Envitonmental Statement

Appendix B
Flow Conditions Report

B

memo

H4725.50_240707

To : EBG: Gert Pomstra, Gerard Spaan
From : Judith van Os
Subject : Gibraltar Eastside, supplementary note on bathing water quality at southern end of Eastern Beach
Date : 24 July, 2007
Cc : Klaas Jan Bos

Introduction

In May 2007, the three volumes of the report on the Eastside Gibraltar Studies were issued by WL | Delft Hydraulics. In Volume 1, Flow conditions, a comment is made on the impact of Eastside Gibraltar on the bathing water quality near the adjacent beaches.

After issue of the final reports, Halcrow requested via EBG a supplementary note regarding the bathing water quality to the north of Eastside Gibraltar, at the southern end of Eastern Beach. This memo elaborates on the conclusions on this issue, as presented in Section 8.4.2 of Volume 1, Flow conditions, of May 2007 (from now on referred to as WL | Delft Hydraulics, 2007-1).

Bathing water quality at Eastern Beach

Due to the construction of Eastside Gibraltar currents along the coast will change. Especially in the corners just north and south of the development the current magnitudes are predicted to reduce. As a result the flushing capacity of these areas may become somewhat lower.

On the basis of interpretation of the simulations in WL | Delft Hydraulics (2007-1), the self-cleansing capacity of the southern end of Eastern Beach (see Figure 1) is expected to be affected by Eastside Gibraltar.

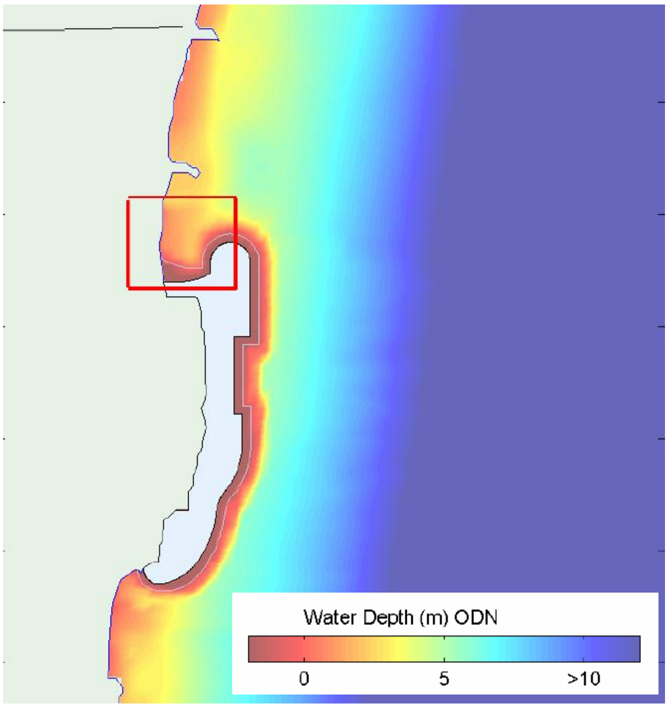

Figure 1 Location of southern end of Eastern Beach

Possible countermeasures to improve the flushing capacity of the area indicated in Figure 1 can be split up into two categories:

1. Active measures to improve the exchange of water between the sheltered area and open sea,
2. Decreasing the northward extension of the land reclamation, so that Eastern Beach becomes more exposed to open sea, thereby increasing natural flushing.

On July 19th 2007, WL | Delft Hydraulics received from EBG a revised layout, which is presented in Figure 2.

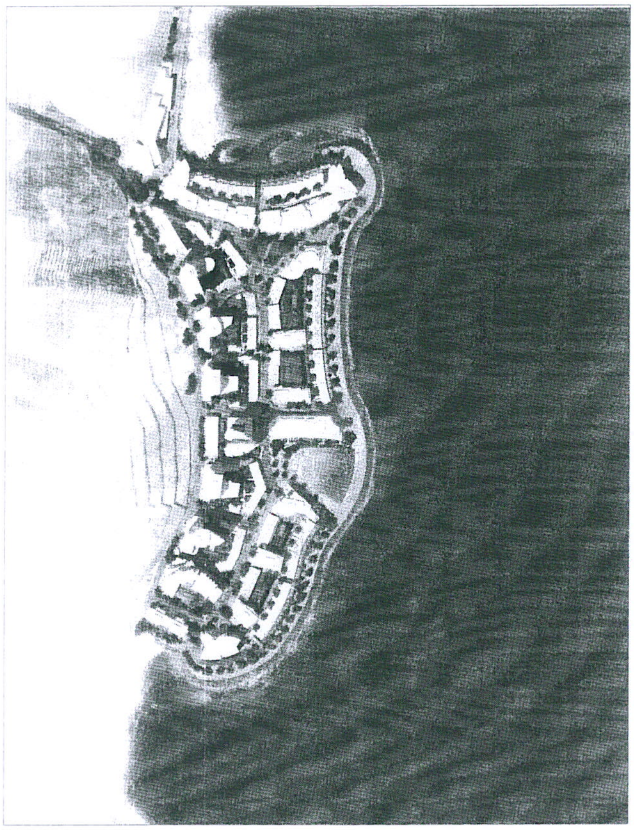

Figure 2 Revised layout of Eastside Gibraltar

In the revised layout, the northward extension is far less pronounced than in the previous layout as studied by WL | Delft Hydraulics in WL | Delft Hydraulics (2007-1) and presented in Figure 1. This adjustment to the layout makes that the southern part of Eastern Beach becomes more exposed to open sea. Based on the layout presented in Figure 2, we judge that the previously mentioned flushing-improving option of a culvert with a pump to open sea (see WL | Delft Hydraulics, 2007-1) is not necessary anymore. The advise to monitor the southern part of Eastern Beach still remains, so that possible water quality issues can be identified in time and dealt with if necessary. If it turns out that additional measures are needed, small scale measures to increase flushing such as fountains or cascades where water flows over the rocks, from the sheltered area towards the sea can provide a solution.

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EBG *Marine Engineering & Construction*

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Volume 1: Flow conditions

Report

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Volume 1: Flow conditions

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Report

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CLIENT:	EBG
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ABSTRACT:

EBG is involved in the development of a new scheme on the east side of Gibraltar. To support the development phase of the scheme, WL | Delft Hydraulics was requested by EBG to execute various hydraulic studies to provide relevant input to the Environmental Impact Assessment process concerning the scheme.

The hydraulic studies carried out to support the Environmental Impact Assessment process address the following aspects:

1. Flow conditions
2. Normal wave conditions
3. Coastal morphology

This report presents the results of the above item 1: Flow conditions

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Executive Summary

General
EBG is involved in a new development on the east side of Gibraltar. To support the development phase of the project, WL | Delft Hydraulics was requested by EBG to execute various hydraulic studies to provide relevant input to the Environmental Impact Assessment process concerning the project. The project is referred to as "Eastside, Gibraltar".

As part of the study various water level, flow and water quality related aspects were evaluated including:

- Existing and future tidal range including sea level rise
- Existing and future storm surge behaviour
- Existing and future current flow patterns around the development
- Prediction of dispersion and fate of rainwater near the development
- Assessment of the beaches to be self-cleansing

The approach and results of the study are presented in this report.

Study approach
The study commenced with a data and literature review to increase the understanding of the hydraulics at the project site. On the basis of this understanding the modelling approach for the present study was determined in terms of model dimensions and relevant processes to be considered.

Following the outcome of the evaluation of the site conditions, a detailed depth averaged (2DH) hydrodynamic flow model was set-up on the basis of WL | Delft Hydraulics' Delft3D-FLOW modelling package. The model covers the east side of Gibraltar and its surrounding waters.

After successful calibration of the model against available ADCP measurements, the model was run for a complete spring-neap cycle both with and without Eastside Gibraltar to determine its impact on the various aspects listed above.

Results
On the basis of the flow model simulations the following was concluded:

- **The impact of the development on the tidal water levels** is negligible: impacts are only observed in the very near vicinity of the development and are nowhere larger than about 5 mm.

- **The impact of the development on the storm surges** (water levels and currents) is expected to be limited to water level changes smaller than 2 cm for all considered storm conditions. The impact on surge currents is concentrated in the direct vicinity of the development. To the north and south of the development, current speeds are expected to decrease, whereas along the sea-side of the development, current speeds are expected to increase up to about 0.3 m/s. The impact of the development on the surge currents is limited to an area of approximately 0.75 km to the south, 0.5 km to the north and 0.3 km

offshore of the development. Outside this area water levels are not expected to change more than 5 mm, and current speeds are not expected to change more than 0.10 m/s.

- **The impact of the development on the tidal and wind driven currents** was predicted to be limited to an area from 0.5 km north of the development to 0.5 km south of the development. In this area, the current magnitudes are expected to decrease with a maximum of 0.3 m/s compared to the present situation. The impact of the development on tidal currents gradually decreases with the distance from the site and depends on the tidal phase.

- **Assessment of the impact of possible pollutant plumes** lead to the following conclusion. Volumes of storm water originating from the runoff system that reach the beaches are relatively low. Only in a worst-case pollution storm water runoff scenario, it is expected that limited amounts of the storm water may reach the beaches in the corner areas of Eastside Gibraltar. No adverse impacts are to be expected on the beaches further away, even after a relatively heavy rain shower.

- It is concluded that the impact of the scheme on the **self-cleansing property of the beaches** will be limited to the southern end of Eastern Beach just north of the development. In this area the existence of the development will cause a decrease of flushing and wave action. Consequently, cleansing measures may be needed in this specific area.

  No significant impact is expected on the beach cleansing characteristics of Spanish beaches, because the tidal range, the wave exposure and water quality for these beaches are not expected to change significantly.

- In the present situation the **bathing water quality** guidelines are only accidentally violated. After construction of the development, the southern end of Eastern Beach will be shielded from the sea currents by the development. Consequently, there will be a higher risk that situations occur in which criteria for the bathing water quality with respect to coliform bacteria will be violated in this area. A noticeable reduction of water transparency or the presence of oil films stemming from sun-bathing oils is expected, rendering the water visually less attractive. Further, there will be a higher potential for accumulation of litter and debris in the future because of the shielded character of the beach.

  No significant impact on bathing water quality is expected on the Spanish beaches, related to the construction of Eastside Gibraltar.

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1 Introduction

1.1 Background

EBG (Europese Bouw Groep) is involved in the development of a new scheme on the east side of Gibraltar. Figure 1.1 indicates the location of the project site. The scheme is planned at the existing Rubble Tip area between Eastern Beach to the north and Catalan Bay to the south. Directly north of Eastern Beach lies the Gibraltar airport runway and the Spanish border. Directly south of Catalan Bay the coastline is formed by rock outcrops. Sandy Bay is located further south (see Figure 1.2).

To support the schemes development phase, WL | Delft Hydraulics was requested by EBG to execute various hydraulic studies to provide relevant input to the Environmental Impact Assessment (EIA) process concerning the scheme. The project is referred to as "Eastside Gibraltar".

EIA scenarios

In accordance with EIA legislation and guidance applied in Gibraltar, various impact scenarios have to be assessed. A brief description of these scenarios is given below.

Eastside Gibraltar Impacts
The development is subject to the EIA process, which requires the project proponent to provide environmental information including descriptions of the likely significant impacts of the proposals in terms of changes to the existing environmental conditions. The proposals include a high quality mixed use residential development on the east side of Gibraltar. Figure 1.2 shows the proposed scheme. The site of the proposed development will utilise the existing area of reclaimed land (presently a rubble tip) and will require a further eastward land reclamation of about 100m.

It is proposed that fill material for the land reclamation will be dredged from the borrow areas as indicated in Figure 1.1. If the material is dredged from one of the borrow areas the expected average deepening will be 0.4m (southern borrow area) or 0.9m (northern borrow area), see EBG (2007).

In-combination Effects
As part of the EIA the impacts of the scheme have to be considered in combination with another development envisaged at the east side. This development envisaged at the east side and considered in this scenario is the Both Worlds Project at Sandy Bay. This relatively small project is located at the southern end of Sandy Bay, see Figure 1.2. The development comprises a small land reclamation with 10-30m seaward extension over a shore parallel distance of about 50-60m. The land reclamation will be protected by a shore protection.

Transboundary Effects
Given the close vicinity of the project location to the Spanish border, the transboundary effects of the above scenarios have to be considered in the EIA process. The location of the border, as derived from the Admiralty Charts, has been included in Figures 1.1 and 1.2, and delineates the border between Gibraltar and Spain's territorial waters for the purpose of assessing transboundary effects.

1.2 Scope of work

The scope of work for the hydraulic studies covers the following:

1. Flow conditions
The flow conditions at the project site have been determined by numerical flow modelling. For this purpose a flow model was prepared for the project area. Simulations were carried out with and without the scheme. This part of the study covers:

- Assessment of impact on tidal characteristics
- Determination of impact on storm surge behaviour
- Assessment of impact on current flow patterns
- Prediction of pollutant dispersion
- Assessment of beach cleansing and bathing water quality

2. Normal wave conditions
Wave conditions were studied to determine the normal wave conditions along the coast at the project site. Simulations were carried out with and without the scheme. This part of the study covers:

- Assessment of offshore and nearshore wave conditions
- Impact of the scheme on the annual nearshore wave climate.

3. Coastal morphology
Various coastal morphology aspects were determined using 2D and 1D morphological models. This part of the study includes:

- Assessment of coastal impact
- Determination of sediment infill rates of dredged areas
- Prediction of dredged plume dispersion
- Impact of the development on the cross-shore beach profiles
- Guidelines on beach maintenance work

The approach and results of the above three study items have been reported in separate volumes.

1.3 Aim of the present report

This report presents results of study item: *1) Flow conditions.*

The following aspects were considered:

- The impact of the scheme on:
  - tidal levels
  - storm surges
  - flow patterns
- Dispersion of rainwater near the scheme
- Potential of the new, enlarged beaches to be self-cleansing

1.4 Outline of the present document

Chapter 2 gives a description of the site conditions based on a data review. The flow model set-up and calibration are discussed in Chapter 3. The remainder of this report describes the following study tasks:

Chapter 4: Impact of the scheme on the tidal levels
Chapter 5: Impact of the scheme on storm surges
Chapter 6: Impact of the scheme on the currents
Chapter 7: Pollutant dispersion
Chapter 8: Beach cleansing and bathing water quality
Chapter 9: Conclusions

2 Site conditions

2.1 General

The hydrodynamics in the Strait of Gibraltar are complex and determined by large-scale (three dimensional) processes resulting from the exchange of water between the Mediterranean and the Atlantic and other circulations within the waters off North-Africa and Southern Spain. As part of the flow modelling study, the relevance of these large scale flow patterns on the flow conditions at the east side of Gibraltar (project site) was reviewed.

This chapter describes the hydrodynamic processes in the Strait of Gibraltar, and the influence of these processes on the flow conditions at the project area. The project area is defined as the scheme and adjacent beaches as well as the dredging areas, see Figures 1.1 and 1.2. This includes nearby Spanish territorial waters and beaches for investigation of possible transboundary effects The findings of this review combined with the requested modelling tasks for this project determined the type (depth averaged/three-dimensional) and extent (model area) of flow modelling required for this project.

2.2 Description of project site

2.2.1 Development area

The sea at the east side of Gibraltar is the most western part of the Mediterranean Sea and is called the Alboran Sea (Fig 2.1). Close to shore the average sea-floor slope is 1:50 until a depth of 100 m. About 10 km from the shore water depths become larger than 500m. This is illustrated in Figure 2.2.

South of Gibraltar runs the Strait of Gibraltar (Fig 2.1), a narrow sea passage between Spain and Morocco, which forms the only connection between the Gulf of Cadiz (Atlantic Ocean) and the Mediterranean Sea. The Strait of Gibraltar has a length of about 60 km, with Europa Point at the east end, and the west end in the Atlantic between Trafalgar and Espartel. The width of the Strait of Gibraltar varies between 44 km and 14 km, and the bathymetry is very irregular with a minimum depth of about 300 m and maximum depths exceeding 900 m.

2.2.2 Wind

The climate of Gibraltar is considerably modified by the local topography and proximity of the Mediterranean and Atlantic Ocean. Gibraltar’s wind conditions are characterised by the local winds called Levante and Poniente. The Levante (winds from the east) most frequently occur in summer (July to October), but may occur any time of the year. The strength is normally not more than moderate during the above period, and it often persists over periods of about fifteen days, exceeding force 3 (Beaufort) on only one day in eight. In winter, however, although less frequent, it sometimes blows hard (8-9 Beaufort). The Levante is occasionally reinforced by the presence of an active depression to the South, and may then intensify suddenly. See the Waves study report for more statistic wind information.

In general the winds near the coast are mainly offshore in winter and onshore in summer. Spring and autumn favour the summer conditions rather than winter. The Poniente or westerly wind blows in any time of the year, and is less strong than Levante. Strong winds or gales from the southwest sector called Vendaval sometimes occur and may cause strong turbulent wind variations at the lee side of the Rock of Gibraltar.

2.2.3 Large scale hydrodynamics

The currents in the Strait of Gibraltar are mainly related to:

1. density gradients (salt, temperature)
2. tide
3. wind.

Further, especially at the east side of Gibraltar currents may be affected by large scale circulations in the Mediterranean, such as the Alboran Gyres.

Density exchange currents

In the Mediterranean Sea the yearly evaporation (0.7 m/yr) is higher than the precipitation (Béranger et al., 2003). To equal the water mass balance of the Mediterranean, there is a continuous inflow of surface water from the Atlantic Ocean to the Mediterranean Sea. Because of the intense evaporation, surface water in the Mediterranean becomes more saline and denser: it therefore sinks towards lower layers in the water column. Also because of the high evaporation rates, the average salinity and density of the water in the Mediterranean Sea is higher than in the Atlantic Ocean. The CANIGO (1999) experiment gives a mean water density in the Atlantic of 1027.2 kg/m^3, and in the Mediterranean of 1029.1 kg/m^3. In the Strait of Gibraltar this density difference reinforces the inflow of Atlantic water in the upper layers, and simultaneously generates a flow of saltier and cold water in a lower layer from the Mediterranean to the Atlantic.

South of Gibraltar the mixing zone (interface) between both layers is about 100 m thick and lies between depths of 20 m and 120 m (CANIGO, 1999; Brandt et all., 2003). To the west, in the direction of the Atlantic, the interface layer lies deeper.

The (easterly) surface currents in this process run parallel to the axis of the strait with the strongest flow on the south side of about 1 m/s, occasionally rising to 2 m/s (Pilot NP67, 2005). This flow decreases close to the coasts, but due to the complexity of the northern coastline small eddies and local currents are generated which form an essential part of the general surface circulation in these areas.

Based on available literature, Figure 2.3 gives an impression of how we expect the density exchange currents influence the surface currents on the east side of Gibraltar. The figure shows a strong jet intruding the Alboran sea from the Strait of Gibraltar which generates a counter-clockwise eddy off the east side of Gibraltar. As a result, in the vicinity of the project area southbound residual currents may be expected.

Because the west-going density currents lie deeper than approximately 60 m (halfway the mixing layer) and the project area is shallower than 60 m, it is not expected that they have significant influence on the flow behaviour at the project site. Further, because of the interface depth (20 m-120 m), no significant stratification in the project area is expected.

These density currents show variations in their intensity because of variations in the depth of the interface between both layers, which are caused by (Lacombe and Richez, 1982):

- Long term variations (seasonal and annual): fluctuations in the evaporation-precipitation budget over the Mediterranean Sea, deep water formation processes, and seasonal winds are factors which influence the long-term variability of the exchange.
- Sub-inertial variations, with periods ranging from days to a few months, are principally forced by the atmospheric pressure fields over the Mediterranean (Candela et al., 1989).
- Tidal variations: the interface between both water masses experiences vertical movements during tidal periods (Candela et al., 1990). In fact, Candela et al. suggest that the interface acts as a membrane between both water masses: the Atlantic water is driven towards the Strait of Gibraltar, during high tide, the interface sinks and the Mediterranean water is driven to the east. Half a cycle later, the outgoing deeper layer pushes the interface up and the Atlantic water is driven westward.

On a shorter scale (from minutes to one hour) also internal wave formation and propagation plays an important role in the exchange process (Global Ocean Associates, 2002).

Another process which may influence the strength of the return current past the site may be the location and size of the so-called Western Alboran Gyre. This anti-cyclonic gyre is induced by the Atlantic surface currents which leave the Gibraltar Strait at the east-side as a jet with speeds larger than 1 m/s (Perkins, Kinder & La Violette, 1990), see Figure 2.4.

The gyre has a circular shape with the strongest gradients and flows on its northern side. Its existence may cause the deflection of the atlantic jet in NE directions. The gyre may drift eastward in times when the inflow from the Atlantic is very strong, or when there is a low pressure area above the Mediterranean Sea and western wind.

When the gyre drifts eastward, the Atlantic jet may become more eastward oriented, which could influence the currents in the project area.

It is expected that all above mechanisms influencing the strength and direction of the Atlantic surface flow, influence the strength of the currents along the east coast of Gibraltar, but not the flow directions at the project site.

Tidal currents

Tidal flow in the area of the Strait of Gibraltar is driven by the tides coming from the Atlantic via the Gulf of Cadiz from the west, and the internally generated tides in the Mediterranean coming via the Alboran Sea. The combined effect of these tides results in a complicated semi-diurnal tidal behaviour in the strait: it is characterised by a large gradient in tidal amplitude: the tidal range reduces from about 2 m in Cadiz on the west side of the strait to approximately 1 m in Gibraltar on the east side. The phase of the dominant M2 tidal component increases with the distance from the Spanish coast in the Strait of Gibraltar (Candela et al, 1990, Sannino et al, 2004). This implies that the largest tidal component runs southward along the east coast of Gibraltar.

The tidal current pattern in the Strait of Gibraltar is mainly barotropic (currents run parallel with the direction of the water level gradient). The tidal streams can reach speeds up to 1 m/s along the axis of the strait, and 1.5 m/s towards the coasts (West Coast of Spain and Portugal Pilot, 2005). Because at the east-side of Gibraltar the tidal flow is no longer confined by the dimensions of the strait, less pronounced tidal streams can be expected there, which is confirmed by tidal stream information for locations A and B on Admiralty Chart 1448, see Figure 2.2. The Admiralty Chart gives a maximum speed of the tidal currents at both locations between 0.3 m/s and 0.4 m/s for spring tide, and about 0.15 m/s during neap tide. The tidal currents are reported to generally run NNE during 5 hours around high water, and SSW at other times (appr. same speed). This is also described by the West Coast of Spain and Portugal Pilot (2005).

Wind

The West Coast of Spain and Portugal Pilot (2005) reports that strong western and eastern winds greatly affect the flow in the vicinity of the Strait of Gibraltar. Implications for the currents and water levels in the project area are subject of the present study (see Chapter 5).

2.2.4 Conditions at the project site

Tidal levels

The vertical tide (water levels) is predominantly semi-diurnal around Gibraltar. Tidal levels applicable to the project site were provided by the Gibraltar Public Works Department (Delft Hydraulics, 2000), and are given in Table 2.1.

These levels were found consistent with tidal levels given in Eastside Gibraltar, Beaches Specification document provided by the Client, and data on the Admiralty Charts 144 and 1448 for Sandy Bay. A comparison with measured water levels is given in Section 4.3.

	level relative to CD (m)	level relative to OD (m)
HAT	1.1	1.0
MHWS	1.0	0.9
MHWN	0.7	0.6
MSL	0.5	0.4
MLWN	0.3	0.2
Alicante Datum	0.2	0.2
MLWS	0.1	0.0
Ordnance Datum	0.1	0.0
CD	0.0	-0.1
LAT	-0.1	-0.2

Table 2.1: Tidal levels at the project site (source: Government of Gibraltar).

Hydronamic water level and current measurements

For Eastside Gibraltar project, Boskalis provided water level and current measurement data collected in the project area by Hydronamic (2006). Hydronamic conducted measurements with two moorings, deployed in two periods of the autumn and winter of 2005. Unfortunately, the measurement data collected at site North was erroneous in both periods due to disturbance by fisherman, and was therefore not used for this study. The positions of the southern moorings were both approximately 2 km SSE from the project site during both measurement periods and are given in the next table and shown in Figure 2.5.

name	Easting (m)	Northing	Depth (m)	ADCP deployment time (MET)
South1	289994.3	4000312.4	~15m	Time of first measurement 06/10/2005 10:13:34 Time of last measurement 09/11/2005 17:23:34
South2	290018.1	4000293.0	~15m	Time of first measurement 11/18/2005 10:53:25 Time of last measurement 1/3/2006 13:43:25

Table 2.2: Locations and deployment periods of the ADCP.

Figures 2.6 and 2.7 show a part (a spring-neap cycle) of the observed water levels and currents.

The two series of 1-month ADCP measurements show the following flow behaviour: In both measurement series there is a clearly dominant south-going current which only during short periods (about 3 hrs) around high water turns northward. During most tidal cycles the maximum current velocity reached a value between 0.4 and 0.7 m/s. The water levels are further investigated in Section 4.3.

The measured vertical current profiles showed no significant variations in flow magnitude and direction. The vertically uni-directional behaviour of the measured currents indicates that there is no significant stratification in the coastal waters within the project area (0 – 50m water depth).

Vertical density profiles

Data of CTD (Conductivity (salinity), temperature and density) measurements from the MEDAtlas (1996) in the vicinity of the project area were analysed to check for indications of stratification in the project area. Figure 2.8a shows the locations of these CTD measurements, and Figure 2.8b shows the corresponding measured salinity profiles. At locations A and B, closest to the project area, no significant stratification is observed in the top 50 m.

2.3 Conclusions

- The currents in the Strait of Gibraltar show a complex three-dimensional behaviour. The currents are induced by density and temperature differences, tidal forcing and wind effects.
- In the project area, close to the shore East of Gibraltar the hydrodynamics are less complex. In the project area the currents are expected to be tide dominated and show no significant stratification.

3 Numerical flow model: set-up and calibration

3.1 General

This chapter describes the set-up and calibration of a detailed depth-averaged (2DH) hydrodynamic flow model covering the east side of Gibraltar and the surrounding waters, based on the conclusions from the previous chapter. The Gibraltar Flow Model is based on Delft3D-FLOW (version 3.53.01.00), WL | Delft Hydraulics' program for hydrodynamic flow simulations.

3.2 Modelling approach

The following steps were carried out to set up the Gibraltar Flow Model:

1. Development of a computational grid covering the area of interest (east coast of Gibraltar);
2. Interpolation of depth information to the grid;
3. Generation of boundary conditions by nesting in a larger tidal model of the Strait of Gibraltar;
4. Initial definition of model parameters like time step, eddy viscosity and bottom roughness.

In the calibration phase, the boundary conditions and the model parameters have been adjusted within the limits of their uncertainties to achieve the best model results compared with the measurement data. The calibration was based upon the comparison of model results with the water level and current measurements from the survey by Hydronamic (period 6 October 2005 - 6 November 2005). See further Section 3.5.

3.3 The Delft3D-FLOW hydrodynamic module

The flow computations were performed using Delft3D-FLOW, the hydrodynamic module of the Delft3D modelling suite of WL | Delft Hydraulics. This program was developed for modelling unsteady water flow and transport of dissolved matter. Delft3D-FLOW solves the three-dimensional shallow water equations for given boundary conditions. The equations are solved by an implicit finite difference method (ADI) on a staggered (spherical or orthogonal curvilinear) grid.

The shallow water equations upon which Delft3D-FLOW is based consist of balance equations for mass (continuity equation), momentum and dissolved matter/heat (transport equation). In the momentum equation the following influences are included:

- advection
- water level gradients
- bottom friction
- Coriolis effects
- momentum exchange induced by turbulence (eddy viscosity)
- wind effects

3.4 Flow model set-up

Conventions and definitions

Units
All parameters and variables have units according to the SI conventions.

Coordinate system
All coordinates in this report are given with respect to the UTM30 - ED50 system.

Vertical reference level
The depth and water level information in the flow model are relative to MSL. Where necessary, depth information given relative to OD was corrected to MSL by adding 0.427m, in accordance with specifications by the Government of Gibraltar.

Time reference
The time reference for the numerical model is defined as time zone UT +01:00 hrs (MET).

Directions
Directions follow the nautical conventions. Flow directions refer to the direction towards which the flow is going. Directions of the flow are given clockwise relative to North. The unit is degrees, where 360 degrees cover the circle. Wind directions refer to the direction from which the wind is coming.

Schematisation

In Chapter 2 it was found that although the hydrodynamics of the Strait of Gibraltar are very complex in nature, the flow behaviour in the project area is less complicated: the measurements give no indication of significant velocity gradients in the vertical (no stratification), and the local flow seems to result from a combined effect of density currents (small), tidal currents and wind effects (based on 2 periods, 2 × 30 days). Since there are no indications that the flow fields in the direct vicinity of the project area show a complex three-dimensional behaviour it was decided to schematise the hydrodynamics of the east side of Gibraltar with a 2DH modelling approach. To avoid effects of boundary conditions on the hydrodynamics in the area of interest a modelling domain was chosen which also covers part of the waters south-west of Gibraltar and the waters north-east of the port of Atunara in relatively shallower water depths, see Figure 3.1.

For the modelling of pollutant dispersion the model was switched to a three-dimensional mode to take local three-dimensional effects such as dispersion into account.

To well resolve the dispersion processes near the scheme and around the dredging locations, flow fields have to be computed which predict possible formation of eddies. For adequately resolving eddies and sharp velocity gradients a high resolution flow model is required: therefore a horizontal resolution of about 10 m to 20 m was defined in the relevant project areas (the areas near the scheme and the dredging areas).

Computational grid

The computational grid of the Gibraltar Flow Model is based on the curvilinear grid technique. This technique allows for curved grid lines, enabling a grid design with a high resolution in the development area, and grid lines that generally follow the shore lines. Water level and current variations are computed at each grid point of the computational grid.

Figure 3.1 shows the computational grid of the Gibraltar Flow Model on top of the bathymetry of the area. The model runs from about 25 km south-west of Gibraltar to about 5 km north-east of Gibraltar and covers the northern coastal slope of the Strait of Gibraltar up to a depth of about 400 m.

The size of the grid cells varies from 150 m × 300 m near the west boundary of the model to approximately 15 m × 15 m near the scheme. Figure 3.2 shows the computational grid in the project area on top of the local bathymetry. In this area two grid variants were used:

- a grid representing the present situation, with grid lines following the present coastline, and
- a grid representing the future situation with the development, with grid lines following the contours of the scheme.

Depth schematisation

The model bathymetry (depth levels on the model grid) was obtained by interpolation of depth levels from the following sources:

- Multi-beam sounding data from the 2005 survey by Boskalis;
- Digitised Admiralty Charts 144, 1448 and 142;
- Water depths from the 1-minute General Bathymetry Chart of the Oceans (GEBCO, 1991).

Figure 3.3 shows the model bathymetry.

Boundary conditions

The water levels and currents on the boundary of the model, the boundary conditions for the Gibraltar Flow Model, were obtained from computations with a model of the Strait of Gibraltar. This is a larger flow model which covers the Strait of Gibraltar and large parts of the Gulf of Cadiz and the Alboran Sea, see Figure 3.4a. This large-scale model was set-up and calibrated to represent the tidal levels in the area of the Gibraltar Flow Model. The main astronomical components M2 and S2 computed by the model deviated less than 10% in amplitude and less than 10 degrees in phase from data from the IHO (International

Hydrographic Office) database for locations in the vicinity of Gibraltar (Algeciras, Gibraltar, Sandy Bay, Tarifa).

Water levels from the Strait of Gibraltar Model were imposed on the north boundary of the Gibraltar Flow Model. The curved outer boundary of the Gibraltar Flow Model runs parallel to ebb and flood streamlines in the Strait of Gibraltar and was therefore implemented as closed boundary. Computed typical flood and ebb flow patterns at the locations of the open boundaries of the detailed model are shown in Figures 3.4b and 3.4c.

Although the positioning of the streamlines play a role, the main flow characteristics in the project area are determined by the geometry of the eastern end of the Gibraltar Strait (which is experienced by the flow as a sudden widening) in combination with the current magnitudes of the average tidal flows in the Gibraltar Strait. The detailed model is therefore considered suitable for the assessed conditions in this report.

The large scale Strait of Gibraltar Model gives a good representation of the tidal currents along the north coast of the Strait of Gibraltar, which corresponded well with current data from the Straits Sailing Handbook 2006 (2006). These tidal currents were used as boundary condition for the west boundary of the Gibraltar flow model. Because of the uncertainty in the magnitude of these currents the magnitude at this (remote) boundary was used as calibration parameter.

3.5 Calibration of the flow model

Calibration of the Gibraltar Flow Model was done by comparison of the modelling results with ADCP current and water level measurement data from the Hydronamic (2006) survey (location South, survey period 1 (October 2005)).

To calibrate the Gibraltar flow model variations of the following parameters were tested:

1. Various boundary configurations;
2. The magnitudes of the current velocities at the west boundary of the model;
3. The computational time step;
4. Turbulence modelling parameters (eddy viscosity).

The calibration runs were carried out without wind.

The simulation results show the development of a large eddy north-east of Europa Point induced by the tidal flood currents passing Europa Point, see Figure 3.5. Due to its turbulent nature this eddy is only partly deterministic. Small natural variations in time and space may cause relatively large spatial and temporal variations in flow magnitudes and directions. Because the center of the eddy passes the ADCP measurement point to the east, the current directions at the ADCP point are mostly southbound.

Figure 3.6 shows the final calibration results. The computed water levels compare well with the observed and hindcast levels. Also the ADCP measured mostly southbound currents, which confirms the existence of the computed eddy. Taking the undeterministic variability of the flow due to turbulent effects around ADCP location South into account, also the computed current magnitudes show a sufficiently good comparison.

It should be noted that around neap tide (e.g. period around 25-10-2005) the wind driven currents may be of the same order of magnitude as the tidal currents, so that relatively larger deviations can be expected between measured (tide + wind) and computed tidal currents (tide only).

Because the results from the tidal model compare reasonably well with the measurements it is concluded that the currents in the project area are mainly tide dominated.

3.6 Verification

Verification of the Gibraltar Flow Model was done by comparison of modelling results (without further calibration or tuning) with ADCP current and water level measurement data from the Hydronamic survey (location South, survey period 2 (December 2005)).

Figure 3.7 shows the verification results. The computed water levels show that the tidal phase compares well with the measurements, but that the tidal amplitudes are about 5 cm higher than the measurements around the neap tides. The computed current magnitudes and directions compare reasonably well with the measurements. This is especially true when it is realised that the ADCP location South is located in a highly turbulent zone close to Europa Point which seems to be characterised by high undeterministic flow fluctuations, see also Chapter 6.

3.7 Application of the model

The verified model was used to investigate the baseline conditions as well as the various impact scenarios outlined in Section 1.1. The application of the model for these scenarios is described below. (See fig. 1.1 and 1.2)

Baseline conditions

Simulations of the baseline conditions were carried out to calibrate and verify the flow model. The simulation results of the verified model were used as reference (baseline) conditions in the assessment of the various impact scenarios.

Eastside Gibraltar impacts

The impact of the scheme was investigated by carrying out similar simulations for the baseline (present) situation and the future situation after construction of the scheme and comparing the results. The scheme was implemented in the model by a local change of the computational grid and bathymetry. The effects of the related dredging works in the borrow areas were assessed in a similar way by locally lowering the bathymetry in the numerical model.

In-combination effects

The location of the Both Worlds Project is indicated in Figure 1.2 on the south. Based on expert judgment, it was decided not to implement a representation of the Both Worlds Project in the model: because of its relatively small scale compared to the Eastside Gibraltar Scheme and the assessed phenomena the expected impact of the Both Worlds Project on the present study is judged negligible.

Transboundary effects

To investigate transboundary effects, results from the impact assessment were investigated with specific attention to effects on Spanish waters and the Spanish beaches.

3.8 Conclusions

- A depth-averaged numerical flow model was set-up, covering the project area and the coastal waters around Gibraltar. The computational grid has a resolution of approximately 15 m × 15 m in the development area;
- The model was successfully calibrated against ADCP measurements of currents and water levels, well representing the flow characteristics at the measurement location;
- The hydrodynamics at the project site are mainly tide dominated. Wind causes relatively small variations in the tidal flow magnitudes and directions;
- A large scale eddy is formed to the East of Europa Point after high water. This eddy causes strong directional and amplitude variations of the currents in the southern borrow area;
- The developed model is suitable to run in 2D and 3D mode to predict the impact of the future developments on various hydrodynamic aspects.

4 Impact of the development on tidal levels

4.1 Objective

The objective of this task was to assess the existing tidal range (water levels) and predict the future tidal range.

4.2 Approach

Data used

The existing tidal range was investigated by analysis of:

- ADCP pressure sensor readings for the periods 6 October 2005 – 9 November 2005 and 18 November 2005 – 3 January 2006 from the Hydronamic survey (2006), location South, provided by the Client, see Section 2.2.3;
- Tidal information (astronomical component sets) for various locations in the vicinity of Gibraltar from the Admiralty Tide Tables (ATT) of the Hydrographic Office (2005), and the tidal database of the International Hydrographic Organisation (IHO);
- Tidal levels as stated by the Government of Gibraltar in the Beaches Specification (from the Employers requirements).

Determination of the existing tide levels

The determination of the tide levels consisted of the following activities:

1. Collection of published tide levels and sets of astronomical components (see above);
2. Analysis of the ADCP pressure sensor readings to derive a consistent set of astronomical components.

This involved the following steps:

1. The pressure readings P were converted to time series of water level variations ζ following: $\zeta = \frac{P - \overline{P}}{\rho g}$, (1)
   where $\overline{P}$ is the time-averaged pressure, g is the gravitational acceleration, and ρ is the water density which was determined based on Eckhard's formula using a temperature of 18 °C and a salinity of 35 ppt;
2. By tidal analysis on the recorded water level time series a consistent set of astronomical constants was derived for the ADCP location South. The resulting set is presented in Table 4.1 below. Figure 4.1 shows a plot of the observed water level time series and the hindcast, which was computed with the components of Table 4.1 . The hindcast shows a

good correspondence with the observed levels. The difference between the observations and the hindcast is called the residual and represents meteorological influences (wind effects, air pressure variations), measurement noise and long term (seasonal, yearly) tidal components which cannot be determined based on one-month measurement periods.

3. For long term tidal components that could not be derived from the measurement data the long-term components set of the harbour of Gibraltar (west side) from the IHO database was added to the above dataset. The additional long term components are listed in Table 4.2.
4. With the combined set of components of Table 4.1 and 4.2 a prediction for 19 years was made from which characteristic tidal levels with respect to mean sea level were computed for the ADCP location South.

constituent name	amplitude (m)	Phase degrees (MET)
K1	0.030	148.2
P1	0.013	108.0
O1	0.013	166.3
Q1	0.006	208.3
OO1	0.002	56.1
RO1	0.003	248.5
SIGMA1	0.003	246.1
CHI1	0.003	176.8
THETA1	0.003	302.7
M2	0.282	74.0
MU2	0.011	51.4
S2	0.101	99.4
K2	0.039	95.8
N2	0.052	50.2
L2	0.006	127.7
2N2	0.008	56.3
KJ2	0.001	96.7
2SM2	0.002	215.4
OQ2	0.003	135.7
M3	0.006	226.2
SO3	0.001	262.4
M4	0.020	219.8
MS4	0.015	274.2
MN4	0.007	164.7
SN4	0.004	245.7
M6	0.001	210.4
2MS6	0.002	229.5

Table 4.1: Astronomical components derived from the ADCP measurements (location South).

SA	0.0520	211.3
SSA	0.0190	99.8
MM	0.0160	180.8
MF	0.0160	19.4
MSF	0.0080	275. 0

Table 4.2: Long term astronomical components from the IHO database.

Determination of the impact of Eastside Gibraltar on the tidal levels

The impact of the development on the tidal levels was investigated with the numerical flow model. A full spring-neap cycle with and without Eastside Gibraltar was simulated without wind. The impact of the development on the tidal water levels was analysed based on the difference between the simulation results.

4.3 Present situation

Table 4.3 below presents an overview of the computed tidal levels relative to Ordnance Datum. The ATT levels were converted to levels with respect to OD by applying OD = CD + 0.088m.

Tidal levels (*m* relative to Ordnance Datum)			
Tidal levels	**ADCP measurements Gibraltar East Side**	**Government of Gibraltar**	**ATT 2006 Gibraltar**
HAT	1.0	1.0	1.0
MHWS	0.9	0.9	0.9
MHW	0.7	-	-
MHWN	0.6	0.6	0.6
MSL	0.4	0.4	0.4
MLWN	0.3	0.2	0.2
MLW	0.1	-	-
MLWS	0.0	0.0	0.0
LAT	-0.2	-0.2	-0.2

Table 4.3: Tidal levels derived for the project area after conversion to levels in Ordance Datum. For MSL the value given by the Government of Gibraltar in the beach specification was used (MSL = OD + 0.427 m). Note: the tidal water levels have been rounded off to one decimal which is common practice in presenting tidal levels.

The tidal range at the project site is only slightly less (about 2 cm) than the range at Gibraltar Port (west side). The tidal levels derived on the basis of the analysed ADCP pressure readings at location South resulted in similar tide levels as published for Gibraltar in e.g. ATT (2006) and by the Government of Gibraltar.

According to ATT the levels of MHWS and MHWN at Sandy Bay are respectively 0.2m and 0.1m lower than the levels at Gibraltar. This could not be confirmed in this study.

On the basis of the above it was decided to use the levels presented by the Government of Gibraltar (see Section 2.2.4) as a further basis of the study.

4.4 Eastside Gibraltar impacts

Figures 4.2a and 4.2b show the maximum impact of the development on the water levels at high and low water respectively during a spring tide. The figures show that the impact of the scheme on tidal water levels is negligible (less than about 5 mm), and only in the very near vicinity of the development.

Since exact dredging volumes are not known at this stage of the project, the impact of dredging works on the tidal water levels was estimated by a conservative approach. With the Gibraltar Flow Model the simulated flow conditions before dredging were compared with the situation after dredging. In the model the sea-bed level was lowered by 0.9 m in the northern borrow area and 0.4 m in the southern borrow area to incorporate the dredging works.

The impact of the dredging works on the tidal levels was analysed for the present situation (without development) and the future situation (with development). Figure 4.3 shows the maximum impact of the dredging on water levels (in mm) compared with the future situation. The simulation results show an impact on the water level only in the southern borrow area; the computed impact in the northern borrow area is smaller than 1 mm. In the southern area the water level differences are below 3 mm, which is negligibly small.

On the basis of the above it is concluded that the impact of the development scheme and the associated dredging works on the tidal water levels is negligible.

4.5 In-combination effects

4.5.1 Introduction

In this study “in-combination effects” are the effects of other developments than the planned development at the ‘Rubble Tip’. In this section the coastal impact of the planned development in combination with the ”Both Worlds” project (planned south of Sandy Bay, see Figure 1.2) is discussed. At present, no other future developments are known.

4.5.2 Both Worlds Project

A small extension of the rocky outcrop just south of Sandy Bay is planned (“Both Worlds” Project, see Figure 1.2). The impact of this project is evaluated on the basis of expert judgement.

Since the size of the Both Worlds project is very limited compared to that of Eastside Gibraltar, and because on the basis of the above presented simulations and analysis, the impact of Eastside Gibraltar on the tidal levels is assessed to be negligible, it is concluded that no cumulative effects on the tidal levels are expected as a result of the combined proposed scheme and Both Worlds Project developments.

4.6 Transboundary effects

Because the Eastside Gibraltar project is located close to the Spanish border, special attention was paid to investigate a possible impact of the developments on the Spanish coast.

On the basis of the above presented simulations and analysis it is concluded that there will be no impact of the development on the tidal water levels along the Spanish coast.

4.7 Conclusions

- Tidal levels were derived for the project area based on the ADCP measurements. They were found to be consistent with the levels provided by the Government of Gibraltar.

- Eastside Gibraltar will have a negligible impact on the tidal water level variations surrounding the development. No impact is expected in Spanish waters.

- The impact of the dredging work for the development on the tidal water levels will be negligible.

5 Impact of the development on storm surges

5.1 Objective

The objective of this task was to identify the existing storm surge behaviour and predict the future storm surge statistics for the project site.

5.2 Approach

The existing storm surge behaviour was assessed on the basis of available data in literature supported by storm surge calculations with the numerical model. The impact of the development on the storm surges was determined on the basis of expert judgement supported by surge calculations. The storm surges were combined with the tidal levels to derive appropriate total extreme water levels (tide plus surge).

5.3 Present situation

Wind set-up

Wind set-up is generated by the wind - water friction forces. For the project site this set-up is mainly caused by winds blowing from the east. These winds result in a water level build up against the east coast of Gibraltar and Spain and coincide with easterly storms. Especially in shallow water this may have a considerable effect on the water level. However, considering the relatively steep foreshore at the eastside of Gibraltar, wind set-up is expected to be small at the project site.

The wind set-up was estimated by simulation of a 1/1, 1/10 and 1/100 year uniform wind speed on a large scale flow model of the Alboran sea. The distance of the easterly boundary of this model to Gibraltar is about 350 km (see Figure 5.1), representing a fetch length that is more or less in accordance with the scale of a storm depression. Figure 5.1 also shows the water level build-up against the Gibraltar coast along a grid line (n=91) for the three considered storm conditions.

Next, the water level variations at the boundary of the Gibraltar Flow model (see Figure 3.1) were retrieved from the large scale flow model of the Alboran sea. The results of the detailed model storm simulations (winds from East) are presented in Figures 5.2.a, 5.3.a and 5.4.a (top panels). The simulations showed water level surges due to winds of less than 0.1 m at the project site (see Table 5.1 below). The computed surge currents during these easterly storm conditions are also limited in magnitude (< 0.2 m/s).

Return period RP (yr.)	wind speed (m/s)	wind set-up Gibraltar east coast (m)
1	16.8	0.03
10	20.7	0.05
100	24.6	0.07

Table 5.1: Computed wind set-up for three extreme easterly wind conditions

It is likely that at the project site the wind direction may be slightly different from the offshore wind because of the land topography of Gibraltar (mountain). The storm simulations with the detailed model were therefore repeated for wind coming from the ENE and ESE. The results of these simulations are presented for the three return periods in Figures 5.2.b-c, 5.3.b-c and 5.4.b-c (top panels), respectively. Compared to the easterly storm conditions, these simulations show more or less similar water level surges but increased surge current magnitudes (up to 0.5 m/s for a 1 in 100 year storm with local wind from the ENE). During ESE wind conditions the surge current will be directed to the North. The occurrence of continuous northerly directed surge currents is however not reported in literature (e.g. Pilot, 2005) nor observed in the measured currents at location South (Hydronamic, 2006).

Barometric pressure

During storms barometric pressure differences result in variation of the water level. As these usually coincide with extreme storm conditions, they must be taken into account. Based on an analysis of the available ADCP measurements for the eastside of Gibraltar and literature these variations were estimated in the range of 0.05 m to 0.2 m.

Sea level rise

Extensive research on sea level rise by the IPCC (2007) indicates a global average sea level rise in the range of 0.2 – 0.6 m over the next century. Following these results the sea level rise included in the extreme water levels has been selected at 0.5 m per century. This value is in accordance with the minimum value guideline provided by the Government of Gibraltar for this project.

Wave set-up

Wave set-up is generated as a result of wave breaking. Given the relatively steep foreshore at the project site, the wave set-up is expected to be small and was neglected.

Extreme water levels

On the basis of a joint probability analysis of tide and surge components the extreme water levels were assessed. Following this analysis the tidal water level component was assessed at a value close to MHWS (OD + 0.9m).

Table 5.2 below presents the resulting extreme water levels for various return periods.

	Return period (RP)		
	1/1	1/10	1/100
Tide (MHWS = OD + 0.9m) Wind set-up/Atmospheric pressure Sea level rise	0.9 0.1 0.5	0.9 0.2 0.5	0.9 0.3 0.5
Total water level (m, OD)	1.5	1.6	1.7

Table 5.2: Extreme water levels (m, OD)

5.4 Eastside Gibraltar impacts

The impact of the development on the storm surges (water levels and currents) was investigated by means of storm surge modelling with the detailed numerical flow model of the surrounding waters of Gibraltar (see Chapter 3).

Simulations with the detailed flow model were carried out for the 1/1, 1/10 and 1/100 year wind conditions, each for three wind directions (E, ENE and ESE), and with and without the scheme. For each of these conditions water level surges and surge currents were computed. The impact of the development on the storm surges and surge currents was analysed based on the differences between the simulation results (computation with development minus computation without development).

1/1 year wind conditions

The Figures 5.2a-c show computed water level surges and surge currents without (top panel) and with scheme (bottom panel) for the 1/1 year storm conditions. The figures show that both with and without the scheme, for all considered wind directions the maximum estimated surge level is everywhere lower than 0.1 m.

The Figures 5.5a-c show computed water level differences for the three 1/1 year storm conditions. All computed water level differences are located at the slopes of the breakwaters and they are everywhere smaller than 0.02 m.

The Figures 5.6a-c show computed current magnitude differences for the three 1/1 year storm conditions. Within a distance of about 200 m from the development surge current magnitudes were found to differ up to 0.2 m/s, with the largest differences directly adjacent to the development. Outside this area estimated impacts are lower than 0.05 m/s.

1/10 year wind conditions

The Figures 5.3a-c show computed water level surges and surge currents without (top panel) and with scheme (bottom panel) for the 1/10 year storm conditions. The figures show that both with and without the scheme, for all considered wind directions the maximum estimated surge level is everywhere lower than 0.1 m.

The Figures 5.7a-c show computed water level differences for the three 1/10 year storm conditions. Most computed water level differences are located at the slopes of the breakwaters and they are everywhere smaller than 0.02 m. At the location of the beach directly north of the development an additional surge of about 0.01 m was computed for ENE wind conditions.

The Figures 5.8a-c show computed current magnitude differences for the three 1/10 year storm conditions. Within a distance of about 200 m from the development surge current magnitudes were found to differ up to 0.2 m/s, with the largest differences directly adjacent to the development. Further than about 500 m from the development impacts are lower than 0.05 m/s.

1/100 year wind conditions

The Figures 5.4a-c show computed water level surges and surge currents without (top panel) and with scheme (bottom panel) for the 1/100 year storm conditions. The figures show that both with and without the scheme, for all considered wind directions the maximum estimated surge level is everywhere lower than 0.1 m.

The Figures 5.9a-c show computed water level differences for the three 1/100 year storm conditions. Most computed water level differences are located at the slopes of the breakwaters and they are everywhere smaller than 0.02 m. At the location of the beach directly north of the development an additional surge of about 0.02 m was computed for the ENE storm.

The Figures 5.10a-c show computed current magnitude differences for the three 1/100 year storm conditions. The largest differences are found close to the northeastern end of the development, where the local surge currents may increase with about 0.3 m/s. Further from the development the impact quickly reduces: at about 200 m from the development the maximum observed surge current magnitudes difference is 0.2 m/s; at about 500 m (north and eastward), and at about 750 m southward from the development the impact is further reduced to maximum differences of about 0.05 m/s.

Overall it is found that during E wind conditions the scheme has no impact on the water level surges as the wind is directed perpendicular to the Gibraltar East coast. Only in case the extreme wind at the project site is from ENE or ESE directions differences in water levels of up to 0.02 m may occur in the vicinity of the development.

The surge current magnitude will decrease immediately upstream and downstream of the development. On the seaside of the development, especially at the corners, current speeds are expected to increase up to about 0.3 m/s. The area of impact of the scheme on surge currents along the coast is estimated at a maximum distance of 0.75 m to the south and 0.5 m to the north of the scheme. An increase of surge current magnitudes is computed immediately offshore of the development (up to a distance of about 0.3 km).

5.5 In-combination effects

It is assessed that, because of the very limited size of the Both Worlds project, no cumulative effect of the Both Worlds project and Eastside Gibraltar on water levels nor current and wind behaviour is expected. Therefore, no effects on storm surge levels and storm surge currents are expected as a result of the combined proposed scheme and Both Worlds Project developments.

5.6 Transboundary effects

Because Eastside Gibraltar is located close to the Spanish border, special attention was paid to investigate a possible impact of the development on the Spanish coast.

On the basis of the above presented simulations and analysis it is found that there will be no impact of the development on storm surge levels and storm surge currents at the Spanish coast.

5.7 Conclusions

In this assessment the surge currents were considered on the basis of direct wind shear. The spatial and temporal barometric pressure variations and/or other large-scale currents were not taken into account.

It is concluded that there is no significant impact of Eastside Gibraltar on water level surges. Water level changes are limited to an area in the direct vicinity of the development and are less than 2 cm for all storm conditions. The impact on surge currents is concentrated in the near vicinity of the development. To the north and south of the development, current speeds are expected to decrease, whereas along the sea-side of the development, current speeds are expected to increase up to about 0.3 m/s. The impact of the development is limited to an area of approximately 0.75 km to the south, 0.5 km to the north and 0.3 km offshore of the scheme. Outside this area water levels are not expected to change more than 5 mm, and current speeds are not expected to change more than 0.10 m/s.

The impact of the development on storm surge levels and on storm surge currents at the Spanish coast is expected to be insignificant.

6 Impact of the development on currents

6.1 Objective

The objective of this task was to identify existing current patterns and to predict future current patterns in and around the proposed Eastside Gibraltar scheme. In addition, effects of the dredging works on current patterns were predicted.

6.2 Approach

The flow conditions in the present and future situation were simulated with the Gibraltar Flow Model over a typical spring-neap cycle for a situation without wind and two typical wind conditions:

1. continuous uniform ENE wind of 10 m/s (60°N)
2. continuous uniform WSW wind of 10 m/s (240°N)

The wind conditions used were selected based on a wind climate analysis, which showed that offshore from Gibraltar dominant wind directions are in the sectors ENE-E (60°-90°) and WSW-W (240°-270°). The wind speed of 10 m/s (Bft 5) is selected as a representative relatively strong wind speed (BMT, 2006).

The impact of the scheme on currents was analysed for the present situation (Section 6.3) and the future situation (Section 6.4). In the description of the currents in the future situation differences with respect to the present situation are analysed. The possible (combined) impact with the dredging works is discussed in Section 6.5. and transboundary effects are described in Section 6.6.

The simulation results are presented in the form of hourly current vector and magnitude plots and animations. To analyse the differences between the present and future simulations, plots and animations showing differences in flow patterns were prepared.

The following table shows the numbers and names of generated plots and animations. All figures and animations can be found on the enclosed CD. Only figures to which is referred to in the text are included as hard-copy in this report.

Section	Figure	Description	Wind	Tidal phase	animation
6.3	6.1 a-l	present situation	no wind	spring	A601.exe A601Z.exe (zoomed)
	6.2 a-l		no wind	neap	A602.exe
	6.3 a-b		ENE 10m/s	spring	A603.exe A603Z.exe (zoomed)
	6.4 a-b		ENE 10m/s	neap	A604.exe
	6.5 a-b		WSW 10m/s	spring	A605.exe A605Z.exe (zoomed)
	6.6 a-b		WSW 10m/s	neap	A606.exe
6.4	6.7 a-l	future situation	no wind	spring	A607.exe A607Z.exe (zoomed)
	6.8 a,b		no wind	neap	A608.exe
	6.9 a-b		ENE 10m/s	spring	A609.exe A609Z.exe (zoomed)
	6.10 a-b		ENE 10m/s	neap	A610.exe
	6.11 a-b		WSW 10m/s	spring	A611.exe A611Z.exe (zoomed)
	6.12 a-b		WSW 10m/s	neap	A612.exe
	6.13 a-l	differences present vs future situation	no wind	spring	A613.exe
	6.14 a,b		no wind	neap	A614.exe
	6.15 a-b		ENE 10m/s	spring	A615.exe
	6.16 a-b		ENE 10m/s	neap	A616.exe
	6.17 a-b		WSW 10m/s	spring	A617.exe
	6.18 a-b		WSW 10m/s	neap	A618.exe
6.5	-	dredging effects present situation	no wind	spring	A619.exe
	-	dredging effects future situation	no wind	spring	A620.exe

Table 6.1: Simulation program with list of figures and animations.

6.3 Present situation

No wind

Currents on the east-side of Gibraltar run mostly parallel to the shore, see e.g. Figure 6.1e and 6.1k (see Table 6.1 for references to all figures and animations for this scenario). The currents at the location of the development site (in front of the rubble tip) are north-going approximately between HW -1hr and LW -2hr and south-going approximately between LW -2hr and HW -1hr. Further south the currents are more influenced by the vortex which detaches from Europa point after HW, see Figure 6.1f.

The highest current velocities close to the shore are found in front of the rubble tip at about HW +1hr HW (north-going) and 1 hr after low water (south-going) with speeds up to approximately 0.3 m/s during spring tide and 0.1 m/s during neap tide, see Figures 6.1e and 6.1k.

Eastward from the rubble tip shoreline the simulations show current speeds with magnitudes up to 0.5 m/s during spring tide and 0.2 m/s during neap tide.

Southeast and east of Europa Point, at the location of the southern borrow area, large current speeds and strong current gradients are simulated for times between HW +1hr and HW +3hr, see Figure 6.1f. Currents are computed to reach speeds over 0.8 m/s (spring tide) in northeast-going direction.

Between HW +1hr and LW the strong current gradient causes the formation and development of a large anti-clockwise vortex (eddy) which causes strong variations in current speeds and direction in the southern borrow area. This vortex induces a southbound current along the southpart of the eastern shore of Gibraltar which can reach speeds of 0.5 m/s close to the shore (and higher offhore).

Around LW, the current east of Europa Point reaches speeds up to 1 m/s during a spring tide, see Figure 6.1j, and 0.5 m/s for a neap tide.

In the northern borrow area maximum current speeds of about 0.5 m/s were simulated for spring tides and 0.3 m/s for neap tides. The currents in this area run parallel to the coast in almost all phases of the tide.

Wind ENE 10 m/s

The current behaviour for an ENE 10 m/s wind condition shows about the same characteristics as simulated for a no-wind condition, see Table 6.1 for relevant figures and animations. The north-easterly wind increases south-going current speeds with about 0.1m/s, and decreases north-going currents also with about 0.1 m/s during spring. During neap tide these difference are between 0.1 m/s and 0.2 m/s. As a result, HW slack is delayed with about 30 minutes, and LW slack occurs about 30 minutes earlier. The wind does not show a clear effect on the strength of the eddy that develops northeast of Europa Point, but it does move the location of the eddy more to the south.

Wind WSW 10 m/s

The overall current behaviour for a WSW 10 m/s wind condition is about the same as for the no-wind condition. The south-westerly wind amplifies north-going currents and reduces the speed of south-going currents with about 0.1 m/s for a spring tide (0.1 m/s to 0.2 m/s for a neap tide).

The current speeds northeast of Europa Point are increased by the southwesterly wind, so that the eddy becomes stronger and the current gradient even more pronounced.

6.4 Eastside Gibraltar impacts

No wind

In the future situation the currents remain mostly north-south oriented and circumvent the development, see e.g. Figures 6.7e and 6.7k (see Table 6.1 for references to all figures and animations for this scenario). The currents in front of the scheme are north-going approximately between HW -1hr and HW +3hr, and south-going between HW +3hr and HW -1hr.

The currents follow the outline of the development smoothly, and no significant flow acceleration due to the development can be observed. This implies that in the wake of the development no detachment and eddy formation occurs.

In the corner areas just north and south of the development current velocities are very weak. The computed velocities in these areas remain below 0.05 m/s in the north and 0.10 m/s in the south during the full tidal cycle due to the sheltering effect of the scheme.

Figure 6.7e shows that between HW and HW +2hr the north-going currents close to the development reach speeds up to 0.4 m/s during a spring tide. Between LW and LW +3hr the south-going currents along the scheme reach speeds of about 0.4 m/s, and higher further offshore, see Figure 6.7l.

Figures 6.13a-l and Animation A616.exe (see Table 6.1) show differences in flow patterns between the simulated future situation and the present situation for a spring tide. The colours represent the difference in current magnitudes. The figures show that the effects of the development on the flow patterns are limited to a coastal section from 500 m south of the scheme to about 500 m north of the scheme. The currents along this stretch of the coast are reduced with respect to the present situation. Future current speeds in this area will fall below 0.2 m/s, whereas at present they range up to 0.4 m/s.

Wind ENE 10 m/s

The general flow patterns computed with the ENE wind show the same characteristics as the no-wind condition. The wind increases south-going currents with about 0.1 m/s and decreases the north-going currents equally during a spring tide. During neap tides the wind effects are somewhat more pronounced and cause differences of about 0.2 m/s.

Figures 6.15a-l and Animation A615.exe (see Table 6.1) show differences in flow patterns between the simulated future situation and the present situation for a spring tide. The results indicate that the area influenced by the development is similar to the no-wind condition, i.e. it stretches about 500 m south and 500 m north from the development. Differences are slightly larger to the south of the development because of the reinforced southbound currents due to the wind direction.

Differences in flow patterns that can be observed around Europa Point are induced by the same mechanism as described above for the no-wind condition.

Wind WSW 10 m/s

The general flow behaviour east of Gibraltar is not significantly influenced by the WSW 10 m/s wind. North-going currents are about 0.1 m/s stronger and south-going currents are slower with about 0.1 m/s for spring tides (0.2 m/s for neap tides). As a result the timing of HW and LW slack is slightly changed (about 30 minutes).

The wind causes a stronger growth and larger extent of the eddy north-east of Europa Point. Strong current gradients occur in the southern borrow area.

Figures 6.17a-l and Animation A617.exe (see Table 6.1) show differences in flow patterns between the simulated future situation and the present situation for a spring tide. The results show that the influence of the development stretches about 500 m north for this wind condition, and that the influence south of the development is limited to a distance of about 200 m. To the north of the development, the current magnitudes will be between 0.1 m/s and 0.2 m/s lower in the future situation than in the present situation (during maximum current speeds in a spring tide).

6.5 Dredging effects

Since exact dredging volumes are not known at this stage of the project, the impact of dredging works as part of the development on the flow conditions was estimated by a conservative approach. With the Gibraltar Flow Model we compared the simulated flow conditions before dredging with the situation after dredging. In the model the sea-bed level was lowered by 0.9 m in the northern borrow area and 0.4 m in the southern borrow area by the dredging works.

The impact of the dredging works on the flow conditions was analysed for the present situation (without development) and the future situation (with development).

Animations A619.exe and A620.exe show the simulation results. In both cases very limited effect on the current patterns is computed as a result of the dredging. In the northern borrow area, currents are not affected. In the southern borrow area, the flow directions and magnitudes are slightly different around LW; the maximum computed current magnitude difference is within 0.05-0.1 m/s during spring tide.

6.6 In-combination effects

On the basis of the above presented simulations and analysis, and because of the very limited size of the Both Worlds project, it is concluded that no cumulative effects on the currents along the east coast of Gibraltar are expected as a result of the combined proposed scheme and Both Worlds Project developments.

6.7 Transboundary effects

Because the Eastside Gibraltar project is located close to the Spanish border, special attention was paid to investigate a possible impact of the developments on the Spanish coast.

On the basis of the above presented simulations and analysis it is found that the impact of the development on currents in the Spanish waters is expected to be negligible.

6.8 Conclusions

- The current patterns east of Gibraltar are mainly tide driven. Strong winds affect the current magnitudes, but not so much the flow patterns. Both in the present situation and the future situation the currents at the project location are mostly north-south oriented, parallel to the coast.

- Eastside Gibraltar does not induce recirculation zones in the lee of the development. Areas with weak currents (lower than 0.1 m/s) will be formed just north and south of the development.

- The effects of the development on the flow patterns are limited to a coastal section from 0.5 km south of the development to about 0.5 km north of the development. In this area, the current magnitudes are expected to decrease with a maximum of 0.3 m/s compared to the present situation. The computed differences in flow velocity gradually decrease the further away from the development.

- Currents in the Spanish waters are not expected to be affected by the proposed development.

- In the northern borrow area maximum current speeds of about 0.5 m/s were simulated for spring tides and 0.3 m/s for neap tides for all conditions. Wind effects cause variations between 0.1 m/s and 0.2 m/s on the currents for 10 m/s wind, depending on the tide.

- Along Eastside Gibraltar the flow will reach maximum speeds of up to 0.4 – 0.5 m/s.

- An integral lowering of the seabed of 0.9 m in the northern borrow area and 0.4 m in the southern borrow area by the dredging works will not lead to any significant effects on the flow conditions.

7 Pollutant dispersion

7.1 Objective

The objective of this task was to assess the dispersion and fate of pollutants such as storm water discharge from Eastside Gibraltar.

7.2 Approach

WL | Delft Hydraulics' particle tracking model Delft3D-PART was used to simulate pollutant dispersion for different discharge scenarios from Eastside Gibraltar.

7.2.1 Delft3D-PART

The Delft3D-PART model simulates the dispersion of pollutants by discharging particles at specified discharge rates and locations. Every particle represents a specific pollutant mass. Resulting concentrations of pollutants are defined by the relative number of particles present in a certain area at a certain time.

Because the actual composition of the pollutants is not known, the initial discharge concentration of the pollutants used can be interpreted as an arbitrary, scalable value. The computed plume dispersion is therefore presented in a relative sense (i.e. percentages of the initial concentration/mass). To simulate the plume dispersion in a statistically realistic way a total of 1 million particles was released at the identified discharge locations at specified discharge rates.

The Delft3D-PART model has to represent many processes that cannot be explicitly resolved, such as small-scale wind effects, local (ship-induced) currents, small structures obstructing the flow etc. Effects of these processes are accounted for by the diffusion/dispersion parameter in the model. It is not possible to analytically determine the exact value of the dispersion parameter to be used in the model. The value for the dispersion parameter used in the model is therefore based on expert opinion.

For particle tracking simulations, the horizontal dispersion coefficient is also time dependent and generally increases with time. In the initial period of time after the release of the particles, the patch of particles is relatively small and the mixing of the particles is caused by small-scale turbulence effects only. However, after some time, the 'cloud' of particles will have spread sufficiently such that larger-scale eddies and circulations will contribute to the mixing effect.

The total dispersion is described by the following formula:

$$D_{x,y} = a \cdot t^b$$

in which:

$D_{x,y}$ = dispersion in x and y direction
a and *b* = dispersion parameters
t = time (particle age)

The diffusion parameter *a* is determined based on sensitivity runs and is set to 1, which is a common value used in these type of studies. Parameter *b* is set to 0.01. The influence of the latter parameter is not significant due to the relative short simulation period.

The hydrodynamic data necessary for the analysis of the dispersion of pollutants were generated with the detailed hydrodynamic model described in Chapter 3.

7.2.2 Discharge scenarios

Based on information from the Client two computations with different pollutant scenarios were defined:

1) Storm water runoff scenario

This scenario consists of the discharge of runoff water from three outfall locations in the development due to rainfall of 50 mm/hour. The total resulting discharge was specified by the Client as 2100 l/sec, based on an approximate drained surface area and a short heavy rain shower. The total discharge was equally divided over the three outfalls, resulting in 2100/3 = 700 l/sec per individual outfall. The discharge locations are indicated in Figure 7.1.

The buoyancy effect of the runoff water is modeled with the particle tracking model by discharging the particles into the top layer of the water column and restricting the vertical dispersion to limit the spreading of particles in the vertical direction.

The duration of the runoff discharge is set to 1 hour and the simulation has a duration of 2 days. These 2 days are chosen during a spring tide, which results in the storm water being transported at maximum distances from the scheme.

2) Conservative discharge scenario

To assess a conservative extent of the pollutant plume (i.e. a worst-case scenario for a pollution impact), a conservative (in duration) scenario has been assessed. This scenario is similar to the storm water runoff scenario, however in this case the discharge lasts three days and the simulation covers a complete spring-neap cycle (15 days). A continuous discharge of runoff water (15 days) is considered to be unrealistic.

