State of Conservation of the World Heritage Property
Qal’at al Bahrain - Ancient Harbour and Capital of Dilmun
(Bahrain) No.1192 (ter)

Progress report prepared by Bahrain Authority for Culture and Antiquities and Site Management Unit of World Heritage Site of Qal’at al Bahrain

November 2018
Introduction

This report has been prepared to update the World Heritage Centre, Advisory Bodies and distinguished members of the World Heritage Committee on the progress made on the items requested by the Committee in 2017. The information provided in this report focuses on the decision 41COM 7B.75 which requested updates on the Nurana Road Connectivity project, heritage legislation, intragovernmental consultation process and Integrated Conservation and Management Plan.

Identification of the Property

**Name of the Property:** Qal‘at al Bahrain – Ancient Harbour and Capital of Dilmun  
**Reference No:** 1192 (ter)  
**State Party:** Bahrain  
**Date of Incription:** 2005 (Minor Boundary Modifications 2008 and 2014)  
**Criteria:** (ii), (iii) and (iv)  
**Property area:** 70.4 ha  
**Buffer zone:** 1,311.8 ha

1. Executive Summary

Following the latest decision 41 COM 7B.75 by the World Heritage Committee at its 41st Session in Kraków, multifaceted actions are undertaken in order to ensure protection, conservation and sustainable management of the site in line with the 2011 UNESCO Recommendation on Historic Urban Landscapes and Integrated Management Plan for Qal‘at al Bahrain 2013-2018.

Bahrain Authority for Culture and Antiquities has submitted an official proposal of four categories of zoning codes to the Authority of Urban Planning, two of which will be directly applicable to Qal‘at al Bahrain.

The initial results of the updated Heritage Impact Assessment carried out by the consultancy appointed by the developer of the road connectivity development for Nurana Island will be submitted in the beginning of December 2018. The details and updates regarding the Road Connectivity project will be included in the HIA.

The intra-governmental cooperation based on the proposal elaborated by Bahrain Authority for Culture and Antiquities (hereinafter BACA) is still an ongoing process. The vision document, zoning proposals and heritage protection strategy of BACA have been integrated in the National Land Policy Strategic Plan and National Land Policy Guidelines, both of which were developed with the involvement of high level governmental officials.

The State of Conservation Report prepared by State Party of Bahrain and submitted in December 2016 foresaw an initial evaluation of the Integrated Conservation and Management Plan of Qal‘at al Bahrain World Heritage Site. The plan included actions to be realized between 2013 and 2018. Initial evaluation shows that 75% of the overall actions have been completed or are ongoing as of today. The protection and management are well functioning. Following the evaluation of the Plan
by the cultural heritage experts of BACA and the Site Management Unit, State Party of Bahrain decided to prolong the period of the action plan. The Integrated Conservation and Management Plan of Qal‘at al Bahrain shall remain as the principal guiding document for the management, conservation and monitoring of the World Heritage Site of Qal‘at al Bahrain.

2. Response of the State Party to the to the Decision of the World Heritage Committee No. 41COM 7B.75

i) Revision of the Heritage Legislation

Bahrain Authority for Culture and Antiquities (BACA) has submitted the official proposal of new zoning codes to the Authority of Urban Planning. The proposal consists of four categories, of which two are applicable to Qal‘at al Bahrain: Archaeological Sites AR (updated) and the Historic Gardens HG (completely new). The main difference between the two is in the permitted functions. While there is strict prohibition of any development on the archaeological sites and only permitted functions are cultural in nature, the historic gardens may have additional function of agricultural production and related to it permission to sell locally grown produce directly from the garden or farm.

These codes are presumed to become part of amended Prime Ministerial Edict No. 28 of 2009: Zoning Regulations for Construction, which is the main source of law when considering private and public development in the Kingdom of Bahrain.

BACA hopes for timely adoption of the new codes, which would constitute a significant progress in the heritage protection policy of the Kingdom.

ii) Updated HIA for Nurana Road Connectivity

This report shall not address the part of the Decision 41 COM 7B.75 related to the Heritage Impact Assessment. All information related to Nurana Road Connectivity Project will be transmitted in the updated comprehensive Heritage Impact Assessment, commissioned by the investor, which is being prepared by a consulting company. The first draft of the HIA is planned for submission to the World Heritage Centre in the beginning of December 2018. The final document will be shared in the middle of January 2019.

iii) The results of the consultation based on the proposal elaborated by BACA aiming at reinforcing the protection of the property’s attributes

The intra-governmental consultation on the proposal of BACA is an ongoing process. Following BACA’s submission of the detailed documents, cooperation continued between Authority for Urban Planning, Bahrain-French Town Planning Initiative (BFTPI) and BACA. BFTPI, which is a strategic partnership initiative, provided a strategic framework for urban development and a master planning for the coastal areas. BACA was recognized as a stakeholder from the beginning
of the process and actively participated in the progress. The vision document, zoning proposals and heritage protection strategy of BACA have been integrated in the National Land Policy Strategic Plan and National Land Policy Guidelines. The mentioned documents were developed with the involvement of 22 governmental entities in a series of workshops, expert meetings and endorsed under the patronage of high-level officials.

In overall, BACA considers that the proposals aiming at reinforcing the protection of the World Heritage property have been well received. BACA continues working in line with them, referring to mentioned documents in every case of intra-governmental correspondence and consultations.

iv) Comprehensive Conservation and Management Plan - revision and continuation.

Integrated Management Plan for Qal’at al Bahrain is the main guiding document being implemented by the Site Management Unit.

The archaeological heritage, underwater archaeological heritage and the agricultural heritage located within the property components are well protected and conserved. The development in the Buffer Zone is strictly controlled and BACA’s experts individually review each case. Large-scale development projects are subject to a separate evaluation with Heritage Impact Assessments. The ongoing process for Nurana Road Connectivity Project is a good example for such practice (please refer to item ii).

Heritage experts of BACA and Site Management Unit have conducted a preliminary evaluation of the Integrated Conservation and Management Plan. The evaluators have analyzed the action plan comprising the total of 408 actions, out of which 266 are regularly repeating actions, such as management unit meetings, maintenance works etc. and 142 one time actions. Initial evaluation shows that 75% of the overall actions have been completed or are ongoing as of today.

19% of actions have not been completed due to various reasons, including requirement of completion of ongoing actions, but also budgetary constraints and external reasons such as governmental restructuration. 6% of the actions have been deemed as no longer required.

Research and situation analysis, which had been conducted for the preparation of the current plan, remain valid and up to date. The comprehensive action plans with open ended and recurring periods shall continue being applied by the Site Management Team. Further actions will continue being prescribed in line with the five strategic objectives:

1. Legal and De Facto Protection,
2. Conservation Management,
3. Administration and Finance,
4. Research,
5. Interpretation, Presentation and Promotion.
Following the above, State Party considers that the Plan remains functional and effective for the conservation and protection of the World Heritage Site of Qal’at al Bahrain; hence, it shall remain as the principal guiding and operational document for the management, conservation and monitoring of the site.

3. Other current conservation issues identified by the State(s) Party(ies) which may have an impact on the property’s Outstanding Universal Value
No issues.

4. Any potential major restorations, alterations and/or new construction(s) intended within the property, the buffer zone(s) and/or corridors or other areas, where such developments may affect the Outstanding Universal Value of the property, including authenticity and integrity.
No major works planned in the site that would affect the Outstanding Universal Value of the property.

5. Public access to the state of conservation report
The State Party of Bahrain has no objections to upload the report for public access.

6. Signature of the Authority
On behalf of the State Party of Bahrain

Mai bint Mohammed Al Khalifa
President of Bahrain Authority for Culture and Antiquities
QAL’AT AL-BAHRAIN: ANCIENT HARBOUR AND CAPITAL OF DILMUN
REPORT ON ROAD CONNECTIVITY SOLUTIONS FOR NURANA AND MARSA-ALSEEF ISLANDS (TUNNEL OPTION)
The Bahrain Authority for Culture and Antiquities is initiating this report, as an addendum to the previously submitted state of conservation report in order to present to the World Heritage Centre a proposed development project within the buffer zone of the World Heritage Site Qal’at al-Bahrain. The project aims to construct a road consisting of a tunnel and a causeway in an approximate distance of 400 metres from the shore of Qal’at al-Bahrain. The tunnel portion is planned to be located within the boundaries of the visual corridor in order to safeguard the visual integrity of the site. The tunnel aims at connecting the new island developments Nurana Island and Marsa Al Seef Island with mainland Bahrain, through Seef District. This option replaces the causeway option, which was discussed with representatives of the World Heritage Centre and ICOMOS in the context of the 42nd session of the World Heritage Committee in July 2018 and is based on earlier reports, which submitted a preliminary Heritage Impact Assessment for a tunnel option.

The Bahrain Authority for Culture and Antiquities would kindly request, that the World Heritage Committee authorizes the construction of this sub-seabed tunnel during its forthcoming session in Baku.

**BACKGROUND**

Since more than six years, local authorities together with the developers of the new island developments are determined to find a suitable road connection for Nurana and Marsa Al Seef Islands, which turned out to be particularly challenging due to the islands’ vicinity to the protected World Heritage Site of Qal’at al-Bahrain. Several options have been proposed throughout the years and studies were carried out accordingly. Two extensive Heritage Impact Assessments (HIA) were undertaken in the years 2012 and 2015, respectively. The proposed N-Road of 2012 was found to severely impact the OUV of the site and was, consequently, abandoned. The HIA and its results were discussed during the 37th World Heritage Committee session in Phnom Penh (37 COM 7B.47).

In 2015, two alternative options were proposed. The first option is a bridge connecting the south-eastern edge of Nurana Island with the mainland next to Karranah village in combination with an on-land road that leads to Al Nakheel Highway. This option was abandoned for various reasons, such as land compensation issues and the fact that Al Nakheel Highway is already congested and does not have the capacity to cater more vehicles. The second proposed option is the bridge and tunnel connecting the south-eastern edge of Nurana with Avenue 58 in Seef that is now under discussion again. The HIA and its results were discussed during the 39th and 41st World Heritage Committee sessions. In its 39th session the Committee requested additional studies to be undertaken before proceeding with the development.

“5. Takes note of the results of the Rapid Heritage Impact Assessment (HIA) on the road connectivity development for Nurana Island and in light of potential negative impact, also requests that the HIA is reviewed on the basis of additional studies recommended by this Rapid HIA to inform the development of design options and submitted to the World Heritage Centre, for review by the Advisory Bodies, prior to any decision concerning the option to connect Nurana Island to the mainland.” (39 COM 7B.48)
In 2016, Bahrain submitted an updated state of conservation report that stated that Bahrain would opt for the tunnel option, which satisfied the World Heritage Committee as it considered the tunnel the only feasible option for the road connectivity development of Nurana. In its 41st session, the Committee hence requested an updated and comprehensive HIA for that matter and an updated state of conservation report to be submitted by 1 December 2018.

“4. Also notes with satisfaction that the tunnel has been adopted as the only feasible option for the road connectivity development for Nurana Island;

[...]

8. Requests the State Party to submit to the World Heritage Centre, as soon as they are available:

a) The results of the updated HIA carried out by the developer of the road connectivity development for Nurana Island, in line with the ICOMOS Guidance on HIAs for Cultural World Heritage Properties” (41 COM 7B.75)

In the meantime, a temporary causeway was proposed and presented to representatives of ICOMOS and the World Heritage Centre during their stay in Bahrain for the 42nd World Heritage Committee session in June/July 2018. The Bahrain government, however, did not approve the temporary causeway, because the government highly favours a permanent solution. For this reason, the tunnel option is being re-assessed.

THE PROPOSED ROAD DEVELOPMENT

The proposed road is planned to connect the south-eastern edge of Nurana Island (26°14’28”N, 50°30’48”E) with mainland Bahrain entering Seef on its western shore (26°14’18”N, 50°31’24”E). The road would be a continuation of the existing Avenue 58. The road consists of three separate phases. The first phase refers to a ramp starting off at the end of Avenue 58 in Seef (26°14’18”N, 50°31’25”E). The second phase concerns the tunnel which is located within the visual corridor of the property. The third phase refers to a causeway that leads to the southern shore of Nurana (26°14’29”N, 50°30’49”E). The ramp and causeway are located within the buffer zone of the site.

DEVELOPMENT DESIGN

The ramp is intended to provide the basis for the inlet from the causeway into the tunnel. It requires a new land reclamation of sufficient height, which does not connect to the mainland or any other existing reclamation.

The tunnel is, in theory, planned to be built three meters below the seabed surface and has, accordingly, a slope of 25% at its inlets. However, the tunnel depth is only to be verified after the geotechnical investigations are finalized, which provide clarification on the location of aquifers and the general ground composition. The proposed tunnel is foreseen to be constructed in cut-and-cover technique; the tunnel is constructed in a shallow trench and then covered over with proper engineering material. The surface is planned to be treated with natural coral reefs. Consequently, temporary dewatering of the tunnel section and pier
foundation is required. A cofferdam is to be built to secure the temporary exsiccation of the construction site. Sheet piles, driven in the ground by a vibratory hammer, will protect the site from water penetration. After construction works are finalized, the steel sheet piles are removed from the site.

The detailed description of the proposed road development, including its specification as well as its constructions method, is part of the HIA to be submitted to the World Heritage Centre by 15 January 2019.

**KEY CONCERNS**

The biggest concern is the protection of the Dammam Aquifer. Should the underground aquifer be damaged, the OUV of the World Heritage Site Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun is likely to be significantly reduced. Adverse impacts would be expected for the vegetation of the palm groves and traditional gardens due to increased salinity levels resulting from salt water seepage into the groundwater. Therefore, detailed investigation of the aquifer including soil investigations are currently being carried out.

Another major concern is the potential existence of underwater archaeological remains in the foreshore area of Qal’at al-Bahrain, which includes the area along the proposed road corridor and its vicinity. Although several walk-over surveys did not show any evidence, it has to be noted that the area is partially silted and that visual inspections alone might not be suffice. Geophysical surveys are thus undertaken in order to ensure the non-existence of underwater archaeological remains.

**DOCUMENTS CURRENTLY IN PREPARATION TO BE SUBMITTED BY 15 JANUARY 2019**

By 15 January 2019 a comprehensive HIA will be submitted to the World Heritage Centre. Besides an introduction to the site, the actual impact assessment, and details concerning the designs and construction methods of the ramp, the causeway and the tunnel, the HIA will include the following studies:

1. Results of the detailed investigation of the aquifer including soil investigations;
2. 3D soil layer visualization of tunnel and aquifer positions based on geophysical analysis;
3. Underwater archaeological geophysical survey of the road corridor and at least 50 meters to each side;
4. Visual impact analysis including renderings;
5. Hydrodynamic studies for the construction period and operation period.

The Bahrain Authority for Culture and Antiquities kindly requests the World Heritage Centre to inform the Authority if these documents are expected to be sufficient or if further documents are required. Furthermore, it would be highly appreciated if the World Heritage Centre could clarify the next steps to be taken.
Road Connectivity for Nurana Island

HERITAGE IMPACT ASSESSMENT (HIA)

Final Report (15 January 2019)
INTRODUCTION

The purpose of this Heritage Impact Assessment (HIA) is to evaluate any potential impacts the proposed road connection consisting of a tunnel and a causeway could have on the World Heritage Site Qal’at al-Bahrain and further cultural heritage assets in its surrounding. The project proposes building a dual carriageway to connect Nurana Island with mainland Bahrain. Considering that the proposed development is located within the buffer zone of a World Heritage Site, the Bahrain Authority for Culture and Antiquities (BACA) requested the developers to seek the approval by UNESCO before any further step is taken.

Think Heritage! was asked to conduct the HIA for the project proposal and to submit the final report to the World Heritage Centre by 15 January 2019 in order to be discussed at the next UNESCO World Heritage Committee session in June/July 2019.

This HIA consists of a textual analysis as well as supporting maps and an annex providing an overview of all identified heritage expressions and the expected impact. The textual description is divided into seven chapters.

The first chapter describes the design and construction methodology of the proposed tunnel and causeway. It also gives a short overview of previously proposed road connections which were not to be found feasible.

The second chapter is dedicated to the methodology of this HIA. It does not only explain the general methodology applied including the grading of impacts and heritage significance, but also includes more specific methodologies for the analysis of the impacts of noise, vibration, air pollution and dust, siltation, aqua dynamics, and visual disturbances.

The third chapter introduces the World Heritage site and provides an in-depth review of the various previous management issues and related World Heritage Committee decisions. The chapter furthermore highlights the various attributes of the site.

The fourth chapter is dedicated to cultural heritage expressions that are not part of the site but are partially located within the property’s buffer zone. These include archaeological heritage, underwater archaeological heritage, and aquatic cultural heritage expressions.

In the fifth chapter, the impacts on the various heritage components are analysed and mitigation measures are suggested that aim to reduce the significance of impact. Each subchapter finishes with a small overview table clearly indicating the significance of heritage, the grade of impact, the significance of impact, and the residual significance of impact if all mitigation measures are applied.

The sixth chapter provides overview tables with the identified heritage expression, an image illustrating it and a brief description. It furthermore indicates the expected impact, the suggested mitigation measures and the significance of impact before and after mitigation.
The seventh chapter provides the conclusion, while the eighth chapter presents the collection of all resources used for this report.

The ninth chapter comprises all relevant maps, starting with the road layout and the study area. Further maps include the identification, grade of heritage significance, significance of impact, and residual impact after mitigation of the attributes conveying OUV as well as further heritage expressions, namely archaeological, underwater archaeological and aquatic cultural heritage expressions.

The annex constitutes the Nurana Access Road (Tunnel Review) Report prepared by AECOM Infrastructure and Environment UK Limited, which also includes the Geophysical Survey Report prepared by Gulf Centre for Geophysical and Water Consulting (GCGC).
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P.O. Box 23940, Muharraq
Kingdom of Bahrain

QUALITY ASSURANCE AUTHORISATION

Title of Project: Nurana Road Connectivity Heritage Impact Assessment (HIA)

Project Number: BH18-09-001

Type of Document: Final Report

Submission Date: 15 January 2019

Author: Melanie Münzner

Maps: Lily Hasbani

Checked by Britta Rudolff

Initials Signature Date: 15/01/2019
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<thead>
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<tr>
<td>BACA</td>
<td>Bahrain Authority for Culture and Antiquities</td>
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<td>BCE</td>
<td>Before Common Era</td>
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<td>CE</td>
<td>Common Era</td>
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<td>Decibels (Adjusted)</td>
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<td>Environmental Impact Assessment</td>
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<td>ERT</td>
<td>Electrical Resistivity Tomography</td>
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<td>HIA</td>
<td>Heritage Impact Assessment</td>
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<td>H.E.</td>
<td>His/Her Excellency</td>
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<tr>
<td>ICOMOS</td>
<td>International Council on Monuments and Sites</td>
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<td>Peak Particle Velocity</td>
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<td>Treated Sewage Effluent</td>
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<td>United Nations Educational, Scientific and Cultural Organisation</td>
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1. Road Connectivity Projects for Nurana Island
1. ROAD CONNECTIVITY PROJECTS FOR NURANA ISLAND

1.1 BACKGROUND: PREVIOUS PROPOSED DEVELOPMENTS AND HERITAGE IMPACT ASSESSMENTS

Since 2012, local authorities together with the developers of Nurana Island are determined to find a suitable road connection for the northern island developments and mainland Bahrain. Due to its vicinity to the protected World Heritage Site of Qal‘at al-Bahrain, it is particularly challenging to find an acceptable solution for the western-most land development, Nurana Island. Several options have been proposed throughout the years and studies were carried out accordingly. Two extensive Heritage Impact Assessments (HIA) were undertaken in the years 2012 and 2015, respectively.

1ST PROPOSED DEVELOPMENT: N-ROAD

In 2012, the Ministry of Works entrusted Think Heritage! to conduct an extensive HIA for the N-Road Development after an urgent response to a request by UNESCO and ICOMOS. The team of Think Heritage! conducted a complete screening, baseline surveys, impact assessment, and preparation of mitigation and adaptation measures that were submitted to UNESCO on 1 February 2013.

The Heritage Impact Assessment highlighted the adverse impacts of the proposed development on the OUV of the World Heritage Site of Qal‘at al-Bahrain: Ancient Harbour and Capital of Dilmun. In addition, it assessed negative impacts on all other relevant heritage expressions identified in the project area, including those of regional, national and local importance, with an emphasis on seven heritage categories: archaeological, underwater archaeological, architectural, urban, agricultural, aquatic cultural and intangible cultural heritage.

Proposed layout of N-Road development

N-Road Development refers to a new traffic artery network that was proposed for connecting the recently reclaimed landmasses of the al-Madina al-Shamaliya (Northern New Town, AMAS) and Nurana to
mainland Bahrain. The N-Road project was divided into three project segments, Phase 1A (W-Link), 1B (Reclamation) and phase 2 (N-Road Bridge, N-Road and S-Link).

The proposed N-Road Development was planned mostly off-shore with the intention to, as much as possible, limit the impact to the existing villages, and to reduce the constantly increasing traffic pressure on Budaiya Highway. Unfortunately, the road corridor was planned in very close vicinity to the World Heritage Site of Qal‘at al Bahrain, cutting through its south-western buffer zone.

While parts of the proposal were approved and are currently implemented or even finalised, those project components that were found to reduce the Outstanding Universal Value of the World Heritage Site were abandoned. This is because UNESCO and ICOMOS did not approve the proposed layout of the N-Road Development.

2ND PROPOSED DEVELOPMENT: TUNNEL (OPTION 1) AND KARRANAH ON-LAND ROAD (OPTION 2)

In 2015, two alternative options were proposed to connect Nurana Island to mainland Bahrain. The first option was a bridge and tunnel connecting the south-eastern edge of Nurana with Avenue 58 in Seef, similar to the footprint of the proposed tunnel and causeway presented in this Heritage Impact Assessment. The tunnel would have been located in the in the visual corridor of Qal‘at al-Bahrain and was suggested exclusively to avoid visual disturbances to the site. The bridge would have been located in the buffer zone but outside the view corridor. The second proposed option was a bridge connecting the south-eastern edge of Nurana Island with the mainland next to Karranah village in combination with an on-land road that leads to Al Nakheel Highway.
would also have been negatively impacted. As a result both options were abandoned until now in order to re-evaluate other options and to conduct further studies concerning the location and fragility of the aquifer.

1.2 Nurana Tunnel and Causeway
The latest proposal to connect Nurana Island with mainland Bahrain revisits the tunnel option. This time, however, the proposed road includes a causeway rather than a bridge. Being a lower structure, the causeway further benefits the visual integrity of the site. The tunnel is located in the visual corridor of the site as no development above sea level is allowed within its boundaries.

The alignment and design of the road, which forms the basis of this Heritage Impact Assessment (HIA), was developed by the developer of Nurana Island (Manara Developments), with technical assistance from AECOM. The following project descriptions and specifications are based on the general layout proposals and information provided by AECOM.

The road is planned as a dual carriageway that connects the south-eastern edge of Nurana Island (26°14'28"N, 50°30'48"E) with mainland Bahrain entering Seef on its western shore (26°14'18"N, 50°31'24"E). The western part of the road, i.e. the part that is located outside the visual corridor, is planned as a causeway, while the eastern part is planned as a tunnel. The eastern end of the tunnel is proposed to join Avenue 58, which runs generally east/west, up to a point approximately 200 metres from the coastline where it curves north to follow the coast. At this location, the view corridor extends to the coastline and therefore the area between Road 2819 and the corridor is very limited. Because of this limited area available to accommodate the tunnel approach ramp, it is considered that connection between the tunnelled link and Road 2819 will need to be made some distance along the current alignment of Road 2819. For this reason, some re-configuration of Road 2819 will be required in order to accommodate the new junction and tunnel approach ramp and some additional land area will be required to accommodate this. The total construction period is estimated to take approximately two years.
**Causeway**

**Specifications**
The causeway is planned as a four-lane road with two lanes for each direction respectively, a safety space in between the two opposite directions, and safety spaces to the outside of the road. At the moment, the road itself is foreseen to have a width of 30 metres, which is the minimum required for such as road. The width might be adjusted in the final design stage.

![Proposed section of causeway (AECOM 2019)](image)

The entire structure, i.e. the reclamation with primary and secondary armour and quarry run is likely to have a width of approximately 45 metres. Yet, the quarry run, which has only a height of 1.1 metres will be submerged most of the time and not be visible. The crest level of the armour is 2.80 metres above the seabed. The road itself has a height of at least 2.50 metres. The primary armour is envisaged to have a natural rock finishing and a thickness of 1.20 metres, while the secondary armour is planned to be 0.55 metres thick.

**Construction Methodology**
First, the site along the proposed causeway footprint needs to be prepared. This will involve clean up and levelling of the existing seabed, which varies at the moment, with bulldozers during low tide. After the site preparation is completed, a trial platform will be constructed. For this, sand is dumbed from a truck and then levelled and compacted with bulldozers. The final compaction of the surface layers is done with rollers. After that, the reclamation fill and flushing pipes are placed at prior identified locations. With the help of a small crane the flushing pipes are placed on a bedding material. The ground around the pipes is stabilised and plain sand placed on top with a long reach excavator. In the following, the platform is raised up to the design crest level by filling in sand layers to achieve the minimum specified compaction criteria. After that, the rock armour is placed along the causeway platform sloping edges. The sloping edges are formed with a long reach excavator and are then covered by hand with geotextile. This is followed by the first armour, which consists of small rocks that are spread on the geotextile as foundation and to keep it in place. The second armour, made of larger rocks, is then placed on top to finish the protection.

Once the construction of the reclamation is finalized, the actual road construction begins. First, a road underlayer mix is placed along the road alignment and compacted. Final levels are achieved with precision using a grader. After that, asphalt pavers are used to place various layers of asphalt, which is then compacted by rollers. In a later stage crash barriers are placed and road marking and street lighting are installed.
TUNNEL Specifications
The tunnel design complies with British Department of Transport Design Standards, namely the Design Manual For Roads and Bridges, BD 78/99 – Design of Road Tunnels and the Design Manual For Roads and Bridges, TD 27/05 – Cross Sections and Headrooms.

The proposed tunnel cross-section is approximately 9.5 metres high, 26.5 metres wide, and is planned to be placed with the top of the structure 3 metres below datum level. A maximum gradient of 4% has been assumed for the approach ramps and the provisional arrangement shows a length of up to 250 metres for these ramps between road level and tunnel portal.

The proposed cross-section includes three cells, two of which each contain two lanes of traffic and a third centre cell containing services and facilitating emergency egress. It is envisaged that emergency exit doors will be provided between the two traffic cells into the central cell at the specified intervals to facilitate exit in the case of emergency, such as tunnel fire. Each of the traffic cells also includes walkways to facilitate evacuation to emergency exits.

Given the relatively short length of the tunnel, longitudinal ventilation using jet fans is planned to be installed.

Further safety recommendations based on the requirements of the BD78/99 design standard and EU Tunnel Safety Directive are also considered in the final tunnel design. These include the provision of normal, safety and evacuation lighting, the provision of emergency stations at least every 150 metres, the provision of water supply at least every 250 metres, the installation of signs for all safety equipment, video monitoring, automatic fire or incident detection, traffic signals before tunnel entrances, radio re-broadcasting for emergency services, provision of facilities for emergency radio messages to tunnel users, provision of loudspeakers to exits, emergency power supply to provide continuation of safety equipment during evacuation, and adequate fire resistance of equipment to maintain safety functions.

The drainage system envisaged for the tunnel includes drainage sumps at each portal to intercept flows from the approach ramps and a central drainage sump close to the lowest point in the tunnel. Drainage sumps
would return liquids to a suitable drainage connection at the surface via sump pumps and rising mains.

It is envisaged that, upon completion, the tunnel will be fully integrated into the wider road network in the area and be adopted by the relevant management authority. In order to comply with safety regulations and recommendations, a dedicated tunnel management will be required. This could be in the form of a management team based in a control centre at the tunnel or a dedicated team incorporated within a general highway control centre.

**Construction Methodology**

There are several available methods of construction which could be considered to create the tunneled highway link, however, the topography of the site, the shallow depth of water on the crossing route, the lack of obstacles and the relatively short length of the tunnel guide strongly towards adopting a cut and cover methodology, which is presented in the following.

Creation of a cut and cover tunnel across the site would require a suitable excavation in which to construct the tunnel allowing least or insignificant detriment to the hydraulic flow. The excavation is envisaged to be carried out in sections of probably 150 metres, split longitudinally to avoid any obstruction to the hydraulic path and traffic. Formation and support of this excavation is a key part of the methodology.

Contiguous bored piles and diaphragm walls are commonly used for excavation support in cut and cover tunneling, however the ground conditions and relatively shallow depth of the tunnel make the use of steel sheet piles a viable and more practical alternative in this case. Unlike the contiguous piles the sheet piles can be retrieved after the construction.

It is anticipated that a temporary piling platform will be required in the form of a causeway constructed along the alignment of the tunnel. This would allow for sheet piling for the tunnel excavation and approach ramps and could be retained outside the visual corridor as causeways are forming part of the highway link.
The depth of the proposed tunnel structure would be approximately 9.5 metres and therefore a depth of excavation below sea level of approximately 15 metres is considered. It is envisaged that this excavation could be achieved by creating a propped cofferdam using sheet piles. Sheet piles would need to extend sufficiently into the seabed to provide lateral resistance and to limit water inflow into the excavation. Suitable de-watering of the excavation would be essential.

The sheet piles would terminate at the interface with competent rock. Excavation below the termination depth of the pile wall within rock would be supported by means of rock bolts and shotcrete if required.

It is assumed that there will be some water ingress into the excavation as the ground comprises fractured and weak rock. Adequate ground improvement in the form of permeation grouting would be required to
limit water ingress during excavation. Additional ground investigation would be required to determine the necessary requirements.

The permanent structure of the tunnel would be cast as a reinforced concrete box in bays within the excavation. The depth of the excavation would be varied at each end of the tunnel to form approach ramps, which would remain as open cuttings with propped reinforced concrete retaining walls in the permanent condition.

On completion, it is envisaged that the sheet piled cofferdam would be backfilled above the tunnel structure and removed, along with the temporary piling platform. The landscape within the visual corridor would therefore be reinstated to its original condition with the highway concealed within the tunnel within this corridor and rising within open cutting outside of the corridor to link with the wider road network.
During construction, the sheet piled cofferdam and platform will extend above sea level to provide an adequate factor of safety against inundation. It is anticipated that the Mean Sea Level (MSL) will be within 0.1 metres of National Survey Data (NSD) at the site and therefore, with allowance for peak water level of 1.3 metres above this and 1 metre wave height in the shallow water at the site, the top of the temporary platform would be located at approximately 2 metres above NSD. An allowance for guarding of the excavation would mean that the temporary works would be within 3.5 metres above NSD and MSL.
2. Scope and Methodology
2. Heritage Impact Assessment: Scope and Methodology

The HIA for the proposed causeway and tunnel is guided by international standards and associated reference documents. The content of this report is meant to enable the World Heritage Committee and its Advisory Body ICOMOS as well as relevant local authorities to gain a full picture of the impacts the project proposal is likely to have on the World Heritage Site of Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun and on other heritage expressions in its buffer zone. The methodology follows the approaches and methods suggested by ICOMOS in its 2011 publication Guidance on Heritage Impact Assessments for Cultural World Heritage Properties (ICOMOS 2011) and takes into consideration past recommendations and decisions issued by UNESCO regarding the World Heritage Site of Qal’at al-Bahrain (see Chapter 3).

2.1 Selection of the Study Area

The study area for this HIA was selected to cover 500 metres on each side of the road development and to incorporate the entire World Heritage property in the south. The 500 metres cover the site’s wider setting including relevant parts of its buffer zone that could potentially be directly or indirectly impacted by the road development.

2.2 Identification of Relevant Heritage Expressions

This HIA applies a comprehensive definition of cultural heritage and takes into consideration assets of all heritage categories. The heritage expressions primarily assessed in this report are the attributes of the World Heritage site. The attributes are identified in the site’s Statement of Outstanding Universal Value (OUV) and described in Chapter 3. The attributes of OUV in Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun comprise terrestrial and underwater archaeological resources as well as agricultural assets in form of palm groves.

Heritage expressions of these three categories - terrestrial archaeology, underwater archaeology, agricultural heritage - and of varied heritage significance extend throughout parts of the wider study area. In addition, the study area includes places associated to aquatic cultural uses. Throughout the report, intangible heritage aspects are discussed in the context of the physical heritage resource or places they are linked to. In the entire study area including the World Heritage property, the identified heritage expressions range from earliest around 2500 BCE to the later decades of the 20th century, as well as intangible heritage expressions which continue to be practiced until present times. Their cultural significance ranges from international, regional, national to local importance.

2.3 Baseline Data, Surveys and Ground Truthing

For this HIA extensive baseline data for all above mentioned heritage categories was available for most of the study area given the extensive surveys carried out during the assessment of the N-Road development in 2012 (Think Heritage!, Ministry of Works 2013) and the tunnel and Karranah on-land road development (Think Heritage! 2015). In order to verify the baseline data from 2012 and 2015, the entire study area was
revisited and ground truthing surveys were undertaken accordingly. Across all heritage categories, the baseline data is informed from field surveys and desk studies, from relevant literature as well as from interviews with local residents and heritage experts. For the field surveys, basic walking and ground truthing methodologies were applied across the different categories. In this context systematic walkover surveys were conducted both on land and offshore, occasionally with the help of vehicles, such as car and boat either in 2012 or 2015 as part of the previous HIAs conducted by Think Heritage! or now in 2018.

2.4 Significance Assessment
In line with best practice standards, the cultural significance of the individual heritage expressions is classified as of international, regional, national or local importance, while also taking into consideration the uniqueness of the element identified as well as its state of preservation. All heritage resources are therefore classified into significance levels ranging in seven steps from negligible to highest. Additionally, few expressions have to be classified as unknown, given that their existence and cultural significance could not been investigated. Attributes of the World Heritage site recognized by UNESCO for their expression of OUV are classified as of highest significance. All other cultural heritage expressions were assessed according to the table below:

<table>
<thead>
<tr>
<th>Significance Grading</th>
<th>(Underwater) Archaeological Heritage</th>
<th>Agricultural/Aquatic Cultural Heritage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>Sites of international importance, such as those inscribed as World Heritage properties. Individual attributes that convey OUV of inscribed or potential World Heritage properties.</td>
<td>Agricultural and aquatic cultural landscapes and features of acknowledged international importance, such as those inscribed as World Heritage properties. Individual attributes that convey OUV of inscribed or potential World Heritage properties.</td>
</tr>
<tr>
<td>Very high</td>
<td>Sites of international interest, which have potential to illustrate OUV. Assets that can contribute significantly to acknowledged international research objectives.</td>
<td>Agricultural and aquatic cultural landscapes and features of international interest, which have potential to illustrate OUV. Other agricultural and aquatic cultural landscapes features of international importance.</td>
</tr>
<tr>
<td>High</td>
<td>Nationally designated archaeological monuments and sites. Undesignated sites of national or regional importance with potential to be designated. Assets that can contribute significantly to acknowledged national or regional research objectives.</td>
<td>Nationally designated agricultural and aquatic cultural landscapes and features. Undesignated agricultural and aquatic cultural landscapes and features of national or regional importance with potential to be designated.</td>
</tr>
<tr>
<td>Medium</td>
<td>Designated or undesignated assets of local importance.</td>
<td>Designated or undesignated agricultural and aqua-cultural landscapes and features of</td>
</tr>
</tbody>
</table>
### Significance Grading

<table>
<thead>
<tr>
<th>Significance Grading</th>
<th>(Underwater) Archaeological Heritage</th>
<th>Agricultural/Aquatic Cultural Heritage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Assets characterised by poor preservation and/or poor survival of contextual associations. Assets of limited value, but with potential to contribute to local research objectives.</td>
<td>Agricultural and aquatic cultural landscapes and features of limited significance or in poor state of preservation. Agricultural and aquatic cultural landscapes of interest to local interest groups.</td>
</tr>
<tr>
<td>Negligible</td>
<td>Assets with very limited or no surviving archaeological interest.</td>
<td>Agricultural and aquatic cultural landscapes and features of very limited or no significance or very poor state of conservation.</td>
</tr>
<tr>
<td>Unknown</td>
<td>The importance of the asset could not be ascertained, for example due to layers of silt and/or sand covering the asset.</td>
<td>Agricultural and aquatic cultural features and landscapes of unknown potential, for example due to lack of accessibility.</td>
</tr>
</tbody>
</table>

### 2.5 Grading of Impact

The grade of impact is assessed in five levels ranging from no change to major change. The assessment does not only take into account the direct impact on the asset but also on the setting. Various impacts were identified, such as noise, vibration, air pollution and dust, visual impact, siltation, or changes in water flow. The methodology for the grading of each of the identified impacts is described in the following chapters.

