Government of Gibraltar

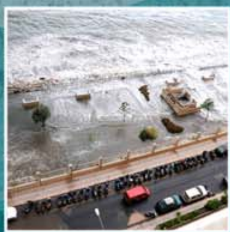
Preliminary Flood Risk Assessment

Final Report

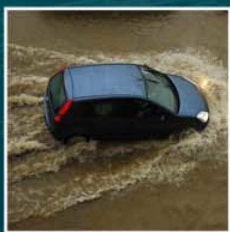
January 2011











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Report for

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Government of Gibraltar

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January 2011

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Contents

1. Introduction

1.1 The Role of a Preliminary Flood Risk Assessment

The EU Floods Directive, published in October 2007, aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. It requires Member States to first carry out a preliminary assessment by 2011 to identify the river basins and associated coastal areas at risk of flooding.

For zones identified as being within an area of "significant" risk to flooding, the Directive requires flood risk maps to be prepared by 2013. Flood risk management plans focused on prevention, protection and preparedness should then be established for the identified zones by 2015.

The Floods Directive has been linked to the Water Framework Directive (WFD), both in terms of scale (WFD River Basin Districts are the level at which risks must be assessed) and timing, requiring flood risk assessments to be reviewed periodically in conjunction with River Basin Management Plans. The WFD has a broad aim to contribute to 'mitigating the effects of floods and droughts', in addition to its primary focus on achieving good ecological status and preventing deterioration of existing status classifications. The Floods Directive can be viewed as the means by which the EU hopes to achieve the effective consideration of floods in parallel with the WFD river basin planning process.

Articles 4 and 5 of the Flood Directive require all member states to undertake a Preliminary Flood Risk Assessment (PFRA), based on available or readily derivable information to assess potential significant risks. This report has been produced for the purpose of complying with Articles 4 and 5 of the Directive, and comprises the PFRA for the Gibraltar River Basin District.

1.2 Structure of this report

This report is structured as follows, to ensure that all the requirements of Article 4 are met:

- Chapter 2: Gibraltar River Basin District, provides a description and maps of the district [as required under Article 4 (2)(a)];
- Chapter 3: Sources of Flooding, outlines the potential flooding sources in the district;
- Chapter 4: Flooding History, summarises the previous flooding incidents in the district [as required under Article 4 (2)(b)];
- Chapter 5: Future Flood Risk, assesses the climate change impacts and likely consequences and significance of future flood events [as required under Article 4 (2)(c), (2)(d) and Article 5];
- Chapter 6 presents the overall summary and conclusions of the PFRA.

2. Gibraltar River Basin District

An Initial Characterisation of the Gibraltar River Basin District (RBD) was prepared in 2005 in partnership between Entec UK Ltd, Northumbrian Water and AquaGib on behalf of the Government of Gibraltar. The Characterisation Report was prepared in accordance with Article 5 of the WFD. A summary of the river basin's environmental characteristics is presented in this Chapter, taken from the 2005 report.

2.1 Topography and Land Use

Gibraltar covers a surface area of approximately 5.8 km^2 and topographically it consists of 2 distinct areas (Figure 2.1): the 'Rock' rising sharply to more than 400 m above sea level with a precipitous east coast facing the Mediterranean and; the more gentle west coast on which the town and harbour are located facing the Bay of Gibraltar. Much of the town and naval base is located on reclaimed land extending into the harbour area, as shown in Figure 2.1.

For about 1 km from the north face of the Rock to the Spanish frontier the land is very flat and is located just above sea-level. This area is known as The Isthmus and is occupied mainly by the Devil's Tower Road commercial and residential areas, Devil's Tower Camp, Four Corners Camp and the airport runway and supporting infrastructure. It is bordered on the west by the Bay of Gibraltar and on the east by the Mediterranean Sea.

At the southern tip of Gibraltar is Europa Point, where the coastal waters of the Bay of Gibraltar meet the Straits of Gibraltar. At the straits the interface between the less saline and cooler Atlantic waters and the deeper Mediterranean waters occurs at a depth of around 250 m.

The majority of the built up area is sited on the more gentle west coast between the airport and the southern plateaux at Europa point. There are however some small settlements at the foot of the east face of the Rock, at Catalan Bay and further south at Sandy Bay.

2.2 Geology

The Gibraltar "Rock" is made up of the Gibraltar Limestone Formation of early Jurassic age. The Limestone Formation is generally a hard rock containing fragmentation and deformations. It is divided into four members ranging from dark grey dolomite to lighter fine grained limestone.

The Isthmus and lower slopes of the Rock are covered by thick superficial Quaternary deposits of sands and scree breccias.

Figure 2.2 presents the geology of the district.

2.3 Climate and Rainfall

Gibraltar experiences a Mediterranean climate with moderate winter rainfall and dry summers. The district has an average annual rainfall of 778 mm (from hourly rainfall provided from 1987 to 2006), which falls principally in the winter months around 75% of which originates from westerly winds. Rain storms can therefore reach high intensities during the winter months. Summers are generally warm and dry, and winter temperatures can fall to close to 0^{o}C.

2.4 Tides

The coastal waters surrounding Gibraltar are subject to ocean currents that are both tidal and non-tidal in origin. Tidal amplitudes in the western Mediterranean Sea are affected by tidal inputs from the Atlantic Ocean, resulting in relatively large amplitudes compared to other areas of the Mediterranean. The tidal range between daily high tides and low tides is approximately between 0.4 and 1.2 metres, as monitored in the harbour of Gibraltar by the Proudman Oceanic Laboratory (http://www.pol.ac.uk/ntslf/gibraltar/).

Non-tidal flows through the Strait of Gibraltar are caused by either:

- Weather - air pressure and the affect of wind on the sea surface;
- Differences between the densities of the Atlantic Ocean and Mediterranean Sea.

2.5 Water Bodies

The Gibraltar RBD and water bodies are defined as shown in Figure 2.3. The RBD does not contain any significant natural surface water courses and four distinct water bodies have been identified:

- Two coastal water bodies;
- Two groundwater bodies (the Northern and Southern groundwater bodies).

Coastal Water Bodies generally extend to one mile from the coastline. The Gibraltar River Basin Management Plan is currently under production, which will review the need to designate the harbour area and northern marina as a Heavily Modified Water Body. The Initial Characterisation Report provisionally designates the harbour area and northern marina as two separate Heavily Modified Water Bodies, and the coastal waters excluding the harbour area and extending to one mile from the coastline comprise the second surface water body in the RBD.

The Northern Groundwater Body is located in the upper aquifer of the Isthmus Sands and there is currently only one licensed abstraction for light industry. Very small quantities are also abstracted from the North Front Cemetary but the quantities abstracted are too small to render licensing. The Southern Groundwater Body is located within the Limestone Bedrock and has been subjected to spillages of hydrocarbons in the past.

2.6 Drainage Infrastructure

Surface water drainage and sewerage infrastructure is based around a large trunk sewer which runs from Line Wall Road southwards to its discharge location at Europa Point. The drainage system is based on historic combined foul and surface water infrastructure. Newer areas have been built with a separated system with limited connectivity between the two for storm overflows.

Areas of the town to the east and upstream of the Trunk Sewer are served by drainage which gravitates into it via combined or foul drainage networks. It is mainly the old town area therefore where the drainage operates under gravity. Areas which cannot gravitate are predominantly separated foul networks which are served by approximately 30 pumping stations (belonging to AquaGib and the MoD) which currently discharge to a variety of points along the Trunk Sewer. These areas include the northern and western parts of the town and the dock area.

In addition there are six storm overflows on the Trunk Sewer which discharge through short outfalls to the sea and the harbour area on the west coast of Gibraltar. The overflow discharges into the harbour area are all generally submerged outfalls. Some of these have been increased in length from their original location as a result of increased land reclamation over the years. This has also led to a subsequent lowering of the outfalls.

The majority of the drainage system is relatively old, and has been subject to collapse in places. Siltation also occurs mainly as a result of the flat gradient of some of the pipes. Maintenance of the pipes takes place to manually remove the accumulated silt, in particular in the trunk sewer.

