European Bank for Reconstruction and Development (EBRD)

Gdansk Port | DCT Terminal 3 (T3) | Poland

Assessment of impacts on marine environment related to capital dredging, Stogi beach morphology and water quality

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Contents

Tables

Figures

Appendices

1. Introduction

1.1 Project Description

The European Bank for Reconstruction and Development (EBRD) (the "Lender") is considering providing finance to the Baltic Hub 3 Project, which foresees an expansion of DCT Gdańsk Sp. z o.o (DCT). The location of this port is shown in Figure 1. The planned project involves the expansion of the existing DCT's deep-water sea container terminal with a new installation - another Terminal T3 (T3) within DCT. The investor of the project is DCT, which operates the existing Terminals - T1 and T2. The project will be implemented in the area administered by the Port of Gdansk Authority SA - only in the marine area.

Figure 1 The Port of Gdańsk, Poland and relevant landmarks.

The construction of the terminal requires dredging works in the sea area adjacent to T3.

A more detailed description of the project can be found in the Non-Technical Summary [1] for this supplementary information package.

1.1.1 Existing studies and consents

An Environmental Impact Assessment (EIA) report [2] was prepared for the proposed Expansion of the DCT Gdansk container terminal in the Northern Port in Gdansk in 2018. DCT obtained an Environmental Decision (ED) [3] for the Project in October 2019.

The EIA report analyses potential negative and positive environmental and social impacts in detail and, together with the ED conditions, proposes mitigation measures to overcome the identified potential adverse impacts. However, dredging activity and associated risks and mitigations approach were not covered in the EIA report to the level of detail expected by the IFC or EBRD requirements.

Based on a review of the EIA report and a study of the existing information, the following key gaps have been identified in relation to the marine impact assessments:

- The impacts on the marine environment related to capital dredging works. The dredging assessed in this report is that associated with the Terminal T3 expansion of the existing DCT's deep-water sea container terminal with a new installation.
- The long term development impact of the T3 including breakwater extension on the nearby Stogi beach morphology and on the sea water quality along the nearby Stogi beach.

This study therefore forms part of a supplementary information package to assess these impacts and associated risks and mitigation approach in line with these requirements.

1.1.2 Scope of Dredging Works

DCT is currently progressing with their plan for the development of T3 which will include capital dredging and land reclamation. The location of the proposed T3 and extent of dredging required is shown in Figure 2. The size of the T3 dredge area is approximately 38 ha (0.38 km^2). The dredging for the port access channel and turning circle, which is ongoing on site, is not part of the T3 development and therefore is not considered as part of the T3 development effects; however, the changes in the seabed bathymetry have been taken into account. The maximum dredge depth is -17.5 m (MSL); however, the dredge tolerances bring this value to -17.8 m (MSL) in the berthing area buffer zone and -19.5 m (MSL) in the rest of the berthing area. The maximum amount of dredge spoil is estimated to be 4,000,000 m^3 (ED, 2019). In terms of land reclamation, the size of the T3 reclamation is approximately 37 ha (0.37 km^2). Future terminal expansions T4 and T5, planned in the longer term after the completion of T3 development, are not considered in this study. The T4 and T5 developments will bring the total reclamation area to 80 ha (0.80 km^2).

The outline construction sequence is as follows:

1. Dredging for approach channels and turning circles (ongoing).
2. Capital dredging associated with the Terminal T3 expansion and associated land reclamation.
3. Piling and general construction of T3.
4. Construction of T4 and T5 at a future date.

It is noted that the above sequence is based on the actual (activity 1) and planned start dates (activities 2-4) while overlapping of activities 1-3 is involved.

Figure 2 The location of the proposed T3 terminal (yellow), dredging for the T3 berthing area (purple), berthing area buffer zone (brown) and approach channels and turning circles (green).

1.2 Report Purpose

The aim of this report is to assess the impacts associated with capital dredging and also the long term impact of the T3 development and the associated extension of the port breakwaters on the nearby Stogi beach morphology and sea water quality in the same area. Mitigation measures for these impacts are then proposed, with a particular focus on environmental monitoring and management in accordance with relevant regulations and best practice. The final objective of this report is to ensure that an adequate level of protection to environmental and social values is provided during and after the dredging activities within the limitations of the available data. This is achieved by:

- Outlining a monitoring programme for relevant physical, environmental and cultural values associated with capital dredging works and the long term development impact of the T3 on the nearby Stogi beach morphology and sea water quality.
- Providing high level recommendations for dredging practices.
- Detailing reporting requirements.
- Specifying management actions.

Based on this report:

- The Contractor shall develop a Dredging Management Plan (DMP) taking into account the assessment of impacts and mitigation measures recommended for the capital dredging works.
- Recommended actions for both, dredging works and long term development impact of the T3 and the associated extension of the port breakwaters on the nearby Stogi beach morphology and sea water quality will feed into the Environmental and Social Action Plan (EBRD, 2022).

1.3 Limitations

While this document aims to provide the highest level of protection possible there are a number of limitations mainly around the paucity of available information and data:

- The baseline data available is described in Section 3. There is limited data available in relation to some of the parameters that are key for dredging impacts assessment (e.g., turbidity).
- A numerical modelling study has not been undertaken to understand the expected dynamics of the dredge plume. Dredge plume modelling is usually used to inform more focused mitigation measures. In the absence of this information a broader suite of mitigation, monitoring and management measures is prescribed.
- The Contractor’s method statement provided by DCT states that a Trailer Suction Hopper Dredger (TSHD) will be used for the dredging and reclamation works. The assessment of impacts has been carried out on this basis.
- This document focuses on the dredging and reclamation works for T3 development and to a lesser extent on the offsite disposal (either offshore and/or on land) of dredged material.

1.4 Regulatory Requirements

The following Standards are applicable to this Project:

- IFC Policy on Environmental and Social Sustainability (2012).
- IFC Performance Standards (2012).
- European Bank for Reconstruction and Development (EBRD)s Environmental and Social Policy (ESP) and Performance Requirements (PRs) (updated in 2019).
- The World Bank Group (WBG) General Environmental Health and Safety (EHS) Guidelines and sector guidelines for Ports, Harbours, and Terminals (2017).
- Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1992 (Helsinki Convention)
- HELCOM Guidelines for Management of Dredged Material at Sea, 2015.
- London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972.

Relevant regulatory requirements also exist at a national (Polish) and EU level, i.e., EU legislation:

- Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste – The Waste Framework Directive.

Polish legislation:

- The Act of Waste of 14 December 2012 (Polish Journal of Laws 2022, item 699).
- The Act on Prevention of Marine Pollution by Ships of 10 August 1995 (Polish Journal of Laws 2020, item 1955).
- Regulation of the Minister of Transport and Construction in the matter of issuing permits for the disposal of dredging spoil into the sea and for dumping waste or other substances in the sea of 26 January 2006 (Polish Journal of Laws 2006, No 22, item 166).
- Regulation of the Minister of Climate on the catalogue of wastes of 2 January 2020 (Polish Journal of Laws 2020, No. 10).

This document also conforms with the Dredging conditions in ED for T3 (RDOŚ-Gd WOO.420.125.2018.AT.11, 2019) [3].

1.5 Related documents

This report should be read in conjunction with the following documents:

- Environmental Impact Assessment Report, 2018 [2]
- Environmental Decision, 2019 [3]
- Non-Technical Summary (NTS), Arup 2022 [1]
- Critical Habitat Assessment (CHA), Arup 2022 [4]
- Environmental and Social Action Plan, EBRD 2022 [5]
- Sediment Transport and Water Quality Numerical Modelling Study (eCoast, 2022) (included in Appendix A)

It should also be noted that this report is informed by the findings of the study Deepwater Container Terminal T3: Dredging Works - Monitoring and Mitigation Measures prepared by eCoast in 2022 in collaboration with Arup.

2. Existing Environment

2.1 Surrounding waterbodies

The Port of Gdansk is located in the south of the Gulf of Gdansk on the south coast of the Baltic Sea. The Gulf of Gdansk is a waterbody formally shared between Poland and Russia. It is a north facing bay with a large sandspit (the Vistula Spit) across the western entrance of the gulf. The mouth of the Vistula River lies approximately 14 km to the east of the port. It is the longest river (1,047 km) of those received by the Baltic Sea and the second largest by catchment area (183,176 km).

2.2 Physical Environment

2.2.1 Wind and Waves

Wind and wave records from a long term hindcast model have been examined. The most frequent winds are in the area are from the west and southwest, usually at a speed less than 14m/s. Some seasonality is seen in the wind climate with lighter winds observed from April to June. Wave directions are primarily from the northwest and north. Other wind and wave directions are observed at the site, but less frequently.

Wave characteristics at the study site in the southwest of the Gulf are strongly affected by the large spit at the western entrance of the gulf and by the port infrastructure to the west of the study site. Significant wave heights (Hs) are typically less than 2 m with an associated peak period (Tp) less than 10 s. However, large wave with Hs >6m and a Tp of 12s are observed occasionally, although rarely. These waves are from the north and are associated with wind speeds greater than 17m/s.

Refer to the Sediment Transport and Water Quality Numerical Modelling Study report in Appendix A (eCoast, 2022) for a full description of wind and wave conditions at the site.

2.2.2 Water Quality

The mean Vistula water discharge into the Gulf of Gdańsk is 1080 m^3/s, with an average sediment suspension load of 14.6 mg L−1 which varies between 8 and 40 mg/dm-3 (Damrat et al., 2013). According to Pruszak et al. (2005), the annual sediment transport into the Gulf of Gdańsk ranges from 0.6 to 1.5 million m^3 of sediment.

According to the EIA report [2]:

- In terms of the ecological status, the Inner Bay of Gdańsk was classified in 2016 as a body of water of poor condition. The classification was based on the research carried out in 2016. The indicators determining the classification of the water body were the content of chlorophyll a, macrozoobenthos, transparency values, as well as the concentration of nutrients - total nitrogen and total phosphorus.

- In previous years, the ecological condition of the bay's waters oscillated between poor and bad. In this respect, the ecological status of this transitional water body does not diverge from the ecological status / potential of other coastal and transitional water bodies, both in the voivodeship and along the entire Polish coast. The reasons for the poor ecological status of the waters of the Inner Gulf of Gdańsk are mainly the load of pollutants carried with the water of the watercourses (mainly the Vistula River), as well as from the municipal sewage treatment plant and from industrial plants.

In terms of water quality, the most pronounced pressure in the Gulf of Gdansk is due to nutrients coming mainly from the Vistula River but also from atmospheric input and the direct sources of the Tri-City area (Gdansk, Gdynia, Sopot) and Kaliningrad. The input of total nitrogen from the Vistula River (118,000 t y−1, on average) amounts to 15%, and the input of total phosphorus (7,000 t y−1, on average) consists of 19% of the total riverine discharge into the Baltic Sea. During the last ten years, several sewage treatment plants have been constructed. As a result of this effort, only 20% of the Polish coast of the Gulf of Gdansk is unavailable for bathing; this is in comparison to the fact that all beaches were closed in the 1980s (Andrulewicz and Witek, 2002). The beach is particularly popular in summer months and has excellent/very good water quality for bathing purposes with 2021 water quality sampling showing E. coli counts of 29 cfu (NPL) / 100 ml and Enterococci counts of 9 cfu (NPL)/100 ml.

The tidal range in the Baltic Sea is very small due to the low connectivity with the North Sea. Overall, tidal ranges are mostly between about 0.02 m and 0.05 m although in the western sea areas, tidal ranges of up to 0.1 m and 0.3 m are observed (Weisse et al., 2021). Non-tidal sea level variability can be significant and maximum sea levels at the Port of Gdansk of 0.38 m are observed with a return period of 1 year and 1.06 m for a 5 year return interval (Royal Haskoning DHV, 2020).

2.3 Ecological Habitats

2.3.1 Protected Areas

Coastal and marine sites of ecological importance have been identified in the vicinity of the study site. These are identified in the Critical Habitat Assessment (CHA) report [4]. The planned development is located within “Zatoka Pucka” Natura 2000 Special Protection Area. The EIA [2] revealed no significant impact on the integrity of the site and the qualifying species if the mitigation measures proposed in the EIA Report are adequately implemented. Nevertheless, parts of the project biodiversity assessment needed to be reviewed and improved to ensure alignment with EBRD PR6 Guidance Note requirements. CHA [4] fully fills the gaps identified in the biodiversity part of EIA report in compliance with the EBRD criteria.

2.3.2 Protected Species

The CHA [4] considers all the species protected within the identified Significant Nature Areas next to the Terminal T3 development which are under protection of the national law – Nature Reserves, European law – SPAs (PLB Natura 2000) and SACs (PLH Natura 2000) and areas protected by international law – IBAs, Ramsar sites. To meet the EBRD PR6 Guidance Note requirements the analyses were focused on the species considered to be Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) according to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species or species that are CR or EN in relevant Polish Red Lists. The aim of those analyses was to identify Priority Biodiversity Features (PBFs) and Critical Habitats (CH), which require specific attention in impact assessment and mitigation planning due to the EBRD PR6.

Among the protected species of animals and plants living next to the Terminal T3 development the following have obtained the PBF status: *Linaria loeselii*, long tailed duck *Clangula hyemalis*, horned grebe *Podiceps auratus*, Baltic Sea sub-population of grey seal *Halichoerus grypus* and Baltic Sea sub-population of harbour porpoise *Phocoena phocoena*.

The marine and coastal areas adjacent to the Terminal T3 development were qualified as Critical Habitat For the following animal species: little tern *Sternula albifrons*, sandwich tern *Thalasseus sandvicensi*, common tern *Sterna hirundo*, Baltic Sea sub-population of grey seal *Halichoerus grypus*, harbour seal *Phoca vitulina* and Baltic Sea sub-population of harbour porpoise *Phocoena phocoena*.

Following determination of Critical Habitat separate appendices have been produced to provide specific details on project impacts and proposed mitigation for any feature(s) triggering Critical Habitat or those that are assigned as a Priority Biodiversity Features; See Appendix A to CHA [4]: Marine Mammal Mitigation Review, and Appendix B to CHA [4]: Ornithology Mitigation Review.

2.4 Social

Stogi beach is adjacent to the proposed development, and it has been awarded a Blue Flag since 2009. It is deemed to have excellent or very good bathing water quality over the last years. This evaluation of bathing water quality is based on water borne concentrations of E. coli and Enterococci though water clarity and other physio-chemical concentrations are also used as indicators.

3. Baseline Data for Dredging

3.1 Baseline Data

The use of CEDA (2015a) for guidance on defining the monitoring regime for the dredging activities is recommended in WBG EHS Guidelines (2017) for environmental monitoring procedures.

CEDA (2015a) provides a comprehensive overview of the purpose and practical application of environmental monitoring and among other points notes the following:

Collection of data prior to dredging works is crucial to first establish understanding of the aquatic system and secondly to set the baseline for environmental management. This information is essential to design an acceptable dredging scheme and associated relevant monitoring programme.

and

In order to predict impacts it is not only important to understand sensitive receptors and the environment, it is also important to understand the changes which are likely to result from the dredging and how these will vary in time and space. This is usually predicted via numerical modelling in advance of the works. Often there is an iterative process whereby the design of the works is modified in light of predicted environmental (and other) factors. Numerical modelling is a powerful and valuable technique, but model predictions must be carefully checked and validated against field measurements and, if possible, against monitoring of relevant parameters during the dredging works.

There is limited baseline data available associated with dredging activities. Baseline knowledge is not specific to the proposed activities. This has a significant impact on the development of the monitoring programme, which has therefore been developed using a precautionary approach.

As per the WBG EHS Guidelines, (2017)

The Dredging Management Plan should be tailored to the project and should define the dredging methodology; identify and assess dredged materials disposal options and sites; characterize the chemical and physical composition and behaviour of the sediments to be dredged; characterize the environmental baseline where the port, harbour, and/or terminal (and disposal area) will be located; define the area of influence with identification, assessment and modelling of sensitive ecological receptors (usually through sediment plume propagation modelling); define mitigation measures to address adverse impacts (for example on aquatic habitat, biodiversity, and water quality), and relevant environmental monitoring parameters and indicators.

These points again highlight the recommendation for specific baseline monitoring and associated numerical modelling of the dispersion of the dredge plume. However, taking into account the programme constraints for this project associated numerical modelling has been assessed as not feasible. It goes on to note:

The timing of dredging activities should consider seasonal factors such as migration periods (e.g., of marine mammals, fish, birds and turtles); breeding and growing seasons (e.g., for marine flora such as eelgrass, coral spawning, turtle nesting); timing of feeding and periods of reduced ecosystem resilience (e.g., after extreme weather events).

Some information exists as to the seasonal behaviour of protected species (See Section 2.3.2) which can be used to guide recommendations around the timing of dredging activities. ED (2019) [3] specifies that dredging works should not be carried out in the period from April 1 to August 31 based on consideration of ecological factors and bird monitoring data.

Baseline monitoring is usually undertaken for a year prior to dredging activities to provide an understanding of seasonal background changes. Given the project constraints the baseline monitoring will be undertaken throughout the months July and August and potentially September (until commencement of the dredging activities) as outlined in Section 6.2.1.

3.2 Sediment Sampling of Dredged Material

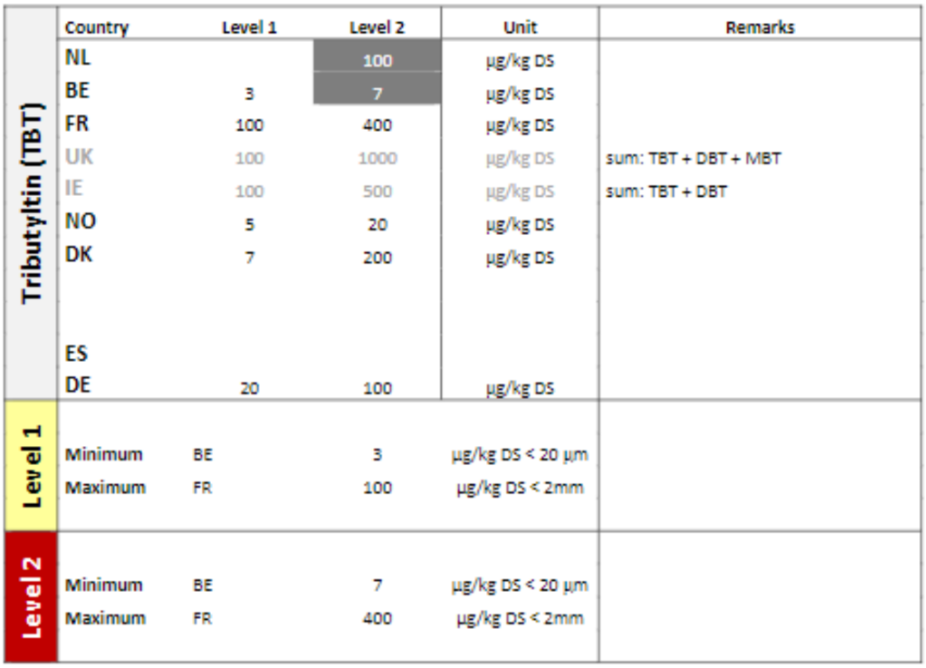
Based on the contamination report (Report on Bottom Sediment Pollution Testing, Extension of Deepwater Container Terminal DCT in Northern Port in Gdansk, INGEO, S01.02.2021, dated 2021-02-12) provided by DCT for the dredging works, the samples tested were “assessed according to the Regulation of the Minister of the Environment from 11 May 2015 on the recovery of waste outside installations and devices”.

102 no. samples were assessed from 9 no. borehole locations and one grab sample. Samples were collected from -6.5m b.s.l. Kr to -25.6 m b.s.l. Kr. It is noted that the proposed dredge covers 38Ha, to a depth of approximately -17.5m b.s.l. Kr.

The sediments within the Project area were generally identified as not contaminated. One location was identified which contained mercury at a concentration above the limits set out in “the Regulation of the Minister of the Environment from 11 May 2015 on the recovery of waste outside installations and devices” with a concentration of 16.13mg/kg of mercury with the specified limit defined as 1 mg/kg. This one location was within the upper sediments within the borehole.

The report did not include a limit for TBT (Tri-Butyl-Tin) and DBT (Di-Butyl-Tin) or MBT (Mono-Butyl-Tin), but concentrations for TBT ranged from 12µg/kg to a maximum of 250µg/kg. As can be seen from the table below which was reproduced from the document “Assessment Criteria for Dredged Material with special focus on the North Sea Region” published by Hamburg Port Authority, 15 June 2011, the average concentration of the tested sediments (126µg/kg) would fall above the level 2 limits (i.e., contaminated sediments) for some countries national guidelines, or else between the level 1 and level 2 limits for others (i.e., marginally contaminated).

Table 1 Extract from Table 3.10 From the “Assessment Criteria for Dredged Material with special focus on the North Sea Region”, HPA, 2011



	Country	Level 1	Level 2	Unit	Remarks
Tributyltin (TBT)	NL		100	µg/kg DS	
	BE	3	7	µg/kg DS	
	FR	100	400	µg/kg DS	
	UK	100	1000	µg/kg DS	sum: TBT + DBT + MBT
	IE	100	500	µg/kg DS	sum: TBT + DBT
	NO	5	20	µg/kg DS	
	DK	7	200	µg/kg DS	
	ES				
	DE	20	100	µg/kg DS	
Level 1	Minimum	BE	3	µg/kg DS < 20 µm	
	Maximum	FR	100	µg/kg DS < 2mm	
Level 2	Minimum	BE	7	µg/kg DS < 20 µm	
	Maximum	FR	400	µg/kg DS < 2mm	

Overall, the materials sampled and tested would be classified as marginally contaminated, based on the available data. One sample was identified as containing notable contamination in relation to mercury. This suggests that other such hotspots of contamination could be encountered during the further sampling and testing.

However, the number of samples collected would not satisfy the requirements of the HELCOM Guidelines (2015) for the characterisation of dredge sediments for disposal at sea and further sediment sampling is required. It is understood that Dredging Contractor is undertaking additional sampling to fulfil requirements of HELCOM Guidelines (2015). Prior to the initiation of dredging activities, it is recommended that additional samples be taken from the dredge area to bring the total number of samples to 50. This will ensure that the proposed dredge sediment is adequately characterised according to the current HELCOM Guidelines (2015).

4. Dredging and Land Reclamation Methodology

In this section, the methodology for the dredging and reclamation works is outlined based on the preferred Contractor’s method statement (extract from their tender submission) which was provided by DCT.

The Contractor has proposed alternative scenarios which involve the use of dredged materials with a higher silt content than DCT's performance requirements allow to be used as fill for the land reclamation. Although the risk of potential E&S impacts is expected to be higher in these scenarios the mitigation measures recommended in this study would still be applicable.

The proposed method of works is as follows.

The dredging works within the T3 dredged area will be carried out using Trailing Suction Hopper Dredger(s) (TSHD). The exact boundaries of the dredged area will be defined by the Contactor subject to DCT's approval and in compliance with the ED [3]. Dredging of the seabed layers that are deemed suitable to be used for the land reclamation, i.e., will not be disposed offshore, will involve overflow from the TSHD hopper into the sea to reduce the content of fines (silty material) prior to discharge into the reclamation area. The dredging of the top seabed layers with high silt content will involve extensive overflow while overflow will be optimised for the other layers (sandy materials).

Proposed methods for discharging dredged material for the enabling and permanent works onsite include rainbowing from the TSHD, pumping via pipelines from the TSHD to the discharge point and use of a spreader pontoon connected to the TSHD.

The reclamation works will start on the northern side of the T3 footprint using rainbowing for 4 weeks. Subsequently, earth bunds will be constructed along the eastern and southern perimeter of T3 consecutively during weeks 5-12 using dredged material discharged by a spreader pontoon. Weir boxes will be installed at the western corner of the T3 reclamation when the perimeter is closed to facilitate dewatering. The reclamation works will progress with the infilling of the remaining area within the T3 footprint by discharging the material through pipelines connected to the dredger between weeks 13-24. The ground improvements work will progress in parallel with the reclamation in a phased manner.

5. Impact Assessment

This report focuses on the direct impacts of dredging works and the long term development impact of the T3 including breakwater extension on the nearby Stogi beach morphology and on the sea water quality along the nearby Stogi beach. Other aspects such as heritage, H&S, UXOs, etc. should be covered separately. A summary of the assessment of wider impacts of the development can be found in the Non-Technical Summary [1] for this supplementary information package.

5.1 Construction Impacts (During Dredging)

Based on the proposed dredging and land reclamation methodology provided by DCT and taking into consideration the proximity of T3 area to the Stogi beach, it is concluded that there is considerable risk that suspended material from the dredging activity may disperse towards the beach impacting environmental and social values.

The Sediment Transport and Water Quality Numerical Modelling study (eCoast, 2022), which can be found in Appendix A, indicates that as construction of the T3 progresses, the new reclaimed area will lead to decreased flushing of the area between the T3 reclamation and Stogi beach. The flushing will decrease from the construction of the bunds for the reclamation area for T3. This is expected to lead to increased accumulation of pollutants that enter this area. Furthermore, suspension of dredged material into the water column may result from spillage at the drag head, through overflow from the TSHD hopper when used and construction of the reclamation including dewatering of the reclaimed land. The potential impacts of the decreased flushing and dredging activities are outlined below.

- Increase in turbidity (decrease in water transparency): Dredging works will result in turbidity which may have a negative impact on aquatic plants according to the ED (2019) [3].

- Water quality during dredging: There is a potential impact on water quality due to release of contaminants from the seabed layers as a result of dredging operations. Also, the construction of the bunds for the reclaimed T3 area will result in gradual reduction of the water flushing in the area between T3 and Stogi beach which will cause a potential for eutrophication and accumulation of marine litter in this area. Potential eutrophication and accumulation of marine litter are considered long term impacts (See Section 5.2).
- Stogi beach sediment quality: There is a potential impact on beach sediment quality due to contamination as a result of dredging operations and accumulation of suspended silt materials both in the emerged section of the beach along the shoreline and the nearshore submerged zone potentially affecting the recreational value of the beach and the bathing areas.
- Birds disturbance: The dredging operations may have an impact on the feeding and breeding grounds of birds and limit bird wintering area. Noise disturbance from the construction phase of T3 and from increased traffic of vessels during operational phase may also cause disturbances to birds. Improper lighting during construction may cause disturbances in the functioning of birds during the night or increased mortality as a result of collisions with the object. Foraging opportunities for birds may also be impacted by the effects of turbidity on marine growth.
- Marine mammals' disturbance: Noise emission as a result of the dredging operations may disrupt the natural behaviour of mammals. High level of underwater noise can damage the animal's hearing apparatus, which results in echolocation disturbance leading to navigation errors, food tracking problem and even the death of the individuals.
- Turbidity potentially reaching the mouth of the Vistula river: the dredge plume and/ or increased turbidity associated to dredging works might reach this area.

