Alba Power Station 5 Block 4
Supplementary ESIA
Groundwater Risk Assessment

March 2023
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Rev. 02

Aluminium
for the world

Environment Arabia

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Approved By	Halel Engineer	
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Table of abbreviations

ACOP	Alba Code of Practice
AEWRD	Agricultural Engineering and Water Resources Directorate
Alba	Aluminium Bahrain BSC
ASTM	American Society for Testing and Materials
BGL	Below Ground Level
BH	Bore Hole
BNSD	Bahrain National Survey Datum
CCGT	Combined Cycle Gas Turbine
CESMP	Construction Environmental and Social Management Plan
Citrus	Citrus Advisors Ltd.
EACS	Environment Arabia Consultancy Services WLL
EPAP	Equator Principles Action Plan
EPC	Engineering Procurement and Construction
ESA	Environmental Site Assessment
ESIA	Environmental and Social Impact Assessment
GE	General Electric
GL	Ground Level
IWPP	Integrated Water and Power Project
kV	Kilovolt
MPW	Mitsubishi Power Ltd.
MW	Mega Watts
NSD	National Survey Datum
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
QEL	Qatar Engineering Laboratory
SCE	Supreme Council for Environment
SEPCO III	SEPCO III Bahrain Construction Company W.L.L.
SHE	Safety Health and Environment
TPH	Total Petroleum Hydrocarbons

1 INTRODUCTION

This report is a part of a suite of documents prepared as supplementary reports to the Environmental and Social Impact Assessment (ESIA) undertaken for the Alba Power Station 5 (PS5) Block 4 project.

1.1 Project description

Aluminium Bahrain B.S.C. (Alba) consistently ranks as one of the largest and most modern Aluminium smelters in the world. Known for its technological strength and innovative policies, Alba enforces strict environmental guidelines, maintains a high track record for safety, and is widely regarded as one of the top performers on a global scale.

Alba PS 5 Block 4 Combined Cycle Power Plant is an expansion of the existing Power Station 5, which was commissioned in 2019 – 2020 and consists of 3 x CCGT Blocks of 1:1:1 configuration, with H class gas turbine technology, GE A650 steam turbine, GE (Alstom legacy) heat recovery steam generator, GE Mark VIe distribute control system. PS5 power is exported to the Alba islanded grid through a recently completed (2019) Siemens 220kV indoor gas insulated switchgear Substation.

PS5 Block 4 Project is the addition of a fourth Block of similar 1:1:1 configuration with J-class gas turbine technology and with minimum nominal ISO rating of a 680.8 MW and it also includes tie into the existing 220kV Substation. A Consortium of Mitsubishi Power Ltd. (MPW) and SEPCO III Electric Power Construction Co. Ltd. (SEPCO III) will execute PS5 Block 4 as the Engineering, Procurement and Construction (EPC) Contractor.

PS5 capacity will increase from 1,800 MW to 2,481 MW. Block 4 Gas turbine unit will have the capability to operate on 100% Khuff gas, 100% Residual will also have the capability to operate on any proportionate mixture of Khuff-residual gas. Generally, concept for the new Block 4 is like the existing Blocks 1 to 3, and the services will be provided from the common facilities from the existing PS5 or other plants within the Alba complex.

Rationale behind the expansion of PS5 Block 4 is the efficiency of this combined cycle power plant is much higher than combined cycle power plants of PS 3 and PS 4. Power Station 3, which is operating on a low load, will be shut down and will be kept as emergency standby. Power station 4 will be running partially.

An ESIA report was submitted to the Supreme Council for Environment on 6th January 2022 and environmental clearance was issued. Alba forwarded the approved ESIA report to BNP Paribas – the coordinator of project finance. BNP Paribas appointed Citrus advisors Ltd. (Citrus) to conduct a review on the report for compliance with Equator Principles 4. Citrus then prepared a report that highlighted some gaps and an Equator Principles Action Plan (EPAP) to address them.

Alba commissioned Environment Arabia Consultancy Services (EACS) to address the gaps in the ESIA and EPAP.

1.2 Scope of the assessment

The objective of the assessment is to determine the nature and magnitude of risks to the groundwater resources at Block 4 construction site. The assessment will:

- Evaluate the nature, magnitude and likelihood of impacts to groundwater quality and levels, and assess potential impacts to other groundwater users;
- If potential impacts are identified, assess whether specific mitigation measures are required to mitigate these risks;
- Evaluate whether existing Alba systems, procedures and requirements are sufficient to manage these risks (including the Contractor Environment and Social Management Plan (CESMP) and management controls); and
- Evaluate whether existing EPC Contractor systems, procedures and requirements are sufficient to manage these risks.

1.3 Documents reviewed

Table 1.1 shows the list of documents reviewed during the preparation of this risk assessment.

Table 1.1 List if documents reviewed

Sl. No.	Document description
1	82902-999-8822-TC-SAT-00001-00 PS5 Block 4 Geotechnical Survey Report
2	ACOP-056-Environmental Monitoring
3	ACOP-065-Environment Emergency Response
4	ACOP-070- Chemicals and Hazardous Materials Management
5	Alba Groundwater Monitoring Plan
6	PS5 Block 4 Chemical Management and Hazard Communication Procedure PS5-B4-01-YDC-GGP-SEP-00020
7	PS5 Block 4 Excavation Procedure PS5-B4-01-YDC-GGP-SEP-00040
8	PS5 Block 4 Pollution Prevention Procedure PS5-B4-01-YDC-GGP-SEP-00018
9	PS5 Block 4 Refuelling Operations Procedure PS5-B4-01-YDC-GGP-SEP-00022
10	PS5 Block 4 Waste Management Procedure PS5-B4-01-YDC-GGP-SEP-00023
11	PS5 Block 4 Excavation Procedure PS5-B4-01-YDC-GGP-SEP-00040
12	PS5 Block 4 Spill Prevention Procedure PS5-B4-01-YDC-GGP-SEP-00021

2 LEGISLATION AND GUIDANCE

2.1 Groundwater laws and regulations

2.1.1 Amiri Decree No. 12 – 1980

This Decree is composed of 23 articles. Article 1 deals with terms and definitions. Article 2 prohibits digging new wells or modifying old ones unless obtaining an authorization from the Ministry of Trade and Agriculture. Article 3 defines zones where it shall be allowed to dig wells. Articles 4-7 define requirements and conditions for the issuance of digging licenses. Article 9 deals with the conditions for the revocation of licenses. Article 10 entrusts the Water Sources Office with the installation of the necessary equipment to calculate the jet and flux of water. Article 12 specifies the works and activities which need to be communicated to the Ministry before its realization. Article 17 entrusts the Minister of Trade and Agriculture with the establishment of the Complaining Committee Article 20 contains offences and penalties.

2.1.2 Amiri Decree No. 12 – 1997

This Legislative Decree amends Legislative Decree No. 12 of 1980 as follows: (a) addition of new terms and definitions to Article 1; (b) the words “Minister of Trade and Agriculture” shall replace the words “Minister of Works and Agriculture”; (c) prohibition of digging wells in the zones of Addamam, Arrass and Umm Arradma; (d) owners of wells and pools will have 6 months to settle their position concerning the installation of the necessary equipment for measuring the flux of water; and (e) owners of wells and pools will have 1 month for registering wells and pools.

2.1.3 Amiri Decree No. 9 – 1999

This Legislative Decree amends article 20, of Legislative Decree No. 12 of 1980 regulating the use of groundwater, on offences and penalties.

2.1.4 Groundwater permits and licenses

Presently groundwater exploration and exploitation are regulated by Agriculture Engineering and Water Resources Directorate (AEWRD) within the Ministry of Municipalities Affairs and Agriculture. The AEWRD issues licenses for:

- Drilling of water well;
- Water well permit;
- Drilling of site investigation boreholes; and
- Groundwater use.

3 IMPACT ASSESSMENT METHODOLOGY

The significance of an impact is a factor of the receptor sensitivity, as well as the magnitude of the impact. **Table 3.1** provides a definition of what constitutes high, medium and low receptor sensitivity.

Table 3.1 Determining receptor sensitivity

Sensitivity	Volume
High	• Variation in flow is close to natural characteristics • Channel morphology is unmodified and in connectivity with its floodplain • A water resource that meets the Project water quality standards. • Principal aquifers which have a high level of water storage, which may support water supply and/or river base flow on a strategic scale. Typically layers of rock or drift deposits that have high intergranular and/or fracture permeability. • A water resource capable of supporting critical habitat under IFC PS6 or high value uses e.g. fisheries, potable water supply • An area lacking water resources. There is significant competition for the existing water supply, and declining or limited recharge within the catchment.
Medium	• A modified but naturalised river, which has been modified in certain aspects only • Some modification of channel morphology • Secondary aquifers including permeable layers capable of supporting water supplies at a local scale, which may form an important source of base flow to rivers, lower permeability layers which may store and yield limited amounts of groundwater due to localised features e.g. fissures. • A water resource that meets some but not all of the Project water quality standards. • A water resource capable of supporting natural habitat under IFC PS6 or medium value uses e.g. irrigation, livestock
Low	• A heavily modified waterbody (channelized, dredged, straightened) • A water resource that does not support critical or natural habitat under IFC PS6 • A water resource that does not meet the Project water quality standards. • Rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow

The magnitude criteria used to determine the magnitude of impact in the assessment are shown in **Table 3.2**.