Key

Fill & Man Made

Post 1985

1900 - 1985

Pre 1900

Engineering Works

Quarry face

Water catchment (now disused)

0 km 1 km

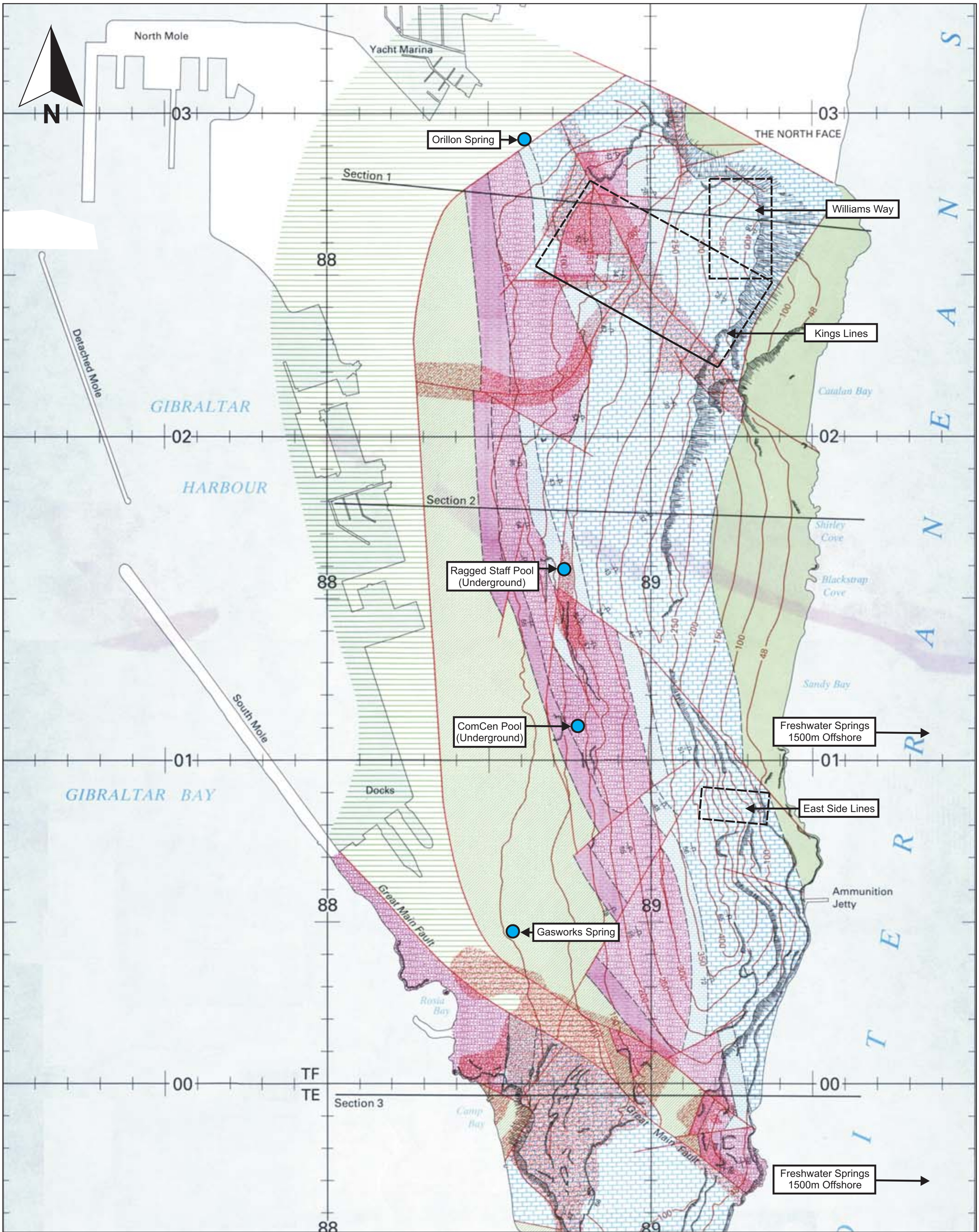
Gibraltar EU Floods Directive
Preliminary Flood Risk Assessment

Figure 2.1
Topography and Man Made Modifications (from Rose and Rosenbaum 1991)

November 2010
27593-B05.cdr parkj

Entec

Reproduced using 'Geology of Gibraltar' 1991.



Key

	Bedrock unknown (obscured by superficial sediments or by the sea)
Tectonic Breccia	
	Source rock indicated where possible
Pre-Quaternary	
	Mudstone, limestone and chert
	Limestone with some dolomite
	Interbedded dolomite and limestone
	Pale grey dolomite
	Dark grey dolomite
	Mudstone, sandstone and dolomite
	Mudstone and sandstone

0 m 500 m

Gibraltar EU Floods Directive
Preliminary Flood Risk Assessment

Figure 2.2
Solid Geology of Gibraltar, Bedrock Waterbody is Within Gibraltar Lines. Fuel Storage Areas, Pools and Main Springs also shown (from Rose and Rosenbaum 1991)

November 2010
27593-B06.cdr parkj

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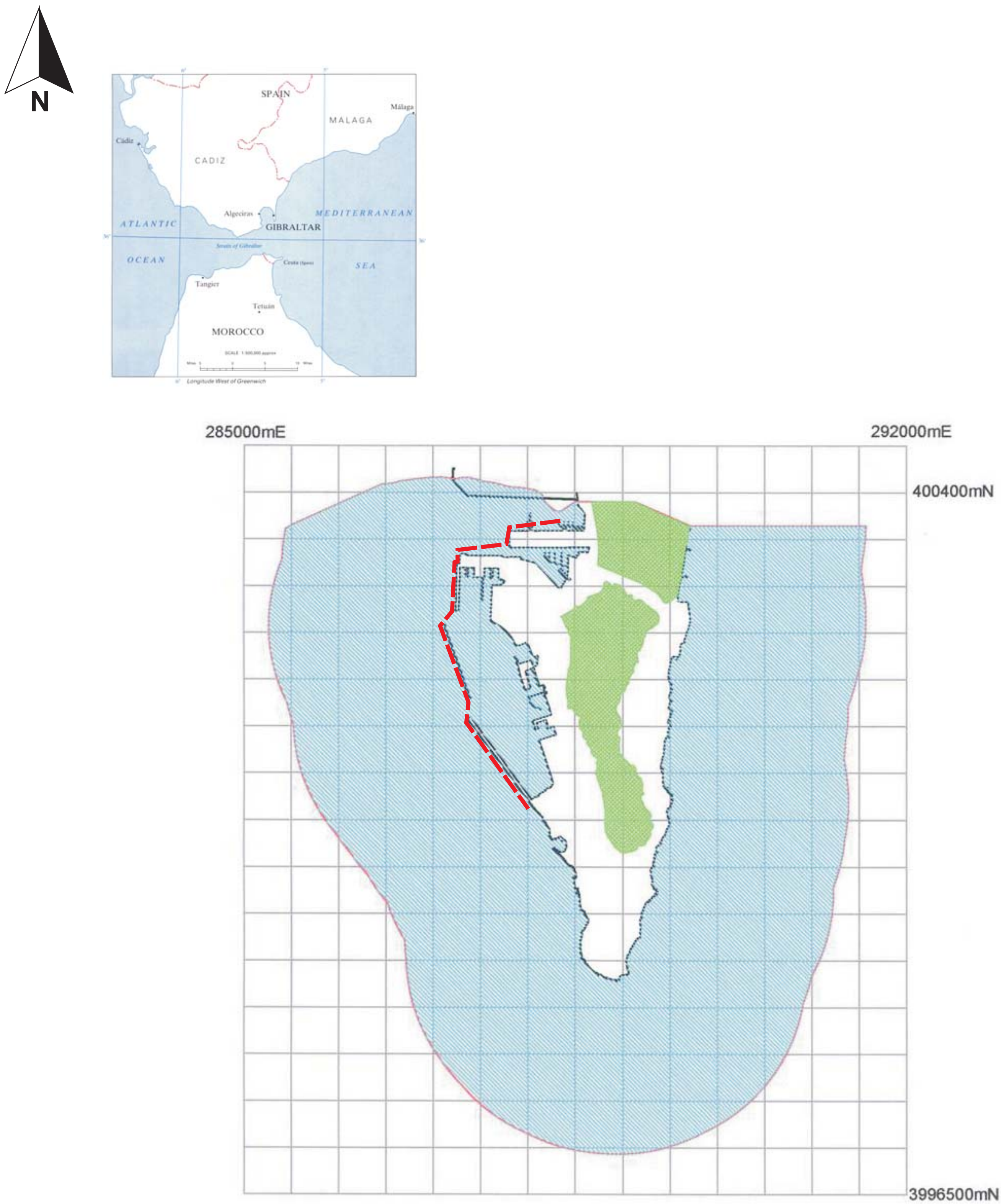
Reproduced using 'Geology of Gibraltar' 1991.



Key

Coastal water	Provisionally identified heavily modified water body
Groundwater	
River basin district boundary	
Rock outline	
Gridline	

0 km — 3 km

Gibraltar EU Floods Directive
Preliminary Flood Risk Assessment

Figure 2.3
Gibraltar River Basin District

November 2010
27593-B07.cdr parkj

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Reproduced using 'Geology of Gibraltar' 1991.

3. Sources of Flooding

There has been no modelling of flooding for Gibraltar or mapping of potential flood risk areas for the river basin district. Information in this section on flooding sources is therefore derived from an assessment of the water bodies in the district and from anecdotal evidence provided at the Inception Meeting with the Department of the Environment. Article 2 of the Directive defines ‘flood’ as meaning *the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral watercourses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems.*

Table 3.1 presents a general overview of all potential flooding sources in line with the Article 2 definition, and therefore excludes sewer flooding. The flooding mechanisms from each source listed in Table 3.1 are described in more detail where appropriate in the subsequent sections of this Chapter.