<table>
<thead>
<tr>
<th>Impact Grading</th>
<th>(Underwater) Archaeological Heritage</th>
<th>Agricultural/Aquatic Cultural Heritage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>Most or all key (underwater) archaeological materials are totally altered and/or comprehensive changes to setting.</td>
<td>Changes to most or all key agricultural or aquatic cultural elements; fundamental changes to use or access.</td>
</tr>
<tr>
<td>Moderate</td>
<td>Changes to many key (underwater) archaeological materials that clearly modify the resource and/or considerable changes to setting that affect the character of the site.</td>
<td>Changes to many key agricultural or aquatic cultural elements; considerable changes to use or access.</td>
</tr>
<tr>
<td>Minor</td>
<td>Changes to key (underwater) archaeological materials that slightly alter the resource and/or slight changes to setting.</td>
<td>Changes to few key agricultural or aquatic cultural elements; slight changes to use or access.</td>
</tr>
<tr>
<td>Negligible</td>
<td>Very minor changes to key (underwater) archaeological materials or setting.</td>
<td>Very minor changes to key agricultural or aquatic cultural elements; very slight changes to use or access.</td>
</tr>
<tr>
<td>No change</td>
<td>No change to (underwater) archaeological remains or setting.</td>
<td>No change to agricultural or aquatic cultural elements.</td>
</tr>
</tbody>
</table>
2.6 IMPACT ASSESSMENT
Based on the above-described assessment of heritage significance and impact grading, the significance of impacts on the heritage resources are categorized according to the table below. The assessment is limited to adverse impact, as a potential beneficial impact could not be identified during the survey.

<table>
<thead>
<tr>
<th>Grade of Impact</th>
<th>No change</th>
<th>Negligible change</th>
<th>Minor change</th>
<th>Moderate change</th>
<th>Major change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>Neutral</td>
<td>Minor adverse</td>
<td>Moderate adverse</td>
<td>Major adverse</td>
<td>Major adverse</td>
</tr>
<tr>
<td>Very high</td>
<td>Neutral</td>
<td>Minor adverse</td>
<td>Moderate adverse</td>
<td>Major adverse</td>
<td>Major adverse</td>
</tr>
<tr>
<td>High</td>
<td>Neutral</td>
<td>Negligible adverse</td>
<td>Moderate adverse</td>
<td>Moderate adverse</td>
<td>Major adverse</td>
</tr>
<tr>
<td>Medium</td>
<td>Neutral</td>
<td>Negligible adverse</td>
<td>Minor adverse</td>
<td>Moderate adverse</td>
<td>Moderate adverse</td>
</tr>
<tr>
<td>Low</td>
<td>Neutral</td>
<td>Neutral</td>
<td>Negligible adverse</td>
<td>Minor adverse</td>
<td>Minor adverse</td>
</tr>
<tr>
<td>Negligible</td>
<td>Neutral</td>
<td>Neutral</td>
<td>Negligible adverse</td>
<td>Negligible adverse</td>
<td>Negligible adverse</td>
</tr>
<tr>
<td>Unknown</td>
<td>Neutral</td>
<td>Cannot be defined</td>
<td>Cannot be defined</td>
<td>Cannot be defined</td>
<td>Cannot be defined</td>
</tr>
</tbody>
</table>

Major adverse impacts identified will need to be prevented through adaptation or, if possible, mitigation measures. Mitigation measures of most varied character depending on the type of heritage and impact can potentially reduce the negative impacts to acceptable levels. Adaptation measures are required where mitigation does not suffice. Adaptation may include changes to the project designs and construction methods or alternative routings at the most.

In cases where the OUV of the World Heritage Site Qal‘at al-Bahrain is affected, the maximum acceptable level of change is negligible adverse impact, while for other heritage expressions the acceptable level is minor adverse impact.

For remaining moderate adverse and minor adverse impacts mitigation strategies have been developed, which either completely eliminate the negative impacts identified or reduce them to negligible impact, if the OUV is concerned, and to minor impacts or less for all other heritage expressions.

2.7 VISUAL IMPACT ASSESSMENT

SCOPE
The visual impact assessment aims at identifying how the visual integrity of the World Heritage Site and its setting will be affected by the proposed temporary causeway. The viewing areas are defined in order to assess the visual impacts when looking from the site, such as visitors would experience it. The anticipated impressions are categorized according to the type and severity of the visual impact.

Viewpoints towards the World Heritage site were not selected as the site is not visible from the beach located north of the proposed road development. This is mainly because the beach is tilted eastwards.
**METHODODOLOGY**

The visual impact assessment was carried out by comparing the current views from the World Heritage Site with the expected appearance of the proposed tunnel and causeway.

A baseline survey was conducted within the World Heritage Site and its buffer zone during which the most critical viewing areas were identified. Photographs were taken from five critical viewing points and are presented in Chapter 5 to demonstrate the visual impacts of the project. Photomontages were prepared in order to identify the visual impacts of the proposed project when looking from the beach area near the Site Museum (view point A), the coastal walkway that leads to the fort (view point B), the elevated terrain on the tell with the view of the visual corridor and the tip of Nurana Island (view point C), and from the fort itself (view points D and E). Photomontages were created by the engineers of AECOM.

The predicted visual impacts are evaluated according to the visibility of the proposed project from the designated key viewpoints, as well as the type and the scale of the visual disturbance that is likely to occur. The analysis of the visual impacts is divided into two categories: short-term impacts that are expected during the construction period (approximately two years) and long-term impacts during the existence of the causeway and tunnel.

**2.8 IMPACTS CAUSED BY VIBRATION AND COMPACTION**

**TYPE OF IMPACT**

Energy from construction processes and traffic movement is emitted into the ground in the form of stress waves. The probable impacts of vibrations created by this stress waves might include damage to the buildings and archaeological remains over and under the surface. Vibrations, especially during ground compression and excavation can disturb the stratigraphy of an archaeological site which would result in a complete loss of context and, therefore, information. In addition, archaeological remains such as pottery and gravesites are generally well-preserved in arid areas by the quasi-fluid supporting effect of fine sand. Significant levels of vibration can overcome the friction forces holding solid particles in place and lead to the liquefaction of sensitive underground soil levels. The danger here is twofold: firstly, the mixing of the substrate would destroy the stratified chronological sequence and, secondly, hollow structures supported from within sediments could collapse completely, in the worst case initiating a cascade effect causing overlying structures to lose their foundations. Built structures above ground are particularly vulnerable to ground vibration if they are structurally unsound, which is the case for the historic buildings in the survey area.
**Methodology**

Standard values for vibration impacts are usually expressed in mm/s, describing the peak particle velocity (PPV), which represents the maximum velocity of individual particles agitated by a passing stress wave. The characteristics and conditions of the underground soil stratigraphy may have profound impacts on the measured vibrations at the same distance but at different directions from the source. Therefore, the calculations utilized to measure the vibration impacts usually include the additional variables corresponding to the soil type or types. Based on these values and because no detailed data is available regarding the exact stratigraphy, for the purpose of this assessment the value of 1.2 mm/s PPV has been adopted as the acceptable limit of vibrations for structures and objects of archaeological heritage significance and 2 mm/s PPV for architectural heritage assets. The Eurocode 3 Guidelines (White et al. 2002) for steel structures describe the maximum acceptable PPV levels for various types of buildings as well as the acceptable values for human impact.

| Maximum acceptable PPV for building types (adapted from White et al. 2002) |
|-----------------------------|-------------|---------------------|
| Structures affected         | Max PPV (mm/s) |
| Buried Services             | 25           |
| Heavy Industry              | 15           |
| Light Commercial            | 10           |
| Residential                 | 5            |
| Architectural Merit         | 2            |
| Archaeological Merit        | 1.2          |

<table>
<thead>
<tr>
<th>Human disturbance level for PPV (adapted from White et al. 2002)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length and type of impact</td>
</tr>
<tr>
<td>&lt; 6 days</td>
</tr>
<tr>
<td>6-26 days</td>
</tr>
<tr>
<td>&gt; 26 days</td>
</tr>
<tr>
<td>Laboratories, hospitals, and libraries</td>
</tr>
</tbody>
</table>

**Vibrations generated by Moving Vehicles**

\[
PPV = 0.0028a \left( \frac{V}{48} \right) t \left( \frac{r}{6} \right)
\]

- \(a\) = maximum height/depth to surface fault (in mm)
- \(V\) = maximum velocity of heavy traffic (in km/h)
- \(t\) = factor for soil type
- \(p\) = 1 if surface fault occurs in both wheel tracks, 0.75 if it occurs only in one
- \(r\) = distance to receptor (in m)

Based on this, the HIA applies a benchmark of two metres to anticipate significant impact due to moving vehicles. Generally, the impact at a distance of 2 metres is already below the acceptable PPV limit of 1.2 mm/s. However, despite coming to similar conclusions, the U.S. Geological Survey in an analogous situation recommended a separation distance of at least 45 metres in between a highway and a valuable heritage site to avoid any potential for impact (King et al. 1985). Consequently, protective zones of more than two metres from moving vehicles should be considered for particularly fragile and valuable heritage resources in the study area.

**Vibrations generated during the construction**

While the vibrations caused by moving vehicles are projected to be relatively minor, the same cannot be said for the vibrations generated during the construction of the causeway and tunnel. Considerable vibrations will be generated by various kinds of heavy machinery which
will be used in the construction process. The equation used to measure the PPV for the construction equipment is as follows:

\[ PPV = PPV_{ref} \left( \frac{7.62}{D} \right)^{1.5} \]

$PPV_{ref}$ = reference PPV of the equipment at 7.62 metres distance from the source (in mm/s)

$D$ = actual distance from the source (in m)

**Impact Grading**

Based on this, the report at hand applies the following benchmarks:

At a distance of 2 metres all but a small bulldozer (under standard operation) exceed the prescribed PPV limit of 1.2 mm/s and could potentially harm sensitive structures.

At a distance of 15 metres, the use of clam shovels, vibratory rollers and all types of pile drivers by far exceed the PPV limit. Even at 30 metres distance pile driving still exceeds the vibration velocity limits.

At 50 metres distance all of the construction methods, except for the upper limits of impact pile driving, are below the prescribed limits.

At 75 metres even the upper limits of impact pile driving are below the safety benchmark.

**2.9 Impact of Noise**

**Type of Impact**

Both during the construction process and during the operation of the completed causeway, noise will be generated that can negatively influence the experience of tourists and local community members visiting Qal’at al-Bahrain or its surroundings. When passing acceptable levels, the increased noise can reduce the overall attractiveness of the site and its currently tranquil atmosphere. With reference to the proposed location of the causeway and tunnel noise has to be considered a significant impact on Qal’at al-Bahrain, both on the short-term during the construction process and on the long-term once the road is operating.

**Methodology**

With regard to the evaluation of noise during the construction phase of the causeway and tunnel the impact magnitude can be calculated based on the machinery used. The below table provides an overview of some machineries and their typical noise level during operation and how the noise attenuates over distance.

The type of surface impacts the transmission and attenuation of the sound waves, which is relevant for this study not only because of the tidal movement but also because the bay is planned to be drained during the time of construction. Thus, the sea floor, made of sand and fossilized coral, is exposed. For this HIA, a reduction ratio of 3 dB(A) per doubling of distance on ‘hard’ surfaces (water, concrete) and 4.5 dB(A) per doubling of distance on ‘soft’ surfaces (normal unpacked earth) is assumed.
The assessment of long-term noise impacts intends to measure the expected ‘line’ noise of the proposed road. The level of noise emitted by traffic can be estimated using specialized software and equations (see below) which take into considerations various factors including the traffic flow, speed limit, road quality but also aspects such as humidity, temperature and vegetation. However, due to the limited reliable data available for this assessment, the noise levels in this HIA were calculated using the equation following the German standard RLS 90 for the distance of 25 meters from the middle of the road:

\[ L(25)m,E = 37.3 + 10 \log[Q(1+0.082P)] \]

$L(25)m,E$ – is an average noise level measurable at a distance of 25 meters from the centre of the road lane;

$Q$ – is the vehicles flow;

$P$ – is the percentage of heavy vehicles.

Information on anticipated traffic loads are fundamental for anticipating the noise impact of the development projects. The new road development is planned as a dual carriageway that caters the total traffic of Marsa Al Seef and Nurana Island for a period of about ten years until the Northern Link Road is finalized and traffic can be partially redirected.

Urban development of the islands will only start once the tunnel is in place, therefore, traffic will be very limited in the beginning and increase over time. The developer provided traffic estimates for the intermediate (2024) and ultimate (2030) phasing years. The data does not differentiate in between light and heavy vehicles. Moreover, the proposed developments of the Marsa Al Seef and Nurana Islands are predominantly residential so that the paramount majority can be considered as light vehicle trips.

<table>
<thead>
<tr>
<th>Type of Machinery</th>
<th>Noise attenuation on soft surfaces dB(A) level at a distance of... in meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backhoe</td>
<td>15* 30 60 120 240 480 960</td>
</tr>
<tr>
<td>Compactor</td>
<td>80 75.5 71 66.5 62 57.5 53</td>
</tr>
<tr>
<td>Dozer</td>
<td>85 80.5 76 71.5 67 62.5 58</td>
</tr>
<tr>
<td>Dump truck</td>
<td>84 79.5 75 70.5 66 61.5 57</td>
</tr>
<tr>
<td>Excavator</td>
<td>85 80.5 76 71.5 67 62.5 58</td>
</tr>
<tr>
<td>Front End Loader</td>
<td>80 75.5 71 66.5 62 57.5 53</td>
</tr>
<tr>
<td>Pumps</td>
<td>77 72.5 68 63.5 59 54.5 50</td>
</tr>
</tbody>
</table>

* Based on U.S. Department of Transportation 2006

<table>
<thead>
<tr>
<th>Type of Machinery</th>
<th>Noise attenuation on hard surfaces dB(A) level at a distance of... in meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backhoe</td>
<td>15* 30 60 120 240 480 960</td>
</tr>
<tr>
<td>Compactor</td>
<td>80 77 74 71 68 65 62</td>
</tr>
<tr>
<td>Dozer</td>
<td>85 82 79 76 73 70 67</td>
</tr>
<tr>
<td>Dump truck</td>
<td>84 81 78 75 72 69 66</td>
</tr>
<tr>
<td>Excavator</td>
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</tr>
<tr>
<td>Pumps</td>
<td>77 74 71 68 65 62 59</td>
</tr>
</tbody>
</table>

* Based on U.S. Department of Transportation 2006
The assumed traffic data estimates that in 2024 the maximum number of trips will be 5,742 in the morning and 6,752 in the evening. In 2030, the numbers are considerable higher due to the increase of the number of residents. The maximum number of vehicles is estimated with 15,849 in the morning and 16,697 in the evening hours.

The estimated noise generated by traffic at the distance of 25 meters from the middle of the road is 75.1 dB(A) for 6,000 vehicles per hour and 80.1 dB(A) for 16,000 vehicles per hour.

The table illustrates how the traffic noise of the source (constituted by traffic of respectively 6,000 and 16,000 vehicles/h) is attenuated over the distance on hard and soft surface.

<table>
<thead>
<tr>
<th>Distance in meters</th>
<th>Noise reduction over ‘soft’ surface (low tide)</th>
<th>Noise reduction over ‘hard’ surface (high tide)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For 6,000 vehicles/h (year 2024)</td>
<td>For 6,000 vehicles/h (year 2024)</td>
</tr>
<tr>
<td></td>
<td>For 16,000 vehicles/h (year 2030)</td>
<td>For 16,000 vehicles/h (year 2030)</td>
</tr>
<tr>
<td>15</td>
<td>75.1 dB(A)</td>
<td>80.1 dB(A)</td>
</tr>
<tr>
<td>30</td>
<td>70.6 dB(A)</td>
<td>75.6 dB(A)</td>
</tr>
<tr>
<td>60</td>
<td>66.1 dB(A)</td>
<td>71.1 dB(A)</td>
</tr>
<tr>
<td>120</td>
<td>61.6 dB(A)</td>
<td>66.6 dB(A)</td>
</tr>
<tr>
<td>240</td>
<td>57.1 dB(A)</td>
<td>62.1 dB(A)</td>
</tr>
<tr>
<td>480</td>
<td>52.6 dB(A)</td>
<td>57.6 dB(A)</td>
</tr>
<tr>
<td>960</td>
<td>48.1 dB(A)</td>
<td>53.1 dB(A)</td>
</tr>
</tbody>
</table>

Besides the surface condition, there are further factors which can influence the attenuation of noise over the distance, e.g., temperature, humidity, wind, and vegetation. However, except of vegetation these other factors were not taken into consideration due to their unstable nature. Dense vegetation can reduce noise levels by 5 dB(A) for every 30 meters of vegetation up to the maximum reduction of 10 dB(A). This was taken into account only for calculating the noise levels for those locations which are shielded from the causeway by dense palm groves.

**Parameter for Impact Assessment**

Noise calculations were carried out as described above. The impact assessment is based on recommended limits of noise levels for various environments (WHO 1999) that are comparable to heritage sites. The table below provides an overview of such limits, for example, a noise level of 60 dB(A) is already considered to disturb a guided tour, considering that the sound pressure level of normal speech is about 50 dB(A). The internationally accepted noise level according to the World Health Organization is at 45 dB(A), which is comparable to the sound pressure level in recreational areas.

<table>
<thead>
<tr>
<th>Comparable values established and value for heritage sites</th>
<th>dB(A) level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disturbance of guided tours</td>
<td>60</td>
</tr>
<tr>
<td>Outdoor living areas, serious annoyance</td>
<td>55</td>
</tr>
<tr>
<td>Outdoor living areas, moderate annoyance</td>
<td>50</td>
</tr>
<tr>
<td>Individual recreation and relaxation, moderate annoyance</td>
<td>45</td>
</tr>
<tr>
<td>Museum, library, exhibition, moderate annoyance</td>
<td>40</td>
</tr>
</tbody>
</table>
The crucial parameter for the impact assessment is the relative location of the heritage asset to the source of noise. Based on the recommendation of the World Health Organisation above and comparative data, the following grading of impact was developed.

<table>
<thead>
<tr>
<th>Grade of Impact</th>
<th>Noise level in dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>≥60</td>
</tr>
<tr>
<td>Moderate</td>
<td>50-59</td>
</tr>
<tr>
<td>Minor</td>
<td>40-49</td>
</tr>
<tr>
<td>Negligible</td>
<td>25-39</td>
</tr>
<tr>
<td>No change</td>
<td>≤24</td>
</tr>
</tbody>
</table>

2.10 Impact of Air Pollution and Dust

Type of Impact

For archaeological sites and historic buildings the impact of dust can be considered to be related mainly to the aesthetic appearance (Saiz-Jimenez 1992). Particularly in close proximity to transport infrastructure, static surfaces are vulnerable to the accumulation of a black crust. To maintain the value of known heritage structures, surface layers would need to undergo a regular cleaning exercise. While the maintenance of antiquities in such a situation can often reduce serious impacts, the presence of hydrocarbons and heavy metals and the added abrasive effect of particulate matter may lead to irreparable damage to particularly porous building materials.

Methodology of Impact Assessment

The health and environmental impacts of particulate matter are well documented and the design of automobiles has been heavily adapted to minimize its release. Despite this, it remains a significant problem in urban and recreational areas. The fine particulate matter released from vehicles is typically composed of carbon, hydrocarbons and heavy metals including chromium, nickel, copper, iron, lead, and manganese (Rodriguez Navarro and Sebastian 1996).

Rodriguez Navarro and Sebastian (1995) demonstrated that an accretion of carbon and heavy metal causes decay in limestone building materials through a catalysed fixation of atmospheric SO₂. Equations (1) to (3) describe the catalytic oxidation of tropospheric sulphate to sulphite, which in the presence of water in the form of precipitation or humidity forms hydrogen sulphate acid. This acid then reacts with the calcium in limestone to form gypsum and produces CO₂, effectively eating away at a limestone façade.

\[
\begin{align*}
(1) & \quad 2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3 \\
(2) & \quad \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 \\
(3) & \quad \text{H}_2\text{SO}_4 + \text{CaCO}_3 \rightarrow \text{CaSO}_4 \cdot \text{H}_2\text{O} + \text{CO}_2
\end{align*}
\]

Surfaces of buildings and archaeological sites therefore have to be regularly cleaned in order to reduce the corrosive process. However, even the most adapted cleaning processes have an erosive impact. Maintenance and cleaning methods available for removal of black crust can be mechanical and/or chemical. In both cases a thin layer of stone is usually removed from the façade along with the intrusive black crust.
(Saiz-Jimenez 1992), which causes long-term reduction of the archaeological remains or built fabric and can therefore not be conducted on very sensitive historical structures.

It is challenging to classify the impact of air pollution because it depends not only on the distance to the road but a variety of other factors. Wind, for instance, can increase the level of particulate matter at distances where it normally does not reach or where there are usually lower concentrations. In contrast, rain or humidity usually lower particulate matter levels in the air. However, for the purpose of easier assessment this HIA will follow an impact grading based on Adams (2015), who categorized three impact zones according to the distance of the source.

Major change is expected in areas located in a distance of up to 50 metres to the road, because concentrations of particulate matter are extremely high in the road’s direct vicinity.

Moderate change is expected in those areas located 50 to 150 metres to the road, because concentrations of particulate matter are still significantly high.

Minor change is expected in 150 metres to 450 metres from the road because particulate matter levels are still elevated.

Negligible change is expected in 450 metres to 2500 metres distance. In this intermittently impact zone the levels of particulate matter vary according to weather conditions and can show very low to slightly elevated levels of particulate matter in the air.

No change is expected beyond a distance of 2500 metres as particulate matter is unlikely to travel that far.

2.11 IMPACT OF Siltation

Type of Impact

Siltation is a common side effect of land reclamations and refers to the pollution of water by increased concentration of suspended sediments and increased accumulation of fine sediments on sea bottoms. It covers underwater archaeological remains and buries them under a thick layer of silt. Increased concentrations of sediments in the water may also affect fish behavior and can hence have an impact on fishing.

Methodology

The impact assessment is mainly based on visual analysis and the comparative analysis of data from similar sites. Existing references that define sedimentation processes during reclamation work were reviewed, such as the study on the effects of reclamation sedimentation on coral reefs in Singapore (Doorn-Groen and Foster 2007). These were reviewed in order to identify the possible extent to which sediment disperses from around reclamation sites and the potential impact this has on underwater archaeological resources. The asset’s relative location to the planned reclamation area forms a crucial parameter in estimating the impact severity.

Future heavy siltation can be expected within a radius of 200 metres from the reclamation which is considered moderate change.
Sites that are located at a distance of 200 to 400 metres from the planned reclamation are subject to minor change depending on the hydrodynamics. They are usually exposed to a lower intensity of siltation.

Sites that are located at a distance of at least 400 metres from the planned reclamation are subject to negligible change due to an even lower intensity of siltation.

Sites are not likely to be impacted by siltation if they are located at a distance of at least 600 metres from a planned development, or in a location with no hydrodynamic stream connection.

2.12 Geophysical Investigations
In previously conducted HIA's the impact on the aquifer was of major concern because the damage to the aquifer and resultant rise of salinity levels of the groundwater would lead to major destruction of heritage resources including some that contribute to the OUV of the World Heritage site. Further concerns were related to the potential existence of hidden underwater archaeological remains in the area foreseen for development. The client therefore commissioned geophysical investigations aiming to determine if the underlying fresh water aquifer would have an influence on the proposed construction depth of the tunnel and to clarify if there are any archaeological remains buried in the sea bed and if an ancient in-filled channel passes through the area foreseen for development. Besides that, shear wave data was also collected during the field works to be processed at the detailed design stage to provide stiffness values at the tunnel depth, which will help to finalize the tunnel design at a later stage.

The geophysical surveys were commissioned using the Gulf Centre for Geophysical and Water Consulting (GCGC) including Electrical Resistivity Tomography (ERT), seismic refraction, and Seismic Multichannel Analysis of Surface Waves (MASW). The bay of Qal’at al-Bahrain is characterized by a very shallow water depth and strong tidal movements. The seismic surveys therefore were mainly land based and were designed to be acquired around the tidal movements at the site. The land seismic surveys (refraction and MASW) were conducted by following the tide out as more land was exposed. The three parallel alignment lines were conducted to approximately 75% completion in this manner. The remaining section of alignment closest to Nurana Island, which was always covered in water, was conducted from a boat which required different equipment and acquisition methods.

To investigate the influence of the fresh water aquifer the electrical resistivity survey was conducted from a suitable vessel around the daily high tides. The marine electrical resistivity method requires a 70 metres electrode cable to be towed behind the vessel which inputs an electrical current into the water column and the potential difference recorded. The entire survey data set was collected from the vessel and good coverage was attained. A small section, (approximately 100 metres) of the northernmost alignment profile at the south of Nurana Island was not possible to survey due to the tight site conditions.
ERT was proposed to identify variations in ground resistivity associated with changes in groundwater composition and/or lithology. The results provide 2D sections of resistivity that can be interpreted in terms of stratigraphy and the hydro-geological conditions of the site. They may also provide clues to geological structures such as faults, fracture zones, clay-enriched areas, depth to bedrock, and dissolution features.

Seismic refraction (onshore and offshore) was used to identify disturbed areas that might be archaeological and to provide geological/geotechnical information.
Masw (onshore and offshore) was also chosen to identify disturbed areas that might be archaeological and to provide geological/geotechnical information. Though Masw data was acquired during the survey, it has not been processed at this stage. It can however be presented at a later stage.

Aecom’s in-house geophysicists undertook a robust quality assessment of all the raw data acquired from the GCGC and determined the reliability of the sub-contractor’s interpretation based on the data quality. It is considered that the data quality is adequate enough to make a considered interpretation of the data set.

Furthermore, the results of the geophysical surveys were correlated with available borehole logs revealing the ground conditions encountered during various investigations carried out in the near-shore marine environment of Bahrain. The purpose is to ascertain the variability in the nature of ground strata between un lithified sediment and lithified rock with depth. More detailed information can be found in the reports of Aecom and GCGC, both annexed to this HIA, and in Chapter 4 concerning the underwater archaeological heritage as well as in Chapter 5 concerning the aquifer.

2.13 Hydrodynamic Modelling

Aecom conducted hydrodynamic (flushing) modelling to establish the baseline conditions of the hydrodynamic and water exchange characteristic of the area and assess the impact of the proposed tunnel and causeway on the existing conditions.

For the baseline conditions, the existing Nurana-Marsa causeway has no openings. With the presence of the solid causeway, the flooding and ebbing tides generally follow a north-south movement on both sides of the development. The basin is open to the east for direct water exchange and is blocked by the existing Nurana-Marsa Causeway on the west. Due to the blockage, a general north-south movement exists as the concentration flushes with the flooding and ebbing tides. As seen with the tracer, areas of high concentration remain in the small lagoon north of Bahrain Fort and in the semi-enclosed area formed by the fishing harbour and the land boundary. High (maximum) concentrations of 86% remain in the semi-enclosed areas after ten days. However, based on the
PIANC guideline for flushing, the average concentration of the tracer ultimately flushes in two days, therefore the flushing of the basin is ‘good’.

In the second scenario the model assumes that the existing Marsa/Nurana transmission causeway is fully developed and has provisions to establish water exchange (e.g. culverts), which are modelled as simple openings distributed evenly along the causeway. Post-construction of the causeway/tunnel and improvement of the Marsa/Nurana causeway, the flushing capability of the existing basin improves and drops below two days, which is still within the limits of the ‘good’ flushing criteria. The causeway link to the tunnel starting from the southern edge of the Nurana development forms a curved arm and a dead-end at the point where it meets the existing Nurana landform. However, this area faces east, which is the same direction of the ebbing currents. Therefore, it was noted that this area flushes well in less than a day and does not cause any stagnant zone.
2.14 CONSULTATIONS

Various personnel of governmental authorities and Manara and AECOM were consulted to obtain information required for the HIA. Think Heritage! would like to express its sincere gratitude for all information provided and the open cooperation including significant support in coping with the limited timeframe available to carry out this HIA.

The Bahrain Authority for Culture and Antiquities was consulted regularly. In addition, this report is significantly informed by previous consultations and cooperation that took place during the HIA for the N-Road Development in 2012 and 2013 and the Rapid HIA in 2015 including consultations of local residents, the Ministry of Works, Municipalities Affairs and Urban Planning, and the Agricultural Engineering and Water Resources Directorate. Public hearings were not foreseen in the scope of this HIA, even though Think Heritage! would have preferred to have the chance to conduct the impact assessment in a more participatory fashion.
3. Qal’at al-Bahrain World Heritage Site
3. WORLD HERITAGE SITE QAL’AT AL-BAHRAIN

3.1 THE SITE AND ITS SETTING

Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun was the Kingdom’s first heritage site to be inscribed on the World Heritage List. It comprises an archaeological tell, underwater archaeological remains as well as an agricultural landscape that together provide insights into more than 5000 years of human occupation including periods in which the settlement served as capital and harbour of the Dilmun Civilization. The capital of Dilmun was known for its palm groves that thrived on fresh water springs. Numerous Sumerian mythological compositions, such as Gilgamesh, or the narrative of the Sumerian Flood refer to Dilmun as “the ‘paradise’ [...] the land of eternal life, the place where the gods send the heroes they have made immortal to enjoy happy days and a peaceful eternity, in a prosperous location, towards the Orient, the place where the sun rises, where the daylight is born” (André-Salvini 2001, p. 32).

The areas beyond the boundaries of the World Heritage site and its buffer zone are culturally rich as well. They contain numerous heritage expressions, both related to and distinct from the World Heritage property. Agricultural lands similar to those located within the World Heritage site extend to its west all along the northern coast. The northern area of Bahrain is one of the richest archaeological landscapes in the Arabian Gulf and has been continuously occupied since the 3rd Millennium BCE. It provides a deep insight into more than 5000 years of historical changes in the Gulf thanks to Bahrain’s strategic position and its favourable hydrological conditions. From the early settlements of Dilmun on to the Kassite, Babylonian, Achaemenid, Tylos and Parthian periods and then further on, to the early Islamic period, the middle ages and the Portuguese era, Bahrain has retained unique archaeological account of each historic period (Kervran, Hiebert, Rougeulle 2005, p. 413ff.). Apart from archaeological resources, there are several architectural heritage features that testify to the more recent history of Bahrain and its cultural identity. Possibly most relevant to the contemporary cultural identity are the living intangible heritage expressions that thrive in the surroundings of the World Heritage site. The most prominent intangible expressions include agricultural and fishing practices that date back to antiquity, several crafts that rely on organic resources from the palm groves, the cultivation and production of medical herbs and substances as well as religious practices.

The site and its setting are not only constituent to the cultural identity of local communities but are also of highest scenic quality and accessible to the public. Particularly the walkways within the World Heritage site, the seashore north of the Site Museum, which is located in the eastern buffer zone of the World Heritage property, as well as the museum’s seaside café are highly frequented by local and foreign visitors.

3.2 REVIEW OF UNESCO DECISIONS

The World Heritage Site Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun was inscribed on the UNESCO World Heritage List in 2005 (UNESCO 2005) during the 29th Session of the World Heritage Committee in Durban, South Africa. Since then, the site has been discussed by the World Heritage Committee almost on an annual basis as part of the State
of Conservation Reports. Initially, as result of the inadequacy of its first Management Plan submitted with the nomination dossier, the focus of the World Heritage Committee was on management mechanisms and strategic planning for the site and its buffer zone.

Starting from as early as 2006, the eminent threat posed by the so-called North Star development (UNESCO 2007) was focused upon, and the UNESCO World Heritage Committee, with the assistance of the UNESCO World Heritage Centre and ICOMOS explored ways and means that could provide opportunities for development in the vicinity of the World Heritage Site which would not affect its Outstanding Universal Value (OUV). Subsequently a first extension of the site boundaries and of the buffer zone was requested so as to identify the site’s underwater components and protect the visual connections between land and sea. Subsequently, a Royal Decree was issued for moving the North Star Project to an alternative location outside the designated visual corridor and reclamation for this project has, in the meantime, been undertaken under its revised name Nurana. This HIA deals with the most recent road connectivity development proposal for Nurana.

The first extension file, requested by the World Heritage Committee, was formally submitted by the Kingdom of Bahrain in 2008 and after its acceptance, the World Heritage Committee included the previously unprotected underwater archaeological assets of the site – the access channel and former light house (sea tower) – as the second key component of the World Heritage Site (UNESCO 2008). In 2011, the official Statement of Outstanding Universal Value was adopted, which now forms the key basis of value attribution and management guidance.

During the extensive studies for the N-Road HIA it became apparent that the OUV is not fully represented by the existing property components and that the palm groves and agricultural areas surrounding the archaeological tell should be included within the property boundaries. Subsequently, a second minor boundary extension file was formally submitted to UNESCO in 2014 and approved accordingly during the World Heritage Committee’s 38th Meeting in Doha, Qatar.

The subsequent paragraphs summarise the discussions held and decisions reached at each step of the process of inscription and management of the World Heritage site. These include extracts from previous decisions taken by the World Heritage Committee, with the exception of the decision related to its Statement of Outstanding Universal Value, which is included in the following sub-chapter.

2005: INSCRIPTION

In 2005 the World Heritage Committee decided to grant Qal’at al-Bahrain, which was then called “Qal’at al-Bahrain Archaeological Site”, UNESCO World Heritage status under criteria (ii), (iii) and (iv) (UNESCO 2005). In its decision the World Heritage Committee further requested the submission of a complete management and conservation plan by 1st February 2006 and stipulated the importance of refraining from approving land reclamations anywhere in front of the site in order to protect the visual integrity of the property. The full Decision No. WHC-05/29COM/8B.26 adopted by the World Heritage Committee reads as follows:
“The World Heritage Committee,

1. Having examined Documents WHC-05/29.COM/8B, WHC-05/29.COM/8B.Add 2 and WHC-05/29.COM/INF.8B.1,

2. Inscribes Qal’at al-Bahrain Archaeological Site (Bahrain) on the World Heritage List on the basis of cultural criteria (ii), (iii) and (iv):

Criterion (ii): Being an important port city, where people and traditions from different parts of the then known world met, lived and practiced their commercial activities, makes the place a real meeting point of cultures – all reflected in its architecture and development. Being in addition, invaded and occupied for long periods, by most of the great powers and empires, left their cultural traces in different strata of the tell.

Criterion (iii): The site was the capital of one of the most important ancient civilizations of the region - the Dilmun civilization. As such this site is the best representative of this culture.

Criterion (iv): The palaces of Dilmun are unique examples of public architecture of this culture, which had an impact on architecture in general in the region. The different fortifications are the best examples of defence works from the 3rd century BC to the 16th century AD, all on one site. The protected palm groves surrounding the site are an illustration of the typical landscape and agriculture of the region, since the 3rd century BC.

3. Requests the State Party of Bahrain to submit by 1st February 2006 complete management and conservation plans for the property;

4. Also requests the State Party to refrain from approving any land reclamation or construction in the sea anywhere in front of the site and that the new construction on existing reclaimed land should be checked up as to protect the visual integrity of the site and to maintain the principal sight lines of the area nominated;

5. Further requests the State Party to firmly integrate the conservation and consolidation of the fortress and of the excavated area in both the management and conservation plans;

6. Further requests the State Party that a report on the progress and implementation of the above-mentioned recommendations be submitted for examination by the Committee at its 30th session (Vilnius, 2006).”

(UNESCO 2005, 29 COM 8B.26)

An important point to note in this decision is that the World Heritage Committee seemed to recognise the risk that reclamation activities and nearby developments could pose to the OUV despite absence of any reference to specific planned projects in the nomination dossier.

2006: NORTH STAR DEVELOPMENT AND KARBABAD FISHING HARBOUR

Less than six months after the formal recognition of the World Heritage Status, the governmental heritage authority (then within the Ministry of Information, later divided into the Ministry of Culture and the National
Authority for Information and Media Affairs, now Bahrain Authority for Culture and Antiquities) was informed about a proposed project planned to be located in the offshore areas and intertidal zone north of Qal’at al-Bahrain. The proposed project included the North Star development and several causeway projects to link the North Star development with the New Northern Town (now referred to as al-Madina al-Shamaliya [AMAS]) as well as the development of a fishing harbour for Karbabad village. At the invitation of the Directorate of Heritage and Archaeology, a joint UNESCO/ICOMOS Advisory Mission visited Bahrain in 2006 and negotiated the preservation needs for the World Heritage property and the potential for development in the sea with the relevant national authorities. At the time, Bahrain was in the process of developing a National Vision 2030 and National Development Strategies, which meant that the UNESCO and ICOMOS representatives could have meetings with all authorities concerned, including the Ministry of Municipalities and Agriculture (later renamed Ministry of Municipality Affairs and Urban Planning, now Ministry of Works, Municipalities Affairs and Urban Planning), the former Ministry of Works and its Special Projects Unit, The Economic Development Board, which coordinated the National Strategy initiatives, and their consultants from Atkins and McKinsey as well as representatives of the Royal Court. Based on the report of agreements provided by the Kingdom of Bahrain and the mission report of the visiting experts, the World Heritage Committee decided in July 2006 at its 30th Session in Vilnius, Lithuania, to delineate a visual corridor, in which any land reclamation in the sea in front of the property would be prohibited in order to preserve its visual integrity, and which has been developed by the State Party in consultation with the World Heritage Centre and ICOMOS during the mission of June 2006, which identified eight defining geographic coordinates.

