L) remediation guideline for sub-fraction “i” (mg/kg). For soil, maximum concentration set at $1x10^6$ mg/kg.

The assumed proportion of each sub-fraction differs for soil and groundwater, since each sub-fraction partitions differently between soil and groundwater. Assumed sub-fraction distributions for soil and groundwater are provided in Table C-10. The assumed sub-fraction distributions in soil are adopted directly from CCME (2008a). The assumed sub-fraction distributions in groundwater are calculated from the soil values by making standard equilibrium partitioning assumptions and using the following equations:

$$G_i = F_{i(soil)} \frac{\rho_b}{\theta_w + \left(K_{oc} \times f_{oc} \times \rho_b\right) + \left(H' \times \theta_a\right)}$$

and

$$F_{i(groundwater)} = \frac{G_i}{\sum_i G_i}$$

Where:
G_i = proportion of sub-fraction i in groundwater (before normalization; dimensionless);
$F_{i(soil)}$ = proportion of sub-fraction i in soil (Table C-10; dimensionless);
$F_{i(groundwater)}$ = proportion of sub-fraction i in groundwater (normalized; Table C-10; dimensionless);
ρ_b = dry soil bulk density (g/cm^3);
θ_w = moisture-filled porosity (dimensionless);
K_{oc} = organic carbon partition coefficient (L/kg);
f_{oc} = fraction of organic carbon (g/g);
H' = dimensionless Henry's Law Constant (dimensionless); and,
θ_a = vapour-filled porosity (dimensionless).

Guideline values for individual exposure pathways have been capped at a maximum value of 30,000 mg/kg to maintain consistency with the Canada-Wide Standard for Petroleum Hydrocarbons in Soil (CCME, 2008a).

2.2.5 Carcinogenic Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) commonly occur as complex mixtures that may include compounds known or suspected to be carcinogenic. Soil and groundwater remediation guidelines have been calculated for benzo[a]pyrene. The benzo[a]pyrene guideline is applied to other carcinogenic PAHs through the use of Potency Equivalence Factors (PEFs). PEFs establish the toxicity of individual carcinogenic PAHs relative to benzo[a]pyrene. The notes in Appendix A and B explain the use of PEFs in more detail.

PEFs are also used in the calculation of soil guidelines for the protection of drinking water. The Risk Specific Dose (RSD) for benzo[a]pyrene is multiplied by the appropriate PEF to derive a RSD for each carcinogenic PAH. This value is then used in the calculation of individual soil guidelines for the protection of drinking water as explained in Section 5.1.2. These guidelines are then used with site-specific soil concentrations to calculate the Index of Additive Cancer Risk (IACR) as explained in the notes in Appendix A.

2.2.6 Water Quality Guidelines

Water quality guidelines for the Alberta Tier 1 chemicals are required as a starting point for calculating soil or groundwater remediation guidelines that are protective of groundwater uses. Values are summarized in Table C-11.

The values for human health were taken from the following sources, in order of preference:

- Health Canada Canadian Drinking Water Quality Guidelines (Health Canada, 2008);
- Drinking water guidelines that were calculated from the oral TRVs summarized in Table C-7 using the Health Canada approach (Health Canada, 1995). The adult exposure parameters used in the calculation are summarized in Table C-1. The proportion of total intake normally ingested in water was assumed to be equivalent to the soil allocation factor (Table C-9) because both are derived in the same manner and are typically equivalent.

The values for ecological receptors were taken from the following sources, in order of preference:

- Alberta Surface Water Quality Guidelines (AENV, 1999); and,
- Livestock or wildlife watering guidelines calculated from published daily threshold exposure doses (DTEDs) and the ecological exposure parameters presented in Table C-5.

3. HUMAN EXPOSURE PATHWAYS

3.1 Direct Contact

The model used to calculate the soil remediation guidelines protective of the human direct soil contact (soil ingestion, dermal contact, and particulate inhalation) is taken without change from CCME (2006a). Based on guidance in CCME (2006a), exposure via particulate inhalation was not considered for volatile compounds (IR_s was set to 0 kg/day for volatile chemicals in the equations below). Parameter values were discussed in Section 2, and parameter values are summarized in Tables C-1 to C-9. Separate calculations are made for carcinogens and non-carcinogenic chemicals.

Non-Carcinogens

$$SRG_{HH} = \frac{(TDI - EDI) \times SAF \times BW}{\left[(AF_G \times SIR) + (AF_L \times IR_S \times ET_2) + (AF_S \times SR)\right] \times ET_1} + [BSC]$$

Where:

SRG_{HH} = human health-based soil remediation guideline (mg/kg);
TDI = tolerable daily intake (mg/kg bw per day);
EDI = estimated daily intake (mg/kg bw per day);
SAF = soil allocation factor (dimensionless);
BW = adult or toddler body weight (kg);
AF_G = absorption factor for gut (dimensionless);
AF_L = absorption factor for lung (dimensionless);
AF_S = absorption factor for skin (dimensionless);
SIR = adult or toddler soil ingestion rate (kg/day);
IR_S = inhalation of particulate matter re-suspended from soil (kg/day);
SR = adult or toddler soil dermal contact rate (kg/day; calculated below);
ET_1 = exposure term 1 (dimensionless) (days/week ÷ 7 x weeks/year ÷ 52);
ET_2 = exposure term 2 (dimensionless) (hours/day ÷ 24); and,
BSC = background soil concentration (mg/kg).

Carcinogens

$$SRG_{HH} = \frac{(RsD) \times BW}{\left[(AF_G \times SIR) + (AF_L \times IR_S \times ET_2) + (AF_S \times SR)\right] \times ET_1} + [BSC]$$

Where:

SRG_{HH} = preliminary human health-based soil remediation guideline (mg/kg);
RsD = risk-specific dose (mg/kg bw per day);
BW = adult body weight (kg);
AF_G = absorption factor for gut (dimensionless);
AF_L = absorption factor for lung (dimensionless);
AF_S = absorption factor for skin (dimensionless);
SIR = adult soil ingestion rate (kg/day);
IR_S = inhalation of particulate matter re-suspended from soil (kg/day);
SR = adult soil dermal contact rate (kg/day);
ET_1 = exposure term 1 (dimensionless) (days/week ÷ 7 x weeks/year ÷ 52);
ET_2 = exposure term 2 (dimensionless) (hours/day ÷ 24); and,
BSC = background soil concentration (mg/kg).

Note that in contrast to the CCME (2006a) protocol, an exposure term based on the exposure scenario is used for commercial and industrial land use for carcinogens.

3.1.1 Soil Dermal Contact Rate

The soil dermal contact rate (SR) is the mass of contaminated soil which is assumed to contact the skin each day. This parameter is calculated as follows (CCME, 2006a):

$$SR = \{(SA_H \times DL_H) + (SA_O \times DL_O)\} \times EF$$

Where:

SR = soil dermal contact rate (kg/day);
SA_H = exposed surface area of hands (m^2);
DL_H = dermal loading of soil to hands (kg/m^2 per event);
SA_O = area of exposed body surfaces other than hands (m^2);
DL_O = dermal loading of soil to other surfaces (kg/m^2 per event); and,
EF = exposure frequency (events/day).

The soil dermal contact rate is calculated separately for toddlers and adults using the parameters in Table C-1.

3.2 Inhalation

Soil and groundwater guidelines protective of the indoor infiltration and inhalation pathway were calculated for volatile organic compounds using the equations from the CCME (2006a) protocol without change for soil and adapted as appropriate for groundwater.

3.2.1 Adjustment Factor

Consistent with the approach taken in CCME (2008a), an adjustment factor of 10 is applied in the equations below for petroleum hydrocarbons (see Section 2.1), to account for empirical evidence that measured indoor air concentrations are typically lower by at least this factor than concentrations predicted from the models below. The adjustment factor takes the value of 1 for all non-petroleum hydrocarbon chemicals, reflecting the lack of any empirical data to support such a factor for these chemicals.

3.2.2 Assumptions

Assumptions implicit in the model include the following:

- contaminant vapour immediately above the groundwater table is assumed to be in equilibrium with contaminant concentrations in the groundwater based on Henry's Law;
- the soil is physically and chemically homogeneous;
- cracks in the building floor slab are filled with dry material of the underlying soil type;
- the moisture content is uniform throughout the unsaturated zone;

- decay of the contaminant source is not considered (*i.e.*, infinite source mass);
- attenuation of the contaminant in the unsaturated zone is not considered, except in the case of hydrocarbons, where the adjustment factor accounts empirically for this and other processes;
- interactions of the contaminant with other chemicals or soil minerals are not considered.

3.2.3 Soil

Non-Carcinogens

$$SRG_I = \frac{(TC - C_a) \times [\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)] \times SAF \times DF_i \times 10^3 \times AF}{H' \times \rho_b \times ET \times 10^6} + BSC$$

Where:
SRG_I = soil remediation guideline for indoor infiltration (mg/kg);
TC = tolerable concentration (mg/m^3);
C_a = background air concentration (mg/m^3);
θ_w = moisture-filled porosity (dimensionless);
K_{oc} = organic carbon partition coefficient (L/kg);
f_{oc} = fraction of organic carbon (g/g);
ρ_b = dry soil bulk density (g/cm^3);
H′ = Henry's Law Constant (dimensionless);
θ_a = vapour-filled porosity (dimensionless);
SAF = soil allocation factor (dimensionless);
DF_i = dilution factor from soil gas to indoor air (calculated below);
10^3 = conversion factor from kg to g;
AF = adjustment factor (10, hydrocarbons; 1, non-petroleum hydrocarbons);
ET = exposure term (dimensionless);
10^6 = conversion factor from m^3 to cm^3; and,
BSC = background soil concentration (mg/kg).

Carcinogens

$$SRG_I = \frac{RsC \times [\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)] \times DF_i \times 10^3 \times AF}{H' \times \rho_b \times ET \times 10^6} + BSC$$

Where:
SRG_I = soil remediation guideline for indoor infiltration (mg/kg);
RsC = risk-specific concentration (mg/m^3);
θ_w = moisture-filled porosity (dimensionless);
K_{oc} = organic carbon partition coefficient (L/kg);
f_{oc} = fraction of organic carbon (g/g);
ρ_b = dry soil bulk density (g/cm^3);
H′ = Henry's Law Constant (dimensionless);
θ_a = vapour-filled porosity (dimensionless);
DF_i = dilution factor from soil gas to indoor air (calculated below);
10^3 = conversion factor from kg to g;
AF = adjustment factor (10, hydrocarbons; 1, non-petroleum hydrocarbons);
ET = exposure term (dimensionless);
10^6 = conversion factor from m^3 to cm^3; and,
BSC = background soil concentration (mg/kg).

Note that in contrast to the CCME (2006a) protocol, an exposure term of 0.2747 (corresponding to exposure to site-related contaminants for 10 hours/day, 5 days/week, and 48 weeks/year) is used for commercial and industrial land use for carcinogens.

3.2.4 Groundwater

Groundwater remediation guidelines were calculated using equations analogous to those above, but with adaptations to account for a groundwater, rather than soil, source.

Non-Carcinogens

$$GWRG_I = \frac{(TC - C_a) \times SAF \times DF_i \times AF}{H' \times ET \times 10^3}$$

Where:
$GWRG_I$ = groundwater remediation guideline for indoor infiltration (mg/L);
TC = tolerable concentration (mg/m^3);
C_a = background air concentration (mg/m^3);
SAF = soil allocation factor (dimensionless);
DF_i = dilution factor from soil gas to indoor air (calculated below);
AF = adjustment factor (10, hydrocarbons; 1, non-petroleum hydrocarbons);
H′ = Henry’s Law Constant (dimensionless);
ET = exposure term (dimensionless); and,
10^3 = conversion factor from m^3 to L.

Carcinogens

$$GWRG_I = \frac{RsC \times DF_i \times AF}{H' \times ET \times 10^3}$$

Where:
$GWRG_I$ = groundwater remediation guideline for indoor infiltration (mg/L);
RsC = risk-specific concentration (mg/m^3);
DF_i = dilution factor from soil gas to indoor air (calculated below);
AF = adjustment factor (10, hydrocarbons; 1, non-petroleum hydrocarbons);
H′ = Henry’s Law Constant (dimensionless);
ET = exposure term (dimensionless);
10^3 = conversion factor from m^3 to L; and,

Note that in contrast to the CCME (2006a) protocol, an exposure term of 0.2747 (corresponding to exposure to site-related contaminants for 10 hours/day, 5 days/week, and 48 weeks/year) is used for commercial and industrial land use for carcinogens.