5.2 Long Term Impacts (After Dredging)

The Sediment Transport and Water Quality Numerical Modelling Study (Appendix A) concluded that it is expected that the breakwaters that were constructed in 2020 will lead to changes to the sediment transport dynamics of Stogi Beach. They will reduce the wave driven accretion at the western end of the beach and will lead to a pattern of accretion along the central region of the beach. Erosion and accretion patterns at the eastern end of the beach are expected to remain largely unaffected.

The model predicts that T3 development will lead to continued accretion of the shoreline in the far western end of Stogi beach which will be exacerbated by wind driven sand transport. The T3 reclamation will not affect sediment transport patterns on the beach to the east of this region.

In relation to Water Quality Modelling, the modelling results indicate that the freshwater plume from the Vistula River disperses widely over the southern Gulf of Gdańsk and reaches the Port of Gdańsk particularly under high flow conditions and easterly wind conditions. The intrusion of the river water in the marine area between the T3 terminal and Stogi beach will be reduced with the T3 development in place due to its effect on ambient current patterns. River water is likely to be one of the largest contributors of bacterial loads to the marine environment. Construction of the T3 development is unlikely to lead to higher bacterial or river borne pollutant concentrations at the western end of Stogi Beach.

The modelling also shows that in the same area flushing in this area will be expected to be on average 7 times slower with the T3 development in place. While the Vistula river water is less likely to enter the region between the T3 terminal and Stogi beach with the T3 terminal in place, once waterborne pollutants enter this area, they will take on average 7 times as long to be removed under natural influences. There is consequently a strong likelihood that this region will become a sink for litter and debris.

Therefore, based on this study, the following potential long term impacts on the marine environment have been identified:

- Change in Stogi beach's morphology: Accretion and/or erosion along Stogi beach is expected to occur due to changes in coastal morpho-dynamics.

The expected accretion in the central area of Stogi beach will have a positive impact for beach users as it will provide additional recreational area to the east of the port facilities. Furthermore, it is not expected that erosion will change significantly as a result of the development; therefore, there is no expected impact on the beach areas available for the birds.

- Long Term water quality: There is the potential for eutrophication and accumulation of marine litter in the area between T3 and Stogi beach due to changes to water circulation and wave climate. This will impact negatively the social and recreational aspects of Stogi beach.

6. Mitigation measures

6.1 Measures to be implemented in advance of the works

In advance of the dredging works progressing, further sampling and testing should be carried out to ensure that the proposed dredge sediment is adequately characterised according to the current HELCOM Guidelines (2015). Prior to the initiation of dredging activities, it is recommended that additional samples be taken from the dredge area to bring the total number of samples to 50. This will ensure that the proposed dredge sediment is adequately characterised according to the current HELCOM Guidelines (2015).

ED (2019) [3] requires that Detailed/Execution Design needs to be based on the results on geological investigation which had not been conducted when the EIA was produced but was subsequently undertaken in June 2019. Therefore, the findings of this investigation need to be considered when developing the new methods for constructing the T3. However, solution adopted should ensure at least the same level of environmental protection as the solutions proposed in the Conceptual Design (which used the geological information gathered for T2 Project), on which the EIA is based.

The EIA report [2] addresses the issue of the excavated dredged material and lists relevant legislation and guidelines to determine whether this material is contaminated or not. Depending on this quality assessment, the options for output disposal could be reviewed. It will be either characterised as waste in which case the principle of Polish Waste Act will be applicable, or it will be used as material for land reclamation (if suitable from an engineering point of view).

Recommendations on how to manage the treatment and disposal of the dredged material shall also be included in Environmental Impact Assessment report which will accompany the application for the permit for the disposal of dredging spoil into the sea and will be subject to the stipulations of this permit (Minister of Transport and Construction, 2006).

Therefore, the following measures are recommended for implementation prior to the commencement of the dredging works:

- Further sampling and testing is legally required to ensure that the proposed dredge sediment is adequately characterised according to Polish legislation, i.e., the Regulation of the Minister of Transport and Construction (2006) and the current HELCOM Guidelines (2015). Sampling of an additional 40 no. locations is required with samples collected over the depth of the proposed dredge and including the over dredge.
- Monitoring to inform baseline data and trigger levels should commence as soon as possible, including monitoring of turbidity and water clarity. The proposed environmental monitoring, including its frequency, is summarised in Table 2 Monitoring frequency and standards during dredging works and Table 3 Monitoring frequency and standards for long-term impacts. A full year of monitoring prior to the commencement of the works is normally advisable, but this is not possible with the current construction programme. Nonetheless, baseline data should be collected be undertaken throughout the months July and August and potentially September (until commencement of the dredging activities) within the current Project programme.

- Fill material to be sourced from existing, operational and permitted offshore borrow sites or quarries. DCT will review Contractor’s method statement for the sourcing of material, operational and environmental permits of the borrow sites or quarries sites. Contamination testing at any other borrow areas to be used for sourcing additional fill material to avoid introducing potentially contaminated material to the T3 site (if needed).

6.2 Measures to be implemented during Construction (Dredging)

The following measures are proposed to mitigate the impact of the proposed dredging works. These should be detailed by the Contractor in the DMP.

6.2.1 Measures to reduce impact of sediment released during dredging

The following mitigation measures are proposed to reduce the impact of sediment released during dredging:

- As per the ED (2019) [3]:
  - Dredging shall not be carried out between the months of April until the end of August.
  - Soft-start procedures should be put in place to deter marine life from the area and reduce noise exposure.
  - Contaminated material shall not be used as reclamation fill.
- Dredging methodology (trailing velocity, suction mouth and suction discharge) to be optimised to reduce dispersal of sediment at the drag head.
- Bunds, silt curtains or bubble screens are recommended to reduce the dispersal of the dredging plume. The construction of bunds is recommended to enclose the area to be reclaimed prior to infilling. Silt curtains can be used prior to the construction of bunds, as long as they can be demonstrated to be effective. The dredge area is a reasonably quiescent location since tidal currents are minimal and wave energy is largely blocked due to the recently constructed breakwaters. Therefore, silt curtains are likely to be an effective solution for containing the dredge plume. The use of bubble screens may also be explored for this purpose. The contractor shall include in the DMP a methodology to control the dispersal of the dredge plume and propose alternative or complementary measures if needed. This includes a deployment plan for the bunds and silt curtains which will suit their methodology and phasing of works and ensure appropriate installation.
- Dredged material to be loaded into a hopper prior to discharge. Where overflow is used, silt curtains will be even more important. Overflow should be limited as much as possible and shall not be allowed if the dredge spoil is contaminated.
- The dredge operation should be adapted dynamically based on real-time monitoring data. While dredge plume modelling has not been undertaken to date, it is expected that northerly winds and energetic wave conditions are likely to cause dispersion of the plume towards the shore. Forecasted and real time (e.g., using the Automatic Weather Station at the port) metocean data should be used in conjunction with real time turbidity monitoring and drone surveys and/or satellite images of the plume extent for operational management of the dredge operations. See Section 6.2.3 for a description of the proposed monitoring measures.
- The dredging contractor shall comply with the relevant Polish legislation, offshore disposal regulations, international treaties (Helsinki Convention, 1992), EBRD Performance Requirements and international best practise in terms of waste management during the dredging works.

6.2.2 Mitigation measures related to dumping at sea

Further sediment sampling shall be carried out prior to the dredging works, as per Section 6.1, to ensure that the material is adequately characterised. Dredged material which is not suitable to be used for the reclamation (See also Section 6.2.1), i.e., contaminated and/ or not suitable from an engineering point of view, can be disposed of at sea.

The Contractor shall apply for a special permit for dumping dredged material at sea, whether contaminated or not, in compliance with the Regulation of Minister of Transport and Construction (2006) and the Helsinki Convention (1992) and associated HELCOM Guidelines (2015) as outlined below.

The following measures are recommended for the dumping of dredged material:

- A suitable dumping site needs to be identified for the disposal of dredged material.
- Overflow should not be allowed when sailing to the offshore disposal site.
- As per the ED (2019) [3] :
  - The Regulation of Minister of Transport and Construction, (2006) is applicable. As stipulated in this ordinance, an application for the permit to dump dredged material should include **a report on the impact of the project of dredging spoil disposal into the sea on the marine environment, along with an indication of practical measures to reduce possible adverse effects.**
  - When dropping the spoil at the disposal site, the position of the hopper should be controlled with the use of navigation devices. The underwater currents and the speed of the vessel's movement should be taken into account and the speed of the dredger disposing of spoil in the disposal site must not exceed 1 knot.
- Based on the assessment of environmental effects, locations for turbidity monitoring in the wider area of interest will be defined and included by the Dredging contractor in their DMP

6.2.3 Environmental monitoring measures

The dredging activities are expected to have some impact on environmental and social values of the marine and coastal environment. This section outlines the monitoring strategy to be used to track effects of the activity during the dredging works.

It should be noted that the baseline data available in relation to dredging is limited and no modelling of the dredge plume has been carried out. Therefore, the monitoring strategy is proposed based on international best practise with control monitoring locations identified to ensure that the effects of the dredging activity are understood in relation to background levels.

6.2.3.1 Dredge Hopper Validation Samples

Samples taken from the TSHD hopper provide assurance that the dredged spoil does not contain levels of contaminants or toxins beyond expected levels. This monitoring is a quality control to provide assurance that dredge area samples are representative of the material being dredged.

It is recommended that five grab samples be collected from the TSHD hopper (assuming a hopper of approx. 15,000m^3 capacity) into laboratory supplied containers. Where overflow is used, it is recommended that the analysis includes overflow samples taken from a well-mixed region near the lower end of the overflow pipe along with estimates of the volume rate of overflow (Aarninkhof, 2008) if possible. The samples will be collected following representative dredging conditions that are typical of dredging operations over the course of the development including typical hopper loading volumes. The samples shall be labelled with details of the dredging circumstances (e.g., hopper number and approximate location). Samples should be collected once a week from the hopper in a manner which ensures samples are representative of different locations throughout the dredging footprint. The samples will be analysed using the same standards applied to the baseline sediment samples (Section 6.1). The dredging contractor may propose adjustments to this monitoring in their DMP for approval.

6.2.3.2 Turbidity and Water Clarity Trigger Levels

Turbidity is the measure of light scattering in water and is one of the primary direct environmental effects of dredging through the release of sediment into the marine environment. Turbidity is often measured in units of NTU or FTU and is commonly used as a proxy for Suspended Sediment Concentration (SSC), Total Suspended Sediment (TSS) or visual water clarity. From the perspective of dredging, it is one of the most useful characteristics to monitor since it provides a direct measurement of dredging effects in the marine environment.

Usually, sensitive receptors are identified, and a baseline dataset of turbidity is recorded at those sites. These data are combined numerical modelling output to provide trigger levels which can be applied to turbidity monitoring throughout the dredging operation. As previously established, these datasets are not available for the area surrounding the proposed dredge area. In the absence of location specific trigger levels, a value for turbidity is required reflective of international standards.

Turbidity varies widely in the coastal marine environment and ecological impacts are largely dependent of the species in question. However, some standards around water clarity do exist for bathing. Water clarity for swimming can be assessed using a black disc test (Davies-Colley, 1991) The ANZECC guidelines (ANZECC and ARMCANZ, 2000) recommend that the black disc visibility should be not less than 1.6 m, which is equivalent to the bottom of the waterbody being visible at an adult chest height of around 1.2 m. Turbidity can be used as a proxy for black disc visibility providing a location specific relationship between the two has been established (e.g., West and Scott, 2016).

It is recommended that a telemetered turbidity meter be deployed offshore from the Stogi beach directly shoreward of the proposed dredging operation providing measurements of turbidity. Proposed monitoring locations are shown in Figure 3. The recommended frequency of this monitoring is outlined in Table 2. Turbidity should be measured using a turbidity measurement device such as FLNTU which is a combination fluorometer and turbidity sensor. The inclusion of a fluorometer can be a useful addition to the dataset as it will provide future understanding of eutrophication in the area. The monitoring should be undertaken as soon as possible prior to the commencement of the dredging operation and multiple coincident black disc visibility tests should be undertaken next to the turbidity meter in a range of metocean conditions. These measurements can then be used to establish a relationship between turbidity and black disc visibility. The trigger level can then be taken to be the turbidity level associated with a black disc visibility of 1.6 m. Monitoring should also be carried out at control locations for comparison with the monitoring data should trigger levels be exceeded. This will help to understand whether the exceedance has occurred due to natural variability or due to the dredging activity. Natural turbidity is likely to arise from wave action or from a plume from the Vistula River.

Therefore, two control locations should be established: one to the east of the monitoring location (C1) and one to the west in a location with a similar wave climate to the monitoring location (C2). The latter of these can be identified using the long-term wave hindcast developed as part of this study (eCoast, 2022).

The recommended location for M1 is 54.38053°, 18.72176° (Latitude, Longitude, WGS 84). The control locations C1 and C2 should be located at 18.70875°, 54.40260° and 18.75561°, 54.37441° respectively. The monitoring and control locations are shown in Figure 3. C1 and C2 may need to be adjusted based on logistical factors. Care should be taken to ensure that M1 and C2 are deployed in similar water depths.

Figure 3 Turbidity monitoring location (M1) and two control locations (C1 and C2)

6.2.3.3 Trigger Level Exceedance Management Plan

As noted in Section 6.2.3.2, turbidity is main parameter that is monitored during a dredging operation. Real-time monitoring allows for the rapid assessment of the effects of the dredging on water quality. and for rapid management responses to any exceedances.

In the absence of baseline data, dredge plume monitoring or identification of specific sensitive marine receptors, the trigger level is chosen as the turbidity standard for swimming as described in Section 6.2.3.2. Once the trigger level has been exceeded at the M1 monitoring location for a period of 3 hours over a rolling 12-hour window, a series of management steps are recommended to understand and potentially mitigate the impacts of the dredge activities:

- A UAV mounted camera should be deployed to provide a visual inspection of the water surface to identify any surface turbidity plumes from the dredging (See Section 6.2.3.4).
- Comparative analysis of the M1, C1 and C2 turbidity monitors will be undertaken by environmental specialists to understand whether or not the exceedance has occurred due to processes independent of the dredging operation. The C1 signal will be used to investigate wave driven sediment transport and C2 will be used to investigate the effect of the Vistula river, these being the most likely external sources of turbidity.
- This analysis will be supplemented by analysis of metocean parameters including the wind, waves and river flow.
- Should the dredging be determined to be responsible for the exceedance, measures should be taken to reduce the release of sediment into the marine environment.
- If no such measures can be identified, the dredging should be stopped until the dredging process can be improved to avoid future exceedances.

- The results of any exceedances should feedback into improvements in the dredging process. This may include alterations to the operational dredging practices and identification of metocean conditions when dredging should not be undertaken.

The recommended frequency of this monitoring is outlined in Table 2. It is recommended that this approach is followed at least for the duration of the dredging of the top seabed layers with high silt content as this will involve extensive overflow and hence higher turbidity (See Section 6.1). This is expected during the first three months of the dredging works. Once that turbidity has been assessed in these conditions over this period, and further to the assessment of the dispersion of the plume based on turbidity measurements and other techniques such as UAV surveys and satellite images, the dredging contractor may propose adjustments to the above process including adjustments in the monitoring frequency in their DMP for approval.

Due to the absence of baseline data, there is a high level of uncertainty about likely background turbidity levels. The trigger level should be subject to review if it is being exceeded frequently due to background processes independent of the dredging activities. This may occur, for example, if the plume from the Vistula river is frequently causing trigger level exceedances at the study site. It is strongly recommended that instrumentation be deployed at the monitoring sites prior to the dredging works commencing to aid in this decision-making process.

6.2.3.4 UAV Surveys of the Plume

Unmanned Aerial Vehicle (UAV or ‘drone’) photographic surveys of the dredge area should be undertaken regularly while dredging activities are underway. This will help to understand the dynamics of a plume associated with the dredging activities. This should be undertaken to coincide with a range of meteorological conditions. The recommended frequency of these surveys is outlined in Table 2.

Any potential turbidity reaching the mouth of the Vistula river should be monitored and avoided.

6.2.3.5 Salinity

Telemetered salinity gauges (measuring conductivity) should be deployed at the M1, C1 and C2 monitoring locations. The recommended frequency of this monitoring is outlined in Table 2. These gauges will serve as a diagnostic tool to understand trigger level exceedances due to intrusion of the Vistula river plume onto the M1 monitoring location. If trigger levels are exceeded at the M1 monitoring station, comparison of salinity data recorded at the M1 station compared with the C1 and C2 salinity data will be useful for determining whether or not the exceedance is due to dredging activity or the influence of the Vistula river plume.

6.2.3.6 Metocean and Meteorological

For the operational management of the dredging operation, both nowcasted and forecasted metocean data should be collected for decision making purposes. The recommended frequency of this monitoring is outlined in Table 2.

- Wave and wind forecasts should be used to for operational planning (e.g., www.buoyweather.com).
- Meteorological data (principally wind data) should be sourced from the port Automatic Weather Station.
- Gauged river flow data for the Vistula river should be sourced from the Tczew flow gauge.

6.2.4 Monitoring Frequency and Standards

Table 2 below summarises the recommended frequency for the proposed monitoring.

Table 2 Monitoring frequency and standards during dredging works

Type of Monitoring	Parameter	Sampling Location	Standard / Parameters	Applicability / Phases			Source	Responsible party
				Pre-Dredging	During Dredging	Post-Dredging and Operational		
Sediment contamination	Contaminants	Dredging area	HELCOM Guidelines (2015) Polish Waste Act	40 additional samples taken and analysed from dredging area to bring total to 50	NA	NA	HELCOM Convention Ministerial Ordinance of 26 January 2006 on the procedure for issuing permits for the disposal of dredging output at sea and for dumping waste or other substances at sea (Journal of Laws, 10.02.2006) ED 2019	EPC Contractor
	Contaminants	TSHD Hopper	HELCOM Guidelines (2015) Polish Waste Act	NA	5 samples taken from the TSHD hopper and analysed once a week	NA	EBRD requirements (Assessment of Impact on Marine Environment)	EPC Contractor
Aerial Photography	Plume visibility	Extent of plume visibility	Best practice	NA	every 2 weeks	NA	EBRD requirements (Assessment of Impact on Marine Environment)	EPC Contractor
Water Quality	Water clarity		Best practice Black disc test	Undertaken weekly beside the FLNTU	Undertaken every 2 weeks beside the FLNTU	NA	EBRD requirements (Assessment of Impact on Marine Environment) WBG EHS Guidelines for Ports, Harbours and Terminals (2017)	EPC Contractor
	Turbidity	Telemetered turbidity monitors to be deployed directly shoreward of the proposed dredging operation and two control locations	Best practice NTU	Sampled every 15 minutes	Sampled every 15 minutes for the first 3 months of dredging activities.	Sampled every 15 minutes for 2 years[1].		EPC Contractor/ TBC post-dredging and Operational

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[1] Post-dredging turbidity (NTU) is monitored as a byproduct of the fluerometry monitoring as it is recorded by the same instrument.

Type of Monitoring	Parameter	Sampling Location	Standard / Parameters	Applicability / Phases			Source	Responsible party
				Pre-Dredging	During Dredging	Post-Dredging and Operational		
		(3 locations: M1, C1 and C2).			Frequency to be re-assessed after this period.			
	Salinity	Telemetered salinity monitors to be deployed directly shoreward of the proposed dredging operation and two control locations.	Best practice Conductivity (salinity)	Sampled every 30 minutes.	Sampled every 30 minutes	NA		EPC Contractor
Metocean data	Recorded river flow	NA	Best practice	NA	Daily analysis data from the Tczew flow gauge	NA	EBRD requirements (Assessment of Impact on Marine Environment) WBG EHS Guidelines for Ports, Harbours and Terminals (2017)	EPC Contractor
	Forecasted waves	NA		NA	Daily analysis of forecasted wave data	NA		EPC Contractor
	Forecasted wind/rainfall	NA		NA	Daily analysis of forecasted wind and rainfall	NA		EPC Contractor

6.2.5 Environmental Management plans

The dredging contractor shall also take into account the following management plans in the DMP

- Biosecurity Management Plan (Ballast water management plan)
  - The purpose of the Biosecurity Management Plan (BMP) is to reduce the risk of a biosecurity incursion from the dredger(s) and any other vessels used for the dredging and reclamation works. The BMP shall conform with the International Convention for the Control and Management of Ships’ Ballast Water and Sediments (IMO, 2004) which came into effect in Poland in 2020. The dredging contractor is legally required to prepare this management plan.
- Ecological Management Plans
  - Marine Mammal Monitoring: Threatened marine mammals include the grey seal (Halichoerus grypus) and the harbour porpoise (Phocoena phocoena) and Harbour seal Phoca vitulina. Monitoring recommendations for these species are provided in the Appendix A to CHA [4]: Marine Mammal Mitigation Review in line with Habitats Directive and EBRD PR6.
  - Avifauna Monitoring Notable threatened bird species include the little ringed plover (Charadrius dubius) and the little tern (Sternula albifrons). Monitoring recommendations for these species are provided in the CHA [4] in line with Habitats Directive and EBRD PR6.

6.3 Long Term Mitigation Measures (After Dredging)

Based on the findings from Sediment Transport and Water Quality Numerical Modelling Study, it is recommended that a long term environmental monitoring strategy will be incorporated in the Company level Environmental Management Plan. The following mitigation measures are proposed in relation to the long term impacts of the T3 including breakwater extension on adjacent beach evolution/ morphology and sea water quality.

6.3.1 Mitigation of Eutrophication

Eutrophication is an undesired ecological condition which mainly occurs due to increased nutrient enrichment. A numerical modelling study of water quality has indicated that there is potential for stagnation and reduced flushing of water in the lee of the proposed T3 development. The modelling also indicates that water from the Vistula river is more likely to become trapped in this enclosed area. Quantifying eutrophication can be achieved through the measurement of a variety of indicators such as dissolved oxygen, nutrient concentrations, chlorophyll-a, etc. Some of these can be monitored using in-situ instrumentation that can provide real time telemetered measurements. We note that monitoring of chlorophyll-a can be achieved using an Fluorometer (FLNTU) which can also measure turbidity. Continuous monitoring of eutrophication using any of the appropriate indicators in the lee of the T3 development is recommended to assess this risk due to changes in circulation patterns. The recommended frequency of monitoring is outlined in Table 3.

6.3.2 Beach Morphology

Sediment transport modelling (Appendix A) indicates that there it is likely that there will be some changes to the current sediment transport regime in the area due to recent extension of the breakwaters as well as the T3 development. As described in Section 5.2, this will likely manifest as reduced accretion at the western end of Stogi beach (present scenario) and possible accretion in the central region followed by future accretion at the western end of Stogi beach (future scenario where the reclamation of the T3 and associated dredging are completed). Regular topographic beach surveys should be undertaken to understand how the shoreline dynamics have changed under the influence of the developments. Analysis of these surveys by a specialist coastal engineer will help to identify trends in accretion and erosion of Stogi beach.

The recommended frequency of monitoring is outlined in Table 3. It is recommended that the frequency of these surveys is re-assessed by DCT after two years following the completion of the reclamation of the T3 terminal.

Should the surveys and assessments by a specialist coastal engineer show that the beach remains stable and subject only to the variations expected as per the Sediment Transport and Water Quality Numerical Modelling Study report in Appendix A (eCoast, 2022), the annual frequency of the surveys can be modified and/or beach morphology evolution assessed by other appropriate methods such as aerial satellite, UAV images, etc.

6.3.3 Marine Litter

The numerical modelling study on water quality (Appendix A) indicated that the area between the T3 reclamation and Stogi beach may act as a sink for marine litter. Regular surveys of marine litter should be undertaken to assess the accumulation of litter in this area. These surveys should align with the existing beach and marine litter surveys (Inspectorate of Environmental Protection, 2020) and where possible OSPAR Commission (2010) guidelines so that existing data can act as a baseline for future data collection. The recommended frequency of monitoring is outlined in Table 3. The survey methods will need to be modified to assess the degree to which litter is accumulating in the lee of the T3 reclamation in contrast other parts of Stogi beach. Additional cleaning measures should be put in place once that this potential impact has been monitored and assessed and appropriate actions to be included in the environmental management plan.

Table 3 Monitoring frequency and standards for long-term impacts

Parameter	Sampling location	Standard- / Parameters	Frequency / Method	Applicability / Phases	Source	Responsible party
Eutrophication	On the lee side of the proposed T3 development and at the two control points (3 locations: M1, C1 and C2)	Standards: WBG EHS Guidelines for Ports, Harbours and Terminals (2017) Parameters: Appropriate indicator such as Chlorophyll-a.	In-situ instrumentation. Monitoring of measurement of indicators such as dissolved oxygen, nutrient concentrations, chlorophyll-a, etc. Real time and continuous monitoring are recommended.	Pre-dredging Phase: Indicator sampled at an appropriate frequency. Dredging Phase: Indicator sampled at an appropriate frequency. Post-dredging Phase including Operational Phase: For 2 years. Indicator sampled at an appropriate frequency.	EBRD requirements (Assessment of Impact on Marine Environment) WBG EHS Guidelines for Ports, Harbours and Terminals (2017)	TBC
Beach Morphology	Stogi beach	The survey methodology should be aligned with the baseline survey (May 2022)	Topographic surveys	Topographic survey undertaken annually after the baseline survey for 8 years (from baseline). Analysis of these surveys will help to identify trends in accretion and erosion of Stogi beach. Annual frequency to be re-assessed after two years following the completion of T3 reclamation.	EBRD requirements (Assessment of Impact on Marine Environment) WBG EHS Guidelines for Ports, Harbours and Terminals (2017)	TBC
Marine Litter	Water basin between the T3 reclamation and Stogi Beach	Aligned with existing beach and marine litter surveys (Inspectorate of Environmental Protection, 2020) and where possible OSPAR Commission (2010) guidelines.	The survey methods will need to be modified to assess the degree to which litter is accumulating on the lee side of the T3 reclamation in contrast with other parts of Stogi beach.	1 survey every 3 months from the commencement of Dredging Phase for 5 years	EBRD requirements (Assessment of Impact on Marine Environment) WBG EHS Guidelines for Ports, Harbours and Terminals (2017)	TBC

7. Reporting

The following reports are recommended to be produced during and after the dredging programme:

- During the dredge programme, monitoring reports presenting analysis of the monitoring data to date should be produced on a monthly basis. The reporting should discuss any trigger level exceedances and subsequent data analysis and changes to dredging operations.
- Reporting should be undertaken on annual basis providing an overview of additional monitoring that is undertaken beyond the timeline of the dredging activity. This will principally cover additional beach surveys.