7.3 Present situation

The assessment of the baseline situation for pollutant dispersion is irrelevant because the pollution sources to be investigated are related to Eastside Gibraltar.

7.4 Eastside Gibraltar impacts

7.4.1 Results

To indicate the extent of the plumes from Eastside Gibraltar, the results are presented as maximum relative concentration plots. These plots show contours of maximum expected plume concentrations relative to the discharge concentration.

1) Storm water runoff scenario

Figure 7.2a-b show the resulting maximum expected relative plume concentrations of the 1-hour storm water discharge. The direction of the tidal current during the storm water discharge determines largely in what direction the plume is transported. In Figure 7.2a, a northward directed current during the discharge is considered, whereas in Figure 7.2b a southward directed current during the discharge is considered. The results show that the impact of the 1-hour discharge is limited. Only close to the development, maximum concentrations above 10% of the source concentration (undiluted = 100%) are reached. The sensitive areas (beaches) approximately 1 km to the north and south of the development will experience relative concentrations in the order of 1 - 2%.

2) Conservative discharge scenario

The results of the conservative discharge scenario are presented in Figure 7.3. The maximum expected relative concentrations in this 3-day continuous discharge scenario are significant (above 10%) close to the development. In this situation, a plume with concentrations between 1 and 10% is formed along the coast over a distance of some kilometers to the north and south. The impact on Catalan Bay, the beach in the southern corner of the development, is around 10 – 20% of the source concentration. The impact on the beach in the northern corner of the development is slightly smaller, between 5 – 10%.

7.4.2 Discussion of results

The future situation with Eastside Gibraltar has an impact on the currents and therefore on the dispersion of pollutants. The development induces an increase of current velocities east of the development and a decrease north and south of the development, where the currents are blocked. Due to the decrease in current velocities along the beaches directly north and south of the development, pollutants can reside longer in those areas than without Eastside Gibraltar.

7.5 In-combination effects

As indicated in Chapter 6, it is expected that there is no cumulative effect of the Both Worlds project and Eastside Gibraltar on currents. Since the dispersive behaviour of pollutants depends on the currents, it is also concluded that no cumulative effects on the dispersion of pollutants are expected as a result of the combined proposed scheme and Both Worlds Project developments.

7.6 Transboundary effects

The direction of the tidal current during the storm water discharge determines largely in what direction the plume is transported. If the heavy rain shower occurs in the period approximately between HW-1 hrs and HW +2 hrs (when the tidal currents along the coast are directed northward) relative concentrations in the order of 1 – 2% may cross the border and reach the most southern parts of the Spanish coast.

7.7 Conclusions

The simulations indicate that the volumes of storm water originating from the runoff system that reach the beaches are relatively low. Only in a worst-case pollution storm water runoff scenario, or after heavy rain showers coinciding with northerly tidal currents (during approximately 6 hours a day), limited amounts of the storm water may reach the beaches north of the Eastside Development. In these adverse conditions, concentrations in the order of 1-2% may cross the border and reach the most southern parts of the Spanish coast.

8 Beach cleansing and bathing water quality

8.1 Objectives

The existing Eastern Beach and Catalan Bay Beach (see Fig. 1.2) will be more shielded from the sea currents and waves after the construction of Eastside Gibraltar. As a result, the flushing and self-cleaning characteristics of the beaches and the swimming waters adjacent to the beaches may be impacted, and the beach water quality may be affected adversely.

The objectives of the beach cleansing and bathing water quality task were to assess:

- Self-cleansing potential of the new beaches through tidal and wave action;
- Bathing water quality.

The assessment was carried out on the basis of expert interpretation of modelling results presented in previous chapters.

8.2 Approach

Beach cleansing

The assessment of beach cleansing was carried out on the basis of the flow and wave-modelling results (see Volume 2: Normal Wave Conditions).

The self-cleansing potential of a beach is determined by the:

- Beach exposure to waves
- Tidal range
- Beach sand characteristics
- Bathing water quality

For each of these items criteria were formulated on the basis of which the present and future situations could be assessed, which are described below.

Beach exposure to waves

Waves generate constant movements of the sand bed and by this action prevent settlement of fines, which are often present in sea water, on the beach and shoreface. Further, wave exposure prevents sea grasses from growing on the shoreface. A good quality beach therefore needs a certain exposure to waves. For beach stability and safe bathing conditions however, the wave exposure should not be too high. Mangor (2005) states that for a good quality beach the significant wave height ($H_{s,\ 12h/y}$), which is exceeded 12 hours per year, should be higher than 1.0 m.

Tidal range

Mangor (2005) reports that to avoid flattening of the foreshore the mean spring tidal range should not be much larger than the yearly-average breaker wave height.

Beach sand characteristics

The quality of the beach fill material determines the permeability of the beach. A high permeability is needed for the beach to drain quickly and to avoid algae growth. Mangor (2005) advises that the sand shall be medium, i.e. 250 μm < D_{50} < 500 μm, preferably coarser than 300 μm. Further, the sand should have a minimum content of fines and no content of organic matter.

Bathing water quality

For adequate self-cleansing of the beach the water quality should preferably meet requirements for bathing water quality. To assess the impact on bathing water quality of Eastside Gibraltar, an inventory was made of pollution sources associated with the recreational use of the beaches, and the hydrodynamics in the planned bathing waters were analysed with the numerical model (see Chapter 3).

In general, most pollution on the beaches is expected to originate from swimmers. An important parameter is therefore the number of swimmers present on the beach. In this assessment, 2 swimmers per meter beach are assumed. A second important parameter is the amount of pollutants brought into the water by swimmers. Relevant pollutants are coliform bacteria, nutrients and pollutants stemming from sunbathing oils.

Indicative dispersion simulations were carried out in which a series of continuous discharges were positioned along the beaches in question, approximately along the 1 m depth line, to represent the scattered nature of the pollutants. By scaling the discharges in the flow model by a realistic value for discharges of the different pollutants, the order of magnitude of the concentrations of these pollutants on the beach was estimated. The results were evaluated on the basis of expert opinion.

The investigation assesses the potential pollution problems that are a direct result from the Eastside Gibraltar scheme. The impact of possible pollution sources from other areas is not taken into account.

In the next sections, the beach cleansing and bathing water quality are separately presented for the following situations:

1. Present situation
2. Situation with Eastside Gibraltar

8.3 Present situation

8.3.1 Beach cleansing

The results of the wave study (Report Volume 2) show that the natural wave exposure on the (unprotected) beaches east of Gibraltar and along the east coast of Spain is such that the significant wave height $H_{s,\ 12h/y}$ is higher than 1.0 m, which is sufficient for self-cleansing.

Because the morphological conditions in the project area are wave-dominated, and the tidal range is moderate (0.9 m between MHWS and MLWS), the tidal range is sufficiently large for a self-cleansing beach.

The Government of Gibraltar (1968) established that beach material at Eastern Beach and Catalan Bay Beach varies in size from sand (with an average diameter of about 340 μm) to pebbles (with an average diameter of 7 cm). This information shows no indication that there is any accumulation of fines that could stimulate algae growth.

From water quality measurements provided by the Client with series of coliform concentrations for the years 2001-2005 for amongst others Eastern Beach and Sandy Bay it was concluded that the water quality meets the requirements for self-cleansing of the beach.

In conclusion the conditions in the present situation meet all requirements for good self-cleansing properties of the beaches along the east side of Gibraltar.

8.3.2 Bathing water quality

From water quality measurements near the beaches from the period 2001-2005 provided by the Client, it was found that in the present situation concentrations only incidentally exceeded the EC Bathing Water Quality Directive Standards for coliform bacteria on both beaches. On the basis of the available data, it could not be established if the swimmers themselves or pollution sources away from the beaches are responsible for these exceedance occasions. It was concluded that under baseline conditions, the flushing of the beach water by marine currents was found to be sufficient to avoid water quality problems (due to local emissions).

8.4 Eastside Gibraltar impacts

8.4.1 Beach cleansing

The results of the wave study (report Volume 2: Normal wave conditions) showed that after construction of Eastside Gibraltar the wave action on the southern part of Eastern Beach will be significantly reduced. The effect of the development on wave heights in this area is illustrated in Figure 8.1 for a typical wave condition. As a consequence, the significant wave height ($H_{s,\ 12h/y}$), which is exceeded 12 hours per year, may become lower than 1.0 m in this area.

The impact of the development on tidal levels was found to be negligibly small (see Chapter 4).

It is concluded that in general the development is expected to have no impact on the self-cleansing properties of the Eastern Beach and Catalan Beach, except at the southern end of Eastern Beach, where the wave action may become lower than needed for self-cleansing of the beach. In this area, beach cleaning measures might be needed (see Fig. 8.2).

8.4.2 Bathing water quality

After construction of Eastside Gibraltar currents along the coast will change. Especially in the corners just north and south of the development the current magnitudes are generally reduced. As a result the flushing capacity of these areas may become somewhat lower.

Based on interpretation of the indicative dispersion simulations, it is concluded that the self-cleansing capacity of Catalan Beach will be minimally affected by the development. The refreshment rates in the bathing area are expected to be slightly reduced compared to the present situation. However, it is not anticipated that algae growth and accumulation will occur, which could reduce the transparency of the water. The refreshment of the bathing waters is also expected to be large enough to prevent the development of visual films of sun bathing oils and accumulation of litter and debris. No increased risk of violation of the Guideline Values for safe bathing water quality with respect to coliform bacteria is expected on Catalan Beach.

On the basis of interpretation of the simulations, the self-cleansing capacity of the southern end of Eastern Beach is expected to be affected by Eastside Gibraltar. It is expected that after construction of the development the risk that Guideline Values for safe bathing water quality (Blue Flag Beach Criteria and exploratory notes, 2006-2007) with respect to coliform bacteria are violated will be larger than in the baseline situation. Likewise, there will be an increased risk for visual deterioration of the bathing water, such as reduced water transparency, the development of films of sun bathing oils and the accumulation of litter and debris. This will be the case especially during conditions with least effective flushing, such as days with minimum wind and tide driven circulation. As a result, maintenance in the form of regularly removing litter and debris from the beach is expected to be needed. On the basis of the available data, it is hard to say whether additional mitigating measures, improving the flushing in this sheltered area, are needed. If this turns out to be the case once the beach is operational, placing of a culvert with a water pump to open sea is an option.

8.5 In-combination effects

As explained in Chapters 4, 5 and 6, no cumulative effect of the Both Worlds project and Eastside Gibraltar is expected on the hydrodynamic parameters along the east coast of Gibraltar. Also, no additional wave shielding due to this project is expected. It can therefore be concluded that no cumulative effects on beach cleansing nor bathing water quality are expected as a result of the combined proposed scheme and Both Worlds Project developments.

8.6 Transboundary effects

8.6.1 Beach cleansing

No significant impact is expected on the beach cleansing characteristics of Spanish beaches, because the tidal range, the wave exposure and water quality for these beaches are not expected to change significantly

8.6.2 Bathing water quality

No significant impact on bathing water quality is expected on the Spanish beaches.

8.7 Conclusions

The self-cleansing potential of the beach and the bathing water quality was assessed based on available data and modelling results presented in previous chapters by means of expert interpretation.

It was found that for sufficient self-cleansing of the existing beaches:

- The wave action is sufficiently high;
- The tidal range is in the right range;
- The beach sand has a sufficiently large grain size.

It is concluded that the impact of Eastside Gibraltar on the self-cleansing property of the adjacent beaches will be limited to the southern end of Eastern Beach just north of the development. In this sheltered area the development will cause a decrease of wave action. During unfavorable conditions, cleansing measures may be needed in this specific area.

No significant impact is expected on the beach cleansing characteristics of Spanish beaches, because the tidal range, the wave exposure and water quality for these beaches are not expected to change significantly.

For the bathing water quality it was found that in the baseline situation the Guideline Values for bathing water quality are violated only incidentally. Compared to the baseline situation, the construction of Eastside Gibraltar is not expected to have a significant impact on the bathing water quality on the beaches south of the development. However, a significant deterioration of the water quality to the north of the development is expected. On the southern part of Eastern Beach, the risk of violation of the Guideline Values for bathing water quality with respect to coliform bacteria is expected to be higher than in the present situation. Further, there will be a higher potential for reduced water transparency, accumulation of litter and debris, as well as an increased risk for the development of visual films of sun bathing oils in this area, due to the shielded character of the beach.

9 Conclusions

This report presented findings and conclusions of study item 1) Flow conditions.

On the basis of available data and flow model simulations the following was concluded:

- **The impact of Eastside Gibraltar on the tidal water levels** is negligible: impacts are only observed in the very near vicinity of the development and are nowhere larger than about 5 mm.

- **The impact of Eastside Gibraltar on the storm surges** (water levels and currents) is expected to be limited to water level changes smaller than 2 cm for all considered storm conditions. The impact on surge currents is concentrated in the direct vicinity of the development. To the north and south of the development, current speeds are expected to decrease, whereas along the sea-side of the development, current speeds are expected to increase up to about 0.3 m/s. The impact of the development on surge currents is limited to an area of approximately 0.75 km to the south, 0.5 km to the north and 0.3 km offshore of the development. Outside this area water levels are not expected to change more than 5 mm, and current speeds are not expected to change more than 0.10 m/s.

- **The impact of Eastside Gibraltar on the tidal and wind driven currents** was predicted to be limited to an area from 0.5 km north of the development to 0.5 km south of the development. In this area, the current magnitudes are expected to decrease with a maximum of 0.3 m/s compared to the present situation. In the first hundreds of meters this decrease in current magnitude is larger than further remote. The impact of the development on tidal currents gradually decreases with the distance from the site and depends on the tidal phase.

- **Assessment of the impact of possible pollutant plumes** lead to the following conclusion. Volumes of storm water originating from the runoff system that reach the beaches are relatively low. Only in a worst-case pollution storm water runoff scenario, it is expected that limited amounts of the storm water may reach the beaches in the corner areas of Eastside Gibraltar. No adverse impacts are to be expected on the beaches further away, even after a relatively heavy rain shower.

- It is concluded that the impact of the scheme on the **self-cleansing property of the beaches** will be limited to the southern end of Eastern Beach just north of the development. In this area the existence of the development will cause a decrease of wave action. Consequently, cleansing measures may be needed in this specific area.

  No significant impact is expected on the beach cleansing characteristics of Spanish beaches, because the tidal range, the wave exposure and water quality for these beaches are not expected to change significantly.

- In the present situation the **bathing water quality** guidelines are only accidentally violated. After construction of the development, the southern end of Eastern Beach will be shielded from the sea currents by the development. Consequently, there will be an increased risk that situations occur in which criteria for the bathing water quality with respect to coliform bacteria will be violated in this area. A noticeable reduction of water transparency or the presence of oil films stemming from sun-bathing oils is expected, rendering the water visually less attractive. Further, there will be a higher potential for accumulation of litter and debris in the future because of the shielded character of the beach.

No significant impact on bathing water quality is expected on the Spanish beaches, related to the construction of Eastside Gibraltar.

References

Ainger, C.M., R J Armstrong and D Butler, Dry weather flow in sewers, CIRIA report R177, ISBN: 0-86017-493-X, 1998

Blue Flag Beach Criteria and explanatory notes, 2006-2007, website: http://www.blueflag.org/publicattachment/BeachCriteriaExplanatoryNotes2006.pdf

Brandt, P., A. Rubino, D. Sein, B. Baschek, A. Izquierdo, J. Backhaus, 2004: Sea level variations in the Western Mediterranean studied by a numerical tidal model of the Strait of Gibraltar, *Journal of Physical Oceanography,* February 2004, p433-446.

Béranger, K., L. Mortier, M. Crépon, 2003: Seasonal variability of water transport through the Straits of Gibraltar, Sicily and Corsica, derived from a high-resolution model of the Mediterranean circulation, *Progress in Oceanography "Special Mediterranean Issue"*.

Candela, J., C. Winant, H. Bryden, 1989: Meteorologically forced subinertial flows through the Strait of Gibraltar. *Journal of Geophysical Research,* vol. 94, no. C9, p12,667-12,679.

Candela, J., C. Winant, A. Ruiz, 1990: Tides in the Strait of Gibraltar. *Journal of Geophysical Research,* vol. 95, no. C5, p7313-7335.

Ciria, 1997, *Dry Weather Flow in Sewers*. CIRIA Report R177, 1997.

Delft Hydraulics, 2000: Gibraltar Beach Development – Volume 1: report on desk study.

EBG, 2007, Technical note: EIA Modelling Input based on Work Method 29/03/2007

GEBCO, Guidelines for the General Bathymetric Chart of the Oceans, International Hydrographic Bureau, September 1991. (website: http://www.ngdc.noaa.gov/mgg/gebco/)

Global Ocean Associates, 2002: An Atlas of Oceanic Internal Solitary Waves - The Strait of Gibraltar, *Prepared for the Office of Naval Research,* code 322PO

Halcrow (Sir William), 1968: Protection and development of the east coast of Gibraltar for tourism.

Hydrographer of the Navy, (2005), Admiralty Tide Tables Volume 2:2006: Europe (excluding United Kingdom and Ireland), Mediterranean Sea and Atlantic Ocean, NP 202-06, Taunton, 2005.

Hydronamic, (2006), Report on current measurements east coast Gibraltar, Sovereign Bay Development, Doc No: 04081-2-R-02-JKGR ADCP report rev b, 16-01-2006.

IPCC, (2007), Climate Change 2007: The Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Summary for Policymakers, http://www.ipcc.ch/SPM2feb07.pdf.

Jerlov, N.G. 1976. *Marine optics*. Elsevier Oceanography Series 14. Elsevier, Amsterdam.

Lacombe, H. & Richez, C. (1982). The regime of the Strait of Gibraltar, in *Hydrodynamics of semi-enclosed seas*, 13-73, Elsevier Sci., New York.

Mancini, J. L., 1978. *Numerical estimates of coliform mortality rates under various conditions*. Jour. Water. Poll. Control Fed. : 2477-2484.

Mangor, K., Successful Waterfront Developments – Work With Nature, ArabianCoast 2005 Keynote Paper. 1st International Conference On Coastal Zone Management and Engineering in the Middle East, 27th – 29th November 2005.

MAST/MEDATLAS Consortium, 1996: MEDATLAS – A composite quality checked hydrographic data set for the Mediterranean Sea. IFREMER.

Mediterranean Pilot NP45, 1966. Volume 1, ninth edition

Perkins, H., Kinder, T., and La Violette, P. (1990). The atlantic inflow in the western alboran sea. *Journal of Physical Oceanography*, 20:242-263

Sannino, G. A Bargagli, V. Artale, Numerical modelling of the semidiurnal tidal exchange through the Strait of Gibraltar, *Journal of Geophysical Research,* vol. 109, C05011.

Send, U and. and B. Baschek, 1999, CANIGO - Canary Islands Azores Gibraltar Observations, MAS3-CT96-0060. Workpackage 4.1: Water exchange through the Strait of Gibraltar, Institut für Meereskunde, Meerephysik, Kiel, Germany.

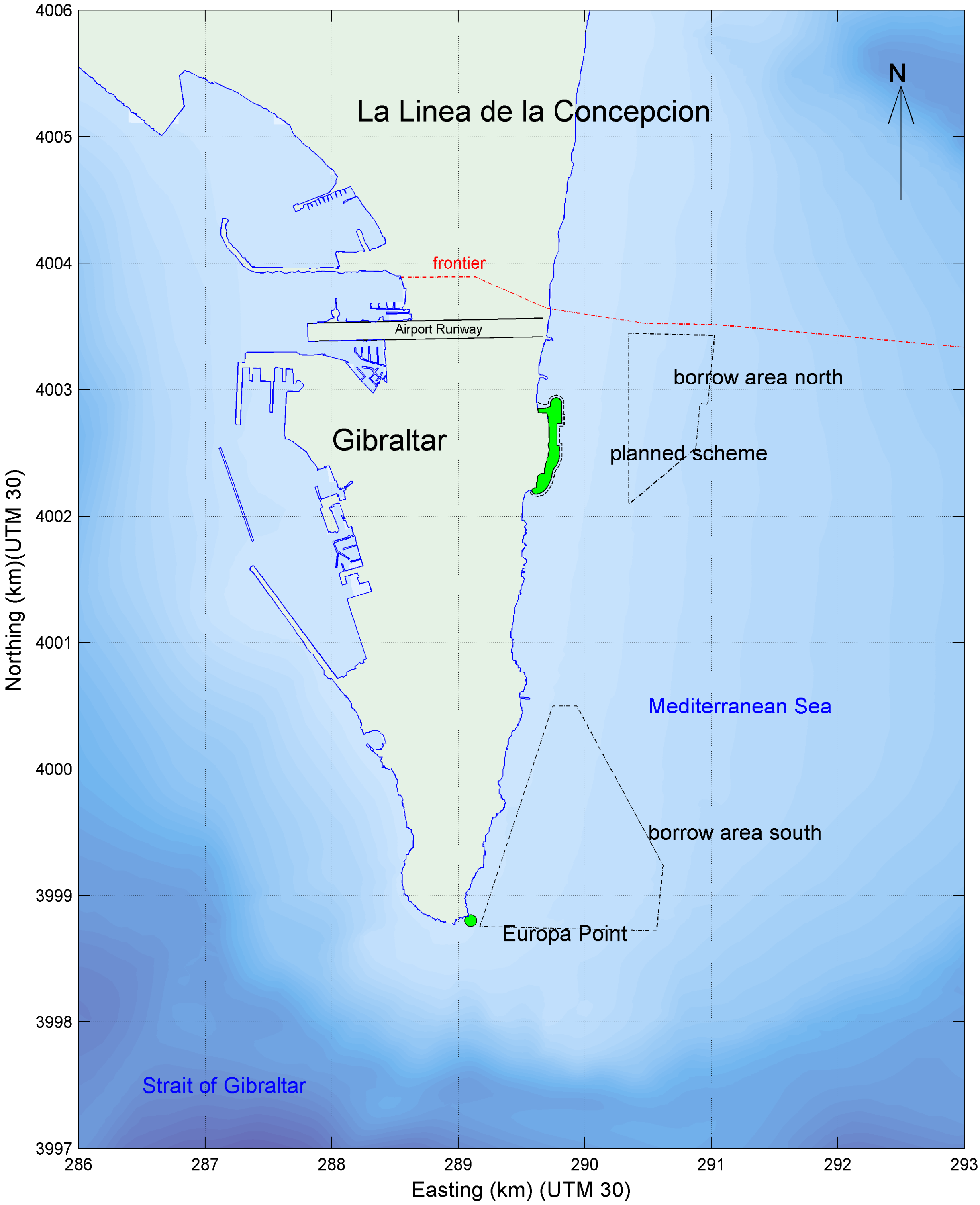
Straits Sailing, The Straits Sailing Handbook 2006, Colin Thomas – P&R Grafis S.A.

West Coast of Spain and Portugal Pilot NP67, 2005, ninth edition.

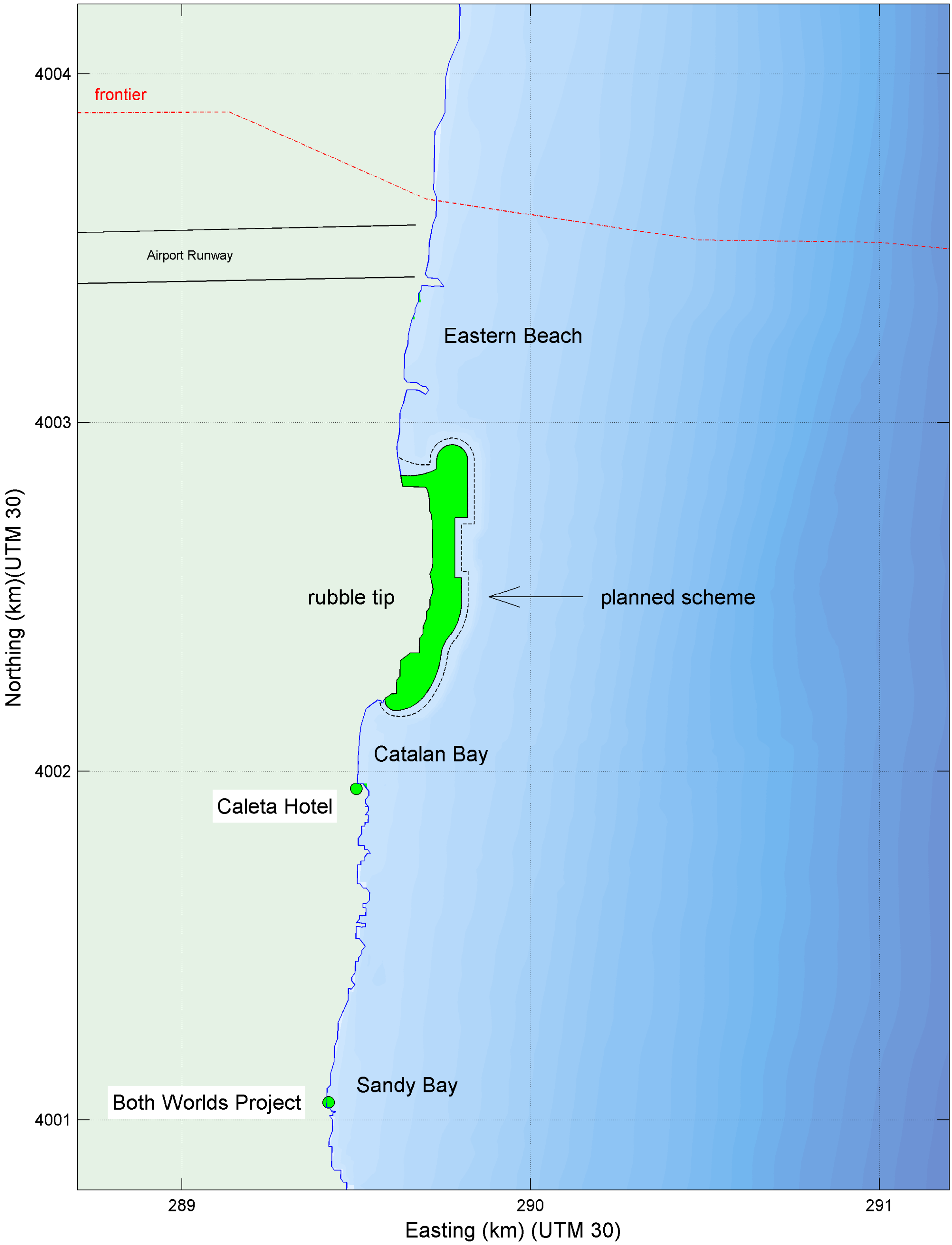
WL | Delft Hydraulics, 2000, Gibraltar Beach Development – Volume V: Report on physical model testing of beach schemes – Wide crested breakwater option, March – April 2000, H3590.

WL | Delft Hydraulics, 2007, Eastside, Gibraltar, Normal wave conditions – May 2007, H4725.50

A Figures



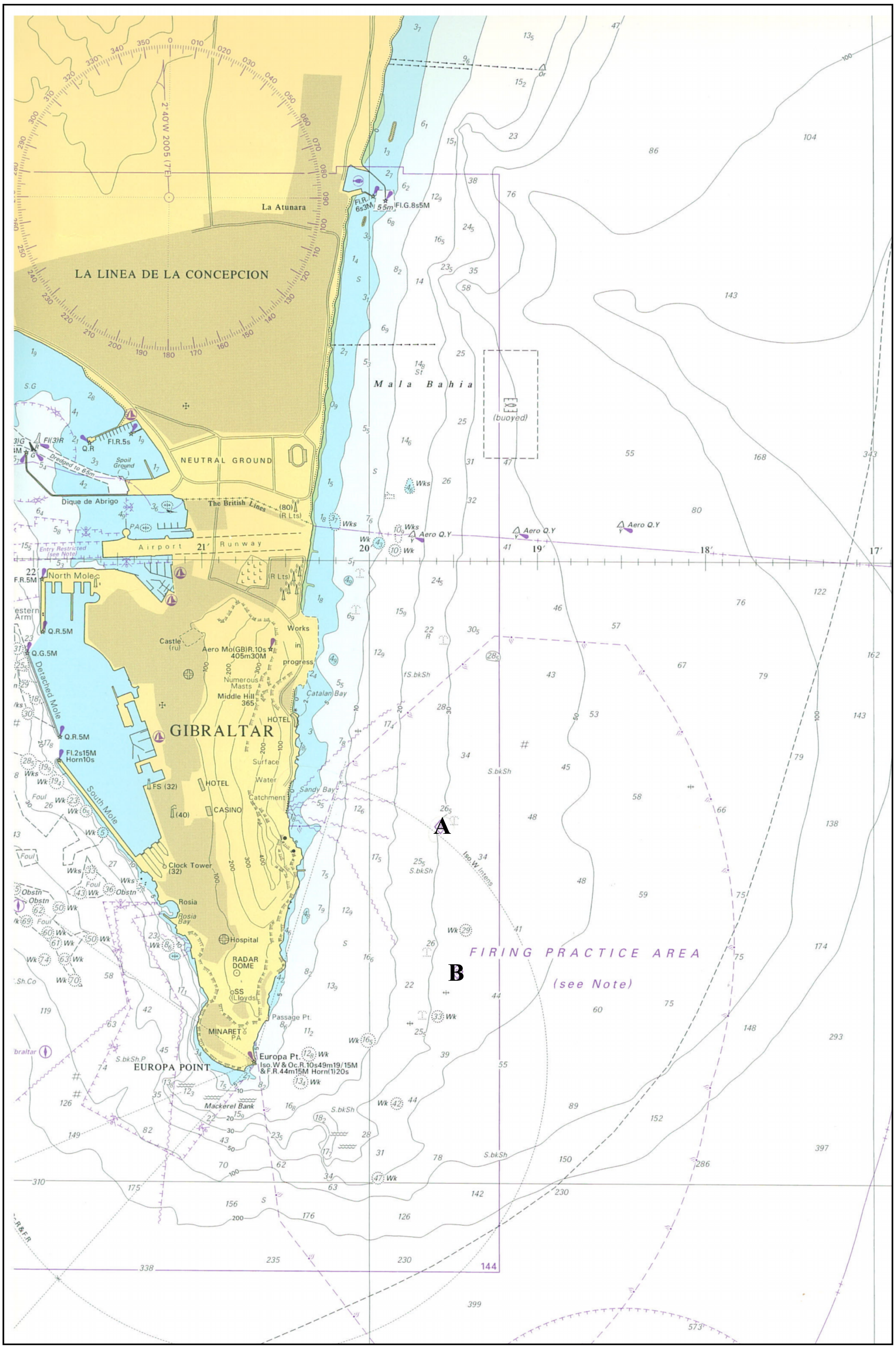
Eastside, Gibraltar Project location		
WL | DELFT HYDRAULICS	H4725	Fig. 1.1



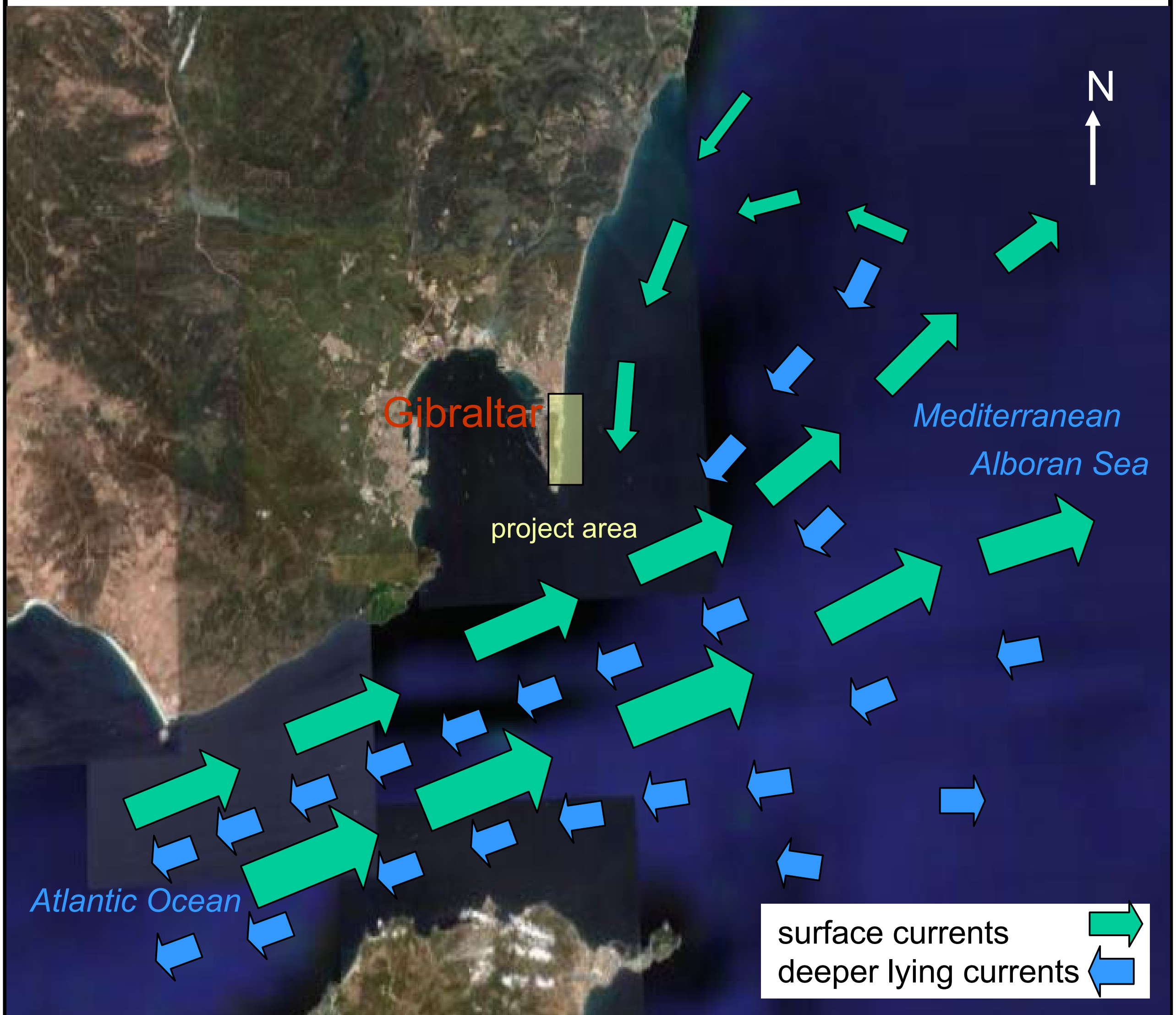
Eastside, Gibraltar
Project site : future situation with scheme

WL | DELFT HYDRAULICS	H4725	Fig. 1.2

Gibraltar and surrounding areas	**Gibraltar Flow Study**	
WL | DELFT HYDRAULICS	**H4725**	**FIG. 2.1**



Admiralty Chart (1448) showing the depth isolines along the coast of the development area. The marks A and B denote locations with tidal stream information on the Admiralty Chart.	**Gibraltar Flow Study**	
WL | DELFT HYDRAULICS	**H4725**	**FIG. 2.2**



Expected patterns of density-driven surface currents (green) in the project area, and patterns of deeper lying currents (dark blue)		
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	**H4725**	**FIG. 2.3**

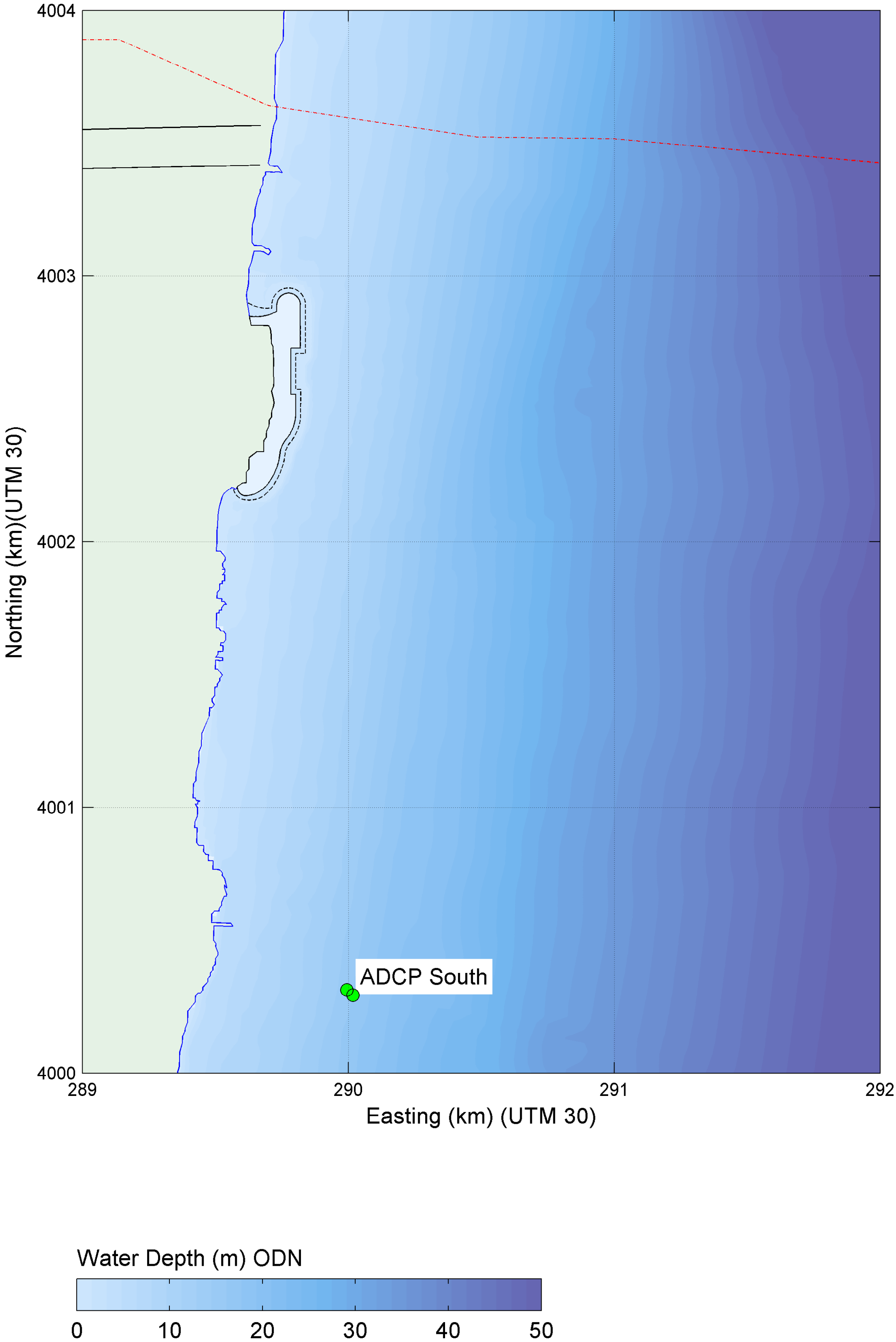
The western Alboran gyre

Gibraltar Flow Study

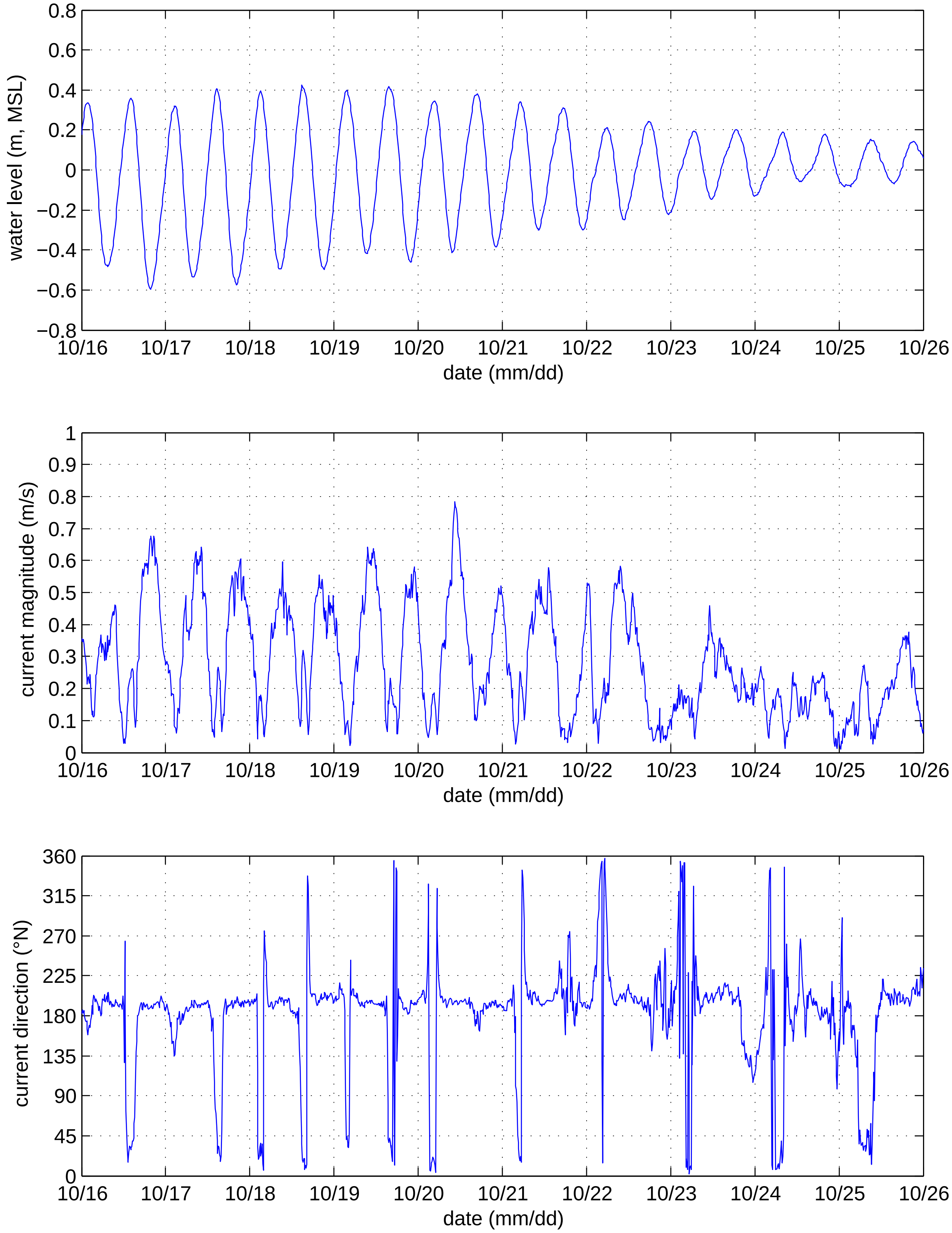
WL | DELFT HYDRAULICS

H4725

FIG. 2.4



Locations of ADCP measurements		Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 2.5



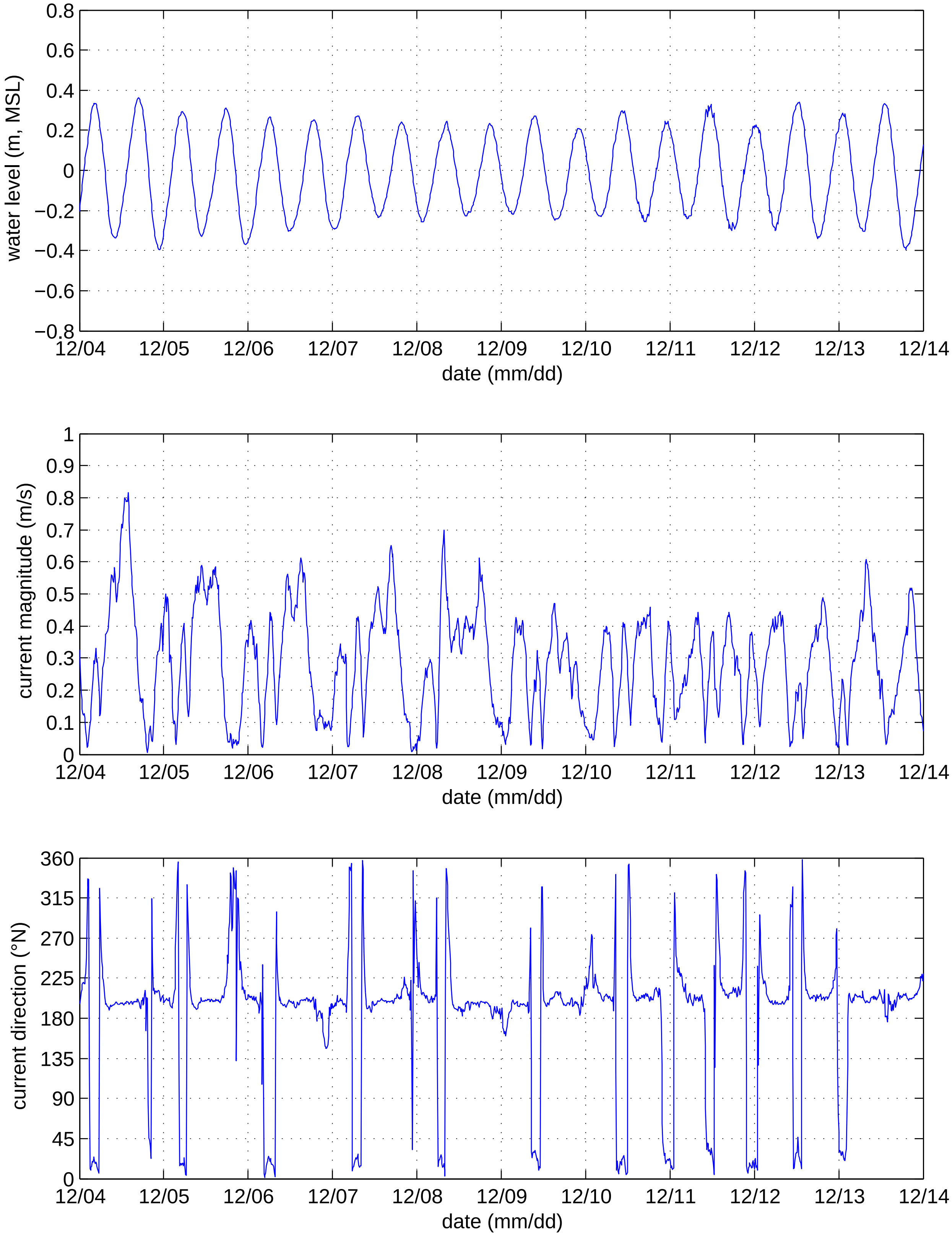
ADCP measurements at location ADCP South (from period 1)
top: water levels ; middle: current magnitudes
bottom: current directions

Gibraltar Flow Study

WL | DELFT HYDRAULICS

H4725

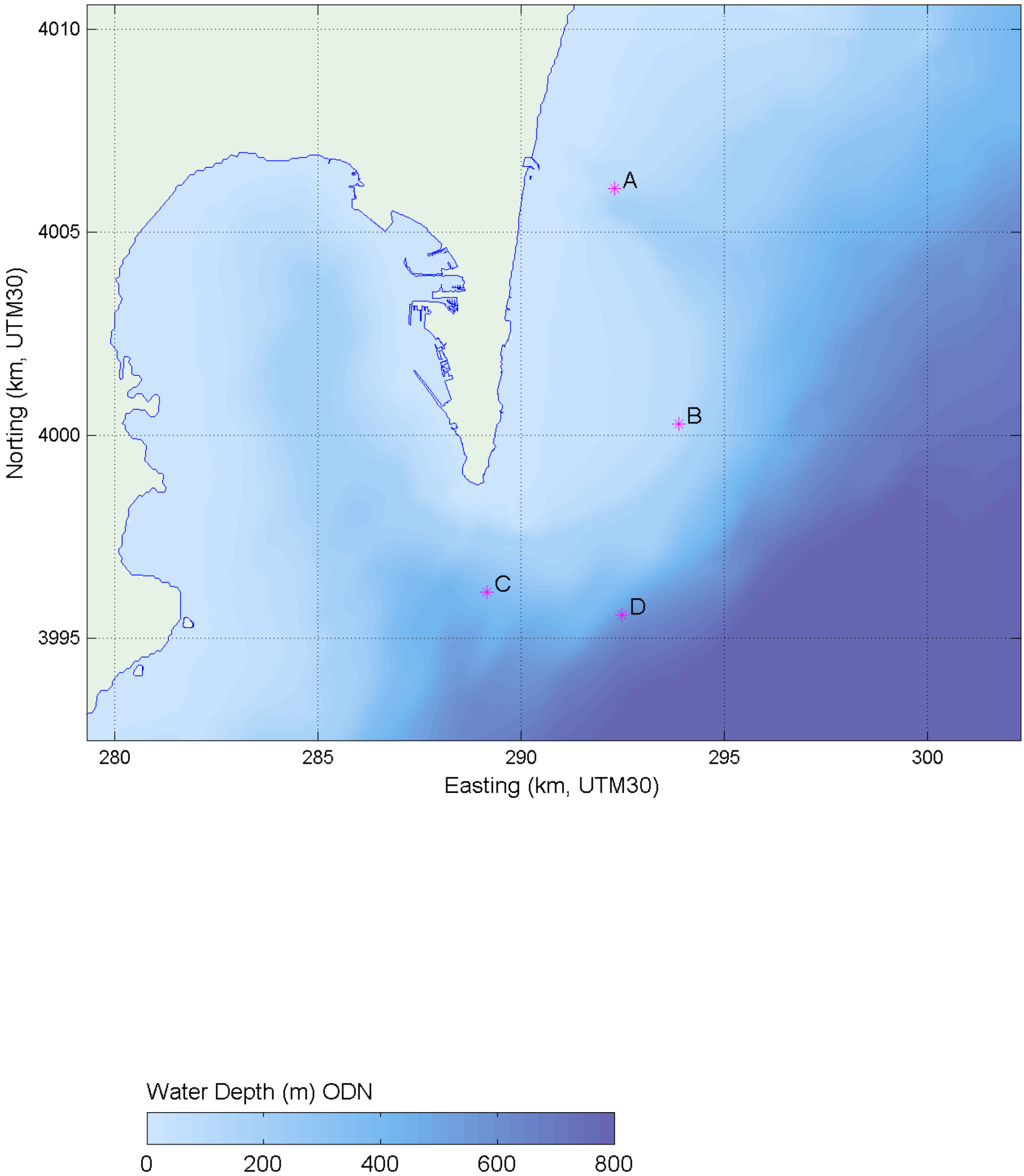
Fig 2.6



ADCP measurements at location ADCP south (from period 2)
top: water levels ; middle: current magnitudes
bottom: current directions

Gibraltar Flow Study

WL | DELFT HYDRAULICS | H4725 | Fig 2.7



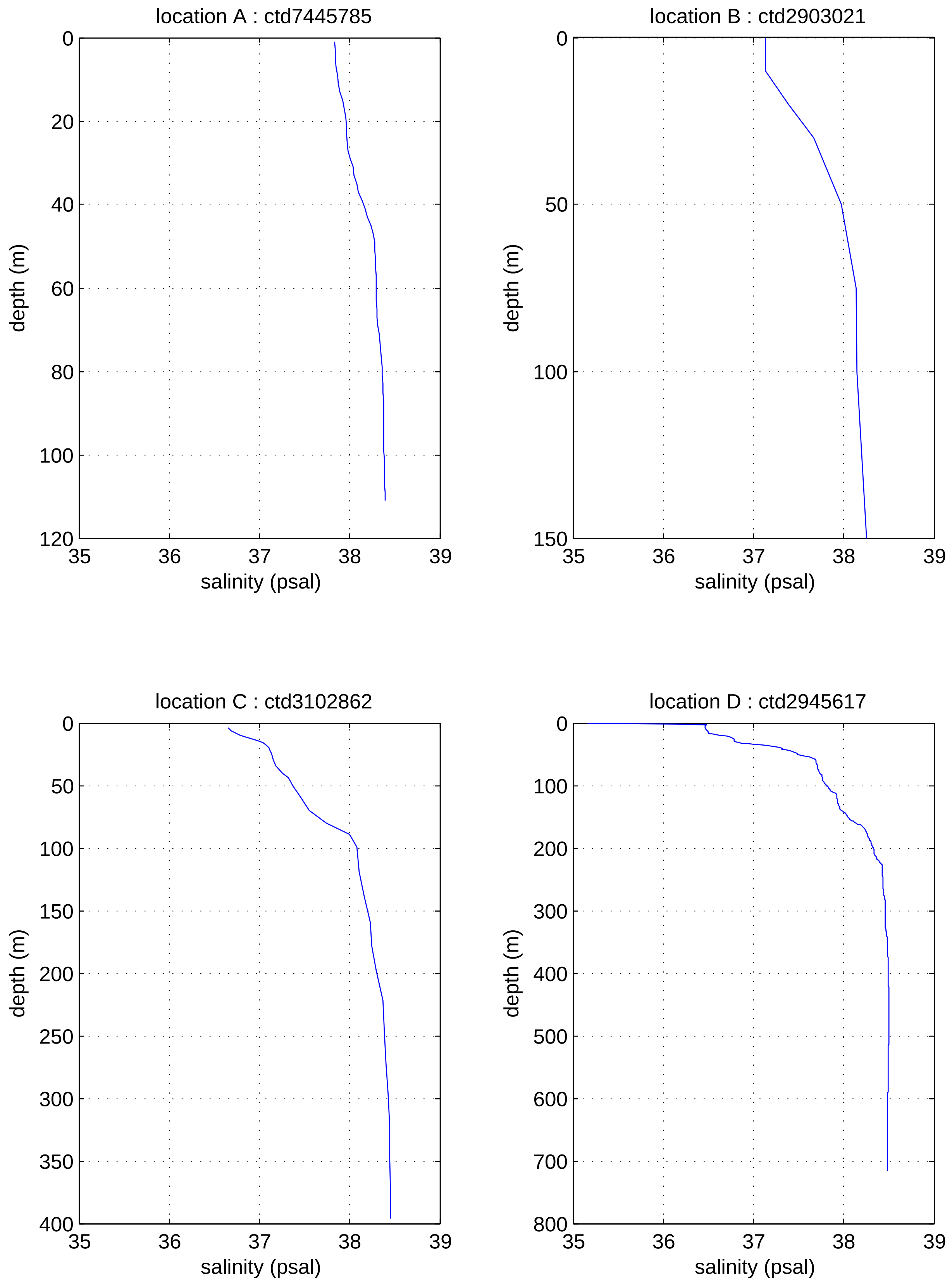
Positions of measured CTD profiles
From MedAtlas database

Gibraltar Flow Study

WL | DELFT HYDRAULICS

H4725

Fig 2.8a



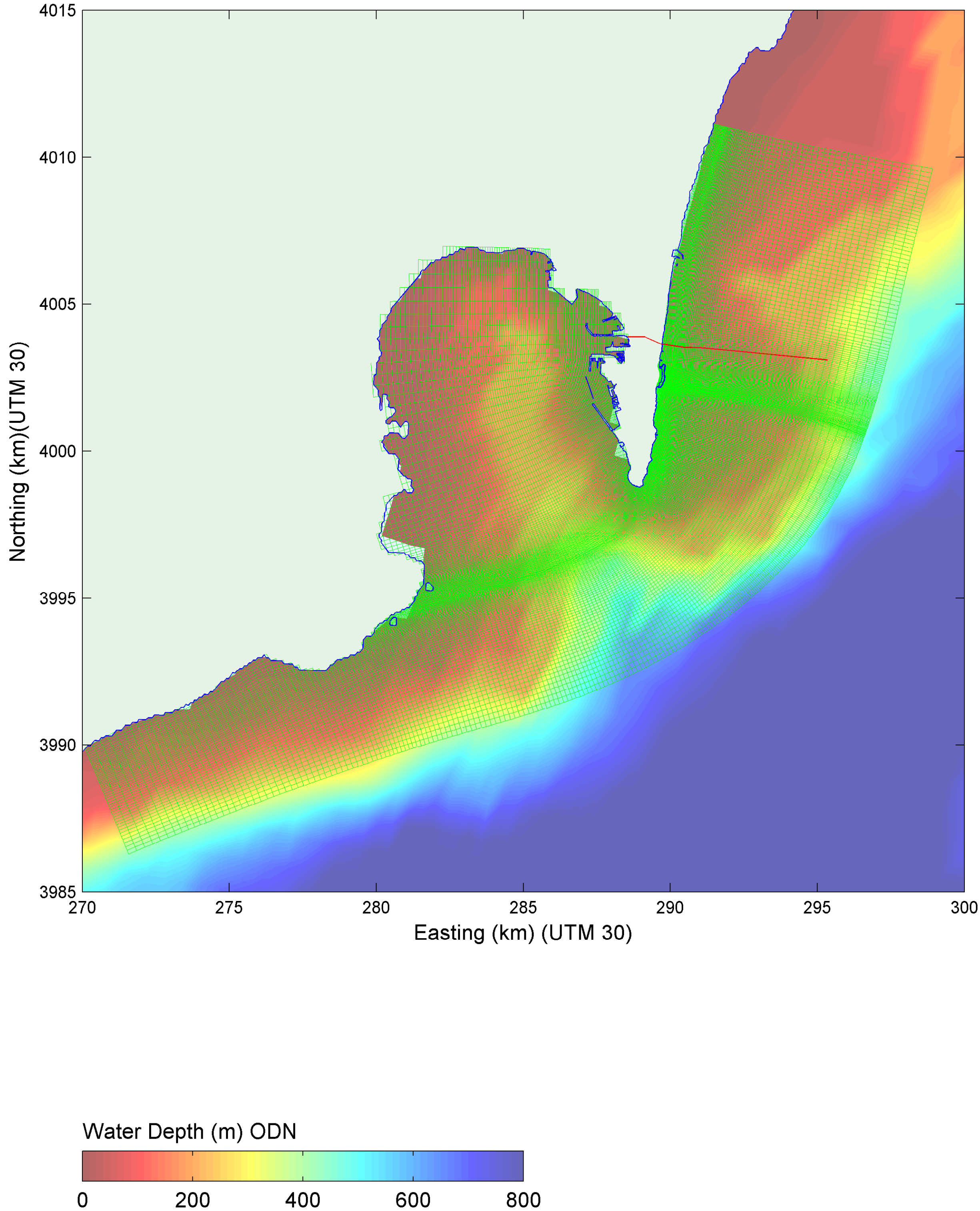
CTD profiles for locations A, B, C and D
From MedAtlas database

Gibraltar Flow Study

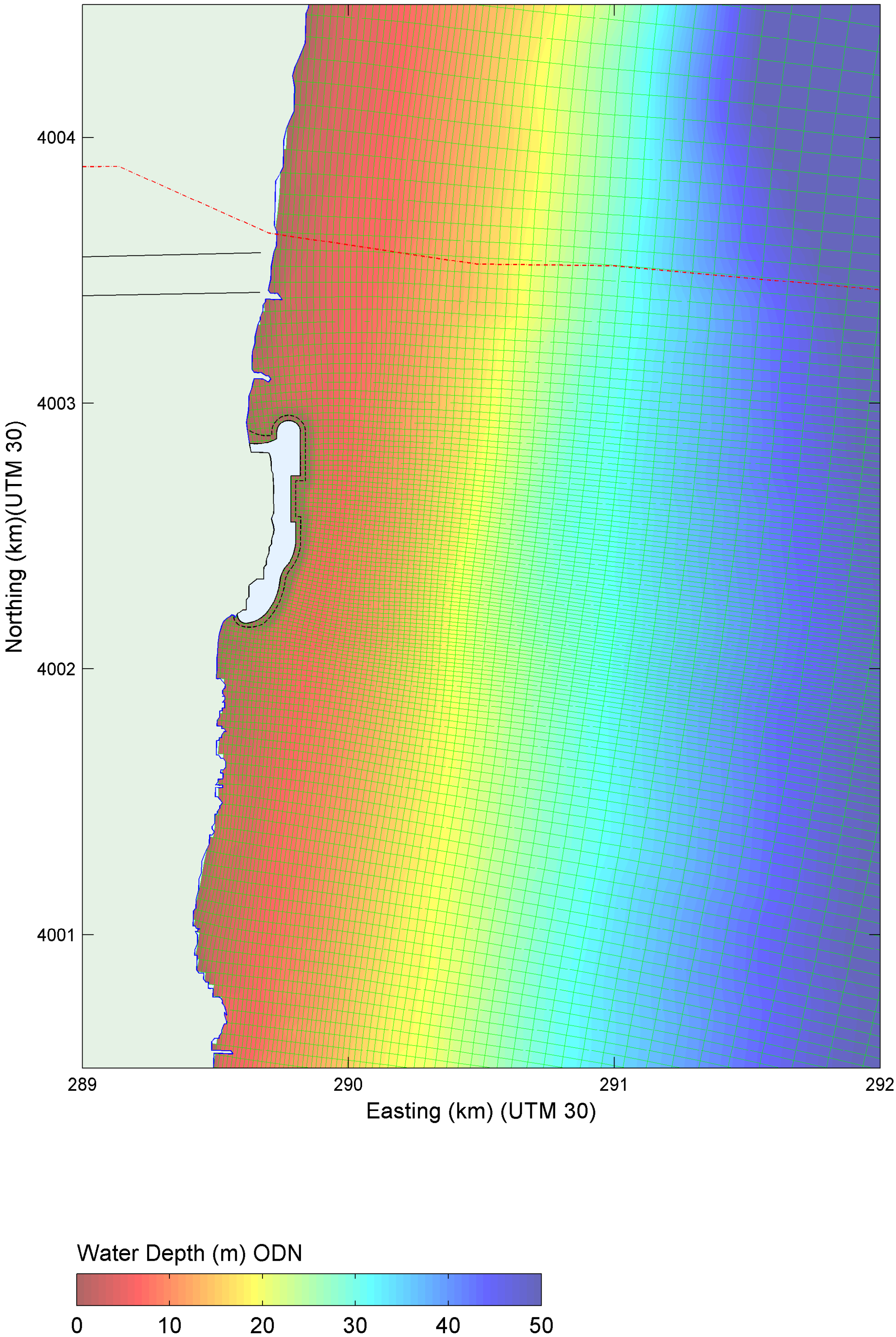
WL | DELFT HYDRAULICS

H4725

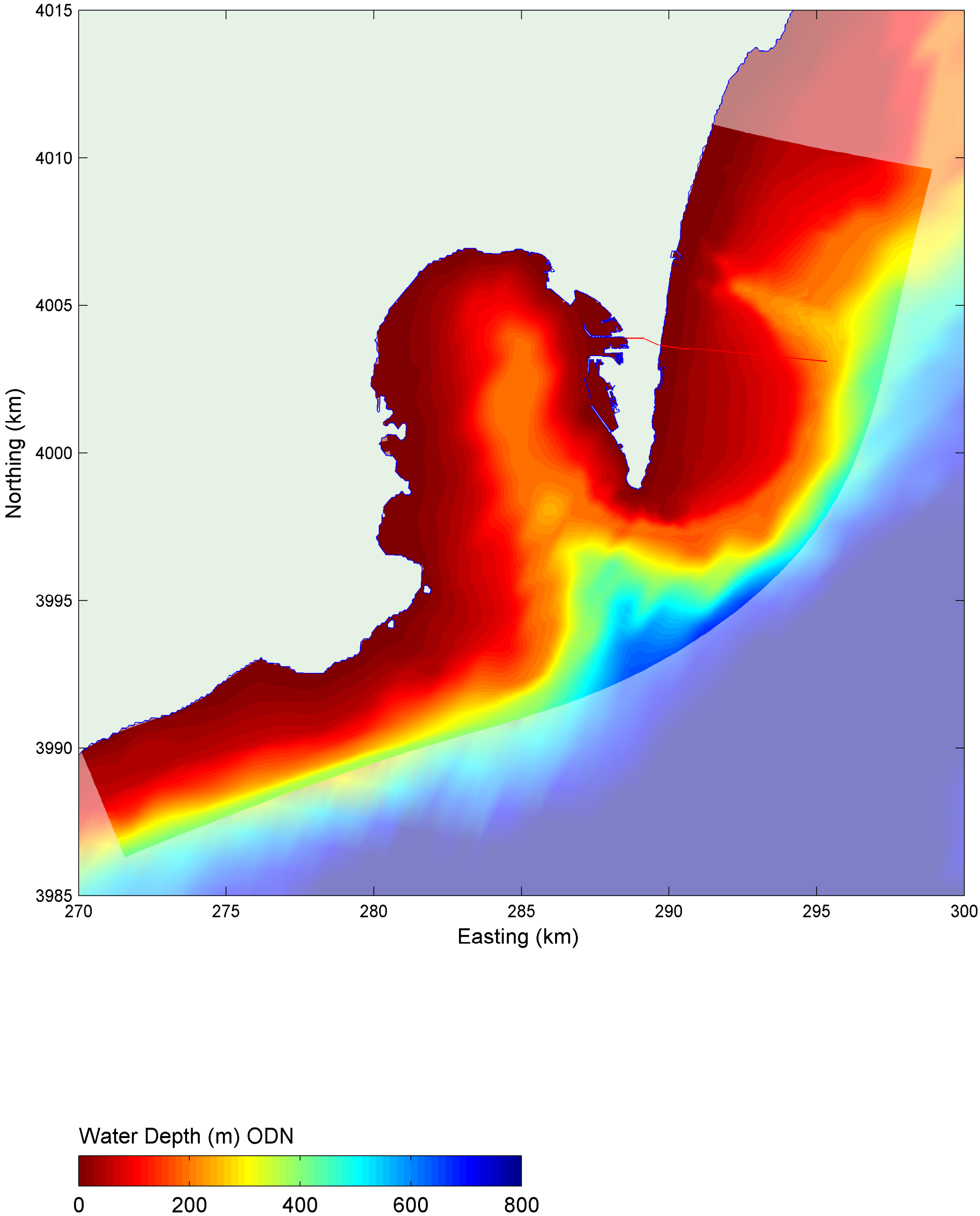
Fig 2.8b



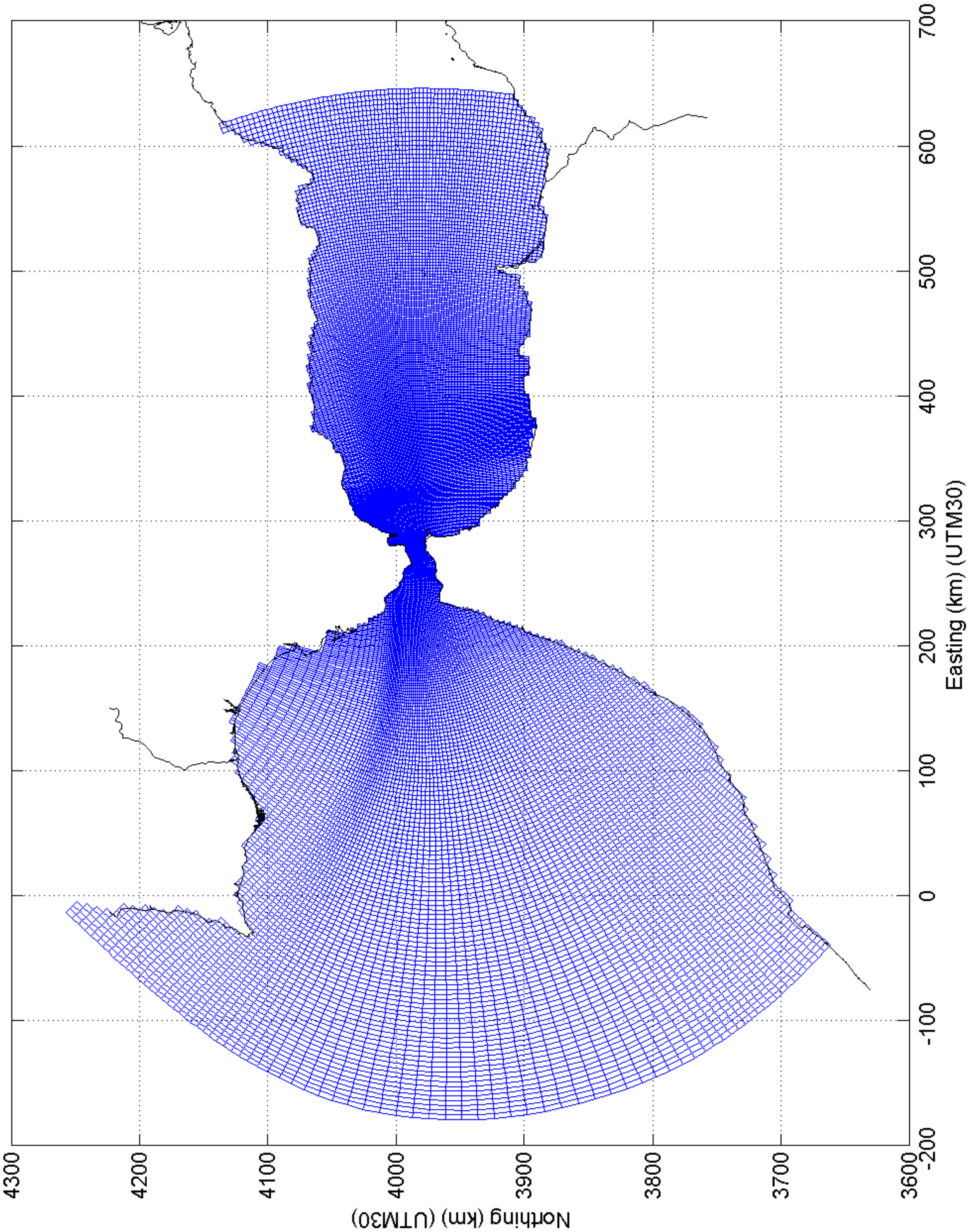
Modelling area and computational grid	model setup	Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 3.1