Table 3.2 Magnitude Criteria

Magnitude	Volume
Large	• Project discharges (planned or unplanned) exceed effluent quality standards or cause breaches of quality standards in the receiving waterbody, which has limited dilution capacity • An event where the potential for natural recovery of water quality, quantity

Magnitude	Volume
	and/or physical disturbance through natural processes is limited and the impact is predicted to be long-term (>1 year) • There is a complete loss of integrity of a groundwater body. • Major changes to geomorphology e.g. channel straightening or channelization which affect all or majority of the watercourse.
Medium	• Project discharges (planned or unplanned) exceed effluent quality standards or cause breaches of quality standards in the receiving waterbody but are rapidly diluted • An event where the water quality, quantity and condition of the receiving waterbody is likely to recover through natural processes and the impact is predicted to be medium-term (6 to 12 months) • There is a loss in integrity of a groundwater body or a loss of part of the groundwater body. • Change to the geomorphology which will not affect the entire water course, but have upstream and downstream impacts resulting in local degradation e.g. permanent works to banks such as piers, localised channel straightening or culverting
Small	• Project discharges (planned or unplanned) do not exceed effluent quality standards or cause breaches of quality standards in the receiving waterbody • An event where the water quality, quantity and condition of the receiving waterbody is predicted to recover rapidly through natural processes and the duration of impact is short-term (<6 months) • Change to the geomorphology which will have upstream and downstream impacts resulting in temporary local degradation e.g. in channel construction activities.
Very Small	• No changes distinguishable from natural variability. • Impacts to water quality that are below applicable limits.

3.1.1 Significance Matrix

The impact magnitude and receptor sensitivity results were combined to determine significance of the effect. This was done using the significance matrix below, whereby effect significance is determined by finding the cell where the impact magnitude and receptor sensitivity results intersects.

Table 3.3 Significance of Impact

Impact Magnitude	Receptor Sensitivity		
	Low	Medium	High
Beneficial	Positive	Positive	Positive
Very Small	Negligible	Negligible	Minor
Small	Negligible	Minor	Moderate
Medium	Minor	Moderate	Major
Large	Moderate	Major	Major

4 GROUNDWATER BASELINE CONDITIONS

4.1 Site location and description

The site location is shown in **Figure 4.1**. The Block 4 site is located within Alba Smelter Complex south of existing Power Station 5. Area allocated for the Block 4 is approximately 20,000 m^2. Site land use comprises of industrial buildings, roadways, pavements and open lands.

The smelter is located on top of a limestone escarpment that slopes west to east toward the sea approximately 3.5 km east of the site. The elevation of the site is around 20-25 m in the west reducing in a gradual slope to around 3 m in the east.

CLIENT: alba Aluminium for the world

LEGEND: PS5 Block 4 area

NORTH ARROW: N

CONSULTANT: Environment Arabia

FIGURE TITLE: Figure 4.1 Site location

DATE: February 2023

DATUM: WGS 1984 UTM Zone 39N

PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment

PREPARED BY: MS

SCALE (A4): 1:33,110

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4.2 General Setting

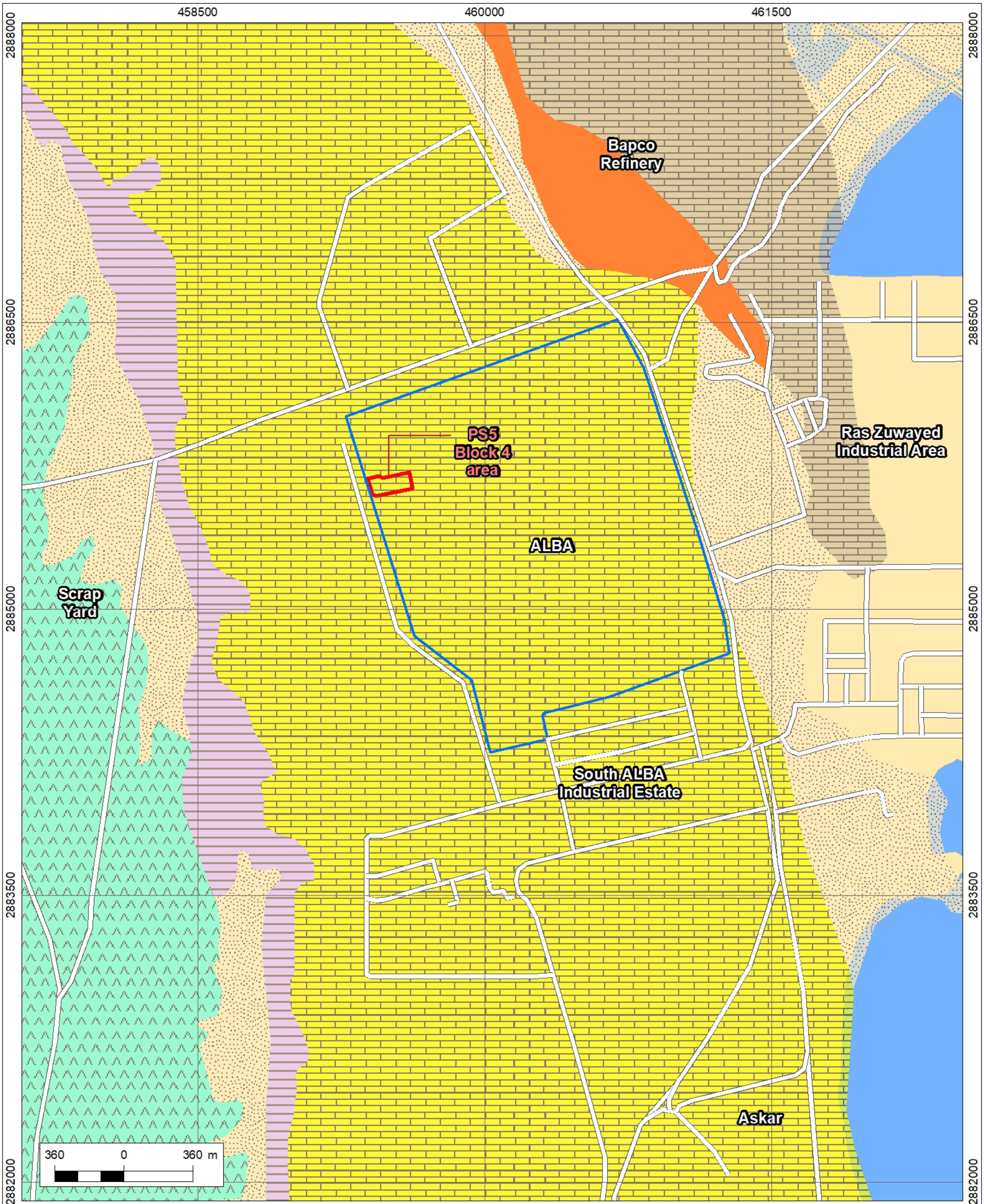
4.2.1 General geology of Bahrain

Figure 4.2 shows an extract of a geological map of Bahrain[1] and **Table 4.1** shows a generalised geological profile of Bahrain from the same reference.

Table 4.1 General geological sequence of Bahrain

Era	Period	Formation	Member	Approximate thickness (m)	Lithology	Hydrogeological significance
Quaternary	Recent	Superficial		-	Aeolianite, bioclastic limestone, beach rock	Unsaturated.
	Pleistocene	Superficial		10	Sand, sabkha deposits	Unsaturated.
Tertiary	Oligocene-Miocene	Jabal cap		33	Dolomitic bioclastic limestone, algal coral breccia	Forms cap to Jabal ad Dukhan.
	Eocene	Neogene		10-60	Marl with subordinate sandy limestone	Confines Dammam aquifers. Basal limestone forms part of the 'A' aquifer.
		Dammam	Alat Limestone	15-25	Fossiliferous dolomitised limestone	Main 'A' aquifer. Formerly sustained small artesian flows. Low productivity. Used in NE and W coast.
			Orange Marl	19-15	Orange-brown dolomitic marl	Confines Aquifer B when present.
			Khobar Dolomite	30-39	Dolomitic limestone	Main 'B' aquifer usually confined. Highly permeable in top 5-10m. Main source of freshwater.
			Khobar Marl	Discontinuous	Marl and shale	Forms part of the 'B' aquitard.
			Alveolina Limestone	c. 10	Friable brown dolarenite	
			Sharks Tooth Shale	8-20	Shale with silty dolomitic limestone	Aquitard.
		Rus		60-150	Chalky dolomitic limestone, shale, gypsum and anhydrite	Part of 'C' aquifer. Aquitard if evaporites present. Brackish groundwater in a lens form.
	Paleocene	Umm Er Radhuma (UER)		115-350	Dolomitic limestone and calcarenite, often argillaceous and bituminous	'C' aquifer in upper UER and Rus. Salinity stratified. Lower UER saline with low permeability.
Mesozoic	Cretaceous	Aruma		c. 400	Mainly shale in the upper part, limestone predominant below	Aruma shales form hydraulic base to Umm Er Radhuma.
Note: Green (Aquifer A); Orange (Aquifer B); Blue (Aquifer C); Grey (confining aquitards). Table based on GDC, 1980						

[1] Groundwater Development Consultants (GDC). 1980. Umm Er Radhuma Study, Bahrain Assignment. Ministry of Works and Agriculture.