3.2.5 Dilution Factor Calculation

This section presents the equations (CCME, 2006a) that were used to calculate the dilution factor in the above equations. The dilution factor (DF_i) was calculated as follows:

$$DF_i = \frac{1}{\alpha}$$

Where:
DF_i = dilution factor from soil gas concentration to indoor air concentration (unitless); and,
α = attenuation coefficient (unitless; see derivation below).

Calculation of α

The attenuation coefficient, α, was calculated using the following equation:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right)}{exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) - 1\right]}$$

Where:

α = attenuation coefficient (dimensionless);
D_T^{eff} = effective porous media diffusion coefficient (cm^2/s; calculated below);
A_B = building area (cm^2);
Q_B = building ventilation rate (cm^3/s; calculated below);
L_T = distance from contaminant source to foundation (cm);
Q_{soil} = volumetric flow rate of soil gas into the building (cm^3/s; calculated below);
L_{crack} = thickness of the foundation (cm);
D_{crack} = effective vapour diffusion coefficient through the crack (cm^2/s; calculated below); and,
A_{crack} = area of cracks through which contaminant vapours enter the building (cm^2).

Calculation of D_T^{eff}:

$$D_T^{eff} \approx D_a \times \left(\frac{\theta_a^{10/3}}{\theta_t^2}\right)$$

Where:
D_T^{eff} = overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm^2/s);
D_a = diffusion coefficient in air (cm^2/s);
θ_a = soil vapour-filled porosity (dimensionless); and,
θ_t = soil total porosity (dimensionless).

Calculation of D_{crack}:

D_{crack} is calculated in exactly the same way as D_T^{eff}, with the exception that the assumption is made that the soil material in the cracks is dry (CCME, 2006a), and accordingly, the air filled porosity is the same as the total porosity, and the equation becomes:

$$D_{crack} \approx D_a \times \left(\frac{\theta_t^{10/3}}{\theta_t^2} \right)$$

Where:
D_{crack} = effective porous media diffusion coefficient in floor cracks (cm^2/s);
D_a = diffusion coefficient in air (cm^2/s);
θ_t = total porosity (dimensionless).

Calculation of Q_B:

$$Q_B = \frac{L_B W_B H_B ACH}{3{,}600}$$

Where:
Q_B = building ventilation rate (cm^3/s);
L_B = building length (cm);
W_B = building width (cm);
H_B = building height (cm);
ACH = air exchanges per hour (h^{-1}); and,
3,600 = conversion factor from hours to seconds.

Calculation of Q_{soil}:

$$Q_{soil} = \frac{2\pi \Delta P k_v X_{crack}}{\mu \ln \left[\frac{2Z_{crack}}{r_{crack}} \right]}$$

Where
Q_{soil} = volumetric flow rate of soil gas into the building (cm^3/s);
ΔP = pressure differential ($g/cm \cdot s^2$);
k_v = soil vapour permeability to vapour flow (cm^2);
X_{crack} = length of idealized cylinder (cm);
μ = vapour viscosity (0.000173 g/cm·s; CCME, 2006a);
Z_{crack} = distance below grade to idealized cylinder (cm); and,
r_{crack} = radius of idealized cylinder (cm; calculated as A_{crack}/X_{crack}).

3.3 Offsite Migration

"Offsite Migration" guidelines are calculated to check that the guideline set for commercial and industrial land use will not result in adjacent more sensitive land being contaminated at levels above the applicable guideline for the sensitive land due to wind and/or water transport of contaminated soil from the commercial or industrial site. The guideline is calculated using the equation provided in the CCME (2006a) protocol:

$$SRG_{OM} = (14.3 \times SRG_A) - (13.3 \times BSC)$$

Where
SRG_{OM} = soil remediation guideline protective of offsite migration (mg/kg);
SRG_A = soil remediation guideline for human direct soil contact for agricultural land use (mg/kg); and,

BSC = background soil concentration (mg/kg).

A similar off-site migration check is calculated for ecological health using the ecological direct contact soil remediation guideline for agricultural land use.

4. ECOLOGICAL EXPOSURE PATHWAYS

4.1 Direct Contact

4.1.1 Soil

The exposure pathway considering direct contact of plants, soil invertebrates and microbes with contaminated soil is an important primary pathway in CCME (2006a), and is also important in the framework under which the Alberta Tier 1 guidelines were developed. Existing CCME soil quality guideline values were adopted for this exposure pathway. The reader is referred to CCME (2006a) for information on the protocol used to develop the existing guidelines for this exposure pathway.

The CCME recently reviewed the direct contact exposure pathway for petroleum hydrocarbon guidelines. As part of the review, a study was commissioned to review currently available data and identify suitable data for guideline derivation. The guideline derivation process followed CCME (2006a) recommendations as closely as possible. Some data came from research programmes that were not related to CCME guideline development, but that were nevertheless deemed to provide important information for guideline development. Alternative data treatments were developed for these data without compromising CCME or Alberta Environment protection goals. Details of the guideline derivation processes are documented in CCME (2008a). To maintain consistency with the CCME approach for benzene, toluene, ethylbenzene, and xylenes, subsoil ecocontact guidelines for petroleum hydrocarbons were set at twice the surface soil guidelines.

4.1.2 Groundwater

The direct contact of shallow groundwater with plants and soil invertebrates pathway is applicable whenever groundwater is present within 3 m of the ground surface. It applies to all land uses, and is based on the corresponding soil guideline. The approach for this exposure pathway for three different chemical classes is provided below.

Non-Polar Organic Compounds

Non-polar organic compounds can partition between soil organic carbon, pore water, and pore vapour, based on well-established partitioning equations. The guideline for this exposure pathway for these chemicals is calculated from existing eco soil contact soil remediation guidelines using standard assumptions for the partitioning of the contaminant between soil and pore water. Separate guidelines are calculated for coarse and fine soils, using the following equation:

$$GWRG_{DC} = SRG_{DC} \frac{\rho_b}{\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)}$$

Where: $GWRG_{DC}$= groundwater remediation guideline protective of direct contact with plants and soil invertebrates in areas of shallow groundwater (mg/L);

SRG_{DC} = soil remediation guideline protective of direct contact with plants and soil invertebrates (mg/kg);
ρ_b = dry soil bulk density (g/cm^3);
θ_w = moisture-filled porosity (dimensionless);
K_{oc} = organic carbon partition coefficient (L/kg);
f_{oc} = fraction of organic carbon (g/g);
H' = dimensionless Henry's Law Constant (dimensionless); and,
θ_a = vapour-filled porosity (dimensionless).

Soil remediation guidelines protective of ecological soil contact are available for selected chemicals in Appendix A.

Salt Compounds

Groundwater guidelines for salts are not calculated in this document.

Metals and Polar Organic Compounds

The potential interactions between metals or polar organic compounds and soils are complex in that they can be highly dependant on various environmental conditions including pH, clay mineralogy, redox conditions, and metal species present. Attempting to set groundwater guidelines for these chemicals for this pathway would involve significant uncertainty, and accordingly, it is recommended that concerns with potential adverse effects on surface soil biota from metals and polar organic compounds in shallow groundwater be addressed on a site-specific basis by analyzing soil samples.

4.2 Nutrient and Energy Cycling

Existing CCME soil quality guideline values were adopted for this exposure pathway. The reader is referred to CCME (2006a) for information on the protocol used to develop the existing guidelines for this exposure pathway.

4.3 Soil and Food Ingestion

The ingestion of contaminants in soil and contaminants bioaccumulated from soil into fodder by livestock or wildlife (soil and food ingestion pathway) forms part of the exposure scenario for natural areas or agricultural land use. Where available, existing CCME guideline values for metals for livestock soil and food ingestion were adopted without change. In general, these guidelines specifically considered livestock species, and so were not extrapolated to wildlife. Existing CCME guidelines for polycyclic aromatic hydrocarbons, polychlorinated biphenyls (PCBs), dioxins and furans, and DDT were also adopted without change for this exposure pathway. However, soil and food ingestion guidelines for these four compounds/groups considered primary, secondary and tertiary consumers, and accordingly the guidelines were considered protective of both livestock and wildlife.

Soil ingestion guidelines were calculated for benzene, toluene, ethylbenzene, and xylenes (BTEX) and petroleum hydrocarbon fractions F1 to F4. Petroleum hydrocarbons and BTEX are not considered to bioaccumulate into potential food species, and accordingly, this guideline considered only soil ingestion for petroleum hydrocarbons. The following equation was used to calculate the soil ingestion guideline for PHCs. Livestock guidelines were calculated using parameters for a cow, as an economically important livestock species. Wildlife guidelines were calculated using parameters for a meadow vole. The meadow vole was selected since small animals are typically maximally exposed to contaminants. Wildlife soil ingestion guidelines calculated using the meadow vole are expected to be protective for the majority of wildlife species.

$$SRG_{SI-L/W} = \frac{0.75 \times DTED \times BW_{L/W}}{SIR_{L/W} \times BF}$$

Where:

$SRG_{SI-L/W}$= soil remediation guideline for soil ingestion - livestock or wildlife (mg/kg);
0.75 = allocation factor (dimensionless);
DTED = daily threshold effect dose (mg/kg-bw/day);
$BW_{L/W}$ = body weight - livestock or wildlife (kg);
$SIR_{L/W}$ = soil ingestion rate - livestock or wildlife (kg/day); and,
BF = bioavailability factor (1.0; assumed).

4.4 Offsite Migration

"Offsite Migration" guidelines are calculated to check that the guideline set for commercial and industrial land use will not result in adjacent more sensitive land being contaminated at levels above the applicable guideline for the sensitive land due to wind and/or water transport of contaminated soil from the commercial or industrial site. The guideline is calculated using the equation provided in the CCME (2006a) protocol:

$$SRG_{OM} = (14.3 \times SRG_A) - (13.3 \times BSC)$$

Where

SRG_{OM}= soil remediation guideline protective of offsite migration (mg/kg);
SRG_A = soil remediation guideline for ecological direct contact for agricultural land use (mg/kg); and,
BSC = background soil concentration (mg/kg).

A similar off-site migration check is calculated for human health using the human direct contact soil remediation guideline for agricultural land use.

5. GROUNDWATER PATHWAYS

This section provides the protocols used to calculate soil and groundwater remediation objectives protective of exposure pathways involving groundwater. The following receptors are considered:

- humans (potable drinking water sourced from groundwater);
- livestock (drinking water from a watering well, dugout, or surface water body potentially connected to contaminated groundwater);
- agricultural crops (irrigated from potentially contaminated groundwater);
- aquatic life (via lateral groundwater transport and discharge into a surface water body); and,
- wildlife (drinking water from a surface water body potentially connected to contaminated groundwater).

In the first three cases, it is assumed that the water well or dugout could potentially be installed at any location, and hence it is assumed that there is no lateral offset between the location where the contaminated soil or groundwater is measured and the receptor.

In the last two cases, a minimum lateral separation of 10 m is assumed between the location where the contaminated soil or groundwater is measured and the receptor (location of surface water body). In cases where contamination is present within 10 m of a surface water body, a Tier 2 or Exposure Control approach is required.

Surface water quality guidelines protective of the above water uses are provided in Table C-11, where available.

5.1 Soil Remediation Guidelines

Soil remediation guidelines for groundwater pathways were calculated using the model and equations from the CCME (2006a) protocol. Soil remediation guidelines for the protection of groundwater are not calculated for inorganic substances due to the uncertainties associated with the partitioning of metals between the adsorbed and dissolved phase as noted above; these substances should be assessed through site-specific groundwater sampling where these pathways are applicable.

