



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 ₆ H ₆	Benzene
C ₇ H ₈	Toluene
C ₈ H 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 ₂ S	Hydrogen Sulphide
H ₂ SO 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

$\mu\text{g}/\text{m}^3$	Microgram per cubic metre
$^{\circ}\text{C}$	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, Tebodoin'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. Tebodoin 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, Tebodoin 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 SO₂ 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 Tebodini 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 Tebodini 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 (km²) 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**.

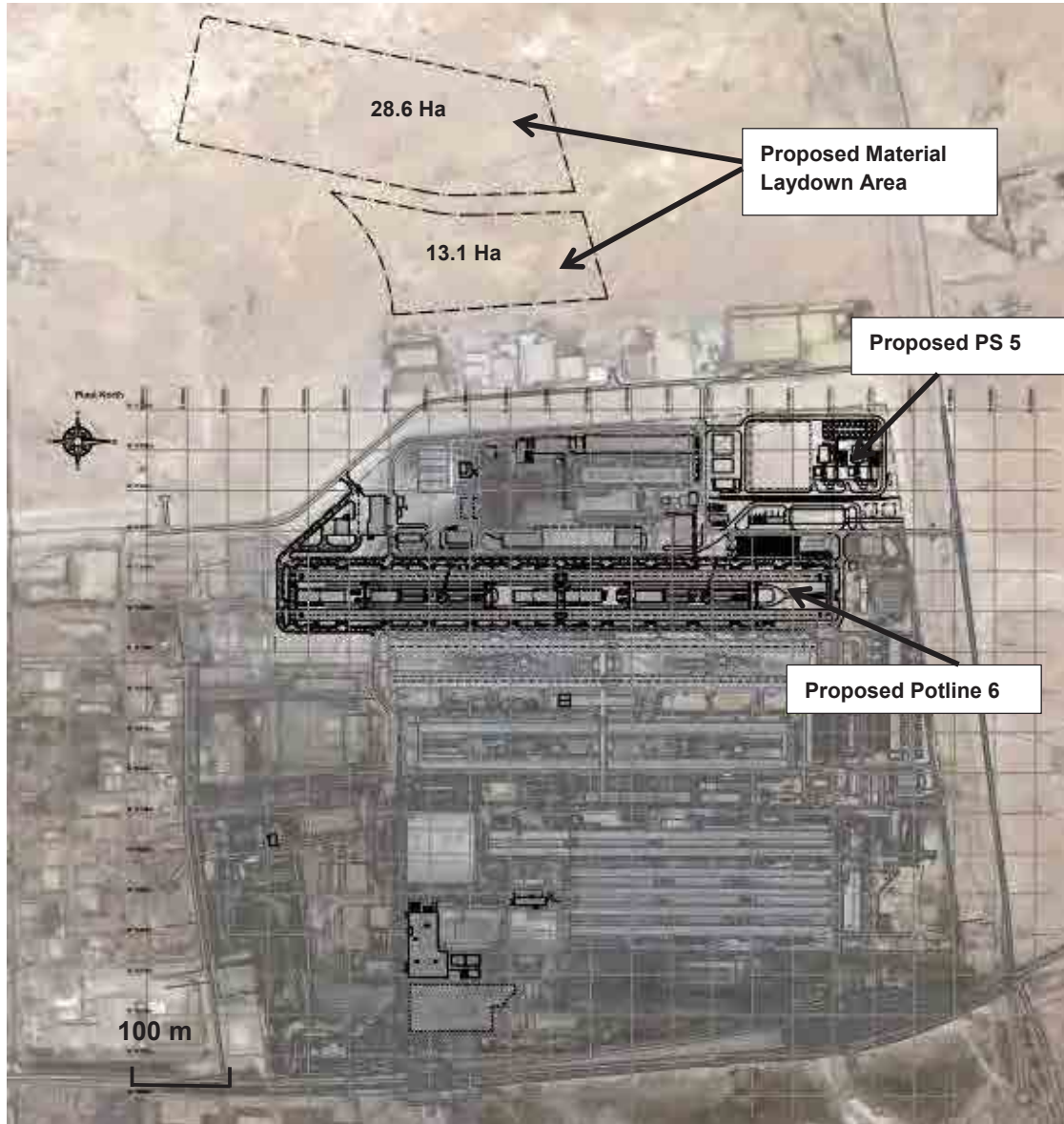


Figure 1: Proposed Location for Potline 6, Power Station 5, and Material Lay-down Area.



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
<p>Framework Convention on Climate Change June 1992</p>	<p>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.</p>
<p>Kyoto Protocol to the Framework Convention on Climate Change – Ratified January 31, 2006</p>	<p>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.</p>
<p>Convention on Biological Diversity – Ratified in 1996</p>	<p>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.</p> <p>The Convention has three main objectives:</p> <ol style="list-style-type: none"> 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.



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Title	Description
<p>Vienna Convention for the Protection of the Ozone Layer – Acceptance on April 27 1990.</p>	<p>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.</p> <p>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.</p>
<p>Montreal Protocol on Substances that Deplete the Ozone Layer – Acceptance on December 23, 1992.</p>	<p>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.</p>
<p>Stockholm Convention on Persistent Organic Pollutants – January 31, 2006.</p>	<p>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.</p>
<p>Convention of the Law of Sea – May 30, 1985.</p>	<p>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.</p>
<p>Convention to Combat Desertification – Acceptance on July 14, 1997.</p>	<p>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.</p>



Title	Description
	The activity contributes to: <ul style="list-style-type: none"> • 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



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#	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,



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#	Local Legislation	Description
		<p>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).</p> <p>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.</p> <p>The resolution also defines the different classifications of hazardous materials into 9 classes.</p>
13	Resolution No. (10) of 2006 with respect to air pollutant emissions	<p>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.</p> <p>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.</p> <p>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.</p> <p>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</p>

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/Nm ³ (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 SO₂)	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 NO₂)	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 (PM₁₀)	24 hour	340 µg/ m ³



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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 µg/ 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 µg/ 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 (NO₂), Sulphur Dioxide (SO₂) 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	30µg/m ³
SO ₂	20 - 30µg/m ³
Fluoride	1µg/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 (NIOSH¹, September 2007 [Ref. 15]) are:

- HF: 2.5 mg/m³ (3 ppm) time weighted average
- SO₂: 5 mg/m³ (2 ppm) time weighted average
- NO₂: 1.8 mg/m³ (1 ppm) short term exposure (15 min)
- Respirable particulate: 5 mg/m³ (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).

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.

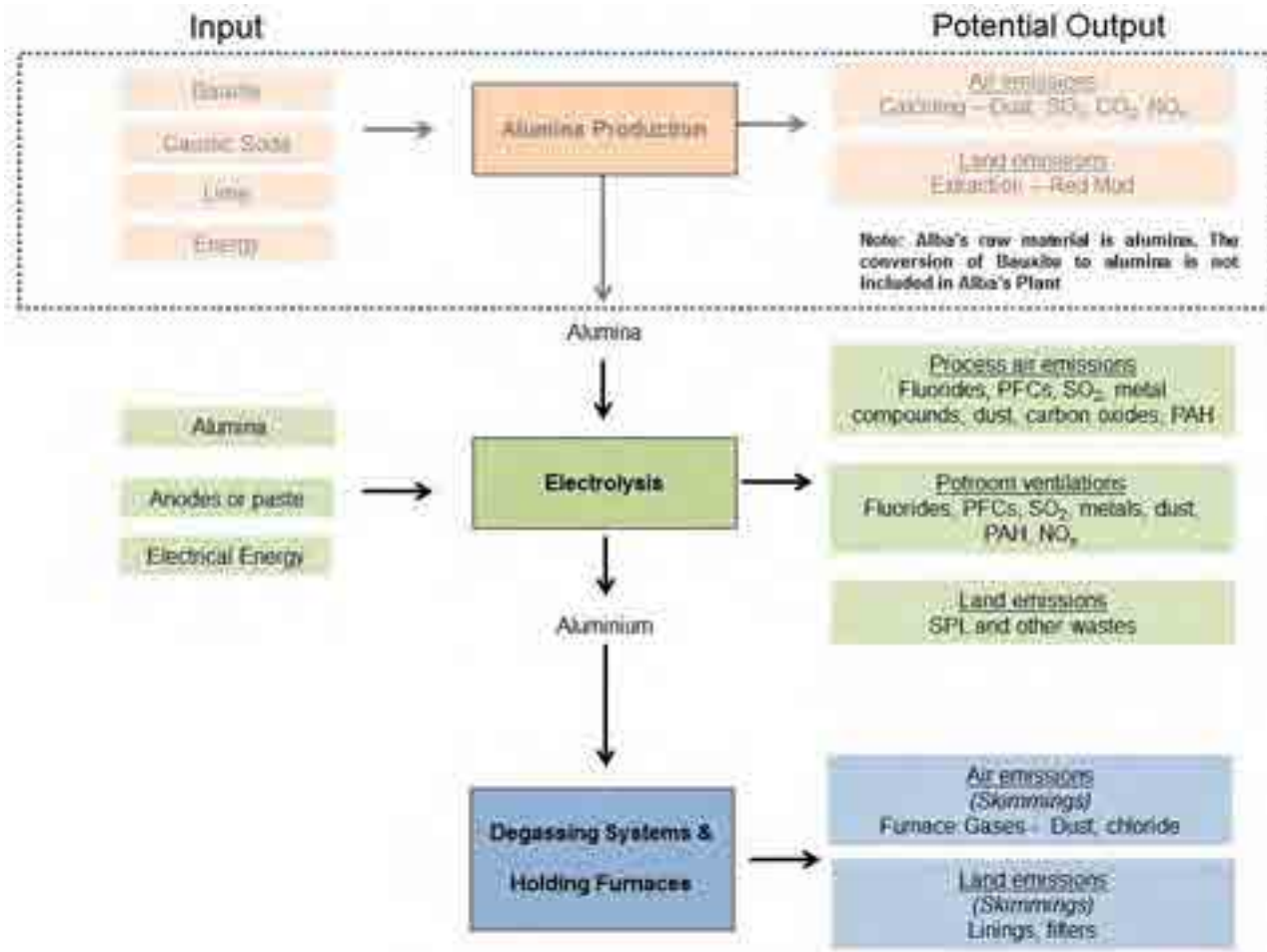


Figure 3: Schematic Overview of the Primary Aluminium Production Process



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 ($^{\circ}\text{C}$) 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.

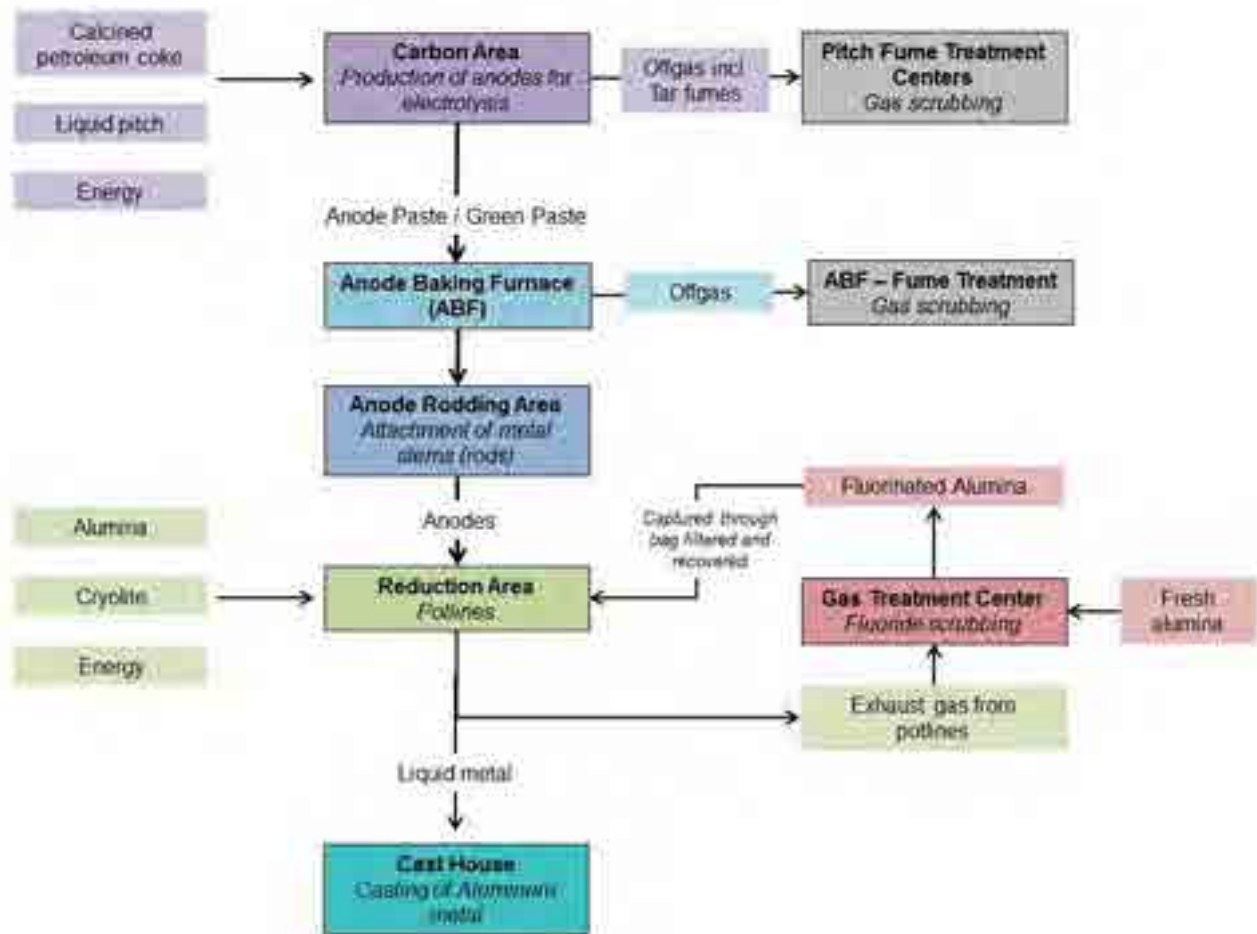


Figure 4: Schematic Overview of Aluminium Smelting Steps

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. The heat 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 (SO₂)

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 SO₂ 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 SO₂ emission points. SO₂ 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 (CO₂)

Carbon dioxide (CO₂) is formed during the combustion of natural gas and also during electrolysis as the anode is consumed and the carbon oxidises to form CO₂. In a similar way to that described for SO₂, the Gas Treatment Centres are the principal emission points for CO₂. Other emission points include the stacks from the remelt/holding furnaces in the casthouse, and the carbon Fume Treatment Centres. CO₂ 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 PM₁₀.

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 effects²) they have powerful global warming properties. In addition, motor vehicles emissions that include SO₂, Nitrogen Oxide (NO), CO₂ 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 m³ per day is discharged via the outfall pipeline during normal operations which includes 3 m³ per day of regeneration waste water from the 2nd pass of the RO-2 plant and 1224 m³ per day of waste water from the 1st pass of the RO-2 plant. Alba plans to eliminate the discharged 1224 m³ 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.

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 intend 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 m³ 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 m³ 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 m³ 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 m³ 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 m³ 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/SCF³ (32.04 Mega Joules per Cubic Metre (MJ/m³)) 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)	Capacity (MW)	Efficiency (at 15 deg C)	Efficiency (at 42 deg C)
	Winter at 25 deg C	Summer		
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%

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 m³/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 m³ 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 m³ 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.

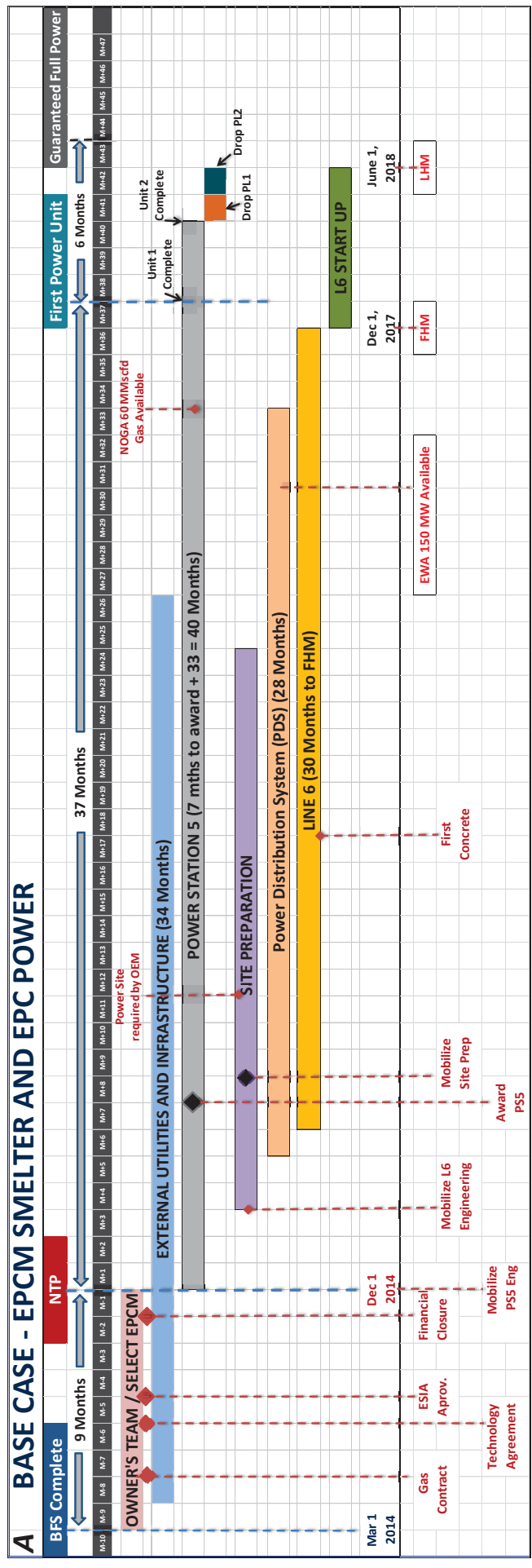


Figure 5: Tentative Construction Schedule

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**.

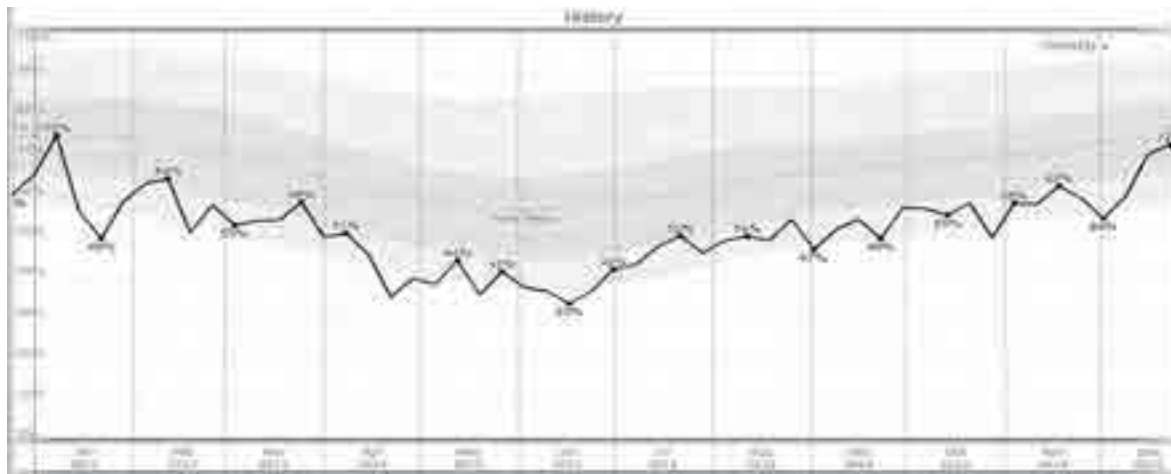


Figure 6: Relative Humidity, Manama- Kingdom of Bahrain (2012)

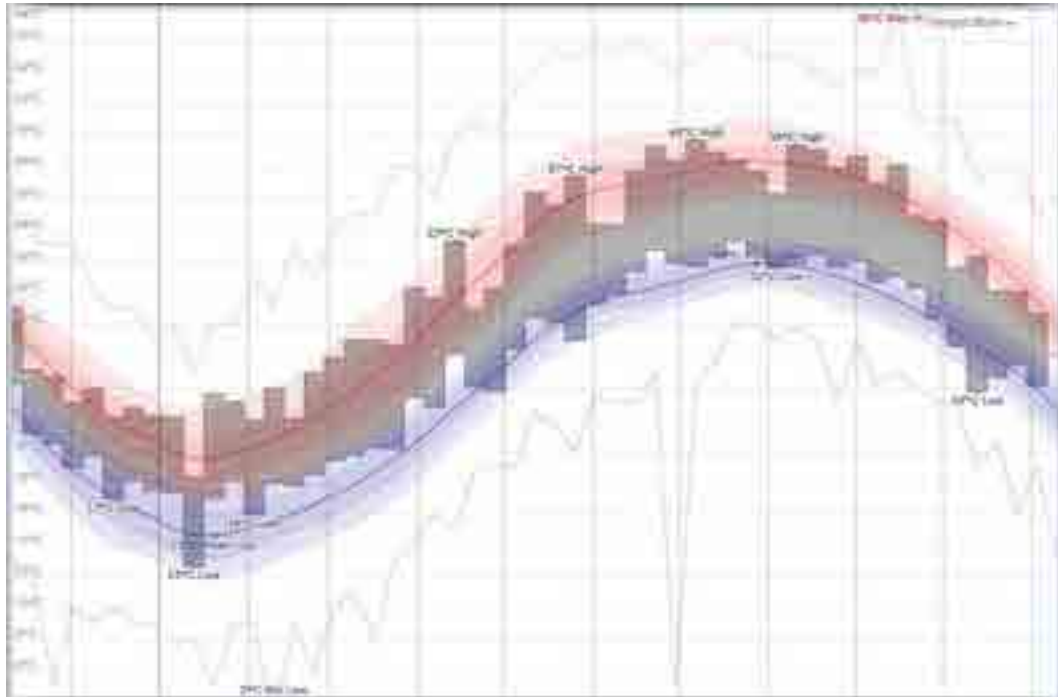


Figure 7: Annual temperatures, Manama- Kingdom of Bahrain (2012)

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).

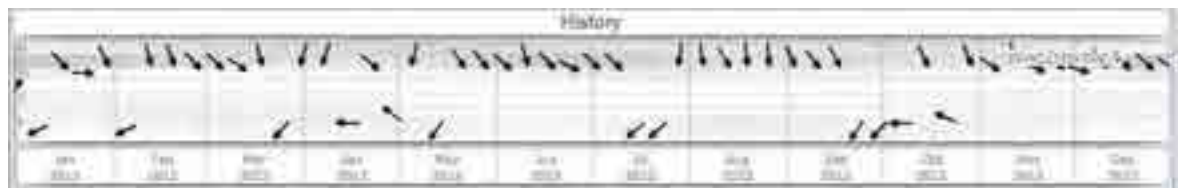
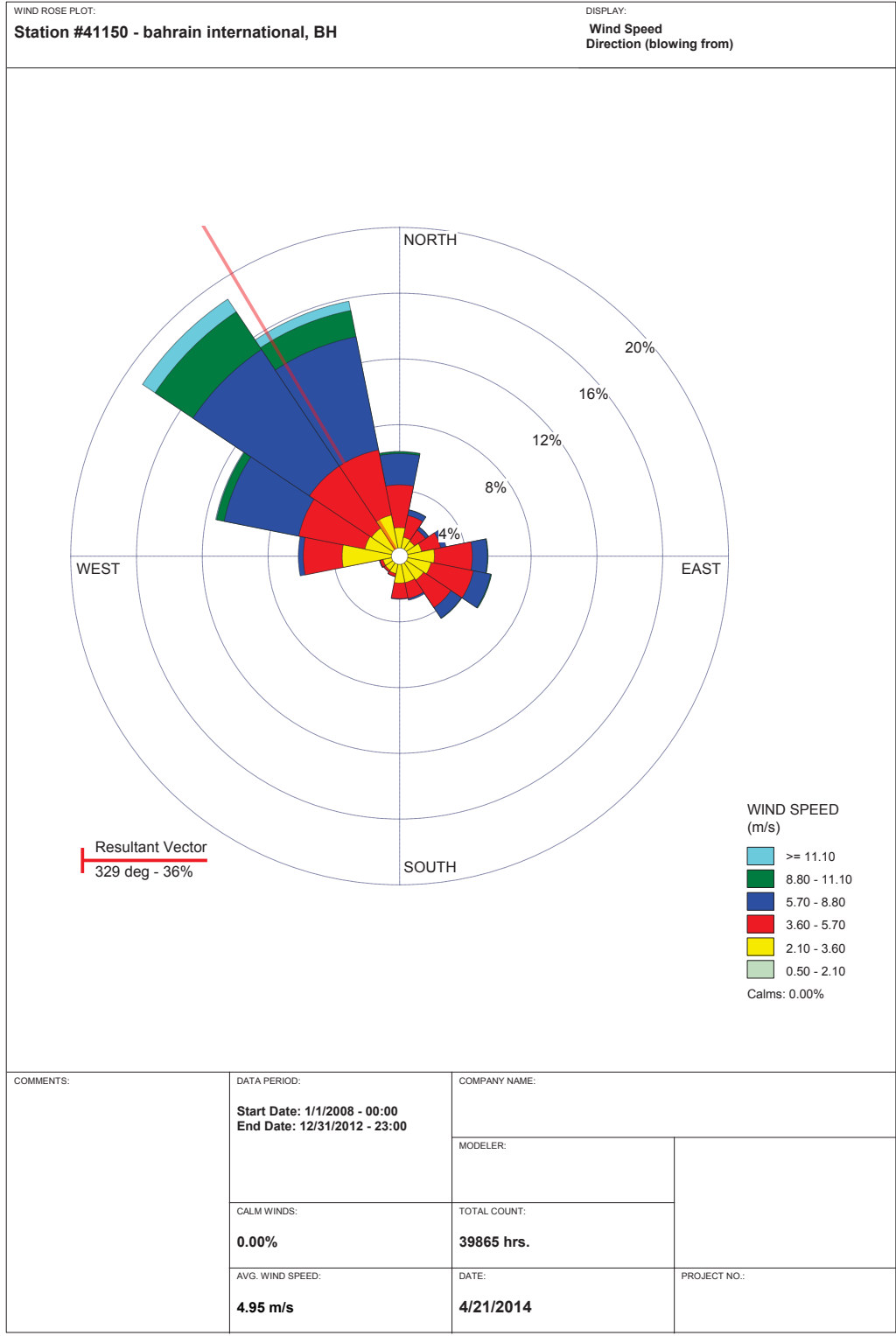


Figure 8: Wind Direction, Manama- Kingdom of Bahrain (2012)



WRPLOT View - Lakes Environmental Software

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; SO₂, Hydrogen Sulphide (H₂S), NO₂, Carbon Monoxide (CO), Ozone (O₃), Inhalable Particulates (PM₁₀ & PM_{2.5}), Ammonia (NH₃), Non-Methane Hydrocarbons (n-ch₄), Benzene (C₆H₆), Toluene (C₇H₈), and p-xylene (C₈H₁₀) 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 SO₂, NO₂ and Inhalable Suspended Solids (Particular Matter (PM₁₀)) did not exceed the stipulated Bahraini standards. The one exception is the 1-hour NO₂ 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/m ³)		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 (PM ₁₀)	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 $\mu\text{g}/\text{m}^3$ which is well below the WHO standard of 1 $\mu\text{g}/\text{m}^3$ (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 (CH₄), 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 sample⁴ 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.

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.

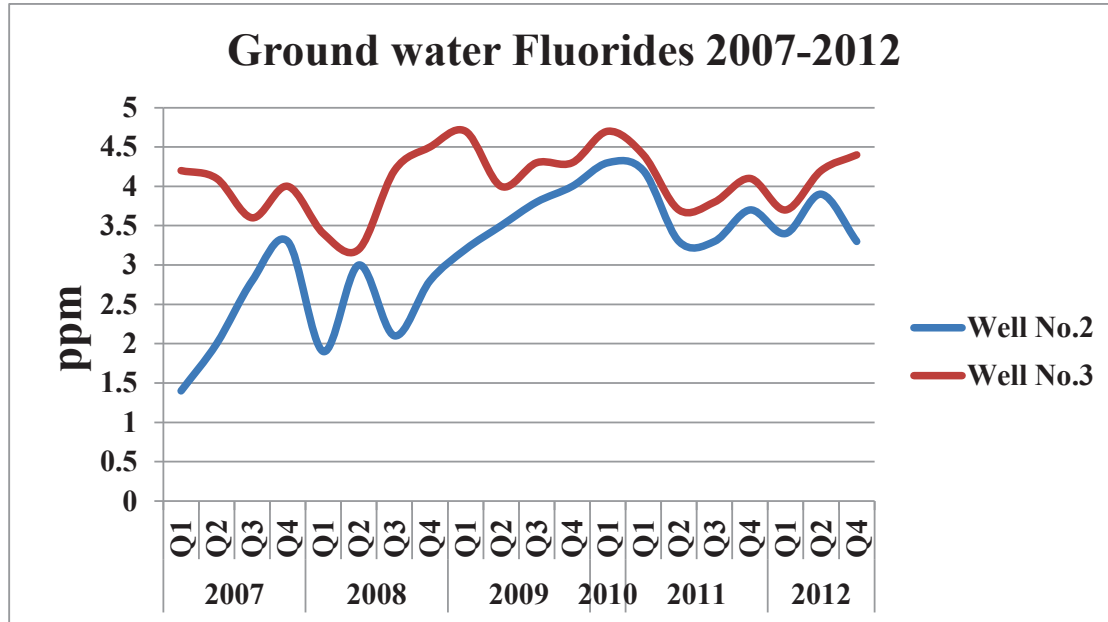


Figure 12: Monitored Fluoride Concentrations, 2007-2012

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.

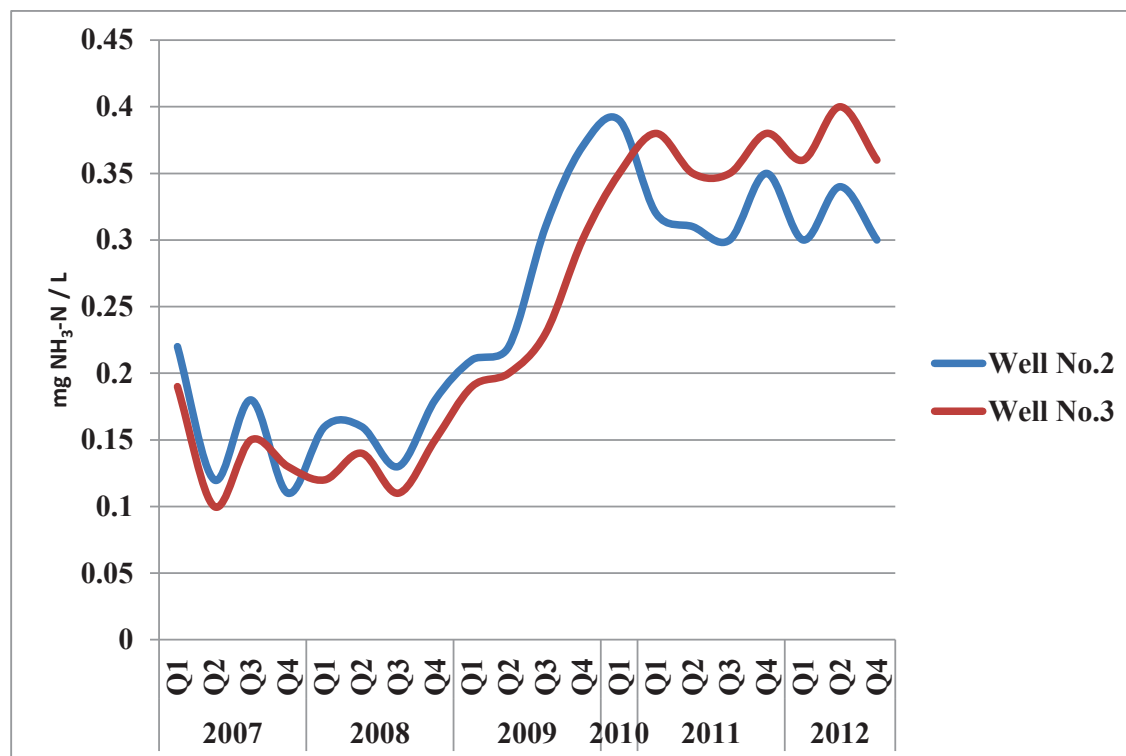


Figure 13: Monitored Ammonical N Concentrations, 2007-2012 [mg NH₃-N / L]

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
<i>Hammadetea salicornici</i>	In land Sub-Sudanian vegetation
<i>Haloxylotea salicornici</i>	Typical coastal vegetation (likely to found in the region of Alba)
<i>Suaedetea deserti</i>	

Plant type	Characteristics
<i>Rhanterium epapposum</i>	The most widespread shrub species
<i>Hammada elegans</i>	
<i>Calligonum omosum</i>	
<i>Zygophyllum qatarense</i>	Low succulent bush
<i>Panicum turgidum</i>	Common grasses
<i>Stipa capensis</i>	
<i>Cyperus conglomerates</i>	Common sedge
<i>Avicennia marina</i>	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
<p>Mammals <i>Arabian Oryx, Reem Gazelle</i></p>
<p>Birds <i>Desert Lark, Crested Lark, Hoopoe Lark, Flamingos</i></p>
<p>Reptiles and Amphibians <i>Jayakar's agama</i></p>
<p>Migrating Birds <i>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</i></p>
<p>Endangered species <i>Arabian Oryx, Saunders Little Terns, Houbara bustard (<i>Chlamydotis undulata</i>)</i></p>



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

PS 5	L6	Laydown Area	1	Area with most vegetation
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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 scarce 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



B



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 km² 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 <i>Avicennia</i> , <i>Phragmites</i> reed beds, <i>Halodule uninervis</i> , <i>Halophila stipulacea</i> , <i>Sargassum</i> , <i>Hormophysa</i> , <i>Padina</i> Corals: <i>Acrophora</i> Filamentous green algae (<i>Ulva</i> , <i>Chaetomorpha</i> , <i>Cladophora</i>)	Sea cow: <i>Dugong dugong</i> Green turtle: <i>Chelonia midas</i> 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 (km²)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 recyclable⁶ 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 km². Askar is operational since 1988 and the site caters to municipal wastes, but also provides to agricultural wastes and non-hazardous industrial wastes.

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 km² of the landfill has been filled to an average waste depth of 15 m. Estimates show that 1.7m³ 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.

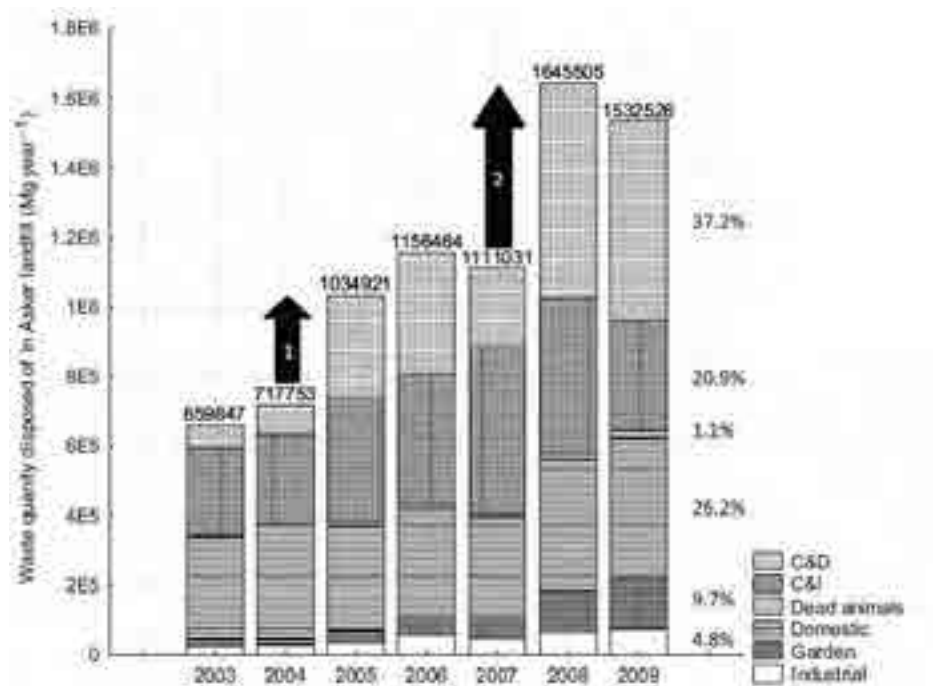


Figure 20: Quantities and Allocations of Non-hazardous Waste - Asker Landfill⁸

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.

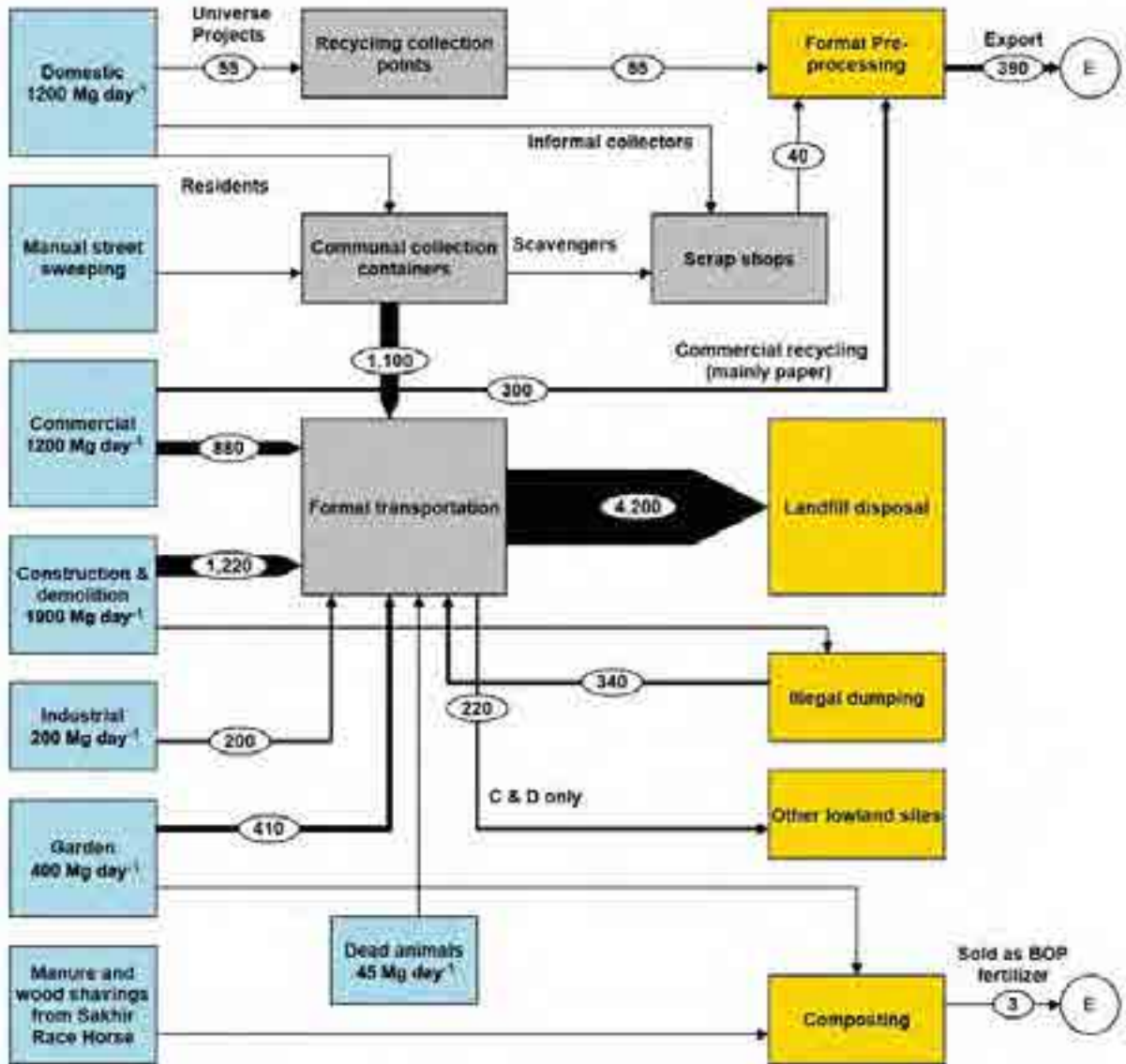


Figure 21: Waste Flow Diagram (Non-hazardous Wastes)⁹

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

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 m³ 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

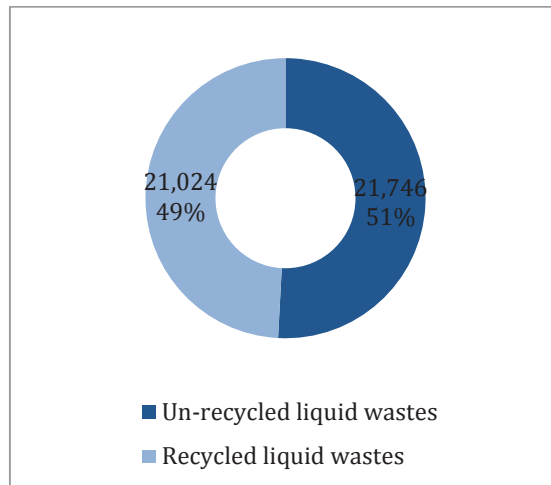
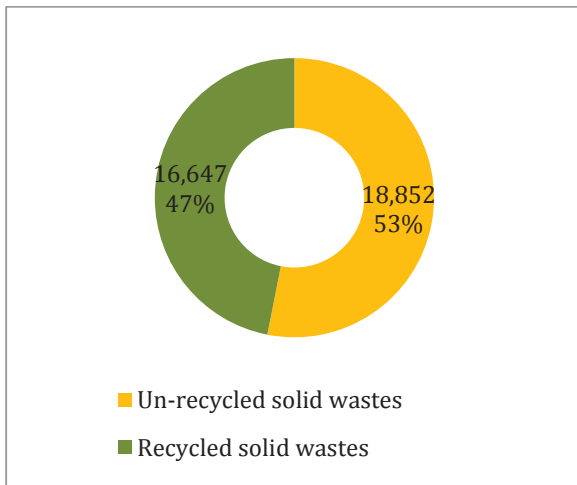
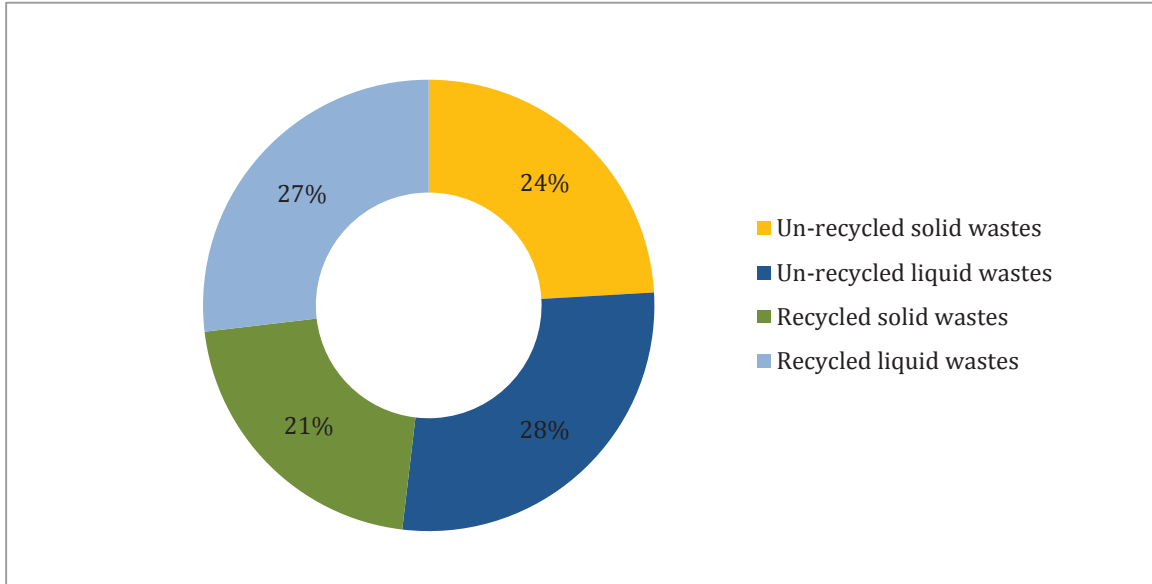
In the Kingdom of Bahrain, medical waste is managed by the Ministry of Health. On a daily basis 7 tonne of health care waste is generated, collected in specialized vehicles and sent to privatised incineration facilities.

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		Un-recycled Wastes	
	Metric Ton / year		Metric Ton / year*
Recycled Solid Wastes	16,647	Un-recycled Solid Wastes	18,852
Recycled Liquid Wastes	21,024	Un-recycled Liquid Wastes	21,746
Total	37,670	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
	Recoverd 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)

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..

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 m³ 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 m³ per day of waste water effluents. Therefore, a total volume of 1,227 m³ 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 m³ 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 m³ per day of waste water from the operations of RO-1 plant;
- 2,448 m³ per day of waste water from the operations of RO-2 plant;
- 3 m³ per day of regeneration waste water from the 2nd pass of RO-2 plant; and
- 1,104 m³ 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 m³ 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 m³ 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 deduced 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.

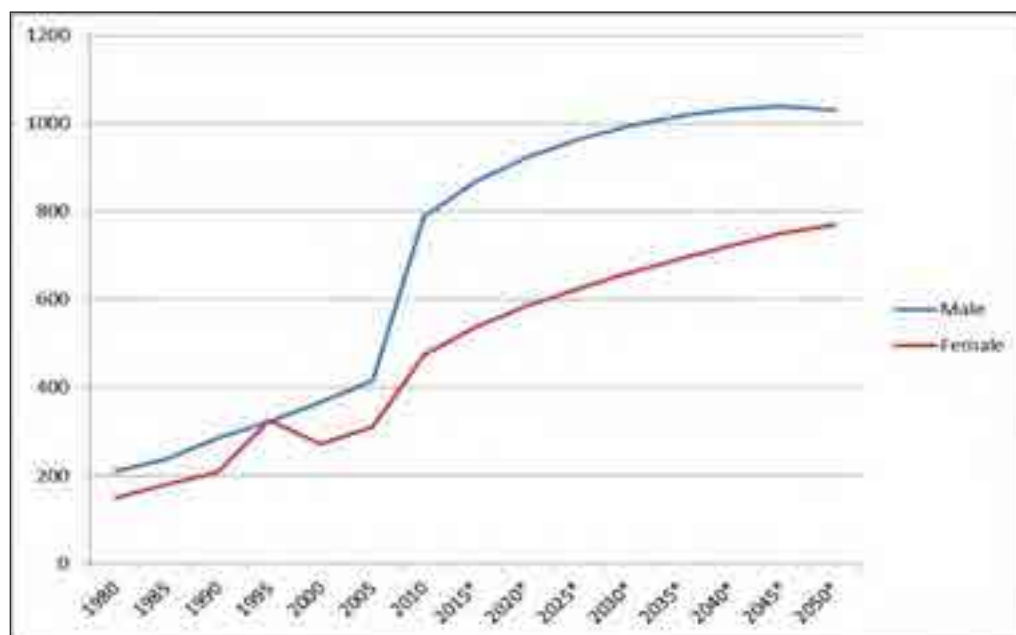


Figure 27: Male and Female Population Size against Time in Bahrain, 1980-2050

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 billion¹².

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

¹² GDP dollar estimates given are derived from purchasing power parity (PPP) calculations 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**

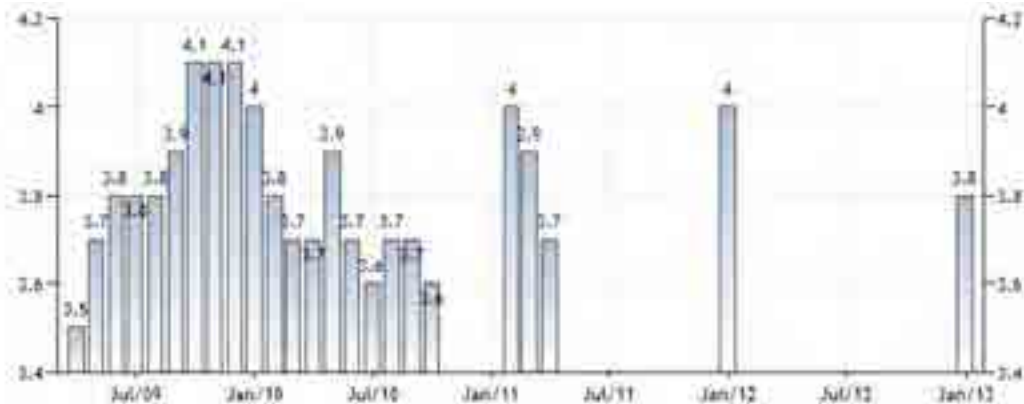


Figure 29: Bahrain Unemployment Rate



As of August 2013, the Bahrain's labour force is made up of 566730.00 employed persons 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

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	Section 6.10, 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 emissions¹⁴
- 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 CO₂, CO, SO₂, 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;

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 tonnes 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 CO₂, 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	<ul style="list-style-type: none"> ▪ 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	<ul style="list-style-type: none"> ▪ Usage of suitable extraction, ventilation and providing screens to contain dust within working area
3	Waste transfer and storage	<ul style="list-style-type: none"> ▪ Enclosed conveyors and chutes



S. No.	Nature of Source	Applicable Control Options
4	On-site traffic movements (paved and unpaved roads)	<ul style="list-style-type: none"> ▪ 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	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ Managing stockpiles by using water sprays (when emptying material bags)
7	Material storage	<ul style="list-style-type: none"> ▪ 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, SO₂, NO_x, HF and PM₁₀ 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 (SO₂, NO_x, HF and PM₁₀)

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 (SO₂)			
Reduction area		kg/t _{Al}	32.0
Anode baking furnace		mg/Nm ³	500
Power station		ppm H ₂ S 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 2¹⁵ to 5 for the following scenarios:

- **Scenario 1:** Existing Operations / Baseline (Potline 1 -5, Power Station 2 – 4)
- **Scenario 2:** Future Maximum¹⁶

Crept Existing Operations + New L6 and Power Station 5 operating at nameplate production capacity. Maximum SO₂ Emission Limit (Bahraini Standard) for reduction area (32 kg SO₂ / t Al).

- **Scenario 3:** Future Mitigated Operations¹⁷:

Crept Existing Operations + New L6 and Power Station 5 operating at nameplate production capacity. SO₂ 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 SO₂ and HF, and is considered to be the worst case scenario.

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 SO₂ 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 SO₂ emissions are caused by the sulphur in the petroleum coke during the production of the anodes. The highest recorded SO₂ 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 SO₂ 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 (SO₂).
 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 SO₂ 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 SO₂" 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	L1 - 5	L6	L1 - 6
			Baseline*	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	L1 - 5	L6	L1 - 6
			Baseline*	Crept		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 CO₂. 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

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 (SO₂, HF, NO₂ 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/Nm³ (IFC Guideline value) but emissions could exceed 1 mg/Nm³ during summer months. Total particulate emissions obtained by well-maintained state-of-the-art system shall emit less than 5 mg/Nm³ 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 SO₂ 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 SO₂ 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 SO₂ 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 ^{3A}	<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	NO _x	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 ₂ S 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 µg/Nm ³	-	-
	BaP [PAH indicator]	<0.5 µg/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	-	-	-
Cathouse 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/Nm ³ ^D	51 mg/Nm ³ ^G	100 mg/Nm ³
	Carbon monoxide	5-100 mg/Nm ³ ^D	-	100 mg/Nm ³
	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 H₂S in the Natural Gas
^E @ 15% O₂

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. Isoleth 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 SO₂ and NO₂ 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 NO₂ concentrations;
- change in SO₂ concentrations;
- change in gaseous Fluoride (HF) concentrations; and



- change in PM₁₀ 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 $\pm 40\%$. 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 NO₂ and PM₁₀ were found to be within all applicable limits for all scenarios. In addition, maximum predicted ground level concentrations of SO₂ were within applicable limits for the annual mean averaging period.

For SO₂, exceedances (see definition below) were predicted for the 24-hour average concentration Bahraini limit (125 $\mu\text{g SO}_2 / \text{m}^3$) for the future Scenario 2 (196 $\mu\text{g SO}_2 / \text{m}^3$) and for Scenario 3 (162 $\mu\text{g SO}_2 / \text{m}^3$). Exceedances were also predicted to the applicable one-hour average concentration limit of 350 $\mu\text{g SO}_2 / \text{m}^3$ for all future scenarios.

In addition, all scenarios predicted exceedances of the annual averaging limit (for vegetation, 1 $\mu\text{g HF} / \text{m}^3$) 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 SO₂ 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 Receptors¹⁹

#	Sensitive Receptor	Bahrain Air Quality Standard ($\mu\text{g}/\text{m}^3$)	Maximum Actual and Predicted (Alba alone) Scenarios Concentrations ($\mu\text{g}/\text{m}^3$)							
			SO ₂			NO ₂			HF	PM ₁₀
			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

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

²⁰ Monitored Background Concentrations



BILFINGER

#	Sensitive Receptor	Bahrain Air Quality Standard ($\mu\text{g}/\text{m}^3$)	Maximum Actual and Predicted (Alba alone) Scenarios Concentrations ($\mu\text{g}/\text{m}^3$)							
			SO ₂			NO ₂			HF	PM ₁₀
			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	Bahrain Air Quality Standard ($\mu\text{g}/\text{m}^3$)	Maximum Actual and Predicted (Alba alone) Scenarios Concentrations ($\mu\text{g}/\text{m}^3$)							
			SO ₂			NO ₂			HF	PM ₁₀
			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 NO₂ 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 predicted 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	Bahrain Air Quality Standard ($\mu\text{g}/\text{m}^3$)	Total Correlated Predicted Concentrations ($\mu\text{g}/\text{m}^3$)						
			SO ₂			NO ₂			PM ₁₀
			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

²¹ Air Monitoring Station

#	Sensitive Receptors ²¹	Bahrain Air Quality Standard ($\mu\text{g}/\text{m}^3$)	Total Correlated Predicted Concentrations ($\mu\text{g}/\text{m}^3$)						PM ₁₀
			SO ₂			NO ₂			
			Annual mean	24 h	1 h	Annual mean	24 h	1 h	
			50	125	350	40	150	200	
		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 SO₂ 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 SO₂ per day (Scenario-1), while the expansion will result in an emission of 151 tonnes SO₂ 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 SO₂ 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 SO₂ concentration at the sensitive receptors is at Ras Hayyan (located downwind of the project site) at 53 $\mu\text{g SO}_2 / \text{m}^3$. The background concentration at this monitoring station is 71 $\mu\text{g SO}_2 / \text{m}^3$. 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 $\mu\text{g SO}_2/\text{m}^3$ 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 $\mu\text{g}/\text{m}^3$ 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 $\mu\text{g}/\text{m}^3$.

6.2.3.2.2 24-Hour Average Concentrations

The maximum 24-hour ground level concentration for baseline condition is 123 $\mu\text{g SO}_2 /\text{m}^3$, for Alba's contribution alone, which is below the Bahraini AAQS of 125 $\mu\text{g}/\text{m}^3$. 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. SO_2 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 predicted SO_2 concentrations were found to be below the stipulated Bahraini AAQS (50 $\mu\text{g SO}_2 /\text{m}^3$) for Alba's contribution alone. The highest predicted annual SO_2 concentration for the baseline conditions is 19 $\mu\text{g}/\text{m}^3$, 31 $\mu\text{g}/\text{m}^3$ for Scenario 2 and 28 $\mu\text{g}/\text{m}^3$ for Scenario-3.

6.2.3.3 NO₂ 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 $\mu\text{g}/\text{m}^3$ vs standard of 200 $\mu\text{g}/\text{m}^3$).

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 $\mu\text{g}/\text{m}^3$ at Maameer²² is only 7% (14.55 $\mu\text{g}/\text{m}^3$). 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 $\mu\text{g}/\text{m}^3$), and by 1.6% for Scenario 3 (from 218 to 221 $\mu\text{g}/\text{m}^3$). Overall, the total correlated maximum hourly NO_2 values will increase by 19 % for Scenario 2 and no increase in the ambient air

²² 1557 exceedances were recorded from 2007- 2012, indicating that the hourly average 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 NO₂ concentration from Alba's existing operations was predicted to be 17 µg/m³ along the facility fence line. The Future case predicted a maximum concentration caused by Alba of 24 µg/m³ and 22 µg/m³ for scenario 2 and 3 respectively. The corresponding 1-hour AAQS is 150 µg/m³.

6.2.3.3.3 Annual Mean Concentrations

As shown in **Table 34**, annual predicted NO₂ concentrations were found to be below the stipulated Bahraini AAQS (40 µg /m³). The maximum predicted annual NO₂ concentration by Alba alone for the baseline conditions is 3 µg /m³, 4 µg /m³ for Scenario 2 and 4 µg /m³ 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 /m³). Note: as stated previously, given the lack of actual data from 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/m³ 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/m³. 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 /m³, 16 µg /m³ for Scenario-2 and 14 µg /m³ 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 PM₁₀ Concentrations

As presented in **Table 34**, the maximum daily PM₁₀ concentration caused by Alba's current operations is 125 µg/m³, which is below the Bahrain AAQS of 340 µg/m³. The emission rates of PM₁₀ 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/m³.

Daily predicted total correlated PM₁₀ concentrations were found to be below the stipulated Bahraini AAQS (340 µg/m³), refer **Table 37**. The monitoring data collected at the ambient air quality stations show higher ambient PM₁₀ 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 SO₂ 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 (NIOSH²³, September 2007 [Ref. 15]) are:

- HF: 2.5 mg/m³ (3 ppm) time weighted average
- SO₂: 5 mg/m³ (2 ppm) time weighted average
- NO₂: 1.8 mg/m³ (1 ppm) short term exposure (15 min)
- Respirable particulate: 5 mg/m³ (8 hour Time Weighted Average).

Since all predicted assessed ambient air quality concentrations for all parameters and all scenarios are in µg/m³ which are far below the above workplace air quality standards (expressed in mg/m³), 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 NO₂ and PM₁₀ after expansion will be in compliance with the applicable standards and guidelines, with the exception for the Maameer location where existing hourly NO₂ values are currently already being exceeded (218µg/m³ versus standard of 200µg/m³).

The total correlated SO₂ 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 SO₂ and HF levels in the area from Alba's fence line 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

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 SO₂ 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 SO₂ and HF concentrations which are likely to occur. As described in **section 6.2.3.6** above, all predicted air quality levels for SO₂ 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 SO₂, NO_x and CO₂ 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 compliant 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 m³/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 m³/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 m³/day. This quantity is not anticipated to increase given that for the expansion project, two (2) new 12,500 m³ 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 (CO₂), 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 m³** 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 (H₂SO₄) 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 m³** 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 (m³)** 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 (m³)** 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 (m³)** 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 Asker 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 m³** 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 m³/day, versus 1,227 m³/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 m³ 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 brought 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 brought 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 contamination²⁴ 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

²⁴ Boron and Sulphur concentrations did exceed the standard levels. The source of boron contamination is presently unknown. It is possible that high levels of boron are „naturally occurring 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 SO₂ 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 guidelines²⁶ 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.

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 scarce 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 1,900m³/year, and gasoline consumption is approximately 190m³/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 m³) 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

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 Hafeera..

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			

³² Normal wastes collected in blue general waste skips

³³ Mostly 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 m³ 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	Calcliner Bag House Ash ³⁴	Calcliner	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

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 Process³⁵

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).							

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 content³⁶ 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 dross³⁸), 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 sent for processing. The recovered aluminium was returned from the processing facility as ingots and recycled into Alba's production process.

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 known 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 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 formed³⁹. Therefore it is important to apply proper storage and handling practices 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 management⁴⁰.

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.

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 (77 deliveries 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 Babco 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



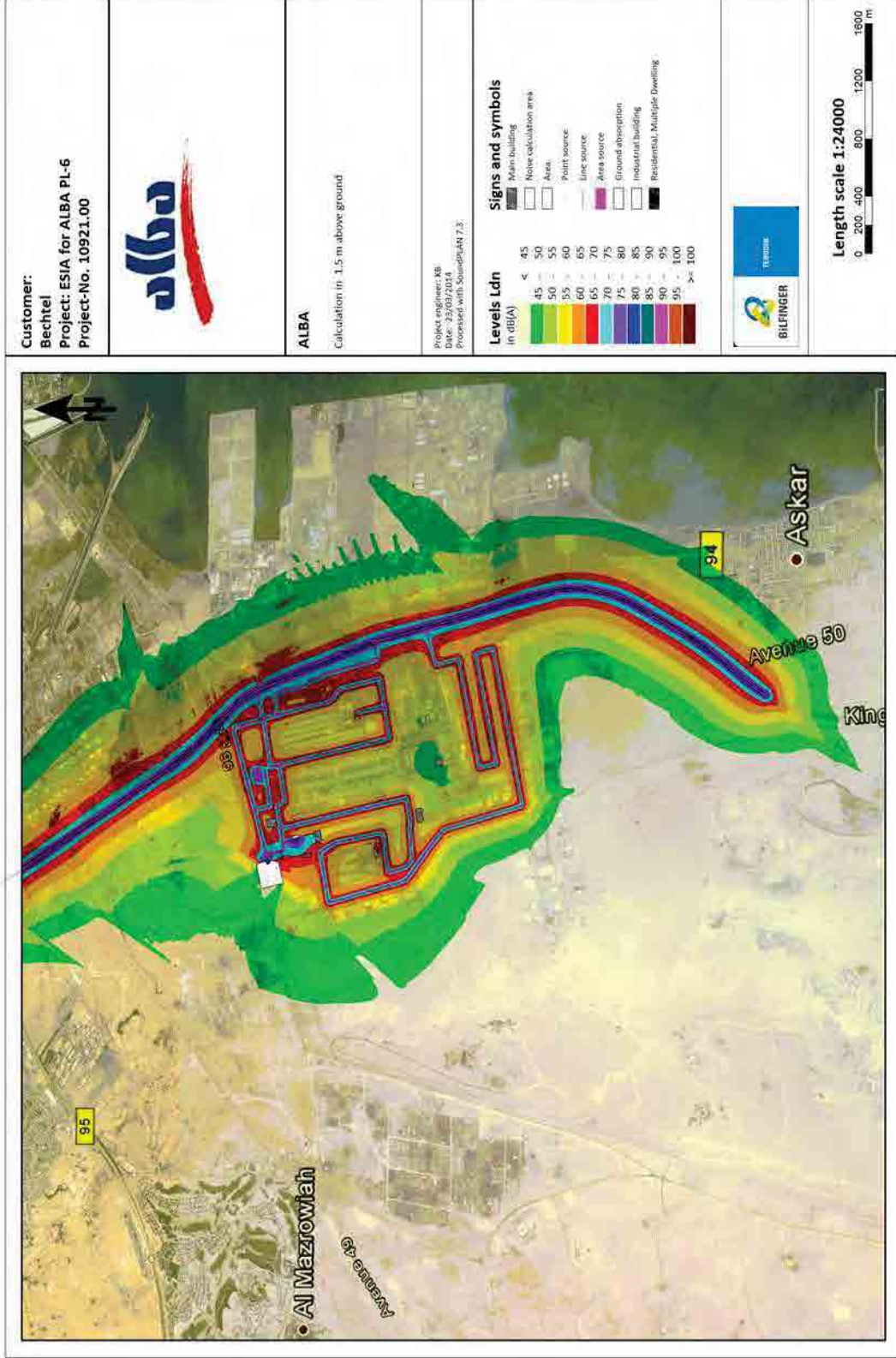


Figure 32: Overview of Noise Contributions from ALBA operations to the surroundings

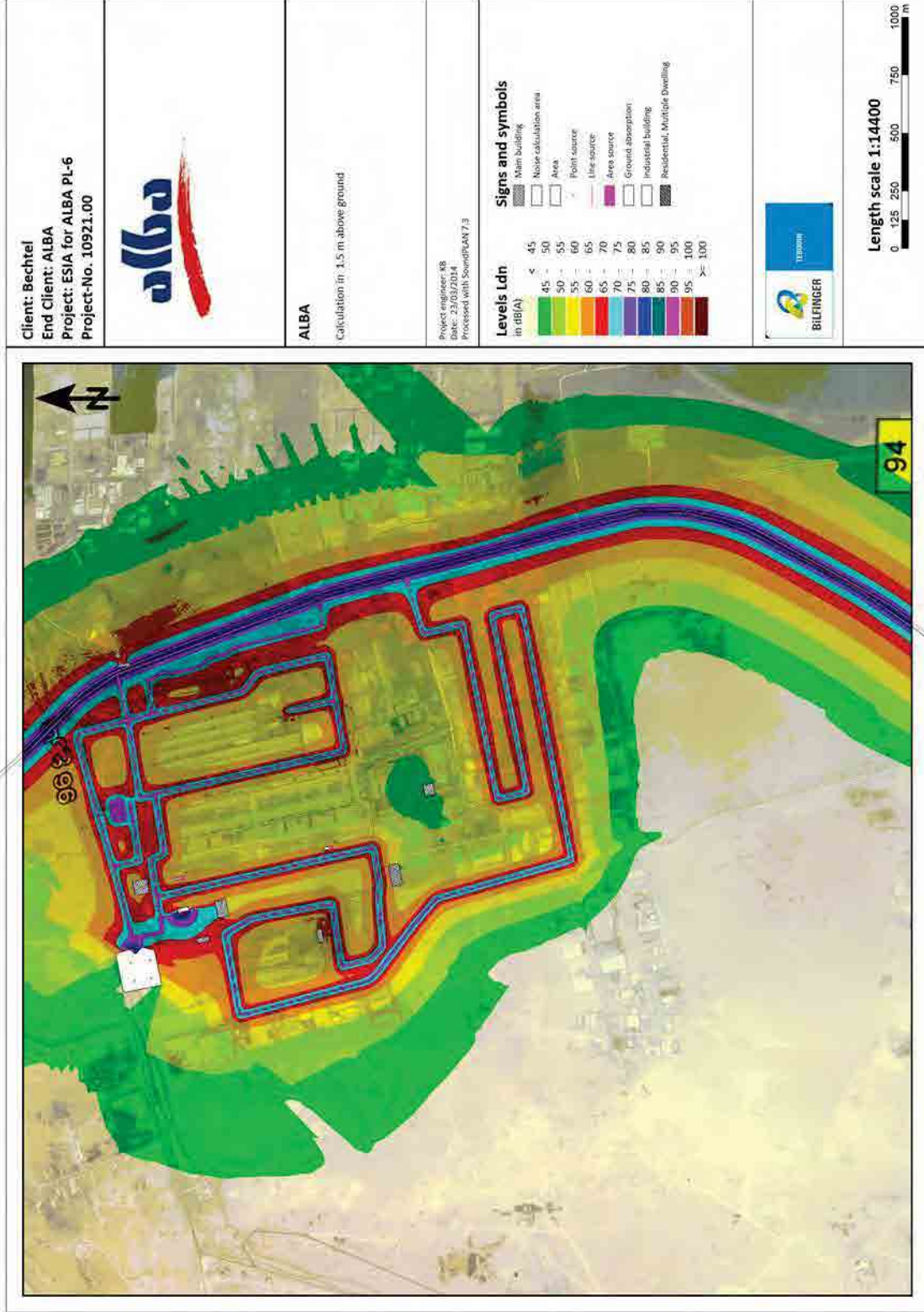


Figure 33: Predicted Noise Levels close to ALBA's fenceline (current operation plus PL6 and PS5)



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 exist(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	<p>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.</p> <p>Adverse effects can be prevented by treatment at source (acoustical insulation, covers), having dedicated high noise areas and mandatory use of suitable hearing protection.</p>
2	Hot Metal	<p>Handling of hot metal (molten aluminium) poses a potentially lethal hazard.</p> <p>However, the risk of contact with hot metal will be minimised/prevented through suitable management controls and design.</p>
3	Electromagnetic Forces	<p>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.</p> <p>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.</p> <p>Exposure to ultra-low frequency electromagnetic fields may occur in reduction plants, especially adjacent to rectifier rooms.</p> <p>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]</p>
4	Air Pollution	<p>For anode changing and other pot operations, pot hoods are removed resulting in a release of air pollutants (HF, dust, PFCs) formed during electrolysis.</p>



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, SO₂, 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.

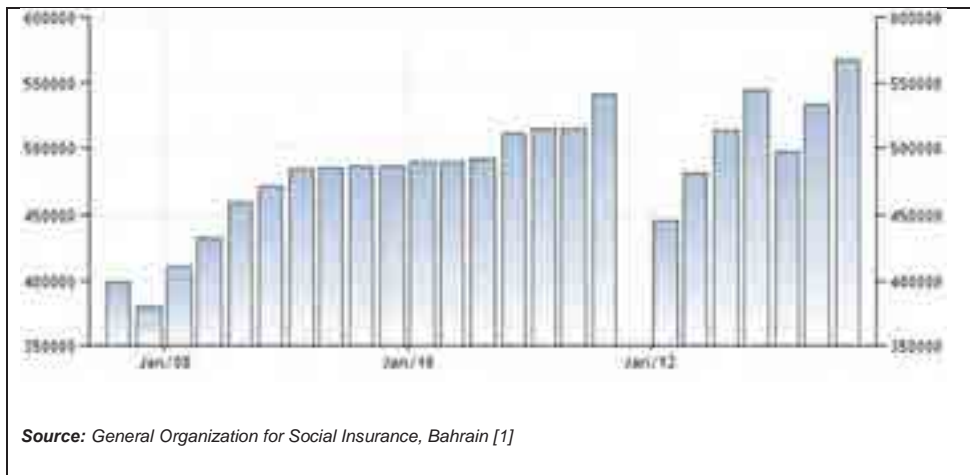


Figure 34: The Workforce in Bahrain, Jan 2008 - August 2013

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 (CO₂) and sulphur dioxide (SO₂). 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 NO_x (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 approximately 13.69 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 Dubai 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 existing 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 SO₂ and HF emissions. The results of the analysis show that the total correlated predicted SO₂ 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 SO₂ and HF levels in the area from Alba's fence line 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 SO₂ 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 requested⁴¹ 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**.

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 partly 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.

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 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.



References

- 1 Bahrain Surface Materials Resources Survey, 1980. Geology, geomorphology and pedology of Bahrain. Edited by J.C. Doornkamp, D. Brunsden and D.K.C. Jones, Geo Abstracts Ltd, Norwich, U.K.
- 2 Al-Hoty Analytical Services, 1990. Pot line 4 Project at North Sitra: Final Report on Ground Investigation. Report No.G/1221 submitted to Bechtel-Lavalin for ALBA B.S.C., Bahrain.
- 3 Kaiser Engineers Ltd., 2000. Line 5 Feasibility Study-Reduction Line 5 Volume III. Submitted to Aluminium Bahrain. Twickenham, UK.
- 4 World wildlife, 2002. Terrestrial Ecoregions: Persian gulf desert and semi-desert (PA1323).
- 5 Hill, K., and Hill, M., Bahrain Wildlife Report. Arabian Wildlife Magazine Vol. 2 No.2.
- 6 Hirschfeld, E., 1995. Birds in Bahrain: A Study of their Migration Patterns 1990-92. Hobby Publication, Dubai, UAE.
- 7 Nightgale, T. and Hill, M., 1993. Birds of Bahrain. Immel, London, UK.
- 8 Voudsen, D.H. 1985a. The Bahrain marine habitat survey. A study of the marine habitats in the waters of Bahrain and their relationship to physical, chemical, biological and anthropogenic influences. Environmental Protection Committee, State of Bahrain.
- 9 Voudsen, DH. 1985b. The Bahrain marine habitat survey. Volume 2. The habitat maps. Environmental Protection Committee, State of Bahrain.
- 10 Lee Long, W.J. and Coles, R.G. 1995. Status of seagrasses in the Great Barrier Reef region. In: Wachenfeld, D., Oliver, J., Davis, K. (eds): Proceedings of the State of the Great Barrier Reef World Heritage Area Workshop. Townsville, Australia.
- 11 EcoMENA – Solid Waste Management in Bahrain, December 2012, url: <http://www.ecomena.org/solid-waste-bahrain>, visited May 2014
- 12 Sabbagh et al. 2012: Resource management performance in Bahrain: a systematic analysis of municipal waste management, secondary material flows and organizational aspects *Waste Manag Res* August 2012 30: 813-824, first published on May 13, 2012
- 13 KMPG International, Infrastructure 100 World Cities Edition (2012)
- 14 *Status of Solid Waste Management in the Kingdom of Bahrain*. Waste and Recycling Middle East, Vol. 003, Issue 6, Nov/Dec 2013.
- 15 NIOSH Pocket Guide To Chemical Hazards, Department of Health and Human Services, Centres for Disease Control and Prevention, National Institute for Occupational Safety and Health, September 2007, DHHS (NIOSH) Publication No. 2005-149
- 16 IFC, April 30, 2007, Environment, Health and Safety Guidelines, Base Metal Smelting and Refining,



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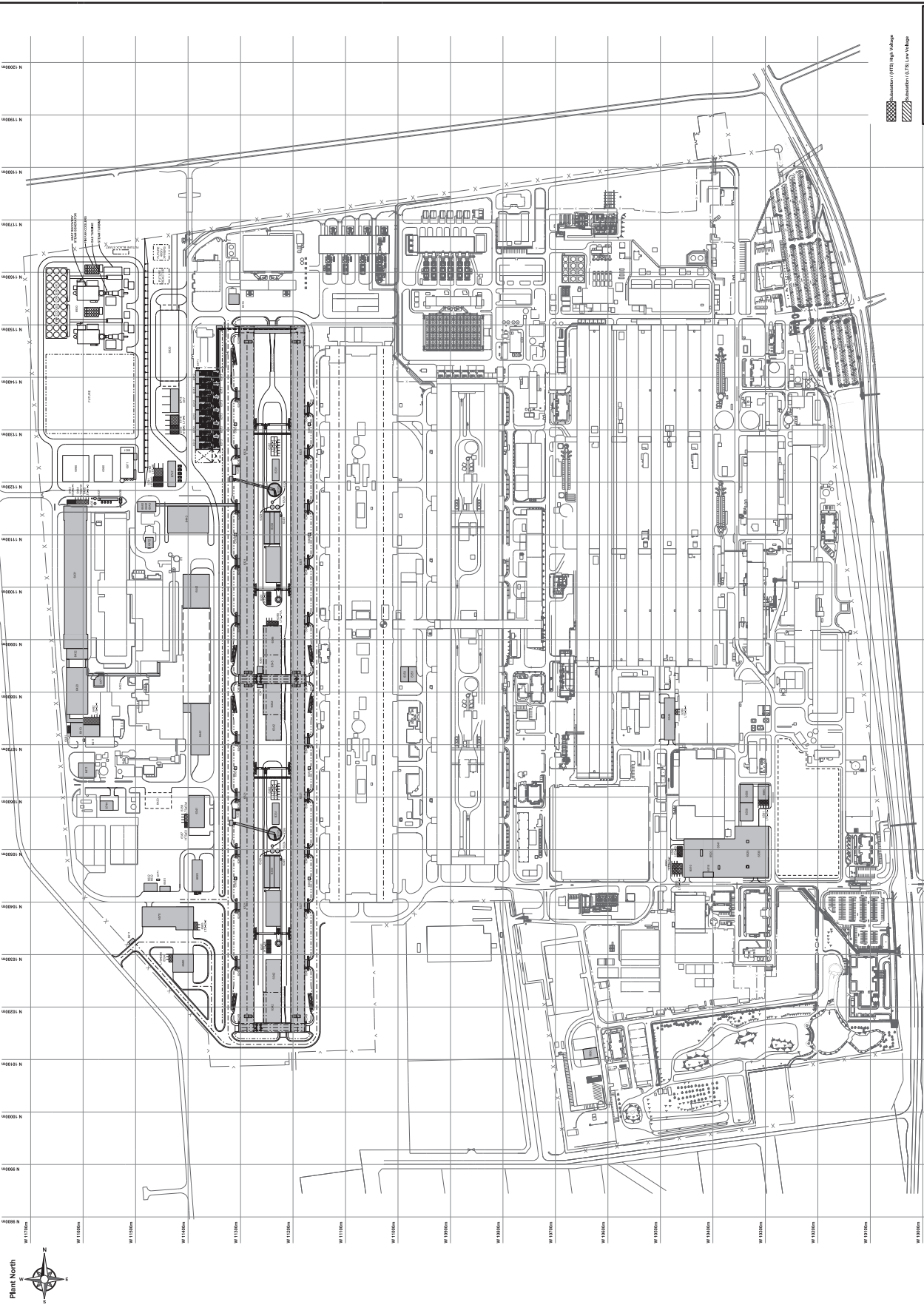
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Appendix 1: Site Layout – Existing Facilities

Alba Line 6 - Facility Descriptions

- 6000 General Corridor
- 6001 2nd Floor Corridor
- 6002 3rd Floor Corridor
- 6003 4th Floor Corridor
- 6004 5th Floor Corridor
- 6005 6th Floor Corridor
- 6006 7th Floor Corridor
- 6007 8th Floor Corridor
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- 6099 100th Floor Corridor



**PRELIMINARY DESIGN
IN PROGRESS**

Bechtel

Alba

Line 6 Feasibility Study
Line 6 - 404 Pits
General Arrangement
Plot Plan

25935-6006-P1-6000-0003 100D

NO.	DESCRIPTION	DATE	BY	CHKD	APP'D
1	ISSUED FOR PERMITTING	11/15/2011	J. SMITH	M. SMITH	J. SMITH
2	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
3	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
4	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
5	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
6	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
7	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
8	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
9	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH
10	ISSUED FOR CONSTRUCTION	11/15/2011	J. SMITH	M. SMITH	J. SMITH



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.

Kingdom of Bahrain
Supreme Council for Environment



مجلس الاعلى للبيئة
البحرين

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				
<i>a. (fugitive) hydrocarbons</i>				
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
<i>b. chlorobenzenes</i>				
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)
<i>c. Chlorophenols</i>				
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
<i>d. Polychlorinated biphenyls (PCB's)</i>				
PCB's (sum 7)	0,01*		1	0,01
<i>e. Other chlorinated hydrocarbons</i>				
Monochlororanilinen (sum)	–		50	30
Dioxin (sum TEQ)	–		0,00018	nvt
Chloronaphthalen (sum)	–		23	6
Pesticides				
<i>a. organochlorine pesticides</i>				
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/l		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
<i>b. Organophosphorus pesticides</i>				
–				
<i>c. Organotin pesticides</i>				

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
<i>d. chloorfenoxo-azijnzuur herbiciden</i>				
MCPA	0,02		4	50
<i>e. other pesticides</i>				
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 TIER 1 SOIL AND GROUNDWATER REMEDIATION GUIDELINES

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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 where 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 Protection¹ 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 1×10^{-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.

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-borne 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 1×10^{-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 6×10^{-8} cm² for Tier 1 guideline derivation.

If the Darcy groundwater velocity exceeds 3×10^{-7} m/s, or vapour permeability is greater than 6×10^{-8} cm² 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 m³. 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 m³, 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 CaCl₂ extraction test. True total barium concentrations from samples that pass the CaCl₂ 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 CaCl₂ 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, acenaphthene, 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

Alberta Environment references are available at: <http://environment.alberta.ca/>

- AENV (Alberta Environment), 1999. Surface Water Quality Guidelines for Use in Alberta. Alberta Environment, November 1999.
- AENV (Alberta Environment), 2000. Industrial Release Limits Policy. Environmental Sciences Division. Alberta Environment Publication # T/569.
- AENV (Alberta Environment), 2001a. Alberta Soil and Water Quality Guidelines for Hydrocarbons at Upstream Oil and Gas Facilities. Environmental Sciences Division, September 2001.
- AENV (Alberta Environment), 2001b. Risk Management Guidelines for Petroleum Storage Tank Sites. Science and Standards Division, Pub No. T/570, October 2001.
- AENV (Alberta Environment), 2001c. Salt Contamination Assessment and Remediation Guidelines. Environmental Sciences Division, Pub No. T/606, May 2001.
- AENV (Alberta Environment), 2005. A Guide to Release Reporting. Alberta Environmental Protection and Enhancement Act. Alberta Environment Publication # 1/792
- AENV (Alberta Environment), 2008. Code of Practice for Land Treatment of Soil Containing Hydrocarbons. Alberta Queen's Printer.
- AENV (Alberta Environment), 2009a. Alberta Tier 2 Soil and Groundwater Remediation Guidelines.
- AENV (Alberta Environment), 2009b. Soil Remediation Guidelines for Barite: Environmental Health and Human Health. Environmental Assurance Division. Alberta Environment.
- AENV (Alberta Environment), 2009c. Assessing Drilling Waste Disposal Areas: Compliance Options for Reclamation Certification. Alberta Environment Pub. No. T/779.
- AEP (Alberta Environmental Protection), 1994. Alberta Tier I Criteria for Contaminated Soil Assessment and Remediation, March 1994. Pub. No. T/475.
- AEP (Alberta Environmental Protection), 1996. Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes. May 1996. Pub. No. T/478
- CAPP (Canadian Association of Petroleum Producers), 2002. Assessment of Monitored Natural Attenuation at Upstream Oil & Gas Facilities in Alberta – Final Report. March 2002. Canadian Association of Petroleum Producers, No. 2001-0010. Document available online at: <http://www.ptac.org/env/dl/envp0202.pdf>
- CCME (Canadian Council of Ministers of the Environment), 1991. Interim Canadian Environmental Quality Criteria for Contaminated Sites. Canadian Council of Ministers of the Environment, Winnipeg. Report CCME EPC-CS34, September 1991.
- CCME (Canadian Council of Ministers of the Environment), 1999 and updates. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg. Published 1999, updated through 2006. information on ordering available online at http://www.ccme.ca/publications/ceqg_rcqe.html
- CCME (Canadian Council of Ministers of the Environment), 2001. Reference Method for the Canada-Wide Standard for Petroleum Hydrocarbons in Soil - Tier 1 Method. PN 1310. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Available online at http://www.ccme.ca/assets/pdf/pah_soqg_ssd_1401.pdf
- CCME (Canadian Council of Ministers of the Environment). 2006. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. PN 1332.

- Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Available on-line at http://www.ccme.ca/assets/pdf/sg_protocol_1332_e.pdf
- CCME (Canadian Council of Ministers of the Environment), 2008. Canada-Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale. Available on-line at http://www.ccme.ca/assets/pdf/pn_1399_phc_sr_std_1.2_e.pdf
- ERCB (Energy Resources and Conservation Board), 1996a. Drilling Waste Management Directive 50. Alberta Energy Resources and Conservation Board. Available on-line at <http://www.ercb.ca/docs/documents/directives/Directive050.pdf>
- ERCB (Energy Resources and Conservation Board), 1996b. Oilfield Waste Management Requirements for the Upstream Petroleum Industry. Directive 58. Alberta Energy Resources and Conservation Board. Available on-line at <http://www.ercb.ca/docs/documents/directives/Directive058.pdf>
- ERCB (Energy Resources and Conservation Board), 1998. A Memorandum of Understanding Between Alberta Environmental Protection and the Alberta Energy and Utilities Board Regarding Coordination of Release Notification Requirements and Subsequent Regulatory Response. Informational Letter 98-1. Dated 6 February, 1998. Available on-line at <http://www.ercb.ca/docs/ils/ils/pdf/il98-01.pdf>
- Government of Alberta, 1993. Conservation and Reclamation Regulation. Chapter 113/1993. Document available online at <http://www.qp.gov.ab.ca>
- Government of Alberta, 2000. Water Act. Revised Statutes of Alberta 2000. Document available online at <http://www.qp.gov.ab.ca>
- Government of Alberta, 2003. Water for Life. Alberta's Strategy for Sustainability. Document available online at <http://www.waterforlife.gov.ab.ca/>
- Government of Alberta, 2006. Environmental Protection and Enhancement Act. Revised Statutes of Alberta 2000, Chapter E-12. with amendments in force as of May 24, 2006. Document available online at <http://www.qp.gov.ab.ca>
- Health Canada, 2000. Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM). Minister of Public Works and Government Services Canada, Cat. H46-1/30-2000E. Available on-line at <http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/norm-mrn/index-eng.php>
- Health Canada, 2004. Federal Contaminated Site Risk Assessment in Canada. Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA). Prepared by: Environmental Health Assessment Services Safe Environments Programme, September 2004. Available online at: http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/partie_i/index-eng.php
- Municipal Affairs and Housing, undated. Advisory Land Use Planning Notes on Abandoned Well Sites. Available online at: http://municipalaffairs.gov.ab.ca/am_advisory_land_use_planning_notes_on%20abandon_well_sites.cfm
- Soil Classification Working Group, 1998. The Canadian System of Soil Classification, 3rd edition. Research Branch, Agriculture and Agri-Food Canada, Publication 1646. NRC Research Press, Ottawa. Available on-line at <http://sis2.agr.gc.ca/cansis/taxa/>
- Wiedemeier, T.H., H.S. Rifai, C.J. Newell, and J.T. Wilson, 1999. Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface. John Wiley and Sons, New York.

TABLES

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Soil Type	Fine					Coarse					Notes	
	Natural Area (mg/kg)	Agricultural (mg/kg)	Residential/ Parkland (mg/kg)	Commercial (mg/kg)	Industrial (mg/kg)	Natural Area (mg/kg)	Agricultural (mg/kg)	Residential/ Parkland (mg/kg)	Commercial (mg/kg)	Industrial (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	6-8.5	1
Cyanide (free)	0.9	0.9	0.9	8	8	0.9	0.9	0.9	8	8	8	2
Fluoride	200	200	200	2,000	2,000	200	200	200	2,000	2,000	2,000	1
Sulphur (elemental)	500	500	500	500	500	500	500	500	500	500	500	3
Metals												
Antimony	20	20	20	40	40	20	20	20	40	40	40	1
Arsenic (inorganic)	17	17	17	26	26	17	17	17	26	26	26	2
Barium (non-barite)	750	750	500	2,000	2,000	750	750	500	2,000	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	140,000	4
Beryllium	5	5	5	8	8	5	5	5	8	8	8	1
Boron (hot water soluble)	2	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	22	2
Chromium (hexavalent)	0.4	0.4	0.4	1.4	1.4	0.4	0.4	0.4	1.4	1.4	1.4	2
Chromium (total)	64	64	64	87	87	64	64	64	87	87	87	2
Cobalt	20	20	20	300	300	20	20	20	300	300	300	1
Copper	63	63	63	91	91	63	63	63	91	91	91	2
Lead	70	70	140	260	600	70	70	140	260	600	600	2
Mercury (inorganic)	12	6.6	6.6	24	50	12	6.6	6.6	24	50	50	2
Molybdenum	4	4	4	40	40	4	4	4	40	40	40	1
Nickel	50	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	2.9	2
Silver	20	20	20	40	40	20	20	20	40	40	40	1
Thallium	1	1	1	1	1	1	1	1	1	1	1	2
Tin	5	5	5	300	300	5	5	5	300	300	300	1
Uranium	33	23	23	33	300	33	23	23	33	300	300	2
Vanadium	130	130	130	130	130	130	130	130	130	130	130	2
Zinc	200	200	200	360	360	200	200	200	360	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	0.078	5
Toluene	0.52	0.52	0.52	0.52	0.52	0.49	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	0.21	5

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Soil Type	Fine					Coarse					Notes
	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	
Land Use	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
Unit											
Xylenes	1.5	1.5	1.5	1.5	1.5	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
Acenaphthene	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
Benz[b+g]fluoranthene	6.2	6.2	-	-	-	6.2	6.2	-	-	-	8
Benz[k]fluoranthene	6.2	6.2	-	-	-	6.2	6.2	-	-	-	8
Benz[ghi]perylene	-	-	-	-	-	-	-	-	-	-	
Benz[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-Dichloroethane	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
	Natural Area (mg/kg)	Agricultural (mg/kg)	Residential/ Parkland (mg/kg)	Commercial (mg/kg)	Industrial (mg/kg)	Natural Area (mg/kg)	Agricultural (mg/kg)	Residential/ Parkland (mg/kg)	Commercial (mg/kg)	Industrial (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	0.18	0.18	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	
Azinphos-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
	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	
Land Use	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
Unit											
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	
Trifluralin	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-ethylhexyl)phthalate	34	34	34	34	34	41	41	41	41	41	

Table 1. Alberta Tier 1 Soil Remediation Guidelines

Soil Type	Fine					Coarse					Notes	
	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)	(mg/kg)	
Dibutyl phthalate	0.54	0.54	0.54	0.54	0.54	0.65	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	8.1	
Diisopropanolamine	14	14	14	14	14	17	17	17	17	17	17	5
Ethylene glycol	60	60	60	60	60	62	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	0.031	
Methylmethacrylate	1.3	1.3	1.3	1.3	1.3	1.8	0.10	0.10	1.3	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	0.062	
Nonylphenol + ethoxylates	2.7	2.7	2.7	2.7	2.7	3.3	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	0.0024	5
Sulfolane	0.18	0.18	0.18	0.18	0.18	0.21	0.18	0.21	0.21	0.21	0.21	5

Soil Type	Fine					Coarse					Notes	
	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)	(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	0.3	10
Uranium-238 (²³⁸ U, ²³⁴ Th, ²³⁴ Pa, ²³⁴ U)	10	10	10	10	10	10	10	10	10	10	10	10
Thorium-230	10	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	0.3	10
Lead-210 (in equilibrium with ²¹⁰ Pb and ²¹⁰ Po)	0.3	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	0.3	10
Thorium-232	10	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	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	0.3	10
Potassium-40	17	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:

$$IACR = \frac{[Benz(a)anthracene]}{1.6 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(b + j)fluoranthene]}{0.74 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(k)fluoranthene]}{0.16 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(g,h,i)perylene]}{32 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(a)pyrene]}{1.7 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Chrysene]}{10 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Dibenz(a,h)anthracene]}{1.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Indeno(1,2,3 - c, d)pyrene]}{13 \text{ mg} \cdot \text{kg}^{-1}}$$

Coarse Soil:

$$IACR = \frac{[Benz(a)anthracene]}{3.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(b + j)fluoranthene]}{1.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(k)fluoranthene]}{0.31 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(g,h,i)perylene]}{63 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(a)pyrene]}{3.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Chrysene]}{19 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Dibenz(a,h)anthracene]}{2.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Indeno(1,2,3 - c, d)pyrene]}{24 \text{ mg} \cdot \text{kg}^{-1}}$$

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 radionuclides are found, the following relationship should be satisfied:
- $$\frac{[\text{Radionuclid e}]_1}{\text{Guideline}_1} + \frac{[\text{Radionuclid e}]_2}{\text{Guideline}_2} + \dots + \frac{[\text{Radionuclid e}]_i}{\text{Guideline}_i} \leq 1$$
- 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
	Natural Area (mg/L)	Agricultural (mg/L)	Residential/ Parkland (mg/L)	Commercial/ Industrial (mg/L)	Natural Area (mg/L)	Agricultural (mg/L)	Residential/ Parkland (mg/L)	Commercial/ Industrial (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 ₂ S)	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
	Natural Area (mg/L)	Agricultural (mg/L)	Residential/ Parkland (mg/L)	Commercial/ Industrial (mg/L)	Natural Area (mg/L)	Agricultural (mg/L)	Residential/ Parkland (mg/L)	Commercial/ Industrial (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	2.2	2.2	2.2	
F2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
Acenaphthene	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	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	
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+g]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
	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	
Land Use	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
Unit									
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	
Azinphos-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	
Bromoxymil	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
	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	0.000035	0.000035	0.000035	0.000035	0.000035	0.000035	0.000035	0.000035	
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
	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	
Land Use									
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	
Nitriotriacetic 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									
Land Use									
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
	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial/ Industrial	
Land Use	(Bq/L)	(Bq/L)	(Bq/L)	(Bq/L)	(Bq/L)	(Bq/L)	(Bq/L)	(Bq/L)	
Unit									
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 Land Use	Fine				Coarse				Notes
	Natural Area (Bq/L)	Agricultural (Bq/L)	Residential/ Parkland (Bq/L)	Commercial/ Industrial (Bq/L)	Natural Area (Bq/L)	Agricultural (Bq/L)	Residential/ Parkland (Bq/L)	Commercial/ Industrial (Bq/L)	
Unit									
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+)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 radionuclides are found, the following relationship should be satisfied:

$$\frac{[\text{Radionuclid } de]_1}{\text{Guideline } 1} + \frac{[\text{Radionuclid } de]_2}{\text{Guideline } 2} + \dots + \frac{[\text{Radionuclid } de]_i}{\text{Guideline } i} \leq 1$$

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 Land Use	Fine				Coarse				Notes
	Natural Area (mg/kg)	Agricultural (mg/kg)	Residential/ Parkland (mg/kg)	Commercial Industrial (mg/kg)	Natural Area (mg/kg)	Agricultural (mg/kg)	Residential/ Parkland (mg/kg)	Commercial Industrial (mg/kg)	
Unit									
Benzene	0.046	0.046	0.046	0.046	0.078	0.078	0.078	0.078	2
Toluene	0.52	0.52	0.52	0.52	0.49	0.49	0.49	0.49	2
Ethylbenzene	0.11	0.11	0.11	0.11	0.21	0.21	0.21	0.21	2
Xylenes	15	15	15	15	28	16	16	28	2
F1	420	420	420	640	420	30	30	440	1, 3
F2	300	300	300	520	300	160	160	520	1, 3
F3	2,600	2,600	2,600	3,500	600	600	600	2,500	1, 3
F4	10,000	10,000	10,000	10,000	5,600	5,600	5,600	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
<i>Topsoil^e</i>					
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
<i>Subsoil^e</i>					
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

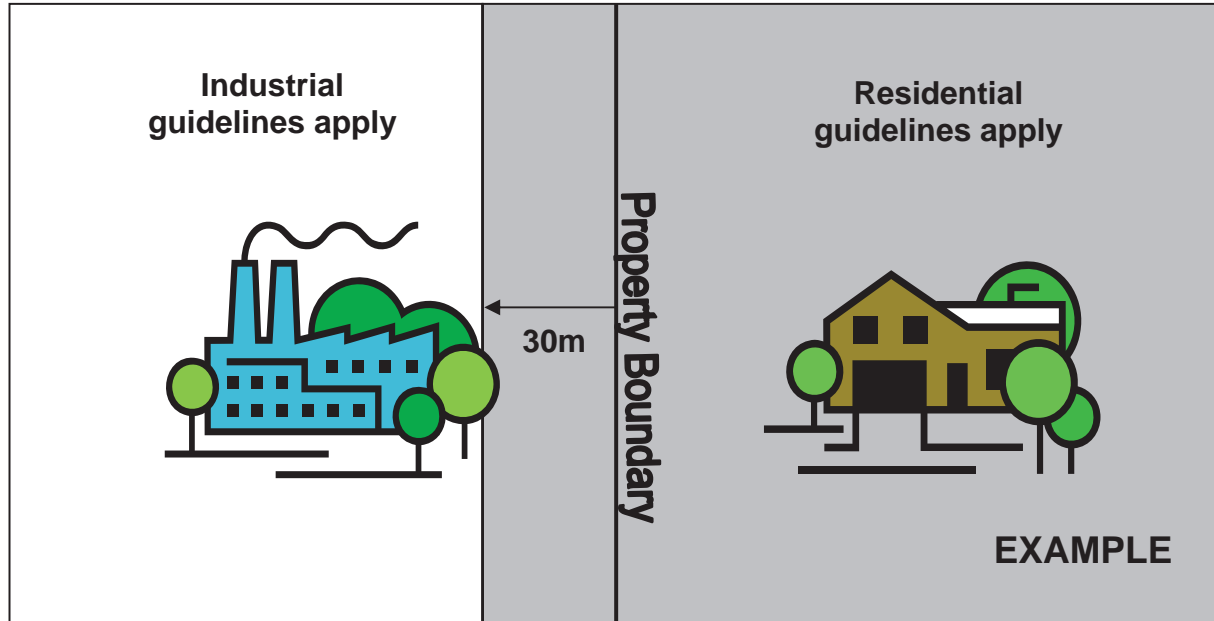
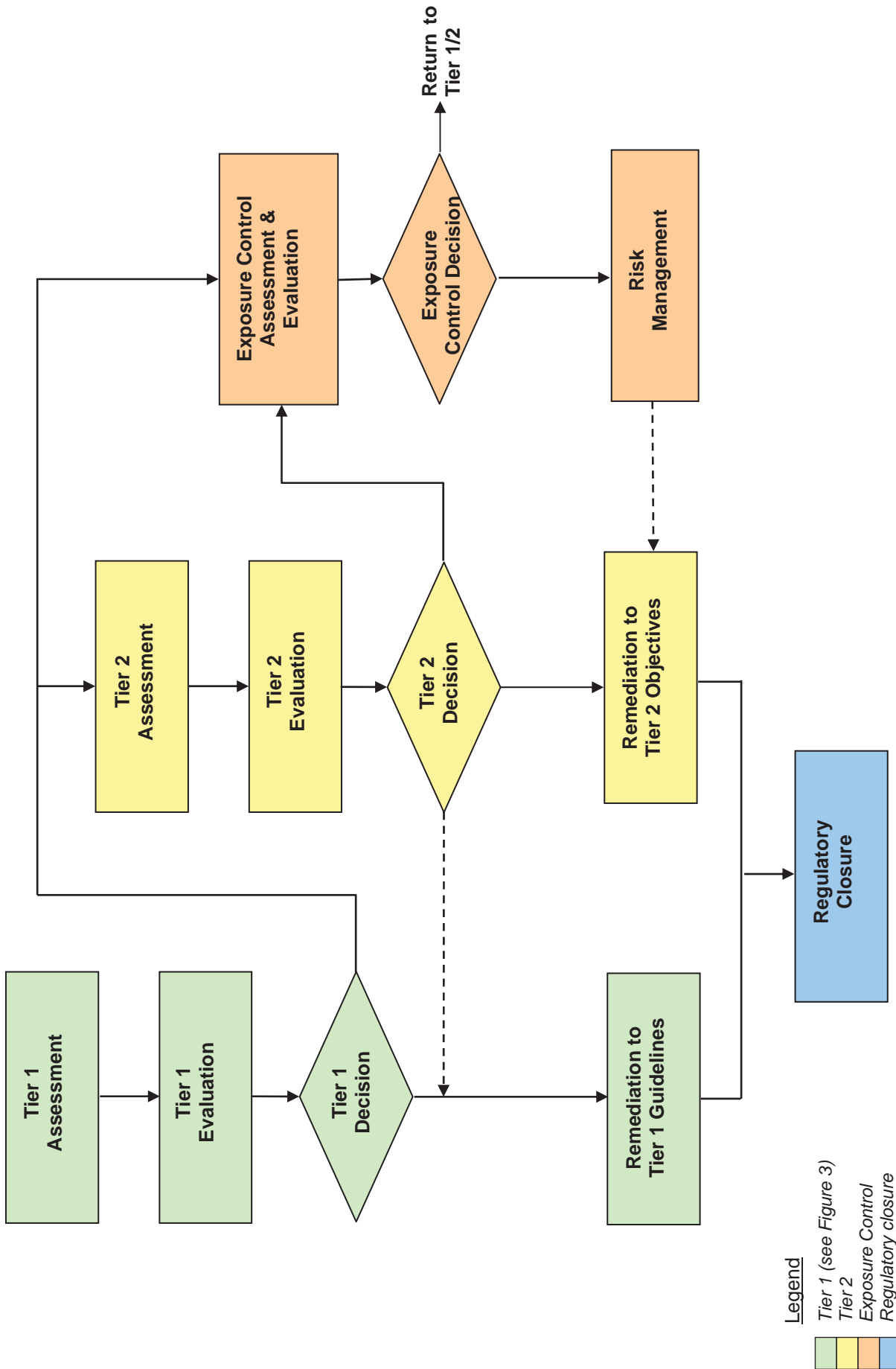
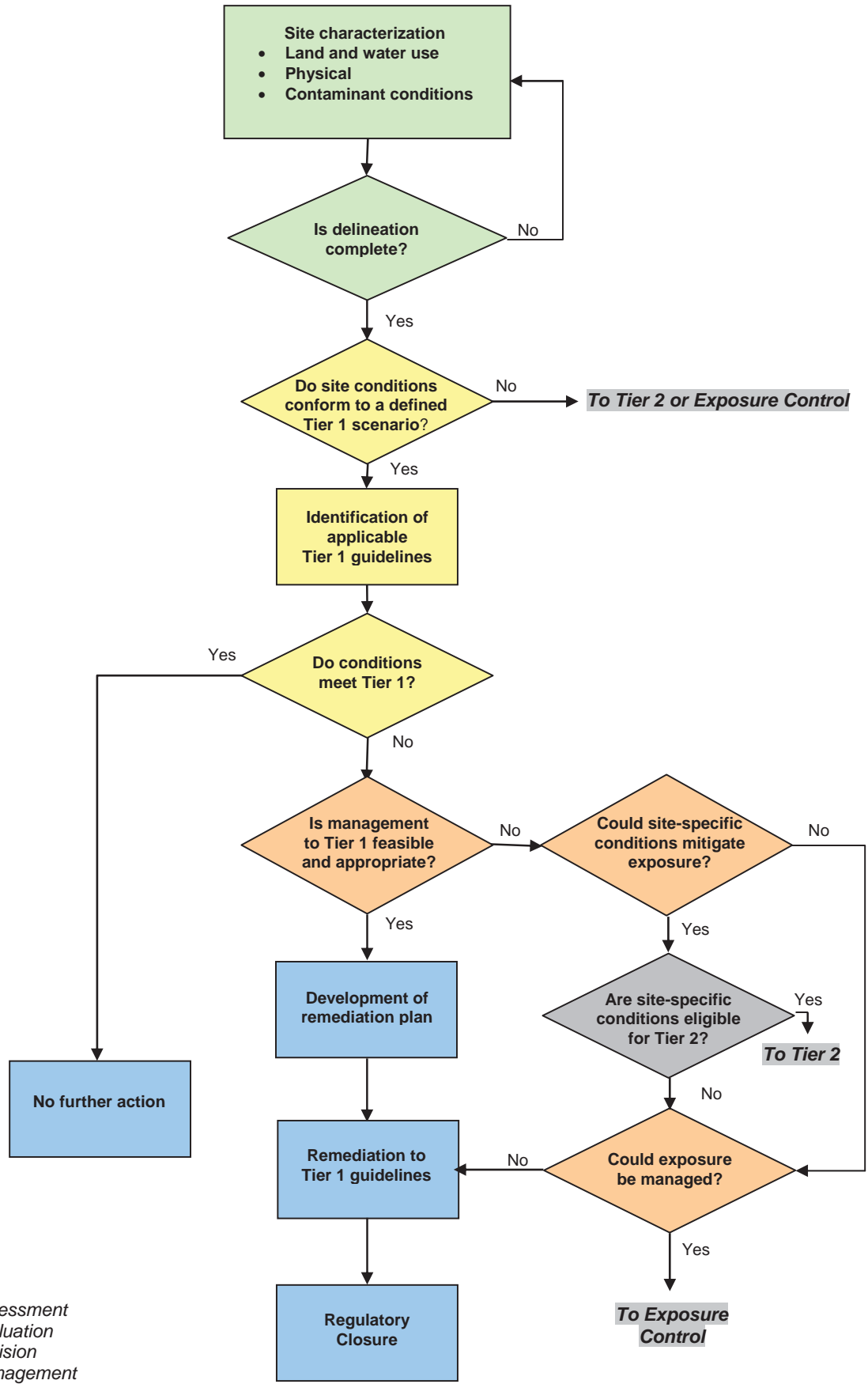


Figure 1: Example of the 30 m buffer zone for the more sensitive land use. The diagram is for illustration purposes and can be applied for any land use scenario where a more sensitive land use is adjacent to a less sensitive land use.



- Legend**
- Tier 1 (see Figure 3)
 - Tier 2
 - Exposure Control
 - Regulatory closure

Figure 2: Implementation Framework for Tier 1, Tier 2 and Exposure Control Guidelines



Legend

- Tier 1 assessment
- Tier 1 evaluation
- Tier 1 decision
- Tier 1 management
- Decision/management outside Tier 1

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 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 Pathway	Overall Guideline		Human Protection of Domestic Use Aquifer		Ecological						Other			
	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Direct Soil Contact		Nutrient Energy/ Cycling Check (mg/kg)	Livestock Soil and Food Ingestion (mg/kg)	Wildlife Soil and Food Ingestion (mg/kg)	Protection of Freshwater Aquatic Life		Protection of Wildlife Water		
					Fine (mg/kg)	Coarse (mg/kg)				Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (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 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 Pathway	Overall Guideline		Human Protection of Domestic Use Aquifer		Ecological				Protection of Wildlife Water		Other Management Limit		
	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Nutrient Energy/ Cycling Check (mg/kg)	Livestock Soil and Food Ingestion (mg/kg)	Wildlife Soil and Food Ingestion (mg/kg)	Protection of Freshwater Aquatic Life Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)
Soil Type													
Building Type													
Unit	5	5	5	5									
Tin	33	33				33							
Uranium	130	130			255								
Vanadium	200	200			200	640							
Zinc													
Hydrocarbons													
Benzene	0.046	0.078	0.046	0.078	-	44	18	73	1.6	15	0.33	-	-
Toluene	0.52	0.49	0.52	0.95	-	2,500	980	250,000	0.49	NGR	1,000	-	-
Ethylbenzene	0.11	0.21	0.11	0.21	-	1,600	640	NGR	540	NGR	17,000	-	-
Xylenes	15	28	15	28	-	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	-	27,000	11,000	30,000	1,300	30,000	30,000	800	700
F2	150	150	1,500	2,900	-	25,000	9,800	30,000	520	30,000	30,000	1,000	1,000
F3	1,300	300	-	-	-	30,000	16,000	-	-	-	-	3,500	2,500
F4	5,600	2,800	-	-	-	21,000	8,400	-	-	-	-	10,000	10,000
Acenaphthene	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	-	61.5	61.5	0.0046	0.0056	NGR	NGR	-	-
Fluoranthene	0.032	0.039	NGR	NGR	-	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 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 Pathway	Overall Guideline		Human Protection of Domestic Use Aquifer		Ecological				Protection of Wildlife Water		Other Management Limit		
	Fine	Coarse	Fine	Coarse	Nutrient Energy/ Cycling Check	Livestock Soil and Food Ingestion	Wildlife Soil and Food Ingestion	Fine	Coarse	Fine	Coarse	Fine	Coarse
	(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)
Soil Type													
Building Type													
Unit													
Benzo[b-i]fluoranthene ^d	6.2	6.2	0.74	1.4	-	6.2	6.2	6.2	NGR	NGR	NGR	NGR	NGR
Benzo[k]fluoranthene ^d	6.2	6.2	0.16	0.31	-	6.2	6.2	6.2	NGR	NGR	NGR	NGR	NGR
Benzo[g,h,i]perylene	-	-	32	63	-	-	-	-	NGR	NGR	NGR	NGR	NGR
Benzo[a]pyrene ^d	0.6	0.6	1.7	3.4	20	0.6	0.6	0.6	0.70	0.77	NGR	NGR	NGR
Chrysene ^d	6.2	6.2	10	19	-	6.2	6.2	6.2	NGR	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	NGR	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	-	-	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 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 Pathway	Overall Guideline		Human Protection of Domestic Use Aquifer		Ecological				Protection of Wildlife Water		Other Management Limit		
	Fine	Coarse	Fine	Coarse	Nutrient Energy/ Cycling Check	Livestock Soil and Food Ingestion	Wildlife Soil and Food Ingestion	Fine	Coarse	Fine	Coarse	Fine	Coarse
	(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)
Soil Type Building Type													
Unit	1.9	3.6	1.9	3.6	-	-	-	-	-	-	-	-	-
1,3,5-Trichlorobenzene	0.042	0.05	3.1	5.9	-	-	-	0.042	0.05	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.37	0.70	0.37	0.70	-	-	-	-	-	-	-	-	-
1,2,3,5-Tetrachlorobenzene	0.19	0.37	0.19	0.37	-	-	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	3.7	4.5	24	47	-	-	-	3.7	4.5	-	-	-	-
Pentachlorobenzene	3.6	7	3.6	7	-	-	-	-	-	-	-	-	-
Hexachlorobenzene	0.0029	0.0034	0.018	0.034	-	-	-	0.0029	0.0034	-	-	-	-
2,4-Dichlorophenol	0.19	0.37	0.19	0.37	-	-	-	0.42	0.5	-	-	-	-
2,4,6-Trichlorophenol	0.039	0.047	0.16	0.31	-	-	-	0.039	0.047	-	-	-	-
2,3,4,6-Tetrachlorophenol	0.024	0.029	6	12	-	-	-	0.024	0.029	-	-	-	-
Pentachlorophenol	0.00025	0.00025	-	-	-	0.00025	0.00025	-	-	-	-	-	-
Dioxins & Furans ^{fg}	1.3	1.3	-	-	-	1.3	1.3	-	-	-	-	-	-
PCBs													
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	-	-	-	-
Azinphos-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 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 Pathway	Overall Guideline		Human Protection of Domestic Use Aquifer		Ecological				Protection of Wildlife Water		Other Management Limit		
	Fine	Coarse	Fine	Coarse	Nutrient Energy/ Cycling Check	Livestock Soil and Food Ingestion	Wildlife Soil and Food Ingestion	Fine	Coarse	Fine	Coarse	Fine	Coarse
	(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	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	-	-	-	BDL	BDL	-	-	-	-
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 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 Pathway	Overall Guideline		Human Protection of Domestic Use Aquifer		Ecological				Protection of Wildlife Water		Other Management Limit	
	Fine	Coarse	Fine	Coarse	Nutrient Energy/ Cycling Check	Livestock Soil and Food Ingestion	Wildlife Soil and Food Ingestion	Fine	Coarse	Fine	Coarse	
	(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	-	-	
Trifluralin	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	-	-	-	14	17	-	-	
Ethylene glycol	60	62	60	68	-	-	-	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	-	-	-	-	-	2.7	3.3	-	-	
Phenol	0.0028	0.0024	1.6	2.3	-	-	-	0.0028	0.0024	-	-	
Sulfolane	0.18	0.21	0.18	0.21	-	-	-	24	18	-	-	

Table A-1. Surface Soil Remediation Guideline Values for Natural Area Land Use - All Exposure Pathway

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. 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:

$$IACR = \frac{[Benz(a)anthracene]}{1.6 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benz(b + j)fluoranthene]}{0.74 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(k)fluoranthene]}{0.16 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(g,h,i)perylene]}{32 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(a)pyrene]}{1.7 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Chrysene]}{10 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Dibenz(a,h)anthracene]}{1.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Indeno(1,2,3 - c,d)pyrene]}{13 \text{ mg} \cdot \text{kg}^{-1}}$$

Coarse Soil:

$$IACR = \frac{[Benz(a)anthracene]}{3.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(b + j)fluoranthene]}{1.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(k)fluoranthene]}{0.31 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(g,h,i)perylene]}{63 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(a)pyrene]}{3.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Chrysene]}{19 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Dibenz(a,h)anthracene]}{2.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Indeno(1,2,3 - c,d)pyrene]}{24 \text{ mg} \cdot \text{kg}^{-1}}$$

- 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 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).

Receptor	Overall Guideline		Human						Ecological										Other						
			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					
Pathway	Fine	Coarse	(mg/kg)	Fine	Coarse	Slab	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	
Soil Type																									
Building Type																									
Unit																									
<i>General and Inorganic Parameters</i>																									
pH (in 0.01M CaCl ₂)	6-8.5	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	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Metals</i>																									
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	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 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).

Receptor	Overall Guideline		Human										Ecological										Other			
	Fine	Coarse	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					
Pathway				Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse			
Soil Type				Basement	Slab																					
Building Type				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	-	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
Acenaphthene	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 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).

Receptor	Overall Guideline		Human										Ecological										Other		
	Fine	Coarse	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		Fine	Coarse	Management Limit		
Soil Type				Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse		
Building Type			Basement	Slab	Basement	Slab	Basement	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)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)		
Fluorene	0.29	0.34	2,700,000	220,000	270,000	8,600	NGR	NGR	NGR	NGR	NGR	15.4	0.29	0.34	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Naphthalene	0.016	0.018	1,800	51	58	2.2	53	28	28	28	2.2	8.8	0.016	0.018	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Phenanthrene	0.051	0.061	-	-	-	-	-	-	-	-	-	43	0.051	0.061	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Pyrene	0.034	0.040	2,100	NGR	NGR	730,000	NGR	NGR	NGR	NGR	7.7	7.7	0.034	0.040	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Carcinogenic PAHs (as B(a)P TPE) ^e	IARC<1.0 ^f	IARC<1.0 ^e	5.3 ^d	NGR	NGR	NGR	IARC<1.0 ^f	IARC<1.0 ^e	IARC<1.0 ^e	IARC<1.0 ^e	IARC<1.0 ^e	-	-	-	-	-	-	-	-	-	-	-	-	-	
Benz[a]anthracene ^f	0.070	0.083	-	-	-	-	1.6	3.1	1.6	3.1	-	6.2	0.070	0.083	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Benz[b]-j]fluoranthene ^f	6.2	6.2	-	-	-	-	0.74	1.4	0.74	1.4	-	6.2	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Benz[k]fluoranthene ^f	6.2	6.2	-	-	-	-	0.16	0.31	0.16	0.31	-	6.2	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Benz[ghi]perylene	-	-	-	-	-	-	32	63	32	63	-	-	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Benz[a]pyrene ^f	0.6	0.6	-	-	-	-	1.7	3.4	1.7	3.4	20	0.6	0.70	0.77	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Chrysene ^f	6.2	6.2	-	-	-	-	10	19	10	19	-	6.2	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Dibenz[ah]anthracene ^f	7.4	8.4	-	-	-	-	1.1	2.1	1.1	2.1	-	-	7.4	8.4	-	-	-	-	-	-	-	-	-		
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	-	1.3	2.4	1.3	2.4	-	-	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR	NGR		
Chlorinated Aliphatics																									
Vinyl chloride	0.0083	0.0034	71	0.009	0.0083	0.00049	0.00034	0.014	0.02	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	0.15	0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	
Trichloroethene (Trichloroethylene, TCE)	0.054	0.012	35	0.31	0.28	0.017	0.012	0.054	0.093	0.054	0.093	3	0.72	0.081	0.13	0.14	-	-	-	-	-	-	-	-	
Tetrachloroethene (Tetrachloroethylene, PCE)	0.69	0.16	530	4.1	3.7	0.22	0.16	0.77	1.4	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	0.025	0.041	-	0.12	0.12	0.062	0.062	-	-	-	-	-	-	-	-	
Dichloromethane	0.052	0.048	990	18	16	1.0	0.71	0.21	0.32	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 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).

Receptor	Overall Guideline		Human										Ecological										Other	
	Fine	Coarse	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	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	
Building Type	-	-	-	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)	
(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 ^s	0.39	0.018	16,000	0.44	0.39	0.024	0.018	0.61	1.1	-	-	-	-	BDL	BDL	-	-	-	-	-	-	-	-	-
1,2-Dichlorobenzene ^s	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	11	11	0.024	0.029	-	-	-	-	-	-	-	-	-

Table A-2. Surface Soil Remediation Guideline Values for Agricultural Land Use - All Exposure Pathways

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Receptor	Overall Guideline		Human						Ecological										Other		
	Fine	Coarse	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	
Pathway				Fine	Coarse	Slab	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	
Soil Type				Basement	Basement	Slab															
Building Type				Basement	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)
Dioxins & Furans ^{b,1}	0.000004	0.000004	0.000004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PCBs	1.3	1.3	22	-	-	-	-	-	33	33	1.3	1.3	-	-	-	-	-	-	-	-	-
Pesticides																					
Aldicarb [‡]	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	-	-	-	7.4	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	-
Azinphos-methyl	0.41	0.75	55	-	-	-	0.41	0.75	-	-	-	-	-	-	-	-	-	-	-	-	-
Bentocarb	0.14	0.21	89	-	-	-	0.14	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-
Bromoxynil [‡]	0.044	0.052	11	-	-	-	0.18	0.35	-	-	-	0.044	0.052	0.097	0.11	-	-	-	BDL	BDL	-
Carbaryl [‡]	1.9	3.6	220	-	-	-	1.9	3.6	-	-	-	BDL	BDL	5.7	6.5	-	-	-	-	-	-
Carbofuran [‡]	0.082	0.089	220	-	-	-	0.68	1.2	-	-	-	BDL	BDL	0.082	0.089	-	-	-	-	-	-
Chlorothaloni	0.0084	0.01	330	-	-	-	27	53	-	-	-	0.0084	0.01	7.9	9.5	-	-	-	0.27	0.32	-
Chlorpyrifos [‡]	3.2	3.8	220	-	-	-	49	95	-	-	-	BDL	BDL	3.2	3.8	-	-	-	-	-	-
Cyanazine [‡]	0.029	0.032	29	-	-	-	0.12	0.21	-	-	-	BDL	BDL	0.029	0.032	-	-	-	BDL	BDL	-
2,4-D [‡]	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	0.015	0.018	1500	1800	-	-	-	-	-	-
Diazinon	2.2	4.2	44	-	-	-	2.2	4.2	-	-	-	-	-	-	-	-	-	-	-	-	-
Dicamba [‡]	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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Receptor	Overall Guideline		Human										Ecological										Other	
	Fine	Coarse	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			
Pathway				Fine	Coarse	Slab	Basement	Basement	Slab	Fine	Coarse	Slab	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse		
Soil Type																								
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)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
Dinoseb [§]	1.1	1.3	22	-	2.8	5.5	-	-	2.8	5.5	-	-	BDL	BDL	10	12	-	-	1.1	1.3	-	-	-	
Diquat	11	21	180	-	11	21	-	-	11	21	-	-	-	-	-	-	-	-	-	-	-	-	-	
Duron	1.9	3.5	350	-	1.9	3.5	-	-	1.9	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	
Endosulfan	0.0085	0.01	210	-	99	190	-	-	99	190	-	-	0.0085	0.01	-	-	-	-	-	-	-	-	-	
Endrin	0.0075	0.009	10	-	2.4	4.7	-	-	2.4	4.7	-	-	0.0075	0.009	-	-	-	-	-	-	-	-	-	
Glyphosate	0.054	0.049	670	-	0.95	1.4	-	-	0.95	1.4	-	-	0.054	0.049	0.23	0.21	-	-	-	-	-	-	-	
Heptachlor epoxide [§]	0.039	0.010	0.46	0.31	0.010	0.012	0.039	0.076	0.039	0.076	-	-	BDL	BDL	0.11	0.13	-	-	-	-	-	-	-	
Lindane [§]	0.11	0.13	6.7	-	0.31	0.6	-	-	0.31	0.6	-	-	BDL	BDL	0.11	0.13	-	-	-	-	-	-	-	
Linuron [§]	0.051	0.059	44	-	0.56	1.1	-	-	0.56	1.1	-	-	0.051	0.059	-	-	-	-	BDL	BDL	-	-	-	
Malathion [§]	0.82	1.3	440	-	0.82	1.3	-	-	0.82	1.3	-	-	BDL	BDL	-	-	-	-	-	-	-	-	-	
MCPA [§]	0.02	0.025	11	-	0.02	0.032	-	-	0.02	0.032	-	-	BDL	BDL	0.026	0.025	-	-	BDL	BDL	-	-	-	
Methoxychlor	0.046	0.056	3500	-	0.046	0.056	-	-	0.046	0.056	-	-	-	-	-	-	-	-	-	-	-	-	-	
Metolachlor	0.048	0.055	110	-	1.3	2.4	-	-	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	-	-	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	-	-	1.1	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-	
Parathion [§]	7.2	14	110	-	7.2	14	-	-	7.2	14	-	-	BDL	BDL	-	-	-	-	-	-	-	-	-	
Phorate	0.075	0.14	4.4	-	0.075	0.14	-	-	0.075	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	
Picloram	0.024	0.022	440	-	0.64	0.94	-	-	0.64	0.94	-	-	0.024	0.022	0.15	0.14	-	-	-	-	-	-	-	
Simazine [§]	0.033	0.038	29	-	0.14	0.25	-	-	0.14	0.25	-	-	0.033	0.038	0.033	0.038	-	-	BDL	BDL	-	-	-	
Tebutiuron [§]	0.12	0.11	1600	-	2.5	3.7	-	-	2.5	3.7	-	-	BDL	BDL	0.12	0.11	-	-	BDL	BDL	-	-	-	
Terbufos	0.08	0.15	1.1	-	0.08	0.15	-	-	0.08	0.15	-	-	-	-	-	-	-	-	-	-	-	-	-	

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).

Receptor	Overall Guideline		Human						Ecological										Other								
	Fine	Coarse	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		Fine	Coarse	Management Limit			
Soil Type	(mg/kg)	(mg/kg)	(mg/kg)	Fine	Coarse	Slab	Fine	Coarse	Slab	Fine	Coarse	(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)		
Building Type			-	Basement			-			-																	
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)	(mg/kg)		
Toxaphene [§]	3.3	4.8	4.8	4,600	3,100	150	170	3.3	6.3	6.3																	
Triallate	0.0077	0.0092	290	-	-	-	-	16	31	31																	
Trifluran	0.038	0.045	110	-	-	-	-	35	67	67																	
Other Organics																											
Aniline [§]	0.36	0.6	160	720	640	34	26	0.36	0.6	0.6																	
Bis(2-ethyl-hexyl)phthalate	34	41	1,000	NGR	NGR	NGR	NGR	3,600	7,000	7,000																	
Dibutyl phthalate	0.54	0.65	1,300	22,000	18,000	9,200	7,400	70	130	130																	
Dichlorobenzidine	4.2	8.1	130	NGR	NGR	NGR	NGR	4.2	8.1	8.1																	
Diisopropanolamine	14	17	22,000	-	-	-	-	130	250	360	360																
Ethylene glycol	60	62	73,000	NGR	NGR	120,000	86,000	60	68	1,100	1,100																
Hexachlorobutadiene	0.026	0.0067	210	0.18	0.16	0.0087	0.0067	0.5	0.95	0.95																	
Methylmethacrylate	1.3	0.10	1,100	3.4	3.0	0.14	0.10	1.3	1.8	1.8																	
MTBE	0.044	0.046	380	1.2	1.1	0.065	0.046	0.044	0.062	0.062																	
Nonylphenol + ethoxylates	2.7	3.3	-	-	-	-	-	-	-	-	5.7	5.7															
Phenol	0.0014	0.0012	2,000	14,000	13,000	660	480	1.6	2.3	20	20																
Sulfolane	0.18	0.18	350	-	-	-	-	0.18	0.21	210	210																

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:

- For more information see *Guidelines for the Remediation and Disposal of Sulphur Contaminated Solid Wastes (AEP, 1996)*
- 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)*
- 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/PCS, 1998) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+h)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 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.
- 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:

$$IACR = \frac{[Benz(a)anthracene]}{1.6 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(b+h)fluoranthene]}{0.74 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(k)fluoranthene]}{0.16 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(g,h,i)perylene]}{32 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(a)pyrene]}{1.7 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Chrysene]}{10 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Dibenz(a,h)anthracene]}{1.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Indeno(1,2,3-c,d)pyrene]}{13 \text{ mg} \cdot \text{kg}^{-1}}$$

Coarse Soil:

$$IACR = \frac{[Benz(a)anthracene]}{3.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(b+h)fluoranthene]}{1.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(k)fluoranthene]}{0.31 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(g,h,i)perylene]}{63 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Benzo(a)pyrene]}{3.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Chrysene]}{19 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Dibenz(a,h)anthracene]}{2.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[Indeno(1,2,3-c,d)pyrene]}{24 \text{ mg} \cdot \text{kg}^{-1}}$$

- Overall guideline value for ecological receptors only.
 - Guideline for protection of aquatic life or irrigation water is below detection limit, groundwater monitoring is required.
 - Expressed as toxic equivalents (TEQs) based on 2,3,7,8-PCDD (See CCME, 1999 and updates)
 - 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 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			
	Fine (mg/kg)	Coarse (mg/kg)	Direct Soil Contact (mg/kg)	Vapour Inhalation		Protection of Domestic Use Aquifer		Direct Soil Contact (mg/kg)		Nutrient/ Energy Cycling Check (mg/kg)	Protection of Freshwater Aquatic Life (mg/kg)		Fine (mg/kg)	Coarse (mg/kg)	Management Limit (mg/kg)	Coarse (mg/kg)
Soil Type																
Building Type																
Unit																
General and Inorganic Parameters																
pH (in 0.01M CaCl ₂)	6-8.5	6-8.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyanide (free)	0.9	0.9	29	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	200	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulphur (elemental) ^a	500	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals																
Antimony	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (inorganic)	17	17	21	-	-	-	-	-	-	-	-	-	-	-	-	-
Barium (non-barite)	500	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barite-barium ^b	10,000	10,000	10,000	-	-	-	-	-	-	-	-	-	-	-	-	-
Beryllium	5	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boron (hot water soluble)	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cadmium	10	10	14	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (hexavalent)	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (total)	64	64	220	-	-	-	-	-	-	-	-	-	-	-	-	-
Cobalt	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper	63	63	1,100	-	-	-	-	-	-	-	-	-	-	-	-	-
Lead	140	140	140	-	-	-	-	-	-	-	-	-	-	-	-	-

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			
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/Energy Cycling Check	Protection of Freshwater Aquatic Life		Fine	Coarse	
Pathway				Fine	Coarse	Basement	Slab	Basement	Slab	Coarse	Slab	Fine	Coarse	Fine	Coarse	
Soil Type				(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
Building Type				Basement	Slab	Basement	Slab	Basement	Slab	Basement	Slab	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)	
Mercury (inorganic)	6.6	6.6	6.6	-	-	-	-	-	-	-	-	12	12	20	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 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 Pathway	Overall Guideline		Human						Ecological				Other		
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/ Energy Cycling Check	Protection of Freshwater Aquatic Life		Fine	Coarse
Soil Type				Fine	Fine	Coarse	Fine	Coarse	Fine	Coarse		Fine	Coarse	Fine	Coarse
Building Type				Basement	Slab	Basement	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)
F3	1,300	300	15,000	-	-	-	-	-	-	-	-	-	-	-	-
F4	5,600	2,800	21,000	-	-	-	-	-	-	-	-	-	-	-	-
Acenaphthene	0.32	0.38	5,300	120,000	99,000	4,800	3,900	NGR	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) ^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	-	-	0.070	0.083	-	-
Benzo[b-f]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 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			
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/ Energy Cycling Check	Protection of Freshwater Aquatic Life		Management Limit		
Pathway				Fine	Coarse	Basement	Slab	Basement	Coarse	Slab	Fine	Coarse	Fine	Coarse	Fine	Coarse
Soil Type				(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)
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)	(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	0.02	-	-	-	-	-	-
1,1-Dichloroethene	0.15	0.021	1,900	0.5	0.46	0.03	0.021	0.15	0.24	0.24	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.054	0.012	35	0.31	0.28	0.017	0.012	0.054	0.093	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	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	0.041	-	-	0.12	0.12	-	-
Dichloromethane (Methylene chloride)	0.1	0.095	990	18	16	1.0	0.71	0.21	0.32	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	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	0.16	-	-	0.059	0.062	-	-
Dibromochloromethane	0.91	0.27	760	11	7.8	0.28	0.27	0.91	1.5	1.5	-	-	-	-	-	-
Chlorinated Aromatics																
Chlorobenzene [§]	0.39	0.018	16,000	0.44	0.39	0.024	0.018	0.61	1.1	1.1	-	-	BDL	BDL	-	-
1,2-Dichlorobenzene [§]	0.097	0.18	16,000	260	230	14	10	0.097	0.18	0.18	-	-	BDL	BDL	-	-
1,4-Dichlorobenzene	0.051	0.098	4,200	17	14	0.91	0.67	0.051	0.098	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	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		
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/ Energy Cycling Check	Protection of Freshwater Aquatic Life		Fine	Coarse
Pathway				Fine	Fine	Coarse	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse
Soil Type				Basement	Slab	Basement	Slab								
Building Type				(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
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)
1,2,4-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 ^{bi}	0.000004	0.000004	0.000004	-	-	-	-	-	-	-	-	-	-	-	-
PCBs	22	22	22	-	-	-	-	-	-	33	33	-	-	-	-
Pesticides															
Aldicarb ⁵	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	-	-
Azinphos-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 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		
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/Energy Cycling Check	Protection of Freshwater Aquatic Life		Fine	Coarse
Pathway				Fine Basement (mg/kg)	Fine Slab (mg/kg)	Coarse Basement (mg/kg)	Coarse Slab (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)		Fine (mg/kg)	Coarse (mg/kg)	Management Limit
Soil Type															
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)
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 [§]	1.9	3.6	220	-	-	-	-	1.9	3.6	-	-	BDL	BDL	-	-
Carbofuran [§]	0.68	1.2	220	-	-	-	-	0.68	1.2	-	-	BDL	BDL	-	-
Chlorothalonil	0.0084	0.01	330	-	-	-	-	27	53	-	-	0.0084	0.01	-	-
Chlorpyrifos [§]	49	95	220	-	-	-	-	49	95	-	-	BDL	BDL	-	-
Cyanazine [§]	0.12	0.21	29	-	-	-	-	0.12	0.21	-	-	BDL	BDL	-	-
2,4-D [§]	0.43	0.67	220	-	-	-	-	0.43	0.67	-	-	BDL	BDL	-	-
DDT	0.015	0.018	220	-	-	-	-	5,900	11,000	12	12	0.015	0.018	-	-
Diazinon	2.2	4.2	44	-	-	-	-	2.2	4.2	-	-	-	-	-	-
Dicamba [§]	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 [§]	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 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		
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/ Energy Cycling Check	Protection of Freshwater Aquatic Life		Fine	Coarse
Pathway				Fine	Coarse	Slab	Basement	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse
Soil Type				(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Building Type															
Unit															
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 [§]	0.039	0.010	0.46	0.31	0.010	0.21	0.039	0.039	0.076	-	-	BDL	BDL	-	-
Lindane [§]	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 [§]	0.82	1.3	440	-	-	-	-	0.82	1.3	-	-	BDL	BDL	-	-
MCPA [§]	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 [§]	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 [§]	2.5	3.7	1,600	-	-	-	-	2.5	3.7	-	-	BDL	BDL	-	-
Terbufos	0.08	0.15	1.1	-	-	-	-	0.08	0.15	-	-	-	-	-	-
Toxaphene [§]	3.3	4.8	4.8	4,600	150	3,100	3.3	6.3	170	150	170	BDL	BDL	-	-

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			
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation			Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/Energy Cycling Check	Protection of Freshwater Aquatic Life		Fine	Coarse	
Pathway				Fine	Coarse	Basement	Slab	Basement	Slab	Coarse	Fine	Coarse	Fine	Coarse	Management Limit	
Soil Type																
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)	(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	34	640	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	22,000	9,200	18,000	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	-	-	14	17	-	-	-
Ethylene glycol	60	62	73,000	NGR	120,000	NGR	86,000	60	68	-	-	1,100	1,100	89	62	-
Hexachlorobutadiene	0.026	0.0067	210	0.18	0.0087	0.16	0.0067	0.5	0.95	-	-	0.026	0.031	-	-	-
Methylmethacrylate	1.3	0.10	1,100	3.4	0.14	3.0	0.10	1.3	1.8	-	-	-	-	-	-	-
MTBE	0.044	0.046	380	1.2	0.065	1.1	0.046	0.044	0.062	-	-	-	-	-	-	-
Nonylphenol + ethoxylates	2.7	3.3	-	-	-	-	-	-	-	-	-	5.7	5.7	2.7	3.3	-
Phenol	0.0028	0.0024	2,000	14,000	660	13,000	480	1.6	2.3	-	-	0.0028	0.0024	-	-	-
Sulfolane	0.18	0.21	350	-	-	-	-	0.18	0.21	-	-	24	18	-	-	-

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).

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/IPC, 1998) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b,f)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 IACR for coarse textured soil would be calculated as follows:

$$\text{IACR} = \frac{[\text{Benz(a)anthracene}]}{1.6 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(b+f)fluoranthene}]}{0.74 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(k)fluoranthene}]}{0.16 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(g,h,i)perylene}]}{32 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(a)pyrene}]}{1.7 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Chrysene}]}{10 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Dibenz(a,h)anthracene}]}{1.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Indeno(1,2,3-c,d)pyrene}]}{13 \text{ mg} \cdot \text{kg}^{-1}}$$

Coarse Soil:

$$\text{IACR} = \frac{[\text{Benz(a)anthracene}]}{3.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(b+f)fluoranthene}]}{1.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(k)fluoranthene}]}{0.31 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(g,h,i)perylene}]}{63 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(a)pyrene}]}{3.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Chrysene}]}{19 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Dibenz(a,h)anthracene}]}{2.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Indeno(1,2,3-c,d)pyrene}]}{24 \text{ mg} \cdot \text{kg}^{-1}}$$

- 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 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	
	Fine (mg/kg)	Coarse (mg/kg)	Direct Soil Contact (mg/kg)	Vapour Inhalation mg/kg	Protection of Domestic Use Aquifer Fine (mg/kg) Coarse (mg/kg)	Off-Site Migration (mg/kg)	Direct Soil Contact Fine (mg/kg) Coarse (mg/kg)	Nutrient/Energy Cycling Check (mg/kg)	Protection of Freshwater Aquatic Life Fine (mg/kg) Coarse (mg/kg)	Off-Site Migration (mg/kg)	Fine (mg/kg)	Coarse (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	140,000	-	-	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	-	-	-	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 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					
	Fine	Coarse	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	
Pathway	(mg/kg)	(mg/kg)	(mg/kg)	Fine Slab	Coarse Slab	Fine (mg/kg)	Coarse (mg/kg)	(mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	(mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	(mg/kg)	Fine (mg/kg)	Coarse (mg/kg)
Soil Type																
Building Type																
Unit																
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
Acenaphthene	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) ^e	IARC<1.0 ^e	IARC<1.0 ^e	8.0 ^d	NGR	NGR	IARC<1.0 ^e	IARC<1.0 ^e	75	-	-	-	-	-	-	-	-
Benzo[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 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					
	Fine	Coarse	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	
Pathway			(mg/kg)	Fine Slab	Coarse Slab	(mg/kg)	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	(mg/kg)
Soil Type	Fine	Coarse		mg/kg	mg/kg											
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)
Benzol[b-j]fluoranthene	-	-	-	-	-	0.74	0.16	0.31	-	-	NGR	NGR	-	-	-	-
Benzol[k]fluoranthene	-	-	-	-	-	0.16	0.16	0.31	-	-	NGR	NGR	-	-	-	-
Benzol[g,h,i]perylene	-	-	-	-	-	32	32	63	-	-	NGR	NGR	-	-	-	-
Benzol[a]pyrene ^f	0.70	0.77	-	-	-	1.7	1.7	3.4	-	72	72	0.70	0.77	290	-	-
Chrysene	-	-	-	-	-	10	10	19	-	-	-	NGR	NGR	-	-	-
Dibenz[a,h]anthracene ^f	7.4	8.4	-	-	-	1.1	1.1	2.1	-	-	-	7.4	8.4	-	-	-
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	13	13	24	-	-	-	NGR	NGR	-	-	-
Chlorinated Aliphatics																
Vinyl chloride	0.014	0.0043	110	0.055	0.0043	0.014	0.014	0.02	0.02	1,000	-	-	-	-	-	-
1,1-Dichloroethene	0.15	0.24	2,900	3.1	0.27	0.15	0.15	0.24	0.24	27,000	-	-	-	-	-	-
Trichloroethene (Trichloroethylene, TCE)	0.054	0.081	54	1.9	0.15	0.054	0.054	0.093	0.093	630	50	50	0.72	0.081	43	-
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.69	0.77	810	26	2	0.77	0.77	1.4	1.4	7,600	-	-	0.69	0.77	-	-
1,2-Dichloroethane	0.025	0.033	4,200	0.37	0.033	0.025	0.025	0.041	0.041	40,000	-	-	0.12	0.12	-	-
Dichloromethane (Methylene chloride)	0.1	0.095	1,500	110	9.0	0.21	0.21	0.32	0.32	14,000	-	-	0.1	0.095	-	-
Trichloromethane (Chloroform)	0.0029	0.003	330	0.15	0.014	0.62	0.62	1.0	1.0	3,100	-	-	0.0029	0.003	-	-
Tetrachloromethane (Carbon tetrachloride)	0.059	0.0068	40	0.09	0.0068	0.092	0.092	0.16	0.16	380	-	-	0.059	0.062	-	-
Dibromochloromethane	0.91	1.5	1,200	76	2.5	0.91	0.91	1.5	1.5	11,000	-	-	-	-	-	-
Chlorinated Aromatics																
Chlorobenzene ^g	0.61	0.22	25,000	2.7	0.22	0.61	0.61	1.1	1.1	230,000	-	-	BDL	BDL	-	-
1,2-Dichlorobenzene ^g	0.097	0.18	25,000	1,700	130	0.097	0.097	0.18	0.18	230,000	-	-	BDL	BDL	-	-
1,4-Dichlorobenzene	0.051	0.098	6,200	100	8	0.051	0.051	0.098	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 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						
	Fine	Coarse	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		
Pathway				Fine Slab	Coarse Slab		Fine	Coarse		Fine	Coarse	Fine	Coarse		Fine	Coarse	
Soil Type				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)
Building Type																	
1,2,3-Trichlorobenzene	0.26	0.31	74	58	2.7	2.7	1.9	3.6	700	-	-	-	-	-	-	-	-
1,2,4-Trichlorobenzene	0.78	0.93	58	51	2.4	2.4	2.0	3.9	540	-	-	-	-	-	-	-	-
1,3,5-Trichlorobenzene	1.9	1.3	69	27	1.3	1.3	1.9	3.6	660	-	-	-	-	-	-	-	-
1,2,3,4-Tetrachlorobenzene	0.042	0.05	110	190	7.9	7.9	3.1	5.9	1,100	-	-	-	-	-	-	-	-
1,2,3,5-Tetrachlorobenzene	0.37	0.70	14	23	1	1	0.37	0.70	130	-	-	-	-	-	-	-	-
1,2,4,5-Tetrachlorobenzene	0.19	0.37	7	12	0.49	0.49	0.19	0.37	66	-	-	-	-	-	-	-	-
Pentachlorobenzene	3.7	4.5	34	1000	70	70	24	47	320	-	-	-	-	-	-	-	-
Hexachlorobenzene	3.6	6	27	85	6	6	3.6	7	260	-	-	-	-	-	-	-	-
2,4-Dichlorophenol	0.0029	0.0034	3,300	NGR	57,000	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	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	4,400	0.16	0.31	3,000	-	-	-	0.039	0.047	-	-	-
Pentachlorophenol	0.024	0.029	340	NGR	950,000	950,000	6	12	3,200	28	28	28	0.024	0.029	160	-	-
Dioxins & Furans ^{hi}	0.000004	0.000004	0.000004	-	-	-	-	-	0.000004	-	-	-	-	-	-	-	-
PCBs	33	33	33	-	-	-	-	-	310	33	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	-	-	-
Azinphos-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 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					
	Fine (mg/kg)	Coarse (mg/kg)	Direct Soil Contact (mg/kg)	Vapour Inhalation (mg/kg)		Protection of Domestic Use Aquifer (mg/kg)		Off-Site Migration (mg/kg)	Direct Soil Contact (mg/kg)		Nutrient/ Energy Cycling Check (mg/kg)	Protection of Freshwater Aquatic Life (mg/kg)		Off-Site Migration (mg/kg)	Management Limit (mg/kg)	
Soil Type	Fine	Coarse	-	Fine Slab	Coarse Slab	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)	(mg/kg)
Chlorpyrifos [§]	49	95	340	-	-	49	95	3,200	-	-	-	BDL	BDL	-	-	-
Cyanazine [§]	0.12	0.21	44	-	-	0.12	0.21	410	-	-	-	BDL	BDL	-	-	-
2,4-D [§]	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 [§]	0.5	0.79	420	-	-	0.5	0.79	4,000	-	-	-	BDL	BDL	-	-	-
Dichlorop-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 [§]	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	-	-	-
Hepachlor epoxide [§]	0.039	0.076	0.69	2.4	0.094	0.039	0.076	6.5	-	-	-	BDL	BDL	-	-	-
Lindane [§]	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 [§]	0.82	1.3	670	-	-	0.82	1.3	6,300	-	-	-	BDL	BDL	-	-	-
MCPA [§]	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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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					
	Fine	Coarse	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		
Pathway				Fine Slab	Coarse Slab	Fine	Coarse		Fine	Coarse		Fine	Coarse		Fine	Coarse	
Soil Type				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)
Building Type																	
Unit	(mg/kg)	(mg/kg)	(mg/kg)														
Parathion ^s	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 ^s	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 ^s	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	-	-	-	-
Trifluralin	0.038	0.045	160	-	-	35	67	1,500	-	-	-	0.038	0.045	-	-	-	-
Other Organics																	
Aniline ^s	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 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 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/PCS, 1998) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benzo[a]anthracene	0.1
Benzo(b+g)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:

$$\text{IACR} = \frac{[\text{Benz(a)anthracene}]}{1.6 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(b+g)fluoranthene}]}{0.74 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(k)fluoranthene}]}{0.16 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(g,h,i)perylene}]}{32 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Chrysene}]}{10 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Dibenz(a,h)anthracene}]}{1.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Indeno(1,2,3-c,d)pyrene}]}{13 \text{ mg} \cdot \text{kg}^{-1}}$$

Coarse Soils:

$$\text{IACR} = \frac{[\text{Benz(a)anthracene}]}{3.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(b+g)fluoranthene}]}{1.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(k)fluoranthene}]}{0.31 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo(g,h,i)perylene}]}{63 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Chrysene}]}{19 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Dibenz(a,h)anthracene}]}{2.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Indeno(1,2,3-c,d)pyrene}]}{24 \text{ mg} \cdot \text{kg}^{-1}}$$

- 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			
	Fine	Coarse	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
Pathway				Fine	Coarse	Fine	Coarse		Fine	Coarse	Fine	Coarse	Fine	Coarse
Soil Type				Slab	Slab	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
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)
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 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					
	Fine	Coarse	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	(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
Acenaphthene	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 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						
	Fine	Coarse	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	Fine	Coarse	Management Limit
Pathway	(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)
Soil Type																	
Building Type																	
Unit																	
Fluorene	0.29	0.34	46,000	91,000	25	28	53	39,000	-	-	-	0.29	0.34	-	-	-	-
Naphthalene	0.016	0.018	34,000	370	-	-	-	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) ^e	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 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								
	Fine	Coarse	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	Fine	Coarse	Management Limit		
Pathway	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	Slab	(mg/kg)	Fine	Coarse	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
Soil Type																			
Building Type																			
Unit																			
(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 [§]	0.61	0.22	300,000	2.7	0.22	0.61	1.1	230,000	-	-	-	BDL	BDL	-	-	-	-	-	-
1,2-Dichlorobenzene [§]	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

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						
	Fine	Coarse	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		
Pathway				Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse
Soil Type				Slab	Slab	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
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)	(mg/kg)	(mg/kg)
Dioxins & Furans ^{ba}	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	-	-	-	-
Azinphos-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

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			
	Fine	Coarse	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	Fine	Coarse	Management Limit	
Soil Type	Fine	Coarse	(mg/kg)	Fine Slab	Fine	(mg/kg)	Fine	(mg/kg)	Fine	(mg/kg)	Fine	Coarse	(mg/kg)	(mg/kg)
Building Type	(mg/kg)	(mg/kg)	(mg/kg)	Slab	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Dinoseb [§]	2.8	5.5	160	-	2.8	5.5	320	-	BDL	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	-	0.0085	-	-
Endrin	0.0075	0.009	130	-	2.4	4.7	150	-	0.0075	0.009	-	0.0075	-	-
Glyphosate	0.054	0.049	4,800	-	0.95	1.4	9,500	-	0.054	0.049	-	0.054	-	-
Heptachlor epoxide [§]	0.039	0.076	2.8	2.4	0.039	0.076	6.5	-	BDL	BDL	-	BDL	-	-
Lindane [§]	0.31	0.6	48	-	0.31	0.6	95	-	BDL	BDL	-	BDL	-	-
Linuron	0.051	0.059	320	-	0.56	1.1	630	-	0.051	0.059	-	0.051	-	-
Malathion [§]	0.82	1.3	3,200	-	0.82	1.3	6,300	-	BDL	BDL	-	BDL	-	-
MCPA [§]	0.02	0.032	80	-	0.02	0.032	160	-	BDL	BDL	-	BDL	-	-
Methoxychlor	0.046	0.056	50,000	-	5,700	11,000	50,000	-	0.046	0.056	-	0.046	-	-
Metolachlor	0.048	0.055	800	-	1.3	2.4	1,600	-	0.048	0.055	-	0.048	-	-
Metribuzin	0.024	0.028	1,300	-	7.8	15	2,600	-	0.024	0.028	-	0.024	-	-
Paraquat (as dichloride)	1.1	2.2	160	-	1.1	2.2	320	-	-	-	-	-	-	-
Parathion [§]	7.2	14	800	-	7.2	14	1,600	-	BDL	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	-	0.024	-	-
Simazine	0.033	0.038	210	-	0.14	0.25	410	-	0.033	0.038	-	0.033	-	-
Tebuthiuron [§]	2.5	3.7	11,000	-	2.5	3.7	22,000	-	BDL	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

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					
	Fine	Coarse	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	(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 [§]	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	-	-	-
Trifluarlin	0.038	0.045	770	-	-	35	67	1,500	-	-	-	0.038	0.045	-	-	-
Other Organics																
Aniline [§]	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/PCS, 1998) scheme, as follows:

Carcinogenic PAH Compound	PEF
Benz[a]anthracene	0.1
Benzo(b+)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 Equivalence 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 IACR for coarse textured soil would be calculated as follows:

$$\text{IACR} = \frac{[\text{Benz}(a)\text{anthracene}]}{1.6 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(b+)j\text{fluoranthene}]}{0.74 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(k)\text{fluoranthene}]}{0.16 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(g,h,i)\text{perylene}]}{32 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(a)\text{pyrene}]}{1.7 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Chrysene}]}{10 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Dibenz}(a,h)\text{anthracene}]}{1.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Indeno}(1,2,3-c,d)\text{pyrene}]}{13 \text{ mg} \cdot \text{kg}^{-1}}$$

Coarse Soil:

$$\text{IACR} = \frac{[\text{Benz}(a)\text{anthracene}]}{3.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(b+)j\text{fluoranthene}]}{1.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(k)\text{fluoranthene}]}{0.31 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(g,h,i)\text{perylene}]}{63 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Benzo}(a)\text{pyrene}]}{3.4 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Chrysene}]}{19 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Dibenz}(a,h)\text{anthracene}]}{2.1 \text{ mg} \cdot \text{kg}^{-1}} + \frac{[\text{Indeno}(1,2,3-c,d)\text{pyrene}]}{24 \text{ mg} \cdot \text{kg}^{-1}}$$

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 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	Ecological										Other		
		Human		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		Fine	Coarse
Pathway	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)
Soil Type	0.046	0.078	0.046	0.078	120	62	-	na	na	73	1.6	0.33	-	-
Building Type	0.52	0.49	0.52	0.95	220	150	-	na	na	250,000	0.49	1,000	-	-
Unit	0.11	0.21	0.11	0.21	240	110	-	na	na	NGR	540	17,000	-	-
Benzene	15	28	15	28	130	190	-	na	na	NGR	250	16,000	-	-
Toluene	420	420	1,100	2,200	420	420	-	na	na	30,000	1,300	30,000	800	700
Ethylbenzene	300	300	1,500	2,900	300	300	-	na	na	30,000	520	30,000	1,000	1,000
Xylenes	2,600	600	-	-	2,600	600	-	na	na	-	-	-	3,500	2,500
F1	10,000	5,600	-	-	11,200	5,600	-	na	na	-	-	-	10,000	10,000
F2														
F3														
F4														

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												
	Fine (mg/kg)	Coarse (mg/kg)	Vapour Inhalation					Direct Soil Contact		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 (mg/kg)						
Soil Type	Fine (mg/kg)	Coarse (mg/kg)	Fine Basement mg/kg	Fine Slab mg/kg	Coarse Basement mg/kg	Coarse Slab mg/kg	Fine mg/kg	Coarse mg/kg	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)	Fine (mg/kg)	Coarse (mg/kg)					
Benzene	0.046	0.078	78	1.7	1.6	0.10	0.14	0.046	0.078	62	120	62	-	-	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	150	220	150	-	-	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	110	240	110	-	-	NGR	540	36	42	NGR	17,000	-	-	-	-	-	-	-	-	-	-	-				
Xylenes	15	16	140,000	280	260	16	23	15	28	190	130	190	-	-	NGR	250	160	180	NGR	16,000	-	-	-	-	-	-	-	-	-	-	-				
F1	420	30	12,000	710	630	30	55	1,100	2,200	420	420	420	-	-	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	300	-	-	30,000	520	16,000	19,000	NGR	30,000	-	-	-	-	-	-	-	-	-	-	-	-	1,000	1,000	
F3	2,600	600	15,000	-	-	-	-	-	-	2,600	600	600	-	-	na	na	na	na	na	na	-	-	-	-	-	-	-	-	-	-	-	-	3,500	2,500	
F4	10,000	5,600	21,000	-	-	-	-	-	-	11,200	5,600	5,600	-	-	na	na	na	na	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 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	
	Fine	Coarse	Direct Soil Contact	Vapour Inhalation		Protection of Domestic Use Aquifer		Direct Soil Contact		Nutrient/ Energy Cycling Check	Protection of Freshwater Aquatic Life		Fine	Coarse
Soil Type	(mg/kg)	(mg/kg)	(mg/kg)	Fine Basement	Fine Slab	Coarse Basement	Coarse Slab	Fine	Coarse	(mg/kg)	Fine	Coarse	(mg/kg)	(mg/kg)
Building Type														
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	1,300
F2	300	160	6,800	3,600	3,300	160	290	1,500	2,900	-	300	300	30,000	520
F3	2,600	600	15,000	-	-	-	-	-	-	-	2,600	600	-	-
F4	10,000	5,600	21,000	-	-	-	-	-	-	-	11,200	5,600	-	-

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 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 Pathway	Overall Guideline		Human						Ecological						Other		
	Fine (mg/kg)	Coarse (mg/kg)	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	Fine	Coarse	Management Limit
Soil Type			-	Fine mg/kg	Coarse mg/kg	Fine mg/kg	Coarse mg/kg	-	Fine mg/kg	Coarse mg/kg	-	Fine mg/kg	Coarse mg/kg	-	Fine mg/kg	Coarse mg/kg	-
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)	(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 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	
	Fine	Coarse	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	Fine	Coarse
Soil Type			-	Fine Slab	Coarse Slab	Fine	Coarse	-	Fine	Coarse	-	Fine	Coarse	-	Fine	Coarse
Building Type			-	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)
Unit	(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 **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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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 ₂ S)	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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)
Soil Type			All (mg/L)						
Unit	see note d	see note d	-	-	-	see note d	see note d	-	-
Silver	0.02	0.02	0.02	-	-	-	-	-	-
Uranium	0.03	0.03	5	-	-	0.03	0.03	-	-
Zinc									
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
Acenaphthene	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	-	-	-	-	-	-
Benzo[a]anthracene ^b	0.000018	0.000018	-	-	-	0.000018	0.000018	NGR	NGR
Benzo[b+g]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	
	Fine (mg/L)	Coarse (mg/L)	All (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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 **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	
	Fine (mg/L)	Coarse (mg/L)		All (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)
PCBs	0.0094	0.0094	0.0094	-	-	-	-	-	-
Pesticides									
Aldicarb	0.001	0.001	0.009	-	-	0.001	0.001	0.001	-
Aldrin	0.0007	0.0007	0.0007	-	-	0.003	0.003	0.003	-
Atrazine and metabolites	0.0018	0.0018	0.005	-	-	0.0018	0.0018	0.0018	-
Azniphos-methyl	0.00001	0.00001	0.02	-	-	0.00001	0.00001	0.00001	-
Bendiocarb	0.04	0.04	0.04	-	-	-	-	-	-
Bromoxynil	0.005	0.005	0.005	-	-	0.005	0.005	0.005	-
Carbaryl	0.0002	0.0002	0.09	-	-	0.0002	0.0002	0.0002	-
Carbofuran	0.0018	0.0018	0.09	-	-	0.0018	0.0018	0.0018	-
Chlorothalonil	0.00018	0.00018	0.14	-	-	0.00018	0.00018	0.00018	-
Chlorpyrifos	0.0000035	0.0000035	0.09	-	-	0.0000035	0.0000035	0.0000035	-
Cyanazine	0.002	0.002	0.01	-	-	0.002	0.002	0.002	-
2,4-D	0.004	0.004	0.1	-	-	0.004	0.004	0.004	-
DDT	0.000001	0.000001	0.093	-	-	0.000001	0.000001	0.000001	-
Diazinon	0.02	0.02	0.02	-	-	-	-	-	-
Dicamba	0.01	0.01	0.12	-	-	0.01	0.01	0.01	-
Dichlofop-methyl	0.0061	0.0061	0.009	-	-	0.0061	0.0061	0.0061	-
Dieldrin	0.000056	0.000056	0.0007	-	-	0.000056	0.000056	0.000056	-
Dimethoate	0.0062	0.0062	0.02	-	-	0.0062	0.0062	0.0062	-
Dinoseb	0.00005	0.00005	0.01	-	-	0.00005	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	0.00002	-
Endrin	0.000036	0.000036	0.0028	-	-	0.000036	0.000036	0.000036	-
Glyphosate	0.065	0.065	0.28	-	-	0.065	0.065	0.065	-
Heptachlor epoxide	0.0000038	0.0000038	0.000052	-	-	0.0000038	0.0000038	0.0000038	-
Lindane	0.00001	0.00001	0.0028	-	-	0.00001	0.00001	0.00001	-

Table B-1. Groundwater Remediation Guideline Values for Natural Areas - All Water Uses

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Water Use	Lowest Guideline		Potable GW	Eco Soil Contact		Aquatic Life		Wildlife Watering	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)
Soil Type			All (mg/L)						
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	-	-
Nitrotriactic 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 **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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)
Soil Type			All						
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+)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 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 (mg/L)	Inhalation		Eco Soil Contact		Aquatic Life		Irrigation (mg/L)	Livestock		Wildlife Watering	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)		All (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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	1	-	-
Nitrate	13	13	45	-	-	-	-	13	13	-	-	-	-	-
Nitrate + Nitrite (as nitrogen)	100	100	-	-	-	-	-	-	-	-	100	100	-	-
Nitrite (as nitrogen)	0.06	0.06	1.0	-	-	-	-	0.06	0.06	-	10	10	-	-
Sodium	200	200	200	-	-	-	-	-	-	-	-	-	-	-
Sulphate	500	500	500	-	-	-	-	-	-	-	1000	1000	-	-
Sulphide (as H ₂ S)	0.002	0.002	0.05	-	-	-	-	0.002	0.002	-	-	-	-	-
Total Dissolved Solids (TDS)	500	500	500	-	-	-	-	-	-	-	-	3000	-	-
Metals														
Aluminium	See note e	See note e	-	-	-	-	-	see note d	see note d	5	5	5	-	-
Antimony	0.006	0.006	0.006	-	-	-	-	-	-	-	-	-	-	-
Arsenic	0.005	0.005	0.01	-	-	-	-	0.005	0.005	0.1	0.025	0.025	-	-
Barium	1	1	1	-	-	-	-	-	-	-	-	-	-	-
Boron	0.5	0.5	5	-	-	-	-	-	-	0.5	5	5	-	-
Bromate	0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-	-
Cadmium	See note e	See note e	0.005	-	-	-	-	see note d	see note d	0.0051	0.08	0.08	-	-
Chromium (Total)	See note e	See note e	0.05	-	-	-	-	see note d	see note d	-	0.05	0.05	-	-
Copper	See note e	See note e	1	-	-	-	-	see note d	see note d	0.2	0.5	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	0.1	-	-

Table B-2. Groundwater Remediation Guideline Values for Agricultural Land - All Water Uses

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Water Use	Lowest Guideline		Potable	Inhalation		Eco Soil Contact		Aquatic Life		Irrigation	Livestock		Wildlife Watering	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)		All (mg/L)	Fine (mg/L)	Coarse (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	-
Acenaphthene	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 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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)			All (mg/L)	Fine (mg/L)
Benzo[b,i]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 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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)			All (mg/L)	Fine (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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)			All (mg/L)	Fine (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 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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)		All (mg/L)	Fine (mg/L)	Coarse (mg/L)	
Simazine	0.0005	0.0005	0.01	-	-	-	-	0.01	0.01	0.0005	0.01	0.01	-	-
Tebuthiuron	0.00027	0.00027	0.66	-	-	-	-	0.0016	0.0016	0.00027	0.13	0.13	-	-
Terbufos	0.001	0.001	0.001	-	-	-	-	-	-	-	-	-	-	-
Toxaphene	0.0000002	0.0000002	0.00043	6.4	0.31	-	-	0.000002	0.000002	-	-	-	-	-
Triallate	0.00024	0.00024	0.12	-	-	-	-	0.00024	0.00024	-	0.23	0.23	-	-
Trifluarin	0.0002	0.0002	0.045	-	-	-	-	0.0002	0.0002	-	0.045	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	-	-	-	-	-
Nitriotrriacetic 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	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+)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 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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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 ₂ S)	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 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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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
Acenaphthene	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+g]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 All (mg/L)	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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 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 All (mg/L)	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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 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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)
Unit	(mg/L)	(mg/L)	All (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	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)
Toxaphene	0.000002	0.000002	0.00043	6.4	0.31	-	-	0.000002	0.000002
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
Nitritotriacetic 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
Benzol[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 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).

Pathway	Lowest Guideline		Potable	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		All (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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 ₂ S)	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-4. Groundwater Remediation Guideline Values for Commercial/Industrial - 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).

Pathway	Lowest Guideline		Potable	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)
Soil Type			All (mg/L)						
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
Acenaphthene	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+g,h,i]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 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).

Pathway	Lowest Guideline		Potable	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		All (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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 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).

Pathway	Lowest Guideline		Potable All (mg/L)	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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
Azinphos-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 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).

Pathway	Lowest Guideline		Potable All (mg/L)	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (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
Nitritriacetic 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 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).

Pathway	Lowest Guideline		Potable	Inhalation		Eco Soil Contact		Aquatic Life	
	Fine (mg/L)	Coarse (mg/L)		All (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (mg/L)	Coarse (mg/L)	Fine (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

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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} cm² for fine soil and 6×10^{-8} cm² 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/m³);
UR = unit risk (Table C-7); (mg/m³) $^{-1}$.

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:

$$SGRG \text{ (mg / kg - bw / day)} = \frac{1}{\sum_i \frac{F_i}{SGRG_i}}$$

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 1x10⁶ 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:

$$G_i = F_{i(\text{soil})} \frac{\rho_b}{\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)}$$

and

$$F_{i(\text{groundwater})} = \frac{G_i}{\sum_i G_i}$$

Where:	G_i	=	proportion of sub-fraction i in groundwater (before normalization; dimensionless);
	$F_{i(\text{soil})}$	=	proportion of sub-fraction i in soil (Table C-10; dimensionless);
	$F_{i(\text{groundwater})}$	=	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

$$SRG_{HH} = \frac{(TDI - EDI) \times SAF \times BW}{[(AF_G \times SIR) + (AF_L \times IR_s \times ET_2) + (AF_S \times SR)] \times ET_1} + [BSC]$$

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

$$SRG_{HH} = \frac{(RsD) \times BW}{[(AF_G \times SIR) + (AF_L \times IR_s \times ET_2) + (AF_S \times SR)] \times ET_1} + [BSC]$$

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 (cm²/s; calculated below);
 A_B = building area (cm²);
 Q_B = building ventilation rate (cm³/s; calculated below);
 L_T = distance from contaminant source to foundation (cm);
 Q_{soil} = volumetric flow rate of soil gas into the building (cm³/s; calculated below);
 L_{crack} = thickness of the foundation (cm);
 D_{crack} = effective vapour diffusion coefficient through the crack (cm²/s; calculated below); and,
 A_{crack} = area of cracks through which contaminant vapours enter the building (cm²).