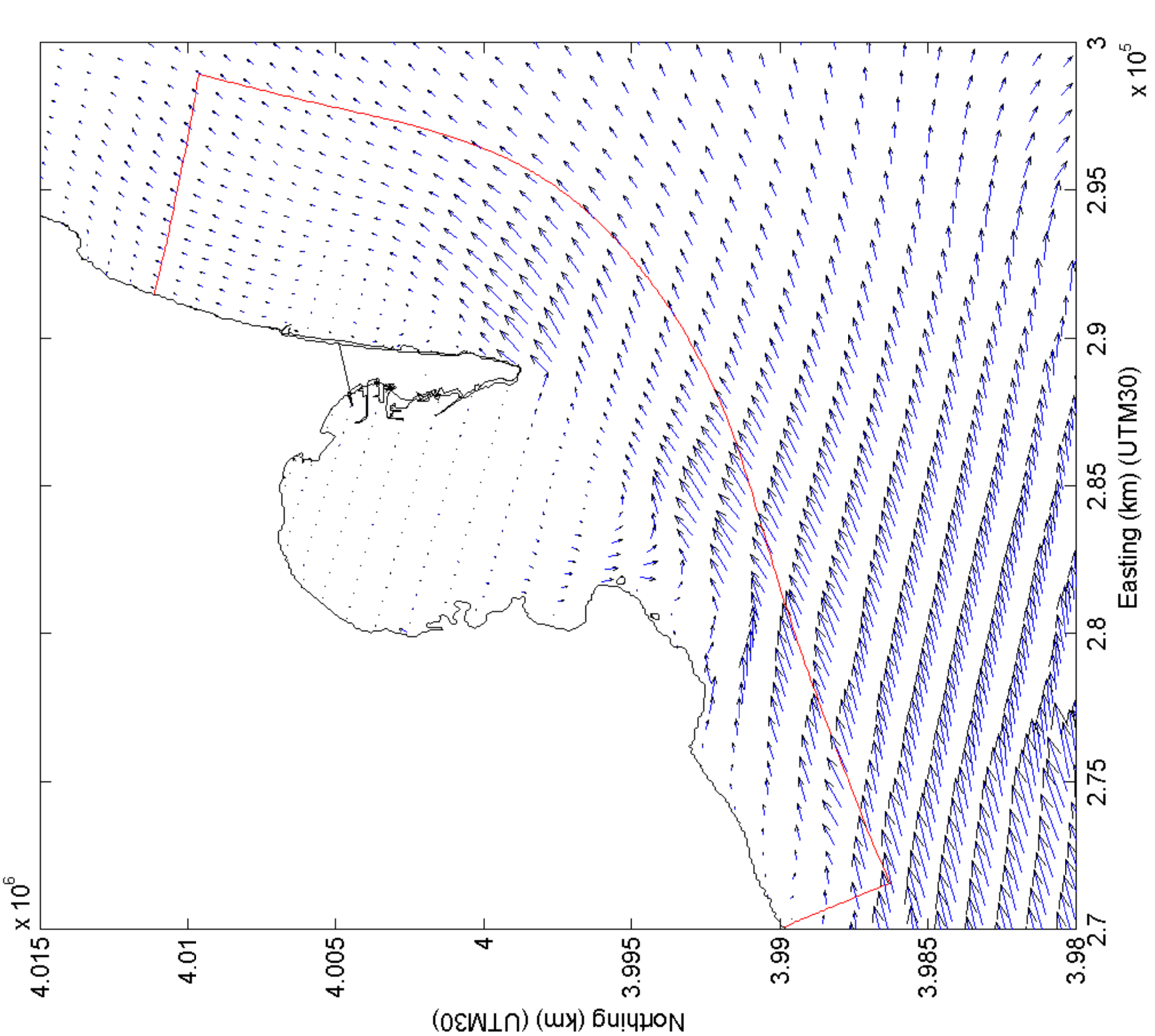
Computational grid in the project area	model setup	Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 3.2



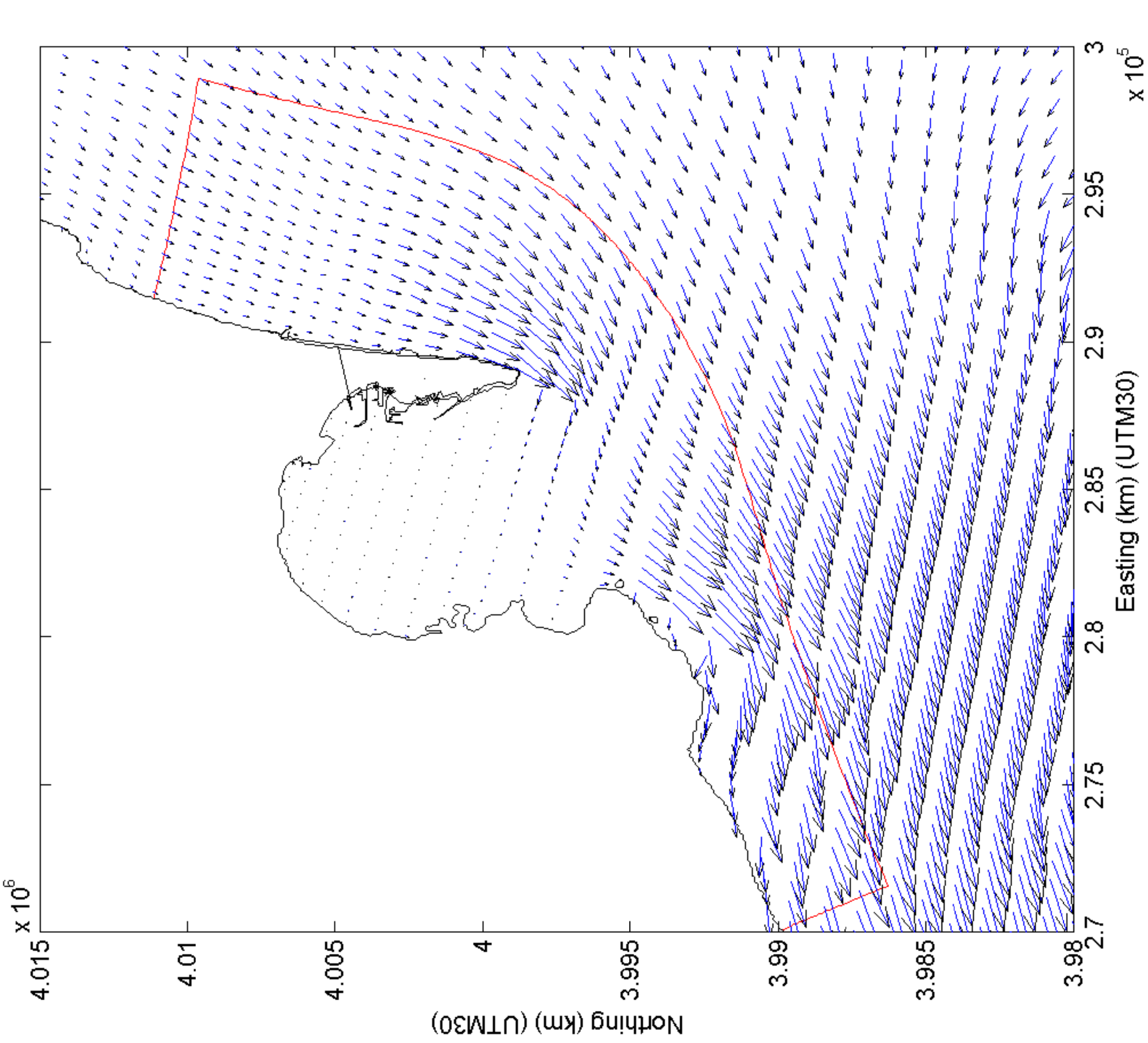
Bathymetry	model set-up	Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 3.3



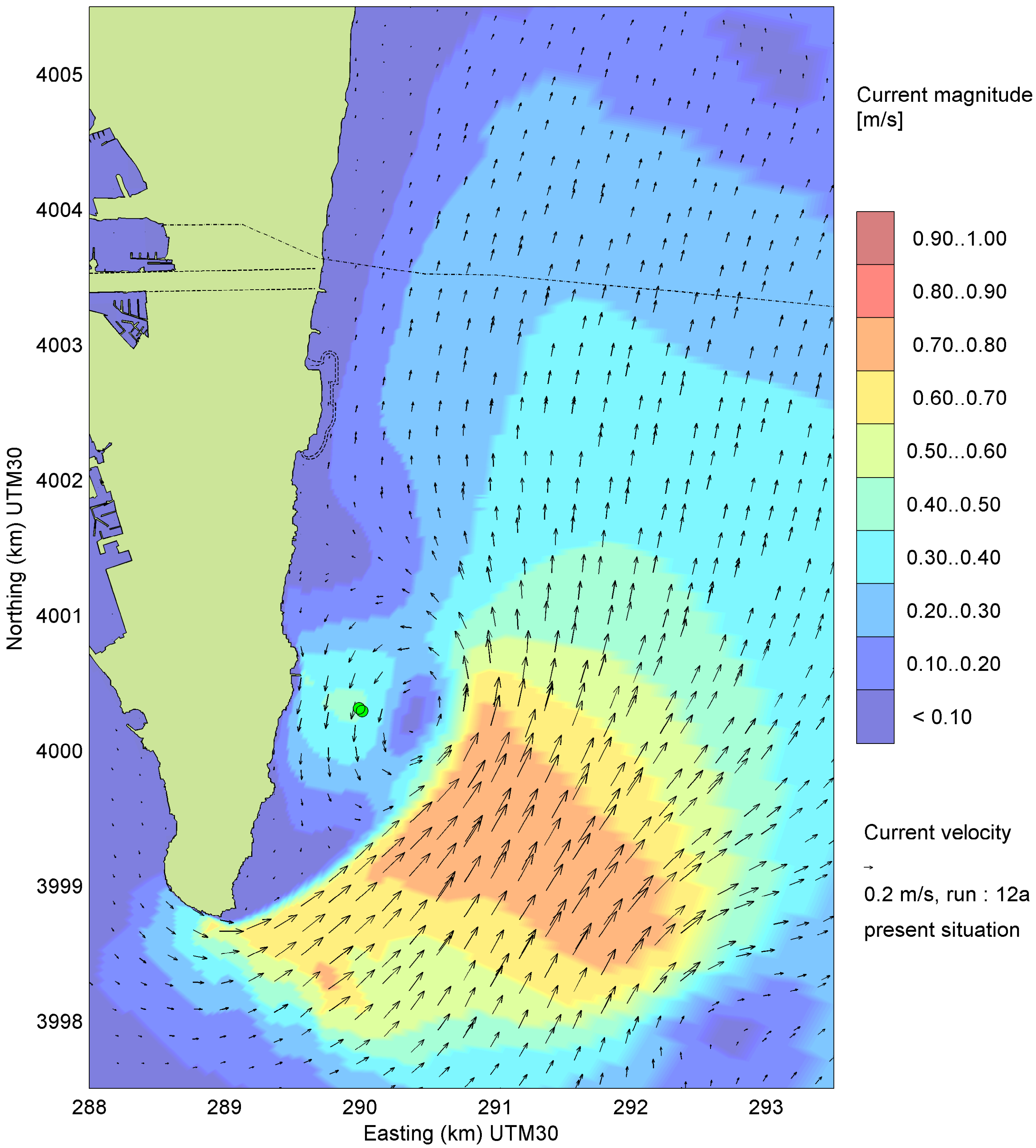
Computational grid Strait of Gibraltar hydrodynamic flow model	model setup	Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 3.4a

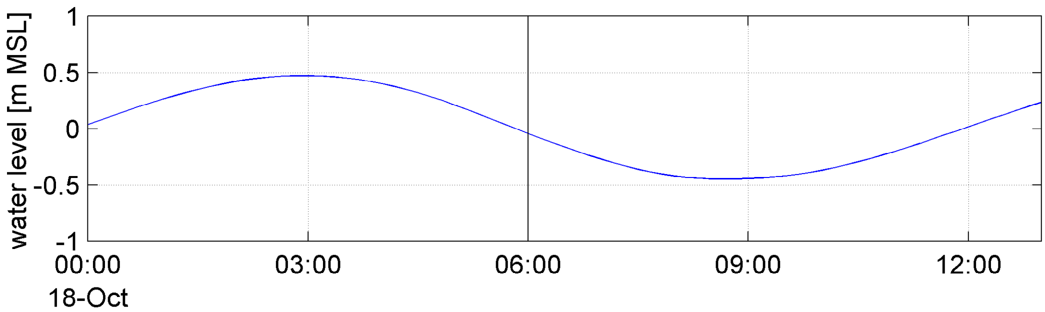


Strait of Gibraltar hydrodynamic flow model Typical velocity field for flood situation Red lines indicate the boundary locations of the detail model	model setup	Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 3.4b

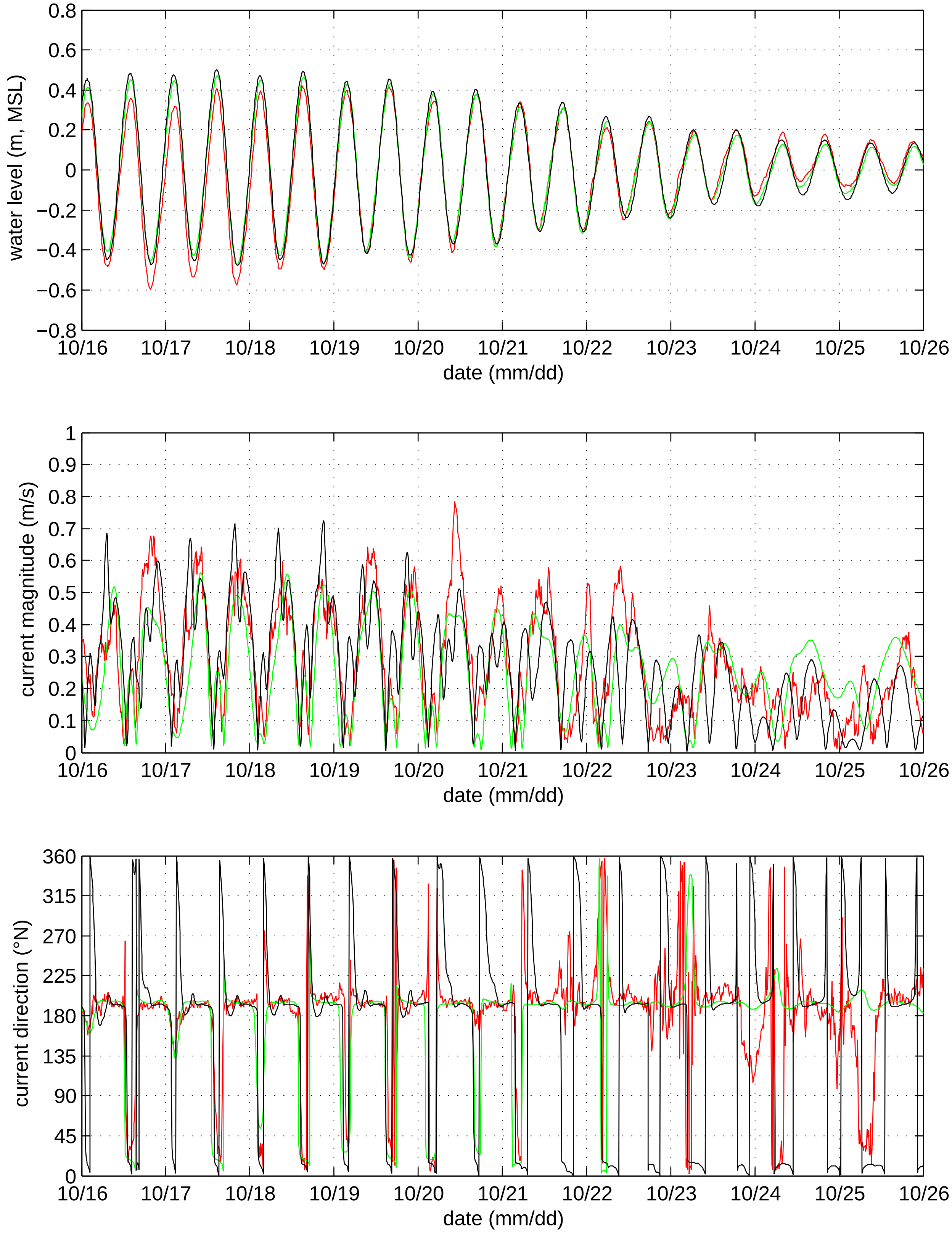


Strait of Gibraltar hydrodynamic flow model Typical velocity field for ebb situation Red lines indicate the boundary locations of the detail model	model setup	Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 3.4c

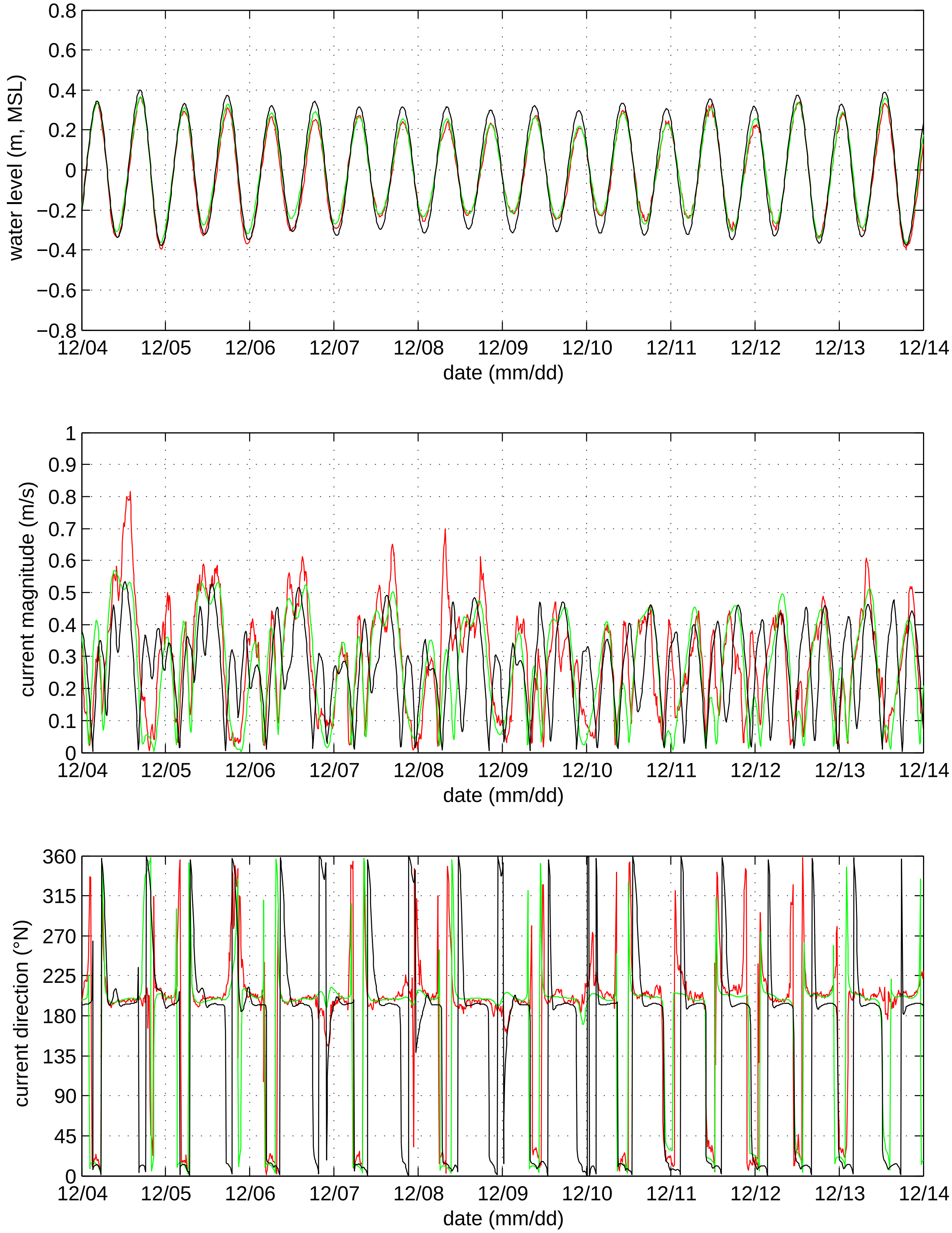




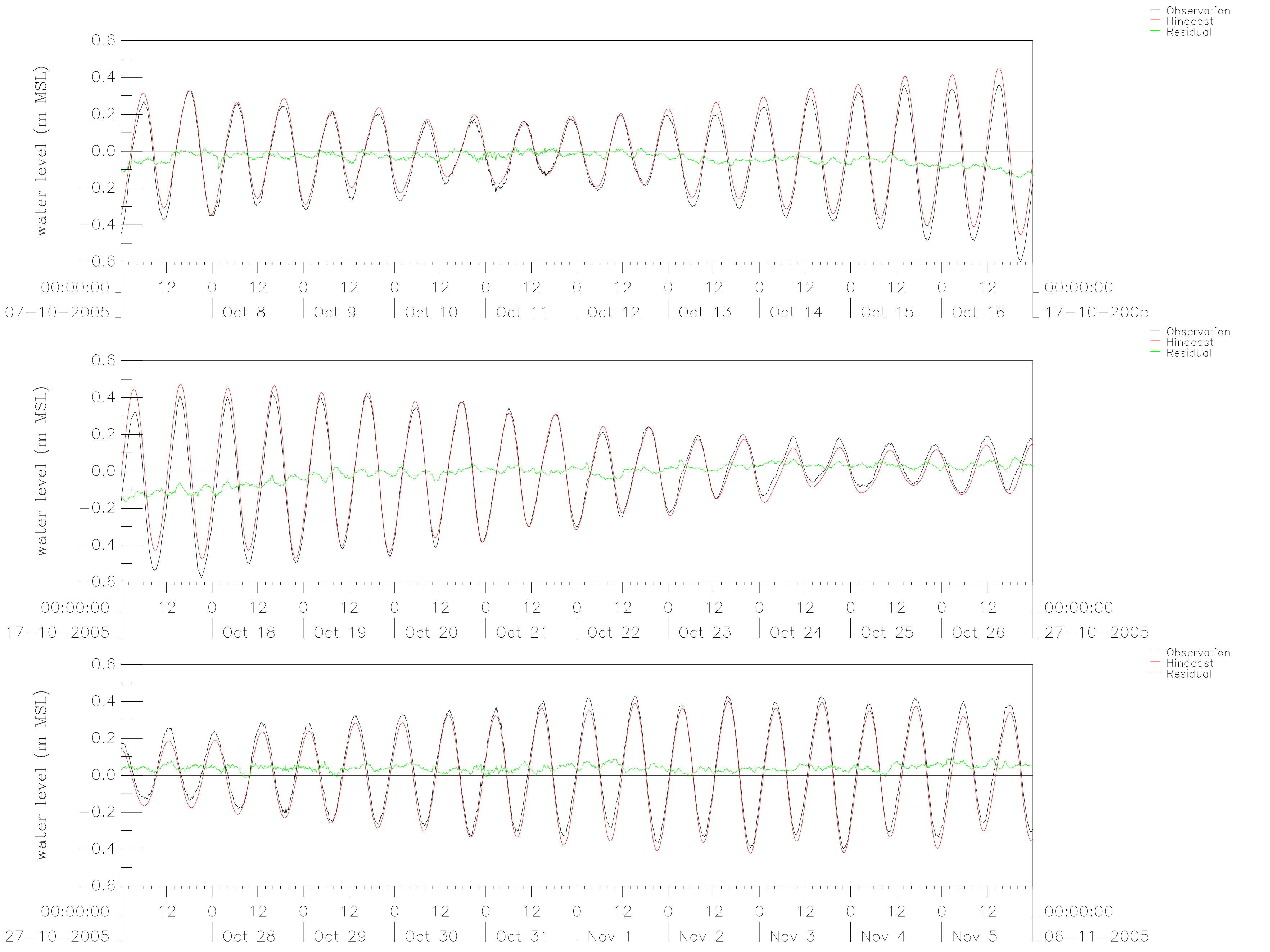
Eddy formation east of Europa Point Adcp locations (green) Current magnitude and velocity vectors	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 3.5



ADCP measurements vs Delft3D computation results at location ADCP south1. adcp (red), computed (black), hindcast (green)	Delft3D	g20
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig 3.6



ADCP measurements vs Delft3D computation results at location ADCP south2. adcp (red), computed (black), hindcast (green)	Delft3D	12a
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig 3.7



WL | DELFT HYDRAULICS

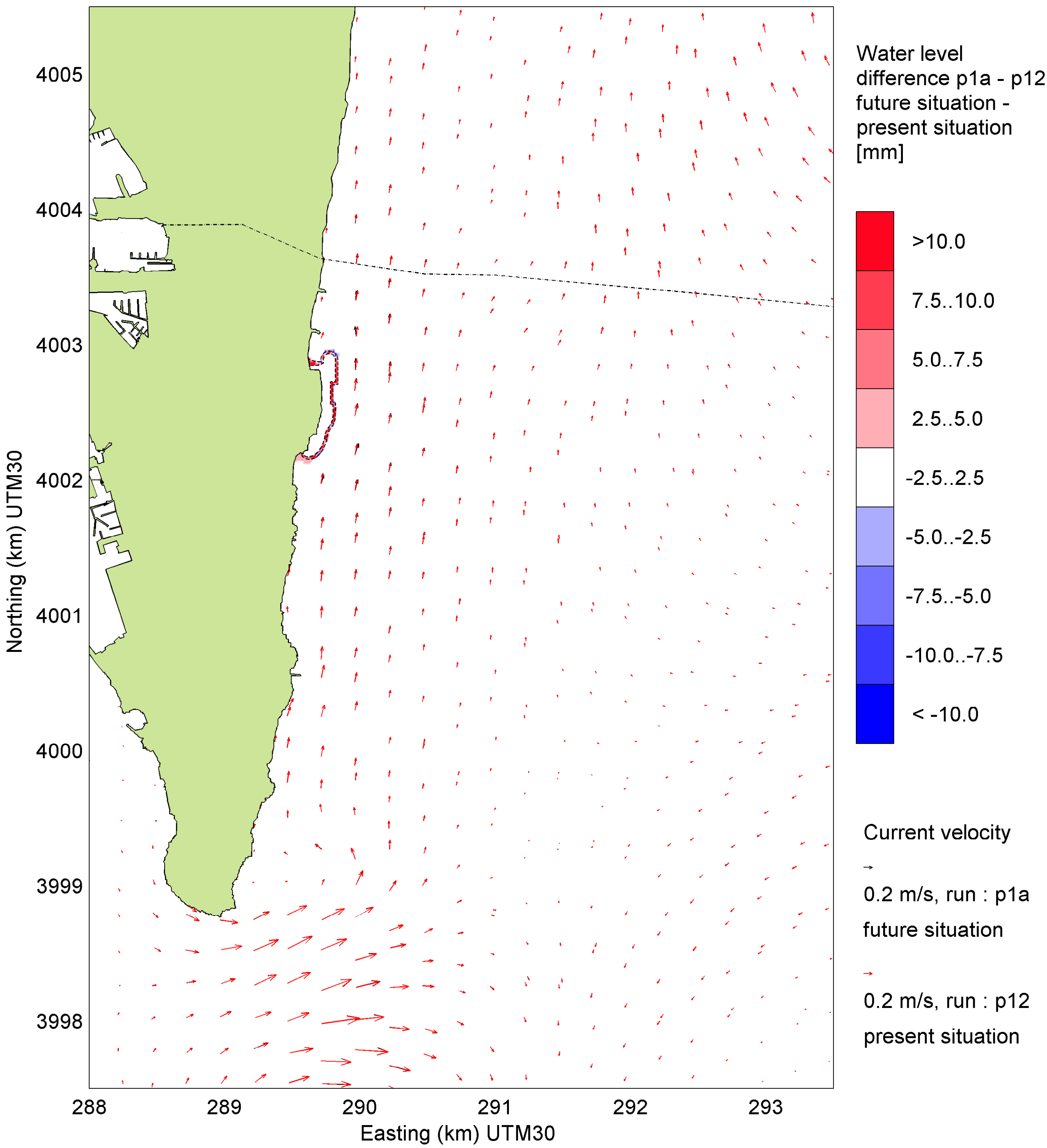
Gibraltar Flow Study
Observed, hindcast and residual water level
ADCP: South, period 1

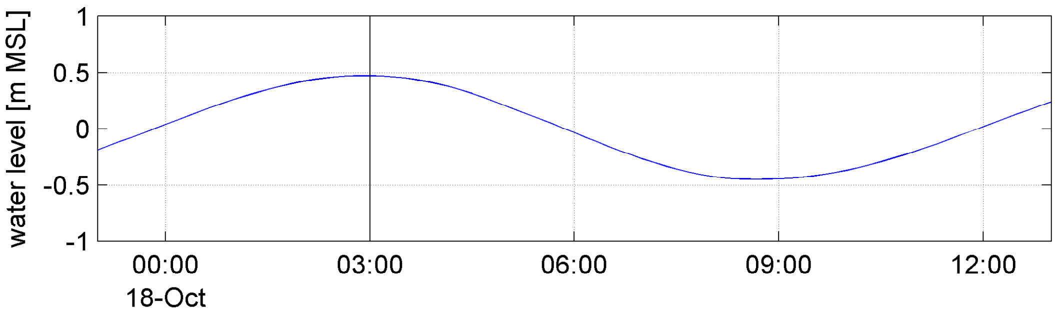
H4725

Tide v3.02

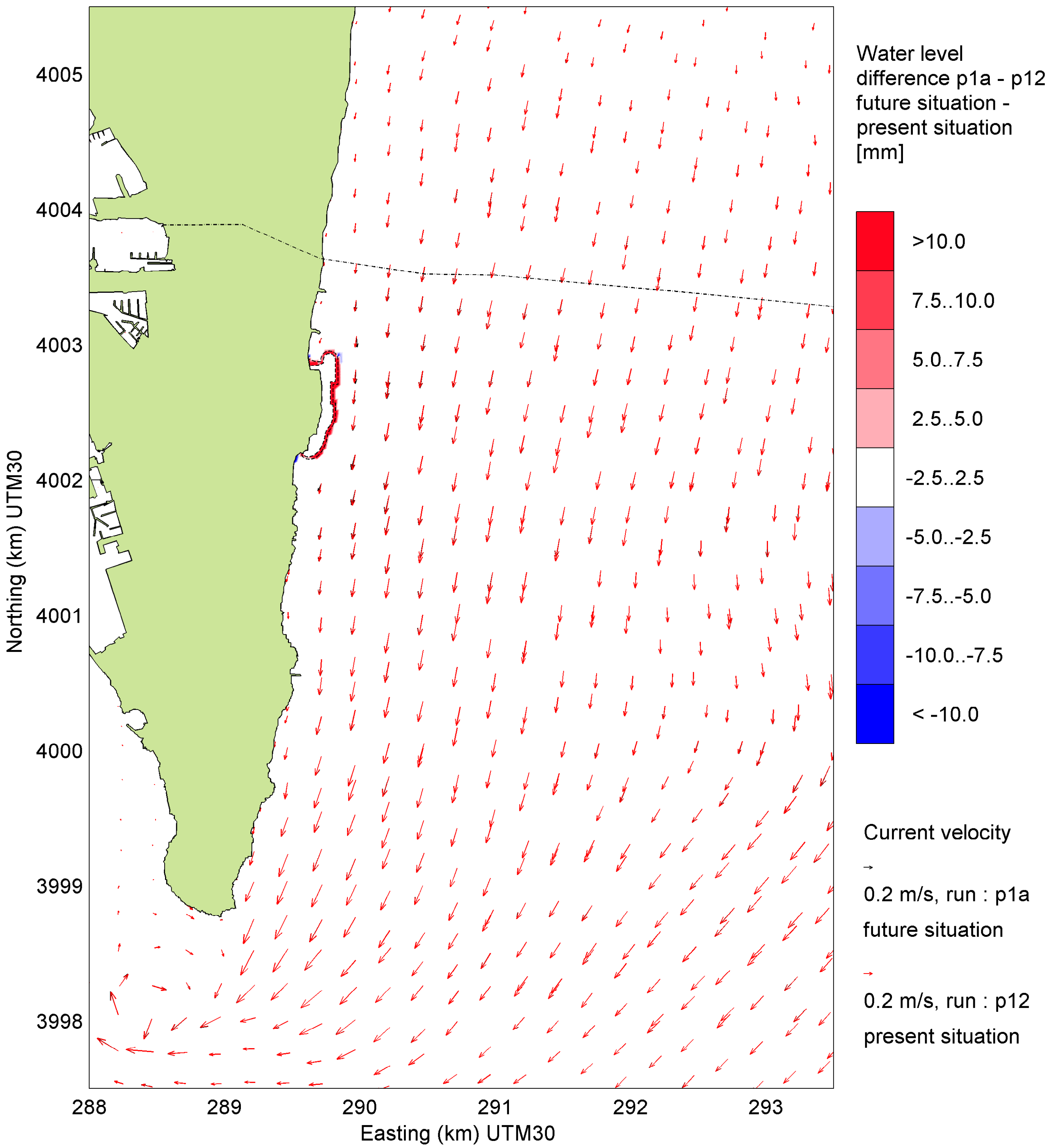
session 3

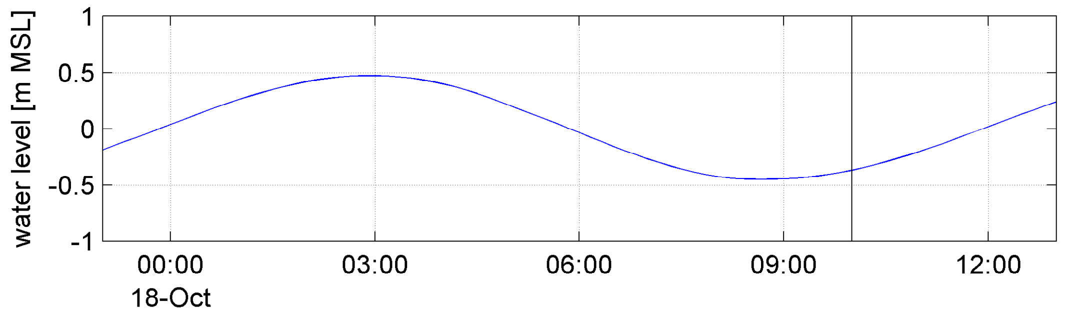
Fig. 4.1



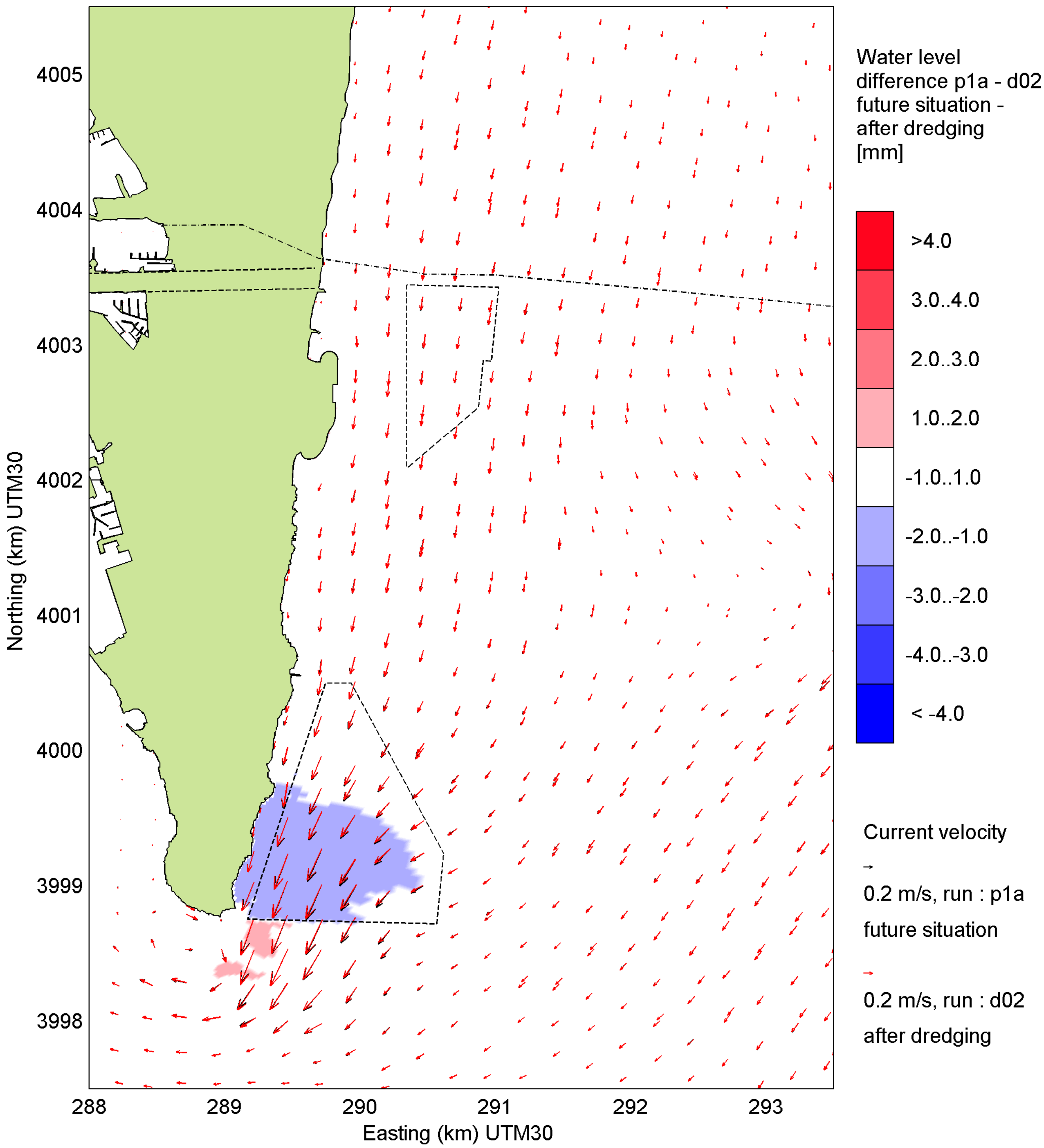


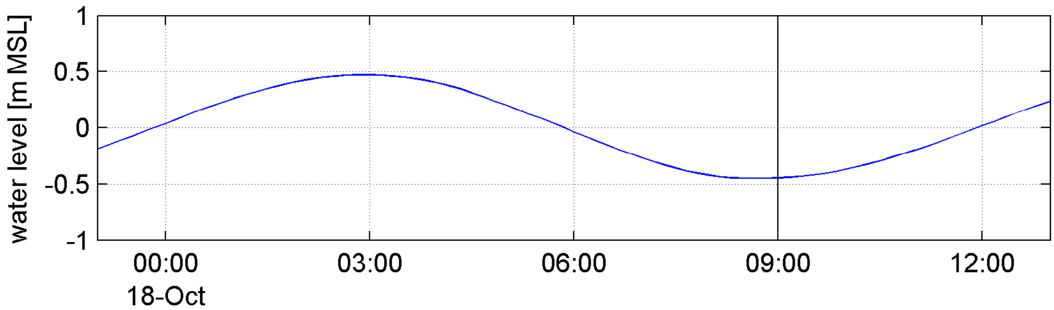
Water level difference (p1a - p12) and velocity vectors, with: p1a : future situation p12 : present situation	H4725	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	Aug 2006	Fig. 4.2a



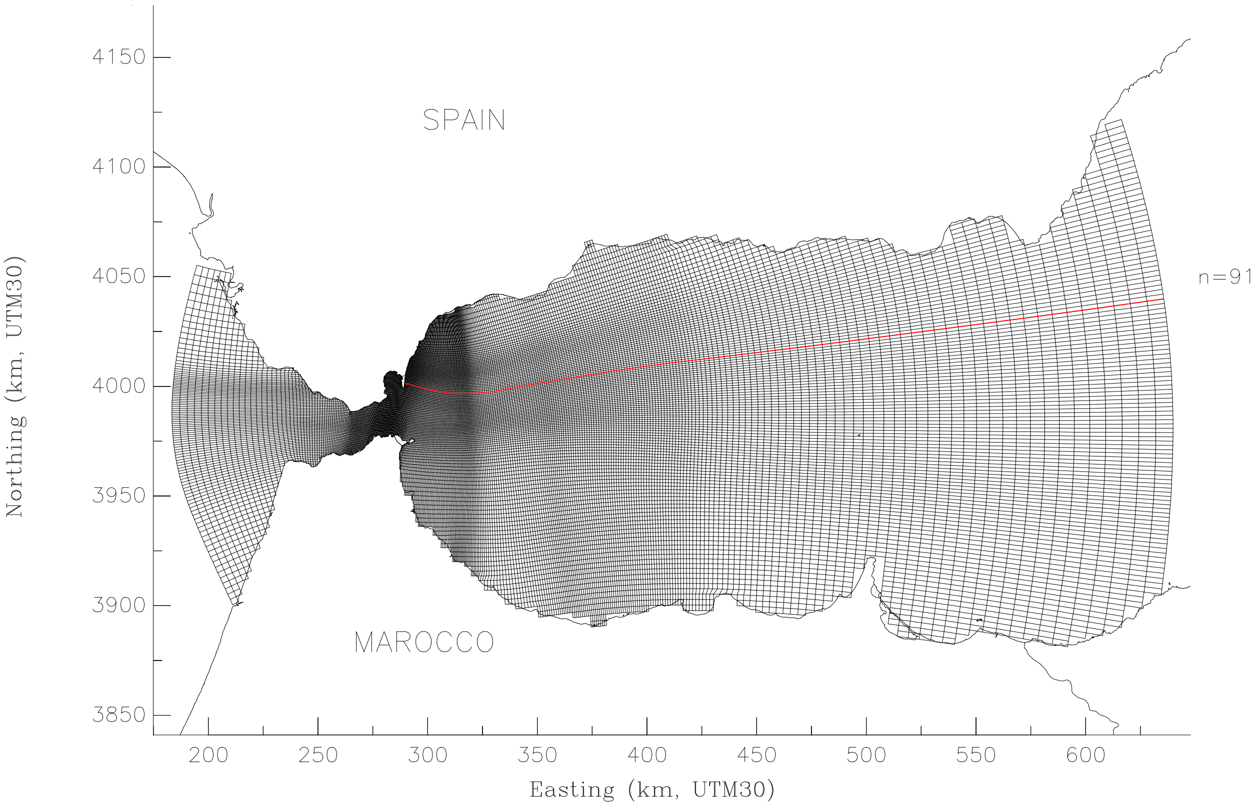


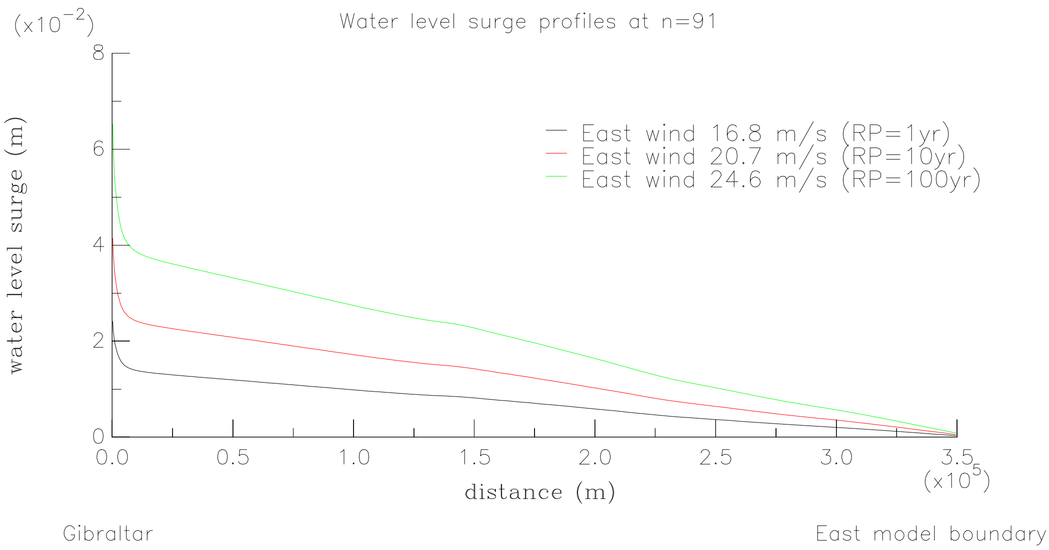
Water level difference (p1a - p12) and velocity vectors, with: p1a : future situation p12 : present situation	H4725	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	Aug 2006	Fig. 4.2b





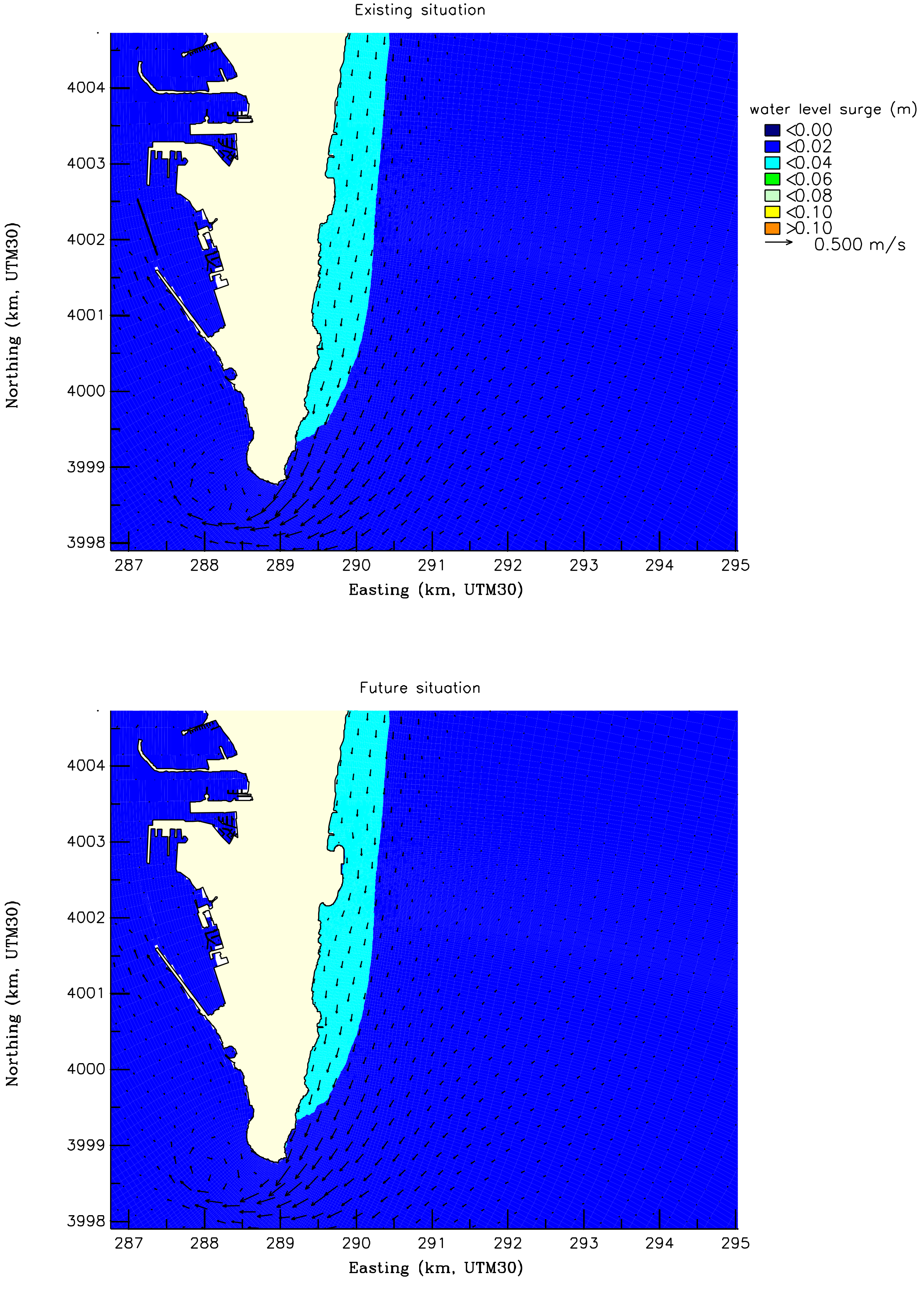
Water level difference (p1a - d02) and velocity vectors, with: p1a: future situation d02: future situation with 0.9m dredged in borrow area North and 0.4m in borrow area South	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 4.3





Top: computational grid of overall model
Bottom: water level surge profiles for three return periods
from the east model boundary to the east coast of Gibraltar (n=91)

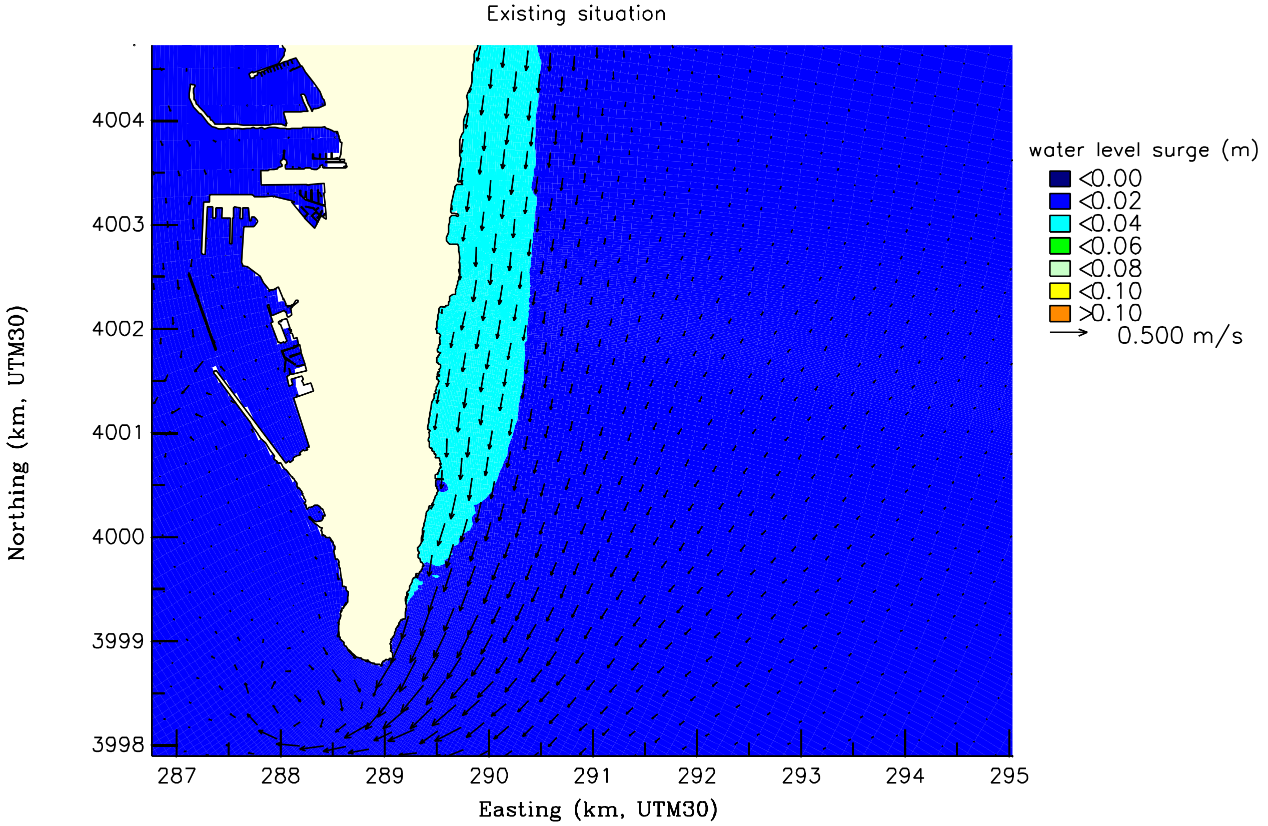
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.1

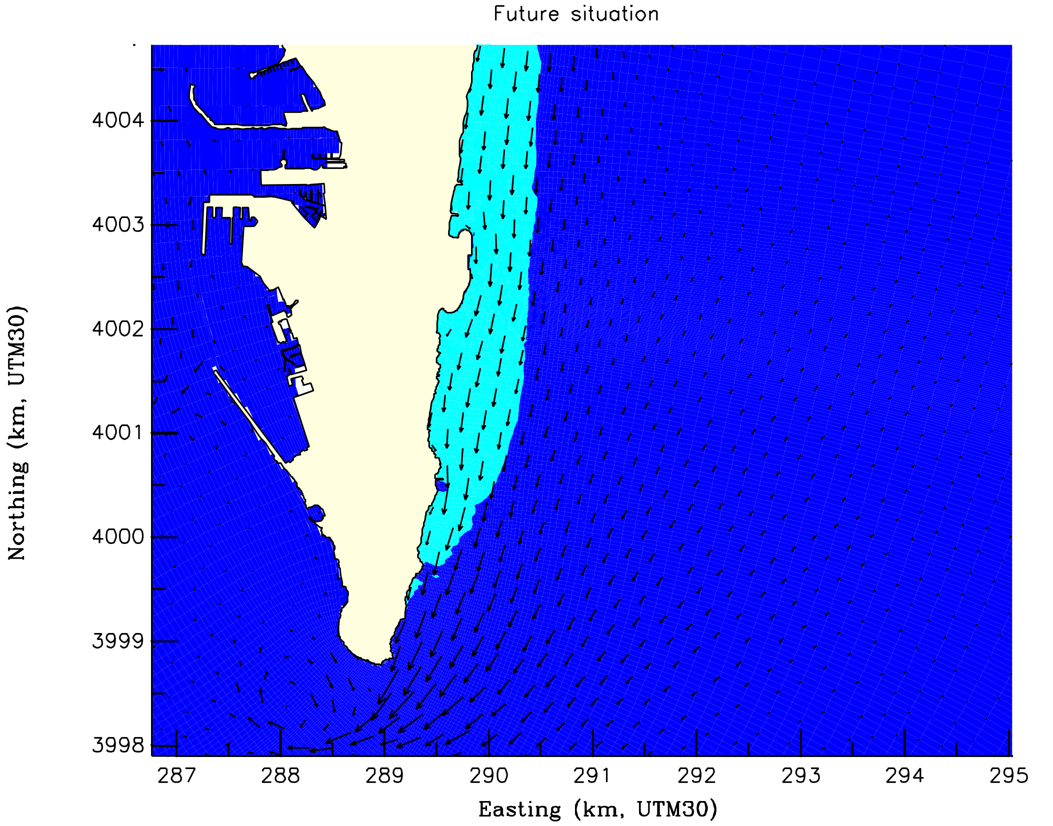


Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=1yr) for the present (top) and future (bottom) situation

E 16.8m/s	RP=1yr
Gibraltar Flow Study	
H4725	Fig. 5.2a

WL | Delft Hydraulics





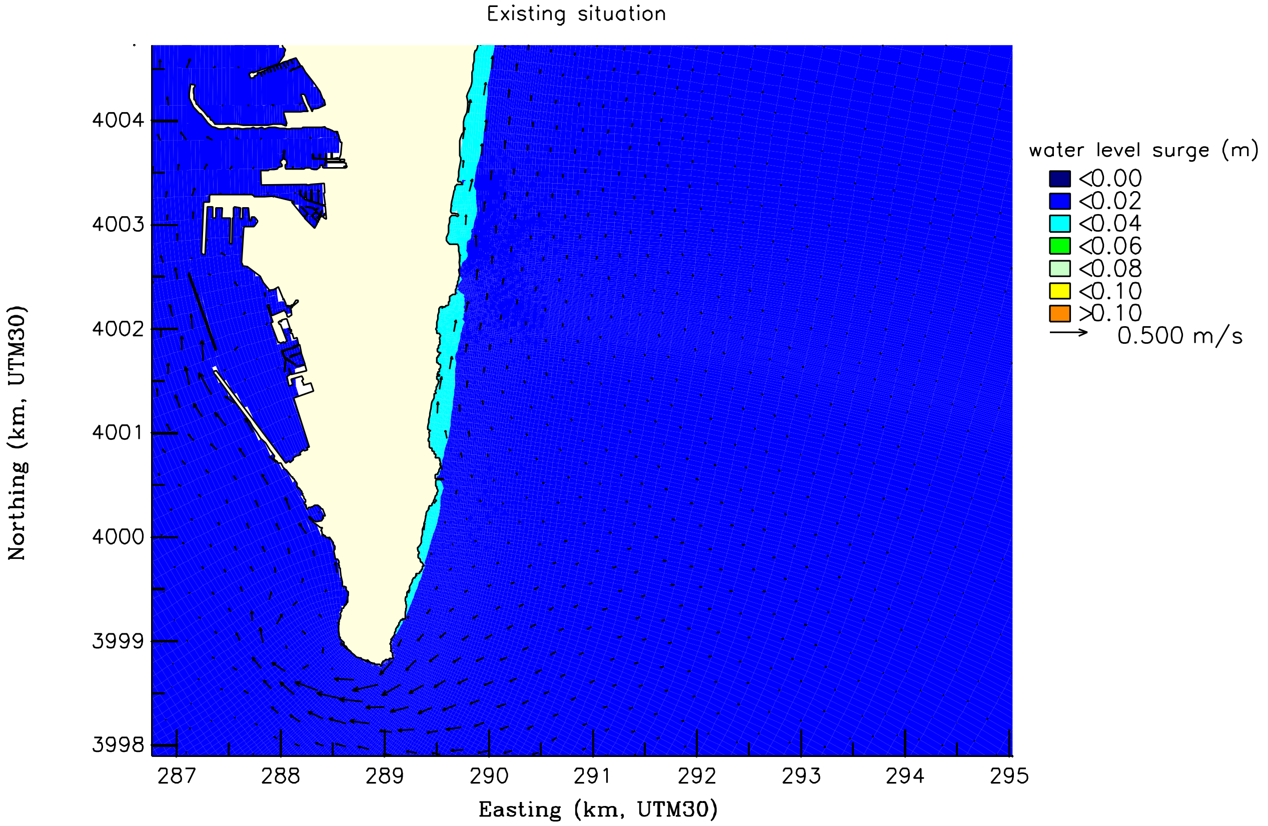
Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=1yr) for the present (top) and future (bottom) situation

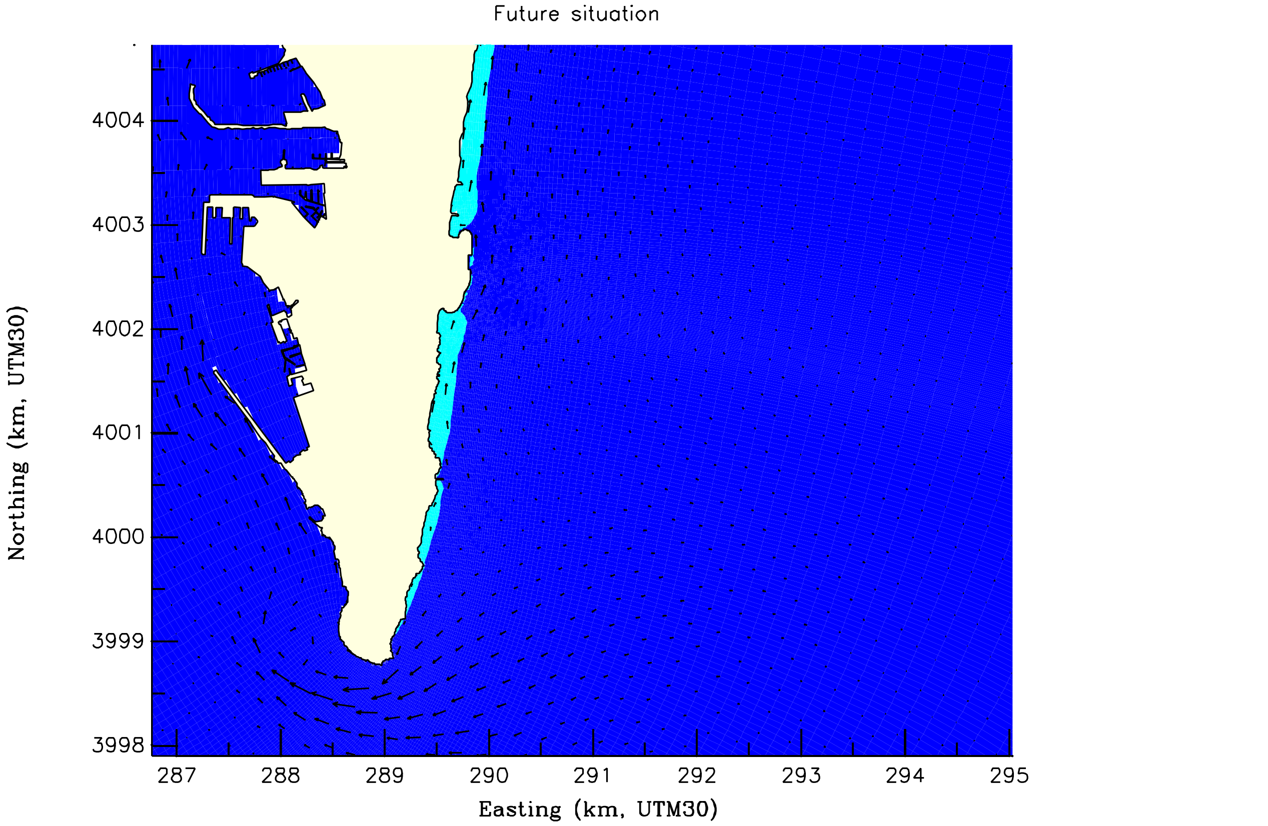
ENE 16.8m/s | RP=1yr

Gibraltar Flow Study

WL | Delft Hydraulics

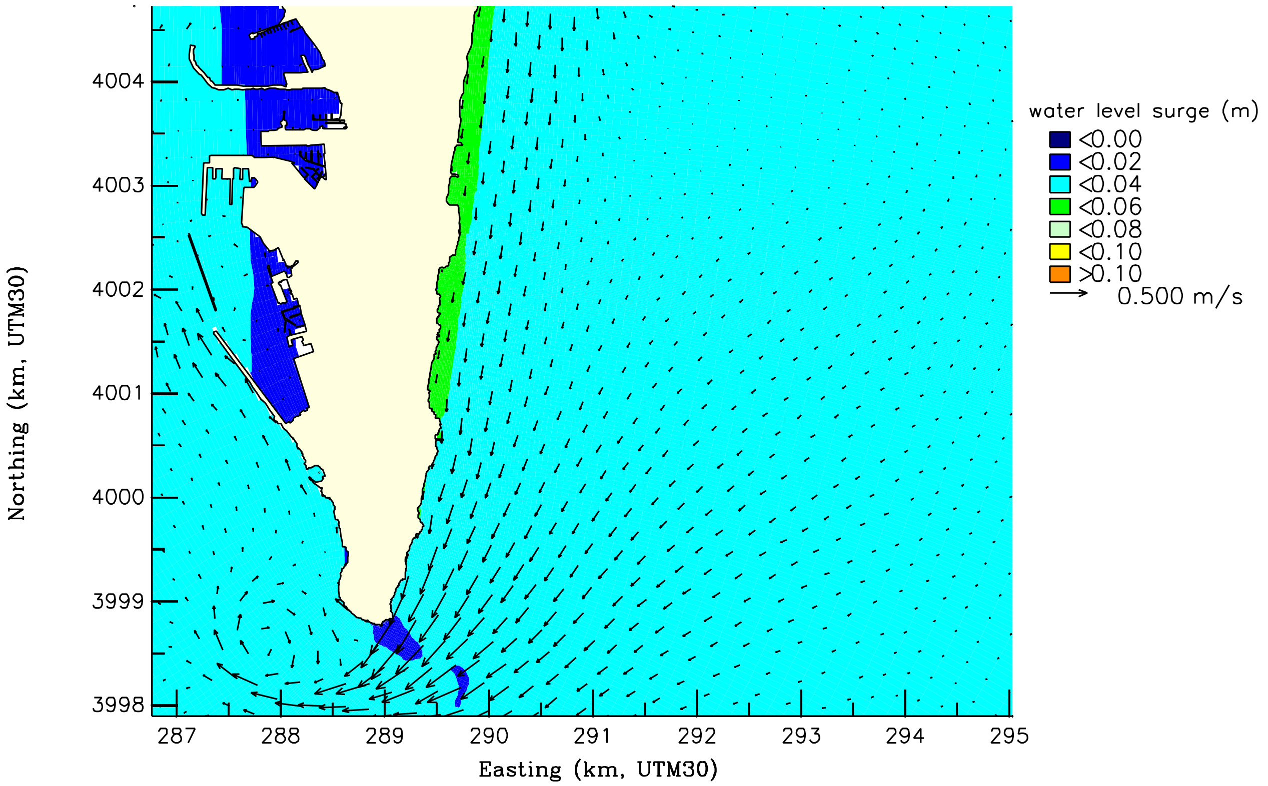
H4725 | Fig. 5.2b



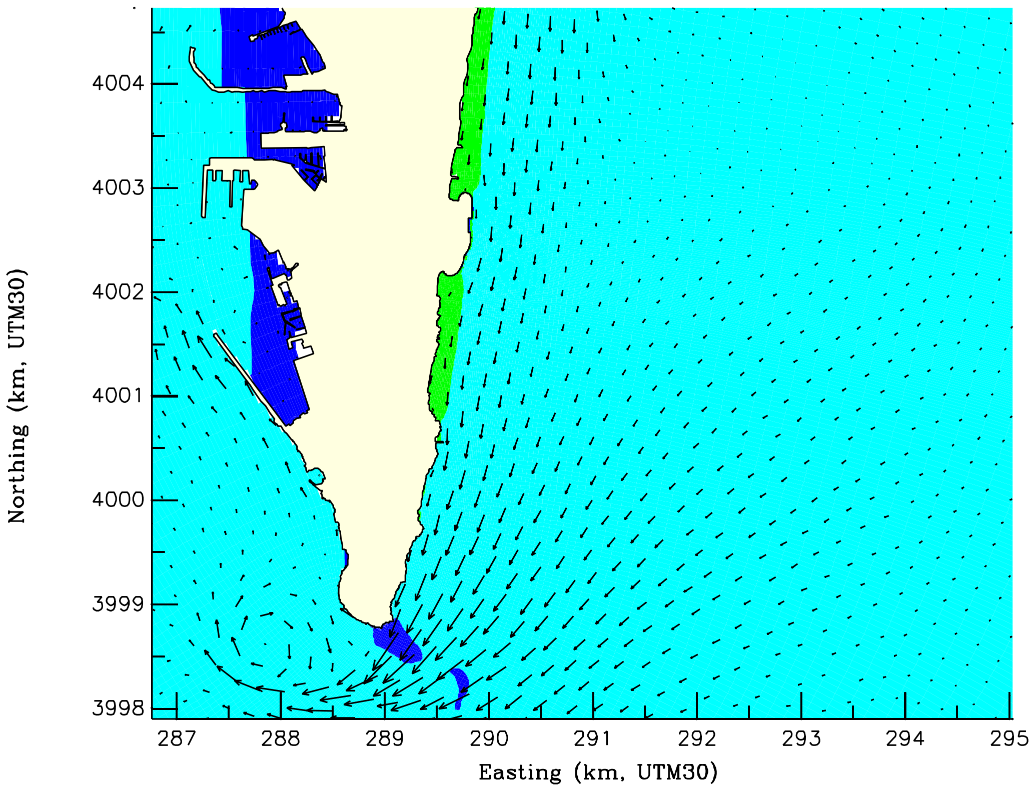


Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=1yr) for the present (top) and future (bottom) situation	ESE 16.8m/s	RP=1yr
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.2c