5.1.1 Model Assumptions

Assumptions implicit in the model include the following:

1. the soil is physically and chemically homogeneous;
2. moisture content is uniform throughout the unsaturated zone;
3. infiltration rate is uniform throughout the unsaturated zone;
4. depletion of the contaminant source is not considered (*i.e.*, infinite source mass);
5. flow in the unsaturated zone is assumed to be one dimensional and downward only (vertical recharge) with dispersion, sorption-desorption, and biological degradation;

6. contaminant is not present as an immiscible phase product;
7. maximum possible concentration in the leachate is equivalent to the solubility limit of the chemical in water under the defined site conditions;
8. groundwater aquifer is unconfined;
9. groundwater flow is uniform and steady;
10. co-solubility and oxidation/reduction effects are not considered;
11. attenuation of the contaminant in the saturated zone is assumed to be one-dimensional with respect to sorption-desorption, dispersion, and biological degradation;
12. dispersion in groundwater is assumed to occur in the longitudinal and transverse directions only and diffusion is not considered;
13. mixing of the leachate with the groundwater is assumed to occur through mixing of leachate and groundwater mass fluxes; and
14. dilution of the plume by groundwater recharge down-gradient of the source is not included.

5.1.2 Guideline Calculation

The soil remediation guideline protective of groundwater uses is calculated in the same way for all five groundwater uses noted at the start of Section 5, using the corresponding surface water quality guideline as the starting point for each, with 2 exceptions. The first exception is that the lateral offset between the point at which the contaminated soil is measured and the surface water body (parameter “x” in the dilutilon factor 4 equation below) is assumed to be 10 m for aquatic life and wildlife watering, and zero for the other water uses. Therefore, dilution factor 4 is only active for aquatic life and wildlife watering and cannot be applied for other pathways. The second exception is that in the calculation of dilution factor 3 for the potable groundwater pathway only, the average thickness of the mixing zone (Z_d) takes the fixed value of 2 m, reflecting the likely minimum screen length for a viable drinking water well. It should be noted that this second point reflects Alberta Environment policy and is not consistent with CCME (2006a).

The model considers four processes:

1. partitioning of the substance from soil to pore water (leachate);
2. transport of the leachate from the base of contamination to the groundwater table;
3. mixing of the leachate with groundwater; and,
4. transport of the substance in groundwater down-gradient to a discharge point.

For each of these four processes, a dilution factor was calculated (DF1 through DF4, respectively). DF1 has units of (mg/kg)/(mg/L) or L/kg. The other three dilution factors are dimensionless [units of (mg/L)/(mg/L)]. The overall dilution factor is used to calculate the soil concentration that is protective of groundwater using the following equations:

$$SRG_{GR} = SWQG_{FL} \times DF$$

$$DF = DF1 \times DF2 \times DF3 \times DF4$$

Where:

SRG_{GR} = soil remediation guideline protective of groundwater pathways (mg/kg);
$SWQG_{FL}$ = corresponding surface water quality guideline (drinking water, aquatic life, livestock or wildlife watering, or irrigation) (mg/L);
DF = overall dilution factor (L/kg);
DF1 = dilution factor for process 1 (L/kg);
DF2 = dilution factor for process 2 (dimensionless);
DF3 = dilution factor for process 3 (dimensionless); and,
DF4 = dilution factor for process 4 (dimensionless).

Dilution Factor 1

Dilution factor 1 (DF1) is the ratio of the concentration of a contaminant in soil to the concentration in leachate that is in contact with the soil. This "dilution factor" represents the three phase partitioning between contaminant sorbed to soil, contaminant dissolved in pore water (*i.e.*, as leachate), and contaminant present as soil vapour. DF1 is calculated using the following equation:

$$DF1 = K_{oc} \times f_{oc} + \frac{(\theta_w + H' \times \theta_a)}{\rho_b}$$

Where:

DF1 = dilution factor 1 (L/kg);
K_{oc} = organic carbon-water partition coefficient (L/kg);
f_{oc} = fraction organic carbon (g/g);
θ_w = water filled porosity (dimensionless);
H' = dimensionless Henry's Law constant (dimensionless);
θ_a = air filled porosity (dimensionless); and,
ρ_b = dry soil bulk density (g/cm^3).

Dilution Factor 2

Dilution factor 2 (DF2) is the ratio of the concentration of a contaminant in leachate that is in contact with the soil, to the concentration in pore water just above the groundwater table. DF2 takes the value 1.00 (*i.e.,* no dilution) for generic guidelines because it is assumed at Tier 1 that the contaminated soil extends down to the water table.

Dilution Factor 3

Dilution factor 3 (DF3) is the ratio of the concentration of a chemical in pore water just above the groundwater table, to the concentration in groundwater beneath the source. This dilution factor reflects a decrease in concentration as leachate mixes with uncontaminated groundwater. DF3 is a function of groundwater velocity, infiltration rate, source length, and mixing zone thickness. The mixing zone thickness is calculated as being due to two processes: i) mixing due to dispersion, and ii) mixing due to infiltration rate. The equations used are as follows:

$$DF3 = 1 + \frac{Z_d \times V}{I \times X}$$

$$Z_d = r + s$$

$$r = 0.01 \times X$$

$$s = d_a\left\{1 - exp\left(\frac{-2.178 \times X \times I}{V \times d_a}\right)\right\}$$

$$V = K \times i$$

Where:

DF3 = dilution factor 3 (dimensionless);
Z_d = average thickness of mixing zone (m);
V = Darcy velocity in groundwater (m/year);
I = infiltration rate (m/year);
X = length of contaminated soil parallel to groundwater flow (m);
r = mixing depth due to dispersion (m);
s = mixing depth due to infiltration rate (m);
d_a = unconfined aquifer thickness (m);
K = aquifer hydraulic conductivity (m/year); and,
i = lateral hydraulic gradient in aquifer (dimensionless).

Note that the parameter Z_d takes the fixed value of 2 m for the drinking water pathway, but is calculated as above for all other pathways.

Dilution Factor 4

Dilution factor 4 (DF4) accounts for the processes of dispersion and biodegradation as groundwater travels downgradient from beneath the source of contamination, and is the ratio of the concentration of a chemical in groundwater beneath the source, to the concentration in groundwater at a distance (10 m for Tier 1 for aquatic life and wildlife watering) downgradient of the source. For distances less than 10 m, a value of 1 should be used for DF4. Consistent with CCME (2006b), the time independent (steady state) version of the equation to calculate DF4 was used:

$$DF4 = \frac{2}{\exp(A) \times [erf(C) - erf(D)]}$$

$$A = \frac{x}{2D_x}\left\{1 - \left(1 + \frac{4L_s D_x}{v}\right)^{1/2}\right\}$$

$$C = \frac{y + Y/2}{2\left(D_y x\right)^{1/2}}$$

$$D = \frac{y - Y/2}{2\left(D_y x\right)^{1/2}}$$

$$L_s = \frac{0.6931}{t_{1/2s}} \times \exp\left(-0.07d\right)$$

$$v = \frac{V}{\theta_t R_s}$$

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

$$D_x = 0.1x$$

$$D_y = 0.01x$$

Where:

DF4 = dilution factor 4 (dimensionless);
erf = the error function;
A = group A (dimensionless);
C = group C (dimensionless);
D = group D (dimensionless);
x = distance to source (10 m, aquatic life and wildlife watering, 0 m other water uses);
D_x = dispersivity in the direction of groundwater flow (m);
L_s = decay constant (1/year);
v = velocity of the contaminant (m/year);
y = distance to receptor perpendicular to groundwater flow (0 m);
Y = source width perpendicular to groundwater flow (m);
D_y = dispersivity perpendicular to the direction of groundwater flow (m);
$t_{1/2s}$ = decay half-life of contaminant in saturated zone of aquifer (years);
d = water table depth (m);
V = Darcy velocity in groundwater (m/year);
θ_t = total soil porosity (dimensionless);
R_s = retardation factor in saturated zone (dimensionless);
ρ_b = dry soil bulk density (g/cm^3);
K_{oc} = organic carbon partition coefficient (mL/g); and,
f_{oc} = fraction organic carbon (g/g).

5.2 Groundwater Remediation Guidelines

It is assumed that a dugout could potentially be constructed at any location on agricultural land and, accordingly, the livestock watering and irrigation water quality guidelines are applicable as groundwater remediation guidelines across all agricultural land. (see Table C-10). Furthermore, it is assumed that a water well could be constructed anywhere within a Domestic Use Aquifer (DUA). Accordingly, drinking water quality guidelines must be applied as groundwater remediation guidelines within the entire DUA . Therefore any modification of these guidelines is considered Exposure Control.

For aquatic life or wildlife watering, it is assumed that there is a minimum 10 m lateral separation between the point of measurement and the surface water body.

5.2.1 Model Assumptions

Assumptions implicit in the model include the following:

- the soil/aquifer material in the saturated zone is physically and chemically homogeneous;
- decay of the contaminant source is not considered (*i.e.*, infinite source mass);
- the contaminant is not present as a free phase product;
- groundwater flow is uniform and steady;
- co-solubility and oxidation/reduction effects are not considered;
- dispersion is assumed to occur in the longitudinal and transverse directions only and diffusion is not considered; and,
- dilution of the plume by groundwater recharge down-gradient of the source is not included.

5.2.2 Guideline Calculation – Aquatic Life and Wildlife Watering

The groundwater remediation guideline protective of aquatic life and wildlife watering is calculated using the following equations.

$$GWRG_{GR} = SWQG_{FL} \times DF4$$

Where:

$GWRG_{GR}$ = groundwater remediation guideline protective of groundwater pathways (mg/kg);
$SWQG_{FL}$ = corresponding surface water quality guideline (aquatic life, or wildlife watering) (mg/L);
DF4 = dilution factor for process 4 (L/kg).

Dilution factor 4 is calculated in the same way as described in Section 5.1.2

For inorganic substances, the aquatic life surface water quality guidelines have been adopted directly because the processes that affect their transport in groundwater do not meet the model assumptions.

6. OTHER CONSIDERATIONS

In addition to the exposure pathways described above, there are a range of other considerations relating to soil and groundwater contamination management including:

- aesthetics/nuisance issues, including smell, taste, and colour.
- concerns with damage to buried infrastructure (concrete foundations, metal pilings or pipelines, fibre-optic communication cables, power cables, polymer piping and joints, etc.); and,
- safety concerns with the possible build-up of flammable vapours or the exposure of workers to dangerous atmospheres, particularly in confined spaces.

In this document, soil ecocontact guideline values that were derived under the CCME (2006a) protocol and previous versions implicitly incorporated the above soil management considerations in the ecological subsoil guidelines. However, separate soil management limits for petroleum hydrocarbons have been developed according to the *Canada-Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil* (CCME 2008a). Specific considerations were given to free phase formation, exposure to workers in trenches, fire and explosive hazards, effects on buried infrastructure, aesthetic considerations, and other technological factors. Not all factors could be explored quantitatively so some decisions were based on a qualitative assessment of information for the given exposure pathway-receptor combination. Where ecocontact subsoil guidelines developed under the CCME protocol (CCME, 2006a or previous versions) remained reasonable for any other management considerations and where no other information could be obtained, values for the ecocontact subsoil guidelines were adopted as management limits.

Regardless of whether specific numerical values have been specified for the above considerations, the proponent is responsible for ensuring that these concerns are addressed by the site remediation and risk management activities.