It is recommended that reports will be passed to a relevant body for review as per the DCT requirements.

8. Conclusions

Mitigation measures are recommended based on the existing baseline data and impacts assessment.

- In relation to the dredging and reclamation works, these should be detailed by the Contractor in their DMP. The DMP shall include:
  - Monitoring strategy to inform baseline data and trigger levels prior to dredging and reclamation works commencing.
  - Monitoring strategy during dredging and reclamation works.
  - Proposed mitigation measures to control release of sediments and potential contaminants and turbidity during dredging and reclamation works and offshore disposal.
- Recommended actions for both, dredging works and long term development impact of the T3 and the associated extension of the port breakwaters on the nearby Stogi beach morphology and sea water quality will feed into the Environmental and Social Action Plan (EBRD, 2022).

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Appendix A

Sediment Transport and Water Quality Numerical Modelling Study

Deepwater Container Terminal T3: Sediment Transport and Water Quality Numerical Modelling Study

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Deepwater Container Terminal T3: Sediment Transport and Water Quality Numerical Modelling Study

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Executive Summary

The Port of Gdańsk is a seaport located in the city of Gdańsk on the southern coast of the Gulf of Gdańsk and is one of the largest seaports on the Baltic Sea. The Gdańsk Deepwater Container Terminal (DCT) is the only truly deep-water container terminal in the Baltic Sea and is the primary gateway for Polish traffic and Baltic transhipment operations.

The existing facility is divided into two main operating areas, known as Terminal 1 (T1) and Terminal 2 (T2). In 2020, two extra segments were added to the existing breakwater. DCT currently has plans for the future development of a Terminal 3 (T3) which will include capital dredging and land reclamation. The area of T3 is approximately 37 ha (0.37 km^2).

Stogi Beach lies directly to the east of the Port of Gdańsk and is a popular bathing beach with swimming water quality rated as excellent. It also provides habitat for a number of threatened bird species.

This study includes:

- A beach morphology evolution study using numerical models to assess potential adverse impacts on the adjacent beach due to the development of T3 and the expansion of the offshore detached breakwaters.
- A numerical modelling study investigating potential water quality issues affecting the coastal zone due to the development of T3.

The numerical modelling components considered three scenarios:

1. The port layout prior to 2020 with T1 and T2 in place but without the breakwater extensions that were built in 2020. None of the proposed dredging is included in this scenario.
2. The port layout as it is currently with T1 and T2 in place and with the breakwater extensions in place as well as the dredging associated with the approach channels and turning circles.
3. The same as Scenario 2 with the addition of the T3 development including dredging of the T3 berthing area.

The scenarios are shown graphically in Figure 5.2.

Beach Morphology

The construction of the T1 terminal in 2005 led to the accretion of the western end of Stogi Beach (adjacent to T1) at a rate of approximately 3.4 m per year from 2008 through 2018. The rate of accretion decreases with distance east of T1 and some erosion is seen in the central and east of central portion of the beach while the far-eastern portion of the beach is broadly stable. The rate of accretion at the western end of the beach is greater than the rate of erosion towards the centre and east of centre suggesting a net accumulation of sediment along the beach. While the source of this sediment is not clear, it most likely comes from offshore.

Results from the modelling indicate that the breakwaters that were constructed in 2020 will lead to changes to the sediment transport dynamics of Stogi Beach. They will reduce the wave driven accretion at the western end of the beach and will lead to a pattern of accretion along the central region of the beach. Erosion and accretion patterns at the eastern end of the beach will remain largely unaffected.

The T3 development will lead to continued accretion of the shoreline in the far western end of Stogi Beach which will be exacerbated by wind driven sand transport. The T3 reclamation will not affect sediment transport patterns on the beach to the east of this region.

Water Quality Modelling

The modelling results indicate that the freshwater plume from the Vistula River disperses widely over the southern Gulf of Gdańsk and reaches the Port of Gdańsk particularly under high flow conditions and easterly wind conditions. The intrusion of the river water in the marine area between the T3 terminal and Stogi Beach is reduced with the T3 development in place due to its effect on ambient current patterns. River water is likely to be one of the largest contributors of bacterial loads to the marine environment. Construction of the T3 development is unlikely to lead to higher bacterial or river borne pollutant concentrations at the western end of Stogi Beach.

The modelling also shows that in the same area, while there is some variability in current patterns under different wind conditions, flushing in this area is on average 7 times slower with the T3 development in place. While Vistula River water is less likely to enter the region between the T3 terminal and Stogi beach with the T3 terminal in place, once waterborne pollutants enter this area, they will take on average 7 times as long to be removed under natural influences. There is consequently a strong likelihood that this region will become a sink for litter and debris.

Contents

Figures

Tables

1 Introduction

1.1 Definitions and Conventions

Units – Unless otherwise stated all measurements are in SI units except for temperature where degrees Celsius is used.

MSL – Mean Sea Level. All depths are stated relative to this datum unless otherwise stated.

H_s – Significant wave height (m).

T_p – Peak wave period (s).

D_p – Peak wave direction (deg true).

1.2 Background

The Port of Gdańsk is a seaport located in the city of Gdańsk on the southern coast of the Gulf of Gdańsk and is one of the largest seaports on the Baltic Sea (Figure 1.1). The Gdańsk Deepwater Container Terminal (DCT) is the only truly deep-water container terminal in the Baltic Sea and is the primary gateway for Polish traffic and Baltic transhipment operations. The terminal has previously undergone an expansion project to extend the facility to include a second deep water terminal to ensure can accommodate all shipping line vessels efficiently. The existing facility is divided into two main operating areas, known as Terminal 1 (T1) and Terminal 2 (T2). DCT currently has plans for the future development of Terminal 3 (T3) which will include capital dredging and land reclamation (Figure 1.2).

In 2020, two extra segments were added to the existing breakwater (Figure 1.3). Proposed dredging activities are presented in Figure 1.4. The size of the T3 dredge area is approximately 38 ha (0.38 km^2). The dredging for the access channel and turning circle is not part of the T3 development and therefore is not considered as part of the T3 development effects. The maximum dredge depth is -17.5 m (MSL); however, the dredge tolerances bring this value to -17.8 m (MSL) in the berthing area buffer zone and -19.5 m (MSL) in the rest of the berthing area. The maximum amount of spoil is estimated to be 4,000,000 m^3 (ED, 2019). In terms of land reclamation, the size of the T3 reclamation is approximately 37 ha (0.37 km^2). Future terminal expansions T4 and T5, planned in the longer term after the completion of T3 development, are not considered in this study. The T4 and T5 developments will bring the total reclamation area to 80 ha (0.80 km^2).

The popular Stogi Beach lies directly to the east of the Port of Gdańsk and is a popular bathing beach. It also provides habitat for a number of threatened bird species (Arup, 2022). It is a medium sand beach (D_{50} = 0.386 mm), 4 km long, 130 m wide at the western end and less than 30 m wide at places on the eastern end (Figure 1.5). The beach is particularly popular in summer months and has excellent/very good water quality for bathing purposes with 2021 water quality sampling showing E. coli counts of 29 cfu (NPL) / 100 ml and Enterococci counts of cfu (NPL)/100 ml[1].

The T3 development forms a semi enclosed basin between the T3 reclamation and Stogi beach (Figure 1.2) which we will refer to as the 'T3 Shadow Zone' throughout this report.

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[1] Gdańsk Stogi water quality reporting

Figure 1.1: The Port of Gdańsk, Poland and relevant landmarks.

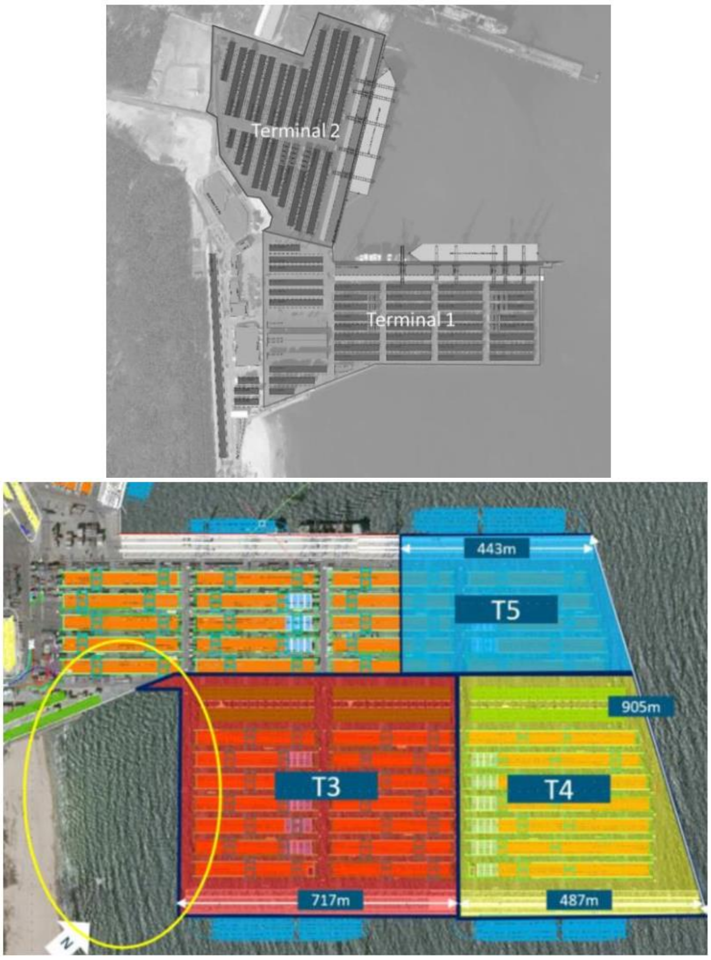

Figure 1.2: Existing facility at the Port of Gdańsk (top) and the proposed expansion (bottom). The yellow circle highlights the enclosed body of water (the 'T3 shadow zone') that will be created following construction of the T3 development.

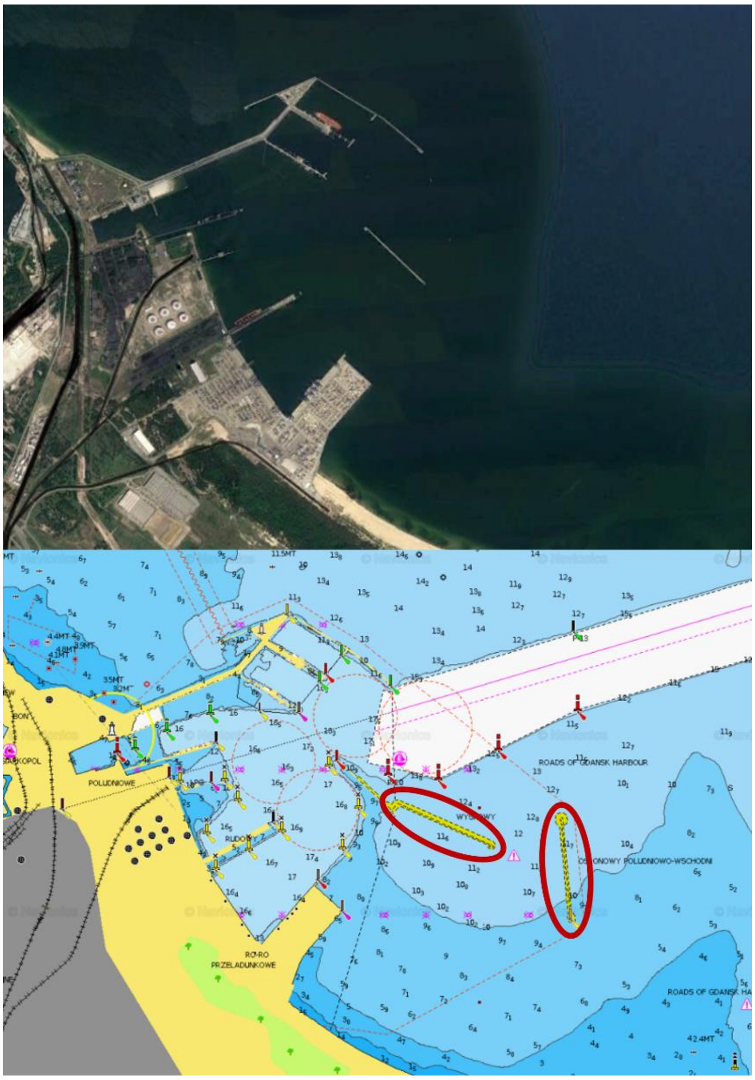

Figure 1.3: The port layout in 2018 (top) and the extra breakwaters added in 2020 (bottom).

Figure 1.4: The location of the proposed T3 terminal (yellow), dredging for the T3 berthing area (purple), berthing area buffer zone (brown) and approach channels and turning circles (green).

Figure 1.5: Stogi Beach (top) and visitor infrastructure at the beach (bottom).

1.3 Purpose

The purpose of this study is to undertake:

- A beach morphology evolution study using numerical models to assess potential adverse impacts on the adjacent beach due to the development of T3 and the expansion of the offshore detached breakwaters.
- A numerical modelling study investigating potential water quality issues affecting the coastal zone due to the development of T3.

2 Data Sources

The following data sources were used to inform the study presented in this report.

Bathymetry data (see Figure 2.1) were sourced from digitised hydrographic charts, port surveys of the T2 and T3 areas provided by DCT, The 2018 EMODnet (resolution ~115 m latitudinal × 47–68 m longitudinal) digital bathymetric dataset (Jakobsson et al., 2019) and a beach topography survey (down to a depth of -1 m) undertaken in May 2022 as part of this study.

Wind and wave data were sourced from the NOAA Wave Watch III 30-year Hindcast Phase 1[2] from the North Sea Baltic 4 min sub-grid (Figure 2.2) for the years of 1979 to 2009. For time periods after 2009, wind data were derived from the ECMWF ERA5 hindcast model (Hersbach et al., 2020).

T3 and dredging specifications were derived from AutoCAD files provided by DCT.

Sediment grain size data were derived from a sediment analysis study[3] undertaken in May 2022 as part of this study. The study analysed samples at 19 locations along Stogi Beach (Figure 2.4).

Satellite imagery was sourced from the Google Earth historical archive and from the Landsat database[4].

River flow data at an hourly sampling rate from the Tczew flow gauge for 2014 to 2021 was provided by the Institute of Meteorology and Water Management - National Research Institute (Poland).

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[2] https://polar.ncep.noaa.gov/waves/hindcasts/nopp-phase1.php

[3] Undertaken by Geoteko Projekty I Konsultacje Geotechniczne (Geoteko Projects and Consultations Geotechniczne), Study number 83/5755/22.

[4] https://www.usgs.gov/landsat-missions

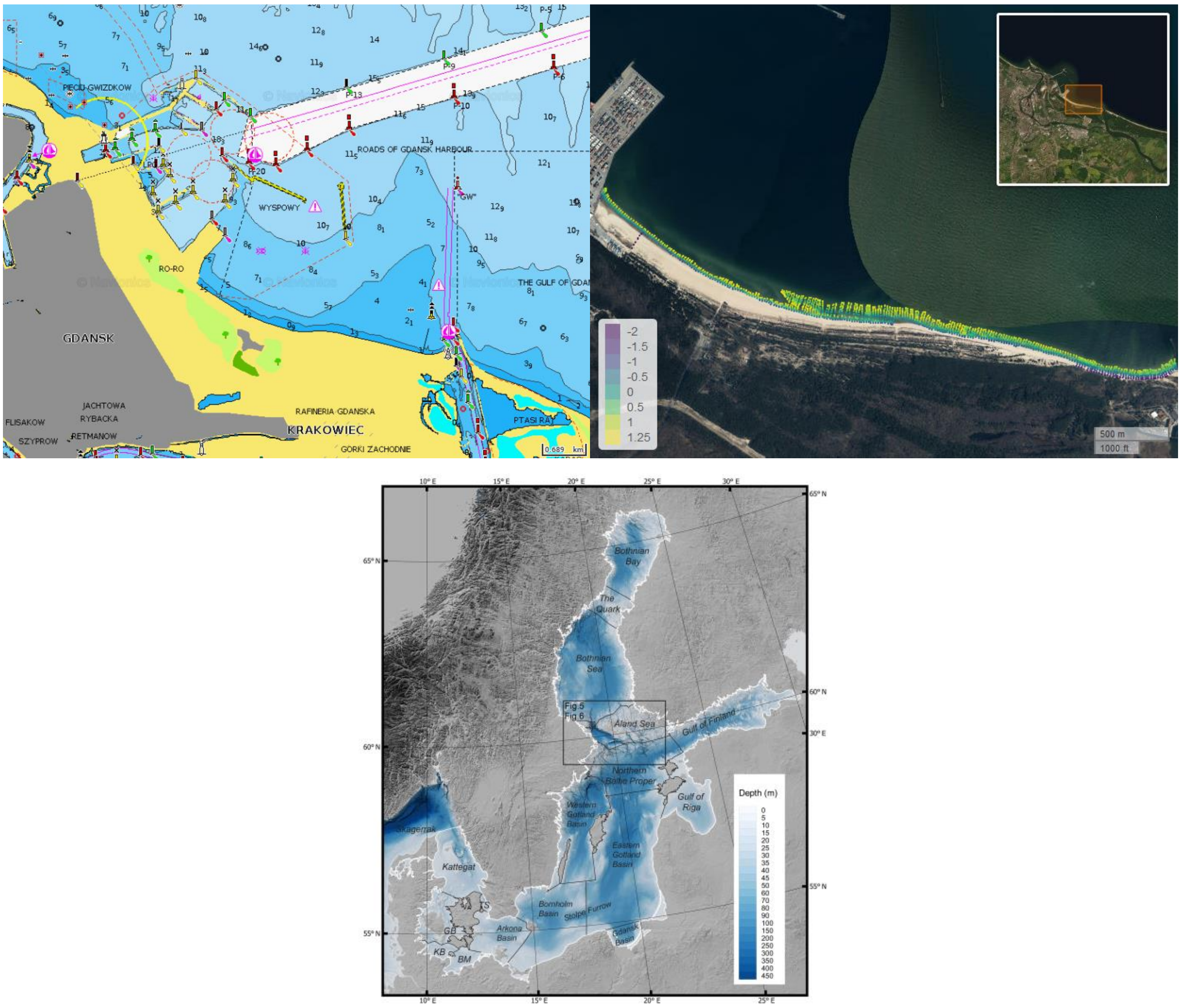

Figure 2.1: Example hydrographic chart (top left), Stogi beach survey (2022) (top right) and the EMODnet bathymetric dataset for the Baltic Sea (bottom).

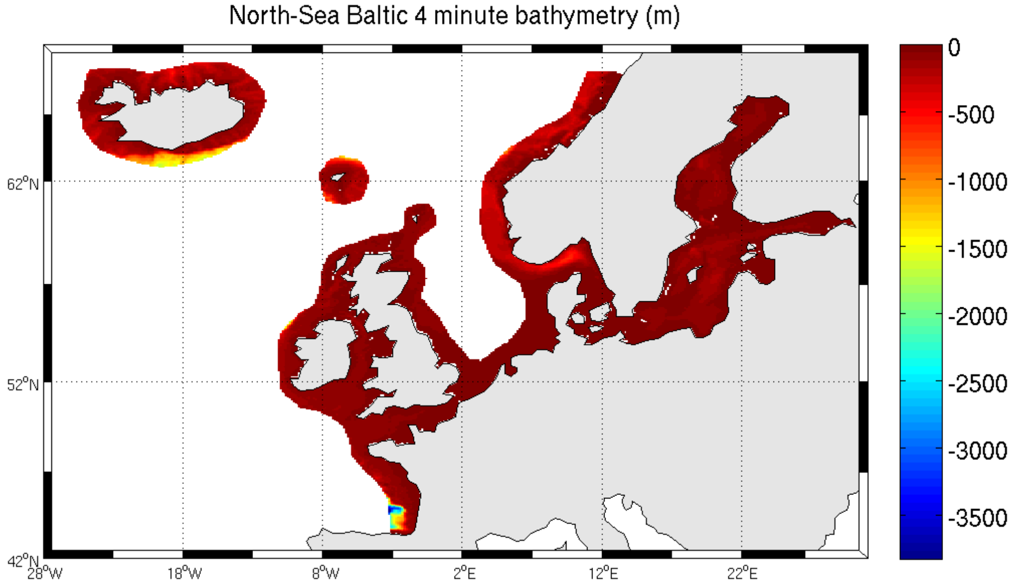

Figure 2.2: NOAA Wave Watch III 30-year Hindcast Phase 1 from the North Sea Baltic 4 min sub-grid (source: NOAA).

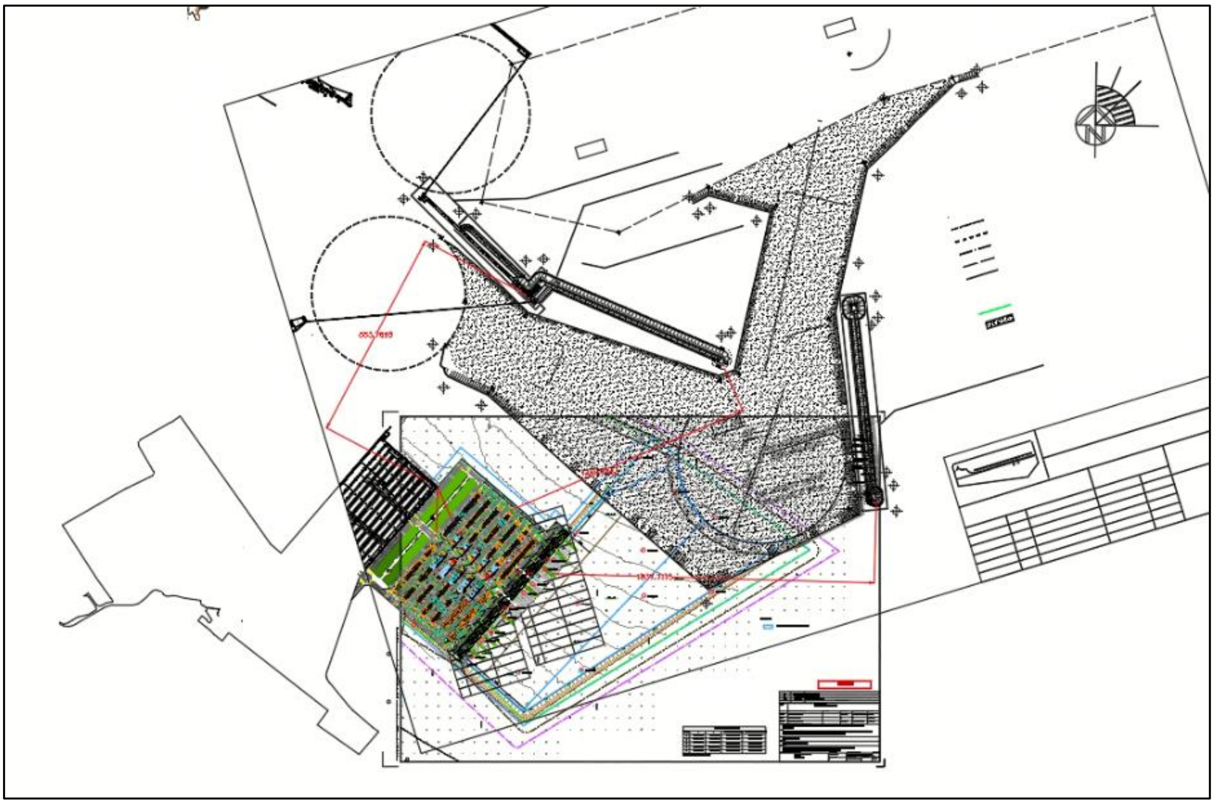

Figure 2.3: AutoCAD drawing of the port developments including the T3 terminal and dredge areas (source: DCT).

Figure 2.4: The 19 sampling locations used for sieve analysis of sediment.

3 Literature Review and Site Description

The Port of Gdańsk is located in the south of the Gulf of Gdańsk which is in the south of the Baltic Sea. The Gulf of Gdańsk is a waterbody that is formally shared between Poland and Russia. It is a north facing bay with a large sandspit (the Vistula Spit) across the western side of the mouth. The mouth of the Vistula River lies 14 km to the east of the port. It is the longest river of those received by the Baltic Sea (1,047 km) and the second largest by catchment area (183,176 km^2).

3.1 Wind and Waves

As part of this study, wind and wave records were extracted from a long-term 30-year wave model at a grid node corresponding to 54.8 N, 19.2 E (Figure 3.1) which is summarised in Figure 3.2 to Figure 3.4. Wind is observed to come from all directions though it is most commonly from the west and southwest with a speed typically less than 14 ms^{-1}. Some seasonality is seen in the wind climate with lighter winds observed from April to June. Wave directions are primarily from the northwest though northerly waves are also commonly observed. Other wave directions are observed, but considerably less frequently.

Significant wave heights (H_s) are typically less than 2 m with an associated peak period (T_p) less than 10s. Scatter plots show that H_s and T_p are strongly associated with wind speed and occasionally, though rarely, H_s exceeds 6 m associated with winds speeds greater than approximately 17 ms^{-1}. These large waves are associated with T_p of nearly 12 s and are from the north. These waves are associated with the largest fetch in the Baltic Sea for the Gulf of Gdańsk (approximately 600 km). It is expected that the wave characteristics at the study site in the southwest of the Gulf will be strongly affected by the large spit at the western entrance of the gulf and by the port infrastructure to the west of the study site.