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 (cm²/s);
 D_a = diffusion coefficient in air (cm²/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 (cm²/s);
 D_a = diffusion coefficient in air (cm²/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 (cm³/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 (cm³/s);
 ΔP = pressure differential (g/cm·s²);
 k_v = soil vapour permeability to vapour flow (cm²);
 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 dilution 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:

$$DF4 = \frac{2}{\exp(A) \times [\operatorname{erf}(C) - \operatorname{erf}(D)]}$$

$$A = \frac{x}{2D_x} \left\{ 1 - \left(1 + \frac{4L_s D_x}{v} \right)^{1/2} \right\}$$

$$C = \frac{y + Y/2}{2(D_y x)^{1/2}}$$

$$D = \frac{y - Y/2}{2(D_y x)^{1/2}}$$

$$L_s = \frac{0.6931}{t_{1/2s}} \times \exp(-0.07d)$$

$$v = \frac{V}{\theta_t R_s}$$

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

$$D_x = 0.1x$$

$$D_y = 0.01x$$

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/>

- AECL (Atomic Energy of Canada Limited), 1990. Hydrogeology of surficial materials of permit areas D and F and the Lee River Study Area in the Whiteshell Research Area. Applied Geoscience Branch, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba. TR-498, January 1990.
- AECL (Atomic Energy of Canada Limited), 1991. Hydrometeorological data for the Dead Creek Watershed, Southeastern Manitoba, 1982-1989. Applied Geoscience Branch, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba. TR-540, April 1991.
- AECL (Atomic Energy of Canada Limited), 1992. Hydrogeology and hydrochemistry for the Rice Creek Watershed of the Whiteshell Research Area 1986-1990. Applied Geoscience Branch, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba. TR-570, December 1992.
- AECL (Atomic Energy of Canada Limited), 1995. Hydrogeology and hydrochemistry of the Atikokan Research Area of Northwestern Ontario. Whiteshell Laboratories, Pinawa, Manitoba. TR-713, December 1992.
- AENV (Alberta Environment), 1999. Surface Water Quality Guidelines for Use in Alberta. Alberta Environment, November 1999.
- AENV (Alberta Environment), 2009. Soil Remediation Guidelines for Barite: Environmental Health and Human Health. Environmental Assurance Division, Alberta Environment.
- ATSDR (Agency for Toxic Substances and Disease Registry), 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. U.S. Department of Health and Human Services. Public Health Service. August 1995.
- ATSDR (Agency for Toxic Substances and Disease Registry), 2005. Toxicological Profile for Naphthalene, 1-Methylnaphthalene, and 2-Methylnaphthalene. U.S. Department of Health and Human Services. Public Health Service. August 2005.
- BCMELP (British Columbia Ministry of Environment, Lands, and Parks), 1996. Overview of CSST Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites.
- CCME (Canadian Council of Ministers of the Environment), 1999 and updates. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg. Published 1999, updated through 2006. Information on ordering available online at http://www.ccme.ca/publications/ceqg_rcqe.html
- CCME (Canadian Council of Ministers of the Environment), 2006a. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. Canadian Council of Ministers of the Environment.
- CCME (Canadian Council of Ministers of the Environment), 2006b. Canadian Soil Quality Guidelines for Diisopropanolamine (DIPA) (Environmental and Human Health Effects). Scientific Supporting Document. Available online at http://www.ccme.ca/assets/pdf/sg_protocol_1332_e.pdf
- CCME (Canadian Council of Ministers of the Environment), 2006c. Canadian Soil Quality Guidelines for Sulfolane (Environmental and Human Health Effects). Scientific Supporting Document. Available online at http://www.ccme.ca/assets/pdf/sulfolane_ssd_soil_water_1.1_e.pdf

- CCME (Canadian Council of Ministers of the Environment), 2006d. Canadian Soil Quality Guidelines for Trichloroethylene (Environmental and Human Health Effects). Scientific Supporting Document. 85pp. Available online at http://www.ccme.ca/assets/pdf/tce_ssd_1393.pdf
- CCME (Canadian Council of Ministers of the Environment), 2008a. Canada-Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale.. Available online at http://www.ccme.ca/assets/pdf/pah_soqg_ssd_1401.pdf
- CCME (Canadian Council of Ministers of the Environment), 2008b. Canadian Soil Quality Guidelines for Polycyclic Aromatic Hydrocarbons (Environmental and Human Health Effects). Scientific Supporting Document. Available online at http://www.ccme.ca/assets/pdf/pah_soqg_ssd_1401.pdf
- EC (Environment Canada), 1999a. Canadian Soil Quality Guidelines for DDT. Environmental Effects. Scientific Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada, Ottawa. December 1999.
- EC (Environment Canada), 1999b. Canadian Soil Quality Guidelines for Ethylene Glycol. Environmental Effects. Scientific Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada, Ottawa. Based on 1997 Assessment. Revised December 1999.
- EC (Environment Canada), 2000. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life and Canadian Tissue Residue Guidelines for the Protection of Wildlife Consumers of Aquatic Biota: Polychlorinated Dibenzo-P-Dioxins and polychlorinated Dibenzofurans (PCDD/Fs). Technical Supporting Document. 2 vols. Report # 1-2. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada, Ottawa.
- EC (Environment Canada), 2001. Canadian Soil Quality Guidelines for Polychlorinated Biphenyls (PCBs). Scientific Supporting Document. Report # 1-2. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada, Ottawa. August, 2001.
- EC (Environment Canada), 2002. Canadian Environmental Quality Guidelines for Nonylphenol and its Ethoxylates. Scientific Supporting Document, Water Sediment and Soil. Report # 1-3. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada, Ottawa. August, 2002.
- EC (Environment Canada), 2004a. Canadian Soil Quality Guidelines for Benzene. Technical Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada, Ottawa.
- EC (Environment Canada), 2004b. Canadian Soil Quality Guidelines for Toluene, Ethylbenzene and Xylenes (TEX). Technical Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada, Ottawa.
- Gustafson, J.B., Tell, J.G., and Orem, D., 1997. Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 3, Selection of Representative TPH Fractions Based on Fate and Transport Considerations. Amherst Scientific Publishers, Massachusetts.
- Health Canada, 1995. Guidelines for Canadian Drinking Water Quality. Part I: Approach to the Derivation of Drinking Water Guidelines. Federal-Provincial-Territorial Committee on Drinking Water, February 1995. Available online at: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/water-eau/part_i-partie_i/partI-partieI-eng.pdf
- Health Canada, 2004a. Federal Contaminated Site Risk Assessment in Canada. Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA). Prepared by:

- Environmental Health Assessment Services Safe Environments Programme, September 2004. Available online at: http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/part-partie_i/index-eng.php
- Health Canada, 2004b. Federal Contaminated Site Risk Assessment in Canada. Part II: Health Canada Toxicological Reference Values (TRVs). Prepared by: Environmental Health Assessment Services Safe Environments Programme, September 2004. Available online at: http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/part-partie_ii/index-eng.php
- Health Canada, 2008. Summary of Guidelines for Canadian Drinking Water Quality. Federal-Provincial-Territorial Committee on Drinking Water, May 2008. Summary available online at: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/index-eng.php
- Keller, C.K., Van der Kamp, G., and Cherry, J.A., 1986. Fracture permeability and groundwater flow in clayey till near Saskatoon, Saskatchewan. *Canadian Geotechnical Journal*, **23**, 229-240.
- NRC (National Research Council), 1996. Nutrient Requirements of Beef Cattle. National Academy Press, Washington, DC.
- ORNL (Oak Ridge National Laboratory), 2006. Risk Assessment Information System. On-Line Database, available at http://risk.lsd.ornl.gov/homepage/rap_tool.shtml
- SRC (Syracuse Research Corporation), 2006. PhysProp Physical Properties Database, available online at <http://www.syrres.com/esc/physdemo.htm>.
- Trudell, M.R., 1994. Soil salinization associated with shallow groundwater flow systems in thin, fractured till moraine. Ph.D. thesis submitted to the Earth Sciences Department of the University of Waterloo, Ontario, Canada.
- US EPA (United States Environmental Protection Agency), 1993. Wildlife Exposure Factors Handbook. Office of Research and Development. December 1993 EPA/600/R-93/187.
- US EPA (United States Environmental Protection Agency), 1994. Chemical Summary for Methyl-tert-Butyl Ether. August 1994 EPA 749 -F-94-017a. Document available at http://www.epa.gov/chemfact/s_mtbe.txt
- US EPA (United States Environmental Protection Agency), 1996. Soil Screening Guidance: Technical Background Document available at <http://www.epa.gov/superfund/health/conmedia/soil/toc.htm>
- US EPA (United States Environmental Protection Agency), 2006. Integrated Risk Information System (IRIS) On-Line Database available at <http://www.epa.gov/iris/>
- Woo, M.K., and Rowsell, R.D., 1993. Hydrology of a prairie slough. *Journal of Hydrology*, **146**, 175-207.
- WHO/IPCS, 1998. Environmental Health Criteria 202: Selected Non-Heterocyclic Polycyclic Aromatic Hydrocarbon. International Program on Chemical Safety, United Nations Environmental Program, World Health Organization. Geneva.

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 x 10 ⁻⁹	1.2 x 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}	<i>mass/mass</i>	0.005	0.005	
Saturated Hydraulic Conductivity	K	<i>m/y</i>	32	320	
Hydraulic Gradient	i	<i>m/m</i>	0.028	0.028	
Recharge (Infiltration) Rate	I	<i>m/y</i>	0.012	0.06	1
Soil Permeability to Vapour Flow	k_v	cm^2	10^{-9}	6×10^{-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

Parameter	Symbol	Unit	Residential Basement		Residential Slab-on-Grade		Commercial Slab-on-Grade		Notes
			Other Hydrocarbons	Petroleum Hydrocarbons	Other Hydrocarbons	Petroleum Hydrocarbons	Other Hydrocarbons	Petroleum Hydrocarbons	
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: surface soil	L _T	cm	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·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 ₇ -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 ₉ -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)				
Acenaphthene	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[<i>a</i>]anthracene	199,526	CCME (2008b)	0.000142	CCME (2008b)	5.01E-02	USEPA (1996)	0.0094	CCME (2008b)		
Benzo[<i>b</i> + <i>j</i>]fluoranthene	93,325	CCME (2008b)	0.000468	CCME (2008b)	2.26E-02	USEPA (1996)	0.00375	CCME (2008b)		
Benzo[<i>k</i>]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'	Source	D _a cm ² /s	Source	Solubility mg/L	Source	Half Life yr	Source
Benzo[<i>g,h,i</i>]perylene	407,380	CCME (2008b)	0.00000597	CCME (2008b)			0.000026	CCME (2008b)		
Benzo[<i>a</i>]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[<i>a,h</i>]anthracene	1,380,384	CCME (2008b)	0.00000622	CCME (2008b)	2.02E-02	USEPA (1996)	0.00249	CCME (2008b)		
Indeno[1,2,3- <i>c,d</i>]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-Tetrachlorobenzene			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)		
Trifluralin	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-ethylhexyl)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_{oc} , rather than a K_{oc} , since diisopropanolamine sorbs to clays in preference to organic carbon.

1. Calculated using the equation $K_{oc} = 0.41 \times K_{ow}$

2. PCBs, dioxins 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-d) ⁻¹	Inhalation UR (mg/m ³) ⁻¹	Source
Metals							
Arsenic (inorganic)					2.8	6.4	HC (2004b)
Barite-barium	0.2	AENV (2009)					HC (2004b)
Hydrocarbons							
Benzene					0.31	0.0033	HC (2004b)
Toluene	0.22	HC (2004b)	3.8	HC (2004b)			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	Inhalation TC mg/m ³	Source	Inhalation UR (mg/m ³) ⁻¹
Pyrene	0.03	0.13	see note 1	
Benzo(a)pyrene			2.3	CCME (2008b)
Halogenated Aliphatics				
Vinyl chloride	0.003	0.1	US EPA (2006)	0.0088
1,1-Dichloroethene	0.05	0.2	US EPA (2006)	
Trichloroethene (Trichloroethylene, TCE)	0.00146	0.04	CCME (2006d)	0.00061
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	0.014	0.36	HC (2004b)	
1,2-Dichloroethane				0.026
Dichloromethane (Methylene chloride)	0.05	3	ORNL (2006)	0.000023
Trichloromethane (Chloroform)	0.01	0.04475	see note 1	0.023
Tetrachloromethane (Carbon tetrachloride)	0.0007	0.00313	see note 1	0.015
Dibromochloromethane	0.02	0.08949	see note 1	
Chlorinated Aromatics				
Chlorobenzene	0.43	0.01	HC (2004b)	
1,2-Dichlorobenzene	0.43	1.92411	see note 1	
1,4-Dichlorobenzene	0.11	0.095	HC (2004b)	
1,2,3-Trichlorobenzene	0.0015	0.00671	see note 1	
1,2,4-Trichlorobenzene	0.0016	0.007	HC (2004b)	
1,3,5-Trichlorobenzene	0.0015	0.0036	HC (2004b)	
1,2,3,4-Tetrachlorobenzene	0.0034	0.01521	see note 1	
1,2,3,5-Tetrachlorobenzene	0.00041	0.00183	see note 1	
1,2,4,5-Tetrachlorobenzene	0.00021	0.00094	see note 1	
Pentachlorobenzene	0.001	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	Inhalation UR (mg/m ³) ⁻¹	Source
Hexachlorobenzene	0.0005	HC (2004b)	0.002237	see note 1	0.83	0.1855	see note 1
2,4-Dichlorophenol	0.1	HC (2004b)	0.447468	see note 1			
2,4,6-Trichlorophenol					0.02	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	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	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							
Triallate	1.30E-02	US EPA (2006)			1.1	0.32	US EPA (2006)
Trifluralin	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-d) ⁻¹	Inhalation UR (mg/m ³) ⁻¹	Source
Dichlorobenzidine					0.0676	0.015107214	HC (2004b) see note 1
Diisopropanolamine	0.39	CCME (2006b)					
Ethylene glycol	2	US EPA (2006)	8.94937	see note 1			
Hexachlorobutadiene					0.078	0.022	US EPA (2006) 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 m³/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	Source
Metals				
Arsenic (inorganic)	1.00	0.03	1.00	HC (2004a)
Barite-barium	1.00	0	1.00	AENV (2009)
Hydrocarbons				
Benzene	1.00	0.08	1.00	HC (2004a)
Toluene	1.00	0.12	1.00	HC (2004a)
Ethylbenzene	1.00	0.20	1.00	HC (2004a)
Xylenes	1.00	0.12	1.00	HC (2004a)
Styrene	1.00	0.20	1.00	CCME (2008a)
Aliphatic C ₆ -C ₈	1.00	0.20	1.00	CCME (2008a)
Aliphatic C ₈ -C ₁₀	1.00	0.20	1.00	CCME (2008a)
Aliphatic C ₁₀ -C ₁₂	1.00	0.20	1.00	CCME (2008a)
Aliphatic C ₁₂ -C ₁₆	1.00	0.20	1.00	CCME (2008a)
Aliphatic C ₁₆ -C ₂₁	1.00	0.20	1.00	CCME (2008a)
Aliphatic C ₂₁ -C ₃₄	1.00	0.20	1.00	CCME (2008a)
Aliphatic C ₃₄	1.00	0.20	1.00	CCME (2008a)
Aromatic C ₈ -C ₁₀	1.00	0.20	1.00	CCME (2008a)
Aromatic C ₁₀ -C ₁₂	1.00	0.20	1.00	CCME (2008a)
Aromatic C ₁₂ -C ₁₆	1.00	0.20	1.00	CCME (2008a)
Aromatic C ₁₆ -C ₂₁	1.00	0.20	1.00	CCME (2008a)
Aromatic C ₂₁ -C ₃₄	1.00	0.20	1.00	CCME (2008a)
Aromatic C ₃₄	1.00	0.20	1.00	CCME (2008a)
Naphthalene	1.00	0.10	1.00	CCME (1999)
Acenaphthene	1.00	0.20	1.00	CCME (2008a)
Fluorene	1.00	0.20	1.00	CCME (2008a)
Fluoranthene	1.00	0.20	1.00	CCME (2008a)
Anthracene	1.00	0.29	1.00	CCME (2008a)
Pyrene	1.00	0.20	1.00	CCME (2008a)
Benzo(a)pyrene	1.00	0.34	1.00	CCME (2008b)
Halogenated Aliphatics				
Vinyl chloride	1.00	0.16	1.00	HC (2004a)

Table C-8. Human Absorption Factors

	Absorption Factors		
	Gut	Skin	Lung
1,1-Dichloroethene	1.00	0.10	1.00
Trichloroethene (Trichloroethylene, TCE)	1.00	0.10	1.00
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene, PCE)	1.00	0.10	1.00
1,2-Dichloroethane	1.00	0.10	1.00
Dichloromethane (Methylene chloride)	1.00	1.00	1.00
Trichloromethane (Chloroform)	1.00	0.10	1.00
Tetrachloromethane (Carbon tetrachloride)	1.00	0.10	1.00
Dibromochloromethane	1.00	0.10	1.00
Chlorinated Aromatics			
Chlorobenzene	1.00	0.10	1.00
1,2-Dichlorobenzene	1.00	0.10	1.00
1,4-Dichlorobenzene	1.00	0.10	1.00
1,2,3-Trichlorobenzene	1.00	0.08	1.00
1,2,4-Trichlorobenzene	1.00	0.08	1.00
1,3,5-Trichlorobenzene	1.00	0.08	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	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	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	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	Skin	Lung
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	0.000007	0.0000025	PSL	0.00000017	PSL	0	assumed	0.2
1,2,3,5-Tetrachlorobenzene	0.0000045	0.0000015	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
Trifluarzin	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 (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED ¹ (mg/kg-bw/d)
General and Inorganic Parameters						
Aluminium		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 ₂ S)	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 (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED ¹ (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 (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED ¹ (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 (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED ¹ (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	2.1424E-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				
Nitriooacetic 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:

$$WQG = \frac{DTED \times BW}{WIR}$$

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



Appendix 5: US EPA Ecological Soil Screening Level for Aluminium

Ecological Soil Screening Level for Aluminum

Interim Final

OSWER Directive 9285.7-60



U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

November 2003

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SUMMARY OF ECO-SSLs FOR ALUMINUM

Aluminum (Al) is the most commonly occurring metallic element, comprising eight percent of the earth's crust (Press and Siever, 1974). It is a major component of almost all common inorganic soil particles, with the exceptions of quartz sand, chert fragments, and ferromanganiferous concretions. The typical range of aluminum in soils is from 1 percent to 30 percent (10,000 to 300,000 mg Al kg⁻¹) (Lindsay, 1979 and Dragun, 1988), with naturally occurring concentrations varying over several orders of magnitude.

EPA recognizes that due to the ubiquitous nature of aluminum, the natural variability of aluminum soil concentrations and the availability of conservative soil screening benchmarks (Efroymson, 1997a; 1997b), aluminum is often identified as a COPC for ecological risk assessments. The commonly used soil screening benchmarks (Efroymson, 1997a; 1997b) are based on laboratory toxicity testing using an aluminum solution that is added to test soils. Comparisons of total aluminum concentrations in soil samples to soluble aluminum-based screening values are deemed by EPA to be inappropriate.

The standard analytical measurement of aluminum in soils under CERCLA contract laboratory procedures (CLP) is total recoverable metal. The available data on the environmental chemistry and toxicity of aluminum in soil to plants, soil invertebrates, mammals and birds as summarized in this document support the following conclusions:

- Total aluminum in soil is not correlated with toxicity to the tested plants and soil invertebrates.
- Aluminum toxicity is associated with soluble aluminum.
- Soluble aluminum and not total aluminum is associated with the uptake and bioaccumulation of aluminum from soils into plants.
- The oral toxicity of aluminum compounds in soil is dependant upon the chemical form (Storer and Nelson, 1968). Insoluble aluminum compounds such as aluminum oxides are considerably less toxic compared to the soluble forms (aluminum chloride, nitrate, acetate, and sulfate). For example, Storer and Nelson (1968) observed no toxicity to the chick at up to 1.6% of the diet as aluminum oxide compared to 80 to 100% mortality in chicks fed soluble forms at 0.5% of the diet.

Because the measurement of total aluminum in soils is not considered suitable or reliable for the prediction of potential toxicity and bioaccumulation, an alternative procedure is recommended for screening aluminum in soils. The procedure is intended as a practical approach for determining if aluminum in site soils could pose a potential risk to ecological receptors. This alternative procedure replaces the derivation of numeric Eco-SSL values for aluminum. Potential ecological risks associated with aluminum are identified based on the measured soil pH. Aluminum is identified as a COPC only at sites where the soil pH is less than 5.5.

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1.0 INTRODUCTION

Aluminum (Al) is the most commonly occurring metallic element, comprising eight percent of the earth's crust. Only oxygen and silicon are more abundant (Press and Siever, 1974). It is a major component of almost all common inorganic soil particles with the exceptions of quartz sand, chert fragments, and ferromanganiferous concretions. The typical range of aluminum in soils is from 1% to 30% (10,000 to 300,000 mg Al kg⁻¹) [compiled by Lindsay (1979) and Dragun (1988)]. In his text book on *Chemical Equilibria in Soils*, Lindsay (1979) used an arbitrary aluminum reference concentration for all soils as averaging 7.1% (71,000 mg Al kg⁻¹).

Aluminosilicates, including the feldspars, micas, and clay minerals, are the most common primary and secondary minerals in soils (McLean, 1965). Aluminum oxide, Al₂O₃, occurs as corundum and emery. The hydroxide, Al(OH)₃, occurs as gibbsite. Diaspore (AlOOH) and cryolite are other sources of soil aluminum (Hesse, 1972). Aluminum also occurs in interlayer positions in clays, often forming complete layers to which the term chlorite is sometimes applied.

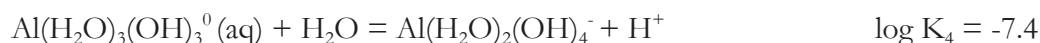
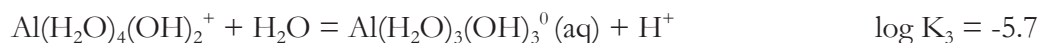
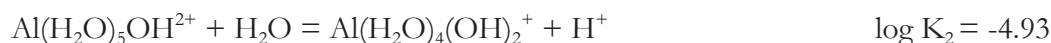
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2.0 ALUMINUM CHEMISTRY

The aluminum ion bonds through oxygen to form a wide variety of functional groups. In igneous rocks, aluminum is largely bonded to oxygen ions in tetrahedral coordination. As the rocks weather, aluminum progressively acquires more octahedral bonding. The weathering release of aluminum from 2:1 layer silicates in soils is enhanced by inputs of acids from the natural decomposition of organic matter and minerals and from pollution (McBride, 1994). Acids as weak as dilute H_2CO_3 have been shown to decompose the silicate and montmorillonite layers facilitating the release of aluminum (Jackson, 1963).

The hydrated aluminum ion (Al hexahydronium ion) is an acid in the general sense that it contains protons (hydrogen ions) removable from the six water molecules ($-\text{OH}_2$) surrounding the aluminum in an octahedral coordination. For simplicity these hydrolysis species are generally written without the hydrated water even though the water is present. This trivalent cation complex occurs in acid solutions of pH 5.0 or 5.2 and below (Jackson, 1963; McLean et al., 1965; Tisdale and Nelson, 1975). As the pH of the soil solution increases, first one and then two of the ($-\text{OH}_2$) groups lose a hydrogen ion to form an ($-\text{OH}$) ion, resulting in di- or mono-valent hydroxyaluminum cations. All three of these cation species are adsorbed by negatively charged (cation) exchange sites in the soil. The di- and monovalent forms are adsorbed more strongly than $\text{Al}(-\text{OH}_2)_6^{3+}$ (McLean et al., 1965; Jackson, 1963). This ion is octahedrally hydrated and therefore less strongly held electrostatically and by hydrogen bonding than are the di- or mono-valent hydroxy-aluminum cations (Jenny, 1961). It is readily displaced from the clay with a neutral salt such as potassium chloride (Jenny, 1961; Jackson, 1963; McLean et al., 1965; Tisdale and Nelson, 1975).

As the pH increases still further, the third ($-\text{OH}_2$) group loses a hydrogen ion, and aluminum hydroxide, $\text{Al}(\text{OH})_3 \bullet 3\text{H}_2\text{O}$, is formed. The steps in the dissociation of protons from the hydrated aluminum ion in dilute solution may be represented by the following equations (Jackson, 1963; Black, 1968; Lindsay, 1979; McBride, 1994; Tisdale and Nelson, 1975):



The concentrations of these species as a function of pH are shown in Figure 2.1.

Once soil pH is lowered much below 5.5, aluminosilicate clays and aluminum hydroxide minerals begin to dissolve, releasing aluminum-hydroxy cations and $\text{Al}(\text{H}_2\text{O})_6^{3+}$ that then exchange with other cations from soil colloids. The fraction of exchange sites occupied by $\text{Al}(\text{H}_2\text{O})_6^{3+}$ and its hydrolysis products can become large once the soil pH falls below 5.0.

Furthermore, as the pH is lowered, the concentration of soluble aluminum, which is toxic, increases (McBride, 1994).

The chemistry of $\text{Al}(\text{H}_2\text{O})_6^{3+}$ (normally written without the water molecules as Al^{3+}) in soil solution is complicated by the fact that soluble inorganic and organic ligands form complexes with Al^{3+} . Whether a ligand increases or decrease aluminum solubility depends on the particular aluminum-ligand complex and its tendency to remain in solution or precipitate. Ligands that increase the overall solubility of aluminum include F^- , oxalate²⁻, citrate³⁻, fulvic acid, and monomeric silicate. Those that decrease the overall solubility of aluminum include phosphate, sulfate, polymeric silicate, and hydroxyl. It is usually the case that a large fraction of the soluble aluminum is found in the form of organic and fluoride complexes. Some of the aluminum may also be complexed with soluble silicate. There is evidence that these various complexed forms of aluminum are much less phytotoxic than soluble Al^{3+} or Al-hydroxy cations. In fact, the Al^{3+} activity in soil solution is better correlated to diminished root growth in acid soils than is total soluble aluminum or exchangeable aluminum as a fraction of cation exchange sites (McBride, 1994).

There is some evidence to suggest that the $\text{Al}_{13}\text{O}_4(\text{OH})_{24}(\text{H}_2\text{O})_{12}^{7+}$ polymeric cation is highly phytotoxic. This is a metastable species, however, that may not exist in soil solutions. It may be formed by localized and transitory high pH conditions created during the titration of aluminum salt solutions with strong base (McBride, 1994).

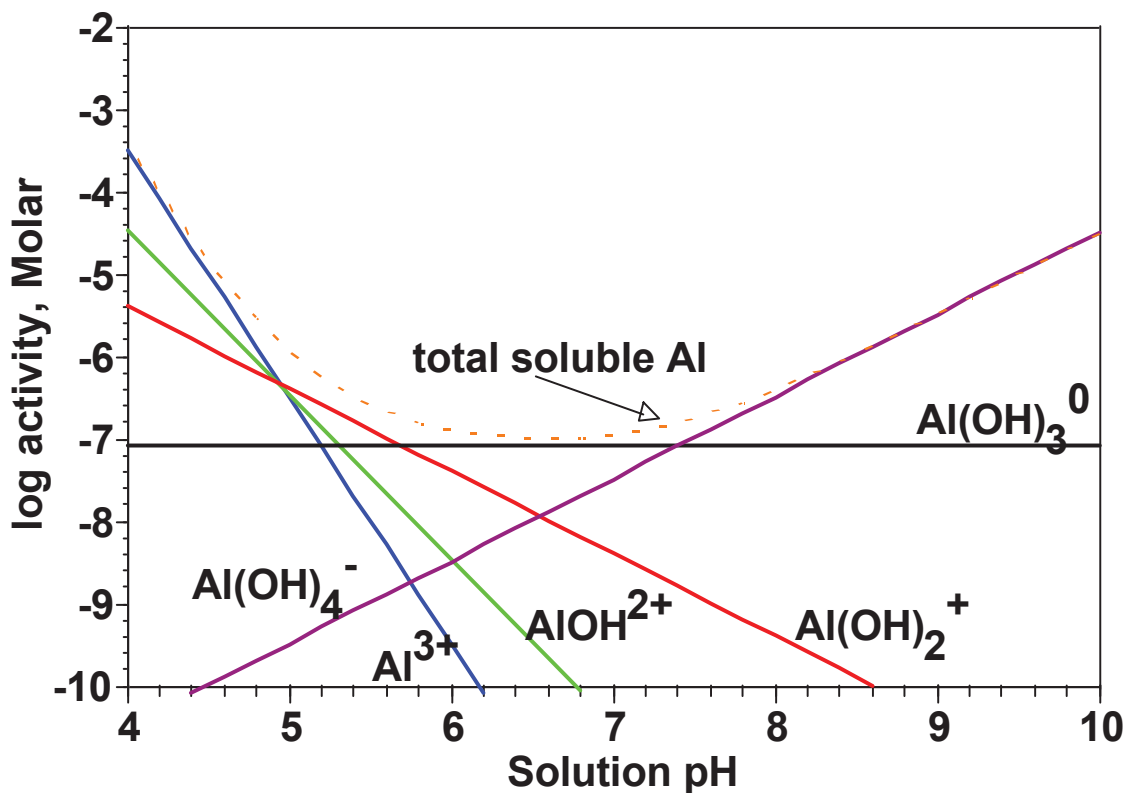


Figure 2.1. Solubility diagram of the most significant species of aluminum in an aqueous solution of AlCl_3 . Gibbsite (Al(OH)_3) is present as the solid phase at all pH values. The broken line depicts total soluble aluminum (sum of all species concentrations). Polymetric aluminum- hydroxy cations are not significant species under the conditions of this system (from McBride, 1994).

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3.0 EFFECTS OF ALUMINUM ON PLANTS

The extensive research literature in the agricultural sciences on the effects of aluminum on plants dates back nearly a century. There is an ongoing need to identify not only the essential plant nutrients but also factors that limit optimal plant growth and productivity. Once aluminum was found to limit plant growth, efforts were made to discover the modes of action for aluminum toxicity, the ways to predict which soils were aluminum toxic, the methods to amend these problem soils to ameliorate aluminum toxicity, and breeding programs to produce aluminum tolerant plants.

3.1 General Effects

The toxic effects of aluminum on plants has been noted by many workers. Toxic levels of aluminum decrease the height and both the fresh and dry weight yields of plants (Rees and Sidrak, 1961; Munns, 1965; Hortenstine and Fiskell, 1961). The effects on roots occur long before any noticeable effects to the tops (McLean and Gilbert, 1927). The first evidence of injury in the roots is a discolored appearance. Then lateral roots become stunted, or fail to develop, and the whole root system fails to elongate (McLean and Gilbert, 1927; and Rhue and Grogan, 1977). This effect on root elongation has also been reported by Clarkson (1965), Matsumoto et al. (1976), Keser et al. (1975), Lafever et al. (1977), Rees and Sidrak (1961), and Fleming and Foy (1968). Injury to roots is characterized by a disorganization of the root cap, root apex, and vascular elements (Fleming and Foy, 1968). According to a study by McLean and Gilbert (1927), it appeared as if aluminum decreased the permeability of the roots to water and nutrients

The toxic effects of aluminum to plants are observed in association with soluble aluminum (Al^{3+}). For example, Mulder et al. (1989) observed a dose response relationship between 'Tyler' wheat root length versus the concentration of Al^{3+} (see Figure 3.1).

In addition, several studies of conifers grown in Al-enriched solutions at a pH lower than 5.5 resulted in reduced root growth rates (Hutchinson et al. 1986), shorter roots, less root mass, and lower root:shoot ratios than controls (Nosko et al. 1988), and reduced root elongation (Eldhuset et al. 1987). When beech trees were exposed to Al-enriched solutions at a pH range of 4.2 to 5.4, their leaves, roots and stems were 21% to 44% lower than controls (Bengtsson et al. 1988) (Sparling and Lowe, 1996).

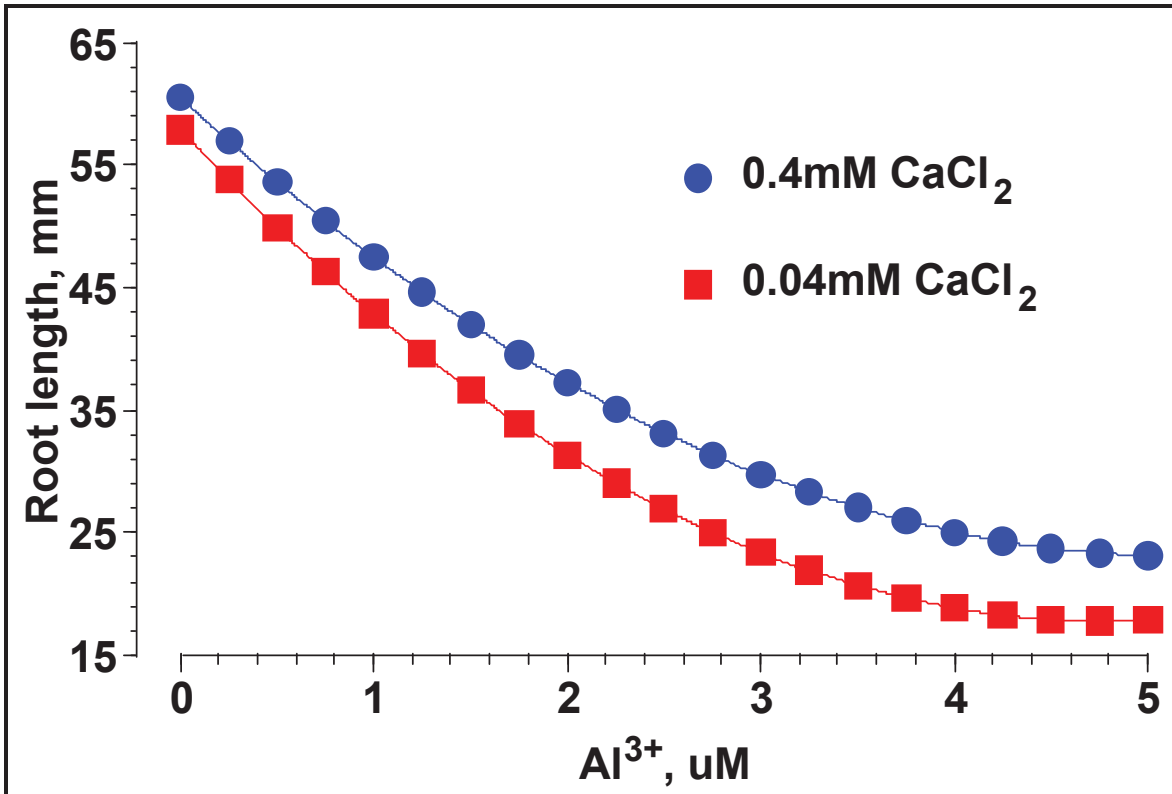


Figure 3.1. 'Tyler' wheat root length versus concentration of Al³⁺ (from Parker et al., 1989).

3.2 Essentiality

Although there is no convincing evidence of its essentiality in plants, aluminum has long been known to be a constituent of a blue pigment in *Hydrangea* (Chenery, 1948). There also have been many examples reported over the past 50 years in which plant growth has been stimulated by subtoxic concentrations of aluminum (Matsumoto et al., 1976; Bertrand and de Wolf, 1968). The beneficial effects of aluminum may relate to reduction by the aluminum of the uptake of a second element present in the root environment at potentially toxic concentrations (Liebig et al., 1942; Suthipradit, 1988). In most cases in which positive effects of aluminum on plant growth have been reported, there has been insufficient supporting information to establish whether or not they were indirect effects mediated through alleviation of toxicity of another element. Most positive responses to aluminum have been observed at nominal aluminum concentrations of ≤ 37 μM . However, because of the ease with which free aluminum ions are lost from solution by complexation, polymerization, and precipitation reactions, the actual aluminum concentrations in solution have probably been much lower (Asher, 1991)

3.3 Effect on Phosphorus and Calcium

In addition to root growth inhibition, a decrease in the uptake and utilization of phosphorus is the primary symptom of aluminum toxicity in some susceptible plant species (MacLean and Chiasson, 1966; Naidoo et al., 1978). Aluminum inactivates phosphorus, primarily within the roots of plants, and thus interferes with the normal phosphate metabolism of plants (Wright, 1943; Wright, 1945; Wright and Donahue, 1953). Naidoo et al. (1978) found that aluminum and phosphorus were mainly concentrated on or in the outer cells of the root caps. Utilizing a scanning electron microscope focused at one point, Naidoo et al. (1978) found that "spot" analysis of the outer cell of snapbean and cotton root caps at high magnification showed that aluminum and phosphorus formed a precipitate at the cell surface when aluminum was present in nutrient solution. Data from Clarkson (1966) indicated that 85 to 95% of the aluminum in the roots was located in the cell wall fraction. This aluminum seemed to fix the phosphorus by an absorption-precipitation reaction, an extension of the reaction found in soils. According to McCormick and Borden (1972 and 1974), the Al-PO_4 precipitate occurred as scattered globules rather than as a continuous layer. The absorption-precipitation phenomenon occurred in the extracellular and intercellular material of the root cap. McCormick and Borden (1972) also concluded that aluminum may not only reduce phosphate availability by preventing the uptake of external sources, but also may be able to "extract" the phosphate from the root tissue and disrupt important metabolic activities.

In addition to the nonmetabolic interaction between aluminum and phosphate at the cell surface or in the free space, a small proportion of the total aluminum found in the root appears to be inside the cell. Internal precipitation of phosphorus cannot explain the rapid cessation of cell division in terms of phosphorus starvation. Any interaction between aluminum and phosphorus must be at a metabolic level rather than a phosphorus deficiency through precipitation in order for cell division to stop suddenly. The results of Clarkson (1965) showing reduction and cessation of root growth might be explained by an effect of aluminum on the turn-over of certain key phosphorylated compounds such as adenosine triphosphate (ATP). Observations suggested

aluminum may either inhibit hexokinase or combine with the substrate to make it unavailable (Clarkson, 1966).

Aluminum within root cells probably accumulates by ion exchange onto enteric phosphorus in the nucleic acids and membrane lipids. aluminum in the nuclei may act directly to reduce or inhibit cell division by interference with nucleic acid replication (Clarkson, 1965; Matsumoto et al., 1976; Naidoo et al., 1978). Ragland and Coleman (1962) and Rees and Sidrak (1961) postulated that aluminum may cause a rearrangement of cell constituents and the protoplasm to coagulate.

Researchers have observed that aluminum causes a calcium deficiency in plants (Long and Foy, 1970; Armiger et al., 1968; Vlamis, 1953; Evans and Kamprath, 1970; MacLean and Chiasson, 1966) which was due not to a deficiency of calcium in the growth medium, but to the detrimental effect of aluminum on adsorption and translocation of calcium.

3.4 Differential Tolerance of Plants to Aluminum Toxicity

Species of plants show a considerable difference in the amount of aluminum they are able to tolerate. Susceptible plants can tolerate no more than one or two parts per million (ppm) in nutrient solutions while other plants can tolerate over 100 ppm with little damage (McLean and Gilbert, 1927; Ligon and Pierre, 1932; Peiffer, 1976; Chapman, 1966). Rhue and Grogan (1977) and Reid et al. (1969) theorized that aluminum tolerance is genetically controlled. Vose and Randall (1962) cite the cation exchange capacity of the roots as a possible factor in aluminum resistance. Tolerance to both aluminum and manganese toxicities was associated with a low cation exchange capacity of the plant root, which favors mono- to di-valent uptake in accordance with the Donnan theory. Naidoo et al. (1978), Keser et al. (1975), and Foy et al. (1978) postulated that tolerant plants have a mechanism for preventing aluminum uptake. Foy et al. (1978) found that certain aluminum-tolerant cultivars of wheat, barley, rice, peas, and corn had the ability to increase the pH of the small quantities of nutrient solutions in which they were grown. The increase in pH decreased the solubility and toxicity of aluminum. The exact physiological mechanism of aluminum- tolerance or toxicity, however, was unresolved (Foy et al., 1978).

4.0 UPTAKE AND ACCUMULATION OF ALUMINUM BY PLANTS

4.1 Plant Uptake of Aluminum

According to Rasmussen (1968), the epidermal cells appear to effectively exclude the aluminum from entering the root at the root cap. The mode of aluminum entry begins with the growth of a lateral root from the pericycle. As the lateral root enlarges, the cells of the endodermis divide, and, as the root forces its way through the cortex of the parent root, the lateral root is encased in an endodermal layer. Once the root breaks through the surface, however, the endodermal layer dies and sloughs-off, creating a path by which aluminum and other elements can penetrate into the cortical and vascular tissue of both the lateral and parent roots.

Bioavailability of aluminum for plant uptake and toxicity is associated with pH, since aluminum is soluble and biologically available in acidic (pH <5.5) soils and waters, but is biologically inactive in circumneutral to alkaline (pH 5.5-8.0) conditions. In alkaline soils and solutions (pH >8.0), the solubility of aluminum increases, but its bioavailability is poorly known (Sparling and Lowe, 1996).

Weathering or acidification to pH below 5.5 increases the dissolution kinetics of Al and places some of the metal into solution, where it is readily bioavailable to living organisms (although dissolved organic carbons, such as F, PO_3^{3-} and SO_4^{2-} can ameliorate toxicity by reducing bioavailability) (Sparling and Lowe, 1996). Once in solution, Al may combine with several organic complexes, especially oxalic, humic, and fulvic acids. Aluminum may also combine with inorganic molecules, including sulfate (SO_4^{2-}), fluoride (F⁻), phosphate (PO_3^{3-}), bicarbonates (HCO_3^-), or hydroxides (OH⁻), depending on the relative concentrations of these anions. Biological activity and toxicity vary with composition. For example, Al sulfates are generally considered less toxic than hydroxide or organically bound Al (Driscoll and Schecher 1988). Aqueous Al (Al^{3+}), however, is more chemically and biologically active than that bound to soil or sediments (Sparling and Lowe, 1996).

Monomeric and hydrolyzed forms of Al [Al^{3+} , $\text{Al}(\text{OH})^{2+}$, $\text{Al}(\text{OH})_2^+$, $\text{Al}(\text{OH})_3$] are typically the most toxic, whereas, polymeric and organically bound forms have slight to no phytotoxicity (Fageria et al. 1988; Taylor, 1988). Often, the sum of the concentrations of monomeric Al is used to estimate the phytotoxicity to a growing medium. Although Parker et al. (1989) contended that polymeric Al can be as toxic as Al^{3+} in nutrient solutions, polymeric Al is generally not soluble in soil and therefore, should not be as toxic. In soil, the concentration of Al^{3+} may suffice to predict toxicity (Sparling and Lowe, 1996).

4.2 Accumulation of Aluminum in Plant Tissue

Root staining techniques have shown that aluminum accumulates principally in the root tips of the main root and lateral root tissue, with small quantities in the cortex and epidermal cells (McLean and Gilbert, 1927; Fleming and Foy, 1968; Matsumoto et al., 1976). Aluminum has a high affinity for pectin so that cell wall surfaces of the Donnan Free Space are the most obvious areas for aluminum to concentrate upon entering the root (Rorison, 1965; Clarkson, 1967).

Data on aluminum uptake by roots suggest that, in the initial stages, most of the aluminum incorporated becomes bound to the adsorption sites in the cell wall, most likely to free carboxyl groups. Aluminum may also be precipitated on the root or cell surfaces as Al(OH)_3 by the hydrolysis of Al(OH)_2 and Al(OH) by free carboxyl groups (Clarkson, 1967). The positively charged amorphous aluminum hydroxides are known to adsorb and precipitate phosphorus from solution, forming $\text{Al(OH)}_2\text{H}_2\text{PO}_4$. This same thing can happen on cell surfaces effectively reducing the concentration of phosphorus available for metabolic uptake (Clarkson, 1967).

5.0 EFFECTS OF ALUMINUM ON SOIL INVERTEBRATES

A preliminary review of the literature revealed only one study on the toxicity of aluminum to earthworms or other soil invertebrates. Van Gestel and Hoogerwerf (unpublished), as reported by Van Gestel (1992), determined the influence of soil pH on the sublethal toxicity of aluminum for *Eisenia andrei* in artificial soil. Effects on growth and reproduction were studied in worms exposed for 6 weeks (Table 5.1). Results were expressed in terms of a No-Observed-Effect-Concentrations (NOEC). They concluded that low soil pH significantly increased aluminum toxicity. At the highest pH tested (7.3), earthworm growth was significantly increased at high aluminum concentrations in soil. This increased growth was not related, however, to the aluminum dose. The effect of aluminum on cocoon production did not seem to be influenced by soil pH. At pH 3.4 (lowest pH reported), all worms died at 1000 mg Al kg⁻¹ dry soil. At this pH level cocoon production was almost completely inhibited at 320 mg Al kg⁻¹, whereas at pH 4.3 and 7.3 it was only halved at this concentration. Cocoon production in control groups was significantly reduced at pH 3.4 compared to the two higher pH soils. Aluminum extracted with 1N calcium chloride appeared to decrease with increasing soil pH. The effects on growth and cocoon production could, however, only partially be related to the amount of free aluminum in the soil. They concluded that other factors apparently also played a role.

Table 5.1. Influence of soil pH on the effect of aluminum on <i>Eisenia andrei</i> in artificial soil (6 weeks exposure).			
Parameter	NOEC (mg Al/kg dry soil) at pH		
	3.4	4.3	7.3
Survival	320	1000 ^a	1000 ^a
Growth	100	1000 ^a	32 ^b
Cocoon production	100	100	100
Cocoon fertility	100	1000 ^a	1000 ^a
Juveniles/fertile cocoons	100 ^a	1000 ^a	1000 ^a

^a Reliability of this value is low due to a low number of cocoons
^b Growth was significantly increased at higher concentrations of aluminum

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6.0 UPTAKE AND ACCUMULATION OF ALUMINUM IN SOIL INVERTEBRATES

Data on the uptake and accumulation of aluminum from soil pore water into soil invertebrates could not be located for review.

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7.0 MEASURING ALUMINUM IN SOILS

When researchers, using nutrient solutions, displaced soil solutions, and soils at various pH levels, discovered that conditions toxic to plants in acid soils were due, in many cases, to toxic levels of aluminum, it was apparent that a way of determining the plant available aluminum could be useful for the evaluation of the potential toxicity of a particular soil. Many different methods of measuring aluminum in soils have been used. Displacement of the soil solution, the use of acid solutions, and buffered and unbuffered salt solutions are reported as methods for extracting aluminum.

7.1 Total Aluminum

Total aluminum is often measured in soils because it provides useful information on the characterization of soils with respect to the origin of parent materials and weathering. It also serves as a basis for calculating the mineralogical composition of the sample (Bertsch and Bloom, 1996). Total soil aluminum as a direct measure of aluminum toxicity, however, appears to have little or no value based on the previously presented information. It is not possible to correlate the soil solution concentration of aluminum to the total soil aluminum measurement. Mulder et al. (1989) measured total soil aluminum (%) and soil solution aluminum in samples collected below plant rooting zones and found no relationship between the two concentrations (Figure 7.1).

7.2 Exchangeable and Extractable Aluminum

Exchangeable and extractable aluminum, displaced most commonly with an unbuffered salt solution such as 1M KCl, 0.5M CaCl₂, or 0.5M BaCl₂, traditionally have had two primary uses. The first is the formulation of lime requirements for acid soils (Kamprath, 1970; Reeve and Sumner, 1970; Amedee and Peech, 1976; Farina et al., 1980; Juo and Kamprath, 1979; Oates and Kamprath, 1983a,b). Second, because of its importance as a predominant cation in acid soils, exchangeable aluminum is a critical variable in establishing effective cation exchange capacity (ECEC) values, which are utilized for soil management and classification purposes, and in evaluating changes in forested soils influenced by acidic deposition and land-use practices (Juo et al., 1976; Pavan et al., 1984; Evans and Zelazny, 1987; Mulder et al., 1987; Lilieholm and Feagley, 1988; Adams et al., 1990; Reuss et al., 1990; Rasmussen et al., 1991). For these applications, investigators are interested in arriving at a reproducible measure of exchangeable Al³⁺ that reflects aluminum exchange equilibria as accurately as possible (Bertsch and Bloom, 1996).

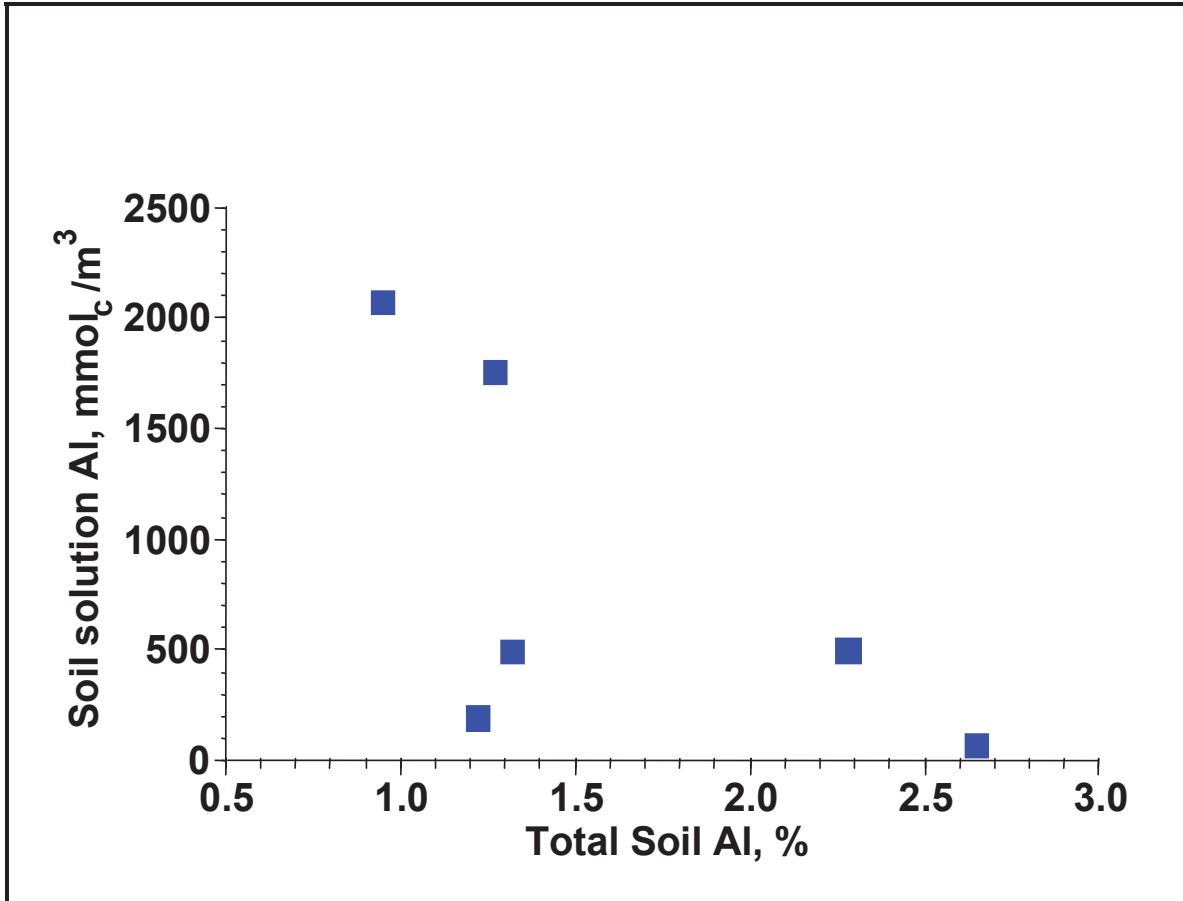


Figure 7.1. Soil solution aluminum collected below plant rooting zones (from Mulder et al., 1989).

7.3 Soluble Aluminum

Soluble aluminum in soil solutions can be an important parameter to study the impact of acidification on forest soils and watershed, the formation (or dissolution) of secondary soil minerals, and to assess aluminum toxicity to plants in acid soils and aquatic organisms in acidified watersheds. Most techniques used to obtain soil solutions for chemical analysis of the typical predominant soil cations (Ca^{2+} , Mg^{2+} , Na^+ , and K^+) also can be used for aluminum. More care is needed, however, since aluminum is typically present in soil solution at much lower concentrations and at much higher concentrations in the whole soil than the other soil cations. Also, the solubility of aluminum is pH dependent and factors that result in change of pH to a value near neutrality can result in loss by precipitation. Many commonly utilized sampling devices can result in either the removal of aluminum through sorption, or contamination of aluminum through dissolution reactions. Collection of samples with low aluminum concentrations require great care to minimize contamination from background sources. Methods of collecting soil solutions in which to measure soluble aluminum include *in situ* sampling with lysimeters, miscible displacement of soils in packed columns, centrifugation with or without a heavy liquid immiscible with water, and filtrations of soil solution samples through a nonreactive membrane filter with pore sizes of 0.45- μm or less (Bertsch and Bloom, 1996).

Mulder et al. (1989) demonstrated that the relationship between soil solution pH and soluble aluminum concentrations and demonstrated that above a pH of 5.0 soluble aluminum is not measured (Figure 7.2). This data supports the conclusion that at a soil pH of 5.0 and higher, soluble aluminum does not occur and toxicity associated with aluminum in soils is not expected.

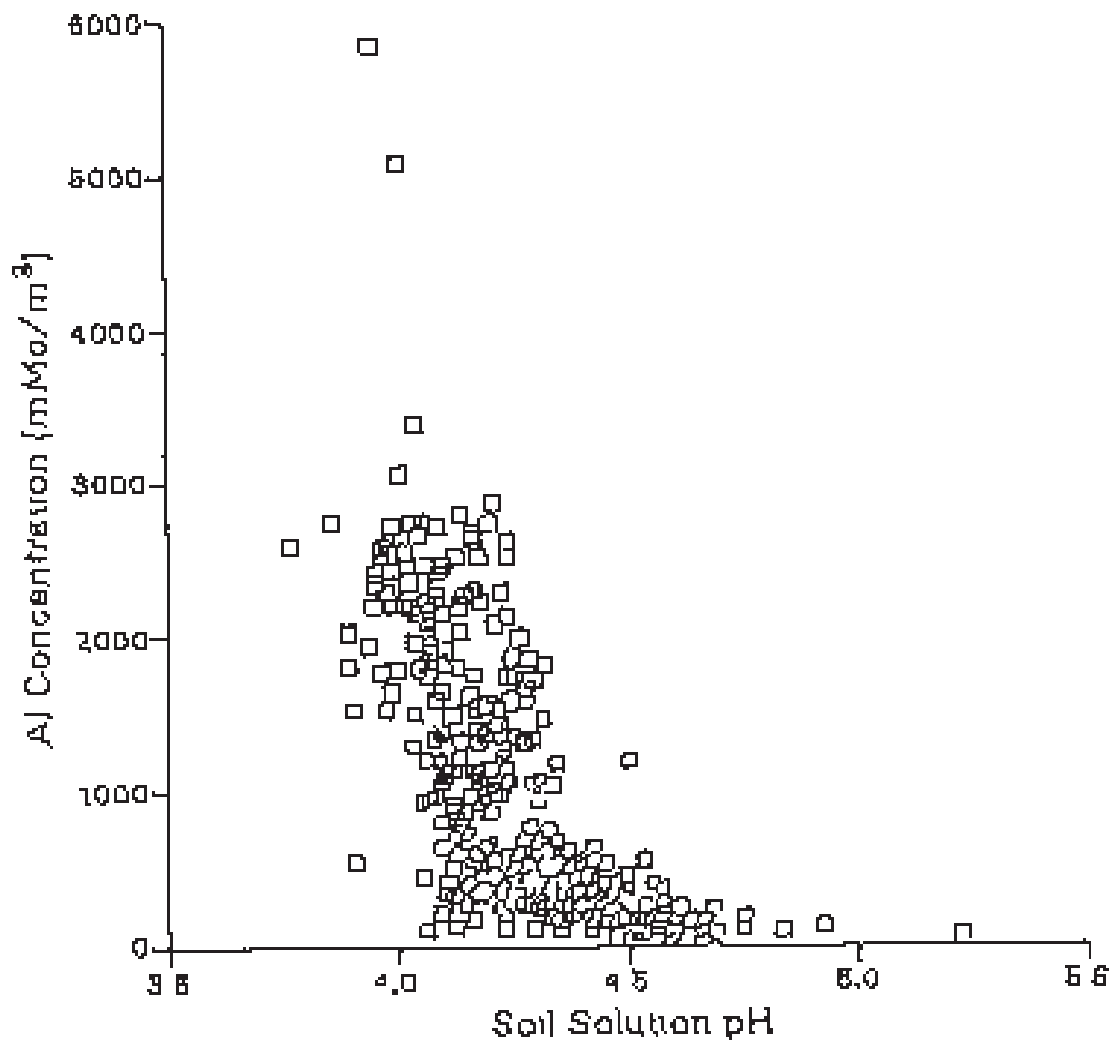


Figure 7.2. Aluminum soil solution concentrations versus soil solution pH in sub-soil solutions (below 50 cm depth) at six study sites (from Mulder et al., 1989).

8.0 CONCLUSIONS ON SCREENING SOILS FOR ALUMINUM TOXICITY

Aluminum (Al) is the most commonly occurring metallic element comprising eight percent of the earth's crust (Press and Siever, 1974). It is a major component of almost all common inorganic soil particles with the exceptions of quartz sand, chert fragments, and ferromanganiferous concretions. The typical range of aluminum in soils is from 1% to 30% (10,000 to 300,000 mg Al kg⁻¹) (Lindsay, 1979 and Dracun, 1988) with naturally occurring concentrations variable over several orders of magnitude.

EPA recognizes that due to the ubiquitous nature of aluminum, the natural variability of aluminum soil concentrations and the availability of conservative soil screening benchmarks (Efroymson, 1997b), aluminum is often identified as a contaminant of potential concern (COPC) for ecological risk assessments. The commonly used soil screening benchmarks (Efroymson, 1997b) are based on laboratory toxicity testing using aluminum solution amendments to test soils. Comparisons of total aluminum soil concentrations to solution based screening values are deemed by EPA to be inappropriate.

The standard analytical measurement of aluminum in soils under CERCLA contract laboratory procedures (CLP) is total recoverable metal. The available data on the environmental chemistry and toxicity of aluminum in soil to plants and soil invertebrates as discussed in the preceding chapters supports the following conclusions:

- Total aluminum in soil is not correlated with toxicity to the tested plants and soil invertebrates.
- Aluminum toxicity is associated with soluble aluminum.
- Soluble aluminum and not total aluminum is associated with the uptake and bioaccumulation of aluminum from soils into plants.

Measurement of Soluble Aluminum in Soils

Chemical and toxicological information suggests that aluminum must be in a soluble form in order to be toxic to biota. It is, however, difficult to measure accurately or with precision the concentration of soluble aluminum in pore water or in soil extracts. The difficulties associated with the measurement of soluble aluminum are discussed in detail in the previous chapters and include the following:

- Contamination problems. Aluminum is ubiquitous and the possibility of contamination of pore water or soil extract samples with aluminum from other sources is high. Sampling requires special handling to minimize background contamination.
- Forms of soluble aluminum which may be toxic are poorly understood

- Techniques for measurement of soluble aluminum are not well developed and would require refinement in order to consistently provide reproducible results that could be used with confidence.

Based on the available information, it is not possible at this time to recommend the direct measurement of soluble aluminum as the method for prediction of toxicity of aluminum in soils. It is possible to recommend as an alternative the measurement of soil pH. The presence of soluble aluminum forms is pH dependent. Thus, the measurement of soil pH provides an indirect but reliable approach for assessing if soluble aluminum could be present. The use of a pH screening level of 5.5 is considered environmentally protective .

Alternative Screening Procedure for Aluminum

Potential ecological risks associated with aluminum in soils is identified based on the measured soil pH. **Aluminum is identified as a COPC only for those soils with a soil pH less than 5.5.** The technical basis for this procedure is that the soluble and toxic forms of aluminum are only present in soil under soil pH values of less than 5.5. Site-specific considerations could, however warrant inclusion of aluminum as a COPC.

9.0 LITERATURE CITED

- Adams, W.A., A.Y. Ali, and P.J. Lewis. 1990. Release of cationic aluminum from acidic soils into drainage water and relationships with land use. *J. Soil. Sci.* 41:255-268.
- Amedee, G., and M. Peech. 1976. The significance of KCl extractable Al(III) as an index to lime requirement of soils of the humid tropics. *Soil Sci.* 121:227-233.
- Al-Khafaji, A.A., and M.A. Tabatabai. 1979. Effects of trace elements on arylsulfatase activity in soils. *Soil Sci.* 127(3):129-133.
- Armiger, W. H., C. D. Foy, A. L. Fleming, and B. E. Caldwell. 1968. Differential tolerance of soybean varieties to an acid soil high in exchangeable aluminum. *Agron. J.* 60:67-70.
- Asher, C.J. 1991. Chapt. 18: Beneficial elements, functional nutrients, and possible new essential elements. pg. 703-723. In J.J. Mortvedt (ed.) *Micronutrients in Agriculture*, 2nd Ed. No. 4, Soil Sci. Soc. Amer. Book Series, Madison, WI USA.
- Bengtsson, B. H. Asp, P. Jensen, D. Berggren. 1988. Influence of aluminum on phosphate and calcium uptake in beech (*Fagus sylvatic*) grown in nutrient solution and soil solution. *Physiol. Plant* 74:299-305.
- Bertrand, D., and A. de Wolf. 1968. Physiologie vegetale. L'aluminium, oligo-element necessaire au maïs. *C.R. Acad.Sci. Ser. 2* 267:2325-2326.
- Bertsch, P.M., and P.R. Bloom. 1996. Chapter 18: Aluminum. In D.L. Sparks (ed.) *Methods of Soil Analysis, Part 3; Chemical Methods*. No. 5. Soil Sci. Soc. Amer, Inc. pg. 517-550.
- Black, C. A. 1968. Soil-plant relationships. 2nd Ed. John Wiley and Sons, Inc., New York.
- Chapman, H.D. 1966. Diagnostic Criteria for Plants and Soils. University of California, Division of Agricultural Sciences.
- Chenery, E.M. 1948. Aluminum in plants and its relation to plant pigments. *Ann.Bot.* 12:121-136.
- Clarkson, D. T. 1967. Interaction between aluminum and phosphorus on root surfaces and cell wall material. *Plant Soil* 27:347-356.
- Clarkson, D. T. 1966. Effect of aluminum on the uptake and metabolism of phosphorus by barley seedlings. *Plant Physiol.* 41: 165-172.

Clarkson, D. T. 1965. The effect of aluminum and some other trivalent cations on cell division in the root apices of *Allium cepa*. *Ann. Bot. N.S.* 29:311-315.

Dragun, J. 1988. *The Soil Chemistry of Hazardous Materials*. Hazardous Materials Control Research Institute. Silver Spring, MD USA.

Driscoll, C.T. and W.D. Schecher. 1988. Aluminum in the environment. In: Sigel, H., and A. Sigel (eds). *Metal Ions in Biological Systems*, Vol. 24. Aluminum and its role in Biology. Marcel Dekker, New York. pp 59-122.

Efroymson, R.A., M.E. Will, and G.W. Suter II, 1997a, *Toxicological Benchmarks for Potential Contaminants of Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process*, ES/ER/TM-126/R2, Oak Ridge National Laboratory, Oak Ridge, TN.

Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997b, *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision*, ES/ER/TM-85/R3, Oak Ridge National Laboratory, Oak Ridge, TN.

Eldhuset, T., A. Goransson, and T. Ingestad. 1987. Aluminum toxicity in forest tree seedlings. In: Hutchinson, T.C., K.M. Meems (eds). *Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems*. Vol. G16, NATO ASI Series. Springer-Verlag, Berlin. pp 401-409.

Evans, A., Jr., and L.W. Zelazny. 1987. Effects of sulfate additions on the status of exchangeable aluminum in a Cecil soil. *Soil Sci.* 143:410-417.

Evan, C. E. and E. J. Kamprath. 1970. Lime responses as related to percent aluminum saturation, solution aluminum, and organic content. *Soil Sci. Soc. Am. Proc.* 34:893-896.

Fageria, N.K., V.C. Baligar, and R.J. Wright. 1988. Aluminum toxicity in crop plants. *J. Plant Nutr.* 11:303-319.

Farina, M.P.W., M.E. Sumner, C.O. Plank and W.S. Letsch. 1980. Exchangeable aluminum and pH as indicators of lime requirement for corn. *Soil. Sci. Soc. Am. J.* 44: 1036-1041.

Fleming, A. L. and C. D. Foy. 1968. Root structure reflects differential aluminum tolerance in wheat varieties. *Agron. J.* 60:172-176.

Foy, C. D., R. L. Chaney, and M. C. White. 1978. The physiology of metal toxicity in plants. *Ann. Rev. Plant Physiol.* 29:511-566.

Hesse, P. R. 1972. *A Textbook of Soil Chemical Analysis*. Chemical Publishing Co., New York.

- Hortenstine, C. C. and J. G. Fiskell. 1961. Effects of aluminum on sunflower growth and uptake of boron and calcium from nutrient solutions. *Soil Sci. Soc. Am. Proc.* 25:304-307.
- Hutchinson, T.C., L. Bozic, and G. Munoz-Vega. 1986. Responses of five species of conifer seedlings to aluminum stress. *Water Air Soil Pollut.* 31:283-294.
- Jackson, M. L. 1963. Aluminum bonding in soils: A unifying principle in soil science. *Soil Sci. Soc. Am. Proc.* 27:1-10.
- Jenny, H. 1961. Reflections on the soil acidity merry-go-round. *Soil Sci. Soc. Am. Proc.* 25:428-432.
- Juma, N.G., and M.A. Tabatabai. 1977. Effects of trace elements on phosphatase activity in soils. *Soil Sci. Soc. Am. J.* 41:343-346.
- Juo, A.S.R., S.A. Ayanlaja, and J.A. Ogunwale. 1976. An evaluation of cation exchange capacity measurements for soils in the tropics. *Commun. Soil Sci. Plant Anal.* 7:751-761.
- Juo, A.S.R. and E.J. Kamprath. 1979. Copper chloride as an extractant for estimating the potentially reactive aluminum pool in acid soils. *Soil Sci. Soc. Am. J.* 43:35-38.
- Kamprath, E. J. 1970. Exchangeable aluminum as a criterion for liming leached mineral soils. *Soil Sci. Soc. Am. Proc.* 34:252-254.
- Keser, M., B. Neubauer, and F. Hutchenson. 1975. Influence of Al^{+3} on developmental morphology of sugar beet roots. *Agron. J.* 67:84-88.
- Lafever, H. N., L. G. Campbell, and C. D. Foy. 1977. Differential response of wheat cultivars to aluminum. *Agron. J.* 69:563-568.
- Liebig, G.F., Jr., A.P. Vanselow, and H.D. Chapman. 1942. Effects of aluminum on copper toxicity, as revealed by solution-culture and spectrographic studies of citrus. *Soil Sci.* 53:341-351.
- Ligon, W. S. and W. H. Pierre. 1932. Soluble aluminum studies. II. Minimum concentrations of aluminum found to be toxic to corn, sorghum and barley in culture solutions. *Soil Sci.* 34:307-321.
- Liliehalm, B.C., and S.E. Feagley. 1988. Effects of simulated acid rain on soil and leachate acidification of a Lexington silt loam. *Soil Sci.* 146:44-50.
- Lindsay, W.L. 1979. *Chemical Equilibria in Soils.* John Wiley & Sons, New York.
- Long, F. L. and C. D. Foy. 1970. Plant varieties as indicators of aluminum toxicity in the A₂ horizon of a Norfolk soil. *Agron. J.* 62:679-681.

- Matsumoto, H., F. Hirasawa, H. Torikai, and E. Takakaski. 1976. Localization of absorbed aluminum in pea roots and its binding to nucleic acid. *Plant and Cell Physiol.* 17:127-137.
- MacLean, A. A. and T. C. Chiasson. 1966. Differential performance of two barley varieties to varying aluminum concentration. *Can. J. Soil Sci.* 46:147-154.
- McBride, M.B. 1994. *Environmental Chemistry of Soils*. Oxford University Press. New York.
- McCormick, L. H. and F. Y. Borden. 1974. The occurrence of aluminum phosphate precipitate in plant roots. *Soil Sci. Soc. Am. Proc.* 38:931-934.
- McCormick, L. H. and F. Y. Borden. 1972. Phosphate fixation by aluminum in plant roots. *Soil Sci. Soc. Am. Proc.* 36:799-802.
- McLean, E. O. 1965. Aluminum. p. 978-998. In C.A. Black (ed.) *Methods of Soil Analysis*, Part II: Chemical and microbiological properties of soils. Am. Soc. of Agron., Inc. Madison, Wis.
- McLean, E. O., D. C. Reicosky, and C. Lakshmanan. 1965. Aluminum in soils: VII. Interrelationships of organic matter, liming, and extractable aluminum with "permanent charge" (KCl) and pH dependent CEC of surface samples. *Soil Sci. Soc. Am. Proc.* 29:374-378.
- McLean, F. T. and B. E. Gilbert. 1927. The relative aluminum tolerance of crop plant. *Soil Sci.* 24:163-176.
- Mulder, J., J.J.M. van Grinsven, and N. van Breemen. 1987. Impacts of acid atmospheric deposition on woodland soils in The Netherlands: III. Aluminum chemistry. *Soil Sci. Soc. Am. J.* 1640-1646.
- Mulder J, N. Van Breemen, L. Rasmussen, and C.T. Driscoll. 1989. Chapter 10: Aluminum Chemistry of Acidic Sandy Soils with various inputs of Acidic deposition in the Netherlands and Denmark. In T.E. Lewis (Ed) *Environmental Chemistry and Toxicology of Aluminum*. Lewis Publishers, pg171-194.
- Munns, D. N. 1965. Soil acidity and the growth of a legume: II. Reaction of aluminum and phosphorus in solution and effects of aluminum, phosphorus, calcium, and pH on *Medicago sativa* L. in solution culture. *Australian J. Agric. Res.* 16:743-755.
- Naidoo, G. J., McD. Stewart, and R. J. Lewis. 1978. Accumulation sites of aluminum in snapbean and cotton roots. *Agron. J.* 70:489-492.
- Nosko, P., P. Brassard, J.R. Kramer, K.A. Kershaw. 1988. The effect of aluminum on seed germination and early seedling establishment, growth, and respiration of white spruce (*Picea glauca*). *Can. J. Bot.* 66:2305-2310.
- Oates, K.M., and E.J. Kamprath. 1983a. Soil acidity and liming: I. Effect of the extracting

solution cation and pH on the removal of aluminum from acid soils. *Soil Sci. Soc. Am. J.* 47:686-689.

Oates, K.M., and E.J. Kamprath. 1983b. Soil acidity and liming: II. Evaluation of using aluminum extracted by various chloride salts for determining lime requirements. *Soil Sci. Soc. Am. J.* 47:690-692.

Parker, D.R. L.W. Zelazny, and T.B. Kinraide. 1989. Chemical Speciation and plant toxicity of aqueous aluminum. In: Lewis, T.E. (ed) *Environmental Chemistry and Toxicology of Aluminum*. Lewis Publishers, Chelsea, MI. pp. 117-145.

Pavan, M.A., F.T. Bingham, and P.F. Pratt. 1984. Redistribution of exchangeable calcium, magnesium, and aluminum following lime or gypsum applications to a Brazilian oxisol. *Soil Sci. Soc. Am. J.* 48:33-38.

Peiffer, R. A. 1976. *Inter- and Intra-Specific Plant Differences in Tolerance to Aluminum*. Ph.D. Thesis. The Pennsylvania State Univ., University Park, Pa.

Press, F. and R. Siever. 1974. *Earth*. W. H. Freeman and Co., San Francisco.

Ragland, J. L. and N. T. Coleman. 1962. Influence of aluminum on phosphorus uptake by snapbean roots. *Soil Sci. Soc. Am. Proc.* 26:88-90.

Rasmussen, H.P. 1968. Entry and distribution of aluminum in *Zea mays*. *Planta* 81: 28-37.

Rasmussen, P.E., S.L. Schiff, and H.W. Nesbitt. 1991. The determination of exchangeable cations in acid soils: Errors caused by weathering reactions during neutral salt extraction. *Can. J. Soil Sci.* 71:155-163.

Rees, W. J. and G. H. Sidrak. 1961. Inter-relationships of aluminum and manganese toxicities toward plants. *Plant and Soils* 14:101-117.

Reeve, N.G. and M.E. Sumner. 1970. Effects of aluminum toxicity and phosphorus fixation on crop growth on Oxisols in Natal. *Soil Sci. Soc. Am. Proc.* 34: 263-267.

Reid, D. A., G. A. Jones, W. H. Armiger, C. D. Foy, E. J. Koch, and T. M. Starling. 1969. Differential aluminum tolerance of winter barley varieties and selections in associated greenhouse and field experiments. *Agron. J.* 61:218-222.

Reuss, J.O., P.M. Walthall, E.C. Roswall, and R.W.E. Hopper. 1990. Aluminum solubility, calcium-aluminum exchange, and pH in acid forest soils. *Soil Sci. Soc. Am. J.* 54:374-390.

Rhue, R. D. and C. O. Grogan. 1977. Screening corn for aluminum tolerance using different calcium and magnesium concentrations. *Agron. J.* 69:755-760.

Rorison, I. H. 1965. The effect of aluminum on the uptake and incorporation of phosphate by excised sanifoin roots. *New Phytol.* 64:23-27.

Sparling, D.W. and T.P. Lowe. 1996. Environmental Hazards of Aluminum to Plants, Invertebrates, Fish and Wildlife. Reviews of Environmental Contamination and Toxicology, Vol. 145. Springer-Verlag New York, Inc.

Suthipradit, S. 1988. *Effects of Aluminum on Growth and Nodulation of Some Tropical Crop Legumes*. Ph.D. thesis. University of Queensland, Australia.

Taylor, G.J. 1988. The physiology of aluminum phytotoxicity. In: Sigel, H., Sigel, A. (eds) *Metal Ions in Biological Systems*, Vol. 24. Aluminum and Its Role in Biology. Marcel Dekker, New York. p. 123-164.

Tisdale, S. L. and W. L. Nelson. 1975. *Soil Fertility and Fertilizers*. 3rd ed. Macmillan Publishing Co., Inc., New York.

Wright, K. E. 1943. Internal precipitation of phosphorus in relation to aluminum toxicity. *Plant Physiol.* 18:708-712.

Wright, K. E. 1945. Internal precipitation of phosphorus in relation to aluminum toxicity. *Plant Physiol.* 18:708-712.

Wright, K. E. and B. A. Donahue. 1953. Aluminum toxicity studies with radioactive phosphorus. *Plant Physiol.* 28:674-680.

Van Gestel, C.A.M. 1992. The influence of soil characteristics on the toxicity of chemicals for earthworms: a review. In P.W. Greig-Smith, H. Becker, P.J. Edwards, and F. Heimbach (eds.) *Ecotoxicity of Earthworms*. Intercept Ltd, Andover, UK. pg. 44-54.

Vlams, J. 1953. Acid soil infertility as related to soil solution solid-phase effects. *Soil Sci.* 75:383-394.

Vose, P. B. and P. J. Randall. 1962. Resistance to aluminum and manganese toxicities in plants related to variety and CEC. *Nature* 196:85-86.