7. REFERENCES

Alberta Environment references are available at: http://environment.alberta.ca/

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Table C-1. Human Receptor Characteristics

Parameter	**Symbol**	**Unit**	**Toddler**	**Adult**
Body Weight	BW	kg	16.5	70.7
Air Inhalation Rate	IR	m^3/d	9.3	15.8
Soil Inhalation Rate	IR_S	kg/d	7.1×10^{-9}	1.2×10^{-8}
Water Ingestion Rate	WIR	L/d	0.6	1.5
Soil Ingestion Rate	SIR	kg/d	0.00008	0.00002
Skin Surface Area				
- Hands	SA_H	m^2	0.043	0.089
- Other	SA_O	m^2	0.258	0.25
Dermal Loading to Skin				
- Hands	DL_H	kg/m^2-event	0.001	0.001
- Other	DL_O	kg/m^2-event	0.0001	0.0001
Dermal Exposure Frequency	EF	events/d	1	1
Exposure Term, agricultural and residential/parkland	ET	-	1	1
Exposure Term, commercial and industrial	ET	-	0.2747	0.2747
Exposure Term, agricultural and residential/parkland	ET_1	-	1	1
Exposure Term, commercial and industrial	ET_1	-	0.6593	0.6593
Exposure Term, agricultural and residential/parkland	ET_2	-	1	1
Exposure Term, commercial and industrial	ET_2	-	0.4167	0.4167

Notes:

All values from CCME (2006a)

Table C-2. Soil and Hydrogeological Parameters

Parameter	Symbol	Unit	Fine Soil	Coarse Soil	Notes
Soil Bulk Density	ρ_B	g/cm^3	1.4	1.7	
Soil Total Porosity	θ_t	cm^3/cm^3	0.47	0.36	
Soil Moisture-Filled Porosity	θ_w	cm^3/cm^3	0.168	0.119	
Soil Vapour-Filled Porosity	θ_a	cm^3/cm^3	0.302	0.241	
Fraction of Organic Carbon	f_{oc}	*mass/mass*	0.005	0.005	
Saturated Hydraulic Conductivity	K	*m/y*	32	320	
Hydraulic Gradient	i	*m/m*	0.028	0.028	
Recharge (Infiltration) Rate	I	*m/y*	0.012	0.06	1
Soil Permeability to Vapour Flow	k_v	cm^2	10^{-9}	$6x10^{-8}$	2

Notes:
All parameters values from CCME (2006a) except as noted
1. *See Section 2.1*
2. *Fine grained value from CCME (2008a)*

Table C-3. Site Characteristics

Parameter	Symbol	Unit	Value
Contaminant Source Width Perpendicular to Groundwater Flow	Y	m	10
Contaminant Source Length Parallel to Groundwater Flow	X	m	10
Contaminant Source Depth	Z	m	3
Distance to Surface Water	x	m	10
Distance to Potable Water User	x	m	0
Distance to Agricultural Water User	x	m	0
Distance from Contamination to Building Slab	L_T	cm	30
Depth to Groundwater (water table)	d	m	3
Depth of Unconfined Aquifer	d_a	m	5

Notes:
All values from CCME (2006a)

Table C-4. Building Parameters

			Residential Basement		**Residential Slab-on-Grade**		**Commercial Slab-on-Grade**		
Parameter	**Symbol**	**Unit**	**Other Hydrocarbons**	**Petroleum Hydrocarbons**	**Other Hydrocarbons**	**Petroleum Hydrocarbons**	**Other Hydrocarbons**	**Petroleum Hydrocarbons**	**Notes**
Adjustment Factor			1	10	1	10	1	10	1,2
Building Length	L_B	*cm*	1,225	1,225	1,225	1,225	2,000	2,000	
Building Width	W_B	*cm*	1,225	1,225	1,225	1,225	1,500	1,500	
Building Height (including basement)	H_B	*cm*	360	360	360	360	300	300	2
Area of Substructure	A_B	cm^2	$2.7x10^6$	$2.7x10^6$	$1.5x10^6$	$1.5x10^6$	$3.0x10^6$	$3.0x10^6$	
Thickness of Floor Slab	L_{crack}	*cm*	11.25	11.25	11.25	11.25	11.25	11.25	
Depth of Floor Slab Below Ground	Z_{crack}	*cm*	244	244	11.25	11.25	11.25	11.25	
Distance from Source to Slab:	L_T	*cm*							
surface soil			30	30	30	30	30	30	
subsoil			30	30	139	139	139	139	
Crack Area	A_{crack}	cm^2	994.5	994.5	994.5	994.5	1,846	1,846	
Crack Length	X_{crack}	*cm*	4,900	4,900	4,900	4,900	7,000	7,000	
Air Exchange Rate	ACH	*exch/hr*	0.5	0.5	0.5	0.5	0.9	0.9	2
Pressure Differential	ΔP	$g/cm \cdot s^2$	40	40	40	40	20	20	

Notes:

All parameters values from CCME (2006a) except as noted

1. *An application factor of 10 is applied to the calculation for hydrocarbons only to account for empirical evidence of reduction in predicted indoor air concentrations. No data are available to support such a correction for non-hydrocarbons, and accordingly no application factor is used for non-hydrocarbons.*
2. *From CCME (2008a)*

Table C-5. Livestock and Wildlife Receptor Characteristics

Parameter	**Symbol**	**Unit**	**Livestock (Cow)** [a]	**Wildlife (Meadow Vole)**
Body Weight	BW	kg	550 [a]	0.017 [c]
Soil Ingestion Rate	SIR	kg/d	0.747 [b]	0.000058 [d]
Water Ingestion Rate	WIR	L/d	100 [a]	0.00357 [a]

Notes:
a. CCME (2006a)
b. NRC (1996)
c. USEPA (1993)
d. calculated; see text

Table C-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Hydrocarbons										
Benzene	81	EC (2004a)	0.225	EC (2004a)	8.80E-02	EC (2004a)	1780	Gustafson et al (1997)	1	BCMELP (1996)
Toluene	234	EC (2004b)	0.274	EC (2004b)	8.70E-02	EC (2004b)	515	Gustafson et al (1997)	0.288	BCMELP (1996)
Ethylbenzene	537	EC (2004b)	0.358	EC (2004b)	7.50E-02	EC (2004b)	152	Gustafson et al (1997)	0.312	BCMELP (1996)
Xylenes	586	EC (2004b)	0.252	EC (2004b)	7.80E-02	EC (2004b)	198	Gustafson et al (1997)	0.501	BCMELP (1996)
Styrene	461	Gustafson et al (1997)	0.123	Gustafson et al (1997)	7.10E-02	Gustafson et al (1997)	300	Gustafson et al (1997)		
F1									1.95	CCME (2008a)
F2									4.79	CCME (2008a)
Aliphatic C_6-C_8	3,981	CCME (2008a)	50	CCME (2008a)	5.00E-02	CCME (2008a)	5.4	CCME (2008a)		
Aliphatic $C_{>8}$-C_{10}	31,623	CCME (2008a)	80	CCME (2008a)	5.00E-02	CCME (2008a)	0.43	CCME (2008a)		
Aliphatic $C_{>10}$-C_{12}	251,189	CCME (2008a)	120	CCME (2008a)	5.00E-02	CCME (2008a)	0.034	CCME (2008a)		
Aliphatic $C_{>12}$-C_{16}	5.01E+06	CCME (2008a)	520	CCME (2008a)	5.00E-02	CCME (2008a)	0.00076	CCME (2008a)		
Aliphatic $C_{>16}$-C_{21}	6.31E+08	CCME (2008a)	4900	CCME (2008a)	5.00E-02	CCME (2008a)	0.0000025	CCME (2008a)		
Aliphatic $C_{>21}$-C_{34}	1.0E+13	CCME (2008a)	5.6E+05	CCME (2008a)	5.00E-02	CCME (2008a)				
Aliphatic $C_{>34}$	1.6E+08	CCME (2008a)	1.2E+08	CCME (2008a)	5.00E-02	CCME (2008a)				
Aromatic $C_{>8}$-C_{10}	1,585	CCME (2008a)	0.48	CCME (2008a)	5.00E-02	CCME (2008a)	65	CCME (2008a)		
Aromatic $C_{>10}$-C_{12}	2,512	CCME (2008a)	0.14	CCME (2008a)	5.00E-02	CCME (2008a)	25	CCME (2008a)		
Aromatic $C_{>12}$-C_{16}	5,012	CCME (2008a)	0.053	CCME (2008a)	5.00E-02	CCME (2008a)	5.8	CCME (2008a)		
Aromatic $C_{>16}$-C_{21}	15,849	CCME (2008a)	0.013	CCME (2008a)	5.00E-02	CCME (2008a)	0.65	CCME (2008a)		
Aromatic $C_{>21}$-C_{34}	125,893	CCME (2008a)	0.00067	CCME (2008a)	5.00E-02	CCME (2008a)	0.0066	CCME (2008a)		
Aromatic $C_{>34}$	1.8E+06	CCME (2008a)	0.000018	CCME (2008a)	5.00E-02	CCME (2008a)				
Acenapthene	2,818	CCME (2008b)	6.56E-03	CCME (2008b)	4.21E-02	USEPA (1996)	3.9	CCME (2008b)		
Acenaphthylene	5,623	CCME (2008b)	0.000478	CCME (2008b)			16.1	CCME (2008b)		
Anthracene	19,953	CCME (2008b)	0.0015	CCME (2008b)	3.24E-02	USEPA (1996)	0.057	CCME (2008b)		
Fluoranthene	41,687	CCME (2008b)	0.000609	CCME (2008b)	3.03E-02	USEPA (1996)	0.26	CCME (2008b)		
Fluorene	4,898	CCME (2008b)	0.00337	CCME (2008b)	3.63E-02	USEPA (1996)	1.9	CCME (2008b)		
Naphthalene	708	CCME (2008b)	0.020441	CCME (2008b)	5.90E-02	USEPA (1996)	31.7	CCME (2008b)		
Phenanthrene	6,607	CCME (2008b)	0.000986	CCME (2008b)	2.72E-02	USEPA (1996)	1.15	CCME (2008b)		
Pyrene	69,183	CCME (2008b)	0.000466	CCME (2008b)	2.72E-02	USEPA (1996)	1.35	CCME (2008b)		
Benz[a]anthracene	199,526	CCME (2008b)	0.000142	CCME (2008b)	5.01E-02	USEPA (1996)	0.0094	CCME (2008b)		
Benzo[b+j]fluoranthene	93,325	CCME (2008b)	0.000468	CCME (2008b)	2.26E-02	USEPA (1996)	0.00375	CCME (2008b)		
Benzo[k]fluoranthene	19,953	CCME (2008b)	0.0000351	CCME (2008b)	2.26E-02	USEPA (1996)	0.0008	CCME (2008b)		

Table C-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Benzo[g,h,i]perylene	407,380	CCME (2008b)	0.00000597	CCME (2008b)			0.000026	CCME (2008b)		
Benzo[a]pyrene	2,187,762	CCME (2008b)	0.0000478	CCME (2008b)	4.30E-02	USEPA (1996)	0.0016	CCME (2008b)		
Chrysene	125,892	CCME (2008b)	0.004	CCME (2008b)	2.48E-02	USEPA (1996)	0.00415	CCME (2008b)		
Dibenz[a,h]anthracene	1,380,384	CCME (2008b)	0.000000622	CCME (2008b)	2.02E-02	USEPA (1996)	0.00249	CCME (2008b)		
Indeno[1,2,3-c,d]pyrene	1,584,893	CCME (2008b)	0.0000677	CCME (2008b)	1.90E-02	USEPA (1996)	0.000022	CCME (2008b)		
Halogenated Aliphatics										
Vinyl chloride	18.6	USEPA (1996)	1.11	USEPA (1996)	1.06E-01	USEPA (1996)	2760	USEPA (1996)		
1,1-Dichloroethene	65	USEPA (1996)	1.07	USEPA (1996)	1.04E-01	USEPA (1996)	2250	USEPA (1996)		
Trichloroethene (Trichloroethylene, TCE)	94	USEPA (1996)	0.422	USEPA (1996)	7.90E-02	USEPA (1996)	1100	USEPA (1996)	2.19	CCME (2006d)
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	265	USEPA (1996)	0.754	USEPA (1996)	7.20E-02	USEPA (1996)	200	USEPA (1996)		
1,2-Dichloroethane	38	USEPA (1996)	0.0401	USEPA (1996)	1.04E-01	USEPA (1996)	8520	USEPA (1996)		
Dichloromethane (Methylene chloride)	23.74	ORNL (2006)	0.133	ORNL (2006)	1.01E-01	ORNL (2006)	1300	ORNL (2006)		
Trichloromethane (Chloroform)	53.0	USEPA (1996)	0.15	USEPA (1996)	1.04E-01	USEPA (1996)	7920	USEPA (1996)		
Tetrachloromethane (Carbon tetrachloride)	152	USEPA (1996)	1.25	USEPA (1996)	7.80E-02	USEPA (1996)	793	USEPA (1996)		
Dibromochloromethane	35	ORNL (2006)	0.032	ORNL (2006)	1.96E-02	ORNL (2006)	2700	ORNL (2006)		
Chlorinated Aromatics										
Chlorobenzene	224	USEPA (1996)	0.152	USEPA (1996)	7.30E-02	USEPA (1996)	472	USEPA (1996)		
1,2-Dichlorobenzene	379	USEPA (1996)	0.0779	USEPA (1996)	6.90E-02	USEPA (1996)	156	USEPA (1996)		
1,3-Dichlorobenzene	434	ORNL (2006)	0.108	ORNL (2006)			125	ORNL (2006)		
1,4-Dichlorobenzene	616	USEPA (1996)	0.0996	USEPA (1996)	6.90E-02	USEPA (1996)	73.8	USEPA (1996)		
1,2,3-Trichlorobenzene	No data, assumed to be equal to other trichlorobenzene isomers									
1,2,4-Trichlorobenzene	1,659	USEPA (1996)	0.0582	USEPA (1996)	3.00E-02	USEPA (1996)	49	ORNL (2006)		
1,3,5-Trichlorobenzene	No data, assumed to be equal to other trichlorobenzene isomers									
1,2,3,4-Tetrachlorobenzene	No data, assumed to be equal to other tetrachlorobenzene isomers									
1,2,3,5-	No data, assumed to be equal to other tetrachlorobenzene isomers									