Table 3.1 Potential Sources of Flooding

Source of Flooding	Risk Present	Notes
Rivers	No risk	There are no watercourses present and therefore there is no risk of river or channel flooding
Rainfall	Risk Present	There is a risk of heavy rainfall ponding on roads and surfaces or exceeding the drainage capacity within the urban areas of the district
Groundwater	No risk	Groundwater flood risk is considered to be minimal. The Southern groundwater body is located within the Rock with a large difference between ground levels and the water table. In addition, both the Southern and Northern aquifers are in close hydraulic continuity with the coastal water body thus minimising the risk of flooding.
Sea	Risk present	Flooding from the sea presents one of the main sources of potential flooding in the district, surrounding Gibraltar on both sides. Flooding could potentially occur from the Mediterranean Sea or from the Bay of Gibraltar as a result of storm surges, wave action or a combination of these with high tides.
Infrastructure (e.g. flood defence failure)	Residual risk present	There is a residual risk that flood defences could fail and cause flooding during extreme tidal events

3.1 Flooding from Rivers

As there are no watercourses present in Gibraltar, there is no source of fluvial or river flooding present.

3.2 Flooding from the Sea

Flooding from the sea occurs infrequently in Gibraltar but can have severe consequences when flooding occurs.

Flooding of coastal areas may be caused by seasonal high tides such as those driven by the spring neap tide cycle, storm surges and where increase in water level above the astronomical tide level is created by strong on-shore winds or by storm driven wave action. All three mechanisms can combine to cause flooding of coastal areas.

Meteorologically-induced sea level rise is the term used to describe the phenomena of deep low pressure weather systems causing the surface of the sea beneath the centre of the depression to dome upwards. The sea surface is raised because the centre of the deep low pressure system is applying less downward force on the sea surface than is being applied by the atmosphere outside the low pressure system. This dome of water advances with the progression of the storm and when the storm makes landfall so does the dome of water or 'storm surge'. If meteorological conditions coincide with astronomically controlled flood tides (Spring tides) then the resultant water level can be even higher and thus flooding can be even more extensive.

In Gibraltar there is the potential for wave action to cause flooding of the coastal areas during storm events with very strong easterly winds. This can affect the eastern coast facing the Mediterranean including Catalan Bay and Sandy Bay, which receive the on-shore winds and are subject to wave overtopping. The western face of the district can also be impacted by easterly storms if waves reflect off the newly reclaimed and much enlarged Port of Algeciras and rebound toward Gibraltar.

The submerged position of the six storm overflows means that the discharge capacity of those pipes is controlled by sea level at all times. Therefore the highest tides or sea levels will result in the lowest capacities to discharge flood flows from rainfall. Where inflow exceeds outflow, surface water may not be able to enter the system and foul flows which overflow from the trunk sewer at a much higher level, may exit the system via lifted manhole covers or gulleys on combined systems. Hence, during periods of extremely high tides, the ability of the sewer system to pass forward large surface water flows is heavily compromised, resulting in localised flooding in low lying areas or areas subject to large volumes of surface water flow.

Flooding incidents that have previously occurred in Gibraltar and affected coastal areas are discussed in Section 4.1.

In response to the potential risk of flooding from the sea in the town and harbour area, sea defences have been constructed to protect existing areas from flood risks. The defences are discussed in more detail in Section 3.5.2 below.

3.3 Flooding from Rainfall

Small scale flooding occurs in Gibraltar frequently as a result of rainfall, although with relatively low consequences. Flooding is caused by heavy rain storms falling onto the impermeable surfaces and low lying areas of the town: the rain storms experienced in Gibraltar tend to be very heavy downpours that can lead to rapid accumulation of surface water which can overload the drainage system very quickly.

Surface water flooding has been known to occur in the lower lying areas of the town. Heavy rain falling onto the higher ground within the urban area and on parts of the Rock, which are steeply sloping, will generate surface run-off that will cause flooding when it reaches the flatter areas of the town.

Surface water drainage in the upper urban areas (including the old town) in Gibraltar is drained by the trunk sewer, which discharges to the sea at Europa Point. It is known that the capacity of the trunk sewer can be reduced by siltation which may also contribute to surface water flooding. Surface water drainage in the lower urban area comprises a number of surface water only outfalls, and six combined storm outfalls.

3.4 Flooding from Groundwater

Groundwater flooding is unlikely to occur in Gibraltar and there have been no recorded incidents of flooding from this source. The Southern groundwater body is located within the Rock and it is anticipated that the large difference between ground levels and the water table in this aquifer will prevent flooding from groundwater sources. The Northern groundwater body is located in an area with much lower elevations, however there are no reported incidents of groundwater flooding. Flooding is thought to be unlikely from the Northern Aquifer because increasing groundwater head is likely to increase outflow to sea rather than cause flooding.

3.5 Infrastructure Flood Risk

3.5.1 Flood Defence Failure

Sea defences are present at numerous locations around the Gibraltar coastline to protect the built environment from wave overtopping and sea water inundation during storm events. A description of the sea defences is presented below and Figure 3.1 shows the indicative locations and types of defences present.

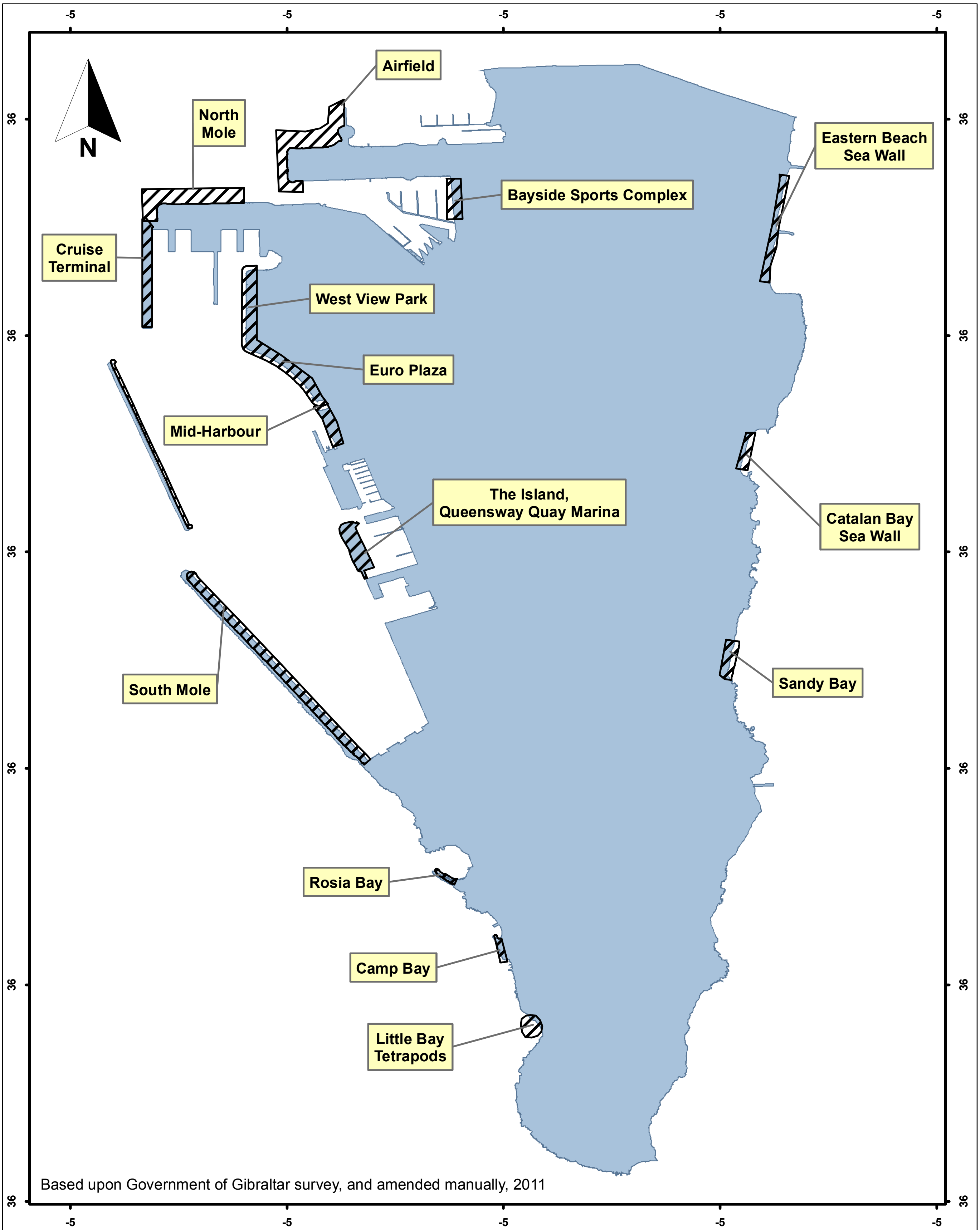
Rock revetments are located in the mid harbour and the southern part of the district in Little Bay and Camp Bay. Those in the harbour area have recently been restored following a storm surge which occurred during a 4 metre swell in 2008 (refer to Chapter 4).