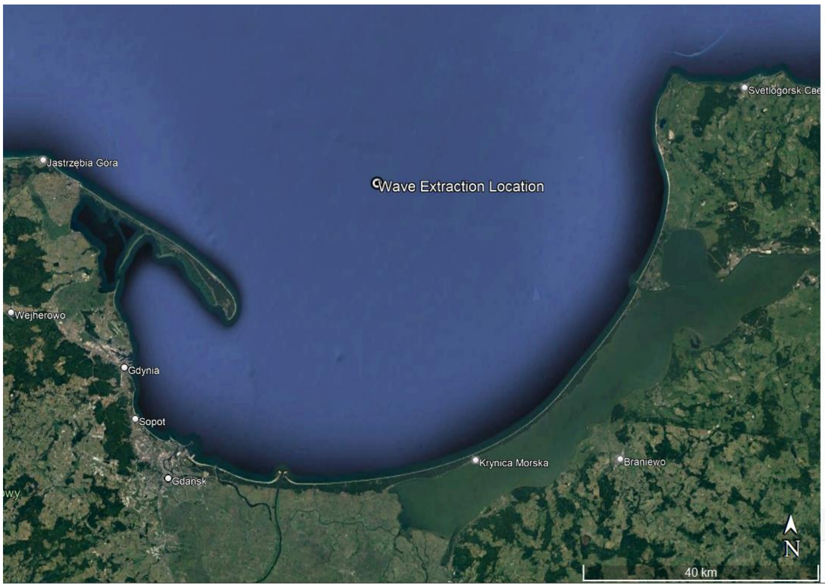

Figure 3.1: Wave model extraction location (54.8N, 19.2E) from the North Sea Baltic 4-minute model which is part of the NOAA Phase 2 wave watch 3 30-year hindcast.

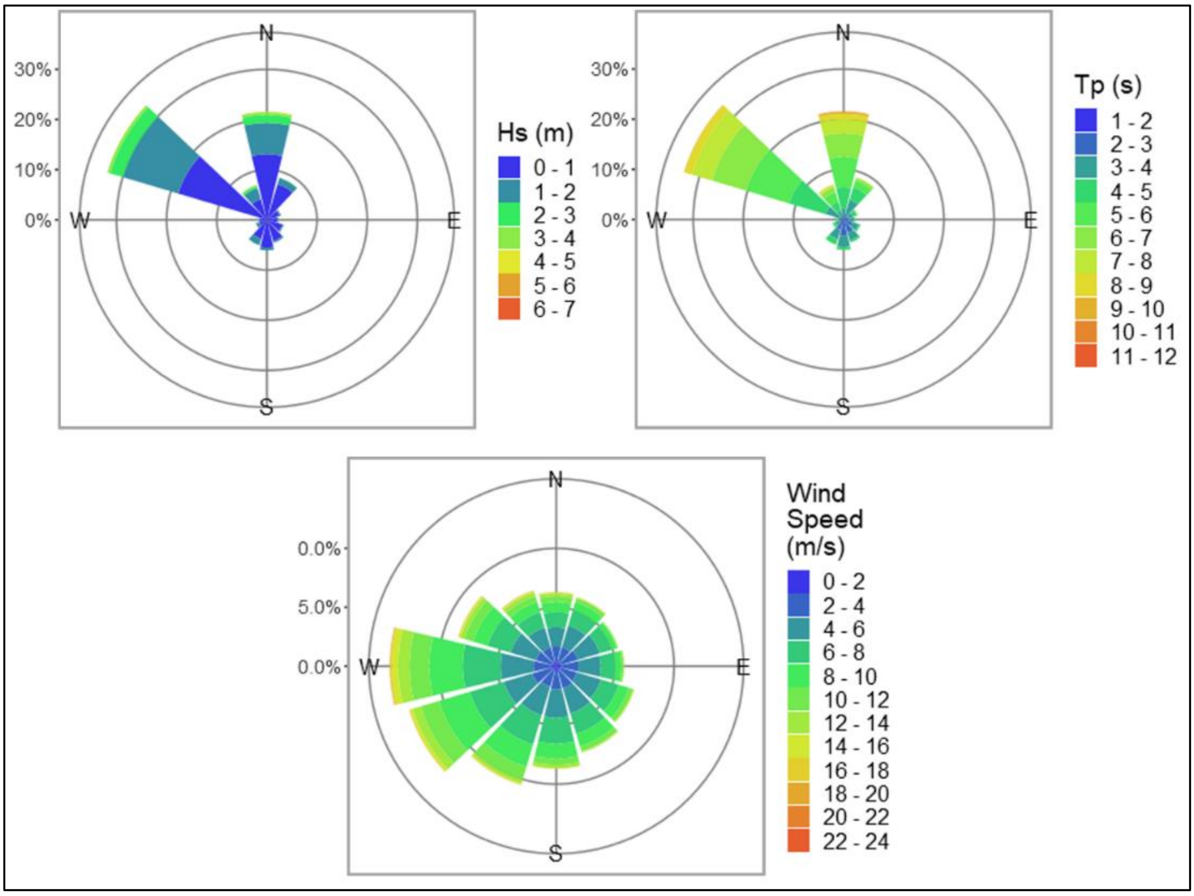

Figure 3.2: Wind and wave roses for 30-year data extracted from the North Sea Baltic 4-minute model which is part of the NOAA Phase 2 wave watch 3 30-year hindcast at a grid node located at 54.8N, 19.2E.

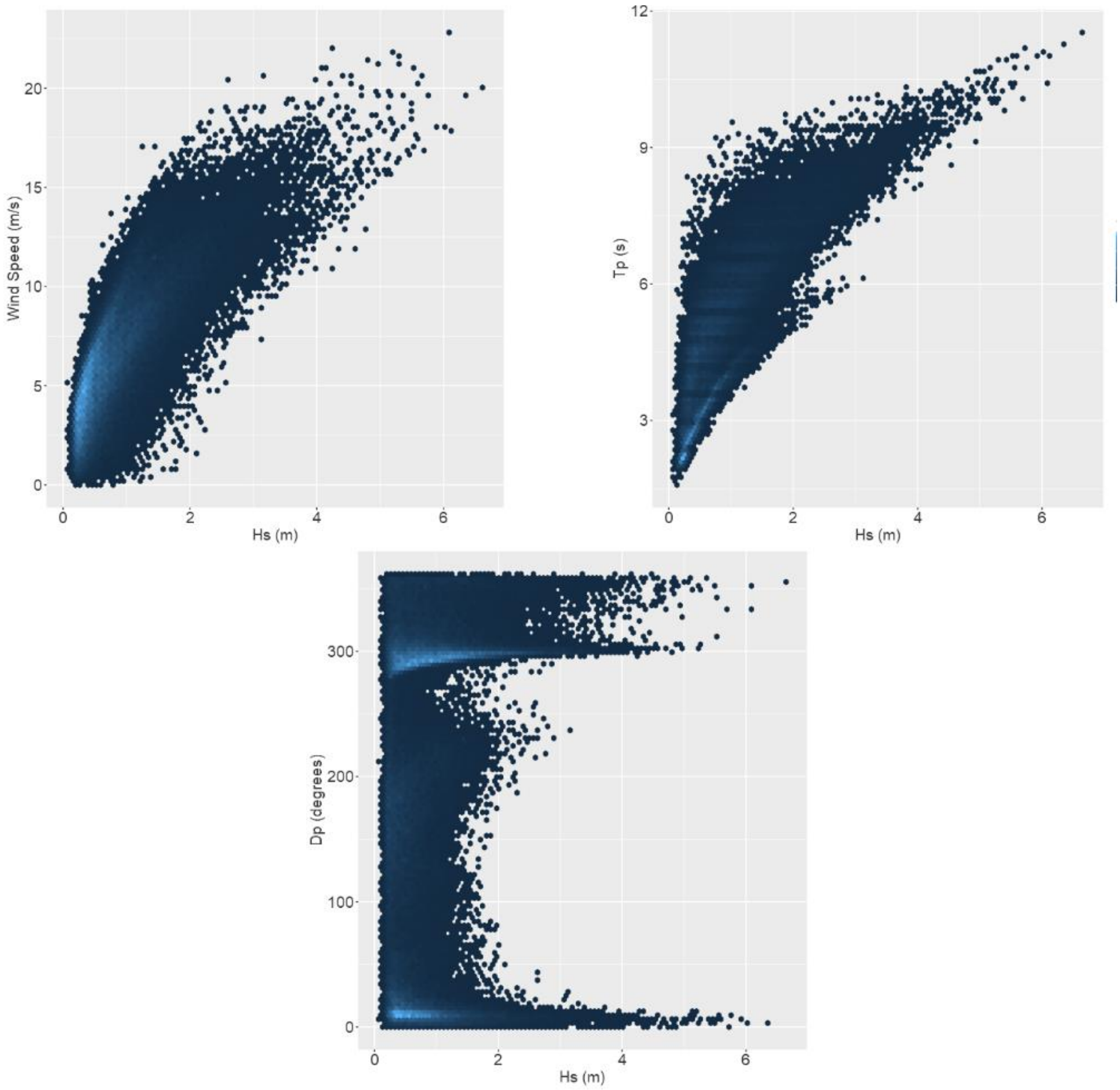

Figure 3.3: Wind and wave scatter plots for 30-year data extracted from the North Sea Baltic 4-minute model which is part of the NOAA Phase 2 wave watch 3 30-year hindcast at a grid node located at 54.8N, 19.2E.

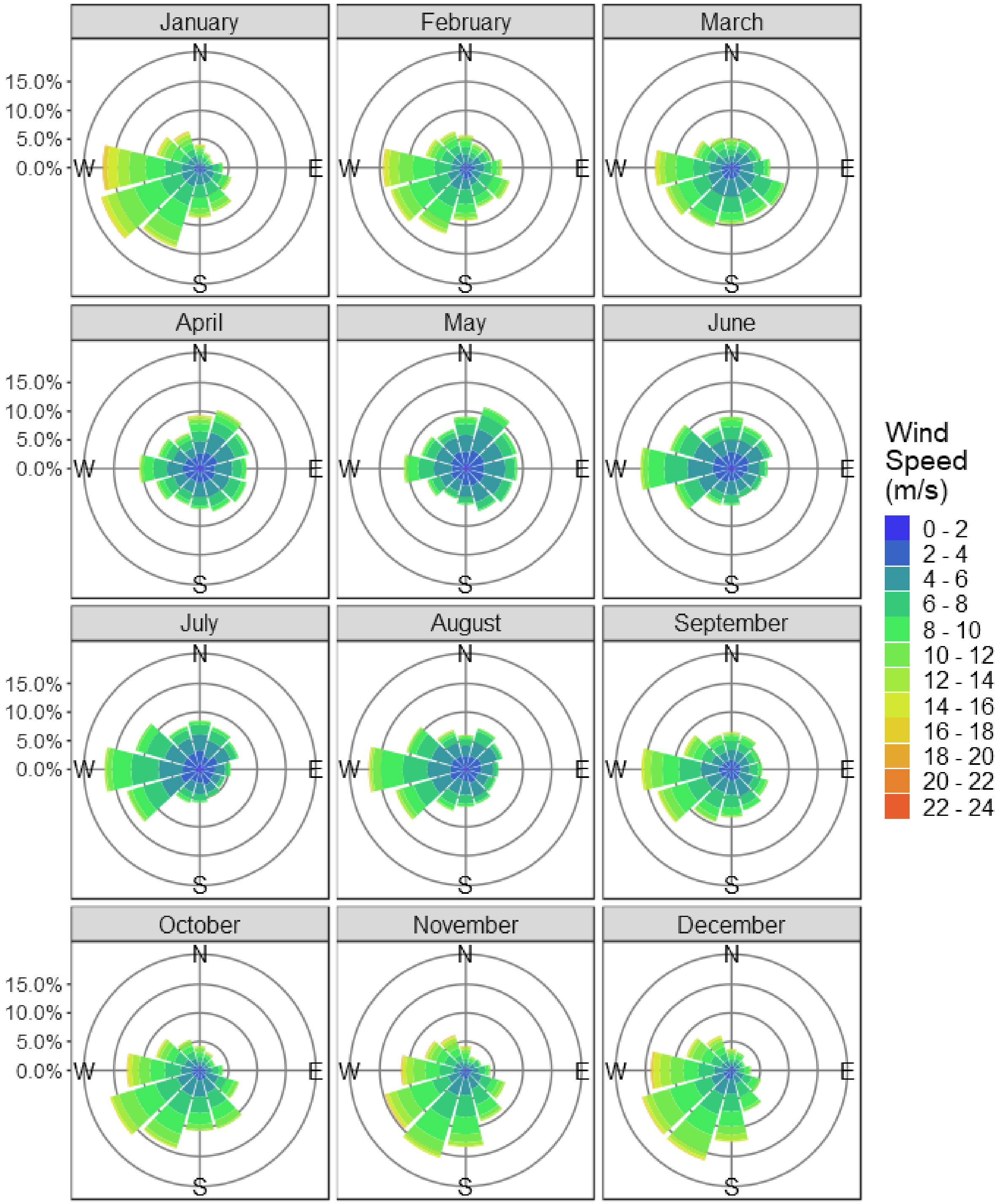

Figure 3.4: Wind roses by month for 30-year data extracted from the North Sea Baltic 4-minute model which is part of the NOAA Phase 2 wave watch 3 30-year hindcast at a grid node located at 54.8N, 19.2E

3.2 Sea Level

The tidal range in the Baltic Sea is very small due to the low connectivity with the North Sea. Overall, tidal ranges are mostly between about 0.02 m and 0.05 m although in the western sea areas, tidal ranges of up to 0.1 m and 0.3 m are observed (Weisse et al., 2021). Non-tidal sea level variability can be significant and maximum sea levels at the Port of Gdańsk of 0.38 m are observed with a return period of 1 year. This increases to 1.06 m and 1.20 m for 5- and 10-year return intervals respectively (Royal Haskoning DHV, 2020).

3.3 Water Quality

The mean Vistula River water discharge into the Gulf of Gdańsk is 1080 m^3 s^{-1}, with an average sediment suspension load of 14.6 mg L^{-1} which varies between 8 and 40 mg dm^{-3} (Damrat et al., 2013). According to Pruszak et al. (2005), the annual sediment load into the Gulf of Gdańsk ranges from 0.6 to 1.5 million m^3 of sediment.

Eutrophication is one of the greatest ecological threats to the Baltic Sea environment[5]. Eutrophication is the increase in the supply of organic matter to an ecosystem through nutrient enrichment and is induced by excessive availability of nitrogen and phosphorus for primary producers (algae, cyanobacteria and benthic macro-vegetation). Most of the nutrients in the Baltic Sea are delivered via freshwater sources (HELCOM, 2018). At the study site, the main source of these nutrients is likely to be the Vistula River which has the highest area specific nutrient loading in the Baltic Sea (HELCOM, 2021a). The input of total nitrogen from the Vistula River (118,000 t y^{-1}, on average) amounts to 15%, and the input of total phosphorus (7,000 t y^{-1}, on average) consists of 19% of the total riverine discharge into the Baltic Sea. The high contribution from the Vistula River is due to the nature of its drainage area, 60% of which is agricultural land. The Vistula River basin is inhabited by 20 million people, i.e. 27% of the entire population inhabiting the drainage area of the Baltic Sea. As a result of anthropogenic pressure, the ecosystem of the Gulf of Gdańsk has been subject to significant changes during the last 50 years. The Inspectorate of Environmental Protection (2020) has undertaken regular sampling of indicators of eutrophication in the Gdańsk Basin including phosphorus, nitrogen, chlorophyll a, water clarity and dissolved oxygen which it presents dating back to 2010. In general, nitrate concentrations have decreased over time while phosphates have increased. This study indicates that chlorophyll a has broadly decreased, though a HELOCM study (2018) indicates that is levels have not changed significantly. Water clarity has shown a slight negative trend. Near the study site monitoring indicates that the spring blossom continues to be the most intensive and higher chlorophyll a concentrations are recorded during this time than in summer. However, the total weight of phytoplankton in the bay in summer is very large (Atkins, 2014).

In terms of bathing water quality, during the last ten years, several sewage treatment plants have been constructed. As a result of this effort, only 20% of the Polish coast of the Gulf of Gdańsk is unavailable for bathing; this is in comparison to the fact that all beaches were closed in the 1980s (Andrulewicz and Witek, 2002). However, Stogi Beach has been rated as having excellent/very good water quality for bathing in recent years.

Marine litter is a considerable and growing problem worldwide. In 2015, a 3-year pilot program for monitoring waste in the marine environment of the southern Baltic Sea was implemented at several locations along the Polish Baltic Sea coastline (see Figure 3.5) (Inspectorate of Environmental Protection, 2020). Since 2018, regular monitoring of waste collected on the shoreline, floating on the water surface and on the seabed has been carried out. While results vary from year to year, the 2020 survey shows that the largest amount of waste was found in Gdańsk (Figure 3.6).

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[5] http://stateofthebalticsea.helcom.fi/pressures-and-their-status/eutrophication/

Figure 3.5: Locations of waste surveys. (Source: Inspectorate of Environmental Protection, 2020).

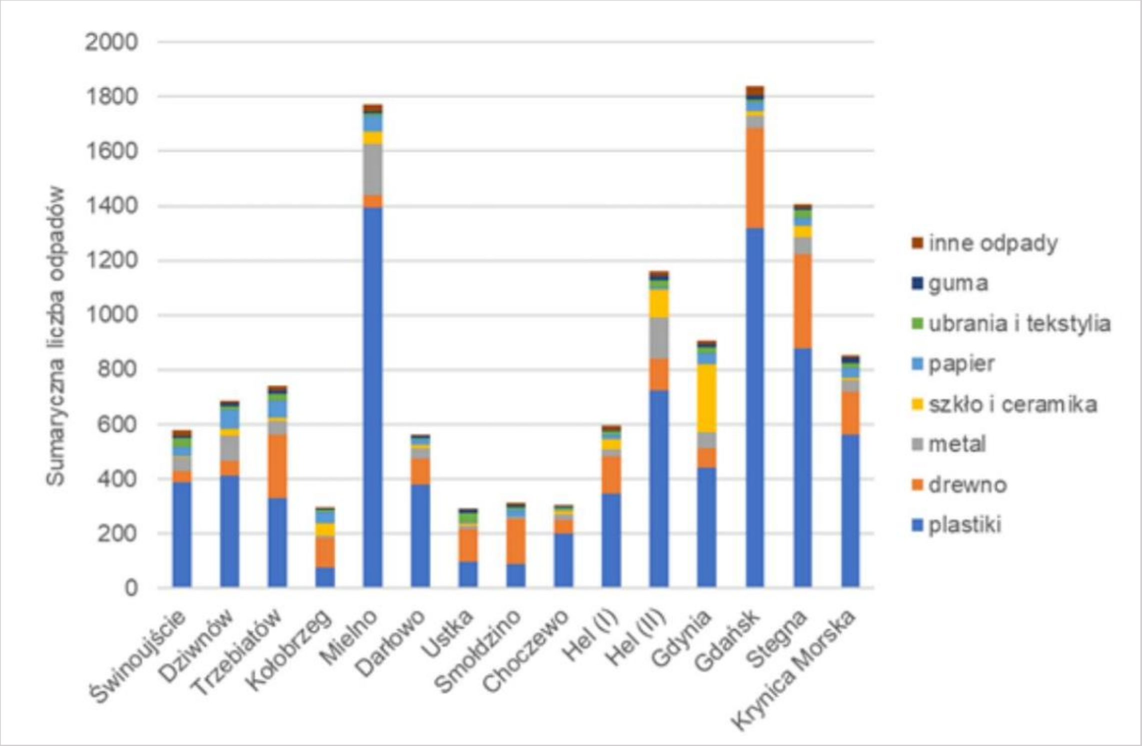

Figure 3.6: Total number of waste items (from four study periods) recorded on individual sections in seven main categories in 2020. The largest number of waste items were found at Gdańsk in 2020. (Source: Inspectorate of Environmental Protection, 2020).

3.4 Climate Change

3.4.1 Waves

A study of climate change effects on wave climate by Bonaduce et al. (2019) predicted only small changes in wave height in the Gulf of Gdańsk by the end of the 21st century (2075-2100) (Figure 3.7). These results show a slight reduction (between 5% and 10%) in winter and little change in summer. HELCOM (2021b) reports that changes in Baltic Sea wave climate are strongly linked to changes in wind climate and are highly uncertain. There is high confidence on reduced ice cover which may increase fetch, and perhaps change the wave climate. By 2100, changes in significant wave height are projected to be around 5% higher than today, particularly in the north and east of the Baltic Sea. However, such changes are superimposed by substantial multi-decadal and inter-simulation variability and are not conclusive.

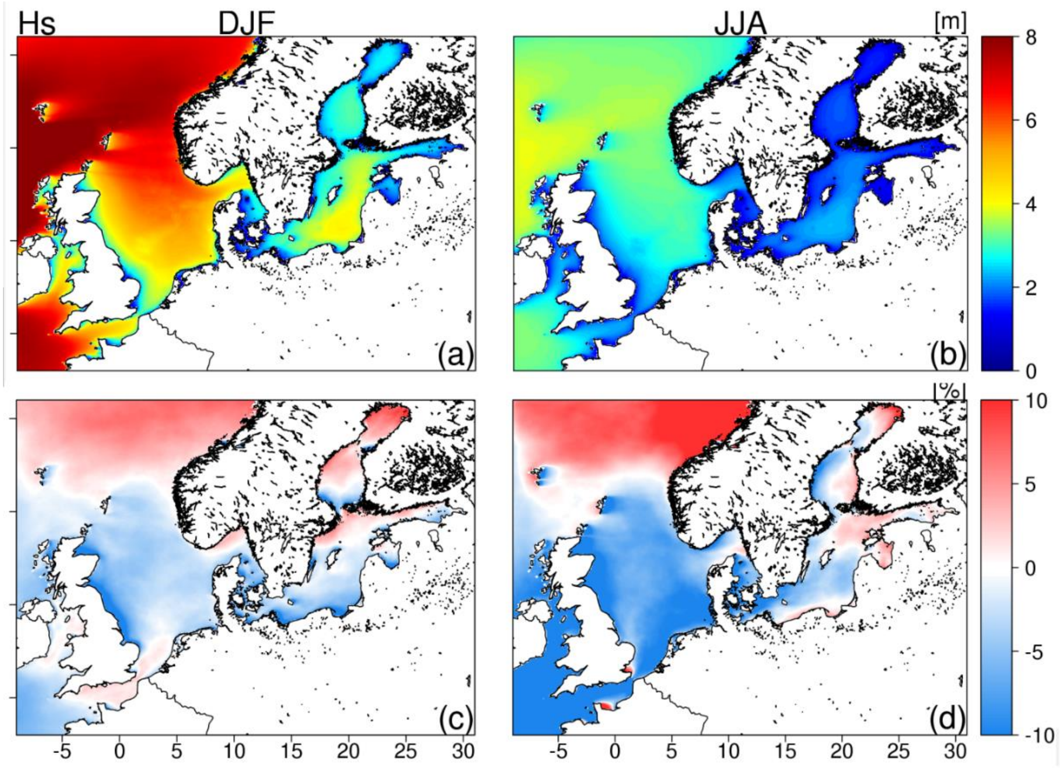

Figure 3.7: Mean future significant wave height (top) during winter (DJF) and summer (JJA) and difference with present day wave climate (bottom) (source: Bonaduce et al.,2019)

3.4.2 Sea Level

Global sea level rise will accelerate. Current projections estimate Baltic Sea level rise to about 87% of the global rate. Estimates for global mean sea level rise by 2100 are 43 cm (RCP2.6) to 84 cm (RCP8.5). The likely ranges for these estimates are 29 to 56 cm (RCP2.6) and 61 to 110 cm (RCP8.5) HELCOM, (2021b).

3.4.3 River runoff

HELCOM, (2021b) reports that no statistically significant change in total annual river runoff has been detected during the last centuries and the large decadal and regional variations occur. In the northern Baltic Sea and the Gulf of Finland, larger river runoff is statistically associated with warmer air temperature and increased precipitation, while further south, decreased annual runoff is associated with rising air temperatures. Over the 20th century, winter discharge has increased, while spring floods have decreased.

The total runoff to the Baltic Sea has been projected to increase from present day by 2-22% with warming temperatures. The increase will take place mostly in the North, with potentially decreasing total runoff in the South while winter runoff will increase due to intermittent melting. On average rivers terminating in the southeast of the Baltic Sea will likely experience a reduction in discharge of approximately 18.25% by 2081 to 2100 (Šarauskienė et al., 2017).

3.4.4 Nutrient Loading of Rivers

Projections suggest that river discharge will decrease in the southern Baltic Sea region thus potentially decreasing waterborne nutrient inputs, respectively (HELCOM, 2021b).

3.4.5 Wind

Projected changes in wind climate are highly uncertain due to large natural variability in the Baltic Sea area. Climate model simulations project a slight but significant wind speed increase in autumn and a decrease in spring (HELCOM, 2021b).

4 Model Scenarios

The numerical modelling components considered three scenarios:

4. The **Previous** scenario: the port layout prior to 2020 with T1 and T2 in place but without the breakwater extensions that were built in 2020. None of the proposed dredging is included in this scenario.
5. The **Present** scenario: the port layout as it is currently with T1 and T2 in place and with the breakwater extensions in place as well as the dredging associated with the approach channel and turning circles.
6. The **Future** scenario: the same as the Present scenario with the addition of the T3 development including dredging of the T3 berthing area.

The scenarios are shown graphically in Figure 5.2.

The ‘Previous’ scenario has been undertaken since the breakwater extensions were constructed recently (2020) and they are expected to have a significant impact on Stogi Beach incident wave climate and sediment transport. A comprehensive assessment of the expected changes to waves and sediment transport due to the T3 development needs to account for the effects of the breakwater extensions in isolation.

5 Beach Morphology

A beach morphology evolution study has been carried out to understand the effects of the T3 development on the local sediment transport regime.

5.1 Methods

This study has been undertaken in three stages:

1. **Historical Shoreline Analysis** using satellite imagery to identify trends in accretion and erosion along Stogi Beach.
2. **Long Term Wave Modelling** to provide a wave record at the study site with and without developments in place.
3. **Sediment Transport Modelling** to understand the changes in the sediment transport regime along Stogi beach with and without developments in place.

For the beach morphology modelling, an additional scenario was included to investigate the effects of climate change which uses the same parameterisation as the *Future* scenario but with incident wave energy reduced by 10% in line with conservative predictions from Bonaduce et al. (2019).