Table C-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Tetrachlorobenzene										
1,2,4,5-Tetrachlorobenzene	1,186	ORNL (2006)	0.0409	ORNL (2006)	2.11E-02	ORNL (2006)	0.595	ORNL (2006)		
Pentachlorobenzene	32,148	USEPA (1996)	0.0287	ORNL (2006)	5.70E-02	ORNL (2006)	0.831	ORNL (2006)		
Hexachlorobenzene	80,000	USEPA (1996)	0.0541	USEPA (1996)	5.42E-02	USEPA (1996)	6.2	USEPA (1996)		
Dichlorophenol	718	ORNL (2006)	0.0000895	ORNL (2006)	3.46E-02	ORNL (2006)	4500	ORNL (2006)		
Trichlorophenol	1,186	ORNL (2006)	0.0000662	ORNL (2006)	2.91E-02	ORNL (2006)	1200	ORNL (2006)		
Tetrachlorophenol	2,002	ORNL (2006)	0.000361	ORNL (2006)	2.17E-02	ORNL (2006)	23	ORNL (2006)		
Pentachlorophenol	2,500	ORNL (2006)	1.00E-06	ORNL (2006)	5.60E-02	ORNL (2006)	14	ORNL (2006)		
Dioxins & Furans [2]										
PCBs [2]										
Pesticides										
Aldicarb	32	ORNL (2006)	5.39E-05	ORNL (2006)	3.05E-02	ORNL (2006)	6030	ORNL (2006)		
Aldrin	106,000	ORNL (2006)	0.0018	ORNL (2006)	1.32E-02	ORNL (2006)	0.017	ORNL (2006)		
Atrazine	230	ORNL (2006)	9.65E-08	ORNL (2006)			35	ORNL (2006)		
Azinphos-methyl	231	SRC (2006) [1]	9.96E-07	SRC (2006)			20.9	SRC (2006)		
Bendiocarb	21	SRC (2006) [1]	1.63E-06	SRC (2006)			260	SRC (2006)		
Bromoxynil	435	ORNL (2006)	5.40E-09	ORNL (2006)	2.01E-02	ORNL (2006)	130	ORNL (2006)		
Carbaryl	242	ORNL (2006)	1.78E-07	ORNL (2006)	2.78E-02	ORNL (2006)	110	ORNL (2006)		
Carbofuran	71	ORNL (2006)	1.26E-07	ORNL (2006)			320	ORNL (2006)		
Chlorothalonil	2,392	ORNL (2006)	8.18E-05	ORNL (2006)			0.6	ORNL (2006)		
Chlorpyrifos	6,829	ORNL (2006)	0.00012	ORNL (2006)			1.12	ORNL (2006)		
Cyanazine	124	ORNL (2006)	1.21E-10	ORNL (2006)			170	ORNL (2006)		
2,4-D	29	ORNL (2006)	1.45E-06	ORNL (2006)	2.31E-02	ORNL (2006)	677	ORNL (2006)		
DDT	794,328	EC (1999a)	3.40E-04	ORNL (2006)	1.37E-02	ORNL (2006)	0.0055	ORNL (2006)		
Diazinon	1,337	ORNL (2006)	4.62E-06	ORNL (2006)	2.06E-02	ORNL (2006)	40	ORNL (2006)		
Dicamba	29	ORNL (2006)	8.91E-08	ORNL (2006)			8310	ORNL (2006)		
Dichlofop-methyl	17,092	SRC (2006) [1]	8.21E-05	SRC (2006)			0.8	SRC (2006)		
Dieldrin	10,600	ORNL (2006)	0.000409	ORNL (2006)	1.25E-02	ORNL (2006)	0.25	ORNL (2006)		
Dimethoate	25	ORNL (2006)	4.29E-09	ORNL (2006)			25000	ORNL (2006)		

Table C-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Dinoseb	3,544	ORNL (2006)	1.86E-05	ORNL (2006)			52	ORNL (2006)		
Diquat	1,933	ORNL (2006)	5.81E-12	ORNL (2006)			708000	ORNL (2006)		
Diuron	136	ORNL (2006)	2.06E-08	ORNL (2006)			42	ORNL (2006)		
Endosulfan	22,000	ORNL (2006)	0.00266	ORNL (2006)	1.15E-02	ORNL (2006)	0.45	ORNL (2006)		
Endrin	10,811	USEPA (1996)	0.000308	USEPA (1996)	1.25E-02	USEPA (1996)	0.25	USEPA (1996)		
Glyphosate	19	ORNL (2006)	1.67E-17	ORNL (2006)	4.37E-02	ORNL (2006)	12000	ORNL (2006)		
Heptachlor epoxide	9,528	USEPA (1996)	0.0447	USEPA (1996)	1.12E-02	USEPA (1996)	0.18	USEPA (1996)		
Lindane	1,352	USEPA (1996)	0.000574	USEPA (1996)	1.42E-02	USEPA (1996)	6.8	USEPA (1996)		
Linuron	350	ORNL (2006)	2.56E-07	ORNL (2006)			75	ORNL (2006)		
Malathion	31	ORNL (2006)	2.00E-07	ORNL (2006)			143	ORNL (2006)		
MCPA	29	ORNL (2006)	5.44E-08	ORNL (2006)			630	ORNL (2006)		
Methoxychlor	80,000	USEPA (1996)	0.000648	USEPA (1996)	1.56E-02	USEPA (1996)	0.045	USEPA (1996)		
Metolachlor	292	ORNL (2006)	3.68E-07	ORNL (2006)			530	ORNL (2006)		
Metribuzin	1,196	ORNL (2006)	4.78E-09	ORNL (2006)			1050	ORNL (2006)		
Paraquat (as dichloride)	1,405	ORNL (2006)	1.32E-11	ORNL (2006)			620000	ORNL (2006)		
Parathion	1,779	ORNL (2006)	1.22E-05	ORNL (2006)	1.70E-02	ORNL (2006)	11	ORNL (2006)		
Phorate	444	ORNL (2006)	0.000179	ORNL (2006)			50	ORNL (2006)		
Picloram	18	ORNL (2006)	2.18E-12	ORNL (2006)			430	ORNL (2006)		
Simazine	149	ORNL (2006)	3.85E-08	ORNL (2006)			6.2	ORNL (2006)		
Tebuthiuron	23	ORNL (2006)	4.91E-09	ORNL (2006)			2500	ORNL (2006)		
Terbufos	979	ORNL (2006)	0.000981	ORNL (2006)			5.07	ORNL (2006)		
Toxaphene	95,816	USEPA (1996)	0.000246	USEPA (1996)	1.16E-02	USEPA (1996)	0.74	USEPA (1996)		
Triallate	1,641	ORNL (2006)	0.000789	ORNL (2006)			4	ORNL (2006)		
Trifluarin	9,682	ORNL (2006)	0.00421	ORNL (2006)	1.49E-02	ORNL (2006)	0.184	ORNL (2006)		
Other Organics										
Aniline	45	ORNL (2006)	8.26E-05	ORNL (2006)	7.00E-02	ORNL (2006)	36000	ORNL (2006)		
Bis(2-ethyl-hexyl)phthalate	111,123	USEPA (1996)	4.18E-06	USEPA (1996)	3.51E-02	USEPA (1996)	0.34	USEPA (1996)		
Dibutyl phthalate	1,460	ORNL (2006)	0.000074	ORNL (2006)	4.38E-02	ORNL (2006)	11.2	ORNL (2006)		
Dichlorobenzidine	7,489	ORNL (2006)	2.09E-09	ORNL (2006)	1.94E-02	ORNL (2006)	3.1	ORNL (2006)		
Diisopropanolamine	*** 2.2	CCME (2006b)	7.00E-06	CCME (2006b)			870000	CCME (2006b)		

Table C-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Ethylene glycol	0.0072	EC (1999b)	2.50E-06	EC (1999b)	0.108	ORNL (2006)	1000000	EC (1999b)		
Hexachlorobutadiene	994	ORNL (2006)	0.421	ORNL (2006)	5.61E-02	ORNL (2006)	3.2	ORNL (2006)		
Methylmethacrylate	10	ORNL (2006)	0.0138	ORNL (2006)	7.70E-02	ORNL (2006)	15000	ORNL (2006)		
MTBE	12	USEPA (1994)	0.023	USEPA (1994)	1.02E-01	ORNL (2006)	51000	USEPA (1994)		
Nonylphenol	141,254	EC (2002)	0.005	EC (2002)			5.43	EC (2002)		
Phenol	12	CCME (1999)	1.60E-05	CCME (1999)	0.082	ORNL (2006)	87,000	CCME (1999)		
Sulfolane	1.2	CCME (2006c)	3.60E-08	CCME (2006c)			1000000	CCME (2006c)		

Notes:

K_{oc} = organic carbon water partition coefficient

H′ = dimensionless Henry's Law Coefficient

D_{air} = diffusion coefficient in air

na = not applicable or not available

****Value presented is a mean K_d, rather than a K_{oc} since diisopropanolamine sorbs to clays in preference to organic carbon.*

1. *Calculated using the equation $K_{oc} = 0.41xK_{ow}$*
2. *PCBs, diozins and furans are groups of chemicals with a wide range of chemical properties. Chemical properties are not provided for these groups.*

CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates, including the scientific supporting documents that are summarized in the CEQG.

Table C-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	**Source**	**Inhalation TC mg/m^3**	**Source**	**Oral SF $(mg/kg\text{-}d)^{-1}$**	**Source**	**Inhalation UR $(mg/m^3)^{-1}$**	**Source**
Metals								
Arsenic (inorganic)					2.8	HC (2004b)	6.4	HC (2004b)
Barite-barium	0.2	AENV (2009)						
Hydrocarbons								
Benzene					0.31	HC (2004b)	0.0033	HC (2004b)
Toluene	0.22	HC (2004b)	3.8	HC (2004b)				
Ethylbenzene	0.1	US EPA (2006)	1.0	US EPA (2006)				
Xylenes	1.5	HC (2004b)	0.18	HC (2004b)				
Styrene	0.12	HC (2004b)	0.092	HC (2004b)				
Aliphatic C_6-C_8	5.0	CCME (2008a)	18.4	CCME (2008a)				
Aliphatic $C_{>8}$-C_{10}	0.1	CCME (2008a)	1.0	CCME (2008a)				
Aliphatic $C_{>10}$-C_{12}	0.1	CCME (2008a)	1.0	CCME (2008a)				
Aliphatic $C_{>12}$-C_{16}	0.1	CCME (2008a)	1.0	CCME (2008a)				
Aliphatic $C_{>16}$-C_{21}	2.0	CCME (2008a)						
Aliphatic $C_{>21}$-C_{34}	2.0	CCME (2008a)						
Aliphatic $C_{>34}$	20	CCME (2008a)						
Aromatic $C_{>8}$-C_{10}	0.04	CCME (2008a)	0.2	CCME (2008a)				
Aromatic $C_{>10}$-C_{12}	0.04	CCME (2008a)	0.2	CCME (2008a)				
Aromatic $C_{>12}$-C_{16}	0.04	CCME (2008a)	0.2	CCME (2008a)				
Aromatic $C_{>16}$-C_{21}	0.03	CCME (2008a)						
Aromatic $C_{>21}$-C_{34}	0.03	CCME (2008a)						
Aromatic $C_{>34}$	0.03	CCME (2008a)						
Naphthalene	0.02	US EPA (2006)	0.003	US EPA (2006)				
Acenaphthene	0.06	US EPA (2006)	0.27	see note 1				
Fluorene	0.04	US EPA (2006)	0.18	see note 1				
Fluoranthene	0.04	US EPA (2006)	0.18	see note 1				
Anthracene	0.3	US EPA (2006)	1.34	see note 1				