The North and South Moles that form the outer edge of the harbour area also afford protection from storm surges, through dissipating wave energy before it reaches built up area.

South of the harbour area at Camp Bay on the western shore of Gibraltar, sea defences in the form of nominal tetrapods and rock gabions are present to dissipate wave action

Along the eastern coast of the district there are sea walls present at Eastern Beach Road and Catalan Bay and recently constructed rock armour at Sandy Bay. There are plans to reclaim an area to the north of Catalan Bay through a privately funded scheme, which will provide some further protection from north easterly storm events at Catalan Bay in addition to the sea wall.

The risk of these defences failing is considered to be minimal, and therefore the risk of flooding from defence failure is not considered further.



Key:

Indicative locations of flood defences

Gibraltar coastline 2011

Gibraltar EU Floods Directive
Preliminary Flood Risk Assessment

Figure 3.1
Indicative Locations of Flood Defences

Project Path:
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Drawings\GIS\27593-B04 Figure 3.3 Indicative
Locations of Flood Defences.mxd

0 1,000 Metres

Scale: 1:25000 @ A4
Geographic Coordinate System - WGS84 Spheroid

January 2011
27593-B04 stokr

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Based Upon Government of Gibraltar survey, updated 2011

4. Flooding History

Gibraltar has experienced numerous floods in recent history, predominantly from storm rainfall events or from storm surges from the sea. There is currently no formal database of flooding records to draw upon. Instead, this section presents an overview of the flooding events that have occurred recently from anecdotal evidence, supported by photographic evidence where available. Figures 4.1 and 4.2 show areas that have previously been flooded.

4.1 Rainfall Flooding

Flooding due to rainfall results from three basic mechanisms:

- Runoff from the Upper Rock flows first in open channels to the head of surface and combined water systems. Where these drainage systems become inundated, overland flow occurs predominantly along roads. This often results in flooding in the lower gradient areas of the town where ponding occurs. Ultimately all of these flows drain to surface water and combined outfalls;

- There are a few areas such as Wellington Front where overland flows find it easier to cross the trunk sewer and drain directly to the lower town area. Here they contribute to surface water ponding which ultimately drains to the surface water and combined outfalls;

- In the lower town area below the level of the trunk sewer flooding occurs predominantly by ponding of rainwater in the low lying depressions. An element of overland flow from the surrounding areas contributes to this.

There are certain areas within the town that are susceptible to flooding during heavy and intense rainfall events. Photographs are previous flooding in the areas discussed are presented in Plates 1 to 8 in Appendix A.

- **Queensway and Wellington Front**. Queensway is prone to surface water flooding along its entire reach especially between the Ragged Staff Roundabout and Wellington Front areas. It is thought that the surface water drainage system backs up, and is also subject to some minor collapses in the pipe network. During heavy downpours standing water will accumulate in many places, where there are predominantly impermeable surfaces combined with a potentially inadequate drainage system. A solution to the issue is currently being investigated. The photograph in Plate 1 shows flooding which occurred in January 2010;

- On the eastern, town side of Wellington Front, ground elevations are approximately 1 metre lower than Queensway and approximately 5 metres lower than land immediately to the east on Line Wall. This area provides car parking spaces for users of the clubs and organisations which occupy the vaults contained within Wellington Front. Flooding occurs in this area due to inadequate drainage which is currently being addressed (see Plate 2);

- **Fish Market and Orange Bastion**. North East of Queensway, the Fish Market Place and Fish Market Lane (near Orange Bastion) both experience flooding during heavy rainfall events. This is considered to be partly due to the expanse of impermeable surfaces combined with the low lying elevations.

Surface water drainage relies on pumping stations in this area to connect to the Trunk Sewer which cannot cope with the pumping demands required during episodes of prolonged and intense rainfall. The photograph in Plate 3 shows surface water ponding that occurred in March 2010;

- **Laguna Estate**. This area is located at the northern end of the town near to Victoria Stadium. The estate is between Winston Churchill Avenue, Devils Tower Road and the Northern Defences. Laguna Estate was historically a marsh, which was later dug out to become a lake (known as The Inundation). It was then later filled to provide building land. Small-scale flooding has taken place in the past during heavy rainfall events due to the combination of the inadequate drainage system and low lying impermeable surfaces. Flooding has been reported to affect businesses in this area (Inception Meeting, 03 March 2010);

- **Rosia Road**. Heavy rainfall during a storm event that occurred in October 2008 led to significant flooding of some the coastal areas (described in more detail in section 4.2 below). The heavy rainfall caused flooding on Rosia Road near to Jumper's Bastion which significantly affected traffic movement. The photograph in Plate 4 shows sediment-entrained flood water on the road and car parking areas. The colour of the water is further indication that this run-off is likely to be generated uphill on the Rock, and that the steepness induces run-off, rather than permitting rain to infiltrate into the ground above the town.

Figure 4.1 presents the location of these areas described above that have previously experienced surface water flooding from heavy rainfall events.

4.2 Flooding from the Sea

Gibraltar has experienced flooding from the sea as a result of storm surges throughout its history, affecting the coastal areas. The section below describes the most recent and most significant flood event from recent history, which occurred on 10 October 2008.

4.2.1 Storm Surge, October 2008

On 10 October 2008 a particularly low pressure storm combined with a high tide and caused a severe storm surge. This caused one of the most significant flooding events in Gibraltar in recent history. Flooding occurred in many coastal areas of Gibraltar as a result of the sea overtopping the sea walls in the harbour area and inundating the east coast settlements. Substantial damage was caused to some buildings in the coastal area. The most damage occurred in the area of the Europlaza residential building and the car parking areas between Morrisons supermarket and the harbour (WestView Park), where the sea wall and rock revetments were breached. Sea water inundated the area and the underground car park beneath the Europlaza, and the loose rocks from the breached defences also caused some of the building damage. This location in the harbour is considered to be currently the most exposed location to storm surges and as a result suffered from the full force of the storm. The photographs in Plates 5 and 6 show the damage to the sea defences at West View Park and the Europlaza building.

Further damage occurred to the North Mole of the harbour including the cruise terminal building, Port Authority building, post office sorting building, highway and the saltwater extraction water mains. The buildings were flooded and also experienced some structural damage and collapse from debris washed in with the sea and from the breached revetments. The road linking the buildings on the North Mole was also significantly damaged and uplifted by the storm surge. Further south of the harbour, both Queensway Quay Marina and the Comorant Boat Camber also sustained damages.

Some damage occurred on the airport runway and jetties near to Western Beach, which were damaged and parts eroded by the force of the water. Buildings and structures along the South Mole also experienced flood damage from being inundated by the force of the storm tide. Other recorded incidents of flooding and damage occurred at Rosia Bay as well as further inland from the wind and rain which affected buildings The storm winds came from an easterly direction and it has been ascertained that the major contributor to the damage caused was the new Algeciras breakwater which reflected the incoming easterly swell towards to Western coastline of Gibraltar (assessment undertaken by Deltares in 2008 and 2009, summarised in email dated 14 December 2010, reference 1203913-000-HYE-0004, see Appendix B)

The eastern coast of Gibraltar is much less developed. However, the two main residential areas at Catalan Bay and Sandy Bay also experienced flood and storm damage during the October 2008 event, and are generally subject to storm damage from storm surges and from coastal erosion. On this side, the Rock slopes steeply into the sea therefore the two settlements at Catalan Bay and Sandy Bay are backed by the steep slopes and are fronted by the sea. Wave action against the steep shore results in gradual erosion of the coastline. During the 2008 event, the beach in front of Sandy Bay was completely inundated and sea defences were damaged. Damage did occur at the sewage pumping station which suffered irreparable structural damage. Plates 7 and 8 show the proximity of the development at Sandy Bay to the shore with collapsed sea defences and Catalan Bay.

Figure 4.2 maps the locations where significant damage occurred as a result of the storm surge event in October 2008. It should be noted however that during this storm event, no residential properties were significantly damaged.

4.2.2 Impacts of the Storm Surge

Apart from the physical damage caused by the storm surge, economic impacts were also observed predominantly due to the damage caused to sea defences alongside West View Park and the East side. The cost of repair to the harbour and Western sea defences sums up to £10 million and accounts for the sum of individual work packages that were required. Some of this repair work is still ongoing. An additional £200,000 was spent on the rock armour at Sandy Bay to prevent further damage to the housing complex immediately behind Sandy Bay known as Both Worlds.