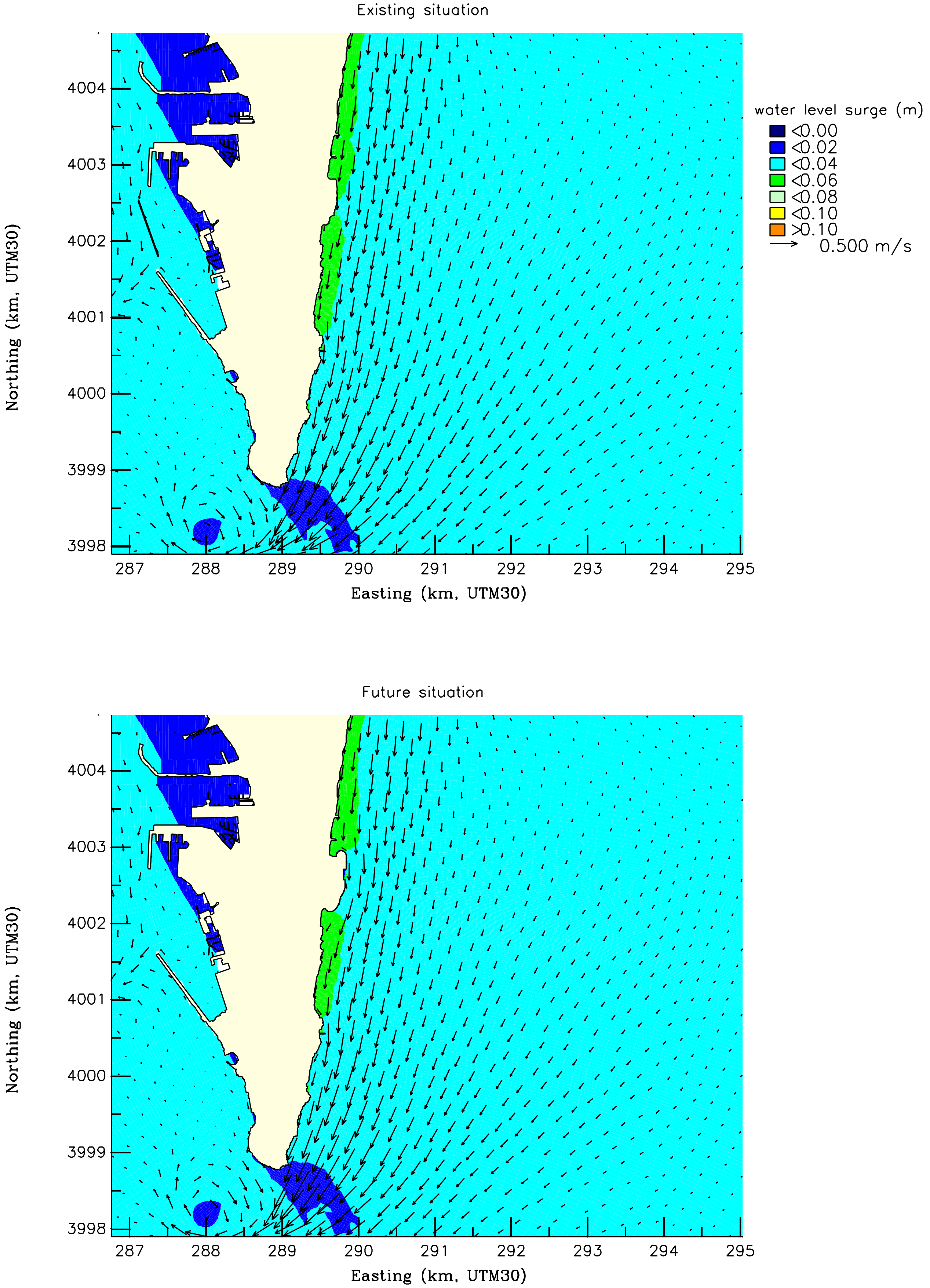
Existing situation



Future situation

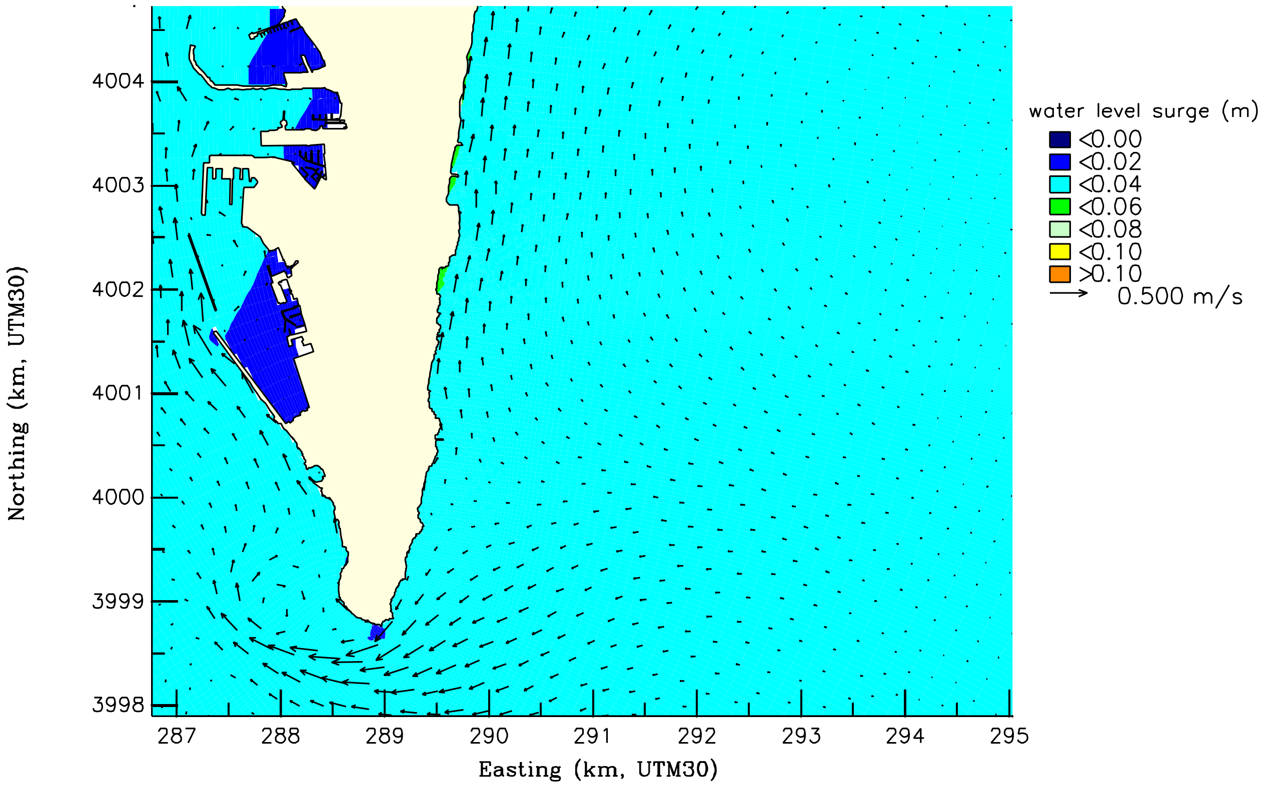


Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=10yr) for the present (top) and future (bottom) situation	E 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.3a

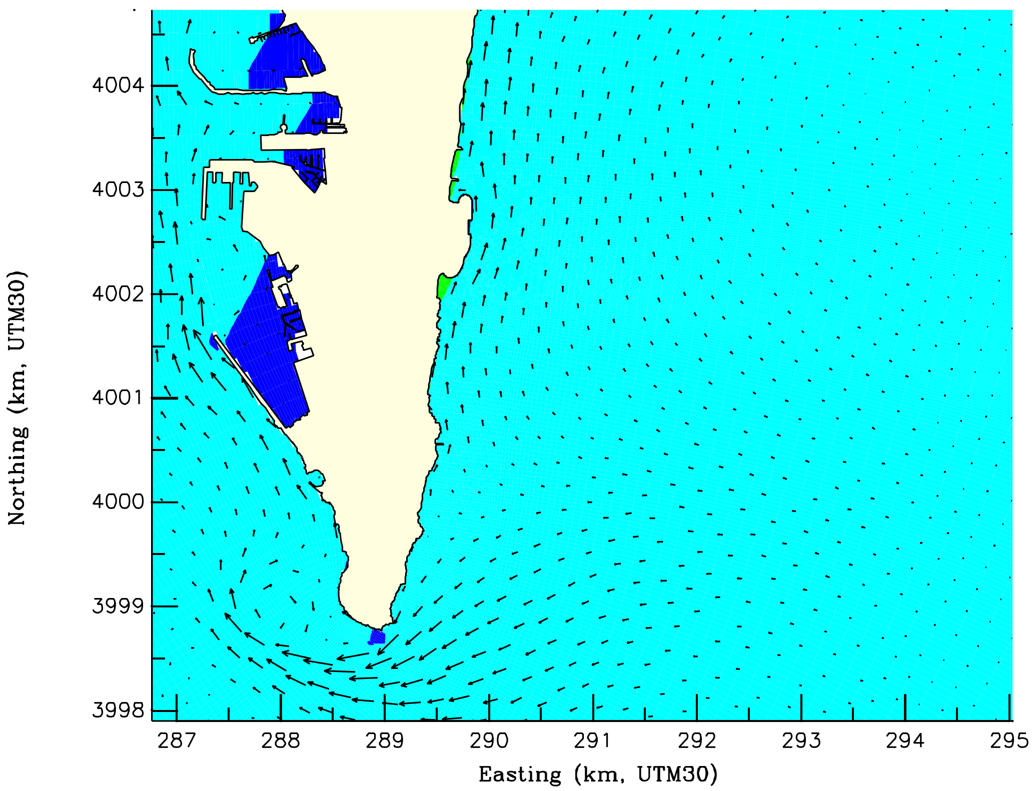


Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=10yr) for the present (top) and future (bottom) situation	ENE 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.3b

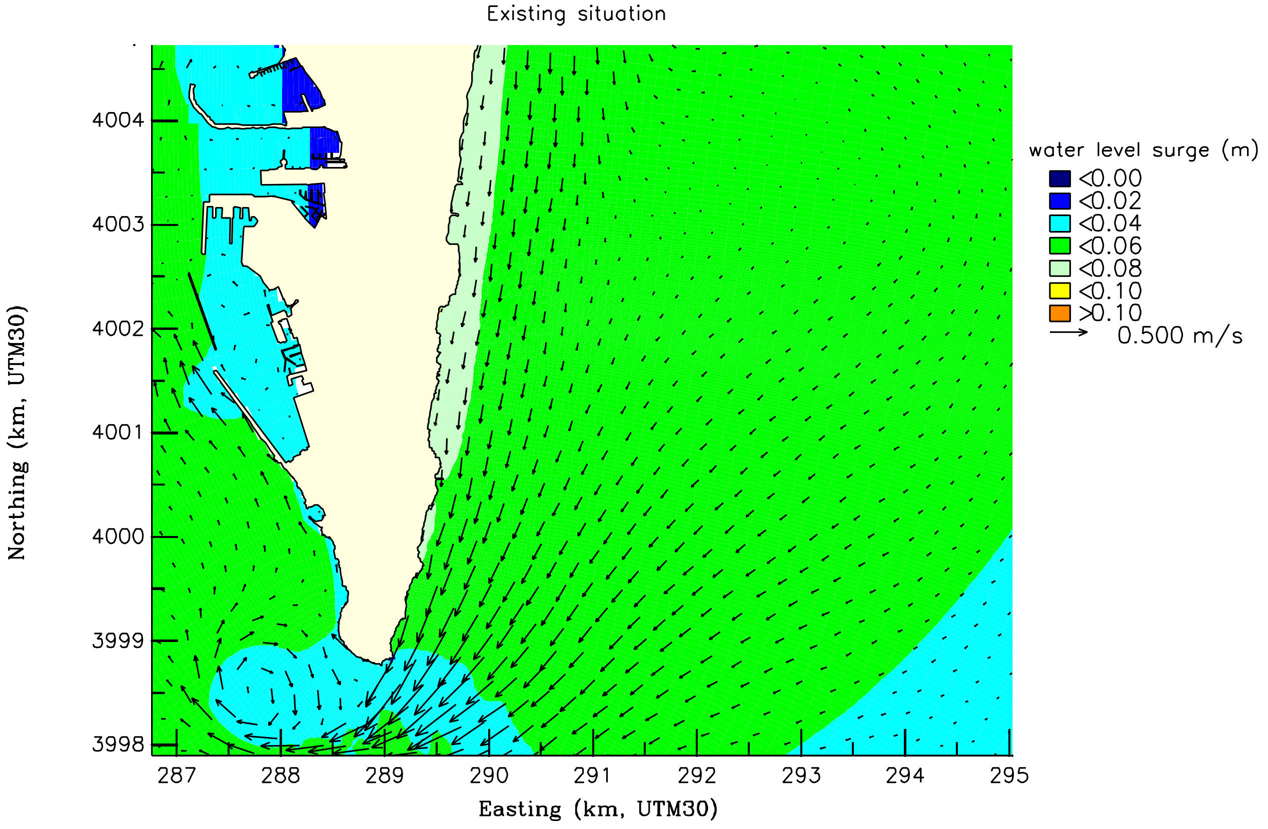
Existing situation

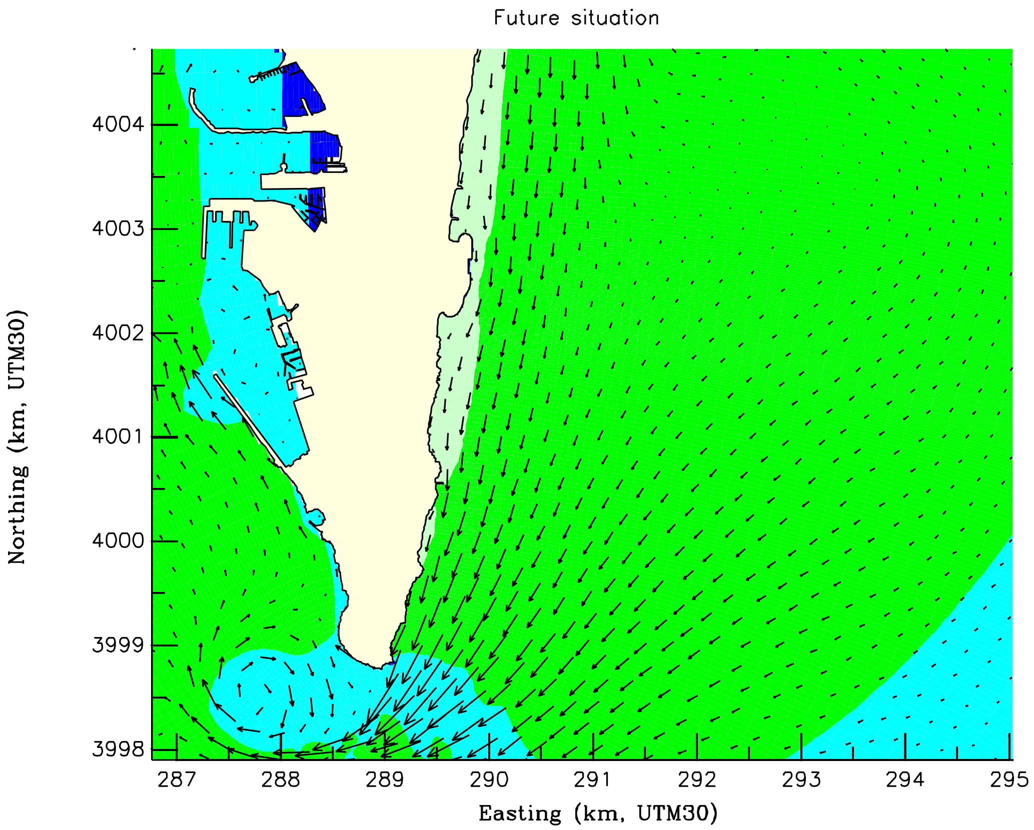


Future situation

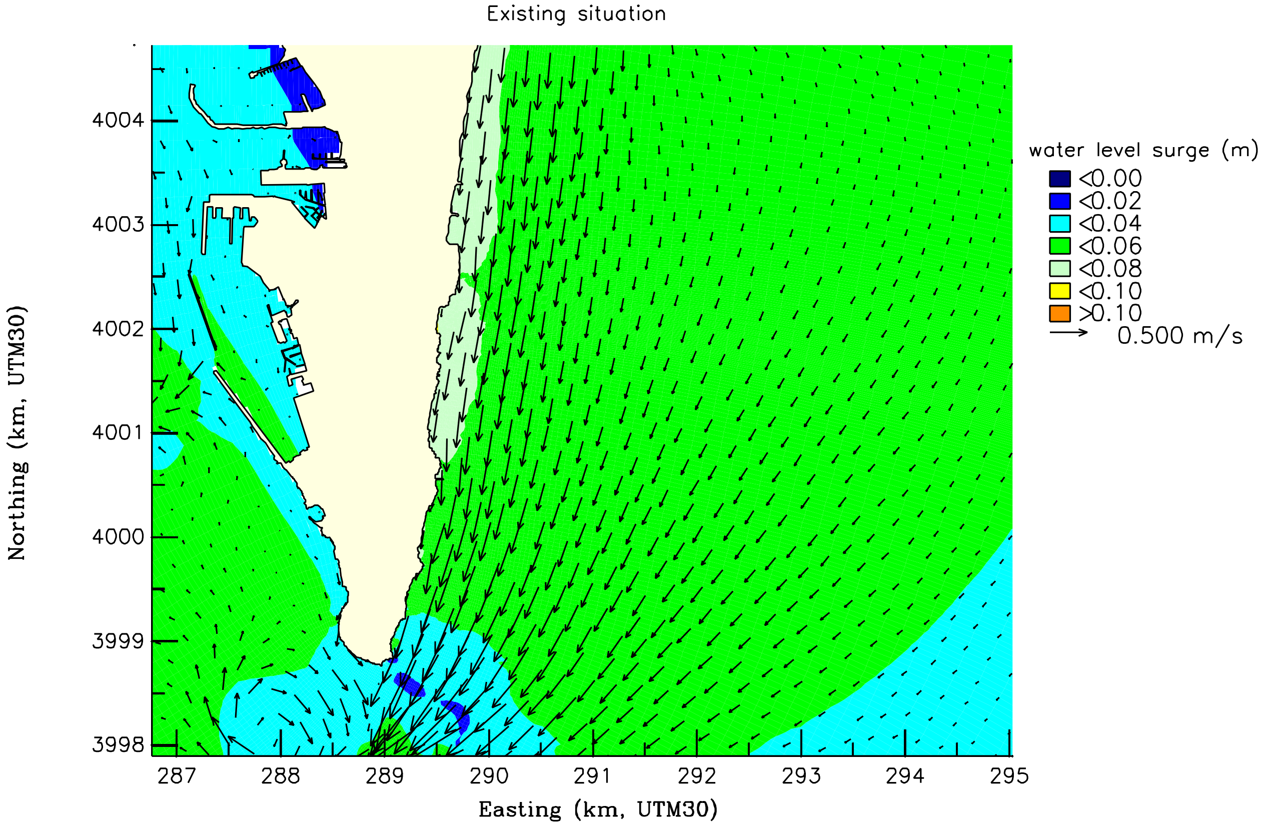


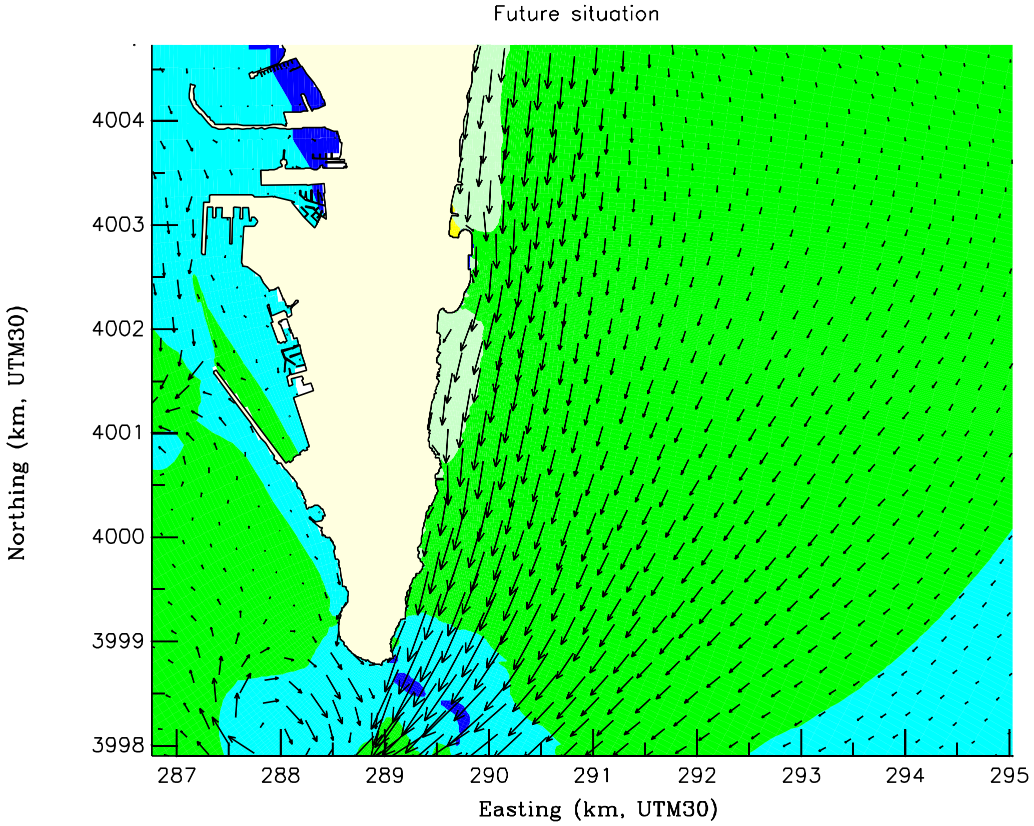
Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=10yr) for the present (top) and future (bottom) situation	ESE 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.3c



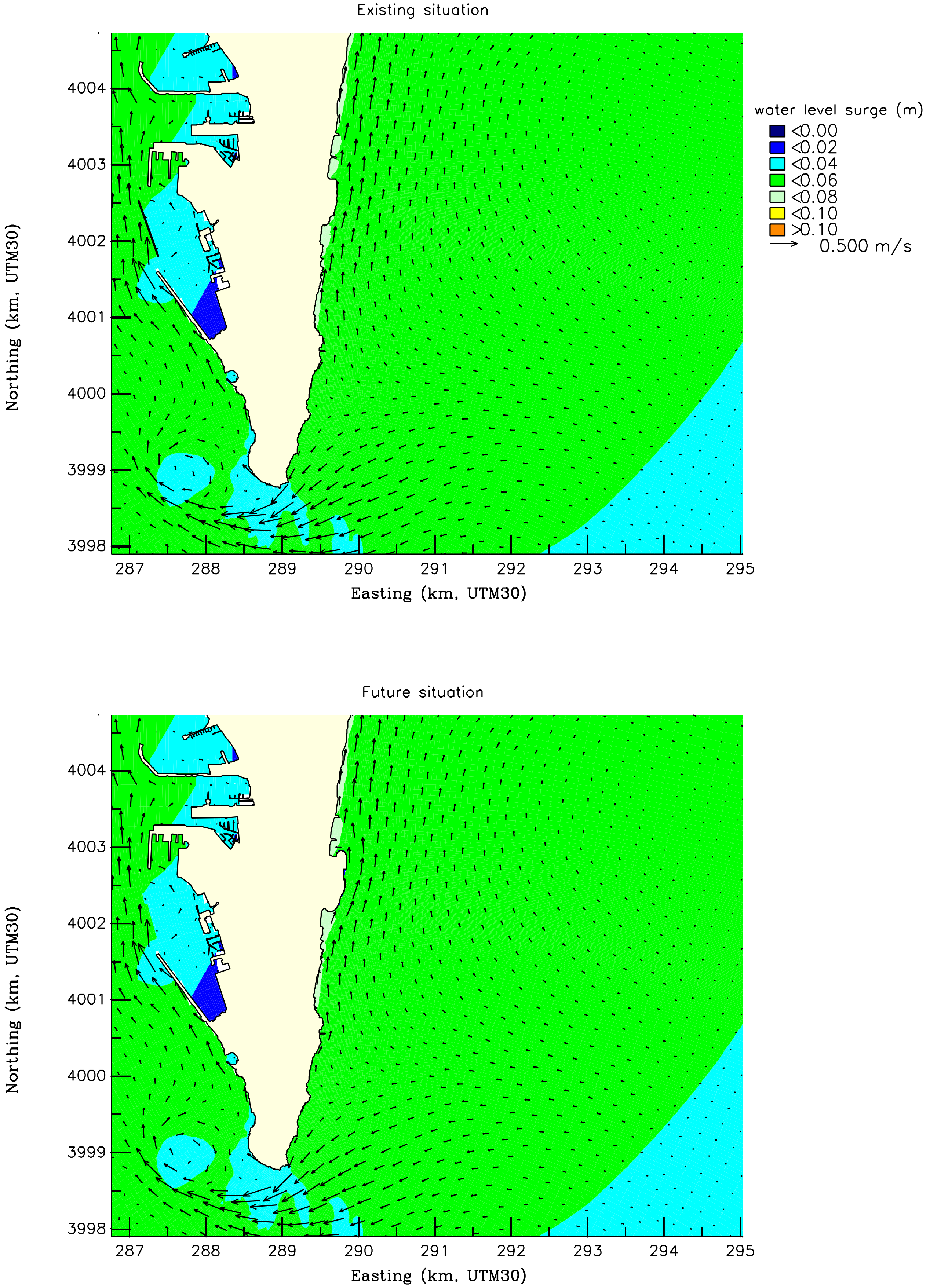


Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=100yr) for the present (top) and future (bottom) situation	E 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.4a

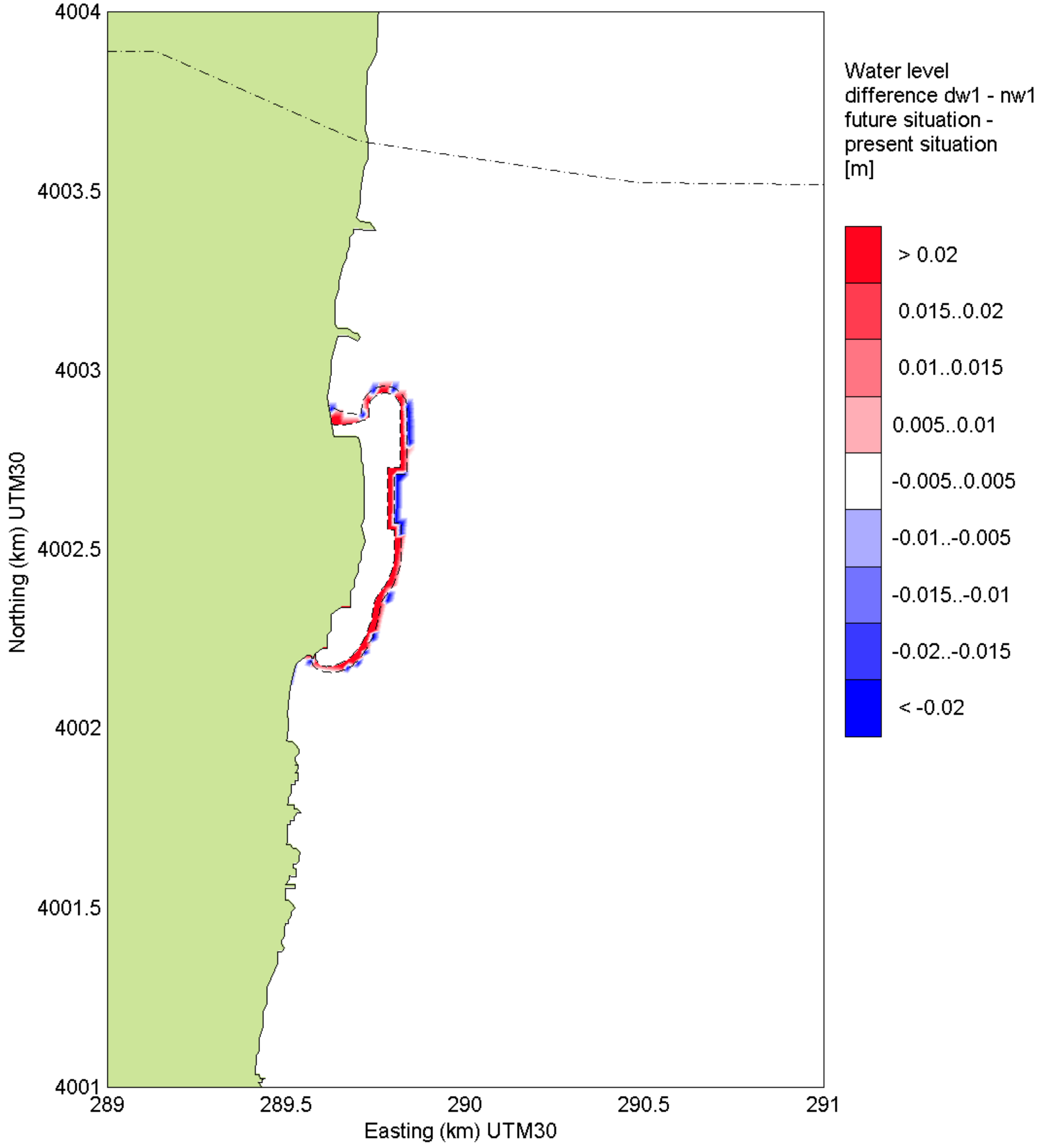




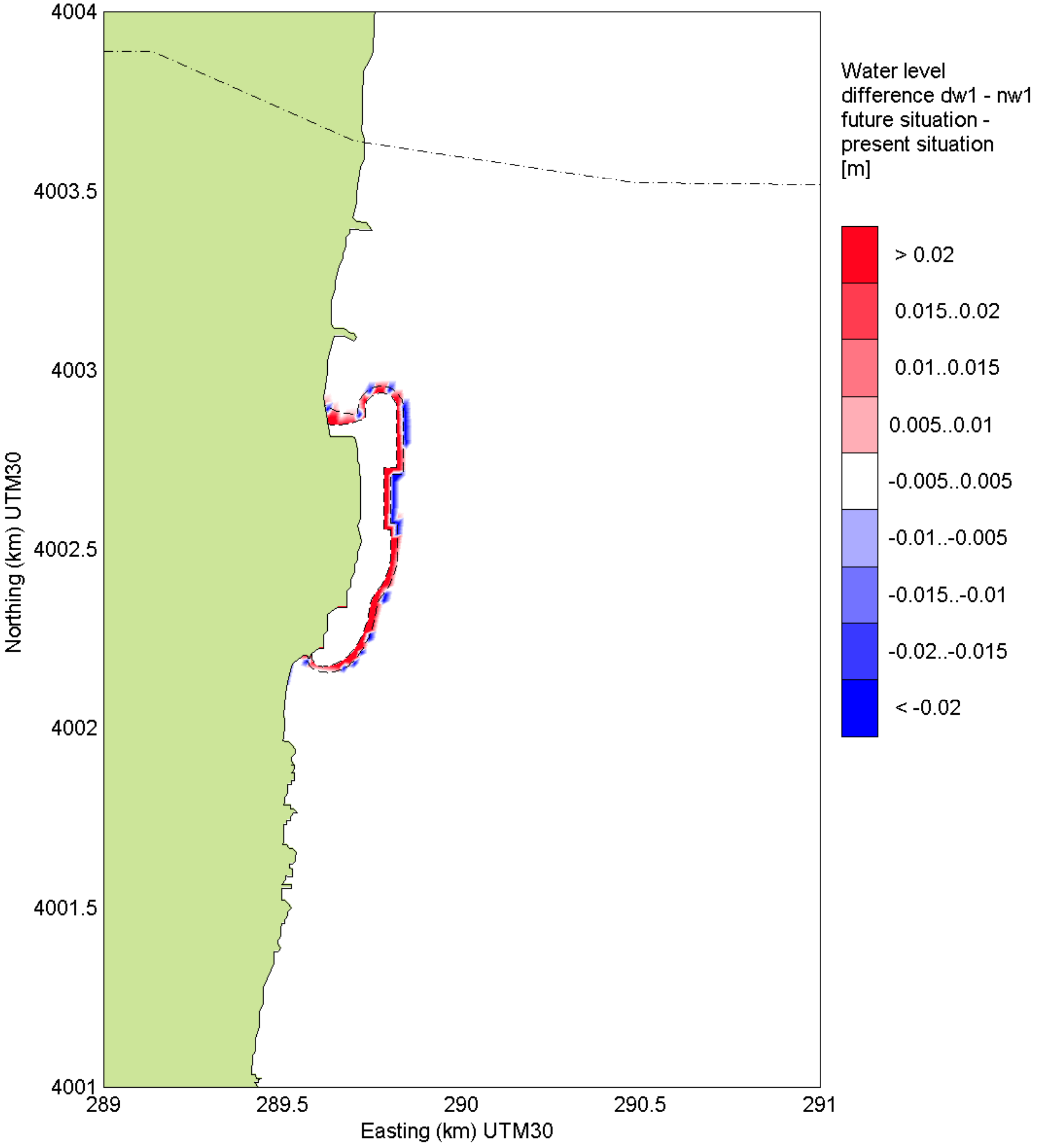
Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=100yr) for the present (top) and future (bottom) situation	ENE 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.4b



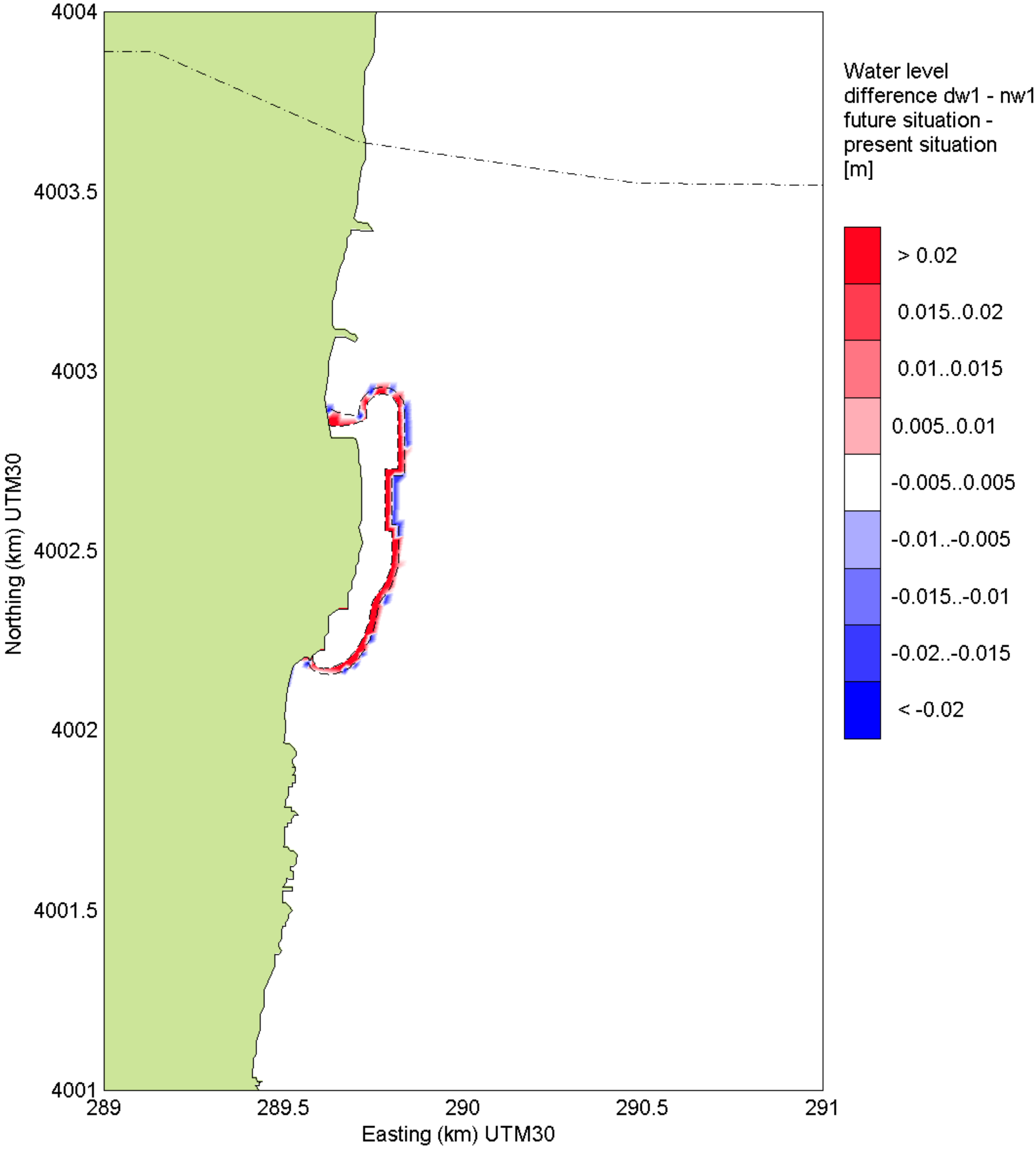
Computed water level surges and flow vectors at the peak of an extreme E storm event (RP=100yr) for the present (top) and future (bottom) situation	ESE 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | Delft Hydraulics	H4725	Fig. 5.4c



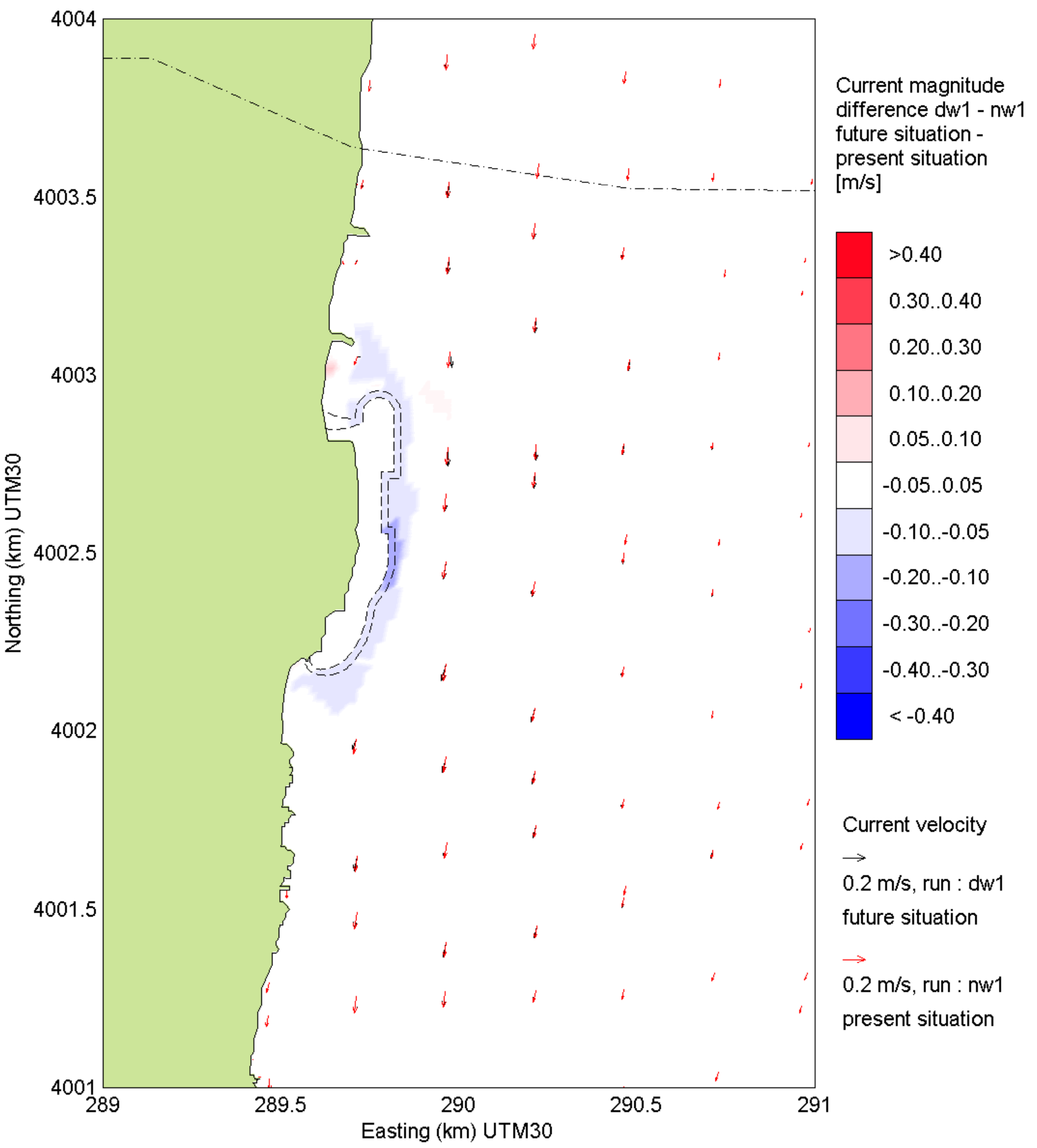
Water level difference (dw1 - nw1), with: dw1: future situation nw1: present situation	E wind 16.8m/s	RP=1yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.5a



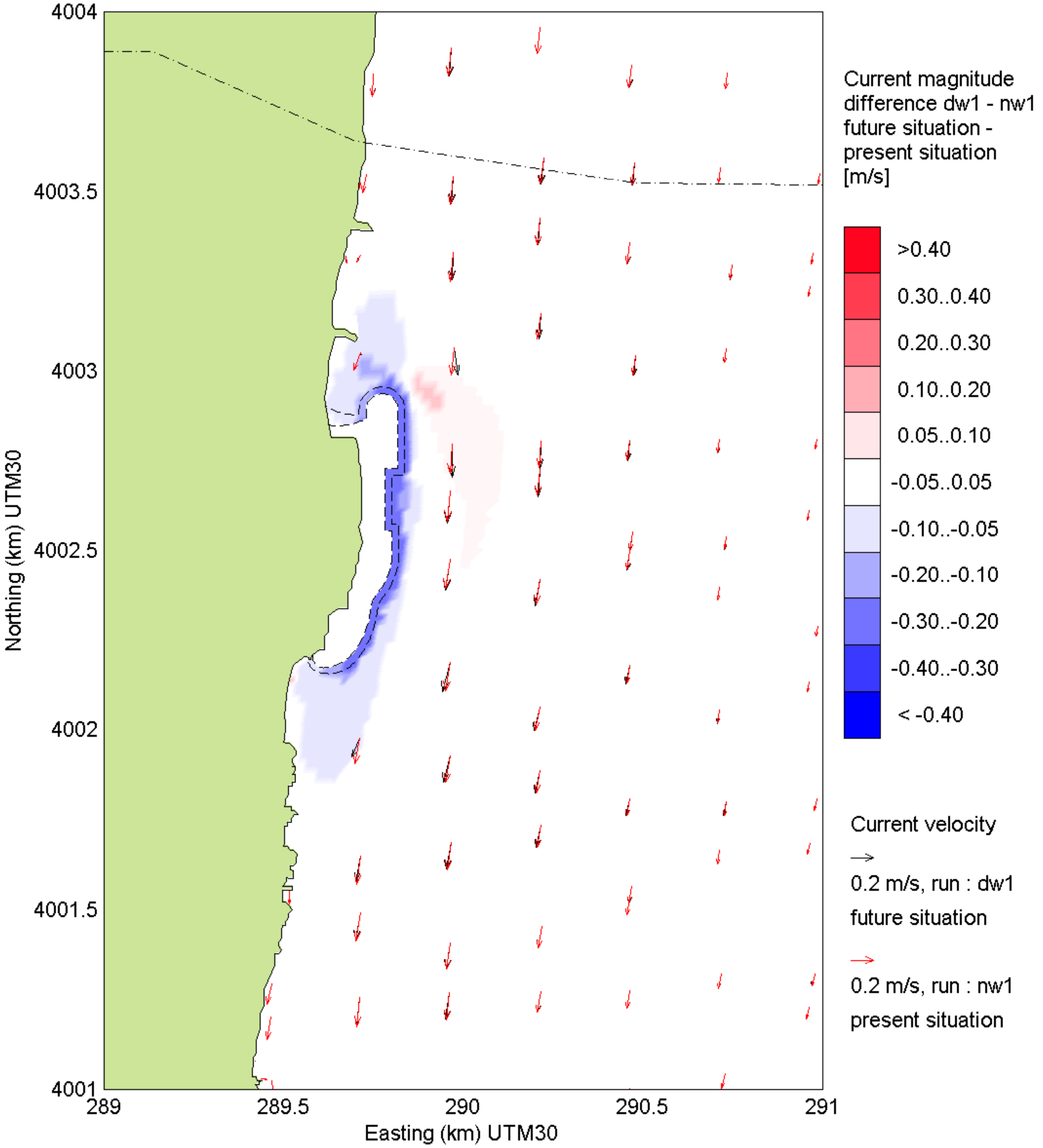
Water level difference (dw1 - nw1), with: dw1: future situation nw1: present situation	ENE wind 16.8m/s	RP=1yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.5b



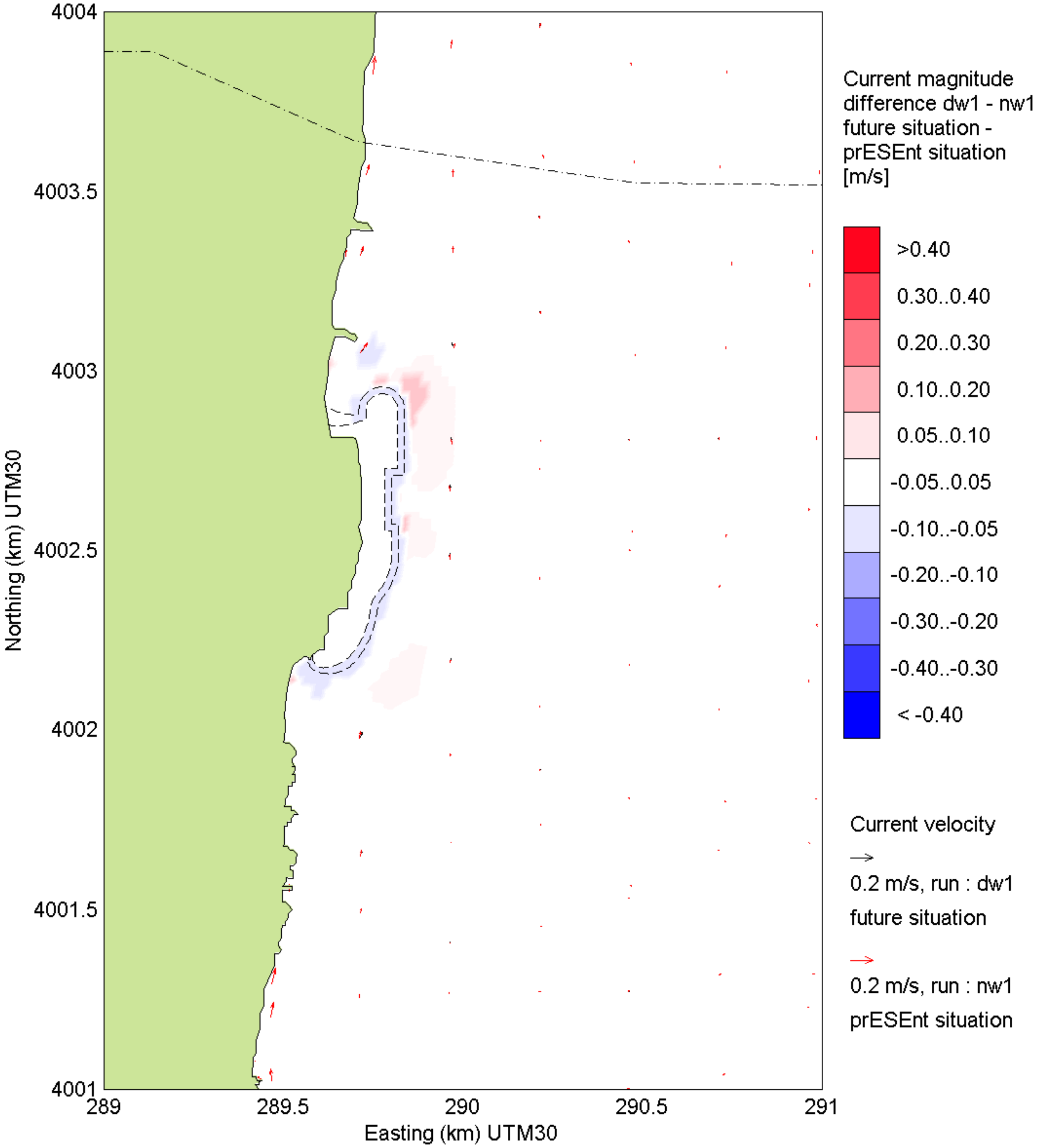
Water level difference (dw1 - nw1), with: dw1: future situation nw1: present situation	ESE wind 16.8m/s	RP=1yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.5c



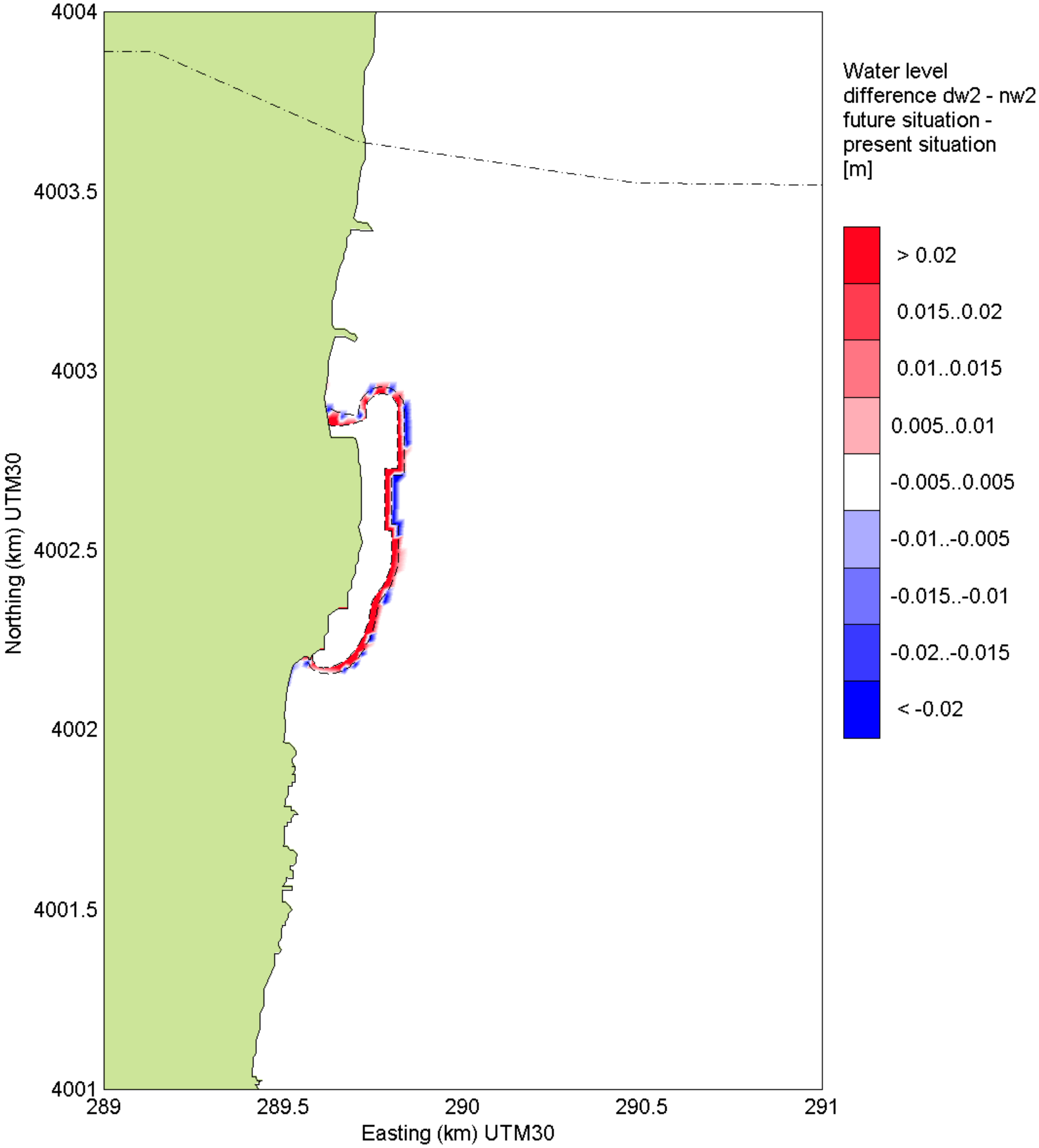
Current magnitude difference (dw1 - nw1) and velocity vectors, with: dw1: future situation nw1: present situation	E wind 16.8m/s	RP=1yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.6a



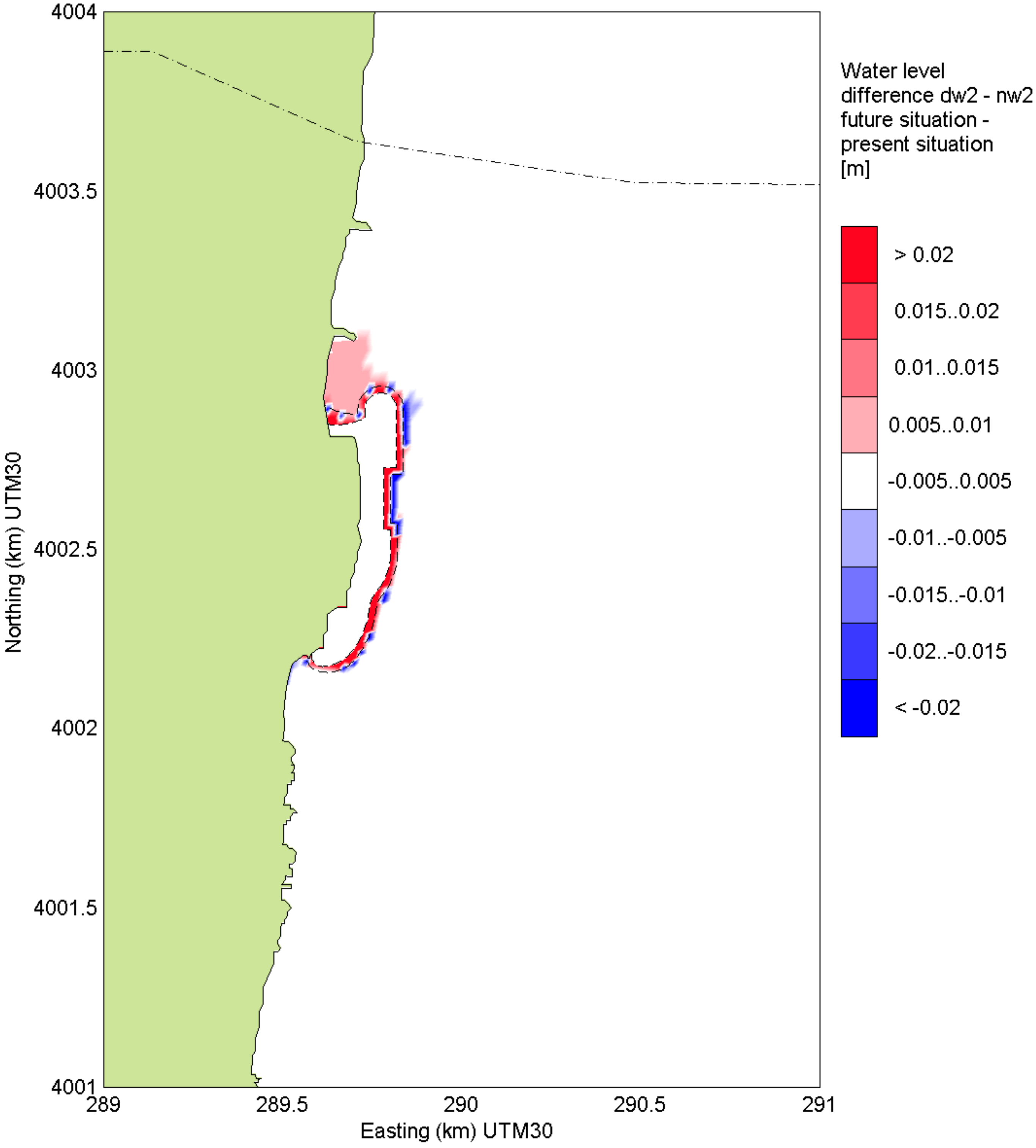
Current magnitude difference (dw1 - nw1) and velocity vectors, with: dw1: future situation nw1: present situation	ENE wind 16.8m/s	RP=1yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.6b



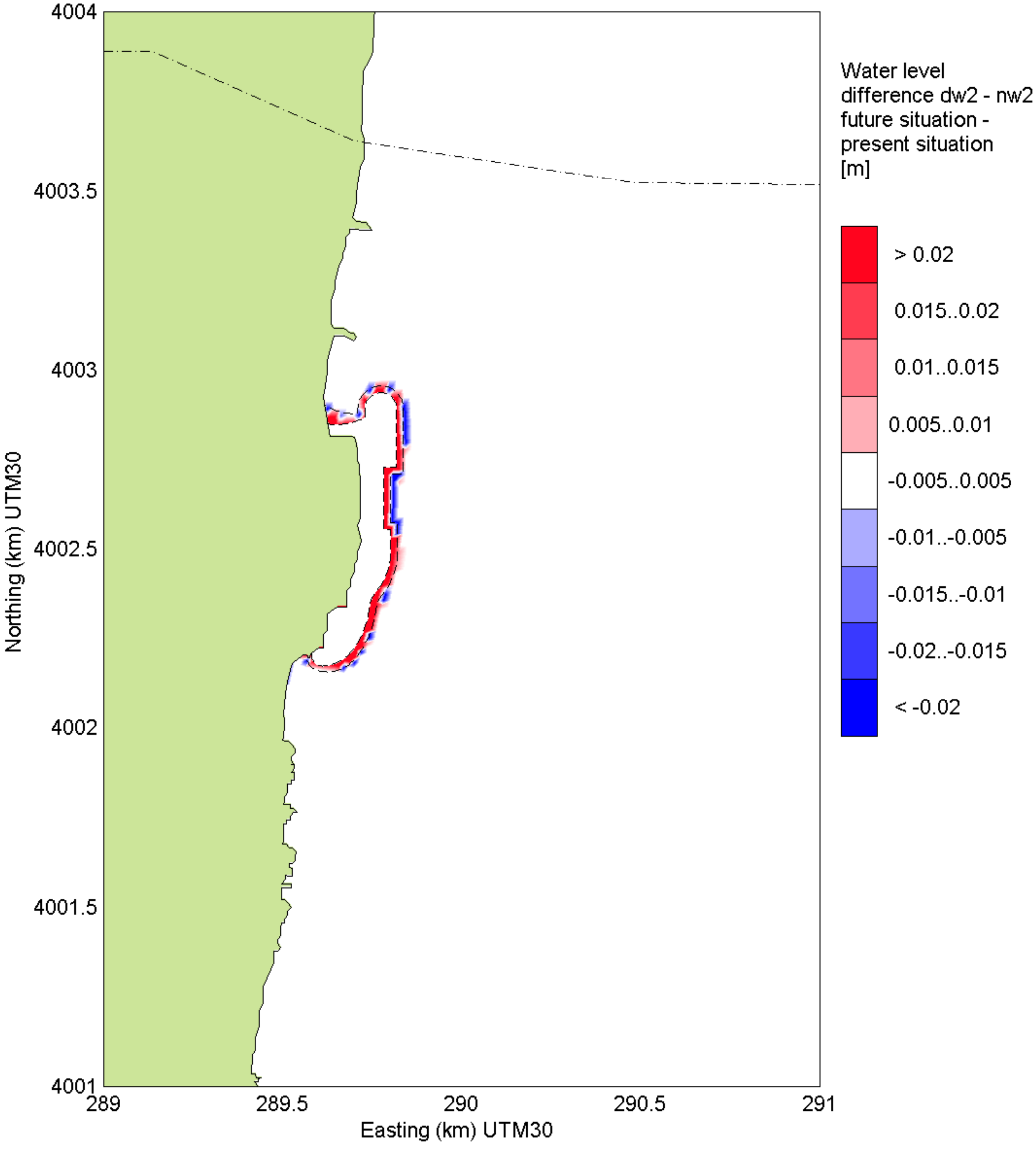
Current magnitude difference (dw1 - nw1) and velocity vectors, with: dw1: future situation nw1: prESEnt situation	ESE wind 16.8m/s	RP=1yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.6c



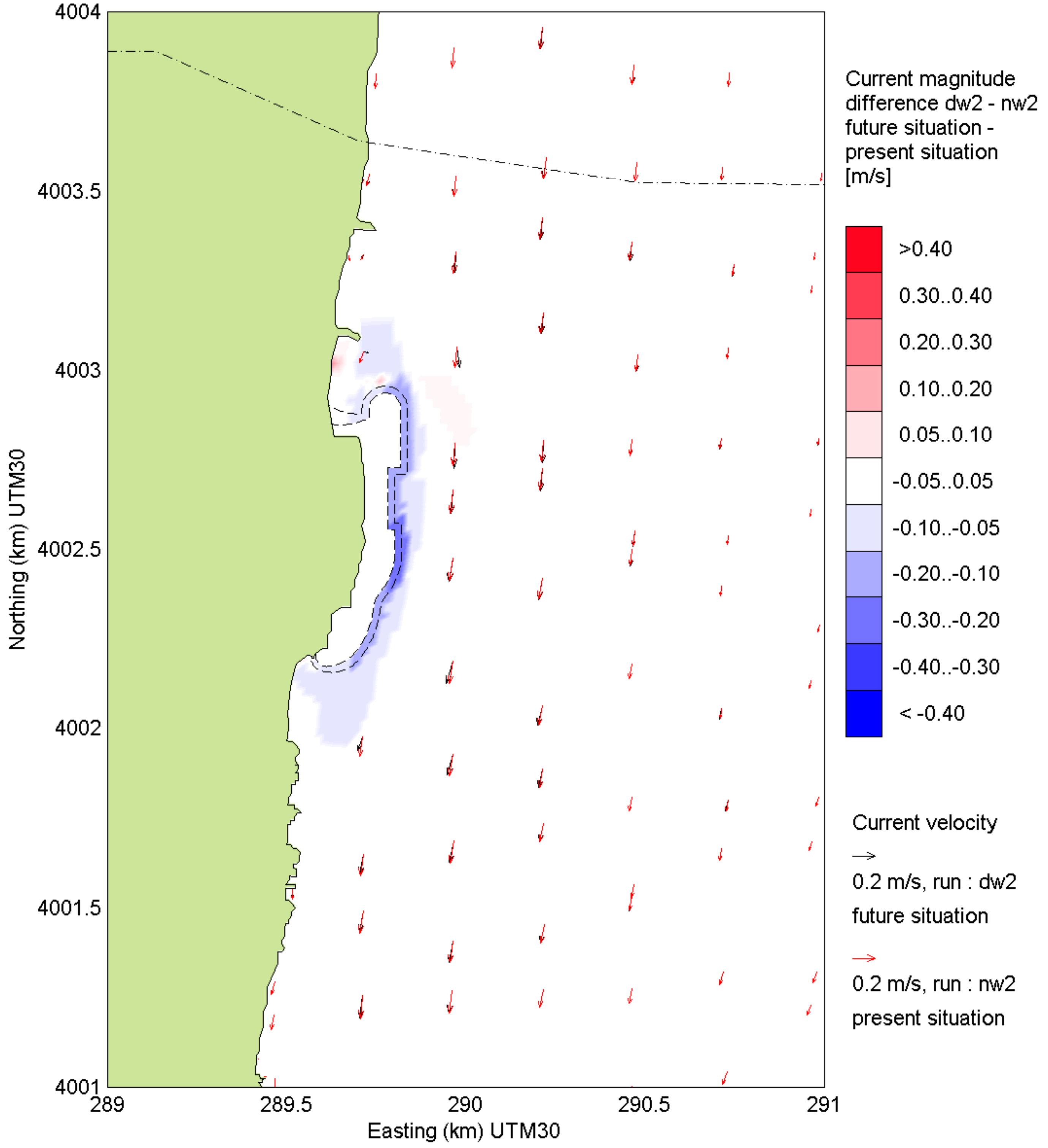
Water level difference (dw2 - nw2), with: dw2: future situation nw2: present situation	E wind 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.7a