Table C-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	Source	Inhalation TC mg/m^3	Source	Oral SF $(mg/kg\text{-}d)^{-1}$	Source	Inhalation UR $(mg/m^3)^{-1}$	Source
Pyrene	0.03	US EPA (2006)	0.13	see note 1				
Benzo(a)pyrene					2.3	CCME (2008b)		
Halogenated Aliphatics								
Vinyl chloride	0.003	US EPA (2006)	0.1	US EPA (2006)	0.26	HC (2004b)	0.0088	US EPA (2006)
1,1-Dichloroethene	0.05	HC (2004b)	0.2	US EPA (2006)				
Trichloroethene (Trichloroethylene, TCE)	0.00146	CCME (2006d)	0.04	CCME (2006d)	0.00025	CCME (2006d)	0.00061	CCME (2006d)
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.014	HC (2004b)	0.36	HC (2004b)				
1,2-Dichloroethane					0.00806	HC (2004b)	0.026	US EPA (2006)
Dichloromethane (Methylene chloride)	0.05	HC (2004b)	3	ORNL (2006)	0.000079	HC (2004b)	0.000023	HC (2004b)
Trichloromethane (Chloroform)	0.01	US EPA (2006)	0.04475	see note 1			0.023	US EPA (2006)
Tetrachloromethane (Carbon tetrachloride)	0.0007	US EPA (2006)	0.00313	see note 1	0.13	US EPA (2006)	0.015	US EPA (2006)
Dibromochloromethane	0.02	US EPA (2006)	0.08949	see note 1				
Chlorinated Aromatics								
Chlorobenzene	0.43	HC (2004b)	0.01	HC (2004b)				
1,2-Dichlorobenzene	0.43	HC (2004b)	1.92411	see note 1				
1,4-Dichlorobenzene	0.11	HC (2004b)	0.095	HC (2004b)				
1,2,3-Trichlorobenzene	0.0015	HC (2004b)	0.00671	see note 1				
1,2,4-Trichlorobenzene	0.0016	HC (2004b)	0.007	HC (2004b)				
1,3,5-Trichlorobenzene	0.0015	HC (2004b)	0.0036	HC (2004b)				
1,2,3,4-Tetrachlorobenzene	0.0034	HC (2004b)	0.01521	see note 1				
1,2,3,5-Tetrachlorobenzene	0.00041	HC (2004b)	0.00183	see note 1				
1,2,4,5-Tetrachlorobenzene	0.00021	HC (2004b)	0.00094	see note 1				
Pentachlorobenzene	0.001	HC (2004b)	0.00447	see note 1				

Table C-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	**Source**	**Inhalation TC mg/m^3**	**Source**	**Oral SF (mg/kg-d)$^{-1}$**	**Source**	**Inhalation UR (mg/m^3)$^{-1}$**	**Source**
Hexachlorobenzene	0.0005	HC (2004b)	0.002237	see note 1	0.83	HC (2004b)	0.1855	see note 1
2,4-Dichlorophenol	0.1	HC (2004b)	0.447468	see note 1				
2,4,6-Trichlorophenol					0.02	HC (2004b)	0.0045	see note 1
2,3,4,6-Tetrachlorophenol	0.01	HC (2004b)	0.04475	see note 1				
Pentachlorophenol	0.006	HC (2004b)	0.02685	see note 1				
Dioxins and Furans	2.00E-09	HC (2004b)						
PCBs	0.001	HC (2004b)						
Pesticides								
Aldicarb	0.001	HC (2004b)						
Aldrin and dieldrin	0.0001	HC (2004b)						
Atrazine and metabolites	0.0005	HC (2004b)						
Azinphos-methyl	0.0025	HC (2004b)						
Bendiocarb	0.004	HC (2004b)						
Bromoxynil	0.0005	HC (2004b)						
Carbaryl	0.01	HC (2004b)						
Carbofuran	0.01	HC (2004b)						
Chlorothalonil	0.015	US EPA (2006)						
Chlorpyrifos	0.01	HC (2004b)						
Cyanazine	0.0013	HC (2004b)						
2,4-D	0.01	HC (2004b)						
DDT	0.01	HC (2004b)						
Diazinon	0.002	HC (2004b)						
Dicamba	0.0125	HC (2004b)						
Dichlofop-methyl	0.001	HC (2004b)						
Dieldrin (see Aldrin and Dieldrin)								
Dimethoate	0.002	HC (2004b)						
Dinoseb	0.001	HC (2004b)						

Table C-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	**Source**	**Inhalation TC** mg/m^3	**Source**	**Oral SF** (mg/kg-d)$^{-1}$	**Source**	**Inhalation UR** (mg/m^3)$^{-1}$	**Source**
Diquat	0.008	HC (2004b)						
Diuron	0.0156	HC (2004b)						
Endosulfan	6.00E-03	US EPA (2006)						
Endrin	3.00E-04	US EPA (2006)						
Glyphosate	0.03	HC (2004b)						
Heptachlor epoxide	1.30E-05	US EPA (2006)			9.1	US EPA (2006)	2.6	US EPA (2006)
Lindane	3.00E-04	US EPA (2006)						
Linuron	2.00E-03	US EPA (2006)						
Malathion	0.02	HC (2004b)						
MCPA	5.00E-04	US EPA (2006)						
Methoxychlor	0.1	HC (2004b)						
Metolachlor	0.005	HC (2004b)						
Metribuzin	0.0083	HC (2004b)						
Paraquat (as dichloride)	0.001	HC (2004b)						
Parathion	0.005	HC (2004b)						
Phorate	0.0002	HC (2004b)						
Picloram	0.02	HC (2004b)						
Simazine	0.0013	HC (2004b)						
Tebuthiuron	7.00E-02	US EPA (2006)						
Terbufos	0.00005	HC (2004b)						
Toxaphene					1.1	US EPA (2006)	0.32	US EPA (2006)
Triallate	1.30E-02	US EPA (2006)						
Trifluarin	0.0048	HC (2004b)						
Other Organics								
Aniline	0.007	HC (2004b)	0.0313	see note 1				
Bis(2-ethyl-hexyl)phthalate	0.044	HC (2004b)	0.1969	see note 1				
Dibutyl phthalate	0.063	HC (2004b)	0.28191	see note 1				

Table C-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	**Source**	**Inhalation TC mg/m^3**	**Source**	**Oral SF $(mg/kg\text{-}d)^{-1}$**	**Source**	**Inhalation UR $(mg/m^3)^{-1}$**	**Source**
Dichlorobenzidine					0.0676	HC (2004b)	0.015107214	see note 1
Diisopropanolamine	0.39	CCME (2006b)						
Ethylene glycol	2	US EPA (2006)	8.94937	see note 1				
Hexachlorobutadiene					0.078	US EPA (2006)	0.022	US EPA (2006)
Methylmethacrylate	0.05	HC (2004b)	0.052	HC (2004b)				
MTBE	0.01	HC (2004b)	0.037	HC (2004b)				
Nonylphenol								
Phenol	0.06	HC (2004b)	0.26848	see note 1				
Sulfolane	0.0097	CCME (2006c)						

Notes:
TRV = toxicity reference value
TDI = tolerable daily intake
TC = tolerable concentration
SF = slope factor
UR = unit risk

1. estimated from the oral TDI assuming an adult body weight of 70.7 kg, and an inhalation rate of 15.8 m^3/d
CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates,
including the scientific supporting documents that are summarized in the CEQG.
HC = Health Canada

Table C-8. Human Absorption Factors

	Absorption Factors					
	Gut	Source	Skin	Source	Lung	Source
Metals						
Arsenic (inorganic)	1.00		0.03	HC (2004a)	1.00	
Barite-barium	1.00		0	AENV (2009)	1.00	
Hydrocarbons						
Benzene	1.00		0.08	HC (2004a)	1.00	
Toluene	1.00		0.12	HC (2004a)	1.00	
Ethylbenzene	1.00		0.20	HC (2004a)	1.00	
Xylenes	1.00		0.12	HC (2004a)	1.00	
Styrene	1.00		0.20	CCME (2008a)	1.00	
Aliphatic C_6-C_8	1.00		0.20	CCME (2008a)	1.00	
Aliphatic $C_{>8}$-C_{10}	1.00		0.20	CCME (2008a)	1.00	
Aliphatic $C_{>10}$-C_{12}	1.00		0.20	CCME (2008a)	1.00	
Aliphatic $C_{>12}$-C_{16}	1.00		0.20	CCME (2008a)	1.00	
Aliphatic $C_{>16}$-C_{21}	1.00		0.20	CCME (2008a)	1.00	
Aliphatic $C_{>21}$-C_{34}	1.00		0.20	CCME (2008a)	1.00	
Aliphatic $C_{>34}$	1.00		0.20	CCME (2008a)	1.00	
Aromatic $C_{>8}$-C_{10}	1.00		0.20	CCME (2008a)	1.00	
Aromatic $C_{>10}$-C_{12}	1.00		0.20	CCME (2008a)	1.00	
Aromatic $C_{>12}$-C_{16}	1.00		0.20	CCME (2008a)	1.00	
Aromatic $C_{>16}$-C_{21}	1.00		0.20	CCME (2008a)	1.00	
Aromatic $C_{>21}$-C_{34}	1.00		0.20	CCME (2008a)	1.00	
Aromatic $C_{>34}$	1.00		0.20	CCME (2008a)	1.00	
Naphthalene	1.00		0.10	CCME (1999)	1.00	
Acenaphthene	1.00		0.20	CCME (2008a)	1.00	
Fluorene	1.00		0.20	CCME (2008a)	1.00	
Fluoranthene	1.00		0.20	CCME (2008a)	1.00	
Anthracene	1.00		0.29	CCME (2008a)	1.00	
Pyrene	1.00		0.20	CCME (2008a)	1.00	
Benzo(a)pyrene	1.00		0.34	CCME (2008b)	1.00	
Halogenated Aliphatics						
Vinyl chloride	1.00		0.16	HC (2004a)	1.00	

Table C-8. Human Absorption Factors

	Absorption Factors					
	Gut	Source	Skin	Source	Lung	Source
1,1-Dichloroethene	1.00		0.10	HC (2004a)	1.00	
Trichloroethene (Trichloroethylene, TCE)	1.00		0.10	HC (2004a)	1.00	
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	1.00		0.10	HC (2004a)	1.00	
1,2-Dichloroethane	1.00		0.10	HC (2004a)	1.00	
Dichloromethane (Methylene chloride)	1.00		1.00		1.00	
Trichloromethane (Chloroform)	1.00		0.10	HC (2004a)	1.00	
Tetrachloromethane (Carbon tetrachloride)	1.00		0.10	HC (2004a)	1.00	
Dibromochloromethane	1.00		0.10	HC (2004a)	1.00	
Chlorinated Aromatics						
Chlorobenzene	1.00		0.10	HC (2004a)	1.00	
1,2-Dichlorobenzene	1.00		0.10	HC (2004a)	1.00	
1,4-Dichlorobenzene	1.00		0.10	HC (2004a)	1.00	
1,2,3-Trichlorobenzene	1.00		0.08	HC (2004a)	1.00	
1,2,4-Trichlorobenzene	1.00		0.08	HC (2004a)	1.00	
1,3,5-Trichlorobenzene	1.00		0.08	HC (2004a)	1.00	
1,2,3,4-Tetrachlorobenzene	1.00		1.00		1.00	
1,2,3,5-Tetrachlorobenzene	1.00		1.00		1.00	
1,2,4,5-Tetrachlorobenzene	1.00		1.00		1.00	
Pentachlorobenzene	1.00		1.00		1.00	
Hexachlorobenzene	1.00		0.13	HC (2004a)	1.00	
Dichlorophenol	1.00		1.00		1.00	
Trichlorophenol	1.00		1.00		1.00	
Tetrachlorophenol	1.00		1.00		1.00	
Pentachlorophenol	1.00		0.11	HC (2004a)	1.00	
Dioxins and Furans	1.00		1.00		1.00	
PCBs	1.00		1.00		1.00	
Pesticides						
Aldicarb	1.00		1.00		1.00	
Aldrin and dieldrin	1.00		0.25	HC (2004a)	1.00	
Atrazine and metabolites	1.00		1.00		1.00	