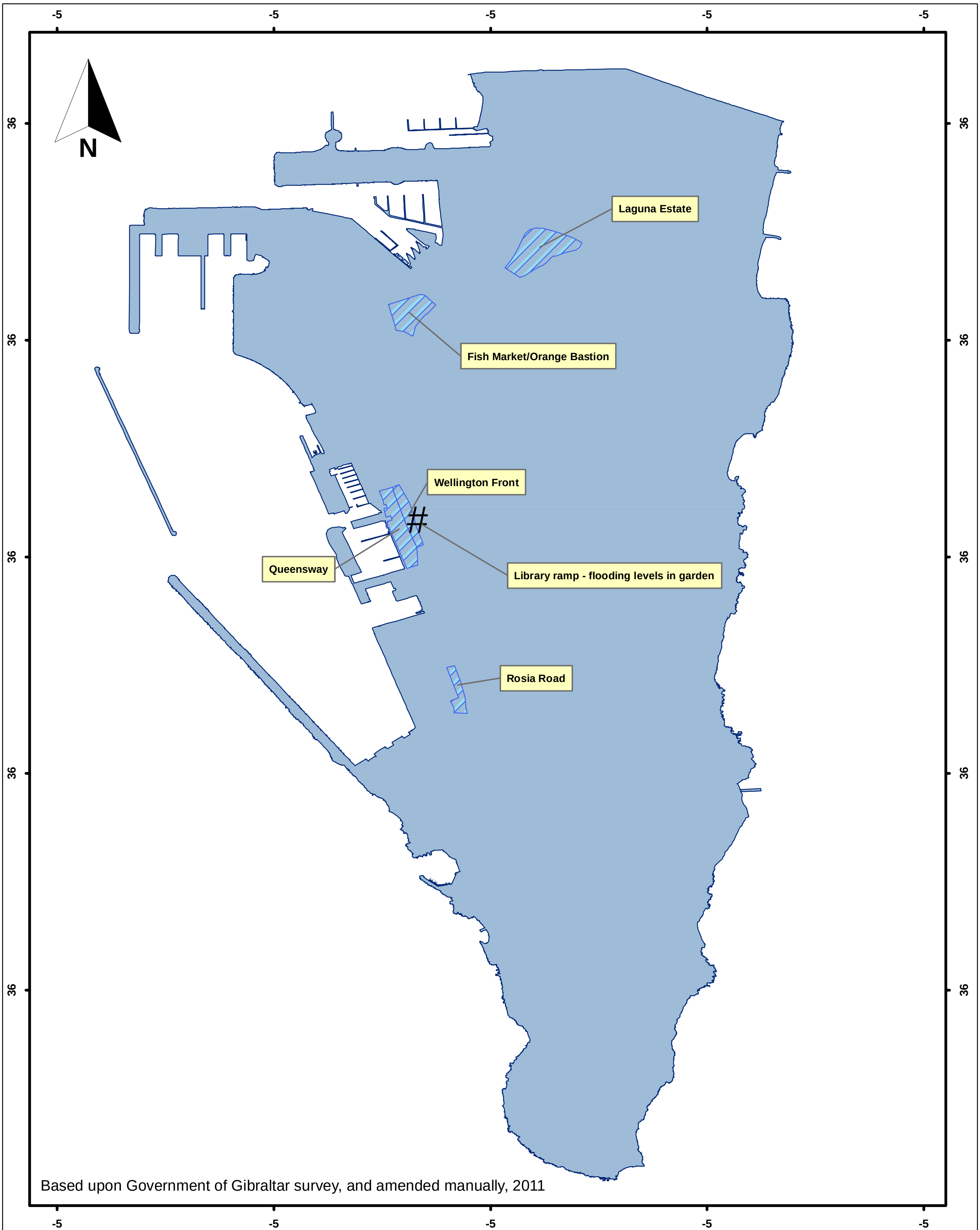
West View Park located immediately behind the defences in the harbour provided a local environmental setting for recreational activities. As a result of the flooding event this area was washed away, removing the park facilities provided for the local community. Rebuilding of the park is ongoing.

Queensway Quay Marina and the Comorant Boat Camber sustained damages although the Queensway Quay Marina developers are concurrently constructing new breakwaters at both entrances to the marina to considerably reduce the risk of damages from storm surges.

Recreational activities such as yachting also suffered from the October flooding. The small boat marina that was situated at Western Beach has been completely destroyed by wave action during repeated storm events. The marina has not been replaced.

As discussed above, the sewage pumping station at Sandy Bay was damaged, impacting on sewerage services to the Both Worlds complex on the eastern side of Gibraltar. Works carried out include placing rock armour along the front of the existing retaining wall along Sandy Bay beach, demolishing damaged structures and repairing the sewage infrastructure at Sandy Bay.

There were no recorded incidents of impacts on human health from this or from previous storm surge flood events in Gibraltar.



Key:

#	Library ramp
(hatched)	Indicative areas of previous surface water flooding
(blue fill)	Gibraltar coastline, 2011

Project Path:
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27593-B01Figure 4.1 Historical Surface Water Flooding.mxd

0 250 500 Metres
Scale: 1:25000 @ A4
Geographic Coordinate System - WGS84 Spheroid

Gibraltar EU Floods Directive
Preliminary Flood Risk Assessment

Figure 4.1
Historical Surface Water Flooding

January 2011
27593-B01 stokr

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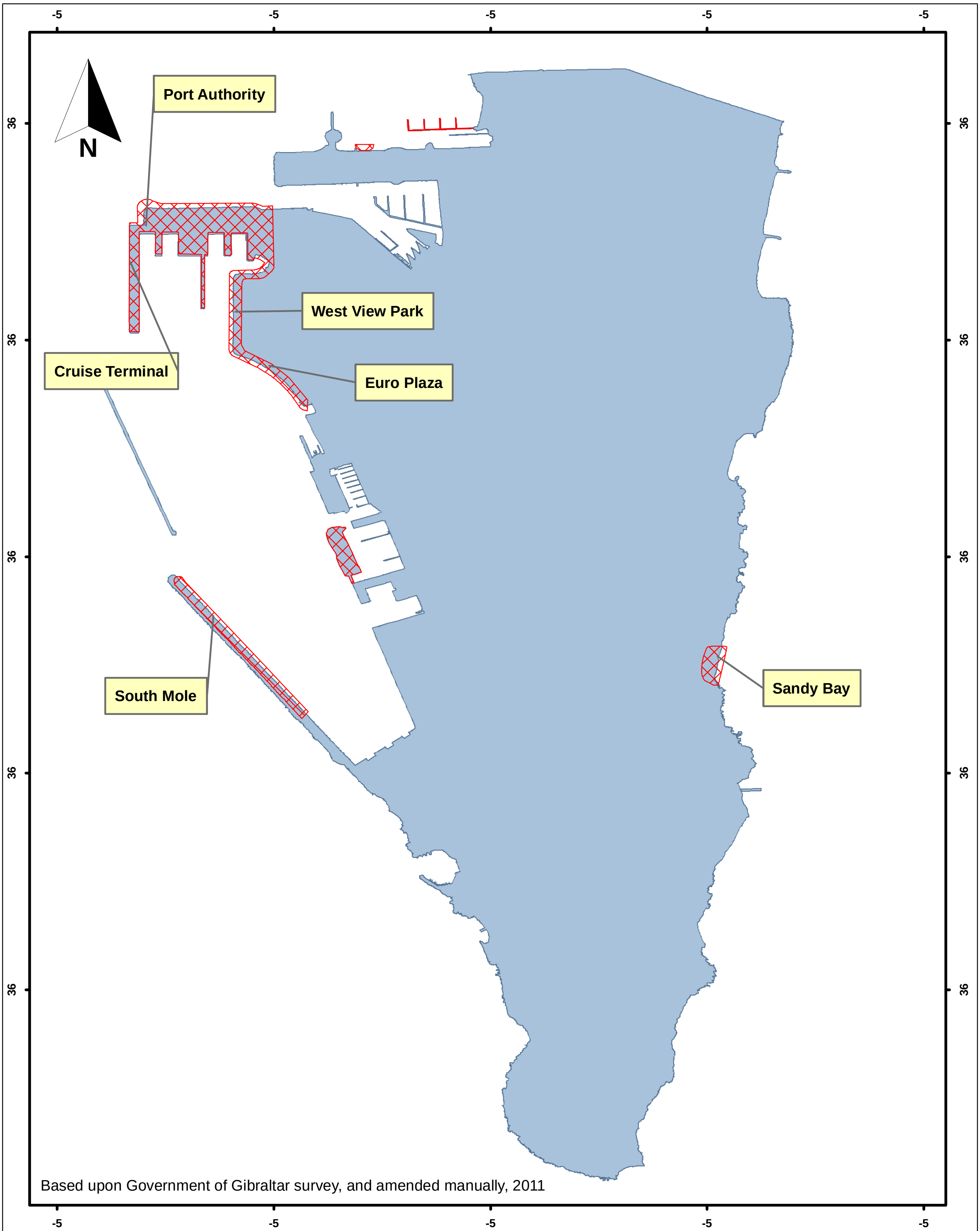
Based Upon Government of Gibraltar survey, updated 2011



Key:

Records of storm surge flood damage October 2008

Gibraltar coastline, 2011

Gibraltar EU Floods Directive
Preliminary Flood Risk Assessment

Figure 4.2
Records of Storm Surge Flood Drainage (October 2008)

0 250 500 Metres
Scale: 1:25000 @ A4
Geographic Coordinate System - WGS84 Spheroid

Project Path: R:\Data\Projects\HM-255\27593 Gibraltar PFRA\Drawings\GIS\27593-B02Figure 4.2 Records of Storm Surge Flood Drainage (October 2008).mxd

January 2011
27593-B02 stokr

Entec

Based Upon Government of Gibraltar survey, updated 2011

5. Future Flooding

5.1 Factors Affecting Future Flood Risk

It is possible that flooding could occur in the future as a result of the same mechanisms that have caused flooding in the past: surface water flooding from heavy rainfall or coastal flooding from storm surges. These issues are discussed in the following sections in more detail. Section 5.2 discusses the significance of future flooding in Gibraltar.