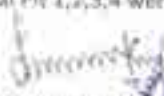
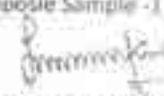



Appendix 6: Results Soil Investigation 2013



Test Report - Chemical Analysis			Page No. 1 of 1
Customer / Contractor	Tebodin Middle East Ltd.	Report No. / Ref. No.	ILS/12/2013/7751_1_Rev1
Address	ALBA	Report Date	02-01-2014
Project Name	ALBA LS & PS5 Modelling of Emissions	Date of sample receipt	11-12-2013
Sample description	Soil	Sample Id. No.	Composite Sample-1
Source / Location	ALBA	Date of test	16-12-2013
Condition of sample during receipt	Satisfactory	Consultant	Bechtel
Parameters	Unit	Test method	Result
Boron	mg/kg	USEPA 6010, 7000	4.34
Chromium	mg/kg		<0.1
Manganese	mg/kg		<0.1
Iron	mg/kg		<0.1
Nickel	mg/kg		<0.1
Copper	mg/kg		<0.1
Zinc	mg/kg		<0.1
Arsenic	mg/kg		<0.1
Molybdenum	mg/kg		<0.1
Cadmium	mg/kg		<0.1
Barium	mg/kg		<0.1
Lead	mg/kg		<0.1
Mercury	mg/kg		<0.01
Magnesium	mg/kg		358
Calcium	mg/kg		1281
Fluoride	mg/kg		3.6
Aluminum	mg/kg		0.13
Cyanide	mg/kg		<0.01
Phosphate	mg/kg		0.1
Sulphur	mg/kg		1920
pH	-	BS 1377-Part 3	8.77
Acid Soluble Sulphates	%		3.04
Acid Soluble Chloride	%		0.21
Total Organic Carbon	%		0.22
Oil & Grease	%	APHA 5520 E	1.00



Test Report - Chemical Analysis			Page No. 2 of 2
Customer / Contractor	Tebodin Middle East Ltd.	Report No. / Ref. No.	ILS/12/2013/7751_1_Rev1
Address	ALBA	Report Date	02-01-2014
Project Name	ALBA LS & PSS Modelling of Emissions	Date of sample receipt	11-12-2013
Sample description	Soil	Sample Id. No.	Composite Sample-1
Source / Location	ALBA	Date of test	16-12-2013
Condition of sample during receipt	Satisfactory	Consultant	Bechtel
Parameters	Unit	Test method	Result
Total Petroleum Hydrocarbons			
Volatile Hydrocarbons (C ₁ -C ₁₀)	µg/kg	ASTM D 6730	< 50
Extractable Petroleum Hydrocarbons(C ₁₁ -C ₄₀)	mg/kg		Not Detected
BTEX			
Benzene	µg/kg	ASTM D 6730	< 50
Ethyl Benzene	µg/kg		< 50
Toluene	µg/kg		< 50
Xylene	µg/kg		< 50
Polyaromatic hydrocarbons			
Naphthalene	µg/kg	EPA-8270	< 50
Acenaphthylene	µg/kg		< 50
Acenaphthene	µg/kg		< 50
Fluorene	µg/kg		< 50
Phenanthrene	µg/kg		< 50
Anthracene	µg/kg		< 50
Fluoranthene	µg/kg		< 50
Pyrene	µg/kg		< 50
Benzo(a)anthracene	µg/kg		< 50
Chrysene	µg/kg		< 50
Benzo(b)fluoranthene	µg/kg		< 50
Benzo(k)fluoranthene	µg/kg		< 50
Benzo(a)pyrene	µg/kg		< 50
Indeno(1,2,3-cd)pyrene	µg/kg		< 50
Dibenzo(a,h)anthracene	µg/kg		< 50
Dibenzo(ghi)perylene	µg/kg		< 50
Remarks:			
1. Test results relate to the sample tested only.			
2. Test Report shall not be reproduced except in full, without written approval of the Laboratory.			
3. Samples from Trial Pit 1,2,3,4 were collected to form Composite Sample -1			
 T. Retna Raj General Manager Approved By		 PVH Murali Krishna Technical Incharge Reviewed by	
		 Christy Nicholas Laboratory incharge Verified by	



Test Report - Chemical Analysis			Page No. 1 of 2
Customer / Contractor	Tebodin Middle East Ltd.	Report No. / Ref. No.	03/12/2013/7751_2_Rev1
Address	ALBA	Report Date	02-01-2014
Project Name	ALBA LS & PSS Modelling of Emissions	Date of sample receipt	11-12-2013
Sample description	Soil	Sample Id. No.	Composite Sample-2
Source / Location	ALBA	Date of test	15-12-2013
Condition of sample during receipt	Satisfactory	Consultant	Bechtel
Parameters	Unit	Test method	Result
Boron	mg/kg	USEPA 6010,7000	5.1
Chromium	mg/kg		<0.1
Manganese	mg/kg		<0.1
Iron	mg/kg		<0.1
Nickel	mg/kg		<0.1
Copper	mg/kg		<0.1
Zinc	mg/kg		<0.1
Arsenic	mg/kg		<0.1
Molybdenum	mg/kg		<0.1
Cadmium	mg/kg		<0.1
Barium	mg/kg		<0.1
Lead	mg/kg		<0.1
Mercury	mg/kg		<0.01
Magnesium	mg/kg		343
Calcium	mg/kg		1386
Fluoride	mg/kg		3.9
Aluminium	mg/kg		0.12
Cyanide	mg/kg		<0.01
Phosphate	mg/kg		0.1
Sulphur	mg/kg		1896
pH	-	BS 1377-Part 3	8.45
Acid Soluble Sulphates	%		4.48
Acid Soluble Chloride	%		0.13
Total Organic Carbon	%		0.19
Oil & Grease	%		1.10
		APHA 5520 E	



Test Report - Chemical Analysis				Page No. 2 of 2
Customer / Contractor	Tebodin Middle East Ltd.	Report No. / Ref. No	IIS/12/2013/7751_2_Rev1	
Address	ALBA	Report Date	02-01-2014	
Project Name	ALBA 15 & P55 Modelling of Emissions	Date of sample receipt	11-12-2013	
Sample description	Soil	Sample id. No.	Composite Sample-2	
Source / Location	ALBA	Date of test	16-12-2013	
Condition of sample during receipt	Satisfactory	Consultant	Bechtel	
Parameters	Unit	Test method	Result	
Total Petroleum Hydrocarbons				
Volatile Hydrocarbons (C ₅ -C ₁₀)	µg/kg	ASTM D 6730	< 50	
Extractable Petroleum Hydrocarbons(C ₁₁ -C ₄₀)	mg/kg		Not Detected	
BTEX				
Benzene	µg/kg	ASTM D 6730	< 50	
Ethyl Benzene	µg/kg		< 50	
Toluene	µg/kg		< 50	
Xylene	µg/kg		< 50	
Polyaromatic hydrocarbons				
Napthalene	µg/kg	EPA 8270	< 50	
Acenaphthylene	µg/kg		< 50	
Acenaphthene	µg/kg		< 50	
Fluorene	µg/kg		< 50	
Phenanthrene	µg/kg		< 50	
Anthracene	µg/kg		< 50	
Fluoranthene	µg/kg		< 50	
Pyrene	µg/kg		< 50	
Benzo(a)anthracene	µg/kg		< 50	
Chrysene	µg/kg		< 50	
Benzo(b)fluoranthene	µg/kg		< 50	
Benzo(k)fluoranthene	µg/kg		< 50	
Benzo(a)pyrene	µg/kg		< 50	
Indeno(1,2,3-cd)pyrene	µg/kg		< 50	
Dibenzo(a,h)anthracene	µg/kg		< 50	
Dibenzo(ghi)perylene	µg/kg		< 50	
Remarks:				
1. Test results relate to the sample tested only.				
2. Test Report shall not be reproduced except in full, without written approval of the Laboratory.				
3. Samples from Trial Pit 6,7,9,11 were collected to form Composite Sample 2				
 T. Retna Raj General Manager Approved By		 H. Murali Krishna Technical Incharge Reviewed by		 Christy Nicholas Laboratory Incharge Verified by



Test Report - Chemical Analysis			Page No. 1 of 2
Customer / Contractor	Tebodin Middle East Ltd	Report No. / Ref. No.	05/12/2013/7751_3_Rev1
Address	ALBA	Report Date	02-01-2014
Project Name	ALBA L5 & PSS Modelling of Emissions	Date of sample receipt	11-12-2013
Sample description	Soil	Sample Id. No.	Composite Sample - 2
Source / Location	ALBA	Date of test	10-12-2013
Condition of sample during receipt	Satisfactory	Consultant	Bechtel
Parameters	Unit	Test method	Result
Boron	mg/kg	USEPA 6010.7000	5.7
Chromium	mg/kg		<0.1
Manganese	mg/kg		<0.1
Iron	mg/kg		<0.1
Nickel	mg/kg		<0.1
Copper	mg/kg		<0.1
Zinc	mg/kg		<0.1
Arsenic	mg/kg		<0.1
Molybdenum	mg/kg		0.1
Cadmium	mg/kg		<0.1
Barium	mg/kg		<0.1
Lead	mg/kg		<0.1
Mercury	mg/kg		<0.01
Magnesium	mg/kg		349
Calcium	mg/kg		1578
Fluoride	mg/kg		4
Aluminum	mg/kg		0.11
Cyanide	mg/kg		<0.01
Phosphate	mg/kg		0.1
Sulphur	mg/kg	2080	
pH		BS 1377-Part 3	8.56
Acid Soluble Sulphates	%		5.89
Acid Soluble Chloride	%		0.46
Total Organic Carbon	%		0.28
Oil & Grease	%	APHA 5520 E	0.90



Test Report - Chemical Analysis

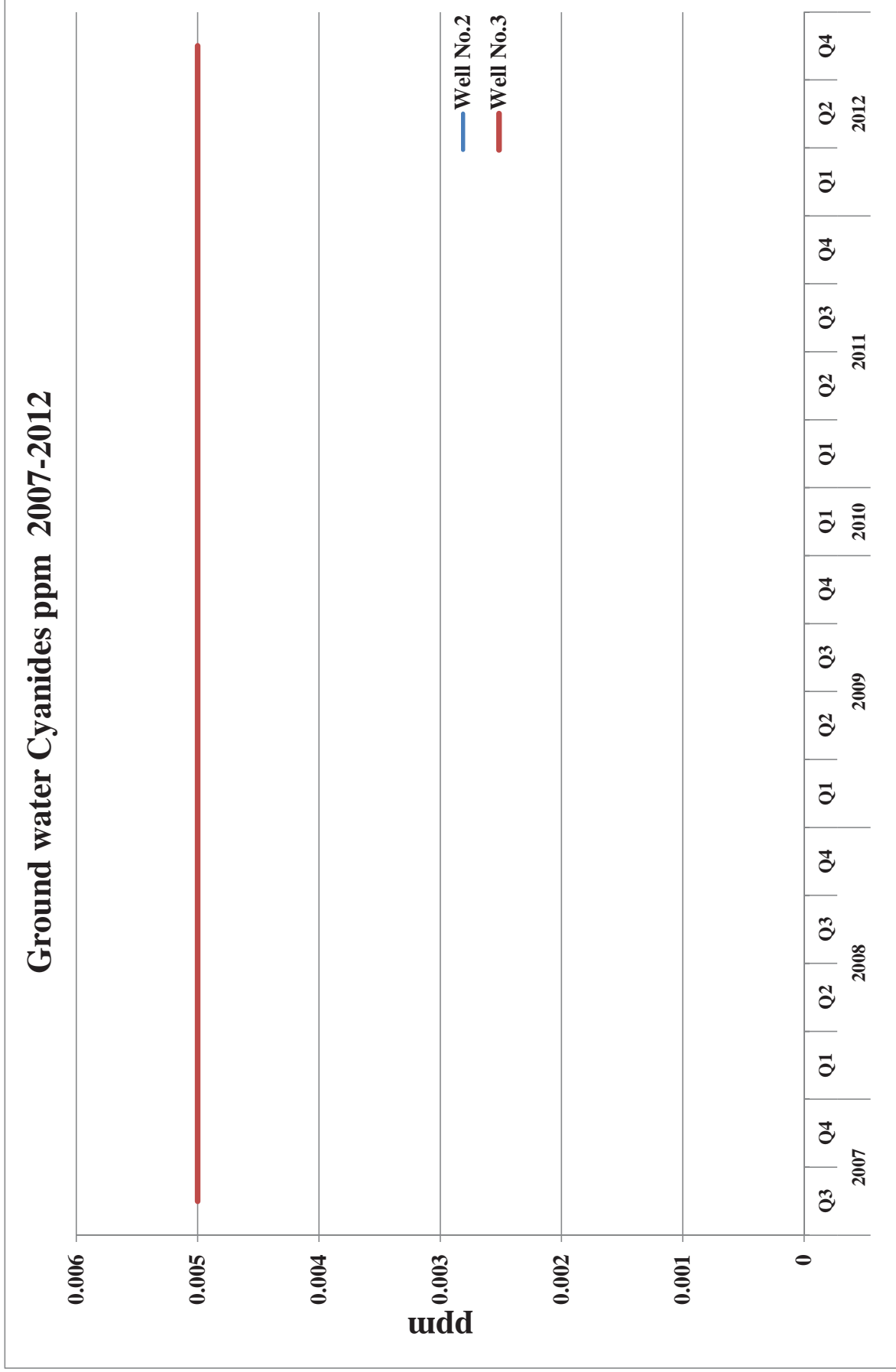
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Sample description:	Soil	Sample Id. No.:	Composite Sample-3
Source / Location:	ALBA	Date of test:	16-12-2013
Condition of sample during receipt:	Satisfactory	Consultant:	Bechtel
Parameters	Unit	Test method	Result
Total Petroleum Hydrocarbons			
Volatile Hydrocarbons (C ₅ -C ₁₀)	µg/kg	ASTM D 6730	< 50
Extractable Petroleum Hydrocarbons(C ₁₂ -C ₄₀)	mg/kg		Not Detected
BTEX			
Benzene	µg/kg	ASTM D 6730	< 50
Ethyl Benzene	µg/kg		< 50
Toluene	µg/kg		< 50
Xylene	µg/kg		< 50
Polyaromatic hydrocarbons			
Naphthalene	µg/kg	EPA 8270	< 50
Acenaphthylene	µg/kg		< 50
Acenaphthene	µg/kg		< 50
Fluorene	µg/kg		< 50
Phenanthrene	µg/kg		< 50
Anthracene	µg/kg		< 50
Fluoranthene	µg/kg		< 50
Pyrene	µg/kg		< 50
Benzo(a)anthracene	µg/kg		< 50
Chrysene	µg/kg		< 50
Benzo(b)fluoranthene	µg/kg		< 50
Benzo(k)fluoranthene	µg/kg		< 50
Benzo(a)pyrene	µg/kg		< 50
Indeno(1,2,3-cd)pyrene	µg/kg		< 50
Dibenzo(a,h)anthracene	µg/kg		< 50
Dibenzo(ghi)perylene	µg/kg		< 50
Remarks:			
1. Test results relate to the sample tested only.			
2. Test Report shall not be reproduced except in full, without written approval of the Laboratory.			
3. Samples from Trial Pit 5,8,10,12 were collected to form Composite Sample -3			
 T. Retna Raj General Manager Approved By		 V.H Murali Krishna Technical Incharge Reviewed by	
		 Christy Nicholas Laboratory Incharge Verified by	

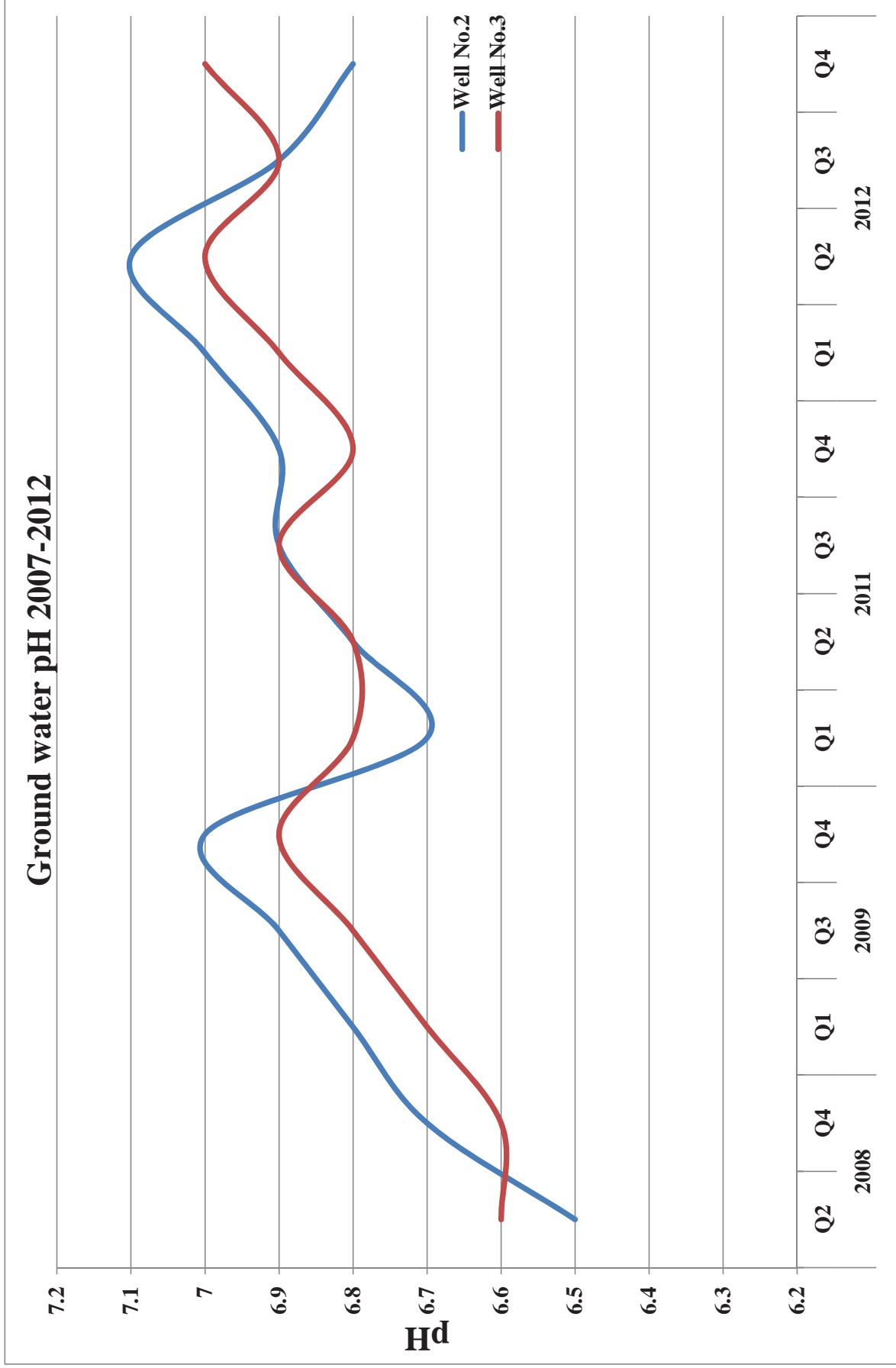


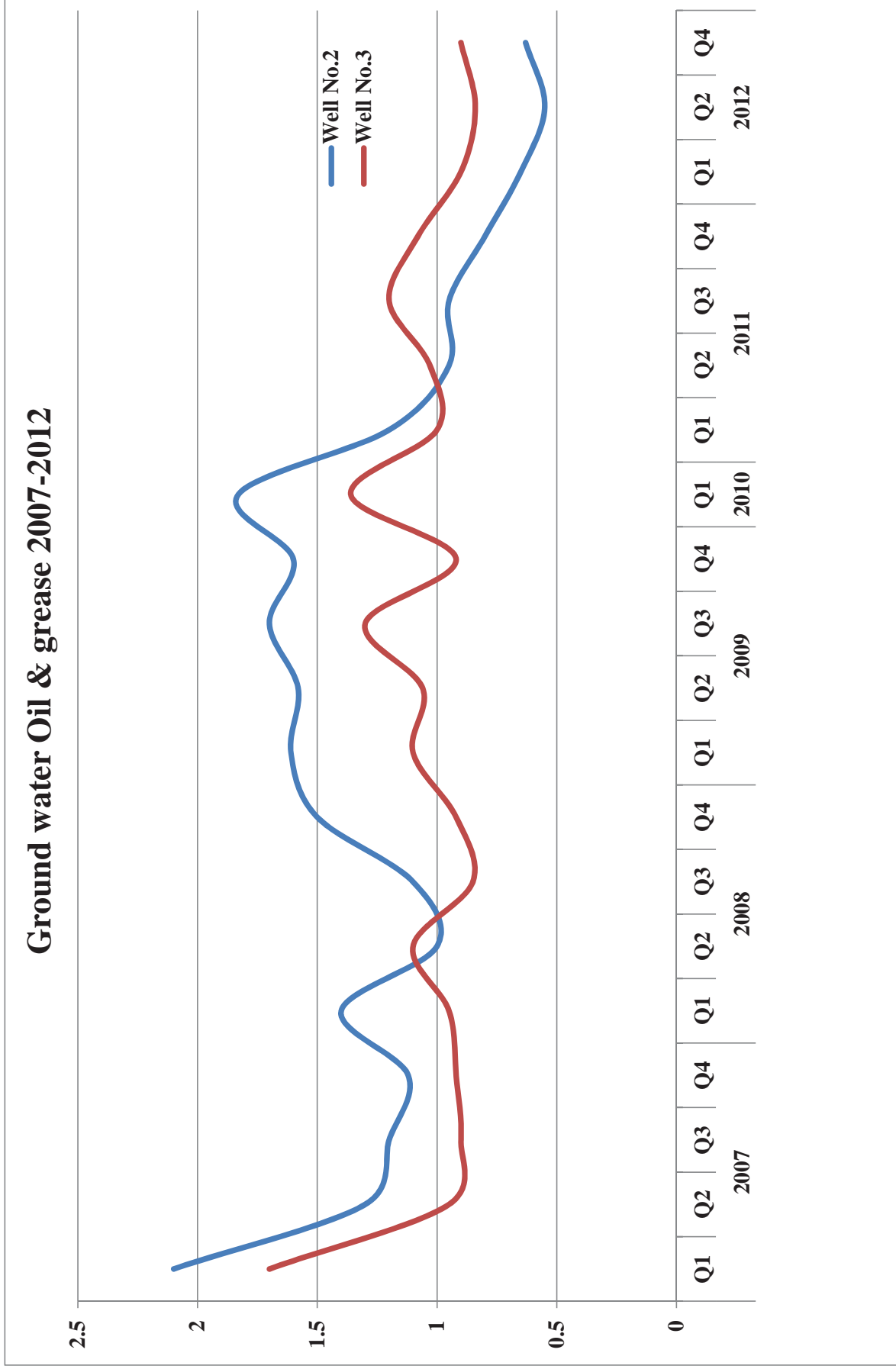
Appendix 7: Groundwater Monitoring Locations

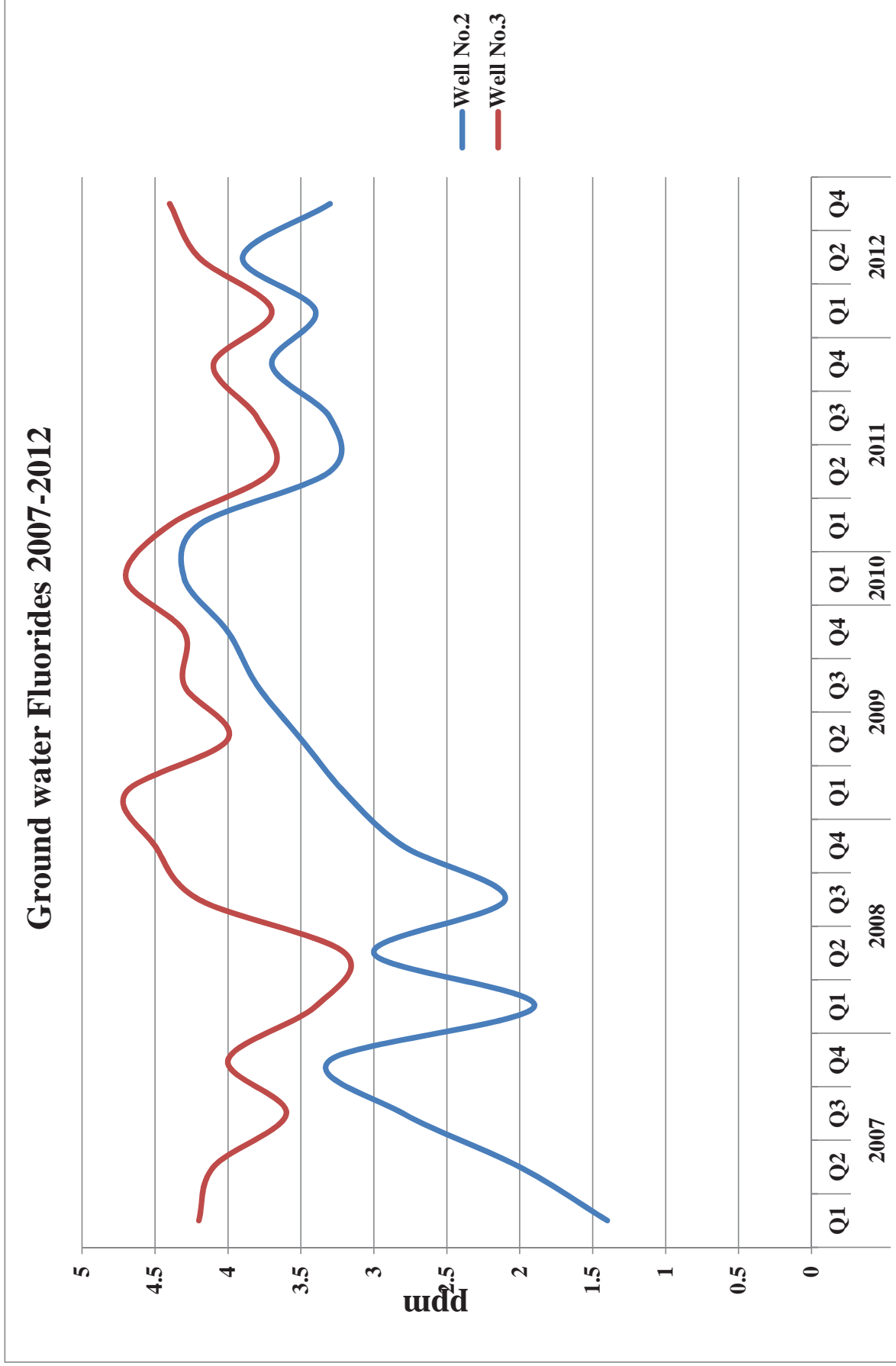


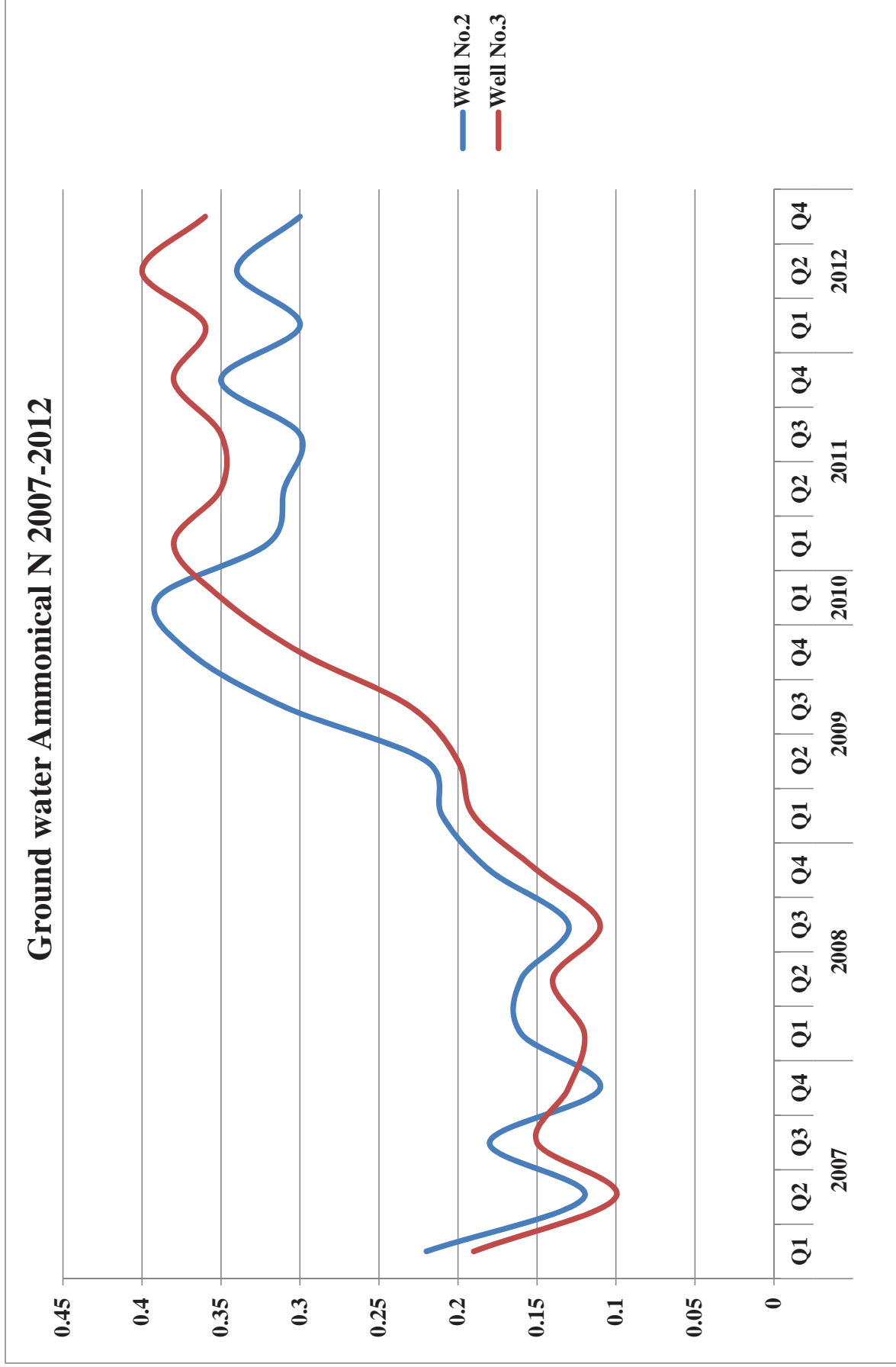
Appendix 8: Results Groundwater Monitoring 2007 – 2012













Appendix 9: Noise Monitoring Results 2013



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

Appendix 9: Noise Monitoring Results

Tebodin

Tebodin Middle East Ltd.
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Tourist Club Area
P.O. Box 2652
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United Arab Emirates

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April 24, 2014
Order number: 10921.00
Document number: 3311001
Revision: 0



Rev.	Date	Description	Author	Checked by
0	24 April 2014	First Issue	KB	MVV

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1.3	Conclusions	9



1 Noise Monitoring

1.1 Introduction

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 are presented in Figure 1 (day-time weekend-day, day-time weekday inside site premises, night-time weekday) and Figure 2 (day-time weekday). The corresponding UTM co-ordinates are listed in Table 1.



Figure 1 Locations of Noise Monitoring – Fence line and inside Alba's site premises



Figure 2: Locations of Noise Monitoring – Day-time, weekday



Table 1: UTM Co-ordinates of Noise Monitoring

Location Number				UTM Co-ordinates	
Day-time			Night-time		
Weekend Day	Week Day	Inside Site Premises	Weekday	Easting	Northing
1	1	-	5	460862 m E	2886035 m N
2	2	-	6	460977 m E	2885684 m N
3	3	-	1	461219 m E	2884945 m N
4	4	-	-	461131 m E	2884932 m N
5	5	-	-	459418 m E	2885583 m N
6	6	-	-	459358 m E	2885786 m N
7	7	-	-	459555 m E	2885112 m N
8	8	-	2	459651 m E	2884846 m N
9	9	-	3	459916 m E	2884649 m N
10		-	-	460989 m E	2884675 m N
11		-	-	460005 m E	2884821 m N
-	10	-	-	459598 m E	2886130 m N
-	11	-	-	459896 m E	2886420 m N
-	12	-	-	467146 m E	2893181 m N
-	13	-	-	458030 m E	2885724 m N
-	14	-	-	456734 m E	2885769 m N
-	-	-	4	459896 m E	2884642 m N
-	-	1	-	460020 m E	2884782 m N
-	-	2	-	460215 m E	2884812 m N
-	-	3	-	459611 m E	2884922 m N
-	-	4	-	459582 m E	2885023 m N
-	-	5	-	460040 m E	2884994 m N
-	-	6	-	460027 m E	2884994 m N



1.2 Monitored Noise Levels

Background noise levels in the area were recorded through monitoring. The noise monitoring results are presented in Table A-1 and A-2 respectively.

Table A- 1: Noise Data Inventory GTC and FTC

#	UTM Coordinates		Sound Pressure Levels in dB(A)					Remarks	Time
	Easting	Northing	L _{eq}	L _{max}	L _{min}	L ₁₀	L ₉₀		
Weekend- 8th February 2014 : Daytime									
1	460862	2886035	69.3	75.8	65.6	70.1	63.6	Close to PL-6 office	12:20
2	460977	2885684	66.5	72.4	60.4	69.1	61.9	Along the eastern fenceline	12:45
3	461219	2884945	71.0	73.7	66.5	71.9	67.0	South Gate- close to emergency clinic- heavy vehicle movements	13:10
4	461131	2884932	64.8	73.2	61.1	68.1	61.9	Fence-line east of ALBA lake	13:30
5	459418	2885583	62.2	64.4	59.8	62.5	61.0	North-west fenceline	13:50
6	459358	2885786	58.3	61.3	56.0	59.4	56.2		14:20
7	459555	2885112	66.5	68.7	65.6	67.2	65.8		14:45
8	459651	2884846	58.5	61.7	51.6	59.7	56.6	South-west corner	15:30
9	459916	2884649	58.5	62.3	56.6	59.7	56.6	Close to Jawad textile mill	15:00
10	460989	2884675	69.1	82.0	49.1	72.5	64.8	Excavation works ongoing close to ALBA lake	15:50
11	460005	2884821	66.0	74.3	60.8	69.5	61.7	South-east fenceline	16:20

Table A- 2: Noise Data Inventory GTC and FTC

#	UTM Coordinates		Sound Pressure Levels in dB(A)					Remarks	Time
	Easting	Northing	L _{eq}	L _{max}	L _{min}	L ₁₀	L ₉₀		
Weekday- 9th February 2014 : Daytime									
1	460862	2886035	69.4	75.6	65.4	70.0	63.4	Close to PL-6 office	9:30
2	460977	2885684	66.0	72.1	60.2	68.7	61.7	Along the eastern fenceline	10:00
3	461219	2884945	70.5	73.8	66.5	71.4	66.9	South Gate- close to emergency clinic- heavy vehicle movements	10:20
4	461131	2884932	64.0	72.5	60.2	67.2	61.4	Fence-line east of	10:30



#	UTM Coordinates		Sound Pressure Levels in dB(A)					Remarks	Time
	Easting	Northing	L _{eq}	L _{max}	L _{min}	L ₁₀	L ₉₀		
								ALBA lake	
5	459418	2885583	62.3	64.2	59.6	62.7	61.1	North-western fenceline	10:45
6	459358	2885786	59.0	62.1	56.4	59.7	56.5		11:20
7	459555	2885112	66.8	69.1	65.8	67.4	66.1		11:45
8	459651	2884846	58.6	61.9	51.8	59.9	56.7	South-west corner	12:30
9	459916	2884649	58.7	62.6	56.5	59.9	56.7	Close to Jawad textile mill	13:00
10	459598	2886130	66.0	73.0	64.8	66.5	65.1	North Gate	13:30
11	459896	2886420	67.3	70.2	65.4	68.5	65.9	Outside PS-4	14:20
Weekday- 10th February 2014 : Daytime									
12	467146	2893181	68.6	71.6	67.4	69.4	62.3	Calciner- close to proposed ship loading area	09:00
13	458030	2885724	73.5	80.0	46.1	48.4	75.4	Camps off-plot ALBA facility: heavy traffic	15:25
14	456734	2885769	61.0	67.8	50.8	65.6	52.6	Golf Course	16:00
Weekday- 9th February 2014 : Night time									
1	461219	2884945	65.6	73.0	60.1	70.0	62.5	Near South Gate	00:15
Weekday- 10th February 2014 : Night time									
1	459651	2884846	58.2	61.6	50.4	59.0	56.3	South-west corner	23:40
2	459916	2884649	57.0	62.0	50.1	59.1	56.1	Close to Jawad textile mill	00:10
3	459896	2884642	67.1	70.2	65.0	68.0	65.7	Outside PS-4	01:30
4	460862	2886035	69.0	75.0	65.4	70.1	63.4	Close to PL-6 office	02:10
5	460977	2885684	66.0	71.3	58.4	68.1	61.4	Along the eastern fenceline	03:15

1.3 Conclusions

As can be seen through the results of the monitoring revealed from the above Tables, the ambient noise levels at all areas (Leq 58.3 dB(A) – 73.5 dB(A)) were noted 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) except for the area close to the clinic where high noise levels were noted from vehicle movements along the nearby highway.



Appendix 10: Waste Water Discharge Quality

Wastewater Analysis - Half Year 1 of 2011

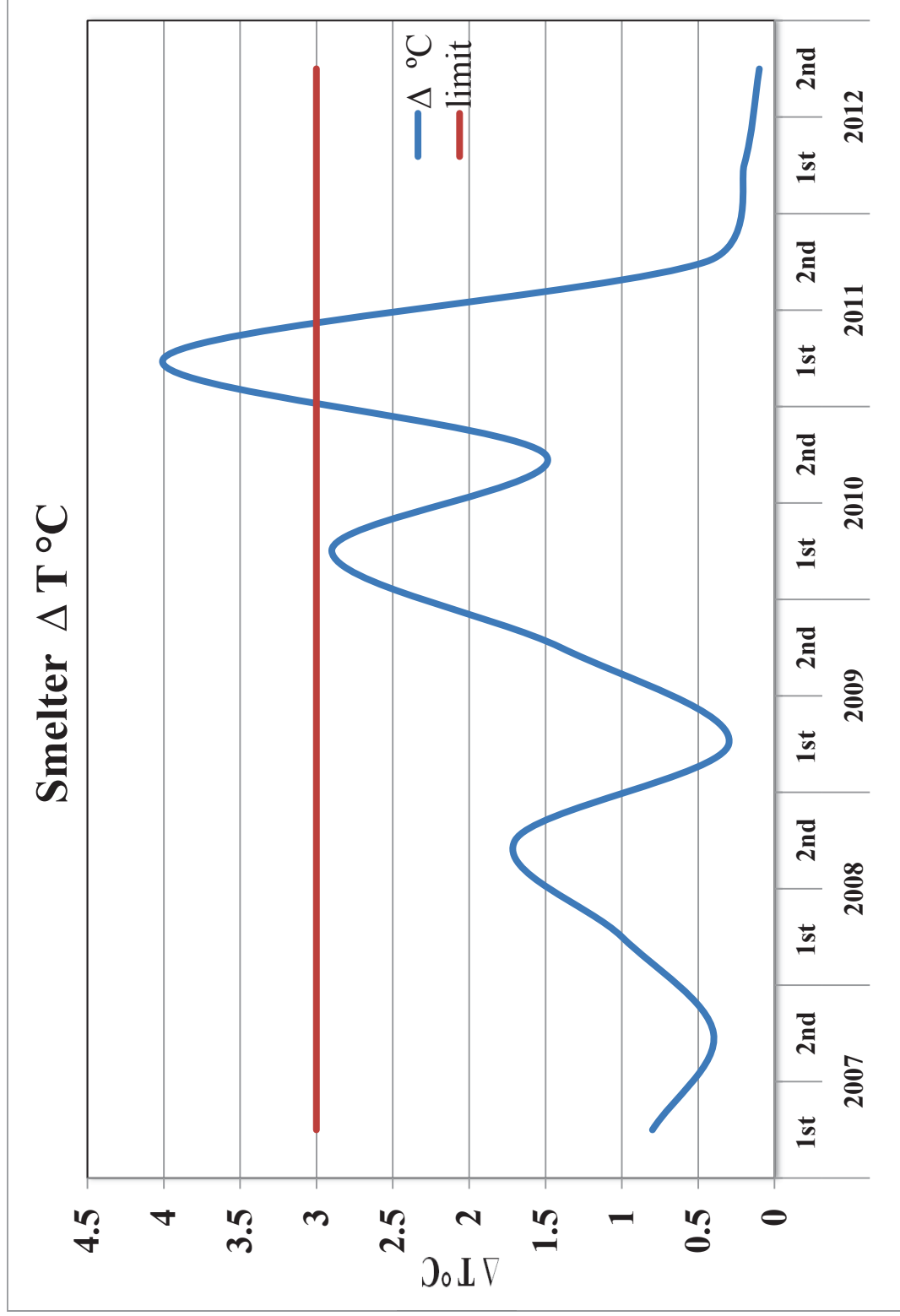
Sl.No:	Parameter	Unit	Permissible Max.*	Result (Smelter)	Result (Calciner)
1	Temperature Delta T	Dt °C	± 3	+1	+1
2	pH	pH	6 – 9	7.3	6
3	Total Suspended Solids	mg/l	35	0.85	1.1
4	Oil and Grease	mg/l	15	0.9	0.8
5	Sulphide	mg/l	1	Nil	Nil
6	Residual Chlorine	mg/l	2	Nil	0.02
7	Total Phosphate (P)	mg/l	2	0.33	0.6
8	B.O.D.	mg/l	50	<10	12
9	Iron	mg/l	10	0.4	0.45
10	Turbidity	N.T.U.	75	2.1	1.5
11	Total Cyanide	mg/l	0.1	<0.005	<0.005
12	Ammonia(As Nitrogen)	mg/l	3	0.45	0.55
13	Floating Particles	mg/m ²	Nil	Nil	Nil
14	Nitrate (NO ₃) as N	mg/l	10	3.77	0.02
15	Nitrite (NO ₂) as N	mg/l	1	0.92	0.01
16	Ch. Oxygen Demand	mg/l	350	88	172
17	Total Kjeldahl Nitrogen	mg/l	10	3.1	2.24
18	Total Organic Carbon	mg/l	50	7.1	10
19	Phenols	mg/l	1	0.07	0.01
20	Arsenic	mg/l	0.5	<0.01	<0.01
21	Cadmium	mg/l	0.05	0.04	< 0.02
22	Total Chromium	mg/l	1	0.06	0.01
23	Copper	mg/l	0.5	0.55	0.28
24	Lead	mg/l	1	< 0.15	<0.15
25	Mercury	mg/l	0.005	<0.001	<0.001
26	Nickel	mg/l	0.5	0.04	0.075
27	Zinc	mg/l	5	1.27	0.01
28	Total Coliforms	MPN/100	10,000	14	13
29	Aluminium	mg/l	25	0.029	<0.01
30	Fluorescent Petroleum Materials	mg/l	0.1	0.07	<0.001

* Gazette Notification dated 12/12/2001



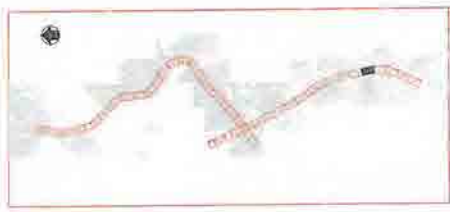
Appendix 11: Marine Ambient Water Temperatures

Appendix 11 – Marine water ambient temperatures





Appendix 12: Road Network



KEYPLAN

LEGEND AND ABBREVIATIONS

- EXISTING:**
- EXISTING RIGHT OF WAY
 - - - EDGE OF ROADWAY
- PROPOSED:**
- PROPOSED ROAD RESERVATION
 - - - EDGE OF SHOULDER
 - EDGE OF CARRIAGEWAY
 - EDGE OF MEDIAN
 - AT GRADE
 - RAMP
 - BRIDGE



F I N A L

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KINGDOM OF BAHRAIN
MINISTRY OF WORKS AND HOUSING
 ROADS PLANNING & DESIGN DIRECTORATE

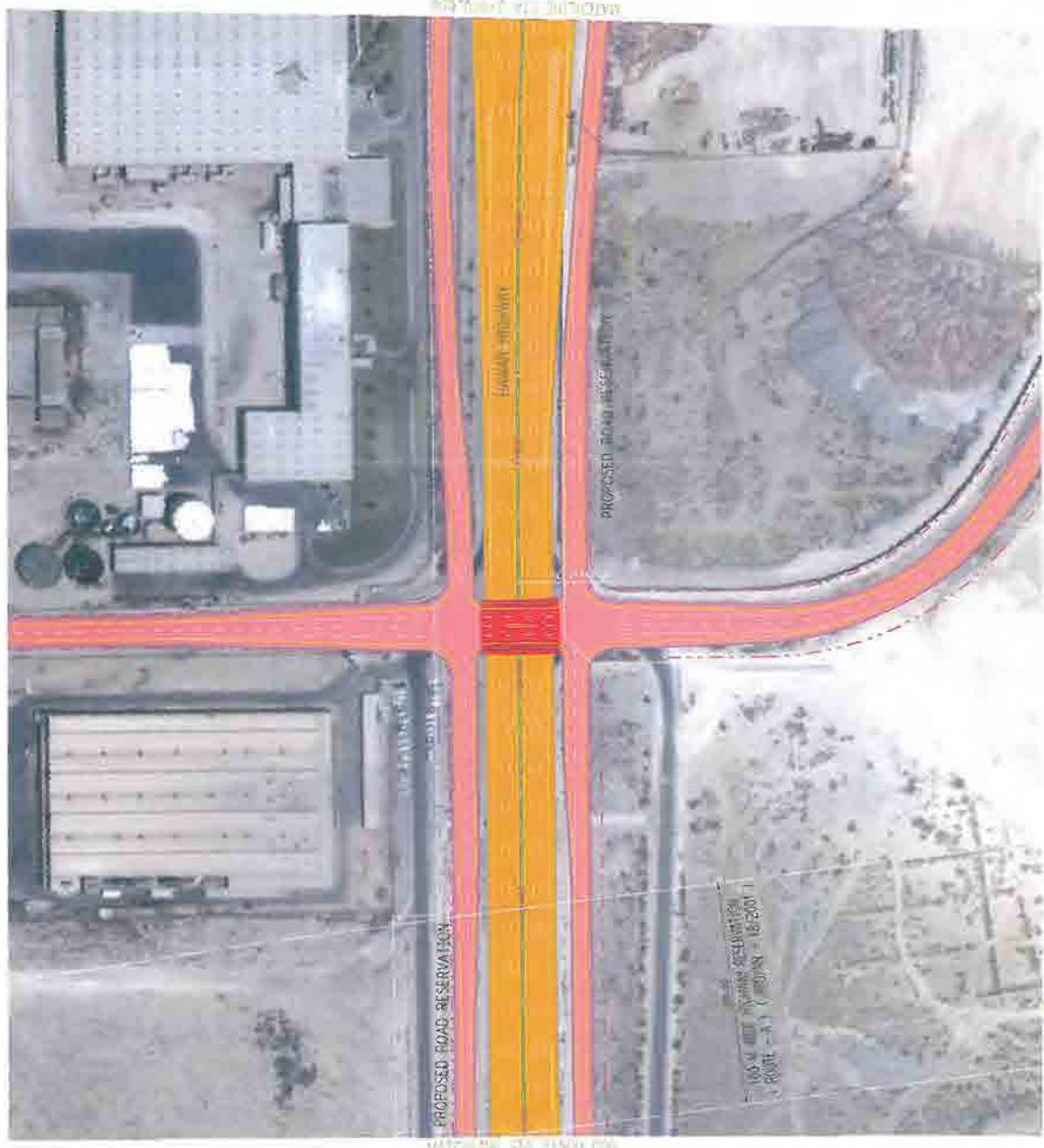


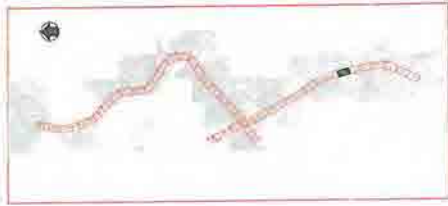
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 TRAFFIC IMPACT STUDY

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 (STA 2+500.000 TO STA 3+000.000)

DESIGNED: RPJ	DRAWN: ZSP	CHECKED: HA
DATE: FEBRUARY 2005	APPROVED: HA	

DWG NO.: 4454200005
 SHEET NO.:





KEYPLAN
LEGEND AND ABBREVIATIONS

- EXISTING:**
- EXISTING RIGHT OF WAY
 - - - EDGE OF ROADWAY
- PROPOSED:**
- - - PROPOSED ROAD RESERVATION
 - EDGE OF SHOULDER
 - EDGE OF CARRIAGEWAY
 - EDGE OF MEDIAN
 - AT GRADE
 - FLYOVER
 - BRIDGE



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KINGDOM OF BAHRAIN
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ROADS PLANNING & DESIGN DIRECTORATE

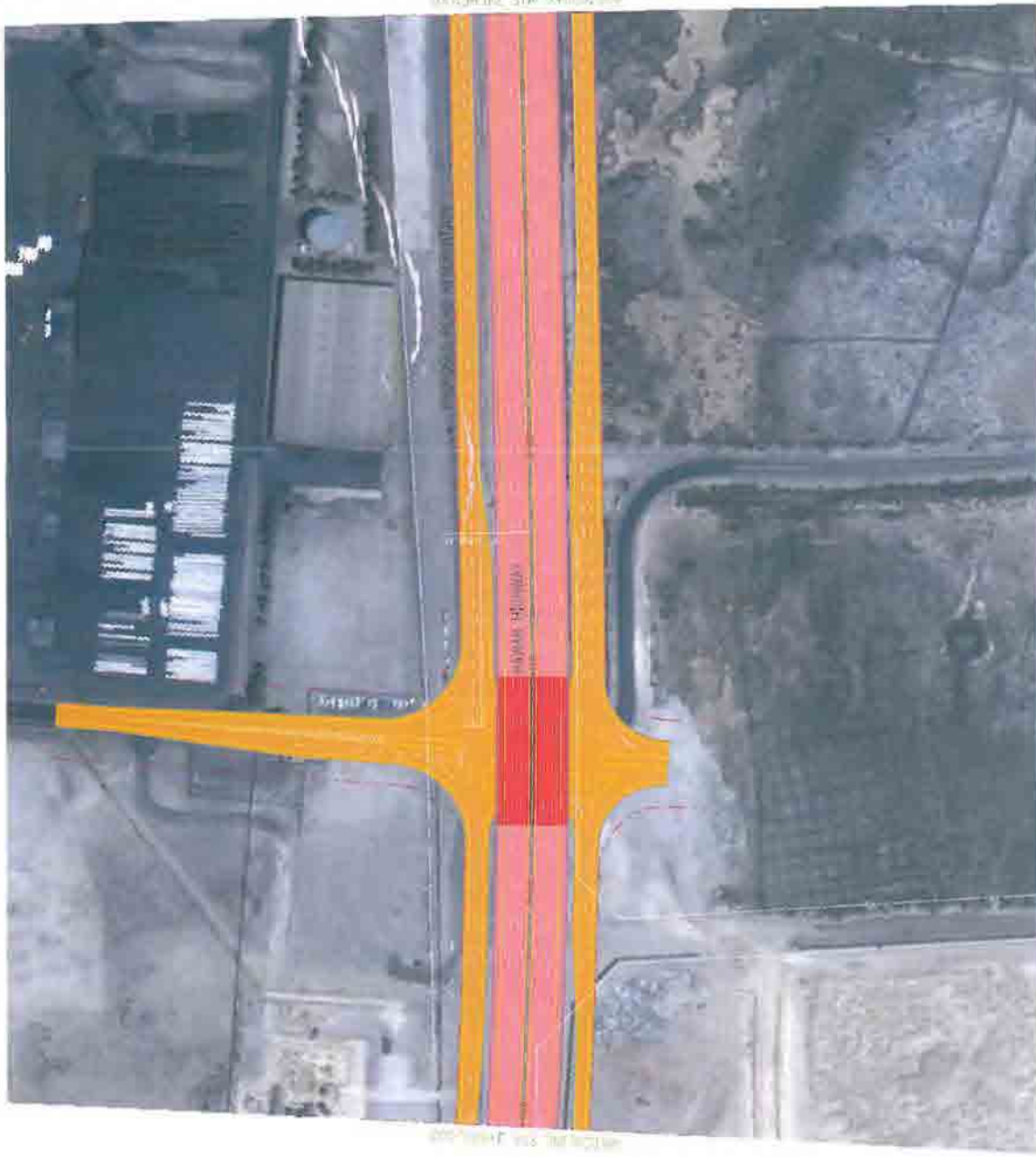


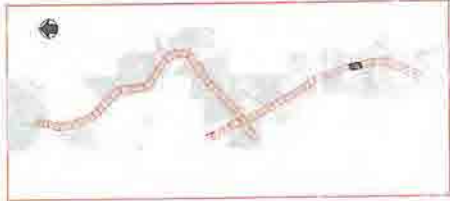
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DESIGNED: R/J | DRAWN: J/S | CHECKED: HA
DATE: FEBRUARY 2005 | APPROVED: HA

DWG. NO.: 6456420001 | SHEET NO.:





KEYPLAN

LEGEND AND ABBREVIATIONS

- EXISTING:**
- - - - - EXISTING RIGHT OF WAY
 - - - - - EDGE OF ROADWAY
- PROPOSED:**
- - - - - PROPOSED ROAD RESERVATION
 - - - - - EDGE OF SHOULDER
 - - - - - EDGE OF CARRIAGEWAY
 - - - - - EDGE OF MEDIAN
 - - - - - AT GRADE
 - - - - - ELEVATOR



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REV.	DATE	DESCRIPTION	APPROVED

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 ROADS PLANNING & DESIGN DIRECTORATE

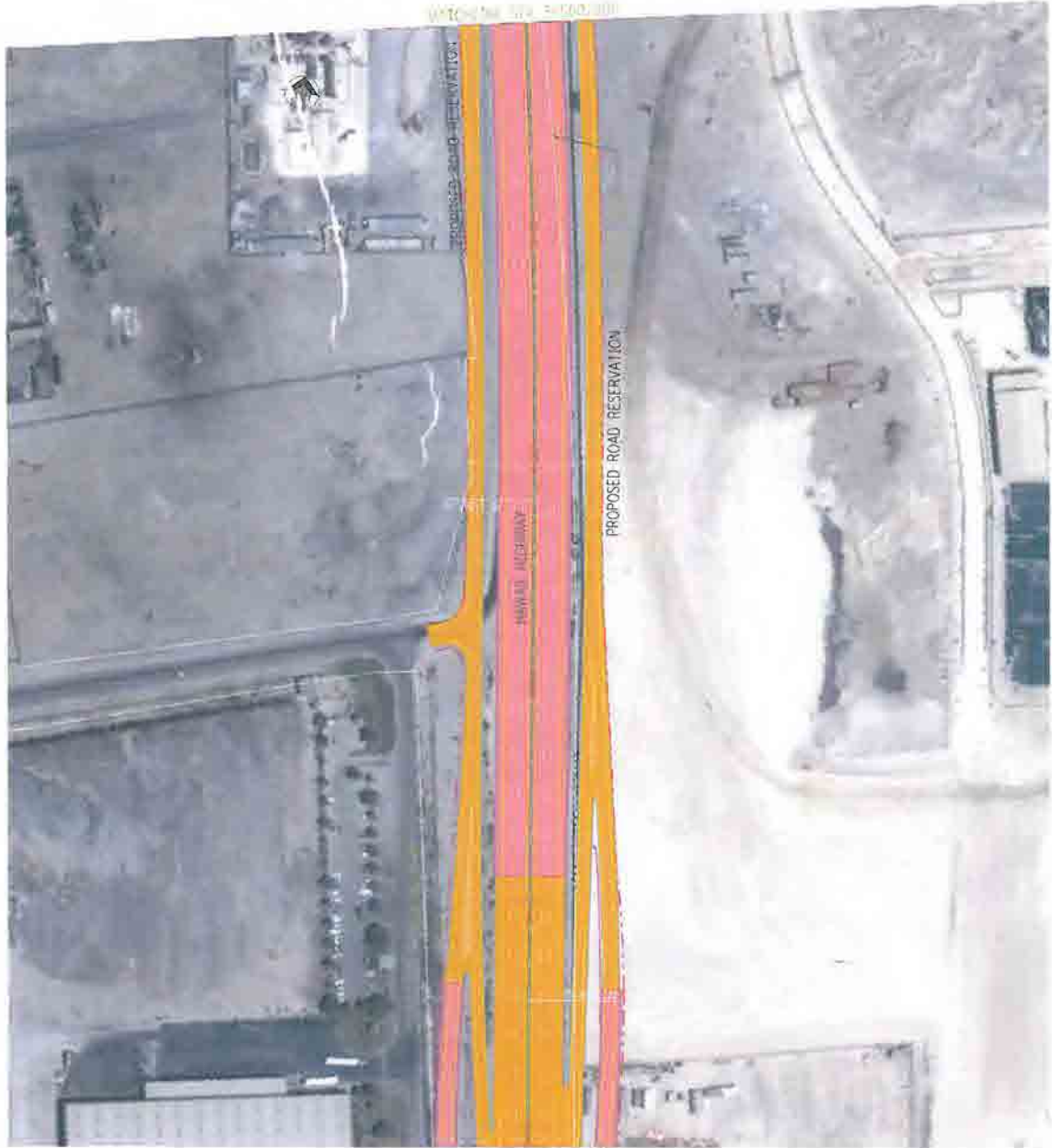


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 TRAFFIC IMPACT STUDY

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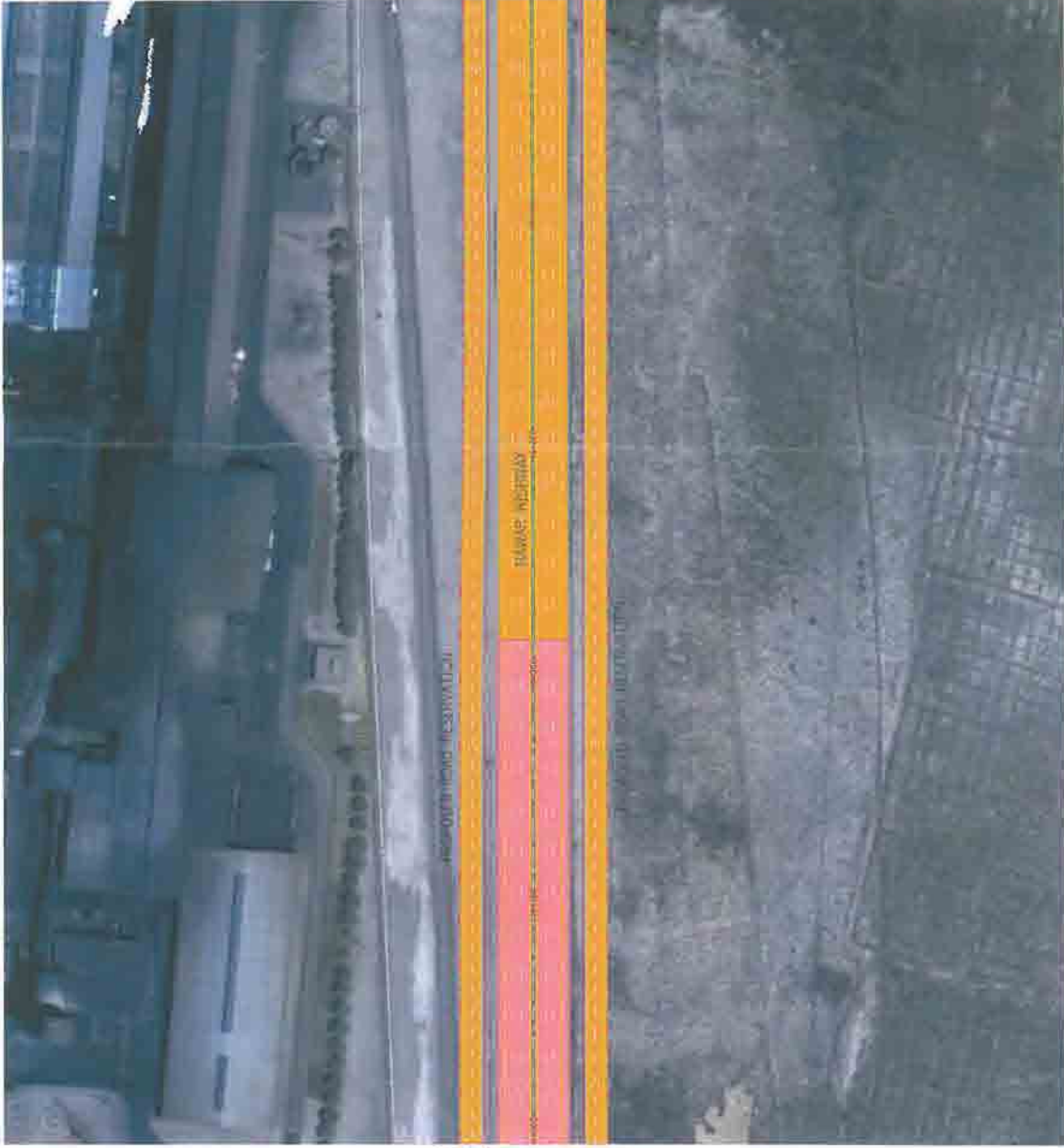
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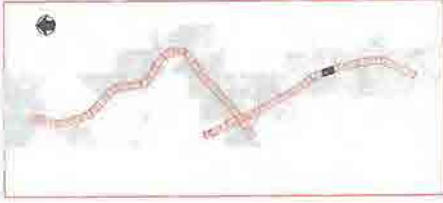
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WATER MARK: 2005



MATCHLINE STA 4+500.000

MATCHLINE STA 4+000.000



KEYPLAN
LEGEND AND ABBREVIATIONS

EXISTING:

- EXISTING RIGHT OF WAY
- EDGE OF ROADWAY

PROPOSED:

- PROPOSED ROAD RESERVATION
- EDGE OF SHOULDER
- EDGE OF CARRIAGEWAY
- EDGE OF MEDIAN
- AT GAUGE
- FLYOVER



F I N A L

REV.	DATE	DESCRIPTION	APPROVED

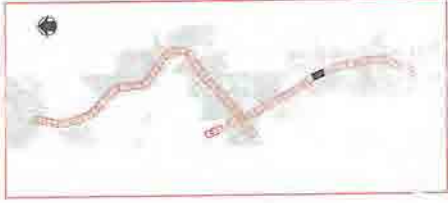
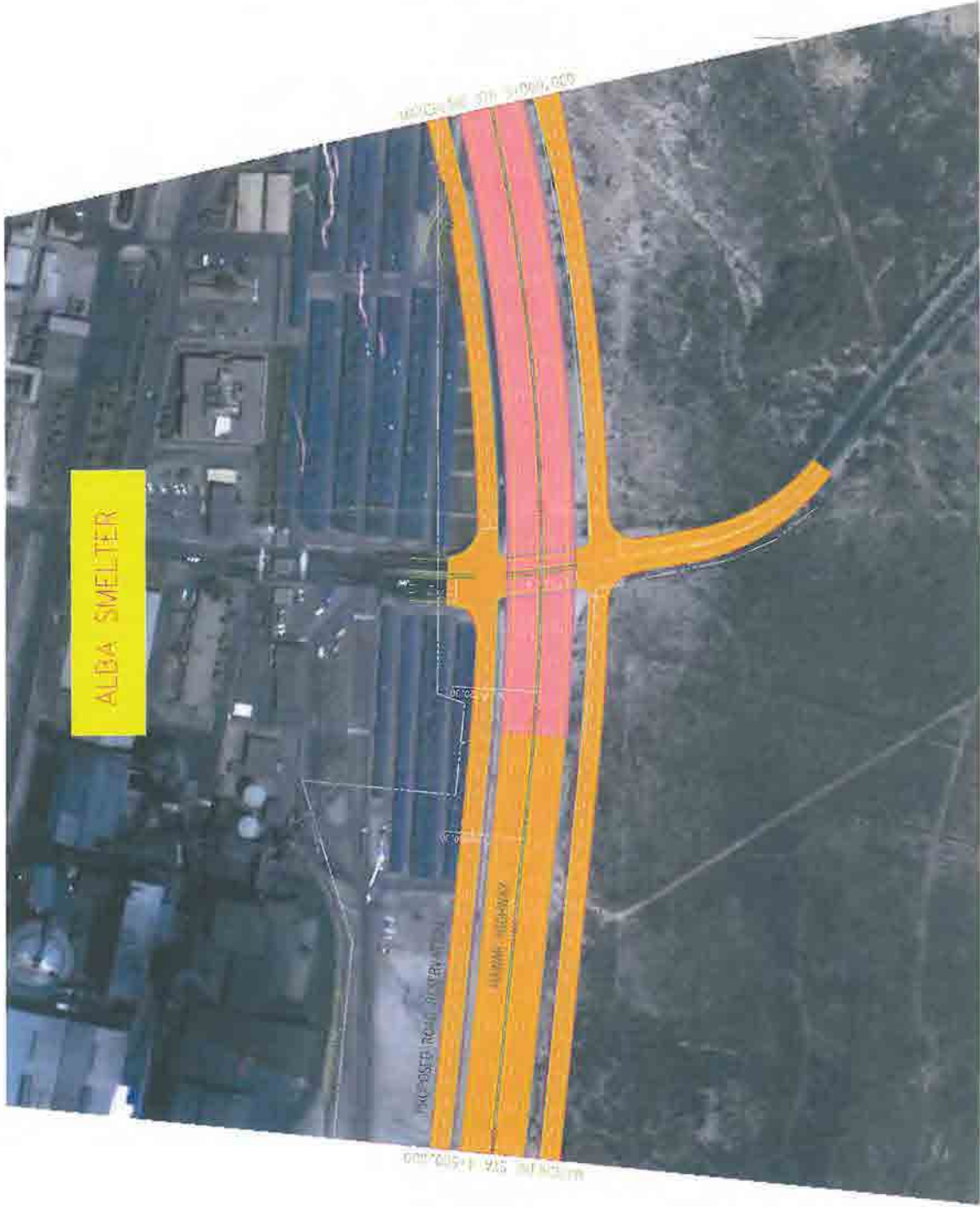
KINGDOM OF BAHRAIN
MINISTRY OF WORKS AND HOUSING
ROADS PLANNING & DESIGN DIRECTORATE



PARSONS
GLOBAL SERVICES LIMITED
CONTRACT: BAHRAIN-QATAR CAUSEWAY
TRAFFIC IMPACT STUDY

DRAWING TITLE: ROADWAY LAYOUT
(STA 4+000.000 TO STA 4+500.000)

DESIGNED: RPJ	DRAWN: JSP	CHECKED: HA
DATE: FEBRUARY 2002	APPROVED: HA	SHT. NO.
DWG NO.: B45942CR008		



KEYPLAN
LEGEND AND ABBREVIATIONS

EXISTING:

- EXISTING RIGHT OF WAY
- EDGE OF ROADWAY

PROPOSED:

- PROPOSED ROAD RESERVATION
- EDGE OF SHOULDER
- EDGE OF CARRIAGEWAY
- EDGE OF MEDIAN
- AT GRADE
- FLOWER



F I N A L

REV.	DATE	DESCRIPTION	APPROVED

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MINISTRY OF WORKS AND HOUSING
ROADS PLANNING & DESIGN DIRECTORATE

PARSONS
GLOBAL SERVICES LIMITED
CONTRACT LICENSE NO. 18/1/02

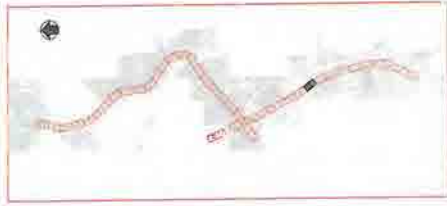
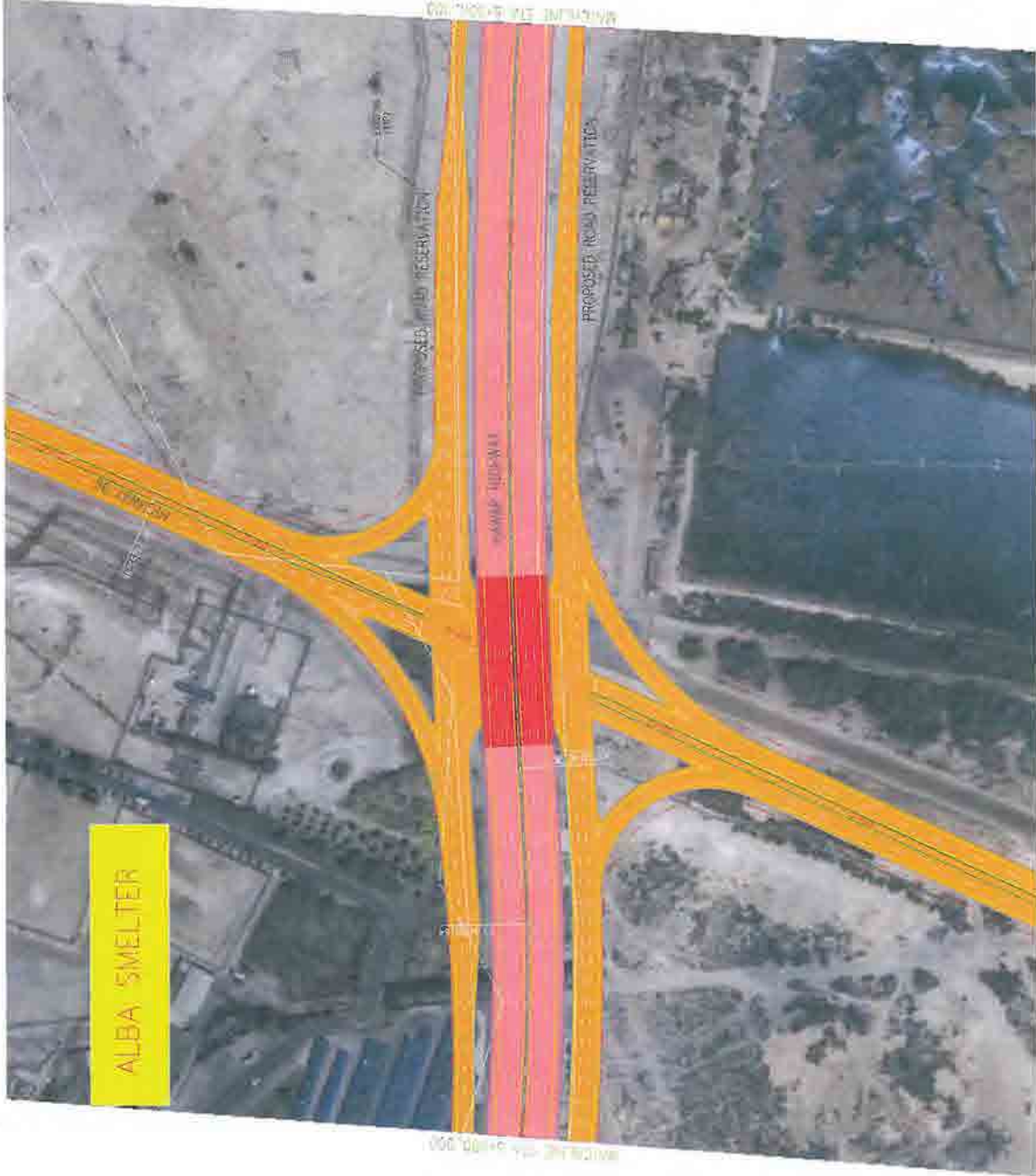
BAHRAIN-QATAR CAUSEWAY
TRAFFIC IMPACT STUDY

DRAWING TITLE
ROADWAY LAYOUT
(STA. 4+500.000 TO STA 5+000.000)

DESIGNED: RPJ	DRAWING: ZJP	CHECKED: TA

DATE: FEBRUARY 2005	APPROVED: HA

DWG NO.: 6456240005 **SHT. NO.**



KEYPLAN

LEGEND AND ABBREVIATIONS

EXISTING:

- EXISTING RIGHT OF WAY
- EDGE OF ROADWAY

PROPOSED:

- PROPOSED ROAD RESERVATION
- EDGE OF SHOULDER
- EDGE OF CARRIAGEWAY
- EDGE OF MEDIAN
- AT GRADE
- FLYOVER
- BRIDGE



F I N A L

REV.	DATE	DESCRIPTION	APPROVED

KINGDOM OF BAHRAIN
MINISTRY OF WORKS AND HOUSING
 ROAD PLANNING & DESIGN DIRECTORATE

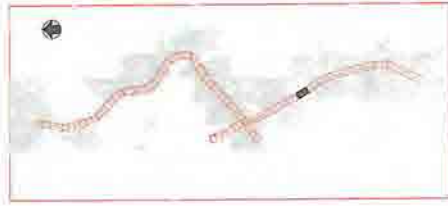


PARSONS
GLOBAL SERVICES LIMITED
 CONTRACT
 BAHRAIN-QATAR CAUSEWAY
 TRAFFIC IMPACT STUDY

DRAWING TITLE
 ROADWAY LAYOUT
 (STA. 5+000.000 TO STA. 5+500.000)

DESIGNED: [REDACTED]	DRAWN: JSP	CHECKED: [REDACTED]
DATE: FEBRUARY 2005	APPROVED: [REDACTED]	

DWG NO. I 54582020010 SHEET NO.



KEYPLAN
LEGEND AND ABBREVIATIONS

- EXISTING:**
- EXISTING RIGHT OF WAY
 - EDGE OF ROADWAY
- PROPOSED:**
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 - EDGE OF SHOULDER
 - EDGE OF CARRIAGEWAY
 - EDGE OF MEDIAN
 - AT GRADE
 - FLOWER



F I N A L

REV.	DATE	DESCRIPTION	APPROVED

KINGDOM OF BAHRAIN
MINISTRY OF WORKS AND HOUSING
 ROADS PLANNING & DESIGN DIRECTORATE

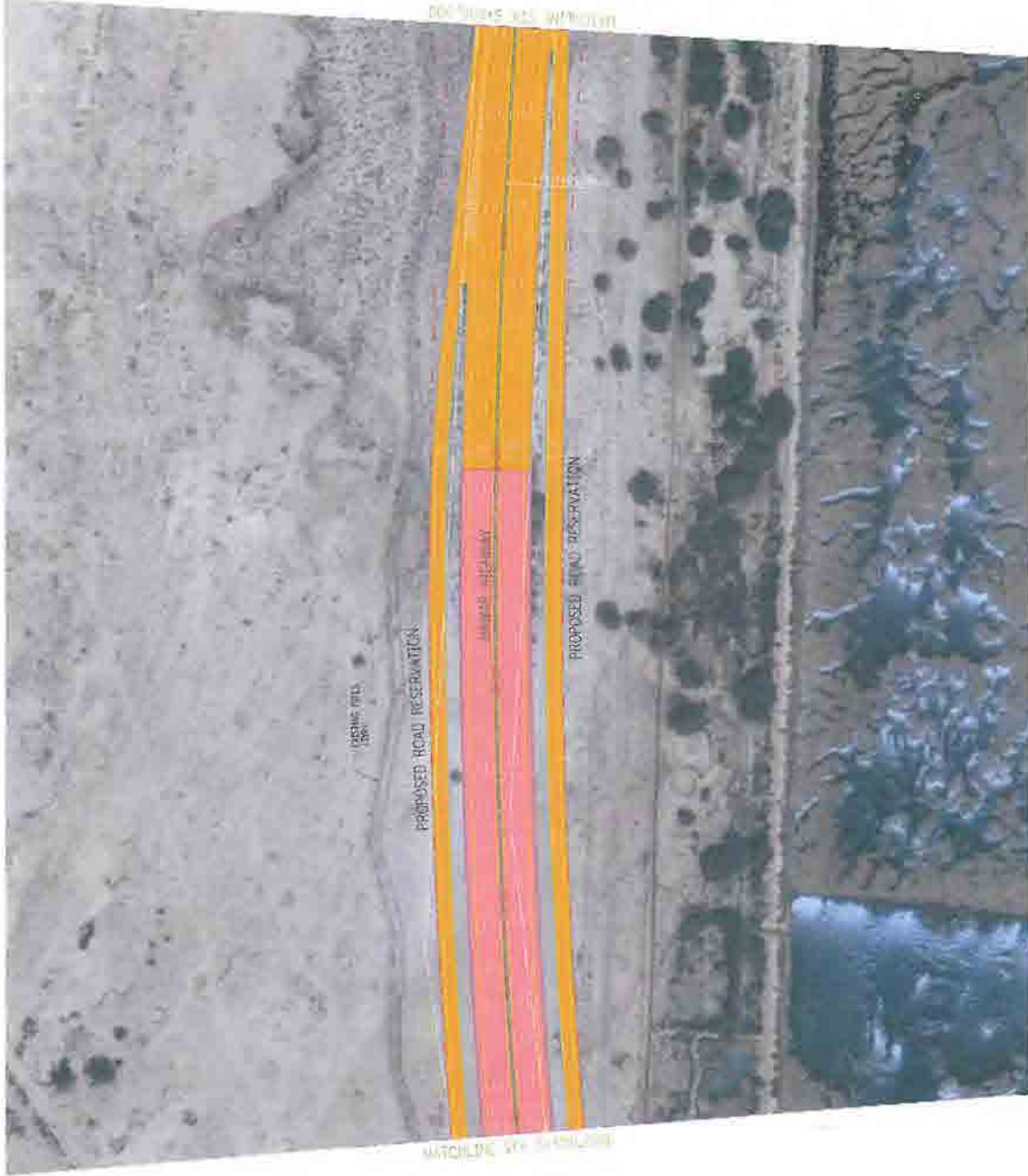


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TRAFFIC IMPACT STUDY

DRAWING TITLE: ROADWAY LAYOUT
STA 5+500.000 TO STA 6+000.000

DESIGNED: RFJ	DRAWN: JSP	CHECKED: HA
DATE: FEBRUARY 2023	APPROVED: HA	

DWG NO.: 6454260611
 SHEET NO.





Appendix 13: One-Day Traffic Survey

MetroCount Traffic Executive

Average Daily Traffic 24 hours

Location: [Hawar Highway] - Near Power Station

Survey Duration: 8:00 Monday, May 20, 2013 => 9:12 Thursday, May 23, 2013

Site No. 37

Direction: Northbound

Hours	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300							
00:15	42	33	29	23	34	152	233	317	315	333	385	372	349	372	329	541	404	366	284	211	109	71	70	73							
00:30	26	19	34	32	68	194	261	382	294	305	395	327	297	357	367	567	351	460	255	179	111	71	83	66							
00:45	17	15	27	26	70	261	305	345	257	325	377	332	379	311	467	459	333	356	283	115	92	103	220	45							
00:60	26	33	22	34	96	210	356	253	324	304	292	306	339	500	525	431	339	281	171	172	111	79	118	40							
Total Hours	110	79	111	114	267	815	1750	1276	1189	1267	1440	1337	1343	1330	1687	1576	1426	1402	911	476	411	322	479	303							
Average Daily Traffic	21702											AM PEAK (09:45 - 10:45)					1461					PM PEAK (14:30 - 15:30)					2100				

Average Daily Traffic 11hr
From 06:00 To 18:00

Northbound	18074
Southbound	17125
Both Direction	35199

Direction: Southbound

Hours	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300							
00:15	57	33	24	27	57	231	727	317	445	383	361	311	331	347	366	381	321	260	180	135	114	100	156	39							
00:30	42	32	17	25	117	366	653	301	394	351	353	335	305	274	264	347	334	233	176	142	126	106	107	37							
00:45	34	28	28	22	144	550	438	339	373	343	309	308	339	260	356	253	235	212	193	153	117	107	94	29							
00:60	43	24	30	63	201	762	435	405	427	395	319	316	331	317	309	216	240	225	184	130	94	165	51	25							
Total Hours	175	116	90	136	516	1908	2252	1361	1631	1471	1341	1263	1304	1294	1197	1129	929	713	540	400	377	407	407	125							
Average Daily Traffic	22097											AM PEAK (05:30 - 06:30)					2692					PM PEAK (14:30 - 15:30)					1393				

[Hawar Highway] - Near Power Station

Average Daily Traffic 24 Hours



Last Five Year Comparison



Last Five Year Comparison





Appendix 14: Four-day Traffic Survey obtained from MoE

Total

Hawar Highway - Highway 96

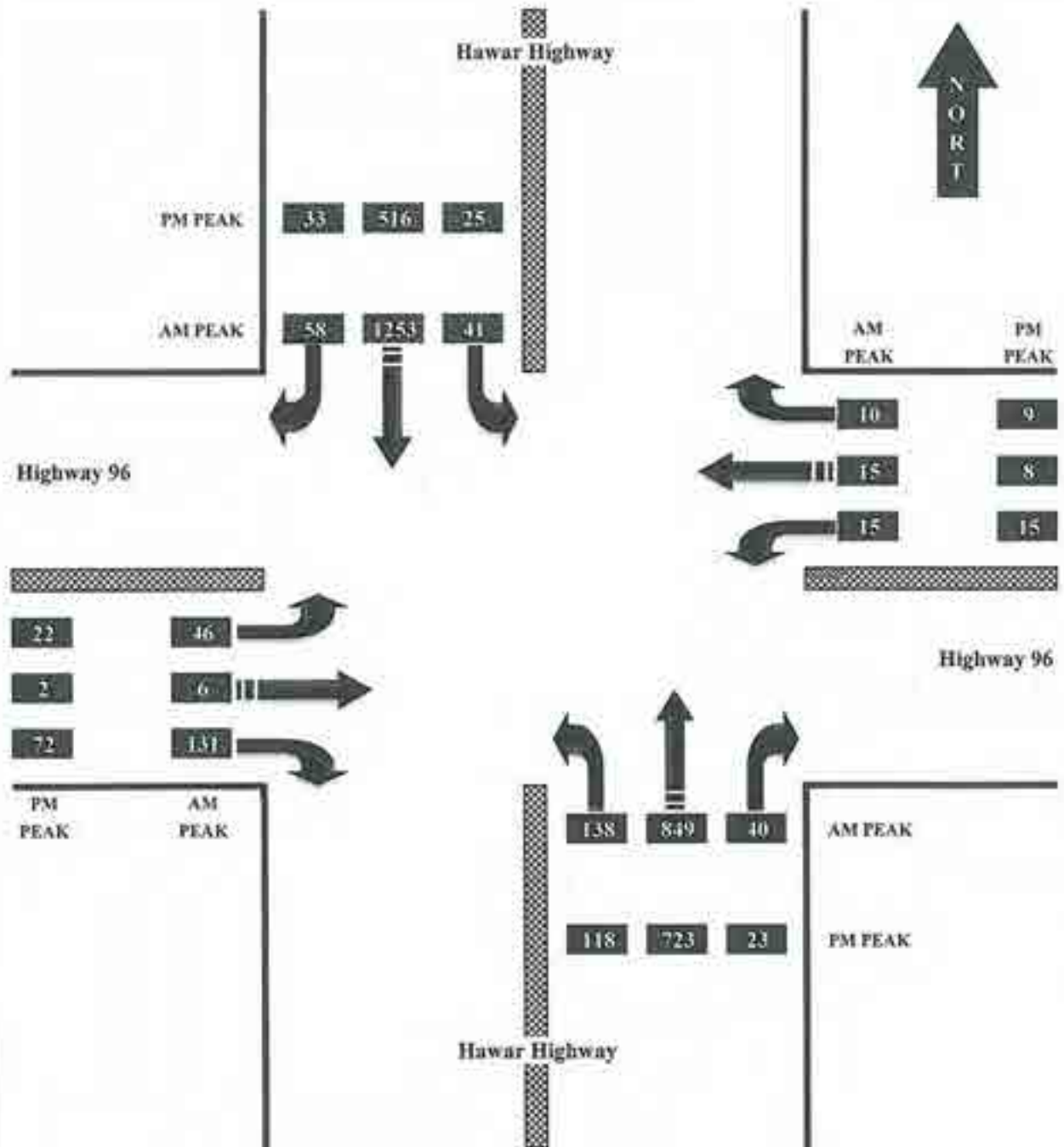
AM PEAK : FLOW(6:30-7:30)

MCC2010110

SITE NO. TSX.067

PM PEAK : FLOW(13:45-14:45)

DATE : Thu. 15/07/2010



TURNING MOVEMENT COUNTS

LOCATION :	Hawar Highway - Highway 96											
DATE :	Thu. 15/07/2010									MCC2010110		
SITE NO.	TSX.067											
	Hawar Highway						Highway 96					
TIME	FROM NORTH			FROM SOUTH			FROM EAST			FROM WEST		
FROM TO	LT	ST	RT	LT	ST	RT	LT	ST	RT	LT	ST	RT
6:30 - 6:45	11	426	16	36	249	14	6	5	1	16	1	43
6:45 - 7:00	8	387	11	38	228	9	3	2	2	9	4	49
7:00 - 7:15	13	247	17	31	190	7	2	4	3	9	1	22
7:15 - 7:30	9	193	14	33	182	10	4	4	4	12	0	17
7:30 - 7:45	7	160	11	29	169	8	4	2	2	10	2	15
7:45 - 8:00	4	148	9	34	183	6	2	5	3	15	1	16
8:00 - 8:15	5	135	12	29	175	5	3	2	2	9	0	20
8:15 - 8:30	3	109	10	31	178	4	4	3	1	7	0	14
TOTAL	60	1805	100	261	1554	63	28	27	18	87	9	196
AV.HOURLY	30	903	50	131	777	32	14	14	9	44	5	98
FLOW(6:30-7:30)	41	1253	58	138	849	40	15	15	10	46	6	131
12:30 - 12:45	7	80	9	28	168	5	4	3	3	6	0	26
12:45 - 13:00	9	85	11	33	186	7	3	6	0	9	1	25
13:00 - 13:15	5	85	8	26	163	4	5	2	1	8	0	23
13:15 - 13:30	6	97	6	25	155	6	3	3	3	10	3	19
13:30 - 13:45	4	98	9	27	167	8	4	4	0	8	2	22
13:45 - 14:00	8	135	10	30	171	5	6	2	3	5	1	23
14:00 - 14:15	6	138	5	26	185	7	3	3	1	6	0	17
14:15 - 14:30	6	134	7	33	190	6	4	1	4	3	0	19
14:30 - 14:45	5	109	11	29	177	5	2	2	1	8	1	13
14:45 - 15:00	3	99	8	24	168	4	3	4	0	6	0	16
TOTAL	59	1060	84	281	1730	57	37	30	16	69	8	203
AV.HOURLY	24	424	34	112	692	23	15	12	6	28	3	81
FLOW(13:45-14:45)	25	516	33	118	723	23	15	8	9	22	2	72

TOTAL FLOWS FOR 4.5 HOURS

7842



Appendix 15: United Nations Population and Development Statistics



1. Population Trends:

a. Population Size of Bahrain

The population of Bahrain increased from 358 thousand in 1980 to approximately 1.3 million in 2010. It is expected that the population will keep on increasing to reach 1.8 million in 2050.

Table 1: Population Size of Bahrain by Sex, 1980 to 2050

Year	Population Size (thousands)		
	Males	Females	Total
1980	209	149	358
1985	238	179	417
1990	285	208	493
1995	323	236	559
2000	366	272	638
2005	415	310	725
2010	788	474	1,262
2015*	868	536	1,404
2020*	923	585	1,508
2025*	963	625	1,588
2030*	994	660	1,654
2035*	1,017	693	1,711
2040*	1,033	724	1,758
2045*	1,039	751	1,790
2050*	1,031	770	1,801

Source: United Nations, World Population Prospects: The 2010 Revision, Available on: http://esa.un.org/unpd/wpp/unpp/panel_indicators.htm

* Projections (medium variant)

b. Population Growth in Bahrain

The growth rate of the population in Bahrain decreased from 3.35 percent to 2.55 percent during the period 1985-2005. This was followed by a sharp increase in the growth rate to 11.09 percent in 2005-2010¹.

Projections show that the growth rate of the Bahraini population will decrease to 2.13 percent in 2010-2015 and this downward trend will continue and will reach 0.13 percent in the period 2045-2050.

Table 2: Population Growth in Bahrain, 1980 to 2050

Period	Population growth rate (%)
1980-1985	3.05
1985-1990	3.35
1990-1995	2.52
1995-2000	2.65
2000-2005	2.55
2005-2010	11.09
2010-2015*	2.13
2015-2020*	1.43
2020-2025*	1.04
2025-2030*	0.82
2030-2035*	0.67
2035-2040*	0.54
2040-2045*	0.36
2045-2050*	0.13

Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)

¹ The net migration rate for 2005-2010 is 90.2 per 1,000 population - ref. Section 2.c.ii.