“The World Heritage Committee,

1. Having examined Document WHC-06/30.COM/7B,

2. Recalling Decision 29 COM 8B.26, adopted at its 29th session (Durban, 2005),

3. Commends the State Party on its commitment for the protection and conservation of the World Heritage property;

4. Notes that priority has been given to the resolution of the main threats which are likely to affect the property (the North Star and causeway projects) and that a revision of the development plan of the northern coast of the country and a zoning plan aiming at controlling the height of the buildings in the areas surrounding the property are currently being discussed by the responsible authorities;

5. Welcomes the proposal to delineate a visual corridor, in which any land reclamation in the sea in front of the property would be prohibited in order to preserve its visual integrity, and which has been developed by the State Party in consultation with the World Heritage Centre and ICOMOS during the mission of June 2006, which identified eight defining geographic coordinates;

6. Supports the possible replacement of the foreseen causeway by a bridge and invites the State Party to consult the World Heritage Centre and ICOMOS on the design of this future project;

7. Invites the State Party to pursue the discussions described in point 4.
here above in order to identify the most appropriate solutions to be included in the future revised development plan;

8. Invites the State Party to submit a proposal for a modification of the boundaries of the inscribed property according to the procedures indicated in paragraphs 163 to 165 of the Operational Guidelines, for revising the core zone to include the ancient channel and the sea tower, and for revising the buffer zone to include the visual corridor as identified in point 5 above;

9. Requests the State Party to officially notify the World Heritage Centre confirming the decision to abandon or relocate the North Star project and endorsing the delimitation of the “visual corridor”, as identified in point 5 here above;

10. Also requests the State Party to report to the World Heritage Centre, by 1st February 2007, on the progress on the application of the measures described in points 5, 6, 7 and 8 above, and also on the elaboration of the management and conservation plans, the definition of the legislative framework for the protection of the World Heritage property, the archaeological survey in the most threatened areas surrounding the core zone and the response to the issues relating to the future re-housing of part of the local community, for examination by the World Heritage Committee at its 31st session in 2007.” (UNESCO 2006, 30 COM 7B.49)

The delineation of the visual corridor mentioned in Paragraph 5 and the support, in principle, for a bridge through the visual corridor mentioned in Paragraph 6 are the key agreements of the decision. The bridge was accepted on the condition that no causeway would be built in the visual corridor or the buffer zone and that the bridge would be positioned at least 3000 metres away from the current shore. In Paragraph 8, furthermore, the World Heritage Committee requested the Kingdom of Bahrain to submit a proposal for boundary extension of the World Heritage Site to include the sea components of the property and formally designate the visual corridor as an extended buffer zone.

2006: NAME CHANGE

In the same year the World Heritage Committee endorsed a change of name of the World Heritage property towards its present name “Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun” to highlight its essential sea components (UNESCO 2006, 8B.1). This request was submitted by the national authorities, who felt that the essential components of the World Heritage property could be more easily communicated with the addition: Ancient Harbour and Capital of Dilmun. As many visitors and Bahrainis continued to mistake the reconstruction of a Portuguese fortress at the same location as the constituting element of World Heritage Value and the revised name was also intended to divert attention from this fortress element. The complete decision WHC-06/30COM/8B.1 reads as follows:

“The World Heritage Committee,

1. Having examined Document WHC-06/30.COM/8B,

2. Approves the proposed name change to the Qal’at al-Bahrain Archaeological Site as proposed by the Bahrain authorities. The name of
the property becomes Qal‘at al-Bahrain - Ancient Harbour and Capital of Dilmun in English and Qal‘at al-Bahreïn - ancien port et capitale de Dilmun in French.” (UNESCO 2006, 8B.1)

2007: FOLLOW UP AND ASSURANCE

In 2007, the Ministry of Information submitted a progress report and draft management plan, which highlighted essential management aspects and regulations concerning the future protection of the buffer zone. The requested dossier for the modification of boundaries to the property was not yet finalised since underwater surveys aimed at identifying the exact location of relevant features were still on-going. The UNESCO World Heritage Committee, in response and considering its discussions during the previous year, reiterated its request to the Kingdom of Bahrain to present a proposal for boundary modifications of the World Heritage site to revise the core zone of the World Heritage site to include the ancient channel and the sea tower, and the buffer zone to include the visual corridor. The complete decision WHC-07/31COM/7B.60 reads as follows:

“The World Heritage Committee,

1. Having examined Document WHC-07/31.COM/7B,

2. Recalling Decision 30 COM 7B.49, adopted at its 30th session (Vilnius, 2006),

3. Notes with satisfaction the progress achieved by the State Party in the implementation of a series of important measures aiming at conserving and protecting the property;

4. Invites the State Party, as mentioned in Decision 30 COM 7B.49, to submit, before 1st February 2008, a proposal for a modification of the boundaries of the inscribed property according to the procedures indicated in Paragraphs 163 to 165 of the Operational Guidelines, for revising the core zone to include the ancient channel and the sea tower, and for revising the buffer zone to include the visual corridor, for examination by the Committee at its 33rd session in 2009;

5. Requests the State Party to send to the World Heritage Centre: a) the written official decisions and explanatory documents (maps, graphics, photos) concerning the relocation of the North Star Project and fishing harbour, as well as the final decisions related to the re-housing of part of the local community, b) the decision to replace the portion of the connecting road located off the northern coast by an appropriate bridge, c) the approved National Planning and Development Strategies for the implementation of the revision of the urban development and zoning plan, d) the legislative framework for the protection of the World Heritage property, e) the draft management and conservation plans;

6. Also requests the State Party to submit, by 1st February 2009, a progress report on the implementation of the above recommendations to be examined by the World Heritage Committee at its 33rd session in 2009.” (UNESCO 2007, 31 COM 7B. 60).

In addition to various other aspects, this decision reiterated the necessity of relocating North Star Project and the need to also relocate the local community of Qala’a Village, based on their own request, to a nearby location. Furthermore, The World Heritage Committee expressed its
appreciation for the draft of the National Development Strategy, which had been submitted and also requested to be made available the final approved version.

2008: EXTENSION OF THE WORLD HERITAGE SITE BOUNDARIES
The extension request was submitted by 1 February 2008 and approved by the World Heritage Committee in the same year. The approval further recommended that if subsequent surveys by underwater archaeological teams reveal additional evidence which may allow the linking of the two parts of the property, a second extension request should be submitted. Decision No. WHC-08/32COM/8B.54 was adopted with the following wording:

“The World Heritage Committee,

1. Having examined Documents WHC-08/32.COM/8B.Add and WHC-08/32.COM/INF.8B1.Add,

2. Approves the minor modification to the property, and the enlarged buffer zone, of Qal‘at al-Bahrain: Ancient Harbour and Capital of Dilmun, Bahrain;

3. Recommends that if subsequently surveys by underwater archaeological teams reveal evidence to link the two parts of the property, the State Party should consider a further enlargement of the property.” (UNESCO 2008, 32 COM 8B.54)

2009: PROGRESS ON MANAGEMENT PLAN
In the following year, the Committee expressed satisfaction about the progress made in the implementation of a series of important measures, in particular the revised draft of the management and conservation plan, which was submitted the same year. The Committee requested that the efforts be continued and that a finalised management and conservation plan be submitted by 2011. The full text of the decision WHC-09/33COM/7B.53 is as follows:

“The World Heritage Committee,

1. Having examined Document WHC-09/33.COM/7B,

2. Recalling Decisions 31 COM 7B.60 and 32 COM 8B.54, adopted at its 31st (Christchurch, 2007) and 32nd (Quebec City, 2008) sessions respectively,

3. Notes with satisfaction the progress achieved by the State Party in the implementation of a series of important measures aiming at conserving and protecting the property;

4. Requests the State Party to provide, by 1 February 2011, three printed and electronic copies of the final integrated management and conservation plan, for review by the World Heritage Centre and the Advisory Bodies.” (UNESCO 2009, 33 COM 7B.53)

However, it should be noted that the requested finalised management and conservation Plan was not submitted in 2011, and in December 2012,
Think Heritage! was requested by the Ministry of Culture to prepare a strategic management plan for the World Heritage site and its buffer zone, which was finalised and adopted in 2013.

2011: NEW STATEMENT OF OUTSTANDING UNIVERSAL VALUE
In 2011, the World Heritage Committee adopted a revised and extended Statement of Outstanding Universal Value, which is presented in chapter 3.4.

2013: STATE OF CONSERVATION REPORT
At the request of the Kingdom of Bahrain, a joint World Heritage Centre/ICOMOS advisory mission was carried out from 27 to 30 July 2012 in order to assess the potential impact of the new infrastructure development to be carried out by the Ministry of Municipalities Affairs and Urban Planning, the “N-Road” project. The proposed route was expected to cross through the buffer zone of the inscribed property, 50 meters from its boundary, where numerous unexcavated archaeological areas and palm grove plantations are located.

The advisory mission concluded that the proposed construction would constitute a threat to the site’s OUV, however, the mission recognised the importance of transportation and connectivity between the Capital and the Northern sectors. Several recommendations were made, including the need to carry out an Environmental Impact Assessment (EIA), including a Heritage Impact Assessment (HIA).

The State of Conservation Report presented to the Committee in 2013 includes the results of the EIA and HIA, which had led to discussions between the concerned authorities in view of developing alternative routings. The decision WHC-13/37.COM/7B.Add adopted by the Committee reads as the following:

“The World Heritage Committee,

1. Having examined Document WHC-13/37.COM/7B.Add,

2. Recalling Decisions 32 COM 8B.54 and 33 COM 7B.53 adopted at its 32nd (Quebec City, 2008) and 33rd (Seville, 2009) sessions respectively,

3. Commends the State Party for its commitment to the conservation and protection of the Outstanding Universal Value of the property including its conditions of integrity, and for its close cooperation with the World Heritage Centre and the Advisory Bodies towards the identification of alternative solutions of the route of the N-Road;

4. Invites the State Party to continue its efforts towards the protection of the property as well as its cooperation with the World Heritage Centre and the Advisory Bodies;

5. Approves the request of the State Party to explore options for the location of the bridge foreseen to cross the visual corridor within a distance ranging from 2 to 3 km to the shore and strongly recommends that priority be given to the options which would provide the maximal distance between the bridge and the shore;

6. Requests the State Party to submit the results of the studies carried out concerning the location and design of the proposed bridge to the World
Heritage Centre for review by the Advisory Bodies before a final decision is taken;

7. Reiterates its request to the State Party to finalize the integrated management and conservation plan for the property and submit, by 1 February 2014, three printed and electronic copies of this plan, for review by the World Heritage Centre and the Advisory Bodies;

8. Also requests the State Party to submit to the World Heritage Centre, by 1 February 2015, an updated report on the state of conservation of the property and the implementation of the above, for consideration by the World Heritage Committee at its 39th session in 2015.” (UNESCO 2013, 37 COM 7B.47)

2013: INTEGRATED CONSERVATION AND MANAGEMENT PLAN FOR QAL’AT AL-BAHRAIN

In 2013, the Management Plan for Qal’at al-Bahrain World Heritage Site was finalised by Think Heritage! and approved by the Ministry of Culture. It was prepared for a period of five years (2013-2018). The plan is structured in five strategic objectives: 1. Legal and De Facto Protection, 2. Conservation Management, 3. Administration and Finance, 4. Research, and 5. Interpretation, Presentation and Promotion. The strategic objectives are followed by a set of action and monitoring plans.

2014: MINOR BOUNDARY MODIFICATION

As requested by UNESCO, a second minor boundary modification was prepared in order to safeguard the previously unprotected attributes associated with the agricultural gardens and palm groves and, by doing so, include all attributes expressing OUV within the property. The modification hence consists of an extension of the World Heritage site’s boundaries to include the palm groves and agricultural areas around the archaeological site and proposes a revised buffer zone adequate to the protection of the enlarged property. The decision WHC-14/38.COM/8B.Add reads as follows:

“The World Heritage Committee,

1. Having examined Documents WHC-14/38.COM/8B.Add, and WHC-14/38.COM/ INF.8B1.Add,

2. Approves the proposed minor modification to the boundary and to the buffer zone of Qal’at al-Bahrain – Ancient Harbour and Capital of Dilmun, Bahrain;

3. Recommends that the State Party provide to the World Heritage Centre:

   a) A copy of the amended Heritage Law, Decree 11 of 1995, which was planned for promulgation in the second quarter of 2014,

   b) An indication of when the current draft Memorandum of Understanding (MoU) that has been created between the Ministry of Culture and the owners of the properties located within the area designated for the extension of the World Heritage property will be concluded and the final copy once it has been concluded,
c) Land use and Zoning regulations which are subcategories of the Physical Planning Legislation of 1994 once they are finalized at their forthcoming revision in late 2014.” (UNESCO 2014, 38 COM 8B.49)

2015: STATE OF CONSERVATION REPORT

After the completion and submission of the Rapid HIA, which analyses the potential impact of the tunnel and bridge and Karranah on-land road and bridge, the World Heritage Committee is taking note of its results and, at the same time, is concerned about the potential negative impacts and hence requests additional studies. Because of its concerns regarding the development pressure on land in the water, the World Heritage Committee requested a state of conservation report to be submitted to the World Heritage Centre in December 2016. The final adopted decision reads as follows:

“The World Heritage Committee,

1. Having examined Document WHC-15/39.COM/7B.Add,

2. Recalling Decisions 37 COM 7B.47 and 38 COM 8B.49, adopted at the 37th (Phnom Penh, 2013) and 38th (Doha, 2014) sessions respectively,

3. Notes the completion and implementation of the comprehensive management and conservation plan;

4. Also notes the delay in the reviewing of the proposed revision of the Heritage Law, as well as in the signature of memoranda of understanding with the owners of lands located within the area designated for the extension of the World Heritage property, and in the revision of land-use and zoning regulations and requests the State Party to provide the World Heritage Centre with information on these matters as soon as progress has been made;

5. Takes note of the results of the Rapid Heritage Impact Assessment (HIA) on the road connectivity development for Nurana Island and in light of potential negative impact, also requests that the HIA is reviewed on the basis of additional studies recommended by this Rapid HIA to inform the development of design options and submitted to the World Heritage Centre, for review by the Advisory Bodies, prior to any decision concerning the option to connect Nurana Island to the mainland;

6. Expresses its concern regarding the important pressure put on the property by the urban development taking place around it and invites the State Party to assess the impacts of proposed long-term development of the setting of the property, including through the approach carried by the Recommendation on the Historic Urban Landscape;

7. Further requests the State Party to submit to the World Heritage Centre, by 1 December 2016, an updated report, including a 1-page executive summary, on the state of conservation of the property and the implementation of the above, for examination by the World Heritage Committee at its 41st session in 2017.” (UNESCO 2015, 39 COM 7B.48)
2017: STATE OF CONSERVATION REPORT

The updated state of conservation report from 2016 stated that Bahrain would opt for the tunnel option, which satisfied the World Heritage Committee as it considered the tunnel the only feasible option for the road connectivity development of Nurana. The Committee hence requested an updated and comprehensive HIA for that matter and a state of conservation report to be submitted by 1 December 2018. Besides the road connectivity issues, the Committee was also concerned about the progress of implementing the management plan as well as revision of the Heritage Law which was not finalised yet. The final decision reads as follows:

“The World Heritage Committee,

1. Having examined Document WHC/17/41.COM/7B.Add.2,

2. Recalling Decision 39 COM 7B.48, adopted at its 39th session (Bonn, 2015),

3. Notes the progress achieved by the State Party in the implementation of the Comprehensive Conservation and Management Plan (2008-2013);

4. Also notes with satisfaction that the tunnel has been adopted as the only feasible option for the road connectivity development for Nurana Island;

5. Further notes that the revision of the Heritage Law is still under revision and invites the State Party to consider this revision as a priority, particularly to enable the signature of memoranda of understanding with the owners of lands located within the area designated for the extension of the property, in order to improve its management and conservation;

6. Urges the State Party to implement fully the Comprehensive Conservation and Management Plan and to include within it the proposals developed by the Bahrain Authority for Culture and Antiquities (BACA) for a vision document, new zoning codes, and requirements for Heritage Impact Assessments (HIAs);

7. Encourages the State Party to pursue the use of the approach carried by the Recommendation on the Historic Urban Landscape as well as the urban study carried out by the Directorate of Urban Planning at national level in order to conduct a wider reflection on the stakes related to the urban development of the areas surrounding the property;

8. Requests the State Party to submit to the World Heritage Centre, as soon as they are available:

   a) The results of the updated HIA carried out by the developer of the road connectivity development for Nurana Island, in line with the ICOMOS Guidance on HIAs for Cultural World Heritage Properties,

   b) The results of the consultation based on the proposal elaborated by BACA aiming at reinforcing the protection of the property’s attributes, including a vision document for the integrated management of the property and its buffer zone, a
new zoning code, specific requirements at the parcel level and a call for HIA for big scale projects around the property;

9. Also requests the State Party to submit to the World Heritage Centre the results of the first review of the Comprehensive Conservation and Management Plan as soon as it has taken place;

10. Further requests the State Party to submit to the World Heritage Centre, by 1 December 2018, an updated report on the state of conservation of the property and the implementation of the above, for examination by the World Heritage Committee at its 43rd session in 2019.” (UNESCO 2017, 41 COM 7B.75)

3.3 DELIMITATION OF THE PROPERTY BOUNDARIES, BUFFER ZONE AND VISUAL CORRIDOR

The World Heritage Site of Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun covers an area of 72.4 hectares and consists of: (1) the ancient tell, which corresponds to the capital city of Dilmun, (2) the underwater archaeological component comprising the access channel to the ancient harbour as well as the remains of the sea tower, and (3) the agricultural gardens and palm groves. All components are surrounded by a shared buffer zone, which includes a visual corridor extending into the sea up to a distance of 12 kilometres.

The ancient tell covers an area of approximately 16.3 hectares. It is surrounded by palm groves and gardens and opens up to the sea in its north. In the south, the tell is bordering Qalah village which consists of a narrow strip of houses. These houses were constructed in the 1970s when the residents were relocated from their houses which were situated on the tell. As a result of the low quality constructions and difficulties the residents faced with sand and erosion in Qalah village, new houses were built to the south of the present village.

The archaeological tell is elevated up to 11.2 metres from the surrounding land levels, which illustrates the enormous gathering of multi-layered archaeological materials. About 15% of the surface area of this component is now occupied by the Portuguese fortress, which was partly reconstructed in the 1980s. It re-visualises the 16th century shape of the military architecture, but does not contribute significantly to the OUV of the site.

The intertidal and underwater component of the property covers an area of 15.7 hectares. It contains a sea channel and the remains of a sea tower. The sea channel reaches the reef platform from the sub-tidal zone at a distance of approximately 1.85 kilometres off shore through an intertidal platform formed by a fossilised coral reef. The tower structure was built on the western edge of the coral reef adjacent to the channel and had probably an indicative function comparable to a lighthouse.

The buffer zone comprises an area of 1311.8 hectares. The two following tables illustrate the exact coordinates of the extent of terrestrial and maritime property areas and the buffer zone as well as of the visual corridor.
The visual corridor is a visual protection zone located within the northern part of the buffer zone. Development in the visual corridor is restricted, land reclamation is completely prohibited and bridges may only be constructed at a distance of two kilometres to the shore.

The map below indicates the boundaries of the property and the buffer zone as well as the outline of the visual corridor.
3.4 Statement of Outstanding Universal Value

The Committee adopts a Statement of Outstanding Universal Value for every new World Heritage Site. This statement of OUV summarises all attributes, including authenticity and integrity that constitute the reference values for which the property was recognised as UNESCO World Heritage. Since 2009, these statements further include a section on protection and management which outlines the key protection schemes and management processes necessary to retain the sites’ OUV in the future. The Statement of Outstanding Universal Value for Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun reads as follows:

“BRIEF SYNTHESIS

Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun is an archaeological site comprising four main elements: an archaeological tell (an artificial hill formed over time by successive occupations) of over 16 hectares, immediately adjacent to the northern coast of Bahrain; a sea tower about 1600m North-West of the tell; a sea channel of just under 16 hectares through the reef near the sea tower, and palm groves.

The palm-groves and traditional agricultural gardens surround the site within the whole area of the land component of the buffer zone, being particularly noticeable on the Western and Northern sides, but also occurring on the Eastern and South-Eastern sides. The property is situated in the Northern Governorate, in Al Qalah village district on the northern coast about 5.5 km West of Manama, the present capital of Bahrain. Qal’at al-Bahrain is an exceptional example of more or less unbroken continuity of occupation over a period of almost 4500 years, from about 2300 BC to the present, on the island of Bahrain. The archaeological tell, the largest known in Bahrain, is unique within the entire region of Eastern Arabia and the Gulf as the most complete example currently known of a deep and intact stratigraphic sequence covering the majority of time periods in Bahrain and the Gulf. It provides an outstanding example of the might of Dilmun, and its successors during the Tylos and Islamic periods, as expressed by their control of trade through the Gulf.

These qualities are manifested in the monumental and defensive architecture of the site, the wonderfully preserved urban fabric and the outstandingly significant finds made by archaeologists excavating the tell.

The sea tower, probably an ancient lighthouse, is unique in the region as an example of ancient maritime architecture and the adjacent sea channel demonstrates the tremendous importance of this city in maritime trade routes throughout antiquity. Qal’at al-Bahrain, considered as the capital of the ancient Dilmun Empire and the original harbour of this long since disappeared civilisation, was the centre of commercial activities linking the traditional agriculture of the land (represented by the traditional palm-groves and gardens which date back to antiquity and still exist around the site) with maritime trade between such diverse areas as the Indus Valley and Mesopotamia in the early period (from the 3rd millennium BC to the 1st millennium BC) and China and the Mediterranean in the later period (from the 3rd to the 16th century AD).

Acting as the hub for economic exchange, Qal’at al-Bahrain had a very active commercial and political presence throughout the entire region.
The meeting of different cultures which resulted is expressed in the testimony of the successive monumental and defensive architecture of the site including an excavated coastal fortress dating from around the 3rd century AD and the large fortress on the tell itself dating from the 16th century which gives the site its name as Qal’at al-Bahrain, together with the wonderfully preserved urban fabric and the outstandingly significant and diverse finds demonstrating a mélange of languages, cultures and beliefs. For example, a madbasa (an architectural element used to produce date syrup) within the tell is one of the oldest in the world and reflects a link to the surrounding date palm-groves, demonstrating the continuity of traditional agricultural practices from the 1st millennium BC.

The site, situated in a very strategic location, was an extremely significant part of the regional Gulf political network, playing a very active political role through many different time periods, which left traces throughout the different strata of the tell. Qal’at al-Bahrain is a unique example of a surviving ancient landscape with cultural and natural elements.” (UNESCO 2011, 35COM 8E)

CRITERIA ADOPTED

Criterion (ii): Being an important port city, where people and traditions from different parts of the then known world met, lived and practiced their commercial activities, makes the place a real meeting point of cultures - all reflected in its architecture and development. Being in addition, invaded and occupied for long periods, by most of the great powers and empires, leaved their cultural traces in different strata of the tell. Criterion (iii): The site was the capital of one of the most important ancient civilizations of the region - the Dilmun civilization. As such this site is the best representative of this culture.

Criterion (iv): The palaces of Dilmun are unique examples of public architecture of this culture, which had an impact on architecture in general in the region. The different fortifications are the best examples of defense works from the 3rd century B.C to the 16th century AD, all on one site. The protected palm groves surrounding the site are an illustration of the typical landscape and agriculture of the region, since the 3rd century BC.

INTEGRITY (2011)

With the extension of the site boundaries to include a second area within the World Heritage property, comprising the ancient sea tower and the historic entrance channel (UNESCO 2008, 32 COM 8B.54), the attributes that express the OUV are now within the property. The extension of the buffer zone, recognised by the same decision, to include the visual corridor in the bay north of the site ensures that the relationship of the two parts of the property to each other and to the sea are maintained. The integration of this buffer zone into the National Planning and Development Strategies (2030) as a development exclusion zone endorsed by a Royal Decree (November 2008) means that the exclusion corridor can only be crossed by a bridge at a minimum distance of 3 km from the shore (State Party’s SoC Report, 5 March 2009), thus ensuring that none of the attributes are threatened by development or neglect.
Apart from natural factors affecting the site through time, such as weathering, erosion, and the harsh and windy climate, there have been no great impacts on it as a result of either natural events or human actions. The many remaining structures, as excavated, are unaltered and have endured through 4 millennia, with some walls still standing to a height of 4.5m. More than 85% of the tell is original and completely undisturbed. The surrounding adjacent landscape (both terrestrial and marine) is preserved and nearby developments, most notably urban developments, have not compromised the visual or physical integrity of the property.

AUTHENTICITY (2005)

Authenticity is demonstrated by the sequence of long occupation, expressed by the depth of the original stratigraphy, which is still in-situ throughout the undisturbed part of the tell (less than 15% has been excavated). The original ensemble of structures, archaic urban fabric, tell, palm groves and marine structures still exists and can be seen today to express the OUV of the site in terms of form, materials and setting.

PROTECTION AND MANAGEMENT REQUIREMENTS (2011)


A zoning plan has been developed, in cooperation with other government departments, to control the height of surrounding buildings and the nature of future urban development, ensuring the maintenance of visual and physical integrity, including the visual corridor and marine elements added to the site by the World Heritage Committee in 2008 (32 COM 8B.54), and allowing for consultation with the managing bodies, the Directorate of Archaeology and Heritage and the Directorate of Museums in the Ministry of Culture, who monitor potential threats to the site and follow up conservation issues. The Directorate of Archaeology and Heritage needs to be consulted before any project is undertaken that threatens any archaeological site (Ministerial Order 1 of 1998).

The site is fenced with on-site security. Visitor access is managed and monitored by the new on-site museum. The museum fulfills a very important role in the presentation/interpretation of the site and raises awareness of visitors, since it has been designed specifically to highlight the features of the Outstanding Universal Value of the property and surrounding buffer zone. No current excavation is allowed, but there are plans for the management of future excavations and a programme of underwater archaeology, including survey of the ancient channel. The village community situated on the southern boundary of the tell is being moved to a new location away from the site.” (UNESCO 2011, 8E)

Although dating from 2011 and neither mentioning the late Committee decisions nor aspects of the new management plan that are relevant to the protection and management of the site, the above Statement of Outstanding Universal Values nevertheless constitutes the most essential reference in assessing heritage impact on World Heritage properties, as it defines the attributes and characteristics that make the site worthwhile for World Heritage listing and describe how these should be preserved. The ICOMOS Guidance on Heritage Impact Assessments for Cultural
World Heritage Properties highlights, that a HIA needs to “respond to the needs of World Heritage sites, through considering them as discrete entities and evaluating impact on the attributes of OUV in a systematic and coherent way” (ICOMOS 2011, p. 3). This HIA will therefore give special attention to the attributes of OUV described in the above-mentioned statement, which are also highlighted in the following.

3.5 IDENTIFICATION OF ATTRIBUTES OF OUTSTANDING UNIVERSAL VALUE

This section aims at identifying the specific attributes, which express the OUV of Qal’at al-Bahrain: Harbour and Capital of Dilmun. In order to identify these, the brief synthesis and definition of criteria in the above-quoted Statement of OUV have been analysed and related to physical features and expressions on site. The summary of this exercise is presented in the table below. It illustrates specific formulations from the brief synthesis of the Statement of Outstanding Universal Value, which capture the most critical elements of OUV and links them to specific attributes located on site.

<table>
<thead>
<tr>
<th>No.</th>
<th>Justification of OUV</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>“Qal’at al-Bahrain: Ancient Harbour and Capital of Dilmun is an archaeological site comprising four main elements: an archaeological tell (an artificial hill formed over time by successive occupations)”</td>
<td>Archaeological remains in tell; Visible features of tell in landscape</td>
</tr>
<tr>
<td>2</td>
<td>“a sea tower about 1600m North-West of the tell;”</td>
<td>Remains of sea tower</td>
</tr>
<tr>
<td>3</td>
<td>a sea channel of just under 16 hectares through the reef near the sea tower”</td>
<td>Remains of sea channel</td>
</tr>
<tr>
<td>4</td>
<td>“…and palm-groves. The palm-groves and traditional agricultural gardens surround the site within the whole area of the land component of the buffer zone, being particularly noticeable on the Western and Northern sides, but also occurring on the Eastern and South-Eastern sides.”</td>
<td>Palm groves; Traditional agricultural gardens; Irrigation channels; Traditional wells</td>
</tr>
<tr>
<td>5</td>
<td>“exceptional example of more or less unbroken continuity of occupation over a period of almost 4500 years”</td>
<td>Archaeological tell and sea components including later additions i.e. Portuguese fortress</td>
</tr>
<tr>
<td>6</td>
<td>“archaeological tell, the largest known in Bahrain, is unique within the entire region of Eastern Arabia and the Gulf as the most complete example currently known of a deep and intact stratigraphic sequence covering the majority of time periods in Bahrain and the Gulf”</td>
<td>Archaeological tell, both excavated and unknown features</td>
</tr>
<tr>
<td>7</td>
<td>“an outstanding example of the might of Dilmun”</td>
<td>Central excavation area; city wall</td>
</tr>
<tr>
<td>8</td>
<td>“and its successors during the Tylos and Islamic periods, as expressed by their”</td>
<td>Central excavation area; city wall; coastal</td>
</tr>
<tr>
<td>No.</td>
<td>Justification of OUV</td>
<td>Attributes</td>
</tr>
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<td>-----</td>
<td>------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9</td>
<td>“The sea tower, probably an ancient lighthouse, is unique in the region as an example of ancient maritime architecture”</td>
<td>Sea tower</td>
</tr>
<tr>
<td>10</td>
<td>“and the adjacent sea channel demonstrates the tremendous importance of this city in maritime trade routes throughout antiquity”</td>
<td>Sea Channel</td>
</tr>
<tr>
<td>11</td>
<td>“Qal’at al-Bahrain, (...) was the centre of commercial activities linking the traditional agriculture of the land (represented by the traditional palm-groves and gardens which date back to antiquity and still exist around the site) with maritime trade between such diverse areas as the Indus Valley and Mesopotamia in the early period (from the 3rd millennium BC to the 1st millennium BC) and China and the Mediterranean in the later period (from the 3rd to the 16th century AD).”</td>
<td>Palm groves; traditional agricultural gardens; sea bay (harbour basin); access channel</td>
</tr>
<tr>
<td>12</td>
<td>“The meeting of different cultures which resulted is expressed in the testimony of the successive monumental and defensive architecture of the site including an</td>
<td>Stratigraphy of site; Central excavation area; coastal fortress; Portuguese fortress</td>
</tr>
<tr>
<td>13</td>
<td>“the wonderfully preserved urban fabric and the outstandingly significant and diverse finds demonstrating a mélange of languages, cultures and beliefs”</td>
<td>Central excavation area; unexcavated remains (supported by finds exhibited in site museum)</td>
</tr>
<tr>
<td>14</td>
<td>“For example, a madbasa (an architectural element used to produce date syrup) within the tell is one of the oldest in the world and reflects a link to the surrounding date palm-groves, demonstrating the continuity of traditional agricultural practices from the 1st millennium BC.”</td>
<td>Madbasa (in Portuguese Fort and Coastal Fortress); palm groves</td>
</tr>
<tr>
<td>15</td>
<td>“The site, situated in a very strategic location, was an extremely significant part of the regional Gulf political network, playing a very active political role through many different time periods”</td>
<td>Coastal setting</td>
</tr>
<tr>
<td>16</td>
<td>“which left traces throughout the different strata of the tell.”</td>
<td>Stratigraphy of archaeological tell</td>
</tr>
<tr>
<td>17</td>
<td>“Qal’at al-Bahrain is a unique example of”</td>
<td>Both site components</td>
</tr>
</tbody>
</table>
Based on the attributes identified in the tabular interpretation of the Statement of Outstanding Universal Value, the key attributes can be grouped as follows:

1) Archaeological tell: preserved archaeological remains in the tell, in particular its stratigraphy, exposure of this stratigraphy in the central excavation area, landscape feature of the tell in its coastal green belt setting;

2) Multilayered cultural and trade encounters expressed in the stratigraphy of the archaeological tell, including later additions of the Tylos period (coastal fortress), Islamic periods (shops in central excavation area and the foundations of the main fort) and Portuguese period (Portuguese Fort). These attributes are supported by archaeological finds presented in the Site Museum;
Islamic-period remains in the Central Excavation Area

3) Sea channel, sea tower, and coastal setting:

Ancient access channel
4) The **agricultural traditions and landscape**, which are formed by the palm groves, traditional agricultural gardens, including wells and irrigation channels, and date presses (madbasa) that can be found within the fortress structures and were also traced during excavations of Dilmun and Tylos remains.
Traditional agricultural garden

Irrigation channels

Ground water well

Madbasa in the Coastal Fortress
Attribute groups one and two are concentrated in the original property component including the entire archaeological tell and supported by archaeological finds in the site museum. Attribute group three is contained in the sea components which were included in the first extension of the property and the wider seaside landscape of the site, including the atmospheric and view relations between land and sea. The fourth group of attributes related to the agricultural heritage is included since the second boundary extension in 2014 was approved. The approximate location of attributes is illustrated in the map below.

3.5 Touristic and Community Uses of the Site
Qal‘at al-Bahrain is one the main tourist attraction in Bahrain and attracts ten thousands of visitors each year. It was nominated one of the ten must see’s of the country and is a fixed component of excursions organised for foreign visitors, especially those arriving by cruise ship. Exact visitor numbers are only available for the Site Museum, as it is the only entity with entrance fee and opening hours and hence the only place where visitors are counted. The site itself is open 24 hours and free of charge. Visitor numbers of the Site Museum range around 10,000 per year. The museum displays a selection of objects that were found at the site during archaeological excavations. The museum also offers an audio guide for the site but most visitors chose to discover the fort and archaeological excavations at their own pace and stroll around the site, enjoying the site’s scenic views and tranquil, rural atmosphere. It can be assumed that the site itself presents much higher visitor numbers because many people choose to visit the site only and neglect the museum.

The Site Museum building hosts a café, which is very popular with local and foreign visitors. Its indoor area and particularly the terrace profit from a stunning view to the World Heritage site and to the adjacent sea. The Site Museum organises a number of annual events, which include talks, cultural activities, guided visits and activities for children in an attempt to promote and raise awareness of the site.

Given their scenic and recreational qualities, the World Heritage site and its direct surroundings play an important role among the local community. In fact, the site constitutes one of the most popular
recreational areas for social and leisure activities. The pathway surrounding the Portuguese Fort is highly frequented by locals going for strolls or even for sport activities such as running.

Although the adjacent beach north of the Site Museum does not form part of the World Heritage site, it is nevertheless linked to the recreational uses. Given that the number of easily accessible public beaches is limited in Bahrain, the beach and intertidal area east of the World Heritage site have become increasingly popular. On any given day of the week, a large number of locals visit the shoreline to picnic, stroll or engage in other leisure activities. The weekends are particularly popular with even greater numbers of locals using the beach with numbers reaching several hundreds of people. As a result, a number of supporting businesses have grown, including occasionally installed jumping castles as well as movable facilities selling ice cream, popcorn and other food. Kite flying and traditional donkey and horse rides range among the activities that can be considered intangible heritage expression alive in the site’s surroundings. While these activities do not disturb the visitor experience at the World Heritage site, the site is very well visible from eastern beach and constitutes an important visual backdrop. An important cultural tradition which takes place at the beach is Hayabiya, also called the Al-Dahiyyah festival. It is celebrated on the tenth day of every Islamic Hijri month of Du al-Hijjah. Children throw palm front baskets with herbs grown inside into the sea during low tide as a ritual action.
4. Heritage Expressions beyond OUV
4. Heritage Expressions beyond OUV

The study area contains three further heritage expressions that are entirely located within the buffer zone of Qal’at al-Bahrain. While these heritage expressions do not have an international designation, they are important on a national or local level and hence are included in this HIA.

4.1 Terrestrial Archaeological Heritage

Definition and Description

Bahrain recognized the kingdom’s rich archaeological heritage and its need for protection in the Legislative Decree No (11) of 1995 concerning the Protection of Artefacts. The decree defines archaeological heritage as the following two types:

A) Immovable Artefacts: Artefacts which are built on the ground, i.e. archaeological mounds, remains of reservations and burial grounds, forts, fortresses, buildings, historical and archaeological houses, water wells and canals, religious buildings i.e. temples, mosques and others whether on the ground, underneath it, or in its territorial waters.