5.1.1 Historical Shoreline analysis

Shoreline analysis was undertaken by examination of historical satellite photography. Imagery was sourced from the Google Earth historical archive and from the Landsat database[6]. Imagery was collated to provide coverage of the whole of Stogi Beach with emphasis on the western end towards the T1 terminal.

The Google Earth imagery provides high resolution but sporadic coverage of the beach from 2008 to 2018. No full coverage Google Earth images of Stogi Beach were available beyond 2018. Landsat imagery was collated from between 1986 and 2020 at varying resolutions. Even at the highest resolution of 10 m, it was not of sufficient quality to make reliable measurements of beach width, though it was useful for identifying construction timelines for local coastal infrastructure.

Beach width was assessed at 14 locations (Figure 5.1) over 24 images and the results are presented in Table 5.2. The first measurement location was chosen at a location 100 m east of the T1 terminal. Examination of the imagery showed this to be a stable location away from the intermittent variable erosion and accretion at the edge of the T1 rock revetment. Subsequent transects were located every 300 m thereafter. Results for this analysis are presented in Section 5.2.1.

Note that these erosion/accretion measurements have been made in the absence of the extra breakwater infrastructure which was built in 2020. The timing of this construction was found by examination of Landsat imagery. The presence of these breakwaters and of the T3 terminal are likely to further change the sediment transport regime in this area.

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[6] https://www.usgs.gov/landsat-missions

Figure 5.1: Beach width measurement locations used to assess historical changes in the width Stogi Beach.

5.1.2 Long Term Wave Modelling

Wave modelling was undertaken using the SWAN wave model (Holthuijsen et al., 2004) which is an industry standard for simulating wave generation and propagation. SWAN is a third-generation ocean wave propagation model which solves the spectral action density balance equation for frequency-directional spectra.

The model setup used a 3-stage nested bathymetry scheme shown in Figure 5.2. Note the large raised bathymetric feature offshore from the eastern end of the beach. The dimensions for each grid are presented in Table 5.1. The nesting scheme allows for increasing model resolution with proximity to the study site. Wave conditions were specified on the northern boundaries using H_s, T_p and D_p extracted from the NOAA Wave Watch III 30-year Hindcast (Section 3.1) at 19.200 E, 54.933 N. Winds were extracted from the same model at 19.200 E, 54.667 N. The 30-year wave hindcast was forced through the model for the 3 model scenarios providing detailed wave conditions at the study site. No measured wave data were available with which to calibrate the wave model and standard settings were used for model parameterisation. Model results are presented in Section 5.2.2.

Table 5.1: Specifications of the SWAN model grids used in this project.

	nx	ny	Cell size (m)
Grid 1	107	69	1000
Grid 2	111	66	200
Grid 3	176	141	40

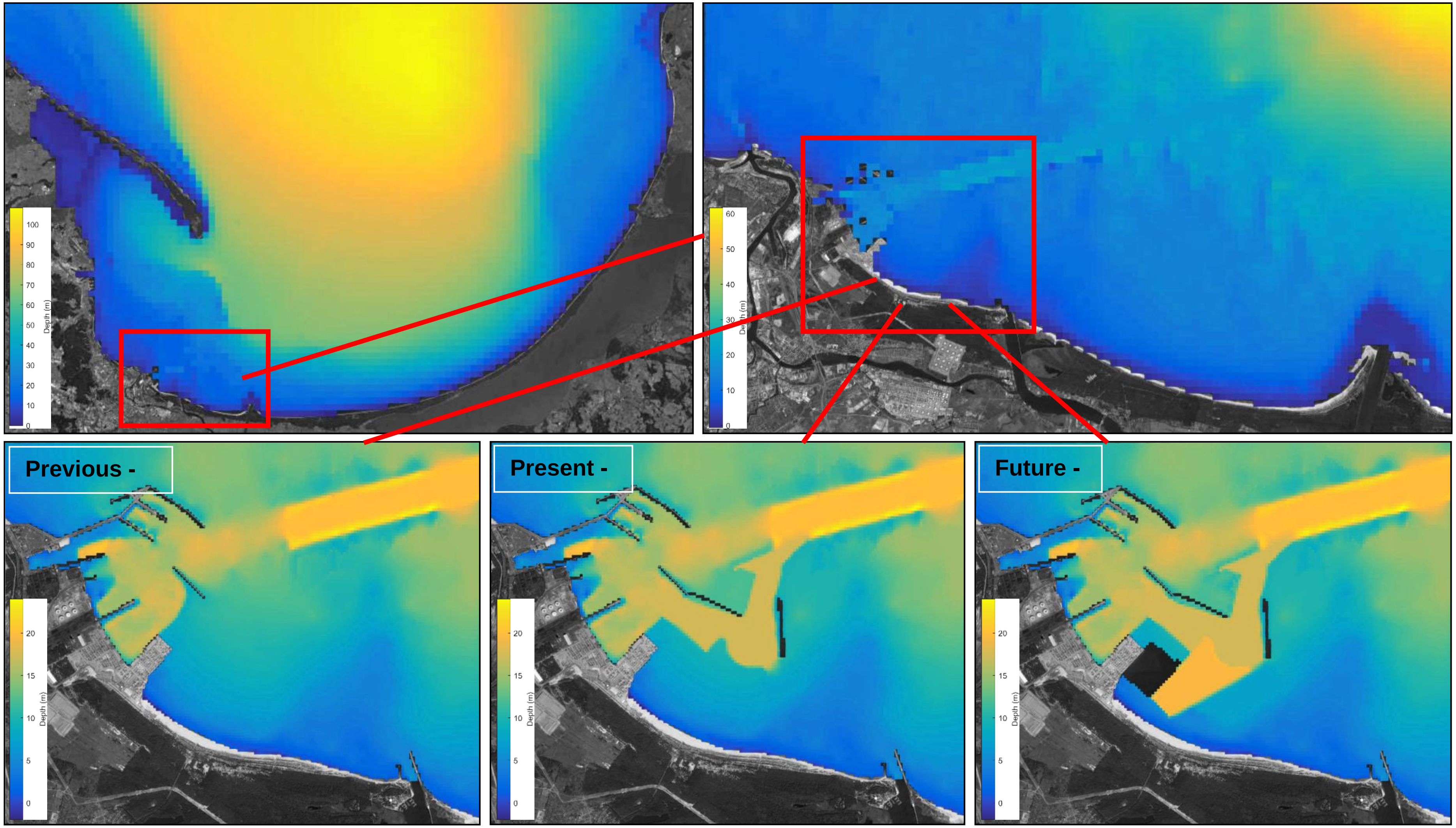

Figure 5.2: SWAN bathymetry grids used in the wave modelling study for the three scenarios.

5.1.3 Beach Morphology Modelling

Beach morphology was modelled using a one-line modelling approach. One-line models are 1-dimensional and they assess longshore sediment flux based on an isobath-normal topography/bathymetry transect. The wave climate was extracted from the long-term wave model at the offshore end of the transects. The wave characteristics extracted from the model were significant H_s, T_p and D_p. The wave record was binned to create a table of representative wave conditions for each transect. These were used as boundary conditions for the model.

For this study we used the GENIUS sediment transport model. GENIUS predicts refraction, breakpoint wave conditions and longshore sediment transport on beaches. It is similar to its well-known counterpart GENESIS (Hanson and Kraus, 1989) but with some extra features including frictional attenuation of wave height and a physics-based treatment of wave transmission across submerged reefs.

The sediment grain size was determined from a survey of Stogi Beach sands undertaken as part of this study (see Section 2). The analysis sampled beach sediment at 19 locations along the beach and showed a very uniform grain size. The average D_{50} grain size across the 19 sampling locations was 0.386 mm.

The one-line model was applied at the 14 locations that were analysed in the historical shoreline analysis (Section 5.1.1). Cross-shore transects at these locations are shown in Figure 5.3. Each transect extends out to the 7 m isobath except for Transects 1 and 2 which are truncated to accommodate the T3 reclamation in the *Future* scenario.

The output from the one-line model is the total along-shore sediment transport rate at discrete points on each transect. Sediment transport rates were aggregated over the time series of wave conditions to calculate the net transport rate over the model period. The model output quantifies the overall magnitude and direction of sediment transport for each transect.

Using the results from the '*Previous'* scenario, a relationship was established between the accretion and erosion rates from the historical shoreline analysis and the modelled sediment transport rates at each transect. This relationship was then used to predict shoreline evolution in the '*Present'* and '*Future'* scenarios. Beach morphology model results are presented in Section 5.2.3.

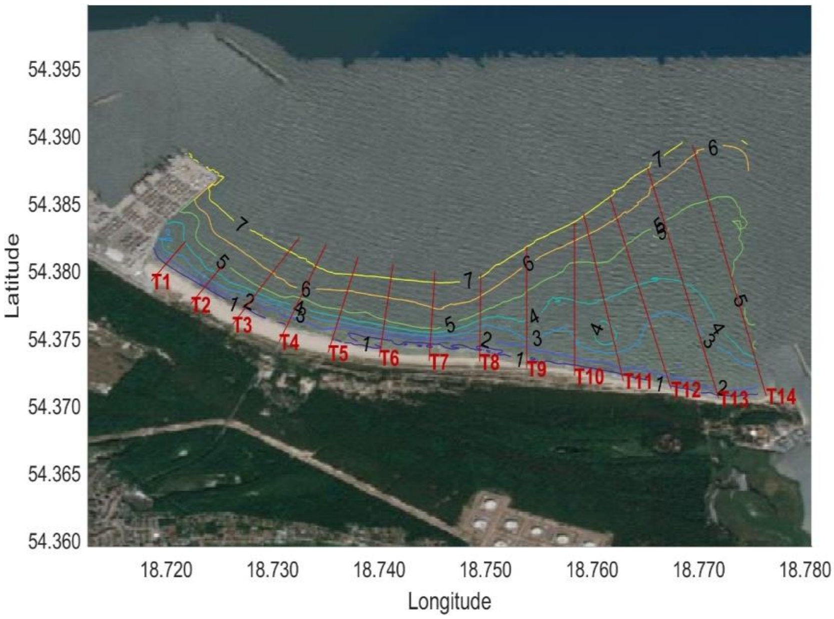

Figure 5.3: Transects for used in the one-line sediment transport modelling superimposed on a bathymetric map. 'T' in the legend here indicates 'Transect'.

5.1.4 Limitations

Historical shoreline analysis was undertaken based only on available historical imagery. If more up to date imagery had been available, it would have been beneficial to analyse the shoreline change since the construction of the additional breakwater structures in 2020. It would also have been useful to have had additional data to understand the change in beach morphology prior to the construction of the T1 terminal.

The boundaries of the wave model used wave parameters (H_s, T_p and D_p) rather than spectral wave boundaries. While spectral boundaries are generally preferable, in this instance wave energy distribution is almost always unimodal due to the fetch limiting characteristics of the Baltic Sea and this reduces the need for spectral boundaries.

One-line wave models do not simulate complex current patterns generated by wave propagation (e.g. rip cells). Nonetheless, Stogi Beach is reasonably straight and uniform therefore it is appropriate for use with a one-line model.

Extrapolating shoreline changes into the future does not account for the changing bathymetric orientation relative to the angle of wave attack. The orientation of the shoreline usually alters over time to be perpendicular to the angle of wave attack at which time a state of equilibrium is reached. For this reason, caution should be applied when extrapolating shoreline change results far into the future.

Measured erosion and accretion rates on Stogi beach indicate that there is net accretion of sediment along the beach and that the beach is likely being nourished by sand from further offshore and this may be connected to the large shallow bathymetric feature offshore from the eastern end of the beach. This extra source of sediment is not included in the one-line model.

No calibration data were available for the long-term wave model. Normally comparison of the model with measured data is an industry standard for wave modelling. However, the wave climate at this location is reasonably simple compared with locations in the open ocean where long period swells coexist with locally generated wind swells.

Berthed ships were not included in the modelling. While it is expected that they will lead to some attenuation of wave energy, they are unlikely to strongly influence the sediment transport regime.

Beach morphology was based on wave driven effects. Aeolian (wind driven) sediment transport was not included in the model.

5.2 Sediment Transport Modelling Results

This section presents the results from the historical shoreline analysis, long term wave modelling and sediment transport modelling.

5.2.1 Historical Shoreline Analysis

Examination of the Google Earth images provides reasonably high resolution (approximately 1 m by 1 m) imagery of Stogi Beach. This imagery was used for examination of beach width evolution between 2008 to 2018. The images are shown for the western end of Stogi beach in Figure 5.9 to Figure 5.11. A zoomed-out version of the same imagery covering Stogi Beach in its entirety is presented in Appendix A. The archive also contains one image from 1985 which shows that the beach was considerably narrower prior to the construction of T1, noting that this image predates the 2005 construction of the T1 terminal by some 20 years.

Through analysis of the imagery, ephemeral bars were observed to occasionally form along the mid-section of Stogi Beach (example in Figure 5.5). The bars often form at an oblique angle to the coastline and are occasionally emergent.

The evolution of beach width over time is shown in Figure 5.6. Results presented here divide the beach into the western, central and eastern sections as depicted in Figure 5.4. There is evidence of ongoing accretion at the western end of the beach (west of Transect 6) throughout the images between 2008 and 2018. The centre and east of centre of the beach (Transect 7 to Transect 11) has shown a trend of ongoing erosion. This erosional trend has been proportionally smaller than the accretion in the west. Apart from fluctuations, the far eastern end of Stogi Beach (Transect 12 to Transect 14) has been reasonably stable (Appendix A) through the analysis period.

Figure 5.4: Stogi Beach to the east of the Port of Gdańsk. The labels provide the naming convention used throughout this report. 'T' in the legend here indicates 'Transect'.

For each transect linear regression was used to calculate the change in beach width per year for each measurement location. An example of this is shown in Figure 5.7 for Transect 1. In this instance the beach is accreting at a rate of 3.4 m/year (95% confidence interval 2.66 to 4.15 m/year). The largest erosion rate (-2.36 m/year) is seen at Transect 8. Beach erosion and accretion rates are summarised in Table 5.3. The regression plots for all the transects are presented in Appendix B.

While considerable accretion has been seen on the western end of Stogi Beach over the available 10-year record of satellite images, proportional erosion has not been seen at the centre and east of centre of the beach. This indicates that there is a source of sediment that is adding to the total volume of beach sand though the source of this additional sediment is not immediately clear. The sediment transport is predominantly from east to west (this in confirmed in later sediment transport modelling – Section 5.1.3). The training walls at the mouth of the Marta Wisla (east) appear to block sediment transport from the east; however, no filet of sand is observed against the eastern training wall (see Figure 5.8) indicating firstly that east to west sediment transport is not significant to the east of the wall and secondly that sand does not bypass the wall in a significant quantity in the nearshore. It is therefore most likely that the additional sediment on Stogi Beach builds up through cross-shore transport (i.e. accretion of sand moved ashore from deeper water offshore). It is possible that the source of this additional sediment is the raised bathymetric feature offshore from the eastern end of the Stogi Beach.

Figure 5.5: Ephemeral emergent bars that observed along the central section of Stogi Beach.

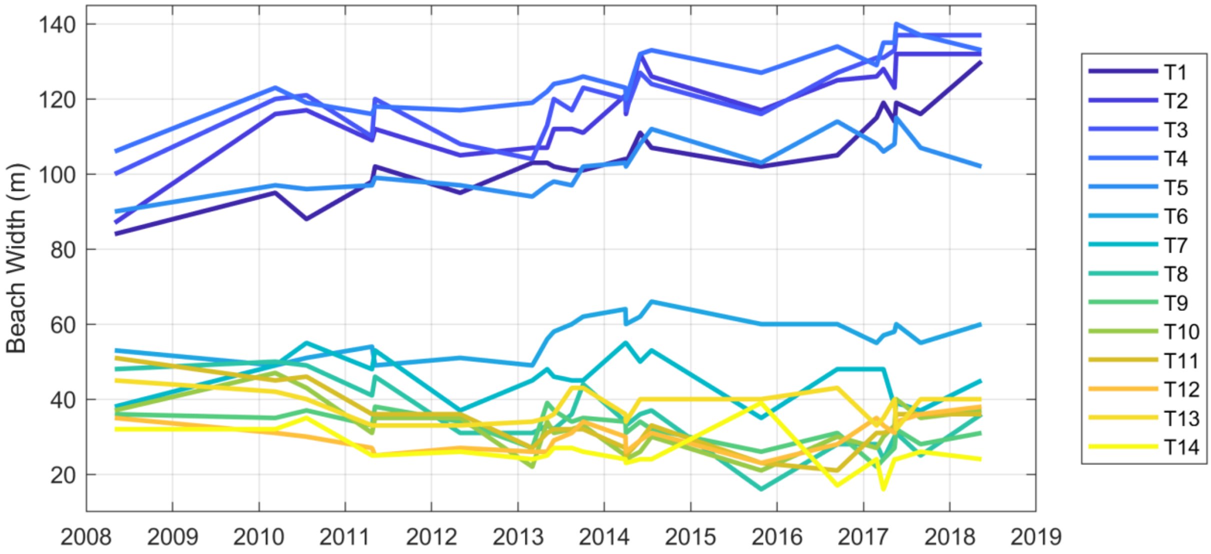

Figure 5.6: Beach width over time at the 10 transects. 'T' in the legend here indicates 'Transect'.

Table 5.2: Measured beach widths at the 14 measurement locations (see Figure 1.1).

Date	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
15/12/1985	25	37	67	90	82	43	42	36	75	67	76	88	116	49
1/05/2008	84	87	100	106	90	53	38	48	36	37	51	35	45	32
11/03/2010	95	116	120	123	97	49	49	50	35	47	45	31	42	32
21/07/2010	88	117	121	119	96	51	55	49	37	43	46	30	40	35
24/04/2011	98	109	110	116	97	54	48	41	33	31	36	27	33	25
7/05/2011	102	112	120	118	99	49	53	46	38	35	36	25	33	25
1/05/2012	95	105	108	117	97	51	37	31	34	35	36	27	33	26
2/03/2013	103	107	104	119	94	49	45	31	27	22	27	26	34	24
4/05/2013	103	107	113	122	97	56	48	33	39	34	31	26	35	25
1/06/2013	102	112	120	124	98	58	46	32	37	31	32	29	36	27
16/08/2013	101	112	117	125	97	60	45	36	34	32	32	31	43	27
3/10/2013	101	111	123	126	102	62	45	44	35	33	32	34	43	26
31/03/2014	104	121	120	123	103	64	55	34	34	25	27	30	36	24
2/04/2014	103	116	117	120	102	60	55	33	31	24	25	26	34	23
1/06/2014	111	132	127	132	108	62	50	36	34	26	29	29	40	24
19/07/2014	107	126	124	133	112	66	53	37	32	30	33	31	40	24
26/10/2015	102	117	116	127	103	60	35	16	26	21	23	23	40	39
12/09/2016	105	125	127	134	114	60	48	28	31	30	21	28	43	17
25/02/2017	115	126	131	129	108	55	48	28	22	27	31	35	33	24
26/03/2017	119	128	131	135	106	57	48	24	24	30	31	33	35	16
12/05/2017	114	123	133	135	108	58	38	30	27	33	32	31	40	24
19/05/2017	119	132	137	140	115	60	39	31	32	40	36	34	32	24
30/08/2017	116	132	137	137	107	55	37	25	28	35	36	36	40	26
15/05/2018	130	132	137	133	102	60	45	36	31	37	36	38	40	24

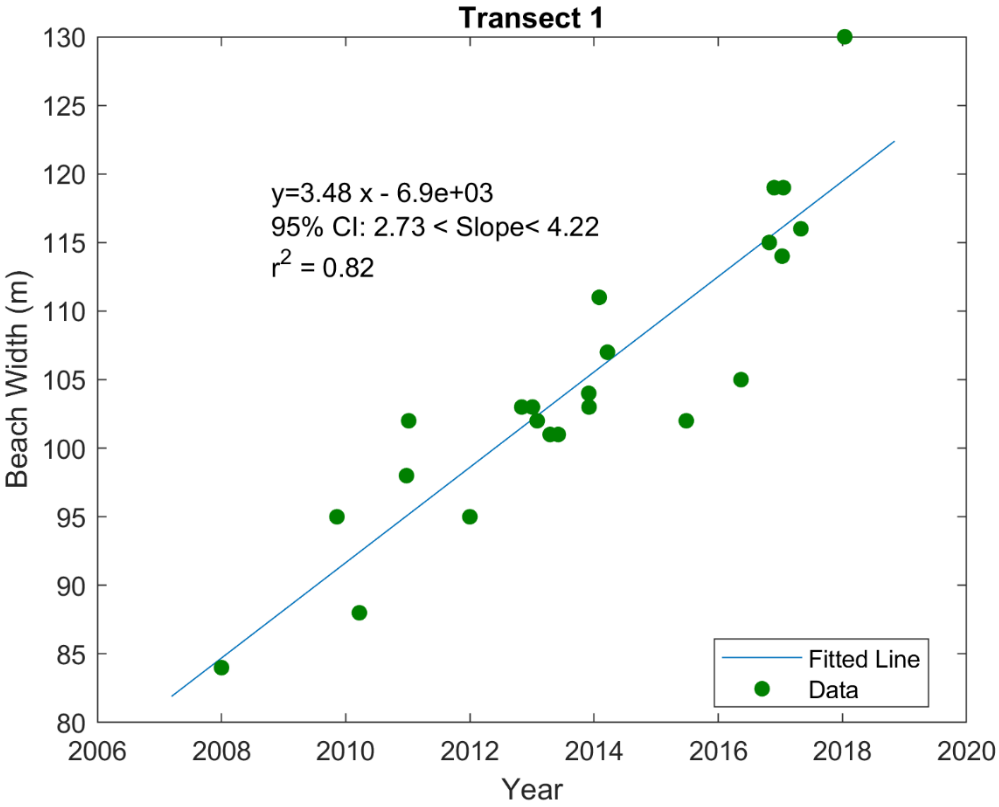

Figure 5.7: Linear regression relating beach width to time. The slope of the line (3.4) indicates the rate of change of beach width in meters per year. The '95% CI' provides a 95% confidence interval around the slope.

Table 5.3: Erosion and accretion rates at each transect considered in this study.

	Rate (m/year)	95% lower	95% upper
Transect 1	3.48	2.73	4.22
Transect 2	3.28	2.19	4.38
Transect 3	3.02	1.98	4.06
Transect 4	2.68	2.04	3.33
Transect 5	1.88	1.19	2.57
Transect 6	0.94	0.24	1.64
Transect 7*	-0.53	-1.54	0.48
Transect 8	-2.36	-3.30	-1.43
Transect 9	-1.13	-1.69	-0.57
Transect 10	-0.73	-1.74	0.29
Transect 11	-1.50	-2.46	-0.54
Transect 12*	0.48	-0.14	1.10
Transect 13*	-0.17	-0.84	0.50
Transect 14	-0.89	-1.62	-0.16

*Confidence intervals bound 0 so likely no trend.

Figure 5.8: The mouth of the Marta Wisla showing no notable fillet on the eastern training wall.

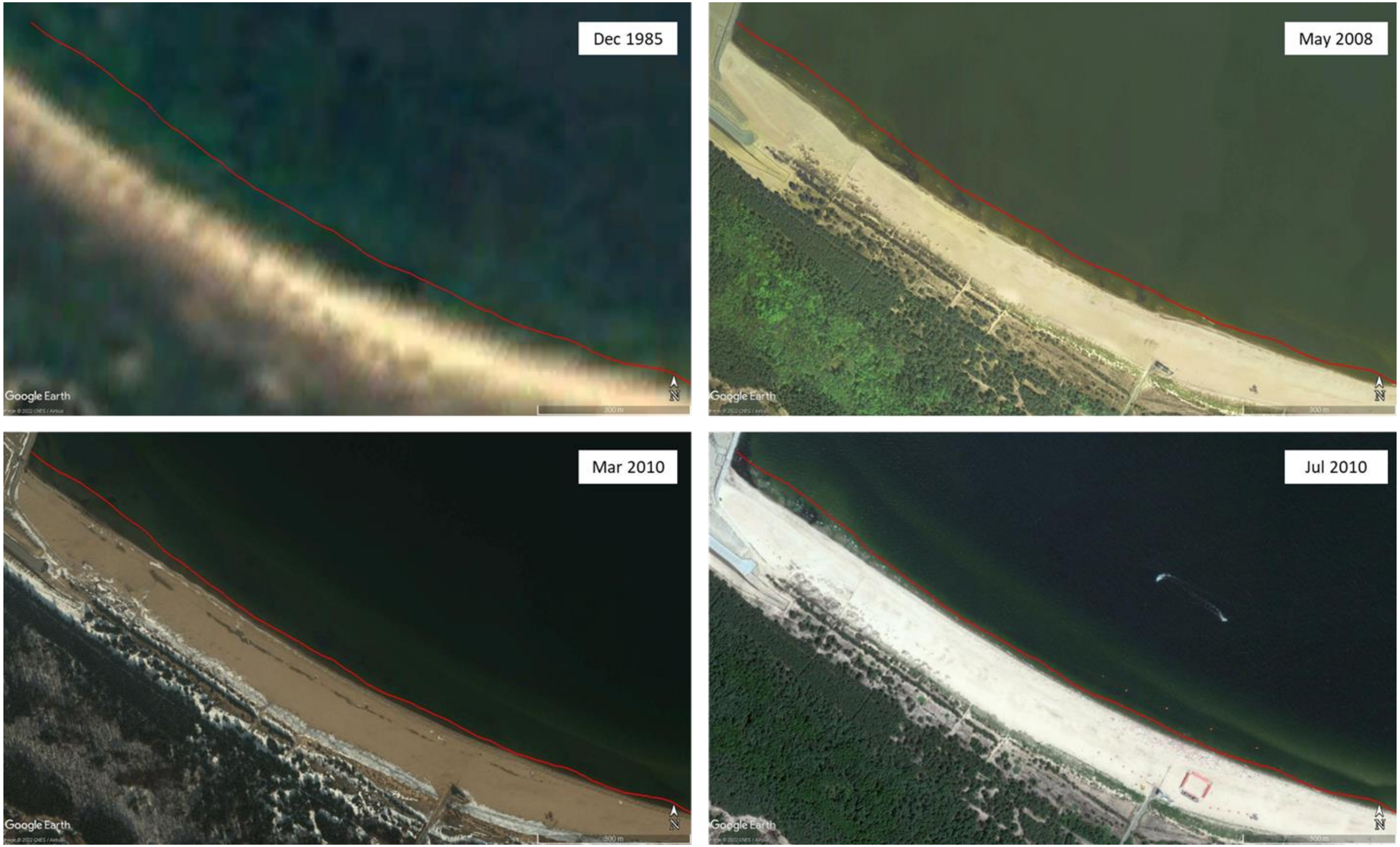

Figure 5.9: The evolution of the western end of the Stogi Beach shoreline. The red line indicates the shoreline in May 2018 for comparison. Source: Google Earth.