CLIENT:

Aluminium for the world

LEGEND:

Alat (orange) Marl
Khobar Limestone
Rus Formation
Alat Limestone
Recent Deposits
Sharks Tooth Shale Group

NORTH ARROW:

CONSULTANT:

Environment Arabia

FIGURE TITLE:

Figure 4.2 Site geology
(GDC, 1980)

DATE: February 2023

DATUM: WGS 1984 UTM Zone 39N

PROJECT TITLE:

ALBA PS5 Block 4 - groundwater risk assessment

PREPARED BY: MS

SCALE (A4): 1:25,620

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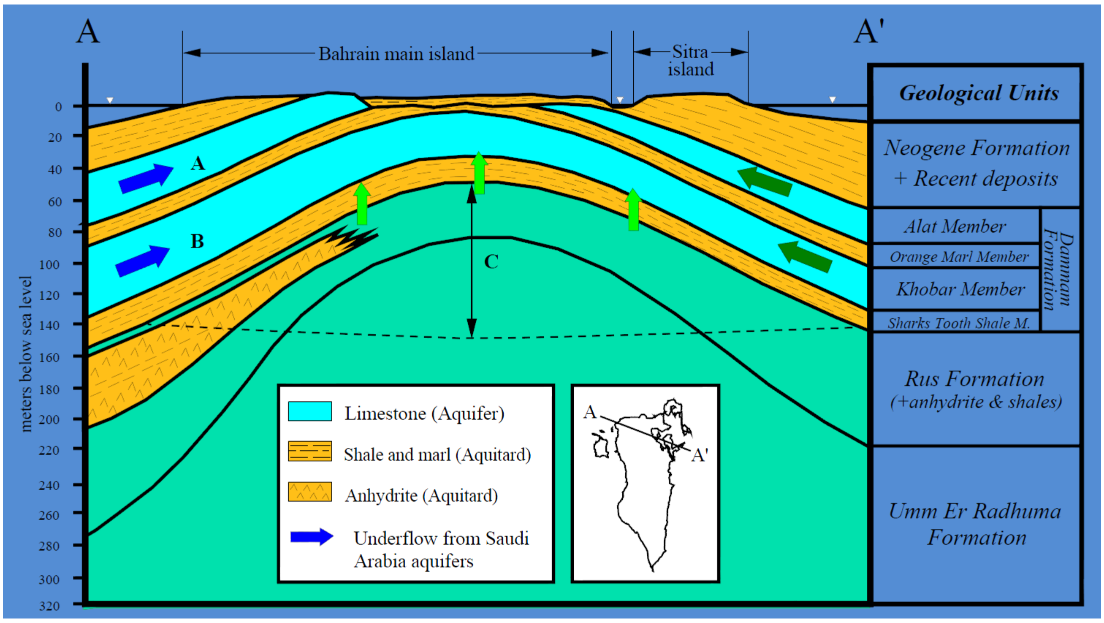
4.2.2 Hydrogeology

The geological units identified in **Table 3.1** contain three distinct aquifers – A, B and C which approximately correspond to the Alat and Khobar member of the Dammam Formation and the Ras-Umm Er Radhuma carbonate respectively. The A, B and C units are at least partly separated and discontinuous due to the presence of low permeability strata (aquitards). Aquifers A and B are considered fresh water and Aquifer C is considered a saline aquifer and requires treatment prior to use as potable water. Aquifers A and B are regional and are recharged by lateral underflow from eastern Saudi Arabia, see **Figure 4.3**.

Figure 4.3 Diagrammatic cross section of Bahrain showing aquifer system



Notes: light green arrow – saline up flow from aquifer C, dark green arrow – potential saline inflow from seawater intrusion.

4.2.2.1 The Dammam Aquifer

The Dammam aquifer is developed in the limestone/dolomite rocks of the Dammam Formation. It consists of two aquifer units termed the Alat Limestone and Khobar limestone/dolomite aquifers. Groundwater salinity in the Dammam aquifers increases in the direction of the regional groundwater flow.

The Alat Limestone is a secondary shallow aquifer (Aquifer A) encountered at depths of between 5-50 m below surface, with an average transmissivity of approximately 350 m^2/day and a permeability averaging at 14 m/day. The total Alat thickness does not normally exceed 40 m. A groundwater contour plot from 2011 for the Alat Limestone (Aquifer A) is shown in **Figure 4.4.**

Below the Alat limestone is the Orange Marl aquitard which ranges in thickness from 9 to 15m, but thickness abnormality is not uncommon (Al-Noaimi, 2004). The Orange Marl is composed of orange to pale yellow, slightly dolomitised, and commonly iron-stained marl, with frequent occurrence of marly limestone.

Below the Orange Marl is the Khobar (Aquifer B) which is a predominantly limestone and dolomitic limestone. In most cases where the Khobar is extensively developed, it is found under artesian conditions, but it is unconfined in the north central, south central and south-eastern parts of the main island of Bahrain (Al-Noaimi, 2004). The Khobar Aquifer ranges in thickness from less than 6 m in the south-eastern coast to over 40 m about the north-eastern and south-western coasts near Al-Jazair (Al-Noaimi, 2004). The Khobar is the major source of groundwater, providing the country with more than 75% of its groundwater supply. It has an average transmissivity of approximately 6,000 m^2/day and a mean permeability value of 314 m/day.

Beneath the Khobar is the Shark Tooth Shale aquitard separating the Dammam formation from the Rus-UER aquifer. It is predominantly a grey-green and blue-grey, sub-fissile, often non-calcareous and pyritic claystone-shale series, with sporadic buff and grey, slightly shaly calcian dolomite, with frequent dark brown lignitic shale (Al-Noaimi, 2004). The depths to the Shark Tooth Shale vary from about 5m near the south-eastern edge of the rim rock to about 135 m in the north-eastern areas, more specifically around Muharraq Island (Al-Noaimi, 2004). The thickness of the Shark Tooth Shale aquitard around Bahrain is normally between 8–20 m.

A groundwater contour plot from 2011 for the Khobar Limestone (Aquifer B) is shown in **Figure 4.5**.

Over the years water extraction increased from these aquifers and in 1995/96 a comparison between the abstraction rate of 218 million m^3/yr and the approximate recharge rate by underflow indicates that the aquifer was being over-extracted by a rate of about 105 million m^3/yr. This over extraction led to an influx of sea water into the north-east and brackish water from the underlying aquifer C in the north west where the salinity increased from the 2,300 ppm level to 11,000 ppm.

This salinity increase was considered to be detrimental to the long-term life of the A and B aquifers and efforts were made to halt the process, such that in 2008 the salinity in the north-west was reduced to 5,000 ppm.

4.2.2.2 The Rus – Umm Er Radhuma Aquifer

The Rus-UER aquifer (Aguifer C) is less important and is developed in the chalky limestone/dolomitic limestone of the Rus Formation, and the dolomitic limestone/calcarenite rocks of the Upper UER Formation. The aquifer is usually reported to be contained with very little natural recharge, i.e. an almost static volume. Annual rain fall in Bahrain is limited and very variable and is insufficient to recharge the aquifer (Zubari 2005, Alshabaani 2008, Atkins 2010).

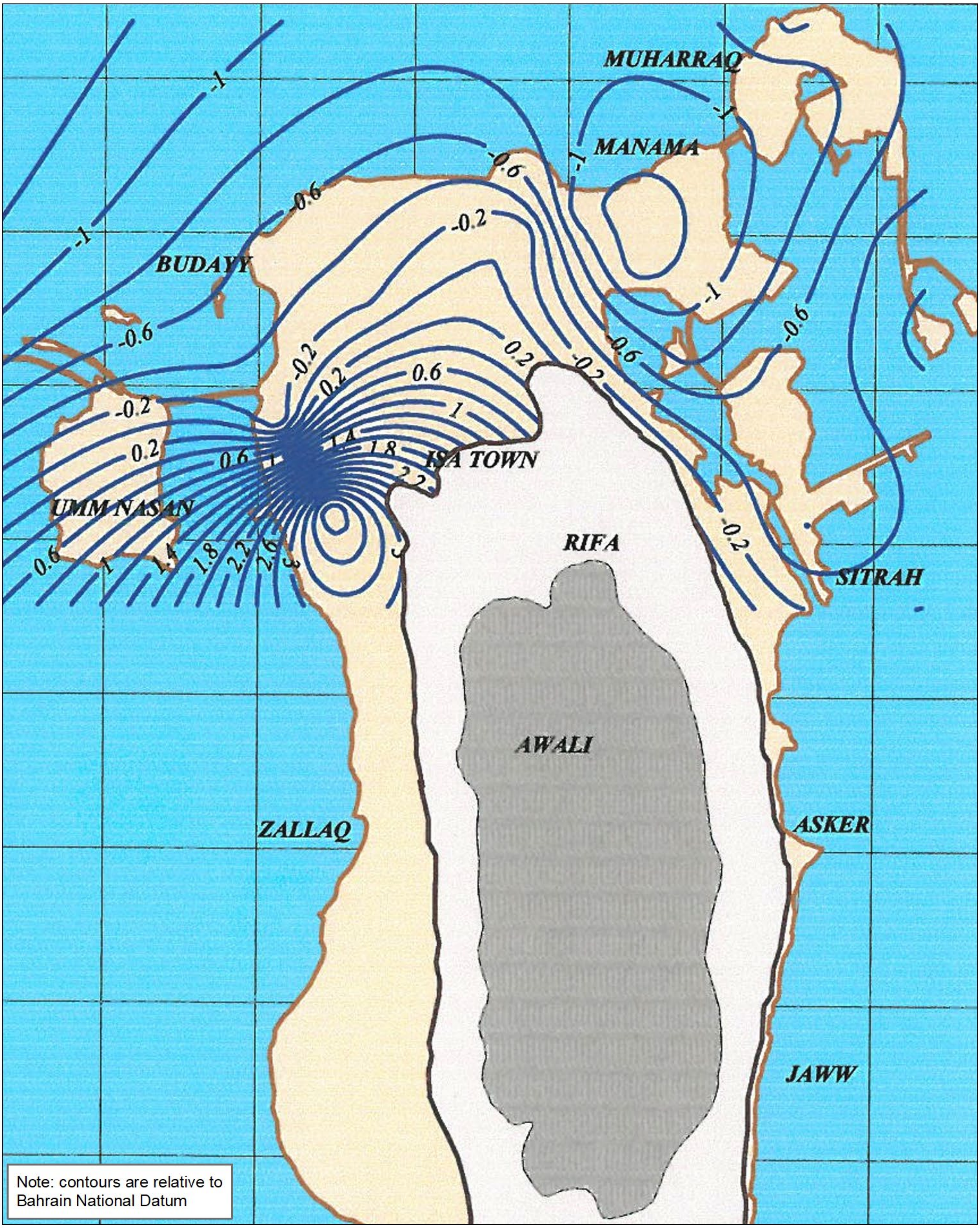
Aquifer C is developed in the Rus Formation and the upper parts of the Umm Er Radhuma (UER) Formation (Paleocene to early Eocene). The Rus Formation is composed of fractured chalky dolomitic limestone, with subsidiary shale and anhydrite intercalations in its upper section. The Rus Formation in the central and eastern parts of Bahrain has undergone extensive solution of its anhydrite which has led to the collapse of the overlying rocks, and more importantly, has reduced the effectiveness of its upper confining layer, which causes a relatively easier migration of its water into aquifer B in those areas. The original groundwater in the aquifer occurs in the form of a brackish water lens (total dissolved solids or TDS of 8,000-15,000 mg/L) in Bahrain main island, with total reserves of about 10,000 million m3 (Zubari 2005). The salinity of groundwater in the aquifer gradually increases with depth. In central Bahrain island, salinity increases from about 8,000 mg/L at the water table, at about 5 m elevation above mean sea level, to about 15,000 mg/L at a depth of about 150 m below mean sea level. A cross section illustrates the salinity levels across the structure with data control wells. The brackish water lens is underlain by brine with a salinity of more than 40,000 mg/L. Due to its high salinity, use of groundwater from the 'C' aquifer is restricted to industrial purposes in the north-central region and to supplying desalination plants on the eastern coast of Bahrain main island (Zubari. W. K. 2005).