2. Indicators of Demographic Transition:

a. Mortality Transition in Bahrain

i. Life Expectancy

Life Expectancy at Birth in Bahrain gained 4.1 years from the period 1980-1985 to the period 2005-2010, increasing from 70.5 years to 74.6 years. It is projected to reach 79.6 years for the period 2045-2050.

Table 3: Life Expectancy at Birth in Bahrain, 1980 to 2050

Year	Life Expectancy at Birth (years)		
	Male	Female	Total
1980-1985	69.3	72.3	70.5
1995-2000	70.8	73.3	71.9
1990-1995	71.7	73.9	72.7
1995-2000	72.6	74.5	73.4
2000-2005	73.3	74.9	74.0
2005-2010	74.0	75.4	74.6
2010-2015*	74.7	76.1	75.3
2015-2020*	75.3	76.7	75.8
2020-2025*	75.9	77.4	76.5
2025-2030*	76.5	78.3	77.2
2030-2035*	77.2	79.0	77.8
2035-2040*	77.7	79.8	78.5
2040-2045*	78.3	80.5	79.1
2045-2050*	78.9	81.1	79.6

Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)

ii. Infant mortality

The Infant Mortality Rate of the Bahraini Population was estimated at 21.9 infant deaths per 1,000 live births in 1980-1985 and decreased to 7.2 infant deaths per 1,000 live births in 2005-2010. It is projected to continue this downward trend to reach 4.3 infant deaths per 1,000 live births in 2045-2050.

Table 4: Infant Mortality Rate in Bahrain, 1980 to 2050

Year	Infant mortality Rate (per 1,000 live births)		
	Male	Female	Total
1980-1985	22.7	21.1	21.9
1985-1990	16.6	16.2	16.4
1990-1995	14.0	14.3	14.1
1995-2000	11.1	11.9	11.5
2000-2005	8.6	9.7	9.1
2005-2010	6.6	7.9	7.2
2010-2015*	6.0	7.4	6.7
2015-2020*	5.6	6.9	6.2
2020-2025*	5.3	6.4	5.8
2025-2030*	4.9	6.0	5.4
2030-2035*	4.5	5.6	5.1
2035-2040*	4.3	5.3	4.8
2040-2045*	4.1	5.0	4.5
2045-2050*	3.9	4.8	4.3

Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)



iii. Under-five mortality

The under-five mortality rate was estimated at 14 deaths under age five per 1,000 live births in 1995-2000, and has decreased to 9 by 2010. It is projected to continue decreasing to reach 6 deaths per 1,000 live births by 2050.

Table 5: Under-Five Mortality Rate in Bahrain, 1980 to 2050

Year	Under-Five Mortality Rate (per 1,000 live births)		
	Male	Female	Total
1995-2000	14	14	14
2000-2005	11	11	11
2005-2010	9	9	9
2010-2015*	8	9	9
2015-2020*	8	9	8
2020-2025*	7	8	8
2025-2030*	7	8	7
2030-2035*	6	7	7
2035-2040*	6	7	6
2040-2045*	6	7	6
2045-2050*	5	6	6

Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)

iv. Maternal mortality

The maternal mortality ratio in Bahrain was estimated at 19 maternal deaths per 100,000 live births in 2008. The presence of a skilled attendant at birth was observed in 97 percent of the deliveries in the period 2000-2010.

Source: World Health Statistics 2011, available on <http://www.who.int/whosis/whostat/2011/en/index.html>

v. Monitoring Progress in Achieving the ICPD+15 targets

Bahrain is performing very well with regard to meeting the global goals set by ICPD for life expectancy, infant mortality, under-five mortality and maternal mortality.

With a life expectancy of 74.0 years registered for the period 2000-2005, 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.

The Kingdom's infant mortality rate for the periods 1995-2000 and 2000-2005 was estimated at 11.5 and 9.1 infant deaths per 1,000 live births indicating that Bahrain has already met the target of 50/70 and of below 50 infant deaths for 2000 and 2005 respectively. The infant mortality rate is projected to continue on decreasing to reach 6.7 infants deaths 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 2015.

The same applies for under-five mortality rate, which was estimated at 14 and 11 deaths per 1,000 live births in the periods 1995-2000 and 2000-2005 respectively (ICPD targets are 50/70 per 1,000 live births for 2000 and below 60 per 1,000 live births for 2005), and is projected to continue decreasing to reach 9 deaths per 1,000 live births in 2015 (ICPD target is below 45 per 1,000 live births for 2015).

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 percent of the deliveries for the period 2000-2010),

The Demographic Profile of Bahrain



insinuating that Bahrain has exceeded the global target set for 2010 (at least 50 to 85 percent of all births should be assisted by a skilled attendant).

b. Fertility Transition in Bahrain

i. Fertility Rate

The total Fertility Rate in Bahrain declined from 4.63 children per woman in 1980-1985 to 2.63 children per woman in 2005-2010. Projections show that total fertility will decline further to reach 2.13 (Replacement level fertility is 2.1) children per woman in 2020-2025 and will keep on declining to reach 1.76 children per woman in 2045-2050.

Table 6: Total Fertility Rate in Bahrain, 1980 to 2050 (children per woman)

Year	Total Fertility Rate (children per woman)
1980-1985	4.63
1985-1990	4.08
1990-1995	3.35
1995-2000	2.89
2000-2005	2.62
2005-2010	2.63
2010-2015*	2.43
2015-2020*	2.27
2020-2025*	2.13
2025-2030*	2.02
2030-2035*	1.92
2035-2040*	1.85
2040-2045*	1.80
2045-2050*	1.76

Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)

ii. Contraceptive prevalence

In 1995, the prevalence of contraceptive use among married Bahraini women was estimated at 61.8 percent. The prevalence of use of modern methods reached 30.6 percent and that of traditional methods 31.2 percent.

Source: United Nations, World Contraceptive Use 2010, POP/DB/CP/Rev2010

c. Migration Transition in Bahrain

i. Internal Migration

The percentage of urban dwellers was estimated at 86.1 percent in 1980. It increased to reach 88.4 percent in 1995 and remained at this level up to 2005. Population projections show that this percentage will continue to increase and will reach 92.3 percent in 2050.

Table 7: Urban and Rural Population in Bahrain, 1980 to 2050

Year	Population (thousands)			Percentage urban	Percentage rural	Year	Annual rate of change of percentage urban (%)	Annual rate of change of percentage rural (%)
	Urban	Rural	Total					
1980	299	48	347	86.1	13.9	1980-1985	0.24	-1.58
1985	360	53	413	87.2	12.8	1985-1990	0.22	-1.60
1990	434	58	493	88.1	11.9	1990-1995	0.06	-0.42
1995	511	67	578	88.4	11.6	1995-2000	-0.00	0.03
2000	574	76	650	88.4	11.6	2000-2005	0.01	-0.08
2005	643	84	728	88.4	11.6	2005-2010*	0.04	-0.34
2010*	701	91	791	88.6	11.4	2010-2015*	0.08	-0.61

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Year	Population (thousands)			Percentage urban	Percentage rural	Year	Annual rate of change of percentage urban (%)	Annual rate of change of percentage rural (%)
	Urban	Rural	Total					
2015*	715	92	807	88.6	11.4	2015-2020*	0.11	-0.88
2020*	784	97	882	89.0	11.0	2020-2025*	0.13	-1.15
2025*	852	101	953	89.4	10.6	2025-2030*	0.14	-1.27
2030*	919	102	1,021	90.0	10.0	2030-2035*	0.13	-1.28
2035*	984	102	1,085	90.6	9.4	2035-2040*	0.12	-1.28
2040*	1,045	101	1,145	91.2	8.8	2040-2045*	0.11	-1.29
2045*	1,099	99	1,198	91.8	8.2	2045-2050*	0.10	-1.30
2050*	1,146	96	1,242	92.3	7.7			

Source: United Nations, World Urbanization Prospects: The 2009 Revision Population Database

* Projections (medium variant)

ii. International Migration

Around 315,403 foreign born persons are expected to live in Bahrain in 2010, representing 39.1 percent of the total Bahraini population. Female migrants would represent 32.9 percent of all migrants for that year.

Table 8a: International Migrant (IM) Stock for Bahrain, 1990 to 2010

Indicator	1990	1995	2000	2005	2010*
Estimated number of IMs at mid-year (total)	173,200	205,977	239,366	278,166	315,403
Estimated number of migrants at mid-year (male)	123,851	144,505	165,553	189,533	211,561
Estimated number of migrants at mid-year (female)	49,349	61,472	73,813	88,633	103,842
Estimated number of refugees at mid-year	965	0	1	0	1
IMs as a percentage of the population	35.1	35.7	36.8	38.2	39.1
Female migrants as percentage of all IMs	28.5	29.8	30.8	31.9	32.9
Refugees as a percentage of international migrants	0.6	0.0	0.0	0.0	0.0

Source: United Nations, World Migration Stock: The 2008 Revision

Available on: <http://esa.un.org/migration/>

* Projections

Table 8b: Annual rate of change of the migrant stock in Bahrain, 1990 to 2010

Year	Annual rate of change of the migrant stock (percent)
1990-1995	3.5
1995-2000	3.0
2000-2005	3.0
2005-2010*	2.5

Source: United Nations, World Migration Stock: The 2008 Revision

* Projections

The annual net migration rate sharply increased from 7.4 migrants per 1,000 population for the period 2000-2005 to 90.2 migrants per 1,000 population for the period 2005-2010.

Table 9: Net Migration in Bahrain, 1980 to 2050

Year	Net Migration (average annual)	
	Rate (per 1,000 population)	Number (thousands)
1980-1985	1.6	1
1985-1990	5.7	3
1990-1995	2.1	1

The Demographic Profile of Bahrain



Year	Net Migration (average annual)	
	Rate (per 1,000 population)	Number (thousands)
1995-2000	6.5	4
2000-2005	7.4	5
2005-2010	90.2	90
2010-2015*	6.2	8
2015-2020*	2.8	4
2020-2025*	1.9	3
2025-2030*	1.9	3
2030-2035*	1.8	3
2035-2040*	1.7	3
2040-2045*	1.7	3
2045-2050*	1.7	3

Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)

3. Population Structure:

a. Bahrain's Population Age Composition

The proportion of the population under 15 years of age has been decreasing since 1980 and is projected to continue this downward trend till the year 2050. At the same time, the proportion of the working-age group (15-64) has been increasing since 1980, where it rose from 63.4 percent to reach a peak of 77.9 percent in 2010. It is projected to start declining after this period and will get to 59.1 in 2050. The proportion of the elderly (65+) population fluctuated between 2.1 percent and 2.7 percent during the period 1980-2010. It is projected to start increasing afterwards and will reach 25.4 percent in 2050.

Table 10: Population Distribution by Broad Age Groups in Bahrain, 1980 to 2050 (percent)

Year	Age (years)			
	0-4	5-14	15-64	65+
1980	13.8	20.6	63.4	2.1
1985	13.9	19.5	63.9	2.7
1990	13.3	19.3	65.2	2.2
1995	10.7	19.4	67.5	2.4
2000	9.4	18.7	69.4	2.5
2005	8.6	18.8	70.1	2.6
2010	7.4	12.7	77.9	2.1
2015*	8.3	12.5	76.8	2.4
2020*	6.9	14.1	75.2	3.8
2025*	5.9	13.9	74.0	6.2
2030*	5.3	11.9	73.8	9.0
2035*	5.3	10.5	71.8	12.4
2040*	5.4	10.1	68.4	16.1
2045*	5.4	10.3	63.7	20.6
2050*	5.0	10.5	59.1	25.4

Source: United Nations, World Population Prospects: The 2010 Revision

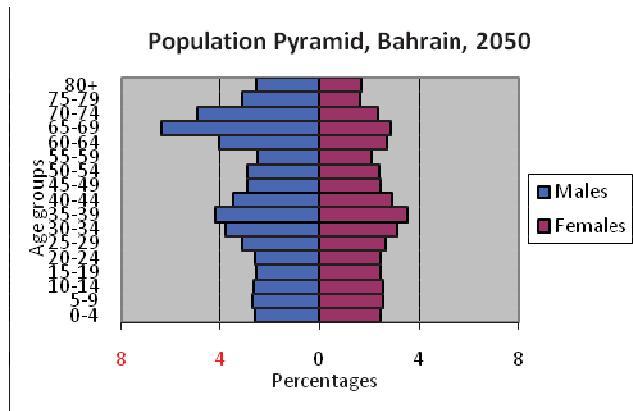
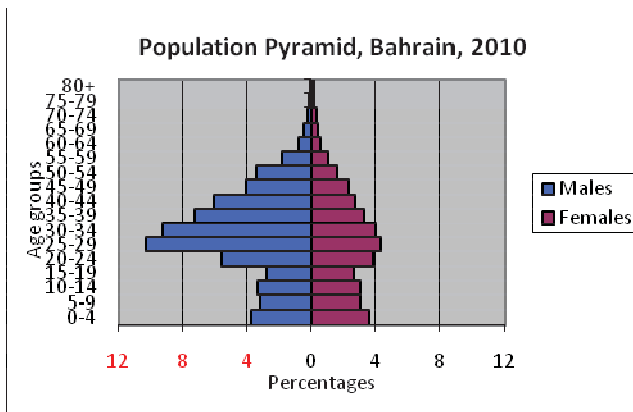
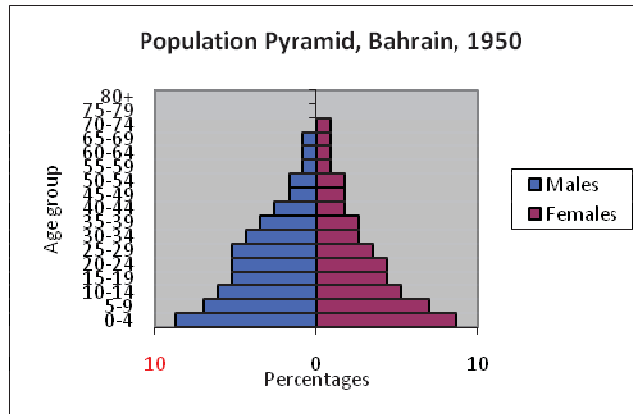
* Projections (medium variant)

The Demographic Profile of Bahrain



b. Changing Age Structure

The population pyramid in Bahrain shows an unbalanced structure for the working-age groups due to high immigration rates and reliance on foreign labour.





c. Bahrain's Youth

In Bahrain, the percentage of youth (15-24) was estimated at 23.0 percent in 1975 (or 39.6 percent of the working-age group). In 2010, the percentage decreased to reach 14.9 percent (or 19.1 percent of the working-age group). It is projected to continue declining to reach 10.0 percent in 2050 (or 17.0 percent of the working-age group).

Table 11: Youth (15-24) in relation to total population and to working-age population (15-64), Bahrain, 1950-2050.

Year	Youth (thousands)	Youth (% of total population)	Working-age population (thousands)	Youth (% of working-age group)**
1950	22	19.1	63	34.9%
1955	24	18	74	32.4%
1960	29	17.7	91	31.9%
1965	34	18.3	96	35.4%
1970	37	17.7	112	33.0%
1975	61	23.0	154	39.6%
1980	79	22.0	227	34.8%
1985	67	16.0	266	25.2%
1990	81	16.4	321	25.2%
1995	92	16.5	377	24.4%
2000	107	16.8	443	24.2%
2005	123	17.0	508	24.2%
2010	188	14.9	983	19.1%
2015*	156	11.1	1,078	14.5%
2020*	164	10.9	1,134	14.5%
2025*	180	11.3	1,174	15.3%
2030*	216	13.1	1,221	17.7%
2035*	224	13.1	1,228	18.2%
2040*	200	11.4	1,202	16.6%
2045*	184	10.3	1,141	16.1%
2050*	181	10.0	1,064	17.0%

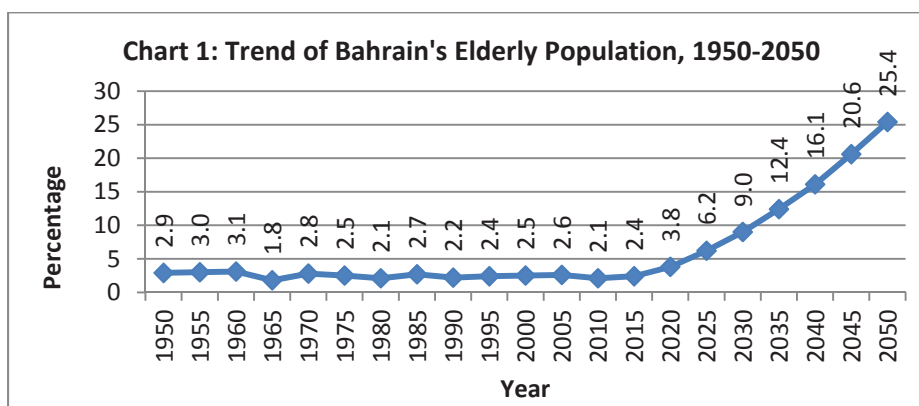
Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)

** ESCWA calculation

d. Bahrain's Elderly

In Bahrain, the percentage of the population aged 65+ increased from 2.9 percent in 1950 to 3.1 percent in 1960, then decreased to reach 1.8 percent in 1965 only to increase again afterwards to 2.8 percent in 1970, fluctuating between 2.7 and 2.1 during the period 1980-2010. It is projected that the percentage of the population aged 65+ will begin to increase starting 2015 and will more than triple (compared to the 2010 rate) by 2025. This upward trend will continue and the percentage of the population aged 65+ to reach 25.4 percent in the year 2050. This rapid demographic change necessitates that policies be put in place to meet the challenges raised by an ageing population.



Source: United Nations, World Population Prospects: The 2010 Revision

e. Bahrain's Dependency Ratios

The total dependency ratio in Bahrain reached its peak in 1965 owing to the high child dependency ratio. It then started decreasing and reached 28 percent in 2010 mainly due to the decrease in the child dependency ratio. It is expected to start increasing again to reach 35 percent in 2025 and 69 percent in 2050 (almost doubling) due to a projected increase in the old-age dependency ratio.

Table 12: Dependency Ratios in Bahrain, 1950-2050 (percent)

Year	Child dependency ratio	Old-age dependency ratio	Total dependency ratio
1950	77	5	82
1955	76	5	81
1960	73	6	79
1965	90	4	94
1970	84	5	90
1975	68	4	72
1980	54	3	58
1985	52	4	57
1990	50	3	53
1995	45	4	48
2000	40	4	44
2005	39	4	43
2010	26	3	28
2015*	27	3	30
2020*	28	5	33
2025*	27	8	35
2030*	23	12	35
2035*	22	17	39
2040*	23	24	46
2045*	25	32	57
2050*	26	43	69

Source: United Nations, World Population Prospects: The 2010 Revision

* Projections (medium variant)



4. Population Policy Profile of Bahrain:

Population policy variable	1976	1986	1996	2009
Population size and growth				
View on growth	Satisfactory	Satisfactory	Satisfactory	Too high
Policy on growth	No intervention	No intervention	No intervention	Lower
Population age structure				
Level of concern about				
Size of the working-age population	..	..	..	Minor concern
Ageing of the population	..	..	..	Minor concern
Fertility and family planning				
View on fertility level	Too high	Satisfactory	Satisfactory	Too high
Policy	No intervention	No intervention	Lower	Lower
Access to contraceptive methods	Indirect support	Direct support	Direct support	Direct support
Adolescent fertility				
Level of concern	..	..	Not a concern	Not a concern
Policies and programmes	..	..	No	No
Health and mortality				
View				
Life expectancy at birth	Unacceptable	Acceptable	Acceptable	Acceptable
Under-five mortality	..	..	Unacceptable	Unacceptable
Maternal mortality	..	..	..	Acceptable
Level of concern about HIV/AIDS	..	..	..	Major concern
Measures to respond to HIV/AIDS*	..	..	..	1,2,3
Grounds on which abortion is permitted**	..	..	1,2,3,5	1,2,3,4,5,6,7
Spatial distribution and internal migration				
View on spatial distribution	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Policies on internal migration				
From rural to urban areas	..	..	..	..
From rural to rural areas	..	..	..	..
From urban to rural areas	..	..	..	..
From urban to urban areas	..	..	..	..
Into urban agglomerations	..	Raise	No intervention	..
International migration				
Immigration				
View	Satisfactory	Too high	Satisfactory	Satisfactory
Policy	Maintain	Lower	No intervention	Maintain
Permanent settlement	..	..	No intervention	..
Temporary workers	..	..	No intervention	Lower
Highly skilled workers	..	..	..	..
Family reunification	..	..	No intervention	Maintain
Integration of non-citizens	..	..	..	..
Emigration				
View	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Policy	Maintain	Maintain	No intervention	No intervention
Encouraging the return of citizens	..	..	No	..

* Measures implemented to respond to HIV/AIDS: (1) blood screening; (2) information/education campaigns; (3) antiretroviral treatment; (4) non-discriminatory policies; (5) distribution of condoms.

** Grounds on which abortion is permitted: (1) to save the woman's life; (2) to preserve physical health; (3) to preserve mental health; (4) rape or incest; (5) foetal impairment; (6) economic or social reasons; (7) on request.

Source: United Nations, World Population Policies, 2009



Appendix 16: Ministry of Culture – Letter Regarding Archaeology and Cultural Heritage



30th March 2014

Mehdi Honar,
Director,
Tebodin Middle East Ltd,
P.O.Box 2822, Manama, Bahrain
Tel: 17700544

Dear Sir,

Referring to your letter dated 10th March 2014 for providing you with archaeological and cultural information on the location of ALBA L6 Expansion Project.

We would like to inform you that Ministry of Culture has no archaeological concern in the project area.

**Director of Archaeology &
National Heritage**

For 



Appendix 17: Air Modelling Methodology



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

Appendix 17: Air Modelling Methodology – CALMET and CALPUFF

Tebodin

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1 CALMET INTRODUCTION

Meteorology determines the transport and dispersion of industrial emissions, and hence plays a significant role in determining air quality downwind of emission sources. For this assessment, meteorological data for the year 2012 was used to define transport and dispersion parameters. The selection of a 1 year period is consistent with the minimum assessment requirement to perform and predict Air Quality Assessment for the regional study area, when using data from a meteorological model such as MM5 (the Fifth Generation NCAR/Penn State Mesoscale Model).

Meteorological characteristics vary with time (e.g., season and time of day) and location (e.g., height, terrain and land use). The CALMET meteorological pre-processing program was used to provide temporally and spatially varying meteorological parameters for the CALPUFF model. This appendix provides an overview of the meteorology and climate for the region as well as the technical details and options that were used for the application of the CALMET meteorological pre-processor for the Project assessment.

1.1 CALMET Domain

The CALMET domain adopted for the Project assessment extends approximately latitude 26.05 in the North 50 km, and longitude 50.61 in the east 50 km. The global study coordinates have been converted to its respective UTM (Universal Transverse Mercator), in km as shown in Figure A- 1. The CALMET domain covers a 2500- km² area.

A horizontal grid spacing of 4 km was selected for the CALMET simulation; the study area therefore corresponds to 13 rows by 13 columns. With this grid spacing, it was possible to maximize run time and file size efficiencies while still capturing large-scale terrain feature influences on wind flow patterns.

Table A- 1: CALMET Domain Coordinates

Domain Extent	Northing (°)	Easting (°)
North East	485322.12	2910507.97
North West	435322.12	2910507.97
South West	435322.12	2860507.97
South East	485322.12	2860507.97



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Figure A- 1: Plant Location with Ambient Monitoring Stations and Sensitive Receptors



1.2 Meteorological Measurements

Meteorological data collected in the area surrounding the Project have been analysed to characterize the regional and local climate.

1.2.1 Ambient Temperature

Table A- 2: summarises the 2008-2012 historical seasonal and annual mean air temperatures in the CALMET Domain. Annual average ambient temperatures range from 26 and 28 °C for Five years (2008-2012). There is generally little variation in mean daily temperatures between the sites on a seasonal and annual basis. Mean daily temperatures for the period 2008-2012 are presented in below table for the weather monitoring station at Bahrain International Airport.

Table A- 2: Historical Seasonal and Annual Mean Daily Temperatures at Meteorological Stations in the Study Area (2000-2012)

Season	Mean Daily Temperature (°C)				
	2008	2009	2010	2011	2012
Winter	33	33	33	33	33
Summer	20	21	22	20	21
Annual	26	27	28	27	27

Notes :
 Winter : May, June, July, August, September and October
 Summer : November, December, January, February, March and April
 Source: Bahrain Airport weather Data

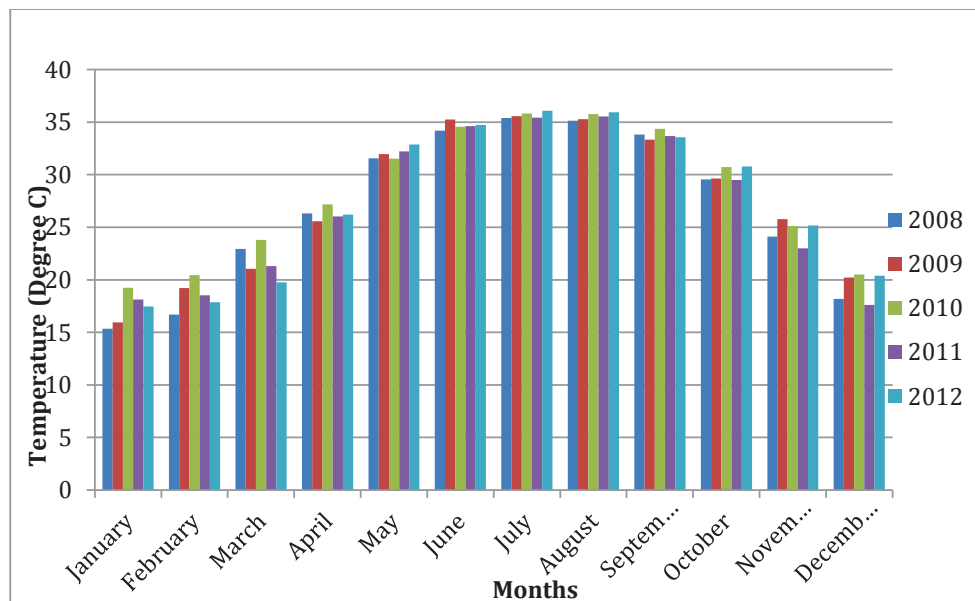


Figure A- 2: Mean Monthly Average Temperatures at Bahrain Airports (2008-2012)



Table A- 3: Annual Mean Daily Temperatures at Meteorological Stations in the Study Area (2012)

Season	Mean Daily Temperature (°C) 2012
Winter	21.1
Summer	33.9
Annual	27.5
Notes :	
Winter : May, June, July, August, September and October	
Summer : November, December, January, February, March and April	
Source: Bahrain Airport Weather Data (NOAA)	

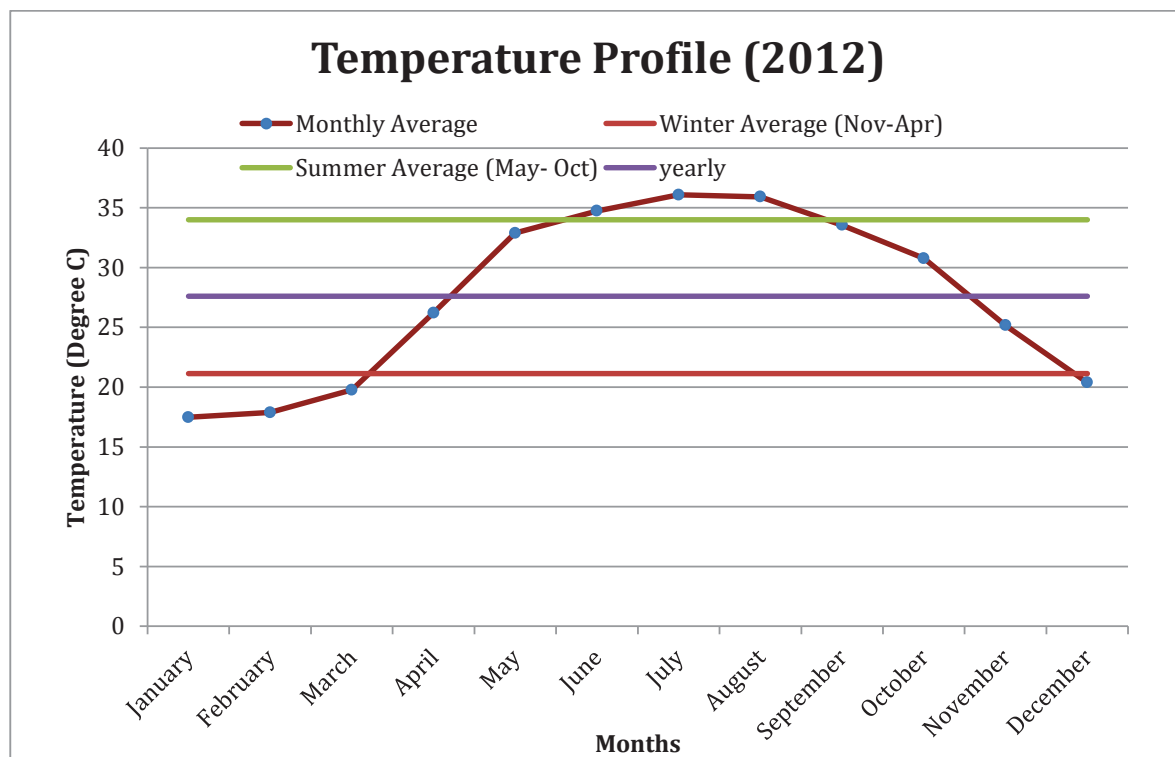


Figure A- 3: Mean Monthly Average Temperatures at Bahrain Airports (2012)

1.2.2 Wind

Wind direction and wind speed are measured at the Environment Bahrain airport locations. A wind rose is a histogram plotted in polar coordinates. The histogram is comprised of 16 bars whose length represents the frequency that the wind blows from one of the 16 cardinal compass points (e.g., N, NNE, NE, and ENE to WNW, NW, and NNW). The bar can be broken down to represent different wind speed classes. Wind roses were prepared from data collected at the continuous monitoring locations in the CALMET Domain. **Figure A- 4:** and **Figure A- 5:** show the wind roses for five years (2008-2012) both individually and combined. The wind class frequency distribution is presented in **Figure A- 6:**

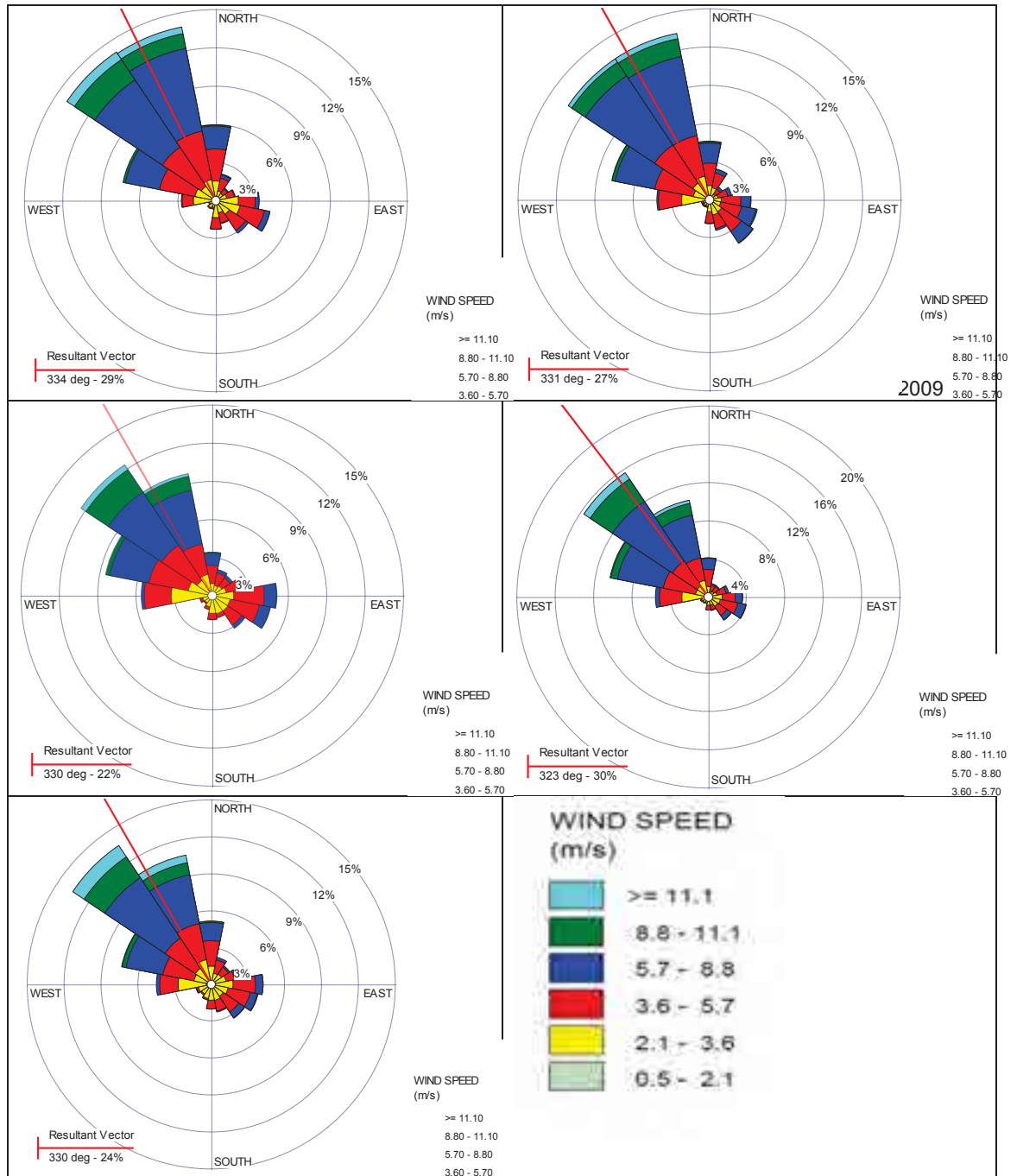


Figure A- 4: Wind Roses 2008, 2009, 2010, 2011 and 2012

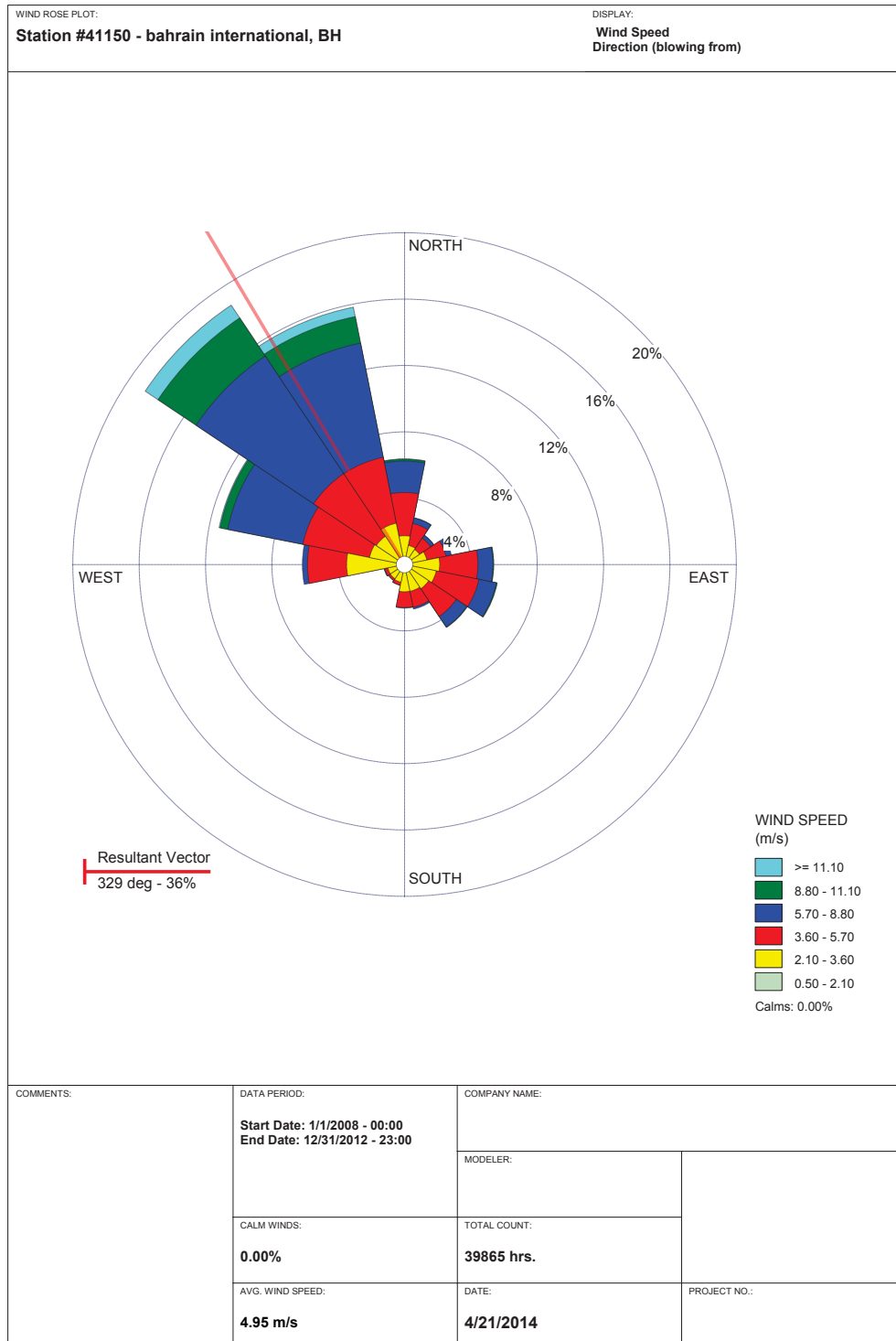


Figure A- 5: Wind Rose for five years (2008-2012)

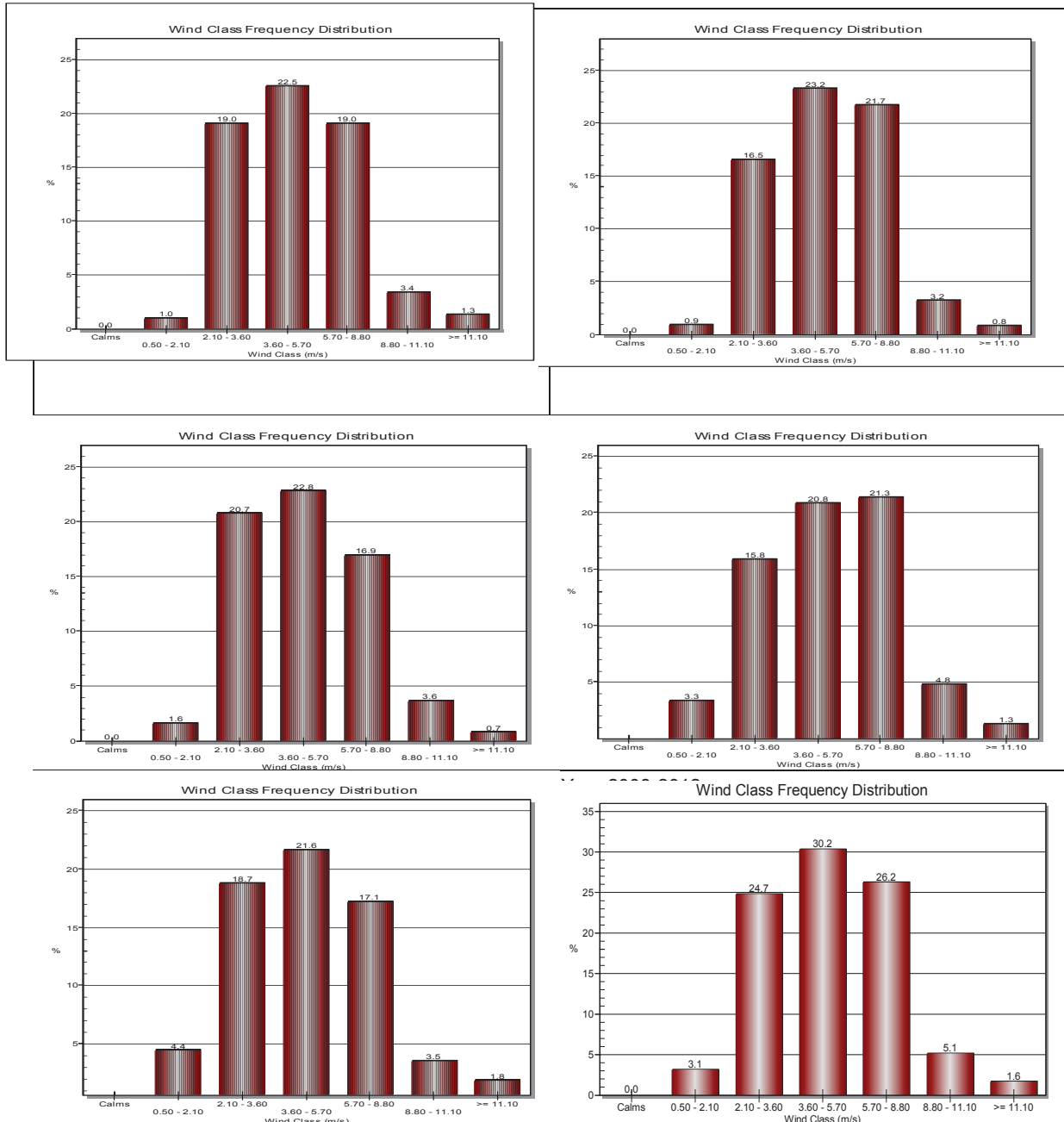


Figure A-6: Wind class Frequency Distribution for years 2008-2012



1.3 Meteorological Predictions

1.3.1 Meteorological Models

Due to the paucity of meteorological data in the region and the question of the representativeness of measured data at a single site being applied to the region, meteorological models have been used to provide spatially and temporally varying wind and temperature fields across a large region. These models can be categorized as either prognostic or diagnostic models:

Prognostic models use meteorological measurements and fundamental equations of atmospheric motion to determine how meteorological conditions will behave between the observing stations. The MM5 model (a Mesoscale meteorological model assimilation produced by Penn State/NCAR) is an example of a prognostic model that has been applied to entire Bahrain Area for air quality assessment purposes. As a part of the modelling assignment, the MM5 model has been applied on a 4 km grid spacing for year 2012.

Diagnostic models use interpolation schemes that rely on empirical relationships to account for topographical or other influences that can occur between the observing sites. The CALMET model is an example of a diagnostic model (Scire et al. 2000). The CALMET model can be applied on a finer scale to the MM5 model output in order to resolve more local-scale terrain influences.

A combination of both models were used for this assessment: the MM5 model output being used to provide an initial guess field with the CALMET model adjusting the initial guess field for the kinematic effects of terrain, slope flows, and terrain blocking effects using the finer scale terrain data to produce a modified wind field. This approach has become the standard for air quality assessments for industrial projects.

While it is clear that the grid points provide a much greater and uniform density across the domain than the locations where meteorological parameters are measured, it must be noted that these are Interpolated / predicted data. Wind, mixing height, and PG stability class data were extracted to show the meteorology specific to the PDA. These are the main parameters that influence transport and dispersion of emissions from the Project.

1.3.2 CALMET Application

The current approved U.S. EPA version of CALMET is Version 5.8, level 070623. For this assessment, a more recent version, Version 6.42 was adopted. A horizontal grid spacing of 4 km was selected for the CALMET simulation; the study area therefore corresponds to 13 rows by 13 columns. With this grid spacing, it was possible to maximize run time and file size efficiencies while still capturing large-scale terrain feature influences on wind flow patterns.

To simulate transport and dispersion processes, it is also important to simulate the representative vertical profiles of wind direction, wind speed, temperature, and turbulence intensity within the atmospheric boundary layer (i.e., the layer within about 2000 metres above the Earth's surface). To capture this vertical structure, eight vertical layers were selected. CALMET defines a vertical layer as the midpoint between two faces (i.e., nine faces corresponds to eight layers, with the lowest layer always being ground level or 10 m). The vertical faces used in this study are 0, 20, 40, 80, 160, 320, 600, 1400 and 2600 m.



The CALMET model was applied for 2012 (i.e., for 8,760 hours). The model requires surface and upper air information. The gridded 3-D meteorological data produced by the MM5 model (a Mesoscale meteorological model assimilation produced by Penn State/NCAR) were used as an initial guess field (Scire et al. 2000). The MM5 Mesoscale data were obtained from Lakes Environmental, Canada on a 4 km grid resolution for the years 2012. The MM5 data were supplemented with meteorological data from Bahrain International Airport. The CALMET model adjusted the initial guess field for the kinematic effects of terrain, slope flows, and terrain blocking effects using the finer scaled CALMET terrain data to produce a modified wind field that was used by the CALPUFF model.

The input parameters for the CALMET control file used in for this assessment are provided in **Table A- 4 to Table A- 11**. The tables indicate “default” values that were identified in the CALPUFF Modelling System Version 6 User Instructions (TRC, 2011). Differences from the default values and the values applied for the assessment of the Sasol Project include:

- **DATUM:** The CALMET default value WGS-84 is the Datum-region for output coordinates were used.
- **NOOBS:** For this assessment, the upper air stations are located outside CALMET domain so option 1 (i.e., surface stations data only) was used to adjust surface field in CALMET model output.
- **BIAS:** These are layer-dependent biases modifying the weights of surface and upper air stations. For this assessment, this parameter is not applicable as only surface station data were used.
- **RMN2:** This is the minimum distance from the nearest upper air station to the surface station for which extrapolation of surface winds at surface station will be allowed. This parameter is not applicable for this assessment as only surface station data were used.
- **IPROG:** The CALMET default value is 0 for not using gridded prognostic model wind data as input and is only applicable for CALMET only using observation data. For this assessment, option 14 was selected as winds from a MM5/3D.DAT file were used as initial guess field.
- **ZUPWND:** used only when parameter IUPWND > 0. This parameter is not applicable for this assessment as IUPWND was set to -1.
- **IRHPROG:** The CALMET default value of 0 is set to use relative humidity data from observations. This default is more appropriate for a model domain that contains a dense surface and upper air station network. For this assessment, a value of 1 was selected to use relative humidity data from the MM5 dataset.
- **ITPROG:** The CALMET default value of 0 is set to use temperature data from observations. This default is more appropriate for a model domain that contains a dense surface and upper air station network. For this assessment, a value of 1 was selected to use temperature data from the MM5 dataset.

Table A- 4: Groups in the CALMET Control File

Input Group	Description	Applicable to Project
0	Input and output file names	Yes
1	General run control parameters	Yes
2	Grid control parameters	Yes
3	Output Options	Yes
4	Meteorological data options	Yes
5	Wind Field Options and Parameters	Yes
6	Mixing Height, Temperature and Precipitation Parameters	Yes
7	Surface meteorological station parameters	Yes
8	Upper air meteorological station parameters	Yes



Input Group	Description	Applicable to Project
9	Precipitation parameters	Yes

Table A- 5: CALMET Model Options Groups 0 and 1

Parameter	Default	Project	Comment
Input Group 0: Input and Output File Names			
NUSTA	-	0	Number of upper air stations
NOWSTA	-	0	Number of overwater met stations
MM3D	-	6	Number of MM4/MM5/3D.DAT (6 monthly files for the 1-year period)
NIGF	-	0	Number of IGF-CALMET.DAT files
Input Group 1: Input and Output File Names			
IBYR	-	2012	Starting year
IBMO	-	1	Starting month
IBDY	-	1	Starting day
IBHR	-	0	Starting hour
IBSEC	-	0	Starting second
IEYR	-	2012	Ending year
IEMO	-	12	Ending month
IEDY	-	31	Ending day
IEHR	-	23	Ending hour
IESEC	-	0	Ending second
ABTZ	-	UTC+3hrs	UTC time zone
NSECDT	3600	3600	Length of modelling time-step (seconds)
IRTYPE	1	1	Run type
LCALGRD	T	T	Special data fields
ITEST	2	2	Flag to stop run after SETUP phase

Table A- 6: CALMET Model Options Group 2: Grid control parameters

Parameter	Default	Project	Comment
PMAP	UTM	UTM	Map projection
IUTMZN	-	39	UTM Zone
UTMHEM	N	N	Hemisphere for UTM projection
DATUM	WGS-84	WGS-84	Datum – region for output coordinate (user defined)
NX	-	13	No. X grid cells
NY	-	13	No. Y grid cells
DGRIDKM	-	4	Grid spacing (km)
XORIGKM	-		Reference coordinate of SW corner of grid cell (1,1) -X coordinate (km)
YORIGKM	-		Reference coordinate of SW corner of grid cell (1,1) -Y coordinate (km)
NZ	-	8	Vertical grid definition: Number of vertical layers
ZFACE	-	0,20,40,80,160,320,600,1400,2600	Vertical grid definition: Cell face heights in arbitrary vertical grid (m)



Table A- 7: CALMET Model Options Group 3: Output Options

Parameter	Default	Project	Comment
Disk Output:			
LSAVE	T	T	Save met. Fields in the unformatted output files
IFORMO	1	1	Type of unformatted output file
Line Printer Output:			
LPRINT	-	T	Print meteorological fields
IPRINF	-	12	Print intervals (hrs)
IUVOU (NZ)	-	1,0,0,0,0,0,0,0	Specify which layers of U,V wind component to print
IWOUT (NZ)	-	0,0,0,0,0,0,0,0	Specify which level of the W wind component to print
ITOUT (NZ)	-	1,0,0,0,0,0,0,0	Specify which levels of the 3-D temperature field to print
Meteorological fields to print:			
Variable	Print? 0 = no print 1 = print		Comment
STABILITY	1		PGT stability
USTAR	0		Friction velocity
MONIN	0		Monin – Obukhov length
MIXHT	1		Mixing height
WSTAR	0		Convective velocity scale
PRECIP	1		Precipitation rate
SENSHEAT	0		Sensible heat flux
CONVZI	0		Convective mixing height
Testing and debug print options for micrometeorological module:			
LDB	F	F	Print input meteorological data and internal variables
NN1	1	1	First time step for which debug data are printed
NN2	1	1	Last time step for which debug data are printed
LDBCST	F	F	Print distance to land internal variables
Testing and debug print options for wind field module:			
IOUTD	0	0	Control variable for writing the test/debug wind fields to disk files
NZPRN2	1	0	Number of levels, starting at surface, to print
IPR0	0	0	Print the interpolated wind components
IPR1	0	0	Print the terrain adjusted surface wind components
IPR2	0	0	Print the smoothed wind components and the initial divergence fields
IPR3	0	0	Print the final wind speed and direction
IPR4	0	0	Print the final divergence fields
IPR5	0	0	Print the winds after kinematic effects are added
IPR6	0	0	Print the winds after the Froude number adjustment is made
IPR7	0	0	Print the winds after slope flows are added
IPR8	0	0	Print the final wind field components



Table A- 8: CALMET Model Options Group 4: Meteorological Data Options

Parameter	Default	Project	Comment
NOOBS	0	1	surface station data was used (no upper air observations)
Number of Surface & Precipitation Meteorological Stations:			
NSSTA	-	0	Number of surface stations
NPSTA	-	0	Number of precipitation stations
Cloud Data Options:			
ICLOUD	0	0	Gridded clouds not used (cloud cover data from Bahrain International Airport were used)
File Formats:			
IFORMS	2	2	Surface meteorological data file format
IFORMP	2	2	Precipitation data file format
IFORMC	2	2	Cloud data file format

Table A- 9: CALMET Model Option Group 5: Wind Field Options and Parameters

Parameter	Default	Project	Comment
Wind Field Model Options:			
IWFCOD	1	1	Model selection variables
IFRADJ	1	1	Compute Froude number adjustment
IKINE	0	0	Computer kinematic effects
IOBR	0	0	Use O'Brien procedure for adjustment of the vertical velocity
ISLOPE	1	1	Compute slope flow effects
IEXTRP	-4	-4	Extrapolate surface wind observations to upper layers (similarity theory used with layer 1 data at upper air stations ignored)
ICALM	0	0	Extrapolate surface winds even if calm
BIAS	0	Not Applicable	Layer-dependent biases modifying the weights of surface and upper air stations
RMIN2	4	Not Applicable	Minimum distance from nearest upper air station to surface station for which extrapolation of surface winds at surface station will be allowed Set to -1 for all surface stations should be extrapolated
I PROG	0	14	Use gridded prognostic wind field model output fields as input to the diagnostic wind field model (from MM5.DAT)
ISTEPPG	1	1	Time step (hours) of the prognostic model input data
IGFMET	0	0	Use coarse CALMET fields as initial guess fields
Radius of Influence Parameters:			
LVARY	F	F	Use varying radius of influence
RMAX1	-	12	Maximum radius of influence over land in the surface layer (km)
RMAX2	-	12	Maximum radius of influence over land aloft (km)
RMAX3	-	5	Maximum radius of influence over water
Other Wind Field Input Parameters:			
RMIN	0.1	0.1	Minimum radius of influence used in the wind field interpolation (km)
TERRAD	-	15	Radius of influence of terrain features (km)
R1	-	3	Relative weighting of the first guess field and observations in the surface layer (km)
R2	-	3	Relative weighting of the first guess field and observations in the layers aloft (km)
RPROG	-	0	Relative weighting parameter of the prognostic wind field



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Parameter	Default	Project	Comment
			data (km)
DIVLIM	5.0E-6	5.0E-6	Maximum acceptable divergence in the divergence minimization procedure
NITER	50	50	Maximum number of iterations in the divergence minimization procedure
NSMTH (NZ)	2,(mxnz-1)*4	2,4,4,4,4,4,4	Number of passes in the smoothing procedure
NINTR2	99	99,99,99,99, 99,99,99,99	Maximum number of stations used in each layer for the interpolation of data to a grid point
CRITFN	1.0	1.0	Critical Froude number
ALPHA	0.1	0.1	Empirical factor controlling the influence of kinematic effects
FEXTR2	NZ*0	0,0,0,0,0,0,0	Multiplicative scaling factor for extrapolation of surface observations to upper layers
Barrier Information:			
NBAR	0	0	Number of barriers to interpolation of the wind fields (not applicable, therefore not used)
KBAR	NZ	8	Level (1 to NZ) up to which barriers apply (not applicable, therefore not used)
XBBAR	-	0	X coordinate of beginning of each barrier (not applicable, therefore not used)
YBBAR	-	0	Y coordinate of beginning of each barrier (not applicable, therefore not used)
XEBAR	-	0	X coordinate of ending of each barrier (not applicable, therefore not used)
YEBAR	-	0	Y coordinate of ending of each barrier (not applicable, therefore not used)
Diagnostic Module Data Input Options:			
IDIOPT1	0	0	Surface temperature (0 = compute internally from hourly surface observation)
ISURFT	-	2	Surface meteorological station to use for the surface temperature
IDIOPT2	0	0	Domain-averaged temperature lapse (0 = compute internally from hourly surface observation)
IUPT	-	0	Upper air station to use for the domain-scale lapse rate
ZUPT	200	200	Depth through which the domain-scale lapse rate is computed (m)
IDIOPT3	0	0	Domain-averaged wind components
IUPWND	-1	-1	Upper air station to use for the domain-scale winds
ZUPWND	1, 1000	Not Applicable	Bottom and top of layer through which domain-scale winds are computed (m). Used only IUPWND > 0
IDIOPT4	0	0	Observed surface wind components for wind field module
IDIOPT5	0	0	Observed upper air wind components for wind field module
Lake Breeze Information:			
LLBREZE	F	F	Use lake breeze module (<i>not applicable therefore not used</i>)
NBOX	-	0	Number of lake breeze regions
XG1	-	0	X Grid line 1 defining the region of interest
XG2	-	0	X Grid line 2 defining the region of interest
YG1	-	0	Y Grid line 1 defining the region of interest
YG2	-	0	Y Grid line 2 defining the region of interest
XBCST	-	0	X Point defining the coastline in kilometres (Straight line)
YBCST	-	0	Y Point defining the coastline in kilometres (Straight line)
XECST	-	0	X Point defining the coastline in kilometres (Straight line)
YECST	-	0	Y Point defining the coastline in kilometres (Straight line)
NLB	-	0	Number of stations in the region



Parameter	Default	Project	Comment
METBXID	-	0	Station ID's in the region

Table A- 10: CALMET Input Model Option

Group 6: Mixing Height, Temperature and Precipitation Parameters

Parameter	Default	Project	Comment
Empirical Mixing Height Constants:			
CONSTB	1.41	1.41	Neutral, mechanical equation
CONSTE	0.15	0.15	Convective mixing height equation
CONSTN	2400	2400	Stable mixing height equation
CONSTW	0.16	0.16	Over water mixing height equation
FCORIO	1.0E-4	1.0E-4	Absolute value of Coriolis (s-1) (adjusted for project site latitude)
Spatial Averaging of Mixing Heights:			
IAVEZI	1	1	Conduct spatial averaging
MNMDAV	1	10	Maximum search radius in averaging (grid cells)
HAFANG	30	30	Half-angle of upwind looking cone for averaging
ILEVZI	1	1	Layer of winds used in upwind averaging
Convective Mixing Heights Options:			
IMIXH	1	1	Method to compute the convective mixing height (Maul-Carson)
THRESHL	0.05	0.05	Threshold buoyancy flux required to sustain convective mixing height growth overland (W/m3)
THRESHW	0.05	0.05	Threshold buoyancy flux required to sustain convective mixing height growth overwater(W/m3)
ITWPROG	0	0	Option for overwater lapse rates used in convective mixing height growth (1=use prognostic lapse rates)
ILUOC3D	16	16	Land use category ocean in 3D.DAT datasets
Other Mixing Height Variables:			
DPTMIN	0.001	0.001	Minimum potential temperature lapse rate in the stable layer above the current convective mixing height (K/m)
DZZI	200	200	Depth of layer above current convective mixing height through which lapse rate is computed (m)
ZIMIN	50	50	Minimum overland mixing height (m)
ZIMAX	3000	3000	Maximum overland mixing height (m)
ZIMINW	50	50	Minimum overwater mixing height (m)
ZIMAXW	3000	3000	Maximum overwater mixing height (m)
Overwater Surface Fluxes Method and Parameters:			
ICOARE	10	10	COARE with no wave parameterization (not applicable therefore not used)
DSHELF	0	0	Coastal/Shallow water length scale (km)
IWARM	0	0	COARE warm layer computation
ICOOL	0	0	COARE cool skin layer computation
Relative Humidity Parameters:			
IRHPROG	0	1	3D relative humidity from observations or from prognostic data 1 = Use prognostic relative humidity
Temperature Parameters:			
ITPROG	0	1	3D temperature from observations or from prognostic data 1 = Use Surface stations (no upper air observations)
IRAD	1	1	Interpolation type
TRADKM	500	500	Radius of influence for temperature interpolation (km)
NUMTS	5	13	Maximum number of stations to include in temperature interpolation



Parameter	Default	Project	Comment
IAVET	1	1	Conduct spatial averaging of temperatures (1 = yes)
TGDEFB	-0.0098	-0.0098	Default temperature gradient below the mixing height over water (K/m)
TGDEFA	-0.0045	-0.0045	Default temperature gradient above the mixing height over water (K/m)
JWAT1	-	55	Beginning land use categories for temperature interpolation over water
JWAT2	-	55	Ending land use categories for temperature interpolation over water
Precipitation Interpolation Parameters:			
NFLAGP	2	2	Method of interpolation
SIGMAP	100	100	Radius of Influence (km)
CUTP	0.01	0.01	Minimum Precipitation rate cut-off (mm/h)

Table A- 11: CALMET Model Option Group 7: Surface Meteorological Station Parameters

Name	ID	X coordinate (km)	Y coordinate (km)	Time Zone	Anemometer Height
BAH	41150	465.052	2905.300	3	10
Note: BAH-Bahrain International Airport					



2 CALPUFF INTRODUCTION

Ambient air quality models are used to predict air quality changes (i.e., changes to ambient concentrations) associated with future emission scenarios. This section discusses the selection and application of the primary dispersion model that was used for the air quality assessment as part of the Environmental and Social Impact Assessment for the proposed Potline 6 and Power Station 5 expansion project at Aluminium Bahrain (ALBA).

2.1 Model Types

Air quality simulation (or dispersion) models provide a scientific means of relating industrial emissions to air quality changes, by using mathematical equations to simulate transport, dispersion, transformation, and deposition processes in the atmosphere. Dispersion models can address a wide range of distance scales (hundreds of metres to thousands of kilometres) and time scales (minutes to years).

Regulatory agencies have relied on dispersion models as part of their approval process. Numerous models are available to predict ambient air quality changes and the appropriate selection depends on project-specific circumstances. In response to the regulatory use of these models, formal guidelines regarding the selection and application of these models have been developed (e.g., U.S. EPA 2005).

2.2 Model Input/output Files

The application of a dispersion model requires the preparation of input files and the analysis of output files.

The input files include the following:

- Control/option information to identify the model run, to select the available technical features, and to control the output options specific to the selected model;
- Source data that identify the locations, emission characteristics (e.g., stack height), and emission rates (e.g., NOX emission rate) for each source;
- Terrain elevations and surface characteristics to account for terrain influences on airflow and turbulence;
- surface characteristics to provide the deposition properties; and
- Meteorological data on an hourly basis to characterize airflow and turbulence in the region.

The output files include the following:

- A summary file to identify the model run and to provide an overview of the run;
- Hourly concentration files for each receptor and meteorological combination;
- Post analysis software of the concentration file to represent identified scenarios; and
- Presentation software is used to re-format the model predictions and to provide concentrations contour plots that to be superimposed over base maps.



2.3 MODEL SELECTION

2.3.1 Model Requirements

For the ALBA project, the selected model must have the ability to account for:

- Multiple point and area sources
- Flat and elevated terrain features
- Dry deposition of gases and particles and chemical transformation of NO₂ and SO₂

These features are required to predict ambient concentrations.

2.3.2 Candidate Models

The CALPUFF model was therefore selected as the preferred model for this assessment. CALPUFF has two options with respect to meteorological data:

- The simple mode assumes a uniform meteorological field over the model domain during a given hour. While this approach is consistent with the AERMOD model, CALPUFF has the advantage of allowing the plume trajectories to vary from hour-to-hour in a systematic manner as the wind direction varies from hour-to-hour. This becomes more important to include when the model is applied to larger domains.
- The CALMET model allows for three-dimensionally varying meteorological fields over the model domain during a given hour.

Dispersion Model:

The CALPUFF (Scire et al. 1999) model is a multi-layer, multi-species, non-steady state puff dispersion model that can simulate the effects of time and space-varying meteorological conditions on substance transport, transformation, and removal. CALPUFF can use the three-dimensional meteorological fields developed by the CALMET model or simple, single station, winds in a format consistent with the meteorological files used to drive the ISCST3 or the AERMOD steady-state Gaussian models.

For this assessment, the CALPUFF model with the three-dimensional CALMET wind field was selected. The CALPUFF model performance was gauged by comparing model predictions to selected observations.

2.4 CALPUFF Model

CALPUFF contains algorithms for near-source effects such as building downwash, transitional plume rise, partial plume penetration, as well as longer-range effects such as chemical transformation, and pollutant removal (wet scavenging and dry deposition). It can accommodate arbitrarily varying point source and area source emissions. Most of the algorithms contain options to treat physical processes at differing levels of detail depending on the requirements for the particular model application:

Atmospheric Dispersion:

Several options are provided in CALPUFF for the computation of dispersion coefficients:



- Similarity theory to estimate turbulence measurement (σ_v and σ_w) from surface heat and momentum fluxes provided by CALMET
- Pasquill-Gifford (PG) or McElroy-Pooler (MP) dispersion coefficients
- Dispersion equations based on the Complex Terrain Dispersion Model (CTDM)
- Hourly values of direct turbulence measurements (σ_v and σ_w)

2.5 MODEL APPLICATION

2.5.1 Model Domain

The CALPUFF model requires the user to define an area where the emissions sources are identified, the meteorological conditions are characterized, and the locations where the air quality changes are to be predicted. The CALPUFF computational domain is selected to represent a 50 km by 50 km area nominally centred over the ALBA Project.

2.5.2 Receptor Locations

Two types of receptors within the Model Domain are defined: nested Cartesian grid points and discrete locations.

2.5.3 Cartesian Grid Receptors

The receptors are based on the following spacing:

- 10 metre receptor spacing along the facility boundary;
- 50 metre receptor spacing within 500 metres from the facility;
- 250 metre receptor spacing from 500 metres to 2 kilometres from the facility;
- 500 metre receptor spacing from 2 kilometres to 5 kilometres from the facility; and,
- 1000 metre receptor spacing beyond 5 kilometres from the facility.

Table A- 12: CALPUFF Study Area Coordinates

Model Domain	Easting (m)	Northing (m)
Northeast Corner	485322.12	2910507.97
Southwest Corner	435322.12	2860507.97
Southeast Corner	485322.12	2860507.97
Northwest Corner	435322.12	2910507.97



2.5.4 Discrete Receptors

In addition, 10 discrete locations corresponding to specific sites of interest are included. Figure A- 7 shows the locations of the discrete receptors that were included in the assessment. These receptors were broadly grouped as follows:

5 ambient air-quality monitoring sites and 5 - sensitive receptors were chosen. Model predictions are compared to measurements at some monitoring sites to gauge the model performance.

Table A- 13: Sensitive Receptor Locations

No.	Receptor Name	Abbreviation Used	UTM E (km)	UTM N (km)
1	Ras Hayyan	MS_RH	461.356	2879.271
2	Hidd	MS_HD	465.063	2906.347
3	Maameer	MS_MA	461.532	2891.34
4	Napeeh Saleh	MS_NS	457.044	2894.759
5	Hamad Town	MS_HT	451.074	2884.502
6	Sanabis	SB	454.8766	2900.187
7	Villas Askar	VA	461.504	2882.467
8	Villas 2	V2	455.7868	2885.161
9	Residential Area & Golf Course	R_G	457.119	2886.07
10	Labour Accommodation	LA	459.967	2887.245
11	East-Riffa	ER	457.83	2888.485
13	Nuwaidrat	NU	460.1753	2890.493
14	Al Eker	AE	460.6759	2891.332
15	Sanad	SD	458.3597	2892.361
16	Sitra	SI	461.224	2893.765

Note:

MS: Ambient Air Monitoring Station



BILFINGER

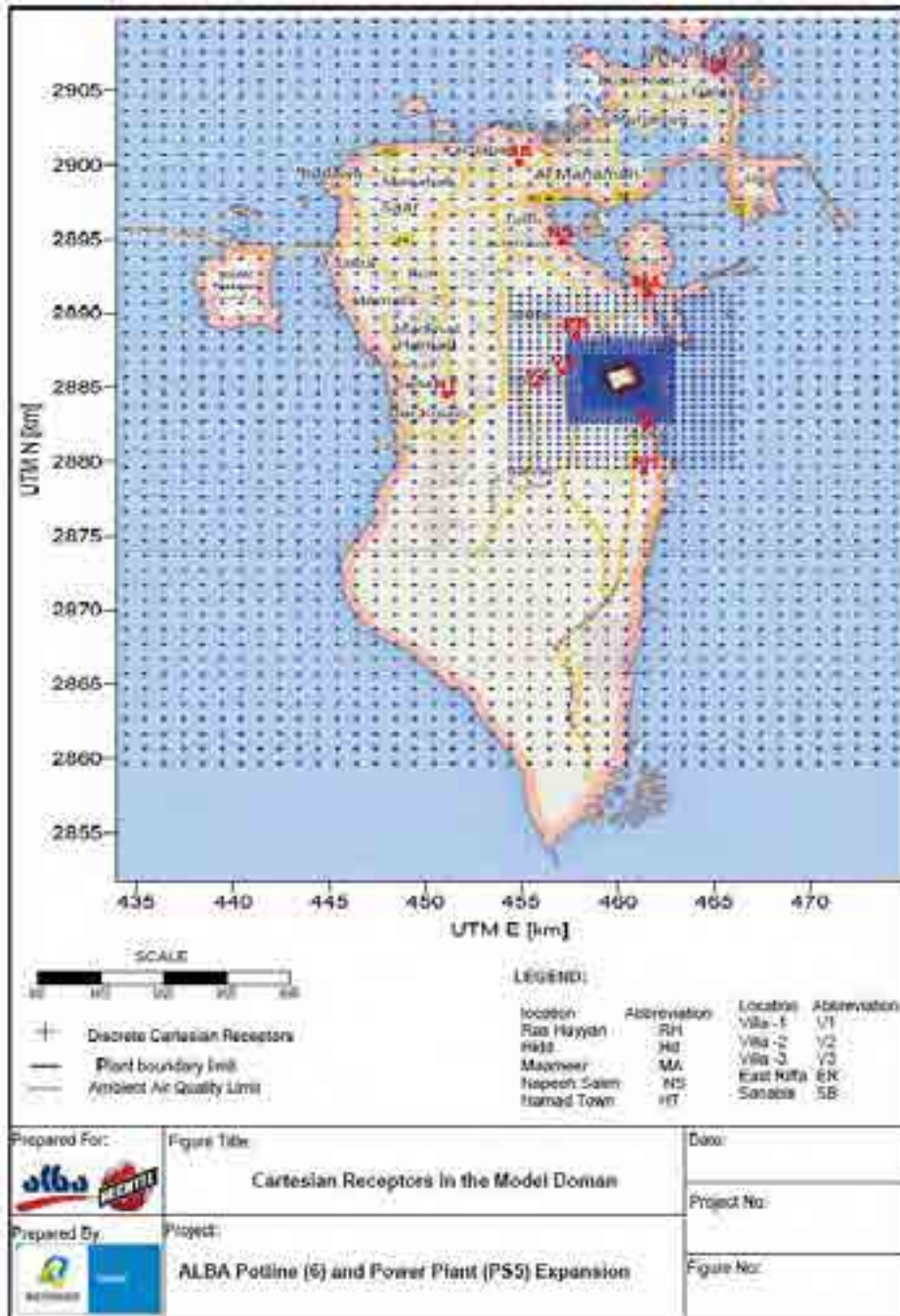


Figure A- 7: Location of Discrete Monitoring Station Receptors



2.5.5 Meteorology

The CALMET diagnostic wind field module was used to provide representative wind, temperature, and turbulence fields. One year (2012) of hourly CALMET input files were prepared and used for this assessment. The meteorology inputs for each year account for seasonal variations in the land cover properties.

2.5.6 Dispersion

The CALPUFF model offers a number of dispersion options. The following identifies the dispersion options that were selected for this assessment:

- The similarity scaling approach to estimate σ_v and σ_w provides a more up-to-date understanding of dispersion in the boundary layer than the historical discrete PG dispersion approach. The similarity approach treats dispersion as a continuous function, whereas the PG approach considers discrete classes. For this reason, MDISP = 2 (Input group 2) is used to select the similarity to change or move to different area.
- The Probability Distribution Function (PDF) approach accounts for downdrafts and updrafts that occur under convective conditions. The PDF approach increases the predicted concentrations resulting from stacks under convective conditions. For this assessment MPDF = 1 (PDF assumed) is selected.
- The Heffter (σ_y) adjustment was used. This approach enhances the lateral horizontal dispersion for large distances. This or a similar type of enhancement is recommended for large distances and thus the default Heffter value of 550 m is adopted (Input group 12).
- The default minimum σ_w values as required as part of Input group 12 were adopted. These values are based on the Briggs (1973) rural dispersion coefficients. These values are consistent with plume behaviour over barren area land use classification.
- The default minimum σ_v values (0.5 m/s) as required as part of Input group 12 were adopted.

This discussion is provided as the selection of the dispersion algorithms can have an influence on the model predictions. The values that were selected are representing our recent understanding of dispersion processes in the atmosphere and are viewed as appropriate for this assessment.

2.5.7 Building Downwash

Buildings or other solid structures may affect the flow of air near a source and cause building downwash effects (e.g., eddies on the downwind side), which have potential to reduce plume rise and affect dispersion. The Huber-Snyder and Schulman-Scire downwash models are both incorporated into CALPUFF. Schulman-Scire option was used to provide to use either model for all stacks, or make the choice on a stack-by-stack and wind sector-by-wind sector basis. Both algorithms have been implemented in such a way as to allow the use of wind direction specific building dimensions. The more advanced treatment of the PRIME downwash model is also incorporated as an option. This includes treating representative streamline patterns and diffusion rates in both the near and far wakes and recirculation effects in the cavity zone. Building downwash mode was part of the assessment.

2.5.8 Terrain Coefficients

Terrain in the study area is described in the CALMET description. While the terrain near the Project is relatively flat, there are locations where higher terrain occurs. As a plume/puff passes over complex terrain, it has the potential to move closer to the ground. The plume path coefficient (PPC) method can be used to account for this



potential decrease in height above the ground. A PPC of 1.0 assumes that the plume trajectory is parallel to the terrain features.

The default CALPUFF values are 0.5, 0.5, 0.5, 0.5, 0.35, and 0.35 for PG stability categories A, B, C, D, E and F, respectively. The selection of these values is not justified in the user guide (Scire et al. 1999). Lott (1984) compared a number of alternate terrain assessment schemes and recommended PPC values of 0.8, 0.7, 0.6, 0.5, 0.4, and 0.3 for Pasquill-Gifford (PG) stability categories A, B, C, D, E and F, respectively. For this assessment, PPC values of 0.8, 0.7, 0.6, 0.5, 0.4, and 0.35 for PG categories A, B, C, D, E and F, respectively, per Davies and Prasad (2005) were adopted.

2.6 Interpretation of Predictions

2.6.1 Comparison to BAAQS

EPA (2010) recommends discarding the eight highest 1-hour predictions at each receptor location during any given year, as these values “are considered outliers and should not be used as the basis for selecting stack height”. This means that the 1-hour Bahrain Ambient Air Quality Standards (BAAQS) values should be compared to the 9th highest prediction, not to the highest prediction. For a one-year period, the 9th highest value corresponds to the 99.9th percentile predicted concentration.

When effecting this comparison, EPA has the expectation that the 9th highest corresponds to a realistic worst-case scenario. Although “realistic” is not defined, one can assume it refers to a normal maximum emissions case that could reasonably be expected during routine operations. Specifically, it does not appear to be associated with maximum emissions due to process upsets or due to pollution-control technology downtime.

EPA also indicates that the second-highest 24-hour average prediction should be compared to the corresponding 24-hour BAAQS (EPA, 2010). The annual average concentration is compared directly to the annual BAAQS. When comparing the 24-hour and annual average concentration to the respective BAAQS, the top eight 1-hour average values are included.

2.6.2 Contour Maps

Predicted concentrations are displayed as contour plots superimposed over a base map of the study areas. The concentration contour plots are based on the maximum values for the one year simulation period. This may result in some “smoothing” of the contours based on tri-angulation statistical method. However, the tabular results are based on direct model output and not on smoothed data.

2.7 CALPUFF Performance

2.7.1 Model Prediction Confidence

Uncertainty associated with dispersion model predictions stems from two main areas (U.S. EPA 2005):



- **Reducible uncertainty**, which results from uncertainties associated with the input values and with the limitations of the model formulations. Reducible uncertainty can be minimized by better (i.e., more accurate and representative) measurements and improved model formulations.
- **Inherent uncertainty**, which is associated with the stochastic nature of the atmosphere and its representation. Models predict concentrations that represent an ensemble average of numerous repetitions for the same nominal event. An individual observed value can deviate significantly from the ensemble value. This uncertainty may be responsible for a $\pm 50\%$ deviation from the measured values.
- 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 $\pm 40\%$. 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 example, an uncertainty of 5° to 10° in the wind direction can produce a concentration error in the 20 to 70% range (U.S. EPA 2005).

The U.S. EPA (2005) provides guidance to decision makers relative to model uncertainty. Specifically, they recommend that the model predictions be accepted as a “best estimate”, until sufficient technical progress has been made to meaningfully implement concepts dealing with uncertainty.

2.7.2 Performance Approach

The performance of the CALPUFF/CALMET model system is determined by comparing model predictions to the Bahrain ambient air quality measurements at the selected monitoring stations. For purpose of gauging model performance, the ambient measurements and predictions are grouped as follows:

Respective to Alba’s location, the nearest upwind monitoring station is Maamer sport club station while the nearest downwind monitoring station is indicated at Ras Hayyan.

1. Askar residential area (Ras Hayyan) Monitoring Station - Downwind
2. Residential Area (Villa 3) and Royal Golf Club (Villa 2) - Upwind; and
3. East-Riffa residential area (upwind)

Ambient monitoring data represent contributions from existing ALBA facility and other industrial and anthropogenic sources in the study area. The model predictions, as applied for this comparison assessment, are done for the project alone contributions and do not include the contributions from sources outside the model domain and other project sources.

Model performance is often gauged by comparing the highest predicted values with the highest measured values as the model is often used to determine compliance with BAAQS. However, the meteorological variability and the emission variability can lead to uncertainties with this type of model performance comparison. For this assessment, the Top-25 1-hour predicted and measured concentrations are also calculated and compared. The use of the Top-25 concentrations is viewed as a more robust indicator than the single highest value (U.S. EPA 1992).

The fractional bias (FB) has also been used as a model performance indicator (U.S. EPA 1992) that is defined as:

$$FB = 2 * \left[\frac{PR - OB}{OB + PR} \right]$$



Where:

- OB = the average of the Top-25 1-hour concentrations observed at a given site.
- PR = the average of the Top-25 1-hour concentrations predicted at the same site.

The FB has the following properties:

- It is bounded ranging from +2.0 (extreme over-prediction) to -2.0 (extreme under-prediction).
- FB values corresponding to over-predictions and under-predictions by a factor of two ranges from +0.67 to -0.67, respectively.
- A FB value of 0.0 indicates perfect agreement.

The use of the absolute fractional bias (AFB) simplifies the comparison calculations. A model is viewed as acceptable if the AFB is less than 0.67; that is, the model is predicting within a factor of two.

The CALPUFF model comparison is undertaken for the existing emissions scenario and focuses on NO₂, SO₂, and PM₁₀ concentration comparisons. Measured and predicted concentrations are compared for the indicated ambient monitoring sites.

2.7.3 Nitrogen Dioxide Comparison

The NO₂ concentrations are influenced by NO_x emissions from industrial and non-industrial sources.

Table A- 14 compares the maximum 1-hour average concentrations measured and predicted at each monitoring site. The predicted values are based on the maximum contribution for the downwind site (Ras Hayyan Monitoring Station). The table provides the predicted-to-measured concentrations and associated Absolute Fractional Bias value. Values greater than unity indicate over-prediction, while values less than unity indicate under-prediction. The Absolute Fractional Bias (AFB) is also shown. AFB values less than 0.67 indicates the model is predicting within a factor of two.

An examination of the results indicates a slight over-prediction at the monitoring station and is within the limits of prediction analysis as per the USEPA modelling guideline and AFB analysis. The slight over-predictions are likely due to over inherent model limitations of CALPUFF of over-predicting at near field receptors.

The comparison between the measured and predicted values was repeated by comparing the average of the Top-25 measured 1-hour concentrations with the average of the Top-25 predicted 1-hour concentrations.

The maximum-to-minimum ratios are similar to the corresponding values based on the maximum 1-hour predictions. The year-to-year variability between the maximum values that are measured in each year is lower for the Top-25 values.

On comparison of the Top-25 1-hour average concentrations measured and predicted at the selected monitoring site. The predicted values are based on the average Top-25 concentrations for each site and measured values at the Ras Hayyan Monitoring Station for the year 2011.



Table A- 14: Comparison of Maximum Measured and Predicted 1-Hour NO2 Concentrations

Bahrain Air Quality Standard (µg/m3)	Predicted Concentrations (µg/m3)			Contribution of Alba to the Monitoring Station %			AFB		
	NO2			NO2			NO2		
	Annual mean	24 h	1 h	Annual mean	24 h	1 h	Annual mean	24 h	1 h
	40	150	200	40	150	200			
Monitored Background Concentrations	1.2	6.1	15				0.44	0.35	0.27
Scenario-1 Existing	1.8	8.7	20	56%	42%	32%			

2.7.4 Sulphur Dioxide Comparisons

The comparison of measured and predicted SO₂ concentrations often provides the best indication of model performance because:

- The emissions originate from a few, well-documented sources.
- Chemical reactions that affect SO₂ concentrations are not significant for the associated transport times between the sources and the monitoring stations.
- There are a number of locations where ambient measurements are taken.

The model predictions, as previously noted, do not account for upset and abnormal events (e.g., upset scenarios) and hence could appear to under-predict relative to the measurements.

Table A- 15 shows the maximum (first highest) predicted SO₂ concentrations for the simulation year for the indicated monitoring station (Ras Hayyan). The table shows the minimum, the maximum, and the average of the first highest values for the five-year period.

The ratio of the maximum-to-minimum concentration is a measure of the temporal robustness of the average maximum to represent typical peak concentrations. Typically if the ratio is 1.5 or less, indicates that the high concentrations are similar and is acceptable. Below table provides the ratio of the predicted-to-measured concentrations. Values greater than unity indicate over-prediction, while values less than unity indicate under-prediction. The absolute fractional bias (AFB) is also shown; values less than 0.67 indicates the model is predicting within a factor of two.