B) Movable Artefacts: Movables which are made and are detached by their nature from the ground or the immovable artefacts change their location without damaging them.

The archaeological heritage of Bahrain is diverse and appears in various forms. It includes settlement structures, sepulchral monuments, graveyards, and religious monuments and other expressions. Settlements and bigger structures often occur in so-called tells, a mound structure created by successive layers forming an archaeological stratigraphy. Depending on the amount and density of archaeological layers, tells can range in heights from one meter to some decameters. A special type of tell are mosque mounds that are referred to as mounds due their relatively small diameter in comparison to their height.

Although findings date back to the Neolithic, Bahrain is best known for the Dilmun Period that started only about 4500 years ago. The Dilmun Period is followed by the so-called Tylos Period, the Achaemenid and Parthian periods, as well as the Islamic periods and the Portuguese era (Kervran, Hiebert, Rougeulle 2005, p. 413ff.).

Besides the main archaeological tell of Qal’at al-Bahrain, the study area comprises one more archaeological site, which is partially located within the property boundaries. The settlement remains, supposedly of the locally legendary Hallat al-Seef, are located directly at the coast (26°14'06"N, 50°30'50"E) next to the sweet water spring that is presented in the section on aquatic cultural heritage. Different stories surround the destruction of the village, which is said to have disappeared 400 years ago. Others speak of only 100 years. The area can roughly be divided into three parts. The eastern part is characterized by a huge sandy area and wild vegetation surrounding it. The central part has some architectural remains and two mosque mounds that show the typical cover of small shells (Insoll 2005, fig. 5.1). Another wild-vegetated field is located in the western part of the area. Although pottery shards were found in the entire area, the highest concentrations were identified in the
eastern and central part. The majority of shards collected belong to the Islamic period. Among them are fragments of turquoise glaze (Frifelt 2001, pl.2), incised decoration on well-levigated glaze (Frifelt 2001, fig.25), a coarse reddish ware with lime inclusions (Frifelt 2001, fig. 61), black paint under transparent glaze (Frifelt 2001, fig. 228), Chinese porcelain (Kervran/Hiebert/Rougeulle 2005, pl. 84), as well as Persian imitation of Chinese porcelain.

SIGNIFICANCE OF HERITAGE EXPRESSIONS
The coastal settlement remains, which most likely can be identified as the remnants of Hallat al-Seef, are considered of high significance as the site is likely to contribute considerable to national research objectives. The importance of the site is also reflected in the manifold stories and legends woven around the disappearance of the village Hallat al-Seef. In any case, the settlement is an excellent example of a typical coastal village that developed at this very spot due to the existence of a coastal sweet water spring. The site’s eastern and archaeologically denser part is located within the property boundaries, while the western part belongs to the buffer zone.

4.2 UNDERWATER ARCHAEOLOGICAL HERITAGE

DEFINITION AND DESCRIPTION
The Kingdom’s Legislative Decree No. (11) of 1995 concerning the Protection of Artefacts acknowledges the value of submerged built or archaeological remains if they are older than 50 years old. This also includes artefacts that are buried in the seabed or lying on it.

Considering that the World Heritage site contains an underwater archaeological component of Outstanding Universal Value, it is likely that the surrounding intertidal areas contain further underwater archaeological remains. As stated earlier, the site of Qal’at al-Bahrain comprises an ancient access channel and the remains of a sea tower, both likely dating back more than 4000 years ago to the Early Dilmun era. Apart from these, no other ancient harbour structures have been found

Archaeological remains at Hallat al-Seef Site
to date. It is possible that artefacts have been dispersed in the wider surroundings of the former harbour of the capital of Dilmun, which gained its prosperity mainly from merchandising various precious goods via an extensive maritime trade network. Besides its function as a maritime trading hub, the surroundings of Qal’at al-Bahrain have repeatedly seen naval battles. Among those best chronicled are the second and third sieges of Bahrain in the 16th century (Kervran 1988). There is hence the potential that remains of historic battles could be found in the foreshore area.

The sea levels of the Arabian Gulf have varied considerably throughout past millennia. Scientific observations conclude that historically “the shoreline was further north and also that the level of the sea was lower than it is today (1.50m), during the Hellenistic and Sasanian periods.” (Kervran, Hiebert, Rougeulle 2005, p. 126) However, at present, precise information, which would determine the exact location of earlier shorelines and positions of the sea, is not available. Despite this uncertainty with regard to the exact locations of historical shorelines, and earlier lower sea levels the discovery of archaeological remains now fully submerged by the sea is considered possible.

Therefore, several ground-truthing surveys were carried out in 2012, 2015, and 2018 in the framework of the impact assessments for the various road connectivity proposals for Nurana Island. During these surveys no evidence for hidden archaeological remains was encountered which might be due to the fact that the coastal and intertidal zones of the area under investigation were heavily impacted by previous developments. Throughout the last years, nearby land reclamations caused sand and sediments to deposit in thick layers. The client hence commissioned a geophysical survey to clarify whether or not the area foreseen for development contains hidden archaeological structures or remains.

Onshore and offshore seismic refraction was carried out, i.e. onshore refraction was carried out during low tide when the sea bed was exposed and offshore refraction was carried out during high tide and in those areas that always contained water, namely the western part of the study area. While the onshore seismic refraction generated reliable data, the offshore data shows a lot of noise and no final conclusions could be drawn from these models regarding the presence of any archaeological features. Anyhow, the onshore data is more crucial because it was generated in the area directly in front of the archaeological tell. If underwater archaeological remains were to be expected than this area would have a much higher potential compared to the western study area.

The refraction models are interpreted as showing porous, weak, rocks without clear lithological layering imaged by the velocity models. The vertical gradient imaged is interpreted as being dominated by the degree of cementation/weathering, by degree of compaction and by pore pressure. The lateral variations are interpreted to be controlled by degree of cementation/weathering and by the distribution of porosity/fracturing. It appears that the lithological boundary between calcarenites and calcilutite does not provide a clear seismic boundary in refraction analysis.
Some areas show low velocity anomalies which could be an indicator for archaeological features such as buried channels. However, since ground truthing surveys could not identify any evidence for archaeological remains and since the area is also modified by traditional fish traps which were placed and removed in the same area, the existence of hidden remains is considered highly unlikely.

Although the existence of hidden archaeological structures is considered to be negligible, during the ground truthing surveys numerous pottery shards were found in the foreshore area, especially in areas with a high density of algae as the shards cannot be moved easily by the tides. In general, it can be said that the density of pottery shards is approximately one shard per square meter in sandy areas and four shards per square meter in areas with sea grass.
SIGNIFICANCE OF HERITAGE EXPRESSIONS

Since the seismic survey did not show clear signs of underwater archaeological remains, the evaluation of the heritage significance is limited to the pottery shards that can be found randomly distributed on the sea floor. Their significance is considered negligible. It is assumed that the sea carried away the shards from the archaeological sites ashore. As mentioned above, the property boundaries of Qal‘at al-Bahrain not only include the main archaeological tell but also an archaeological site of national importance, which is located at the very western property boundary. The site itself is covered with hundreds of pottery shards and so is the beach next to it. The shore of the main archaeological tell, on the other hand, does not present a high density of pottery shards which is mainly owed to regular clean ups of the shoreline. Another indicator for the recent movement of the shards is their position on top of the silt layers, which only deposited in the last decade. The shards themselves are considered of negligible archaeological value since almost all of them are of the non-diagnostic type. Moreover, they are not in their original archaeological context and even if a particularly impressive shard would be found, scientifically it would be of limited value.
4.3 **Aquatic Cultural Heritage**

**Definition and Description**

To date there is no universally accepted definition of aquatic cultural heritage. Several different definitions circulate among heritage experts. Some experts, for example, include underwater archaeological heritage but others do not. In the paper at hand, underwater archaeological heritage is separated and addressed in an individual category considering its importance for Bahrain. The following definition of aquatic cultural heritage shall serve the purpose of this HIA:

Aquatic cultural heritage shall be understood as terrestrial or submerged sites that reflect the relationship between humans and the water. These can include man-made structures like harbours as well as natural occurring phenomena.

Bahrain possesses a variety of aquatic heritage assets. Living in an archipelago, Bahraini people interacted with the sea at all times. Fishing has always been a major component of subsistence and, as a result, there are numerous fishing harbours along Bahrain’s coastline. The study area comprises only one harbour. The Karranah fishing harbour (26°14’18”N, 50°30’47”E) is a comparatively small harbour hosting only about 30 smaller fishing boats. Karbabad fishing harbour is considerably bigger but located just beyond the area under investigation (26°14’34”N, 50°31’41”E).

**Hadrah**, traditional fishing traps, are another type of aquatic cultural heritage. Due to Bahrain’s shallow waters, its coastline is highly influenced by the tides. Local fishermen developed a traditional fishing trap (hadrah) that takes advantage of that peculiarity. While at high tide hadrah are largely submerged, the currents caused by the low tide float fish inside the trap. These hadrah can reach dimensions up to 100 meters in length and 60 meters in width. They underwent a long evolution to reach their present design. These traditional fish traps are nowadays the physical expressions of intangible heritage traditions, which testify to long-standing aquatic cultural techniques. They also require specific skills to be constructed and maintained. Moreover, they are subject to customary law and are either inheritable or waqf properties (Serjeant 1994). The study area comprises a total of five hadrah.
Hadrah 1 (26°14′33″N, 50°31′17″E)

Hadrah 2 (26°14′27″N, 50°31′09″E)

Hadrah 3 (26°14′29″N, 50°31′05″E)

Hadrah 4 (26°14′21″N, 50°30′57″E)
Unique geological features are natural sweet water springs that can occur on land as well as underwater. Scholars believe that the name Bahrain, which literally means “two seas”, derives from the combination of salty seawater surrounding the island and sweet water gushing from the surface (Lombard, Alsendi 2000, p. 12). These springs guaranteed fertility and prosperity for Bahrain’s inhabitants since millennia. Although nowadays most of the sweet water springs have run dry (Serjeant 1993), few of them still exist. The study area comprises four springs. Three springs are located in the bay of Qal’at al-Bahrain (26°14’04”N, 50°31’16”E) and one spring in the coastal area next to the archaeological remains of Hallat al-Seef (26°14’07”N, 50°30’52”E). All of them are marked by stone circles; the spring in Hallat al-Seef additionally has a pathway of laid out stones leading to it.
Significance of Heritage Expressions

Karranah village is a traditional fishing village (Ministry of Culture 2010, p. 35). Its harbour is not only related to intangible heritage expressions and cultural traditions, but also a means of livelihood. The local fishermen’s subsistence, therefore, depends on the access to the sea. However, the heritage significance of Karranah harbour is considered low because it has been constructed only recently and does not reflect an age-long traditional use in that specific location. Its heritage significance is limited to its function as access point to intangible aquatic cultural practices. While such access has to be ensured, it can in theory be granted from different locations.

Hadrah are considered of medium heritage significance due to their relevance for local fisheries and their inherent intangible heritage expressions. Besides providing a considerable income, hadrah are a legacy of craftsmanship and traditional knowledge. Construction and annual renovation of hadrah and all its components is a community-based activity and requires the presence of a bannai, an expert of fish trap building.

All four sweet water springs located in the study area are considered to be of high heritage significance since they are among the last existing examples in Bahrain. Nowadays, numerous inland and coastal sweet water springs and wells dried out because too many wells were drilled in the last decades (Serjeant 1993). The plentiful supply of sweet water springs made Bahrain a splendid island since ancient times because they not only assured the supply of potable water but also made Bahrain a fertile land. The sweet water springs contributed significantly to the island’s prosperity and are, moreover, associated with intangible heritage expressions, such as the use of sweet water shells, widely spread around the springs, to decorate sacred areas like mosque mounds and graves (Insoll 2005, Fig. 5.1). The three springs situated in Qal’at al-Bahrain bay are relatively new as they appeared only after the construction of Nurana Island. The location and marking of the forth well however suggests a long tradition of usage. Its importance is accordingly high and inclusion in the National Heritage Register should be considered.
5. Potential Impacts and Mitigation Measures
5. POTENTIAL IMPACTS AND MITIGATION MEASURES

5.1 IMPACTS ON AQUIFER

TYPE AND SIGNIFICANCE OF IMPACT

In previously conducted HIA’s the impact on the aquifer was of major concern because the potential damage to the aquifer and resultant rise of salinity levels of the groundwater would lead to major destruction of heritage resources including some that contribute to the OUV of the World Heritage site. The agricultural lands in the study area and throughout Northern Bahrain rely on the groundwater from the aquifers for irrigation. In addition, the aquifer is the source of groundwater of all fresh water springs in the study area and beyond it.

The main groundwater source in Bahrain comes from four aquifers which stretch from the central part of Saudi Arabia’s Ad Dahna Sahara to the north of Qatar at a depth of 20 to 700 meters (Al Bin Ali 1980). The upper aquifer, referred to as Alat of aquifer A, ranges in depth from 0 to 50 meters, bellow which lies Aquifer B also known as Khobar at a depth of up to 110 meters (ibid.). The permeability of the upper aquifer A and the lower B is very high. These two aquifers are together called Dammam aquifer and constitute the main groundwater source for both agricultural irrigation and domestic use in the north of Bahrain. Below aquifer Dammam are the Rus Umm Er Radhuma (UER) aquifer, which is used for industrial purposes, and the Alwesea aquifer.

Concerns regarding damaging the aquifer were mainly owed to the limited information available. Therefore, the client commissioned a comprehensive geophysical survey of the study area. The survey results were also correlated with existing boreholes.

The data shows relatively conductive materials with no clearly defined change in electrical properties within the subsurface but with higher resistance values towards the surface (increasing in thickness and resistance to the East), gradually becoming more conductive with depth through the unit.
The increase in conductivity with depth is likely to be due to one of the following reasons. Either porosity may be lower in a well-cemented layer immediately below the surface, becoming more porous with depth, or the shallowest layer may be composed of more resistive material, underlain by a less resistive layer. There may also be variations in the conductivity of the pore waters. In this case the higher resistivity suggests lower salinity. The latter of these options may indicate higher volumes of freshwater in the near surface to the east of the tunnel. This could be due to shallow springs, the known fresh water outfall in this area or rainfall, possibly compounded by the thickness of superficial deposits holding water and regular exposure during low tides.

The data suggests materials with resistance values consistent with materials in full or partial connection with the tidal waters and that the underlying aquifer is not present within the depths specified for the survey (12 metres). As such the proposed base of the tunnel would not be within the aquifer. The depth to the aquifer itself has not been established from this survey.

**Suggested Mitigation Measures**

It is recommended to conduct boreholes of at least 20 metres depth to verify the non-existence of the aquifer or any other potentially existing water-bearing strata feeding the near-by sweet water springs. The concept design of the tunnel will be developed accordingly and avoid intercepting such strata. This may include reviewing the requirements for tension piles or the depth of tension piles below the tunnel structure.

5.2 Impacts on Attributes of OUV

Potential impacts of the development projects on attributes and information sources of OUV of Qal’at al-Bahrain Site are best identified in relation to the attributes’ location and features. For this purpose the four groups identified above shall once more serve as guidance for the analysis.

**Attribute Group 1: Archaeological Tell**

**Type and Significance of Impacts**

The archaeological tell is located in a distance of about 500 metres from the proposed development and, therefore, change caused by vibration from construction machinery or traffic is not anticipated.

There is, however, a negligible impact caused by air pollution and dust. The main risks to the preserved archaeological remains in the tell and the exposed stratigraphy in the central excavation area comprise of soiling (the accumulation of a very thin layer of exogenous particles, which can transform into a “crust with increasing adhesion and cohesion” (ICOMOS 2010, p. 60) and corrosion, resulting respectively from the particulate matter and sulfur dioxide emitted during the burning of fossil fuel – in operating equipment during the construction phase and by vehicles once the proposed road is operational. Since these archaeological remains have survived with a high degree of integrity despite their coastal location, it can be assumed that the impacts of corrosion resulting from air pollution will only become visible in the long run. Since the severity of change is expected to increase only with the passage of time, the grade of
change is considered to be negligible. Due to the assets highest heritage significance, the significance of change is likely to be minor adverse.

In addition, the landscape feature of the tell is likely to suffer an adverse impact due to eutrophication, which results from accumulation of excess nitrogen in soil and its subsequent leaching to waters. Eutrophication can gradually result in reduced species diversity and increase the vulnerability of vegetation to insects, fungal diseases or drought (UNECE 2012). The anticipated change for the archaeological tell is negligible and the scale of negative impact is, correspondingly, minor adverse.

**Suggested Mitigation Measures**
Mitigation strategies for reducing the impact of corrosion/soiling include establishing regular monitoring procedures to keep track of the respective level corrosion/soiling, cleaning masonry surfaces using recognised conservation methods, when necessary to arrest deterioration or remove heavy soiling.

Recommended mitigation strategies for reducing the impact of eutrophication include implementation of research and monitoring programs to understand the levels and effects of eutrophication on site and to guide development of adaptive management strategies.

<table>
<thead>
<tr>
<th>Attribute Group 1: Archaeological Tell</th>
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<tbody>
<tr>
<td>Heritage Significance</td>
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<td>Scale of Negative Impact</td>
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<tr>
<td>Significance of Impact</td>
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<tr>
<td>Residual Impact after Mitigation</td>
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<th>Attribute Group 2: Multilayered Encounters</th>
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<tr>
<td>Heritage Significance</td>
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<td>Scale of Negative Impact</td>
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<td>Significance of Impact</td>
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<td>Residual Impact after Mitigation</td>
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</table>
Attribute Group 3: Sea Channel, Sea Tower, and Coastal Setting

**Type and Significance of Impacts**

The attributes of the trade-related seaside setting and the coastal access are reflected in the underwater archaeological component of the property. The closest distance in between the ancient access channel and the causeway which includes the creation of a reclamation is about 400 metres and hence there is the chance of negligible change caused by siltation. Following the nearby reclamation of Nurana siltation has increased severely in the past years and the sea channel is progressively silted. This tendency is likely to worsen with additional reclamation activity for the construction of the causeway. However, it has to be noted that the causeway is comparatively small and short and that it is only the southern area of the access channel that reaches close to the development. The anticipated grade of change is therefore negligible. Considering the highest heritage significance of the asset, the significance of change is minor adverse.

The sea tower is likely to remain unaffected by siltation and vibration thanks to its location of about 900 metres away from the development.

The main impact of air pollution on the sea tower will be soiling and corrosion, whereas the sea channel and the coastal setting will be affected by eutrophication and ocean acidification. These result respectively from accumulation of excess nitrogen in soil and its subsequent leaching to waters, and mixing of excess carbon dioxide in seawater. Like in the cases of other archaeological heritage components mentioned above, the severity of change due to corrosion is expected to be negligible and the impact minor adverse.

There will be temporal visual impacts on the coastal setting which are further described in the visual impact assessment section. The grade of change is considered major for the period of construction. However, since the time of construction is limited to two years and no long-term visual impacts are expected, the final grade of change is negligible and the significance of change consequently minor adverse. The impact can be further reduced to negligible adverse if the proposed mitigation measures are applied.

**Suggested Mitigation Measures**

When approaching the construction site from either Nurana or Seef, vehicles and machinery should keep a distance of at least 20 meters to the access channel. For better orientation, it is advised mark the channel with buoys or by any other non-intrusive means.

Although in theory siltation is a reversible impact, it would further reduce the state of conservation of the sea component. It is therefore suggested to introduce clearing procedures to remove silt and accumulated waste.

Mitigation strategies for reducing the impact of ocean acidification include incorporating an indicator for tracking the level of ocean acidification, and, as far as possible, avoiding activities that may intensify the process.
Mitigation measures for the visual impact are discussed in the relevant chapter below.

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<th>Attribute Group 3: Sea Tower and Sea Channel</th>
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<td>Heritage Significance</td>
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<td>Scale of Negative Impact</td>
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<td>Significance of Impact</td>
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<td>Residual Impact after Mitigation</td>
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<tr>
<th>Attribute Group 3: Coastal Setting</th>
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<td>Heritage Significance</td>
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<td>Scale of Negative Impact</td>
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<td>Significance of Impact</td>
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<td>Residual Impact after Mitigation</td>
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**Attribute Group 4: Agricultural Landscape and related Traditions**

The palm groves and the traditional agricultural gardens will be affected by eutrophication and acidification of soil and water. These will result respectively from accumulation of excess nitrogen in soil and its subsequent leaching to waters, and increased deposition of sulfur dioxide and reactive nitrogen in soil and water. Furthermore, as nitrogen is a nutrient, an increase in the nitrogen deposits can potentially affect plant biodiversity. While this phenomenon is already an on-going process in result of existent pollutants in the area, it is difficult to judge the proportional increase that would come with the operation of the proposed road, without embarking on detailed and long term studies during the first years of operation. The scale of negative impact is likely to be minor adverse.

Air pollution seems to be the only relevant impact on the agricultural landscape component. Since the aquifer does not seem to be impacted by the construction of the tunnel, no other adverse change to the agricultural landscape could be identified. There is also no other impact anticipated for built features related to the agricultural heritage, such as wells and irrigation channels in the palm groves and garden or to the ancient date press in the fortress.

**SUGGESTED MITIGATION MEASURES**

It is recommended to implement monitoring programs to understand the levels and effects of eutrophication on the agricultural component and to guide development of adaptive management strategies.

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<th>Attribute Group 4: Agricultural Landscape</th>
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<td>Heritage Significance</td>
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<td>Scale of Negative Impact</td>
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<td>Significance of Impact</td>
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<tr>
<td>Residual Impact after Mitigation</td>
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</tbody>
</table>
5.3 Visual Impact Analysis

View to Qal’at al-Bahrain

The site presents a high visual integrity when viewed from its direct surroundings. Most of its components including the fort, the archaeological tell, and the authentic palm groves are best visible from the adjacent, not built-up area in the north of the Site Museum. This beach is highly frequented by visitors, who enjoy the unique view towards the site and the sea. While from the southern part of the beach the site and the sea together create a unique scenery with the sea in the foreground, the view from the northern part is different. In fact, the coastline is tilted towards the east and as a result Qal’at al-Bahrain gradually looses its relation to the sea and can eventually only be seen via the beach. Consequently, the proposed development does not affect the integrity of the view towards the site.
**Views from Qal’at al-Bahrain**

The view from Qal’at al-Bahrain is highly characterized by its natural coastal setting. Visitors can enjoy the sea view from almost all the areas of the site, unless inside the Portuguese Fort or the gardens. Therefore, special attention is given to the analysis of the proposed road’s visual impact from the site towards the sea. The five chosen viewpoints represent the areas that are most frequented by visitors.

**Viewpoint A**

The first viewpoint (A) is located next to the entrance area. Visitors usually enter the site through a gate next to the Site Museum, where they first encounter the unique view of the site and its seascape. From this point, the site is visible to the very left, however, when looking towards the proposed road development, the tell and its gardens are out of sight. Although it is the viewpoint located closest to the underwater archaeological component, the sea tower is too far to be seen. The view is mainly characterized by the open sea, a few distant hadrah and parts of Nurana Island.

The causeway and western ramp into the tunnel would be visible only in the very distance, beyond the protected view corridor. The eastern entrance to the tunnel would be out of sight.
Viewpoint B
The second viewpoint (B) is located along the coastal walkway that leads up the archaeological tell to the Portuguese Fort. In the foreground, the three sweet water springs can be observed. Otherwise it allows a view towards the open sea and the Site Museum to its right; in the distance the urban development of Seef coast is visible. The view towards the west is blocked of by Sh. Ebrahim Garden.

The development will not be visible from this viewpoint as the view is limited to the view corridor, which contains the tunnel. The western causeway is out of sight.

Viewpoint C
Viewpoint C is located on elevated terrain south of the Coastal Fortress, from where the visual corridor, the south-eastern tip of Nurana Island, and the Site Museum can be seen.

The causeway can partially be seen in the distance, beyond the protected view corridor. Otherwise the view is undisturbed.
Viewpoint D
The last two viewpoints are located inside the fort and are therefore the highest. Viewpoint D can be found in the eastern corner of the Portuguese Fort, from where the sea, the Site Museum and part of the Seef urban development can be seen. The view is partially blocked by Sh. Ebrahim Garden in the west.

The view from this location remains completely undisturbed. The causeway is not visible from this viewpoint.

Viewpoint E
Viewpoint E constitutes the highest accessible point in the fort and is located in its south-western corner. Most other areas within the fort do not allow for a sea view because they are surrounded by high walls. Nurana Island is very well visible from this viewpoint, albeit slightly blocked by Sh. Ebrahim Garden in the foreground. The Portuguese Fort itself obstructs the view towards the Site Museum and the eastern part of the visual corridor.

The proposed causeway is almost completely obstructed by the palm grove in the foreground.
While negligible or no impact is expected during the operation of the causeway and tunnel, considerable adverse impact is expected during their construction. But since the construction period is limited to about two years, the visual disturbances are not permanent and are hence considered negligible. Though the photomontages only show the proposed road development, construction vehicles are likely to penetrate the same area. During the construction phase, the sea view is only gradually blocked off. The bay will constantly be flushed because the tunnel will be built in portions of approximately 150 metres.

**Suggested Mitigation Measures**

The view corridor is planned to be completely free of any visual disturbances. However, the causeway will start right after the boundary of the visual corridor and will be partially visible from diverse viewpoints. Several mitigation measures have already been discussed with the developer; this includes keeping the height of the reclamation as low as possible as well as a natural finishing of the rock armour that blends in with the surrounding. If all proposed measures are implemented and taking into account the temporary existence of the construction site, the impact can be reduced to negligible adverse.

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<thead>
<tr>
<th>Heritage Significance</th>
<th>Scale of Negative Impact</th>
<th>Significance of Impact</th>
<th>Residual Impact after Mitigation</th>
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<tbody>
<tr>
<td>Highest</td>
<td>Negligible change</td>
<td>Minor adverse</td>
<td>Negligible adverse</td>
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### 5.4 Noise Impacts on Visitor Experience

**Type and Significance of Impacts**

Besides visual disturbances, which are extensively discussed above, the visitor experience is likely to be impacted by noise. This applies mainly to the construction phase but, although to a lesser extent, also to the operation of the causeway and tunnel. Noise is not expected to impact any of the other identified heritage categories.

The crucial parameter for the impact assessment is the relative location of the heritage asset to the source of noise. It was hence decided to analyse the impact on the heritage expression based on the closest possible vicinity to the source of noise. The closest distances from the construction site to each asset are as the following:

<table>
<thead>
<tr>
<th>Asset (closest distance to source)</th>
<th>Noise levels in dB(A)</th>
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<tbody>
<tr>
<td></td>
<td>Excavator</td>
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<td></td>
<td>Soft</td>
</tr>
<tr>
<td>Site Museum (360m)</td>
<td>64.7</td>
</tr>
<tr>
<td>Coastal Walkway (480m)</td>
<td>62.5</td>
</tr>
<tr>
<td>Portuguese Fort (600m)</td>
<td>61.4</td>
</tr>
<tr>
<td>Portuguese Fort (600m)</td>
<td>51.4</td>
</tr>
</tbody>
</table>

The noise levels will vary during the different phases of construction, not only because of the different machineries used but also because of the distance of the work to the site. Most impact is expected during the construction of the eastern part of the tunnel which would have a
minimum distance of 480 metres to the nearest archaeological site, the Coastal Fortress, and 360 metres to the Site Museum. The noise intensity of most construction vehicles ranges around 80 dB(A) to 85 dB(A). Excavators and bulldozers are among the noisiest construction vehicles, compactors are at the lower end. They were therefore chosen to represent the expected noise levels. During high tide, i.e. when the noise waves travel over a hard surface, maximum levels of 67 dB(A) (compactor) to 72 dB(A) (excavator, dump truck) are expected for the terrace of the Site Museum and 66 dB(A) to 71 dB(A) along the coastal walkway, where the Coastal Fortress is located. During low tide, i.e. soft surface condition, maximum noise levels would reach 60.5 dB(A) to 65.5 dB(A) near the Site Museum and 59 dB(A) to 64 dB(A) near the Coastal Fortress. The scale of negative impact is hence considered major and the significance of impact is major adverse.

However, most visitors do not spend much time in aforementioned locations but in the area around or inside the Portuguese Fort. The centre of the Portuguese Fort is located at a distance of about 600 metres from the development and most part of it is shielded from the sea by a circa 100 metres thick stretch of palm grove. Dense vegetation can reduce noise levels by 5 dB(A) for every 30 meters of vegetation and up to a maximum reduction of 10 dB(A). This was taken into account for calculating the noise levels for the Portuguese Fort. Maximum noise levels for the Portuguese Fort during high tide are therefore 59.25 dB(A) for excavators and 54.25 dB(A) for compactors. During low tide maximum noise levels reach 51.4 dB(A) and 46.4 dB(A) respectively. The negative impact is hence considered to be minor to moderate.

It has to be noted, that the numbers mentioned above are the levels to be expected during the last phase of construction. The construction will start from the west to the east. The material for constructing the reclamation and the road are dumped on Nurana Island and vehicles are planned to always access the construction site from this point. Which means that the great majority of time, noise levels are likely to be much lower.

The noise during the operation of the road is of less adverse impact compared to the noise generated during the construction phase for two main reasons. Firstly, the “linear” noise caused by constant traffic is perceived as less disturbing compared to the sudden and rather unexpected sounds some construction machinery produces and, secondly, the actual dB(A) levels are lower. Furthermore, traffic noise is limited to the causeway and the on-land road. The tunnel, which constitutes the major part of the road and which is located in front of the site, completely blocks traffic noise.

<table>
<thead>
<tr>
<th>Asset (closest distance to source)</th>
<th>Noise levels in dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6,000 vehicles (2024)</td>
</tr>
<tr>
<td></td>
<td>Soft      Hard</td>
</tr>
<tr>
<td>Site Museum (360m)</td>
<td>54.8 59.1 62.3 66.6</td>
</tr>
<tr>
<td>Coastal Walkway (460m)</td>
<td>52.6 57.6 60.1 65.1</td>
</tr>
<tr>
<td>Portuguese Fort (600m)</td>
<td>51.5 56.85 59 64.35</td>
</tr>
<tr>
<td>Portuguese Fort (600m)</td>
<td>41.5 46.85 49 54.35</td>
</tr>
<tr>
<td>taking into account the natural</td>
<td></td>
</tr>
<tr>
<td>vegetation barrier</td>
<td></td>
</tr>
</tbody>
</table>
In 2024, about 6,000 vehicles are expected during peak hours in the morning and evening. In fact, the numbers in the morning are slightly lower and in the evening higher, but for easier calculation the mean value is used. Highest noise levels are expected for the nearest point of interest which is the terrace of the Site Museum. Noise levels are likely to vary in between 54.8 dB(A) and 59.1 dB(A) depending on the surface condition. The area near the Coastal Fortress will be exposed to about 52.6 dB(A) to 57.6 dB(A). Noise levels for the Portuguese Fort, taking into account the natural shield formed by the palm grove, are expected to reach 41.5 dB(A) to 46.85 dB(A). The scale of impact for the Site Museum and the Coastal Fortress is moderate and for the Portuguese Fort it is likely to be minor.

In 2030, when Nurana and Marsa Al Seef Islands are expected to be almost fully developed, vehicular trips are expected to increase by more than double. An average of 16,000 vehicles is estimated for the peak hours. The higher amount of cars influences the noise levels. The Site Museum is likely to be exposed to 62.3 dB(A) to 66.6 dB(A), the Coastal Fortress to 60.1 dB(A) to 65.1 dB(A), and the Portuguese Fort to 49 dB(A) to 54.35 dB(A). This results in a major noise impact for the two closer assets, and minor to moderate impact for the Portuguese Fort. However, it has to be noted that these relatively high numbers are only expected in about ten years time when Nurana and Marsa Al Seef Islands are completely developed. Moreover, it has to be noted that the numbers used for the calculations are during peak hours during the morning and evening when the residents of the islands commute to work.

Consequently, noise levels are considerable lower during the rest of the day and hence during the main visitation hours of the site.

**SUGGESTED MITIGATION MEASURES**

Noise levels during the construction phase are the highest, although as mentioned above the numbers used only apply to the last phase of construction when the easternmost part of the tunnel is built. The most common measure to reduce the impacts of noise is the temporary installation of site hoardings, which should be applied once the reclamation is in place. Furthermore, it is suggested to only use new or very well maintained machinery in order to avoid increased noise levels generated by old engines. It is also recommended to construct the tunnel, or at least its eastern part, in an accelerated speed in order to reduce the period of construction noise.

Mitigation measures for the operation of the road have already been discussed with the developer and, as a result, it was agreed that the speed limit for the road was reduced from 70 kilometres per hour to 50 kilometres per hour. If these measures are implemented the impact can be reduced to negligible adverse.

<table>
<thead>
<tr>
<th>Noise Impacts on Visitor Experience</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heritage Significance</strong></td>
<td>Highest</td>
</tr>
<tr>
<td><strong>Scale of Negative Impact</strong></td>
<td>Minor to major change</td>
</tr>
<tr>
<td><strong>Significance of Impact</strong></td>
<td>Moderate to Major adverse</td>
</tr>
<tr>
<td><strong>Residual Impact after Mitigation</strong></td>
<td>Negligible adverse</td>
</tr>
</tbody>
</table>
5.5 Impacts on Terrestrial Archaeological Heritage (beyond OUV)

Type and Significance of Impacts
The archaeological site of Hallat al-Seef is located at least 400 metres from the proposed development. The distance is beyond the suggested impact zone and, hence, no impact caused by vibration is anticipated.

Negligible adverse impact is expected to be caused by air pollution and dust, resulting from the particulate matter and sulfur dioxide emitted by vehicles.

Suggested Mitigation Measures
Monitoring and cleaning procedures should be implemented to further reduce the adverse effects of air pollution and dust.

<table>
<thead>
<tr>
<th>Terrestrial Archaeological Heritage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritage Significance</td>
<td>High</td>
</tr>
<tr>
<td>Scale of Negative Impact</td>
<td>Negligible change</td>
</tr>
<tr>
<td>Significance of Impact</td>
<td>Negligible adverse</td>
</tr>
<tr>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
</tbody>
</table>

5.6 Impacts on Underwater Archaeological Heritage (beyond OUV)

Type and Significance of Impacts
During the cleaning processes for the preparation of the construction site it is very likely that pottery shards laying on top of the seabed are removed. This is considered to be of negligible change, as the sea would have carried away the pottery shards sooner or later. Moreover, the shards are already out of context and cannot contribute relevant data to the research.

Suggested Mitigation Measures
No mitigation measures are required.

<table>
<thead>
<tr>
<th>Pottery shards</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritage Significance</td>
<td>Negligible</td>
</tr>
<tr>
<td>Scale of Negative Impact</td>
<td>Negligible change</td>
</tr>
<tr>
<td>Significance of Impact</td>
<td>Neutral</td>
</tr>
<tr>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
</tbody>
</table>
5.7 Impacts on Aquatic Cultural Heritage (Beyond OUV)

Type and Significance of Impacts
Karranah harbour remains functional both during the construction period and the operation of the proposed road. The only inconvenience for the fishermen will be to circumnavigate the causeway in order to leave the bay and to reach the open sea. This diversion will add about 300 metres to their route, which is considered a negligible impact. During the time of construction the length of detour varies according to the section of the tunnel that is currently being built and consequently dewatered.

The functionality of four hadrah located within the study area is likely to be impaired once the causeway and tunnel are being built. Hadrah 4 and 5 are situated south of the proposed causeway in a rather shallow area. Though water flow models show that the area is flushed, it is uncertain whether the angle and strength of water flow is sufficient for the efficient use of these two hadrah. The anticipated grade of impact is therefore moderate. Hadrah 2 and 3 are located north of the tunnel and very close to the causeway. Both hadrah are likely to be affected by a change of water flow during the time of construction but should be fully functional once the tunnel is finalized. Hadrah 1 is located at a distance of almost 400 metres to the proposed development and changes are therefore not expected. Since hadrah are considered to be of medium heritage significance, the expected significance of change for hadrah 1 is neutral, for hadrah 2 and 3 negligible adverse due to the limited time of impact, and for hadrah 4 and 5 major adverse impact is anticipated.

No change is anticipated for the four sweet water springs due to their distance of at least 400 metres to the development and the fact that the aquifer seems to be unaffected.

Suggested Mitigation Measures
No mitigation measures are required for Karranah harbour.

The owners of negatively affected hadrah should be compensated for any loss. In case readjustment of the hadrah is considered feasible and ensures continued use, sufficient amounts of financial resources should be made available.

No mitigation measures are required for the four sweet water springs.