In addition, the baseline study by Walsh 2009 stated that gross alpha radiation is recorded as 74 Becquerels per kg (Bq/kg), and gross beta radiation is 15Bq/kg. World Health Organization guidance screening levels for drinking-water of 0.5 Bq/kg for gross alpha activity and 1 Bq/kg for gross beta activity are both significantly exceeded. It is probable that the radiation derives from zones of high uranium content. A number of such zones are present and recorded as high gamma ray zones on electric logging.

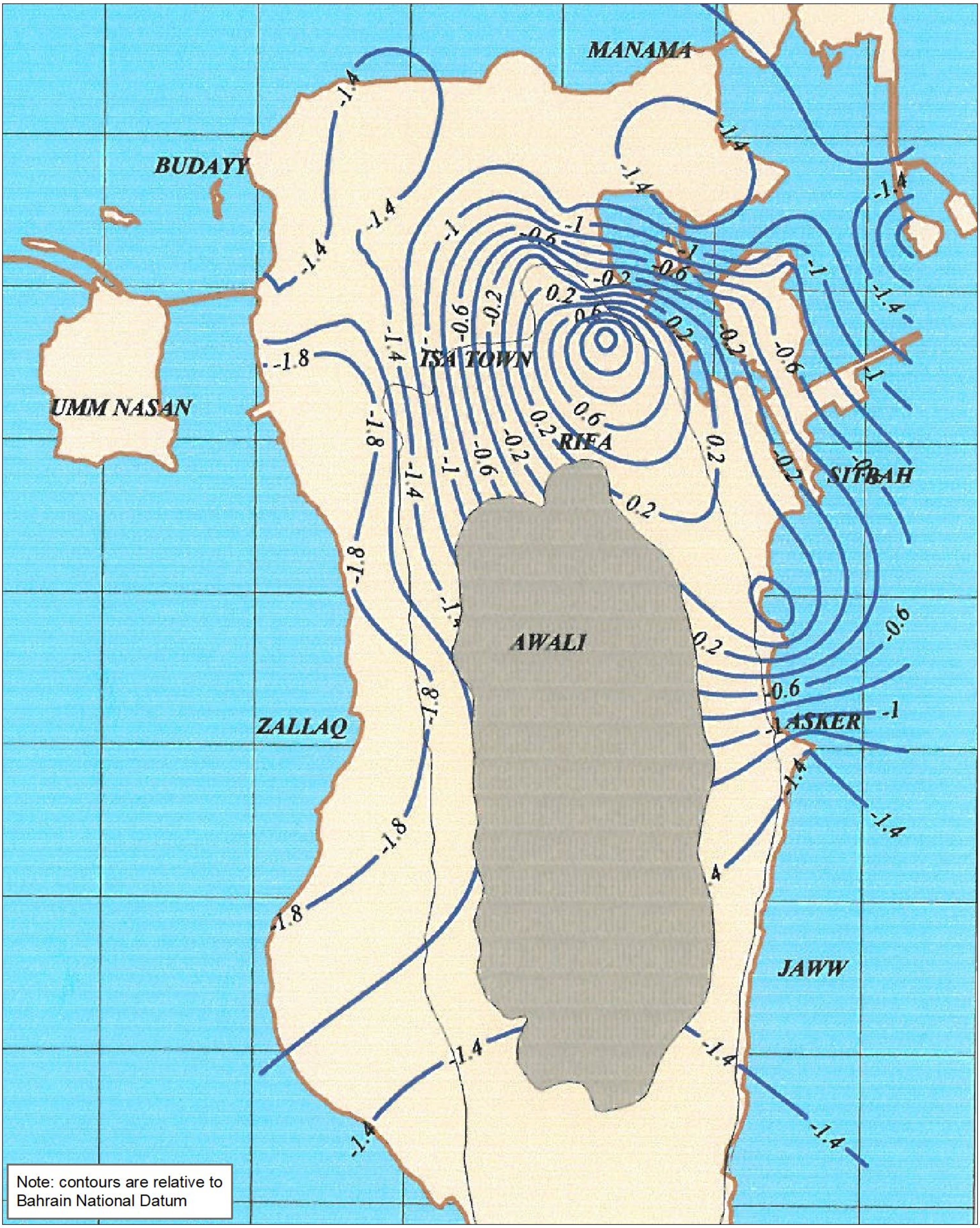
In 1965 produced water from oil field production began to be injected into aquifer C and is currently believed to be the main recharge mechanism (Atkins 2010). From 1975 onwards, with a significant increase in 1985 when the Abu Jarjur reverse osmosis plant was completed, water has been extracted from aquifer C for agricultural and industrial purposes.

It should be noted that water from aquifer C does not support natural habitats as it is not present at ground surface.

A groundwater contour plot from 2011 for the Rus-UER (Aquifer C) is shown in **Figure 4.6**.



CLIENT: Aluminium for the world	LEGEND: Groundwater Contour		NORTH ARROW:
CONSULTANT: Environment Arabia	FIGURE TITLE: Figure 4.4 Alat Limestone Groundwater Contour Plot	DATE: February 2023	DATUM: WGS 1984 UTM Zone 39N
	PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment	PREPARED BY: MS	SCALE (A4): NOT TO SCALE



CLIENT: alba Aluminium for the world

LEGEND: Groundwater Contour

NORTH ARROW: N

CONSULTANT: Environment Arabia

FIGURE TITLE: Figure 4.5 Khobar Formation Groundwater Contour Plot

DATE: February 2023

DATUM: WGS 1984 UTM Zone 39N

PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment

PREPARED BY: MS

SCALE (A4): NOT TO SCALE

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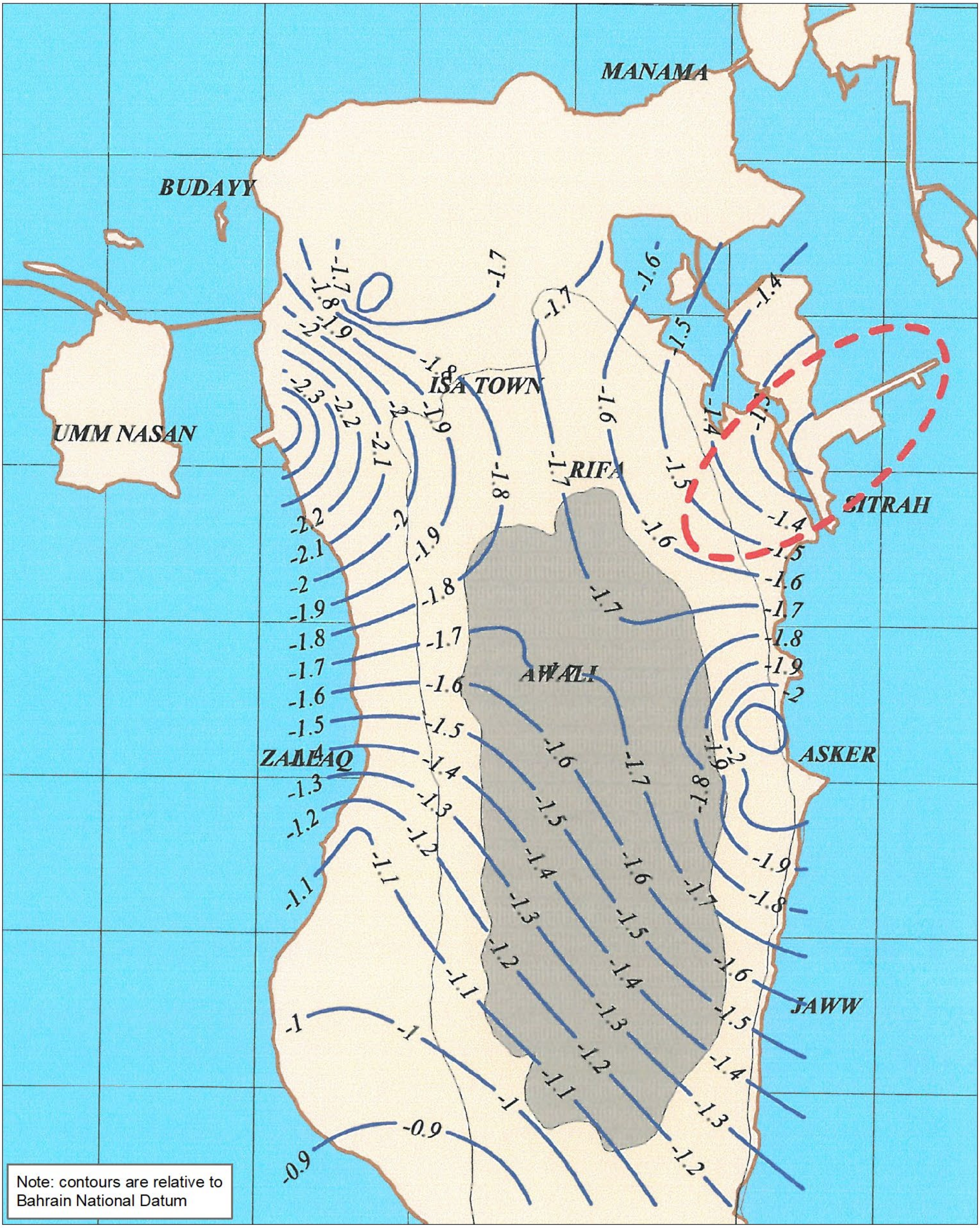

CLIENT: Aluminium for the world	LEGEND: Groundwater Contour		NORTH ARROW:
CONSULTANT: Environment Arabia	FIGURE TITLE: Figure 4.6 Rus UER Formation Groundwater Contour Plot	DATE: February 2023	DATUM: WGS 1984 UTM Zone 39N
	PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment	PREPARED BY: MS	SCALE (A4): NOT TO SCALE

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4.3 Block 4 – baseline conditions

In order to understand the geological conditions, soil structure and groundwater levels in the Project area, Alba has conducted a geotechnical investigation at Block 4 site. Qatar Engineering Laboratories (QEL) was commissioned by SEPCO III to perform the Geotechnical Site Investigation for the project.