The under-estimation of the SO₂ concentrations at the Ras Hayyan Industrial monitoring station is likely due to not including short-term peak emissions in the model input. If the facility had been emitting at average emission rate, then the associated predicted 1-hour SO₂ concentration would be around 87% of total monitored value at Ras Hayyan. The Top-25 comparison averages out the extreme SO₂ concentrations that are associated with intermittent high SO₂ emission events, providing a more representative indicator of typical peak values. The



comparison between the Top-25 average measured and predicted concentrations indicates a general tendency to over predict at most monitoring stations reasonable model performance.

Table A- 15: Comparison of Maximum Measured and Predicted 1-Hour SO₂ Concentrations

Bahrain Air Quality Standard (µg/m ³)	Predicted Concentrations (µg/m ³)			Contribution of Alba to the Monitoring Station %			AFB		
	SO ₂			SO ₂			SO ₂		
	Annual mean	24 h	1 h	Annual mean	24 h	1 h	Annual mean	24 h	1 h
	50	125	350	50	125	350			
Monitored Background Concentrations	5.60	29.19	71.08				-0.48	-0.30	-0.30
Scenario-1 Existing	3.45	21.58	52.54	62%	74%	74%			

2.8 Summary and Conclusions

2.8.1 Model Application

The CALPUFF dispersion model (Version 6.42, Level 110325) was selected as the primary air quality assessment tool to predict ambient concentrations for the ALBA Project assessment. The following were adopted for the application of the model:

- 8,708 gridded receptor grid points are selected for the 50 km by 50 km Model Domain. An additional 10 ambient monitoring locations were also selected.
- One year meteorological data for the period January 2012 to December 2012 was used. The MM5 data provided by Lakes Environmental, Canada was used by the CALMET model to provide the meteorological data for the CALPUFF model.
- The CALPUFF model is applied to the baseline/existing condition and 2- Future Scenarios (Future Scenario 1- Future Maximum Emissions and Future Scenario -2 Future Mitigated Emissions), using the source and emission inventory information described in the air quality assessment section of the main report.
- The OLM is used to estimate ambient NO₂ concentrations from the predicted NO_x values. Hourly O₃ concentrations from the five monitoring stations are used for this task.
- The approach and input parameters were examined to best represent air quality changes due to the project. These were examined in conjunction with the emission sources.

2.8.2 Model Prediction and Ambient Measurement Comparison

A comparison between the model predictions of the maximum 1-hour, the Top-25 1-hour, and the annual average concentrations and ambient measurements was undertaken. The results of this comparison indicate:

There is a good agreement between predictions and measurements for the Top-25 1- hour NO₂ concentrations, and for the annual average NO₂ concentrations at both the exposed industrial and residential sites. The Top-25 1-hour NO₂ concentrations tend to be over-predicted by 40% at the Industrial sites. The annual average NO₂ concentrations tend to be over-predicted by 56% at the industrial sites. There is closer agreement for the annual



averages at the exposed industrial and residential sites. The over-prediction is largely attributed to overestimating industrial emissions.

The model under-predicts the Top-25 1-hour SO₂ concentrations by 30 to 40%, and the annual average SO₂ concentrations by 50%. The under-prediction at one industrial site is due to emission variability for an adjacent industrial source.

The prediction and measurement comparisons of SO₂ and NO₂ concentrations are seen as providing a representative indication of the model performance. The ability of the model to predict concentrations for other emissions depends on the level-of-confidence associated with estimating the other emission rates.



3 SUPPLEMENTARY - CALPUFF Model Input Options

For the purposes of organization, the CALPUFF control file defines 18 input groups as identified in below table. For many of the options, default values used in the absence of site/project specific data.

Table A- 16 through Table A- 24 indicates the input parameters, the US EPA default options, and the values used for this assessment. For the most part, the US default options are selected to examine transport distances greater than 40 km. For this application, the assessment focusses primarily on transport distances less than this distance. For this reason, non-default parameters are selected, and the following discusses the rational for selecting these options:

- MBDW: The updated PRIME approach (Option 2) is used to simulate building downwash effects associated with the Project structures instead of the default and older ISC (Option 1) approach.
- MSPLIT: Puff splitting is necessary for large model domain.
- MCHEM: The chemical transformation rates are computed internally using (RIVID/ARM3) scheme rather than the older MESOPUFF II scheme.
- MDISP: Dispersion coefficients from internally calculated sigma v, sigma w using micrometeorological variables (u^* , w^* , L, etc.) (Option 2).
- DATUM: The World Geodetic System 1984 Spheroid coordinates are used as these are consistent with the applied CDED terrain data.
- LSAMP: Sampling grid is not used for this assessment. 8,708 discrete receptors as indicated in Input Group 17 were used.
- ICFRQ: Concentration fields are printed to output list file every 24-hours. This is more a "user defined" rather than "default" parameter.
- IDFRQ: Concentration fields are printed to output list file every 24-hours. This is more a "user defined" rather than "default" parameter.
- BCKO3: Background ozone concentrations (ppb) are based on measurements in the domain rather than a generic default values.
- BCKNH3: Background ammonia concentrations (ppb) are based on measurements in the model domain rather than default values.
- XSAMLEN: Maximum travel distance of slug or puff in meteorological grid units during one sampling unit. A preferred value of 10 has been specified in CALPUFF protocol documents.
- MXNEW: Maximum number of puffs released from one source during one time step. A preferred value of 60 has been specified in CALPUFF protocol documents.
- MXSAM: Maximum number of sampling steps during one time step for a puff. A preferred value of 60 has been specified in CALPUFF protocol documents.
- PPC: The default CALPUFF values are 0.5, 0.5, 0.5, 0.5, 0.35, and 0.35 for PG stability categories A, B, C, D, E and F, respectively

The performance of the CALPUFF/CALMET model system as applied with these respective assumptions has been compared top ambient measurements and has been found to provide representative predictions.



Table A- 16: Input Groups in the CALPUFF Control File

Input Group	Description	Applicable to Project?
0	Input and output file names	Yes
1	General run control parameters	Yes
2	Technical options	Yes
3	Species list	Yes
4	Grid control parameters	Yes
5	Output options	Yes
6	Sub grid scale complex terrain inputs	No
7	Dry deposition parameters for gases	No
8	Dry deposition parameters for particles	No
9	Miscellaneous dry deposition for parameters	No
10	Wet deposition parameters	No
11	Chemistry parameters	Yes
12	Diffusion and computational parameters	Yes
13	Point source parameters	Yes
14	Area source parameters	Yes
15	Line source parameters	Yes
16	Volume source parameters	No
17	Non-gridded (discrete) receptor information	Yes

Table A- 17: CALPUFF Model Options Groups 1 and 2

Input Group 1: General Run Control Parameters

Parameter	US EPA Default	Project	Comments
METRUN	0	0	All model periods in met file(s) will be run
IBYR	-	2012	Starting year
IBMO	-	1	Starting month
IBDY	-	1	Starting day
IBHR	-	0	Starting hour
XBTZ	-	+3	Base time zone (3 = Eastern Africa)
NSPEC	-	12	Number of chemical species
NSE	-	8	Number of chemical species to be emitted
ITEST	-	2	Program is executed after SETUP phase
MRESTART	-	0	Do not read or write a restart file during run
NRESPD	-	24	File updated every 24 periods
METFM	1	1	CALMET binary file (CALMET.MET)
AVET	60	60	Averaging time in minutes
PGTIME	60	60	PG Averaging time in minutes

Input Group 2: Technical Options

Parameter	US EPA Default	Project	Comments
MGAUSS	1	1	Gaussian distribution used in near field
MCTADJ	3	3	Partial plume path terrain adjustment
MCTSG	0	0	Scale-scale complex terrain not modelled



Parameter	US EPA Default	Project	Comments
MSLUG	0	0	Near-field puffs not modelled as elongated
MTRANS	1	1	Transitional plume rise modelled
MTIP	1	1	Stack tip downwash used (may overestimate flare stack concentrations)
MBDW	1	2	PRIME Method is used to simulate building downwash
MSHEAR	0	0	Vertical wind shear (not used)
MSPLIT	0	1	Puffs are split (necessary for a large domain)
MCHEM	1	3	Transformation rates computed internally using (RIVID/ARM3) scheme
MAQCHEM	0	0	Aqueous phase transformation not modelled
MWET	1	1	Wet removal modelled
MDRY	1	1	Dry deposition modelled
MTILT	0	0	Gravitational settling (plume tilt) is not modelled
MDISP	3	2	Dispersion coefficients from internally calculated sigma v, sigma w using micrometeorological variables (u*, w*, L, etc.)
MTURBVW	3	3	Use both σ_v and σ_w from PROFILE.DAT to compute σ_y and σ_z (n/a)
MDISP2	3	3	PG dispersion coefficients for rural areas (computed using ISCST3 approximation) and MP coefficients in urban areas when measured turbulence data is missing
MTAULY	0	0	Draxler default 617.284 (s)
MTAUADV	0	0	No turbulence advection
MCTURB	1	1	Standard CALPUFF subroutines
MROUGH	0	0	PG σ_y and σ_z is not adjusted for roughness (not applicable)
MPARTLBA	1	1	Partial plume penetration of elevated inversion modelled for the buoyant area sources
MPARTL	1	1	Partial plume penetration of elevated inversion
MTINV	0	0	Strength of temperature inversion computed from default gradients
MPDF	0	1	PDF used for dispersion under convective conditions
MSGTIBL	0	0	Sub-grid TIBL module not used for shoreline
MBCON	0	0	Boundary concentration conditions not modelled
MSOURCE	0	0	Individual source contributions not saved
MFOG	0	0	Do not configure for FOG model output
MREG	1	0	Do not test options specified to see if they conform to regulatory values

Table A- 18: CALPUFF Model Options Groups 3 and 4

Input Group 3: Species List-Chemistry Options

CSPEC	Modelled ¹	Emitted ²	Dry Deposition ³	Output Group Number
SO ₂	1	1	1	0
SO ₄ ²⁻	0	0	0	0
NO	0	0	0	0
NO ₂	1	1	1	0
HNO ₃	0	0	0	0
NO ₃ ⁻	0	0	0	0
NO _x	1	1	0	0
PM10	1	1	0	0
HF	1	1	1	0
PF	0	1	0	0



CO	0	1	0	0
NOTES:				
¹ 0=no, 1=yes				
² 0=no, 1=yes				
³ 0=none, 1=computed-gas, 2=computed particle, 3=user-specified				
Options are shown for the common air contaminants (CACs).				

Input Group 4: Map Projection and Grid Control Parameters

Parameter	US EPA Default	Project	Comments
PMAP	UTM	UTM	Universal Transverse Mercator
FEAST	0	0	False Easting (km) at the projection origin
FNORTH	0	0	False Northing (km) at the projection origin
IUTMZN	-	39	UTM zone
UTMHEM	N	N	Northern Hemisphere for UTM projection
DATUM	WGS-84	NAR-C	NAS-C used for output coordinates
NX	-	50	Number of X grid cells in meteorological grid
NY	-	50	Number of Y grid cells in meteorological grid
NZ	-	11	Number of vertical layers in meteorological grid
DGRIDKM	-	1	Grid spacing (km) to match CALMET
ZFACE	-	0, 20, 40, 80, 160, 320, 600, 1400, 2600	ZFACE
XORIGKM	-	434.42	Reference X coordinate for SW corner of grid cell (1,1) of meteorological grid (km)
YORIGKM	-	2559.665	Reference Y coordinate for SW corner of grid cell (1,1) of meteorological grid (km)
IBCOMP	-	1	X index of lower left corner of the computational grid
JBCOMP	-	1	Y index of lower left corner of the computational grid
IECOMP	-	50	X index of the upper right corner of the computational grid
JECOMP	-	50	Y index of the upper right corner of the computational grid
LSAMP	T	F	Sampling grid is not used
IBSAMP	-	1	X index of lower left corner of the sampling grid
JBSAMP	-	1	Y index of lower left corner of the sampling grid
IESAMP	-	50	X index of upper right corner of the sampling grid
JESAMP	-	50	Y index of upper right corner of the sampling grid
MESHDN	1	1	Nesting factor of the sampling grid

Table A- 19: CALPUFF Model Option Group 5

Input Group 5: Output Option

Parameter	US EPA Default	Project	Comments
ICON	1	1	Output file CONC.DAT containing concentrations is created
IDRY	1	1	Output file DFLX.DAT containing dry fluxes is created
IWET	1	1	Output file WFLX.DAT containing wet fluxes is created
IT2D	0	0	2D Temperature
IRHO	0	0	Density
IVIS	1	0	Output file containing relative humidity data is not created



Parameter	US EPA Default	Project	Comments
LCOMPRS	T	T	Do not perform data compression in output file
IQAPLOT	1	1	Create a standard series of output files (e.g., locations of sources, receptors, grids ...) suitable for plotting
IMFLX	0	0	Do not calculate mass fluxes across specific boundaries
IMBAL	0	0	Mass balances for each species are not reported hourly
ICPRT	0	0	Do not print concentration fields to the output list file
IDPRT	0	0	Do not print dry flux fields to the output list file
IWPRT	0	0	Do not print wet flux fields to the output list file
ICFRQ	1	24	Concentration fields are printed to output list file every 24-hour
IIDFRQ	1	24	Dry flux fields are printed to output list file every 24-hour
IWFRQ	1	24	Wet flux fields are printed to output list file every 24-hour
IPRTU	1	3	Units for line printer output are in $\mu\text{g}/\text{m}^3$ for concentration and $\mu\text{g}/\text{m}^2/\text{s}$ for deposition
IMESG	2	2	Messages tracking the progress of run are written on screen
LDEBUG	F	F	Logical value for debug output
IPFDEB	1	1	First puff to track
NPFDEB	1	1	Number of puffs to track
NN1	1	1	Meteorological period to start output
NN2	10	10	Meteorological period to end output

Input Group 5: Output Option

Species	Concentrations		Dry Fluxes Printed		Wet Fluxes Printed		Mass Flux	
	Printed		(0 = no, 1 = yes)		(0 = no, 1 = yes)			
	(0 = no, 1 = yes)							
	Printed	Saved to Disk	Printed	Saved to Disk	Printed	Saved to Disk	Printed	Saved to Disk
SO2	0	1	0	1	0	1	0	1
SO4 ²⁻	0	1	0	1	0	1	0	1
NO	0	1	0	1	0	1	0	1
NO ₂	0	1	0	1	0	1	0	1
HNO ₃	0	1	0	1	0	1	0	1
NO ₃ ⁻	0	1	0	1	0	1	0	1
NO _x	0	1	0	1	0	1	0	1
CO	0	1	0	1	0	1	0	1
PM10	0	1	0	1	0	1	0	1
HF	0	1	0	1	0	1	0	1
PF	0	1	0	1	0	1	0	1
RSC	0	1	0	1	0	1	0	1

Table A- 20: CALPUFF Model Option Groups 6 and 7

Input Group 6: Sub-Grid Scale Complex Terrain Inputs

Parameter	US EPA Default	Project	Comments
NHILL	0	0	Number of terrain features (not applicable)
NCTREC	0	0	Number of special complex terrain receptors (not applicable)



Parameter	US EPA Default	Project	Comments
MHILL	-	2	Hill data created by OPTHILL & input below in Subgroup (6b); Receptor data in Subgroup (6c) (not applicable)
XHILL2M	1	1	Conversion factor for changing horizontal dimensions to metres (not applicable)
ZHILL2M	1	1	Conversion factor for changing vertical dimensions to metres (not applicable)
XCTDMKM	-	0	X origin of CTDM system relative to CALPUFF coordinate system (km) (not applicable)
YCTDMKM	-	0	Y origin of CTDM system relative to CALPUFF coordinate system (km) (not applicable)

Input Group 7: Dry Deposition Parameters for Gases

Species	US EPA Default	Project	Comments
SO ₂	0.1509	0.1372	Diffusivity
	1000	1000	Alpha star
	8	8	Reactivity
	0	0	Mesophyll resistance
	0.4	0.03311	Henry's Law coefficient
NO	-	0.2203	Diffusivity
	-	1	Alpha star
	-	2	Reactivity
	-	94	Mesophyll resistance
	-	18	Henry's Law coefficient
NO ₂	0.1656	0.1585	Diffusivity
	1	1	Alpha star
	8	8	Reactivity
	5	5	Mesophyll resistance
	3.5	3.5	Henry's Law coefficient
HNO ₃	0.1628	0.1041	Diffusivity
	1	1	Alpha star
	18	18	Reactivity
	0	0	Mesophyll resistance
	8E-08	1E-07	Henry's Law coefficient

Table A- 21: CALPUFF Model Option Groups 8, 9, 10, and 11

Input Group 8: Dry Deposition Parameters for Particles

Species	US EPA Default	Project	Comments
SO ₄ ²⁻	0.48	0.48	Geometric mass mean diameter of SO ₄ ²⁻ [µm]
SO ₄ ²⁻	2	2	Geometric standard deviation of SO ₄ ²⁻ [µm]
NO ₃ ⁻	0.48	0.48	Geometric mass mean diameter of NO ₃ ⁻ [µm]
NO ₃ ⁻	2	2	Geometric standard deviation of NO ₃ ⁻ [µm]
NO ₃ ⁻	2	2	Geometric standard deviation of NO ₃ ⁻ [µm]



Input Group 9: Miscellaneous Dry Deposition Parameters

Parameters	US EPA Default	Project	Comments
RCUTR	30	30	Reference cuticle resistance (s/cm)
RGR	10	10	Reference ground resistance (s/cm)
REACTR	8	8	Reference pollutant reactivity
NINT	9	9	Number of particle size intervals for effective particle deposition velocity
IVEG	1	1	Vegetation in non-irrigated areas is active and unstressed

Input Group 10: Wet Deposition Parameters

Species	US EPA Default	Project	Comments
SO ₂	3.21E-05	3.21E-05	Scavenging coefficient for liquid precipitation [s ⁻¹]
	0	0	Scavenging coefficient for frozen precipitation [s ⁻¹]
SO ₄ ²⁻	1.00E-04	1.00E-04	Scavenging coefficient for liquid precipitation [s ⁻¹]
	3.00E-05	3.00E-05	Scavenging coefficient for frozen precipitation [s ⁻¹]
NO	2.85E-05	2.90E-05	Scavenging coefficient for liquid precipitation [s ⁻¹]
	0	0	Scavenging coefficient for frozen precipitation [s ⁻¹]
NO ₂	5.13E-05	5.10E-05	Scavenging coefficient for liquid precipitation [s ⁻¹]
	0	0	Scavenging coefficient for frozen precipitation [s ⁻¹]
HNO ₃	6.00E-05	6.00E-05	Scavenging coefficient for liquid precipitation [s ⁻¹]
	0	0	Scavenging coefficient for frozen precipitation [s ⁻¹]
NO ₃ ⁻	1.00E-04	1.00E-04	Scavenging coefficient for liquid precipitation [s ⁻¹]
	3.00E-05	3.00E-05	Scavenging coefficient for frozen precipitation [s ⁻¹]

Input Group 11: Chemistry Parameters

parameters	US EPA Default	Project	Comments
MOZ	1	1	
BCKO3	12*80	12*30	Background ozone concentration (ppb)
BCKNH3	12*10	3.99, 4.36, 5.72, 5.20, 5.19, 5.89, 6.07, 7.12, 5.59, 4.72, 3.79, 5.35	Background ammonia concentration (ppb)
RNITE1	0.2	0.2	Night-time NO ₂ loss rate in percent/hour
RNITE2	2	2	Night-time NO _x loss rate in percent/hour
RNITE3	2	2	Night-time HNO ₃ loss rate in percent/hour
MH202	1	1	Read hourly H ₂ O ₂ concentrations from the H ₂ O ₂ .DAT file (not applicable)
BCKH202	12*1	12*1	Monthly background H ₂ O ₂ concentrations (used for aqueous phase transformations, not applicable)
BCKPMF	-	Not used	Fine particulate concentration for secondary organic aerosol option, used only for MESOPUFF II scheme for OH
OFRAC	-	Not used	Organic fraction of fine particulate for secondary organic aerosol option, used only for MESOPUFF II scheme for OH
VCNX	-	Not used	VOC/NO _x ratio for secondary organic aerosol option, used only for MESOPUFF II scheme for OH



Table A- 22: CALPUFF Model Option Group 12

Input Group 12: Diffusion/Computational Parameters

parameters	US EPA Default	Project	Comments	
SYTDEP	550	550	Horizontal size of a puff in metres beyond which the time dependant dispersion equation of Heffter (1965) is used	
MHFTSZ	0	0	Do not use Heffter formulas for sigma z	
JSUP	5	5	Stability class used to determine dispersion rates for puffs above boundary layer	
CONK1	0.01	0.01	Vertical dispersion constant for stable conditions	
CONK2	0.1	0.1	Vertical dispersion constant for neutral/stable conditions	
TBD	0.5	0.5	Use ISC transition point for determining the transition point between the Schulman-Scire (Schulman et al., 1998) to Huber-Snyder Building Downwash scheme	
ISIGMAV	1	1	Sigma-v is read for lateral turbulence data	
IMIXCTDM	0	0	Predicted mixing heights are used	
XMLEN	1	1	Maximum length of emitted slug in meteorological grid Units	
XSAMLEN	1	10	Maximum travel distance of slug or puff in meteorological grid units during one sampling unit	
MXNEW	99	60	Maximum number of puffs or slugs released from one source during one time step	
MXSAM	99	60	Maximum number of sampling steps during one time step for a puff or slug	
NCOUNT	2	2	Number of iterations used when computing the transport wind for a sampling step that includes transitional plume rise	
SYMIN	1	1	Minimum sigma y in metres for a new puff or slug	
SZMIN	1	1	Minimum sigma Z in metres for a new puff or slug	
SZCAP_M	5.00E+06		Maximum sigma z in metres to avoid numerical problem in calculating time or distance	
Stability class	Parameter			
	Minimum turbulence velocities sigma-v (SVMIN)		Minimum turbulence velocities sigma-w (SWMIN)	
	Minimum turbulence		Minimum turbulence	
	(σ _v) (m/s)		(σ _v) (m/s)	
	Land	Water	Land	Water
	A	0.5	0.37	0.2	0.2
B	0.5	0.37	0.12	0.12
C	0.5	0.37	0.08	0.08
D	0.5	0.37	0.06	0.06
E	0.5	0.37	0.03	0.03
F	0.5	0.37	0.016	0.016
parameters	US EPA Default	Project	Comments	
CDIV	0.0, 0.0	0.0, 0.0	Divergence criteria for dw/dz in met cells	
NLUTBIL	4	4	Search radius for nearest land and water cells used in the subgrid TIBL module	
WSCALM	0.5	0.5	Minimum wind speed allowed for non-calm conditions (m/s)	



parameters	US EPA Default	Project	Comments
XMAXZI	3000	3000	Maximum mixing height in metres
XMINZI	50	50	Minimum mixing height in metres
WSCAT	1.54	1.54	Wind speed category 1 [m/s]
	3.09	3.09	Wind speed category 2 [m/s]
	5.14	5.14	Wind speed category 3 [m/s]
	8.23	8.23	Wind speed category 4 [m/s]
	10.8	10.8	Wind speed category 5 [m/s]
PLX0	0.07	0.07	Wind Speed Power Law Exponent (Stability class A)
	0.07	0.07	Wind Speed Power Law Exponent (Stability class B)
	0.1	0.1	Wind Speed Power Law Exponent (Stability class C)
	0.15	0.15	Wind Speed Power Law Exponent (Stability class D)
	0.35	0.35	Wind Speed Power Law Exponent (Stability class E)
	0.55	0.55	Wind Speed Power Law Exponent (Stability class 5)
PTG0	0.02	0.02	Potential temperature gradient for E stability [K/m]
	0.035	0.035	Potential temperature gradient for F stability [K/m]
PPC	0.5	0.8	Plume Path Coefficient (Stability class A)
	0.5	0.7	Plume Path Coefficient (Stability class B)
	0.5	0.6	Plume Path Coefficient (Stability class C)
	0.5	0.5	Plume Path Coefficient (Stability class D)
	0.35	0.4	Plume Path Coefficient (Stability class E)
	0.35	0.3	Plume Path Coefficient (Stability class 5)
SL2PF	10	10	Slug-to-puff transition criterion factor equal to sigma y/length of slug
NSPLIT	3	3	Number of puffs that result every time a puff is split
IRESPLIT	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0	0, 0, 0, 0,0,0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0	Time(s) of day when split puffs are eligible to be split once Again
ZISPLIT	100	100	Minimum allowable last hour's mixing height for puff Splitting
ROLDMAX	0.25	0.25	Maximum allowable ratio of last hour's mixing height and maximum mixing height experienced by the puff for puff splitting
NSPLITH	5	5	Number of puffs that result every time a puff is horizontally split
YSPLITH	1	1	Minimum sigma-y of puff before it may be horizontally split
SHSPLITH	2	2	Minimum puff elongation rate due to wind shear before it may be horizontally split
CNSPLITH	1.00E-07	1.00E-07	Minimum concentration of each species in puff before it may be horizontally split
EPSSLUG	1.00E-04	1.00E-04	Fractional convergence criterion for numerical SLUG sampling iteration
EPSAREA	1.00E-06	1.00E-06	Fractional convergence criterion for numerical AREA sampling iteration
DRISE	1	1	Trajectory step length for numerical rise
HTMINBC	500	500	Minimum height (m) to which BC puffs are mixed as they are emitted (MBCON=2 ONLY)



parameters	US EPA Default	Project	Comments
RSAMPBC	10	10	Search radius (km) about a receptor for sampling nearest BC puff.
MDEPBC	1	1	Concentration is NOT adjusted for depletion

Table A- 23: CALPUFF Model Option Groups 13, 14, and 15

Input Group 13: Point Source Parameters

Parameters	US EPA Default	Project	Comments
NPT1	-	Varies by scenario	Number of point sources with constant stack parameters or variable emission rate scale factors
IPTU	1	1	Units for point source emission rates are g/s
NSPT1	0	Varies by Scenario	Number of source-species combinations with variable emissions scaling factors
NPT2	-	0	Number of point sources with variable emission parameters provided in external file

NOTES:

'-' symbol indicates that the parameter was not applicable to the Project assessment

Input Group 14: Area Source Parameters

Parameters	US EPA Default	Project	Comments
NAR1	-	Varies by Scenario	Number of polygon area sources
IARU	1	1	Units for area source emission rates are g/m ² /s
NSAR1	0	Varies by Scenario	Number of source species combinations with variable emissions scaling factors
NAR2	-	0	Number of buoyant polygon area sources with variable location and emission parameters

NOTES:

'-' symbol indicates that the parameter was not applicable to the Project assessment

Input Group 15: Line Source Parameters

Parameters	US EPA Default	Project	Comments
NLN2	-	Varies by scenario	
NLINES	-	0	
ILNU	1	1	
NSLN1	0	0	
MXNSEG	7	7	
NLRISE	6	6	

NOTES:

'-' symbol indicates that the parameter was not applicable to the Project assessment



Table A- 24: CALPUFF Model Option Groups 16 and 17

Input Group 16: Volume Source Parameters

Parameters	US EPA Default	Project	Comments
NVL1	-	Varies by scenario	
IVLU	1	1	
NSVL1	0	0	
NVL2	0	0	

NOTES:

'-' symbol indicates that the parameter was not applicable to the Project assessment

Input Group 17: Discrete Receptor Information

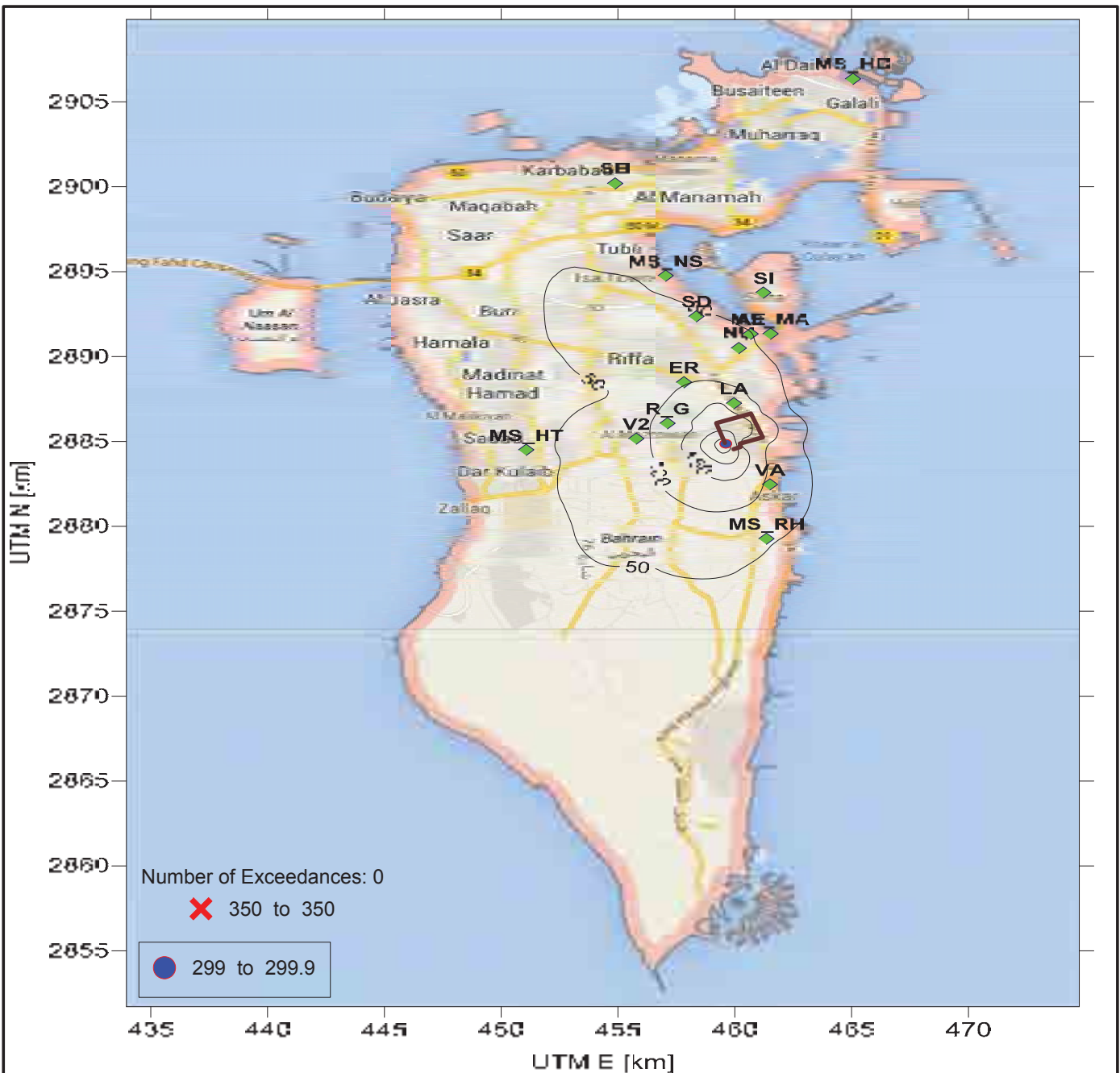
Parameters	US EPA Default	Project	Comments
NREC	-	17828	Number of non-gridded receptors

NOTES:

'-' symbol indicates that the parameter was not applicable to the Project assessment



Appendix 18: Air Dispersion Isopleths





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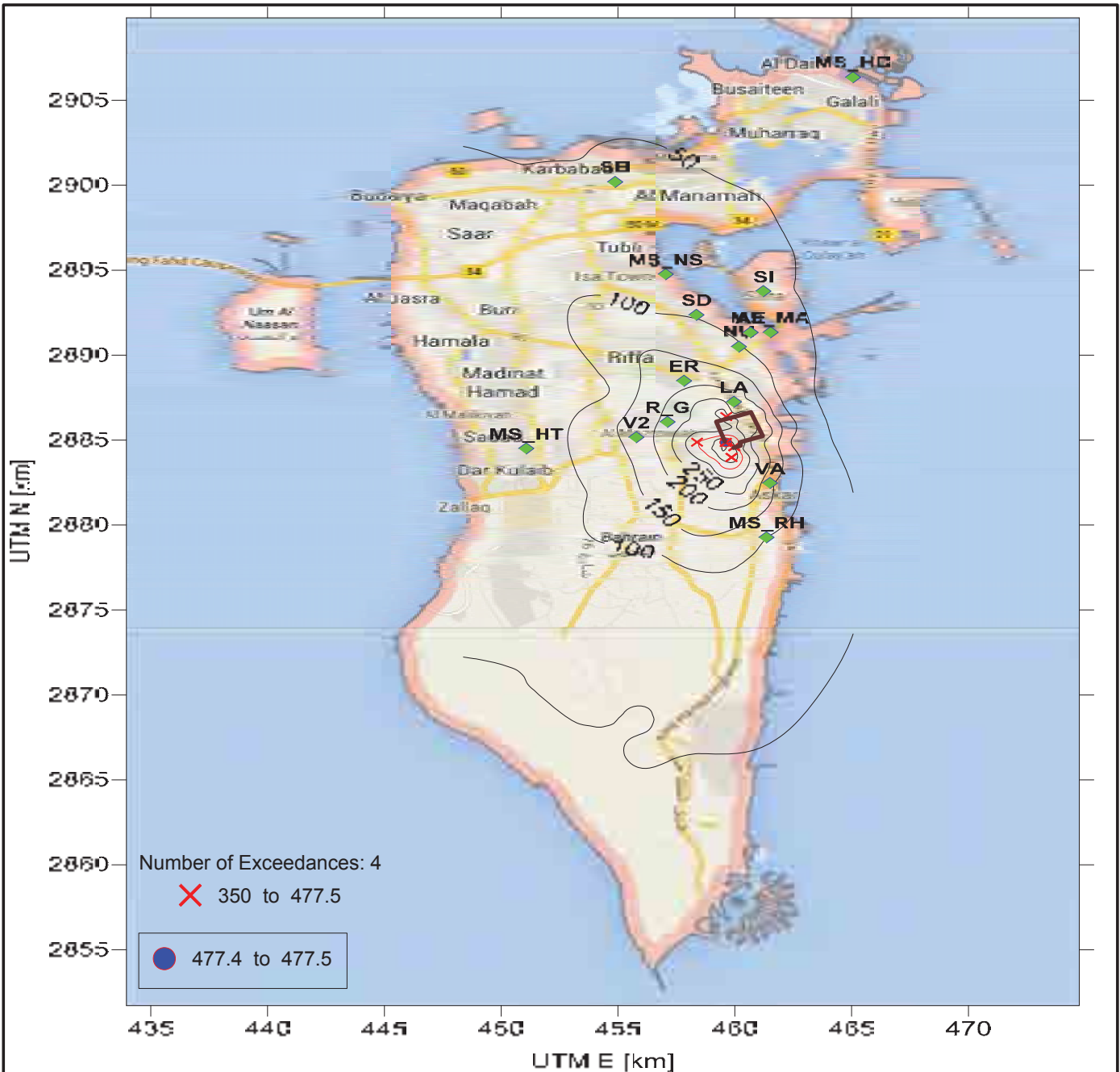
Ambient Air Quality Standards

Time Weighted Average - Hourly: 350 ug/m3
 Maximum Predicted Concentration: 300 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Hourly Average Concentration - SO₂ Baseline Scenario - 1 Existing Emission Sources	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 2



Number of Exceedances: 4
 X 350 to 477.5
 ● 477.4 to 477.5

LEGEND:

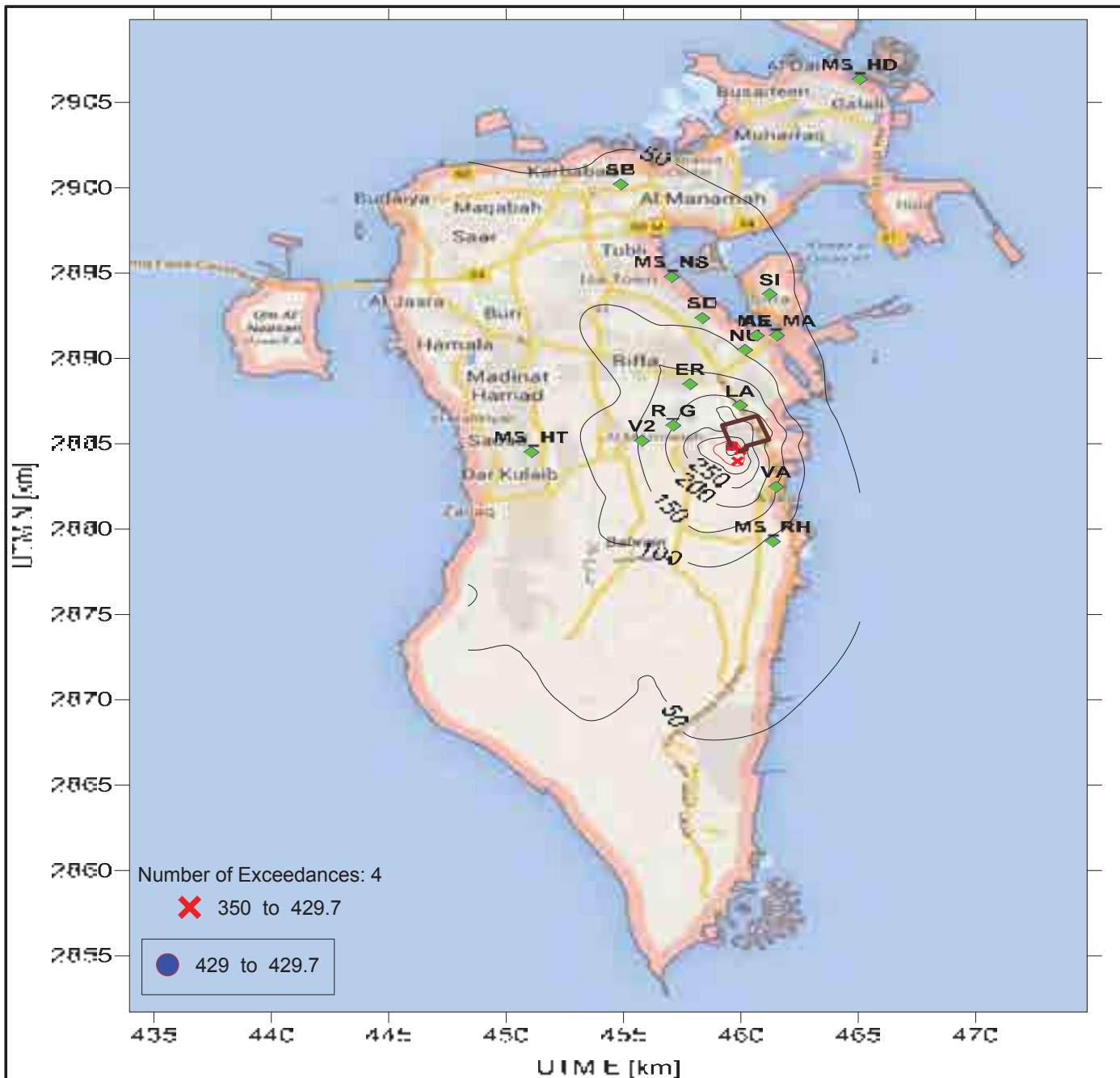
Ambient Air Quality Standards

Time Weighted Average - Hourly: 350 ug/m3
 Maximum Predicted Concentration: 477 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Hourly Average Concentration - SO₂ Future Scenario -2	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 3



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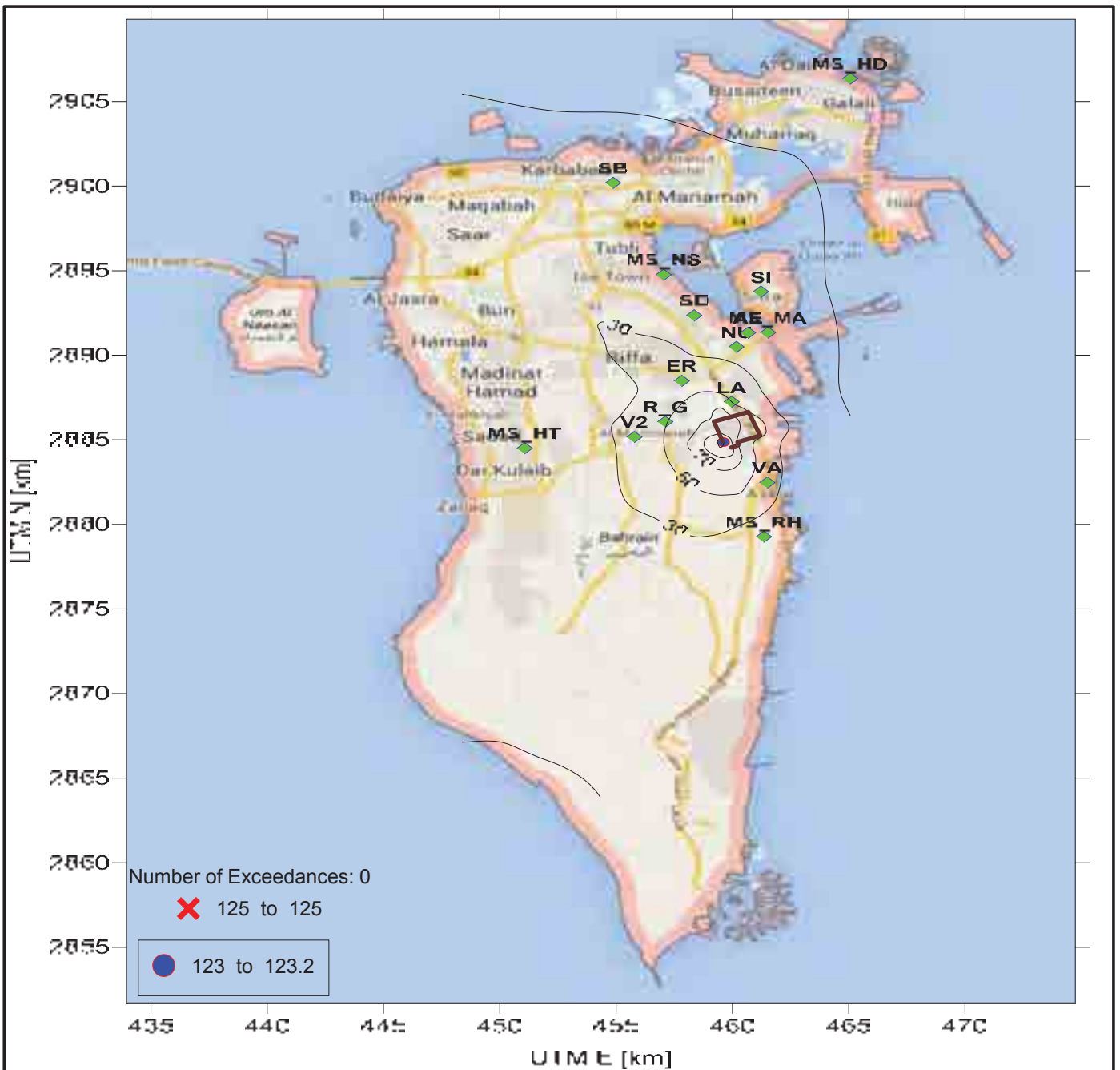
Ambient Air Quality Standards

Time Weighted Average - Hourly: 350 ug/m³
 Maximum Predicted Concentration: 430 ug/m³

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Hourly Average Concentration - SO₂ Future Scenario-3	Date: March, 2014
	Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion



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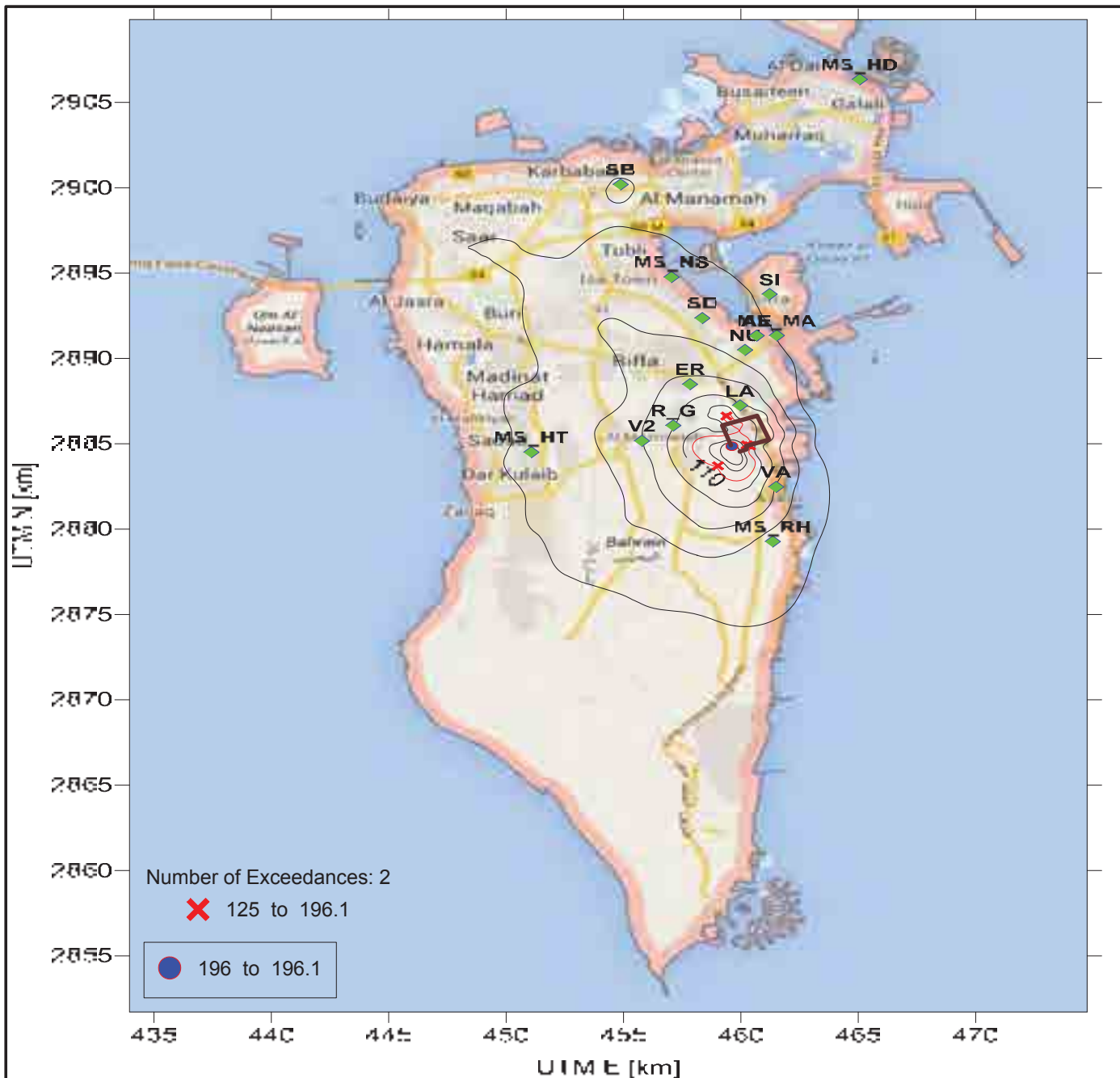
Ambient Air Quality Standards

Time Weighted Average - Daily: 125 ug/m³
 Maximum Predicted Concentration: 123 ug/m³

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'aameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area R_G & Golf Course	R_G			

Prepared For:	Figure Title:	Date:
	Daily Average Concentration - SO₂ Baseline Scenario - 1 Existing Emission Sources	March, 2014
Prepared By:	Project:	Project No:
	ALBA Potline (6) and Power Plant (PS5) Expansion	10921.00
		Figure No:
		5



Number of Exceedances: 2

✘ 125 to 196.1

● 196 to 196.1

LEGEND:

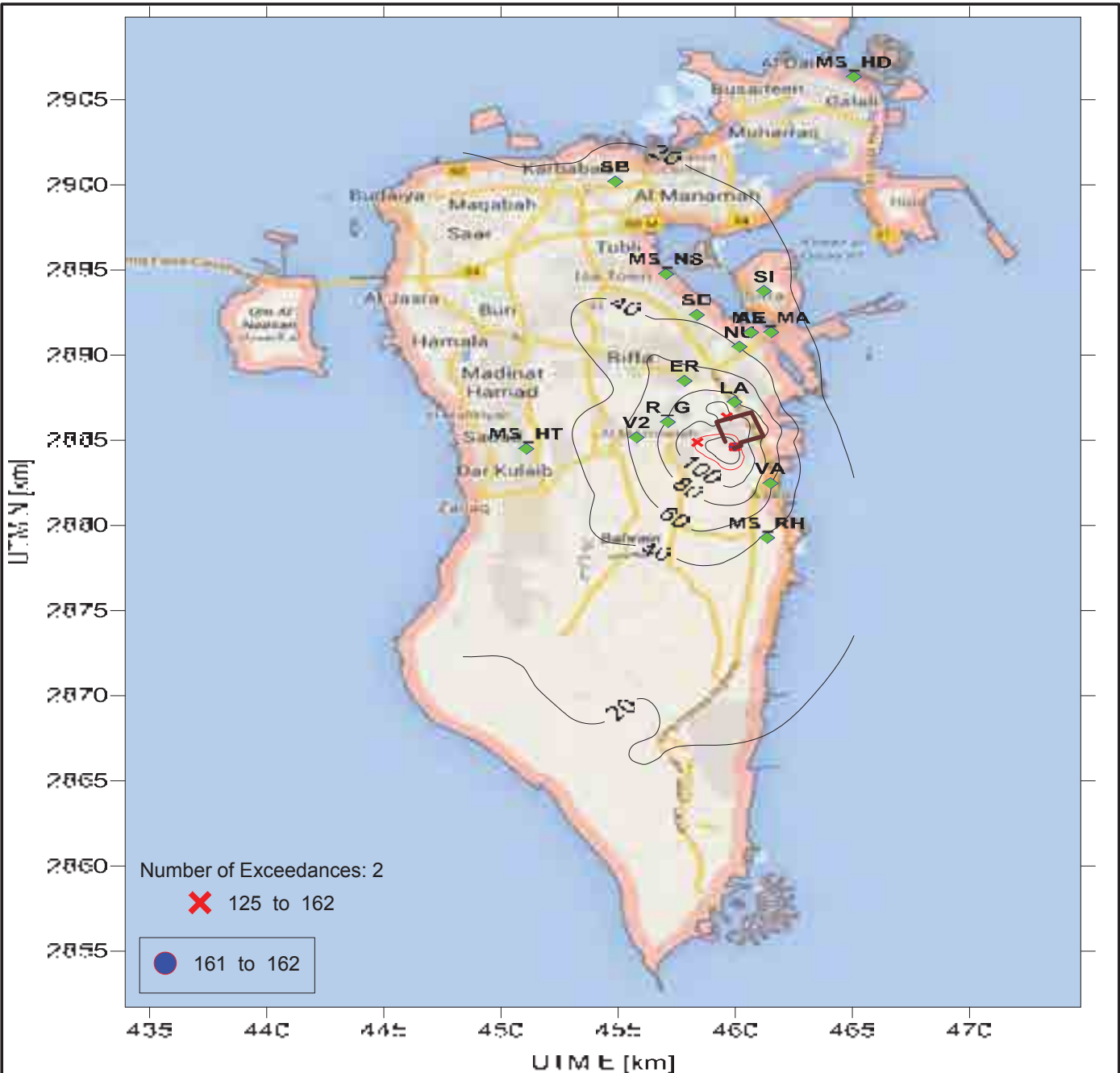
Ambient Air Quality Standards

Time Weighted Average - Daily: 125 ug/m3
 Maximum Predicted Concentration: 196 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Daily Average Concentration - SO₂ Future Scenario-2	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 6



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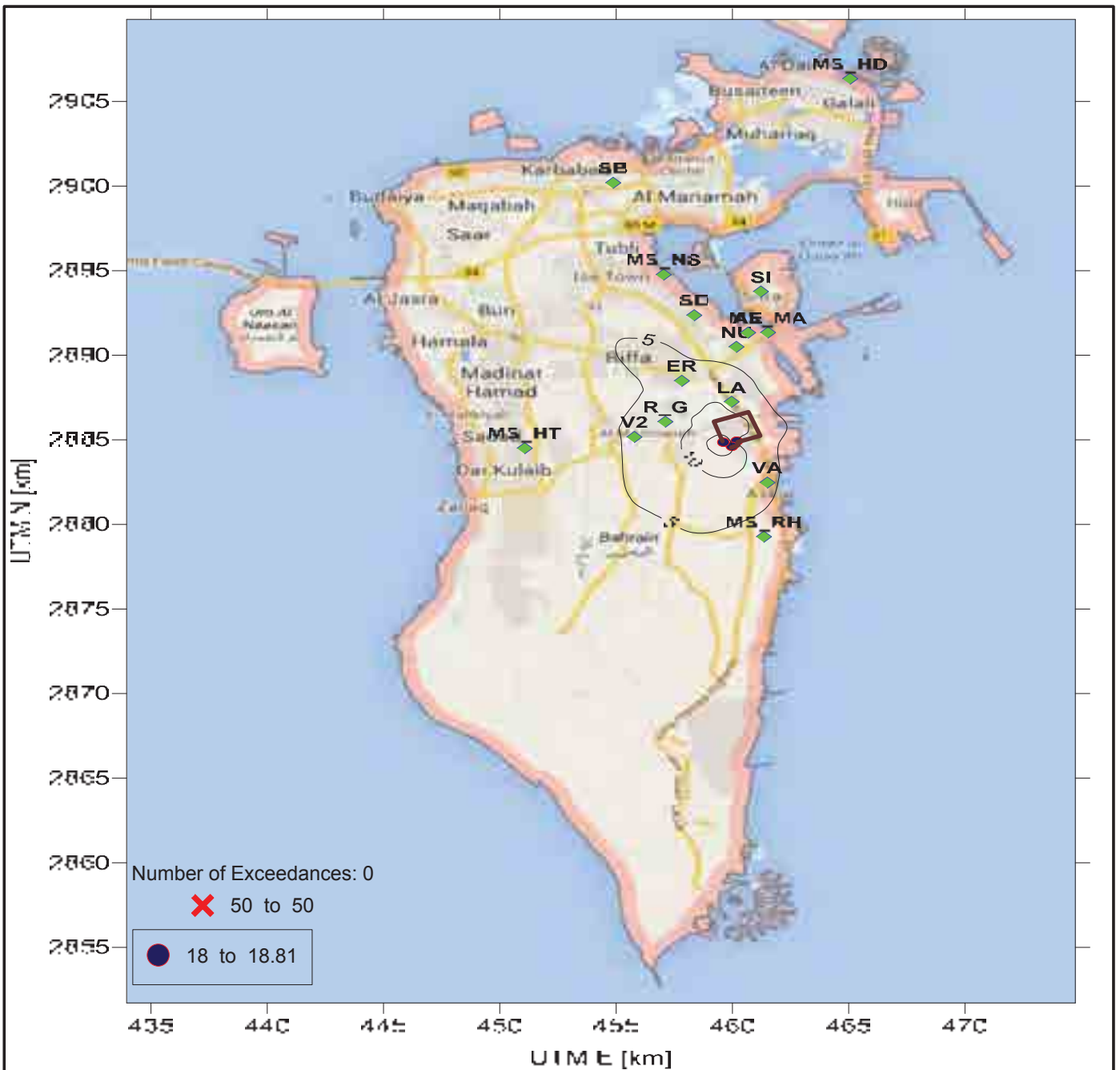
Ambient Air Quality Standards

Time Weighted Average - Daily: 125 ug/m3
 Maximum Predicted Concentration: 162 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Daily Average Concentration - SO₂ Future Scenario-3	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 7





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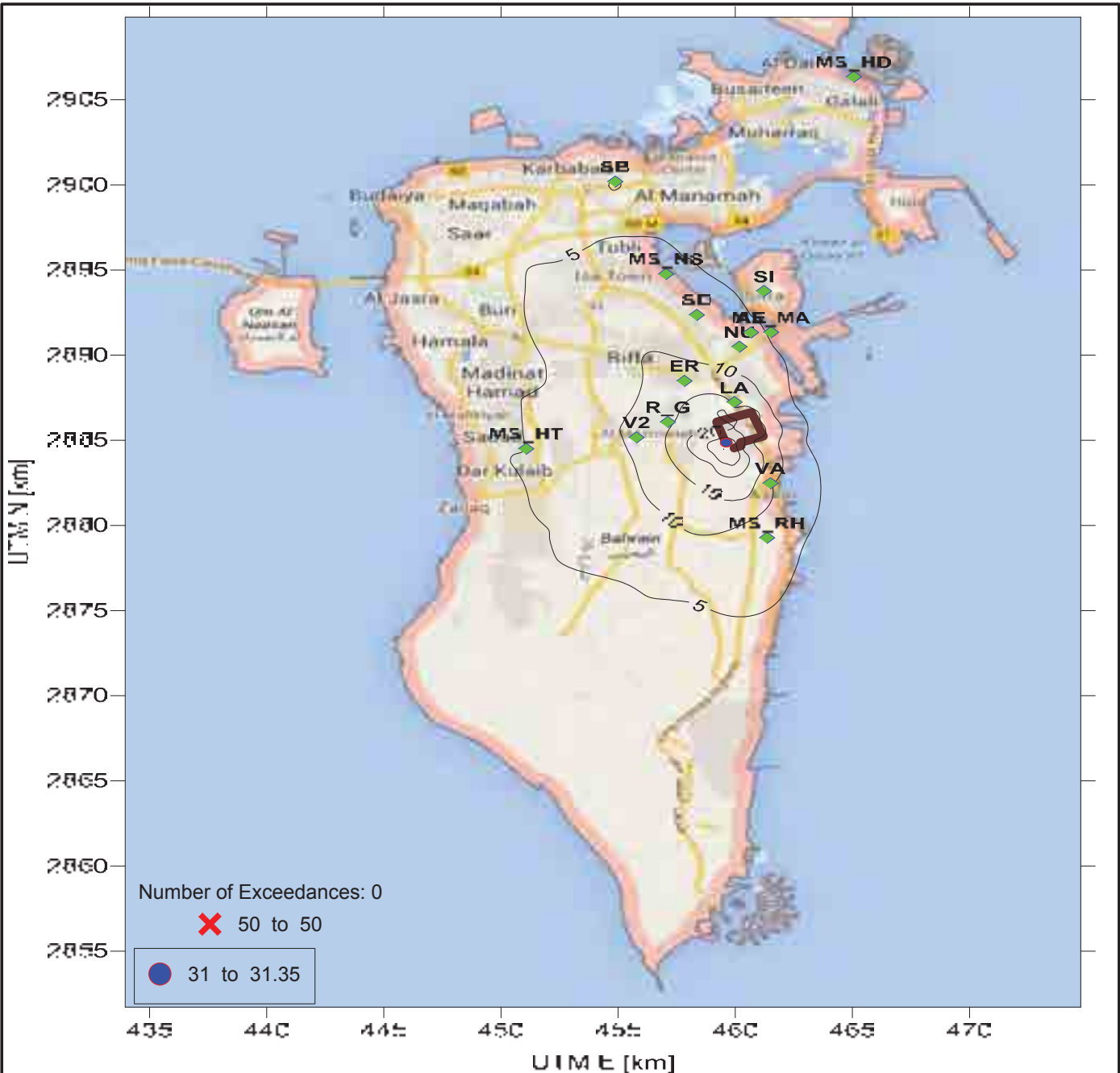
Ambient Air Quality Standards

Time Weighted Average - Annual: 50 ug/m3
 Maximum Predicted Concentration: 19 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	ResidentialArea & Golf Course	R_G			

Prepared For: 	Figure Title: Annual Average Concentration - SO2 Baseline Scenario - 1 Existing Emission Sources	Date: March, 2014
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Project No: 10921.00
		Figure No: 8





LEGEND:

Ambient Air Quality Standards

Time Weighted Average - Annual: 50 ug/m3
 Maximum Predicted Concentration: 31 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Annual Average Concentration - SO₂ Future Scenario -2	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 9



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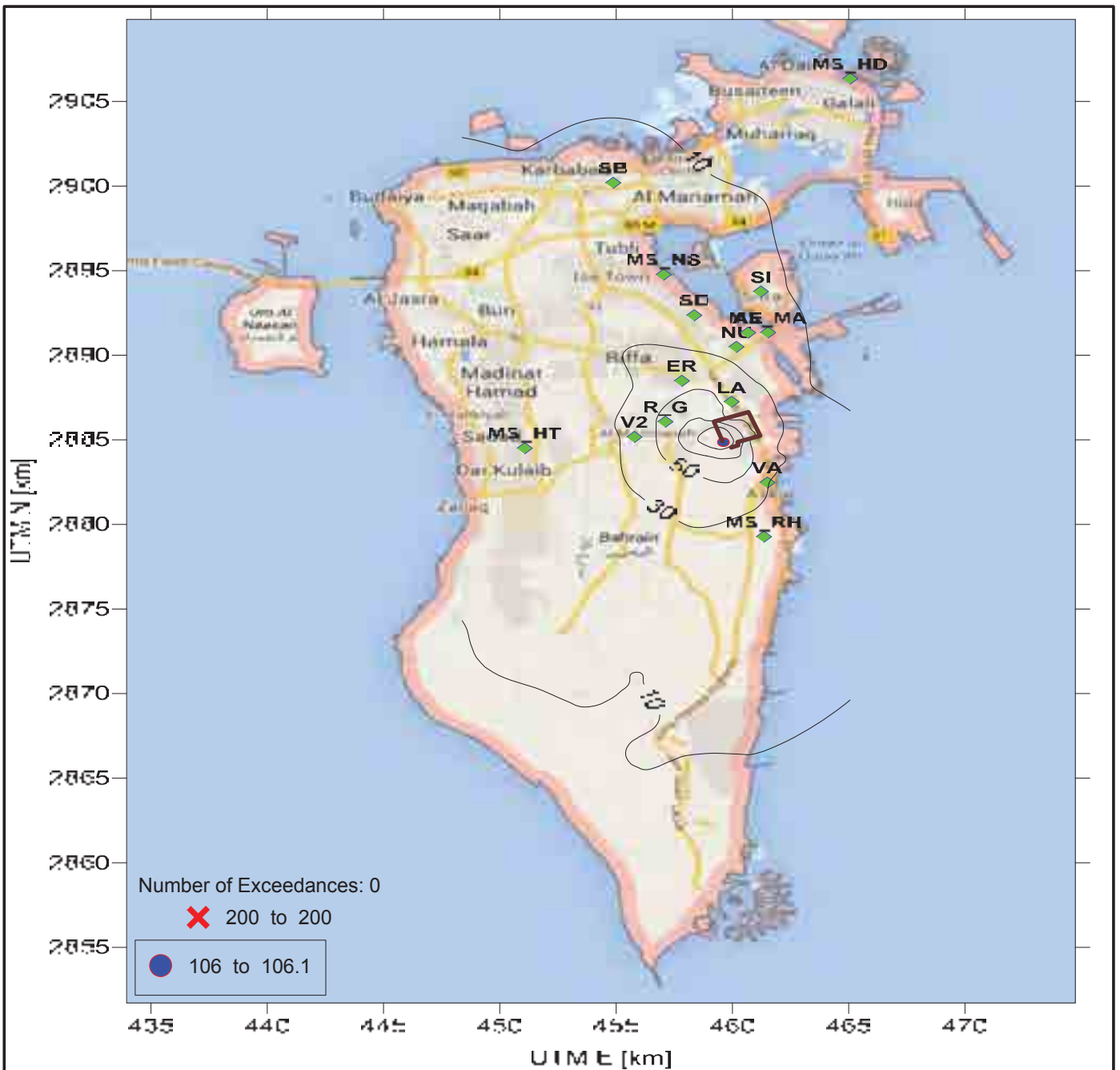
Ambient Air Quality Standards

Time Weighted Average - Yearly: 50 ug/m3
 Maximum Predicted Concentration: 28 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Annual Average Concentration - SO₂ Future Scenario-3	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 10





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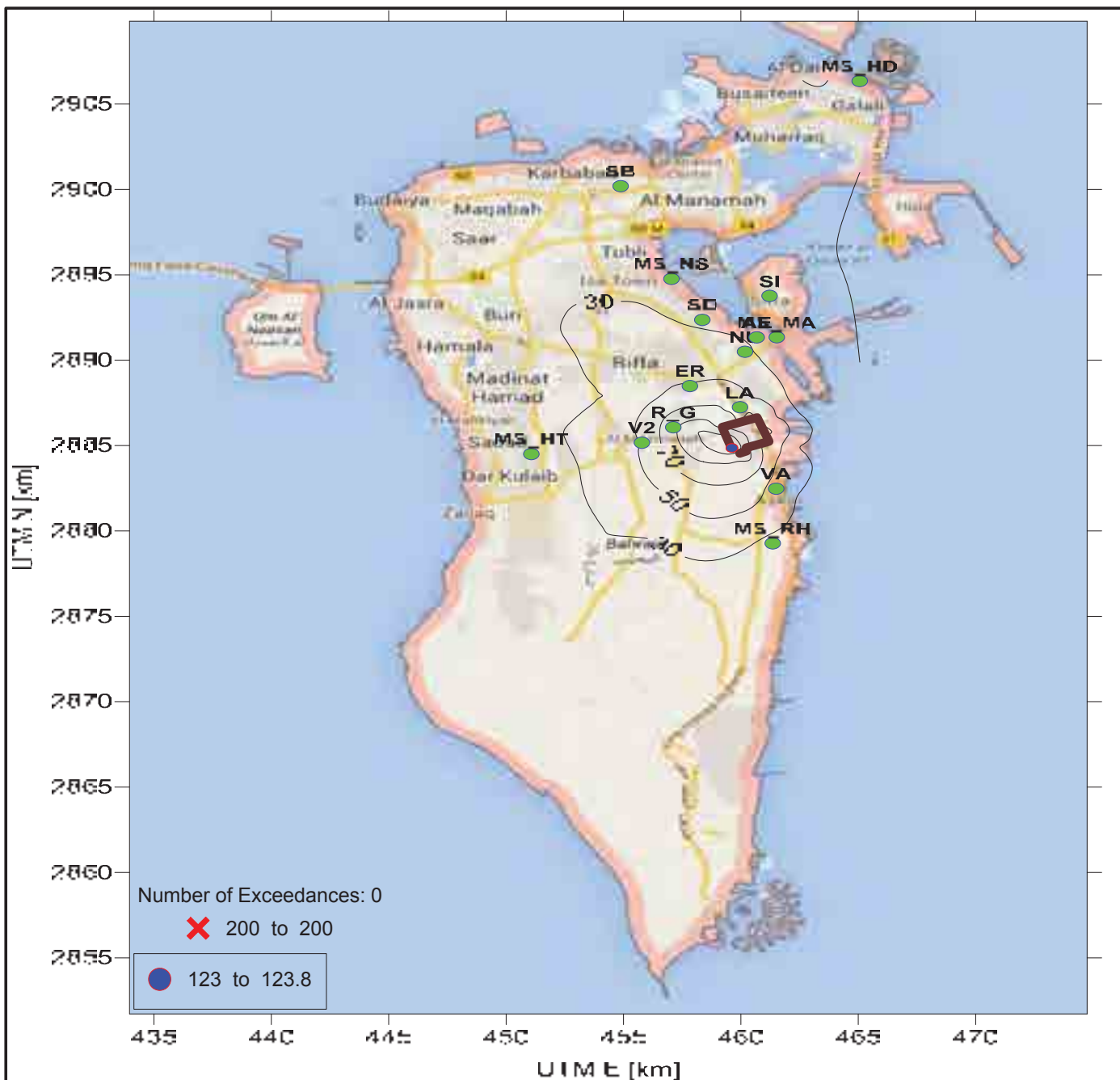
Ambient Air Quality Standards

Time Weighted Average - Hourly: 200 ug/m³
 Maximum Predicted Concentration: 106 ug/m³

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	ResidentialArea & Golf Course	R_G			

Prepared For: 	Figure Title: Hourly Average Concentration - NO2 Baseline Scenario - 1 Existing Emission Sources	Date: March, 2014
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Project No: 10921.00
		Figure No: 11





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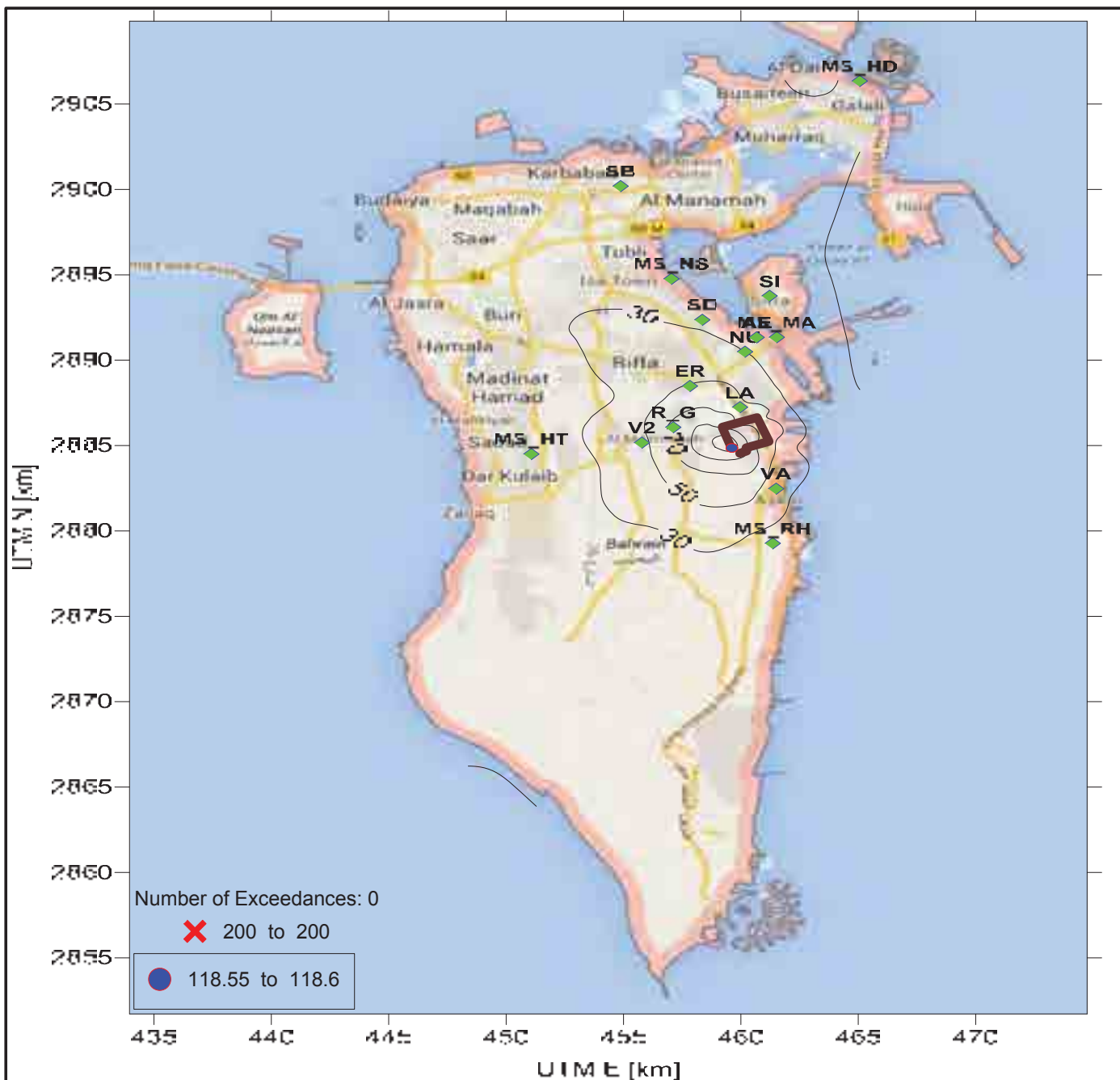
Ambient Air Quality Standards

Time Weighted Average - Hourly: 200 ug/m3
 Maximum Predicted Concentration: 124 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Hourly Average Concentration - NO₂ Future Scenario -2	Date: March, 2014
	Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Project No: 10921.00
		Figure No: 12



LEGEND:



Ambient Air Quality Standards

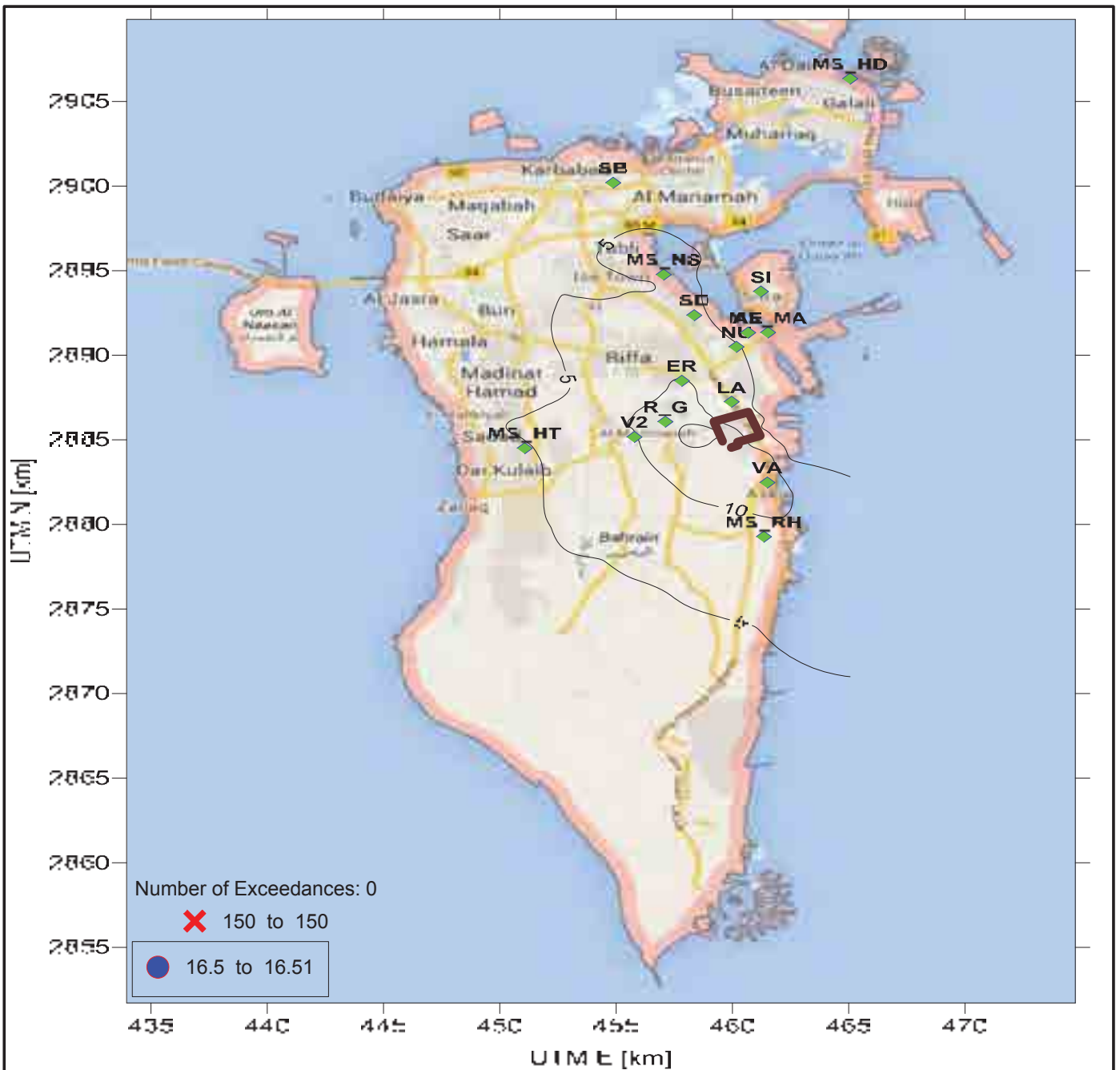
Time Weighted Average - Hourly: 200 ug/m³
 Maximum Predicted Concentration: 119 ug/m³

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

Number of Exceedances : 0

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Hourly Average Concentration - NO₂ Future Scenario-3	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 13





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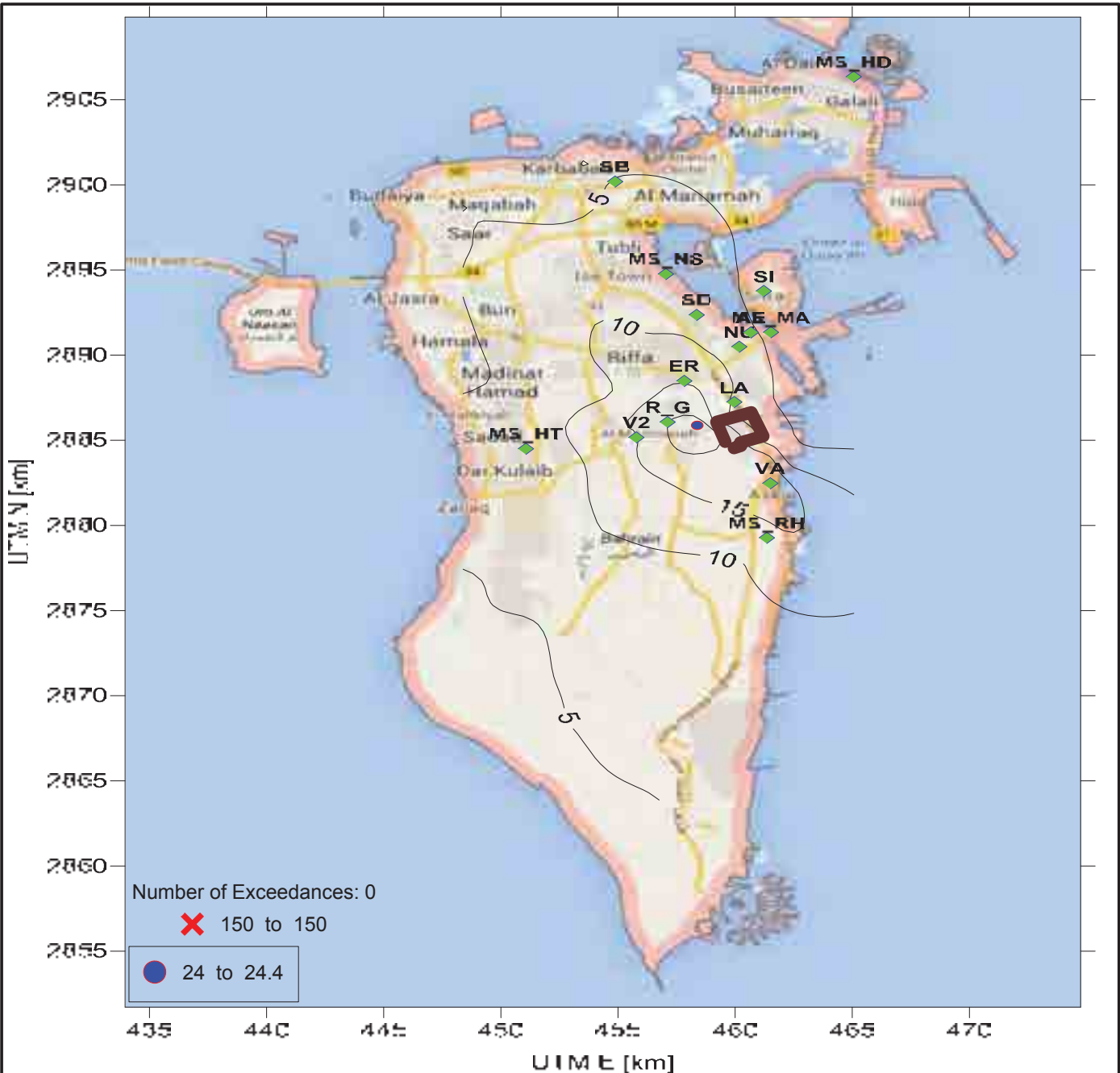
Ambient Air Quality Standards

Time Weighted Average - Daily: 150 ug/m3
 Maximum Predicted Concentration: 17 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	ResidentialArea & Golf Course	R_G			

Prepared For:	Figure Title:	Date:
	Daily Average Concentration - NO₂ Baseline Scenario - 1 Existing Emission Sources	March, 2014
Prepared By:	Project:	Project No:
	ALBA Potline (6) and Power Plant (PS5) Expansion	10921.00
		Figure No:
		14