5.1.1 Future Rainfall Events

The areas susceptible to surface water flooding (Figure 4.1) include Queensway, Wellington Front, Rosia Road, Fish Market and Laguna Estate. New stormwater pumps have been installed at Fish Market so this area should now have a reduced risk of flooding. Flooding along Queensway is currently being investigated by Entec on behalf of the Government of Gibraltar, to identify a potential solution to increase the capacity of the drainage network to cope with storm rainfall events. The delivery of infrastructure improvements in this area will aim to reduce the flood risk from surface water. It might be reasonable to conclude therefore that the engineering work will potentially reduce the flooding extent along Queensway between Ragged Staff roundabout and Wellington Front.

The remaining areas at risk from surface water flooding (Wellington Front, Rosia Road and Laguna Estate) will continue to be at risk during intense rainfall events without further investigations and engineering solutions, but could be managed if investment in engineering becomes available.

The Gibraltar Climate Change Programme, 2008, states that the predicted effects of climate change in the Western Mediterranean are expected to include lower levels of rainfall but a change in the distribution and intensity of rainfall. This means that rainfall storms may become heavier leading to an increase in flooding. The extent of flooding in the areas currently at risk could potentially increase therefore, with higher intensity rainfall events. If rainfall intensities increase, future flooding in the town areas could affect some transport routes and cause damage to ground floors of offices and residential buildings.

5.1.2 Future Sea Flooding Events

The storm surge that caused damage of coastal areas in October 2008 was the most significant flooding event in recent history. Whilst storm surges could potentially reoccur around Gibraltar, the probability of a surge occurring of the same magnitude will be relatively small. As previously stated, the major contributor to the problems encountered on the 10th October 2008 was the Algeciras breakwater (review undertaken by Deltares, email dated 14th December 2010). Since then, those above-water perforations on the side of the new breakwater at Algeciras that had not been opened at the time (only some of the above water perforations were open) and all of the below water perforations (none of the below water perforations had been opened at that time), have been opened. These perforations act as wave dampeners so the situation that arose in October 2008 should not be repeated although clearly the situation will never revert to what it was before the breakwater was constructed. Furthermore, the replacement of the sea defences in the harbour has enabled a higher degree of protection to be provided: the renewed sea defences are considerably higher than the defences that have been replaced, such that if the same magnitude storm occurred, overtopping would not be possible. Therefore it is not considered that significant damage would occur in the same areas that were flooded in 2008, due to the renewed defences and the correct operation of the Algeciras breakwater.

Flooding and coastal erosion to the eastern side of Gibraltar is likely to continue, impacting the settlements at Catalan Bay and Sandy Bay, however significant damage is not anticipated due to the elevated height of some of the buildings, and because of number of properties likely to be affected is small. At the time of writing, a new access road is being constructed which will be tunnelled beneath the airport runway and will emerge on the eastern side of Gibraltar. Numerous design considerations are being implemented to minimise any potential flood risks associated with storm surges. On the eastern wall forming the South Approach Ramp, the concrete parapet will act as a security fence and a flood defence barrier from the south portal of the Gibraltar Airport Tunnel to Sunrise View apartments. The Contractor shall determine in the detailed design the actual height of the concrete barrier required to meet the following flood protection criteria:

- Protect the Airport Approach Road from flooding under the event of the high tide and storm waves that would cause the most onerous design conditions with a 1:200 year return period. The concrete parapet level shall be set to provide this level of protection with overtopping discharge kept below 0.01 litres/s/m at all locations**;**

- The design shall comply with the requirements of BS 6349 Maritime Structures, recommendations and guidance contained in EurOtop Wave Overtopping of Sea Defences and Related Structures: Assessment Manual, August 2007 (www.overtopping-manual.com) and the other Standards referred to in AIP Document Ref. 13803/AIP/03;

- Sea level rise of 0.5m will be taken into consideration in line with climate change predictions for the Mediterranean (see below).

The potential for part of the access road to be susceptible to flooding from storm surges, due to its proximity to the eastern shore will therefore be minimised.

Flooding events could also be affected in the future from the potential impacts of climate change such as changes to weather, rainfall patterns and sea level. The Gibraltar Climate Change Programme (2008) indicates that a predicted increase in sea level in the order of 0.48m is a reasonable figure to be applied to Gibraltar, based on best estimates of between 0.28 and 0.58m above 1989 to 1999 sea levels. The replacement sea defences have taken account of potential sea level rise from climate change impacts so that the height of the sea wall is greater than predicted future sea levels. The Moles forming the harbour area are also above this predicted future level, and therefore afford continuing protection to the harbour and town area from storm surges.

With the provision of renewed defences in the harbour and on the North Mole, the impact on the residential areas of the harbour, the structural defences and the economy is likely to be minimised. Flooding within much of this area would be a residual risk only, as much of the land benefits from sea defences and raised ground levels, however it is recognised that there is a low risk of defences being overtopped. There are, however, other small areas of the harbour that potentially remain exposed to future storm surges. For example, there is a low risk that the harbour moles may experience damage in the future, as well as the more temporary berthing platforms in the marinas, with the exception of Queensway Quay Marina where new breakwaters are being constructed.

Future storm surges could also cause flooding and coastal erosion to areas near Camp Bay and Little Bay. These two areas do not contain any buildings but inundation of the land could potentially occur during low probability future storm surges. On the eastern side of Gibraltar, future flooding could potentially impact existing buildings in Catalan Bay and Sandy Bay. These latter two areas are considered to be in the highest risk areas of Gibraltar, although the risk is still considered to be low.

5.2 Significant Flood Risk Areas

The Directive requires that areas where “potential significant flood risks exist or might be considered likely to occur”. The definition of ‘significant’ in relation to flood risks is not, however, provided.

Flood risk is generally considered to be low in Gibraltar, however it should be acknowledged that flood risks exist, and future development and planning should take these risks into account. Therefore, for the purposes of this report, two levels of flood risk have been identified, as defined below:

- Level 1, indicates areas of land that might become inundated during flooding events from storm surges or heavy rainfall, but where significant damage is unlikely to occur;
- Level 2, which indicates significant Flood Risk Areas, as required by Article 5 of the Floods Directive, where potentially significant damage could occur to residential properties, the economy, human health or the environment including cultural heritage.

5.2.1 Level 1 Land Inundation

As discussed above, the flood risks from storm surges are not considered to be significant due to the presence of flood defences and raised ground levels. Flood risks from rainfall are not considered to be significant as this flooding type occurs frequently in Gibraltar and has not previously caused significant effects. However, it is acknowledged that flood risks will continue to occur. Table 5.1 lists areas within Level 1 flood risk areas in Gibraltar, which could potentially be inundated in the future, but are not expected to have significant impacts. Development proposed within these areas should consider potential risks and where required demonstrate the necessary mitigation to safeguard future development from flood damage.