Table C-8. Human Absorption Factors

	Absorption Factors					
	Gut	Source	Skin	Source	Lung	Source
Azniphos-methyl	1.00		1.00		1.00	
Bendiocarb	1.00		1.00		1.00	
Bromoxynil	1.00		1.00		1.00	
Carbaryl	1.00		1.00		1.00	
Carbofuran	1.00		1.00		1.00	
Chlorothalonil	1.00		1.00		1.00	
Chlorpyrifos	1.00		1.00		1.00	
Cyanazine	1.00		1.00		1.00	
2,4-D	1.00		1.00		1.00	
DDT	1.00		1.00		1.00	
Diazinon	1.00		1.00		1.00	
Dicamba	1.00		1.00		1.00	
Dichlofop-methyl	1.00		1.00		1.00	
Dieldrin (see Aldrin and Dieldrin)	1.00		1.00		1.00	
Dimethoate	1.00		1.00		1.00	
Dinoseb	1.00		1.00		1.00	
Diquat	1.00		1.00		1.00	
Diuron	1.00		1.00		1.00	
Endosulfan	1.00		0.20	HC (2004a)	1.00	
Endrin	1.00		0.25	HC (2004a)	1.00	
Glyphosate	1.00		1.00		1.00	
Heptachlor epoxide	1.00		0.20	HC (2004a)	1.00	
Lindane	1.00		1.00		1.00	
Linuron	1.00		1.00		1.00	
Malathion	1.00		1.00		1.00	
MCPA	1.00		1.00		1.00	
Methoxychlor	1.00		0.20	HC (2004a)	1.00	
Metolachlor	1.00		1.00		1.00	
Metribuzin	1.00		1.00		1.00	
Paraquat (as dichloride)	1.00		1.00		1.00	
Parathion	1.00		1.00		1.00	

Table C-8. Human Absorption Factors

	Absorption Factors					
	Gut	**Source**	**Skin**	**Source**	**Lung**	**Source**
Phorate	1.00		1.00		1.00	
Picloram	1.00		1.00		1.00	
Simazine	1.00		1.00		1.00	
Tebuthiuron	1.00		1.00		1.00	
Terbufos	1.00		1.00		1.00	
Toxaphene	1.00		1.00		1.00	
Triallate	1.00		1.00		1.00	
Trifluarin	1.00		1.00		1.00	
Other Organics						
Aniline	1.00		1.00		1.00	
Bis(2-ethyl-hexyl)phthalate	1.00		0.02	HC (2004a)	1.00	
Bis(Chloro-methyl)ether	1.00		1.00		1.00	
Dibutyl phthalate	1.00		1.00		1.00	
Dichlorobenzidine	1.00		0.54	HC (2004a)	1.00	
Diisopropanolamine	1.00		0.25	CCME (2006b)	1.00	
Ethylene glycol	1.00		1.00		1.00	
Hexachlorobutadiene	1.00		0.20	HC (2004a)	1.00	
Methylmethacrylate	1.00		1.00		1.00	
MTBE	1.00		0.10	HC (2004a)	1.00	
Nitriloacetic acid	1.00		1.00		1.00	
Nonylphenol	1.00		1.00		1.00	
Phenol	1.00		0.26	HC (2004a)	1.00	
Sulfolane	1.00		1.00		1.00	
Trihalomethanes - total (THMs)	1.00		1.00		1.00	

Notes:

Sources only provided where an absorption factor other than 1.0 is used.

CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates, including the scientific supporting documents that are summarized in the CEQG.

HC = Health Canada

Table C-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
Metals								
Arsenic (inorganic)	na	na	CCME (1999)	na	CCME (1999)	10	CCME (1999)	0.2
Barite-barium	0.014	0.014	AENV (2009)	na	AENV (2009)	325	AENV (2009)	0.25
Hydrocarbons								
Benzene	na	na	-	na	-	0	assumed	na
Toluene	0.0028	0.0028	EC (2004b)	0.0442	EC (2004b)	0	assumed	0.5
Ethylbenzene	0.0029	0.0029	EC (2004b)	0.0075	EC (2004b)	0	assumed	0.5
Xylenes	0.0079	0.0079	EC (2004b)	0.00182	EC (2004b)	0	assumed	0.5
Styrene	0.00071	0.00027	PSL	0.00028	PSL	0	assumed	0.5
Aliphatic C_6-C_8	0.02334	0.02334	CCME (2008a)	0.09111	CCME (2008a)	0	assumed	0.5
Aliphatic $C_{>8}$-C_{10}	0.0103	0.0103	CCME (2008a)	0.03881	CCME (2008a)	0	assumed	0.5
Aliphatic $C_{>10}$-C_{12}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.5
Aliphatic $C_{>12}$-C_{16}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.5
Aliphatic $C_{>16}$-C_{21}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.6
Aliphatic $C_{>21}$-C_{34}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.6
Aliphatic $C_{>34}$	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.8
Aromatic $C_{>8}$-C_{10}	0.00938	0.00938	CCME (2008a)	0.03745	CCME (2008a)	0	assumed	0.5
Aromatic $C_{>10}$-C_{12}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.5
Aromatic $C_{>12}$-C_{16}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.5
Aromatic $C_{>16}$-C_{21}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.6
Aromatic $C_{>21}$-C_{34}	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.6
Aromatic $C_{>34}$	0	0	CCME (2008a)	0	CCME (2008a)	0	assumed	0.8
Naphthalene	0.00053545	0.00021231	ATSDR (2005)	0.00095	ATSDR (2005)	0	assumed	0.5
Acenaphthene	0	0	assumed	0	assumed	0	assumed	0.5
Fluorene	0.00902	0.00358	ATSDR (1995)	0.016	ATSDR (1995)	0	assumed	0.5
Fluoranthene	0	0	assumed	0	assumed	0	assumed	0.5
Anthracene	0.00502	0.00199	ATSDR (1995)	0.0089	ATSDR (1995)	0	assumed	0.5
Pyrene	0.00620	0.00246	ATSDR (1995)	0.011	ATSDR (1995)	0	assumed	0.5
Benzo(a)pyrene	na	na	-	na	-	0.07	CCME (2008b)	na
Halogenated Aliphatics								
Vinyl chloride	0	0	assumed	0	assumed	0	assumed	0.2

Table C-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
1,1-Dichloroethene	0	0	assumed	0	assumed	0	assumed	0.2
Trichloroethene (Trichloroethylene)	0.00053	0.00041	CCME (2006d)	0.0014	CCME (2006d)	0	assumed	0.2
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0	0	assumed	0	assumed	0	assumed	0.2
1,2-Dichloroethane	0.0006	0.0005	PSL	0.0018	PSL	0	assumed	0.2
Dichloromethane (Methylene chloride)	0.00558	0.00471	PSL	0.0063	PSL	0	assumed	0.2
Trichloromethane (Chloroform)	0.004315	0.00361	PSL	0.0063	PSL	0	assumed	0.2
Tetrachloromethane (Carbon tetrachloride)	0	0	assumed	0	assumed	0	assumed	0.2
Dibromochloromethane	0	0	assumed	0	assumed	0	assumed	0.2
Chlorinated Aromatics								
Chlorobenzene	0.000122	0.000066	PSL	0.00016	PSL	0	assumed	0.2
1,2-Dichlorobenzene	0.00004	0.00003	PSL	0.1	PSL	0	assumed	0.2
1,4-Dichlorobenzene	0.0014	0.0009	PSL	0.0028	PSL	0	assumed	0.2
1,2,3-Trichlorobenzene	0.00023	0.00024	PSL	0.0008	PSL	0	assumed	0.2
1,2,4-Trichlorobenzene	0.0006	0.00045	PSL	0.0018	PSL	0	assumed	0.2
1,3,5-Trichlorobenzene	0.00032	0.00025	PSL	0.0008	PSL	0	assumed	0.2
1,2,3,4-Tetrachlorobenzene	0.0000007	0.00000025	PSL	0.00000017	PSL	0	assumed	0.2
1,2,3,5-Tetrachlorobenzene	0.00000045	0.00000015	PSL	0.00000017	PSL	0	assumed	0.2
1,2,4,5-Tetrachlorobenzene	0.0000007	0.0000002	PSL	0.00000017	PSL	0	assumed	0.2
Pentachlorobenzene	0.000002	0.0000005	PSL	0.0000001	PSL	0	assumed	0.2
Hexachlorobenzene	0.0000178	0.0000028	PSL	0.00000015	PSL	0	assumed	0.2
2,4-Dichlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
2,4,6-Trichlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
2,3,4,6-Tetrachlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
Pentachlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
Dioxins and Furans	7.1E-09	1.33E-09	EC (2000)	0	assumed	0	assumed	0.25
PCBs	7.6925E-06	0.00000254	EC (2001)	0	assumed	0	assumed	0.2
Pesticides								
Aldicarb	0	0	assumed	0	assumed	0	assumed	0.2
Aldrin and dieldrin	0	0	assumed	0	assumed	0	assumed	0.2

Table C-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
Atrazine and metabolites	0	0	assumed	0	assumed	0	assumed	0.2
Azinphos-methyl	0	0	assumed	0	assumed	0	assumed	0.2
Bendiocarb	0	0	assumed	0	assumed	0	assumed	0.2
Bromoxynil	0	0	assumed	0	assumed	0	assumed	0.2
Carbaryl	0	0	assumed	0	assumed	0	assumed	0.2
Carbofuran	0	0	assumed	0	assumed	0	assumed	0.2
Chlorothalonil	0	0	assumed	0	assumed	0	assumed	0.2
Chlorpyrifos	0	0	assumed	0	assumed	0	assumed	0.2
Cyanazine	0	0	assumed	0	assumed	0	assumed	0.2
2,4-D	0	0	assumed	0	assumed	0	assumed	0.2
DDT	0	0	assumed	0	assumed	0	assumed	0.2
Diazinon	0	0	assumed	0	assumed	0	assumed	0.2
Dicamba	0	0	assumed	0	assumed	0	assumed	0.2
Dichlofop-methyl	0	0	assumed	0	assumed	0	assumed	0.2
Dieldrin (see Aldrin and Dieldrin)								
Dimethoate	0	0	assumed	0	assumed	0	assumed	0.2
Dinoseb	0	0	assumed	0	assumed	0	assumed	0.2
Diquat	0	0	assumed	0	assumed	0	assumed	0.2
Diuron	0	0	assumed	0	assumed	0	assumed	0.2
Endosulfan	0	0	assumed	0	assumed	0	assumed	0.2
Endrin	0	0	assumed	0	assumed	0	assumed	0.2
Glyphosate	0	0	assumed	0	assumed	0	assumed	0.2
Heptachlor epoxide	0	0	assumed	0	assumed	0	assumed	0.2
Lindane	0	0	assumed	0	assumed	0	assumed	0.2
Linuron	0	0	assumed	0	assumed	0	assumed	0.2
Malathion	0	0	assumed	0	assumed	0	assumed	0.2
MCPA	0	0	assumed	0	assumed	0	assumed	0.2
Methoxychlor	0	0	assumed	0	assumed	0	assumed	0.2
Metolachlor	0	0	assumed	0	assumed	0	assumed	0.2
Metribuzin	0	0	assumed	0	assumed	0	assumed	0.2
Paraquat (as dichloride)	0	0	assumed	0	assumed	0	assumed	0.2

Table C-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
Parathion	0	0	assumed	0	assumed	0	assumed	0.2
Phorate	0	0	assumed	0	assumed	0	assumed	0.2
Picloram	0	0	assumed	0	assumed	0	assumed	0.2
Simazine	0	0	assumed	0	assumed	0	assumed	0.2
Tebuthiuron	0	0	assumed	0	assumed	0	assumed	0.2
Terbufos	0	0	assumed	0	assumed	0	assumed	0.2
Toxaphene	0	0	assumed	0	assumed	0	assumed	0.2
Triallate	0	0	assumed	0	assumed	0	assumed	0.2
Trifluarin	0	0	assumed	0	assumed	0	assumed	0.2
Other Organics								
Aniline	0	0	assumed	0	assumed	0	assumed	0.2
Bis(2-ethyl-hexyl)phthalate	0.01892	0.0058	PSL	0.031	PSL	0	assumed	0.2
Bis(Chloro-methyl)ether	0	0	assumed	0	assumed	0	assumed	0.2
Dibutyl phthalate	0.005	0.0019	PSL	0.00285	PSL	0	assumed	0.2
Dichlorobenzidine	0	0	assumed	0	assumed	0	assumed	0.2
Diisopropanolamine	0	0	assumed	0	assumed	0	assumed	0.33
Ethylene glycol	0.0344	0.0167	PSL	0	PSL	0	assumed	0.33
Hexachlorobutadiene	0.00012	0.00003	PSL	0.00006	PSL	0	assumed	0.2
Methylmethacrylate	1.13E-07	0	PSL	2.44E-07	PSL	0	assumed	0.2
MTBE	0.00000067	0.0000005	PSL	0.0000015	PSL	0	assumed	0.2
Nonylphenol	na	na	-	na	-	0	assumed	na
Phenol	0	0	assumed	0	assumed	0	assumed	0.2
Sulfolane	0	0	assumed	0	assumed	0	assumed	0.33

Notes:

na = not available or not applicable

EDI = estimated daily intake

C_a = background indoor air concentration

SAF = soil allocation factor

PSL = Priority Substance List assessment under Canadian Environmental Protection Act (CEPA) for corresponding substance.

CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates, including the scientific supporting documents that are summarized in the CEQG.

Table C-10. Petroleum Hydrocarbon Subfraction Distribution

Soil				
	TPH Sub-fraction (Proportion of Total Fraction Mass)			
Fraction	**Fraction 1**	**Fraction 2**	**Fraction 3**	**Fraction 4**
Aliphatics				
C6-C8	0.55			
C>8-C10	0.36			
C>10-C12		0.36		
C>12-C16		0.44		
C>16-C21			0.56	
C>21-C34			0.24	
C>34				0.8
Aromatics				
C>7-C8				
C>8-C10	0.09			
C>10-C12		0.09		
C>12-C16		0.11		
C>16-C21			0.14	
C>21-C34			0.06	
C>34				0.2
Sum of all subfractions	1	1	1	1

Notes:

Source: CCME (2008a)

Groundwater				
	TPH Sub-fraction (Proportion of Total Fraction Mass)			
	Fine Soil		**Coarse Soil**	
Fraction	**Fraction 1**	**Fraction 2**	**Fraction 1**	**Fraction 2**
Aliphatics				
C6-C8	0.5768		0.6047	
C>8-C10	0.0663		0.0632	
C>10-C12		0.0239		0.024
C>12-C16		0.0015		0.0015
Aromatics				
C>7-C8				
C>8-C10	0.3569		0.3321	
C>10-C12		0.6029		0.6034
C>12-C16		0.3718		0.3711
Sum of all subfractions	1	1	1	1

Notes:

Source: CCME (2008a)

Subfraction distribution in groundwater not required for F3 and F4 due to low aqueous solubility

These values were calculated from the soil subfraction distributions above
based on equilibrium partitioning assumptions, see text.

Table C-11. Surface Water Quality Guidelines

	Drinking Water	Aquatic Life	Irrigation	Livestock Water	Wildlife Water	DTED [1]
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/kg-bw/d)
General and Inorganic Parameters						
Aluminum		see note 3	5	5		
Ammonia		see note 3				
Chloride	250	230	100			
Cyanide	0.2	0.005				
Fluoride	1.5	0.12	1	1		
Nitrate	45					
Nitrate + Nitrite (as nitrogen)				100		
Nitrite (as nitrogen)	1.0	0.06		10		
Sodium	200					
Sulphate	500			1000		
Sulphide (as H_2S)	0.05	0.002				
Total Dissolved Solids (TDS)	500		500	3000		
Metals						
Antimony	0.006					
Arsenic (inorganic)	0.01	0.005	0.1	0.025		
Barium	1					
Boron	5		0.5	5		
Cadmium	0.005	see note 3	0.0051	0.08		
Chromium (total)	0.05	see note 3	0.0049	0.05		
Copper	1	see note 3	0.2	0.5		
Iron	0.3	0.3	5			
Lead	0.01	see note 3	0.2	0.1		
Manganese	0.05		0.2			
Mercury	0.001	see note 3		0.003		
Nickel		see note 3	0.2	1		
Selenium	0.01	0.001	0.02	0.05		
Silver		see note 3	0.02	0.05		
Uranium	0.02		0.01	0.2		
Zinc	5	0.03	1	50		
Hydrocarbons						
Benzene	0.005	0.37		0.088	0.076	0.08
Toluene	0.024	0.002		4.91	4.25	4.46
Ethylbenzene	0.0024	0.09		3.20	2.77	2.91

Table C-11. Surface Water Quality Guidelines

	Drinking Water	Aquatic Life	Irrigation	Livestock Water	Wildlife Water	DTED[1]
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/kg-bw/d)
Xylenes	0.3	0.18		13.1	11.3	11.9
Styrene	2.828	0.072				
Aliphatic C_6-C_8	136.85815	0.0465		53.6	46.4	48.72
Aliphatic $C_{>8}$-C_{10}	2.46675	0.0076		53.6	46.4	48.72
Aromatic $C_{>8}$-C_{10}	0.84205	0.14		53.6	46.4	48.72
F1				53.6	46.4	48.72
Aliphatic $C_{>10}$-C_{12}	2.75	0.00118		49.2	42.6	44.73
Aliphatic $C_{>12}$-C_{16}	2.75	0.000074		49.2	42.6	44.73
Aromatic $C_{>10}$-C_{12}	1.1	0.096		49.2	42.6	44.73
Aromatic $C_{>12}$-C_{16}	1.1	0.0554		49.2	42.6	44.73
F2				49.2	42.6	44.73
F3				79.7	69.0	72.45
F4				42.0	36.4	38.22
Acenapthene	1.414	0.0058		NGR	NGR	70
Acenaphthylene[2]		0.046				
Anthracene	7.07	0.000012		NGR	NGR	200
Fluoranthene	0.942666667	0.00004		NGR	NGR	50
Fluorene	0.942666667	0.003		NGR	NGR	50
Naphthalene	0.471333333	0.0011		NGR	NGR	28.6
Phenanthrene		0.0004		NGR	NGR	140
Pyrene	0.707	0.000025		NGR	NGR	25
Benz[a]anthracene		0.000018		NGR	NGR	20
Benzo[b+j]fluoranthene[2]		0.00048		NGR	NGR	20
Benzo[k]fluoranthene[2]		0.00048		NGR	NGR	20
Benzo[g,h,i]perylene[2]		0.00017				
Benzo[a]pyrene	0.00001	0.000015		NGR	NGR	2
Chrysene[2]		0.0014		NGR	NGR	20
Dibenz[a,h]anthracene[2]		0.00026				
Indeno[1,2,3-c,d]pyrene[2]		0.00021				
Halogenated Aliphatics						
Vinyl chloride	0.002					
1,1-Dichloroethene	0.014					
Trichloroethene (Trichloroethylene, TCE)	0.005	0.021		0.05		
Tetrachloroethene (Tetrachloroethylene,	0.03	0.111				

Table C-11. Surface Water Quality Guidelines

	Drinking Water	Aquatic Life	Irrigation	Livestock Water	Wildlife Water	DTED [1]
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/kg-bw/d)
Perchloroethylene, PCE)						
1,2-Dichloroethane	0.005	0.1		0.005		
Dichloromethane (Methylene chloride)	0.05	0.0981		0.05		
Trichloromethane (Chloroform)	0.093	0.0018		0.1		
Tetrachloromethane (Carbon tetrachloride)	0.005	0.0133		0.005		
Tribromomethane				0.1		
Dibromochloromethane	0.188533333			0.1		
Chlorinated Aromatics						
Chlorobenzene	0.03	0.0013				
1,2-Dichlorobenzene	0.003	0.0007				
1,3-Dichlorobenzene		0.15				
1,4-Dichlorobenzene	0.001	0.026				
1,2,3-Trichlorobenzene	0.014	0.008				
1,2,4-Trichlorobenzene	0.015	0.024				
1,3,5-Trichlorobenzene	0.014					
1,2,3,4-Tetrachlorobenzene	0.032	0.0018				
1,2,3,5-Tetrachlorobenzene	0.0038					
1,2,4,5-Tetrachlorobenzene	0.0020					
Pentachlorobenzene	0.0094	0.006				
Hexachlorobenzene	0.000568			0.00052		
2,4-Dichlorophenol	0.0003	0.0002				
2,4,6-Trichlorophenol	0.002	0.018				
2,3,4,6-Tetrachlorophenol	0.001	0.001				
Pentachlorophenol	0.03	0.0005				
Dioxins and Furans	1.17833E-07					
PCBs	0.009426667					
Pesticides						
Aldicarb	0.009	0.001	0.0549	0.011		
Aldrin	0.0007	0.003				
Atrazine and metabolites	0.005	0.0018	0.01	0.005		
Azinphos-methyl	0.02	0.00001				
Bendiocarb	0.04					

Table C-11. Surface Water Quality Guidelines

	Drinking Water	Aquatic Life	Irrigation	Livestock Water	Wildlife Water	DTED [1]
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/kg-bw/d)
Bromoxynil	0.005	0.005	0.00033	0.011		
Carbaryl	0.09	0.0002		1.1		
Carbofuran	0.09	0.0018		0.045		
Chlorothalonil	0.1414	0.00018	0.0058	0.17		
Chlorpyrifos	0.09	0.0000035		0.024		
Cyanazine	0.01	0.002	0.0005	0.01		
2,4-D	0.1	0.004		0.1		
DDT	0.09333	0.000001				
Diazinon	0.02					
Dicamba	0.12	0.01	0.000006	0.122		
Dichlofop-methyl	0.009	0.0061	0.00018	0.009		
Dieldrin	0.0007	0.000056				
Dimethoate	0.02	0.0062		0.003		
Dinoseb	0.01	0.00005	0.016	0.15		
Diquat	0.07					
Diuron	0.15					
Endosulfan	0.05656	0.00002				
Endrin	0.002828	0.000036				
Glyphosate	0.28	0.065		0.28		
Heptachlor epoxide	5.17949E-05	0.0000038				
Lindane	0.002828	0.00001		0.004		
Linuron	0.018853333	0.007	0.000071			
Malathion	0.19	0.0001				
MCPA	0.004713333	0.0026	0.000025	0.025		
Methoxychlor	0.9	0.00003				
Metolachlor	0.05	0.0078	0.028	0.05		
Metribuzin	0.08	0.001	0.0005	0.08		
Paraquat (as dichloride)	0.01					
Parathion	0.05	0.000013				
Phorate	0.002					
Picloram	0.19	0.029		0.19		
Simazine	0.01	0.01	0.0005	0.01		
Tebuthiuron	0.659866667	0.0016	0.00027	0.13		
Terbufos	0.001					

Table C-11. Surface Water Quality Guidelines

	Drinking Water	Aquatic Life	Irrigation	Livestock Water	Wildlife Water	DTED[1]
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/kg-bw/d)
Toxaphene	0.000428485	0.0000002				
Triallate	0.122546667	0.00024		0.23		
Trifluarin	0.045	0.0002		0.045		
Other Organics						
Aniline	0.065986667	0.0022				
Bis(2-ethyl-hexyl)phthalate	0.41	0.016				
Bis(Chloro-methyl)ether	2.14242E-06					
Dibutyl phthalate	0.59	0.019				
Dichlorobenzidine	0.006972387					
Diisopropanolamine	3.6	1.6	2			
Ethylene glycol	31.42222222	192				
Hexachlorobutadiene	0.006042735	0.0013				
Methylmethacrylate	0.47					
MTBE	0.015	10				
Nitriloacetic acid	0.4					
Nonylphenol		0.001				
Phenol	0.5656	0.004		0.002		
Sulfolane	0.09	50	0.5			
Trihalomethanes - total (THMs)	0.1					

Notes:

See text for guideline sources

1. DTED = daily threshold effect dose from CCME (1999, 2008a). Included where used to calculate livestock and wildlife watering guidelines according to:

$$WQG = \frac{DTEDxBW}{WIR}$$

Where:

WQG = water quality guideline (mg/L)
DTED = daily threshold effect dose (mg/kg-bw/d)
BW = body weight (kg)
WIR = water ingestion rate (L/d)

2. Aquatic life guideline from CCME (2008b)

3. See Surface Water Quality Guidelines for Use in Alberta (AENV, 1999)

NGR - no guideline required, calculated value > solubility