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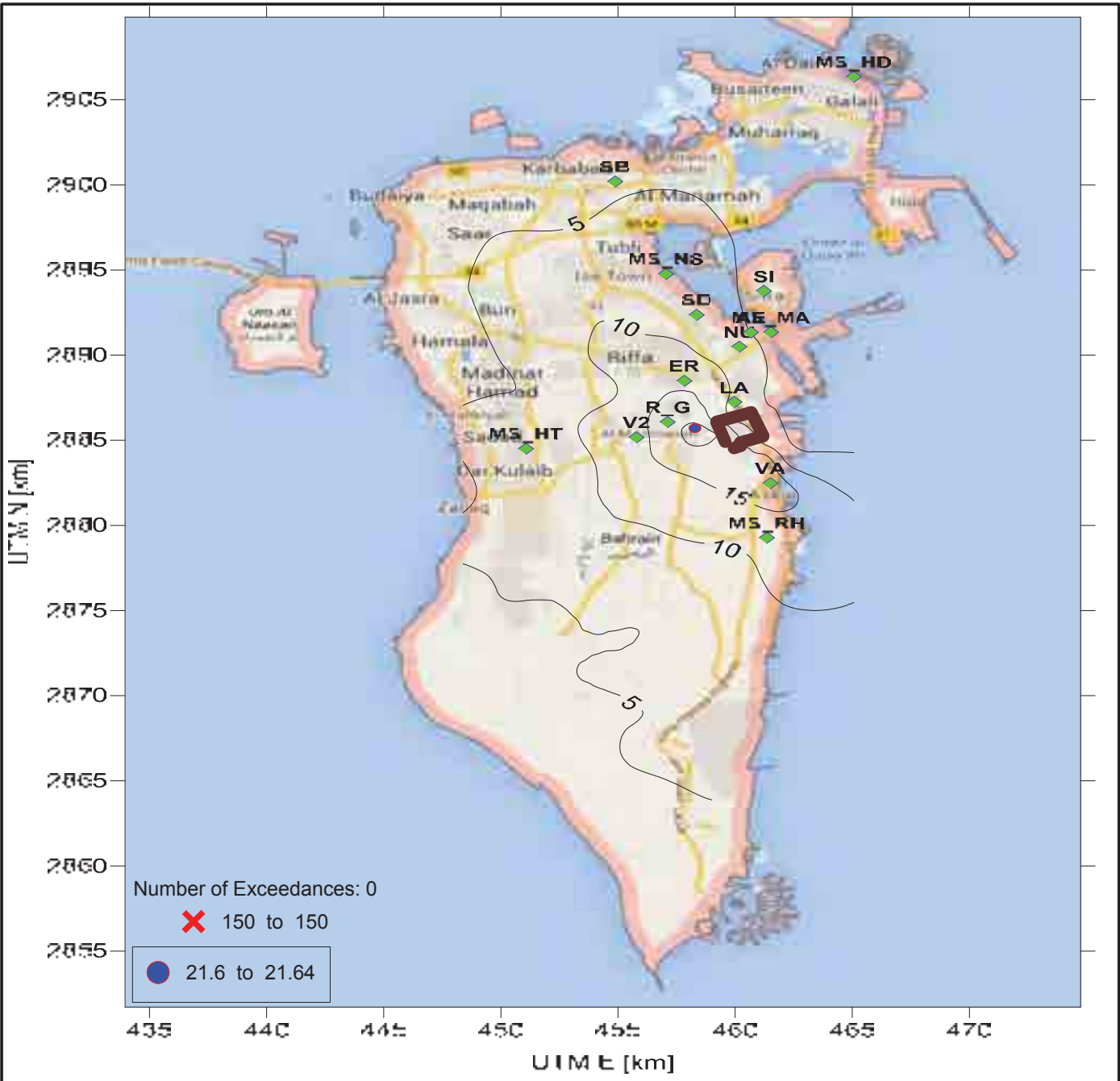
Ambient Air Quality Standards

Time Weighted Average - Daily: 150 ug/m3
 Maximum Predicted Concentration: 24 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'aameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For:	Figure Title:	Date:
	Daily Average Concentration - NO₂ Future Scenario -2	March, 2014
Prepared By:	Project:	Project No:
	ALBA Potline (6) and Power Plant (PS5) Expansion	10921.00
		Figure No:
		15



Number of Exceedances: 0
 X 150 to 150
 ● 21.6 to 21.64

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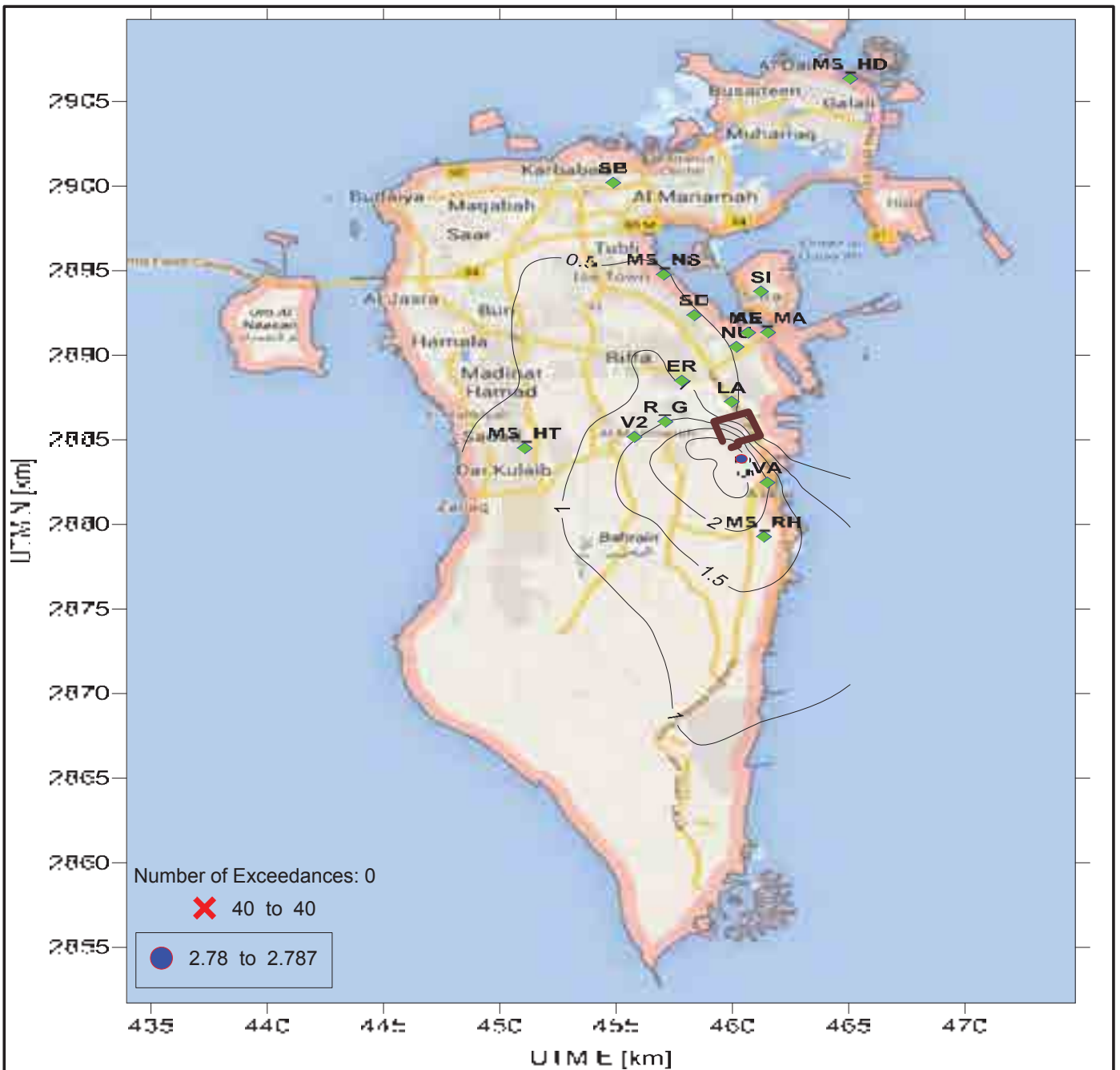
Ambient Air Quality Standards

Time Weighted Average - Daily: 150 ug/m3
 Maximum Predicted Concentration: 22 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Daily Average Concentration - NO₂ Future Scenario-3	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 16





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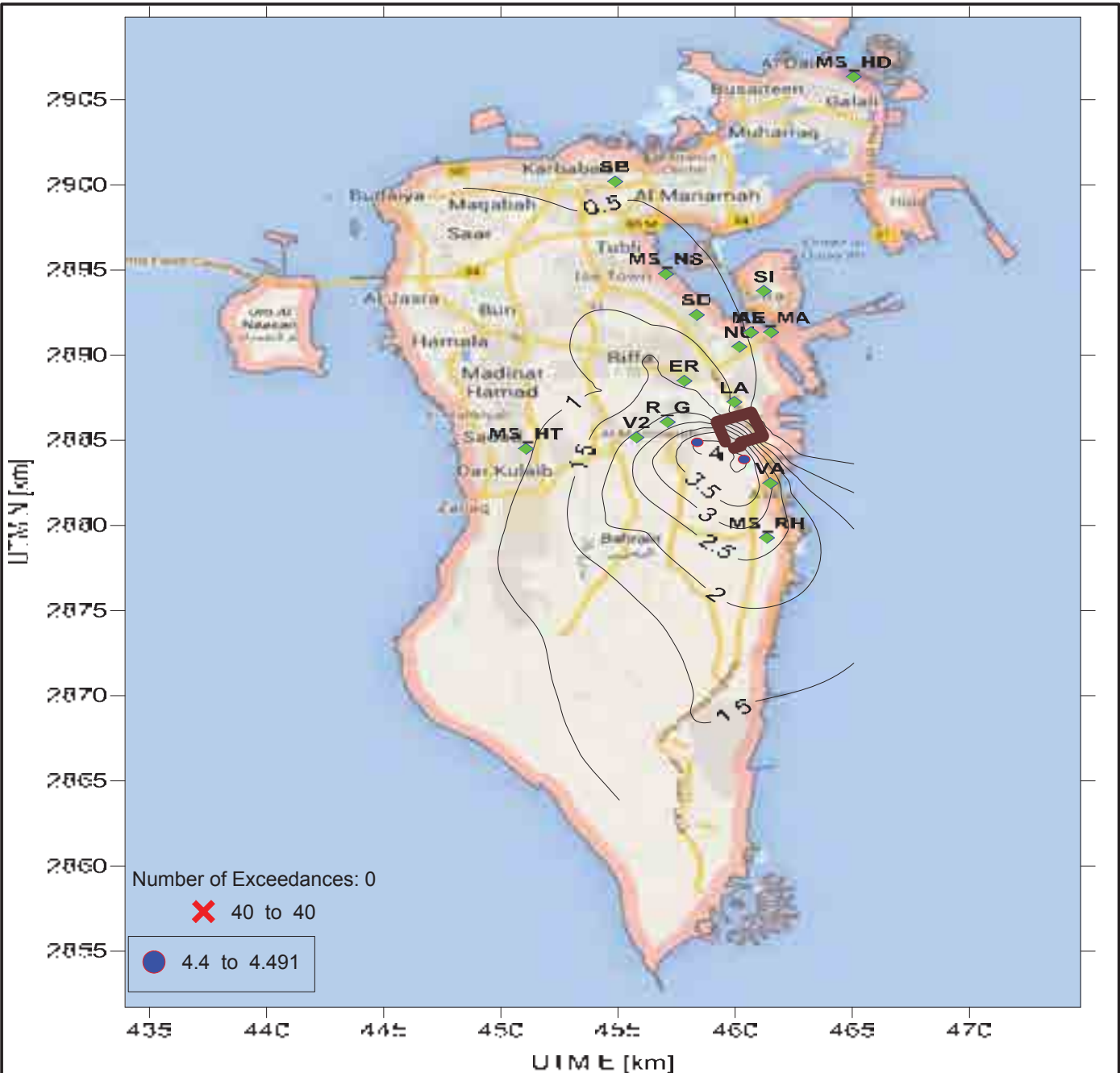
Ambient Air Quality Standards

Time Weighted Average - Annual : 40 ug/m³
 Maximum Predicted Concentration: 3 ug/m³

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'aameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	ResidentialArea & Golf Course	R_G			

Prepared For:	Figure Title: Annual Average Concentration - NO₂ Baseline Scenario - 1 Existing Emission Sources	Date:
		March, 2014
Prepared By:	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Project No:
		10921.00
		Figure No:
		17



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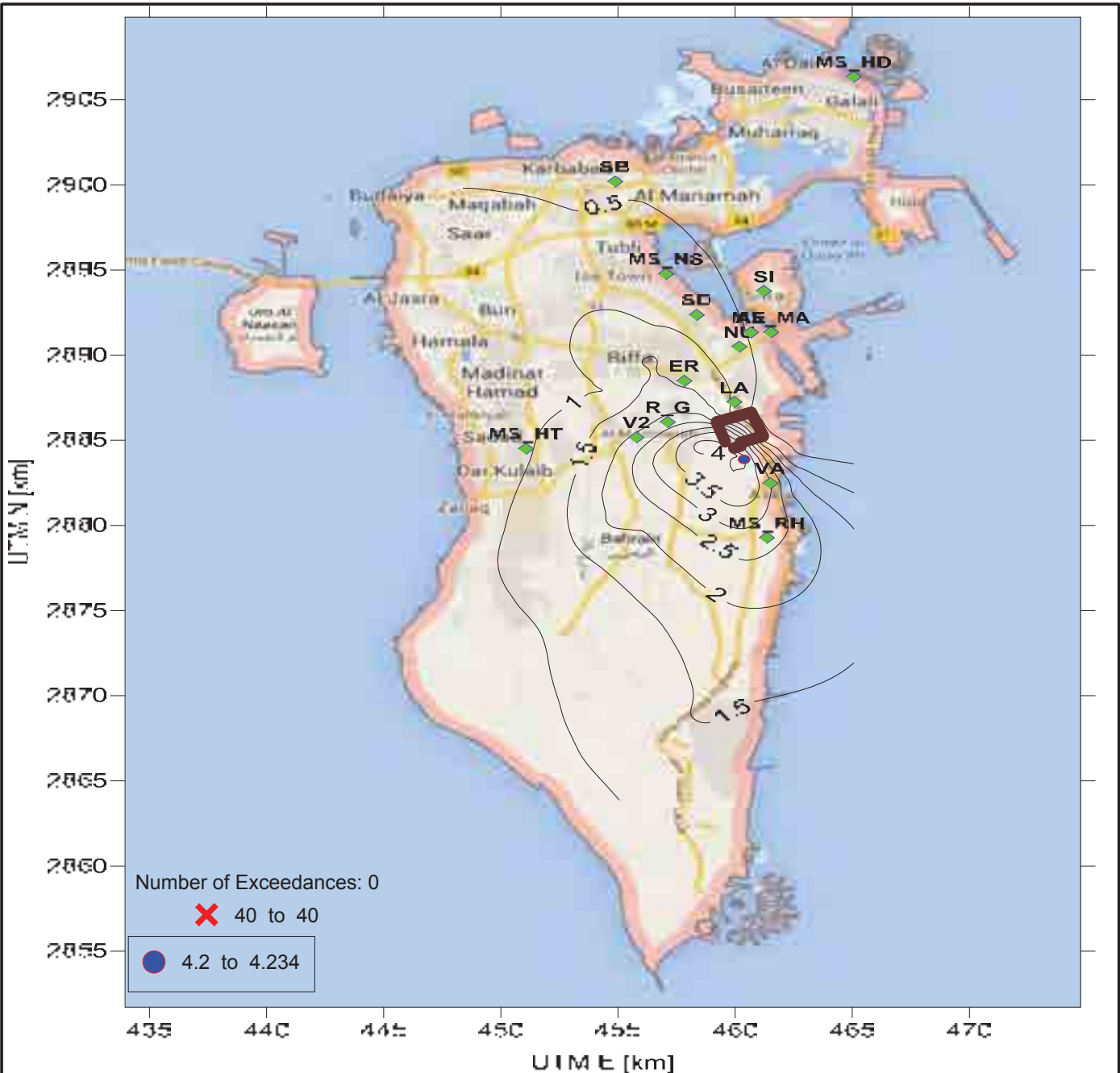
Ambient Air Quality Standards

Time Weighted Average - Annual: 40 ug/m3
 Maximum Predicted Concentration: 4 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	ResidentialArea & Golf Course	R_G			

Prepared For: 	Figure Title: Annual Average Concentration - NO₂ Future Scenario-2	Date: March, 2014
	Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion



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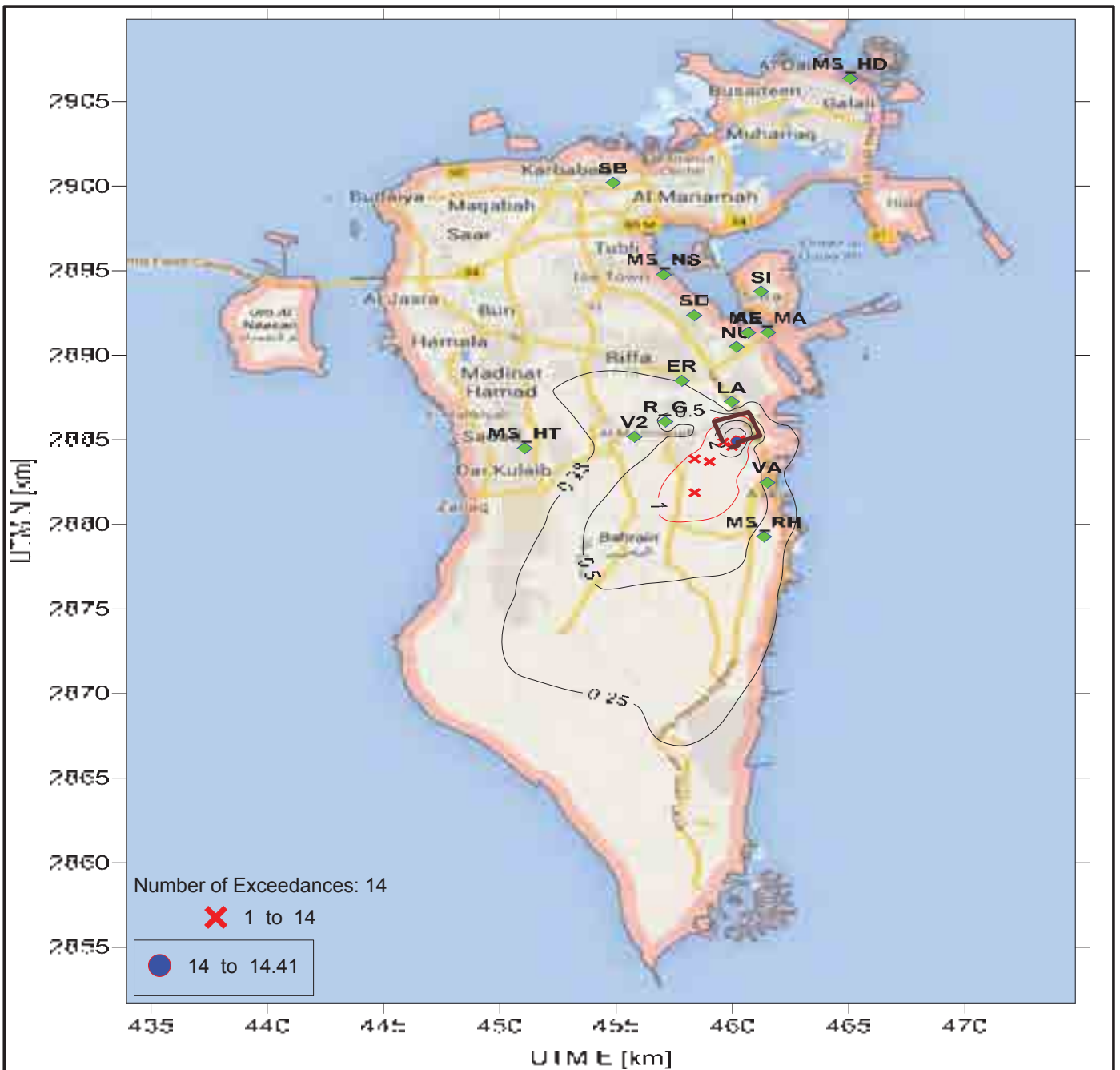
Ambient Air Quality Standards

Time Weighted Average - Annual: 40 ug/m3
 Maximum Predicted Concentration: 4 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Annual Average Concentration - NO₂ Future Scenario-3	Date: March, 2014
		Project No: 10921.00
Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Figure No: 19



Number of Exceedances: 14

X 1 to 14

● 14 to 14.41



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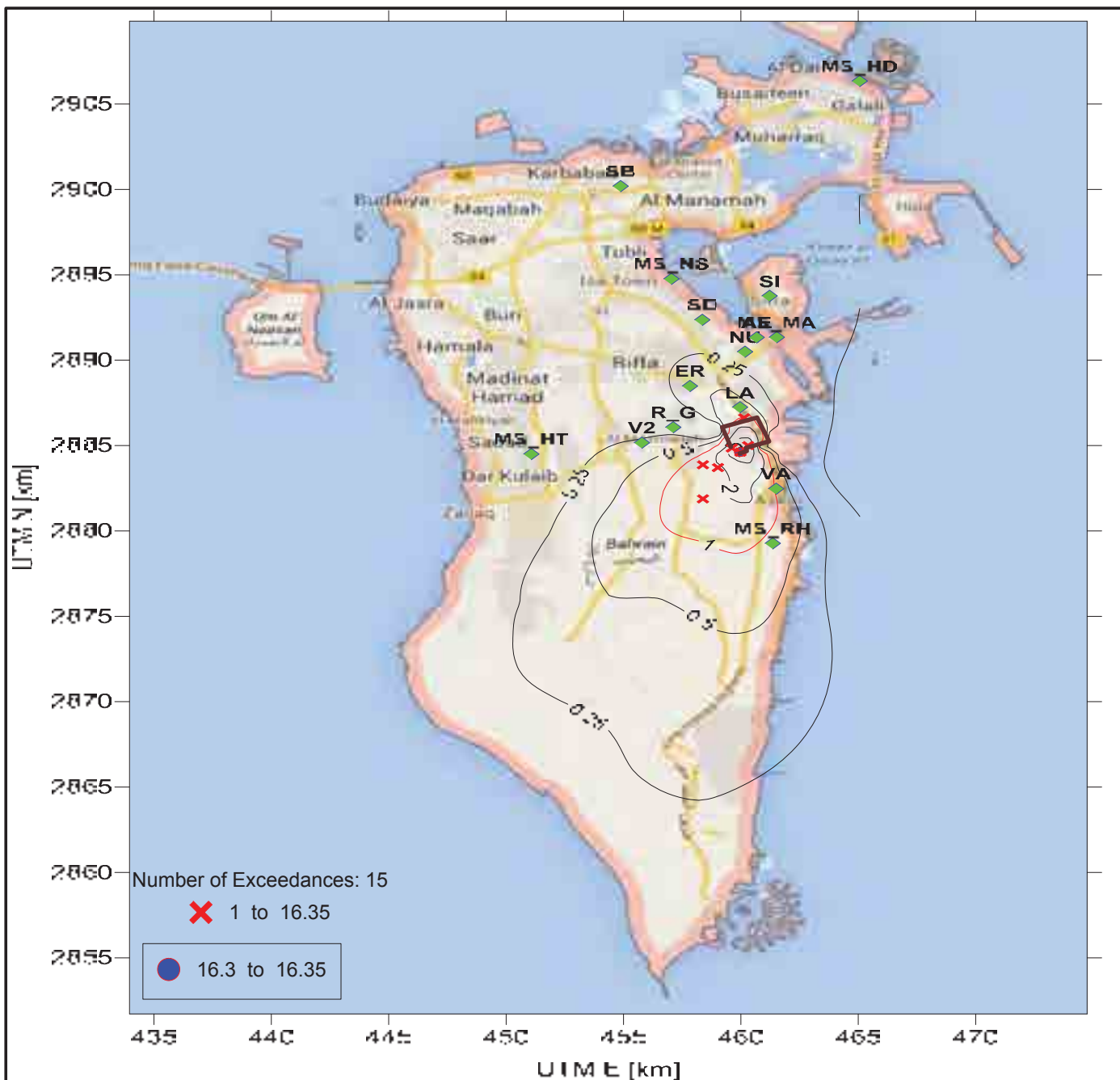
Ambient Air Quality Standards

Time Weighted Average - Annual : 1 ug/m3
 Maximum Predicted Concentration: 14 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'aameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	ResidentialArea & Golf Course	R_G			

Prepared For:	Figure Title:	Date:
	Annual Average Concentration - Gaseous Fluoride (HF) Baseline Scenario - 1 Existing Sources	March, 2014
Prepared By:	Project:	Project No:
	ALBA Potline (6) and Power Plant (PS5) Expansion	10921.00
		Figure No:
		20



LEGEND:

Ambient Air Quality Standards

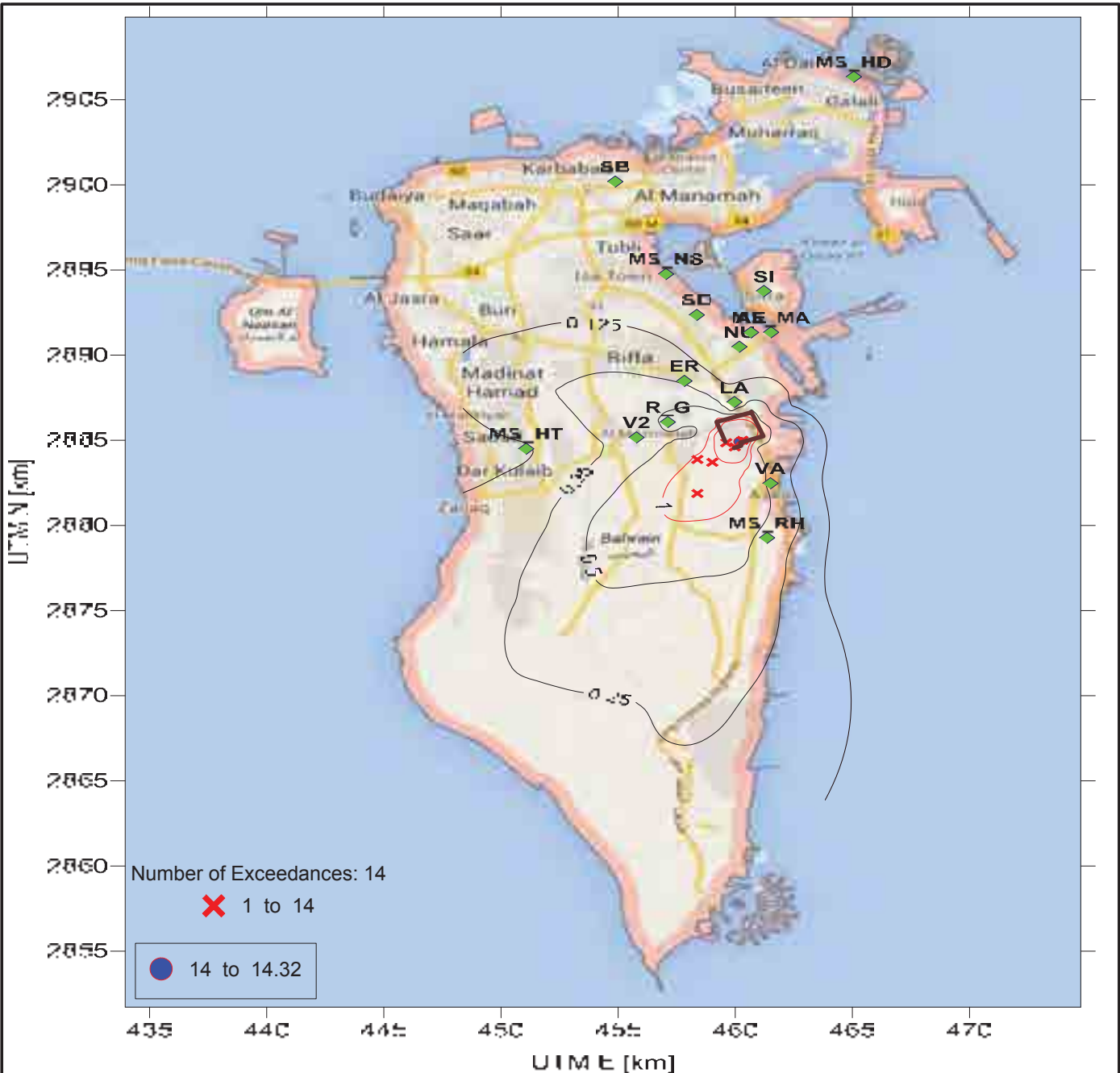
Time Weighted Average - Annual: 1ug/m3
 Maximum Predicted Concentration: 16 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

Number of Exceedances : 0

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For:	Figure Title:	Date:
	Annual Average Concentration - Gaseous Fluoride (HF) Future Scenario-1	March, 2014
Prepared By:	Project:	Project No:
	ALBA Potline (6) and Power Plant (PS5) Expansion	10921.00
		Figure No:
		21



Number of Exceedances: 14
 X 1 to 14
 ● 14 to 14.32

LEGEND:



Ambient Air Quality Standards

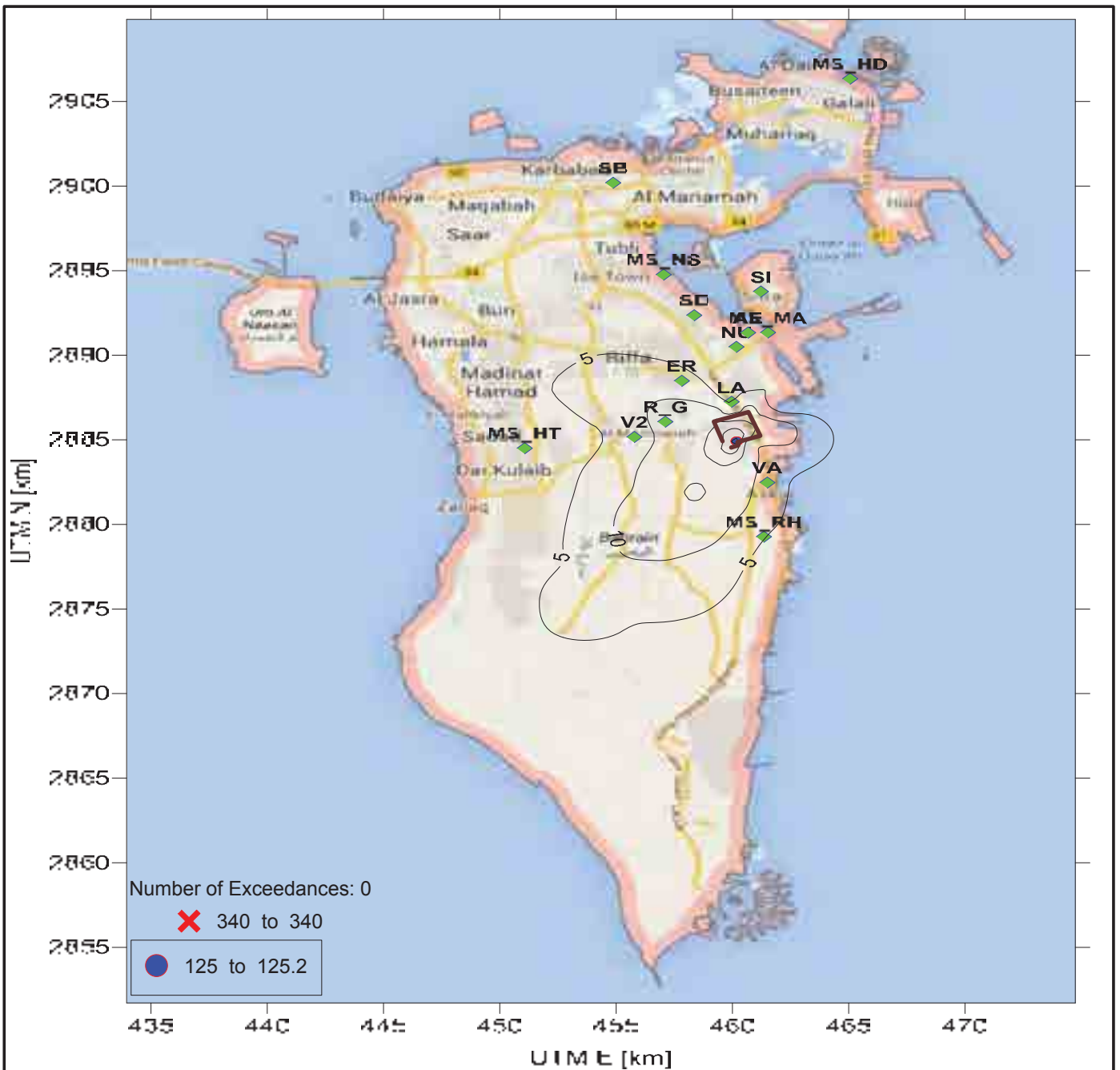
Time Weighted Average - Annual: 1 ug/m3
 Maximum Predicted Concentration: 14 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

Number of Exceedances : 0

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Annual Average Concentration - Gaseous Fluoride (HF) Future Scenario-2	Date: March, 2014
	Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion
		Figure No: 22



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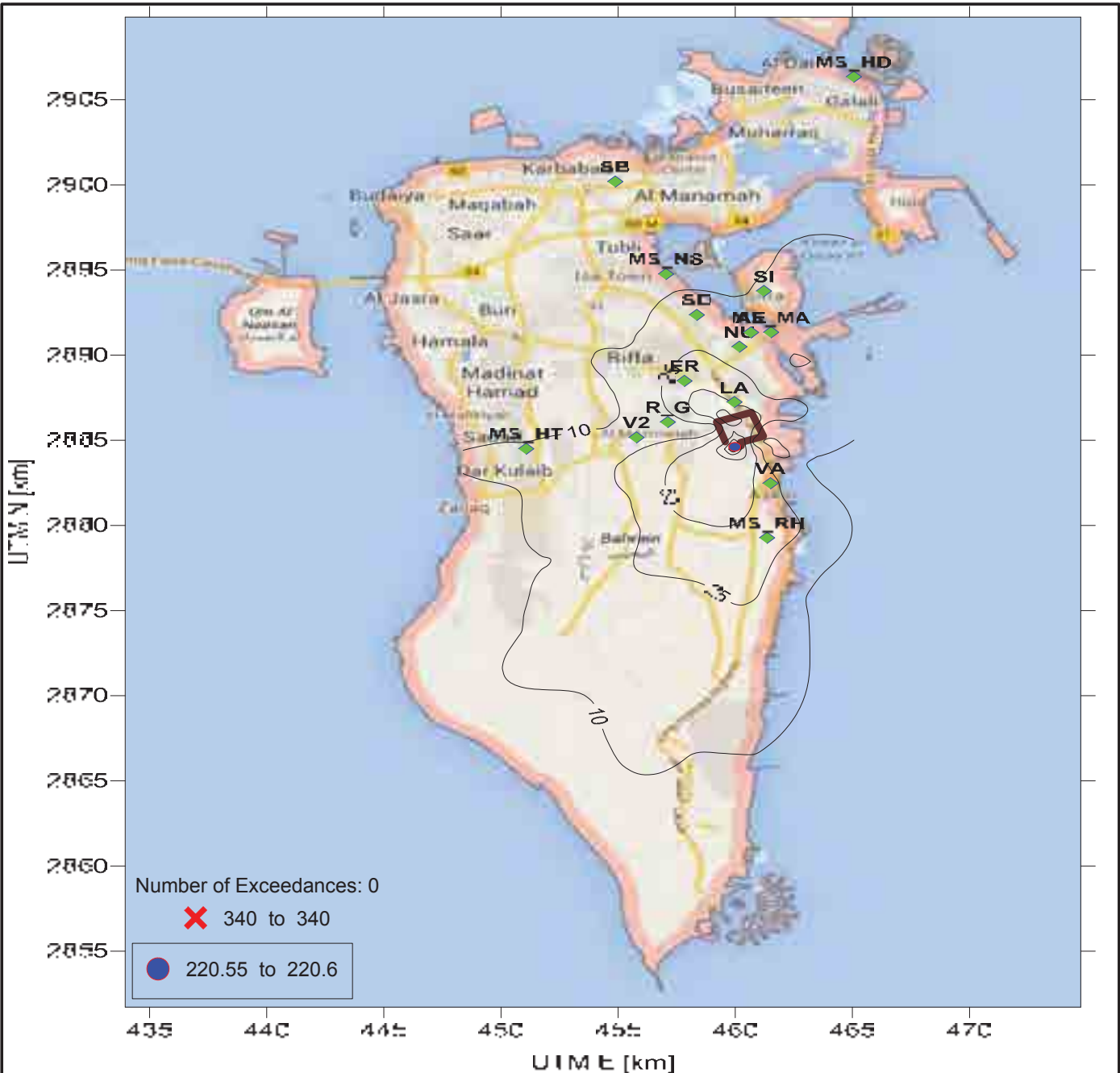
Ambient Air Quality Standards

Time Weighted Average - Daily : 340 ug/m³
 Maximum Predicted Concentration: 125 ug/m³

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'aameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For:	Figure Title:	Date:
	Daily Average Concentration - PM₁₀ Baseline Scenario - 1 Existing Sources	March, 2014
Prepared By:	Project:	Project No:
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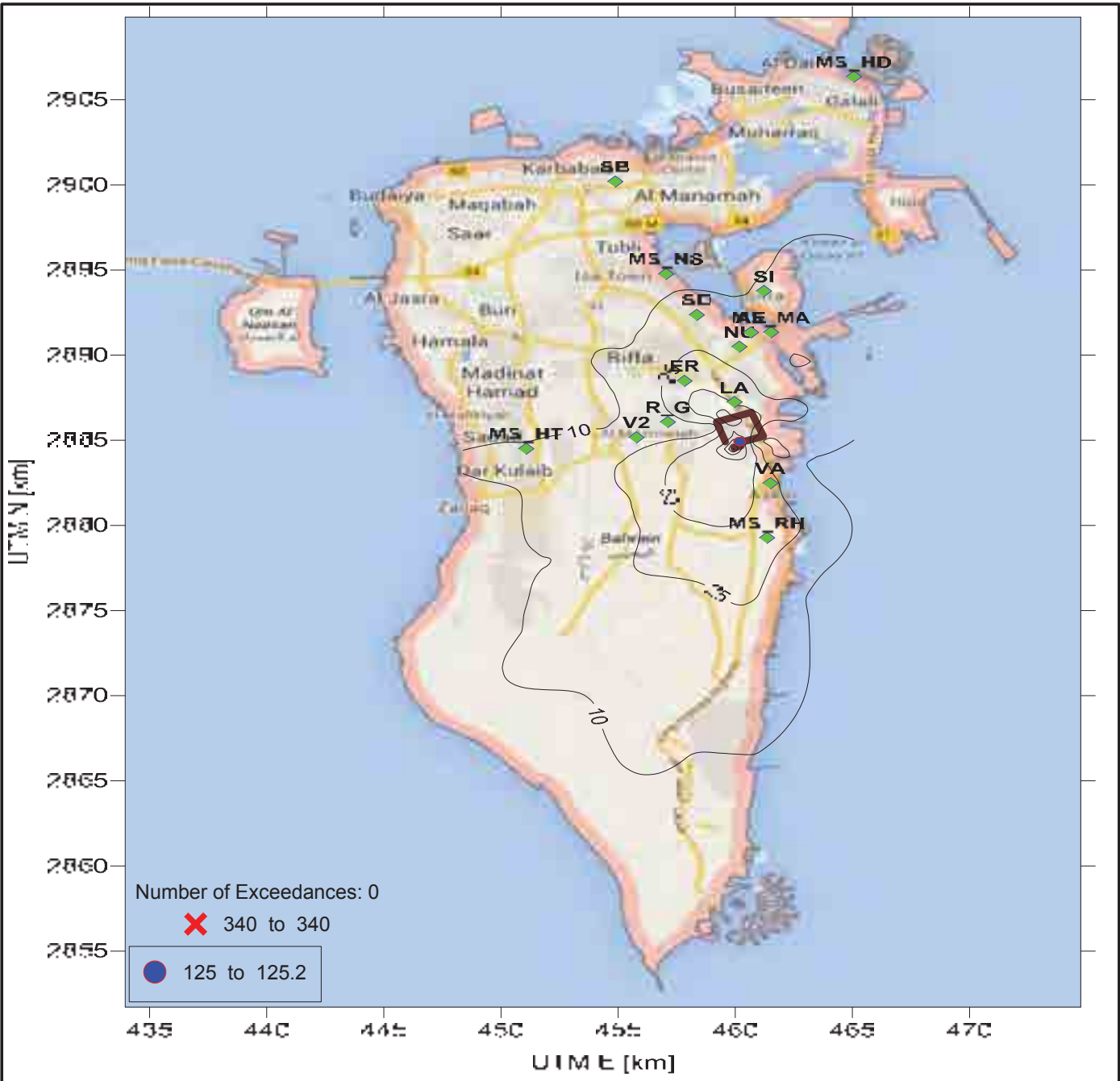
Ambient Air Quality Standards

Time Weighted Average - Daily: 340 ug/m3
 Maximum Predicted Concentration: 221 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For:	Figure Title:	Date:
	Daily Average Concentration - PM₁₀ Future Scenario-2	March, 2014
Prepared By:	Project:	Project No:
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		Figure No:
		24





LEGEND:

Ambient Air Quality Standards

Time Weighted Average - Daily: 340 ug/m3
 Maximum Predicted Concentration: 221 ug/m3

- Plant boundary limit
- Ambient Air Quality Limit
- ◆ Receptor Locations
- Maximum Concentration

No.	Location	CODE	No.	Location	CODE
1	Ras Hayyan	MS_RH	10	Labour Accommodation	LA
2	Hidd	MS_HD	11	East-Riffa	ER
3	Maameer	MS_MA	12	Ma'ameer	MA
4	Napeeh Saleh	MS_NS	13	Nuwaidrat	NU
5	Hamad Town	MS_HT	14	Al Eker	AE
6	Sanabis	SB	15	Sanad	SD
7	Villas Askar	VA	16	Sitra	SI
8	Villas 2	V2			
9	Residential Area & Golf Course	R_G			

Prepared For: 	Figure Title: Daily Average Concentration - PM₁₀ Future Scenario-3	Date: March, 2014
	Prepared By: 	Project: ALBA Potline (6) and Power Plant (PS5) Expansion	Project No: 10921.00
		Figure No: 25



Appendix 19: SPL Treatment



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

Appendix 19: Options for the treatment of Spent Pot Liners

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June 09, 2014
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Rev.	Date	Description	Author	Checked by

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1 Options for the treatment of SPL

Due to its toxicity Spent Pot Liner (SPL) has been identified in the ESIA as the most significant waste stream that is generated by Alba. For Potline 6, SPL generation would start approximately four (4) years after starting up on the Potline when the pot relining sequence is initiated. From that time, SPL will be generated on a steady basis.

Alba's current disposal practice is in line with that stipulated by the authorities. However it is recommended that Alba continues to pursue options for improved disposal. Therefore, different options for SPL disposal are detailed in this Annexure.

1.1 Introduction

As indicated in the Environmental and Social Impact Assessment (ESIA), 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"). A schematic overview of a pot is presented in **Figure A1**.

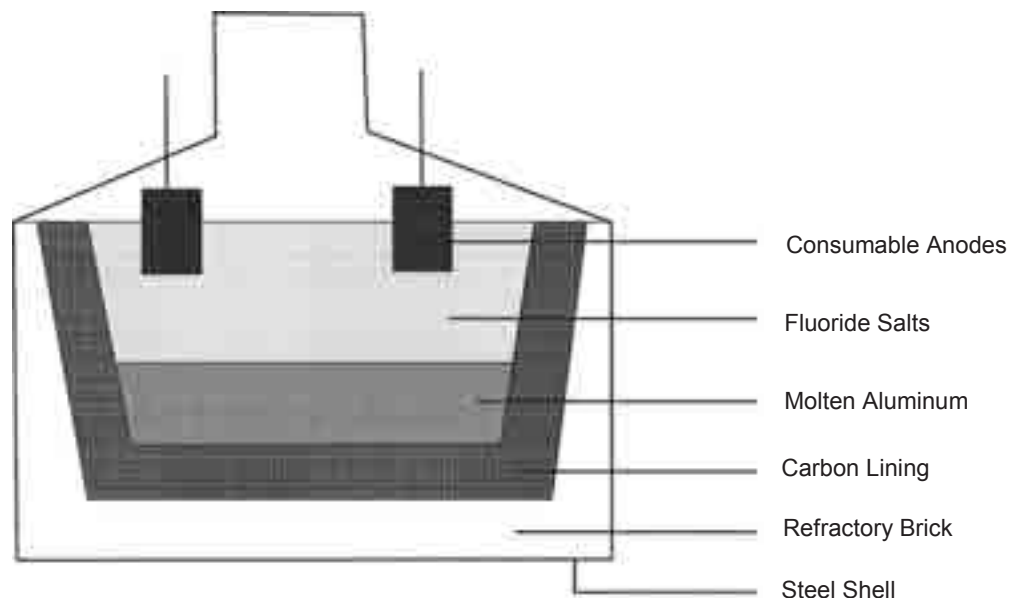


Figure A1: Simplified Diagram of a Typical Electrolysis Pot¹

¹ Adapted from US EPA - Best Demonstrated Available Technology (BDAT) Background Document For Spent Aluminum Potliners – K088



First of all it is to be noted that safe disposal of SPL is an issue that challenges the global primary aluminium production sector. Currently, SPL (EWC Number 161101) is an absolute hazardous waste material, as defined in the European Waste Catalogue (EWC). In addition, the United States Environmental Protection Agency (US EPA) has categorized SPL under number K088 (primary aluminium smelter waste).

The US EPA has identified management techniques for K088 waste, such as recycling, reclamation, reuse, stabilization, chemical precipitation, and treatment. In May 2000, the Agency has identified a "best" demonstrated technology (BDAT) for SPL treatment (Reynolds Process and the Ormet/Vortec Process). In addition, the US EPA conducted an economic assessment of Land Disposal Restrictions (LDR) Treatment in the same year. It needs to be taken into consideration that the above mentioned documents were established more than a decade ago. However, the US EPA does not have more recent publications regarding SPL.

1.2 Overview

Over the years, many studies focused on disposal options for SPL. In general, however, most of these studies have focused on the "first cut" as the "second cut" is not currently regulated as a hazardous waste (and is generally disposed of in landfills).

Disposal options for this first cut include straight disposal to landfill, macro encapsulation and landfilling, mixing with "anti-agglomeration" agents incinerated and then landfilled (the Reynolds Process) and high temperature oxidation and then landfilling the resulting slag (the Ausmelt Process).

In addition to disposal options, recycling options include vitrification (the Ormet/Vortec Process) and use as a supplemental fuel in an industrial furnace. The only option which has the technical possibility to recycle or reuse both cuts, is the use in a cement kiln. Thereby, the carbon fraction may be used as a fuel and the refractory portion can be used as a raw materials substitute.

In line with Best Available Technology, the available recovery routes are:

- Re-use in cement manufacturing; ceramics or brick industries;
- Re-use as a secondary raw material (rock wool, salt slags recovery, etc.);
- Re-use as a fuel;
- Re-use as a carburiser (steel industry).

Seven options for SPL treatments and their respective advantages and disadvantages are presented in **Table A1**. Based on the (dis)advantages the applicability of each option was assessed. Subsequent sections provide details on the selected options for SPL treatment in the Kingdom of Bahrain.



Table A1: Options for SPL treatment

#	Method		Advantages	Disadvantages	Option
1	Non-Treatment	<p>Recycling in cement kilns</p> <p>Introduction of spent pot lining into a cement kiln destroys the contaminants (cyanides, PAH's) and bounds fluorides with calcium present in the cement or lime, rendering the substance non-hazardous.</p>	<ul style="list-style-type: none"> No previous treatment required, full recycling of refractory and carbon sections Neutralisation of hazardous compounds 	<ul style="list-style-type: none"> Logistic difficulties (transport) 	Yes
2	Non-Treatment	<p>Recycling as road foundation</p> <p>Refractory of spent pot lining is used as road foundation material. The risk of leaching is reduced, especially in areas with low precipitation, however the chance of leaching remains.</p>	<ul style="list-style-type: none"> No prior treatment required, only recycling of refractory material ('second cut'). 	<ul style="list-style-type: none"> Risk of leaching of cyanides remains, due to the remaining hazardous material ("first cut" this method it is not preferred. 	No
3	Treatment	<p>Alcoa Portland SPL process</p> <p>In a process containing two main stages, SPL is processed in an Ausmelt furnace, where the cyanide is destroyed, and HF is produced. The HF gas is then put through a gas conversion process, where it is converted into aluminium fluoride and recycled back into the Aluminium process.</p>	<ul style="list-style-type: none"> Destruction of cyanide, recycling of fluoride Production of safe slag that can be used as a raw material in other activities. 	<ul style="list-style-type: none"> Logistics of utilizing slag related to the quantity of the SPL waste. 	Yes



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#	Method	Advantages	Disadvantages	Option
4	<p>Alcan Low-Caustic Leach and Lime Process (LCLL)</p> <p>In the Alcan Low-Caustic Leach and Lime Process (LCLL) finely ground SPL is leached with caustic to remove the fluorine, free and complexed cyanide, alumina, and some silica into the leach liquor. Cyanide is then destroyed by hydrolysis in a high pressure autoclave. The remaining liquor is evaporated to a 50% caustic solution and separated by filtration from sodium fluoride crystals through a difficult filtration process. This sodium fluoride can be converted into aluminium fluoride or calcium fluoride by aqueous processes</p>	<ul style="list-style-type: none"> Several elements are recycled for reuse 	<ul style="list-style-type: none"> Difficult process to implement The second stage of process is difficult (specialised expertise, and there are some other difficulties with the process).* Due to the complexity and accompanying problems it is not considered 	No
5	<p>Comalco Comtor process</p> <p>The Comtor process consists of two main stages. After suitable preparation, the spent pot lining is fed into a calcining stage. In this stage the leachable cyanides are destroyed and generated gases are controlled through a filtration system. The released fluorine can be recovered or stabilised. The residue consists mainly of refractory materials, which is no longer considered hazardous waste</p>	<ul style="list-style-type: none"> Destruction of cyanide and treatment of fluoride. Existing and new calcining facilities. 	<ul style="list-style-type: none"> Not known if it is feasible in Alba's facilities 	Yes

* The placement of the lower valued caustic product and carbon product in many localities will be challenging; The caustic liquor is extensively recycled in the process leading to the possibility of impurity build-up in the circuit; The Alcan process will also require more sophisticated technical management (hydrometallurgists) to operate effectively.



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#	Method	Advantages	Disadvantages	Option
6	<p>Reynolds Metals rotary kiln process</p> <p>The Reynolds treatment process entails the crushing and sizing of spent pot liner materials, the addition of roughly equal portions of limestone and brown sand as flux, and the feeding of the combined mixture to a rotary kiln, heated to 650°C, for thermal destruction of cyanide and PAH's and binding or fluoride into calcium fluoride.</p>	<ul style="list-style-type: none"> • Destruction of Cyanide and neutralisation of fluoride. 	<ul style="list-style-type: none"> • The addition of brown sand prevents the mixture from clogging in the kiln but creates approximately 2.5 times the amount of waste (although non-hazardous). 	No
7	<p>Ormet Process using a Combustion Melting System</p> <p>The SPL is fed with sand and limestone to a CMS™ process to melt, or vitrify, the raw materials at high temperatures. Products and residuals of the process include the vitrified material (or glass frit) and air pollution control wastes consisting of bag house dust and dry scrubber residue.</p>	<ul style="list-style-type: none"> • Destruction of Cyanide and fluoride volatilizes and is removed in air pollution control wastes. 	<ul style="list-style-type: none"> • The process generates non-hazardous glass frit that contains the hazardous constituents which will pose pressure on landfill. 	No
8	<p>Befesa Integral Waste Recovery Method</p> <p>Befesa, an international company specializing in the integral management of Industrial wastes, established five SPL recovery plants in Europe. New technologies for integral waste recovery are emerging in Europe providing major Aluminium producers with a definitive solution.</p>	<ul style="list-style-type: none"> • Befesa aims to be established in the Gulf Region by 2017 • Integrated Approach whereby all cyanides and soluble fluoride salts are removed. All of the solid metals obtained are reused, closing the cycle for aluminium waste recycling and using every part of the aluminium-containing waste. 	<ul style="list-style-type: none"> • Technical details on removal method not available at this stage. 	Yes



1.3 Cement Industry

Two options are possible for waste management of SPL's in the cement industry. The carbon fraction can be used for its calorific value and the refractory can be used as a raw material substitute.

1.3.1 First Cut - Carbon Fraction

Tests have shown that well sorted carbon fractions of the carbon fractions could be used blended with coal (2% of the SPL mixture) without causing any negative effect on the production process. Stack emissions and quality of the clinker produced during the process were not affected as a result of the presence of SPL.

1.3.2 Second Cut - Refractory Fraction

The presence of alumina and silica in SPL allow it to be used as cement raw material. These elements are present in the quarry materials, and in some cases may not be present in sufficient levels. In certain cases addition of these materials may even be necessary.

1.3.3 Application to Alba

From the perspective of feasibility, cement industry management of SPL depends mostly on whether the local cement industry is willing or can absorb the material, and if it is feasible to transport the material. It will be up to Alba to negotiate with cement companies, the following section will examine the other factors.

In both cases (fuel and refractory) careful attention has to be paid to the balances of fluoride and calcium where the SPL will be recycled. The amount that can be introduced will depend on the ratio of these elements that already present in the natural raw materials.

Generally, the SPL content in cement is less than 1% by weight. Considering the amount of future SPL waste production (7,961 tonnes of hazardous SPL for future L6 and crept L1-5), a significant amount of cement production is required (over 7.96 million tonnes cement). Assuming a truck load of 35 tonnes (Dutch Load Standard), 228 truckloads per year are required to transport the material. The amount of truckloads needed to transport the material suggests that transport of the material is an impediment of the technology / method.

On the one side transportation is a disadvantage of the SPL treatment / disposal method, however on the other side all parts of the SPL can be used in the cement industry. With other management techniques, the hazardous materials are destroyed in the treatment process, but slag remains. Thus leaving the task of finding a way of properly disposing and/or using the slag.

As previous mentioned, the environmental benefits of using the cement industry to recycle SPL are that the Hazardous elements in the SPL are destroyed or neutralised. Cyanides are combusted and fluorides are bound in the cement mix. Research has shown that residual impacts from this process are minimal. It should be noted that the transport needed might cause other environmental impacts.



1.4 Alcoa Portland SPL process

The process was developed at Alcoa's Portland aluminium smelter in conjunction with Ausmelt Ltd and Australia's Commonwealth Scientific Industrial Research Organisation (CSIRO) to render harmless spent pot linings, produced by aluminium smelters.

The Alcoa Portland SPL Process consists of two main stages. In the first, after suitable preparation (crushing, making briquettes, and screening), the spent pot lining is fed into an Ausmelt designed top submerged-lance furnace, where the cyanide-forming chemicals are destroyed at temperatures of 1,250 °C and the contained fluoride is driven off as hydrogen fluoride. The residue (material remaining in the furnace or slag) is a granulated vitreous material known as 'synthetic sand' (slag). In the second stage, a gas-conversion process, developed by Portland Aluminium, converts the hydrogen fluoride off-gases, which have cooled and filtered, into aluminium fluoride in a multistage fluidised bed reactor. The aluminium fluoride is recycled into the aluminium smelting process as a replacement for imported aluminium fluoride.

The synthetic sand produced in the first stage of the process has been cleared by the Victoria EPA for unrestricted use in applications such as road building and concrete, providing that it continues to have a fluoride leachability measure of less than 15 ppm. According to Alcoa, the process achieves this standard.

The plant has been commissioned in 2001 with a capacity of 12,000 tonnes per year.

1.4.1 Application to Alba

At the practical level, the Alcoa Portland Process appears to have several advantages. For example it is sufficiently developed to be commercialised² with acceptable levels of risks and it also has the additional value of producing a high value aluminium fluoride product that can be recycled back into the aluminium production process. In addition to this, and as a result of the raw material recycling, it is also claimed to be economically viable.

From an environmental perspective and in considering needed mitigation, the process has several benefits, such as

- The destruction of cyanide component of the SPL;
- The recovery of the fluoride components as aluminium fluoride for re-use in the aluminium smelting process; and
- Generation of a slag output product that is not harmful to the environment and can be safely used as safe road surfaces, foundations or in the cement industry.

² The process has been patented (approved or file) through international patent Application WO 94/22604, 6 April 1993: "Combustion of SPL via Top Submerged Lance Smelting" and through Provisional Patent application Number PR 5194 "Process for the Production of the Aluminium Fluoride".



The Alcoa Portland Process eliminates the environmental impacts that result from cyanide and fluoride contamination. The remaining slag could also be used as a raw material in road construction or in the cement industry. Using this as a mitigation measure would greatly reduce the impacts of additional waste production in the proposed expansion.

Unfortunately, a negative practical issue that remains for this method of SPL management is finding an environmentally (avoiding excessive transport) and logistically feasible way for use remaining slag material. Tebodin believes that this issue could be solved in cooperation with local road contractors or government officials.

1.5 Comalco Comtor process

The Comtor process was developed by Comalco at Boyne Island smelters in Australia. Research has revealed very little detail on the method. As already mentioned the Comtor process consists of two main stages. After suitable preparation of the SPL, crushing the spent pot lining to usable feed size, the spent pot lining is fed into calcining stage where the leachable cyanides are destroyed and generated gases are controlled through a filtration system. The released fluorine can be recovered or stabilised. The residue consists mainly of refractory materials, which are no longer considered hazardous waste.

1.5.1 Application to Alba

When viewing the Comtor SPL process with the perspective of practical application, it seems to offer an interesting option. The Comtor relies on the high temperatures generated in the calcining process and advance fluoride fume treatment to reduce the hazardous components of SPL. Alba already possesses advanced fume treatment knowledge (GTC and FTC) and has just constructed a new calcining facility. Little information is available on the details of the method. Thus further research and engineering would be needed to assess the technical feasibility. One possible disadvantage of this method results because of the impure composition of SPL. SPL can become 'sticky' when heated at high temperatures leaving residue in furnaces. This would cause additional difficulties for calcining and may affect the effectiveness of the calcining process.

From an environmental perspective and in considering needed mitigation, the process eliminates the environmental dangers from cyanide, and fluoride. Actual reduction of environmental damage caused by fluoride would depend on the effectiveness of the fluoride scrubbing. A danger exists of transferring environmental impact from the ground to the air. As with the slag that remains in the Alcoa process, a suitable logistical and environmental manner would have to be found for its' recycling.

1.6 Other Options

In addition to the options discussed above, the following information can be useful to get an overview of the possibilities for treatment of SPL.



1.6.1 Alcoa Quebec SPL process

Lacking options in the Quebec region to recycle spent pot lining, Alcoa's three Canadian smelters sourced alternatives in the United States and Germany that increased the amount of SPL they recycled to 90% in 2010 while saving US\$2 million in costs.

Government regulations for recycling SPL and an insufficient customer base in the Quebec region where the smelters are located stymied efforts to find a local economically viable recycling solution. As a result, the Canadian smelters sent a portion³ of their SPL to Alcoa's Gum Springs, Arkansas, facility in the United States for processing.

As part of a recycling program, a large portion of the first cut (carbon fraction) is sent to Germany where it is used as an alternative fuel source. In addition, the refractory waste and remaining carbon material is sent to U.S.-based cement manufacturers where the waste is used as a mineraliser. This strategy resulted in recycling of over 90% of the total SPL waste.

1.6.2 Tetronics' technology

Tetronics Ltd is specialized in of Waste Recovery Plants. The company patented a Direct Current (DC) Plasma Arc plant technology, which can be seen as a sustainable alternative for waste management using ultra-high temperatures to melt, gasify or vaporise any waste material, in order to treat, recover or generate commercial products.

Tetronics has experience and know how in the characterisation and treatment of SPL and worked in close collaboration with one of the world's largest aluminium producers, with an annual output of 4 million tonnes of aluminium.

1.6.3 Befesa Integral Waste Recovery Method

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).

Befesa approach seeks to remove the cyanides and soluble fluoride salts. All of the solid metals obtained are reused, closing the cycle for aluminium waste recycling and using every part of the aluminium-containing waste. However, technical details on the specific approach are not available at this stage.

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, United Arab Emirates to treat SPL waste from GCC countries. As Befesa aims to be established in the Gulf Region by 2017, Alba might be one of their future clients.

³ 11% in 2008



1.7 Mitigation of Spent Pot Lines

Table A3 summarizes the reduction of SPL waste and environmental impacts.

In general, all methods could lead to the reduction of 2,848 tonnes of SPL waste and the reduction of approximately 50% of un-recycled or treated solid waste. Each method also destroys cyanide and deals with fluoride. The environmental threat of these compounds is therefore also mitigated to different extents. These methods have another positive environmental side effect, in that the use of raw material used in for road construction and/or cement industry can be reduced by use of the inert slag.

Table A3: Reduction of SPL waste and environmental impacts

	Reduction of non-recycled Wastes	Environmental benefits /drawbacks
Cement industry	SPL is 100% recycled Cyanide destroyed Fluoride neutralised	Impacts mitigated Air quality impacts result from transport
Alcoa Portland spent pot lining process	100% of SPL can be recycled Cyanide destroyed Fluoride recycled	Impacts mitigated if slag can be utilised Fluoride is recycled
Comalco Comtor process	100% of SPL can be recycled Cyanide destroyed Fluoride neutralised	Impacts mitigated if slag can be utilised

It is suggested that Alba applies one of these methods to their waste management plan to mitigate the environmental impact of SPL in the proposed expanded operations. Furthermore, possible implementation of the Befesa technology in the gulf region provides future options to fully recycle Alba's SPL waste.



2 References

1. US EPA - Best Demonstrated Available Technology (BDAT) Background Document For Spent Aluminum Potliners – K088 (31 May 2000)
2. US EPA - Economic Assessment of the Revised LDR Treatment Standards for Spent Aluminum Potliner (K088) (23 May 2000)
3. Managing Wastes from Aluminium Smelter Plants. B. Mazumder and B.K. Mishra. Published by Woodhead Publishing India Pvt. 2011
4. Alcoa Inc. - Fluoride-containing hydraulic cements and methods of making the same (2008)



Appendix 20: Noise Modelling

Tebodin Middle East Ltd.
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Revision: 0
April 24, 2014
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Client: **Bechtel**

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

Appendix 20: Noise Modelling

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1 Noise Modelling

1.1 Introduction

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.

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.

The propagation methodology adopted within the SoundPLAN model was the ISO 9613 'Acoustics – Attenuation of Sound during Propagation Outdoors' This methodology takes account of the following physical effects:

- Geometrical divergence;
- Atmospheric absorption;
- Ground effect;
- Reflection from surfaces; and
- Screening by obstacles.

This method is applicable in practice to a great variety of noise sources and environments. It is applicable, directly or indirectly, to most situations concerning: industrial noise sources, road or rail traffic, construction activities, and many other ground-based noise sources.

1.2 Background Noise Levels

Prior to modelling, background noise levels in the area were recorded through monitoring. The noise monitoring results are presented in Table A-1 and A-2 respectively. The results of the monitoring were used as input to the noise model to evaluate the overall contributions from PL-6 operations.

Table A- 1: Noise Data Inventory GTC and FTC

#	UTM Coordinates		Sound Pressure Levels in dB(A)					Remarks	Time
	Easting	Northing	L _{eq}	L _{max}	L _{min}	L ₁₀	L ₉₀		
Weekend- 8th February 2014:Daytime									
1	460862	2886035	69.3	75.8	65.6	70.1	63.6	Close to PL-6 office	12:20
2	460977	2885684	66.5	72.4	60.4	69.1	61.9	Along the eastern fenceline	12:45
3	461219	2884945	71.0	73.7	66.5	71.9	67.0	South Gate- close to emergency clinic- heavy vehicle movements	13:10



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#	UTM Coordinates		Sound Pressure Levels in dB(A)					Remarks	Time
	Easting	Northing	L _{eq}	L _{max}	L _{min}	L ₁₀	L ₉₀		
4	461131	2884932	64.8	73.2	61.1	68.1	61.9	Fence-line east of ALBA lake	13:30
5	459418	2885583	62.2	64.4	59.8	62.5	61.0	North-west fenceline	13:50
6	459358	2885786	58.3	61.3	56.0	59.4	56.2		14:20
7	459555	2885112	66.5	68.7	65.6	67.2	65.8		14:45
8	459651	2884846	58.5	61.7	51.6	59.7	56.6	South-west corner	15:30
9	459916	2884649	58.5	62.3	56.6	59.7	56.6	Close to Jawad textile mill	15:00
10	460989	2884675	69.1	82.0	49.1	72.5	64.8	Excavation works ongoing close to ALBA lake	15:50
11	460005	2884821	66.0	74.3	60.8	69.5	61.7	South-east fenceline	16:20

Table A- 2: Noise Data Inventory GTC and FTC

#	UTM Coordinates		Sound Pressure Levels in dB(A)					Remarks	Time
	Easting	Northing	L _{eq}	L _{max}	L _{min}	L ₁₀	L ₉₀		
Weekday- 9th February 2014: Daytime									
1	460862	2886035	69.4	75.6	65.4	70.0	63.4	Close to PL-6 office	9:30
2	460977	2885684	66.0	72.1	60.2	68.7	61.7	Along the eastern fenceline	10:00
3	461219	2884945	70.5	73.8	66.5	71.4	66.9	South Gate- close to emergency clinic- heavy vehicle movements	10:20
4	461131	2884932	64.0	72.5	60.2	67.2	61.4	Fence-line east of ALBA lake	10:30
5	459418	2885583	62.3	64.2	59.6	62.7	61.1	North-western fenceline	10:45
6	459358	2885786	59.0	62.1	56.4	59.7	56.5		11:20
7	459555	2885112	66.8	69.1	65.8	67.4	66.1		11:45
8	459651	2884846	58.6	61.9	51.8	59.9	56.7	South-west corner	12:30
9	459916	2884649	58.7	62.6	56.5	59.9	56.7	Close to Jawad textile mill	13:00
10	459598	2886130	66.0	73.0	64.8	66.5	65.1	North Gate	13:30
11	459896	2886420	67.3	70.2	65.4	68.5	65.9	Outside PS-4	14:20
Weekday- 10th February 2014: Daytime									
12	467146	2893181	68.6	71.6	67.4	69.4	62.3	Calciner- close to proposed ship loading area	09:00
13	458030	2885724	73.5	80.0	46.1	48.4	75.4	Camps off-plot ALBA facility: heavy traffic	15:25
14	456734	2885769	61.0	67.8	50.8	65.6	52.6	Golf Course	16:00
Weekday- 9th February 2014: Night time									
1	461219	2884945	65.6	73.0	60.1	70.0	62.5	Near South Gate	00:15



#	UTM Coordinates		Sound Pressure Levels in dB(A)					Remarks	Time
	Easting	Northing	L _{eq}	L _{max}	L _{min}	L ₁₀	L ₉₀		
Weekday- 10th February 2014:Night time									
1	459651	2884846	58.2	61.6	50.4	59.0	56.3	South-west corner	23:40
2	459916	2884649	57.0	62.0	50.1	59.1	56.1	Close to Jawad textile mill	00:10
3	459896	2884642	67.1	70.2	65.0	68.0	65.7	Outside PS-4	01:30
4	460862	2886035	69.0	75.0	65.4	70.1	63.4	Close to PL-6 office	02:10
5	460977	2885684	66.0	71.3	58.4	68.1	61.4	Along the eastern fenceline	03:15

As can be seen through the results of the monitoring revealed from the above Tables, the ambient noise levels at all areas were noted to (Leq 58.3 dB(A) – 73.5 dB(A)) be within the applicable limits set by the World Bank for industrial and commercial locations (70 dB (A) for both day- and night-time) except for the area close to the clinic where high noise levels were noted from vehicle movements along the nearby highway.

1.3 Emissions Inventory

Subsequent to noise monitoring, a noise emissions inventory was developed using the details of the various noise generating sources added to the facility from PL-6 operations. The details of the same including the sources identified and their duration of operation as well as their respective sound power levels are as presented in Table A-3 and Table A-4 respectively. It has to be stated that below sound pressure levels are estimations based on current information.

Table A- 3: Noise Data Inventory GTC and FTC

#	Generation Source	No. of Sources	Source Location		Nature of Noise Generation (Continuous / Intermittent)	Noise Level Sound Pressure Level
			Easting	Northing		
1.0	North GTC - Main ID Fans	Total 6				
a)	North GTC- Fan No 1	1	459867	2885557	Continuous	Fan casing - 77 dB(A) @ 1m Motor - 81 dB(A) @ 1m
b)	North GTC- Fan No 2	1	459869	2885546	Continuous	
c)	North GTC, Fan No 3	1	459872	2885532	Continuous	
d)	North GTC- Fan No 4	1	459874	2885521	Continuous	
e)	North GTC, Fan No 5	1	459876	2885510	Continuous	
f)	North GTC, Fan No 6	1	459878	2885500	Intermittent	
2.0	North GTC - Stack	1	459903	2885468	Continuous	Sound Power Level at discharge: 103 dB(A)
3.0	South GTC - Main ID Fans	Total of 6				
3.1	South GTC, Fan No1	1	460001	2884917	Continuous	Fan casing - 77



#	Generation Source	No. of Sources	Source Location		Nature of Noise Generation (Continuous / Intermittent)	Noise Level Sound Pressure Level
			Easting	Northing		
3.2	South GTC, Fan No 2	1	460004	2884905	Continuous	dB(A) @ 1m Motor - 81 dB(A) @ 1m
3.3	South GTC, Fan No 3	1	460006	2884893	Continuous	
3.4	South GTC, Fan No 4	1	460008	2884881	Continuous	
3.5	South GTC, Fan No 5	1	460011	2884869	Continuous	
3.6	South GTC, Fan No 6	1	460013	2884858	Intermittent	
4.0	South GTC - Stack	1	460037	2884823	Continuous	Sound Power Level at discharge: 103 dB(A)
5.0	L6 FTC - Main ID Fans	Total of 4				
5.1	Fan No 1	1	459554	2885587	Continuous	Fan casing - 77 dB(A) @ 1m Motor - 81 dB(A) @ 1m
5.2	Fan No 2	1	459548	2885586	Continuous	Same as above
5.3	Fan No 3	1	459542	2885585	Continuous	Same as above
5.4	Fan No 4	1	459537	2885584		Same as above
6.0	FTC - Stack	1	459524	2885579	Continuous	Sound Power Level at discharge: 103 dB (A)
7.0	Rectifiers	Total of 6				
7.1	Rectifier No 1	1	459685	2885857	Continuous	83 dB(A) @ 1m
7.2	Rectifier No 2	1	459688	2885832	Continuous	83 dB(A) @ 1m
7.3	Rectifier No 3	1	459693	2885807	Continuous	83 dB(A) @ 1m
7.4	Rectifier No 4	1	459697	2885782	Continuous	83 dB(A) @ 1m
7.5	Rectifier No 5	1	459702	2885758	Intermittent	83 dB(A) @ 1m
7.6	Rectifier No 6	1	459707	2885733	Intermittent	83 dB(A) @ 1m

Table A- 4: Noise Data Inventory Power Station 5

Source	No. of Sources	LwA per 1/3 octave band (centre frequency)										Building Height	
		Total	31.5	63	125	250	500	1000	2000	4000	8000		LwA
CT package													
Inlet	Total of 2	120	113	110	100	88	86	76	87	91	98	18.0	
Inlet Plenum	Total of 2	120	114	111	102	87	89	97	90	86	102	3.5	
Turbine compartment vent	Total of 2	108	110	105	103	100	98	104	99	94	108	6.0	



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Source	No. of Sources	LwA per 1/3 octave band (centre frequency)										Building Height	
		Total	31.5	63	125	250	500	1000	2000	4000	8000		LwA
fan (inside bld)													
Exhaust Diffuser (inside building)	Total of 2	133	125	114	112	110	104	103	102	97	112	5.0	
Load compartment (inside bld)	Total of 2	105	105	105	100	97	94	97	93	92	102	5.0	
Accessory compartment (inside bld)	Total of 2	105	106	103	101	98	95	98	95	91	103	3.5	
Generator (inside bld)	Total of 2	112	116	112	98	100	102	101	96	93	107	5.0	
Turbine compartment vent fan	Total of 2	104	102	107	102	98	98	94	95	92	103	8.5	
Exhaust compartment vent fans	Total of 2	102	101	107	99	96	95	92	92	91	101	8.5	
Bypass stack (~35m)	Total of 2	129	127	123	121	118	117	112	102	100	121	35.0	
CT Fin Fans	Total of 36	104	108	108	105	102	100	97	95	90	105	4.0	
STG package (inside metal siding bld)	Total of 2	118	125	121	114	112	110	110	108	104	117	15.0	
ST Fin Fans	Total of 36	104	108	108	105	102	100	97	95	90	105	4.0	
HRSG Package													
HRSG inlet	Total of 2	123	122	115	112	108	101	98	92	88	109	15.0	
HRSG body	Total of 2	122	118	111	106	100	93	88	86	80	103	27.0	
HRSG stack exit (~50m)	Total of 2	120	122	122	120	113	100	80	74	73	115	50.0	
HRSG stack breakout	Total of 2	97	99	101	100	90	89	64	54	60	95	0-50	
BFW pumps	Total of 4	103	108	115	110	105	105	107	104	95	112	2.0	
ACC tower fan noise (per fan) 15cells per tower	Total of 30	107	110	109	106	100	100	95	92	85	105	20.0	
CCW pumps (inside STG building)	Total of 4	90	90	89	90	88	90	91	82	76	95	2.0	
STG transformer	Total of 2	110	112	110	108	104	102	100	98	94	108	5.5	
CTG transformer	Total of 2	110	112	110	108	104	102	100	98	94	108	5.5	
Fuel Gas Compressors	Total of 2	112	114	114	113	112	110	107	106	105	115	3.5	



Appendix 21: SCE Guideline for CEMP



EIA- 12

Construction Environmental Management Plan (CEMP) Guidelines

Objective: To provide a transparent framework with clear accountabilities for managing the preparation of the Construction Environmental Management Plan (CEMP) in order to manage the environmental effects associated with the project in order to achieve acceptable environmental outcomes.

Required CEMP Content and Recommended Format:

The content of a CEMP may vary by project as the size and scope of a construction project. To promote familiarity and ease of use, a recommended format for the CEMP is provided in the following table, and an overview of the individual CEMP sections is described below. Where other formats are used, the content of each CEMP must include, at a minimum, all of the sections listed in the table. The CEMP also should include a list of acronyms and abbreviations, a glossary of terms, and full references to sources of information.

Recommended Format for the CEMP		
Section 1	Project Title	Cover Page Table of content List of Tables List of Figures List of Abbreviations Definition of Terms
Section 2	Project Team Identification (Stackolder)	
Section 3	Introduction	
Section 4	Project Description	4.1 Location 4.2 Planned Construction Activities
Section 5	Environmental Management	5.1 Policy Statement 5.2 Environmental Management Systems 5.3 Roles and Responsibilities 5.4 Regulations and Requirements 5.5 Environmental Awareness and Training



		<p>5.6 Document Review and Updates</p> <p>5.7 Environmental Commitments</p> <p>5.8 Coordination with External Entities and Addressing Complaints</p>
Section 6	Environmental Impacts	<p>6.1 Air Emissions Impacts</p> <p>6.1.1 Dust</p> <p>6.1.2 Gaseous Pollutants and Particulate Matter Impacts</p> <p>6.1.3 Odour</p> <p>6.2 Surface Water Impacts</p> <p>6.3 Soil and Groundwater Impacts</p> <p>6.4 Terrestrial Ecology Impacts</p> <p>6.4.1 Discharges to Land</p> <p>6.4.2 Ecosystem (Fauna)</p> <p>6.4.3 Ecosystem (Flora)</p> <p>6.5 Marine Ecology Impacts</p> <p>6.5.1 Discharges to Marine Waters</p> <p>6.5.2 Ecosystem (Fauna)</p> <p>6.5.3 Ecosystem (Flora)</p> <p>6.6 Noise and Vibration Impacts</p> <p>6.7 Traffic Impacts</p> <p>6.8 Waste Management Impacts</p> <p>6.8.1 Solid Waste</p> <p>6.8.2 Liquid Waste (Effluent)</p> <p>6.8.3 Hazardous Waste</p> <p>6.9 Other Environmental Impacts</p>
Section 7	Environmental Mitigation Measures	<p>7.1 Air Quality Control Plan</p> <p>7.1.1 Dust Management</p> <p>7.1.2 Gaseous Pollutants Management</p> <p>7.1.3 Odour Management</p> <p>7.2 Erosion and Sediment Control Plan</p> <p>7.3 Soil and Groundwater Contamination Control Plan</p> <p>7.4 Terrestrial Ecology Control Plan</p> <p>7.4.1 Terrestrial Ecological Management</p> <p>7.5 Water Quality and Marine Ecology Control Plan</p> <p>7.5.1 Wastewater Management</p> <p>7.5.2 Marine Ecological Management</p>



		<p>7.6 Noise and Vibration Control Plan</p> <p>7.7 Traffic Control Plan</p> <p>7.8 Waste Management Control Plan</p> <p>7.8.1 Minimization, Reuse, and Recycling</p> <p>7.8.2 Solid Waste Management</p> <p>7.8.3 Liquid Waste (Effluent) Management</p> <p>7.8.4 Hazardous Waste Management</p> <p>7.8.5 PCBs, Asbestos, and Ozon-Depleting Substance Management</p> <p>7.8.6 Use of Environmental Service Providers for Waste Management</p> <p>7.9 Chemical and Hazardous Materials Management</p> <p>7.10 Contingency Plan</p> <p>7.11 Emergency Management Plan</p> <p>7.11.1 List of Emergency Coordinators</p> <p>7.11.2 Emergency Procedures</p> <p>7.12 Security Plan</p> <p>7.13 Infrastructure Plan</p>
Section 8	Monitoring and Auditing	<p>8.1 Environmental Performance Monitoring</p> <p>8.2 Reporting Requirements</p> <p>8.2.1 Incident Reports</p> <p>8.2.2 Periodic or Quarterly Performance Reports</p> <p>8.2.3 Monitoring Compliance Reports</p> <p>8.2.4 Environmental Checklists</p>
Section 9	Documentation	
Section 10	Annexes	



1. Section One: Project Title

- At a minimum, the cover page of the CEMP should include the following:

- ✓ Project title;
- ✓ The proponent's name, address, and contact information;
- ✓ The consultant's name, contact information;
- ✓ The contractor's name and contact information

After cover page following to be included:

- Table of content
- List of Tables
- List of Figures
- List of Abbreviations
- Definition of Terms

2. Section Two: Project Team Identification (Stakeholder)

The purpose of the stakeholder list is to establish communication channels that will enable more effective control of environmental-related issues. The stakeholder list should identify relevant government agencies, potentially affected parties and the community. A public information and stakeholder consultation program is to be prepared and implemented by the proponent to ensure that the public is familiar with the issues related to the project and that stakeholders are consulted on pertinent issues. Stakeholder list could include the proponent, the environmental consultant, lead contractors, subcontractors and any appointed environmental managers (or other identifiable titles for the persons in charge of implementing the contents of the CEMP).

This section should outline a program for community consultation and communications during the construction.

3. Section Three: Introduction

The introduction should provide a discussion on the reasons or necessity of the project, nature of the project, steps led to the selected project, and if the project is part of a larger proposal.

The project developer must be clearly identified, the consulting team who carried out the assessment;

This section should:

- ✓ Describe consultation activities undertaken during the preparation of the CEMP;
- ✓ Outline the outcomes of consultation undertaken during the CEMP preparation process, the issues and suggestions raised by stakeholders or members of the public;



This section should include the environmental permit given for the project. This section should include information about the status of approval for any additional licenses or permits required to perform construction activities.

4. Section Four: Project Description

The Project Description section should include information on the location, overall project planned construction activities, project schedule and milestones, as discussed below.

4.1 Location

The Location section should include a general description of the location.

This section should include details regarding the current condition of the environment at areas potentially impacted by construction activities at the site and surrounding area, and should accomplish the following:

- ✓ Briefly describe the existing environment for each environmental component at the site and surrounding areas. Relevant information may include previous or current land use, monitored noise levels, the presence of soil or groundwater contamination, air quality or water quality measurements, the presence of wildlife, marine resources, or vegetation;
- ✓ Reference baseline data taken from the EIA performed for the project or other studies where baseline data adequately represent the condition of the environment on the proposed project site and adjacent surroundings;
- ✓ Identify sensitive receptors located in the vicinity of the proposed project site, including justification for how the sensitive receptors were determined.

Provide maps that show the geographic location of the project area and surroundings, the maps should show the relative location of sensitive receptors to the project site, including the distance, It should provide maps that. Maps should include all necessary information, such as key, scale, north arrow, legend, location of sensitive receptors, and distance to sensitive receptors

4.2 Planned Construction Activities

This section should cover project construction phases “if any”. For example, if activities will be conducted in separate phases, and the CEMP is being submitted only for one particular phase of the development, then this section should describe those activities.

This section should include:

- ✓ Method statement describing the planned construction activities, the discussion may include but are not limited to excavation, demolition, works related to earthworks,

infrastructure, dewatering, piling, enabling works, rerouting of pipes, and site remediation, along with typical construction activities;

- ✓ Commencement and completion dates (if the project to be completed in phases, then separate dates for each phase to be provided);
- ✓ Working hours, including the activities required to be undertaken outside these hours;
- ✓ Employees number;
- ✓ Plant and equipment to be used;
- ✓ Location of the site facilities

The CEMP should provide sufficient technical detail to allow for DEAP reviewers to determine the potential impacts.