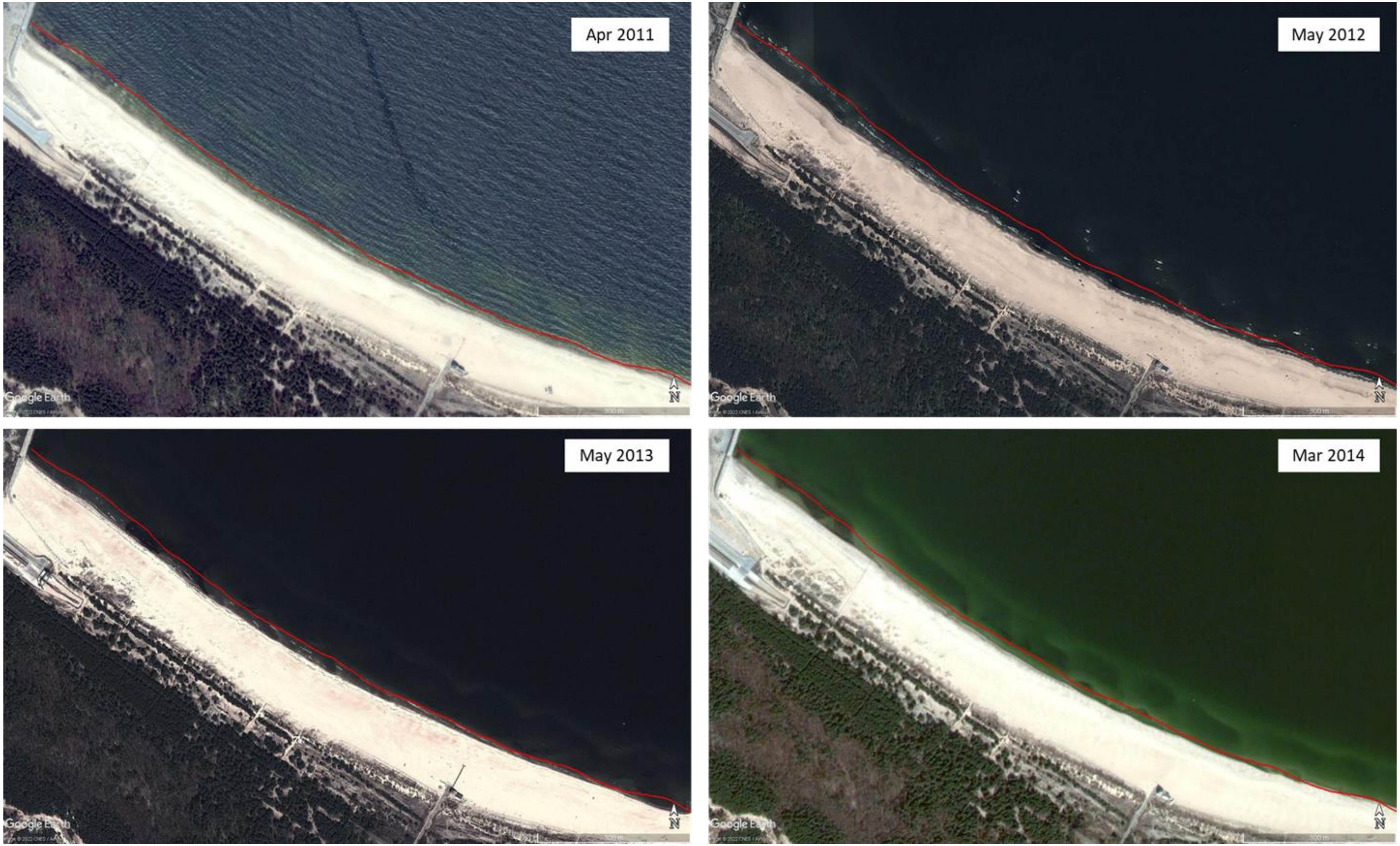

Figure 5.10: The evolution of the Stogi Beach shoreline at the western end. The red line indicates the shoreline in May 2018 for comparison. Source: Google Earth.

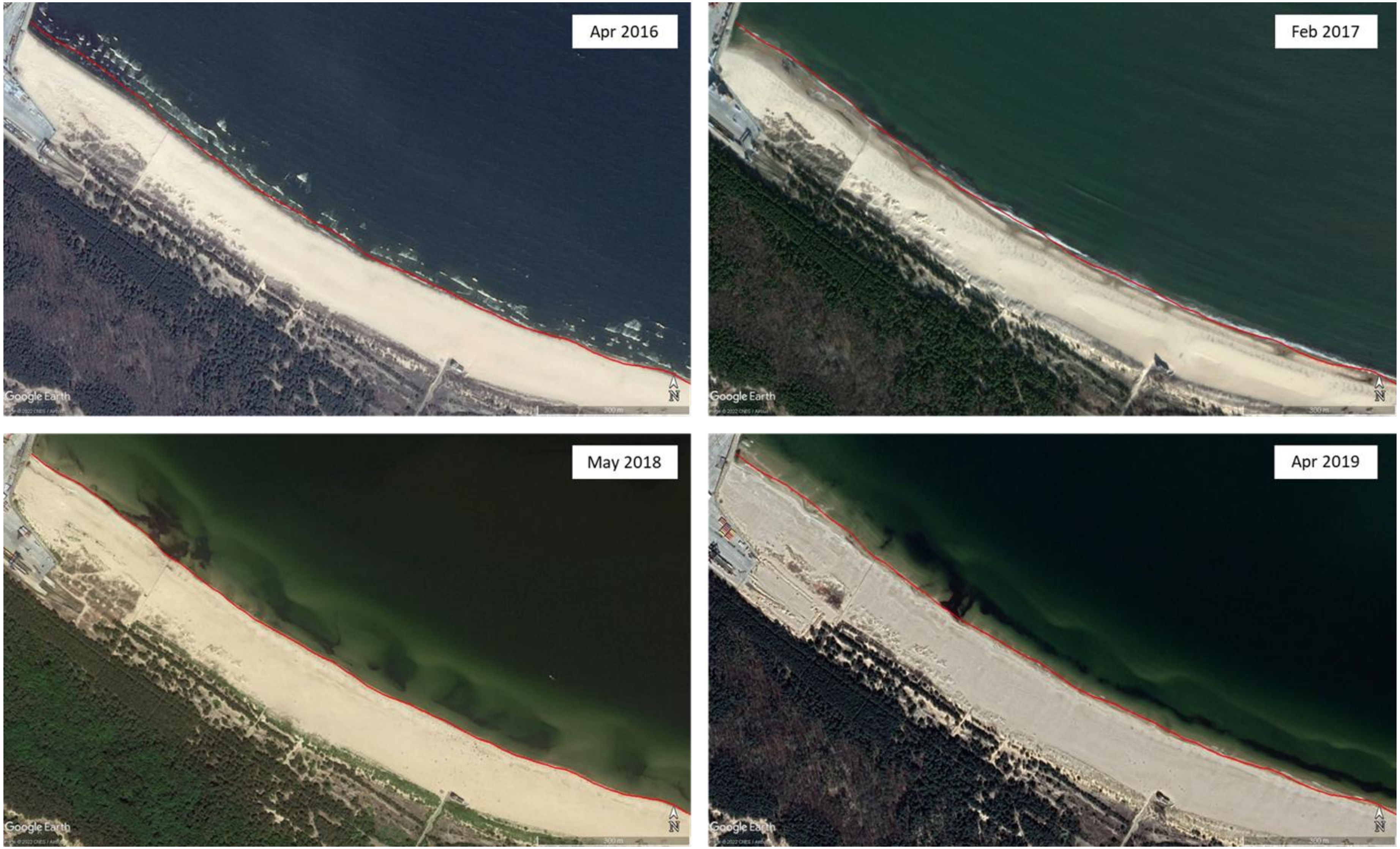

Figure 5.11: The evolution of the Stogi Beach shoreline at the western end. The red line indicates the shoreline in May 2018 for comparison. Source: Google Earth.

5.2.2 Long Term Wave Modelling

The long term wave modelling produced a 30-year record of wave conditions at the study site providing a comprehensive description of the variability of wave conditions at the port. A summary of wave conditions offshore from the port is shown in Figure 5.12. Overall, the waves are from the NE with most NW wave energy blocked by the Vistula Spit. Significant wave heights are generally less than 3 m and are usually between 0.5 and 1 m.

The variability in local wave energy around the port are shown for a moderate 0.5 m H_s NE wave condition (Figure 5.13) and a large 3 m Hs NE wave condition (Figure 5.14) for the *Previous*, *Present* and *Future* scenarios. For the moderate wave condition, the breakwater extensions (*Present* scenario) reduce the wave energy reaching the western segment of the beach considerably though on the eastern segment, the wave conditions remain unchanged. The addition of the T3 development (*Future* scenario) leads to a further reduction in wave energy at the far western end of the beach. The same effect is seen in the large wave condition. In this case however the wave field is more strongly modified by wave-seabed interactions including strong focusing over the raised bathymetric feature offshore from the eastern end of the beach and refraction around the edges of the dredged channels.

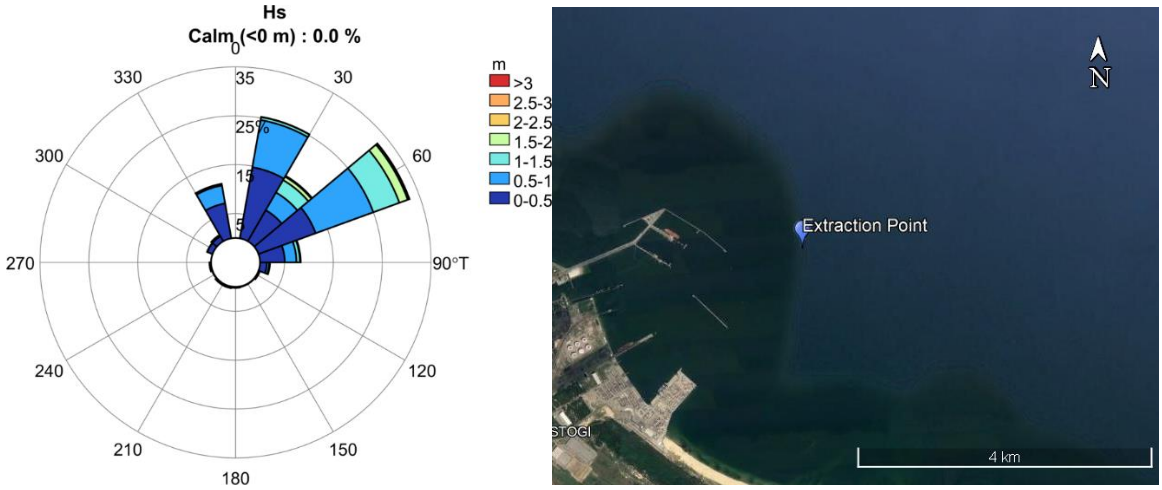

Figure 5.12: Wave rose (left) summarising the wave climate directly offshore from the Port of Gdańsk (right).

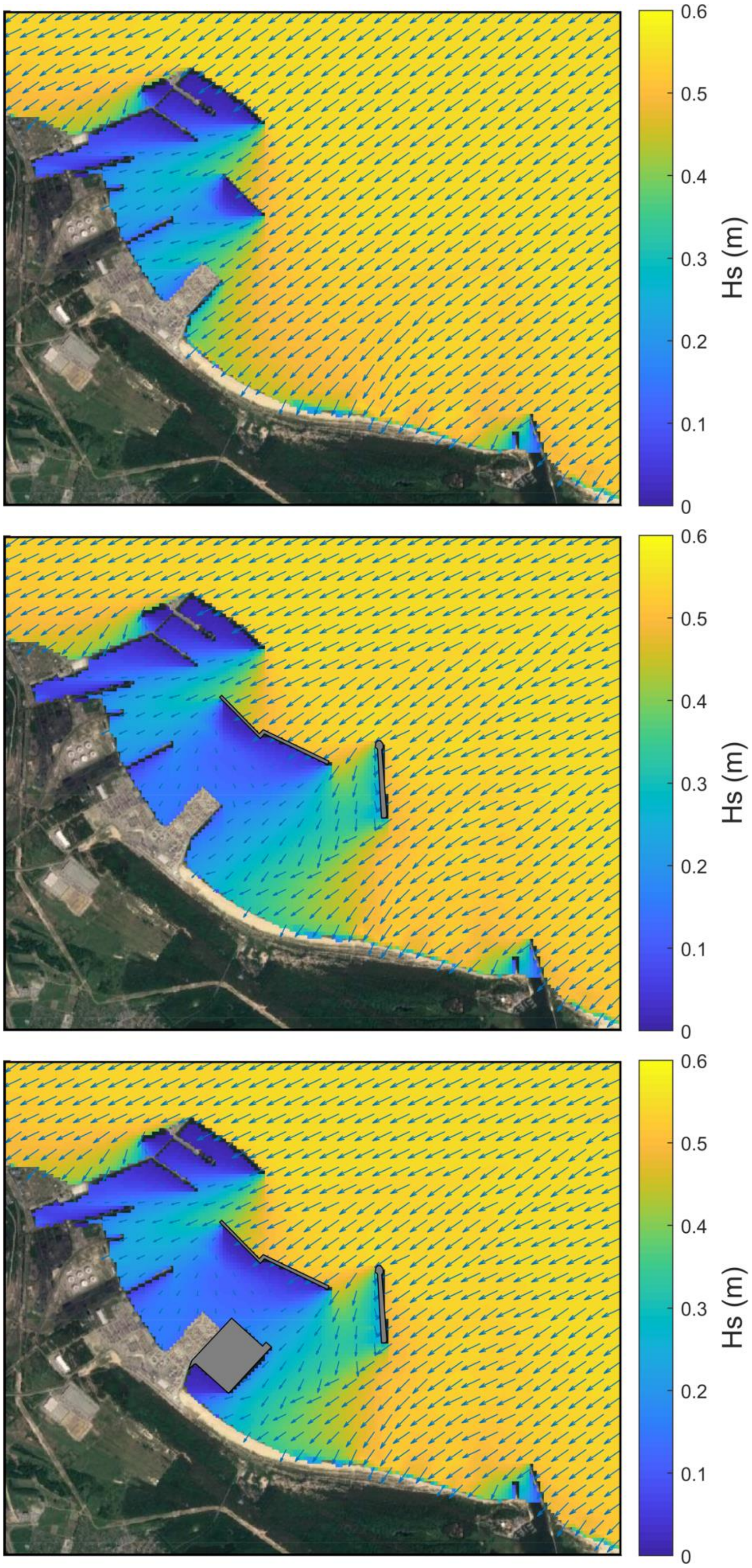

Figure 5.13: Significant wave height for a moderate 0.5 m NE wave condition for the *Previous* (top), *Present* (middle) and *Future* (bottom) scenarios.

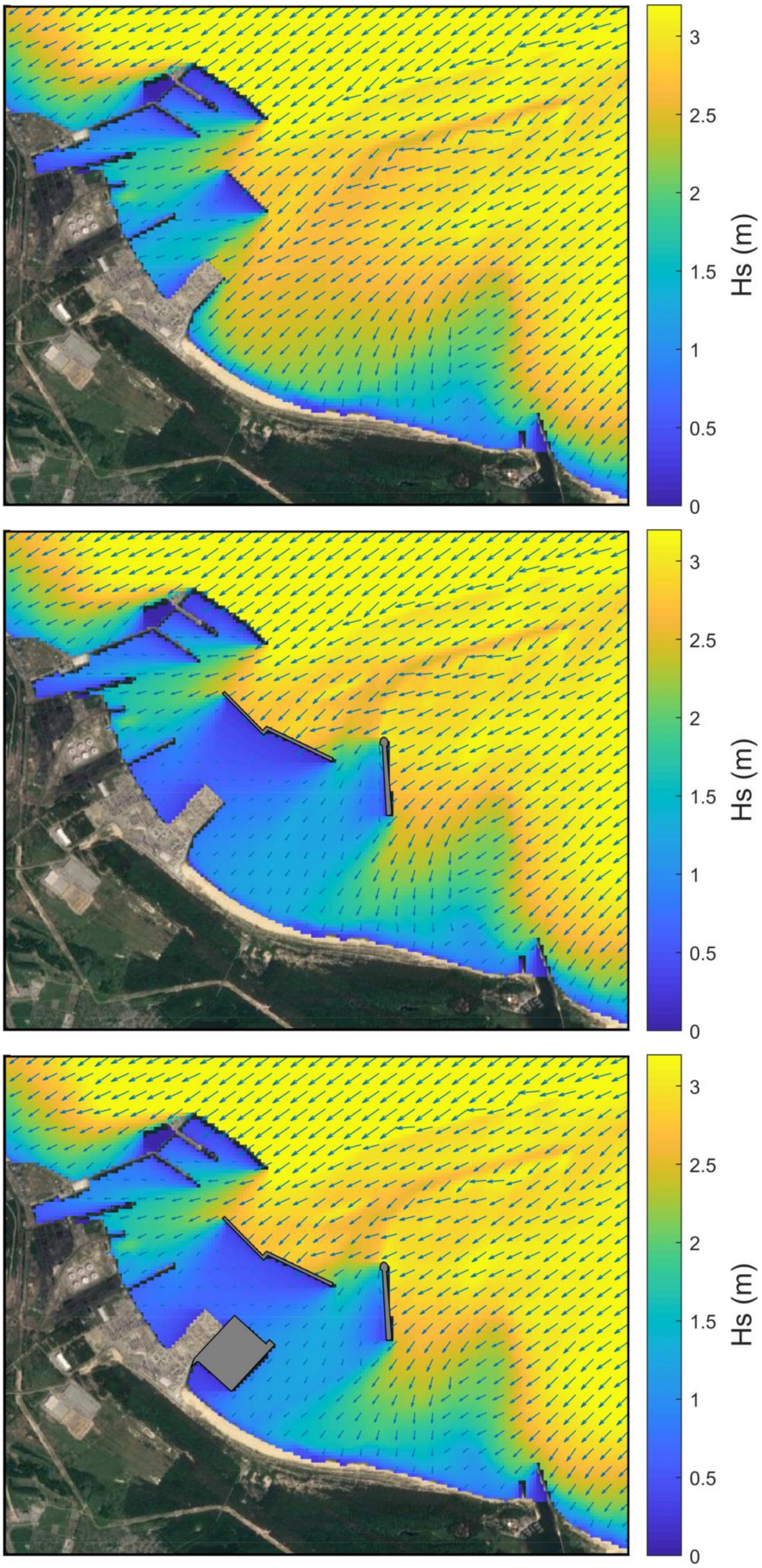

Figure 5.14: Significant wave height for a large 3 m NE wave condition for the *Previous* (top), *Present* (middle) and *Future* (bottom) scenarios.

5.2.3 Sediment Transport Modelling

The one-line sediment transport modelling approach provides an estimate of annual net sediment flux across each transect. The difference between the net flux at a transect and its neighbour provides an estimate of sediment flux anomaly for each transect (Figure 5.15). The sediment anomaly quantifies net accretion or erosion of sediment at that location. While this is useful for estimating the direction of movement of the shoreline it does not directly provide an estimate of shoreline change at each location. A relationship can be formed between sediment flux anomaly and the measured rate of shoreline change at each location (Section 5.2.1). This is shown graphically in Figure 5.16. This relationship can then be used to infer rates of shoreline change for other scenarios based on the modelled annual sediment flux.

Shoreline change is shown for the *Previous*, *Present* and *Future* scenarios in Figure 5.17 to Figure 5.19 for 10 and 20 years beyond the 2018 baseline case.

The *Previous* shoreline change shows accretion at the western end of the beach and less pronounced but nonetheless significant erosion towards the centre and east of centre of the beach. At the far eastern end of the beach, the shoreline is reasonably stable.

For the *Present* scenario, some erosion is seen at the far western end of the beach. The area of strong accretion moves from the western end of the beach eastwards towards the central area. A pattern of erosion is still seen eastwards from central region of the beach. As in the *Previous* scenario, no erosion is evident in the far eastern end of the model domain.

Shoreline change for the *Future* scenario is very similar to the *Present* scenario except for a return to a pattern of accretion at the far western end of the beach due to the wave shadowing effect of the T3 reclamation.

With the breakwaters in place very little wave energy reaches the western end of Stogi Beach and it is further reduced with the addition of the T3 reclamation. This means that very little wave driven sediment mobilisation is likely to occur in the T3 shadow zone. As noted in Section 5.1.4, Aeolian (wind driven) sediment transport is not included in the model though wind effects are likely to lead to additional accretion of sediment in the T3 shadow zone. The T1 and T3 reclamations will block wind energy from the west and northwest that may otherwise lead to the eastward transport of sediment from this region.

The effects of climate change on the Future scenario are presented in Figure 5.20. The reduced wave energy associated with future climate change will lead to reduced rates of erosion and accretion along the beach.

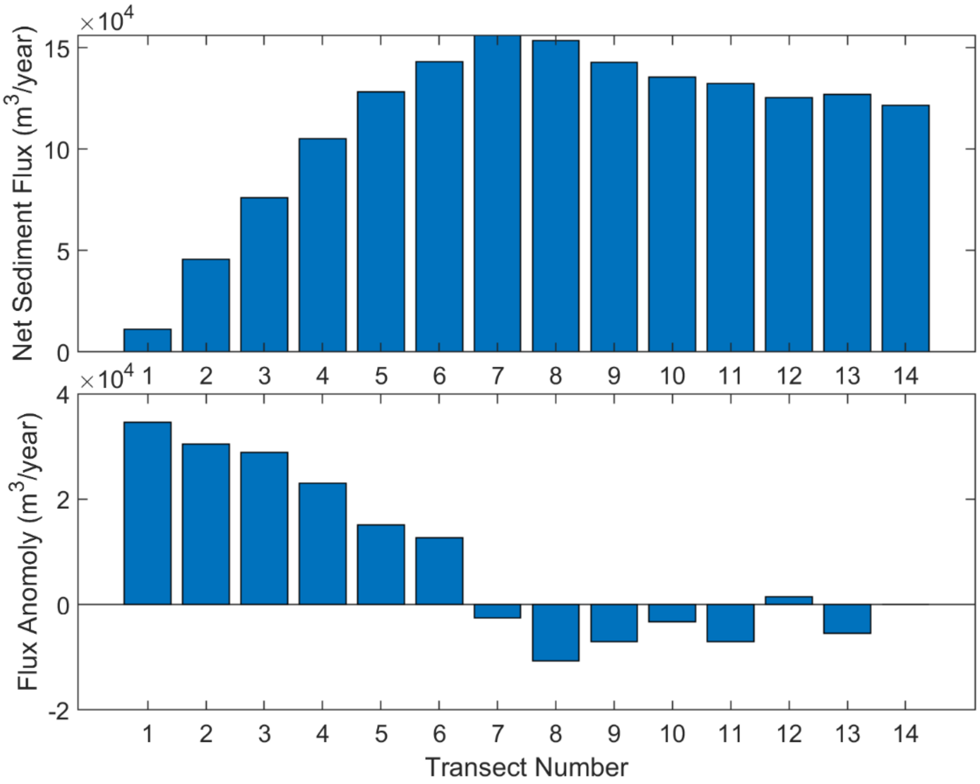

Figure 5.15: Output from Genius showing the net flux at each transect (top) and flux anomaly at each transect (bottom).

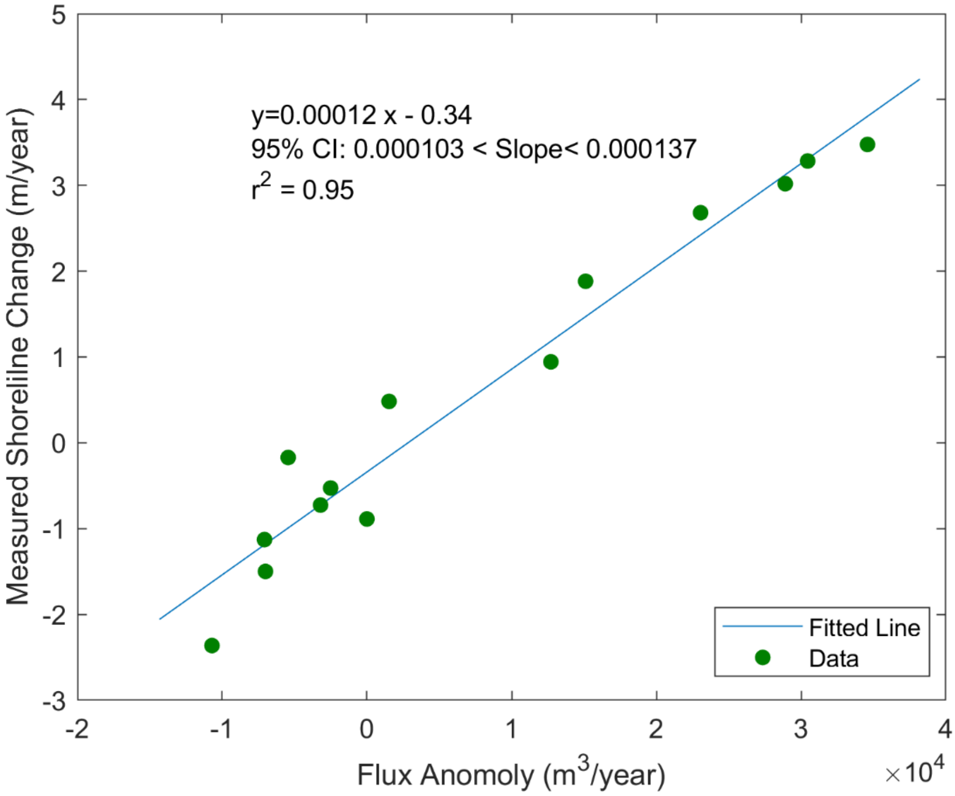

Figure 5.16: Relationship between modelled sediment flux anomaly and beach width change from historical shoreline analysis.