4.3.1 Field Work

The field work commenced on 3rd March 2022 and was completed on 31st March 2022.

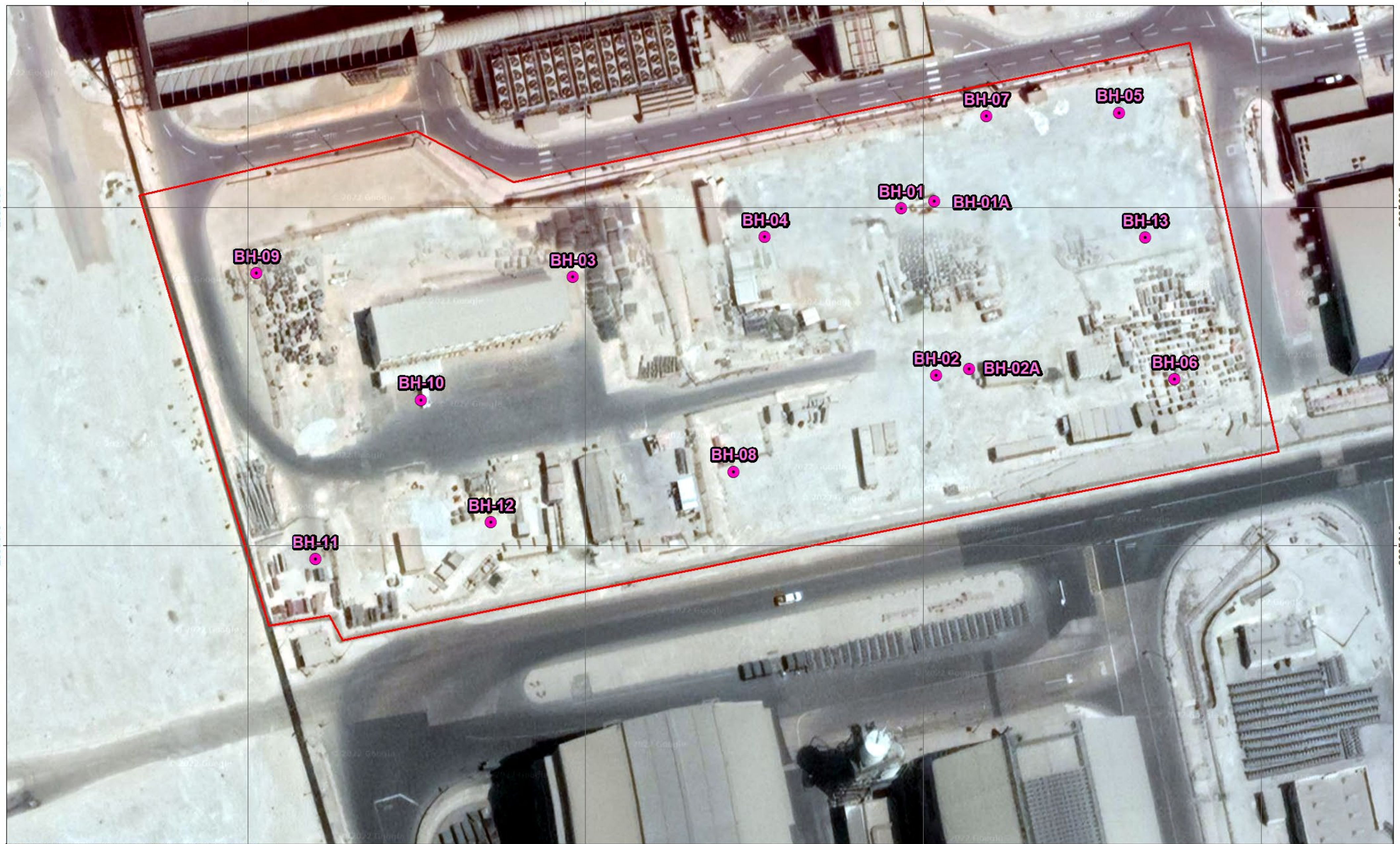
4.3.1.1 Boreholes

Boreholes were drilled by rotary core drilling methods. One (1) TOHO–d2k92-p2 and one (1) TOHODH-2D percussion-boring rigs with rotary attachments were employed for this work. Water was added to assist boring and as a flushing medium for rotary coring. The borehole locations are shown in **Figure 4.5**. The UTM coordinates, levels with respect to BNSD and dates of drilling works is provided in **Table 4.2** below.

Table 4.2 Borehole details

Borehole code	Easting	Northing	Borehole elevation BNSD*	Planned depth (m)	Final depth (m)
BH-01	459545.50	2885679.68	23.61	30.00	30.00
BH-01A	459552.34	2885681.13	23.54	30.00	30.00
BH-02	459552.75	2885645.02	23.58	30.00	30.15
BH-02A	459559.62	2885646.44	23.67	30.00	30.00
BH-03	459477.45	2885665.43	27.01	30.00	20.00
BH-04	459517.23	2885673.77	23.61	30.00	20.05
BH-05	459590.67	2885699.53	23.74	30.00	20.20
BH-06	459602.20	2885644.25	23.71	30.00	20.10
BH-07	459563.17	2885698.76	23.64	30.00	20.00
BH-08	459510.77	2885625.12	23.51	30.00	20.00
BH-09	459411.84	2885666.25	26.91	30.00	20.00
BH-10	459445.98	2885639.99	26.99	30.00	20.00
BH-11	459424.05	2885606.99	27.14	30.00	20.10
BH-12	459460.46	2885614.60	27.02	30.00	20.30
BH-13	459596.09	2885673.68	23.64	30.00	20.00

*BNSD – Bahrain National Survey Datum



CLIENT: Aluminium for the world	LEGEND: Boreholes; PS5 Block 4 boundary	SCALE BAR: 0 — 0.04 km		NORTH ARROW: N
CONSULTANT: Environment Arabia	FIGURE TITLE: Figure 4.7 Borehole locations	DATE: February 2023	DATUM: WGS 1984 UTM Zone 39N	REFERENCE: (from the client)
	PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment	SCALE (A4): 1:1,037	PREPARED BY: MS	

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4.3.2 Strata conditions

4.3.2.1 Borehole profile

The surface and subsurface ground materials in the study area can be divided into the following types as summarised in **Table 4.3** below. Borehole profile is presented in **Figure 4.8**.

- Gravels of Limestone or Residual Soil; and
- Limestone/Chalky limestone/Limestone Conglomerate rock (at places interbedded with Calcisiltite (carbonate siltstone) and Calcilutite (carbonate mudstone)).

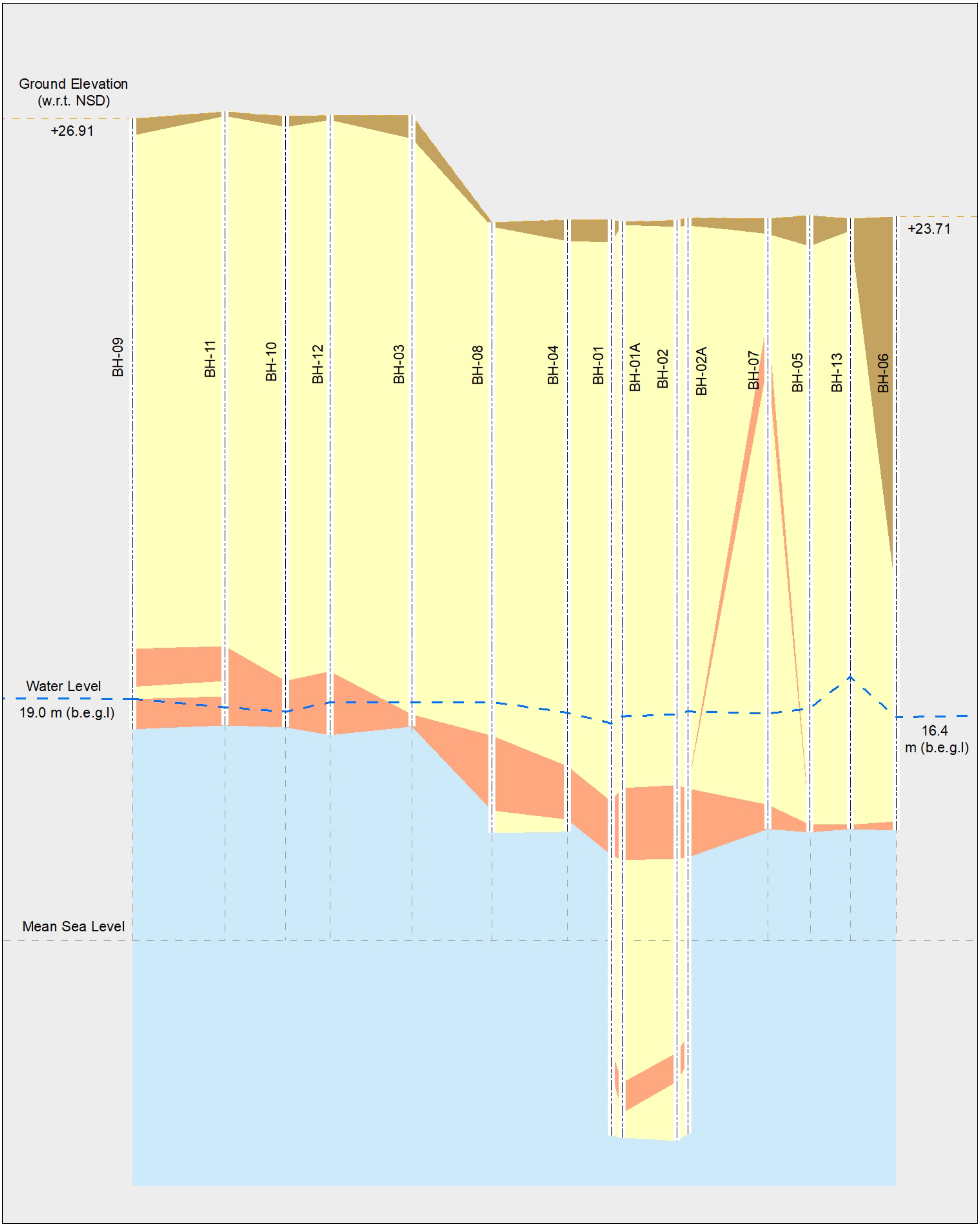
Table 4.3 Soil and rock formation with approximate boundaries