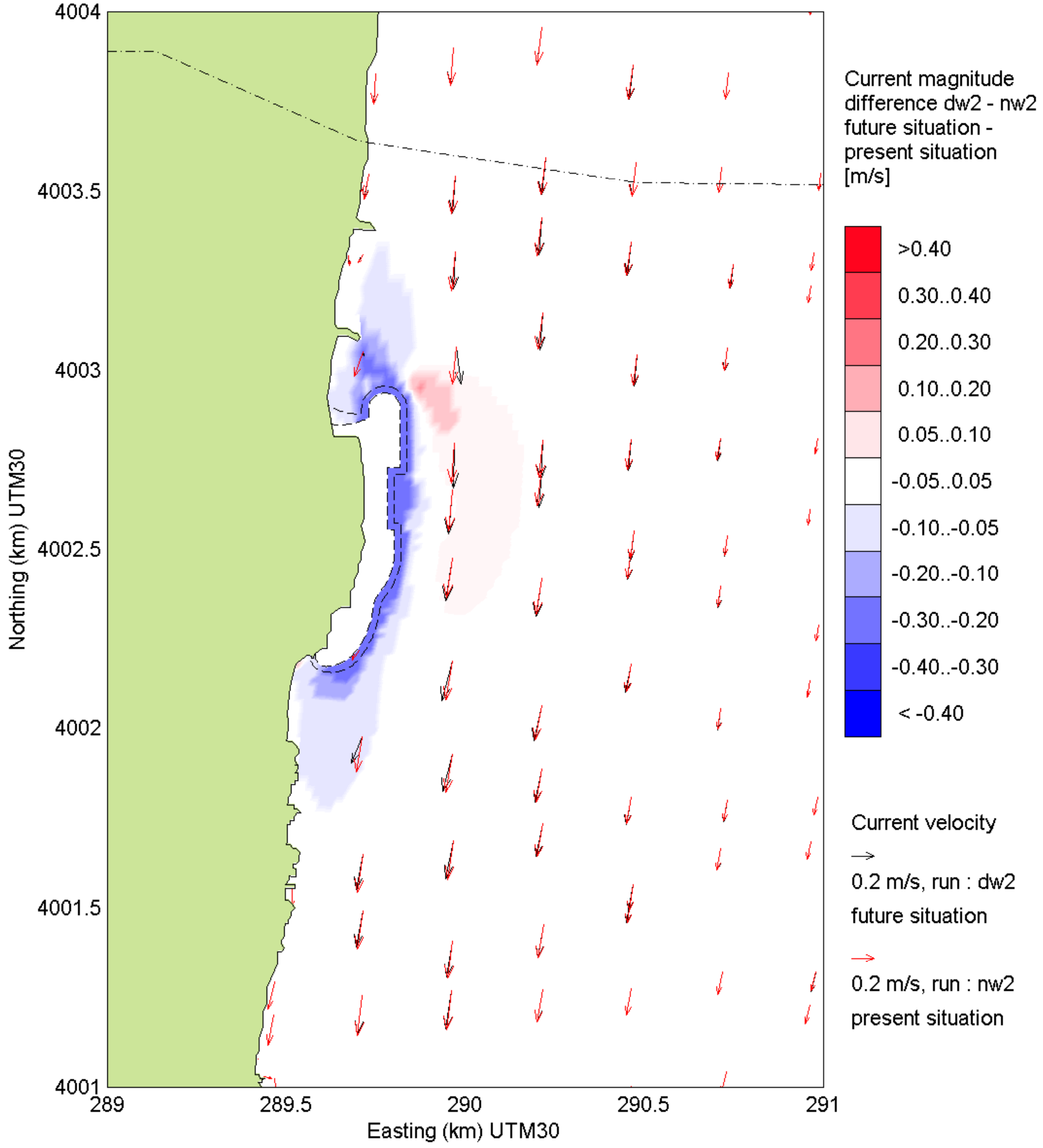
Water level difference (dw2 - nw2), with: dw2: future situation nw2: present situation	ENE wind 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.7b



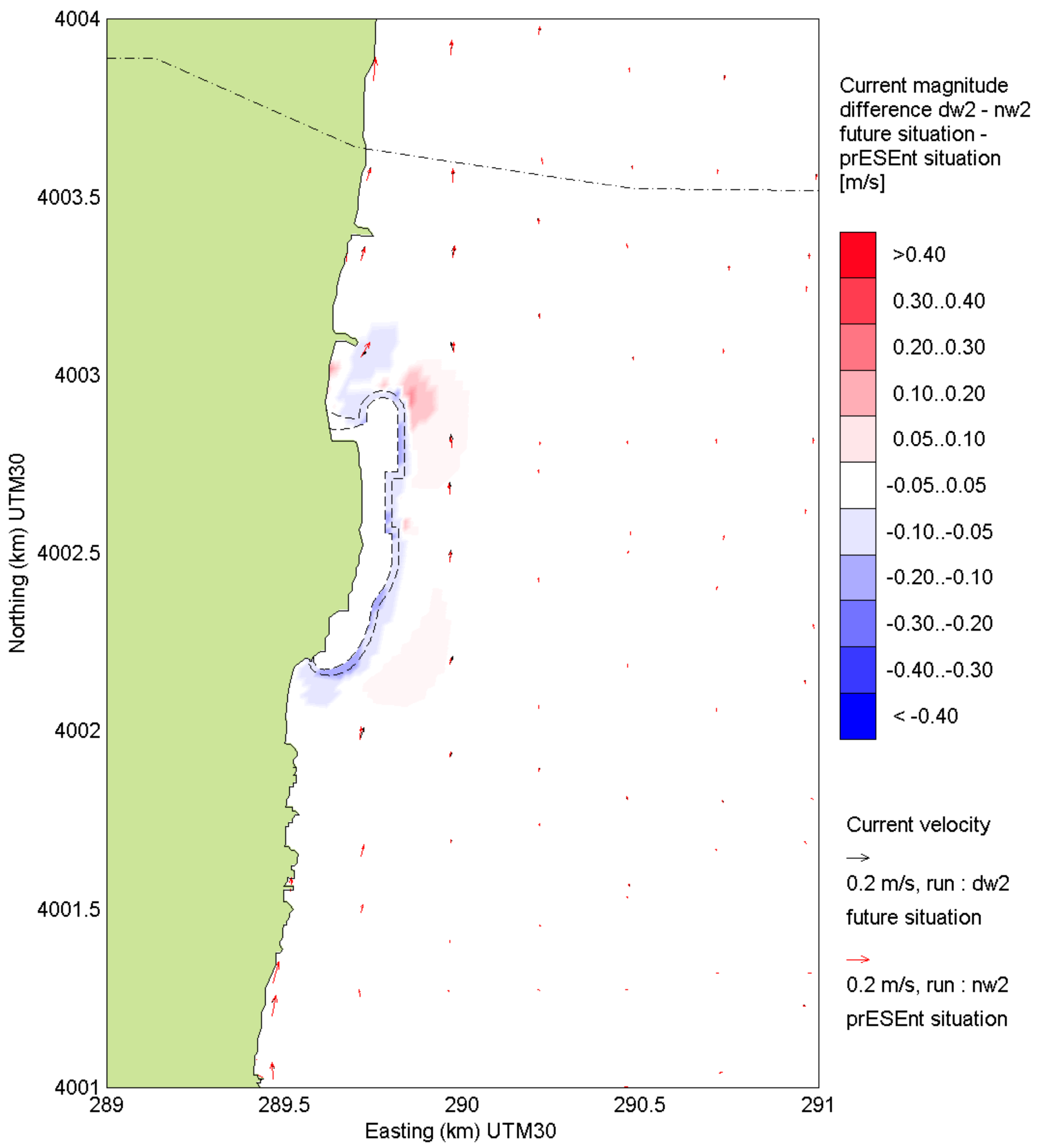
Water level difference (dw2 - nw2), with: dw2: future situation nw2: present situation	ENE wind 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.7c



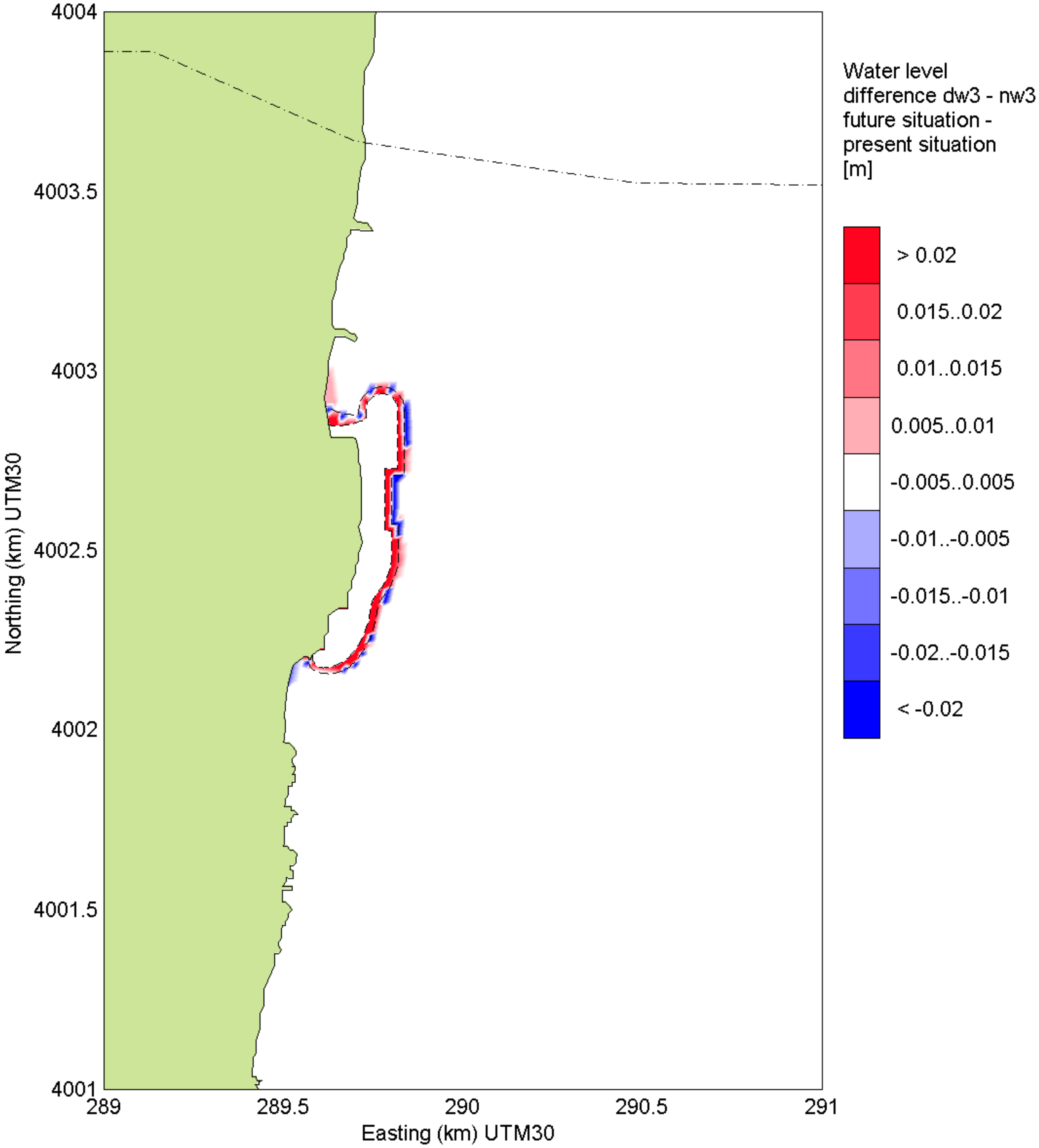
Current magnitude difference (dw2 - nw2) and velocity vectors, with: dw2: future situation nw2: present situation	E wind 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.8a



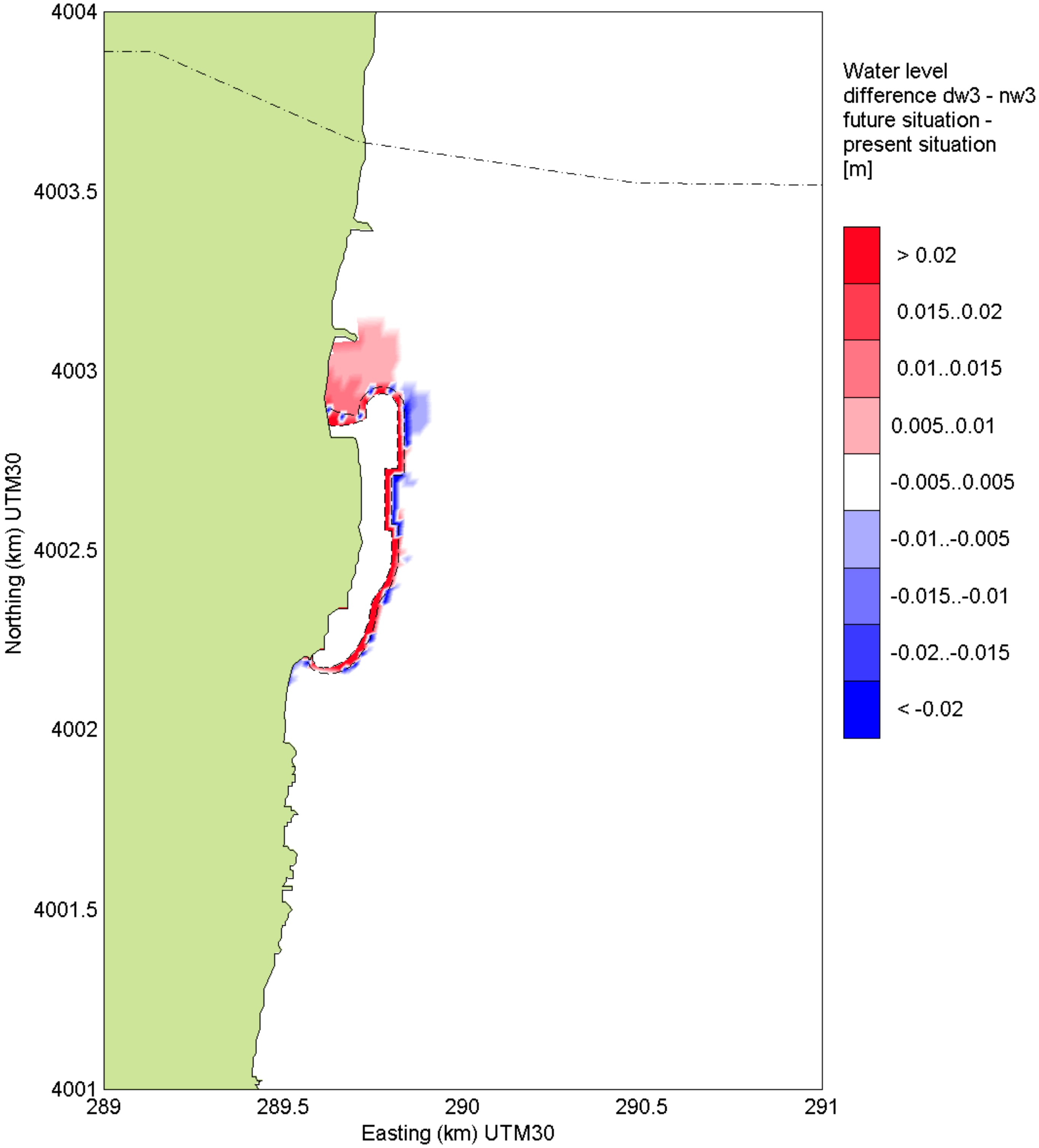
Current magnitude difference (dw2 - nw2) and velocity vectors, with: dw2: future situation nw2: present situation	ENE wind 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.8b



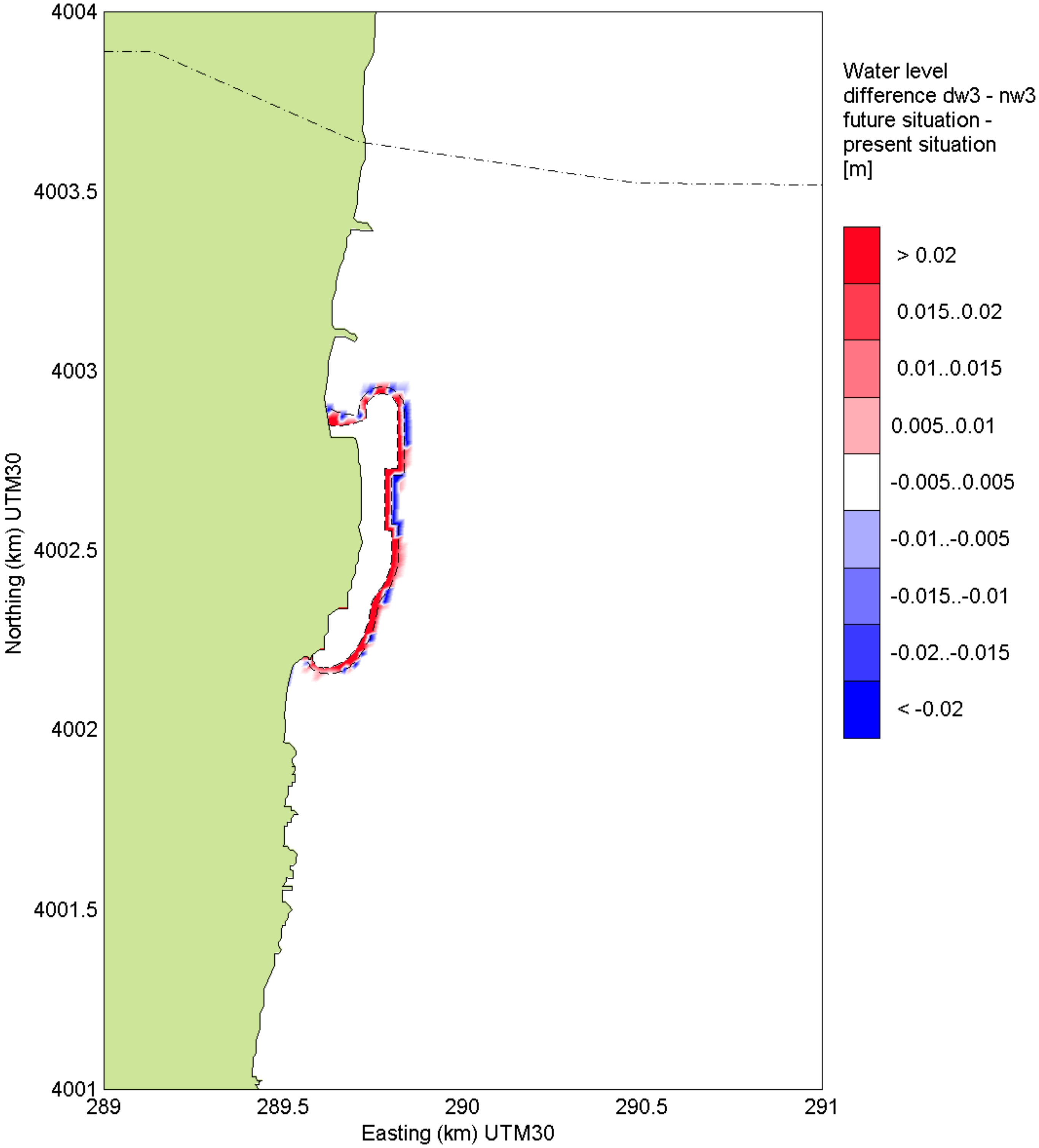
Current magnitude difference (dw2 - nw2) and velocity vectors, with: dw2: future situation nw2: prESEnt situation	ESE wind 20.7m/s	RP=10yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.8c



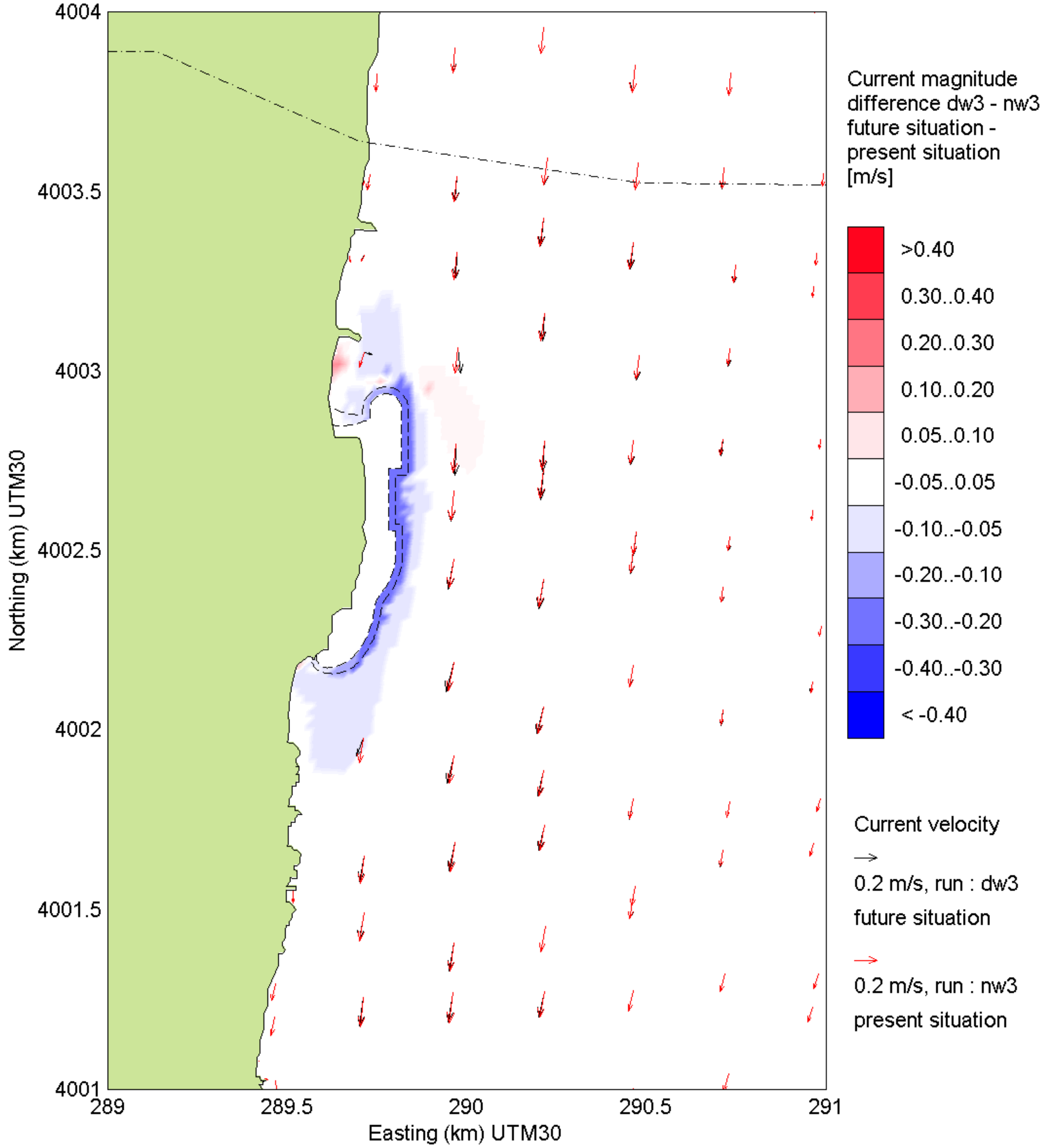
Water level difference (dw3 - nw3), with: dw3: future situation nw3: present situation	E wind 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.9a



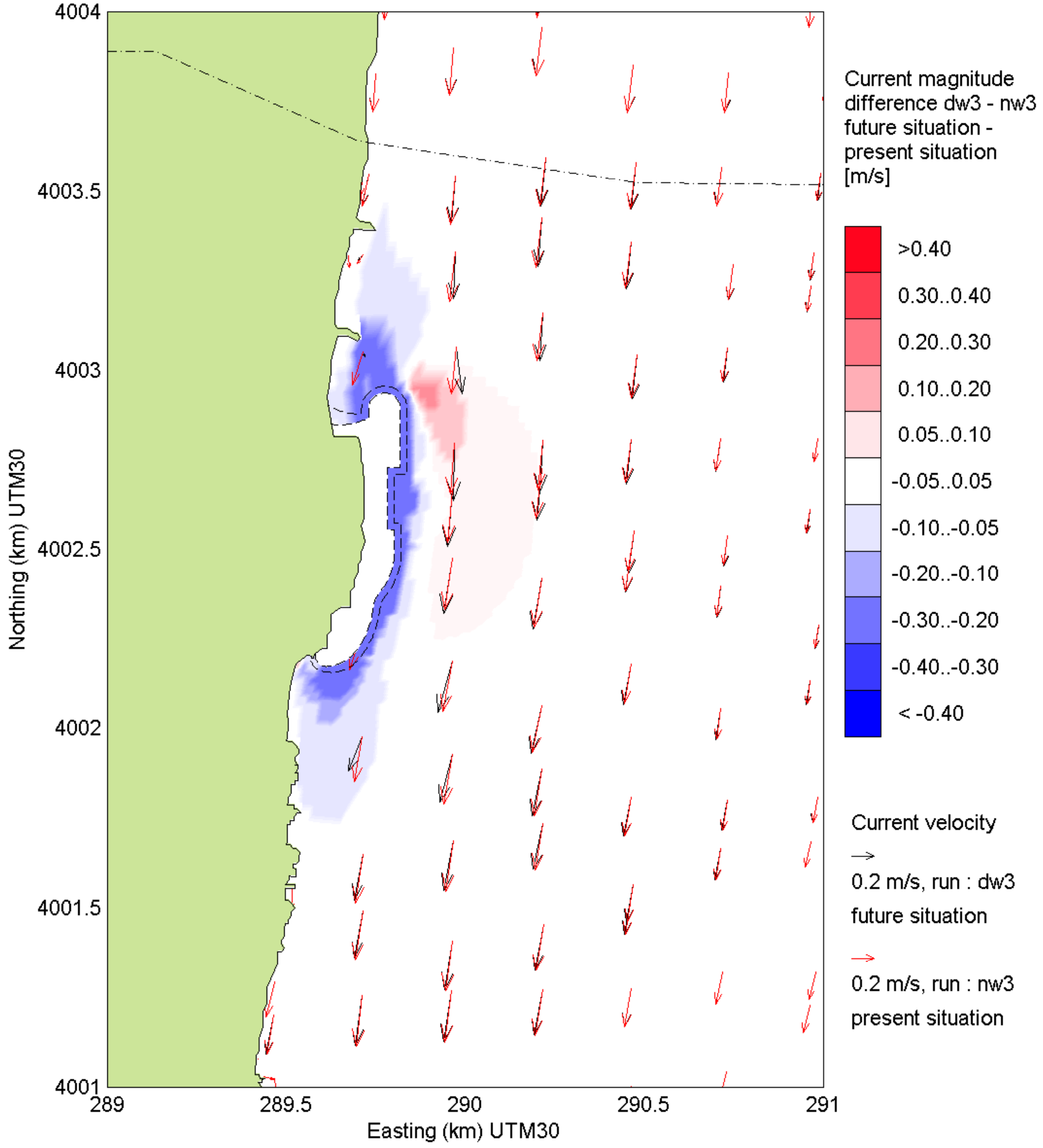
Water level difference (dw3 - nw3), with: dw3: future situation nw3: present situation	ENE wind 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.9b



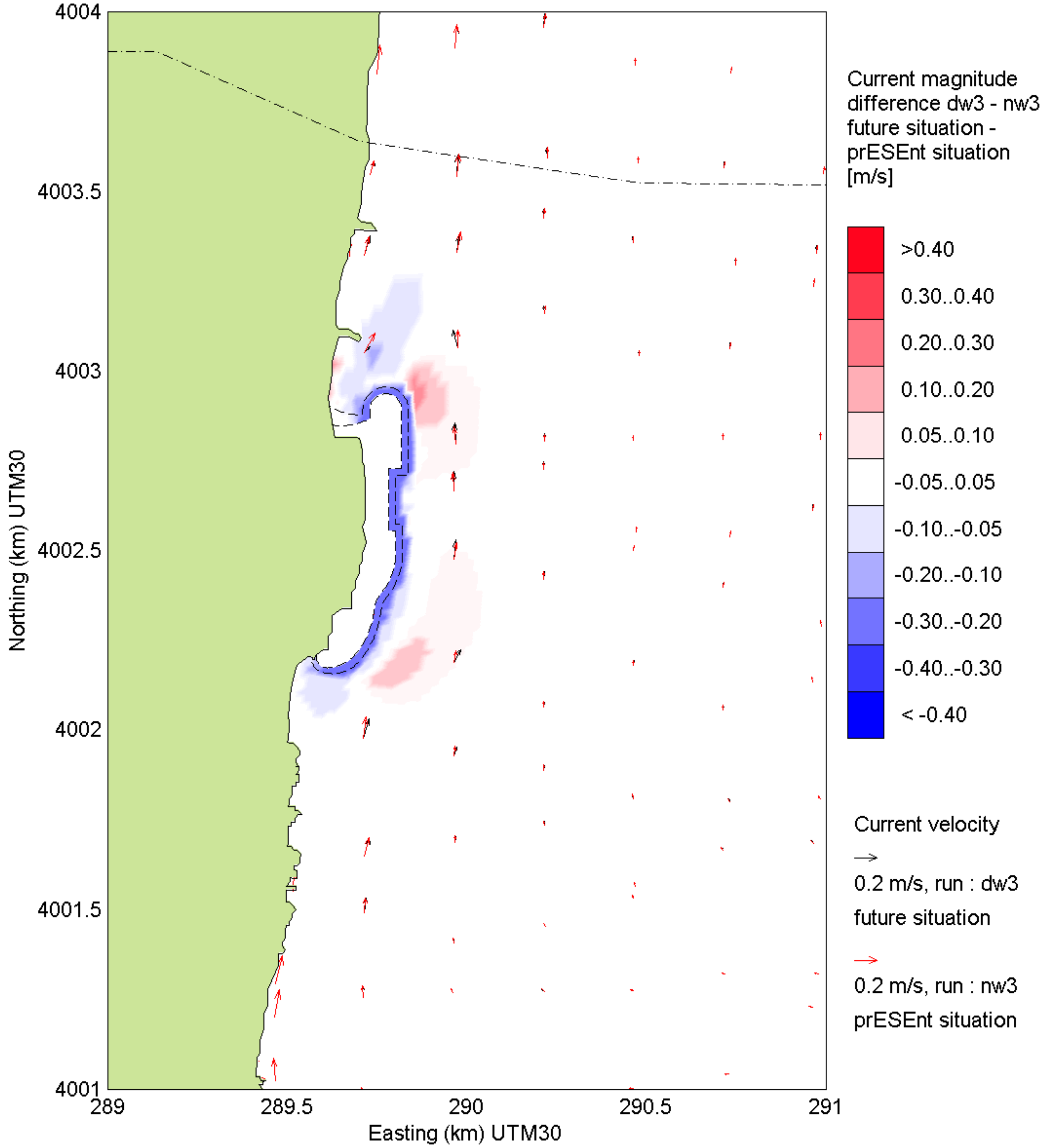
Water level difference (dw3 - nw3), with: dw3: future situation nw3: present situation	ESE wind 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.9c



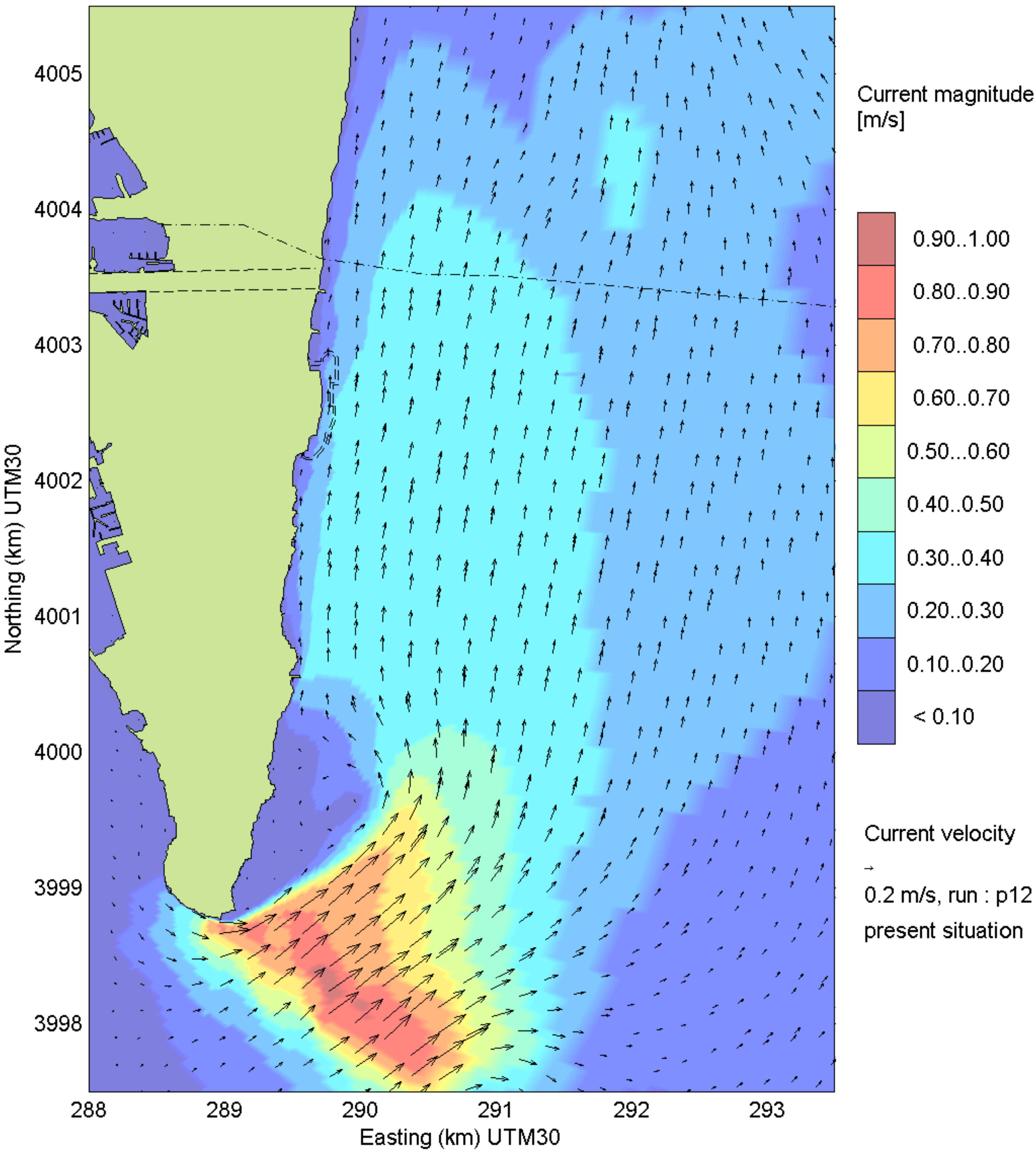
Current magnitude difference (dw3 - nw3) and velocity vectors, with: dw3: future situation nw3: present situation	E wind 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.10a

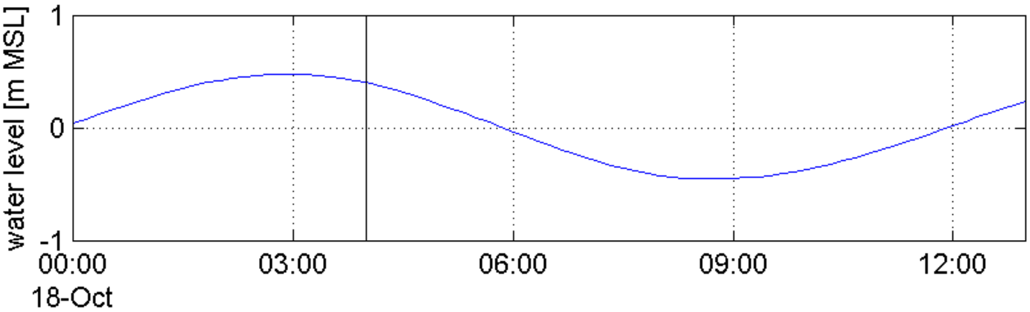


Current magnitude difference (dw3 - nw3) and velocity vectors, with: dw3: future situation nw3: present situation	ENE wind 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.10b

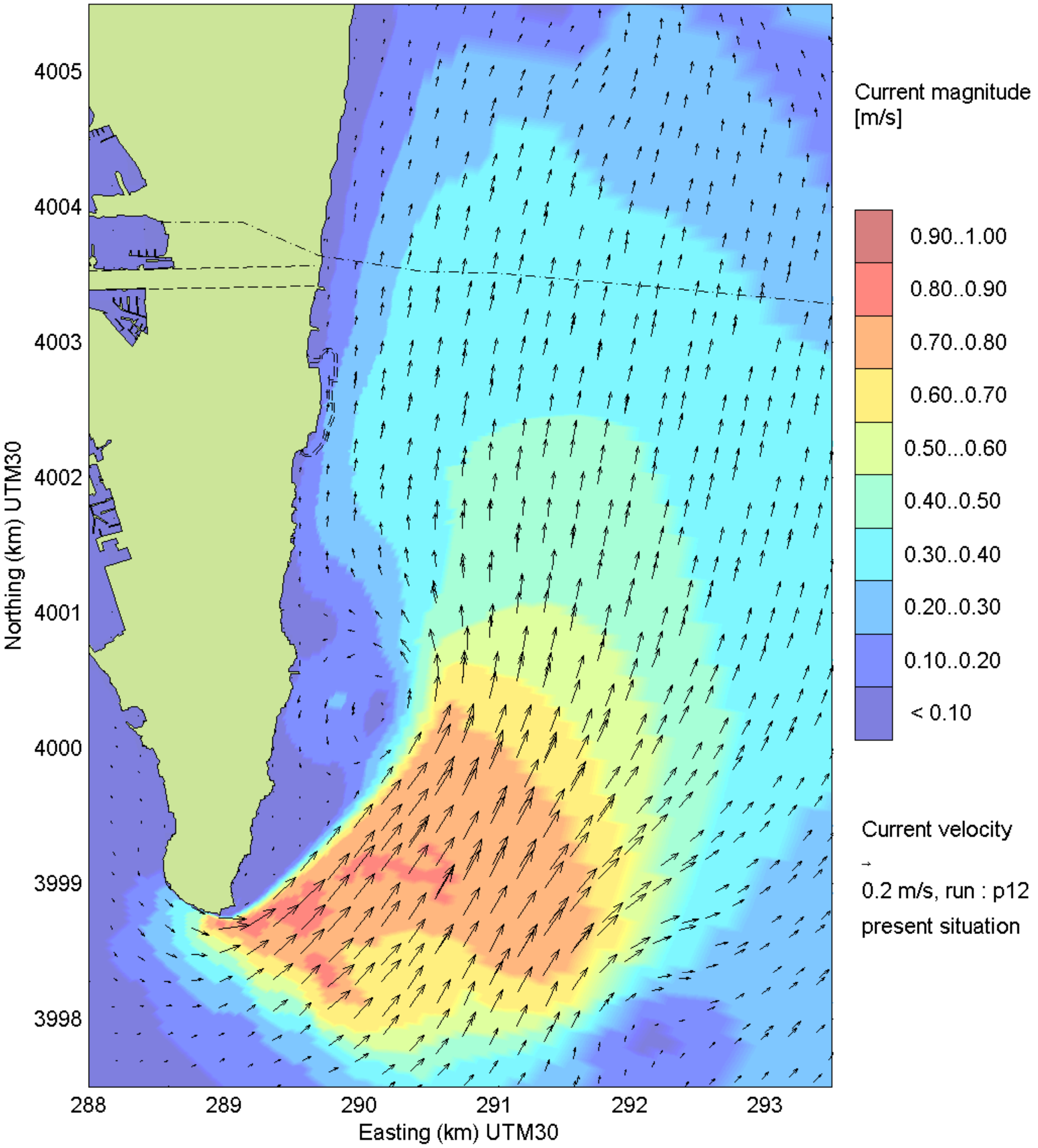


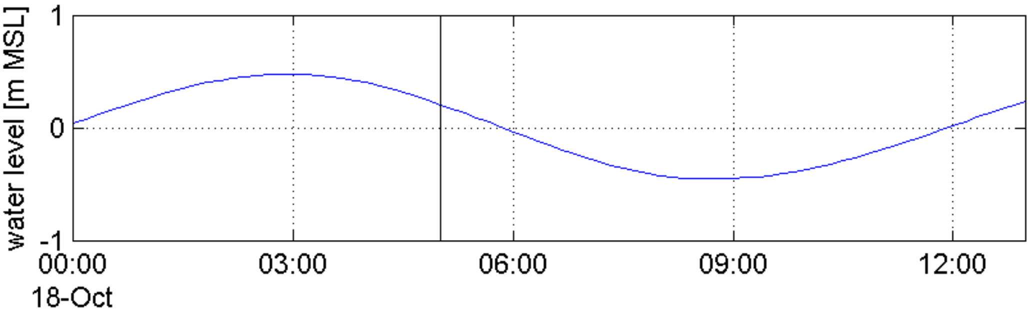
Current magnitude difference (dw3 - nw3) and velocity vectors, with: dw3: future situation nw3: prESEnt situation	ESE wind 24.6m/s	RP=100yr
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 5.10c



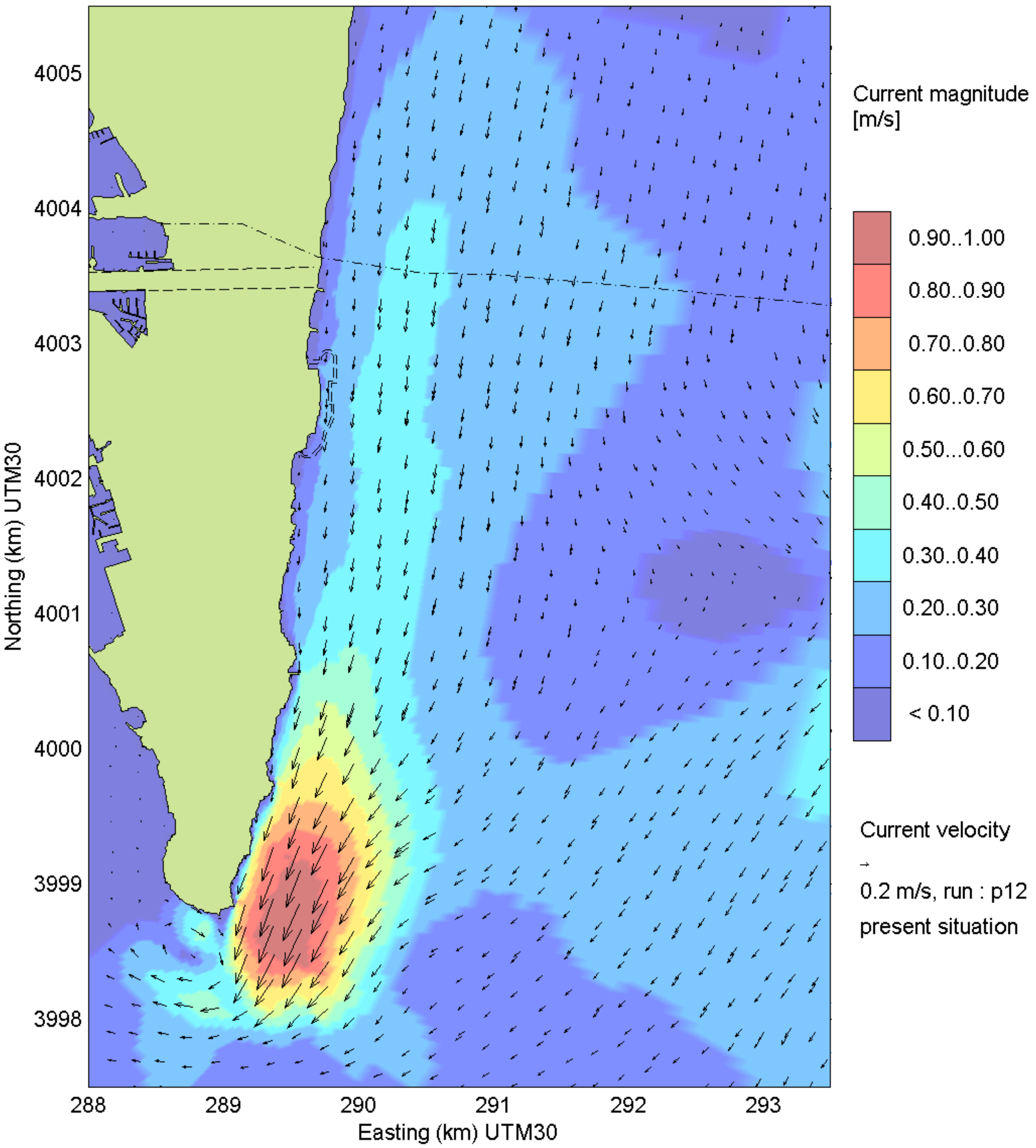


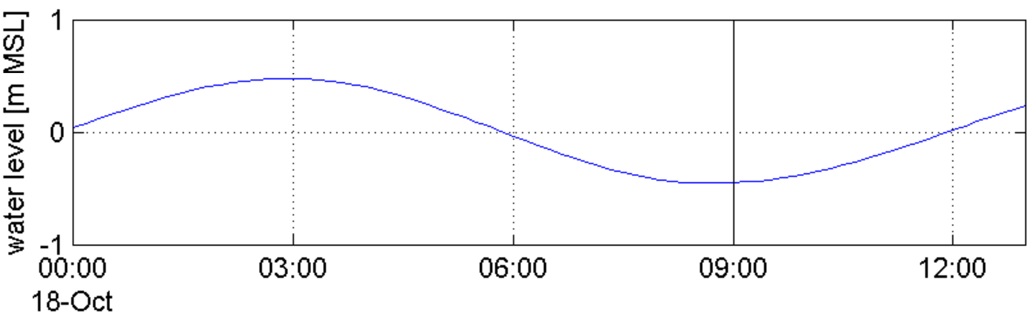
Current magnitude and velocity vectors p12 present situation	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.1e



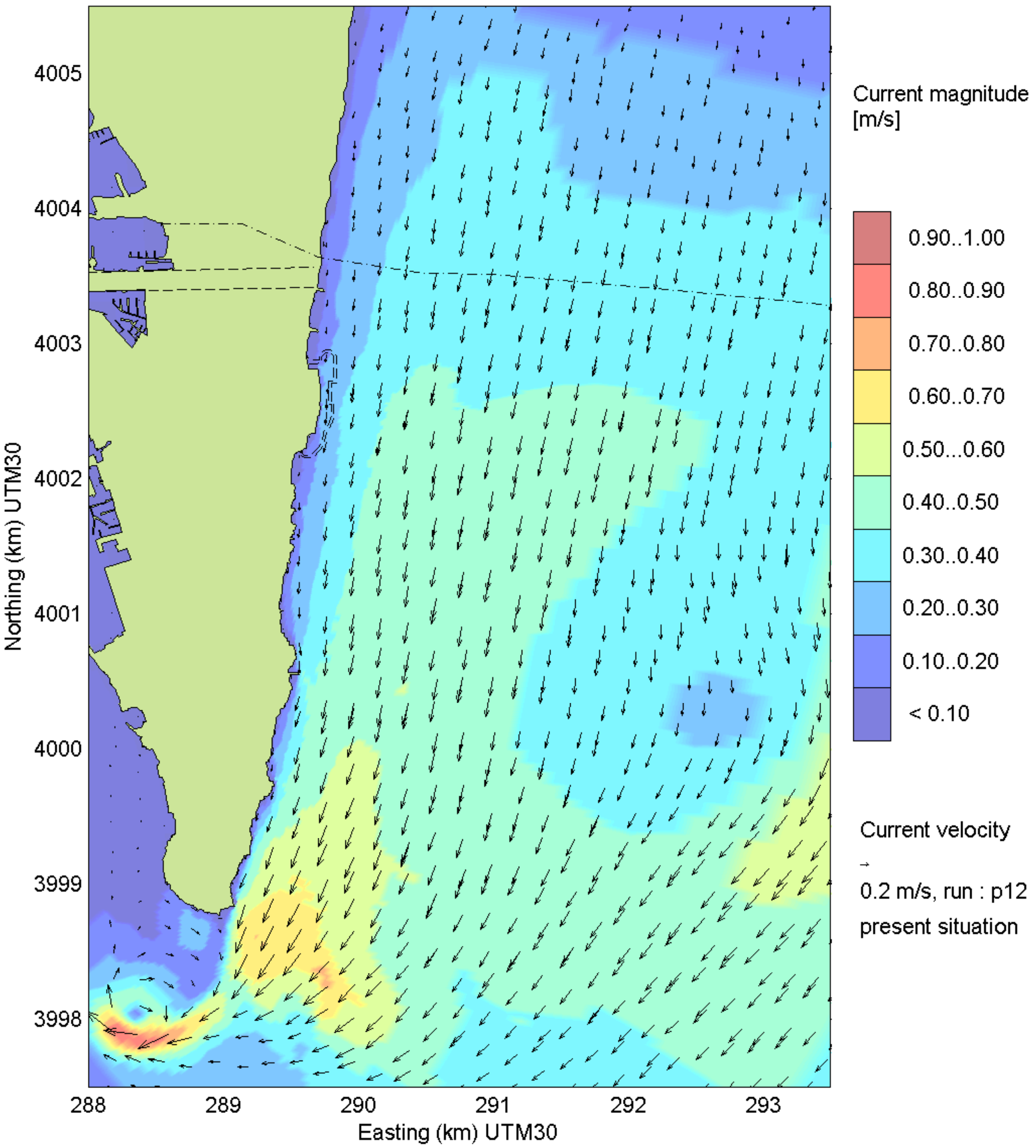


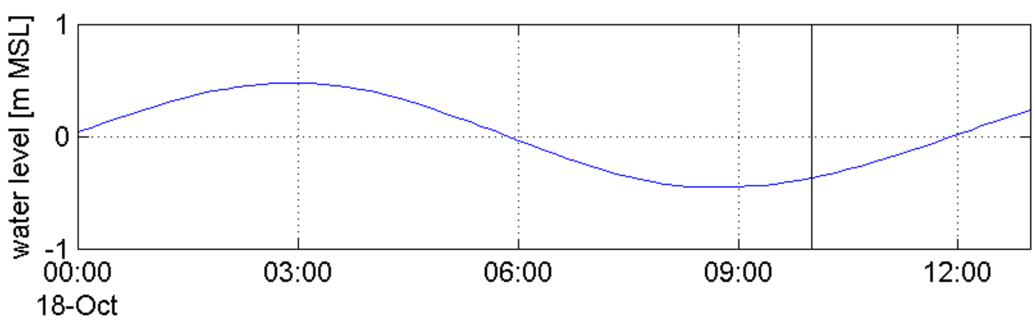
Current magnitude and velocity vectors p12 present situation	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.1f



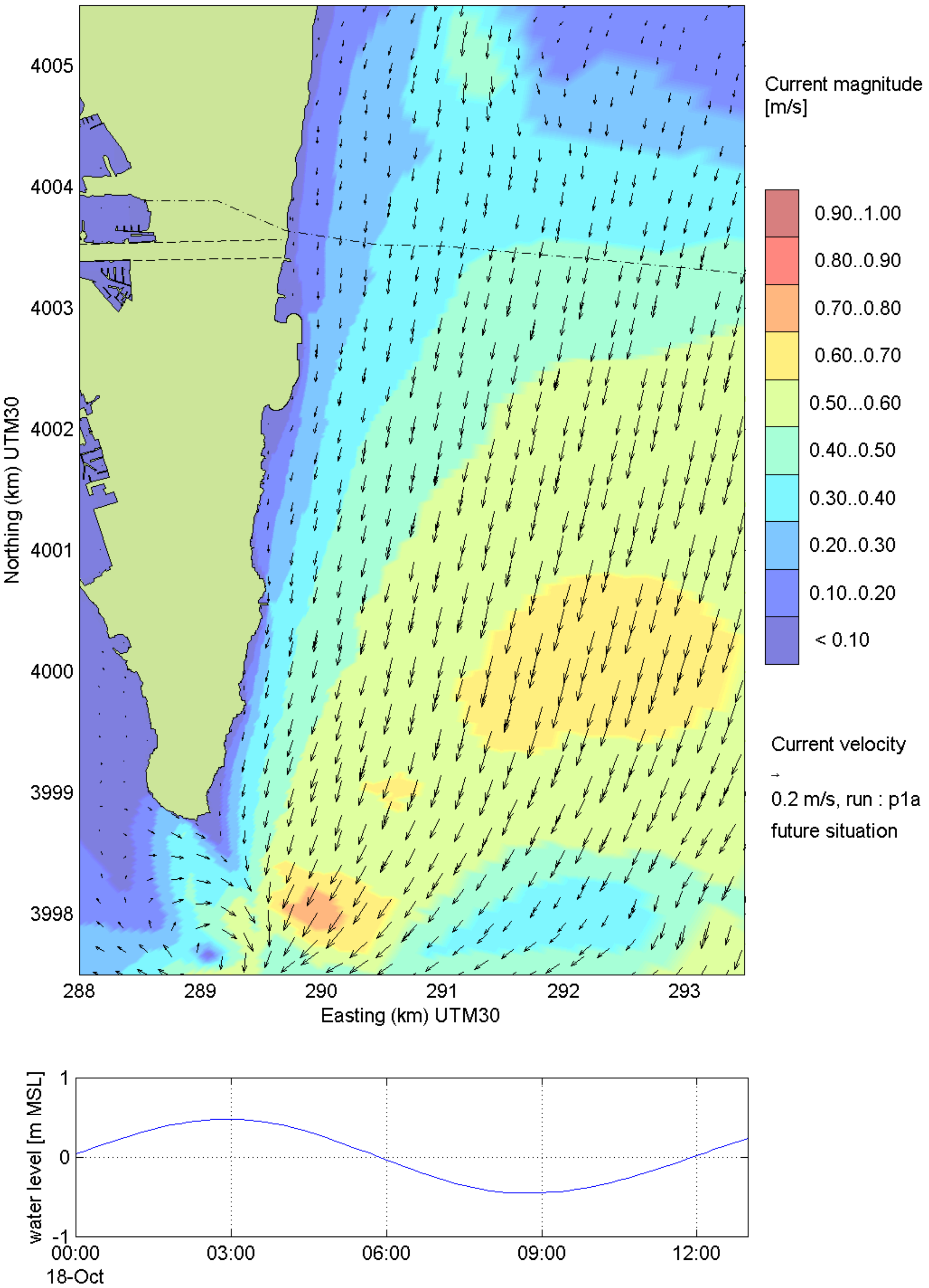


Current magnitude and velocity vectors p12 present situation	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.1j

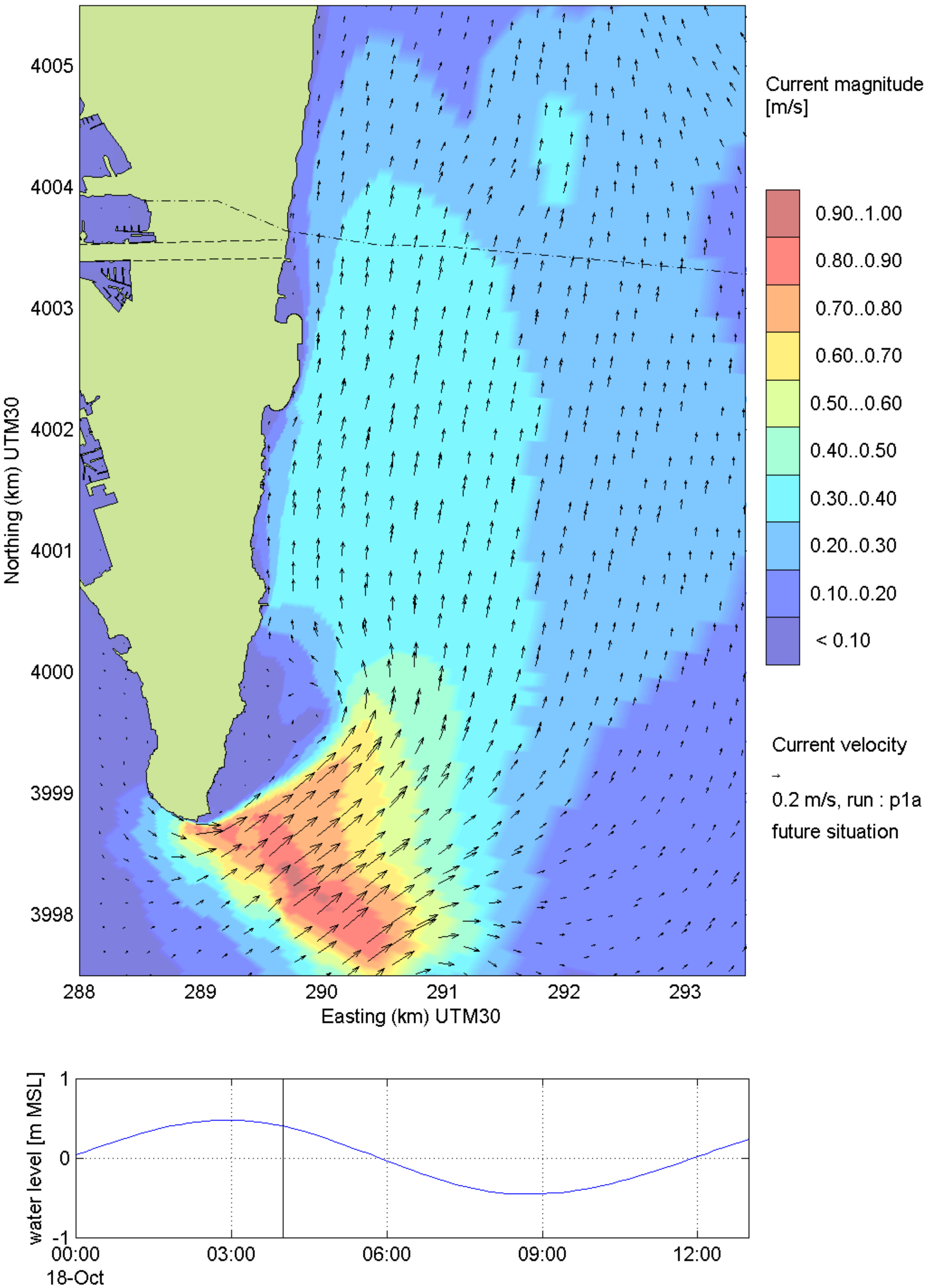




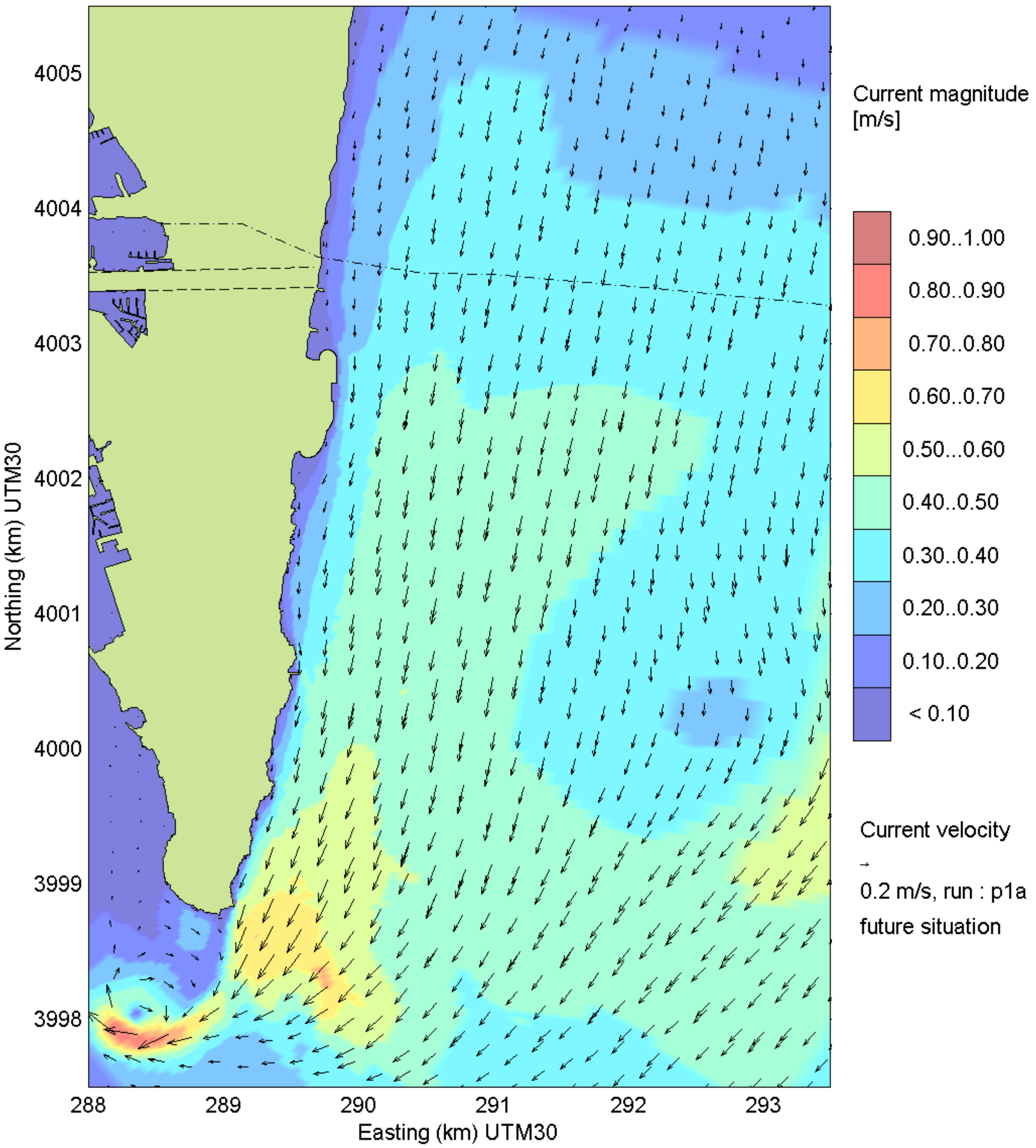
Current magnitude and velocity vectors p12 present situation	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.1k

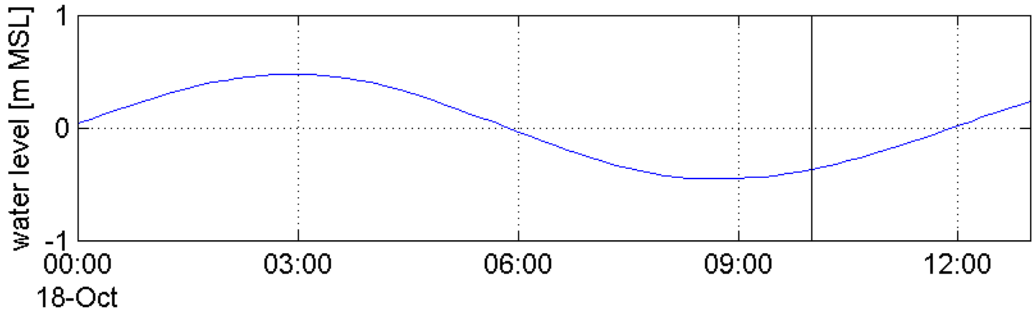


Current magnitude and velocity vectors p1a future situation	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.7a

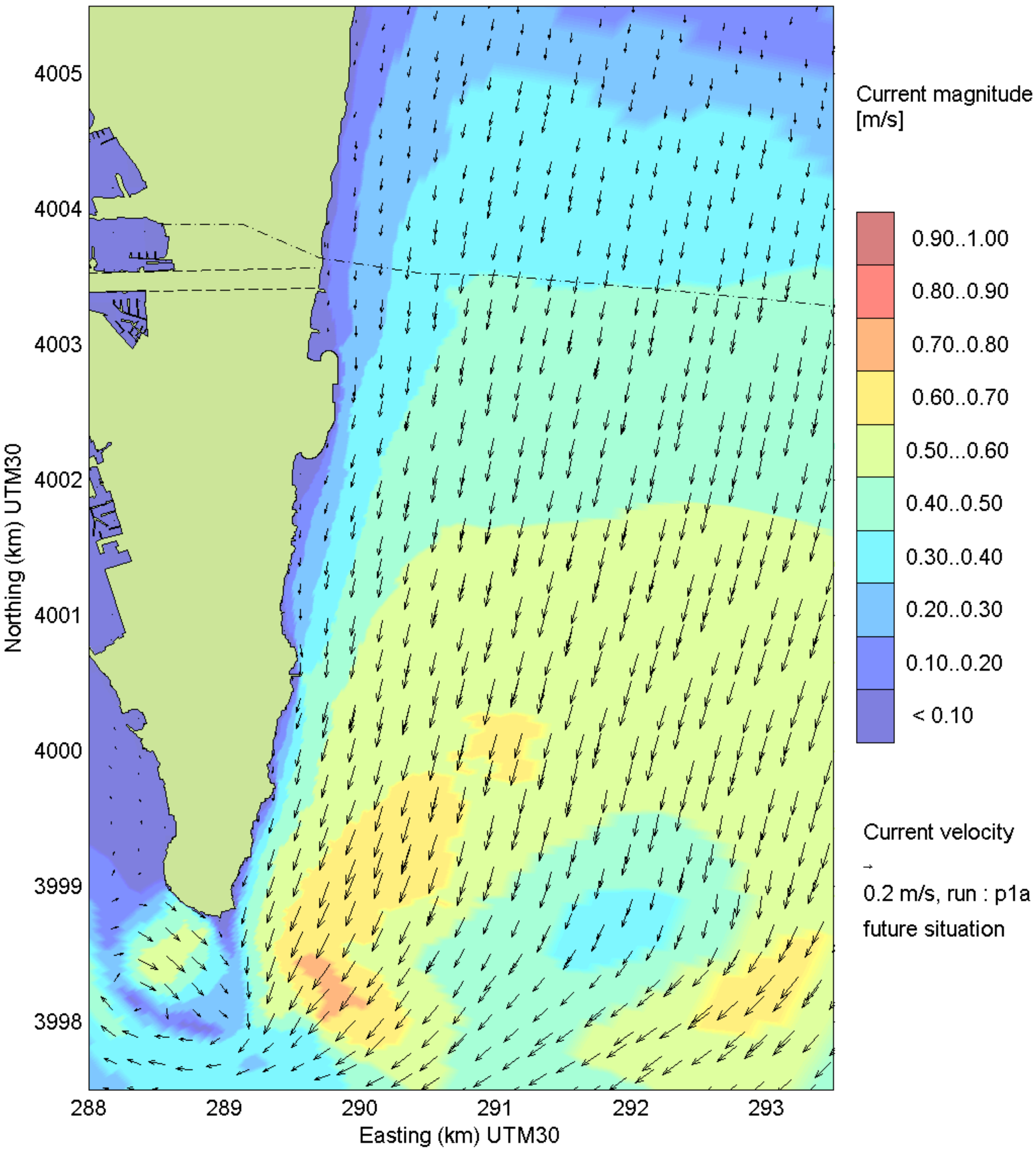


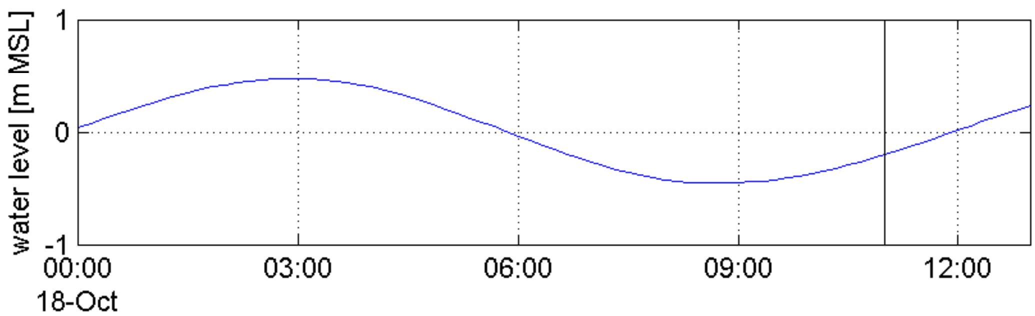
Current magnitude and velocity vectors p1a future situation	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.7e





Current magnitude and velocity vectors p1a future situation	no wind	spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.7k