<table>
<thead>
<tr>
<th>Karranah Harbour</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritage Significance</td>
<td>Low</td>
</tr>
<tr>
<td>Scale of Negative Impact</td>
<td>Negligible change</td>
</tr>
<tr>
<td>Significance of Impact</td>
<td>Neutral</td>
</tr>
<tr>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hadrah 1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritage Significance</td>
<td>Medium</td>
</tr>
<tr>
<td>Scale of Negative Impact</td>
<td>No change</td>
</tr>
<tr>
<td>Significance of Impact</td>
<td>Neutral</td>
</tr>
<tr>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
<tr>
<td>Hadrah 2 and 3</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>-------</td>
</tr>
<tr>
<td>Heritage Significance</td>
<td>Medium</td>
</tr>
<tr>
<td>Scale of Negative Impact</td>
<td>Negligible change</td>
</tr>
<tr>
<td>Significance of Impact</td>
<td>Negligible adverse</td>
</tr>
<tr>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hadrah 4 and 5</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritage Significance</td>
<td>Medium</td>
</tr>
<tr>
<td>Scale of Negative Impact</td>
<td>Moderate change</td>
</tr>
<tr>
<td>Significance of Impact</td>
<td>Moderate adverse</td>
</tr>
<tr>
<td>Residual Impact after Mitigation</td>
<td>Negligible adverse</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sweet water springs 1, 2, 3, and 4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritage Significance</td>
<td>High</td>
</tr>
<tr>
<td>Scale of Negative Impact</td>
<td>No change</td>
</tr>
<tr>
<td>Significance of Impact</td>
<td>Neutral</td>
</tr>
<tr>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
</tbody>
</table>
6. Overview of all Heritage Expressions and their related Significance, Impact, and suggested Mitigation Measures
6. **OVERVIEW OF ALL HERITAGE EXPRESSIONS AND THEIR RELATED SIGNIFICANCE, IMPACT, AND SUGGESTED MITIGATION MEASURES**

6.1 **ATTRIBUTES OF OUV**

**ATTRIBUTE GROUP 1: ARCHAEOLOGICAL TELL**

<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| ![Photo 1](image1.png) | Preserved archaeological remains and stratigraphy inside the tell | Impact: eutrophication  
Mitigation Measure: monitoring | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral |
| ![Photo 2](image2.png) | Exposed stratigraphy in the Central Excavation Area | Impact: corrosion resulting from air pollution  
Mitigation Measure: monitoring, cleaning | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral |
| ![Photo 3](image3.png) | Landscape feature of the tell | Impact: eutrophication  
Mitigation Measure: monitoring | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral |
**Attribute Group 2: Multilayered Encounters**

<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| ![Portuguese Fort](photo1.jpg) | Portuguese Fort | Impact: corrosion resulting from air pollution  
Mitigation Measure: monitoring, cleaning | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral | |
| ![Coastal (Tylos) Fortress](photo2.jpg) | Coastal (Tylos) Fortress | Impact: corrosion resulting from air pollution  
Mitigation Measure: monitoring, cleaning | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral | |
| ![Islamic remains in the Central Excavation Area](photo3.jpg) | Islamic remains in the Central Excavation Area | Impact: corrosion resulting from air pollution  
Mitigation Measure: monitoring, cleaning | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral | |
<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| ![Ancient access channel](image1.png) | Ancient access channel | **Impact:** siltation, eutrophication, disturbance during construction  
**Mitigation Measure:** monitoring, cleaning, keep distance during construction phase, mark channel with buoys | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral |
| ![Sea tower](image2.png) | Sea tower | **Impact:** corrosion resulting from air pollution  
**Mitigation Measure:** monitoring, cleaning | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Neutral |
| ![Coastal setting](image3.png) | Coastal setting | **Impact:** visual disturbance during time of construction, part of causeway is visible  
**Mitigation Measure:** natural finishing of rock armour | Heritage Significance: Highest  
Scale of Impact: Negligible change  
Significance of Impact: Minor adverse  
Residual Impact after Mitigation: Negligible adverse |
**ATTRIBUTE GROUP 4: AGRICULTURAL LANDSCAPE AND RELATED TRADITIONS**

<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Palm groves" /></td>
<td>Palm groves</td>
<td>Impact: eutrophication</td>
<td>Mitigation Measure: monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scale of Impact</td>
<td>Negligible change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
<tr>
<td><img src="image2.png" alt="Traditional agricultural gardens" /></td>
<td>Traditional agricultural gardens</td>
<td>Impact: eutrophication</td>
<td>Mitigation Measure: monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scale of Impact</td>
<td>Negligible change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
<tr>
<td><img src="image3.png" alt="Irrigation channels" /></td>
<td>Irrigation channels</td>
<td>Impact: none</td>
<td>Mitigation Measure: not required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scale of Impact</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
<tr>
<td><img src="image4.png" alt="Wells" /></td>
<td>Wells</td>
<td>Impact: none</td>
<td>Mitigation Measure: not required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scale of Impact</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual Impact after Mitigation</td>
<td>Neutral</td>
</tr>
</tbody>
</table>
### 6.2 Visitor Experience

<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| ![Photo](image1) | **World Heritage Site Qal’at al-Bahrain**  
**Description:** The site with its museum is one of Bahrain’s major tourist attractions and is also highly frequented by local visitors | **Impact:** noise, visual (both mainly limited to the time of construction)  
**Mitigation Measure:** during construction phase: installation of site hoarding, use of new machinery, accelerated speed |  
**Heritage Significance:** Highest  
**Scale of Impact:** Minor to major change  
**Significance of Impact:** Major adverse  
**Residual Impact after Mitigation:** Negligible adverse |
### 6.3 Heritage Expressions beyond OUV

#### Terrestrial Archaeological Heritage

<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| ![Image](image1.png) | Archaeological Site Hallat al-Seef  
Location: 26°14'06"N, 50°30'50"E  
Description: The site's central part has some architectural remains and two mosque mounds. Pottery sherds were found in the entire area, the highest concentrations were identified in the eastern and central part. | Impact: none  
Mitigation Measure: not required | Heritage Significance: High  
Scale of Impact: No change  
Significance of Impact: Neutral  
Residual Impact after Mitigation: Neutral |

#### Underwater Archaeological Heritage

<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| ![Image](image2.png) | Pottery shards  
Location: entire study area  
Description: Pottery sherds of various kind but mainly of the non-diagnostic type can be found in the entire study area. It is assumed that they derive from the shore and were carried away by the tides. | Impact: Pottery sherds will be removed during construction site preparation measures  
Mitigation Measure: not required | Heritage Significance: Negligible  
Scale of Impact: Negligible change  
Significance of Impact: Neutral  
Residual Impact after Mitigation: Neutral |
### Aquatic Cultural Heritage

<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| ![Photo](image1) | **Karranah Fishing Harbour**  
**Location:** 26°14’18”N, 50°30’47”E  
**Description:** Fishing Harbour for about 30 boats used by local fishermen from Karranah village. The harbour was built recently.  
**Impact:** Boats need to circumnavigate the causeway in order to leave the bay  
**Mitigation Measure:** not required | **Heritage Significance** Low  
**Scale of Impact** Negligible change  
**Significance of Impact** Neutral  
**Residual Impact after Mitigation** Neutral | |
| ![Photo](image2) | **Hadrah 1**  
**Location:** 26°14’33”N, 50°31’17”E  
**Description:** Smaller type hadrah in use and good state of conservation  
**Impact:** none  
**Mitigation Measure:** not required | **Heritage Significance** Medium  
**Scale of Impact** None  
**Significance of Impact** Neutral  
**Residual Impact after Mitigation** Neutral | |
| ![Photo](image3) | **Hadrah 2**  
**Location:** 26°14’27”N, 50°31’09”E  
**Description:** Bigger type hadrah in use and need for maintenance  
**Impact:** change of water flow  
**Mitigation Measure:** financial compensation | **Heritage Significance** Medium  
**Scale of Impact** Negligible change  
**Significance of Impact** Negligible adverse  
**Residual Impact after Mitigation** Neutral | |
| ![Photo](image4) | **Hadrah 3**  
**Location:** 26°14’29”N, 50°31’05”E  
**Description:** Smaller type hadrah in use and need for maintenance  
**Impact:** change of water flow  
**Mitigation Measure:** financial compensation | **Heritage Significance** Medium  
**Scale of Impact** Negligible change  
**Significance of Impact** Negligible adverse  
**Residual Impact** Neutral | |
<table>
<thead>
<tr>
<th>Photo</th>
<th>Name/Description</th>
<th>Type of Impact and Suggested Mitigation Measures</th>
<th>Assessment after Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Hadrah 4" /></td>
<td>Hadrah 4  Location: 26°14’21”N, 50°30’57”E  Description: Smaller type hadrah in use and need for maintenance</td>
<td><strong>Impact:</strong> change of water flow  <strong>Mitigation Measure:</strong> financial compensation</td>
<td>Heritage Significance: Medium  Scale of Impact: Moderate change  Significance of Impact: Moderate adverse  Residual Impact after Mitigation: Negligible adverse</td>
</tr>
<tr>
<td><img src="image2" alt="Hadrah 5" /></td>
<td>Hadrah 5  Location: 26°14’22”N, 50°30’51”E  Description: Smaller type hadrah in use and need for maintenance</td>
<td><strong>Impact:</strong> change of water flow  <strong>Mitigation Measure:</strong> financial compensation</td>
<td>Heritage Significance: Medium  Scale of Impact: Moderate change  Significance of Impact: Moderate adverse  Residual Impact after Mitigation: Negligible adverse</td>
</tr>
<tr>
<td><img src="image3" alt="Sweet water springs 1, 2, and 3" /></td>
<td>Sweet water springs 1, 2, and 3  Location: 26°14’04”N, 50°31’16”E  Description: Three natural sweet water springs with constant water flow, surrounded by stone circles</td>
<td><strong>Impact:</strong> none  <strong>Mitigation Measure:</strong> not required</td>
<td>Heritage Significance: High  Scale of Impact: No change  Significance of Impact: Neutral  Residual Impact after Mitigation: Neutral</td>
</tr>
<tr>
<td><img src="image4" alt="Sweet water spring 4" /></td>
<td>Sweet water spring 4  Location: 26°14’07”N, 50°30’52”E  Description: A natural sweet water springs with constant water flow, surrounded by stone circles and stone walk way</td>
<td><strong>Impact:</strong> none  <strong>Mitigation Measure:</strong> not required</td>
<td>Heritage Significance: High  Scale of Impact: No change  Significance of Impact: Neutral  Residual Impact after Mitigation: Neutral</td>
</tr>
</tbody>
</table>
7. Conclusion
7. CONCLUSION

The information gathered for this HIA shows once more the cultural richness of the World Heritage Site Qal’at al-Bahrain and its wider surrounding. Besides the various attributes of OUV that include archaeological, underwater archaeological and agricultural assets, further cultural heritage sites were identified within the study area. Among them are an archaeological site of national importance and various aquatic cultural heritage assets that are associated with intangible heritage use.

The road connectivity of Nurana Island to mainland Bahrain is under discussion since several years and various proposals were studied in the past of which none was considered feasible. The tunnel option, which is presented in this HIA, was already investigated in 2015 although with slightly different specifications. At that time crucial information was not available and the admissibility of the project proposal hinged on the question whether the tunnel could be built and operated without damaging the Dammam aquifer that was assumed to be located in the study area. For the purpose of this HIA three different types of geophysical surveys (ERT, seismic refraction, MASW) were conducted and cross-checked with various existing boreholes. The accumulated data shows that the aquifer is not located within the study area. It can hence be assumed that the construction of the tunnel would not impact the Dammam aquifer. In any case, for the final design of the tunnel and the identification of the best suitable construction technique the developer envisions to conduct further studies of the ground, including a study of the stiffness of the ground and more boreholes. According to the developer, the tunnel design and construction methodology will be adjusted in the unlikely event that new studies show that the aquifer or any other water bearing strata could be impacted.

Another major concern in previous HIA’s was the potential existence of underwater archaeology that could be negatively impacted by any development in the bay area. Seismic refraction models now suggest that there is no evidence for archaeological assets along the footprint of the road and at least 50 metres to each side. Walkover surveys further underpin the findings of the geophysical study. Numerous pottery shards can be found in the offshore area but are likely deriving from the shore and are therefore out of context. Their cultural significance is considered negligible.

The visual integrity of the World Heritage site is maintained as there is no development above sea level within the boundaries of the visual corridor. The causeway is visible in the distance but only from the very eastern part of the property. Major visual impact is limited to the construction period that is foreseen to last a maximum of two years. That also applies to the impact of noise that is expected to be of major adverse during the time of construction and of negligible adverse once the causeway and tunnel are operational. It is suggested to install noise barriers during the construction period and to encourage the use of new or very well maintained machinery.

Besides the visual and noise disturbances, very limited impact on the World Heritage site and its surrounding are expected. Air pollution and
dust may cause negligible changes to archaeological and agricultural heritage assets that can be controlled by monitoring and cleaning exercises. Vibration caused by machinery and traffic is not expected to have any impact on the cultural heritage, because all identified assets are located beyond the impact zone.

Impact on aquatic cultural assets is also limited. The harbour remains functional, though boats have to take a detour of circa 300 metres once the road is functional, which is considered a negligible impact. The changed aqua dynamics are likely to impact four hadrah. Two of them only during the time of construction phase and two are most likely not feasible anymore once the causeway is in place. The Directorate for Fisheries foresees compensation for such events and has a well-established system.

If all recommendations are followed, it can be assumed that the overall impact on OUV is negligible and that the project proposal can be realized without significant changes to the World Heritage site and its wider surrounding.

In addition, it is recommended to provide relevant information about the development project to visitors and local communities. This can include an information panel placed at the entrance to the site as well as community outreach activities.
8. Resources
8. RESOURCES


Think Heritage!, Ministry of Works (2013): Heritage Impact Assessment (HIA) for the N-Road Development in the Kingdom of Bahrain, Muharraq: Think Heritage!.


9. Maps
Map 1. Proposed road connection

- **Orange**: Boundary of the UNESCO World Heritage Site
- **Blue**: Buffer zone of the World Heritage Site
- **Pink**: Proposed road connection
- **Dotted**: Tunnel connection

Source: BACA/AECOM - amended by Think Heritage
Map 2. Study area

- **Orange**: Boundary of the UNESCO World Heritage Site
- **Blue**: Buffer zone of the World Heritage Site
- **Pink**: Proposed road
- **Red Dots**: Tunnel connection
- **Red**: Study area

Source: BACA/AECOM - amended by Think Heritage
Map 3.1 Attributes expressing OUV - identification

- **Boundary of the UNESCO World Heritage Site**
- **Buffer zone of the World Heritage Site**
- **Proposed road** → **Tunnel connection**
- **Agricultural traditions and landscape**
- **Archaeological tell**
- **Multilayered encounters**
- **Visual corridor and coastal setting**
- **Sea channel**

Source: BACA/AECOM - amended by Think Heritage
Map 3.3 Attributes expressing OUV-significance of impact

- Orange: Boundary of the UNESCO World Heritage Site
- Blue: Buffer zone of the World Heritage Site
- Pink: Proposed road; ... Tunnel connection
- Red: Major adverse
- Orange: Moderate adverse
- Beige: Minor adverse
- Yellow: Negligible adverse
- Green: Neutral

Source: BACA/AECOM - amended by Think Heritage
Map 3.4 Attributes expressing OUV - remaining impact after mitigation

- **Boundary of the UNESCO World Heritage Site**
- **Buffer zone of the World Heritage Site**
- **Proposed road** — Tunnel connection
- **Major adverse**
- **Moderate adverse**
- **Minor adverse**
- **Negligible adverse**
- **Neutral**

Source: BACA/AECOM - amended by Think Heritage
Map 4.1 Visual impact assessment - view points

- **Orange** Boundary of the UNESCO World Heritage Site
- **Blue** Buffer zone of the World Heritage Site
- **Pink** Proposed road
- **Dotted Line** Tunnel connection
- **Red** View points

Source: BACA/AECOM - amended by Think Heritage
Map 4.2 Visual impact assessment - view area

- Orange: Boundary of the UNESCO World Heritage Site
- Blue: Buffer zone of the World Heritage Site
- Pink: Proposed road
- Dotted: Tunnel connection
- Purple: View area

Source: BACA/AECOM - amended by Think Heritage
Map 5.1 Noise impact assessment-construction phase

- Orange: Boundary of the UNESCO World Heritage Site
- Blue: Buffer zone of the World Heritage Site
- Magenta: Proposed road
- Dotted line: Tunnel connection
- Dash line: Distances

Source: BACA/AECOM - amended by Think Heritage
Map 5.2 Noise impact assessment-operation phase

- Orange: Boundary of the UNESCO World Heritage Site
- Blue: Buffer zone of the World Heritage Site
- Pink: Proposed road
- Dotted: Tunnel connection
- Dashed: Distances

Source: BACA/AECOM - amended by Think Heritage
Map 6.2 Archaeological heritage - heritage significance

- **Orange**: Boundary of the UNESCO World Heritage Site
- **Blue**: Buffer zone of the World Heritage Site
- **Pink**: Proposed road
- **Dots**: Tunnel connection

- **Red**: Highest significance
- **Dark Pink**: Very high significance
- **Light Pink**: High significance
- **Yellow**: Medium significance
- **Light Green**: Low significance
- **Light Blue**: Negligible significance

Source: BACA/AECOM - amended by Think Heritage
Map 6.3 Archaeological heritage - significance of impact

- **Boundary of the UNESCO World Heritage Site**
- **Buffer zone of the World Heritage Site**
- **Proposed road**
- **Tunnel connection**
- **Major adverse**
- **Moderate adverse**
- **Minor adverse**
- **Negligible adverse**
- **Neutral**

Source: BACA/AECOM - amended by Think Heritage
Map 6.4 Archaeological heritage - remaining impact after mitigation

- **Orange**: Boundary of the UNESCO World Heritage Site
- **Blue**: Buffer zone of the World Heritage Site
- **Pink**: Proposed road
- **Dotted Pink**: Tunnel connection

- **Red**: Major adverse
- **Orange**: Moderate adverse
- **Yellow**: Minor adverse
- **Light Yellow**: Negligible adverse
- **Green**: Neutral

Source: BACA/AECOM - amended by Think Heritage
Map 7.1 Underwater archaeological heritage - heritage identification

- **Orange**: Boundary of the UNESCO World Heritage Site
- **Blue**: Buffer zone of the World Heritage Site
- **Pink**: Proposed road
- **Dashed Pink**: Tunnel connection
- **Yellow**: Underwater heritage study area

Source: BACA/AECOM - amended by Think Heritage
Map 7.2 Underwater archaeological heritage - heritage significance

- **Orange**: Boundary of the UNESCO World Heritage Site
- **Blue**: Buffer zone of the World Heritage Site
- **Pink**: Proposed road and Tunnel connection
- **Red**: Highest significance
- **Pink**: Very high significance
- **Magenta**: High significance
- **Yellow**: Medium significance
- **Green**: Low significance
- **Light Blue**: Negligible significance

Source: BACA/AECOM - amended by Think Heritage
Map 7.3 Underwater archaeological heritage - significance of impact

- **Orange** boundary of the UNESCO World Heritage Site
- **Blue** buffer zone of the World Heritage Site
- **Pink** proposed road
- **Dotted Pink** tunnel connection
- **Red** major adverse
- **Dark Orange** moderate adverse
- **Light Orange** minor adverse
- **Light Yellow** negligible adverse
- **Green** neutral

Source: BACA/AECOM - amended by Think Heritage
Map 7.4 Underwater archaeological heritage - remaining impact after mitigation

- **Orange**: Boundary of the UNESCO World Heritage Site
- **Blue**: Buffer zone of the World Heritage Site
- **Pink**: Proposed road ... Tunnel connection
- **Red**: Major adverse
- **Orange**: Moderate adverse
- **Light yellow**: Minor adverse
- **Light green**: Negligible adverse
- **Green**: Neutral

Source: BACA/AECOM - amended by Think Heritage
Map 8.2 Aquatic cultural heritage - heritage significance

- Boundary of the UNESCO World Heritage Site
- Buffer zone of the World Heritage Site
- Proposed road: Tunnel connection
- Highest significance
- Very high significance
- High significance
- Medium significance
- Low significance
- Negligible significance

Source: BACA/AECOM - amended by Think Heritage
Map 8.3 Aquatic cultural heritage - significance of impact

- Orange: Boundary of the UNESCO World Heritage Site
- Blue: Buffer zone of the World Heritage Site
- Pink: Proposed road
- Dots: Tunnel connection
- Red: Major adverse
- Orange: Moderate adverse
- Light Orange: Minor adverse
- Yellow: Negligible adverse
- Green: Neutral

Source: BACA/AECOM - amended by Think Heritage
Map 8.4 Aquatic cultural heritage - remaining impact after mitigation

- **Boundary of the UNESCO World Heritage Site**
- **Buffer zone of the World Heritage Site**
- **Proposed road** → **Tunnel connection**
- **Major adverse**
- **Moderate adverse**
- **Minor adverse**
- **Negligible adverse**
- **Neutral**

Source: BACA/AECOM - amended by Think Heritage
Map 9. Sites associated with Intangible Heritage

- **Orange** Boundary of the UNESCO World Heritage Site
- **Blue** Buffer zone of the World Heritage Site
- **Pink** Proposed road •• Tunnel connection
- **Red** Direlict religious site
- **Yellow** Basketry ware manufacturing and sale
- **Red** Mosque, matam, shrine
- **Light Blue** Palm water factory

Source: BACA/AECOM - amended by Think Heritage
10. Annex
Nurana Access Road

Tunnel Overview

Ns Real Estate Company W.L.L

Project number: 60578140

January 2019
Quality information

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Revision History

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Figure 9: Examples of bedrock core material from the Manama area, immediately east of the proposed tunnel alignment. 26
Executive Summary

AECOM have been appointed by the Ns Real Estate Company W.L.L. to assess the construction and impact of the proposed tunnelled highway connection between Northern District of Manama and the Nurana development. This link has been previously suggested out of a Strategic TIA study to ease the traffic flow of link road connection with Sheikh Khalifa Bin Salman Highway.

The proposed connection is located offshore, through a visual corridor emanating from the UNESCO heritage site at Qal’at Al-Bahrain, in which development above sea level is not permitted and therefore a tunnelled connection is considered to be the only workable option.

The assessment confirms that the construction of the proposed tunnel will have minimal permanent impact on the visual corridor with some temporary disruption during the construction phase.

The existing studies and investigations indicate that there is a minimal risk of impact on the Alat aquifer within the 12m depth of the proposed tunnel alignment.

This report discusses outcomes of the numerical hydrodynamic (flushing) modelling, geophysical investigations, hydrogeological condition assessments relevant to site to elaborate on the design constraints as well as the tunnel alignment and construction constraints and methods thereof.

Having evaluated the constraints on the development alongside relevant site conditions, the developed proposal is for a four-lane tunnelled highway constructed using cut and cover methodology within the visual corridor and associated approach ramps linking the tunnel with the existing and proposed road network.

It is concluded from the assessment that construction of a tunnelled highway crossing is feasible at the location however the impact of the proposed works on the site require to be managed and designed to ensure that design constraints be respected and followed. It is considered that the construction options are tightly constrained by the particular layout of the site and planning constraints imposed by the adjacent UNESCO heritage site.

It could be noted that from the conducted hydrodynamic (flushing) modelling the proposed causeway connection to the tunnel would not have any significant impact on the existing flushing and water exchange characteristics.

The Electrical Resistivity Tomography (ERT) survey suggests that the underlying aquifer is not present within the depths specified for the survey at 12 meters. As such the proposed base of the tunnel would not be within the aquifer.

As for the seismic refraction survey showed that there is no clear evidence of an ancient in-filled channel in the area covered.

Current studies and site investigations did not reveal a certain evidence of an aquifer, ancient channel or archaeological artefacts of significant size within exploration depth of the investigations (i.e. 12m below seabed level). However, to ensure that none of the potential water-bearing strata or freshwater springs are damaged or disturbed during construction a final due diligence investigation that includes verifying of hydrogeological and geophysical data will be conducted in the detailed design stage of the project. This will be required to minimise the risks of construction impact on the surrounding area.
1. Introduction

AECOM have been appointed to provide an updated pre-concept design for a tunnelled highway connection between the Northern District of Manama and the Nurana development which will form a technical basis for the Heritage Impact Assessment to be submitted to World Heritage Council (WHC). This report provides details of the basis and developed pre-concept design. The concept is based on a design concept previously developed within a feasibility report prepared by Scott Wilson Ltd (now part of AECOM) in May 2010.

The previous tunnel concept has been updated to accommodate proposed changes in the highway alignment for the connection together with investigation work carried out since the original study.

The proposed highway link passes to the north of the Qal’at Al-Bahrain Archaeological Site, which is an UNESCO world heritage site. In order to preserve the visual corridor to the north from this site, no development is permitted above sea level. For this reason, a tunnelled connection has been proposed with the highway surfacing outside the visual corridor.

The location of the site is shown below in Figure 1.

Figure 1: Location Plan
2. Reference Data

The following reference data has been provided forms the basis for the study:

- Briefing Document – Marsa Al Seef Project RFP – Tunnel Feasibility Study, HAJ, 10th November 2009
- Kingdom of Bahrain, Ministry of Information, Sector of culture and national heritage Qal‘at al-Bahrain archaeological site (the ancient capital of Dilmun) action plan and progress report towards a management system for Qal‘at al-Bahrain archaeological site, February 2006
- The Marsa Al Seef Strategic Traffic Study (dated 14th October 2009) by COWI
- Bathymetrical Data Extracted from the Canal Flushing Study, Atkins
3. Existing Site Conditions

3.1 Topographical Conditions

Level data from large scale mapping of the area indicates that the terrain at either end of the proposed tunnel link is predominantly flat. With either end of the proposed tunnel link approximately 3m above datum. Photographs of the area are shown below.

Figure 2: Photograph of the Western Area of the Site taken from Bahrain Fort

Figure 3: Photograph of the Eastern Area of the Site taken from Bahrain Fort
3.2 Marine Conditions

Bathymetry data from the Marsa Al Seef Canal Flushing Study suggests that the sea bed is approximately 1m above National Survey Datum (NSD) level in the vicinity of the proposed tunnel link.

Charts describe the area as ‘Sand, Coral and Rock’ with ‘Numerous Fish Traps’.

3.2.1 Numerical Hydrodynamic (Flushing) Modelling

AECOM conducted hydrodynamic (flushing) modelling to establish the baseline conditions of the hydrodynamic and water exchange characteristic of the area and assess the impact of the proposed tunnel causeway on the existing conditions.

3.2.1.1 Methodology

The 2D numerical modelling was conducted with the application of the state-of-the-art MIKE 21 flexible mesh hydrodynamic and advection-dispersion modules (MIKE 21 FM HD/AD). MIKE 21 FM HD/AD is a modelling system for 2D free-surface flows and mass transportation. It is based on the numerical solution of the two-dimensional incompressible Reynolds averaged Navier-Stokes equations invoking the assumptions of Boussinesq and of hydrostatic pressure, and the advection-dispersion equation. The model consists of continuity, momentum, mass conservation, temperature, salinity and density equations and it is closed by a turbulent closure scheme. It simulates water level variations and flows and associated mass transport processes in response to a variety of forcing functions in lakes, estuaries and coastal regions. The effects and facilities include:

- bottom shear stress;
- wind shear stress;
- barometric pressure gradients;
- Coriolis force;
- momentum dispersion;
- sources and sinks;
- evaporation;
- flooding and drying;
- wave radiation stresses.

The spatial discretization of the primitive equations is performed using a cell-centered finite volume method. The spatial domain is discretized by subdivision of the continuum into non-overlapping flexible unstructured elements/cells that can be triangles or quadrilateral elements. Unlike traditional grid models, the flexible mesh model can have areas of increased resolution within a single mesh file. An explicit scheme is used for time integration.

MIKE 21 FM HD/AD is used for simulations of hydraulic and environmental phenomena in lakes, estuaries, bays, coastal areas and seas.

The flushing modelling was conducted with application of MIKE 21 FM Advection-Dispersion (AD) Module that simulates the resulting transport of material (conservative tracer) based on the hydrodynamic circulations that are simulated by the hydrodynamic model. The flushing model would share the same model domain and mesh with the hydrodynamic modelling.

Modelling was conducted for the existing/baseline condition and future condition with the proposed Tunnel/Causeway configuration.
The flushing modelling references international guidelines and common practice standards for ensuring that appropriate water exchange is permitted to the existing developments following the construction of the tunnel.

3.2.1.2 Assessment Criteria
The PIANC guideline of “flushing time” – the time required to reduce initial pollutant concentrations within a semi-enclosed waterbody to a prescribed value (e-folding value). The e-folding value is defined as $1/e = 36.8\%$ of initial tracer concentration, $e=2.71828$. In other words, the time it takes for the initial concentration to drop below 36.8\% and not exceed this value thereafter is recorded as the flushing time. The general goal is to reach the e-folding value in eight tidal cycles (four days) (PIANC, 2008).

This criterion is consistent with the recommendation of the US Environmental Protection Agency (EPA, 1985), who defines a complete water exchange of a water body in four days to be “good”, 10 days as “fair”, and “poor” if longer time was required.

Table 3-1: US Environmental Protection Agency Recommended Flushing Classifications

<table>
<thead>
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<th>Flushing Time</th>
<th>Flushing Condition Classification</th>
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<td>&lt; =4 days</td>
<td>“Good”</td>
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<tr>
<td>&lt; =10 days</td>
<td>“Fair”</td>
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<tr>
<td>&gt; 10 days</td>
<td>“Poor”</td>
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3.2.1.3 Flushing of Existing Conditions (Baseline)
The following section describes the flushing capabilities surrounding the project site for the Existing Condition. For reference, the flushing of the semi-enclosed areas for the Existing Condition are shown in the spatial distribution plots for initial conditions (Day 0), 1 day, 2 days, and 4 days. In addition to this, the reduction in average concentration of all components are plotted over a 4 day period.

For the Baseline Conditions, the existing Nurana-Marsa causeway has no openings. With the presence of the solid causeway, the flooding and ebbing tides generally follow a north-south movement on both sides of the development. This phenomenon is further described in the paragraphs below.

The basin is open to the east for direct water exchange and is blocked by the existing Nurana-Marsa Causeway on the west. Due to the blockage, a general north-south movement exists as the concentration flushes with the flooding and ebbing tides. As seen with the tracer, areas of high concentration remain in the small lagoon north of Bahrain Fort and in the semi-enclosed area formed by the fishing harbour and the land boundary. High (maximum) concentrations of 86\% remain in the semi-enclosed areas after 10 days. However, based on the PIANC guideline for flushing, the average concentration of the tracer ultimately flushes in 2 days, therefore the flushing of the basin is ‘good’.

The western side of the existing Marsa/Nurana causeway was also modelled. This area is open for direct water exchange on the west and is blocked by the Nurana-Marsa Causeway on the east. During flooding, with a predominant southeast flow, fresh water enters the basin, mixes, and leaves in the next ebbing tide. During ebbing, along the southern Nurana-Marsa causeway, the fasht almost dries out completely, however, the concentrations remain high as high concentration returns to the basin with the next flooding tide. After 10 days, maximum concentrations of 88\% exist, especially in the semi-enclosed corner formed between the southern Nurana-Marsa Causeway and the coastline. Other areas of higher concentration include the semi-enclosed area formed between Marsa and the northern Nurana-Marsa Causeway. Based on the PIANC Guideline for acceptable flushing, the average concentration of Component 4 flushes within 3 days.
## Existing Basin

### Initial Condition - Day 0

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value

### 1 Day

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value

### 2 Days

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value

### 4 Days

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value

## Western Side of the Existing Marsa/Nurana Causeway

### Initial Condition - Day 0

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value

### 1 Day

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value

### 2 Days

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value

### 4 Days

- Concentration ranges from 0 to 100
- Basin 1: Undefined Value
### Existing Basin

<table>
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<th>Concentration - Trace (μg/L)</th>
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<table>
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<th>Western Side of the Existing Marsa/Nurana Causeway</th>
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10 Days

**Figure 4: Existing Flushing Diagrams**

#### 3.2.1.4 Post-Tunnel Construction Flushing

This section describes flushing capabilities of the areas described in the previous section (i.e. the baseline condition) following the completion of the tunnel/causeway configuration.

In this scenario the model also assumes that the existing Marsa/Nurana transmission causeways is fully developed and has provisions to establish water exchange (e.g. culverts), which are modelled as simple openings distributed evenly along the causeway covering a total length equal to 20% of the overall causeway length.

Post-construction of the causeway/tunnel and improvement of the Marsa/Nurana causeway, the flushing capability of the Existing Basin improves and drops below 2 days, which is still within the limits of the ‘good’ flushing criteria. The causeway link to the tunnel starting from the southern edge of the Nurana development forms a curved arm and a dead-end at the point where it meets the existing Nurana landform. However, this area faces east, which is the same direction of the ebbing currents. Therefore, it was noted that this area flushes well in less than a day and does not cause any stagnant zone.

On the opposite (i.e. western) side of the Marsa/Nurana transmission causeway, the flushing significantly improves due to the culverts constructed along the transmission causeway. It is also observed from the model that the causeway connection to the tunnel has a negligible impact on the hydrodynamic patterns of the western side of the Marsa/Nurana transmission causeway.

The tracer concentrations for both conditions on Days 0, 1, 2, 4 and 10 are shown in the following Figure 5.

The average reduction in concentrations of the tracer is also plotted on Figure 6, where the red line represents concentration with the existing basin, blue line represents the west of the Marsa/Nurana transmission causeway and the green line shows the PIANC criteria.
<table>
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Overall, it was concluded that construction of the access causeway/tunnel configuration would not have any significant impact on the existing flushing and water exchange characteristics of the basin.

### 3.3 Ground Conditions

#### 3.3.1 General Geology

The Kingdom of Bahrain consists of a broad asymmetrical dome, oriented in a north-south direction consisting of Eocene and Miocene sediments and sedimentary rocks of Tertiary Age dipping gently towards the island margins (Figure 7). The Tertiary rocks are surrounded by flat-lying superficial deposits of Pleistocene and Recent deposits of Quaternary Age, and in particular forming an extensive area in the north of the island where the proposed site of the tunnel is located, as well as the east, west and southern parts of the island. These Quaternary deposits do not appear to be affected by the up-doming. The landform in the central part of the island is dominated by a group of hills with associated escarpments, backslopes and interior playa basins.

The bedrock geology of the centre of Bahrain Island consists of Eocene sedimentary rocks, except for a small occurrence of younger cap rock to the Jabal ad Dukhan in the centre of the island believed to be Miocene in age and referred to as the Jabal Cap Formation. The Eocene rocks are divided into the older Rus Group comprising of carbonate rocks, and the younger Damman Group, again comprising of carbonate rocks with subordinate mudstone
deposits. Generally, the interface between the Damman and Rus groups is marked by a 'shale' horizon, which marks the base of the Dammam Group. The Rus Group includes the Hafirah and Awali Carbonate Formation, generally consisting of dolosiltites, dolomites and dolomitic limestone with admixtures of quartz and clay. The Dammam Group includes the Jabal Hisai, Al Buhayar, Dil'Rafah and Foraminiferal Formations, and the West Rifa Flint Formation, comprising of dolomitic limestone, dolomites, dolosiltites, mudstone, chalky limestone, with gypsiferous horizons and the West Riffa Flint Formation.

The tectonic activities associated with the development of the Arabian Gulf formed the pericline dome structure of the island formed by the massive limestones of the Foraminiferal Carbonate, Al Buhair and West Riffa Flint Formations of the Damman Group. Subsequent erosion of the exposed landmass removed the crest of the structure exposing the older rocks of the Dil'Rafah and the Rus Group in the core of the former dome. Subsequently the sediments forming the Jabal Cap Formation were deposited on the eroded surface, with further erosion producing the present landform comprising of an interior basin floored by the Rus Group, and surrounded by an almost continuous multiple escarpment feature exposing the younger Dummam Group carbonate rocks. The inland geology is complicated by cross-folds producing a complex assemblage within the interior basin composed of playa basins, desert landforms, with exposures of bedrock and bedrock superficially covered by thin soils. The Al Buhair Carbonate and West Riffa Flint Formation form extensive dipslopes behind the escarpment sloping gently towards the sea and cover broad areas in the north and south of the island. It is uncertain whether the tectonic effects seen inland extend to the offshore area.