Borehole no.	Gravels of limestone (m)	Limestone / chalky limestone/limestone conglomerate (m)	Calcisiltite / calcilutite (m)
BH-01	GL-0.75	0.75-19.05	19.05-20.80
		20.80-27.15	27.15-27.85
		27.85-30.00	
BH-01A	GL-0.10	0.10-18.55	18.55-28.20
		28.20-27.20	27.20-27.67
		27.67-30.00	
BH-02	GL-0.20	0.20-18.50	18.50-20.90
		20.90-27.25	27.25-28.20
		28.20-30.15	
BH-02A	GL-0.25	0.25-18.70	18.70-20.95
		20.95-26.80	26.80-27.65
		27.65-30.00	
BH-03	GL-0.75	0.75-19.60	19.60-20.00
BH-04	GL-0.70	0.70-17.90	17.90-19.65
		19.65-20.05	
BH-05	GL-1.00	1.00-19.95	19.95-20.20
BH-06	GL-12.50	12.50-19.80	19.80-20.10
BH-07	GL-0.50	0.50-3.20	3.20-4.75
		4.75-19.20	19.20-20.00
BH-08	GL-0.15	0.15-16.80	16.80-19.25
		19.25-20.00	
BH-09	GL-0.55	0.55-17.35	17.35-18.60
		18.60-19.00	19.00-19.50
		19.50-20.00	
*BH-10	0.05-0.35	0.35-18.50	18.50-20.00
BH-11	GL-0.15	0.15-17.50	17.50-18.65
		18.65-19.15	19.15-20.10
BH-12	GL-0.15	0.15-18.20	18.20-20.30
BH-13	GL-0.40	0.40-19.85	19.85-20.00

**In BH-10, asphalt layer was evident between GL-0.05m*

***Cavity detected in:*

1. *BH-06 between 0.40m-0.60m BEGL.*
2. *2. BH-2A between 2.05m-2.50m BEGL.*



CLIENT:

Aluminium for the world

LEGEND:

Boreholes
Ground Elevation
Calcisiltite
Limestones
Water level
Limestone Gravels

NORTH ARROW: NOT APPLICABLE

CONSULTANT:

Environment Arabia

FIGURE TITLE: Figure 4.8 Borehole profile

DATE: February 2023

DATUM: WGS 1984 UTM Zone 39N

PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment

PREPARED BY: MS

SCALE (A4): NOT TO SCALE

Environment Arabia

4.3.2.2 Groundwater level

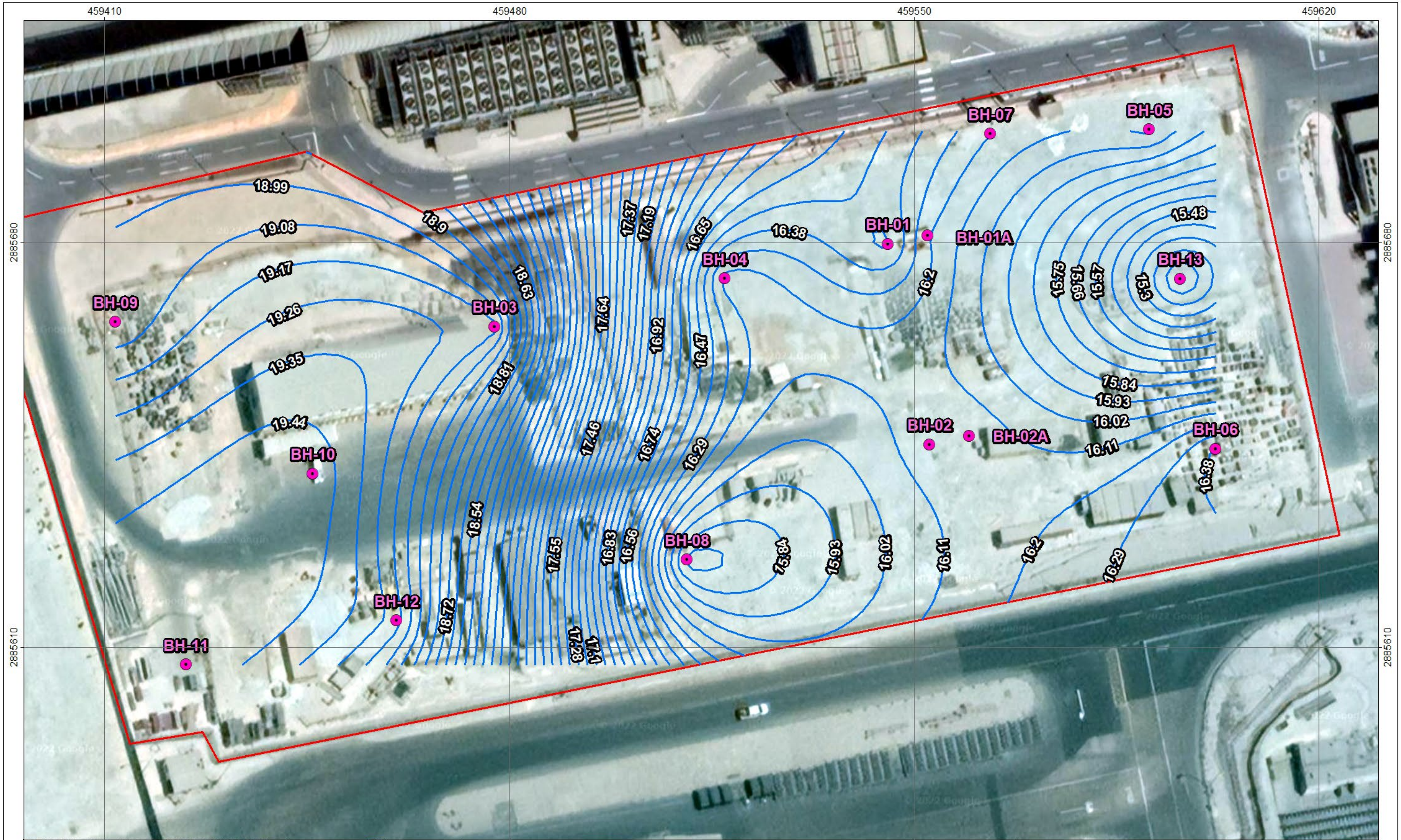
Groundwater was encountered during the geotechnical investigation. Water levels within the boreholes were measured manually using electronic dip meter with buzzer during the investigation period and is tabulated in **Table 4.4** below. These measured values reflect the prevailing groundwater levels at the time of investigation and could fluctuate at times by up to several hundred millimetres due to a combination of climatic, tidal and seasonal effects. Any dewatering activities in the adjacent area also will affect these levels.

Groundwater contours within the site are visualized in **Figure 4.9** and **Figure 4.10**.