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p1a future situation</td><td>no wind</td><td>spring</td></tr>
<tr><td colspan="2">Gibraltar Flow Study</td></tr>
<tr><td>WL | DELFT HYDRAULICS</td><td>H4725</td><td>Fig. 6.7l</td></tr>
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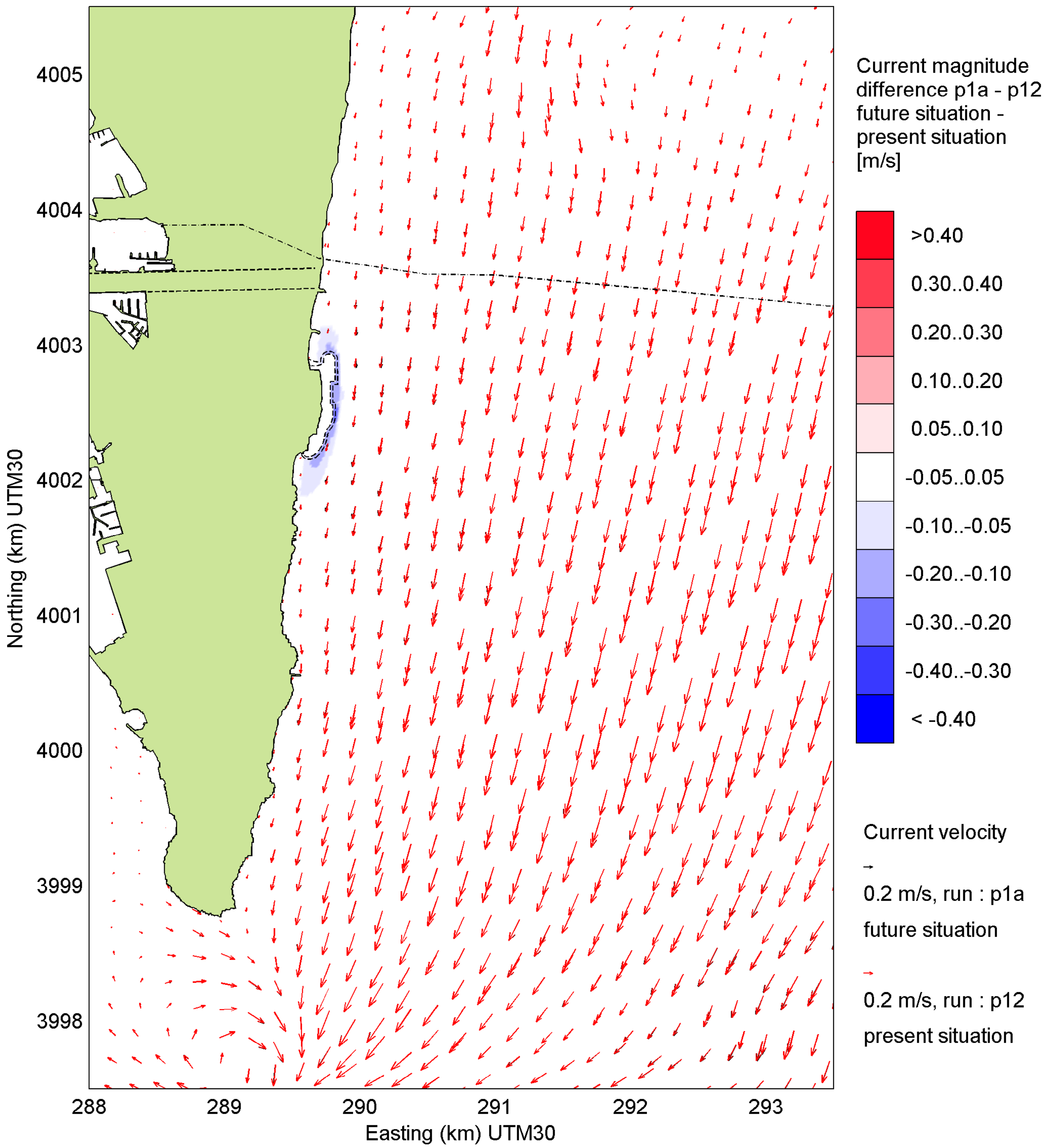
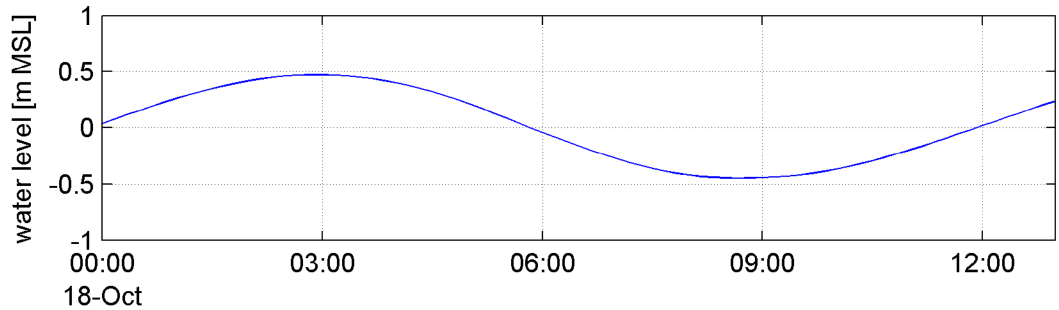
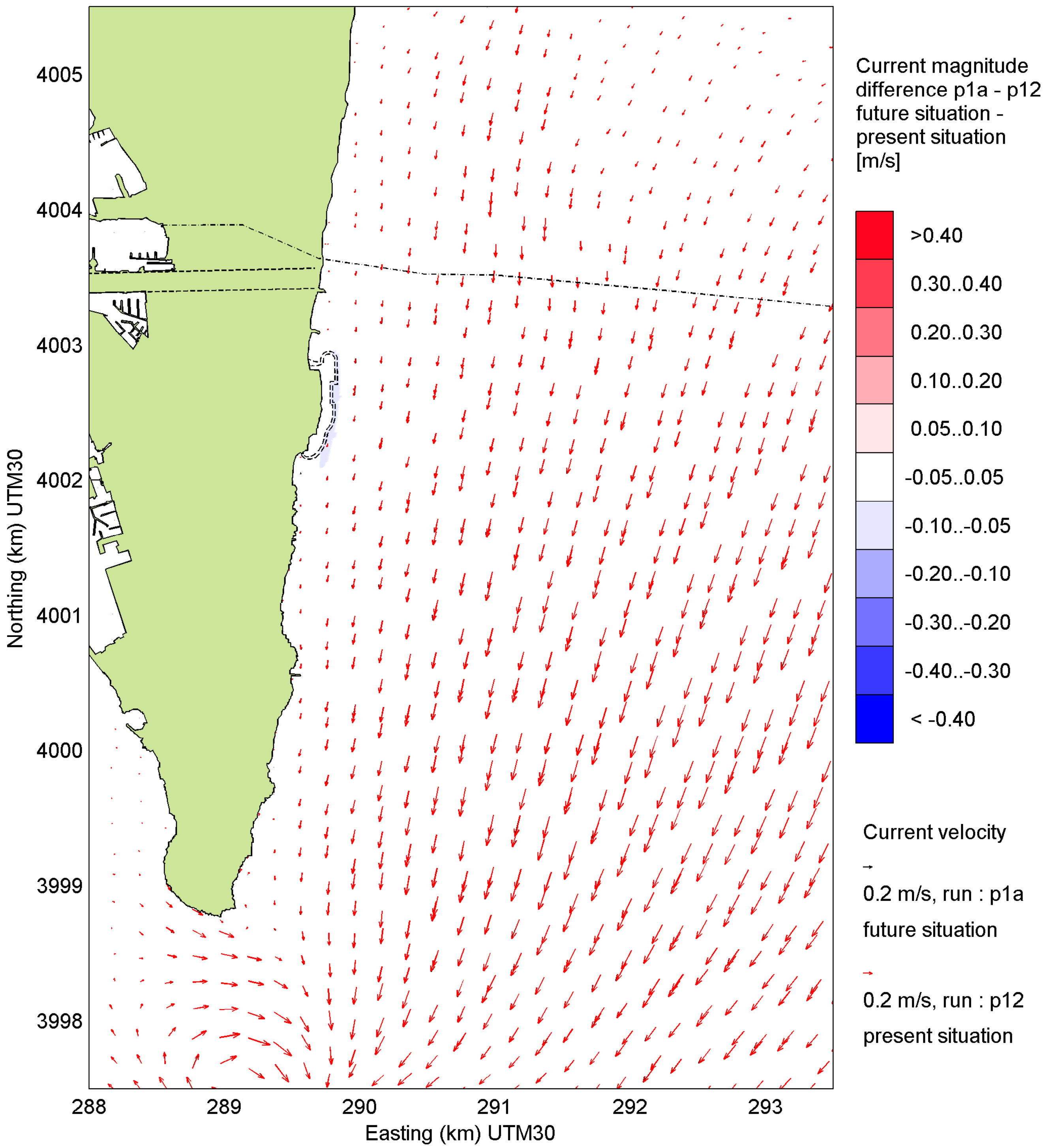
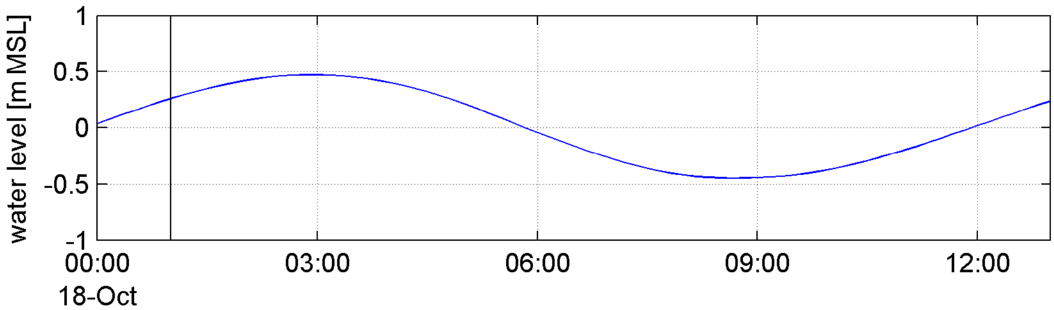


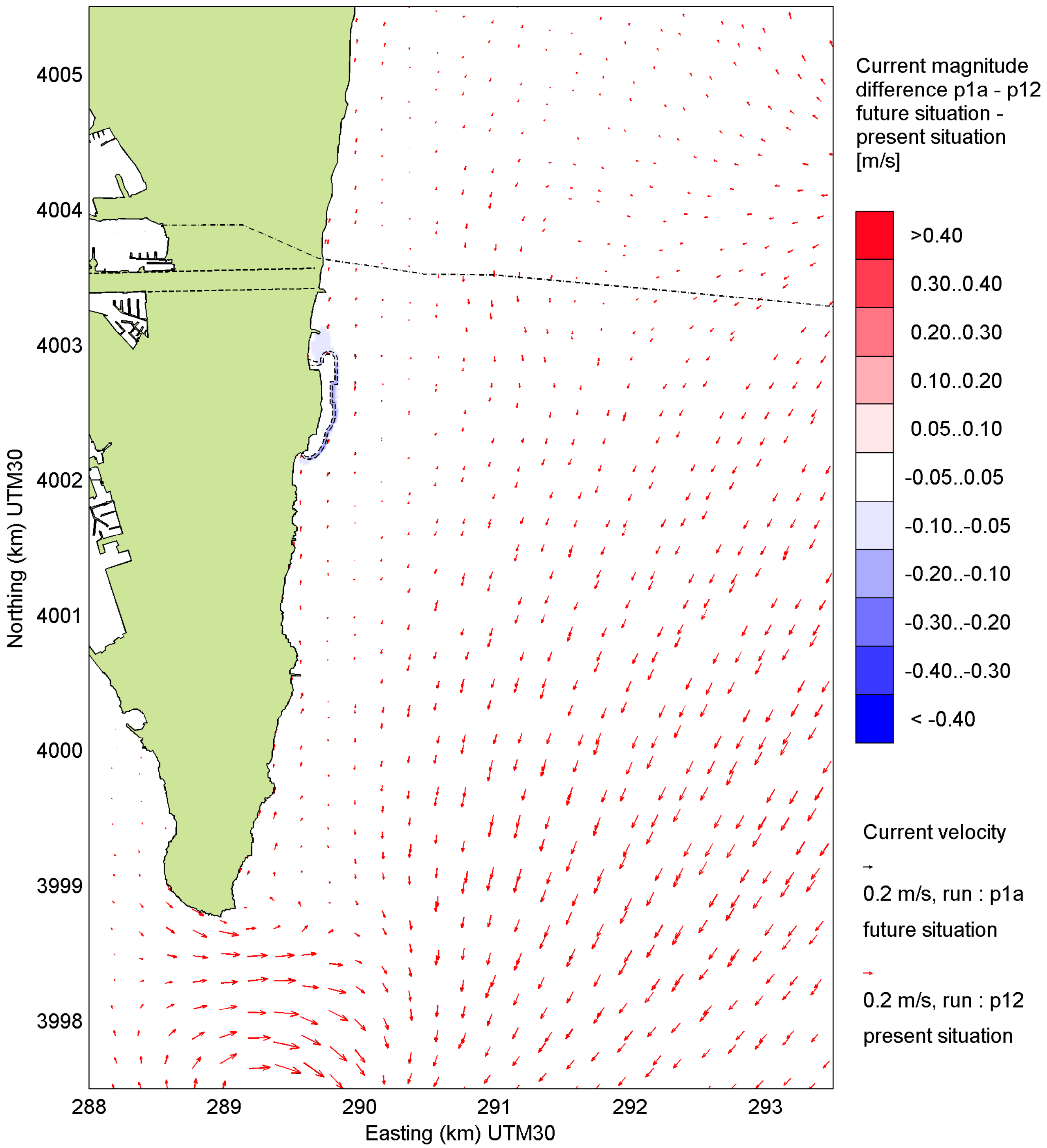


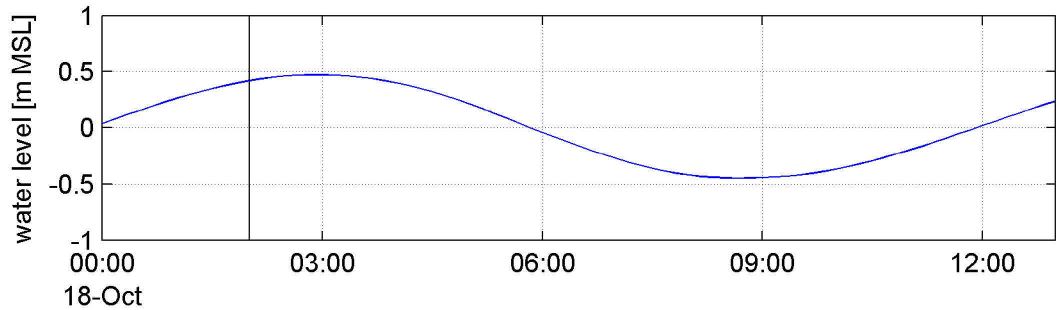
Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13a



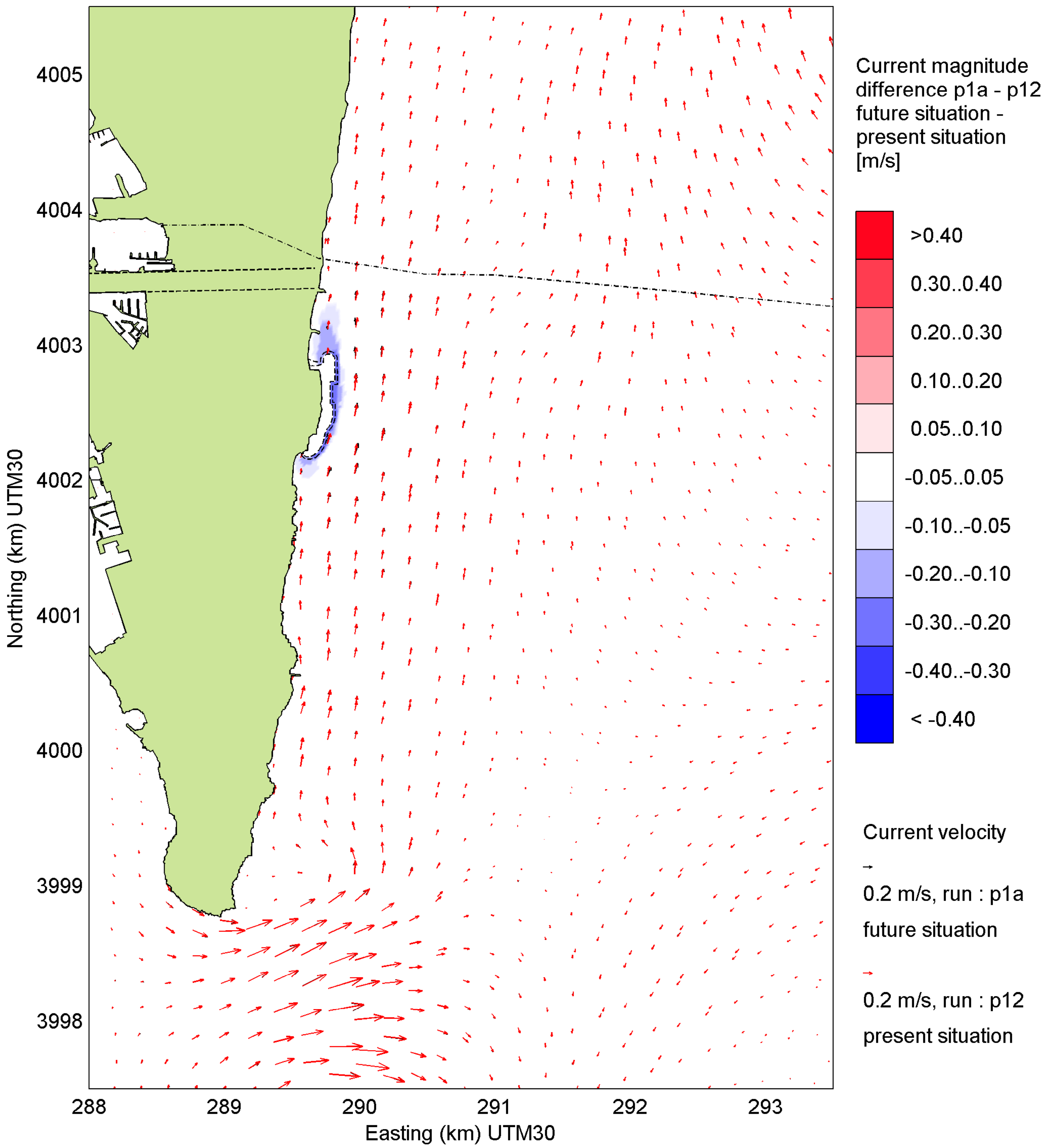


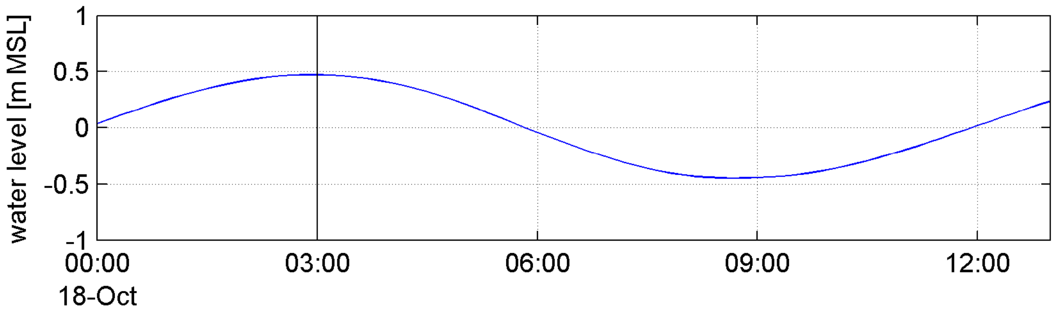
Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13b



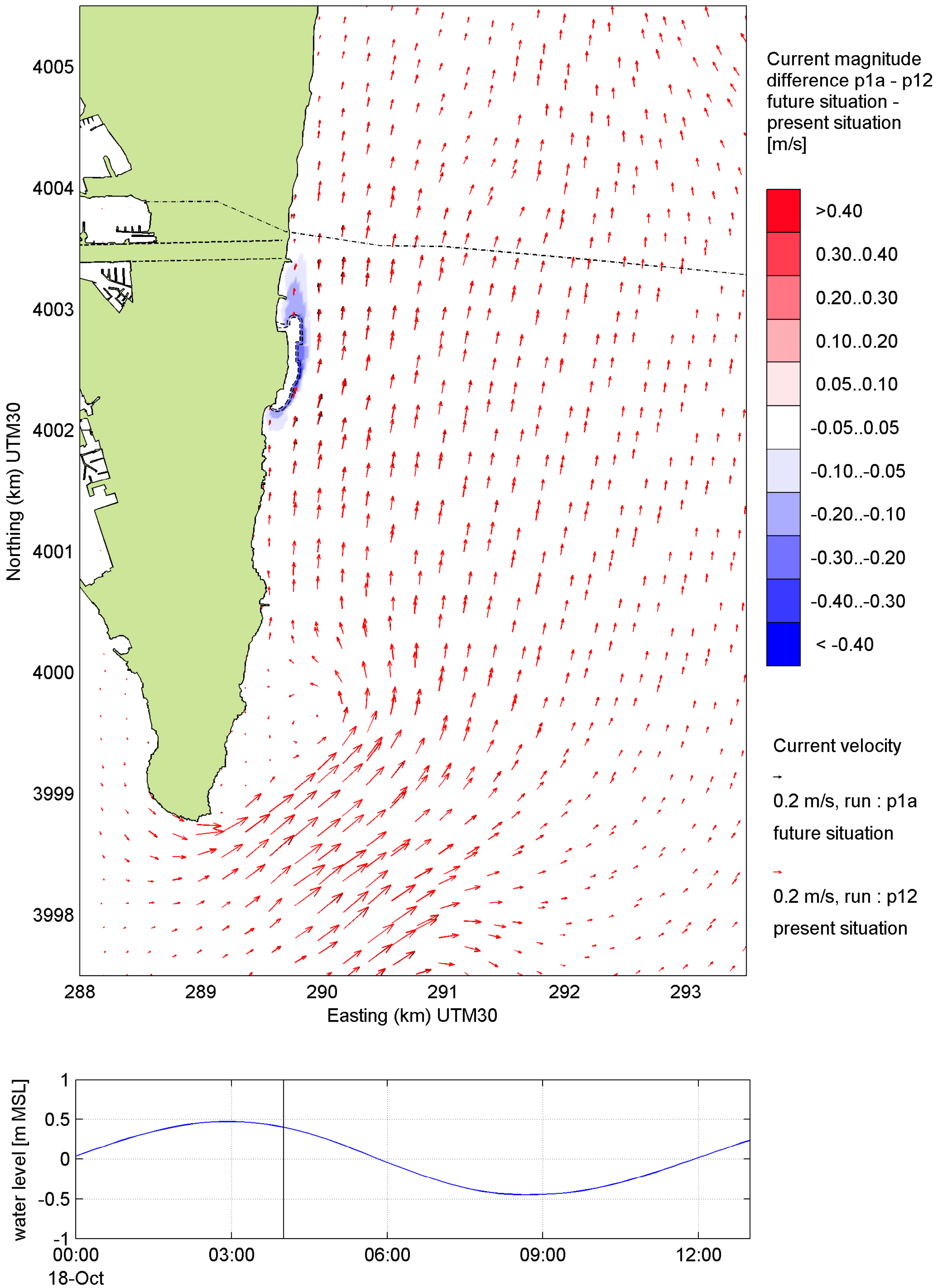


Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13c

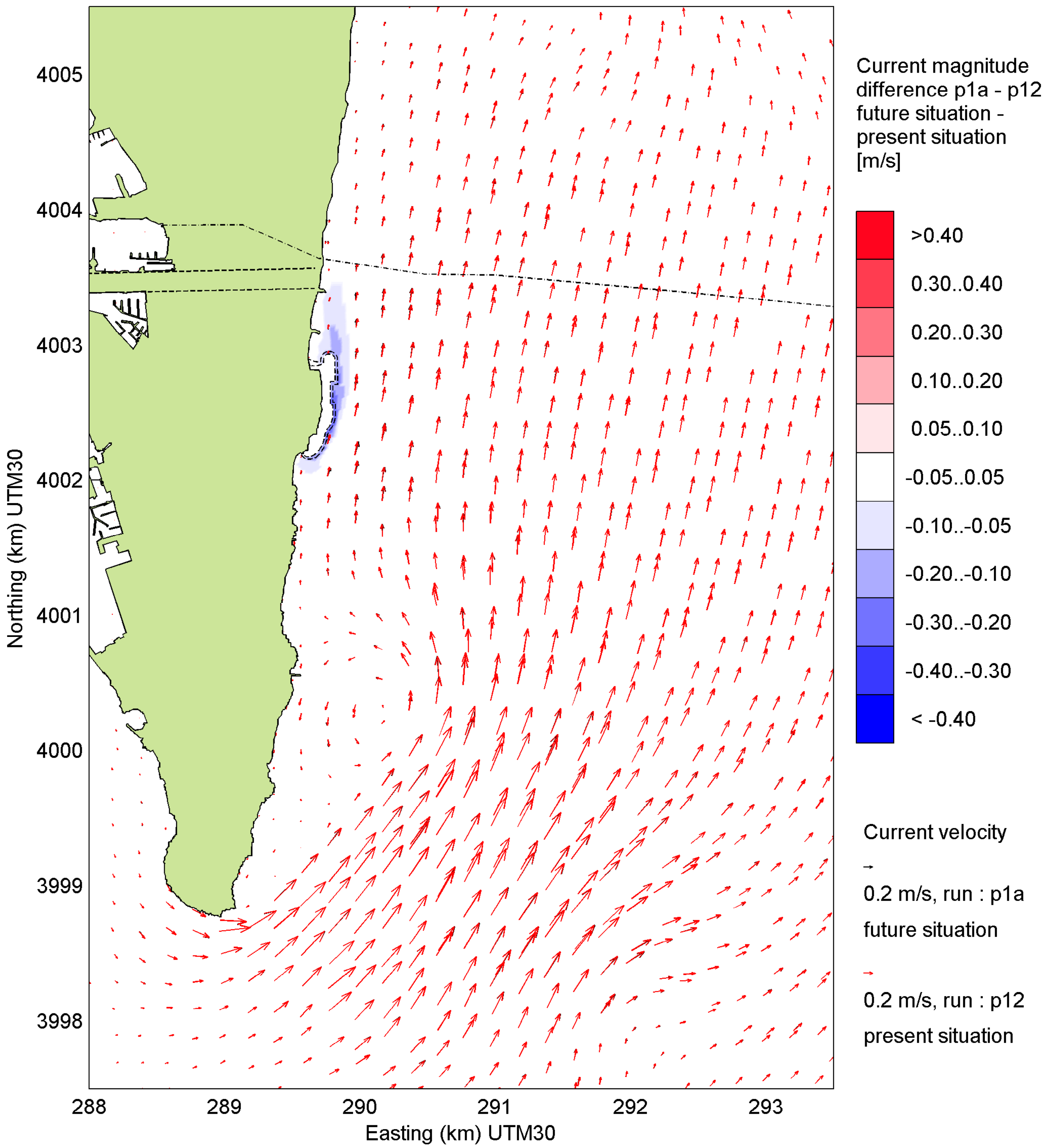


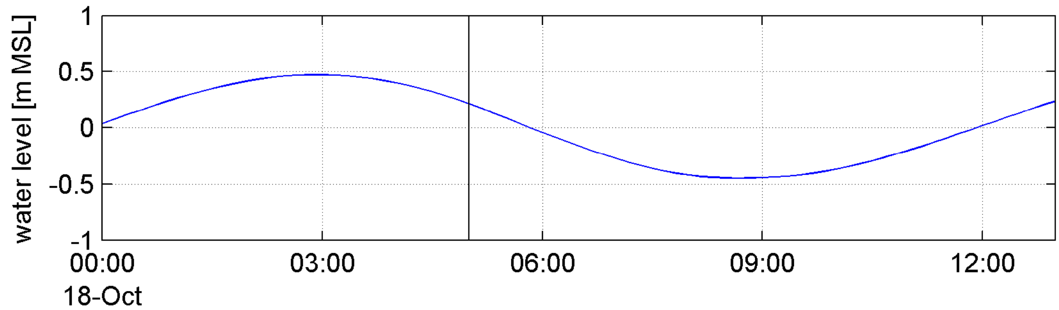


Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13d

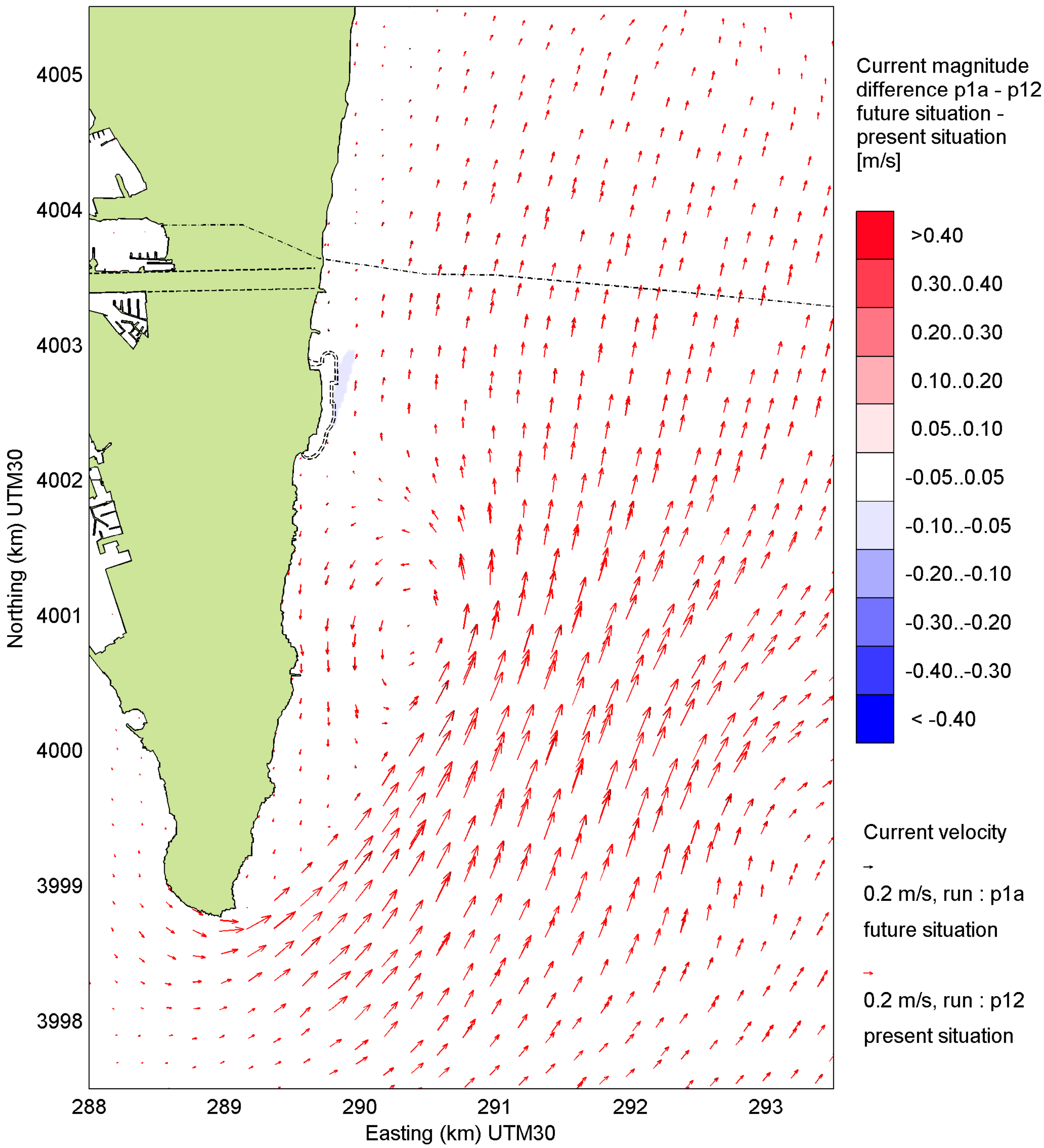


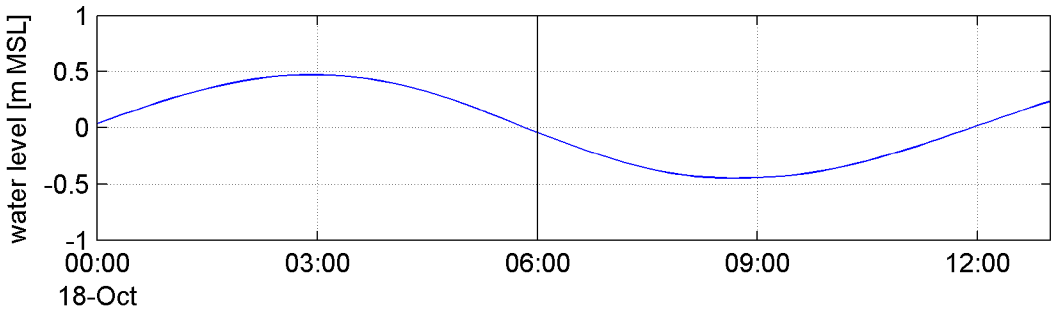
Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13e



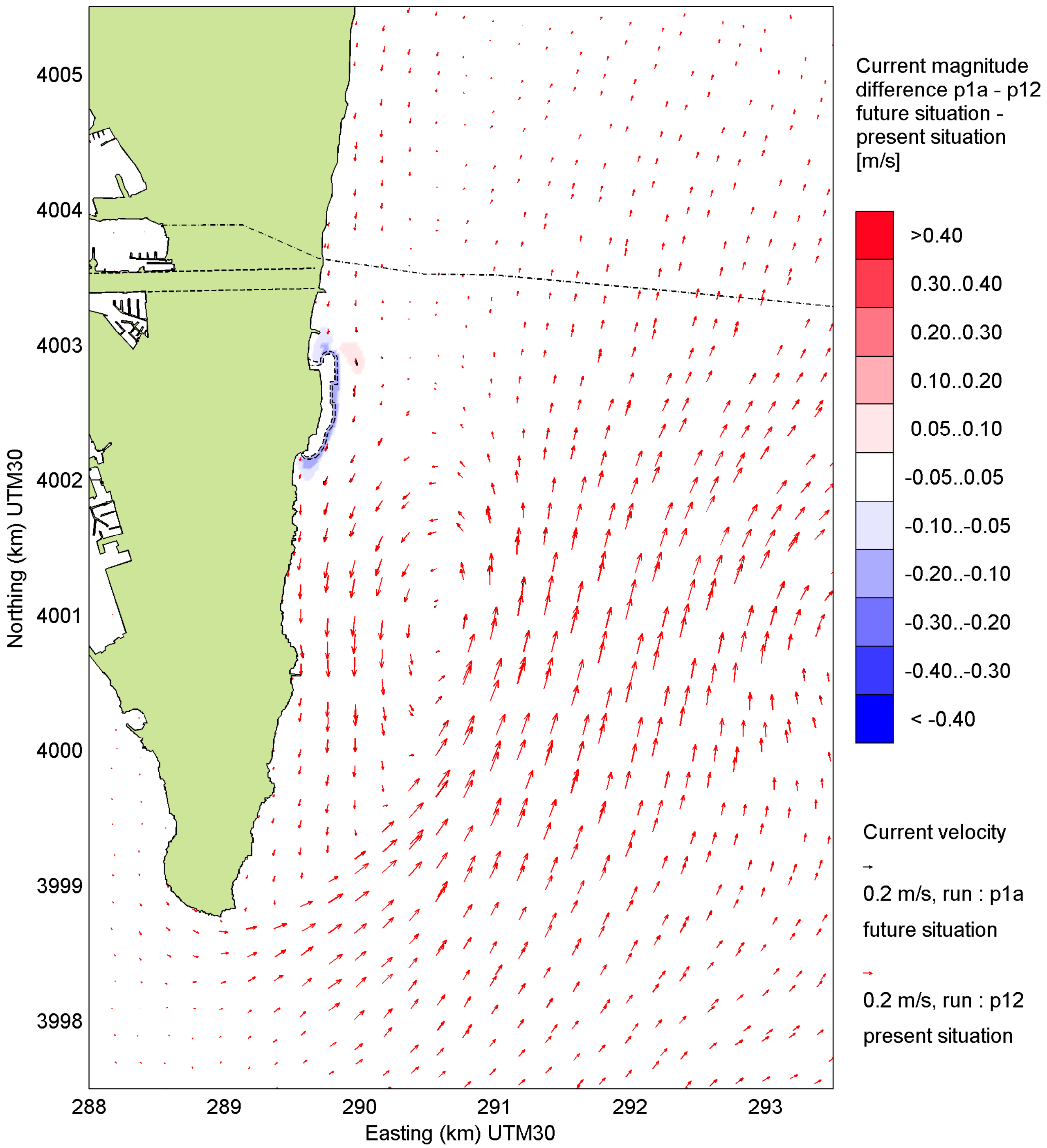


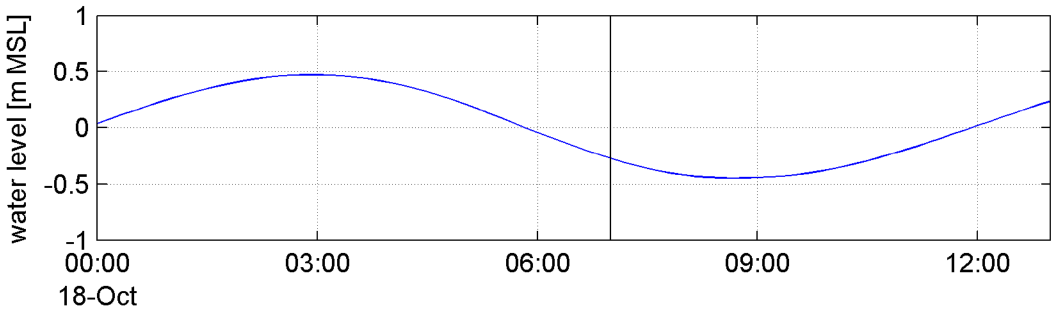
Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13f



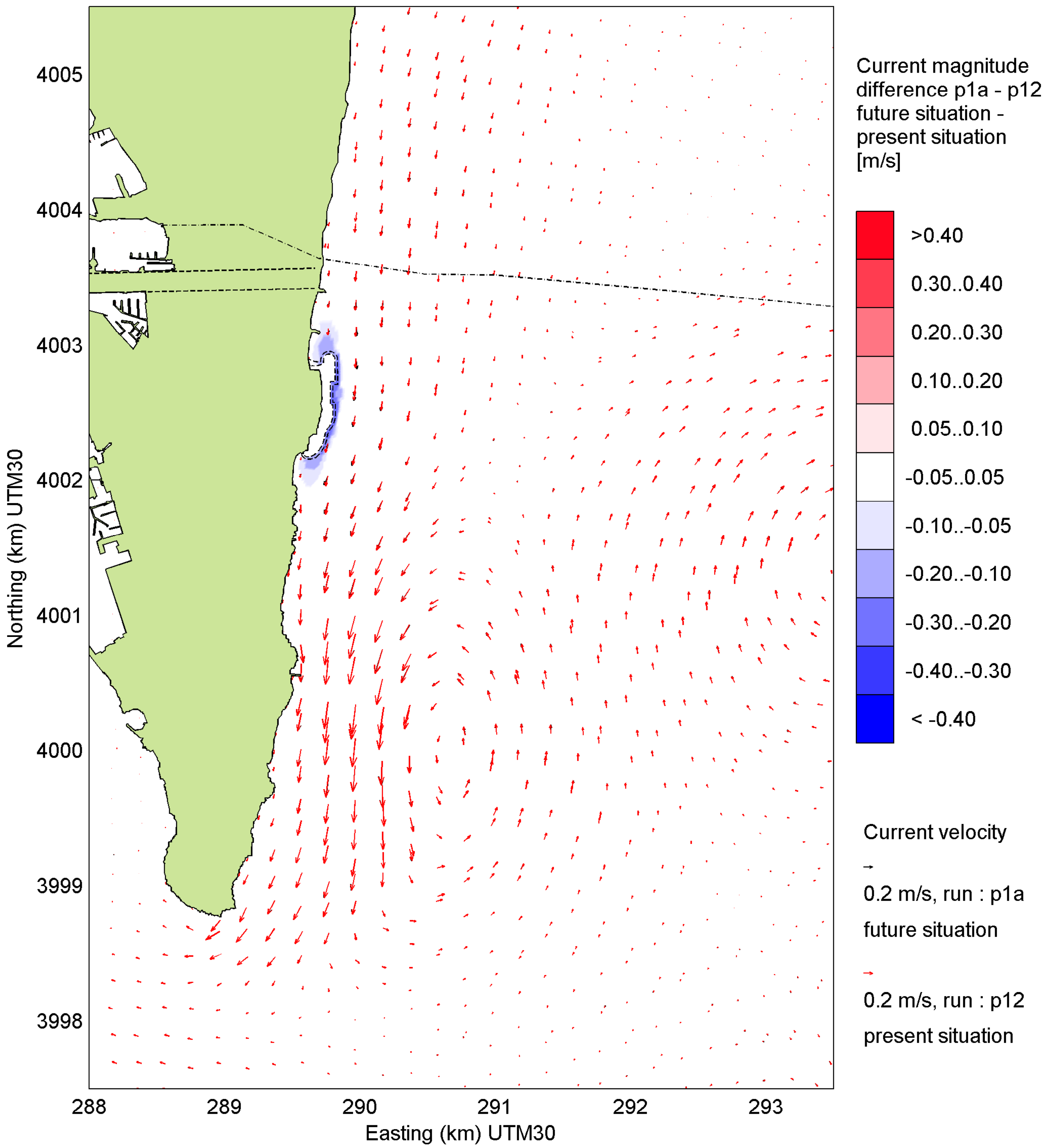


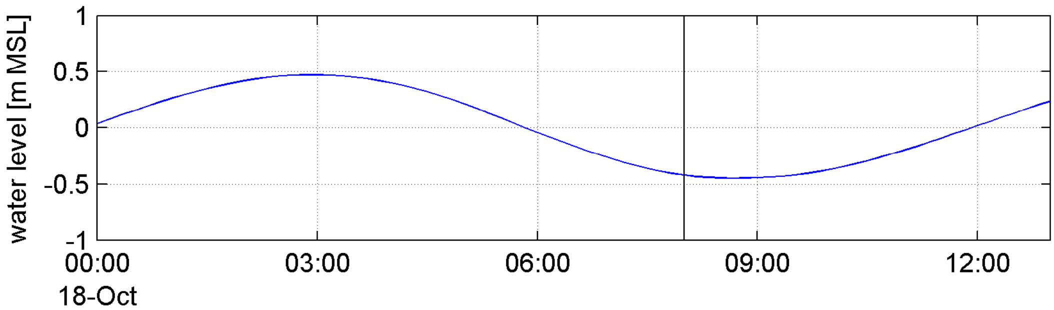
Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13g



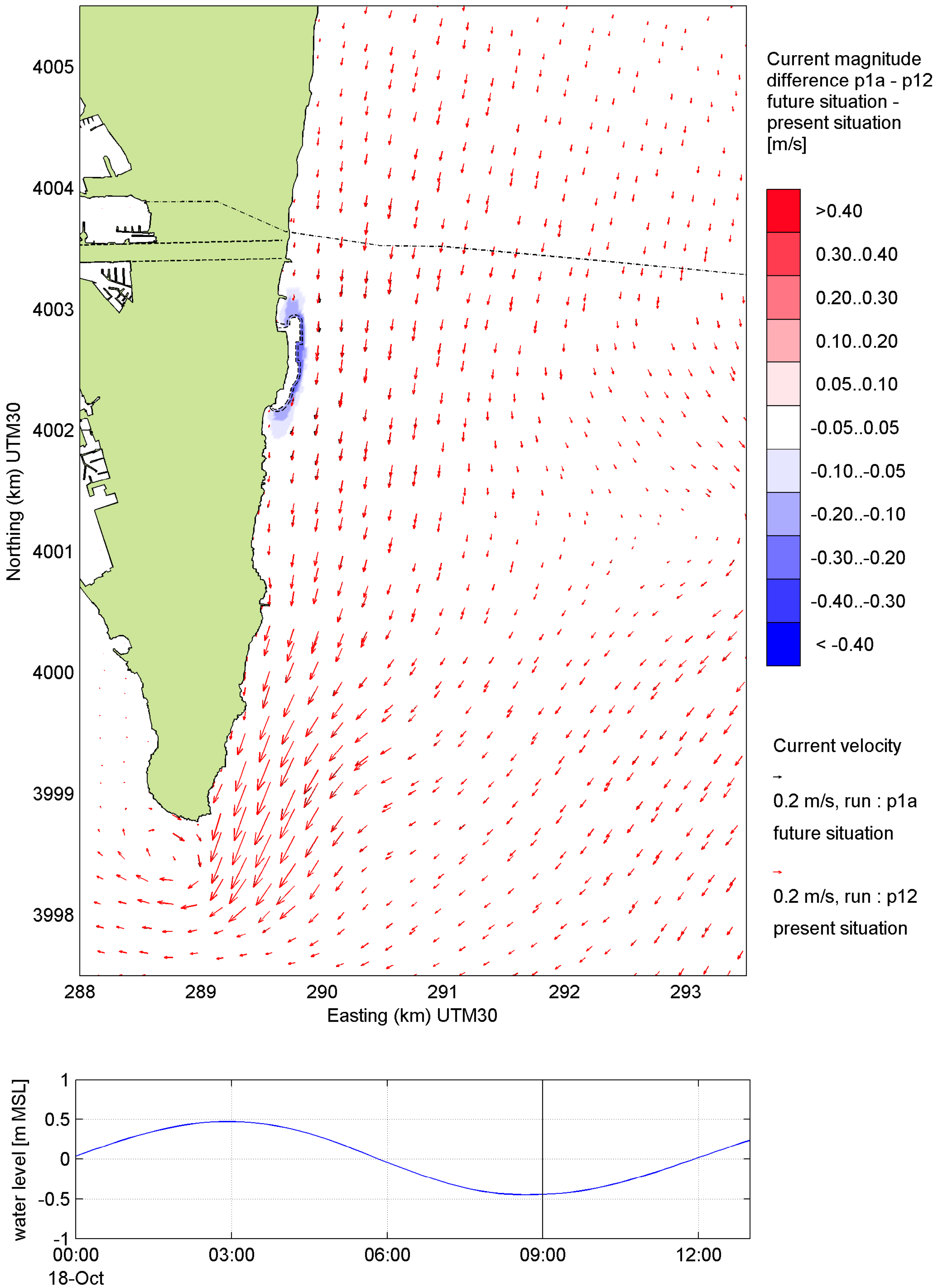


Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13h

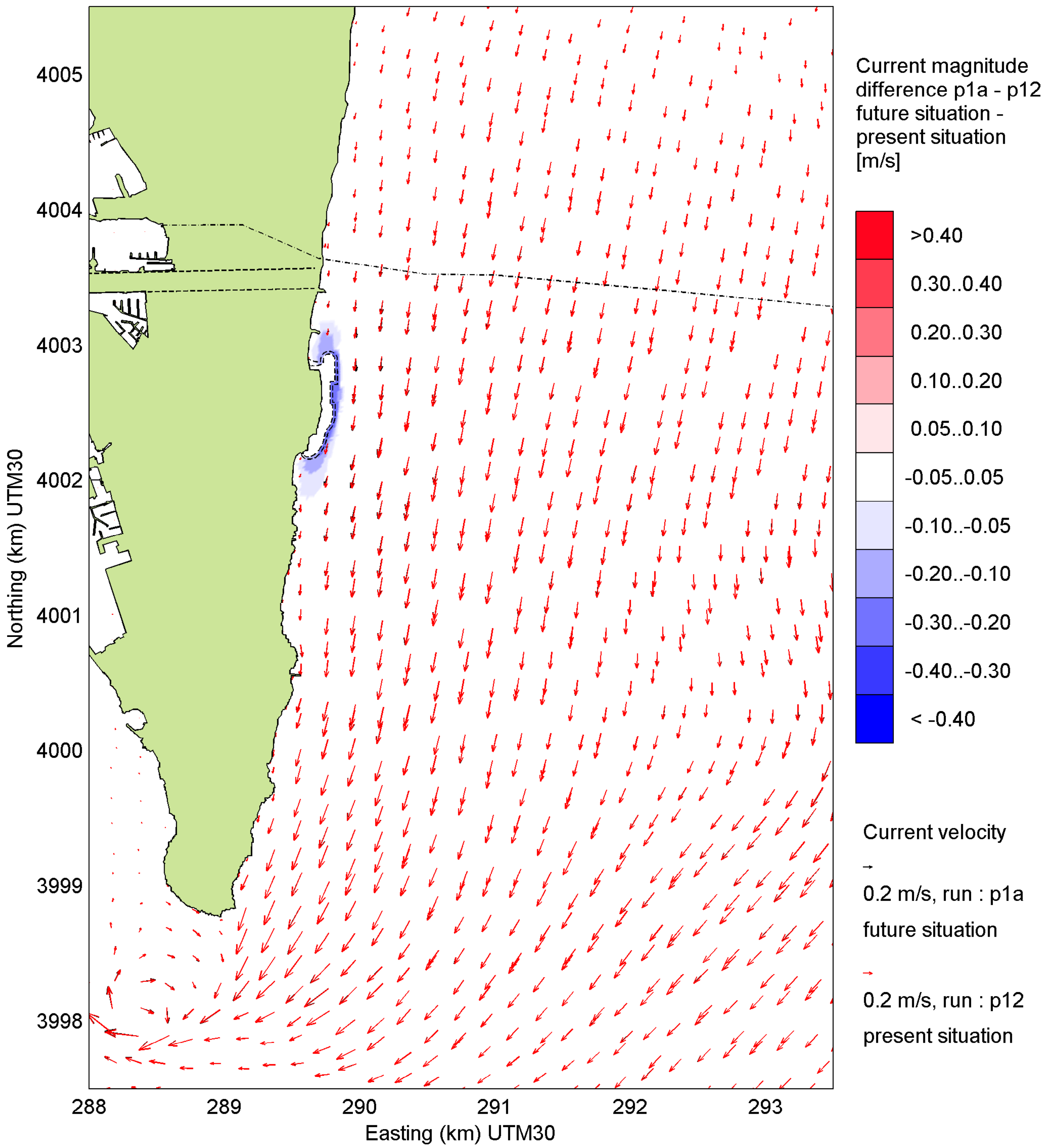


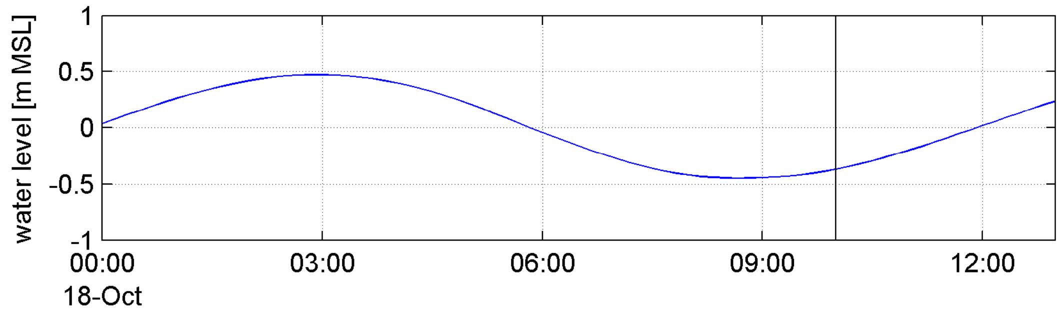


Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13i

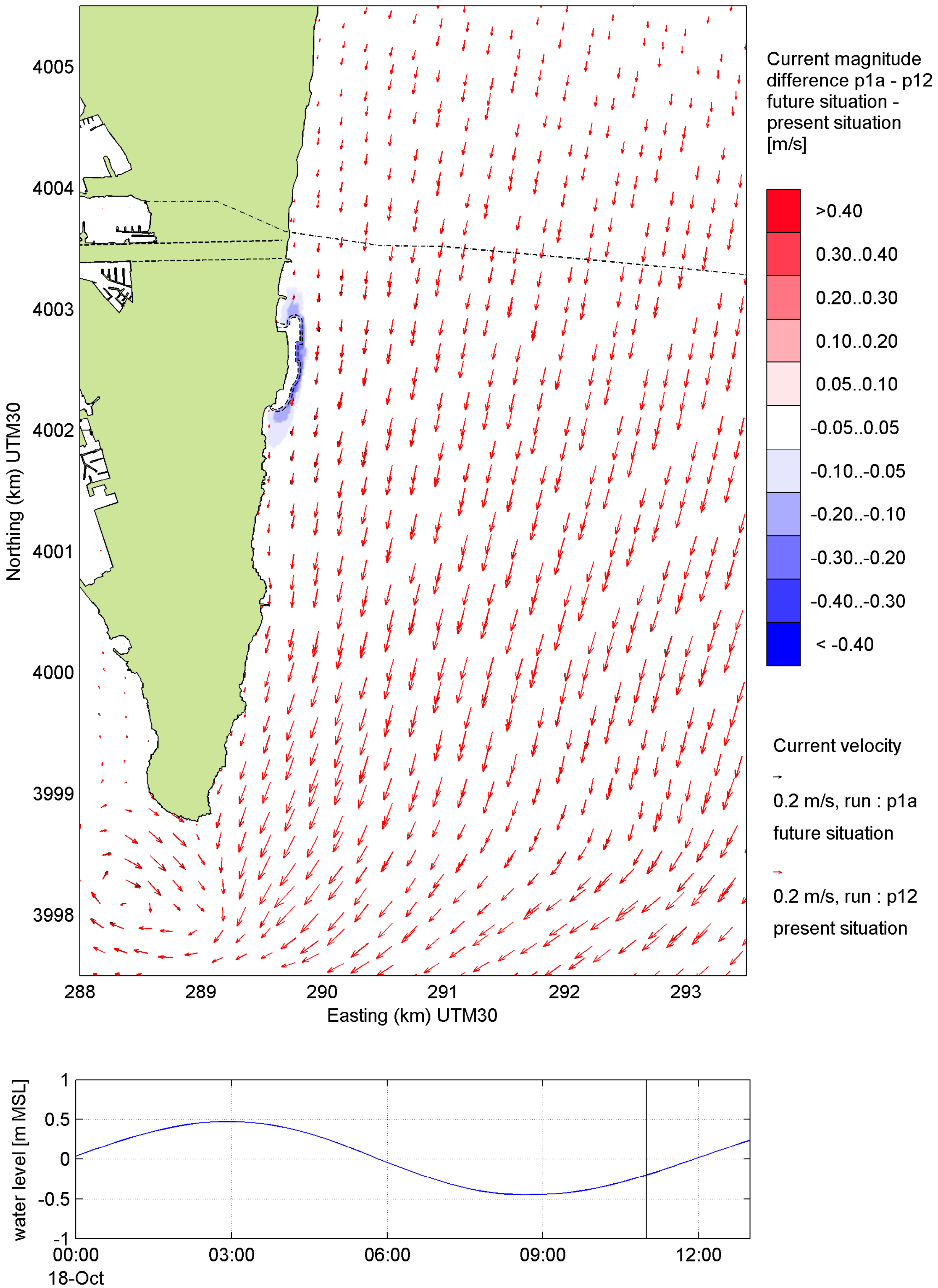


Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13j

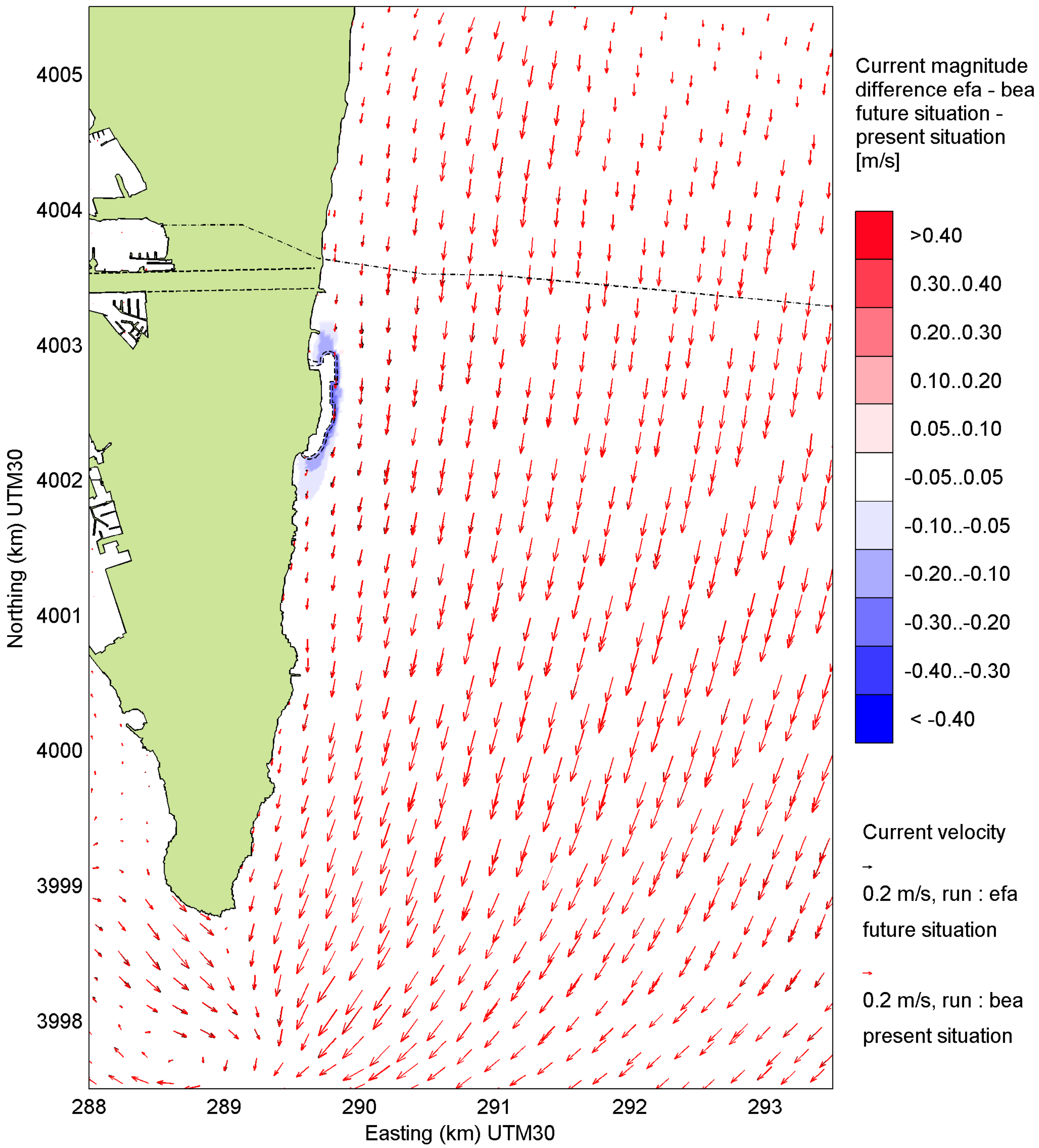


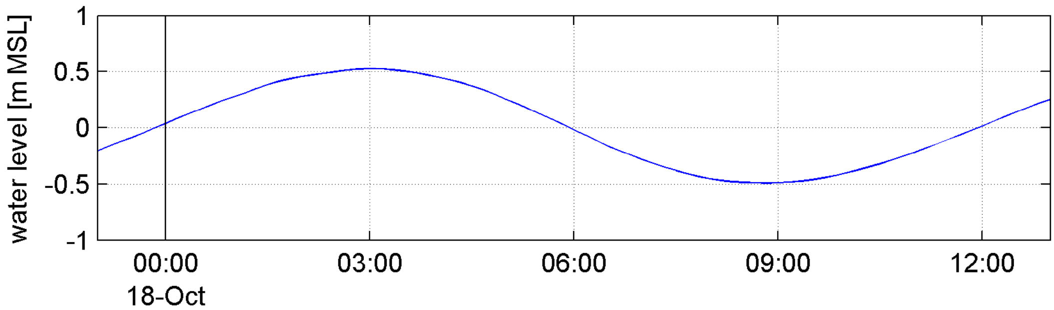


Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13k

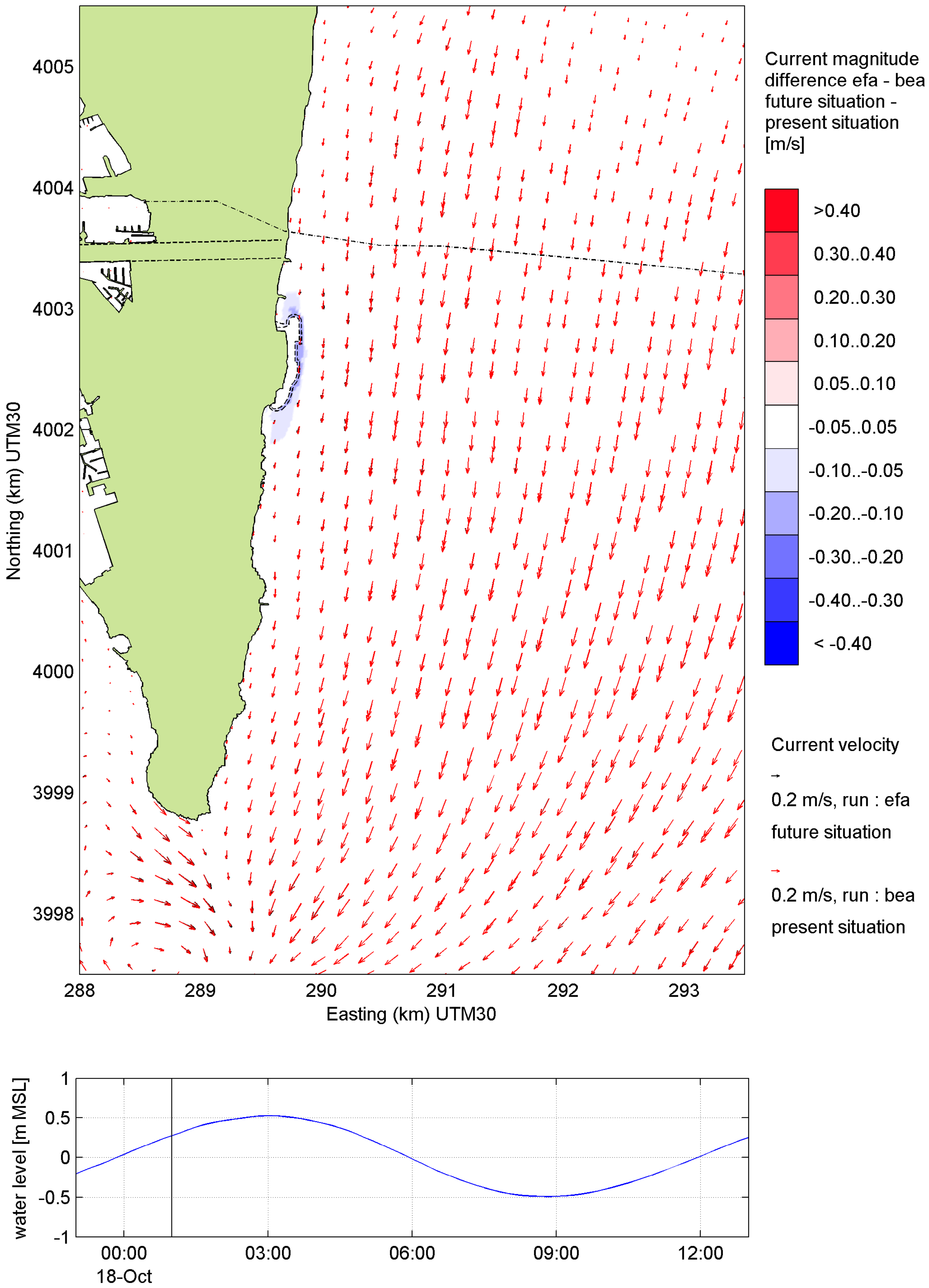


Current magnitude difference (p1a - p12) and velocity vectors, with: p1a: future situation p12: present situation	no wind	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.13l

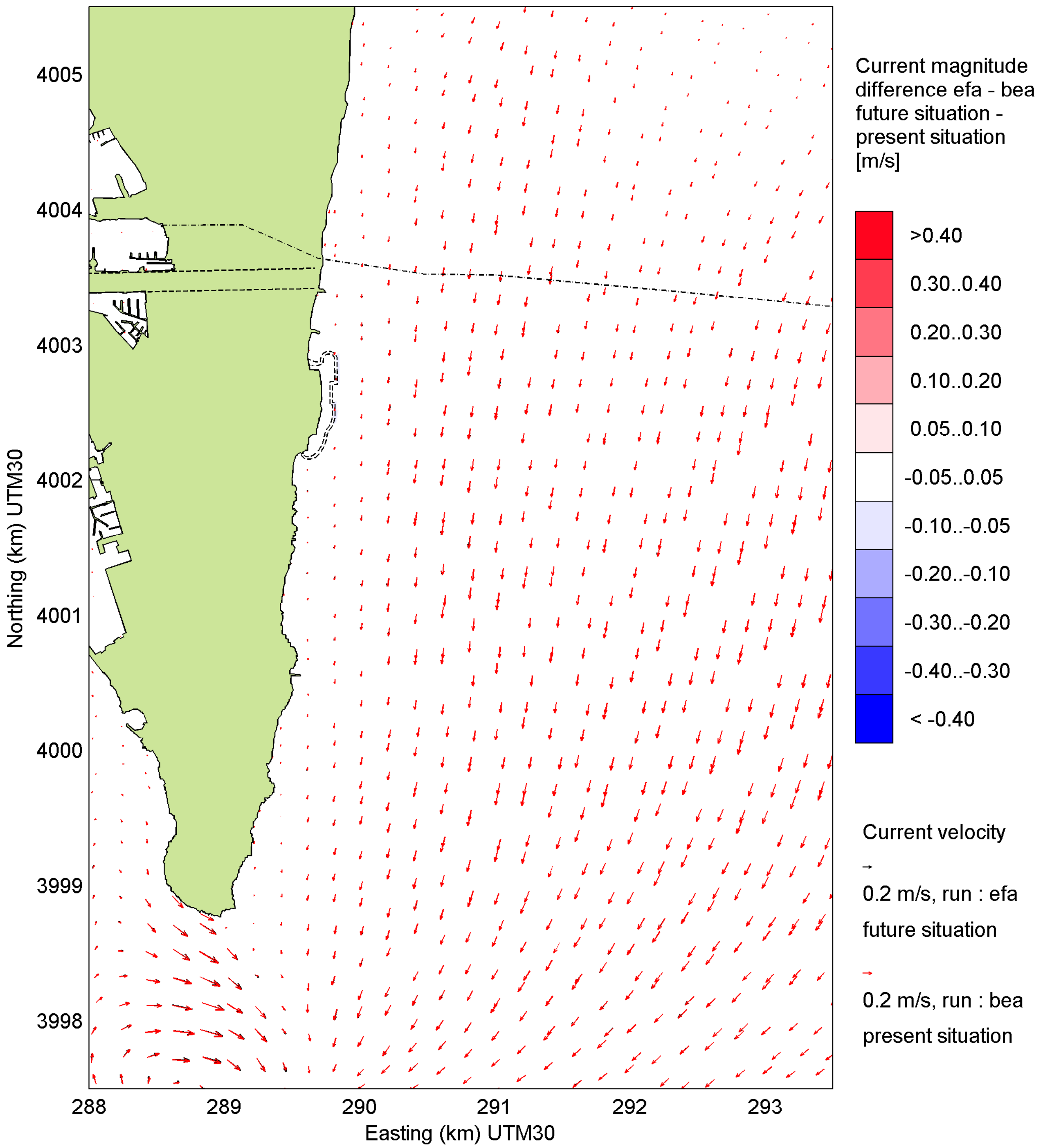


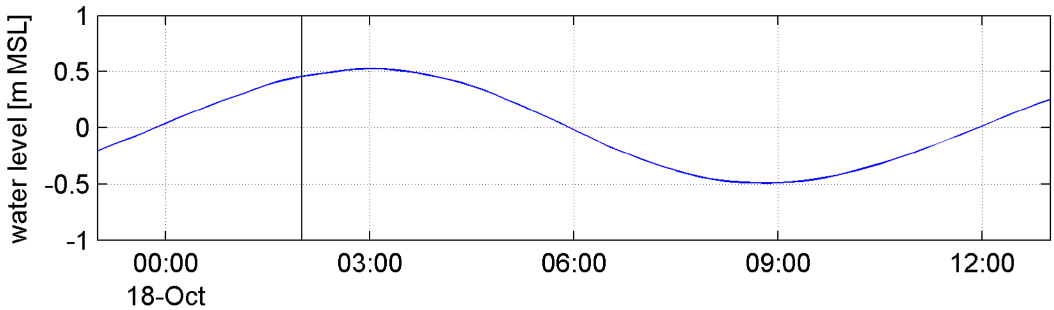


Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15a

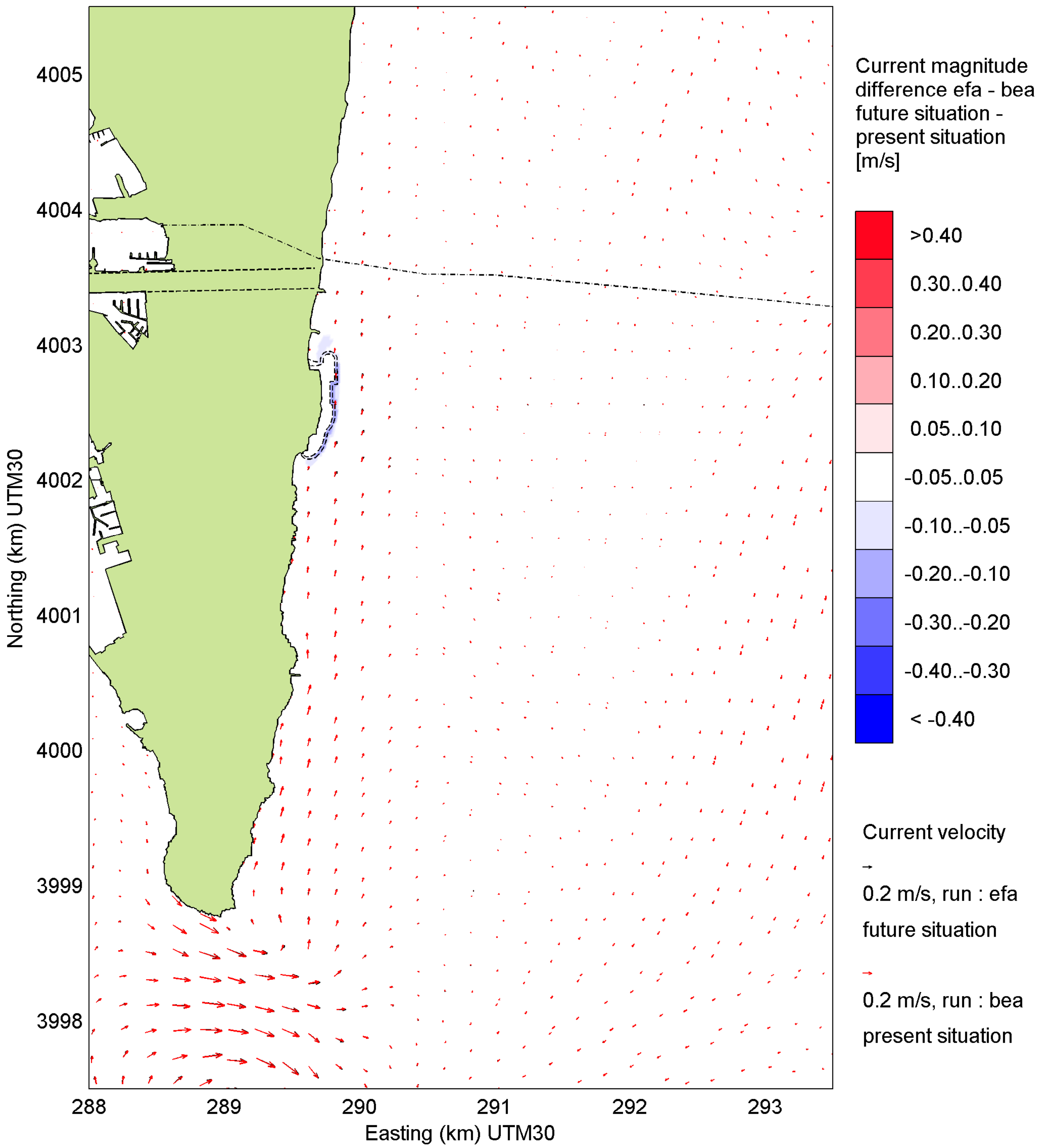


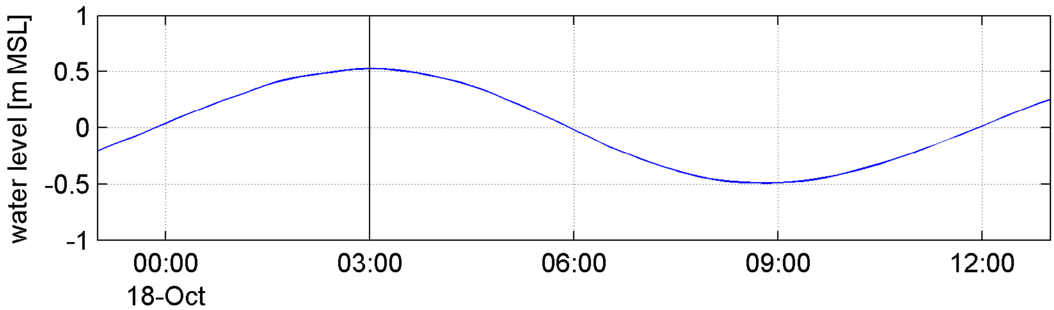
Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15b