The inland higher ground is surrounded by coastal lowlands, where the solid geology at the base of the backslope gives way to a fringe of younger unconsolidated, superficial deposits laid down by a combination of aolian and marine processes. The northern part of Bahrain Island, where the site is located, consists of subdued landforms where elevation is generally less than 5m above mean sea level. Along the coast, the northern plain consists of unconsolidated loam, comprising sandy-silty-clay of roughly equal portions. The unconsolidated loams overlie sands and carbonate-rich muds at depth of between 1m and 3m below ground. The loams formed in mangrove swamps which extended over sands levelled by aolian and marine processes. The coastal areas are affected by recent geomorphological activity with waters of high salinity and temperature facilitating the rapid deposition of carbonate and evaporite sediments in complex shoal water environments and strong tidal currents. This environment produces sediment transport by waves forming as poorly indurated weakly cemented rock like horizons confined between un lithified, uncemented sediments. The extensive areas of relatively young shallow marine sediments fringe with coastal dunes, flat intertidal flats, algal flats, mangrove swamps and salt encrusted sabkhas generally composed of sandy deposits. The northern portion of Bahrain is located in the area dominated by carbonate-rich sands. The offshore deposits typically comprise silt and carbonate sand largely derived from the exposed floor of the Arabian Gulf.

Typically, offshore developments in the Manama area are likely to encounter shelly carbonaceous sand with variable amounts of calcareous muds. Due to marine level fluctuations during the Quaternary the exposure of marine sediments have produced cementation and development of Quaternary limestone deposits, occasionally capping un cemented sediment. Shallow groundwater is present in the coastal areas with continuity of shallow fresh and saline water in near shore areas. Submarine springs occur between Manama and Sitra, and also between Manama and Muharraq Island.
Figure 7: Geological Map
3.3.2 Review of Available Ground Investigation Data

Generic Investigations

A review of available borehole logs revealing the ground conditions encountered during various ground investigations carried out in the near-shore marine environment of Bahrain have been examined. The purpose is to ascertain the variability in the nature of ground strata between unlithified sediment and lithified rock with depth. The location of the various investigations is shown in Figure 8 and a summary of the findings presented below.

Hidd Development Project – 500m offshore from the east coast off Muharraq and 3km south of Amwaj Island, and greater than 14km east northeast of the proposed tunnel alignment: A total of 25 boreholes were formed offshore from jacked platforms at water depths of between 0.7m and 7.5m

• Boreholes were formed to depths of between 2.8m and 26m below sediment-line
• Boreholes typically show a variable lithology comprising of alternating unlithified sediments typically comprising calcareous sand or sandy silt, occasionally with gravel and clay.
• Sediments variable interbedded with apparently non-persistent lithified rock, of typically between 0.3m and 2.3m bed thickness, including very weak to weak moderately weathered siltstone; moderately strong limestone, occasionally gypsiferous; weak to moderately strong sandstone occasionally with solution cavities; very weak mudstone.
• Occasional boreholes show unlithified sediment extending to depths of up to 24m below sediment-line.

PK Development – Located on the southern end of Bahrain Island, and approximately 45-50km to the south of the site: Data comprises of 3 borehole records formed to depths of between 5m and 15.50m below sediment line.

• From sediment-line to depths of between 0.5m and 1m the sediment is described as very softy slightly sandy silt with sand and organic odour.
• A single borehole reveals caprock of conglomerate sandstone and fine limestone extending to 1m overlying consolidated silt.
• Alternating horizons of very stiff to hard silt; very weak to weak moderately weathered siltstone; and occasional limestone and sandstone horizons. The silt and siltstone beds are typically recorded as 1m thickness. The horizons extend to depths of 14.5m below sediment-line.
• Boreholes are terminated in a very weak to weak light grey and light brown moderately weathered highly fractured siltstone, proved by coring between 1m and 2.5m of rock material.

Diyar Al Muharraq Project – Located offshore to the north of Muharraq Island, and greater than 9km northeast of the proposed tunnel location: Date comprises of 2 boreholes records formed to depths of 14m and 15.45m below sediment-line.

• BH-1 indicates very loose becoming medium dense carbonate and silica sand, and very soft sandy silty clay/clayey silt with some gravel extending to 7.5m below sediment-line, over; very weak to weak thinly bedded calcarenite (carbonate sandstone) and calcsiltite (carbonate siltstone) extending to the base of the hole. Rotary core drilling was attempted from a depth of 11.5m with poor to zero recovery.
• BH-10 indicates very weak to weak thinly bedded calcarenite (carbonate sandstone) and calcsiltite (carbonate siltstone extending to the base of the hole, with shelly sand recovered between 0.15m and 1.20m below sediment-line. Rotary core drilling was attempted from a depth of 8m with poor recovery, with significant improvement in the final core run from 13m depth.
attempted from a depth of 8m with poor recovery, with significant improvement in the final core run from 13m depth.

Local Ground Investigation

Ground investigation records in connection with the offshore Marsa Al Seef development were made available for review. Two sets of data were inspected recording the ground conditions a few hundred meters to the west of the tunnel alignment. The investigations are considered to reveal the ground conditions likely to be encountered in the area of proposed tunnel construction.

Al Nurana Project – Located a few hundred meters offshore immediately to the north of Karanah and immediately to the west of the western portal of the proposed tunnel: Date comprises of 2 boreholes records formed to depths of 10.45m and 15.00m below sediment-line. The water depth is recorded between 1.4m and 1.7m.

- BH-14 indicates very loose becoming medium dense sand with shells to 7m; over stiff to hard light brown silt proved to a depth of 10.45m below sediment-line.
- BH-15 indicates very loose becoming medium dense sand with shells to 5m; over hard yellow brown becoming grey silt to 9.0m; over very weak moderately weathered light grey fractured siltstone proved to a depth of 15m below sediment-line. Core recovery of the siltstone between 9m and 15m is recorded as full total core recovery.

Marsa Al Seef Reclamation and Dredging Design – carried out for Global Real Estate Development Co with Haj acting as project manager. The investigation was completed in April 2010 by Al Hoty Analytical Services.

The ground investigation was carried out using cable percussive boring with rotary coring follow-on techniques deployed from a jacked-up platform. Review data comprised 22 boreholes formed to depths of between 10m and 20m below Sea Bed Level (bSBL). The cable percussive boring included recovery of bulk samples and performance of in situ SPT tests with recovery of disturbed samples. SPT refusal is given as N = 50+ on the logs and is followed by borehole progression by rotary coring techniques.

The area covered by the ground investigation covers an area extending approximately 3.5km in a south to north direction, and approximately 1.7km in an east to west direction and extends to approximately 4km off-shore.

Generally, the ground strata encountered in the boreholes was similar and is summarised from the borehole log descriptions as follows:

- Very loose light grey silty, gravelly fine to coarse carbonate and siliceous Sand, gravel consists of shells and shell fragments; extends to depths of between 1m and 5.5m bSBL; not recorded in a single borehole; occasional reference is made on 4 borehole records to shallow cemented horizons described as calcarenite or limestone, typically proved over a thickness of between 0.4m and 0.5m, at depths ranging from sea bed level to 2.25m bSBL; over
- Firm to very stiff light yellow to light grey slightly sandy, slightly gravelly Silt / Clay; extends to depths of between 2.5m and 6.5m bSBL, with the strata ranging between 1m and 4m thickness; over
- Extremely weak thinly to medium bedded, closely fractured yellow Calcisiltite (calcareous siltstone), highly to moderately weathered; locally interbedded with mudstone; extends to depths of between 3.85m and 9.8m bSBL, with the strata ranging between 0.85m and 3.3m thickness; not recorded in a single borehole; over
- Very weak to weak medium to thickly bedded closely to medium fractured, yellow to light grey Calcinilutite (calcareous mudstone), highly to moderately weathered; extends to depths of between 13.3m and 17.85m bSBL, with the strata ranging between 5.5m and
11.75m thickness; many of the boreholes formed to 10m bSBL terminated in the calcilutite horizon; over

- Very weak to weak thin to medium bedded closely to medium fractured off white, vuggy Limestone, highly to moderately weathered; encountered at depths of between 13.30m and 17.85m bSBL, with the strata proved to a thickness of at least 6.7m, with deeper boreholes terminating at a depth of 20m bSBL in this horizon.

Borehole water observations are generally recorded between 4.22m and 11.1m above SBL. No data is given for platform elevations and specific water strikes.

**Nurana Development Phase 1 Heritage Feasibility Study** – carried out by Al Hoty Analytical Services for Manara Development Company at the proposed Nurana Development Site in Karranah.

The boreholes were drilled by a combination of cable percussion and rotary coring methods using a Dando 3000MK2 Rig, a tripod cable percussion rig with rotary attachment.

Data comprises of 11 boreholes records formed to depths of 10m. Generally, the ground strata encountered in the boreholes was similar and is summarised from the borehole log descriptions as follows:

- Medium dense, brownish and light grey slightly silty, slightly gravelly, fine to coarse sand was encountered at depths from 0m up to 5.90m, over;
- Very weak to weak, thinly to medium bedded light grey vuggy Calcarenite was encountered and extends depths between 2.5m to 7.2m, over;
- Weak to medium, medium to thickly bedded grey Calcilutite, which extends to depths of between 3.5m and 10.0m (BH termination).
- On one occasion in borehole NT-105L Calcsiltite was recorded as very weak to weak, thinly to medium bedded at a depth of 5.75m to 8.70m, overlying Calcilutite
- On two occasions in boreholes NT-204L and NT-205L, Limestone was recorded to be underlying Calcilutite at depth of between 6.40m and 10.0m (BH termination). The limestone was described as being weak to moderately strong, thin to medium bedded, light grey and vuggy.
Figure 8: Ground Investigation Location Plan
3.3.3 **Geophysical Study**

A geophysical survey was commissioned by the client to determine if the underlying fresh water aquifer would have an influence on the proposed construction depth of the tunnel and determine if an ancient in-filled channel passes through the line proposed of the tunnel.

Shear wave data was also collected during the field works to be processed at the detailed design stage to provide stiffness values at the tunnel depth, which will aid tunnel design.

Surveys were commissioned using the Gulf Centre for Geophysical and Water Consulting (GCGC) including the following techniques:

- **Electrical Resistivity Tomography (ERT)** was proposed to identify variations in ground resistivity associated with changes in groundwater composition and/or lithology. Larger archaeological features can also be revealed though this is not the primary aim of the technique.

- **Seismic refraction (onshore and offshore)** to identify disturbed areas that might be archaeological and to provide geological/geotechnical information

- **Seismic Multichannel Analysis of Surface Waves (MASW)** (onshore and offshore) to identify disturbed areas that might be archaeological and to provide geological/geotechnical information. The site under investigation is an inter-tidal area between the southern Nurana island and a spur to the east of the Bahrain fort. The seismic surveys therefore were mainly land based and were designed to be acquired around the tidal movements at the site. The land seismic surveys (refraction and MASW) were conducted by following the tide out as more land was exposed. The three parallel alignment lines were conducted to approximately 75% completion in this manner. The remaining section of alignment closest to Nurana Island, which was always covered in water, was conducted from a boat which required different equipment and acquisition methods.

To investigate the influence of the fresh water aquifer the electrical resistivity survey was conducted from a suitable vessel around the daily high tides. The marine electrical resistivity method requires a 70m electrode cable to be towed behind the vessel which inputs an electrical current into the water column and the potential difference recorded. The entire survey data set was collected from the vessel and good coverage was attained. A small section, (approximately 100m) of the northernmost alignment profile at the south of Nurana Island was not possible to survey due to the tight site conditions.

AECOM’s in-house geophysicists undertook a robust quality assessment of all the raw data acquired from the surveys and determined the reliability of the sub-contractor’s interpretation based on the data quality. It is considered that the data quality is adequate enough to make a considered interpretation of the data set.

Whilst the resistivity survey has detected anomalies in a confined area which has higher resistivity at the south east portion of the tunnel alignment, it provided no evidence of an in-filled channel on any of the survey lines.
3.3.3.1 Electrical Resistivity Tomography (ERT)

The ERT survey was specified by the client to achieve a depth of 12m to provide coverage to the proposed depth of the tunnel & immediately below.

Surveys included three parallel lines along the proposed orientation of the tunnel and nine profiles approximately perpendicular to the tunnel. Surveys were conducted at high tide using a 10 channel resistivity meter using a towable streamer with 5m electrode separation and readings collected at 1 second intervals (nominally 2m). Data was collected in conjunction with a GPS input and echo sounder to provide locational accuracy and allow appropriate correction of water depths during the ERT inversions.

The data can be summarised as follows:

- Data quality for the ERT survey is good
- Models from the inversions are acceptable for this environment with RMS misfits of <15% and good correlation where modelled profiles cross.
  - There is some potential for variance in modelling from the effects of the water, but this does not have a significant impact on the interpretation of the model.
  - The model required manual manipulation in some areas. A good best fit of the data is believed to have been achieved.

The data shows relatively conductive materials with no clearly defined change in electrical properties within the subsurface but with higher resistance values towards the surface (increasing in thickness and resistance to the East), gradually becoming more conductive with depth through the unit.

The data suggests materials with resistance values consistent with materials in full or partial connection with the tidal waters and that the underlying aquifer is not present within the depths specified for the survey (12m). As such the proposed base of the tunnel would not be within the aquifer. The depth to the aquifer itself has not been established from this survey.

The increase in conductivity with depth is likely to be due to one of the following reasons:

- Porosity may be lower in a well-cemented layer immediately below the surface, becoming more porous with depth.
- The shallowest layer may be composed of more resistive material, underlain by a less resistive layer.
- There may be variations in the conductivity of the pore waters. In this case the higher resistivity suggests lower salinity.

The latter of these options may indicate higher volumes of freshwater in the near surface to the east of the tunnel. This could be due to shallow springs, the known fresh water outfall in this area or rainfall, possibly compounded by the thickness of superficial deposits holding water and regular exposure during low tides.

The dredged channel is associated with a reduction in modelled resistivity evident in several profiles. A buried historic channel would be likely to produce a comparable feature. Similar localised features are evident elsewhere in the data, but not forming any linear pattern consistent with a manmade channel. As such there is no evidence from this data set to suggest a historic infilled channel.
3.3.3.2 Seismic Refraction

Basis of QC and Interpretation of Seismic Refraction

Seismic refraction is intended to be used in a horizontally layered earth environment with each subsequent layer increasing in hardness and hence in seismic velocity due to overburden pressure.

The borehole logs do indicate layered sedimentary materials with increasing depth. The upper Calcarenite layer is very weak, weathered and porous with a change of material around 5.5m to 6m below the subsurface to weak Calclutite which again is weathered and porous, however not as porous as the overlying material. There would likely be a very discrete increase in velocity between the two materials due to the subtle change in material structure.

It is clear from the borehole logs and core photographs that it is beyond the capability of the refraction method to detect this change as there is not sufficient contrast (change) at the interface between the two material types.

The refraction cross sections produced by the sub-contractor must be viewed as velocity sections – not geological sections. It is best considered that the profiles are ‘weathering’ profiles with no geological assignment.

The sections provided by the contractor (GCGC) do not show coherence from profile to profile when analysing the 3 profiles identified as Centre, Northern and Southern. The centre profile shows a decrease in velocity in the centre section whereby the other outlying profiles show an increased velocity in this area. It is therefore unlikely that the geology would change significantly enough to show this velocity contrast change from profile to profile. It is therefore recommended that this data be re-processed, and the first break arrival picks checked by AECOM Geophysics prior to any velocity models being produced.

The data quality for all the works carried out have been performed using Seisimager software with a view of the raw seismic records and sections provided by the client being reviewed.

The QC phase of work has been split into two main categories:

1. Land Seismic Refraction
2. Marine Seismic Refraction

The land refraction data can be broadly categorised as generally fairly noisy but good enough to pick first arrivals with some filtering and advanced processing on the dataset. Additionally, sometime break issues have been identified on some of the shots indicating triggering problems which may either be site related or equipment related. A 10 millisecond delay setting in the instrument would have alleviated this issue during acquisition as the pre-trigger information would have been preserved in the recorded data. A detailed list of each line and the relevant information can be provided in a table if required.

The marine refraction/MASW data has a significant amount of low frequency noise present on the records and beyond the mid-point of the spread. This is likely due to insufficient seismic energy being transmitted through the ground and the data acquired in a noisy environment. A larger source would have alleviated some of the issues with this dataset as would stacking of the data. Despite this noise, some of the data can be filtered and processed to bring out the relevant signal response and improve the signal-noise ratio, allowing enough coherent information to produce the velocity models required. It should be noted that the data isn’t ideal but may the best that could have been achieved in the timescale and budgetary constraints. AECOM Geophysics would recommend that a selection of this data be re-processed to check the models provided by the subcontractor as being accurate. A table denoting the characteristics of each line of data can be provided on request.
The seismic data has seismic velocities present that would indicate weathered and fresh rock being close to the surface with a thin covering of sand in places. The velocity models provided are not geological cross sections and further work would be required to combine the geology from available boreholes to produce a meaningful interpretation.

From the data it is evident that the weathering profile of the rock is variable across the site with sharp contrasts on velocities being noted from the sections provided by the client. Given the seismic velocities exceeding 3000 m/sec, this would also indicate fresh rock being present below the surface in places. The velocity profiles provided by the subcontractor are therefore considered to be weathering profiles along the alignment, though they may not be considered entirely reliable due to the variability seen in the cross sections when compared to each other.

It should be noted that the main purpose of the refraction survey was to provide indicative information on the presence of an ancient in-filled channel to the east of Nurana Island. Based on the quality of the geophysical data described above, we conclude that there is no clear evidence of an ancient in-filled channel in the area covered by this survey.
3.3.4 Hydrogeology Conditions

On the island of Bahrain there are three principal limestone aquifers, these are laterally continuous to the same geological formation that also outcrop in Saudi Arabia. These are, from youngest to oldest: Alat Aquifer, Khobar Aquifer and the Rus/ Umm Er Raduma Aquifer. These three aquifers are also referred to by the letters ‘A’, ‘B’ and ‘C’. The aquifers are separated by low permeability marl horizons.

The aquifer systems in the vicinity of the proposed Nurana Tunnel comprise the Alat aquifer that lies at a depth of about 12 m near to the eastern portal but is at a shallower depth to the south of the tunnel alignment towards the Qal‘at Al Bahrain Fort being probably identified in two other site investigation boreholes. The Alat aquifer is capped and thus confined by a layer of calcilutite. Above this low permeability horizon are calcaranite and sand which are considered to be in hydraulic connection with the sea.

The Alat limestone aquifer contains relatively freshwater that fed the springs that occur near the shoreline or within the inter-tidal zone. The sand/calcarenite aquifer is expected to be saline with a similar chemistry to sea water.

A ground investigation was undertaken as described section 3.3.2 in 2015 to 2016. The investigation aimed to provide information on the geological strata to depth of up to 25m depth and to construct a network of boreholes suitable to monitor the groundwater levels and water quality in two separate groundwater bodies. The complete investigation was not undertaken and only some of the boreholes to monitor the shallowest saline groundwater were drilled. Preliminary results are available from a ground investigation in 2019 with, as yet, only one borehole has been drilled to a depth of 23m. It can be considered from the results that the Alat Aquifer can be found at this approximate depth. Groundwater levels are near to sea level in the sand/calcarenite aquifer and are anticipated to fluctuate in response to the tidal level. In the Alat aquifer the groundwater level is expected to be slightly higher than the shallower aquifer for at least part of the tidal cycle. The head in the Alat aquifer drives the flow in the freshwater springs.
3.3.5 **Anticipated Ground Conditions**

Based on the findings of the reviewed ground investigation data, it is likely that the ground conditions revealed by boreholes formed in connection with the Nurana Project and boreholes BH31 and BH-34 formed in the southeast corner of the Marsa Al Seef Reclamation investigation, adjacent to the proposed tunnel location - are likely to be typical of site conditions. These proved the following general ground lithology:

- a loose to medium dense sand with shells to depths of between 5m and 7m below sea bed level; overlying
- unlithified silt / clay deposits extending to depths of between 5m and 10.45m below sea bed level; overlying
- very weak siltstone becoming mudstone extending to depths of 9.8m and 16m below sea bed level; overlying
- very weak to weak vuggy limestone proved to a depth of 20m below sea bed level.

It is likely that the deposits proved will be in saturated and likely to be in hydraulic continuity with the saline water, and fresh groundwater near to shore.

The calcareous siltstone / calcareous mudstone horizons are described as being vuggy, observation of core from the western Manama area confirm such descriptions, as can be seen in Figure 9. The distribution of vugs will influence ground bearing conditions and connectivity may influence groundwater transmission and bear influence on the proposed construction.

Vugs in siltstone (central core section) and limestone (core to the left). Mudstone (right hand core) contains significantly less voids.  
Vugs, locally interconnected lined with calcite crystals in limestone.

**Figure 9: Examples of bedrock core material from the Manama area, immediately east of the proposed tunnel alignment.**

Based on the findings of the other ground investigation data reviewed, it is possible that unlithified sediments may be present at shallow depths below the lithified siltstone and limestone, and within a depth range that may be affected by the proposed construction.
4. **Design Criteria and Constraints**

4.1 **Tunnel Safety Requirements**

4.1.1 **Design Standards**

It is understood that the tunnel will be required to comply with British Department of Transport Design Standards.

- Design Manual for Roads and Bridges, BD 78/99 – Design of Road Tunnels
- Design Manual for Roads and Bridges, TD 27/05 – Cross Sections and Headroom

4.1.2 **Other Design References**

The following documents will be referred to as examples of industry best practice.

- Urban road tunnels recommendations to managers and operating bodies for design, management, operation and maintenance, PIARC, 2008
- Directive 2004/54/EC of the European parliament and of the council of 29 April 2004 on minimum safety requirements for tunnels in the trans-European road network

4.2 **Traffic Flow Requirements**

The Marsa Al Seef Strategic Traffic Study (dated 14th October 2009) by COWI provides inbound and outbound peak traffic flows of 1548 and 2344 vehicles/hour respectively. Corresponding to this traffic flows the Bahrain Road Design Manual requires 2x2 lane configuration for the tunnel.

4.3 **Constraints**

The action plan for management of the Qal’at Al-Bahrain archaeological site proposes that no development above sea level is to be permitted within the visual corridor extending north from this site.
4.4  Tunnel Space Proofing & Geometry

4.4.1  Tunnel Alignment

The tunnel alignment is constrained by the proposed Junctions with Road 2819 and by the UNESCO visual corridor.

A provisional tunnel cross-section has been prepared which is approximately 9.5m high and is assumed to be placed with the top of the structure 3m below datum level. A maximum gradient of 4% has been assumed for the approach ramps and the provisional arrangement shows a length of up to 250m for these ramps between road level and tunnel portal.

The eastern end of the link is proposed to join Avenue 58, which runs generally east / west, up to a point approximately 200m from the coastline where it curves north to follow the coast. At this location, it is understood from the heritage action plan that the UNESCO corridor extends to the coastline and therefore the area between Road 2819 and the corridor is very limited. Because of this limited area available to accommodate the tunnel approach ramp, it is considered that connection between the tunnelled link and Road 2819 will need to be made some distance along the current alignment of Road 2819. For this reason, some re-configuration of Road 2819 will be required in order to accommodate the new junction and tunnel approach ramp.

4.4.2  Tunnel Cross-Section

A provisional tunnel cross-section has been prepared based on traffic requirements, safety requirements, ventilation and structural considerations.

The proposed cross-section includes three cells, two of which each contain two lanes of traffic and a third centre cell containing services and facilitating emergency egress. It is envisaged that emergency exit doors will be provided between the two traffic cells into the central cell at the specified intervals to facilitate exit in the case of emergency, such as tunnel fire. Each of the traffic cells also includes walkways to facilitate evacuation to emergency exits.

Given the relatively short length of the tunnel, longitudinal ventilation using jet fans has been assumed.

4.4.3  Safety Recommendations

The following safety recommendations are made based on the requirements of the BD78/99 design standard and EU Tunnel Safety Directive where these are considered relevant to the proposed tunnel link:

- Tunnel should be divided into 2 or more cells to provide a place of safety in the event of a fire
- Gradients should be minimised, and it is recommended that they are limited to a maximum of 4% to avoid elevated ventilation requirements
- Emergency exits should be positioned at least every 500m
- Lay-bys required at least every 1000m
- Drainage to be provided, suitable for dealing with flammable liquid spills unless transport of dangerous goods is prevented
- Structure to be designed for suitable fire resistance
- Provision of normal, safety and evacuation lighting
- Provision of mechanical ventilation
- Provision of emergency stations at least every 150m
- Provision of water supply at least every 250m
- Signs for all safety equipment
- Provision of a control centre with dedicated tunnel management
- Video monitoring
- Automatic fire or incident detection
- Traffic signals before tunnel entrance
- Radio re-broadcasting for emergency services
- Provision of facilities for emergency radio messages to tunnel users
- Provision of loudspeakers to exits
- Emergency power supply to provide continuation of safety equipment during evacuation
- Adequate fire resistance of equipment to maintain safety functions

It is recommended that the tunnel layout and systems are designed with reference to a suitable risk assessment process such as the QRAM system developed by PIARC.

4.5 Tunnel Drainage

Tunnel drainage will be required to deal with potential seepage through the completed structure as well as inflow from the portals and potential leakage from vehicles in the tunnel.

It is recommended that facility is provided to deal with the potential for leakage of dangerous liquids from vehicles within the tunnel or on the approaches. The drainage system should therefore be designed to isolate the two traffic cells and prevent flammable or harmful liquids passing between the two.

The drainage system envisaged would include drainage sumps at each portal to intercept flows from the approach ramps and a central drainage sump close to the lowest point in the tunnel. Drainage sumps would return liquids to a suitable drainage connection at the surface via sump pumps and rising mains.

4.6 Operations and Management

It is envisaged that, upon completion, the tunnel will be fully integrated into the wider road network in the area and be adopted by the relevant management authority.

In order to comply with safety regulations and recommendations, a dedicated tunnel management will be required. This could be in the form of a management team based in a control centre at the tunnel or a dedicated team incorporated within a general highway control centre.

Whichever management structure is put in place, the management of the tunnel will be an ongoing responsibility with an ongoing cost for the life of the structure in addition to operation costs associated with tunnel services and maintenance.
5. Concept Design

Options for construction of the proposed highway tunnel link have been evaluated with due consideration of the local topography, ground conditions, site and planning constraints.

The key constraint requiring consideration of a tunneled highway connection is the restriction on development in the UNESCO Visual Corridor, which the highway connection is required to cross. This corridor dictates the extent of a tunneled solution as a bridge or causeway would otherwise offer the most economical solution for a crossing of the lagoon.

Given the comparatively high construction and operational costs of a tunneled solution, it is advantageous to limit the length of the link constructed within a tunnel. This length will also be limited by the length required for approach ramps to take the road from surface level to the level required beneath the gulf.

5.1 Construction

There are several available methods of construction which could be considered to create the tunneled highway link however the topography of the site and length of the tunnel required guide consideration strongly towards adopting a cut and cover methodology.

Adopting a bored tunnel methodology can be ruled out because of the comparatively short length of the tunnel, which makes the use of an appropriate tunnel boring machine prohibitively expensive and the depth required to suitable ground conditions unobtainable within the required length.

Use of immersed tube techniques in which tunnel sections are floated into place within a dredged channel would often be suitable for a short water crossing of this type however the method relies on obtaining a suitable dry-dock in which to construct the tunnel sections and sufficient depth of water to allow them to be floated into position. Neither of these conditions can be practically satisfied at this site and therefore this construction method is unlikely to be suitable.

The most appropriate construction option for this location is considered to be provided by the cut and cover tunnel method. This involves the excavation of an open excavation in which the tunnel structure is constructed and subsequently backfilled. The shallow depth of water on the crossing route, the lack of obstacles and the relatively short length required mean that this method is most suitable for the site.

Sketches showing an outline construction methodology are included in Appendix B.

5.2 Key Assumptions

The following key assumptions have been made in the assessment and development of the chosen design option:

- It has been assumed that no permanent structures will be permitted within the UNESCO development corridor, but that temporary construction works will be permitted providing that archaeological and planning conditions are met.
- It is assumed that the required volumes of suitable fill can be provided for temporary and permanent causeway construction.
5.3 Construction Methodology

Having reviewed the site conditions and construction options, the following outline proposals have been developed.

Creation of a cut and cover tunnel across the site would require a suitable excavation in which to construct the tunnel allowing least or insignificant detriment to the hydraulic flow. The excavation is envisaged to be carried out in sections, split longitudinally to avoid any obstruction to the hydraulic path and traffic. Formation and support of this excavation is a key part of the methodology.

Contiguous bored piles and diaphragm walls are commonly used for excavation support in cut and cover tunnelling, however the ground conditions and relatively shallow depth of the tunnel make the use of steel sheet piles a viable and more practical alternative in this case. Unlike the contiguous piles the sheet piles can be retrieved after the construction.

It is anticipated that a temporary piling platform will be required in the form of a causeway constructed along the alignment of the tunnel. This would allow for sheet piling for the tunnel excavation and approach ramps and could be retained outside the UNESCO visual corridor as causeways forming part of the highway link.

Depth of the proposed tunnel structure would be approximately 9.5m and therefore an appropriate depth of excavation below seabed will be considered protecting the aquifer. It is envisaged that this excavation could be achieved by creating a propped cofferdam using sheet piles. Sheet piles would need to extend sufficiently into the seabed to provide lateral resistance and to limit water inflow into the excavation. Suitable de-watering of the excavation would be essential.

The sheet piles would terminate at the interface with competent rock. Excavation below the termination depth of the pile wall within rock would be supported by means of rock bolts and shotcrete if required.

It is assumed that there will be some water ingress into the excavation as the ground comprises fractured and weak rock. Adequate ground improvement in the form of permeation grouting would be required to limit water ingress during excavation. Additional ground investigation would be required to determine requirements at the detailed design stage.

The permanent structure of the tunnel would be cast as a reinforced concrete box in bays within the excavation. The depth of the excavation would be varied at each end of the tunnel to form approach ramps, which would remain as open cuttings with propped reinforced concrete retaining walls in the permanent condition.

On completion, it is envisaged that the sheet piled cofferdam would be backfilled above the tunnel structure and removed, along with the temporary piling platform. The landscape within the UNESCO visual corridor would therefore be reinstated to its original condition with the highway concealed within the tunnel within this corridor and rising within open cutting outside of the corridor to link with the wider road network.

5.3.1 Construction Duration

It is anticipated that construction of the proposals would take approximately 2 years.
6. Conclusions

6.1 Developed Proposal

Proposals developed and discussed in the preceding sections are the subject of Concept Design drawings contained within Appendix A.

6.1.1 Technical Issues

The proposed methodology is not considered to present unusual technical difficulties as it is based on established methods. The following factors are considered to be particularly relevant and should be given further consideration.

- The methodology is dependent on the ground conditions encountered on site. Recommendations for further due diligence investigation will be done to clarify and support the current data received and allow the proposed methodology to be verified.
- The developed proposal is for a relatively shallow alignment to limit excavation and spoil disposal. Initial assessments show that backfill volumes alone may not resist buoyancy effects and therefore additional stabilisation such as tension piles may be required. This will require further review at later stages when the proposals and Ground Model are more fully developed.

6.1.2 Land Reclamation

As part of the proposals, some temporary and permanent reclamation will be required to form the piling platforms in the temporary case and the permanent causeway accommodating the western approach ramp.

6.2 Concluding Statements

It is concluded from the assessment and discussions outlined above that construction of a tunnelled highway crossing is feasible at the location however the impact of the proposed works on the site require to be managed and designed to ensure that design constraints be respected and followed. It is considered that the construction options are tightly constrained by the particular layout of the site and planning constraints imposed by the adjacent UNESCO heritage site.

It could be further noted that from the conducted hydrodynamic (flushing) modelling for the established baseline conditions of the hydrodynamic and water exchange characteristic of the area as well as the impact of the proposed tunnel on the existing conditions the overall, construction of the access causeway and tunnel configuration would not have any significant impact on the existing flushing and water exchange characteristics.

The Electrical Resistivity Tomography (ERT) survey that was used to identify variations in ground resistivity associated with changes in groundwater composition and/or lithology, concluded that the data shows relatively conductive materials with no clearly defined change in electrical properties within the subsurface but with higher resistance values towards the surface (increasing in thickness and resistance to the East), gradually becoming more conductive with depth through the unit.

The data suggests materials with resistance values consistent with materials in full or partial connection with the tidal waters and that the underlying aquifer is not present within the depths specified for the survey at 12 meters. As such the proposed base of the tunnel would not be within the aquifer.

As for the seismic refraction (onshore and offshore) survey that was used to identify disturbed areas that might be archaeological and to provide geological/geotechnical information showed based on the quality of the geophysical data, that there is no clear evidence of an ancient in-filled channel in the area covered by this survey.
To ensure that none of the potential water-bearing strata or freshwater springs are damaged or disturbed during construction a final and more detailed due diligence investigation that includes verifying of hydrogeological and geophysical data will be conducted. This will be required to minimise the risks of construction impact on the surrounding area. It is envisaged that the design would be developed to avoid intercepting such strata. This will include review of the requirement for tension piles or the depth of tension piles below the tunnel structure.
Appendix A – Concept Design Drawings
BORE HOLE COORDINATES

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<tr>
<th>BORE HOLE No.</th>
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<th>NORTHING</th>
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</table>

NOTES
1. ALL COORDINATES ARE IN METRES AND REFERENCE TO BAHRAIN GRID.
2. ALL LEVELS ARE IN METRES AND REFER TO BAHRAIN NATIONAL HEIGHT DATUM.
1. ALL COORDINATES ARE IN METRES AND REFER TO BAHRAIN GRID.
2. ALL LEVELS ARE IN METRES AND REFER TO BAHRAIN NATIONAL HEIGHT DATUM.
3. FOR BOREHOLE SETOUT COORDINATES REFER TO DRG 8140-ACM-XX-XX-DR-SK-01000.
1. All coordinates are in metres and refer to Bahrain Grid.
2. All levels are in metres and refer to Bahrain National Height Datum.
3. For borehole setout coordinates refer to DRG 8140-ACM-XX-XX-DR-SK-01000.
TYPICAL CROSS SECTION - 60m R.O.W.

TYPICAL CROSS SECTION - 25m R.O.W.
Appendix B – Outline Construction Methodology
1. Initial condition

2. Reclaim temporary construction platforms, install sheet pile wall

3. Prop walls, dewater and excavate fill within, progressively
4. Excavate lower coffer dam and install lower struts

5. Excavate to lower formation level within limestone progressively installing ground support bolts/anchors.
6. Install tension piles for resisting uplift of the tunnel.

7. Cast tunnel base slab
8. Cast tunnel structure

9. Backfill

10. Replace berms within cofferdam and remove prop
11. Withdraw piles and flood area

12. Remove construction platforms
Appendix C – Geophysical Survey Report
GEOPHYSICAL SURVEY REPORT

Project
Nurana Island Access Tunnel

Location
Nurana Island
Bahrain
Geophysical Survey Report

Project
Nurana Island Access Tunnel

Location
Nurana Island, Bahrain

Reported by: M Harwood BSc PhD
S Shahzad BSc MSc

Job Reference GC-GP-18-56

Report Reference Report_GC-GP-18-56_Nurana VER 1.1

Date: January 2019
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1 INTRODUCTION

1.1 Background

Gulf Centre for Geophysical and Water Consulting (GCGC) were commissioned by AECOM Bahrain (the Client) to undertake geophysical investigation of a site lying between Karbabad Beach and Nurana Island, on the northern coast of Bahrain (Figure 1). The onsite survey work was completed between the 15\textsuperscript{th} to the 28\textsuperscript{th} December 2018.

The survey area is an intertidal area. Consequently, the survey used a combination of land-based techniques deployed at low tide, and marine techniques, deployed at high tide. The marine part of the survey was run from a small, shallow draft vessel. Full details of the vessel are provided in Appendix A.

Nurana Island is reclaimed land which is presently undeveloped. Vehicular access to the island is currently via an unmetalled track across a small causeway at the western end of the island. In the long term, construction of a larger access road is proposed and this road is planned to be built within a tunnel below the tidal flat that separates the island from the mainland. The area surveyed covers a 100m x 1000m corridor centred along the proposed route.

To the south of the survey site lies Qal’at al-Bahrain (also known as Bahrain Fort). This is a culturally very important archaeological site listed by UNESCO as a World Heritage Site. Further details can be obtained from the UNESCO website (https://whc.unesco.org/en/list/1192). The tidal flats and foreshore surveyed by this work will have used for many centuries by the inhabitants of Qal’at al-Bahrain and by visiting traders and one of the aims of this survey was to assess if there are archaeological features not previously mapped that could be impacted by the proposed construction works.

The second aim of the survey was to try and identify any aquifers located below the site. The aquifers of Bahrain are protected and any new constructions must be designed to avoid damage to them.

The third aim of the survey was to provide additional geological, hydrogeological and geotechnical data to the Client that may aid them in design and construction of the proposed road.
The aims of the survey can be summarised as:-

1. To identify archaeological features
2. To identify and locate aquifers
3. To provide geological, hydro-geological and geotechnical information

1.2 Site Description

The site is between Karbabad Beach to the east and Nurana Island to the northwest, on the northern coast of Bahrain.