Table 4.4 Groundwater level

Borehole no.	Borehole elevation with respect to NSD*	Standing water level depth in (m) below existing ground level	Standing water level elevation in (m) with respect to NSD
BH-01	+23.61	16.50	+7.11
BH-01A	+23.54	16.20	+7.34
BH-02	+23.58	16.30	+7.28
BH-02A	+23.67	16.17	+7.50
BH-03	+27.01	19.21	+7.80
BH-04	+23.61	16.15	+7.46
BH-05	+23.74	16.14	+7.60
BH-06	+23.71	16.40	+7.31
BH-07	+23.64	16.20	+7.44
BH-08	+23.51	15.70	+7.81
BH-09	+26.91	19.00	+7.91
BH-10	+26.99	19.50	+7.49
BH-11	+27.14	19.50	+7.64
BH-12	+27.02	19.22	+7.80
BH-13	+23.64	15.00	+8.64

*NSD – National Survey Datum



CLIENT: alba Aluminium for the world

LEGEND: Boreholes — Contours (0.09 m interval) — PS5 Block 4 boundary

SCALE BAR: 0 — 0.035 km

NORTH ARROW: N

CONSULTANT: Environment Arabia

FIGURE TITLE: Figure 4.9 Groundwater contour within the PS5 Block 4 area

DATE: February 2023

DATUM: WGS 1984 UTM Zone 39N

REFERENCE: -

PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment

SCALE (A4): 1:845

PREPARED BY: MS

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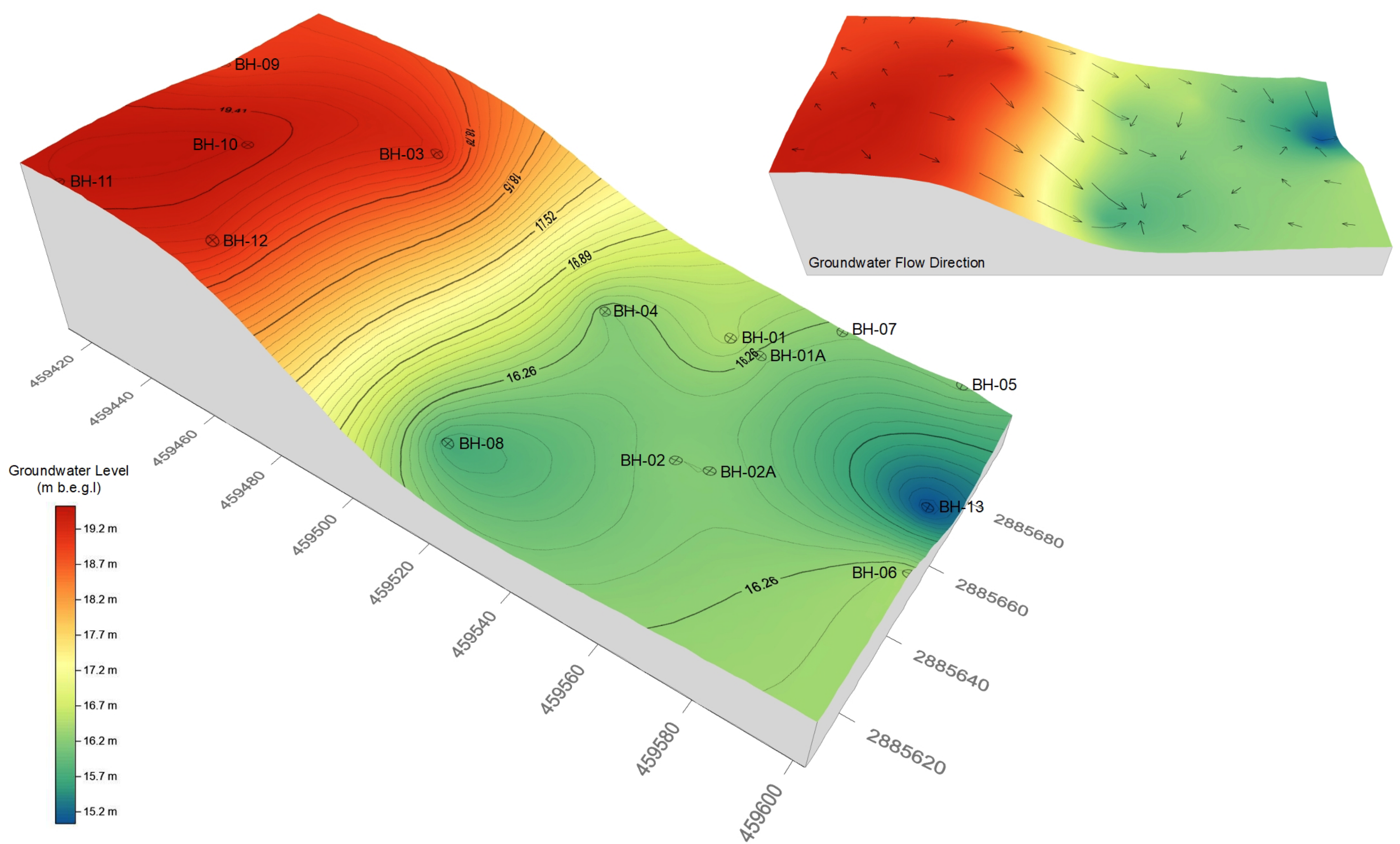

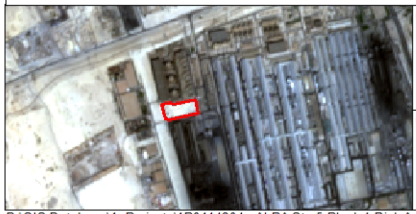

CLIENT: Aluminium for the world	LEGEND: — Contour (m) → Flow direction	SCALE BAR: NOT TO SCALE		NORTH ARROW:
CONSULTANT: Environment Arabia	FIGURE TITLE: Figure 4.10 3D groundwater contour within the PS5 Block 4 area	DATE: February 2023	DATUM: WGS 1984 UTM Zone 39N	REFERENCE: -
	PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment	SCALE (A4): 1:9,944	PREPARED BY: MS	

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4.3.2.3 Laboratory analysis results – groundwater samples

Groundwater samples collected from the boreholes were sent for analysis. Laboratory analysis results are presented in **Table 4.5**.

Table 4.5 Groundwater analysis results

BH No.	pH@25°C	TDS (mg/l)	Sulphate as SO4 (mg/L)	Chloride as Cl (mg/l)
BH-02	7.08	4,220	390	2,570
BH-02A	7.31	4,210	390	2,550
BH-04	7.39	3,620	340	2,170
BH-05	8.04	3,130	260	1,860
BH-07	8.01	3,390	320	2,040
BH-10	7.82	3,900	360	2,340
BH-11	7.74	4,470	420	2,710
BH-12	7.88	3,150	290	1,920
BH-13	7.96	3,410	320	2,060

4.3.2.4 Receptor Sensitivity

A receptor sensitivity analysis was conducted following the criteria set out in **Table 3.1** from **Section 3** above and is presented in **Table 4.6**.

Table 4.6 Receptor sensitivity analysis

Receptor	Receptor sensitivity	Justification
Groundwater quality	**Low**	No groundwater abstraction/use will be required during the construction or operational phases of the project. The Khobar limestone formation (Aquifer B) is separated from Alat limestone (Aquifer A) by an Orange Marl aquitard which ranges in thickness from 9 to 15m, but thickness abnormality is not uncommon. The Orange Marl is impermeable and composed of orange to pale yellow, slightly dolomitised, and commonly iron-stained marl, with frequent occurrence of marly limestone which will act as a geological barrier. The project site is close to other industries which could present potential source of contamination to groundwater resources.

5 GROUNDWATER RISK ASSESSMENT

The geological map (**Figure 4.2**) indicates that the Khobar limestone (Aquifer B) outcrops over the entirety of Alba Smelter Complex. Along the coastal fringe to the east of Alba, the Khobar limestone is overlain with recent deposits (presumably marine) as well as made ground due to land reclamation. To the west of Alba, the land drops down the escarpment to a plain that occupies the centre of Bahrain (Awali oil and gas field). In this area the Khobar is not present at considerable depth (40m, BGL in the centre of the oil and gas field).

To the north west of the site, at Bapco Refinery, the Alat Limestone outcrops. This is underlain by Orange Marl which is an aquiclude. The Khobar limestone is beneath this.

With respect to the study site, groundwater levels for 2011 in the Khobar Limestone (Aquifer B) is shown in **Figure 4.5**.

5.1 Risks to existing water abstraction in Bahrain

Water is abstracted by a wide range of private and public bodies across the whole of Bahrain. The Agricultural Engineering and Water Resources Directorate (AEWRD) divides the country up into 33 regions for the purpose of administration. **Figure 5.1** presents the groundwater abstraction areas in Bahrain. From **Figure 5.1**, it is evident that, there are no known groundwater abstractions from the Khobar Aquifer (Aquifer B) for private or public use within the vicinity of Block 4 site.

The groundwater users within a 2 km radius of Block 4 site are Bapco Refinery and Ras Abu Jarjur Desalination Plant which both abstract groundwater from the Rus / Umm Er Radhuma formations (Aquifer C). The refinery uses approximately 5,450 m^3/day which for their firewater system and cooling towers from approximately 150 m BGL. The Ras Abu Jarjur desalination plant, located south-east of the Block 4 site produces 7,273 m^3/day of desalinated water for public supply.

The PS5 Block 4 Project Management team confirmed that the boreholes were drilled for assessing the geological conditions and it is not intended to abstract groundwater during the construction and operational phases of the Project. The water requirement for Block 4 construction and operation will be met by the existing Demin Water network. Therefore, there will be **no impacts** to the Aquifer B groundwater users during construction of relation to PS5 Block 4.

CLIENT:

Aluminium for the world

LEGEND:

Abstraction Areas

NORTH ARROW:

CONSULTANT:

Environment Arabia

FIGURE TITLE:	DATE:	DATUM:
Figure 5.1 Groundwater Abstraction Areas	February 2023	WGS 1984 UTM Zone 39N

PROJECT TITLE:	PREPARED BY:	SCALE (A4):
ALBA PS5 Block 4 - groundwater risk assessment	MS	NOT TO SCALE

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Environment Arabia

5.2 Risks to groundwater quality

During construction works, contamination of groundwater would be possible in the event of any accidental spills of fuel and chemicals to ground, or due to poor storage practices of hazardous materials, particularly liquids, or poor waste management practices if losses were to reach groundwater resources through the overlying soil structures.

Site hydrogeological characteristics indicates the Aquifer B groundwater flow is from the north-west to the south-east of Block 4 site (see **Figure 4.5** and **Figure 4.9)**. There are no Aquifer B abstraction wells present to the south-east of Block 4 (Figure 5.1). Furthermore, The Khobar limestone formation (Aquifer B) is separated from Alat limestone (Aquifer A) by an Orange Marl aquitard which ranges in thickness from 9 to 15m, but thickness abnormality is not uncommon (see **Section 4.2.2.1**). The Orange Marl is impermeable and composed of orange to pale yellow, slightly dolomitised, and commonly iron-stained marl, with frequent occurrence of marly limestone which will act as a geological barrier. Furthermore, a review of Alba ACOP's and EPC contractor's procedures indicates the adequate management measures are in place to minimise potential spills and losses to the ground (**Section 5.3**). Therefore, in the event of a spill or leak to the ground during construction, the magnitude of impact to groundwater quality is assessed to be **small** (ref **Table 3.1**).