5. Section Five: Environmental Management

This section should include information regarding the policy statement, Environmental Management Systems, project personnel roles and responsibilities, Environmental Health and Safety EHS regulations and requirements, environmental awareness training, CEMP review and updates, and environmental commitments. The following subsections provide instructions as to the required information that proponents should include for this section of the CEMP.

5.1 Policy Statement

The Policy Statement section should describe the proponent's commitment to environmental protection, health, and safety management and compliance with applicable regulations.

5.2 Environmental Management Systems

The Environmental Management Systems section should discuss the way in which the plan corresponds to the proponent's and/or the main contractor's Environmental Management Systems or the Construction Environment, Health and Safety Plan (EHSMS) Regulatory Framework.

5.3 Roles and Responsibilities

Roles and Responsibilities section should include the roles and responsibilities of personnel in relation to implementation, management, and review. It is the responsibility of all contractors and subcontractors to adhere to requirements contained in the approved EIA, CEMP and all applicable environmental regulations. CEMP adherence to regulations should be contained in any contractual documents between the entities. CEMP should accomplish the following:

- ✓ Provide the names, positions, and contact information of personnel involved with ensuring the proper implementation of the CEMP. For those positions for which



personnel have not yet been assigned, the proponent should note this information within the CEMP;

- ✓ Clearly discuss the roles and responsibilities of the proponent, contractors, and subcontractors identified and the interrelationships between these entities “Clearly defined roles and responsibilities will help to ensure that the CEMP is an effective document that will be properly implemented by all personnel involved during the construction process”;
- ✓ Provide organizational flowcharts or other diagrams of key personnel “For the better understanding of the relationships between the key individuals among each of the entities”

5.4 Regulations and Requirements

The Regulations and Requirements section should detail the legal framework and requirements to be adhered to during construction and should include the following information:

- ✓ A listing of the applicable environment regulations with which the proponent will comply; this list should include local, national, and international rules and standards or agreements;
- ✓ A listing of any applicable environmental standards, such as air quality or water quality concentrations...etc. The CEMP should also provide sufficient information to clearly define these standards;
- ✓ Information about the conditions contained in any additional licenses required to perform construction activities;
- ✓ A listing of any voluntary agreements, stakeholder agreements, or procedural requirements that must be adhered to during construction

5.5 Environmental Awareness and Training

The Environmental Awareness and Training section should include an overview of the proponent’s systematic program to ensure that employees are aware of the CEMP and other environmental requirements. The CEMP should define the competency of the training provider, the frequency of training, and the levels of training for personnel. This information should include, but not be limited to, the following:

- ✓ A description of the environmental awareness and training program for personnel, contractors, and subcontractors needed to comply with measures contained within the CEMP;
- ✓ Identification of training needs, including general knowledge of the CEMP and activity specific guidance for different activities (e.g., the handling of hazardous waste, operation of certain equipment);



- ✓ Established procedures for maintaining records of all training to be performed, including the name of the person trained, the date of training, the name of the trainer, and a description of the training content

5.6 Document Review and Updates

The Document Review and Updates section should establish procedures for the periodic review of the CEMP to ensure that the plan's contents are correct and that it is being properly implemented. These reviews will ensure that—"should conditions arise that alter the plan's contents or requirements—the CEMP remains updated to reflect these changes".

In this section, the project proponent should accomplish the following:

- ✓ Demonstrate how the proponent intends to keep the CEMP as a "live" document, capable of modification during the project's life cycle and as circumstances dictate;
- ✓ Indicate who will regularly review, update the CEMP as construction progresses;
- ✓ Outline procedures for the periodic review of the CEMP to ensure that its contents are correct and that it is being properly implemented

5.7 Environmental Commitments

The Environmental Commitments section should include a summary of the environmental commitments that will be made to manage potential environmental effects. The CEMP environmental commitments statement should describe the following:

- ✓ Adherence to all outcomes and obligations of this CEMP;
- ✓ Proposed mitigation measures and monitoring activities against all residual impacts, unexpected releases, and anything that compromises worker safety;
- ✓ The nature of the work to be undertaken;
- ✓ The objectives to be met;
- ✓ Responsible body for the CEMP environmental commitments;
- ✓ Who is responsible for monitoring and recording that the CEMP environmental commitments are properly fulfilled;

Each CEMP environmental commitment containing the information in the above list should be numbered and indexed in the body of the CEMP to allow for quick reference. The CEMP should also be designed to allow interested parties to determine whether relevant issues have been addressed.

5.8 Coordination with External Entities and Addressing Complaints

The Coordination with External Entities and Addressing Complaints section should provide a management system to receive and address complaints, manage

correspondence with any parties that may be affected by the construction activities (e.g., local communities that may be affected by noise or vibration ...etc.), document the complaints, and address the corrective actions to be implemented to rectify any deviation from performance standards.

6. Section Six: Environmental Impacts

The Environmental Impacts section of the CEMP should outline the specific construction activities at the project site and on the surrounding environment and note any significant impacts. The plan should also explain the methodology used for determining significant impacts and reference any previously performed environmental studies that provide more extensive assessment of these impacts (e.g., EIA, EHIA). If an environmental study was performed, the proponent should ensure that the impacts discussed in the study are included in the CEMP. If no prior environmental study was performed, the CEMP should include in-depth analysis of the identification of potential impacts and how significant impacts were chosen. The environmental impacts that must be assessed in this section are, at a minimum, air emissions, surface water, soil and groundwater, terrestrial ecology, marine ecology, noise and vibration, traffic, and waste management, as discussed below.

6.1 Air Emissions Impacts

The Air Emissions Impacts section should include, but not be limited to, information regarding dust, gaseous pollutants and particulate matter (PM), and odor. The following subsections provide further information on these components.

6.1.1 Dust

Dust or PM may be emitted from various construction activities, including demolition, traffic along unpaved roads, wind from soil stockpiles, and graded or desert soil. Therefore, this section should accomplish the following:

- ✓ Identify all types of dust emissions and sources present during different phases of construction, as well as other pertinent information related to these components;
- ✓ List Kingdom of Bahrain emission standard limits and other known international standards if needed

6.1.2 Gaseous Pollutants

Gaseous pollutants, such as Nitrogen oxides (NO_x), sulphur oxides (SO_x), and volatile organic compounds (VOCs) ...etc may be emitted from various construction activities, including the burning of fossil fuel from vehicles and equipment. Therefore, this section should include, but not be limited to, the following information:

- ✓ Identification of all types of gaseous emissions, sources, and flow rates present during different phases of construction, as well as other pertinent information related to these components;
- ✓ A detailed table that shows the fuel consumed for all construction equipment, including fuel type (e.g., diesel, gas), consumption rates, source(s), the units that are operated, and the estimated quantity to be stored on site;
- ✓ A listing of applicable emission standard as per the Ministerial Order No. 10 of 1999 and relevant amendment and other known international standards if required.

6.1.3 Odor

Construction activities have the potential to cause odor problems, which can be a nuisance and cause negative health impacts. Therefore, the CEMP should take into account the presence of compounds that cause odors and must, at a minimum, accomplish the following:

- ✓ Identify and describe the likely source(s) of odor;
- ✓ Specify the qualities or characteristics of any odors (e.g., fishy, almond ...etc.);
- ✓ Determine the concentration by measuring the amount of odor-causing chemicals in an air sample;
- ✓ Discuss the anticipated odor intensity;
- ✓ Identify the relevant maximum allowable limits from international standards

6.2 Surface Water Impacts

The Surface Water Impacts section should provide detailed surface water impacts related to storm water. This information should include, but not be limited to, the following:

- ✓ A base map that contains boundary lines of the projected industry site and the nearest storm drain;
- ✓ An analysis of site limitations and development constraints that includes factors such as slope, soil erodibility, depth to bedrock, depth to seasonal high water, and soil percolation to facilitate the evaluation of site suitability for proposed storm water and erosion-control facilities in relation to the overall development proposal

6.3 Soil and Groundwater Impacts

The Soil and Groundwater Impacts section should include, but not be limited to, the following information:

- ✓ A summary of the site's geology;
- ✓ Soil and groundwater characteristics (e.g., chemical and physical analyses, ground stability);
- ✓ A description of the site hydrogeology, including a description of aquifers, groundwater availability and use, and groundwater flow;

- ✓ Potential impacts from construction activities to the soil and ground water

6.4 Terrestrial Ecology Impacts

The Terrestrial Ecology Impacts section should include information on discharges to land and impacts on wildlife and vegetation, as discussed below:

6.4.1 Discharges to Land

This section should describe potential impacts to land on site and in surrounding areas from construction activities including, but not limited to the following:

- ✓ A description of discharge point(s) and disposal method(s);
- ✓ Information on volumes of discharge;
- ✓ The proximity of the event;
- ✓ Chemical and physical properties of any discharges;
- ✓ A description of any flora or fauna in the terrestrial environment—specifically endangered or sensitive species—that are likely to be impacted;
- ✓ The relevant allowable limits from DEAP, or other international standards

6.4.2 Ecosystem (Fauna)

This section should describe potential impacts to habitats of terrestrial ecosystem (Fauna) from construction activities, including habitats located on site and off site

6.4.3 Ecosystem (Flora)

This section should detail potential impacts to ecosystem (Flora) from construction activities, including ecological areas located on site and off site

6.5 Marine Ecology Impacts

The Marine Ecology section should include information on discharges to marine waters; ecosystem, as discussed below:

6.5.1 Discharges to Marine Waters

This section should describe potential impacts to marine waters from construction, excavation, and dewatering activities including, but not limited to, the following information:

- ✓ A description of discharge point(s) and disposal method(s);
- ✓ Information on volumes of discharge;
- ✓ The proximity of the event, process, or activity to the marine environment;
- ✓ A list of chemical and physical properties of any marine discharges, including thermal and toxic characteristics;
- ✓ A description of any flora or fauna in the marine environment—specifically endangered or sensitive species—that are likely to be impacted;
- ✓ The relevant maximum allowable Marine discharge limits as stated by Kingdom of Bahrain Environmental Standards, or international standards should be referenced

6.5.2 Ecosystem (Fauna)

This section should describe potential impacts to habitats of marine life from construction activities, including marine life located on site and off site

6.5.3 Ecosystem (Flora)

This section should describe potential impacts to marine vegetation from construction activities, including ecological areas located on site and off site

6.6 Noise and Vibration Impacts

The Noise and Vibration Impacts section should provide an overview of the noise and vibration produced from the construction activities that includes the following information:

- ✓ Noise and vibration sources from construction equipment and activities;
- ✓ Expected noise and vibration levels under different scenarios, including both individual and cumulative sources;
- ✓ Applicable allowable limits;
- ✓ Noise level at the site boundary;
- ✓ Noise level at identified sensitive areas near the project site;
- ✓ List of the acoustic performances of machines and equipment, including occupational noise classifications provided with an accompanying noise contour map;
- ✓ Modelling or monitoring, if deemed necessary, to demonstrate the noise impact in the surrounding environment, including sensitive areas.

6.7 Traffic Impacts

The Traffic Impacts section should provide a description of the traffic impacts produced from the construction activities. This information should include, but not be limited to, the following:

- ✓ A description of the potential impacts to traffic from construction related activities, including those from the closing of streets and those from increased vehicle usage for construction equipment, supplies, and disposal activities

6.8 Waste Management Impacts

The Waste Management Impacts section should provide information on activities to be conducted during construction, including, but not limited to, activities to manage solid waste, liquid waste, and hazardous waste, as described below:

6.8.1 Solid Waste

This section should provide a detailed description of the anticipated solid and semi-solid wastes that will be generated during the construction processes. This information should include, but not be limited to, the following:

- ✓ The sources of solid waste and maximum generation rates;

- ✓The type of solid waste (e.g., industrial) and its nature (i.e., hazardous, non-hazardous);
- ✓Physical, chemical, and biological properties of the solid wastes before and after treatment and a comparison with the concerned party's solid and semi-solid waste disposal limits
- ✓Identification of materials to be recycled and methods to do so;

6.8.2 Liquid Waste (Effluent)

This section should provide detailed information about anticipated wastewater generated during the construction process. This information should include, but not be limited to, the following:

- ✓Identification of all liquid effluents source(s) (e.g., cooling, cleaning), type (hazardous, non-hazardous), and the discharges rate;
- ✓Method of treatment (if present), treatment capacity, treatment efficiency, , chemical(s) used, , and type and quantities of liquid and solid wastes generated;
- ✓Methods of liquid waste storage before and after treatment;
- ✓Specification regarding the point of discharge, the final discharge (e.g., sea, sewer network, storm water network), and transportation (if present);
- ✓A no-objection letter from the concerned parties if the effluent is to be discharged to the sewer or storm water network;
- ✓DEAP, concerned parties (e.g. Ministry of Works) discharge limits

6.8.3 Hazardous Waste

This section should provide detailed information about anticipated hazardous waste generation during the construction process. This information should include, but not be limited to, the following:

- ✓Identification of all hazardous waste streams and include the type(s), quantities, and source(s);
- ✓Information on the storage locations of hazardous wastes and associated potential impacts to the environment from spills

6.9 Other Environmental Impacts

The Other Environmental Impacts section should include information regarding health and safety impacts, as well as other impacts deemed as important to the project.

7. Section Seven: Environmental Mitigation Measures

As part of the CEMP procedures for managing and mitigating impacts of the project, the proponent should prepare and implement control plans, which should include, but not be limited to, the elements described in the following subsections. The proponent should

thoroughly address site-specific mitigation measures for the applicable environmental components discussed in Sections 7.1 through 7.14 of this guidance.

Mitigation strategies should be based on the best available management practices and technologies that will eliminate or minimize adverse impacts to health, safety, and environment in the project site and the surrounding area.

Considerations for providing environmental mitigation measures include the following:

- ✓ Thoroughly address site-specific mitigation measures for the applicable environmental components that are discussed below;
- ✓ Incorporate mitigation measures identified in any previously performed EIA studies for the identified impacts;

The proponent should provide the following control plans in the CEMP:

- ✓ Air Quality Control Plan;
- ✓ Erosion and Sediment Control Plan
- ✓ Soil and Groundwater Contamination Control Plan;
- ✓ Terrestrial Ecology Control Plan;
- ✓ Water Quality and Marine Ecology Control Plan;
- ✓ Noise and Vibration Control Plan;
- ✓ Traffic Control Plan;
- ✓ Waste Management Control Plan;
- ✓ Chemical and Hazardous Materials Control Plan;
- ✓ Contingency Plan;
- ✓ Emergency Management Plan;
- ✓ Infrastructure Plan

An overview of the mitigation measures included in these control plans is provided below. Where generalized mitigation measures are provided in the sections below “note that these are provided only for clarification and are not to be taken as the only measures to be considered”.

A sample list of mitigation measures for typical construction activities is provided in Annex 1 of this document. This list does not represent all mitigation options, and proponents should choose best available practices and technologies specific to their construction activities and the project site. A table listing all mitigation measures to be implemented for the project (listed by environmental aspect and including those intended to address cumulative impacts) should be included in the main CEMP document.



7.1 Air Quality Control Plan

The Air Quality Control Plan should provide the control measures to be used to minimize air emissions from all construction activities. In each specific control identified below (i.e., dust management, gaseous pollutants management, and odor management), the plan should discuss procedures for the periodic inspection and routine maintenance of equipment in accordance with the manufacturer's instructions. These procedures should also include documentation requirements for all inspections and maintenance activities.

7.1.1 Dust Management

The section on dust management should provide mitigation measures used to address dust issues arising from sources such as demolition, eroded soil, cleared lands, stockpiles, transportation of materials, machinery, and dirt roads. Mitigation measures for dust management also may include those measures taken to prevent erosion and sediment runoff.

7.1.2 Gaseous Pollutants Management

The section on gaseous pollutants management should provide mitigation measures used to minimize gaseous pollutant air emissions from all construction activities. Control measures may include, but are not limited to, the use of low-sulphur or alternative fuels, the application of emissions-control equipment, or the selection of materials that minimize the emission of gaseous pollutants.

7.1.3 Odor Management

The control plan section on odor management should provide mitigation measures used to minimize odor from all construction activities.

7.2 Erosion and Sediment Control Plan

Large projects usually involve extensive land disturbance, such as removing vegetation and reshaping topography, which make the soil vulnerable to erosion. Soil removed by erosion may become airborne, thereby creating a dust problem, or the soil may be carried by rain water into marine environments, thereby causing physical, chemical, biological, and economic impacts to the waters. To address these issues, the Erosion and Sediment Control Plan should include, but is not limited to, the following information:

- ✓ When considering land disturbance and its potential impacts, the CEMP should give priority to preventative rather than treatment measures. When developing erosion control options, proponents should obtain information about the erosion potential of the site where soil disturbance is planned (erosion potential is determined by the soil type and structure, vegetative cover, topography, and climate) and the nature of the land-clearing to be performed. Erosion will also be affected by the type, nature, and intensity of the earthworks

7.3 Soil and Ground Water Contamination Control Plan

The Soil and Groundwater Contamination Control Plan should outline measures to manage and minimize the impact of the project on soil and groundwater. This plan should include, but not be limited to, the following information:

- ✓ Documentation of the measures used to ensure that oil and hazardous materials are properly contained to prevent contamination of soil and groundwater;
- ✓ As necessary, a listing of the measures needed to remove or remediate previously identified contaminated soil onsite from prior industrial activities

7.4 Terrestrial Ecology Control Plan

The Terrestrial Ecology Control Plan should provide information that accomplishes those aspects outlined below.

7.4.1 Terrestrial Ecological Management

The section on terrestrial ecological management should provide information that accomplishes the following:

- ✓ Describes the procedures used to control and prevent releases to on-site and surrounding terrestrial ecological systems;
- ✓ Discusses procedures to help protect terrestrial ecology, including endangered species;
- ✓ References any prior studies performed that address terrestrial ecology in the vicinity of the project area;
- ✓ Discusses the procedures for clearing activities at the construction site and surrounding area;
- ✓ Identifies buffer zones to be created to protect undisturbed areas;
- ✓ Describes the measures to be taken to re-plant or compensate for any removed vegetation

7.5 Water Quality and Marine Ecology Control Plan

The Water Quality and Marine Ecology Control Plan should include, but is not limited to, information regarding wastewater management and marine ecological management, as discussed below:

7.5.1 Wastewater Management

The section on wastewater management should include, but not be limited to, the following information:

- ✓ A description of the measures to be taken for the control, collection, treatment, or removal of wastewater produced during the construction phase;
- ✓ Where applicable, a description of the systems and procedures established for wastewater produced at housing camps for construction labour



7.5.2 Marine Ecological Management

The control plan section on marine ecological management should include, but not be limited to, information regarding the following:

- ✓ The procedures and mitigation measures to be used to prevent contamination or damage to storm water drains and waterways;
- ✓ A discussion of the measures taken to protect marine ecology, which could be impacted by construction activities

7.6 Noise and Vibration Control Plan

The Noise and Vibration Control Plan should outline measures to minimize the impacts on local noise levels and vibrations from the construction activities and should accomplish the following:

- ✓ Identify the suitable noise suppression or abatement measures required to ensure that ambient noise level concentrations do not exceed limits for both workers on site and for nearby receptors;
- ✓ Discuss the measures that will be employed to minimize vibration and the procedures that will be used to notify potentially impacted receptors about these operations

7.7 Traffic Control Plan

The Traffic Control Plan should outline measures to minimize the impacts on local traffic from the construction activities and should accomplish the following:

- ✓ Discuss the measures to minimize traffic disturbances and associated impacts from noise;
- ✓ Describe the procedures for public notification of any anticipated traffic-related concerns, such as street closings;
- ✓ Identify access roads for construction vehicles and safety measures used for pedestrian access and crossings

7.8 Waste Management Control Plan

The Waste Management Control Plan should outline the management of wastes during the construction phase, including the classification of liquid and non-liquid wastes and a description of how these wastes will be managed. As described below, the Waste Management Control Plan should include information on methods for minimizing or recycling wastes, with specific procedures for solid waste management, liquid waste management, hazardous waste management, and the handling or removal of polychlorinated biphenyls (PCBs), asbestos, and ozone-depleting substances. This plan also should include information about the selected waste management service provider.



7.8.1 Minimization, Reuse, and Recycling

The section on minimization, reuse, and recycling should discuss the measures that will be used to avoid/minimize, reuse, and recycle wastes generated at the construction site. Measures may include technological applications, segregation of waste streams, purchasing decisions, the selection of construction materials.

7.8.2 Solid Waste Management

The section on solid waste management should include, but not be limited to, the following information:

- ✓ The procedures for solid waste management, including on-site activities related to collection, storage, transportation, processing, and disposal;
- ✓ If necessary, a description that differentiates between the procedures used for different waste streams

7.8.3 Liquid Wastes (Effluent) Management

The section on liquid waste management should provide on-site mitigation measures for the reduction, collection, and disposal or treatment of liquid wastes from construction activities.

7.8.4 Hazardous Waste Management

The section on hazardous waste management should include, but not be limited to, the following information:

- ✓ The procedures to be used for the reduction, collection, handling, and storage of hazardous wastes from construction activities;
- ✓ Information on hazardous waste identification processes, along with labeling and documentation requirements for waste-transfer notes.

7.8.5 PCBs, Asbestos, and ozone-depleting substances Management

The section on PCBs, asbestos, and ODS management should establish procedures for the proper identification, handling, and removal of these materials, as encountered during the removal, renovation, or demolition of any buildings on site.

7.8.6 Use of Environmental Service Providers for Waste Management

For the identified wastes, the control plan should provide information about the registered environmental service provider that will be used to handle the collection, transportation, and disposal of wastes. It is important to note that only these providers are authorized entities to receive waste. A list of environmental service providers can be obtained from the Waste Control Section of GDEWP.

7.9 Chemical and Hazardous Materials Control Plan

The Chemical and Hazardous Materials Control Plan should provide information that, at a minimum, accomplishes the following:



- ✓ Discusses the measures that will be taken to minimize the risks associated with chemical, fuel, and oil spills and accidents; these measures can include, but are not limited to, monitoring purchasing requirements, product substitutions, design features for containment, operational controls, work practices, labeling, and storage requirements;
- ✓ Specifies the document-control procedures for maintaining material inventories and Material Safety Data Sheets

7.10 Contingency Plan

The Contingency Plan should outline the procedures established and equipment available to respond to spills during construction activities and should, at a minimum, achieve the following:

- ✓ Identify potential sources of spills and the measures in place to control them, Include maps showing the presence of chemical, oil, and hazardous waste storage locations, structures and equipment for diversion and containment of spills, and the location of spill response equipment;
- ✓ Establish procedures for responding to spills of oil and hazardous materials;
- ✓ Provide information about the presence of spill-response equipment throughout the construction site;
- ✓ Define the roles & responsibilities of all personnel involved in responding to spills;
- ✓ Clearly define immediate actions to be taken to address spills;
- ✓ Discuss the measures for containment, cleanup, and disposal of contaminated materials and soil;
- ✓ Describe notification requirements for both internal and outside spill-response teams, and provide contact information for these individuals along with local emergency agencies (in close coordination with GDEWP);
- ✓ Establish documentation procedures for identifying the root causes, corrective and preventative actions, and setting time lines for their implementation

7.11 Emergency Management Plan

The Emergency Management Plan should outline the procedures established to respond to emergencies during construction activities. This plan should include, but not be limited to, a list of emergency coordinators and emergency procedures, as discussed below.

7.11.1 List of Emergency Coordinators

The Emergency Management Plan should include an up-to-date list of names, addresses, and telephone numbers for emergency coordinators.

7.11.2 Emergency Procedures

The Emergency Management Plan should provide the following information regarding emergency procedures:



- ✓ Describe the actions to be taken in response to emergency situations, such as fires, explosions, or the unplanned releases of hazardous materials where hazards exist;
- ✓ Provide evacuation plans for the site, including procedures and routes;
- ✓ Describe any arrangements agreed to with Ministry of Interior, hospitals, contractors, ...etc., and emergency response teams to coordinate emergency response services

7.12 Security Plan

The Security Plan should discuss the control measures to contain and secure the site.

7.13 Infrastructure Plan

The Infrastructure Plan should describe the measures taken to ensure protection of infrastructure (e.g. water systems, transmission lines) during the construction phase.

8. Section Eight: Monitoring and Auditing

The Monitoring and Auditing section of the CEMP should include, but not be limited to, information regarding the monitoring and auditing of environmental performance, as well as information on reporting requirements, environmental checklists, and monitoring review, as discussed below:

8.1 Environmental Performance Monitoring

The CEMP should include information about monitoring requirements for environmental performance. At a minimum, this section should accomplish the following:

- ✓ Discuss how identified impacts will be monitored, including the indicators to be measured, the methods and sampling locations, frequency of measurements, detection limits, corrective actions, and the party who will conduct monitoring;
- ✓ Provide corrective actions procedures for non-compliance with monitoring;
- ✓ Specify notification requirements to responsible personnel and the time frames for notification for corrective actions to be performed;
- ✓ Identify the frequency and content of monitoring reports for internal use and those required to be submitted to DEAP for review;

8.2 Reporting Requirements

The CEMP should outline procedures for reporting requirements, including the frequency and content of required reports (it should be noted that some of the below mentioned report could be included in one report), such as the following:

- ✓ Pre-operation compliance reports;
- ✓ Incident reports;
- ✓ Periodic or annual environmental progress reports;



- ✓ Non-compliance reports;
- ✓ Corrective action reports;
- ✓ Complaints reports;
- ✓ Any special reports required by government agencies.

The following subsections provide further detail on the types of reporting-requirements information that should be included in the CEMP.

8.2.1 Incident Reports

A proponent must notify DEAP and other relevant authorities as soon as practicable about any environmental incident with actual or potential significance for impacts on the environment. The CEMP should state that, should an incident occur, the proponent must inform DEAP and other relevant authorities immediately and provide an incident report to DEAP outlining the details of the incident within 3 days of the incident. Incidents reports could include the following:

- ✓ Fuel or chemical spills;
- ✓ System failures or malfunctions;
- ✓ Other emergencies (e.g., natural disasters);
- ✓ Other events that led to non-compliance with environmental standards/requirements

8.2.2 Periodic or Quarterly Performance Reporting

The CEMP should submit within 3 months of the date of approval of the CEMP and monthly thereafter environmental progress reports for the construction project. This report should accomplish the following:

- ✓ Identify the standards, performance measures, and legal requirements that apply to the project construction;
- ✓ Assess the environmental performance of the project construction to determine whether it is complying with these standards, performance measures, and legal requirements;
- ✓ Identify any non-compliance with the conditions of this CEMP or any standards, performance measures, or legal requirements that apply to the project and occurred during the reporting period;
- ✓ If any non-compliance is identified, describe the actions and measures that will be performed to ensure compliance, clearly indicate who is or will be performing these actions and measures, when they will be conducted, and how the effectiveness of these measures will be monitored over time;
- ✓ Include a copy of complaints for the quarter and a description of actions taken or being taken to address registered complaints;

- ✓ Provide the results of all environmental monitoring required by the environmental permits, including interpretations and trends or exceptions in these results

8.2.3 Monitoring Compliance Reports

The Monitoring Compliance Reports section of the CEMP should include information regarding the following:

- ✓ Establish a program to monitor environmental compliance of construction activities in accordance with the established procedures defined in the CEMP. These activities may include daily, weekly, or periodic inspections;
- ✓ Provide procedures that establish corrective actions for non-compliance with established CEMP procedures and identify the root causes for the issue. These corrective actions should not only provide an immediate but also help ensure that similar non-compliance will not be repeated;

8.2.4 Environmental Checklists

The CEMP should include checklists to be used during site inspections. These checklists must be specific to the mitigation measures that will be used and allow for clear distinction about whether the measures are being implemented effectively.

9. Section Nine: Documentation

The CEMP should include requirements to maintain copies of the CEMP, the plans contained within the CEMP, changes to any of these plans, and training records or rosters, audits, monitoring data, and reports submitted to DEAP, other agencies, or local authorities. These documents should be easily accessible for inspection.

10. Section Ten: Annexes

The CEMP should include annexes detailing the information described in the previous sections.

Required annexes of the CEMP should include, but not be limited to, the following information:

- ✓ References and sources of information that were used to prepare the CEMP (e.g., previous environmental studies for the project, best international practices used);
- ✓ Material Safety Data Sheets;
- ✓ Environment policy;
- ✓ Environment manuals;



-
- ✓ Large-scale drawings and diagrams (e.g., site layout, machinery and equipment layout, process flow diagrams, piping and instrumentation diagrams, emissions points, sewer and storm water systems);
 - ✓ Records, checklists, and log templates for inspections, monitoring, maintenance;
 - ✓ Complaint procedures;
 - ✓ training activities



Appendix 22: Mitigation Measures for EPC Contractor



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

Appendix 22 - General Mitigation Measures to be implemented by the EPC Contractor

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Abbreviations

Alba	Aluminium Bahrain
AST	Above-ground Storage Tanks
BAT	Best Available Technology
CEMP	Construction Environmental Management Plan
dB(A)	A-weighted decibels
DG	Diesel Generator
EMEP	Emergency Management and Evacuation Plan
EPC	Engineering, Procurement and Construction
ESIA	Environmental and Social Impact Assessment
EWA	Electricity and Water Authority
HSE	Health, Safety and Environment
MSDS	Material Safety Datasheet
MTPA	Metric Tonnes per Annum
NOC	No Objection Certificates
PPE	Personal Protective Equipment
PS	Power Station
SO₂	Sulphur Dioxide
TME	Tebodin Middle East Ltd.
UST	Underground Storage Tanks
STP	Sewage Treatment Plant



1 Introduction

As part of the ESIA study, impacts with regards to the construction phase of the expansion project were assessed to the extent possible. As only limited information with regards to the construction phase is available at this stage of the project, the ESIA recommended and the Supreme Council for Environment requested for the preparation of a Construction Environmental Management Plan (CEMP) in order to further detail the environmental impacts related to construction phase.

The current document presents general minimisation measures that shall be implemented by the concerned Engineering, Procurement and Construction (EPC) contractor. These minimisation measures are presented in the form of control plans for the affected environmental components. It is to be noted that the control plans are generic and more specific control plans need to be developed as part of the CEMP.

2 Environmental Control Plans

This section present the construction environmental management plans which contain general minimisation and mitigation measures to be implemented during the construction phase of the expansion project.

The various environmental control plans portray control procedures and preventive measures which are devised to be implemented by the EPC contraction during the construction works in an attempt to minimise or alleviate the associated environmental impacts.

The following control plans are included in subsequent sections:

- 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



2.1 Air Quality Control Plan

Based on the Best Available Technology (BAT), the following control measures have been devised to reduce the impact on the ambient air quality of the project area and the occupational health of workers.

2.1.1 Dust Management

The most prevalent construction emission is fugitive dust. Therefore the following control measures are devised to reduce fugitive dust to As Low As Reasonably Practicable (ALARP) and are expected to be implemented on site by the EPC contractor where applicable.

#	Control Measures – Dust
1	Daily dust suppression through periodic water sprinkling by tankers storing water retained from dewatering activities. The reuse of retained water reduces the consumption of fresh water but also, the saline properties of brackish waters have better dust suppression properties than fresh water.
2	The speed of all vehicles traveling onsite shall be limited to 20 km/hr and unpaved hauled roads should be sprinkled with water to suppress dust generated from vehicle movement.
3	Open-bodies trucks hauling sand, gravel, or soil between on-site and off-site areas are to be fully covered by a Tarpaulin and sprayed with water to avoid loss of materials in transport and generation of dust.
4	Minimum drop heights shall be used during material transfer.
5	Stockpiles should be placed in a sheltered area and away from site boundaries as to contain dust travelling.
6	Limit the area subject to excavation, grading and other construction activity at any one time.
7	Train all site personnel to be fully understands activities that generate dust and measures that should be undertaken to reduce dust emissions.
8	Stockpiles onsite shall be minimised to the extent feasible. Stockpiles should have a maximum height of about 2 m, or equal to or lower than the average height of surrounding structures.
9	Particulate dust masks and safety eye goggles are to be worn as Personal Protective Equipment (PPE) as instructed by the site supervisor.



2.1.2 Gaseous Pollutants Management

The following control measures shall be implemented in order to minimise the combustion and vehicle exhaust emissions generated from the construction activities.

#	Control Measures – Gaseous Pollutants
1	Periodic maintenance such as engine maintenance, lubrication, filter cleaning / replacement, oil changes, replacement of required spares etc., of construction equipment and mobile generators are conducted so as to reduce emissions.
2	Switch off or throttle down the construction equipment and vehicles, when not in use, in order to minimize emissions.
3	Do not overload trucks.
4	Cleaner fuel alternatives such as low sulphur diesel shall be considered if accessible. Fuel with only 0.5% sulphur content shall be used which in turn will reduce SO2 emissions.
5	Periodic visual checks of all vehicles and machinery on site shall be conducted to detect any black smoke emitted from combustion engines.
6	All welding operations shall be carried out in enclosed areas in order to limit impacts from welding fumes.

2.1.3 Odour Management

The following control measures shall be implemented in order to minimise the occurrence of foul odour generated from the construction activities or facilities made available for workers on site.

#	Control Measures - Odour
1	Food waste from the site office and accommodation camps shall be stored in designated food waste skips which shall be securely sealed shut with their respective lids to prevent secondary ecological impact and odour, and to ensure feral animals and vermin cannot feed on the debris.
2	All holding tanks/ drains shall be adequately closed/sealed (as applicable) to minimize odour emissions.
3	Any spillages onto land shall be immediately cleaned and disposed of as hazardous waste by an approved environmental service provider.
4	Strict prohibition of any open fire and incineration of any type of materials.



2.2 Erosion and Sediment Control Plan

The main objective of the erosion and run-off environmental control plan is to implement procedures that will avoid or minimise soil erosion from disturbance of land caused by construction activities. Erosion and subsequent run-off can occur as a result of construction activities such as removal of the sand dune, traffic and equipment movement on site, and lack of vegetation and dryness of soil. This enhances the potential for the movement of pollutants entering the soil through spills and leakages. Soil removed by erosion may also become airborne and create a dust problem. In the event of heavy rainfall, storm water may lead to the increased flow of contaminated soils and waters and as a result contaminate the groundwater. The likelihood of rainfall is very low and thus the impact of storm water is significantly reduced. However, control measures to reduce abnormal flow and erosion are provided below.

#	Control Measures – Erosion and Sediment
1	Permits/ No Objection Certificates (NOC) should be obtained from the Concerned Authorities prior to start of activities related to the construction of the roads and utilities infrastructure.
2	Keep land clearance to a minimum.
3	Wherever possible, avoid clearing areas of highly erodible soils and steep slopes, which are prone to water and wind erosion.
4	Dry stockpiled material shall be stored at a minimum distance of 10m from the nearest water source.
5	Surface runoff from the disturbed soils on the construction area shall be constantly controlled and minimized.
6	Site staff shall visually monitor storm water contamination.
7	Off road travel shall be restricted (where possible) to minimize land disturbance.
8	Appropriate spill control measures and handling procedures to be provided at lay down areas and storage areas to prevent runoffs.

2.3 Soil and Groundwater Contamination Plan

To avoid or reduce the potential risk of contamination to the soil and groundwater, the measures in this control plan can be categorized into three (3) sections based on best practice techniques:

- Fuel and Chemical Handling and Storage
- Erosion and Run-off Management
- Leaks and spills direct into the soil



Impact to soil and groundwater is probable through oil spill and leakages. Therefore, great efforts shall be made and appropriate mitigations measures shall be implemented to avoid seepage and spills of oil and other hazardous substances into the soil.

To protect the project site soil and groundwater mediums from oil and hazardous material spills, refer to Section 2.8; Chemical and Hazardous Materials Control Plan.

Based on BAT the following control measures have been devised to reduce the impact on soil and groundwater of the project area.

#	Control Measures – Soil and Groundwater
1	All hazardous construction materials like fuel, oils and paint shall be stored and handled in leak-tight, bunded containers and placed in dedicated locations with impervious flooring with adequate bund to prevent leakage or spills to the ground/groundwater.
2	All hazardous materials stored on site shall be properly labelled and segregated according to their chemical properties in order to avoid any adverse chemical reactions.
3	During fuelling of equipment and machinery, including the Diesel Generator (DG) sets, drip trays shall be placed to prevent leakage of fuel to the ground/groundwater.
4	Operators have to be instructed to notify their supervisors in the event of a spill/leak is identified, in order to immediately apply the emergency response procedures (clean up, etc.) followed by the necessary corrective action (maintenance, replacement of machinery) to avoid re-occurrence.
5	Regular inspection and maintenance of the construction machinery and vehicles to confirm they are not leaking. All static equipment shall be provided with drip trays.

2.4 Water Quality Control Plan

Wastewater will be generated due to construction, including sanitary wastewater from project site office, labour shed toilets etc. The following control measures shall be implemented in order to ensure that wastewater is properly handled and disposed-off site.

#	Control Measures – Wastewater Management
1	Adequately sized holding tanks shall be used for the collection of sanitary wastewater and the same shall be transferred to the nearest Sewage Treatment Plant (STP) on a daily basis.
2	Hazardous waste and hazardous chemicals (raw materials) shall be segregated and stored in appropriate protected and enclosed areas.
3	The storage skips / areas for each type of waste shall be clearly identified and marked.



#	Control Measures – Wastewater Management
4	Storm water shall be ensured to be clear of any contamination and drained onto land.
5	Water from dewatering activities shall be collected in storage tanks and subsequently pumped to the nearby evaporation lagoon.
6	Regularly service and maintain sanitary system (such as portable toilets, septic tanks, sewage network etc.) in site.

2.5 Noise and Vibration Control Plan

Control measures to minimise the noise impacts during the construction works are provided in this Noise and Vibration Environmental Control Plan.

The most important control measure to ensure compliance of Bahrain’s noise limits and to reduce the impact of construction noise on nearby residents is to preferably carry out all activities with high noise impacts during the day rather than at night, and to locate these activities as far away as possible from the site boundary and from any sensitive receptors.

The following control measures based on best practice techniques shall also be strictly implemented on site where applicable.

#	Control Measures – Noise and Vibrations
1	Construction equipment to be oriented away from sensitive receptors as feasible.
2	Noise levels of 70 dB (A) shall be maintained at the fence lines of the construction site.
3	Workers on site shall be provided with adequate PPE so as to alleviate noise levels to below 85 dB (A).
4	All significant noise generating equipment shall be provided with dampeners
5	Appropriate signboards indicating high noise areas shall be displayed at the construction site
6	Periodic maintenance such as engine tuning, lubrication, filter cleaning / replacement, oil changes, replacement of required spares etc., of noise generating equipment such as DG units, air compressors and other construction equipment to be conducted so as to reduce the equipment noise levels, emissions and maintain efficiencies.
7	Simultaneous operation of multiple high noise sources to be minimized to reduce cumulative noise level impacts.



#	Control Measures – Noise and Vibrations
8	Equipment and vehicles that may be in use only intermittently to be shut down during idling periods, or throttled down to a minimum.

2.6 Traffic Control Plan

Improperly managed traffic and extended congestions shall cause noise and emissions of various air pollutants such as carbon monoxide, oxides of nitrogen, sulphur dioxide, and particulate matter along the traffic routes.

Control measures to reduce the anticipated impacts of increased traffic levels to and from the site during construction are provided below.

#	Control Measures – Traffic
1	Vehicles speed shall be limited to 20 km/hr close to community sensitive areas (schools, nearby residential areas).
2	Trucks shall be covered with tarpaulin while transporting materials.
3	Certified drivers shall be used for transportation of men and materials.
4	Periodic maintenance of all the vehicles shall be conducted.
5	Carrying out the works with special attention, where restrictions are imposed by physical obstructions, i.e. Overhead power lines, slip roads, etc.
6	A safe zone has to be provided between live traffic lanes and the working area (this includes equipment, plant, tools, excavated materials, etc.)
7	Adequate barriers are provided to protect the workforce, portable vertical barriers shall be considered.
8	Where half constructed or constructed but not opened to traffic shall be covered with Jersey barriers on both the ends of the road.
9	Access / egress locations for site transport shall be kept to a minimum, preferably one at every work area.
10	Adequate measures shall be implemented to prevent traffic coming into contact with temporary / permanent structures, i.e. by using temporary barriers.
11	Adequate temporary lighting shall be provided wherever it is required.
12	All access routes shall be clearly signed and maintained



13	Arrangements shall be made to reduce the need to reverse vehicles. Where this is not possible, a trained banksman must be provided.
14	All appropriate personnel shall wear high visibility clothing.
15	Precautions like goal post are to be in place for overhead cables.
16	Underground cable and pipes shall be protected with adequate covering and markings.
17	Working area shall be defined in the live road/footway using cautionary boards and flag men which includes the areas for storage of tools and equipment and space to move around the job.
18	The equipment shall not be left on roadway overnight.
19	Not close any lanes of road without approval from Client's representative, suitable signage and devices shall be erected in accordance with instructions from Client.
20	A minimum of seven meter wide temporary roadway for traffic in two-way sections and 5 meter for one way work shall be provided.

2.7 Waste Management Control Plan

This control plan provides control measures to minimise waste and to ensure that proper management and disposal of all wastes (solid and liquid) generated is considered. It is important to note that all waste shall be collected and disposed of by a CWM approved environmental service provider.

The following hierarchy for waste management is always preferred:

- Waste avoidance and/or reduction;
- Reuse; and
- Recycle

Diverting the waste stream in these ways means that waste storage, treatment and disposal options can be reduced. Minimizing the amount of waste on site not only does it protect the environment, but also cut down costs that may be incurred by the EPC contractor or the proponent for handling and disposing of the waste. Construction sites should pursue this hierarchy and seek out waste minimisation opportunities first and foremost, followed by proper waste storage and disposal.

2.7.1 Minimisation, Reuse and Recycling

The EPC contractors waste management plan shall promote the minimisation, reuse, and recycling of wastes generated at the project site through the re-use of materials such as; timber, metals, paper, etc.



Accordingly, wastes deemed recyclable shall be segregated and stored in a separate, designated skips and placed in an accessible location. The stored recyclables shall be utilized in any foreseen potential of re-use otherwise, the materials shall be sent to an appropriate recycling facility via an approved environmental service provider.

The control measures to further minimise the quantity of hazardous and non-hazardous wastes generated on-site are outlined as below.

#	Control Measures – Waste Minimization
1	For overall waste minimization during construction, reduction, reuse and recycling options must be implemented wherever possible.
2	As part of waste minimization, only required material shall be purchased. In case small amount of material are required, this shall be borrowed from other sites.
3	Materials shall be stored as advised by the manufacturer.
4	Good housekeeping shall be ensured throughout the site.
5	Non-recyclable materials shall be substituted by recyclable materials where possible.
6	Hazardous material shall be replaced by non-hazardous material where possible.
7	Material suppliers shall be insisted on packing the material with recyclable material such as cardboard.
8	An inventory shall be maintained to prevent from ordering excess material.
9	Unused surplus material which is sealed shall be exchanged for the required material where possible.
10	Wastes such as spent oil, water based paints, asphalt waste etc. shall be recycled for re-use.

The two main categories of waste which are expected to be generated during construction works include:

- Non-hazardous waste such as paper, packaging and boxes, kitchen and office waste, cardboard, etc.
- Hazardous waste such as oil and lubricants, batteries, cans and small drums, filters, possible asbestos used in isolation materials, ducting, flooring, tube lights etc.

The following section provides specific control measures for waste handling of the non-hazardous and hazardous waste generated during construction.

2.7.2 Non-Hazardous Waste Management

In order to ensure proper management of non-hazardous waste the below control measures shall be implemented. In addition, training and education shall be provided to employees and waste manifest shall be established to keep track of the quantity and quality of wastes produced during construction. Records shall be maintained on regular basis and



periodically the information shall be forwarded to the concerned parties and to the Health, Safety and Environment (HSE) department.

#	Control Measures – Non-Hazardous Waste
1	Recyclable and non-recyclable waste shall be stored separately.
2	Different waste types shall not be mixed as this can cause chemical reactions and making recycling impossible.
3	Different colours of closed containers or different sizes shall be used to identify different types of wastes.
4	Regular waste collection shall be insured to prevent overflow.
5	Waste shall not be buried, used as backfill or for landscaping purposes.
6	To the greatest extent possible, excavated materials shall be reused in filling operations or in other processes.
7	All food waste shall be properly stored in sealed tops to minimize the possibility of vermin manifestation.
8	Domestic waste shall be disposed via an approved service provider.
9	Waste storage areas shall be kept clean, well-organized, and equipped with ample clean-up supplies as appropriate for the materials being stored.

2.7.3 Hazardous Waste Management

It is of vital importance to manage the hazardous waste generated throughout the project construction activities. To minimise the risk of pollution from the handling and storage of hazardous substances the following management practices shall be adopted to reduce the possibility of spills, to prevent incorrect waste disposal and to prevent the lack of arrangement in waste management resources.

#	Control Measures – Hazardous Waste
1	All hazardous waste produced shall be collected separately, in polyethene bags and brought to a dedicated storage area away from drainage systems.
2	A temporary area shall be designated until the hazardous waste is collected by an approved service provider.
3	Temporary storage bins shall be lined with trash cover and shall always be available in the site where



#	Control Measures – Hazardous Waste
	hazardous substances are in use.
4	Temporary storage bins shall be cleared at regular frequency to avoid overflow or spills from waste containers.
5	Handling of hazardous substances shall be in accordance with the manufacturer’s specifications and legal requirements.
6	Hazardous wastes shall be stored in enclosed and secured storage areas.
7	Supervisors shall ensure that employees who might be exposed to hazardous substances are adequately protected and informed about the safe and proper methods for handling.
8	No dumping, discharge and spillage of hazardous waste shall be allowed.
9	Separate containers, bins or skips shall be provided for hazardous waste.
10	All hazardous materials are to be stored in minimum quantities and in a manner that prevents any potential contamination/ safety risk as per their respective MSDS.

2.7.4 Use of Environmental Service Providers for Waste Management

As previously mentioned, the EPC contractor shall use the services of an approved company for the handling, transport and disposal of the various waste streams.

2.8 Chemical and Hazardous Materials Control Plan

The EPC contractor shall established work instructions for hazardous materials required for the construction project. A copy of the Material Safety Datasheet (MSDS) of all chemicals and solvents planned utilised in the construction activities such as; cement, thinner and epoxy paint should be maintained and made available upon request with the concerned HSE manager. The additional control measures for the control of hazardous chemicals on-site are detailed below.

#	Control Measures – Chemicals and Hazardous Materials
1	Materials to be stored as per MSDS provided.
2	Staff shall be educated on the storage requirements.
3	Workmen shall be trained in usage, supervision and observation to reduce the risk from incorrect usage of hazardous materials.
4	Materials storage containers shall be labelled according to their content.



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#	Control Measures – Chemicals and Hazardous Materials
5	Appropriate handling methods are established for diesel and aforementioned chemicals. Any spills/leaks shall be immediately remediated in accordance with contingency plan to reduce contamination of soil and groundwater.
6	Containers shall be regularly checked for damage and leakages.
7	Chemical hazard information (material safety data sheets/labelling) shall be used to define which chemicals have the potential to cause an emergency, in order to target its chemical response planning.

2.9 Contingency Plan

An accidental spillage can mainly occur from chemical, hazardous and oil handling and storage activities on site. To minimise the risk associated with leakage and spills of hazardous materials on to the surrounding environment, the below listed mitigation measures are expected to be considered by the EPC contractor.

#	Control Measures – Accidental Releases
1	Enclosed and secluded storage areas (adequately designed to protect from rains and to prevent any run off) with impervious flooring, bunds, covers/roof and with spill collection and safety facilities to be provided for storage of hazardous materials such as lube oils, toxic and flammable chemicals, cleaning solvents, paints, fuels, etc., according to applicable regulations and MSDS.
2	Onsite fuel storage tanks, if any, to be provided with secondary containment and spill collection facilities. Properly lined areas with spill collection facilities to be provided for loading/unloading of hazardous materials.
3	Roofed and ventilated area with adequate safety protection to be provided for storage of gas cylinders.
4	Onsite and offsite emergency response plans to be established for handling any potential emergency situations due to accidental release of hazardous materials
5	Appropriate handling methods and facilities to be established for hazardous materials. Any spills/leaks to be immediately remediated to minimize contamination of soil and groundwater.
6	Provide secondary containment when hazardous materials are stored in bulk quantities (~55 grams per litre).
7	Routine/Daily checks in the hazardous material storage area to be performed by store keeper and weekly by HSE staff.
8	Maintain good housekeeping practices for all chemical materials. Chemicals should be arranged as per the chemical compatibility chart.



#	Control Measures – Accidental Releases
9	Monthly inspections of the hazardous material storage area, secondary containment, and concrete bunds of 110% surrounding any present Above-ground Storage Tanks (AST) or Underground Storage Tanks (UST) need to be logged.

The prevention of spills and leaks shall be the primary measure taken by the EPC contractor during the construction activities. However, in the unforeseen event of accidental spills and leaks of chemicals and hazardous materials and the potentially significant impact that can occur on the environment, spill response procedures have been developed in this section. The purpose of these procedures is to allow an immediate and effective response that shall limit the environmental impact as much as possible. The magnitude of the spill shall determine the extent of the actions that have to be taken. Therefore a spill clean-up procedure shall be established.

2.9.1 Spill Clean-up Procedure

An incidental spill is defined as either an incident, which can be absorbed or controlled by personnel working in the immediate area, or releases, which do not present any health or safety hazards.

Response actions and procedures shall be contingent upon the nature and quantity of the materials that are released. Therefore, to determine the level of spill response capabilities required, it shall be determined what chemicals are present at the site and in what quantities. In subsequent sections, the different steps to be taken in case of a spill are detailed.

2.9.1.1 Early Detection

Regular inspections of the construction site shall be carried out to enable early detection. Awareness sessions of potential pollution risks should be conducted onsite to ensure personnel are familiar with the procedures to follow during the advent of a spill occurrence. To be noted, it is the responsibility of all employees to be familiar with procedures relevant to early detection.

2.9.1.2 Notify the HSE Manager

Each member of the construction staff shall be introduced to the designated site HSE manager during their HSE introduction and associated trainings. Awareness sessions on emergency services and response procedures shall be provided to all onsite personnel.

2.9.1.3 Assess the Risk

Before attempting to clean up a spill, make sure to take into account everything that might be affected by that spill. Look at the risks to human health, the environment and property. If possible, identify the spilled material and determine how much has spilled. Use the container's label or the MSDS to identify the liquid and the primary dangers posed to spill responders and the environment.

2.9.1.4 Confine the Spill

The spill area shall be limited by blocking, diverting or confining the spill. Next, the spread of the liquid shall be stopped before it has a chance to contaminate a water source. Spill kits containing absorbents are designed to facilitate a quick, effective response. Non-absorbent barriers such as containment boom are available to confine liquids, minimise the spill area, and protect drains.



2.9.1.5 Stop the Source

After the spill is confined, stop the source of the spill. This may simply involve turning a container upright, closing a valve, or plugging a leak from a damaged drum or container. Be sure to transfer liquids from the damaged container to a new one.

2.9.1.6 Evaluate Incident/ Implement Clean-up

Once the spill is confined and the source has been stopped, a plan of action for implementing the spill clean-up is developed. Absorbents that are chemically compatible with the liquid spilled shall be used throughout the spill area. Once the absorbents are saturated, they should be properly disposed. Sorbents do not render liquids non-flammable, neutral or less-hazardous and shall take on the characteristics/properties of whatever liquid is absorbed. Therefore, all measures must be taken as if you were handling the liquid itself. Sorbents do not make the liquid less hazardous. Always refer to the MSDS for the chemical absorbed before proceeding.

2.9.1.7 Decontaminate

Decontaminate the site, personnel and equipment by removing or neutralizing the hazardous materials that have accumulated during the spill. This may involve removing and disposing of contaminated media, such as earth, that were exposed during the spill incident.

Contaminated soils and used clean-up materials (if any) shall be treated as hazardous waste and stored in containers within a designated and earth-bunded storage area. The approved service provider shall collect and consequently dispose of the waste. To be noted, site HSE manager shall retain waste manifest and waste logs/consignment notes of the same.

2.9.1.8 Spill Response Materials

Spill response/pollution control materials, such as sand/adsorbents, sand bags, buckets and shovels, storage containers, and foam fire extinguisher, shall be stored in a safe location on site in close proximity to the waste storage and vehicle re-fuelling areas. These materials are to be used to contain and clean up accidental spills with special care taken in its disposal. The concerned HSE Manager shall keep stocks of spill response materials well maintained and replenished.

2.9.2 Documentation of Incident

It is the responsibility of all personnel to report accidents, incidents, near misses and dangerous occurrences occurred at work site. EPC Contractor shall prepare an Incident procedure. This procedure should include topics such as:

- Tasks and responsibilities
- Seriousness of the incident
- Investigation methodology to identify the root causes of accidents, incidents, dangerous occurrence and non-conformances.
- Routing of incident reports, time frame and close-out.



2.10 Emergency Management Plan

The EPC contractor shall develop an Emergency Management and Evacuation Plan (EMEP) for the proposed construction works. The EMEP describes the actions to be taken in response to emergency situations for all site personnel including employees, first aider, engineers/foremen, project manager and safety engineers.

Project personnel shall be familiar with the requirements of this plan. The procedures and measures included in this Plan shall be explained to all the workers involved during toolbox and kick-off meetings and/or during induction training. As proof of attendance, the HSE Manager shall maintain the toolbox, induction and training attendance form.

2.11 Security Plan

In order to carry out the security of the construction site, the EPC contractor shall establish a security team, led by the Security Inspector, to cordon off the site and control the persons and vehicles. The team members shall help the fire fighting team and guide external agencies like the Fire Brigade to the place of emergency.

During the construction project it shall be ensured that only authorised personnel and vehicles are allowed to enter the Site. Furthermore, a register of all personnel on the Site at any time shall be recorded. In addition, safety barriers shall be provided at the perimeter of the Site. This safety barrier shall be sufficient to prevent unauthorized entry to the Site.

All access points shall have vehicle barriers or gates. All access points shall be secured when not supervised by security staff, and safety barriers shall be installed around any works in public areas. Moreover, access into hazardous areas shall be controlled.

Security staff shall receive the appropriate training and shall be issued with mobile phones, or other suitable means of communication.



Appendix 23: Approved Waste Transporters

SUPREME COUNCIL FOR ENVIRONMENT
DIRECTORATE OF ENVIRONMENTAL ASSESSMENT & CONTROL

LIST OF APPROVED HAZARDOUS & OILY WASTE TRANSPORTERS-2014

#	Organization	Contact Name	Job Title	Work Tel.	Mobile	Fax No.	P. O. Box	Approved Vehicle Nos.	E-mail
1	AGAS Lubes	Mr. K. A. Padmanabhan	Vice President	17822240	39607324 39125520	17822241	15360	BRN- 8301 and 14256	agas@batelco.com.bh tampis@batelco.com.bh
2	Al Buraq	CANCELLED							
3	SPHINX SERVICES	Hussain Kamal Moh'd Rafie	M. D T. Foreman	17700222	39456224 39622517	17700443	1940	BRN- 13837, 10434, 11564, 12252, 14116, 10952, 11481, 1131, 11990, 12044, 12034, 11011 & 13276	sphinx@batelco.com.bh
4	AL-TAWFEEK	Mr. JayaRajan Padiyath	Senior Manager	17786368	36040802	17786869	24349	BRN- 14491, 13964, 14133, 14117, 10190, 11025, 11285, 11988, 12441, 12258, 13404, 13237 & 11640.	Tawfeek@batelco.com.bh
5	Al Faisal Clearing & Transport Agency Co.	Mr. Faisal Hasan Rahma Tahir	General Manager	17737585	39458854 36533502	17737678	32230	BRN-31541, 31928, 35748, 37865, 40734, 41116, 41661, 42537, 42697, 43185, 43186, 43896, 43377, 43396, 44930, 46927, 46940, 46993, 33100, 49191, 37254, 49676, 33235, 40495, 31806, 31811, 33055, 40823, 30553, 32034, 70584, 70585, 73810, 73902, 5595, 30892, 34799 & 36760	tahir@alfaisal-logistics.com

6	REDMACK	Mr. Fawaz Al Manai Mr. Suri cam	G. M E.	17700370	39418814 39647775	17700376	29040	BRN- 1984, 12522, 13154, 1507 & 11783	redmack@batelco.com.bh
7	ASCON	Mr. A. Aziz Moh'd Al Sayed Mr. Kabindra	G. M Sales Engineer	17343953	39653113 39817028	17343738	24565	BRN- 12873, 10663, 15433 & 15750, 16261, 16477, 17651, 17507, 17506, 18019, 18018, 18388, 15917, 16402, 15472 & 15846.	ascon_bh@hotmail.com
8	ABU OBAID CONTRACTING EST	Mr. Abdul Al Ameer Essa	General Manger	17700204	39444689	17702314	26437	BRN-38722	Abuobaid@batelco.com.bh
9	BRAMCO	Mr. Ashok Kumar Mr. Raspal Singh	Vice President Asst. Manager	17270439	39662348 39657293	17230614	20260	BRN- 47260, 78092 & 8203	rashpal@bramcogroup.com
10	Gulf City Cleaning Company	Mr. James Adrian Cockrem	Operations Manager	17729151	39402485	17825278	669	BRN- 19521, 18764, 47234, 12904, 18766 and 12453	nasswmg@batelco.com.bh
11	General Cleaning Maintenance Services	Mr. Ravi Moorthy	General Manager	17754909	39644168	17754727	20117	BRN- 18249, 18248, 18444, 16449, 16786, 13170, 13994, 13703, 11589, 10793, 10649, 10856, 13834, 13973, 15440, 15513, 13104, 13675, 1589, 15592, 16563, 16780, 45506, 32347, 42327, 45288, 71901 & 71207	gcms@batelco.com.bh
12	Naval Support Activity	Mr. Awmi Al Masri	Regional Environmenta I Coordinator	17854603	39463697	17853028	116	45087,52829	awni.almasri@me.navy.mil
13	Nidukki Trading Company	Mr. Nasser Mattar	Operations Manager	17731648	39645649	17456217	1382	BRN- 16596, 15791, 16035, 16812, 14358, 12544, 10922, 17477, 18160, 19224, 19225, 19523, 18113, 15807, 1764, 10178, 15375, 15641, 15648, 14637, 15376, 11137, 11702, 51293, 77508, 78654, 8192 7 46854	operations@nidukki.bh Nasser@nidukki.bh

14	Mechanical Contracting Services Company (MCSC)	Mr. Wassim Abu Hamad	General Manager (Projects)	17623723	39208104	17624082	5238	BRN- 48582, 44485, 47983, 47984, 47985, 47986, 47490, 47491, 47492 and 47493.	kl_wilson@mcsbahrain.com
15	Qatar Factory	Mr. Abdul Nabi Al Saffar	Managing Director	17877447	39458737	17786929	3233	BRN- 30059,44273,42790	Saffar01@batelco.com.bh
16	Mayoof Sanitary Cleaning Services	Mr. Ebrahim Abdul Karim		17643664	39449009	17644626	33878	BRN-149 &13447	
17	Contractor Recycling Company	Mr. Ghulam Bahadur Khan	Director	17232740	39792221	17232760	2304	BRN- 33782, 44456 and 44408.	ctckhan@hotmail.com cte@emirates.net.ae
18	Osrex International	Mr. Kaythar Ramzi	General Manager	17702399	36767617	17702858	70108	BRN- 60731,15479,39331,10747 & 10746	reemco2006@yahoo.com
19	Crown industries	Mr. Thiyaga Rajan	Operations Manager	17830038	39653700	17830379	11101	BRN-44766, 72280 &3337	crownmet@batelco.com.bh
20	Al Dewaniyah Metal Scrap	Mr. Mohammad Abdull Al Shiwiy	Manager	17225999	39063853	17211599	24500	BRN-75881 & 75882	
21	Senior Oil Traders	Mr. Periyasamy P.	Manager	17211099	39901848	17213181	2596	BRN-32964 and 46219	oilstar@batelco.com.bh
22	Europe Scandinavian Trading WLL	Mr. Ibrahim Abdulla Shaikh	Chairman	17715775	39411127	17742979	26600	BRN-79288	euroscand@gmail.com
23	Al Amal Petrochemicals	Mr. Abdul KHakim Al Shimmiri	Director	17292565	39661998	17290818	5067	BRN-35786	hakeem@alamaltravel.com
24	Ahmed Mansoor Al Ali	Mr. Ali Abdulla Al Aali	Director			17262323	778	BRN- 49041, 7308, 7309, 7585, 7586, 7629, 7831, 70124, 70233, 73849, 73850, 73907, 73919, 78338, 78339 & 79250	

25	Al Faraj Trading & Services	Mr. Yaqoob Ali Faraj Hussain Alshalaan	Manager/HSE Manager	17700130	39456656 36044573	17700230	2663	BRN- 78608, 78609, 30722, 79266, 41756, 8271, 43798, 73163, 33403, 33938, 34813, 80871, 47311, 47312, 72514, 47858, 75300, 77502, 75302, 75079, 43983, 75081, 77069, 34354, 77881, 35039, 40560, 8552, 8551, 8553, 39003, 75080, 75750, 75751, 75078, 78600 & 32202.	Alihojja99@hotmail.com
26	Skyline Trading Corporation WLL	Mr. Wasim ul Haq	Manager	17598008	39472725	17590338	3207	77131& 77132	Stc3207@batelco.com.bh
27	Bahrain Environment al Protection SPC	Mr. Abdul Aziz	GM	17211099	-	17213181	2596	43874	bahrainenvprotection@batelco.com.bh
28	Al Arayeded Transport	Mr. Shukri Abdulamer Ali Salem al Arayeded	Manager	17732013	363333512	17736836	70097	8767, 76287, 10972 & 17551	alarrayd@batelco.com.bh
29	Al Alawaji Al Saudia Holding Company	Mr. Hasan Saleh Al Ebrahim	Technical manager	17741691	39923636	17741695	3045	71806, 71807, 71959, 71960, 71961, 71962, 71963, 71964, 71965, 76566	
30	Union Logistic Company	Mr. Mohammed Jaffer Durazi	Manager	17402848					

31	Buchem Industries Services Middle East	Mr. Markus Waldherr	Managing Director	17875254	17878530	33668	14779, 18878, 1353,36313 &66886	bahrain@buchen.net
32	Pars Palace Lubricants Co.	Mr. Khalil Shareef	Manager		17910885	1164	80846 &73349	Pars.co@hotmail.com
33	Al Haram Metals Co. WLL	Mr. Umair Ahmed	Supervisor	17704470	17704104	38175	079968 & 079969	syedzas@batelco.com.bh
34	Bahrain Medical & Industrial Gas Company	Mr. Ali Ameer	Manager	17400469	17400391	778	15059	bmigp@batelco.com.bh
35	Las vegas cargo & Cleaning Services	Mr. Ahmed Yousuf Ghuloom Ebrahim	Director	17703290	17703291	22667	8703	lasvegas@batelco.com.bh
36	Joz construction	Mr. Mohammad Joz	Director	17223423	17213015	283	76432	jozgroup@batelco.com.bh
37	SPECTRUM Cleaning Company	Hisham Kooheji	General Manager	77122441	17700969	756	BRN 19674- 4631- 8272- 43265- 39052- 17037	ABDULRAZAK@MMKOOHJIGROUP.COM.BH
38	NASSER ABD MOHAMMAD COMPANY	Nasser Abd Mohammad Mr. Shehab		17700888	17700488		BRN 72935- 72936	namcosafety@gmail.com
39	Desert Eagles Services	Abdulla Habib Almughni/ Hassan Al Mughni	Director	77063838	77063839	75236	BRN- 19501, 1386, 19021, 11078, 12098, 11456, 18568, 16228, 16229 and 16316	d.e.cargo.s@gmail.com

40	Sun Gulf Gate Commercial Trading	Mr. Nixon Lewis	Director	39147515	39455811 & 39108565		13256	BRN 48673, 48674 & 37283	Sungulfgate@gmail.com Sungulfgate@hotmail.com
41	RB Hilton	Mr. Ebrahim Zajki	Maintenance Operations Manager	17700380	39695737	17700833	26208	BRN- 81292, 32331 & 77499	Ebrahim.zaki@capeplc.me
42	Bahrain Maintenance and Diving Services WLL	Mr. Mohammed Musayeb	Director	17700731	39660173	17701473	26195	BRN- 32109, 79505, 3104, 48481 and 12427	bmds@batelco.com.bh
43	Ebrahim Hasan Mahdi Contracting Est.					17703141	29022		
44	Gulf Acid Industries	Ms. Nawal Mohammed Nass			39450917			BRN-8538	
45	Al Door Excavation & Building Contractor			17877246		17877249	32187	BRN- 85698,78988,78986,85713	aldoorexavations@gmail.com
46	Tareq Mohammed Al Areeky & Bros. Co.	Mr. Tareq			33299666 /966-505806845		1233, Al-Khobar		
47	Anbar Trading Est.	Mr. Anbar Mubarak				17764931		BRN-14183,11999,56172	
48	Middle East Recycling Co.WLL	Mr. Ashik Ali Kutay	Director	77052250	39478439	17910039	-	BRN-75881, 13022	Ashik@recycleagewll.com

49	Al Khabbaz Collection of Cooking Oil	Mr. Abdul Hussain Abdulla Naser Al Khabbaz	Director	33032283	39299322	-	Flat 21, Building 754, Road 2131 Block 421 Jidhafs	BRN 37283 & 43190	Ahussain.alkabaz@hotmail.com
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Appendix 24: Approved Oily Waste Transporters



**Supreme Council for Environmental
Directorate of Environmental Assessment & Control**

LIST OF OILY WASTE TRANSPORTERS -2014

#	Organization	Contact Name	Job Title	Work Tel.	Mobile	Fax No.	P. O. Box	Approved Vehicle Nos.	E-mail
1	AGAS Lubes WLL	KA Padmanbhan	Vice President	17822240	39607324	17822241	15360	8301,14256	agas@batelco.com.bh
2	Qatar Factory	Abdul Nabi Al Saffar/ Harbinder Singh	Managing Director	17877447	39458737 39195585	17786929	3233	30059,44273,42790	Saffar01@batelco.com.bh
3	Mayoof Sanitary Cleaning Services	Ebrahim Abdul Karim		17643664	39449009	17644626	33878	149 &13447	
4	Contractor Recycling Company	Mr. Akram	Director	17232740	39792221 39527330	17232760	2304	33782,44456,44408 & 73007	cte@emirates.net.ae
5	Osrex International	Kaythar Ramzi	General Manager	17702399	36767617	17702858	70108	60731,15479,39331,10747 & 10746	reemco2006@yahoo.com
6	Al Dewaniyah Metal Scrap	Mr. Mohammad Abdull Al Shivy	Manager	17225999	17211599	39063853	24500	75881 & 75882	
7	Senior Oil Traders	Mr. Periyasamy P.	Manager	17211099	17213181	39901848	2596	32964	oilstar@batelco.com.bh
8	Europe Scandinavian Trading WLL	Mr. Ibrahim Abdulla Shaikh	Chairman	17715775	17742979	39411127	26600	79288	euroscand@gmail.com
9	Al Amal Petrochemicals	Mr. Abdul KHakim Al Shimmiri	Director	17292565	17290818	39661998	5067	35786	hakeem@alamaltravel.com
10	Nidukki Trading Company	Nasser Mattar	Director	17731648	39645649	17456217	1382	16596, 15791, 16035, 12544,	operations@nidukki.bh Nasser@nidukki.bh
11	Al Haram Metals Co. WLL	Mr. Umair Ahmed	Supervisor	17701470	39414185	17704104	38175		syedzas@batelco.com.bh

12	Pars Palace Lubricants Co.	Mr. Khalil Shareef	Manager			17910885	1164	80846 & 73349	Pars.co@hotmail.com
13	Sun Gulf Gate Commercial Trading	Mr. Nixon Lewis	Director	39147515	39455811 & 39108565		13256	BRN 48673, 48674 & 37283	Sungulfgate@gmail.com Sungulfgate@hotmail.com
14	Middle East Recycling Co. WLL	Ashik Ali Kutay	Director	77052250	39478439 , 39947333	17910039	-	75881. 13022	Ashik@recycleagewll.com
15	Al Khabbaz Collection of Cooking Oil	Mr. Abdul Hussain Abdulla Naser Al habbazK	Director	33032283	39299322	-	Flat 21, Building 754, Road 2131 Block 421 Jidhafs	BRN 37283 & 43190	Ahussain.alkabaz@hotmail.com



Appendix 25: Equator Principles



Client: **Bechtel**

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

Appendix 25 - Equator Principles

Tebodin

Tebodin Middle East Ltd.

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Abbreviations

Alba	Aluminium Bahrain
AP	Action Plan
CO₂	Carbon Dioxide
EHS	Environment, Health and Safety
EIA	Environmental Impact Assessment
EPFI	Equator Principles Financial Institutions
ESIA	Environmental and Social Impact Assessment
ESMP	Environmental and Social Management Plan
ESMS	Environmental and Social Management System
GHG	Green House Gas
IFC	International Finance Corporation
ISO	International Organization for Standardization



1 Introduction

1.1 Equator Principles

Industrial Projects can have adverse impacts on people and on the environment. The Equator Principles Financial Institutions (EPFIs) have adopted the Equator Principles (June 2013) in order to ensure that the Projects EPFI finance and advice on are developed in a manner that is socially responsible and reflects sound environmental management practices. Negative impacts on project-affected ecosystems, communities, and the climate should be avoided where possible. If these impacts are unavoidable they should be minimised, mitigated, and/or offset.

The Equator Principles are intended to serve as a common baseline and framework. The EPFI will not provide Project Finance or Project-Related Corporate Loans to Projects where the client will not, or is unable to, comply with the Equator Principles.

1.2 Background

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.

An EIA was prepared by Tebodin in 2003 for the proposed expansion of Potline 5 and Potline 6. However, Potline 6 was never constructed nor commissioned. Alba received approval for the EIA in 2003 from the regulatory authorities.

As part of the financing process for the expansion project, the project will have to comply with the Equator Principles.



2 Applicable Equator Principles and local standards

The Equator Principles, World Bank guidelines and IFC Performance standards were compared with local laws, regulations and guidelines with regard to Social and Environmental topics.

Table 1 presents the summary of the analysis. It can be concluded that the majority of the Standards and Principles are present in both international and local standards and legislation.

The main gap that exists between Equator Principles and local requirements is that IFC and Equator Principles have detailed regulations addressing potential social impacts of a project. Detailed requirements for a social impact assessment are not present in local legislation.

When Equator Principles and IFC standards are not applicable, this is indicated in table 1 as "N.A."

Table 1: Equator Principles applicability to project

Equator Principles	Local HSE Laws, Guidelines and Procedures
Principle 1: Review and Categorization	Yes, as per Ministerial Order No. (1) of 1998
Principle 2: Environmental and Social Assessment, possible contents	Bahrain is a Non-Designated Country and does not have specific guidelines for content of ESIA report.
Principle 3: Applicable Environmental and Social Standards ¹	
- Performance Standard 1: Assessment and Management of Environmental and Social Risks and Impacts	Yes
- Performance Standard 2: Labor and Working Conditions	As per Bahrain Labour Law
- Performance Standard 3: Resource efficiency and Pollution Prevention	Yes
- Performance Standard 4: Community Health, Safety and Security	Yes
- Performance Standard 5: Land Acquisition and Involuntary Resettlement	N.A.
- Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources	Yes
- Performance Standard 7: Indigenous Peoples	N.A.
- Performance Standard 8: Cultural Heritage	Project will have no impact
Principle 4: Environmental and Social Management System and Equator Principles Action Plan	Yes
Principle 5: Stakeholder Engagement	Yes
Principle 6: Grievance Mechanism	Yes
Principle 7: Independent Review	N.A. for Alba directly
Principle 8: Covenants	Applicable
Principle 9: Independent Monitoring and Reporting	Depending on EPFI
Principle 10: Reporting and Transparency	Applicable



Note 1: Principle 3 of the Equator Principles states the following: “For projects located in non-designated countries, the Assessment process evaluates compliance with the then applicable IFC Performance Standards on Environmental and Social Sustainability (Performance Standards) and the World Bank Group Environmental, Health and Safety Guidelines (EHS Guidelines)” (Exhibit III).



3 Detailed Review Equator Principles

3.1 Equator Principle 1 - Review and Categorization

3.1.1 Introduction

The Equator Principles use a system of social and environmental categorisation, based on IFC's environmental and social screening criteria, to reflect the magnitude of impacts understood as a result of assessment. These categories are:

- Category A – Projects with potential significant adverse social or environmental impacts that are diverse, irreversible or unprecedented;
- Category B - Projects with potential limited adverse social or environmental impacts that are few in number, generally site-specific, largely reversible and readily addressed through mitigation measures; and
- Category C – Projects with minimal or no social or environmental impacts.

The ALBA line 6 expansion project will be located in Bahrain. According to the World Bank, Bahrain is identified as a High income – non-OECD country (country not a member of the Organisation for Economic Co-operation and Development). Furthermore, Bahrain is considered a 'Non-Designated Country' as Bahrain is not found on the list of Designated Countries on the Equator Principles Association website.

3.1.2 Social and Environmental Impacts

The ALBA line 6 expansion project will be situated on a developed industrial site with an area of approximately 2 km². The proposed site is property of ALBA and is considered as a brownfield development.

An ESIA had been prepared previously for the project in 2003. The ESIA identified the environmental and social impacts of the project. In addition, impacts are identified in the present (2014) ESIA.

3.1.3 Categorisation of the Project

Based upon the present 2014 ESIA, the ALBA line 6 expansion project will have potential limited adverse social or environmental impacts and is therefore considered a Category B project.

3.2 Principle 2 - Environmental and Social Assessment

The present ESIA was prepared in line with Bahraini requirements, starting with the preparation of an Environmental Scoping Report and subsequently the ESIA report. Bahrain does not have detailed guidance documents for contents of an ESIA report. Below table indicates if the topics have been addressed in the present ESIA study.

Table 2 Principle 2 requirements

Principle 2: Environmental and Social Assessment, possible contents	Local HSE Laws, Guidelines and Procedures
a) Assessment of the baseline environmental and social conditions	Yes
b) Consideration of feasible environmentally and socially preferable alternatives	Yes
c) Requirements under host country laws and regulations, applicable international treaties and agreements	Yes
d) Protection and conservation of biodiversity (including endangered species	Yes



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Principle 2: Environmental and Social Assessment, possible contents	Local HSE Laws, Guidelines and Procedures
and sensitive ecosystems in modified, natural and critical habitats) and identification of legally protected areas	
e) Sustainable management and use of renewable natural resources (including sustainable resource management through appropriate independent certification systems)	Not specifically. Included in alternatives section
f) Use and management of dangerous substances	Yes
g) Major hazards assessment and management	No major hazards envisaged
h) Efficient production, delivery and use of energy	Yes
i) Pollution prevention and waste minimization, pollution controls (liquid effluents and air emissions), and solid and chemical waste management	Yes
j) Viability of Project operations in view of reasonably foreseeable changing weather patterns/climatic conditions, together with adaptation opportunities	Included in CALPUFF air dispersion model, inclusive of meteorological data
k) Cumulative impacts of existing projects, the proposed project, and anticipated future projects	Yes; however, limited information available regarding future projects
l) Respect of human rights by acting with due diligence to prevent, mitigate and manage adverse human rights impacts	Not included in ESIA; however Bahraini labour Law No. 36 of 2012
m) Labour issues (including the four core labour standards), and occupational health and safety	Yes
n) Consultation and participation of affected parties in the design, review and implementation of the project	Bahrain does not have specific public consultation requirements. Ministry of Environment distributes ESIA report to other Government and private agencies with a vested interest in the project
o) Socio-economic impacts	Yes
p) Impacts on affected communities, and disadvantaged or vulnerable groups	Yes
q) Gender and disproportionate gender impacts	N.A.
r) Land acquisition and involuntary resettlement	N.A.
s) Impacts on indigenous peoples, and their unique cultural systems and values	N.A.
t) Protection of cultural property and heritage	Yes
u) Protection of community health, safety and security (including risks, impacts and management of project's use of security personnel)	Not included; however, project will take place in secured facility.
v) Fire prevention and life safety	No

3.3 Principle 3 - Applicable Environmental and Social Standards

For Projects located in Non-Designated Countries, such as Bahrain, the Assessment process evaluates compliance with the applicable IFC Performance Standards on Environmental and Social Sustainability (Performance Standards) and the World Bank Group Environmental, Health and Safety Guidelines (EHS Guidelines) (Exhibit III).

The guidelines are indicated in section 3.4 of the ESIA report and are considered throughout the study.

3.4 Principle 4 Environmental and Social Management System and Equator Principles Action Plan

For all Category A and Category B Projects, the EPFI will require Alba to develop or maintain an Environmental and Social Management System (ESMS).



Principle 4 requires Alba to prepare an Environmental and Social Management Plan (ESMP) to address issues raised in the Assessment process and to incorporate actions required to comply with the applicable standards.

Alba has an ISO 14001 accredited Environmental Management System. The ESIA provides mitigation measures, recommendations, management plan and monitoring plan to ensure environmental and social impacts are avoided or minimized.

3.5 Principle 5 Stakeholder Engagement

For all Category A and Category B Projects, the EPFI will require Alba to demonstrate effective Stakeholder Engagement as an ongoing process in a structured and culturally appropriate manner with Affected Communities and, where relevant, Other Stakeholders.

The ESIA report will be issued to the Bahrain Ministry of Environment, who will subsequently distribute the ESIA report to other Government and private agencies with a vested interest in the project.

ALBA will be requested to make the appropriate Assessment Documentation readily available to the Affected Communities, and where relevant to Other Stakeholders, in the local language and in a culturally appropriate manner.

A minimum requirement, as per Principle 10, is to have a summary of the ESIA report available on Alba's web site.

3.6 Principle 6 Grievance Mechanism

Providing a mechanism for individuals to register any written grievances relating to the Potline 6 Expansion project is an important part of fulfilling the social commitments to the communities within which Alba operates and ensuring effective management of the project.

The grievance mechanism will have to fulfil the following key objectives:

- Provide a clear and accessible avenue for affected people to raise an issue or a dispute during the course of the project;
- Enable people to register a written grievance/complaint without fear of intimidation, persecution or adverse consequence, including the ability to remain anonymous if the person so wishes;
- Provide a mechanism to ensure that a written grievance receive an appropriate level of management enabling appropriate and mutually acceptable corrective actions to be identified and summarily implemented, where required;
- Ensure that complainants receive clear and direct communication on the result of an investigation of their written grievance and the outcomes of any corrective actions in a designated timescale (where complainants do not retain anonymity);
- Verify whether complainants are satisfied with the receipt and resolution of their written grievance/complaint (where complainants do not retain anonymity);



- Promote the relationship and reputation of Alba in the local community; and
- Provide a useful indicator of project and contractor performance.

High numbers of written grievances may point to a need to adjust work practices or procedures in order to reduce adverse effects or conflicts with affected households and communities.

A selection of mechanisms will need to be established (e.g. web-based interface, postal address, email mailbox) that will enable grievances to be received and responded to as appropriate to the concern raised.

3.7 Principle 7 Independent Review

EPFI will determine if an independent review of the ESIA will be required. The Independent Review would be carried out by an Independent Environmental and Social Consultant in order to assist the EPFI's due diligence, and assess Equator Principles compliance.

3.8 Principle 8 Covenants

Alba will have to covenant in the financing documentation to comply with all relevant host country environmental and social laws, regulations and permits in all material respects.

Furthermore, Alba will have to covenant the financial documentation:

- a) to comply with the Environmental Social Management Plans (ESMPs) and Equator Principles Action Plan (AP) (where applicable) during the construction and operation of the Project in all material respects; and
- b) to provide periodic reports in a format agreed with the EPFI (with the frequency of these reports proportionate to the severity of impacts, or as required by law, but not less than annually), prepared by in-house staff or third party experts, that
 - I. document compliance with the ESMPs and Equator Principles AP (where applicable), and
 - II. provide representation of compliance with relevant local, state and host country environmental and social laws, regulations and permits; and
- c) to decommission the facilities, where applicable and appropriate, in accordance with an agreed decommissioning plan.

3.9 Principle 9 - Independent Monitoring and Reporting

Project Finance

To assess Project compliance with the Equator Principles and ensure ongoing monitoring and reporting after Financial Close and over the life of the loan, the EPFI will, for all Category A and, as appropriate, Category B Projects, require the appointment of an Independent Environmental and Social Consultant, or require that Alba retain qualified and experienced external experts to verify its monitoring information which would be shared with the EPFI.

Project-Related Corporate Loans



For Projects where an Independent Review is required under Principle 7, the EPFI will require the appointment of an Independent Environmental and Social Consultant after Financial Close, or require that Alba retain qualified and experienced external experts to verify its monitoring information which would be shared with the EPFI.

3.10 Principle 10 – Reporting and Transparency

The following client reporting requirements are in addition to the disclosure requirements in Principle 5:

- Alba will have to ensure that, at a minimum, a summary of the ESIA is accessible and available online.
- Alba will have to publicly report GHG emission levels (combined Scope 1 and Scope 2 Emissions) during the operational phase for Projects emitting over 100,000 tonnes of CO2 equivalent annually (in line with Annex A of the Equator Principles).