Most of the site consisted of a tidal flat. This sloped very gently towards the north and northwest. The flat was exposed at low tide in the eastern and central part of the site but remained covered by 20 to 40cm of water at the northwest end of the survey even at the lowest point of the tide.

At high tide the deeper parts of the site were covered by up to 2.4m of water while surveying was accomplished in depths as small as 0.8m in the shallower, eastern end of the site. The safe window of opportunity was found to be no more than one to one and a half hours either side of high tide.

Most of the site was composed of a hard, well-cemented surface, planar with only very low undulations. A small hand sample of this material was found to consist of a coarse bioclastic/quartz grainstone/packstone with calcareous matrix and cement. This is very likely to be equivalent to the calcarenites described in Section 1.3.4, below, from onsite borehole logs. This planar surface was covered in the central part of the site with a very thin veneer of mobile sand, silt and mud. To the northwest, where the surface is clearly very rarely exposed the surface seems to be present and is exposed in patches but is covered by a thicker layer of soft sediment forming very low banks and mounds. Close to Karbabad Beach in the east a thicker wedge of sand, silt and mud is present, fringing the beach itself.

A dredged channel crosses the centre of the site, running SW – NE from a fishing boat quay out to the open sea to the northeast of Nurana Island.

Several large, permanent fish traps, constructed from wire mesh, wood and rope and fastened to the sea bed using steel pegs, were present on the site. Also present were corroded steel
pegs remaining from older fish traps, now gone. All these structures caused serious problems with deployment and safe navigation of the marine elements of the survey.

In addition to the permanent fish traps there were several smaller “pot” type fish traps deployed by local fishermen across the site. These also caused navigation issues but did not damage equipment even when snagged. They did cause delays while kit was disentangled.

The craft of local fishermen were present, tending fish traps and transiting across the site. These crews were informed of the need to remain away from the survey vessel and caused no serious problems.

The area was also used occasionally by recreational vessels – and, in particular, by “jet-skis”. These could potentially have caused serious issues as they approached at very high speeds giving no warning at all. However, the survey was completed without a problem from these vessels.

1.3 Geology of the area

The following (Section 1.3.1 to 1.3.3) was drawn from an account kindly provided by the Client and is reproduced here with little editing. The author was Dudley M. English, AECOM Senior geotechnical Engineer.

1.3.1 Geological Origin and Structure of Bahrain

The Kingdom of Bahrain is constituted of 36 islands, islets and patches of coral reef located in the Arabian Gulf between Qatar and Saudi Arabia. Bahrain is the main island, 30 km in length and 10 km in width. Other smaller islands are: Al Muharraq, Sitrah, Umm Al-Nassan, Nabih Saleh, Hawar and Jiddah.

The regional geological structure dips gently eastwards from Saudi Arabia into the Gulf, being interrupted by a number of north–south trending, anticlinal structures, among them being the Bahrain Dome, situated with the shallow tectonic depression of the Gulf of Salwa. Beneath the northern and eastern territorial waters of Bahrain the eastern flanks of the Bahrain Dome merge with the regional strata dip, giving rise to the surrounding shallow seas of the Arabian Gulf.

Bahrain Island is composed almost exclusively of Eocene sedimentary strata, except for the localised Miocene cap that occurs on Jabaal ad Dukhan. Two distinct strata groups are present
(Table 1), the Dammam Group that comprises much of the face and backslope of the central escarpment feature, and the older Rus Group, being confined to the floor of the inner basin. A variable coastal fringe of mainly unconsolidated Pleistocene and recent Holocene sediments exists; narrow in the east but becoming broader around the north of Bahrain.

To the south of Bahrain, the Gulf of Salwa represents a shallow tectonic depression, formed in the late Tertiary period, approximately 7 million years ago, by down warping of the earth’s crust. At that time the sea had reached a maximum elevation of 150m above present-day levels. This brought about depositional environment typical of shallow carbonate-shelf marine deposits, including limestones, marls, siliciclastics and evaporites.

Global cooling and the onset of glacial conditions in higher latitudes marked the beginning of the Flandrian Period, some 18,000 years ago. The sea then reached a minimum elevation of some 120m below its current day level, thus exposing the previously deposited marine sediments to sub-aerial and fluvial weathering processes.

As the climate steadily moderated towards the end of the period and into the beginning of the Holocene Period, 10,000 years ago, the Gulf gradually again became inundated. However, this process was far from regular and large zones of the region experienced irregular periods of sub-aerial and marine sedimentation.

The presence of gypsum and carbonate cementation in the Arabian Gulf soil profiles is typical. Gypsum is encountered either as layers or as disseminated crystals. When high temperatures, low rainfall and frequent winds combine to produce excessive evaporation of lagoon waters and seawater, the resulting high salinities cause evaporite minerals to be deposited. Gypsum is one of the less soluble of these salts and was therefore precipitated in relatively large amounts and in various forms. Thick accumulations may develop on tidal flats periodically flooded by saline water. Thin crusts usually inter-bedded with the prevailing sediments may be precipitated from standing water in confined lagoons.

Carbonate cementation of loose particles requires little change in environmental conditions and may take place concurrently with submarine deposition. Often precipitation of cement in coarse grained sediments is very much localised both laterally and vertically, such that recently cemented carbonate layers, cap-rock, may frequently overlie uncemented soil material.
Cementation may also occur under hot, arid, sub-aerial and hypersaline lagoonal conditions; like those imposed during the recession of the sea in the Arabian Gulf during the glacial periods. Upward movement of saline groundwater induced by high evaporation rates at ground level transports salts to the surface where they are precipitated, binding loose sediments to form a hard, cemented layer of duricrust or cap-rock. An additional effect of the sub-aerial period on these soils was to generate over-consolidation characteristics by the processes of desiccation and the removal of overburden by aeolian erosion processes.

1.3.2 Geological Sequence
Bahrain is part of the structural province of Arabia. The geological sediments exposed at surface are dominated by Tertiary calcareous sediments overlain by Pleistocene and Recent deposits. Tertiary and older rocks are folded in domes and anticlines with a north-south trend. Regionally, Quaternary and Recent sediments exist in off dome synclinal areas exposed mainly in Dammam (Saudi Arabian coastal region) and Bahrain.

A summary of the regional geology and the hydrogeological units that constitute Bahrain is provided in Table 1. Of the overall geological sequences, only the Quaternary and Upper Tertiary (Neogene and Dammam Formations), described below, are germane to the project.

1.3.2.1 Quaternary and Recent Deposits
Quaternary and Recent deposits are characterised by unconsolidated to partially cemented carbonate sand which is fine to coarse grained, highly calcareous and often clayey and silty with abundant marine shell fragments. These deposits are typical of coral reef or tidal flat environments.

The Ra’s al Aqr Formation is generally of the order of 10m in thickness and present around the outside of the central dome beneath the Holocene sedimentary deposits, locally present up to 50m thick. It unconformably overlies the Neogene and comprises caprock limestone, a mud flood deposit and calcisiltites. The calcisiltites are very pale orange, grey or white thinly bedded, fine to very fine-grained dolomitised carbonate siltstones that sometimes contain fossils and coarser dolosands.
### Litho-Stratigraphic Profile of Bahrain [Based on Birch & al. Arrayedh : 1985]

<table>
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<tr>
<th>ERA</th>
<th>PERIOD</th>
<th>FORMATION</th>
<th>MEMBER</th>
<th>THICKNESS (approx. m)</th>
<th>LITHOLOGY</th>
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<td>Ra’s Al Aqr</td>
<td>Superficial</td>
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<td>10</td>
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</tr>
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- Unconformable Boundary
- Erosion Surface

Table 1 - Litho-Stratigraphic Profile of Bahrain [Based on Birch & al Arrayedh : 1985]
1.3.2.2 Neogene Formation
The underlying Neogene Formation comprises an undifferentiated sequence of mudrocks, calcisiltite and calcilutite. The basal unit of the Neogene is a thin sandy limestone that is considered to constitute the uppermost component of the Alat (A) Aquifer.

The Neogene thickens laterally away from the flanks of the Bahrain Dome and rests unconformably upon the Dammam Formation, (Figure ), the topmost member of which (the Alat Limestone) comprises the primary element of the A Aquifer. The Neogene mudrocks, with low intrinsic permeability, act as an aquitard that substantially confines the A aquifer.

Figure 2 - Geological Profile SW – NE from Manama to Galali
[Illustrating lateral thickening of the Neogene and deepening of the A Aquifer towards the NE]  [after Larsen: 1983]

1.3.3 Hydrogeology
There are three principal aquifers in Bahrain, their relative position within the regional stratigraphic sequence being highlighted in Table 1. Each of the aquifers comprises predominantly fractured limestone and is separated from one another by layers of shale or marl.

- A Aquifer – Alat (Basal Neogene and Upper Dammam)

The A Aquifer comprises the basal limestone of the Neogene and the Alat Limestone member of the Dammam Formation, which is locally exposed or hydraulically connected to the surface in the north of Bahrain and on the Hawar Islands.
• **B Aquifer – Khobar (Middle Dammam)**
  Aquifer B comprises the Khobar Formation which is exposed in an elongate ring around the centre of the island and is the most important freshwater aquifer in Bahrain.

• **C Aquifer – Rus (upper part of the C Aquifer), merging into the Palaeocene below**
  Aquifer C is made up of the Rus (exposed in the middle of the island) and the underlying Umm Er Radhuma formations. The C Aquifer contains brackish water and can sustain the highest production rate in Bahrain.

1.3.3.1 **Alat Limestone [A] Aquifer**
The Alat aquifer outcrops inland close to Dammam as well as at the centre of Bahrain. This unit is mainly composed of grey fine-grained limestone with low porosity at the top grading towards a chalky and slightly calcarenitic composition at the bottom. Borehole data analysed from the al Muharraq Island (to the east of this survey site) indicates that the level at the top of the A aquifer (Neogene-Alat) ranges between 19m and 51m below surface.

The Alat limestone is a good aquifer. A regional hydrogeological conceptual model proposed by Wright (1983) indicates that this aquifer is regionally recharged in Dammam (50km north-west of Bahrain). The aquifer flowpath follows the regional dip in an easterly direction under the Neogene confined deposits to discharge partially as springs and also as upward vertical leakage in Bahrain. Where high permeability exists, the Neogene and Alat aquifers are understood to be acting as one single unit known as the A aquifer (GDC, 1980). Locally the A aquifer displays upwards flow leakage, as identified by spring discharges and the upwards vertical leakage on sabkha deposits, in Saudi Arabia and Bahrain. Hydraulic connections and groundwater flow between the A aquifer and the overlying deposits are known to exist to the south-west of Diyar al Muharraq.

Several nearshore springs have been recorded to the north of al Dair, Samheej and Galali by GDC (1980), being associated with fissuring and localised collapse of the seabed shallow bedrock formations. Similar nearshore springs can be seen close to Qal’at al Bahrain (personal observation of the author). The observed flow rates emerging from the A aquifer system have diminished significantly over recent decades, associated with over-pumping and depletion of the underlying aquifer systems.
The Alat Limestone aquifer produces water with salinity between 1,450mg/l and 2,500mg/l, which is consistent with the salinity of groundwater around the area of Dammam. This unit, together with the Khobar (B) Aquifer, constitute the main sources of water in the area reported by GDC (1980).

1.3.4 Site geology derived from borehole logs

A set of exploratory boreholes were drilled in 2015 and the results made available by the Client (Al Hoty Analytical Services Report No. G/3680/HM January 2016; Factual Report on Ground Investigation, Nurana Development Phase 1: Heritage Feasibility Study in Karranah, Kingdom of Bahrain.).

The locations of these boreholes is shown in Figure 3. A selection of the logs from the boreholes closest to the site are displayed graphically in Figure 4.

The logs indicate the presence of variable thickness of Recent unconsolidated superficial deposits. These are described as sands, gravels, or as sandy fill material. NT_118L is on Nurana Island which know to be composed of dredged marine sand sourced offshore. Anecdotal evidence obtained during the survey suggested that the Karbabad Beach area occupied by NT_101L, NT_103L and NT_105L was also built up from dredged sand. To the south the superficial deposits may be fill, windblown deposits or may be unconsolidated Quaternary material.

Beneath the superficial deposits lies a layer of calcarenites. These are thin to medium bedded, weak to very weak vuggy limestones and sandy limestones. They are variably described as highly to moderately weathered and with closely to medium spaced fractures.

In most of the boreholes the calcarenites are underlain by very weak to weak, medium to thickly bedded, calcilutites which are moderately weathered and closely to medium spaced fractures. The exceptions are NT_103L, which shows calcarenites to the full depth, and NT105L which shows and interval of calcisiltite between the calcarenites and the underlying calcilutites.

These calcareous units are likely to form part of the Pleistocene Ra’s al Aqr Formation, which has an upper limestone unit over muddier deposits (Table 1).

It is worth noting that two logs (NT_204L and NT_205L) record limestone beneath the calcilutites. This may be important as the limestone may form the top of the Neogene or even
the Alat Formation, rising close to surface and, if so, could be part of the A Aquifer, close to surface, onshore to the south of the survey site.

2 SURVEY DESIGN

2.1 Survey design

The following investigation techniques were used in the survey:

- Electrical Resistivity Tomography (ERT) to identify variations in ground resistivity that might reveal changes in groundwater composition and/or lithology. Larger archaeological features might also be revealed though this is not the primary aim of the technique.
- Seismic refraction (onshore and offshore) to identify disturbed areas that might be archaeological and to provide geological/geotechnical information
- Seismic Multichannel Analysis of Surface Waves (MASW) (onshore and offshore) to identify disturbed areas that might be archaeological and to provide geological/geotechnical information. Note that the Client specified MASW data acquisition but not processing at this stage. The MASW data may be processed and presented at a later stage.

2.2 Survey methods

2.2.1 Electrical Resistivity Tomography (ERT)

Electrical resistivity tomography (ERT) was selected with the aim of helping to characterise the subsurface geology and hydrology of the site. The results provide 2D sections of resistivity that can be interpreted in terms of stratigraphy and the hydro-geological conditions of the site. They may also provide clues to geological structures such as faults, fracture zones, clay-enriched areas, depth to bedrock, dissolution features.

The electrodes were deployed at high tide as an IRIS towable streamer with 13 graphite electrodes. The two current electrodes were steel sleeves placed around the streamer. The
streamer was configured to float at, or just below, the surface. The data were acquired using an IRIS Syscal Pro High Power 10 channel resistivity meter controlled by IRIS Sysmar software running on a laptop. A live GPS NMEA string and a depth reading were added to each resistivity reading from a Garmin GPS and echo sounder. The Garmin echo sounder had to be deployed on a temporary mount on the side of the vessel. Simultaneous readings were taken from the permanent echo sounder on the vessel and from the Garmin unit. This was important as working in very shallow water tended to deflect the sensor of the Garmin. The difference between the two units was used to correct the depths used in the final ERT inversions.

Once acquired, the resistivity data were downloaded using Syscal Prosys software and checked for electrode spacing, array type and subjected to QA filtering; the data were corrected for depth at this stage and then exported to ascii format. The ascii files were then imported into RES2DINV software.

The data inversions were carried out by using various inversion routines and the best suited parameters were selected. RMS misfit values for the models were found to be between 9 and 15%, which is considered acceptable in these conditions. The final models were then exported to graphic format for 2D display and to MapInfo/Discover software for 3D modelling and analysis.

2.2.2 Onshore seismic refraction
Seismic refraction was selected to provide a velocity model of the subsurface. Such a model can reveal localised variations caused by both natural and anthropogenic processes and may thus provide clues to archaeological features, natural channels, lateral sedimentological and diagenetic variations and stratal layering.

The geophones were deployed at 2m intervals on the exposed surface, either directly into soft sediment or into sand bags placed on hard surfaces. The geophones were linked by a multicore spread cable to a Geometrics 24 channel Geode. The Geode was controlled by and recordings made onto a laptop running Geometrics Seismodule Controller software. The source used was a sledge hammer and plate. Triggering was accomplished using an inertia switch mounted on the hammer. Shots were taken at short off-end locations (5m off-end forward and reverse) and at 6m intervals between first (offend) and second (in-spread) shots and at 4m interval within the spread. To reduce the background noise level, each shot was
staked 2-3 times, when stacking modified the arrival time of seismic signal (due to low repeatability of sledge hammer source) the whole record was repeated.

The spreads were positioned using a Garmin Montana 650 GPS unit.

The resulting data were downloaded, backed up each day and subjected to initial QA. The initial QA included the following steps;

1- Location and geometry of the shots and geophone spread, each shot was recorded with unique file ID, shot location, spread location and line location. Errors in geometry registration in data acquisition were logged in the field logs along with accurate geometry.

2- Quality of seismogram in terms of ease of P-wave refraction identification

3- Errors in delay time generated by pre-shot triggers or post-shot triggers were checked for each shot record, these records were omitted from further processing.

4- Noise level, initial filtering applied to improve P-wave refraction arrival to validate or reject the records

5- Updating the field log with initial QA results and observations to be used at processing stage.

5- Re-acquisition of noisy records.

2.2.3 Offshore Seismic refraction

The offshore seismic refraction used a Geometrics Microeel hydrophone streamer deployed behind a shallow draft vessel. The streamer consisted of 24 channels, each channel being composed of a group of three pressure sensors. The sensors were spaced 3.125m, the entire array being 71.875m long. The first sensor was deployed 25m behind the vessel, from the port quarter. The source was a bubble pulsar deployed 15m behind the vessel, from the starboard quarter. The first hydrophone and the bubble pulsar were 10m apart. The streamer was hydrostatically adjusted to float at 0.5m below surface.

The streamer was connected to a Geometrics 24 channel Geode. The Geode was controlled by and recordings made onto a laptop running Geometrics Marine Seismodule Controller software.
A Hemisphere GPS receiver was mounted on the source. A NMEA string from the GPS was connected to the Laptop and the position of each shot recorded on the seismic shot record header, The data were recorded in SEGD format.

The vessel was piloted along designed survey profiles at a speed of 2-4 knots.

Triggering was accomplished by using two guns of HM 620 Bubble Pulser, each of which generate in 350-1000Hz (at 10dB down) frequency and can produce approximately 50 Joules of energy in each pulse. The bubble pulsar can send repeatable pulses every 0.125 second operating on a 240 VAC power. A sample interval of 0.7s with 0.150s record length was used in this project, each pulse produced a record which was saved automatically.

2.2.4 Onshore Multi-Channel Analysis of Surface Waves (MASW)

The multichannel analysis of surface waves (MASW) method was selected with aim of evaluating the elastic condition (stiffness) of the ground for geotechnical engineering purposes. It is also possible that the resulting velocity/stiffness models may reveal additional archaeological or geological information.

The data were acquired at the same time and using the same method described above in Section 2.2.2. The onshore seismic survey was configured to allow for the extraction of both refraction and MASW models from the same records.

2.2.5 Offshore Multi-Channel Analysis of Surface Waves (MASW)

Whilst it was considered possible that the records acquired for offshore seismic refraction might contain some information that could be used to provide MASW models the method used is not well-suited to this. In particular the bubble pulsar does not provide the low frequency signal required for good MASW modelling and MASW readings should be taken with the spread stationary rather than moving. Consequently, an additional set of recordings were made using the same sensor equipment but with a different source and different approach.

A short length of chain was attached via a 3m lead rope to the rear of the hydrophone streamer to create a drag and keep the streamer straight for the short period of time required for a shot when the vessel slows down. The vessel was moved short distances along the designed profiles and then several shots stacked quickly as the vessel came to a halt but before it started
drifting uncontrollably. The source used was a steel pipe dropped to the sea bed and struck with a heavy hammer. Triggering was by a simple electrical contact between pipe and hammer.

For offshore MASW, the record length of the seismic records was increased to 0.5ms to allow surface wave terrain to be recorded. At each shot location along the predetermined survey line, the vessel would slowdown/halt and 3 shots were taken within a few seconds (3-5) and the vessel moved to next shot location in 8-10 seconds. The movement of the vessel straightened the streamer for the next shot. The 3 shots at each location were stacked in the processing stage.

The initial QA of MASW records carried out in this manner showed presence of surface wave modes after filtering out of the high frequencies, however, detailed analysis would guide on the final outcome of the marine MASW.

### 2.3 GIS, Topographic Survey and Navigation

The positioning of the profiles onshore was accomplished using a Garmin Montana 650. The recorded waypoints were downloaded into a GIS workspace in MapInfo/Discover software. In addition, a transect was recorded at low tide along the entire design centreline using a Trimble R2 GPS receiver to provide a sub-metre precision elevation profile. The transect data are given below in Table 2 and shown in Figure 4.

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Table 2: Topographic survey along the proposed centre line of the Access Route. Note that this line is as supplied by the Client December 2018 and has subsequently been revised. Coordinates given are Decimal Degrees, WGS84 Datum. Elevations are meters above.

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All GPS data were recorded in geodetic coordinates (latitude and longitude (WGS84). The GIS workspace was operated in latitude and longitude. Where required, the data were subsequently translated to UTM 39N (Ain Al Abd Datum) coordinates using MapInfo/Discover for presentation.

The same GIS workspace was used for vessel navigation. The Trimble R2 receiver was mounted on the vessel and configured to output an NMEA string to a laptop running MapInfo/Discover. The real-time position and track of the vessel was displayed and recorded on two screens – one for the survey geophysicist and a second for the skipper of the vessel. The skipper used the navigation screen to run transects along designed profiles, albeit around onsite obstacles. The geophysicist used the navigation screen to start and end survey runs and to give the skipper additional instructions.

2.4 Acquisition – Locations, equipment, parameters and processing

2.4.1 Locations
The locations covered by the ERT profiles are shown in Figure 5.
The locations covered by the onshore refraction seismic work are shown in Figure 6.
The locations covered by the offshore refraction seismic work are shown in Figure 7.
The locations covered by the onshore and offshore MASW work are shown in Figure 8.

The start and end coordinates of all profiles are given in Table 3 below.
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Table 3: Start and end coordinates of all geophysical profiles. UTM 39N Ain Al Abd Datum

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2.4.2 ERT Acquisition

**Acquisition Method:** Floating electrodes Marine Electrical Resistivity Tomography

**System:** Syscal Pro high power controlled by IRIS Sysmar software on laptop. Garmin GPS and Echo Sounder

**Channel:** 10  **Configuration:** Reciprocal Wenner Schlumberger  **Electrode Spacing:** 5m

**Stations:** 13  **Roll Along:** N/A

**Depth:** 10-12m  **Cycle:** 3-6 **Measurements:**; Time/GPS recorded, set to 1 second or 2m minimum. Actual spacing controlled by vessel speed. Lat/Long/Depth (from echo sounder) recorded on each resistivity reading.

**Output:** Maximum 800V, 25 Amps with internal convertor and 24V battery

**ERT Processing and Inversion**

**Filtering:** Prosys Auto and Manual

**Inversion:** Standard least square constraints

**Software:** RES2DINV

2.4.3 Onshore Seismic refraction

**Shot Interval:** 4m in spread, 6m offend  **Geophone Spacing:** 2m

**Logger:** 24 channel Geometrics Geode  **Trigger:** Time 0 on shot

**Geophone Type:** Vertical 4.5 Hz  **Active Channel:** 24

**Shot to First Geophone Distance:** 5m for offend, 1m in-spread  **Spread Length:** 48m

**Type of Source:** Sledge Hammer

**Stack limit:** 3-5  **Record Length:** 0.5s

**Sampling Interval:** 0.125ms  **Recording Sensitivity Level:** 0.1 to 0.5 v

Refraction processing and inversion
Software: SeisImager (Pickwin for picking, Plotrefa for inversion and Geoplot for plotting)
Geometry Import: Onsite and geoedit
Inversion: Tomography
Iterations: 10
Number of layers: 20
Layer Model: 1400m/s, 2500m/s and 3700m/s
Depth conversion: Auto

Output: ASCII, clipboard and pdf.
Drafting: Coral Draw

2.4.4 Offshore seismic refraction
Shot Interval: 0.75s, for processing each shot at approx. 15m taken.
Geophone Spacing: 3.125m
Trigger: Time 0 on shot
Geophone Type: Geometrics Microeel hydrophone streamer
Active Channel: 24 ground (3 hydrophone in each group)
Shot to First Geophone Distance: 10m
Spread Length: 71.875m
Type of Source: Bubble Pulser
Stack limit: 1
Record Length: 0.150s
Sampling Interval: 0.125ms
Recording Sensitivity Level: 1v to 10v

Refraction processing and inversion
Software: SeisImager (Pickwin for picking, Plotrefa for inversion and Geoplot for plotting)
Geometry Import: Onsite and geoedit
Inversion: Tomography
Iterations: 10
Number of layers: 20
Layer Model: 1400m/s, 2500m/s and 3700m/s
Depth conversion: Auto

Output: ASCII, clipboard and pdf.
Drafting: Coral Draw
2.4.5 Onshore MASW

Shot Interval: 4m in spread, 6m offend  
Geophone Spacing: 2m
Logger: 24 channel Geometrics Geode  
Trigger: Time 0 on shot
Geophone Type: Vertical 4.5 Hz  
Active Channel: 24
Shot to First Geophone Distance: 5m for offend, 1m in-spread  
Spread Length: 48m
Type of Source: Sledge Hammer
Stack limit: 3-5  
Record Length: 0.5s
Sampling Interval: 0.125ms  
Recording Sensitivity Level: 0.1 to 0.5 v

MASW Processing and Inversion
Software: Surfseis 4.2 and Parkseis
Geometry Import: Scripted
Dispersion Curve mode: Fundamental mode and higher mode
Overtone Images: varying between minimum to high
Dispersion curve picking: Manual adjustment to auto picked DC
Spatial Resolution: 55% H 55% V
Inversion: Each curve separately with equal weight
Iterations: 10
Number of layers: 20
Depth conversion: Auto

Output: ASCII and Surfer format with topography incorporated
Drafting: Autocad in .dwg format (model space and layouts for presentation)

2.4.6 Offshore MASW

Shot Interval: 0.75s, for processing each shot at approx. 15m to be used.
Geophone Spacing: 3.125m
Logger: 24 channel Geometrics Geode  
Trigger: Time 0 on shot
Geophone Type: Geometrics Microeel hydrophone streamer  
Active Channel: 24 ground (3 hydrophone in each group)
Shot to First Geophone Distance: 10m  
Spread Length: 71.875m
Type of Source: Bubble Pulser
Stack limit: 1  
Record Length: 0.150s
Sampling Interval: 0.125ms  
Recording Sensitivity Level: 1v to 10v

MASW Processing and Inversion
Software: N/A
Geometry Import: N/A
Dispersion Curve mode: N/A
Overtone Images: N/A
Dispersion curve picking: N/A
Spatial Resolution: N/A
Inversion: N/A
Iterations: N/A
Number of layers: N/A
Depth conversion: N/A

Output: N/A
Drafting: N/A

*MASW results are not part of this report and will be finalized at later stage.

3 RESULTS

In the following sections, the results of the geophysics surveys are described and discussed in some detail.

3.1 Quality Control and Quality Assessment

The geophysical data were collected with normal operating procedures as outlined by the instrument manufacturers and GCGC company policy. On completion of the survey, the data were downloaded from the survey instruments and backed-up appropriately. The acquired data set were initially checked for errors that may be caused by instrument noise, low batteries, power lines, positional discrepancies, etc. and any field notes were either written up or incorporated in the initial data processing stage. The dataset was processed using the standard processing routines and once completed, the resulting plots were subject to peer review to ensure the integrity of the interpretation. In all cases the raw data were supplied to the Client for their own review where they considered it appropriate.

With respect to the ERT data; the data were found to be of good quality. The inversions produced models with RMS misfits of <12%. Given the mobile nature of the survey and the high inherent resistivity contrasts between high salinity water and limestones this is considered acceptable. For comparison, land-based static ERT surveys in favourable conditions typically
give models with RMS misfits of 5-10%. It was found that the model layering had to be manually controlled to ensure that the sea water layer was not mixed with the sub-sea readings. It is thought this is a function of the strong contrast between the seawater layer (which was fixed at 0.2 Ohm.metres by empirical trials during modelling) and the underlying readings. If this was not done, it was found that the model could not cope with the contrasts introduced. Early models showed anomalies in the east, on the southern profile and on Cross Line 1. These anomalies were further tested and found to be due to the problem described above. In the case of these two profiles the seabed profile was smoothed to ensure that the seabed profile did not cross layers of grid blocks and when this was done the anomalies disappeared from the models. It is stressed that the smoothing was not applied to the measured readings – these retained their measured values and true calculated depths.

In the onshore seismic refraction, on the easternmost 2-4 spreads the geophones were placed with spikes driven into soft sediment, providing good coupling and did not suffer excessively from background (wind and wave) noise. However, further westward, the surface was hard and mostly covered with very shallow (approx. 10cm) water which increased the noise level from wind and waves. To overcome this situation, sand bags were placed on the rocky surface with geophones installed on top of them. This helped in reducing the both wind and wave noise to the extent where data could be used with basic filtering. A band pass filter with 20 to 50 Hz low cut, up to 20dB, and 500-1000Hz high cut with 20dB, was used to remove long wavelength noise. The picks were checked for reciprocity and the difference in travel time was adjusted or repicked. The RMS error was generally less than 1.5ms for onshore records.

The offshore seismic refraction showed a similar seismic character. The records were generally less noisy and normalized gain enhanced the P-wave refraction event for picking. When required, a band pass filter, similar to those used on onshore seismic, was applied. The data recorded in high waves were noisy. For processing, records with low noise and approximately 15m interval were first selected for picking and analysis. RMS error for initial 0 - 81.875m of each record was high (in the range of 2ms) due low redundancy and on higher chainages it was below 1.5ms. The initial 0 - 81.875m of all seismic refraction have not been presented and were positioned outside the survey corridor to avoid such problem. The offshore seismic recordings with floating streamer and shots in one direction would not allow reciprocity of the refraction to be checked and travel time difference calculated - this remains a known problem in the offshore refraction surveys. Efforts were made to analyse 5-10 records in every 81.875m to have redundant records for tomographic inversion.
3.2 ERT - Results and Interpretation

The results of the ERT profiling are shown in Figures 12 to 20. Each figure shows the measured apparent resistivity pseudosection and the modelled resistivity profile. Each figure is annotated to indicate the main features. The main features identified in the ERT survey are shown in map form in Figure 21.

Several main trends and features can be observed from the profiles. In general, the resistivities in the subsurface are low (<10 Ohm.metres). The models all show a thin shallow layer of low resistivity immediately below the sea bed. The units below are more resistive. In the eastern part of the survey there is a tendency for resistivity to decrease slightly downwards. An uppermost layer (from 4 to 10 Ohm.metres) passes downwards without a well-defined boundary to a lower layer (1 to 4 Ohm.metres). The upper layer thickens somewhat to the east and is thickest at the eastern ends of the central and southern profiles and in the southern part of cross-line 1. The modelled resistivity also increases somewhat with the thickening trends observed. In the west of the area the lower layer of slightly reduced resistivity is not seen everywhere; here, resistivity increases slightly downwards.

The dredged channel is associated with a reduction in modelled resistivity in the northern, central and southern profiles. Similar localised reductions are seen elsewhere on other profiles, where these can be seen to cross three or more profiles the features have been digitised and are shown in map form in Figure 21. It should be noted that none of these are well-defined and that the lineations defined are subjective and speculative.

The horizontal layering is taken to indicate that the shallow sub-surface in the east and south of the survey is very slightly more resistive than the material 5 – 10m deeper. This may be a function of several different scenarios, or a combination of these.

- Porosity may be lower in a well-cemented layer immediately below the surface and the material becomes more porous downwards. This is certainly possible, but all the borehole logs suggest the shallow material is likely to be vuggy, porous calcarenite, underlain by less porous calcilutites.
- The shallower layer may be composed of material inherently more resistive and is underlain by a less resistive layer. The borehole-derived stratal model suggests calcarenites underlain by calcilutites. Much depends here on the true nature of the cored lithologies. A lithology with a higher content of mineralogical clay will be inherently less resistive than a lithology richer in calcite, quartz or lithic grains. However, the term “calcilutite” does not necessarily mean that the mud-sized fraction
is mineralogical clay, it could equally be calcareous mud. A calcarenite is strictly a limestone composed of sand-sized grains; not necessarily of quartz or lithic grains. It is certainly possible that the calcilutite contains a high proportion of detrital or authigenic clay minerals and, if so, this would result in the reduced resistivity seen in the lower part of the pet models.

- There may be variations in the inherent conductivity of the pore waters. In this case the higher resistivity indicates slightly lower salinity. This is a reasonable model to explain the observations. Fresh water is less dense than saline brines and will tend to form a layer floating at the top of the water column if not otherwise constrained or subjected to mixing. The tidal flats are an evaporative environment and it is possible that any brines concentrated by evaporation will tend to sink to the lower part of any porous layer connected to the surface. Likewise, any freshwater input to the system will tend to form a more resistive layer at the top. The, apparently land-attached, shallow wedges of higher resistivity seen here are consistent with freshwater lenses extending out from the shore. The greater lens seen in the east, compared to the much smaller occurrence seen in cross-line 8 in the northwest, could indicate higher volumes of freshwater input here (possibly from freshwater springs and risings, from the known outfall or even from simple rainfall on the shoreline superficial deposits). The thicker superficial sands and silts in the east may also tend to hold freshwater as a shallow layer and it may also be significant that the eastern part of the site is exposed at low tide while the central and western parts are almost always covered with seawater.

One of the aims of the survey was to try to assess if a confined aquifer was present in the shallow subsurface. The models are not consistent with the presence of any such aquifer. The models suggest rather layering in sediments in full or partial connection with the tidal waters. Evidence of a confined aquifer would be expected to present as a well-constrained layer or boundary in the lower part of the models and this is not seen.

One low resistivity feature is seen to extend across three or more profiles which is clearly correlated with the modern dredged channel and is thought to indicate increased downward passage of brine along the channel. It would be reasonable to expect any older dredged or excavated channels to show similar results. Three other groups that appear to form linear features are indicated in Figure 21. These are not conclusive in their nature and only the easternmost falls along a line that is suggestive of channels dredged for access to an ancient harbour. The latter feature does not trend northward directly towards the break in the outer
reef. It could conceivably link the area that is deepest in the present day southwards towards Qal'at al Bahrain.

3.3 Refraction - Results and Interpretation

The results of the refraction modelling are shown in Figures 22 to 44. Each figure shows a tomographic model and a layered model. Each figure is annotated to indicate the main features. All the figures display two models: a tomographic model and a 3 layer model. The tomographic model attempts to suggest a velocity model with many layers and to honour closely lateral and vertical variations - the method best suits situations where a sharp break in refraction arrival is not present and the refraction event is rather gradually changing with distance from the source. The 3 layer model reduces the complexity and attempts to offer a solution that may be more geologically realistic in terms of horizontal stratal layering.

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<td>1900-3600</td>
<td>2.5-2.9</td>
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<td>2500-3300</td>
<td>2.5-2.7</td>
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Table 4: Typical rock velocities, from Bourbié, Coussy, and Zinszner, Acoustics of Porous Media, Gulf Publishing
Interpretation of the modelled P-wave velocities (Vp) is generally accomplished by reference to published typical values for various media (Table 4). In addition, these typical Vp values are modified by the porosity at all scales from intra-particle to visible open fractures, temperature, pore fluid composition, saturation and pore pressure. The latter effect is more pronounced in softer low velocity rocks.

See https://pangea.stanford.edu/courses/gp262/Notes/8.SeismicVelocity.pdf and references therein for more information on these subjects.

### 3.3.1 Onshore profiles

The 3 axial profiles and two transverse profiles were acquired and are shown in Figures 22 to 27.

A shallow very low velocity layer is present in places (<2000m/sec), though often absent. In places this very low velocity layer thickens markedly. This material is likely to indicate a cover of soft sediment (most likely to be true in the east and close to Nurana Island in the northwest). In areas where sediment is apparently not present it may indicate areas where the rock is substantially weakened by extensive fracturing, very high porosity, less well-developed cementation (or where deep weathering has effectively removed cement) or possibly areas where a depression in the rockhead is infilled with less cohesive material, though not visible at surface.

Over most of the area surveyed a clearly defined refractor was not identified. The models suggest a subsurface composed of weak (2000 – 3000m/sec) to moderately strong (3000 – 4500m/sec) material. Velocities increase downward but also apparent are lateral changes where weaker material extends deeper or where stronger material rises closer to surface. By comparison with the available borehole logs we expect this material to consist of variably weathered calcarenites overlying calcilutites and/or calcisiltites. All these are essentially porous media and all described as weak to very weak and with common fractures and discontinuities.