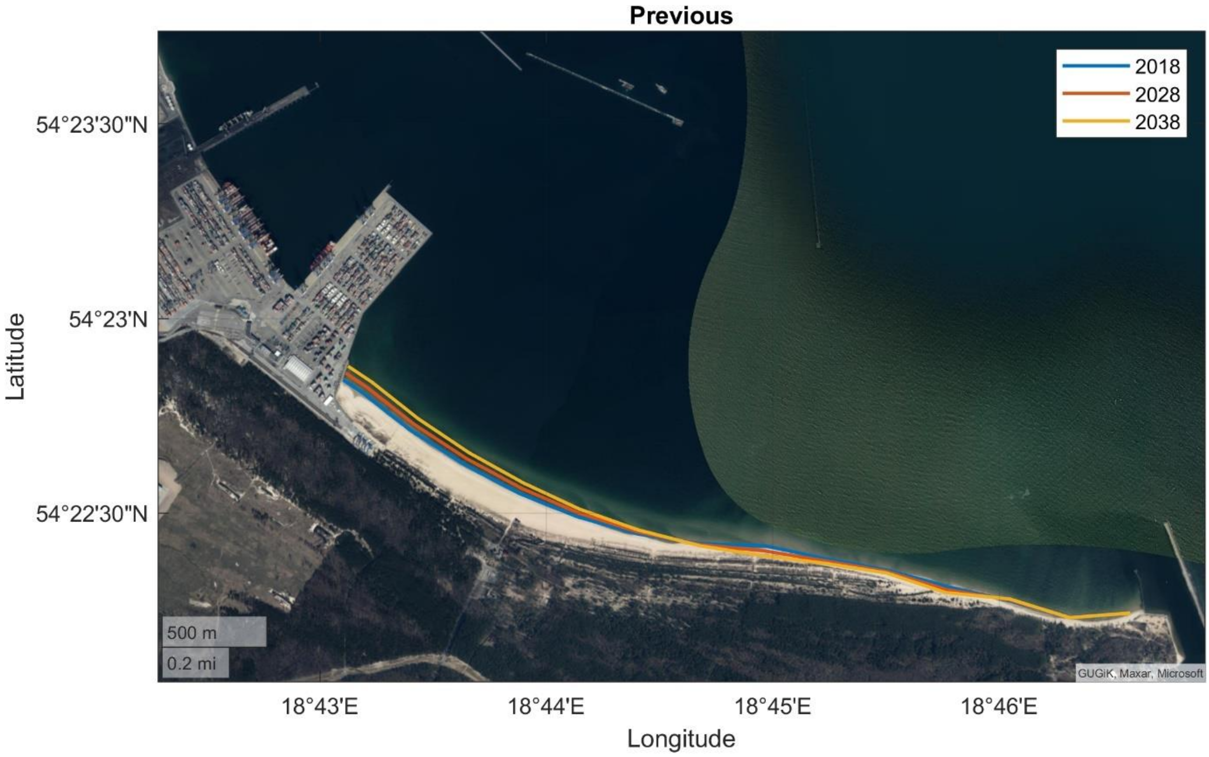

Figure 5.17: Predicted shoreline change for the '*Previous*' scenario showing continued accretion at the western end of the beach and less pronounced erosion towards the east.

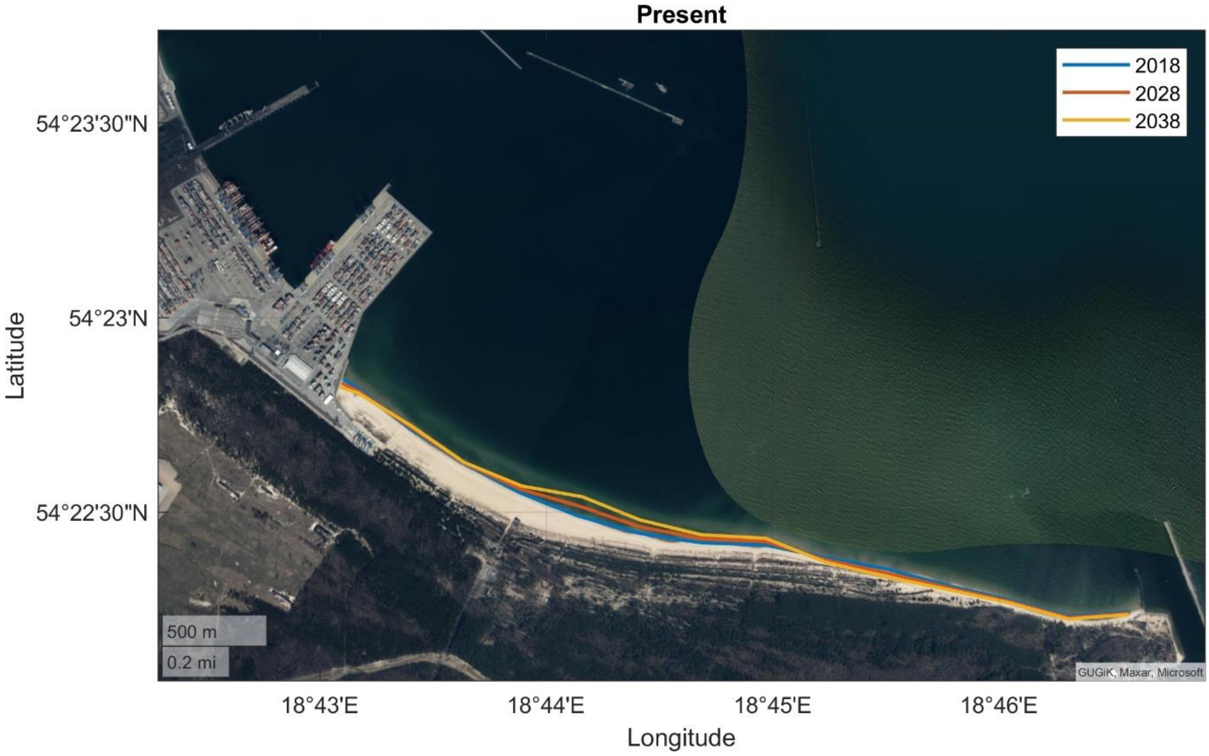

Figure 5.18: Predicted shoreline change for the '*Present*' scenario.

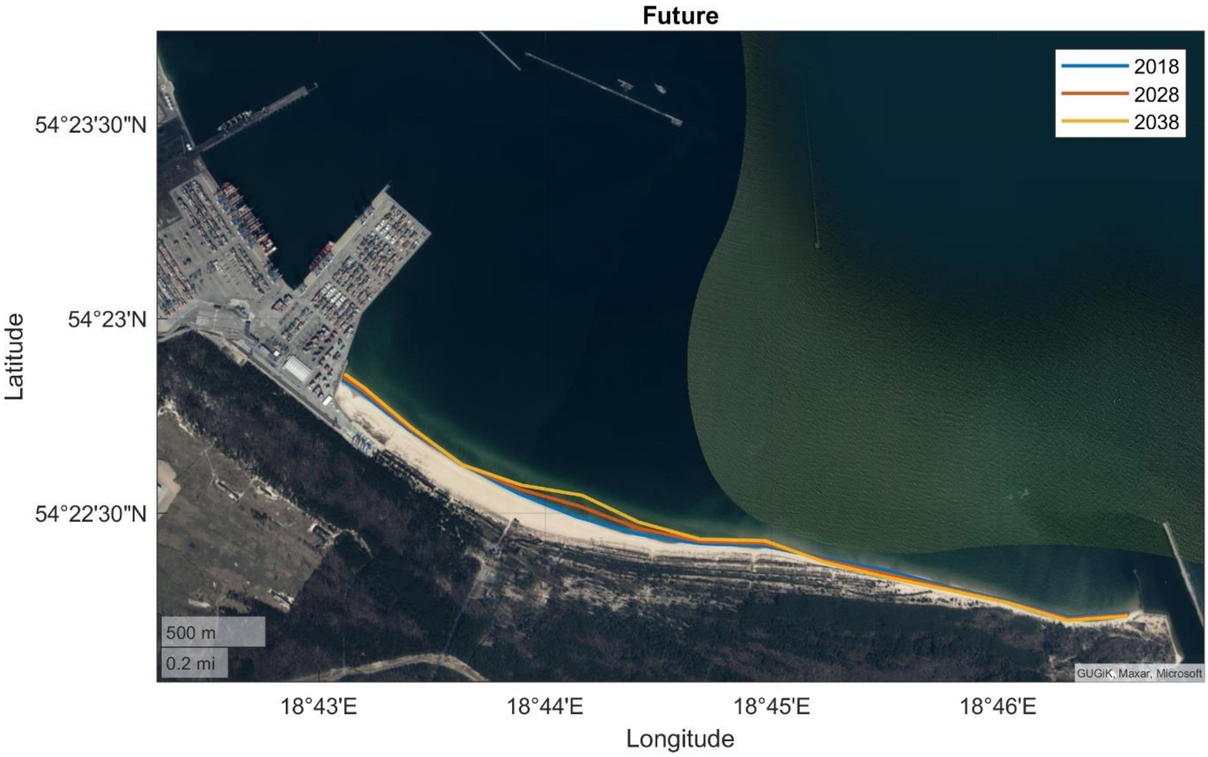

Figure 5.19: Predicted shoreline change for the '*Future*' scenario.

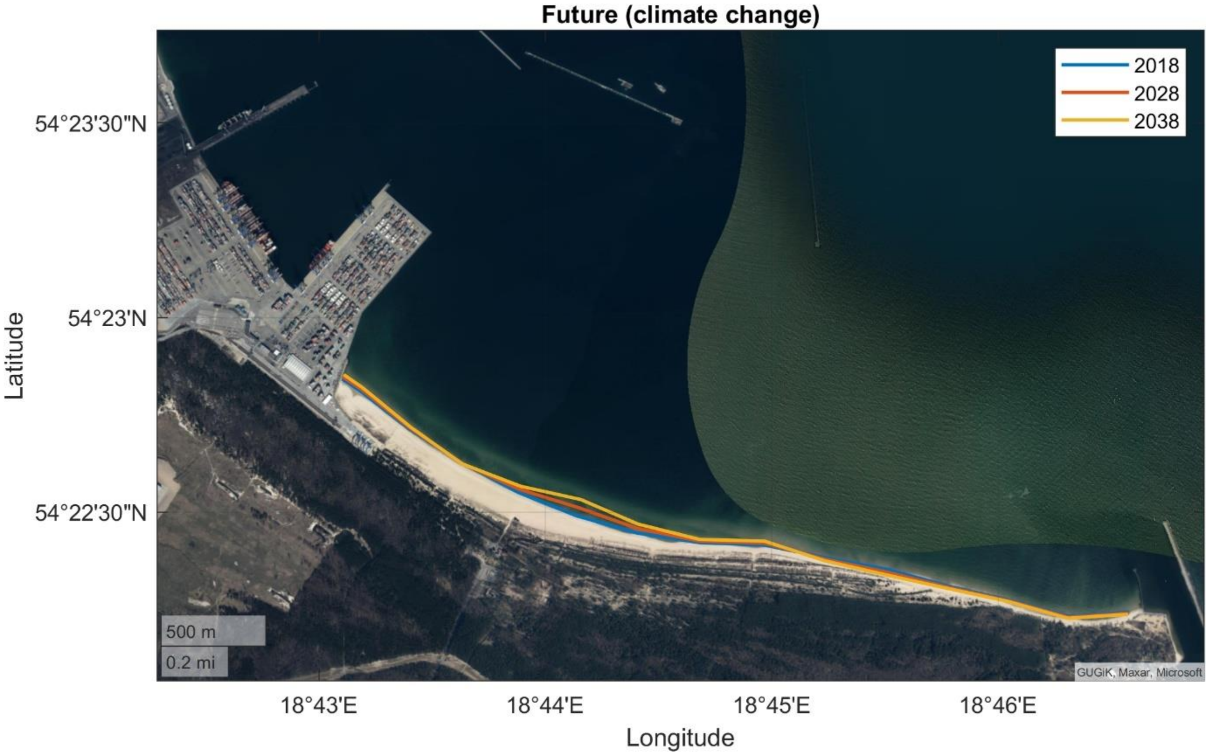

Figure 5.20: Predicted shoreline change for the '*Future*' scenario including the effects of climate change.

5.3 Conclusions

The construction of the T1 terminal in 2005 led to the accretion of the western end of Stogi Beach (adjacent to T1) at a rate of approximately 3.4 m per year from 2008 through 2018. The rate of accretion decreases with distance east of T1 and some erosion (-1.2 m per year) is seen in the central to east of central portion of the beach while the far-eastern portion of the beach is broadly stable. The rate of accretion at the western end of the beach is greater than the rate of erosion towards the centre and east of centre suggesting a net accumulation of sediment along the beach. While the source of this sediment is not clear, it most likely comes from offshore.

Results from the modelling indicate that the breakwaters that were constructed in 2020 will lead to changes to the sediment transport dynamics of Stogi Beach. They will reduce the wave driven accretion at the western end of the beach and will lead to a pattern of accretion along the central region of the beach at a rate of 2.6 m per year. Erosion and accretion patterns at the eastern end of the beach will remain largely unaffected.

The T3 development will lead to continued accretion of the shoreline in the far western end of Stogi Beach (1.5 m per year) which will be exacerbated by wind driven sand transport. The T3 reclamation will not affect sediment transport patterns on the beach to the east of this region.

The results for the three model scenarios are shown schematically in Figure 5.21 to Figure 5.23.

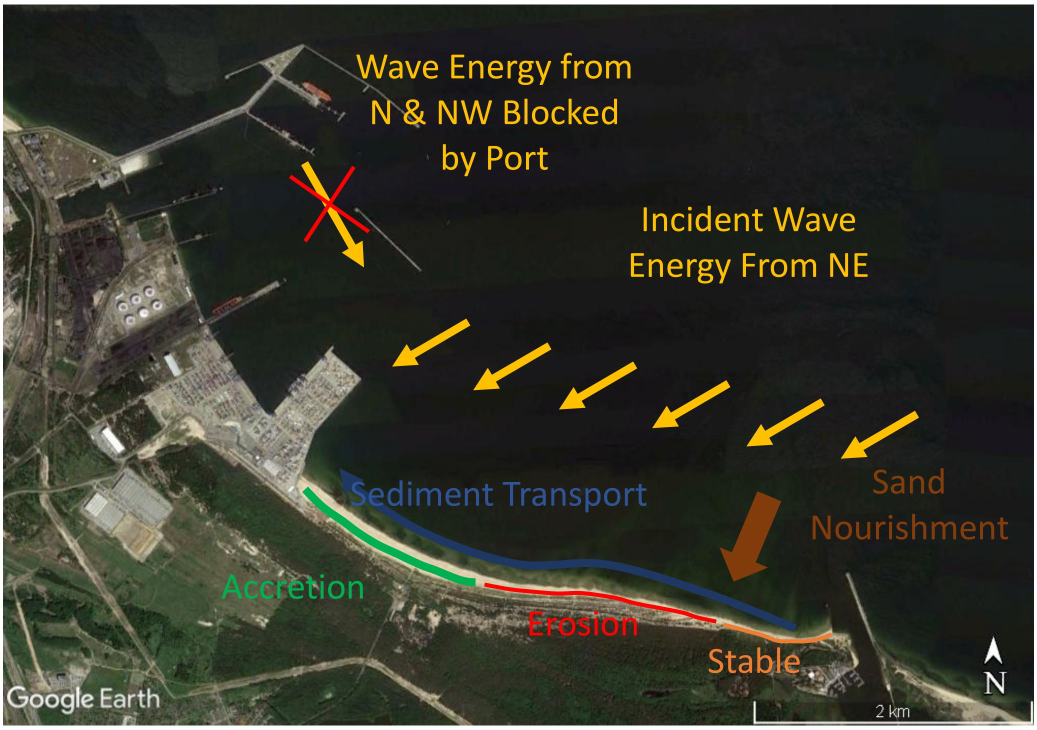

Figure 5.21: Schematic illustration of the sediment transport scheme for the *Previous* scenario.

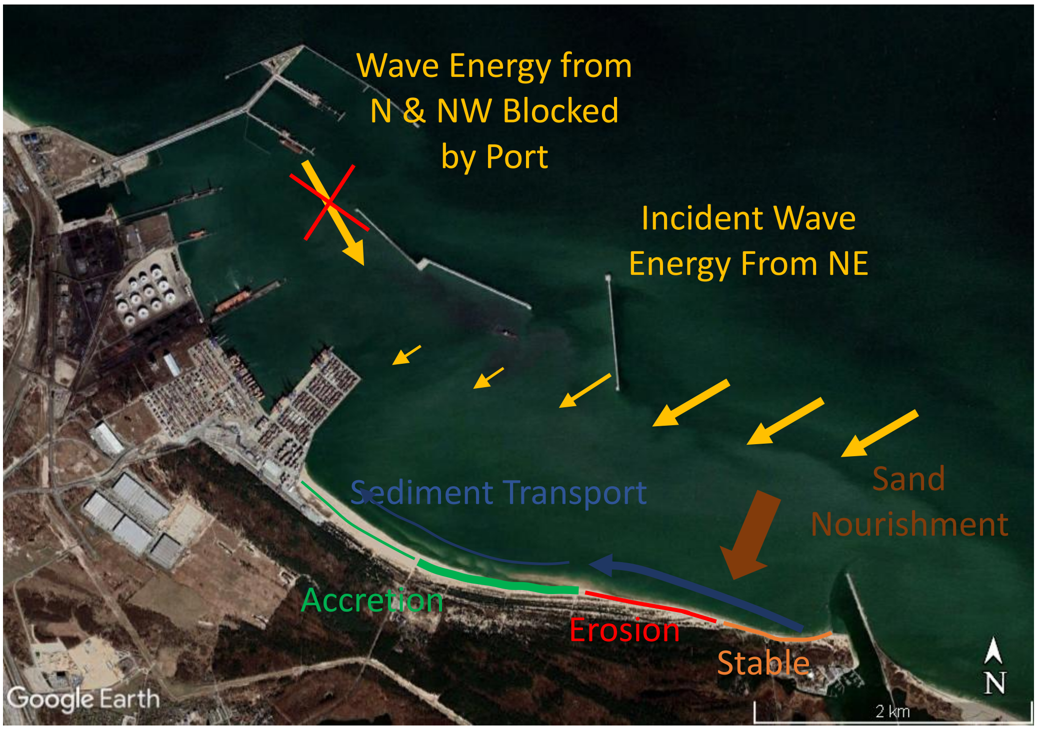

Figure 5.22: Schematic illustration of the sediment transport scheme for the *Present* scenario.

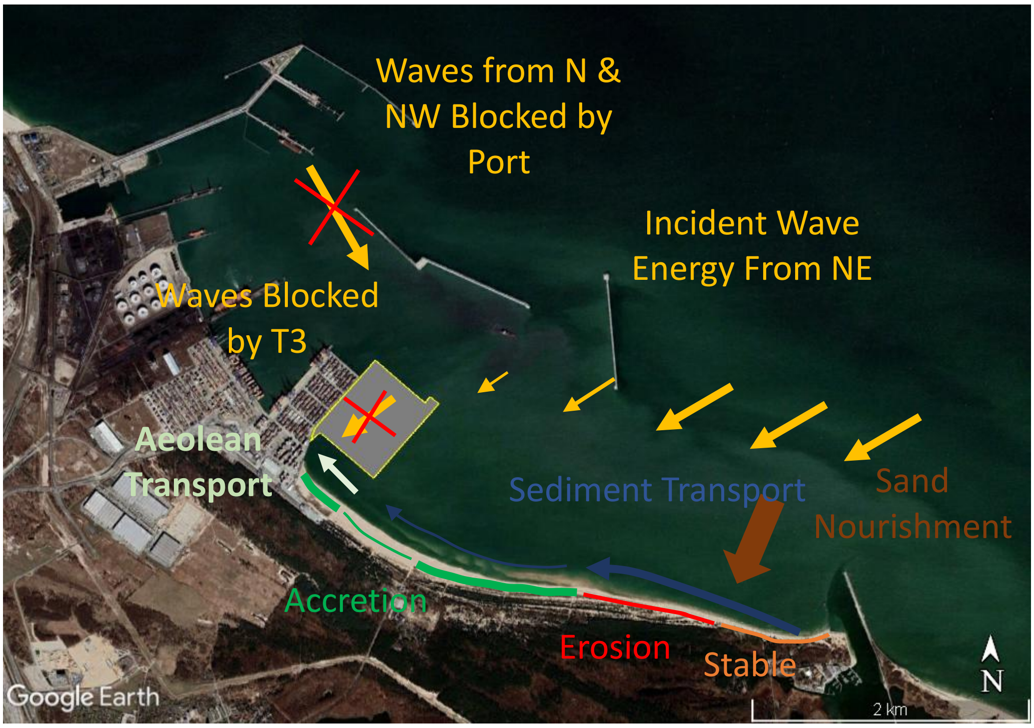

Figure 5.23: Schematic illustration of the sediment transport scheme for the *Future* scenario.

6 Water Quality Modelling

The development of the T3 terminal could lead to potential water quality issues affecting the coastal zone. This may occur due to trapping of Vistula River water or from stagnation of coastal waters. In this section the potential implications of the T3 terminal and breakwaters in the water quality of the adjoining areas are assessed.

6.1 Method

Effects on water quality have been investigated using a numerical modelling approach. The scenario definitions are the same as those used in the beach morphology modelling (see Section 5.1).

6.1.1 River Plume Modelling

The Vistula River is one of the largest rivers received by the Baltic Sea and a significant contributor of nutrients to the marine environment (Section 2). There is potential for changes in the dispersion of the river plume in the vicinity of the port due to the construction of the T3 Terminal. The modelling presented here simulates the dispersion of the river plume with and without the T3 Terminal and breakwaters in place.

The hydrodynamic modelling software used for this project is D-Flow Flexible Mesh (D-Flow FM) by Deltares which is part of the Delft3D FM Suite (Deltares, 2019). This Flexible Mesh (FM) model uses unstructured grids, with 3- to 6-sided cells and allows for irregular shapes. This grid format allows model cell shape and size to be manipulated based on the morphology in areas of interest, negating the need for multiple model domains and making simulations more accurate and efficient.

This model here was developed in 3D using five sigma-layers with layer thicknesses of 1%, 9%, 20%, 30% and 40%. The model was driven by ECMWF winds (19.0 E, 54.5 N) and freshwater input from the Vistula River. River boundary flows were derived from the Tczew flow gauge. Background and open boundary salinity was set 35 psu and river water salinity was set to 0 psu. The thinnest layers are at the water surface and they capture the buoyant river plume and surface layer wind effects. Temperature was omitted from the model as temperature derived gradients are unlikely to be strong drivers of currents near the shoreline. Tidal forcing was also omitted as tidal ranges in the Baltic Sea are negligible. The model was run for a 6-month period between 1 January and 1 August 2021 capturing periods of moderate and high flow from the Vistula River.

Model results for the *Future* scenario were scaled to reflect an estimated 18.25% climate change induced reduction in discharge from rivers (by 2081 to 2100) that terminate in the southeast of the Baltic Sea (mean of RCP 2.6, 4.5, 6.0 and 8.5) as outlined in Section 3.4.3 (Šarauskienė et al., 2017). Model results are presented in Section 6.2.1.

6.1.2 Flushing Rate

A potential cause of decreased water quality is stagnation of the T3 shadow zone. The T3 reclamation may lead to reduced current speeds in that area which would decrease flushing rates. This has been assessed by tracking a conservative tracer released in this region of the course of a model run for the *Present* and *Future* scenarios. The model was run using 8 scenarios for 4 cardinal (N, E, S, W) and 4 intercardinal (NE, SE, SW, NW) wind directions. Representative wind speeds were estimated by binning the long-term wind record and calculating the mean wind speed for each scenario. A spin up period of 2 days was used to initiate the hydrodynamic model. At this point a conservative tracer was released into the T3 shadow zone and allowed to disperse under the hydrodynamic conditions. The quantity of tracer remaining in the enclosed area was tracked through a weeklong model run for each wind condition with and without the T3 reclamation and associated dredging in place. Comparison plots provide an indicative quantification of the reduction in the flushing rate. Model results are presented in Section 6.2.2.

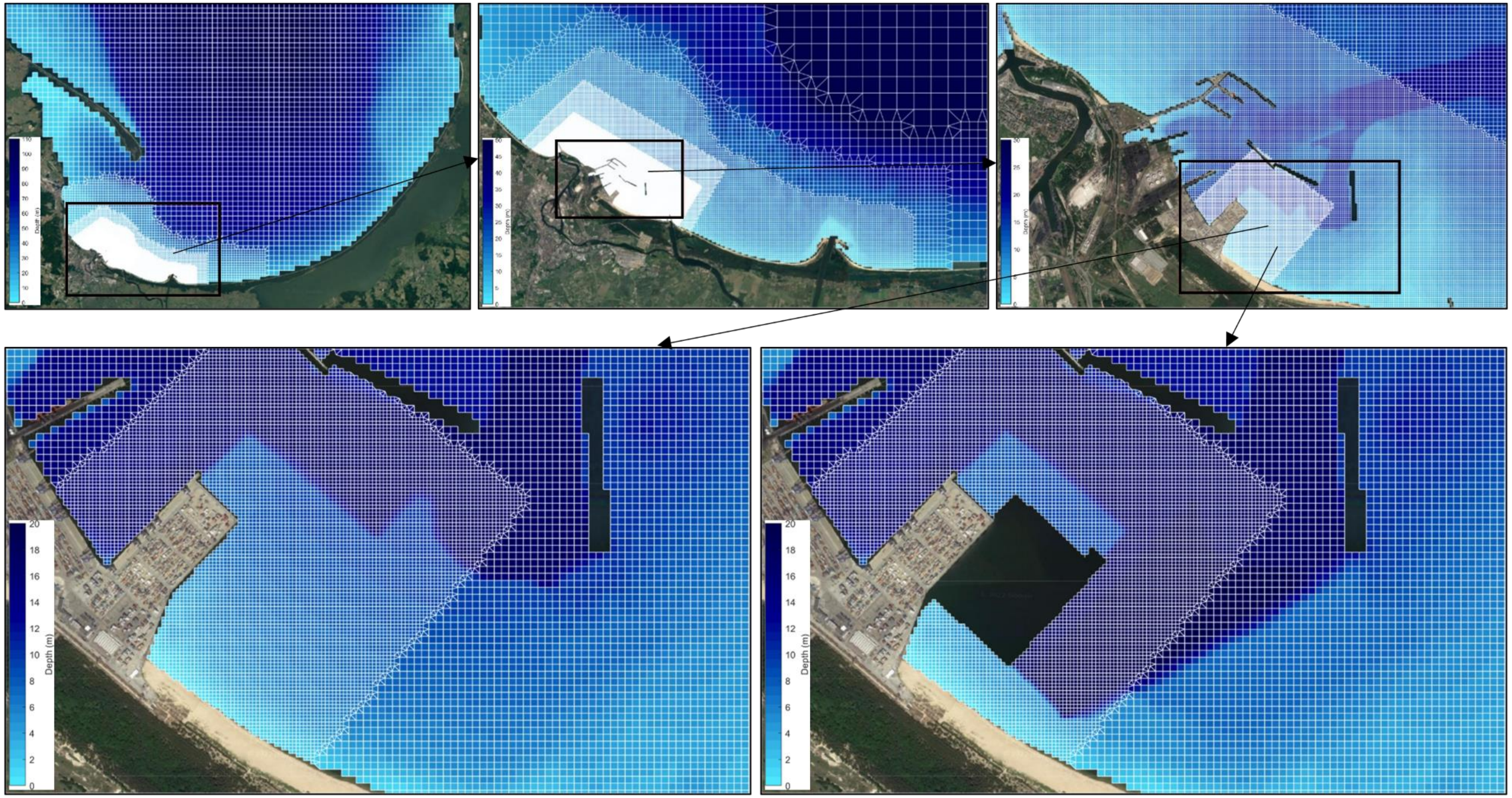

Figure 6.1: The bathymetry grid used for the Hydrodynamic model with increasing resolution with proximity to the T1 and T3 terminals.