Table 5.1 Level 1 Land Inundation Areas

Location	Flooding Source	Notes
Laguna Estate	Rainfall	Small scale flooding has known to occur in the past due to the combination of low lying impermeable surfaces and inadequate drainage systems. Potential for flooding to occur in the future from the same mechanisms. Flooding has not previously caused significant damage and is not expected to do so in the future.
Wellington Front	Rainfall	Flooding has occurred in the past as a result of inadequate drainage, with the potential for flooding to occur again in the future. Whilst flooding here may cause some traffic disruption, it has not previously caused significant damage and is not expected to do so in the future.
Rosia Road	Rainfall	Roads were flooding in this areas during the October 2008 storm surge event, as a result of heavy rainfall coinciding with the storm. Traffic was disrupted and potential exists for similar consequences if future rainfall events occur of the same magnitude.
Western Beach	Storm Surge	This area was flooded during the October 2008 storm surge. As a result of the Algeciras breakwater now being fully opened and operational, it is not anticipated that flood damage will occur in the future, however there is a low probability of the land being inundated during unprecedented conditions
Harbour Moles	Storm Surge	The harbour moles are constructed as flood defences for the harbour area. The North Mole experienced some structural damage during the October 2008 storm event. Future storm surges have minimal potential of repeating this damage, partly as a result of the Algeciras breakwater being fully opened. However, there is minimal risk of the moles experiencing wave overtopping due to their location in the harbour, however future damage is not anticipated.
Camp Bay	Storm Surge	Parts of the beach at Camp Bay are potentially at low risk of being inundated during future storm surge events. Some flood defences are located here, and there are no buildings that could be affected. The area is highlighted as potentially being inundated by flood water to ensure any future development takes account of flood risks.
Little Bay	Storm Surge	Parts of the beach at Little Bay are potentially at low risk of being inundated during future storm surge events. Some flood defences are located here, and there are no buildings that could be affected. The area is highlighted as potentially being inundated by flood water to ensure any future development takes account of flood risks.
Sandy Bay	Storm Surge	Sandy Bay experienced flood damage to defences during the storm surge event in October 2008, however no residential properties were damaged. The flood defences have now been repaired, and although this area remains at risk to future flooding, the risk is considered to be low.
Catalan Bay	Storm Surge	Catalan Bay experienced flooding during the storm surge event in October 2008, however no properties were damaged as they are elevated above the beach and sea level. Although this area remains at risk to future flooding, the risk is considered to be low.

Surface water flooding has occurred along Queensway and at the Fish Market area in the past, however investigations into drainage solutions are being carried out at Queensway, and new stormwater pumps have been installed at Fish Market. These areas are therefore not included in areas of Level 1 land inundation areas.

As a result of renewed defences in the harbour area, flooding is not expected to occur to areas that were inundated during the 2008 surge event. This includes the Europlaza, West View Park and Queensway Marina.

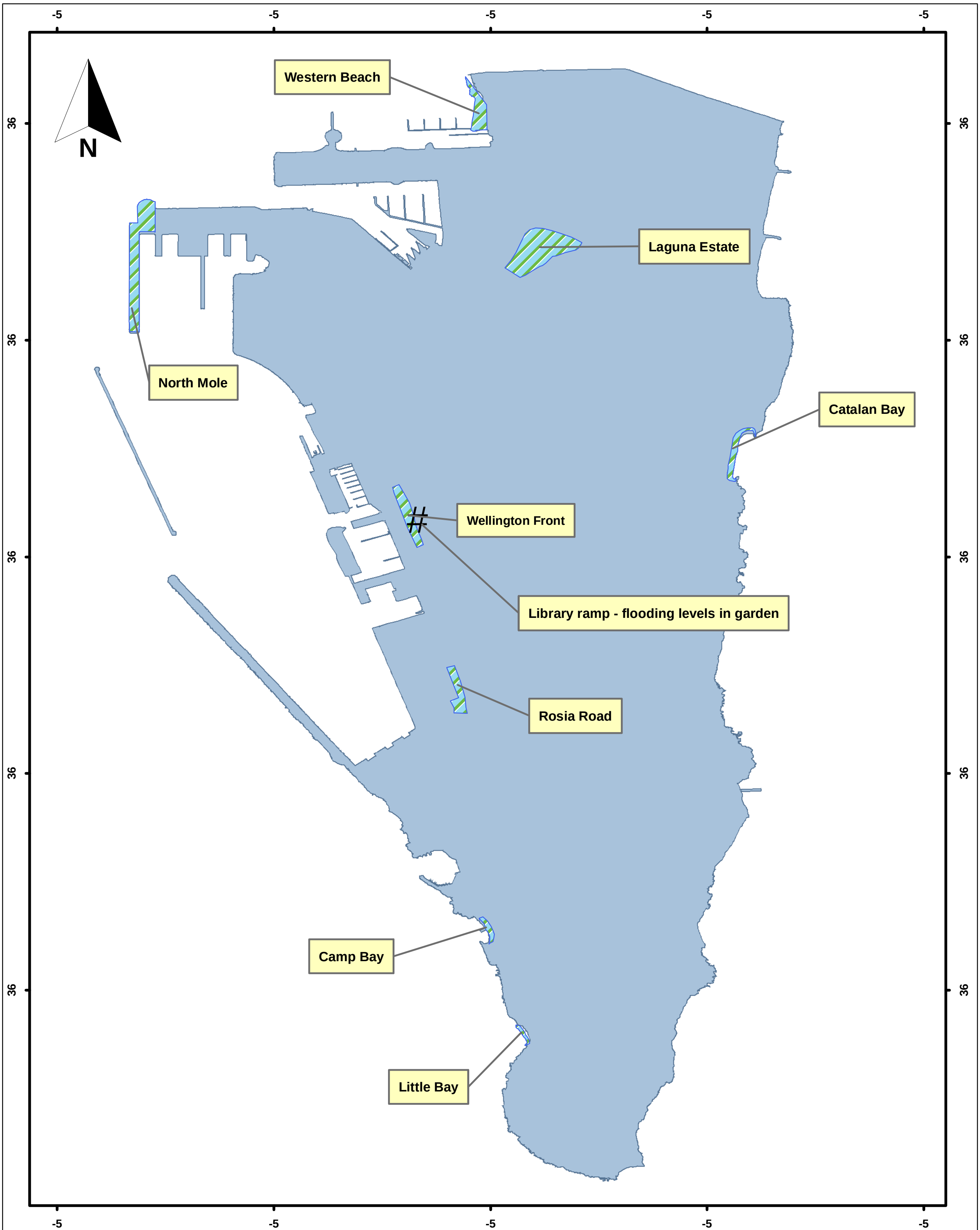
Figure 5.1 also shows areas of Gibraltar potentially at risk of land inundation from flooding. .

5.2.2 Level 2 Significant Flood Risk

As discussed above in Section 5.1 and 5.2.1, future flood risks in Gibraltar are not considered to be significant. Although significant damage occurred to flood defences and harbour areas during the storm surge event in 2008, flood defences have since been replaced and constructed to a higher level of protection, also taking into account potential sea level rises. Furthermore, the Algeciras breakwater was considered to have contributed to the damage during this event, which reflected the incoming easterly swell towards to Western coastline of Gibraltar. Only some of the above-water perforations on the side of the new breakwater at Algeciras were opened and none of the below water perforations were opened at that time. These perforations are designed to act as wave dampeners and have since all been fully opened so the situation that arose in October 2008 should not be repeated.

Flood risks from rainfall are not considered to be significant as this flooding type occurs frequently in Gibraltar and has not previously caused significant effects.

Section 5.2.1 acknowledges that some areas will potentially experience some degree of flooding in the future, however the impacts are not considered to be significant as significant damage to people, properties, the environment or the economy are not anticipated. There are therefore no Level 2 Significant Flood Risk Areas identified for Gibraltar.



Key:

\# Library ramp

Areas at risk of land inundation

Gibraltar coastline, 2011

Gibraltar EU Floods Directive
Preliminary Flood Risk Assessment

Figure 5.1
Level 1 Risk Areas: Areas at Risk of Land Inundation

Project Path:
R:\Data\Projects\HM-255\27593 Gibraltar PFRA\Drawings\GIS\27593-B03a Figure 5.1 Areas Potential at Risk of Future Flooding.mxd

0 250 500 750 Metres

Scale: 1:25000 @ A4
Geographic Coordinate System - WGS84 Spheroid

January 2011
27593-B03a stokr

Entec

Based Upon Government of Gibraltar survey, updated 2011

6. Summary and Conclusions

This report has been prepared to comply with Articles 4 and 5 of the Floods Directive, which require all member states to undertake a Preliminary Flood Risk Assessment (PFRA), based on available or readily derivable information to assess potential significant risks. This report comprises the PFRA for the Gibraltar River Basin District.

There has been no modelling of flooding for Gibraltar or mapping of potential flood risk areas for the river basin district, therefore the information used in this report has been derived from an assessment of the water bodies in the district and from anecdotal evidence provided at the Inception Meeting with the Department of the Environment.

Gibraltar has experienced numerous floods in recent history, predominantly from storm rainfall events or from storm surges from the sea. Small scale flooding occurs in Gibraltar frequently as a result of rainfall, although with relatively low consequences. Flooding from the sea occurs infrequently in Gibraltar but can have severe consequences when flooding occurs. There are no rivers in Gibraltar therefore no fluvial flood risks are present. Groundwater flooding is unlikely to occur in Gibraltar and there have been no recorded incidents of flooding from this source.

The locations which have experienced flooding in the past are summarised in Table 6.1 below.