The significance of groundwater quality impacts are determined using the criteria listed in **Table 3.1**, **Table 3.2** and **Table 3.3.** From the assessment it can be concluded that the significance of risks to groundwater quality due to construction activities is **negligible** (**Table 5.1**).

Table 5.1 Significance assessment

Receptor	Receptor sensitivity	Impact magnitude	Impact significance
Groundwater	Low	small	Negligible

5.2.1 Other sources of contamination

It should be noted that as Alba complex is close to other industries which present potential sources of contamination to groundwater. Alba has a groundwater monitoring programme in place to provide ongoing monitoring in order to identify monitor trends in the groundwater quality over time. Industries within close proximity to the site with a potential to contaminate groundwater include:

- West Point Home – chemicals, fuel, process waste water, effluent treatment;
- Middle East Recycling Co. – fuel, chemicals and oil;
- Kingdom Oil Recycling Co. – fuel, chemicals and oil;
- Al Mazara'a Industrial Park – fuel, chemicals and oil;
- Bapco Refinery – oil products;
- AGAS Lubes – diesel and lubricating oil;
- Riffa Power Station – diesel, lubricating oil, water treatment chemicals;
- Ras Zuwayed and Ras Abu Jarjur – fuels, oils, chemicals;
- Awali Oil and Gas Field – oily wastes, fuel, lubricating oil; and
- Scrap Yards – lubricating oil, fuel, acid, lead (from batteries).

5.3 Review of Alba and EPC Contractor's procedures

The best way to prevent the pollution of underlying groundwater is to prevent the potential for spills and losses and therefore the potential for contamination at source. A review of the Alba ACOP's and EPC contractor's procedures, indicates that adequate management measures are in place to minimise the potential for spills and losses to ground, along with spill containment and response in the event of any loss. The measures can be found in the following plans and procedures:

- Alba Code of Practice (ACOP):
  - ACOP – 056 Environmental monitoring;
  - ACOP – 065 Environmental emergency response;
  - ACOP – 070 Chemical and hazardous materials management; and
  - Groundwater monitoring plan.
- EPC Contractor:
  - Chemical management and hazard communication;
  - excavation procedure;
  - pollution prevention procedure;
  - spill prevention procedure;
  - refuelling operations procedure; and
  - waste management procedure.

Both Alba ACOP's and the EPC contractor's procedures lists spill prevention measures which include the following:

- maintenance of plant and equipment involving activities with the potential for leakage and spillage should only be undertaken within the areas appropriately equipped to control these discharges or off site;
- minor maintenance of facilities where there is the potential for spillage should be done within a bunded area or drip tray;
- storage of oils, chemicals, fuel and waste within the work area should be limited to the absolute minimum volume and to be removed from the Project as quick as possible;
- containers shall not be filled to more than 90% of its capacity;
- tanks and vessels shall be protected with a secondary containment with 110% capacity of the total volume of the tank/vessel;
- in terms of waste management, secondary containment systems should be constructed with materials appropriate for the wastes being contained and adequate to prevent loss to the environment.

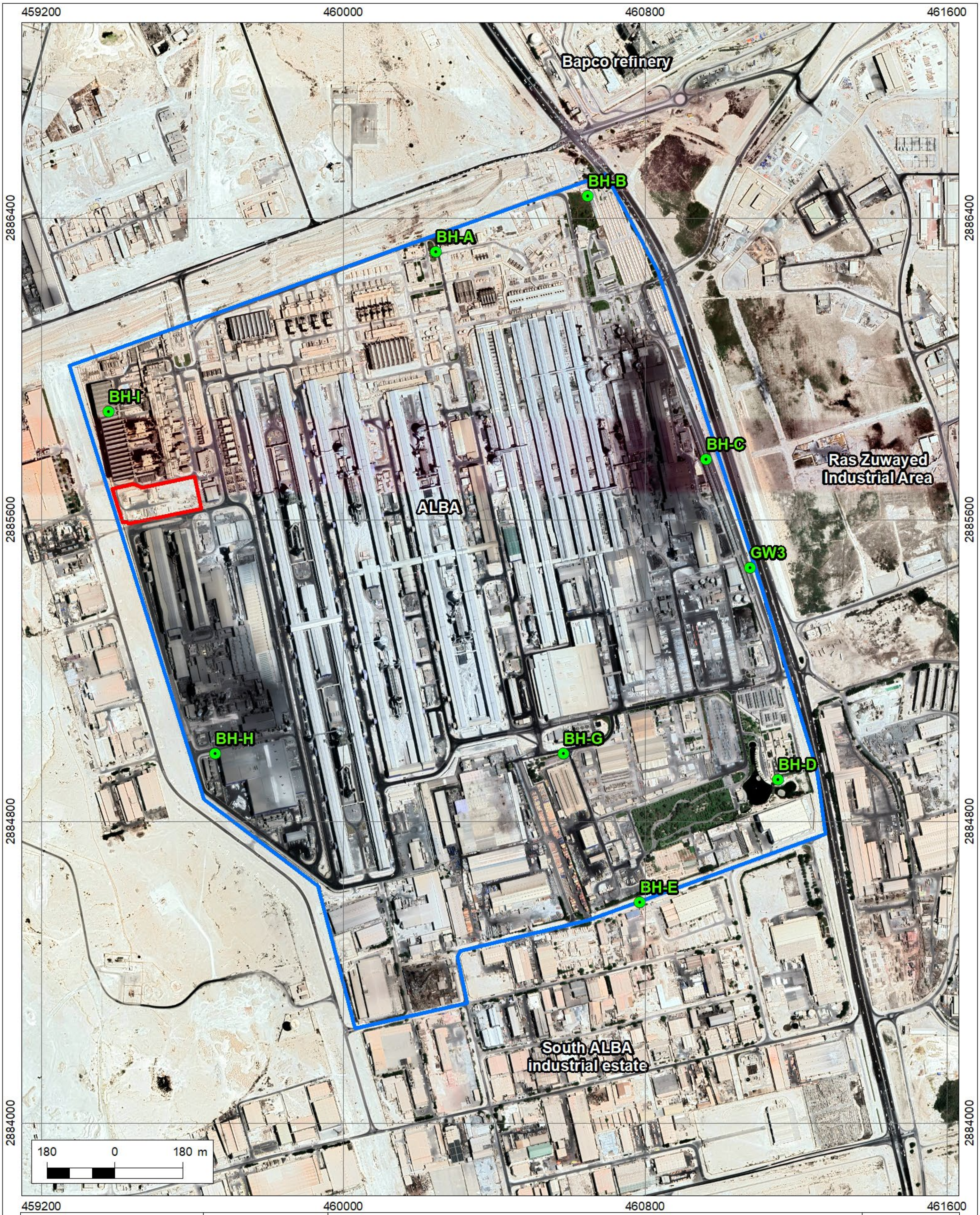
Refuelling procedures include the following measures:

- The refuelling area shall be hard barricaded. The hard barricade shall be arranged taking into account an access and an egress point for the vehicles;
- drip trays shall be available immediately below the refuelling point to contain any dripping and/or spills, if any happens to occur;
- the fuel storage area must also be located away from drainage channels;
- if diesel leakages are observed during the liquid transfer, the operation shall be stopped immediately. The Permit to Work shall be suspended, and the leaks shall be repaired outside the site. Vehicle, maintenance operations are not allowed in the site;
- The transfer of fuel must be stopped prior to overflowing. The vehicle's diesel tank shall not be overfilled for any reason.

In addition, spill containment kits shall be present at the site to respond to any materials spilt, including permanent kits at the refuelling area and storage area, with quantities and characteristics compatible with the chemicals stored.

5.3.1 Groundwater monitoring

As mentioned above Alba has a groundwater monitoring programme in place that conducts groundwater sampling and analysis on a quarterly basis at nine (9) monitoring wells (see **Figure 5.2**). The monitoring points are located upstream (representative of water flowing into Alba complex) and downstream (representative of water flowing out of Alba complex) in accordance with Standard Operating Procedure (SOP) No. 75-22 Groundwater Monitoring. Parameters analysed in each sample taken include pH, soluble fluorides, ammoniacal nitrogen, total cyanides, oil and grease. Additional sampling will be carried out if any exceedances are found.



CLIENT: alba Aluminium for the world	LEGEND: Groundwater monitoring locations; ALBA boundary; PS5 Block 4 site			NORTH ARROW: N
CONSULTANT: Environment Arabia	FIGURE TITLE: Figure 5.2 Groundwater monitoring locations		DATE: February 2023	DATUM: WGS 1984 UTM Zone 39N
	PROJECT TITLE: ALBA PS5 Block 4 - groundwater risk assessment		PREPARED BY: MS	SCALE (A4): 1:12,935

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5.4 Conclusion

From **Section 5.1** and **Section 5.2** above, it can be concluded that:

- There are no known groundwater abstractions from the Khobar Aquifer (Aquifer B) for private or public use within the vicinity of the Block 4 site. No groundwater abstraction/use will be required during the construction or operational phases of the project. Therefore, there will be no impacts to the Aquifer B groundwater users during construction and operations in relation to PS5 Block 4.
- A review of Alba ACOP's and EPC contractor's procedures indicates that adequate management measures are in place to minimise potential spills and losses to the ground. Furthermore, the Khobar limestone formation (Aquifer B) is separated from Alat limestone (Aquifer A) by an Orange Marl aquitard which is impermeable and composed of orange to pale yellow, slightly dolomitised, and commonly iron-stained marl, with frequent occurrence of marly limestone and will act as a geological barrier. Hence, it can be concluded that the significance of risks to groundwater quality due to construction activities is negligible**.**

6 REFERENCES

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