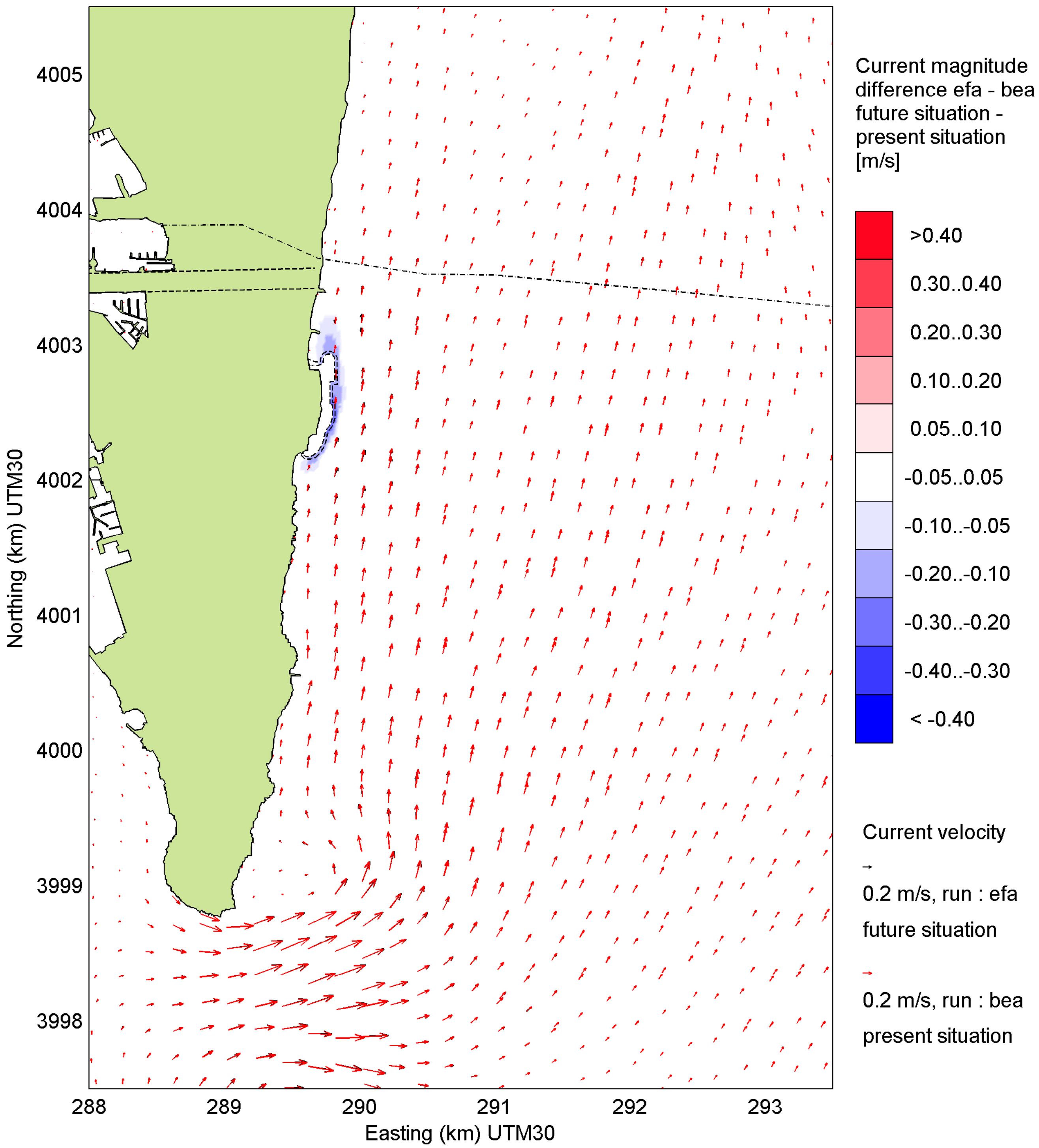


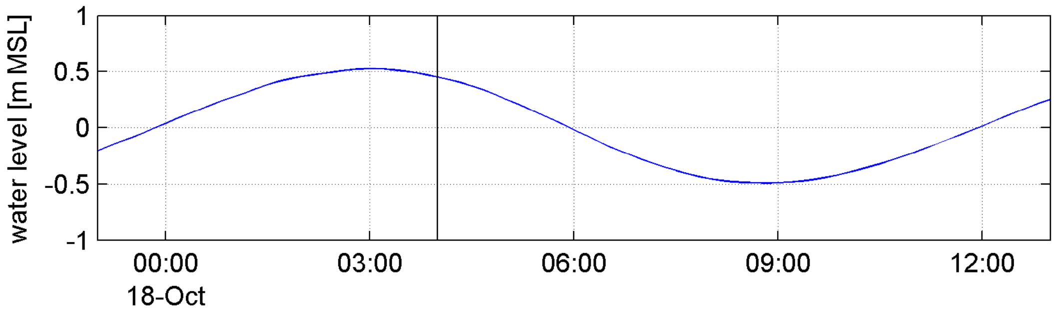
Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15c



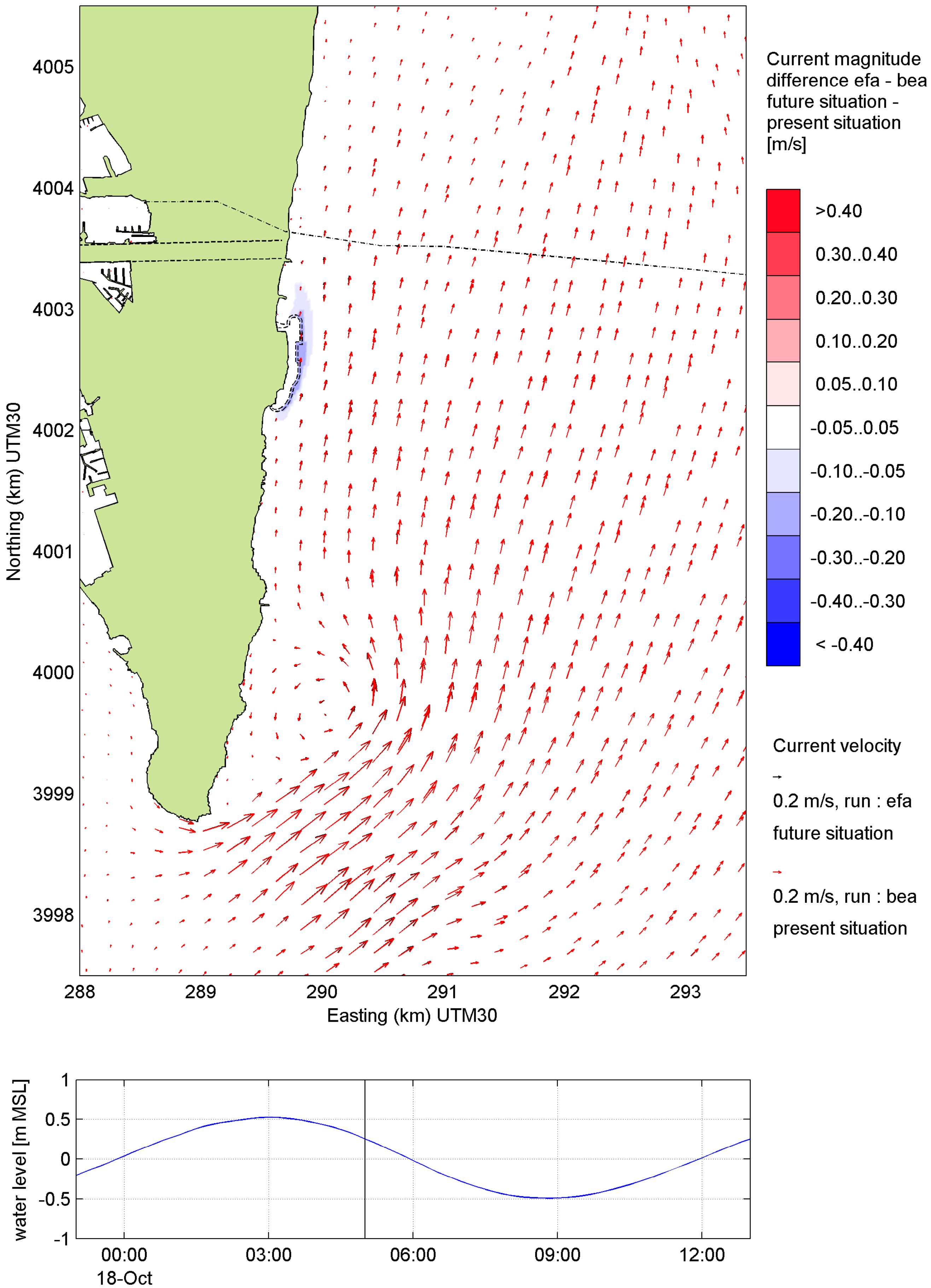


Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15d

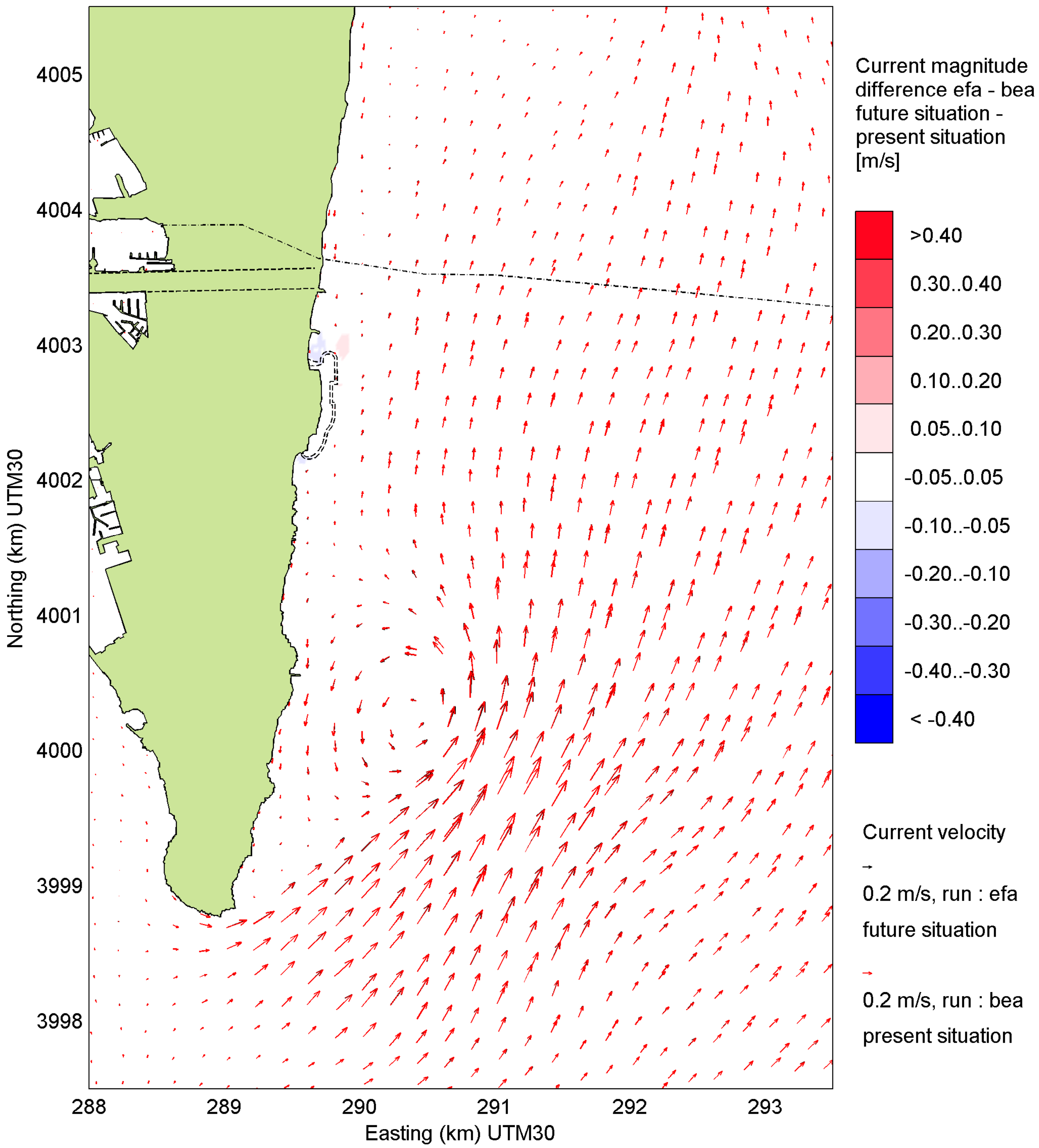


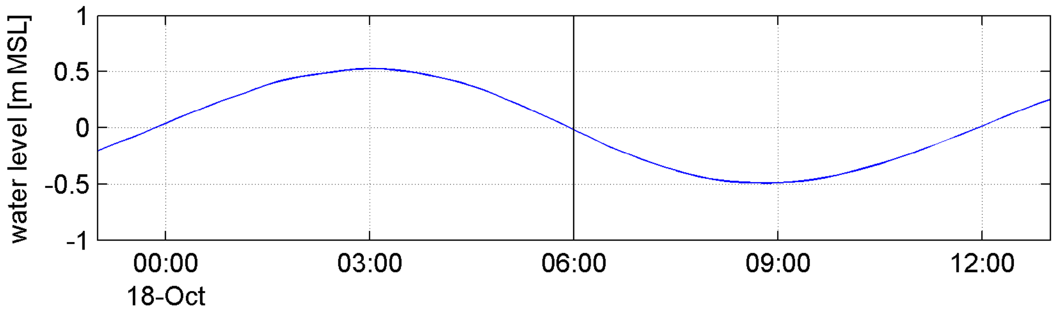


Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15e

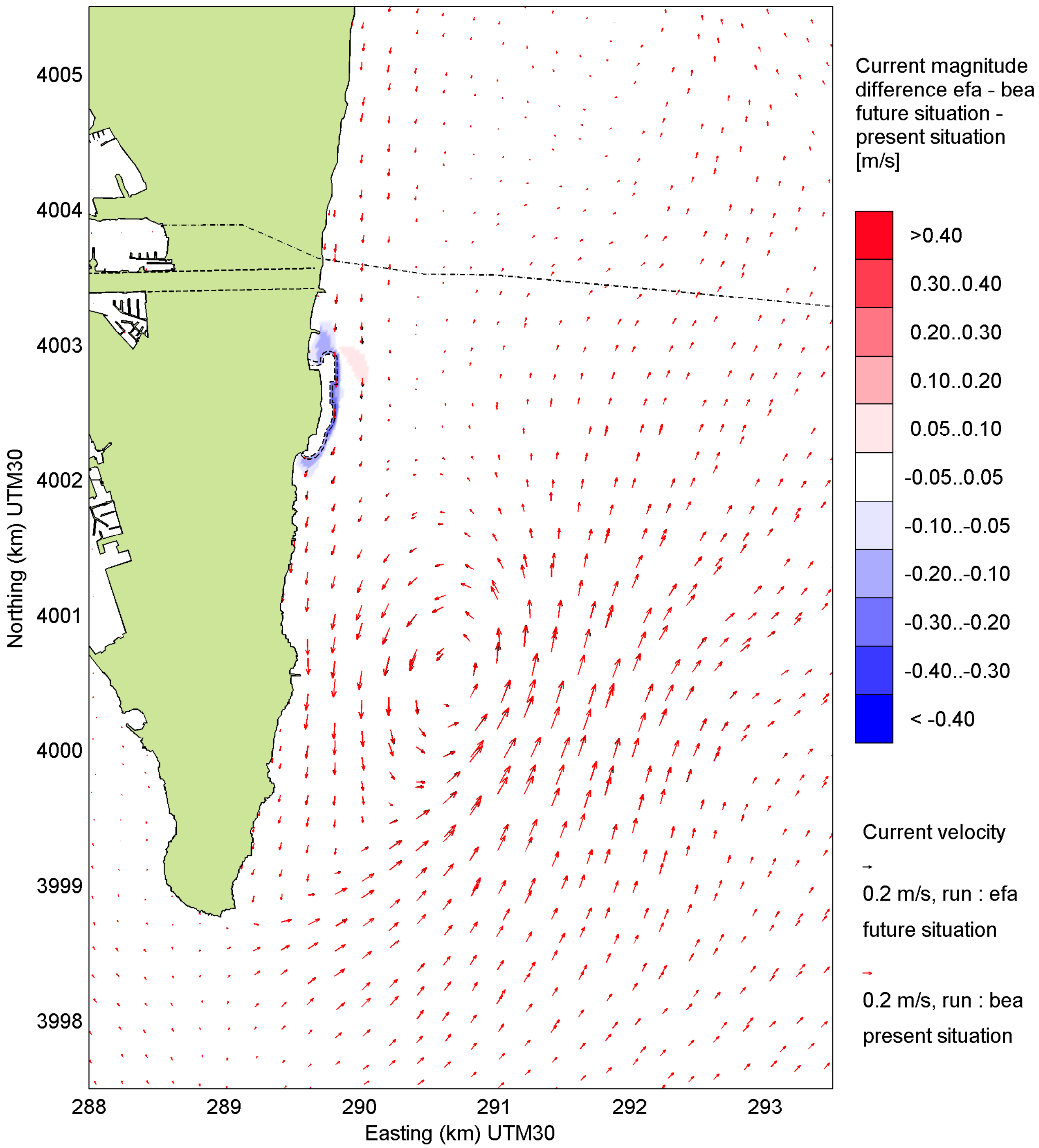


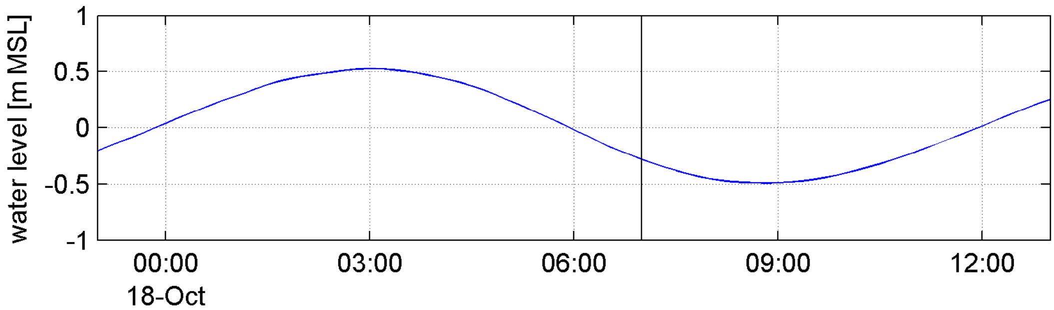
Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15f





Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15g





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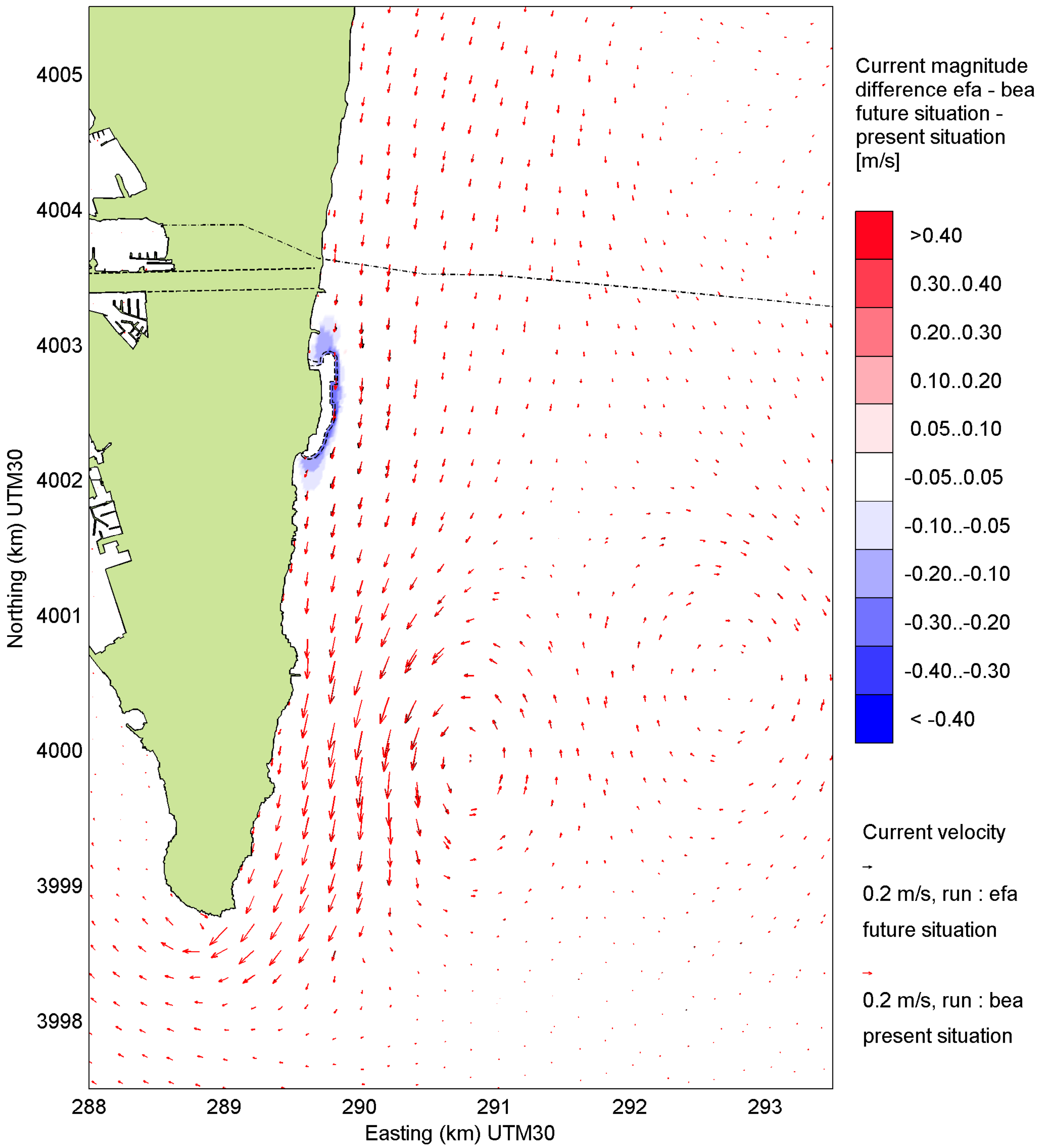
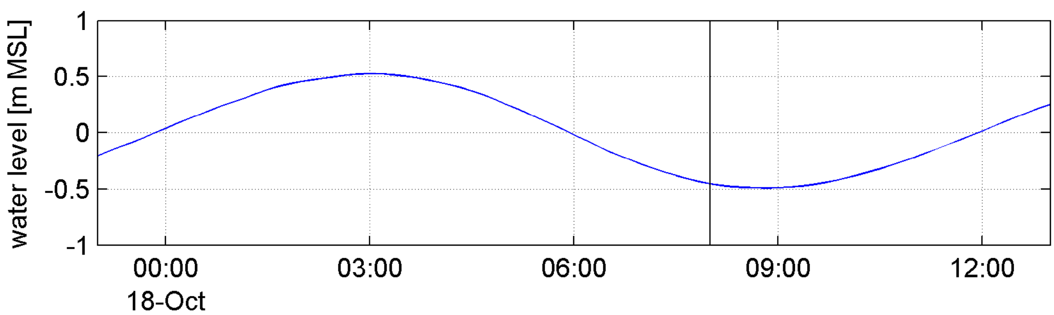
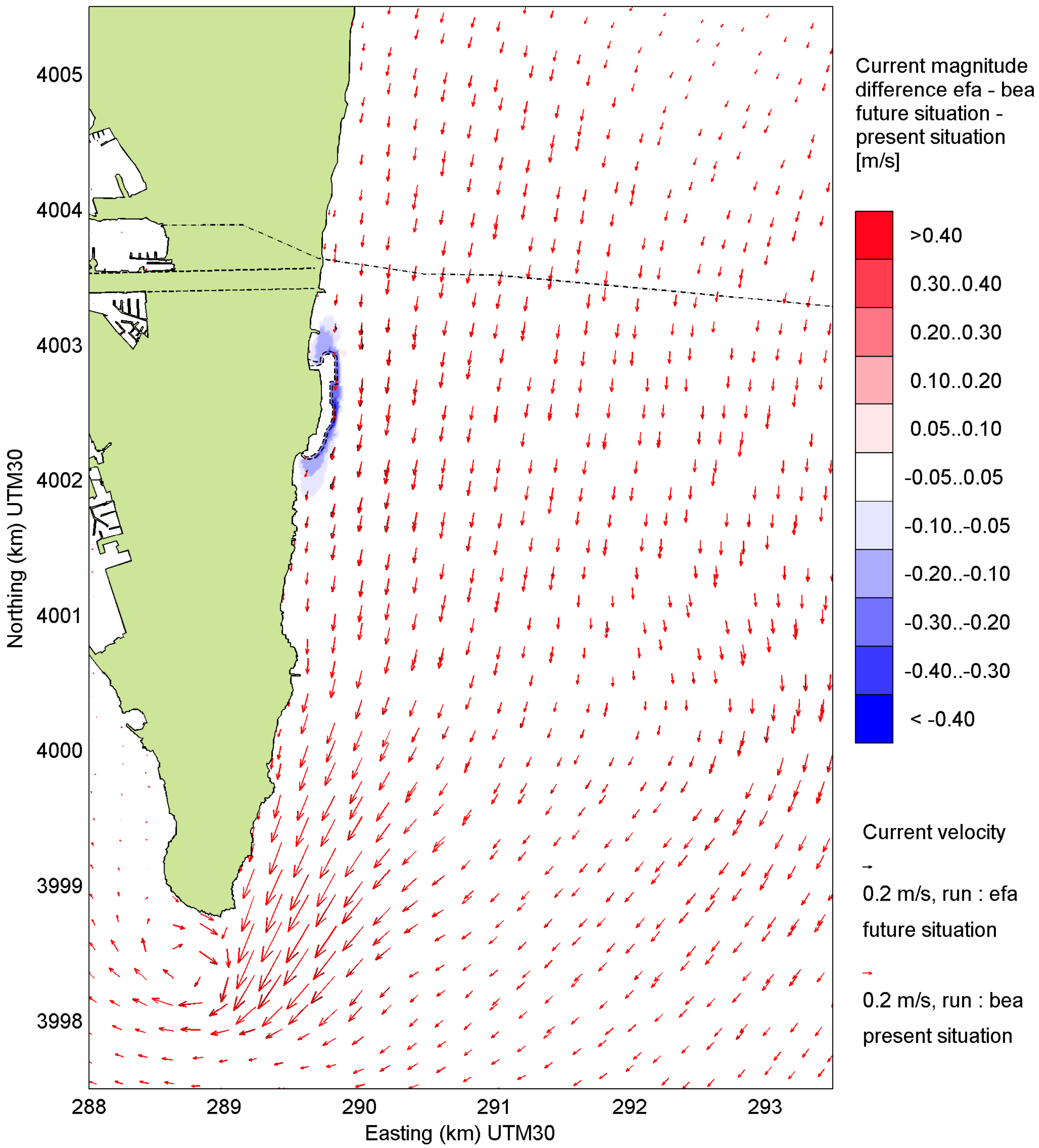
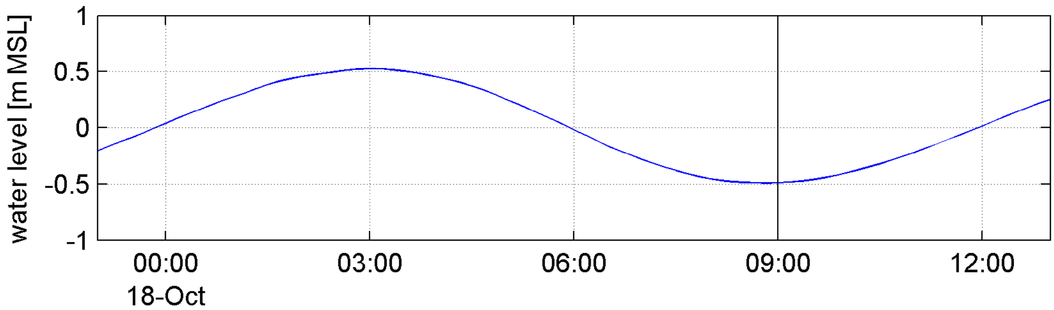
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15h



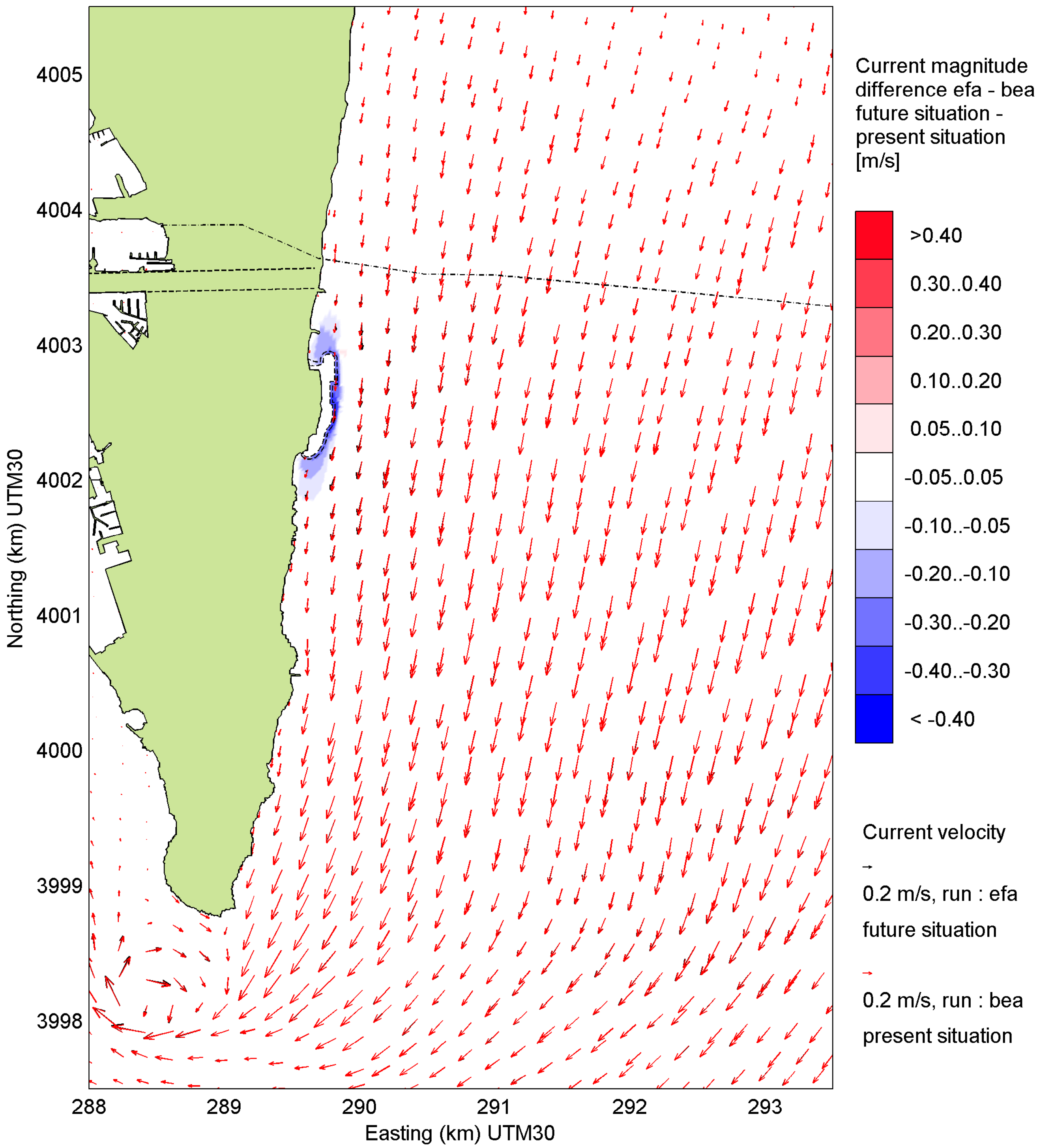


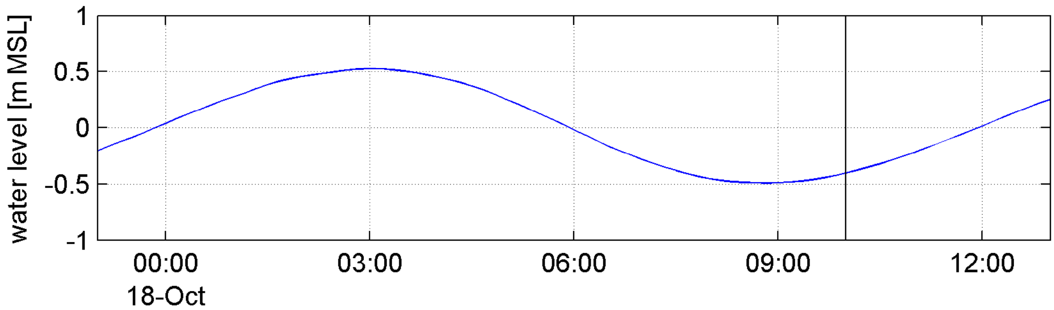
Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15i



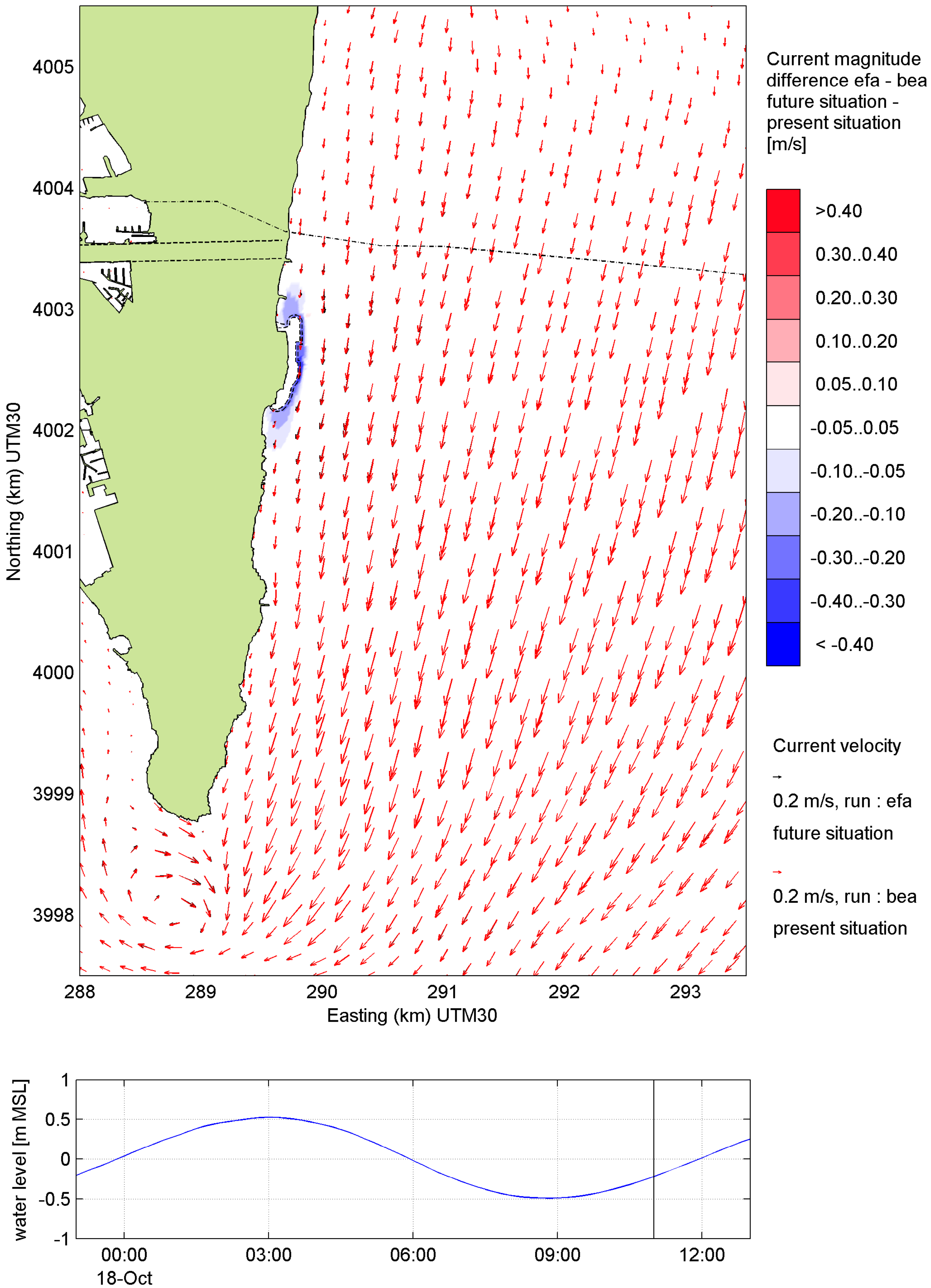


Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15j

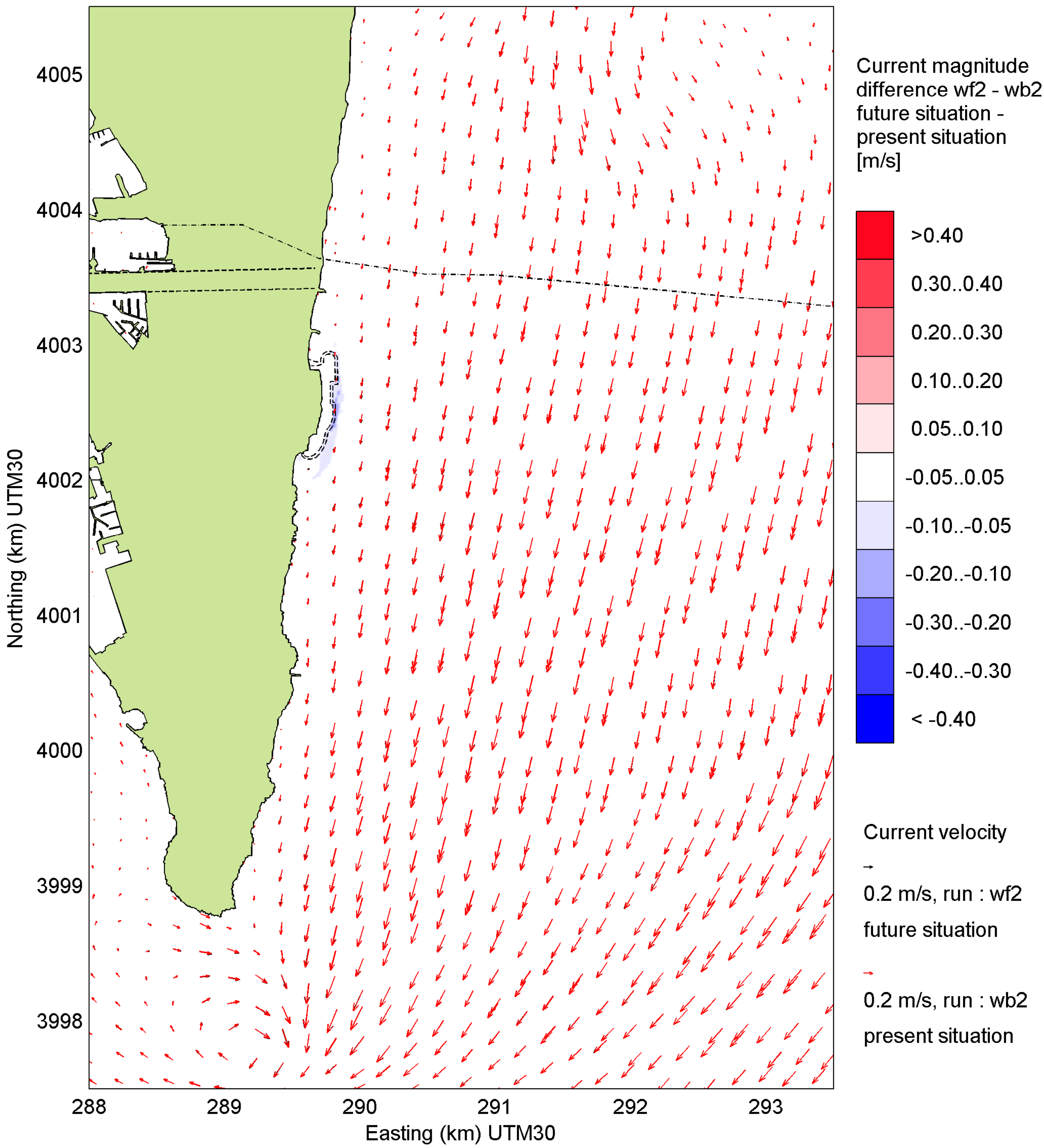


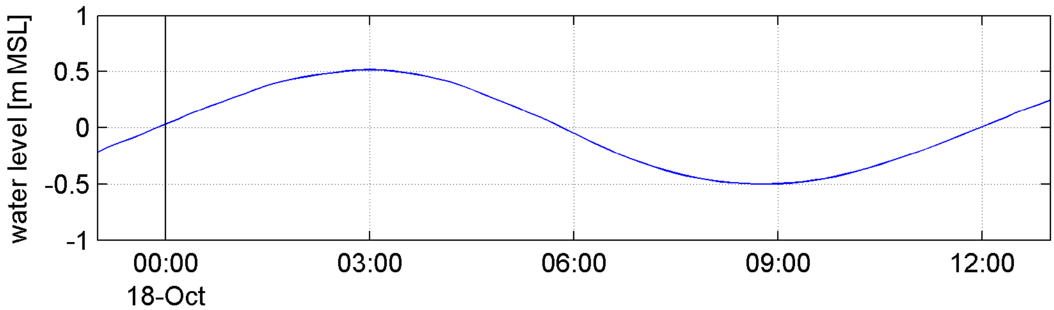


Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15k

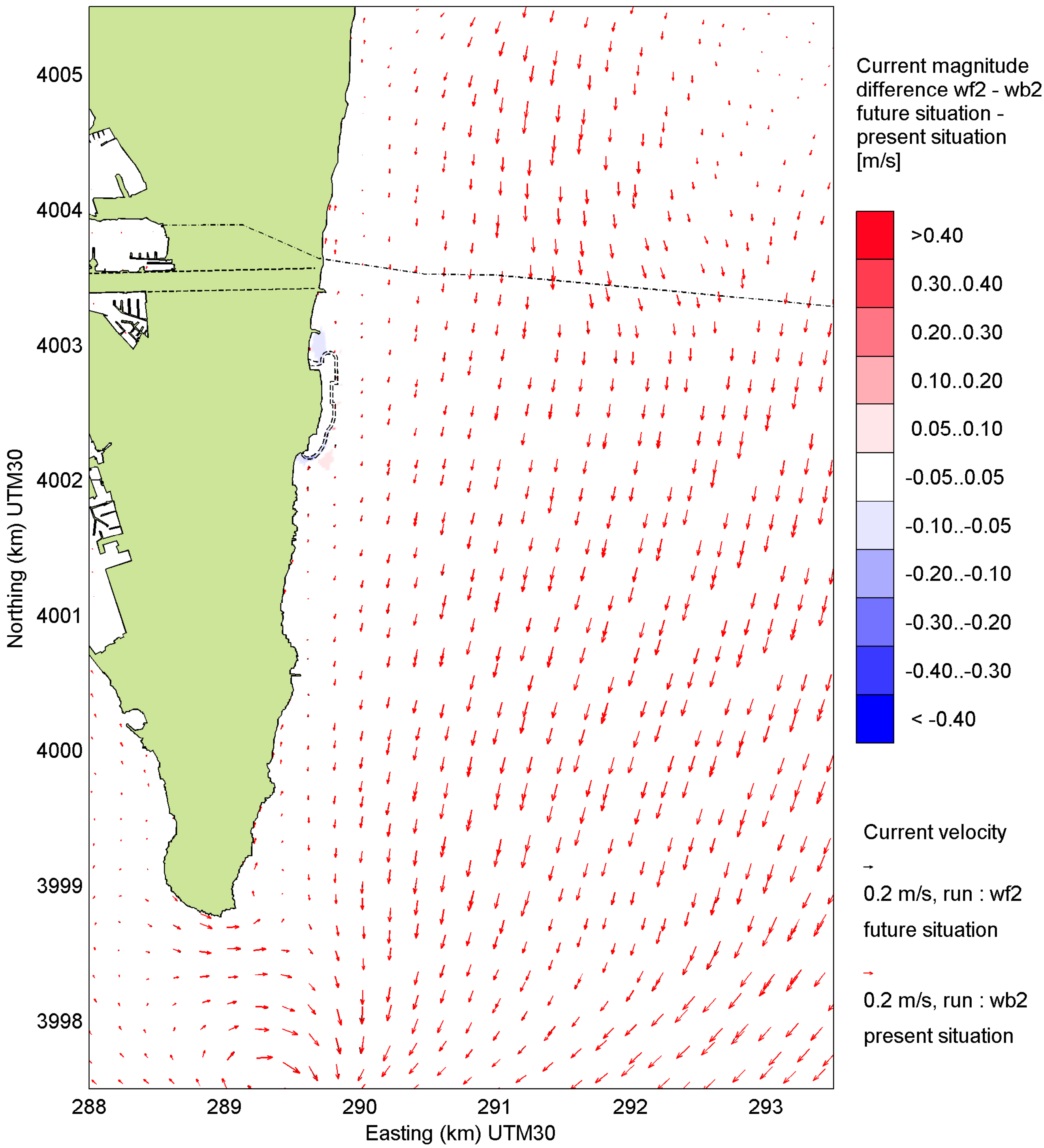


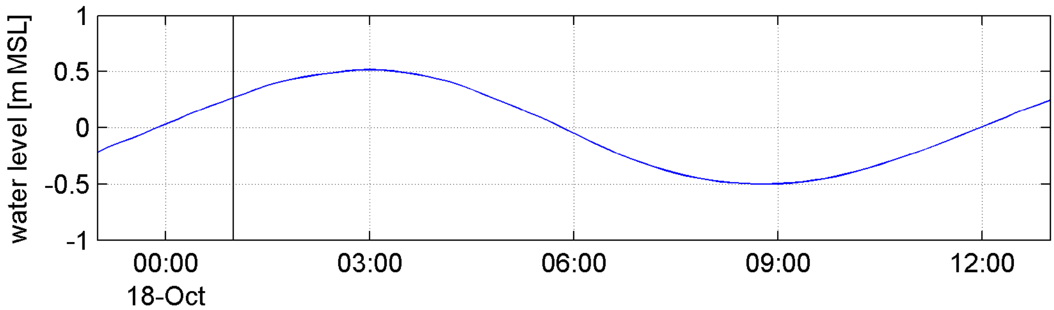
Current magnitude difference (efa - bea) and velocity vectors, with: efa: future situation bea: present situation	ENE wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.15l



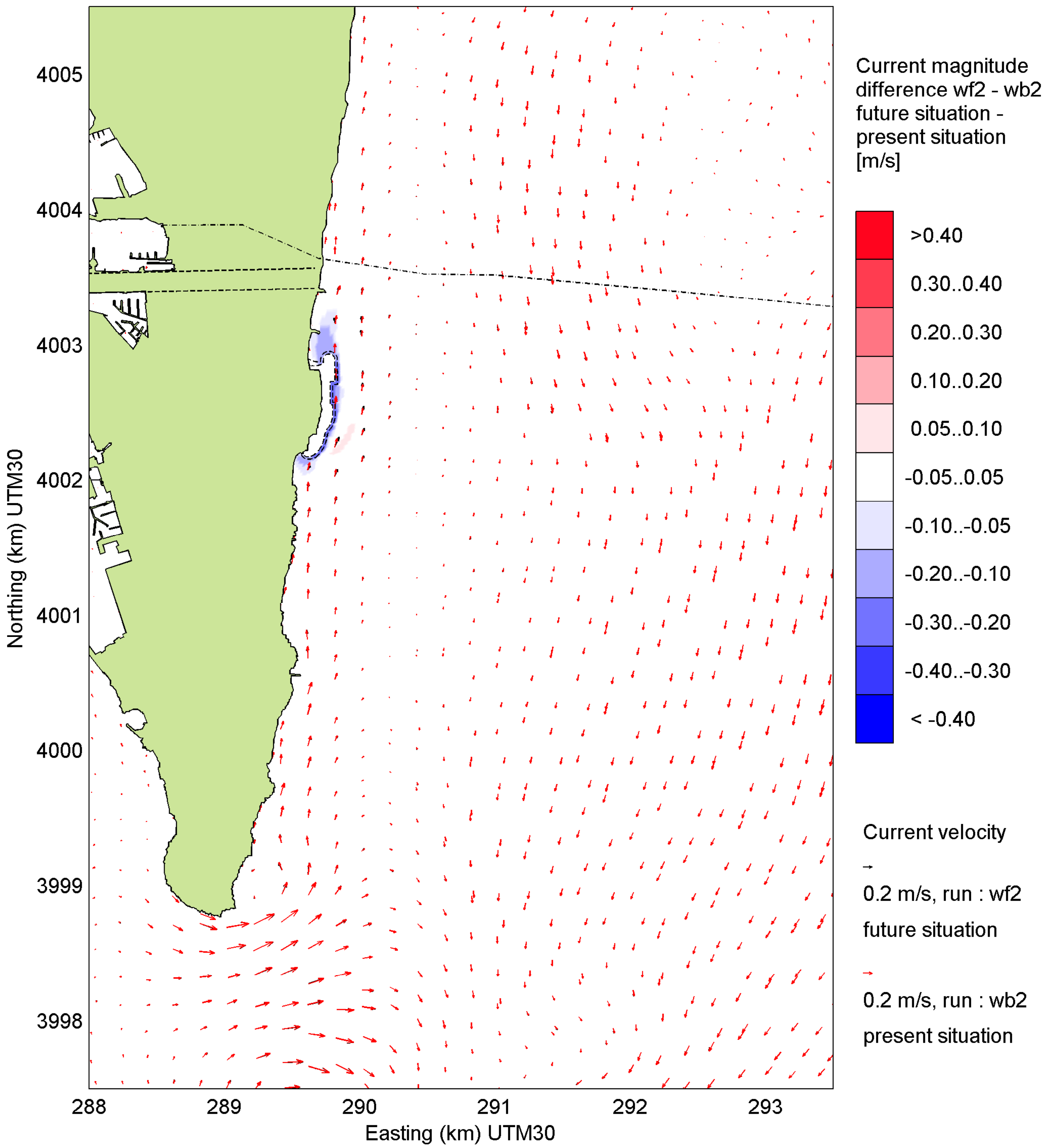


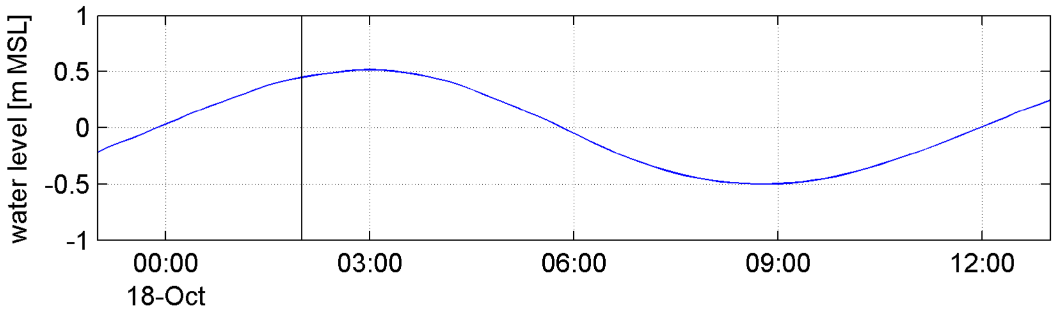
Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17a



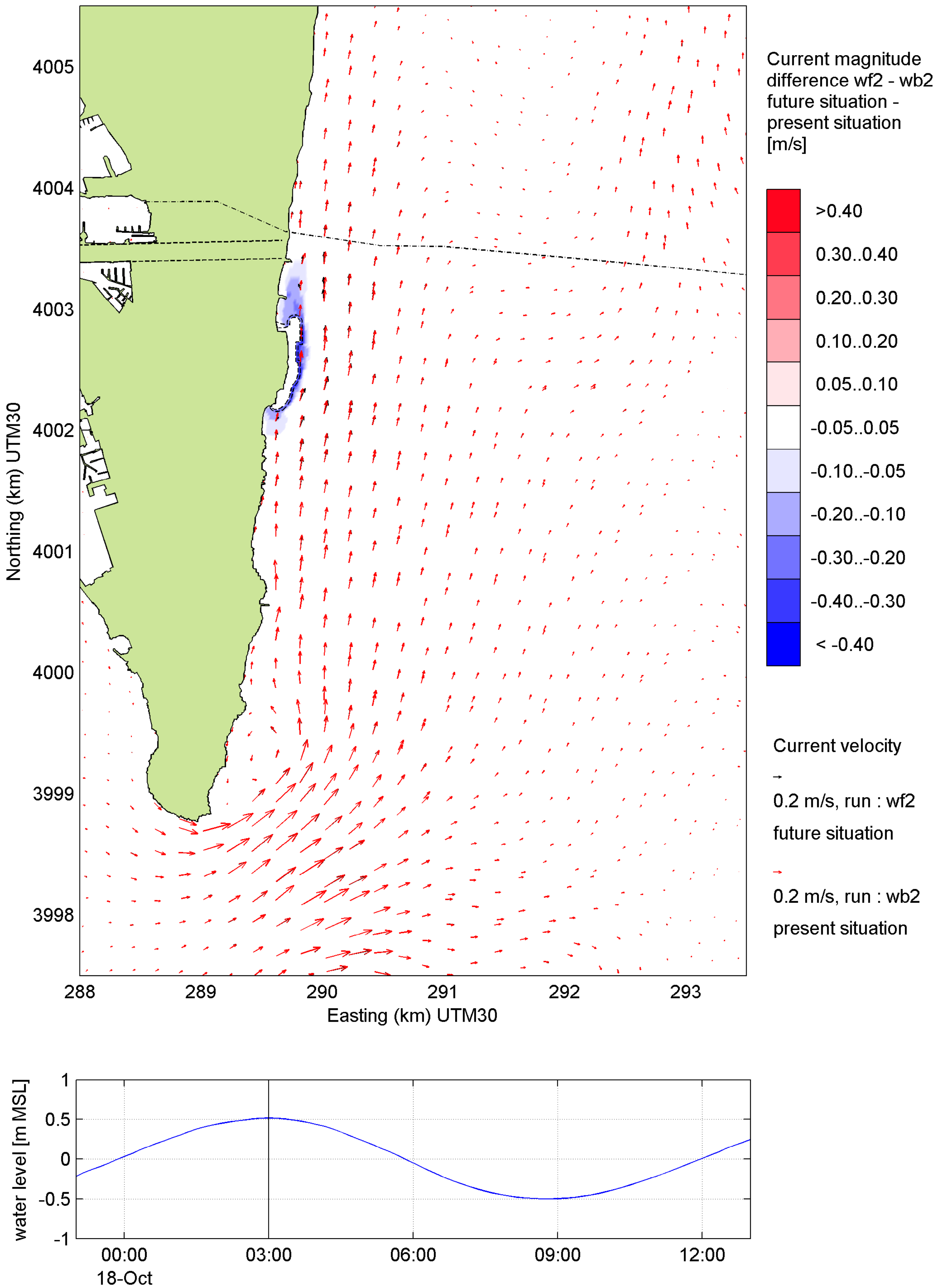


Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17b

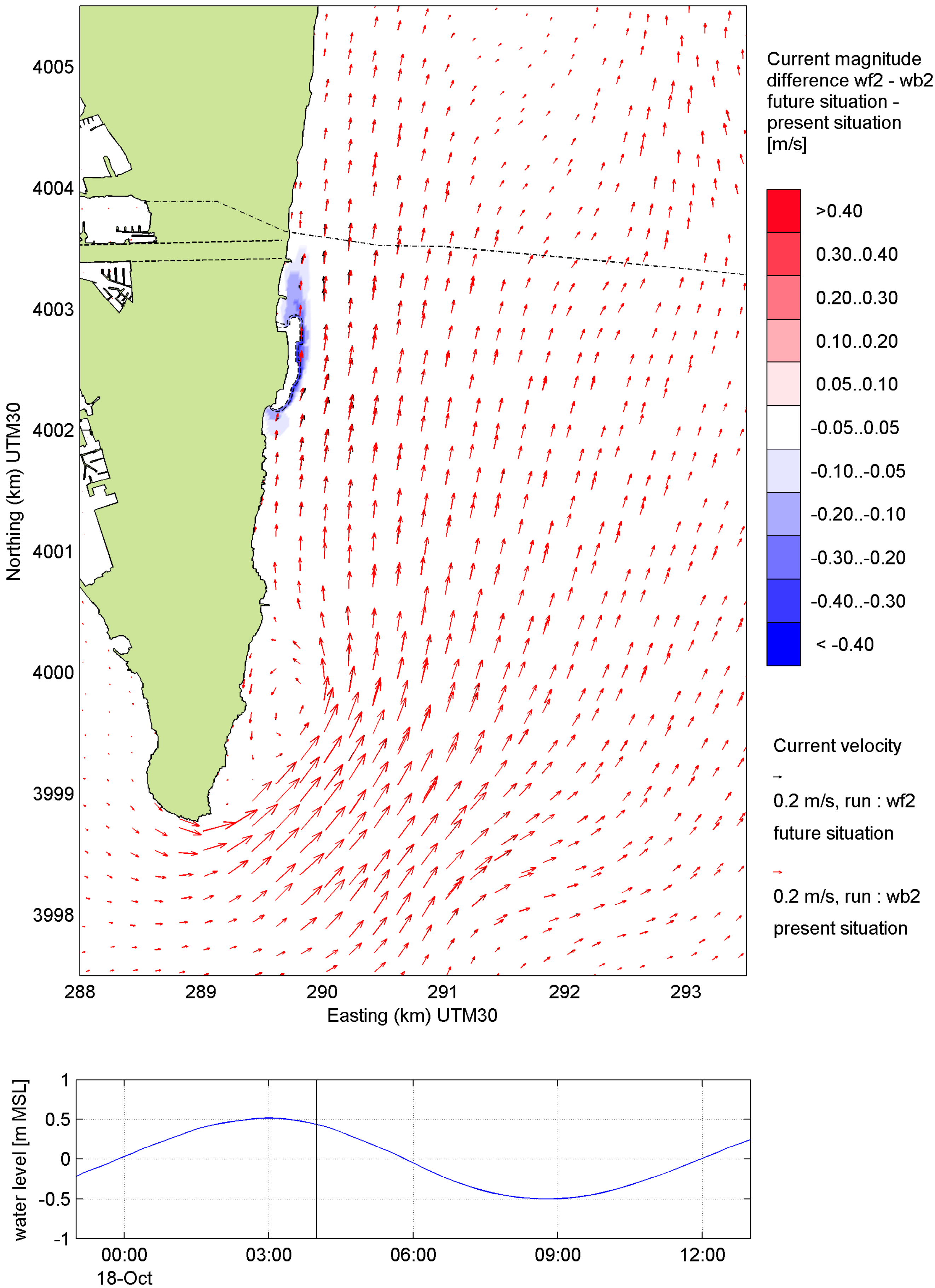




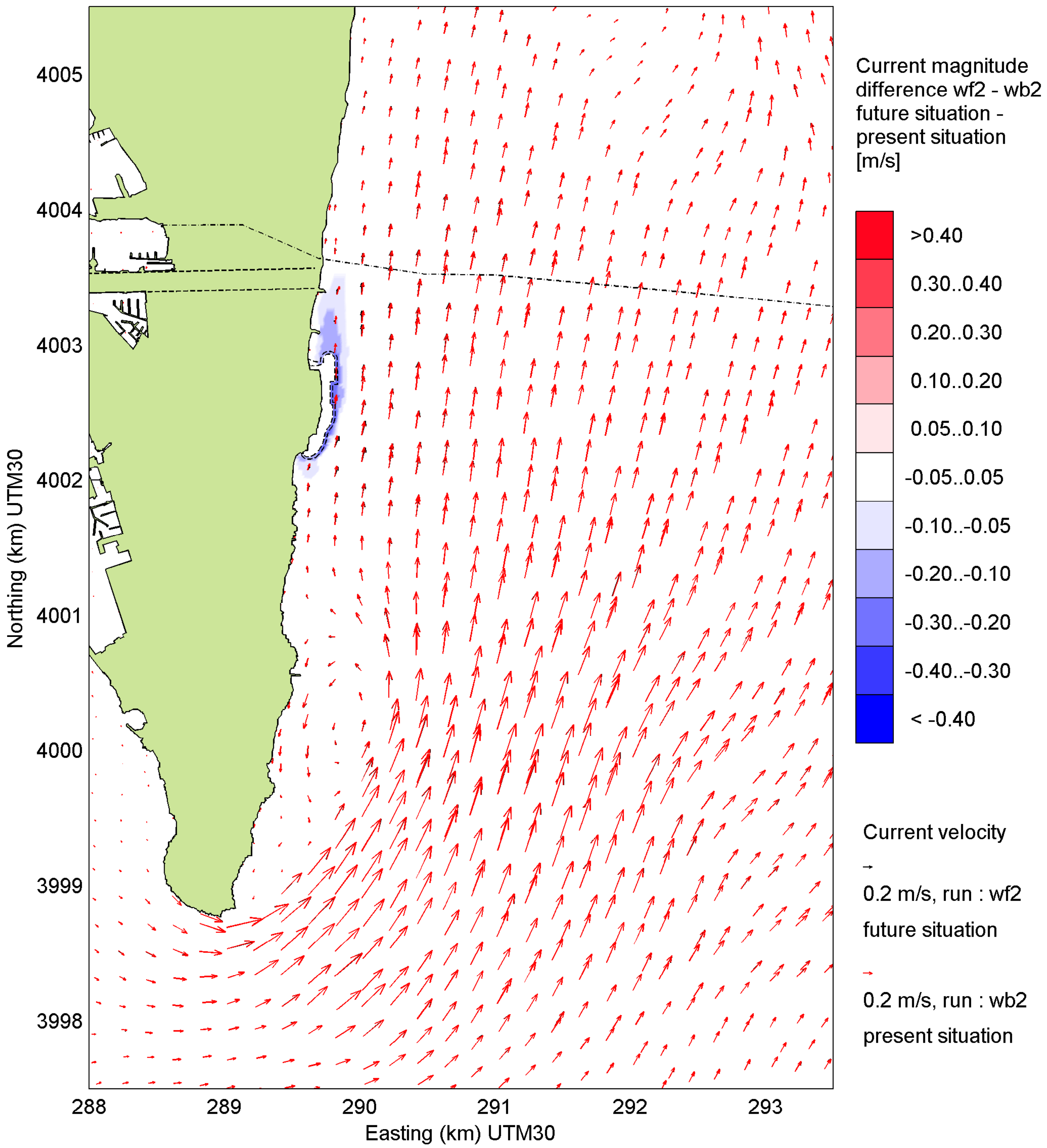
Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17c