Table 6.1 Previous Flooding Incidents

Location	Flooding Source	Description of Flood Event	Significance
Queensway and Wellington Front	Rainfall	The surface water drainage system backs up, and is also subject to some minor collapses in the pipe network. During heavy downpours standing water will accumulate in many places, where there are predominantly impermeable surfaces combined with a potentially inadequate drainage system. A solution to the issue is currently being investigated	There have been no significant consequences to human health, the economy, the environment or to cultural heritage from flooding at this location.
Fish Market and Orange Bastion	Rainfall	The expanse of impermeable surfaces combined with the low lying elevations and a surface water drainage system that relies on pumping stations results in surface water flooding. The pumps in this area connect to the Trunk Sewer and cannot cope with the pumping demands required during episodes of prolonged and intense rainfall	There have been no significant consequences to human health, the economy, the environment or to cultural heritage from flooding at this location.

Location	Flooding Source	Description of Flood Event	Significance
Laguna Estate	Rainfall	Small-scale flooding has taken place in the past during heavy rainfall events due to the combination of the inadequate drainage system and low lying impermeable surfaces.	There have been no significant consequences to human health, the economy, the environment or to cultural heritage from flooding at this location, although some minor impacts on business have previously occurred.
Rosia Road	Rainfall	Heavy rainfall caused flooding on Rosia Road near to Jumper's Bastion which significantly affected traffic movement.	There have been no significant consequences to human health, the economy, the environment or to cultural heritage from flooding at this location.
Europlaza and West View Park	Storm Surge	Car parking areas, recreational areas and some building damage occurred during the October 2008 storm surge in this area, as a result of sea defences being overtopped	There have been no significant consequences to human health, the environment or to cultural heritage from flooding at this location. Significant consequences to the economy resulted from the 2008 event, from the cost of repair and replacement to sea defences.
North Mole, Port Authority & post office building & highway	Storm Surge	Structural damage occurred to the North Mole and to some buildings in this area as a result of the 2008 storm surge event.	There have been no significant consequences to human health, the environment or to cultural heritage from flooding at this location. Significant consequences to the economy resulted from the 2008 event, from the cost of repair to structural damage in this area.
Airport runway	Storm Surge	Structural damage occurred runway as a result of the 2008 storm surge event.	There have been no significant consequences to human health, the environment or to cultural heritage from flooding at this location. Significant consequences to the economy resulted from the 2008 event, from the cost of repair to structural damage in this area.
Western Beach	Storm Surge	Some jetties in this area experienced damage during the 2008 storm surge event.	There have been no significant consequences to human health, the economy, the environment or to cultural heritage from flooding at this location.
Catalan Bay	Storm Surge	Wave action resulted in flooding of this area during the 2008 event	There have been no significant consequences to human health, the economy, the environment or to cultural heritage from flooding at this location.
Sandy Bay	Storm Surge	During the 2008 event, the beach in front of Sandy Bay was completely inundated and sea defences were damaged. The sewage pumping station at this location suffered irreparable structural damage.	There have been no significant consequences to human health, the environment or to cultural heritage from flooding at this location. Some consequences to the economy resulted from the 2008 event, from the cost of repair to structural damage in this area.

The table above demonstrates that the most significant consequences of flooding in Gibraltar occurred during the unprecedented storm in 2008, when flood defences in the harbour area were breached. It is also considered that the flooding was made worse by the Algeciras breakwater, where openings designed to absorb wave energy were not fully opened, resulting in reflection of the storm waves toward Gibraltar.

The openings in the breakwater are now fully operational, therefore future damage from reflected waves is not expected to occur in Gibraltar. Furthermore, the damaged flood defences in the harbour have been reconstructed to a higher level of protection, so that if the same magnitude storm were to occur, the defences would not be overtopped. Significant consequences of flooding are not expected to reoccur in Gibraltar.

In recognition that although significant damage may not occur, but that some areas may experience flooding, a two tiered assessment of flood risk has been undertaken. Figure 5.1 illustrates areas at a Level 1 risk of being inundated from heavy rainfall or storm surges, so that future planning can take account of flood risks. These do not constitute areas of potentially significant flood risk. There are no areas identified in Gibraltar that are within the Level 2 significant flood risk areas.

7. References

Entec UK Limited, Northumbrian Water Ltd, and AquaGib Ltd, 2005, *Gibraltar River Basin District - Initial Characterisation, Summary report of the characterisation, impacts and economics analyses required by Article 5 of the Water Framework Directive,*

Entec UK Limited, February 2008, *Wastewater Infrastructure Overview Strategic Study*, 21054/040/056

Department of the Environment, Government of Gibraltar, 2008, *The Gibraltar Climate Change Programme 2008*

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Appendix A
Photos

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Plate 1: Queensway and Wellington Front

Plate 2: Wellington Front

Plate 3: Fish Market

Plate 4: Rosia Road

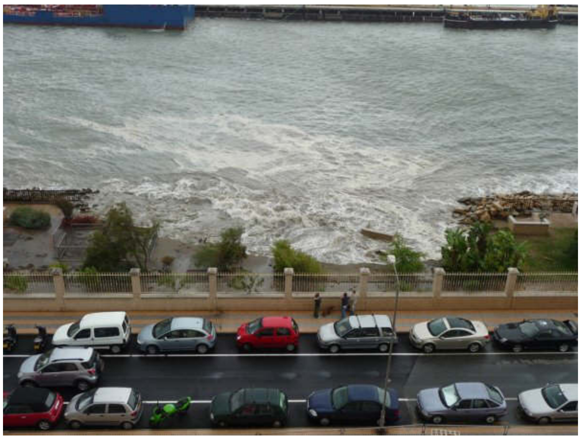

Plate 5: West View Park

Plate 6: Europort Building

Plate 7: Sandy Bay

Plate 8: Catalan Bay

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Appendix B
Summary of Wave Studies for Gibraltar Harbour

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Memo

To
Gibraltar Land Reclamation Company Limited, attn. H. de Bos

Date	Reference	Number of pages
14 December 2010	1203913-000-HYE-0004	2
From	**Direct line**	**E-mail**
Ben de Sonneville	+31 (0)88 33 58 274	ben.desonneville@deltares.nl

Subject
Summary of wave studies for Gibraltar Harbour

Introduction

The storm of 10 October 2008 caused severe damage to the coast of Gibraltar. Following the storm, Deltares was requested to perform an analysis of the storm severity (Deltares, 2008) and to determine the present extreme wave climate with special attention to the influence of wave reflection at the detached breakwater at Algeciras (Deltares, 2009). This document contains a brief summary of the results of above mentioned studies.

Severity of 10 October 2008 storm

In Deltares (2008), the severity of the storm of 10 October 2008 was estimated as follows:

Table 1: Severity of storm of 10 October 2010

Parameter	Return period	Value
Maximum wind speed	40 years	23 m/s (approx. 95ºN)
Maximum significant wave height	30 years	6.3 m (approx. 95ºN)
Maximum water level	10 years[1]	1.02 m CD

Extreme wave climate

Wave modelling performed in Deltares (2009) revealed that eastern storm conditions (95ºN) result in the most severe wave conditions inside the Gibraltar Bay and Gibraltar Harbour, when compared with extreme conditions from other directions. Under these conditions, the resulting wave height is a combination of incoming and reflected wave components. Inside Gibraltar Harbour, local reflections play a large role because of the large number of vertical quay walls. The estimated 1/100 year significant wave heights inside the Gibraltar Harbour ranged between 1.0-3.5m.

Influence of detached breakwater at Algeciras

The effect of the detached breakwater at Algeciras was assessed by comparing wave characteristics in Gibraltar with and without harbour extension, under identical eastern wave conditions. Wave modelling indicated an additional south-western peak in the wave directional spectrum caused by reflection off the new harbour extension, leading to a wave height increase inside Gibraltar Harbour, depending strongly on the location inside the harbour and the status of the caisson chambers at Algeciras (whether they are perforated or not).

During the storm of 10 October 2008, the caisson chambers of the recently constructed detached breakwater at Algeciras were not yet fully operational, i.e. only some of the perforations above the water line were open and none below the water line. Therefore, the

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[1] This return period was based on the measured storm surge.

Deltares

reflection coefficient during that storm was estimated to be about 95%, while presently (in fully perforated state) it is estimated to be approximately 70%.

At the northern harbour entrance, the increase in wave height due to the detached breakwater at Algeciras is presently estimated to be about 20% (with a reflection coefficient of 70%) and is estimated to have been about 30-35% during the storm of 10 October 2008 (with a reflection coefficient of 95%). At the southern entrance, the increase in wave height is presently estimated to be about 10% and is estimated to have been about 20% during the storm of 10 October 2008. Within Gibraltar Harbour, the present increase is estimated to be in the range of 5-40%, with an estimated increase of 5-60% during the storm of 10 October 2008. Within Gibraltar Harbour, the actual increase depends strongly on the location.

Author		Reviewer		Approver	
B. de Sonneville	[signature]	S. Caires	[signature]	K.J. Bos	[signature]

References

Deltares, 2008: Draft results on analysis of 10 October 2008 storm. Prepared for Van Oord.
Deltares, 2009: West Gibraltar; Extreme wave conditions. Prepared for Van Oord.