The refraction models are interpreted as showing porous, weak, rocks without clear lithological layering imaged by the velocity models. The vertical gradient imaged is interpreted as being dominated by the degree of cementation/weathering, by degree of compaction and by pore pressure. The lateral variations are interpreted to be controlled by degree of cementation/weathering and by the distribution of porosity/fracturing. It appears that the
lithological boundary between calcarenites and calcilutite does not provide a clear seismic boundary in refraction analysis.

The main features from these velocity models that may be significant in terms of buried channels are indicated in map form in Figure 45.

### 3.3.2 Offshore profiles

16 profiles were acquired and the resulting velocity models are shown in Figures 28 to 44. The method used has resulted in datasets with lower resolution than the onshore data and the resulting models are consequently much simpler with little lateral variations imaged.

The velocities modelled are comparable to those from the onshore models. A thin superficial layer with low velocity is underlain by the bulk of the material which has velocity increasing downwards from $<2000\text{m/sec}$ to $\sim 4000\text{m/sec}$.

There is some evidence of a thicker area of shallow, weak material in the northwest of the survey. This is seen in lines 3, 12, 13, 23 and 26. This may suggest less cementation, higher porosity, more fracturing, or deeper weathering in this area. Close to Nurana Island this is also likely to include an apron of unconsolidated sand derived from the island itself.

These models support the suggestion that a clear velocity boundary that might act as refractor is not present and that the situation is more likely to be a gradational downward increase in velocity. This downward increase in $V_p$ could be associated with increases in cementation, decreases in weathering, decreases in porosity/fracturing and increases in pore pressure.

No clear evidence of any channels, including the modern dredged channel, is seen in these models and no conclusions can be drawn from these models regarding the presence of position of any archaeological features. The modern channel is 2m deep or less and situated within rocks with $V_p$ of 2500m/sec or more. This feature is not seen as a refractive feature as the difference in travel time is too small to pick.

### 4 Discussion

The ERT models have provided information on the hydrogeology. There is no clear layering that suggests a confined aquifer, an observation that suggests a system likely to be in hydrological connection with the sea when inundated by the tide and with any freshwater input
from the adjacent land or from below in the form of springs. The modelling process suggested that the seawater itself is highly saline – a resistivity of 0.2 Ohm.Metres produced consistent and stable results. This is at the low end of the expected range but is not unexpected for conditions inshore in the Arabian Gulf. The modelled resistivity in the subsurface is higher (generally less than 10 Ohm.metres) but not high enough to suggest impermeable rocks or a completely freshwater body.

The disposition of the higher resistivity zones modelled suggests a wedge that is land-attached in the east and extends westwards along the southern edge of the area surveyed. It is possible to hypothesise that a similar zone may be present to the south of the present survey but this is conjecture. This zone of slightly higher resistivity could arise simply from the presence of a less permeable unit. However, the onshore refraction results suggest that the rock in the subsurface is generally weak throughout, and that there are lateral variations in velocity that are consistent with a laterally variable weathering profile. The borehole logs all record bedded, porous, vuggy, fractured, calcareous units. It is difficult to reconcile impermeable limestones with the velocity models and the borehole logs. Instead, it is suggested that the wedge of elevated resistivity observed is more likely to be associated with slightly less saline porewater. This could arise from input of freshwater from land or below as described above, or, by density stratification within the system itself. In either case, a lack of mixing is implied.

A third source of freshwater is present. An outfall lies within the survey area on Karbabad Beach. During the survey work this was constantly pumping fresh water out onto the supratidal area. If this outfall is operating continually it means that freshwater is constantly entering the system at this point. This water is only mixed with the seawater at high tide. The rest of the time it is sinking into the soft sediment and presumably into the porous rock beneath.

As pointed out above, the refraction survey suggests a laterally variable weathering profile. This is consistent with the borehole logs. Weathering degrades the strength of the rock in several ways, dissolution removes cement, it also enlarges pores. The samples examined on site often contained a high proportion of bioclasts derived from bivalves and gastropods, these are aragonitic or contain a high proportion of aragonite. Aragonite is susceptible to dissolution in meteoric waters and will selectively pass into solution – resulting in voids and vugs. In a mature limestone these vugs are refilled with deposits of calcite but the logs suggest that in these rocks the recrystallisation process is not well-advanced. The logs also record numerous fractures and discontinuities. These also tend to be enlarged by weathering processes.
The offshore refraction survey is lower resolution than the onshore work. The best results to assess the nature of the subsurface are the models derived from the onshore work. The lack of lateral variations over tens of meters in the offshore results does not imply that they are not there. Comparison of the two sets of models where they overlap suggests that the weaker zones modelled in the onshore work are not detected in the offshore work. There are larger scale trends detected in the offshore models – specifically that there is thicker, upper zone of weaker rock in the northwest. It is suggested that the offshore refraction work provides a generalised picture within which weaker zones are likely to exist but that are not modelled.

The refraction surveys are interpreted to indicate that the distinction between calcarenite and calcilutite is not visible in terms of Vp. The velocity model seems to be dominated rather by lateral changes in the strength of the rock (controlled by the weathering processes mentioned above) and downward increases likely to be dominated by rising porewater pressure and changes in the physical properties associated with pressure, such as the closure of fractures.

A similar point can be made about the ERT models. It was stated above that the resistivity layering is consistent with a hydrogeological interpretation. It appears that there is little clear geo-electrical distinction between the calcarenites and the calcilutites. It is probably true that the relative porosity and permeability of the two lithological units have some influence on the geo-electrical properties, but any effect is too subtle to model. It is more likely that the variations in porosity and pore pressure implied in the velocity models also control the degree of saturation, degree of mixing and hence composition of the pore water. It is therefore also likely that these are the main controls on the geo-electrical model rather than the lithology. The high conductivity of the pore waters makes it more likely that this is the case than in a terrestrial survey on a low conductivity groundwater body, where the lithology would be expected to have a much more important effect.

It was evident from the borehole logs discussed in Section 1.3 that a limestone unit is present beneath the calcilutites onshore to the south of the site. There is little evidence of a significant irregular surface rising in the seismic profiles. This interpretation relies on an appreciable velocity contrast and if no such contrast is present then such a unit would not be modelled. If such a limestone was present, and was an aquifer, then evidence could be expected in the ERT models of a higher resistivity body rising from depth and none such is imaged.

Some features have been identified in both the ERT models and in the onshore refraction models that could be weaker or more conductive zones. None of these are conclusive...
evidence of an infilled channel – either they are weak anomalies or do not fall along a likely line. During the survey work the entire area has been traversed on foot by several people. It is by no means conclusive, but, no visible evidence was seen of any such feature, despite the thin or absent cover of sediment in the area thought most likely to host any such channel. The anomalous features have all been indicated in map form and some or a selection of these should perhaps be further investigated.

5 Conclusions

- ERT data were successfully acquired. The models from the data are presented and discussed.

- The variations revealed suggest systematic changes which are interpreted as indicating control by porewater composition rather than lithology.

- A layer or wedge of slightly higher resistivity in the east and south of the survey is interpreted as less saline porewater. This may be sourced from; the adjacent land (including a pumped outfall), from uprising springs or by density stratification.

- The presence of a layered, confined aquifer is not suggested by these results.

- There is no evidence in the resistivity or refraction models suggesting a water-bearing limestone rising below the site as an irregular body.

- Where the resistivity models indicate any feature that could be construed as evidence for an archaeological channel these have been indicated in map form.

- A high-resolution seismic refraction dataset was acquired where possible – in the east and centre of the site. The velocity models derived from the data are presented and discussed.

- The velocity models reveal that most of the site is underlain by rock that is of moderate strength. There are significant lateral variations in Vp and these are ascribed to variations in the weathering profile and associated porosity/fracture distribution. Some localised features of shallow low-velocity material are identified, and these are indicated in map form.
• A lower resolution marine seismic refraction dataset was acquired over the whole site. These models are also presented and discussed.

• The marine survey models are in broad agreement with the high-resolution dataset but do not reveal the lateral variations seen in the latter. By correlation between the two it is suggested that zones of lower strength are present but not imaged in the lower resolution models.

• A MASW dataset has been acquired but has not been processed or presented here.

6 Recommendations

• The geophysics should be ground-truthed by intrusive investigations if possible. The results of any such investigations can be cross-correlated with the models presented here and the interpretations may be modified and improved by this.

• MASW data have been recorded but not processed. Client may wish these data to be presented as they may provide useful information for engineering purposes.

• Having spent a considerable time on the site GCGC suggest that should further MASW data be required effective and efficient data acquisition is possible. The offshore refraction data can also be tested for surface wave analysis if required.

• The offshore seismic datasets were configured to include information that could be processed and analysed with respect to high-resolution reflection profiles. The Client may wish these data to be presented as they may provide useful information for engineering purposes.
References

Bourbié, Coussy, and Zinszner, 1987 - Acoustics of Porous Media, Gulf Publishing

GDC., 1980 – Umm Er Radhuma Study: Vol 3 Bahrain Assignment, Groundwater Sources


Wright et al 1983 – Hydrology and Groundwater in Bahrain – Arab Water Tech Conf Dubai 1983

Disclaimer
This report represents an opinionated interpretation of the geophysical data. It is intended for guidance with follow-up invasive investigation. Features that do not produce measurable geophysical anomalies or are hidden by other features may remain undetected. Geophysical surveys compliment invasive/destructive methods and provide a tool for investigating the subsurface; they do not produce data that can be taken to represent all of the ground conditions found within the surveyed area. Areas that have not been surveyed due to obstructed access or any other reason are excluded from the interpretation.
FIGURE 1: Map showing location of the site
Legend Title

- Fill
- Gravel
- Highly weathered calcarenite
- Moderately weathered calcarenite
- Moderately weathered calcilitite
- Highly weathered calcisiltite
- Sand
- Silt

FIGURE 3: Geological cross-sections from borehole logs.
FIGURE 4: Elevation profile across the site.
FIGURE 7: Map showing location of offshore refraction profiles.
Lower resistivity features may indicate areas where porewaters have greater salinity.

Low resistivity immediately below the seabed is likely to indicate brine saturated layer.

Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content.

Slight reduction in resistivity at the base of the model may indicate higher salinity, increased porosity or increased clay content.

Location of modern dredged channel

Approximate zone where projected line from Qal'at al Bahrain to the reef break crosses the ERT profile.
Lower resistivity features may indicate areas where porewaters have greater salinity

Low resistivity immediately below the seabed is likely to indicate brine saturated layer

Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content

Slight reduction in resistivity at the base of the model may indicate higher salinity, increased porosity or increased clay content

Location of modern dredged channel

Approximate zone where projected line from Qal'at al Bahrain to the reef break crosses the ERT profile

FIGURE 10: ERT Centre profile. Measured apparent resistivity and modelled resistivity
Lower resistivity features may indicate areas where porewaters have greater salinity

Low resistivity immediately below the seabed is likely to indicate brine saturated layer

Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content

Slight reduction in resistivity at the base of the model may indicate higher salinity, increased porosity or increased clay content

Location of modern dredged channel

Approximate zone where projected line from Qal'at al Bahrain to the reef break crosses the ERT profile

FIGURE 11: ERT South profile. Measured apparent resistivity and modelled resistivity
Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content.

Slight reduction in resistivity at the base of the model may indicate higher salinity, increased porosity or increased clay content.

Low resistivity immediately below the seabed is likely to indicate brine saturated layer.

Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content.

FIGURE 12: ERT Cross Line 1 profile. Measured apparent resistivity and modelled resistivity.
Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content

Low resistivity immediately below the seabed is likely to indicate brine saturated layer

Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content

FIGURE 13: ERT Cross Line 2 profile. Measured apparent resistivity and modelled resistivity
Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content.

Low resistivity immediately below the seabed is likely to indicate brine saturated layer.

Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content.

FIGURE 14: ERT Cross Line 3 profile. Measured apparent resistivity and modelled resistivity.
Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content.

Low resistivity immediately below the seabed is likely to indicate brine saturated layer.

Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content.

FIGURE 15: ERT Cross Line 4 profile. Measured apparent resistivity and modelled resistivity.
FIGURE 16: ERT Cross Line 5 profile. Measured apparent resistivity and modelled resistivity.
Low resistivity immediately below the seabed is likely to indicate brine saturated layer.

Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content. In this profile the measured readings show very little lateral variation and the undulations evident in the model may be minor instability in the modelling process.

FIGURE 17: ERT Cross Line 6 profile. Measured apparent resistivity and modelled resistivity.
Low resistivity immediately below the seabed is likely to indicate brine saturated layer.

Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content. In this profile the measured readings show very little lateral variation and the undulations evident in the model may be minor instability in the modelling process.

FIGURE 18: ERT Cross Line 7 profile. Measured apparent resistivity and modelled resistivity.
Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content.

Low resistivity immediately below the seabed is likely to indicate brine saturated layer.

Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content.

**FIGURE 19:** ERT Cross Line 8 profile. Measured apparent resistivity and modelled resistivity.
Low resistivity immediately below the seabed is likely to indicate brine saturated layer

Lateral variations in resistivity may indicate changes in porewater salinity, porosity or clay content

Slightly elevated resistivity may indicate lower salinity wedge, zone of lower porosity or lower clay content

FIGURE 20: ERT Cross Line 9 profile. Measured apparent resistivity and modelled resistivity
Profile-South

Relatively high Vp indicates stronger areas. This may be due to lower degree of weathering, fewer fractures or more completely cemented material.

Lower velocity indicates weaker, less well consolidated or more highly weathered material.

Survey layout

Approximate zone where projected line from Qal'at al Bahrain to the reef break crosses the refraction profile.

NURANA ACCESS PROJECT GEOPHYSICS

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<td>1st revision</td>
<td>M Harwood</td>
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FIGURE 22: Seismic Refraction Sections Southeast Profile-Land Based
Profile-Centre_Part 1

Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
Fewer fractures or more completely cemented material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material

Survey layout

FIGURE 23: Seismic Refraction Sections Central Profile Part 1-Land Based
Profile-Centre_Part 2

Relatively high Vp indicates stronger areas. This may be due to lower degree of weathering, fewer fractures or more completely cemented material.

Lower velocity indicates weaker, less well consolidated or more highly weathered material.

FIGURE 24: Seismic Refraction Sections Central Profile Part 2-Land Based
FIGURE 25: Seismic Refraction Sections Northern Profile-Land Based
Profile-T 1

Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
fewer fractures or more completely cemented material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material

Survey layout

FIGURE 26: Seismic Refraction Sections Profile T1-Land Based
Profile-T 2

Tomography Section

P-wave velocity
- 4380
- 3750
- 3120
- 2490
- 1860
- 1230
- 600
(m/sec)

Chainage (m)

Elevation (m)

2500
1400

3 Layer Model

Survey layout

Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
fewer fractures or more completely cemented
material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material

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PROJECT GEOPHYSICS

SITE: Bahrain Nurana

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Drawing ref: GC-GRP-19-96-Nurana Land SET_1.1

FIGURE 27: Seismic Refraction Sections Profile T2-Land Based
**Line 1**

**Survey Layout**

- Relatively high Vp indicates stronger areas
  - This may be due to lower degree of weathering,
    fewer fractures or more completely cemented material
- Lower velocity indicates weaker, less well consolidated
  or more highly weathered material

**FIGURE 28: Seismic Refraction Sections Line 1-Offshore**

**NURANA ACCESS PROJECT GEOPHYSICS**

- **SITE**: Bahrain Nurana
- **Name**: S Shahzad 07/01/2019
- **Date**: 07/01/2019
- **1st revision**: M Harwood 12/01/2019
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- **Approved**: M Harwood 12/01/2019

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Scale
H: 1:2000
V: 1:500
Line 2

Lower velocity indicates weaker, less well consolidated or more highly weathered material.

Relatively high Vp indicates stronger areas. This may be due to lower degree of weathering, fewer fractures or more completely cemented material.

Approximate zone where projected line from Qa‘at al Bahrain to the reef break crosses the refraction profile.

Survey layout

FIGURE 29: Seismic Refraction Sections Line 2-Offshore
Line 3

Lower velocity indicates weaker, less well consolidated or more highly weathered material.

Relatively high Vp indicates stronger areas. This may be due to lower degree of weathering, fewer fractures or more completely cemented material.

Survey layout

FIGURE 30: Seismic Refraction Sections Line 3-Offshore

NURANA ACCESS PROJECT GEOPHYSICS

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Drawing ref: GC-OP-19-54/Nurana-ref/Geop_v1.1
Line 11

Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
fewer fractures or more completely cemented material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material

Survey layout

FIGURE 31: Seismic Refraction Sections Line 11-Offshore
FIGURE 32: Seismic Refraction Sections Line 12-Offshore

Survey layout

Approximate zone where projected line from Qal'at al Bahrain to the reef break crosses the reflection profile

Scale
H: 1:1000
V: 1:500

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Site | Bahrain Nurana
---|---
Name | Date
1st draft | S Shahzad 07/01/2019
1st revision | M Harwood 12/01/2019
2nd revision | Approved M Harwood 12/01/2019

Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
fewer fractures or more completely cemented material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material
Relatively high Vp indicates stronger areas. This may be due to lower degree of weathering, fewer fractures or more completely cemented material.

Lower velocity indicates weaker, less well consolidated or more highly weathered material.

Approximate zone where projected line from Qal'at al Bahrain to the reef break crosses the refraction profile.

**SITE**

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FIGURE 33: Seismic Refraction Sections Line 13-Offshore
Line 14

Survey layout

Approximate zone where projected line from Qal'at al Bahrain to the reef break crosses the refraction profile

FIGURE 34: Seismic Refraction Sections Line 14-Offshore
Line 15

Relatively high Vp indicates stronger areas. This may be due to lower degree of weathering, fewer fractures or more completely cemented material.

Lower velocity indicates weaker, less well consolidated or more highly weathered material.

Survey layout

Approximate zone where projected line from Qatif of Bahrain to the reef break crosses the refraction profile

FIGURE 35: Seismic Refraction Sections Line 15-Offshore

NURANA ACCESS PROJECT GEOPHYSICS

SITE

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>S Shahzad</td>
<td>07/01/2019</td>
</tr>
<tr>
<td>M Harwood</td>
<td>12/01/2019</td>
</tr>
<tr>
<td>Approved</td>
<td>12/01/2019</td>
</tr>
</tbody>
</table>

Prince Muhamed bin Saad Bin Abdelaziz Road
PO 231780, 11231 Riyadh
Tel: +966 (11) 4899990
www.ggc.com.sa,
info@ggc.com.sa

Drawing ref: GC-GP-11.0-Si/44-Geophysics/Geophysics Line 15 Offshore_01
Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
fewer fractures or more completely cemented material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material

Survey layout

Approximate zone where projected line from Qal'at
of Bahrain to the reef break
crosses the refraction profile

FIGURE 36: Seismic Refraction Sections Line 16-Offshore
Line 17

Survey layout

Approximate zone where projected line from Qatar to Bahrain to the reef break crosses the refraction profile

Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
fewer fractures or more completely cemented material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material

FIGURE 37: Seismic Refraction Sections Line 17-Offshore
FIGURE 38: Seismic Refraction Sections Line 18-Offshore
Line 22

Survey layout

NURANA ACCESS PROJECT GEOPHYSICS

Prince Muharad bin Saad Bin Abdelaziz Road
PO 231783, 11321 Riyadh,
Tel: +966 (11) 4899990
www.ggpc.com.sa
info@ggpc.com.sa

FIGURE 39: Seismic Refraction Sections Line 22-Offshore
Lower velocity indicates weaker, less well consolidated or more highly weathered material.

Relatively high Vp indicates stronger areas. This may be due to lower degree of weathering, fewer fractures or more completely cemented material.

Survey layout

Approximate zone where projected line from Qatif at Bahrain to the reef break crosses the refraction profile.

NURANA ACCESS PROJECT GEOPHYSICS

Prince Muharred bin Saad Bin Abdelaziz Road
PO 231783, 11321 Riyadh, Tel: +966 (11) 4899990
www.ggpc.com.sa, info@ggpc.com.sa

FIGURE 40: Seismic Refraction Sections Line 23-Offshore
FIGURE 41: Seismic Refraction Sections Line 24-Offshore
**Line 26**

- **Northeast** to **Southwest**
- **Elevation (m)**
- **Chainage (m)**
- **P-wave velocity**

- **Relatively high Vp indicates stronger areas.** This may be due to lower degree of weathering, fewer fractures or more completely cemented material.
- **Lower velocity indicates weaker, less well consolidated or more highly weathered material.**

**Survey layout**

**Approximate zone where projected line from Qatif at Bahrain to the reef break crosses the refraction profile**

---

**NURANA ACCESS PROJECT GEOPHYSICS**

<table>
<thead>
<tr>
<th>SITE</th>
<th>Bahrain Nurana</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name</strong></td>
<td><strong>Date</strong></td>
</tr>
<tr>
<td>1st draft</td>
<td>S Shahzad</td>
</tr>
<tr>
<td>1st revision</td>
<td>M Harwood</td>
</tr>
<tr>
<td>2nd revision</td>
<td>M Harwood</td>
</tr>
<tr>
<td>Approved</td>
<td>M Harwood</td>
</tr>
</tbody>
</table>

Prince Muhamed bin Saad Bin Abdelaziz Road
PO 231783, 11321 Riyadh,
Tel: +966 (11) 4899990
www.ggc.com.sa,
info@ggc.com.sa

Drawing ref: GC-0P-19-BN/GeophysicsRef_01.1

**FIGURE 43: Seismic Refraction Sections Line 26-Offshore**
Line 27

P-wave velocity

Chainage (m)

Elevation (m)

Southeast

Northwest

Scale
H: 1:2200
V: 1:500

Relatively high Vp indicates stronger areas
This may be due to lower degree of weathering,
fewer fractures or more completely cemented material

Lower velocity indicates weaker, less well consolidated
or more highly weathered material

Survey layout

Approximate zone where projected line from Oaf at
al Bahrain to the reef break crosses the refraction profile

Scale
H: 1:2200
V: 1:500

NURANA ACCESS
PROJECT GEOPHYSICS

FIGURE 45: Map showing location of low velocity anomalies
Appendix A: Library photos of the vessel Jana
Navigation License

코스투드 해군 본부는 다음에 기재된 이름이 капит안을 가지고 있는 승선용 선박을 인증합니다:

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Certificate</th>
<th>Level 2</th>
<th>Valid until</th>
</tr>
</thead>
<tbody>
<tr>
<td>YARA</td>
<td>No. 7762</td>
<td>(Passengers)</td>
<td>2019/01/28</td>
</tr>
<tr>
<td>JANA</td>
<td>No. 10163</td>
<td>(Passengers)</td>
<td></td>
</tr>
<tr>
<td>REEF ARABIA 1</td>
<td>No. 10719</td>
<td>(Service)</td>
<td></td>
</tr>
</tbody>
</table>

NAME: Mr. JAAFAR JUMA HABIB KADHEM
NATIONALITY: BAHRAINI
CPR: 800605470

NOTE: The vessel is allowed to sail 10 miles from main land only and to operate from sunrise to sunset only. The owner comply with the passengers number permitted by Coastguard for each vessel.
RENEWAL ENDORSEMENT

Cover: Marine Hull Insurance

Endorsement Type: Policy Renewal

Endorsement No.: 1801MMHI000351REN

Policy No.: 1201MMHI000070

Takaful Participant: ENVIRONMENT ARABIA CONSULTANCY SERVICES W.L.L

Policy Period: From 23/05/2018 00:00:00 To 22/05/2019 23:59:59

Policy Sum Covered: BHD15,200.000

Renewal Contribution: BHD900.000

It is hereby declared and agreed that the above mentioned policy is renewed for a further period of 1 Year(s) from 23/05/2018 to 22/05/2019 [both days inclusive] for a total Takaful sum covered of BHD15,200.000.

Details of Risk:

<table>
<thead>
<tr>
<th>Name of Vessel</th>
<th>JANA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material of Hull</td>
<td>Fiber Glass</td>
</tr>
<tr>
<td>Model</td>
<td>2012</td>
</tr>
<tr>
<td>Length</td>
<td>29ft</td>
</tr>
<tr>
<td>Breadth</td>
<td>8.5ft</td>
</tr>
<tr>
<td>Draft</td>
<td>1.0ft</td>
</tr>
<tr>
<td>Depth</td>
<td>2.0ft</td>
</tr>
<tr>
<td>Height</td>
<td>7.54ft</td>
</tr>
<tr>
<td>Gross Tonnage</td>
<td>1.6 T</td>
</tr>
<tr>
<td>Registration No.</td>
<td>BH 10163</td>
</tr>
<tr>
<td>Type and Power of Engine</td>
<td>Yamaha 230 HP</td>
</tr>
<tr>
<td>No. of Engines</td>
<td>2</td>
</tr>
<tr>
<td>No. of Crew &amp; Passenger</td>
<td>9 Passengers Insured under P&amp;I cover</td>
</tr>
<tr>
<td>Colour of Hull</td>
<td>White</td>
</tr>
<tr>
<td>Territorial Limit</td>
<td>Bahrain Water</td>
</tr>
<tr>
<td>Purpose of use</td>
<td>Passenger</td>
</tr>
<tr>
<td>Sum Covered:</td>
<td>Hull Value including Machinery BHD 15,200.000</td>
</tr>
</tbody>
</table>
Deductibles: BHD 1,000,000 Each and every loss

Name Of Crew:
1) Anik MD Nab Mia - 840242328
2) Zakir Hossain Abdul Motalab - 840407343
3) Anthony Nicholas Janson - 703828808
4) Sarah Ben Arfa - 800337174
5) Michael Kevin Arora - 690325606
6) Jaafar Juma Habib Kadhem - 800605470.

Conditions and Warranties:
Condition 1. Institute Yacht Clauses cl 328 dated 1/1/1985 but clause 5.1 deleted and clause no 19 applied.
Condition 2. Cyber Clause
Condition 3. Radioactive Contamination etc. Exclusion Clause
Condition 4. Excluding War and terrorism.
Condition 5. Liability Exclusion Clause B (Amended)
Condition 6. Nuclear Energy Risks Exclusion Clause
Condition 7. Seaworthiness certificate from local authority
Condition 8. Registration / ownership card from coastguard
Condition 9. Passenger Liability & Cargo Fright is excluded
Condition 10. The Place of Arbitration : GCC Arbitration Council
Condition 11. The Choice of Law & Jurisdiction : The Kingdom of Bahrain
Condition 12. Takaful Principles and Conditions
Condition 14. Excluding Piracy absolutely
Condition 15. Excluding Riot, Strick, and malicious damage.
Recommendation 1: To provide the boat with 4 rubber finders to be fixed on the boats sides to protect the boats edges.
Recommendation 2: To provide the boat with first Aid kit.
Recommendation 3: to service the existing fire extinguisher after the expiry date and to repeat this process every 6 months.
Warranted: the boat should be kept in one of the clubs in Kingdom of Bahrain.

In consideration whereof a renewal contribution of BHD900.000 is hereby charged to the participant.

All other Terms, Conditions and Exclusions remain unaltered.

Signed for & on behalf of
TAKAFUL INTERNATIONAL CO.

Dated: 13.05.2018

Authorized Signatory
**Vessel / Boat Registration Certificate (less than 150 tons)**

**Certificate No.**: 0044/18

<table>
<thead>
<tr>
<th>Date of Registry</th>
<th>Vessel No.</th>
<th>Vessel Name</th>
<th>Vessel Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/05/2012</td>
<td>10163</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Vessel Details**

- **Type**: Boat / قارب
- **Hull Type**: Fiberglass / فايبر جلاس
- **Passengers**: 1
- **Hull Color**: White / أبيض
- **Date and Place of Build**: 2012, Kingdom of Bahrain

<table>
<thead>
<tr>
<th>Hull No.</th>
<th>Net Tonnage</th>
<th>Gross Tonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1201</td>
<td>1.6 طن</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth</th>
<th>Beam</th>
<th>L.O.A</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 قدام</td>
<td>8.5 قدام</td>
<td>29 قدام</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engines Serial No.</th>
<th>Type &amp; power of the Engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>000/000</td>
<td>Yamaha 2× 115 hp.</td>
</tr>
</tbody>
</table>

**Owner Details**

- **Owner's Name**: ENVIRONMENT ARABIA CONSULTANCY SERVICES W.L.L.
- **Address**: P.O. BOX 10379, Manama, Kingdom of Bahrain

**Remarks**

- **Valid Till**: 22/05/2018
- **Issued at Bahrain on**: 23/05/2021

**CoastGuard Commander**

[Signature]
## Passenger Boat Permit

<table>
<thead>
<tr>
<th>Certificate No.</th>
<th>123</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DATE OF BUILD</strong></td>
<td>2012</td>
</tr>
<tr>
<td><strong>REGISTRATION NO.</strong></td>
<td>10163</td>
</tr>
<tr>
<td><strong>PORT OF REGISTRATION</strong></td>
<td>BAHRAIN</td>
</tr>
<tr>
<td><strong>CALL SIGN</strong></td>
<td>A9D3162</td>
</tr>
<tr>
<td><strong>BOAT NAME</strong></td>
<td>JANA</td>
</tr>
<tr>
<td><strong>LOAD WEIGHT</strong></td>
<td>1.6 TONS</td>
</tr>
<tr>
<td><strong>MAX LENGTH</strong></td>
<td>29 FT</td>
</tr>
<tr>
<td><strong>SURFACE DIMENSION</strong></td>
<td>8.5 FT x 29 FT</td>
</tr>
<tr>
<td><strong>ENGINE DETAILS</strong></td>
<td>YAMAHA 2 x 115HP</td>
</tr>
<tr>
<td><strong>HULL COLOR</strong></td>
<td>WHITE</td>
</tr>
<tr>
<td><strong>HULL TYPE</strong></td>
<td>FIBER GLASS</td>
</tr>
<tr>
<td><strong>FIRST AID BOXES</strong></td>
<td>1 BOX</td>
</tr>
<tr>
<td><strong>SPARE ANCHORS</strong></td>
<td>01</td>
</tr>
<tr>
<td><strong>NOS. OF LIFE RAFTS</strong></td>
<td>--</td>
</tr>
<tr>
<td><strong>NOS. OF LIFE JACKET</strong></td>
<td>08</td>
</tr>
<tr>
<td><strong>NOS. OF LIFE RINGS</strong></td>
<td>02</td>
</tr>
<tr>
<td><strong>MAXIMUM PASSENGERS</strong></td>
<td>04</td>
</tr>
<tr>
<td><strong>MINIMUM CREWS</strong></td>
<td>02</td>
</tr>
</tbody>
</table>

**TRANSPORTATION WOMEN & CHILDREN IS ALLOWED / NOT ALLOWED**

**ISSUED ON DATE** 24/05/2018

According to article 14 of Law no. 20 for the year 1979 amended by Law no. 13 for the year 2000 and the article 3 to 6 of ministerial order no. 13 for the year 2007.

**VALID UNTIL** 28/01/2019

**NOTE:** The vessel is allowed to sail 10 miles from main land only, and to operate from sunrise to sunset only.
**SHIP STATION LICENCE**  
**LICENCE DE STATION DE NAVIRE**  
**LICENCA DE LA ESTACION DE BARCO**

<table>
<thead>
<tr>
<th>No.</th>
<th>Issue Date</th>
<th>Valid Until</th>
<th>輻射許可証書</th>
<th>Callign &amp; Identification</th>
<th>Owner of Ship</th>
<th>Public Correspondence Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.07.2012</td>
<td>14/01/2018</td>
<td>31/12/2018</td>
<td>A9D3162 MMSI: 408549000 Reg.No.: 10163</td>
<td><strong>JANA</strong></td>
<td><strong>ENVIRONMENT ARABIA</strong> P.O. Box: 10379 BAHRAIN</td>
<td>CV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment and Type</th>
<th>Power (Watts)</th>
<th>Class of Emission</th>
<th>Frequency Bands or Assigned Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitters (VHF)</td>
<td>25.00</td>
<td>16K0G3E</td>
<td>VHF</td>
</tr>
<tr>
<td>Other Equipment (AIS)</td>
<td>25.00</td>
<td>GMSK</td>
<td>VHF</td>
</tr>
<tr>
<td></td>
<td>2200.00</td>
<td>PON</td>
<td>X-BAND</td>
</tr>
</tbody>
</table>

Director of Wireless Licensing, Frequency & Monitoring

Telephone: (+973) 17-715030, Facsimile: (+973) 17-715030, P.O. Box 26627, Manama – The Kingdom of Bahrain
dwlfm@iga.gov.bh
CONFIRMATION OF COVER

<table>
<thead>
<tr>
<th>Type:</th>
<th>PROTECTION &amp; INDEMNITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date:</td>
<td>15th January 2018</td>
</tr>
<tr>
<td>M.M.A.L. Member:</td>
<td>Being a reinsurance of Takaful International Co. Bahrain and subject to a claims control clause for the account of Environment Arabla Consultancy Services W.L.L as Owner &amp;/or as Manager. Reinsurance order hereto 100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vessel Name</th>
<th>Type</th>
<th>Flag / Class</th>
<th>Built</th>
<th>GT</th>
<th>ETC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Jana&quot;</td>
<td>Service boat</td>
<td>Bahrain / TBA</td>
<td>2012</td>
<td>1.6</td>
<td>As agreed</td>
</tr>
<tr>
<td>Number of Crew: 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period:</th>
<th>12 months as from 2nd February 2018.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trading Warranty:</td>
<td>Bahraini waters only.</td>
</tr>
<tr>
<td>Conditions:</td>
<td>As per Association Rules for Class I P &amp; I excluding liability to Cargo and property onboard and liability arising out of any actual scuba diving activities.</td>
</tr>
<tr>
<td>Limit of Liability:</td>
<td>USD 2,000,000 any one accident or occurrence, but crew/passenger liability limited to maximum of USD 30,000 per crew member any one accident or occurrence and passenger liability limited to a maximum of USD 20,000 per passenger any one accident or occurrence.</td>
</tr>
<tr>
<td>Deductibles:</td>
<td>USD 2,500 in respect of Crew/Passenger claims any one person any one accident or occurrence. USD 1,000 in respect of RDC/FFO claims any one accident or occurrence except claims in respect of damage to rigs and/or platforms which are subject to a deductible of USD 5,000 any one accident or occurrence. USD 3,000 or 10% of Total claim in respect of all claims following Total and/or Constructive Total Loss of vessel, whichever the greater. USD 2,000 in respect of all other claims any one accident or occurrence except 1/3rd smuggling fines/penalties relating to drugs. All associated costs arising from investigating the claims are to be borne by Member if a claim falls below the applicable deductible.</td>
</tr>
<tr>
<td>Call Warranty:</td>
<td>Payable in full within 30 days of due date, time being of the essence, otherwise insurance automatically cancelled with the Association accepting no liability arising from any incident. Canceling Returns Only.</td>
</tr>
</tbody>
</table>
**MARITIME MUTUAL**

<table>
<thead>
<tr>
<th>Warranties:</th>
<th>Warranted fully completed and signed proposal of entry form to be received within 30 days of attachment of cover.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warranted Crew contracts to be submitted prior to attachment to the Association for approval.</td>
</tr>
<tr>
<td></td>
<td>Warranted not to exceed licensed passenger limits.</td>
</tr>
</tbody>
</table>

| Information: | Crew: 2  
|             | Passengers: 5  
|             | First Notification of claims to be reported to:-  
|             | Far East P&I Services Pte. Limited.  
|             | Telephone: +65 6220 9690  
|             | Fax: +65 6323 5176  
|             | PIC: Tey Choon Wee  
|             | For more information: www.maritime-mutual.com |

For and on behalf of Maritime Pacific P&I Services Limited as Manager's Correspondent for Maritime Mutual Insurance Association (NZ) Limited
Top: Bubble pulsar and Microeel deployed from the vessel

Bottom: Transiting to site at dawn Bubble Pulsar on front deck

Appendix B: Site photos
Top: View of the seismic control station with Nav screen on the left

Bottom: Close up of the seismic control screen

Appendix B: Site photos
Top: Marine ERT streamer deployed from the rear of the vessel
Bottom: ERT control station

Appendix B: Site photos
Top: ERT power supply and IRIS Syscal Pro

Bottom: Overview of the vessel during ERT survey. Note Microeel stowed in foreground

Appendix B: Site photos
Top: Onshore seismic on soft sediment close to Karbabad. Note outfall in background. Geophones planted in sediment.

Bottom: Seismic survey further from shore. It was found inadvisable to take the pickup out and all kit was hand-carried. Note geophones on sandbags on hard surface.

Appendix B: Site photos
Top: View of Geophones mounted on sandbags on hard surface. Note this amount of water cover is typical of conditions at low tide.

Bottom: Overview of site at low tide showing fish traps. Nurana Island in background.

Appendix B: Site photos
Top: View of site from Nurana Island at low tide. Note cover of water lenses.

Bottom: View of site from Qal' al al Bahrain. Note freshwater springs (circular structures) on the foreshore.

Appendix B: Site photos