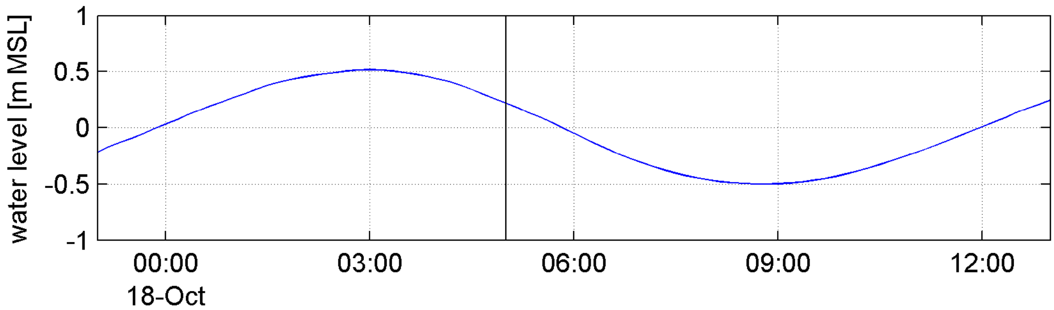


Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17d

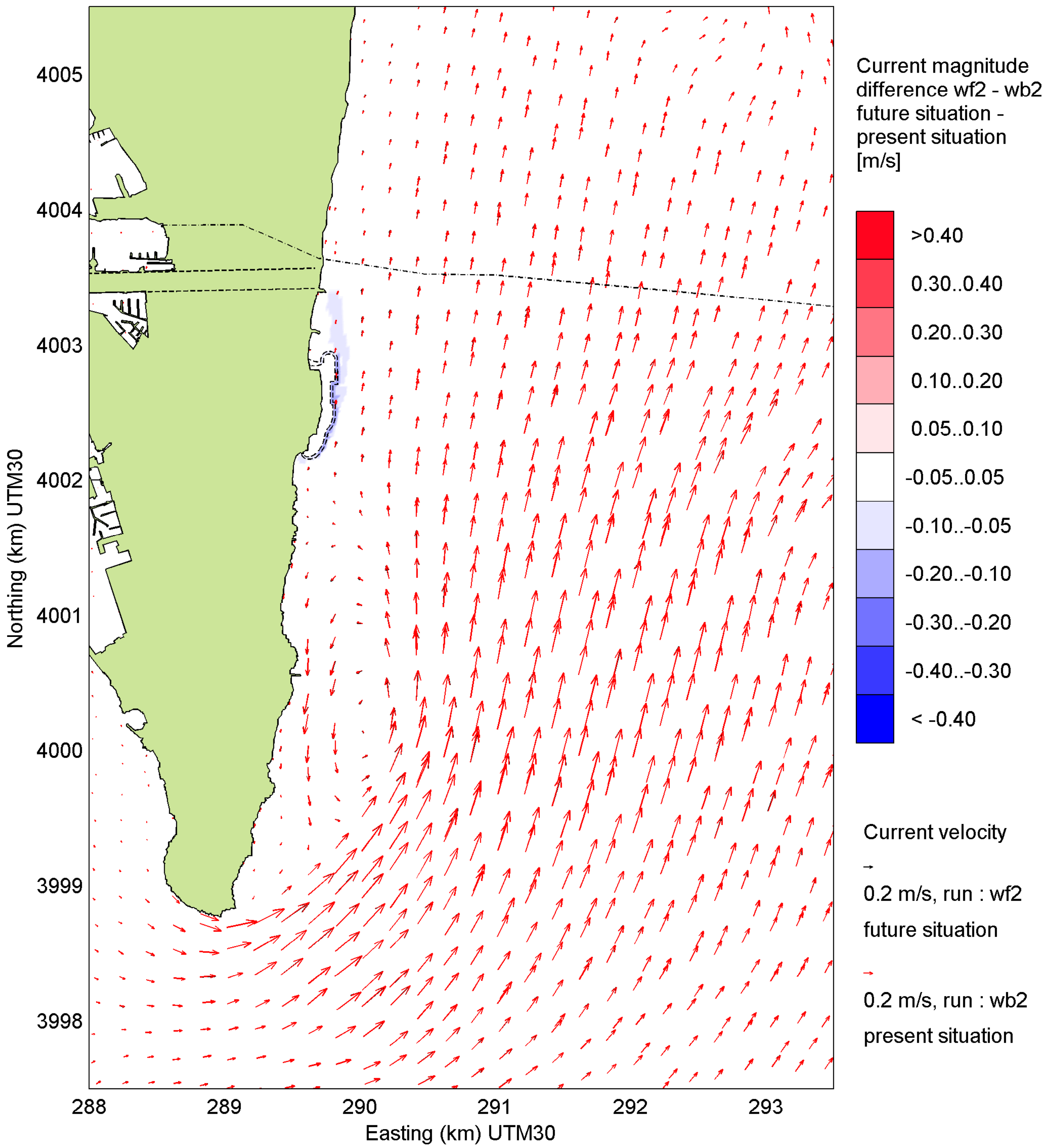


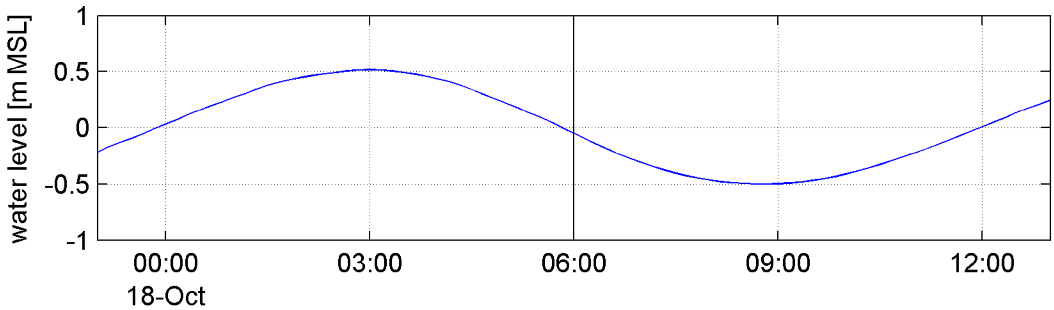
Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17e





Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17f



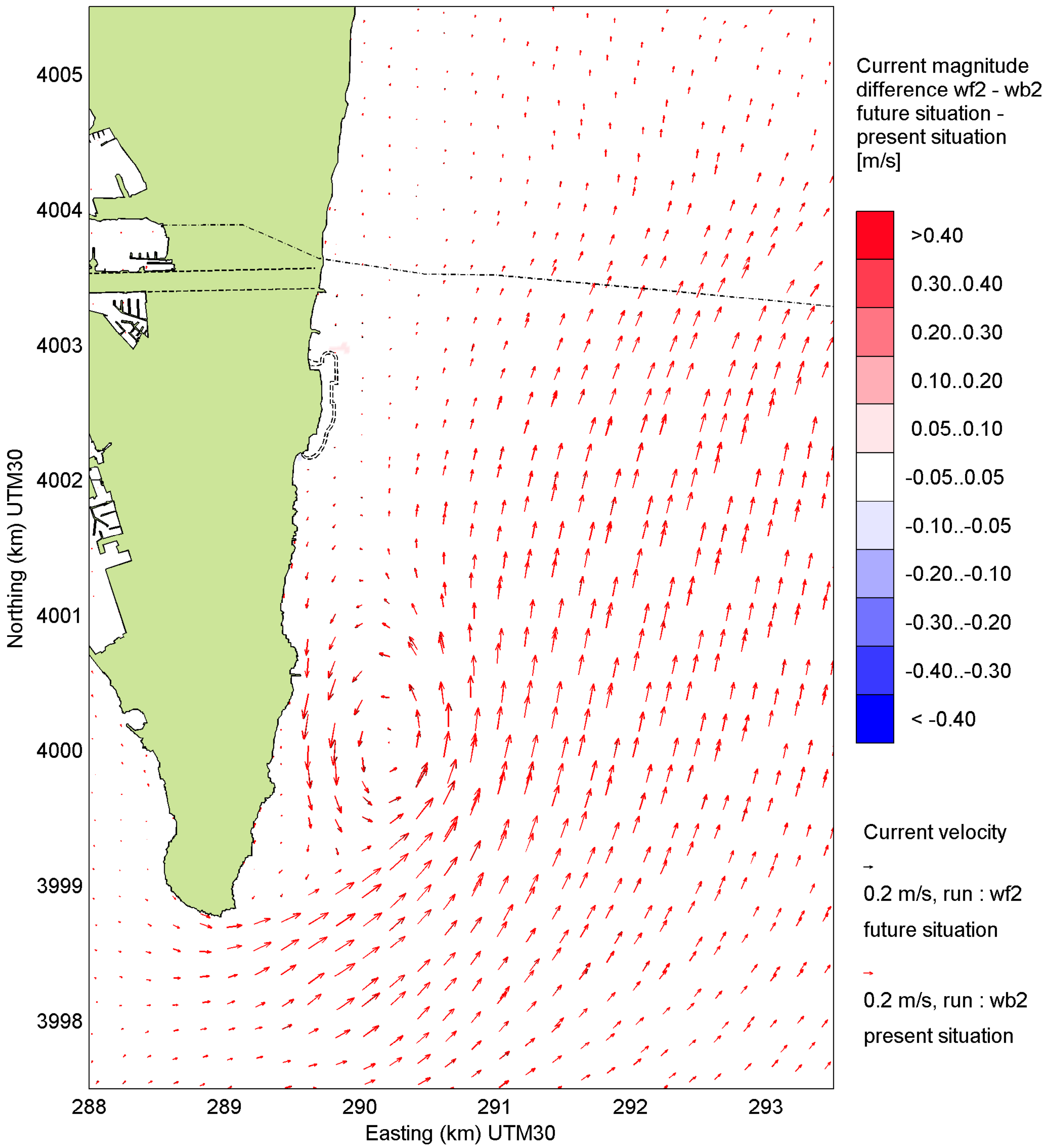


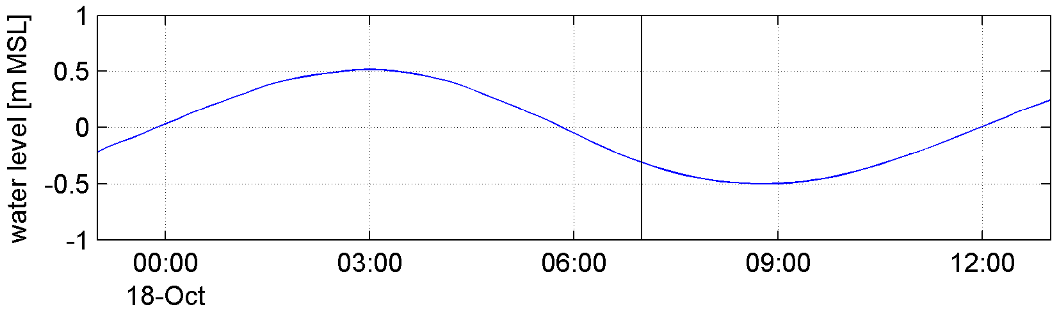
Current magnitude difference (wf2 - wb2) and velocity vectors, with:
wf2: future situation
wb2: present situation

WSW wind 10m/s | Spring

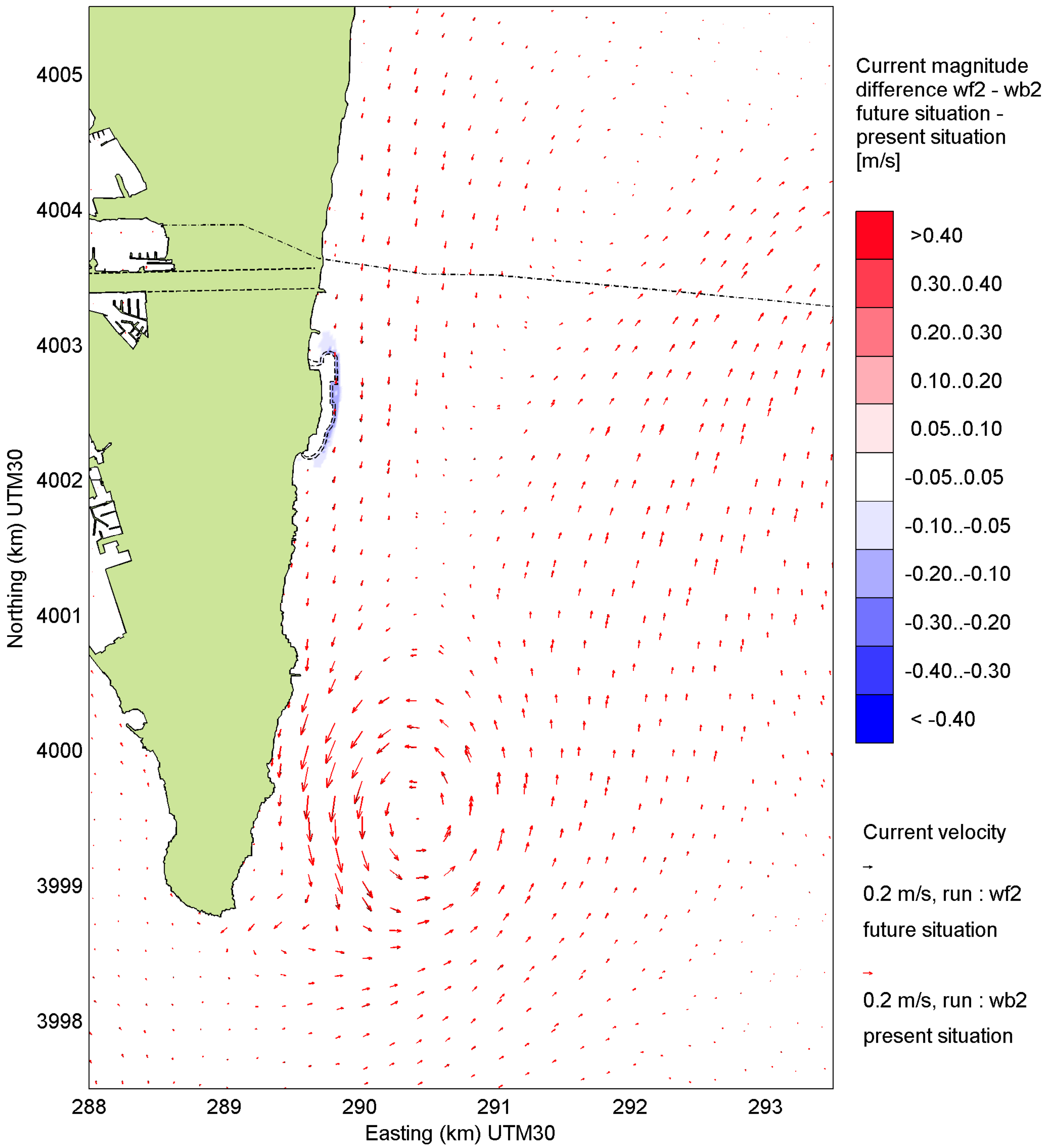
Gibraltar Flow Study

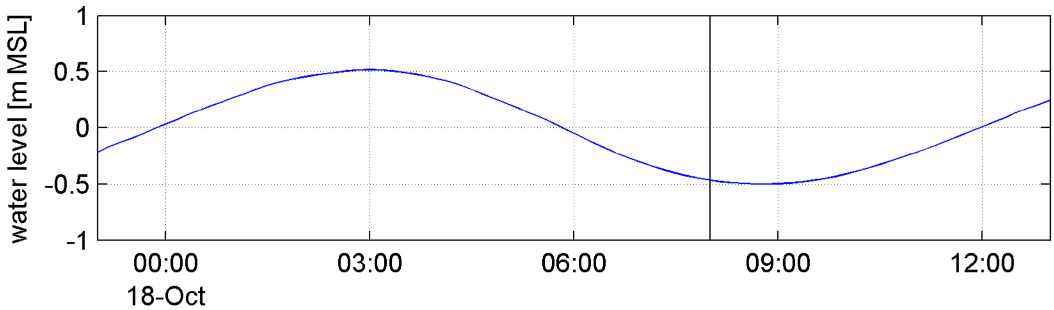
WL | DELFT HYDRAULICS | H4725 | Fig. 6.17g



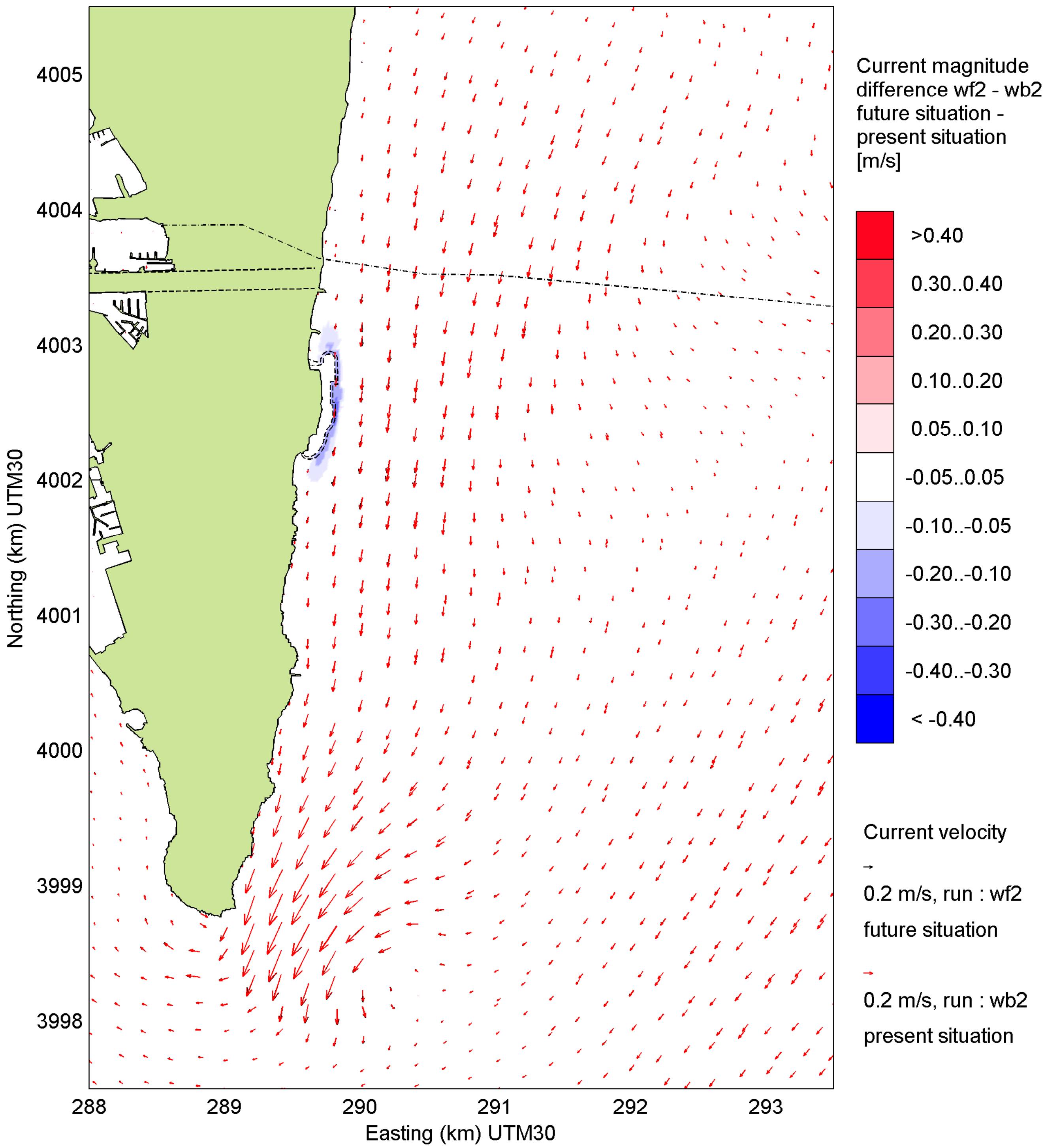


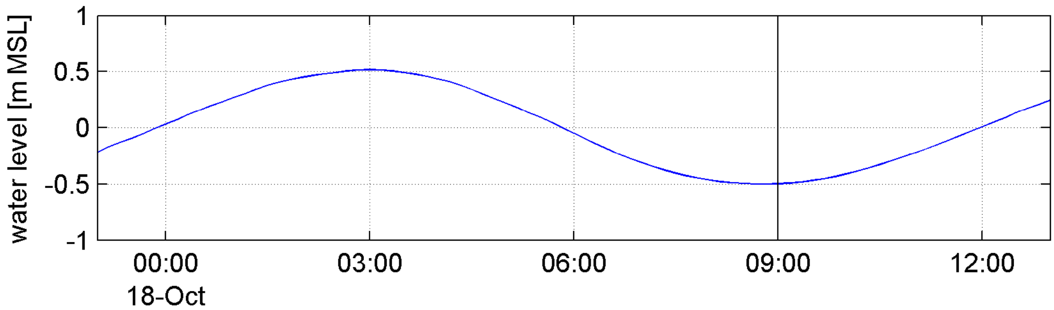
Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17h



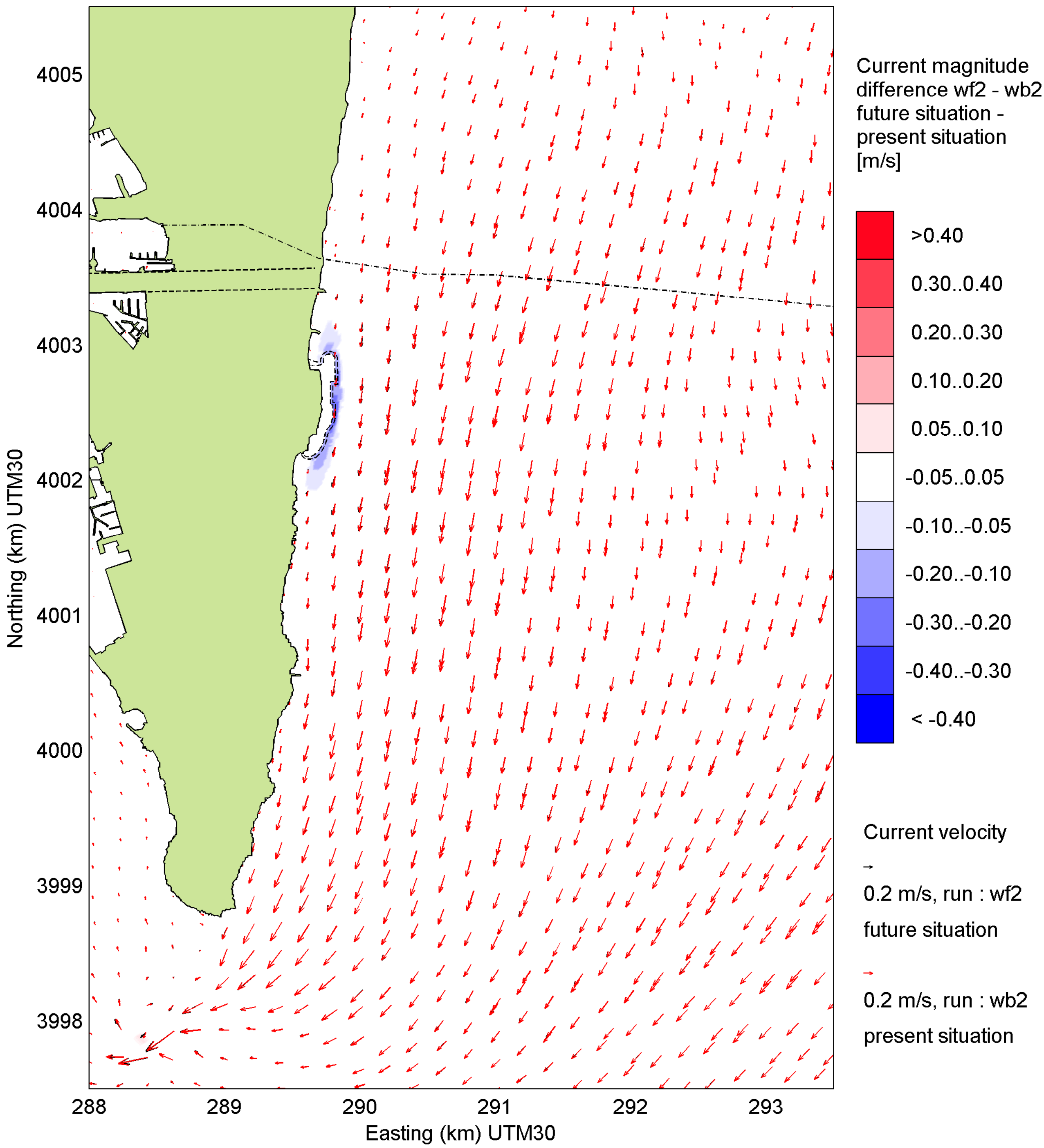


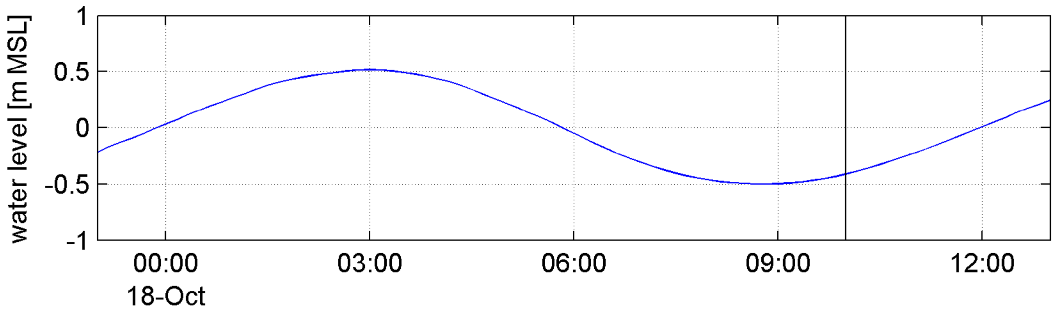
Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17i



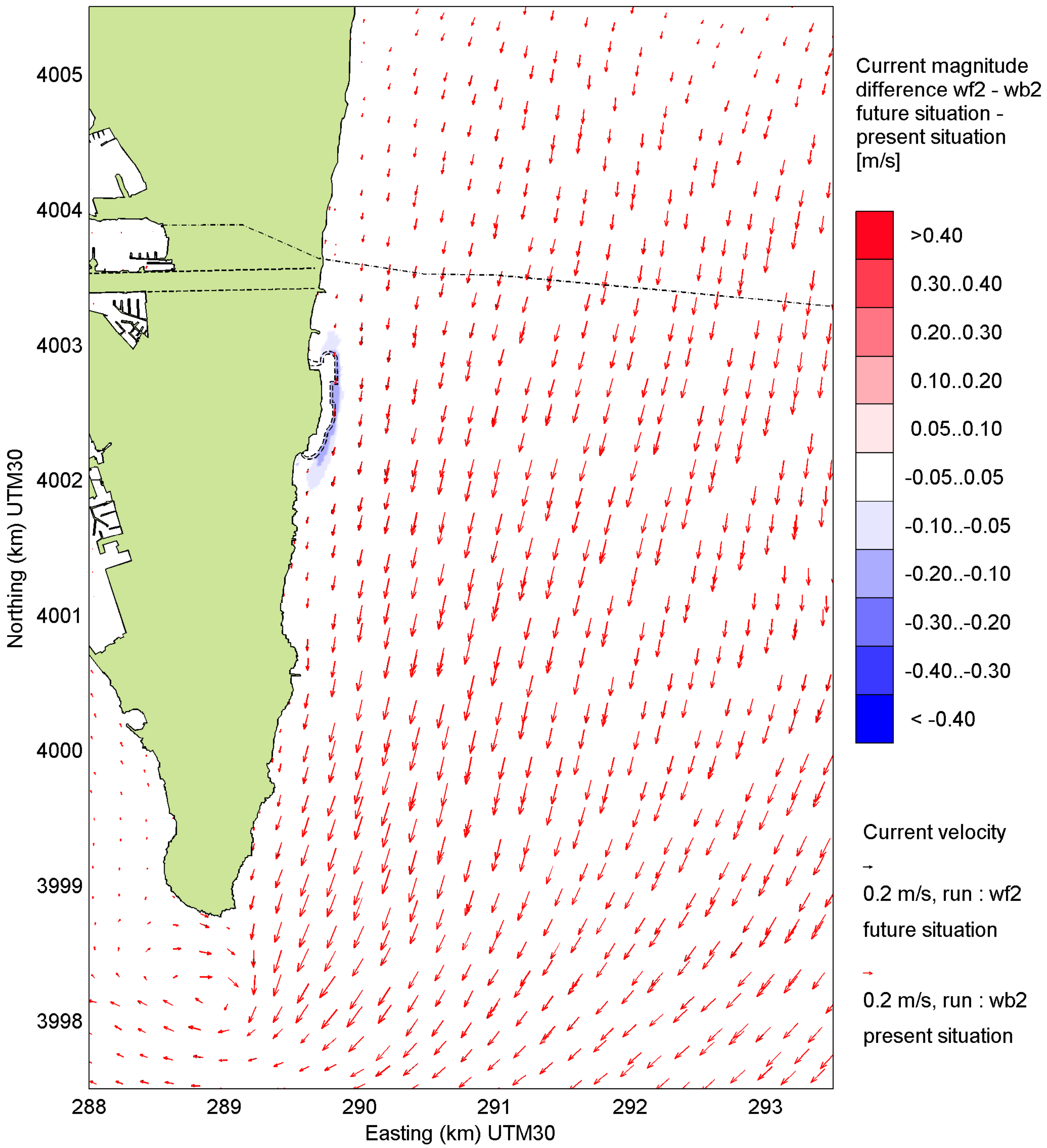


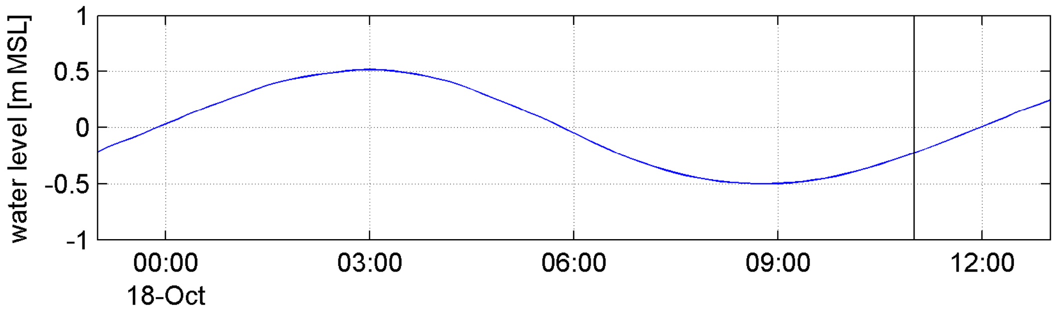
Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17j



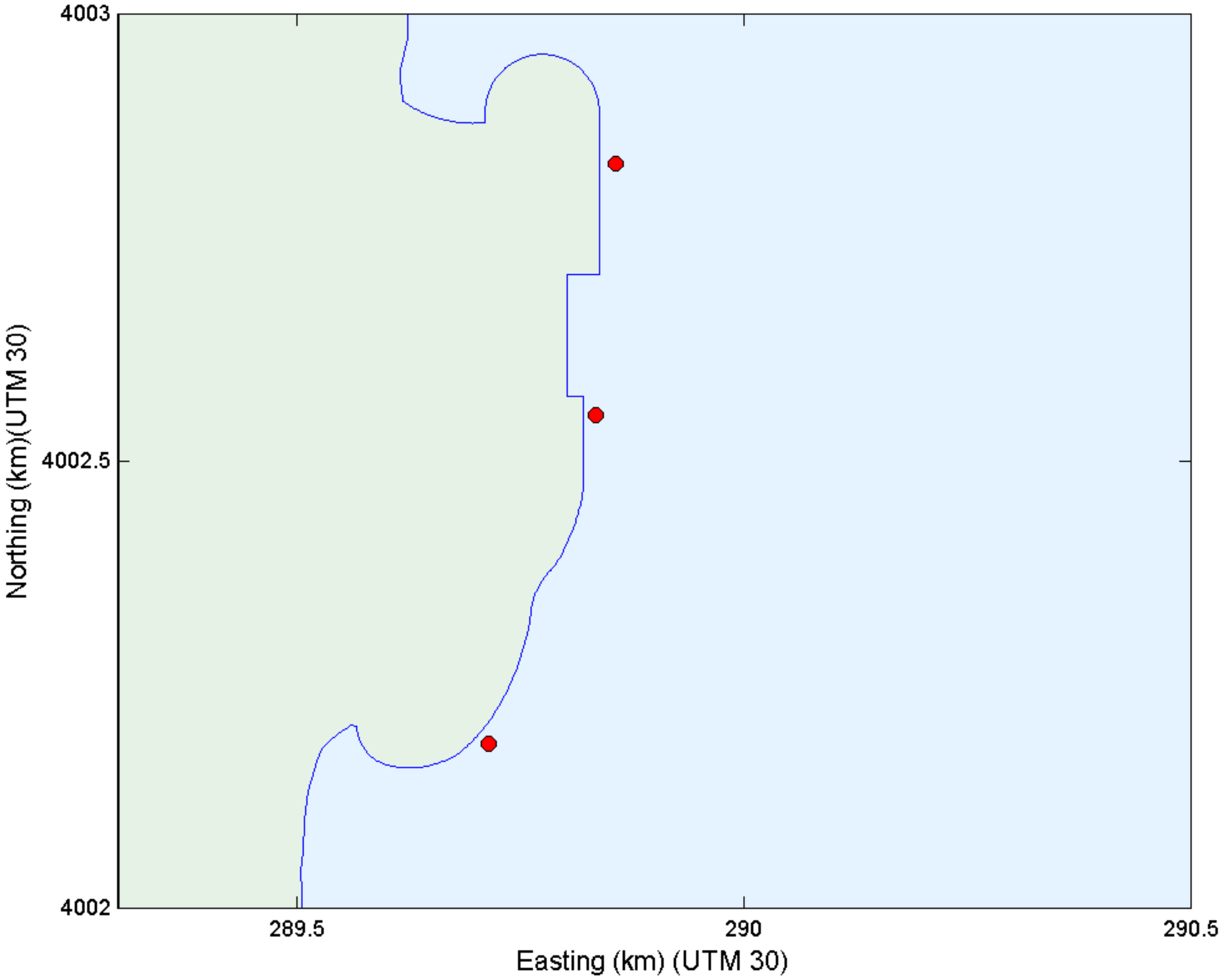


Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17k

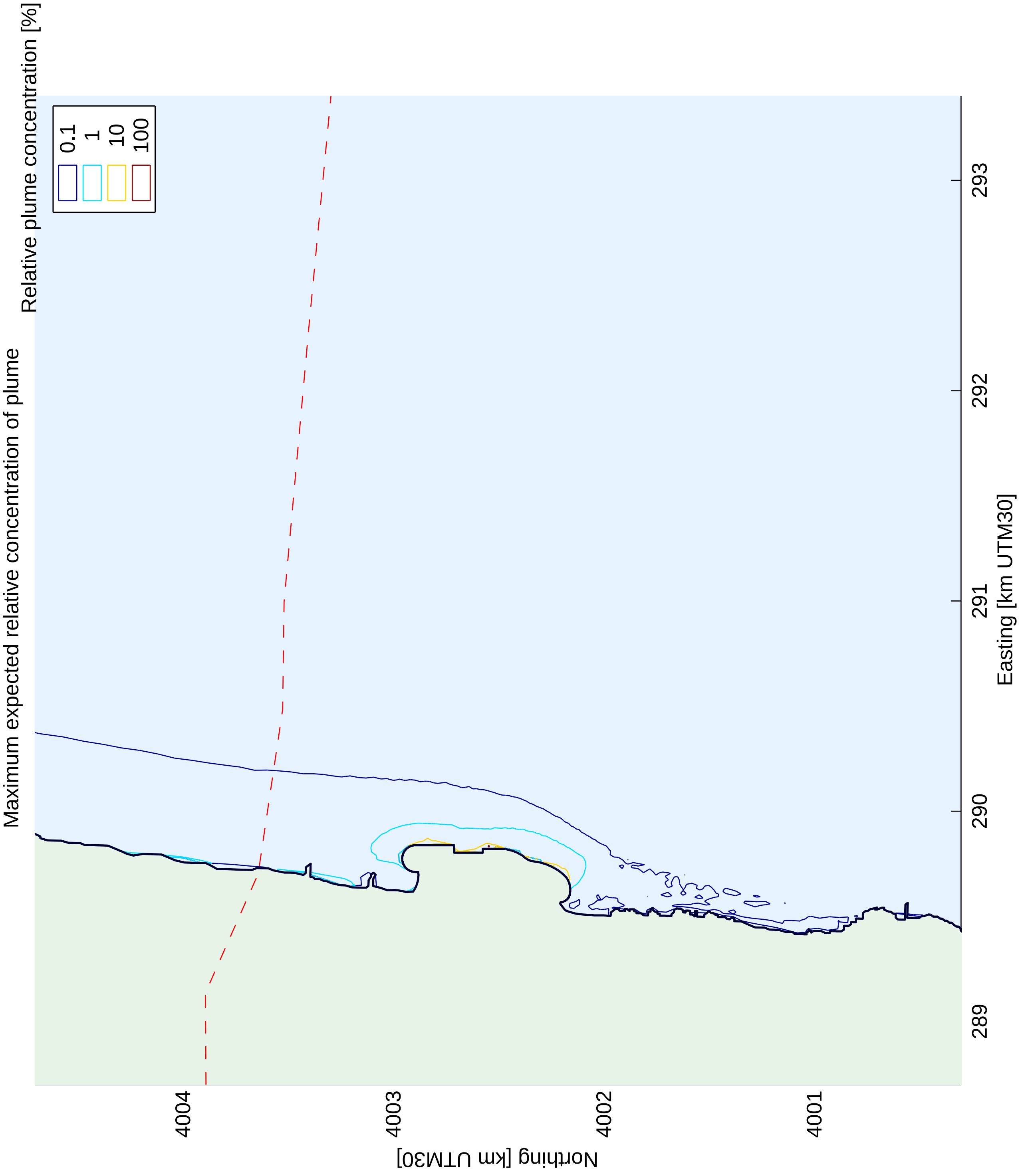




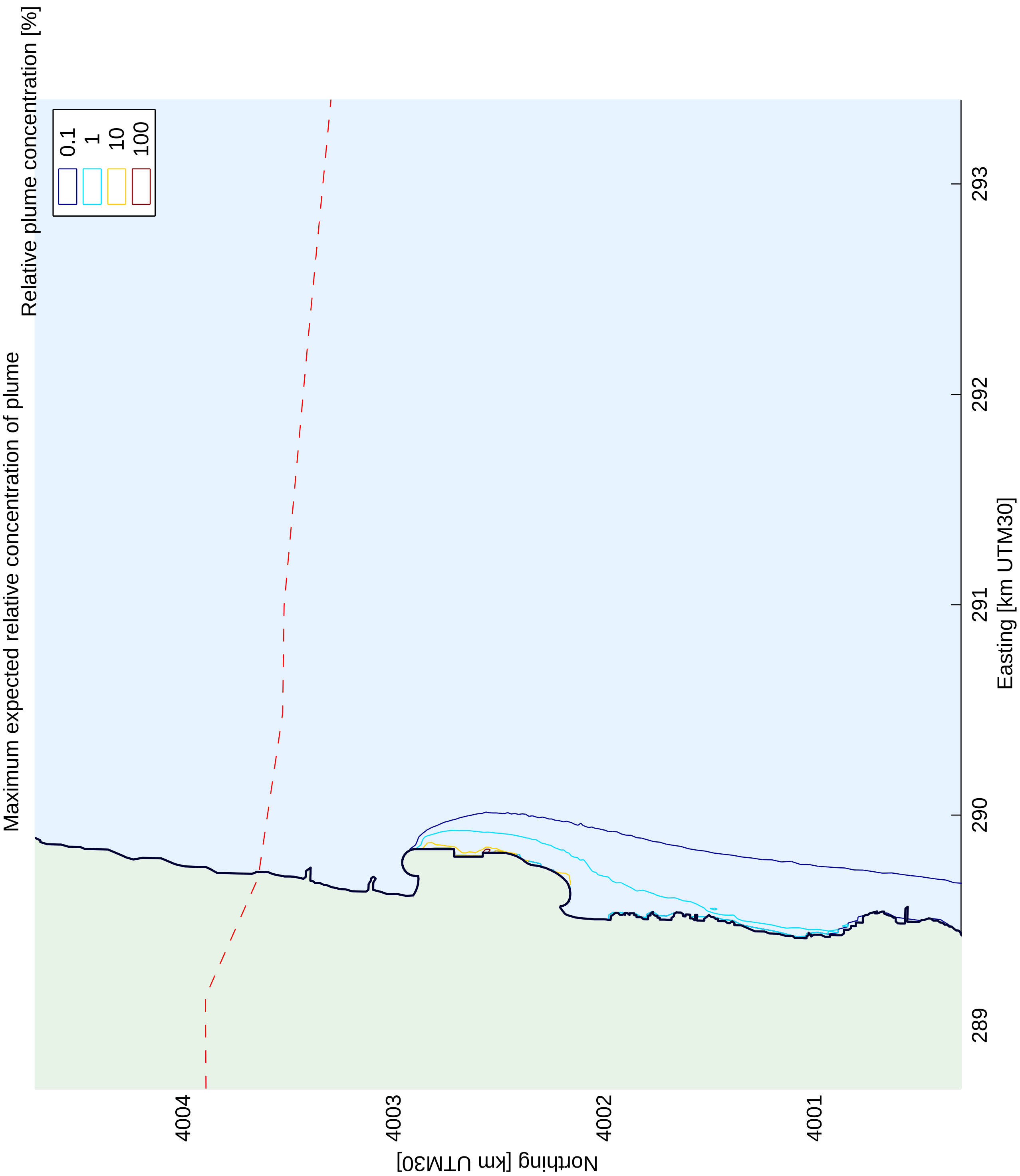
Current magnitude difference (wf2 - wb2) and velocity vectors, with: wf2: future situation wb2: present situation	WSW wind 10m/s	Spring
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 6.17l



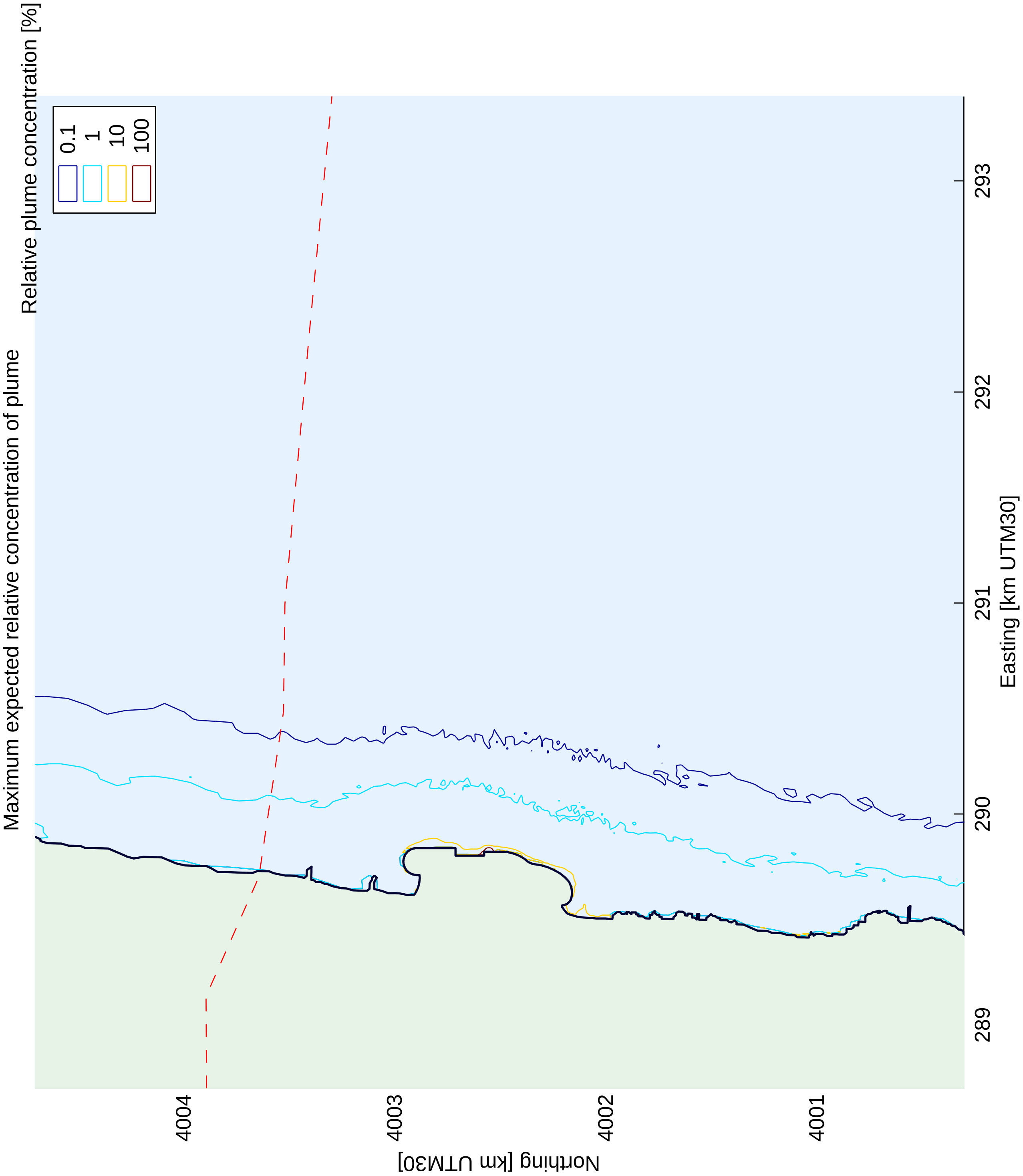
Eastside Development, Gibraltar Red dots indicate water run-off discharge locations	Delft3D-PART	
WL | DELFT HYDRAULICS	H4725	Fig. 7.1



Maximum expected relative plume concentrations Concentrations relative to source concentration Scenario 1: storm water run−off. Spring tide, initial northward current	RunID: part01a	
	Delft3D−PART	
WL | DELFT HYDRAULICS	H4725	Fig. 7.2a



Maximum expected relative plume concentrations Concentrations relative to source concentration Scenario 1: storm water run−off. Spring tide, initial southward current	RunID: part01b	
	Delft3D−PART	
WL | DELFT HYDRAULICS	H4725	Fig. 7.2b



Maximum expected relative plume concentrations Concentrations relative to source concentration Scenario 2: conservative discharge scenario	RunID: part03	
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WL | DELFT HYDRAULICS	H4725	Fig. 7.3a

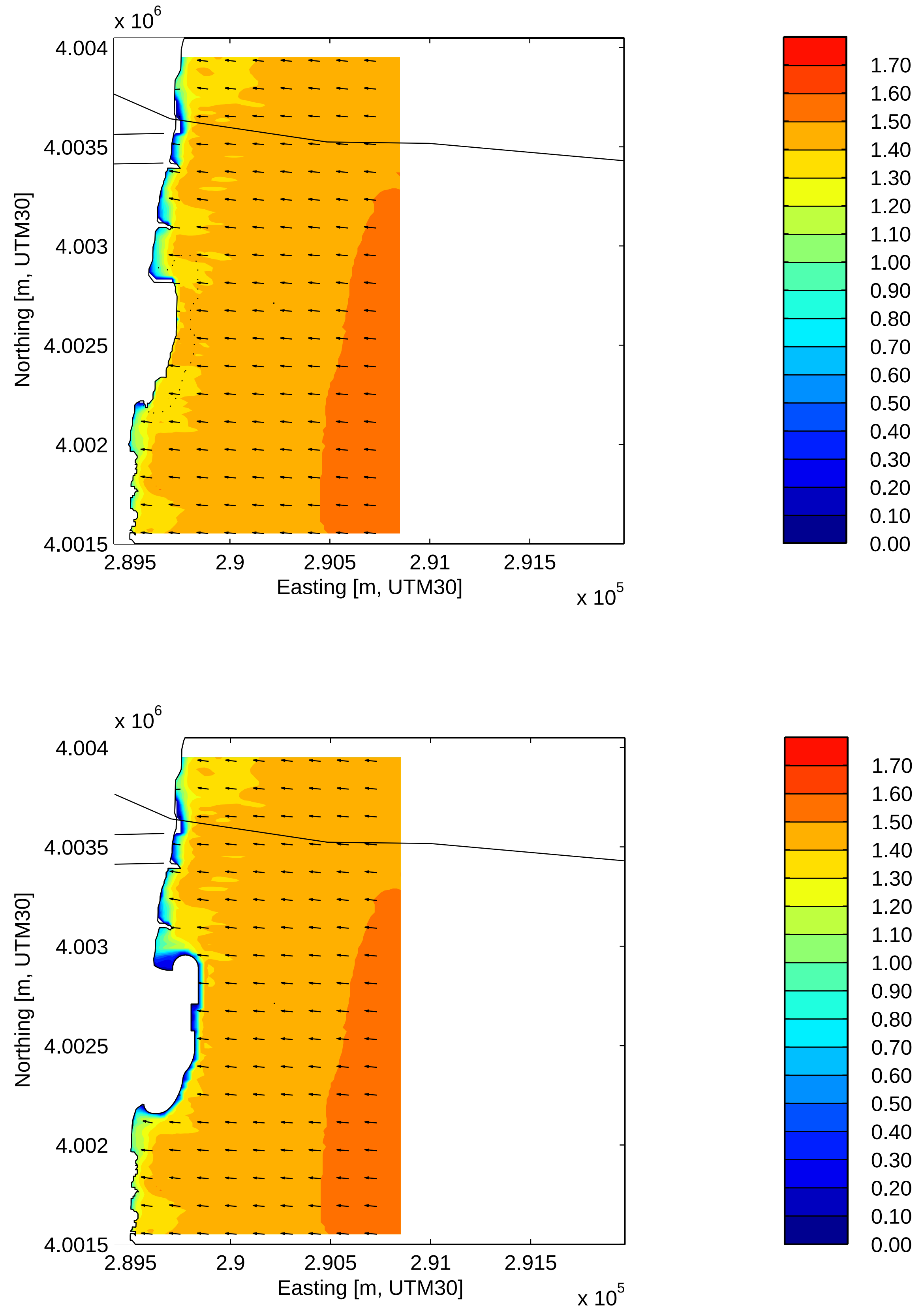
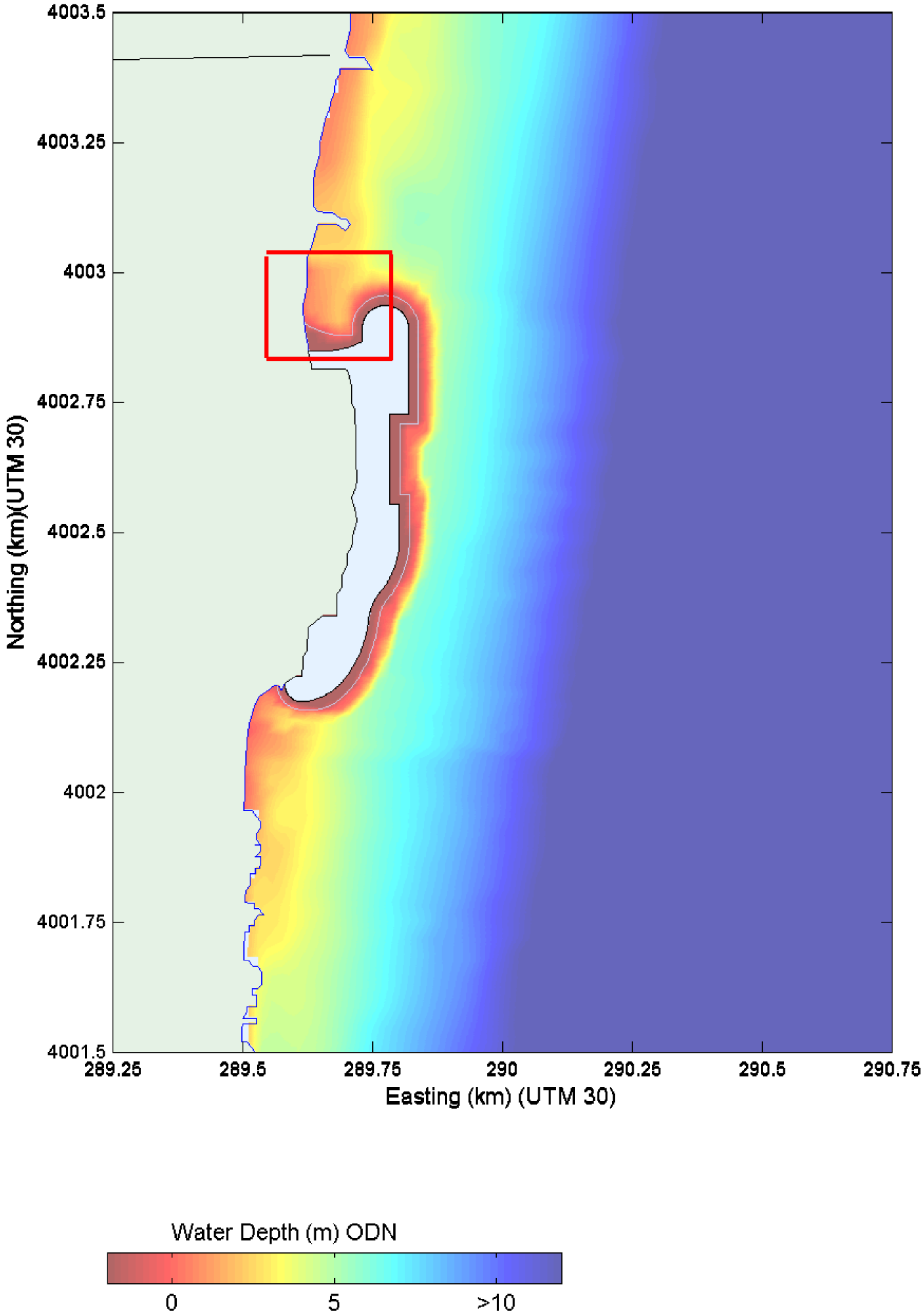


Illustration of the effect of the Easside Development Scenario 34, Normal Wave Study, Vol. 2. H_{sig} (m)	Delft3D−WAVE	
WL | DELFT HYDRAULICS	H4725	Fig. 8.1



Beach area which is expected to need some maintenance		Delft3D
	Gibraltar Flow Study	
WL | DELFT HYDRAULICS	H4725	Fig. 8.2

B EBG Technical Note

MCB (Gibraltar) Ltd

PROJECT NR: 30.3126

EASTSIDE DEVELOPMENT,
GIBRALTAR

EBG *Marine Engineering & Construction*

DOCUMENT TITLE:

EIA Modelling: Sediment Plume
Input based on Work Method

01	EFU	04-04-2007	Project information corrected	GSP	MLI
00	EFU	29-03-2007	For information – based on Masterplan March 2007	GSP	MLI
Rev	Author	Date	Description / Reason for Issue	Checked	Approved

Document Number: **EBG - TN - 300**

Technical Note

EBG

Project:	**Eastside Gibraltar** **30.3126**	Page: Date: Rev. No.:	1 of 5 29/03/2007 00
Title:	**EIA Modelling: Sediment Plume Input based on Work Method**	Prep.: Chkd./App.:	EFU GSP/MLI

1 INTRODUCTION

WL | Delft Hydraulics is preparing a hydrodynamic model for the Environmental Impact Assessment (EIA) of the Eastside Gibraltar project. This Technical Note presents an indication of the losses during dredging as expected by the Contractor. The loss estimates will be used by WL | Delft Hydraulics in the Delft3D modelling of sediment dispersion.

2 INFORMATION

2.1 PROJECT INFORMATION

Roughly three types of main marine works can be distinguished: dredging of trenches for the breakwaters (~35,000m^3), secondly the rockworks, approximately 750,000 ton rock (exclusive Accropods and concrete blocks) will be placed by various equipment and finally the material supply for the reclamation works (~800,000m^3). The sand dredged from the trenches will be used in the reclamation.

During the execution of the project various types of equipment will be used, a global time scheme for the main works is presented in Figure 1. The duration of each activity is presented in weeks. A Backhoe Dredger will start dredging at the beginning of the project. It will dredge the trenches for the rockworks which will take about 3 weeks. The dredged material (~35,000m^3) will be used in the reclamation.

At the same time the rock works will start, a Side Stone Dumping Vessel (SSDV) and land-based equipment will carry out these works. The installation of all rock works will take about 45 weeks.

When the breakwaters are partly completed, a Trailing Suction Hopper Dredger (TSHD) will carry out the sand supply for the reclamation. Part of the rubble tip can also be used for the reclamation. The sediment dispersion calculations will be based on the assumption that the total volume of suitable material from the rubble tip is approximately 200,000m^3. The remaining part for the required reclamation volume will be sand, i.e. the TSHD will dredge a total of 600,000m^3.

The complete project (including stockpiling of rock, land works, etc.) will take about 18 to 24 months.

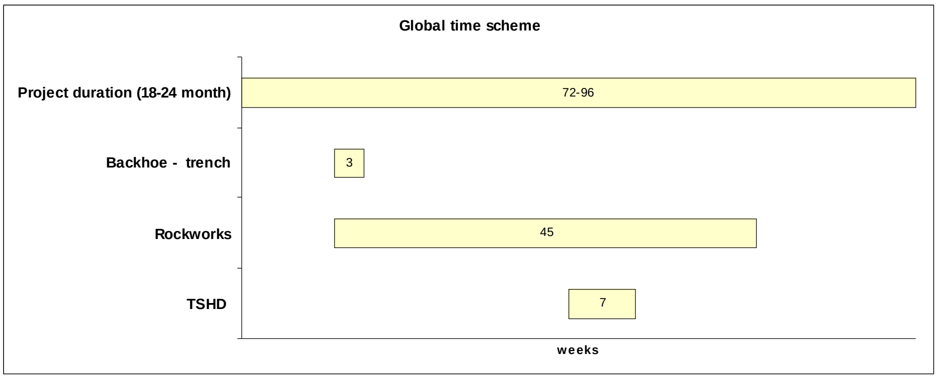


Figure 1 Global time scheme of main works

2.2 SOIL DATA

A geotechnical investigation has been performed. Preliminary grain size distributions are available for the EIA modelling. The average grains size distribution for the Northern Borrow Area is presented in Appendix I.

The in-situ density is estimated to be 1,950kg/m^3. The grain size in the trench is expected to be about the same as the Northern Borrow Area, the in situ density is 1,900kg/m^3.

	Northern Borrow Area	Southern Borrow Area
D(90) [mm]	0.946	0.964
D(80) [mm]	0.330	0.497
D(70) [mm]	0.280	0.390
D(60) [mm]	0.258	0.339
D(50) [mm]	0.238	0.296
D(40) [mm]	0.220	0.271
D(30) [mm]	0.195	0.248
D(20) [mm]	0.166	0.227
D(10) [mm]	0.110	0.195

Table 1 Grain size distribution borrow areas

2.3 EQUIPMENT

Three peaces of main equipment are proposed for the project, a Backhoe Dredger Razende Bol with Split Hopper Barge HAM 586 (750m^3), Trailing Suction Hopper Dredger type Ham 311 (2,175m^3) and Side Stone Dumping Vessel like HAM 601 (1,000 ton) or equivalent.

3 INITIAL SPILL

3.1 TRENCH DREDGING

The Backhoe Dredger will perform the trench dredging. The grain size distribution of the spill from the Backhoe Dredger will be equal to the in-situ grain size distribution of the trench. As the grain size distribution of the trench is only known from previous sampling yet, it seems reasonable to assume that the grain size distribution is equal to the Northern Borrow Area.

Disposal of sediment dredged from the trench by the Backhoe Dredger is done by a Split Hopper Barge (SHB ~750m^3).

Loading	240 min (175m^3/OH)
Sailing / positioning	20 min
Dumping	5 min
Sailing empty	5 min
	270 min

Spill BHD during loading	**5% ≡ 4.7kg/s** in-situ grain size (10% < 100µm)
Spill SHB during dumping	**5% ≡ 222kg/s** < 100µm

The grain size distribution of the spill during dumping is expected to be 100% < 100µm and 40% < 63µm.

3.2 BORROW AREA

TSHD cycle:

dredging	45 min
sailing loaded	30 min
connecting	20 min
pumping ashore	50 min
sailing empty	20 min
	165 min

Production per week:	106,000m^3/wk
Spill during dredging	Northern Borrow Area:
	10% ≡ 2,175/(45*60)*1,950kg/m^3*0.10 **= 157kg/s**
Spill during dredging	Southern Borrow Area:
	7% ≡ 2,175/(45*60)*1,950kg/m^3*0.07 **= 110kg/s**

The Southern Borrow Area contains slightly less fines, for this reason the overflow losses in the Southern Borrow Area will be slightly less as well.

The grain size distribution of the spill will be the difference between the in-situ grain size distribution and the calculated grain size distribution in the hopper, as presented in Appendix I. The grain size distributions of spill are approximately the same for both borrow areas. The grain size distribution of spill has been calculated with data from the Northern Borrow Area. The grain size distribution of the spill can be summarized as follows:

Grain size [µm]	% min	% max
200-150	**10**	20
150-63	**30**	40
63-30	30	**40**
<30	10*	**20***

* assumed

Table 2 Grain size distribution

It is proposed to do the EIA modelling with the most conservative grain size distribution, which is the grain size distribution with the highest percentage of fines (bold printed values in Table 2).

3.3 ROCK WORKS

The rock works (construction of breakwaters and coastal defence) will be carried out using different equipment. As the works can not yet be divided between land based equipment and Side Stone Dumping Vessel (SSDV), calculations should be performed with the initial loss for the SSDV for all rockworks, as this is the most conservative scheme.

SSDV cycle:

loading	2 hr
sailing loaded	1 hr
positioning/dumping	1 hr
sailing empty	1 hr
	5 hr

Production per week	27,552ton/wk
Spill during dumping	**1% ≡ 2.8kg/s**

The spill is expected to contain 50% sand (~150µm) and 50% of fines (<63µm).

3.4 RECLAMATION WORKS

The reclamation works will be an open reclamation, losses are difficult to predict for these situations but theoretically all sediments with a grain size larger than 63µm will settle within 100 meter and all fines (<63µm) will be suspended. This will be **0.5%** of all sediment brought into the reclamation area or beach nourishment. During heavy sea states, losses may be greater temporarily. This will be reduced as much as possible by construction of the breakwaters in an early stage.

Spill during disposal: **0.5% ≡** 2,175 $m^3/(50*60)*1,950 kg/m^3*0.005$ **= 7kg/s**

4 DEEPENING OF BORROW AREAS

The average deepening of the borrow areas can be calculated by dividing the borrow area surface area by the total dredged quantity.

Assumptions

- It is assumed that the total quantity is dredged from one borrow area and the dredging is equally distributed over the complete area.
- The total quantity of sand supply which is needed the works is expected to be 600,000m^3.

The borrow area's are displayed at drawing EBG-DR-10.352 (Appendix II).

Calculation

Southern Borrow Area (1,600,000m^2)

Expected deepening: $$\frac{0.6 \cdot 10^6 m^3}{1.6 \cdot 10^6 m^2} = 0.4m$$

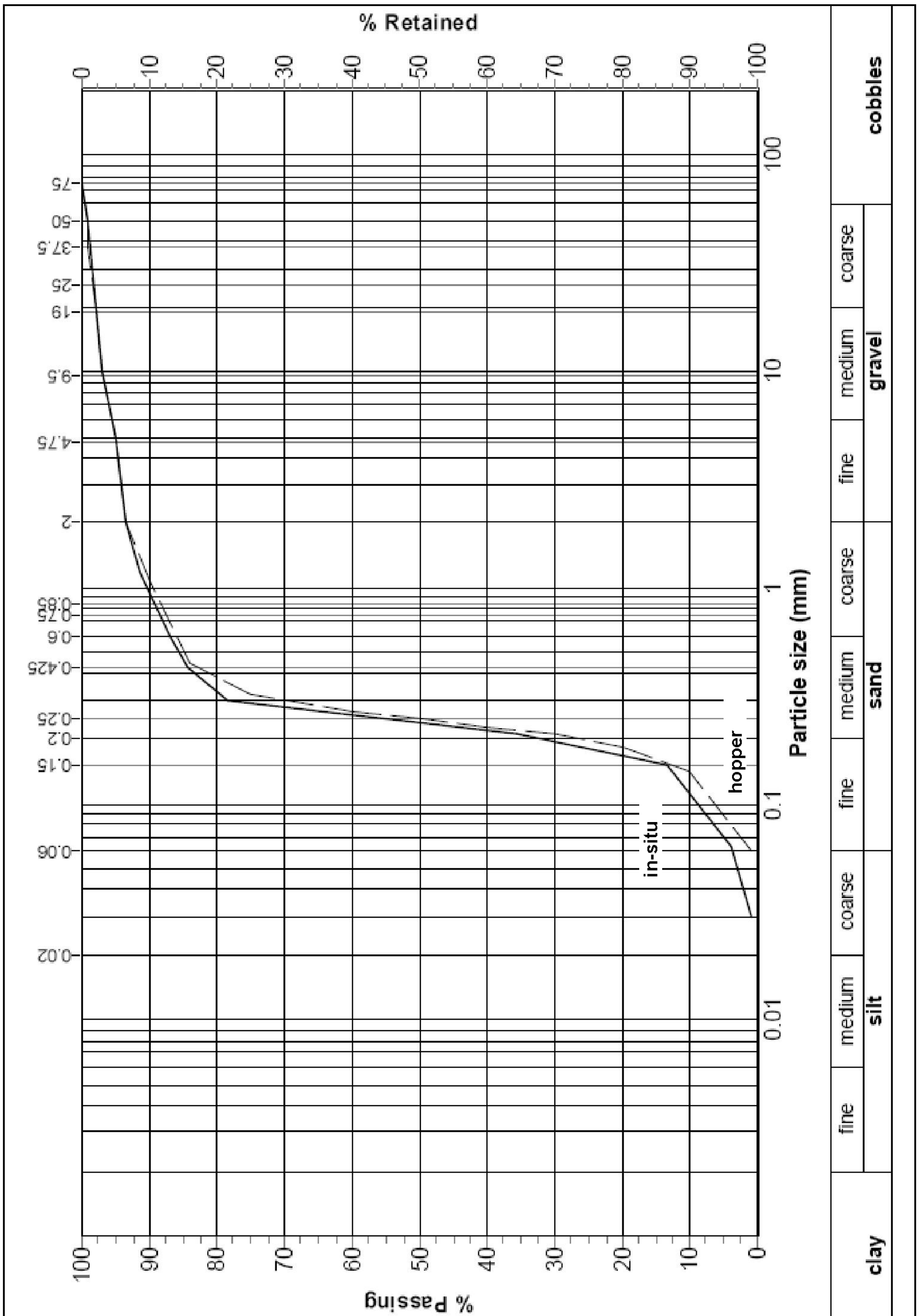
Northern Borrow Area (660,000m^2)

Expected deepening: $$\frac{0.6 \cdot 10^6 m^3}{0.66 \cdot 10^6 m^2} = 0.9m$$

5 DISCUSSION AND CONCLUSION

The presented fluxes (printed in bold in this document) are proposed for sources in the hydrodynamic modelling of the dredging plume. It should be noted that they only occur during the actual dredging/dumping works, these periods are mentioned for each source. Production of the proposed equipment and execution times are all based on preliminary information, for this reason conservative assumptions haven been made.

Appendix I



Particle Size Distribution **Eastside Development, Gibraltar** **Northern Borrow Area** **Grain Size Distribution In-situ and in Hopper**	Pr. no. 30.3126 Calc by CLD Date 27/07/06

Appendix II Drawing Proposed Borrow Areas: EBG-DR-10.352.pdf