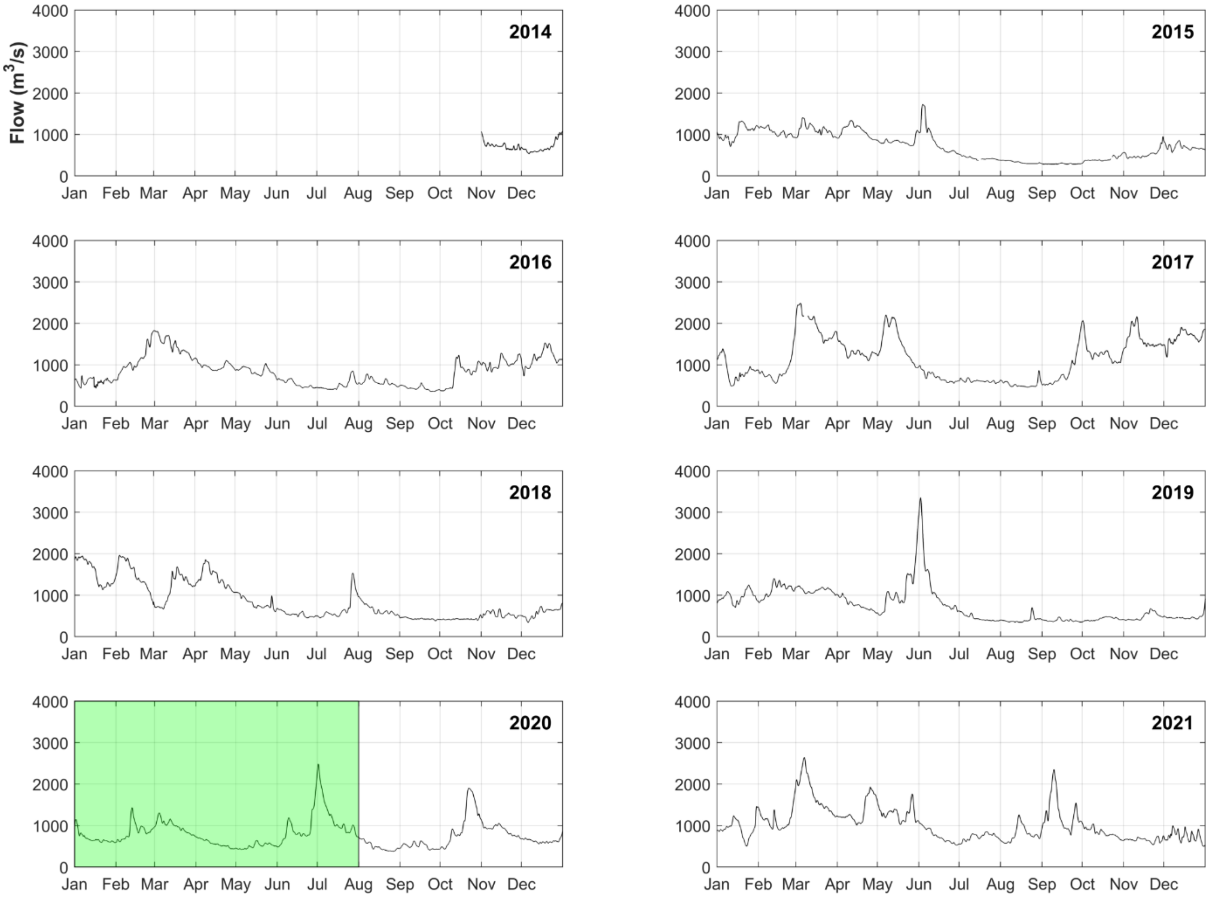

Figure 6.2: River flow data form the Tczew gauge for the years 2014 to 2021. The green rectangle indicates the period simulated by the hydrodynamic model.

6.1.3 Limitations

The hydrodynamic model does not derive current fields due to variability in broadscale temperature and salinity gradients. While salinity and temperature are important drivers of currents in the Baltic Sea, the strongest currents in the nearshore are likely to be wind driven.

Wave driven currents are not included in the hydrodynamic model. Preliminary investigations with a coupled wave model showed that they were not strong drivers of currents except very close to the shore.

A clamped 0 m sea level (MSL) was applied to the open boundary sea level and sea level variability was not included. While there is some sea level variability in the Gulf of Gdańsk, it is unlikely to be a significant driver of currents since tidal amplitudes in this area are negligible.

6.2 Water Quality Modelling Results

6.2.1 River Plume Modelling

The hydrodynamic model run simulated a period of moderate and high river flow from the Vistula River to assess the footprint of the freshwater plume in the marine environment. Modelled salinity was converted to dilution through the following relationship:

$$d = \frac{35}{35 - s}$$

Where *s* is salinity and *d* is dilution.

Minimum and median dilutions for the Previous, Present and Future scenarios are shown in Figure 6.3 and Figure 6.4 respectively. The results show that the port area is impacted by the river plume with minimum dilutions during the model run between 4 and 7-fold in the Previous scenario. The additional breakwaters in the Present scenario cause a general reduction in river water intrusion into the inner port area. In the Future scenario, the T3 terminal reduces the intrusion T3 shadow zone with minimum dilutions raising from 4-fold in the Present scenario to 6-fold in the Future scenario. The median dilution in the T3 shadow zone is approximately 20-fold for all scenarios. Overall, there is no significant difference in median dilution patterns between the three scenarios. Considering reduced river flow due to climate change projections (2081-2100), dilution throughout the model domain is higher overall (Figure 6.5). In the lee of the T3 development median dilution increases to 27-fold.

A timeseries of surface model output extracted at the western end of Stogi Beach shows salinity through the course of the model run (Figure 6.6). In the *Future* scenario, the salinity values are generally higher, more smoothed and show less short-term variability than the *Previous* and *Present* scenarios.

Residual (vector averaged) depth averaged current speeds are shown for the three scenarios in Figure 6.7. The results show a slight reduction in residual current speeds in the western end of Stogi Beach which would be expected to lead to a reduced intrusion of river water into this area.

Currents generated by the outflow of freshwater from the Vistula River mouth are largely confined to the river mouth and do not impinge on the Port area. Surface and depth averaged currents are shown in Figure 6.8 at the peak of a high flow event confirm this.

Overall, the results indicate that the addition of the T3 development will reduce the intrusion of Vistula River plume at the western end of Stogi Beach. River water is likely to be one of the largest contributors of bacterial loads to the marine environment. Construction of the T3 development is unlikely to lead to higher bacterial or pollutant concentrations at the western end of Stogi beach carried by Vistula River water.

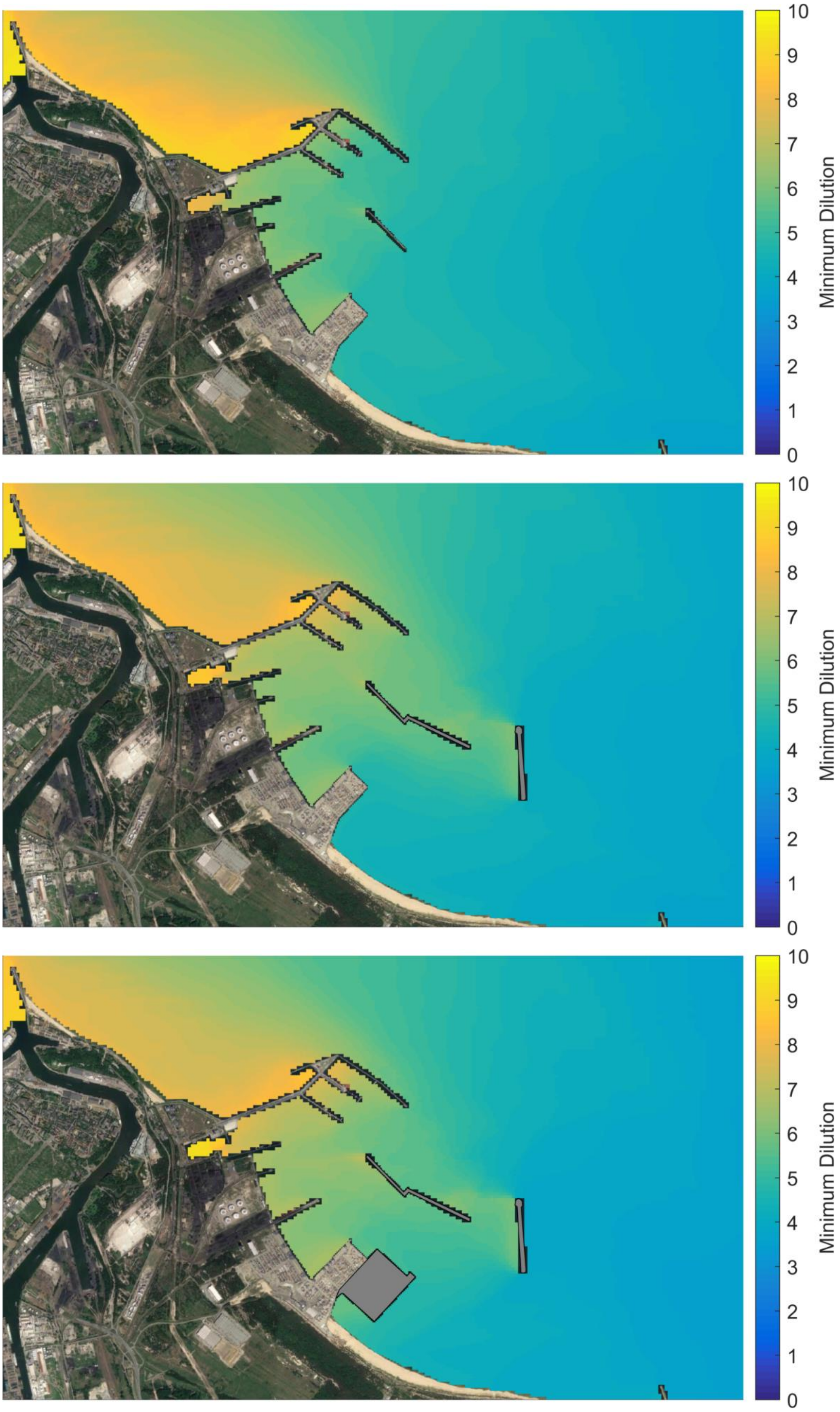

Figure 6.3: Minimum surface layer dilution in the port area for the *Previous* (top) *Present* (middle) and *Future* scenarios (bottom).

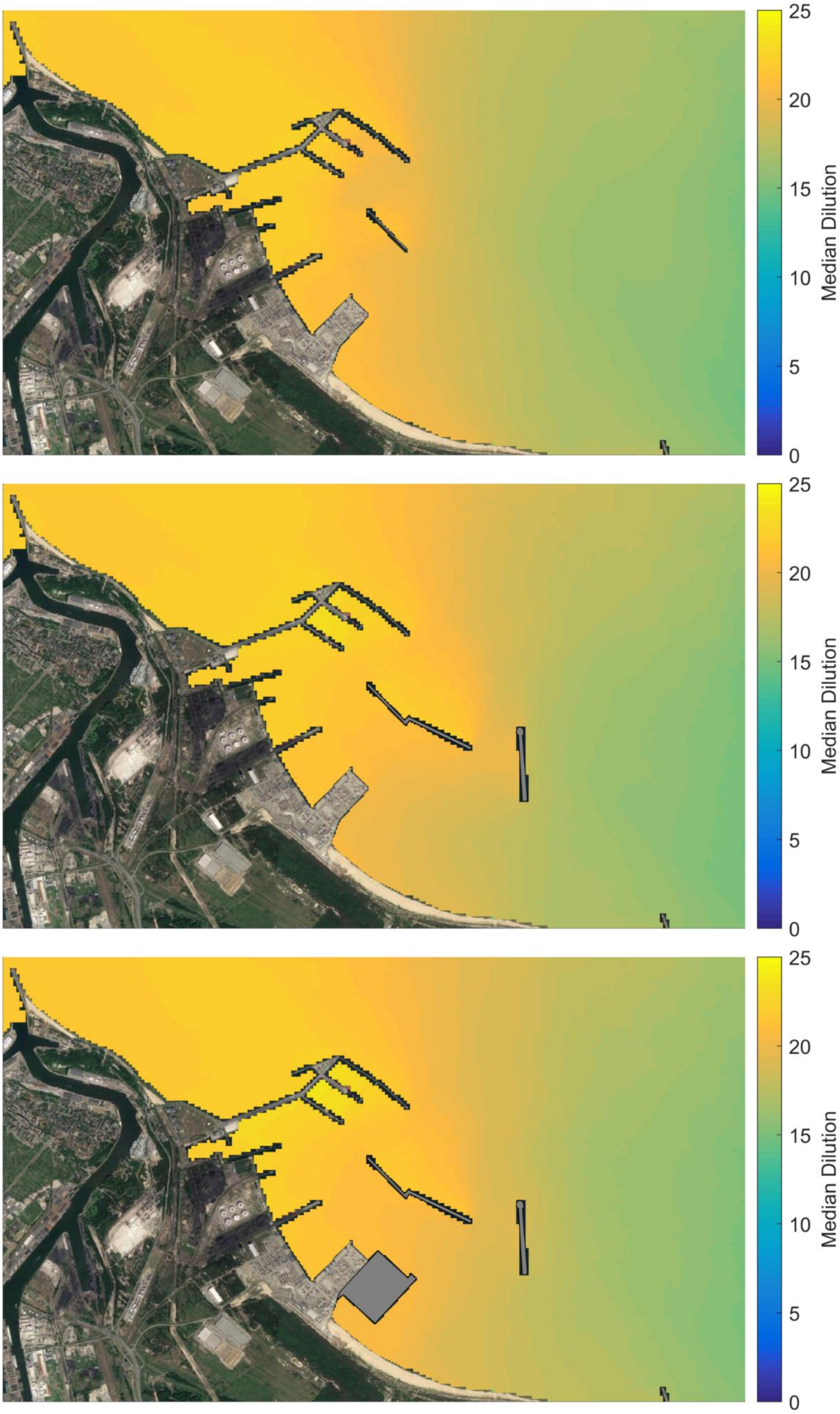

Figure 6.4: Median dilution in the port area for the *Previous* (top) *Present* (middle) and *Future* scenarios (bottom).

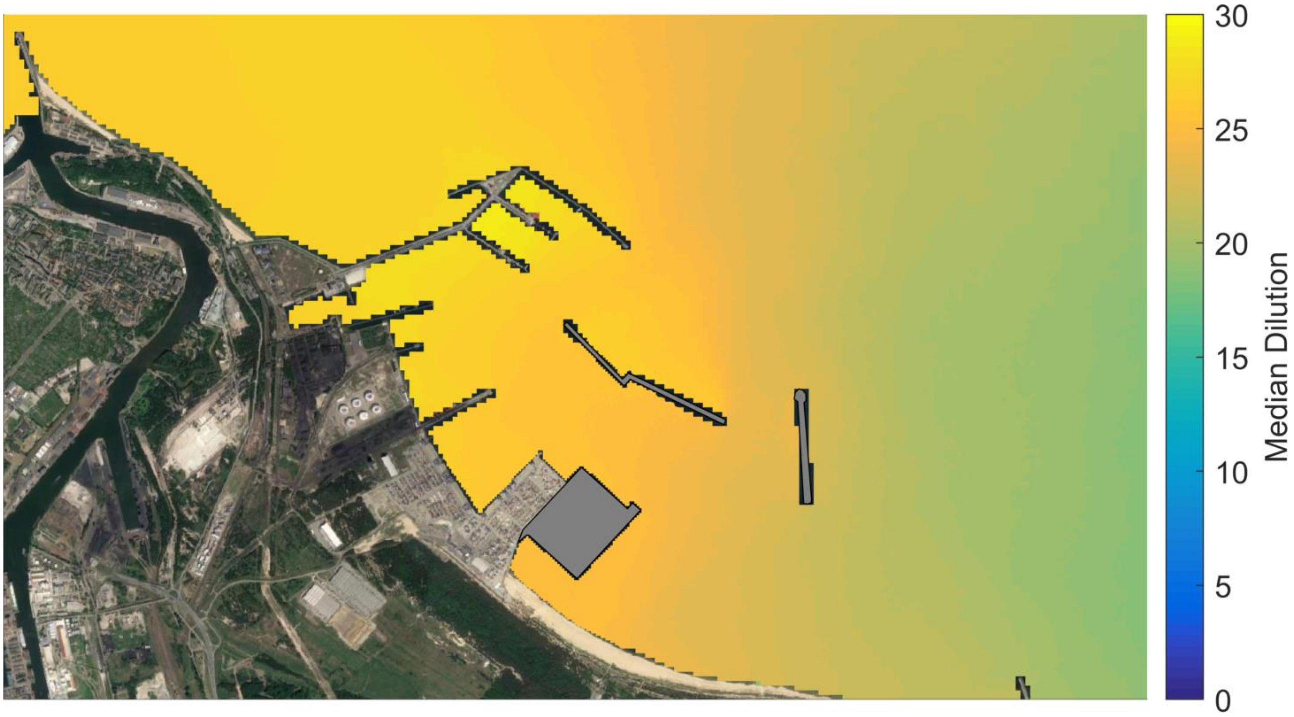

Figure 6.5: Median dilution in the port area for the Future scenarios scaled for a predicted 18.25% reduction in river flow due to climate change effects for between 2018 and 2100.

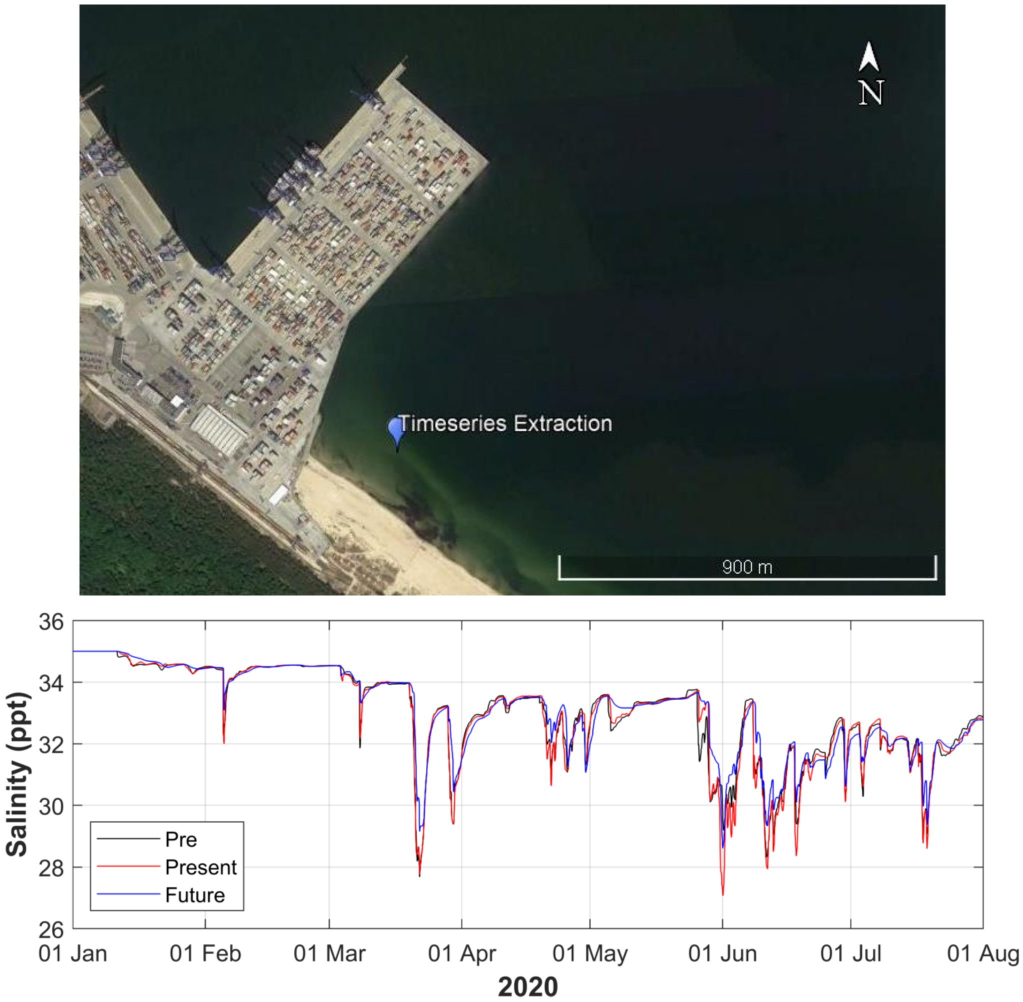

Figure 6.6: Salinity over the course of the model runs at a single location in the area enclosed between the T3 terminal and Stogi Beach.

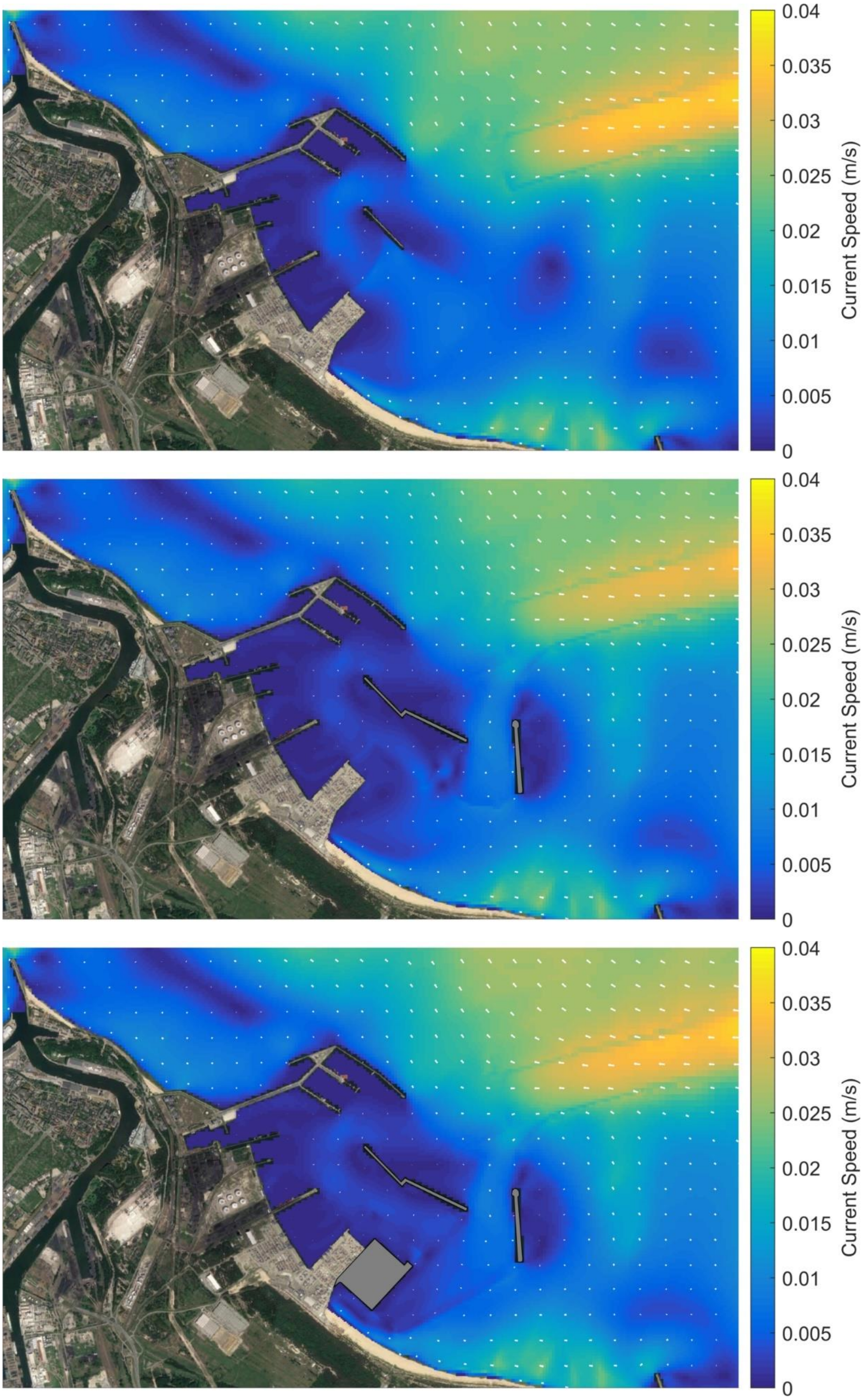

Figure 6.7: Depth averaged residual (vector averaged) current speeds for the *Previous* (top) *Present* (middle) and *Future* scenarios (bottom).

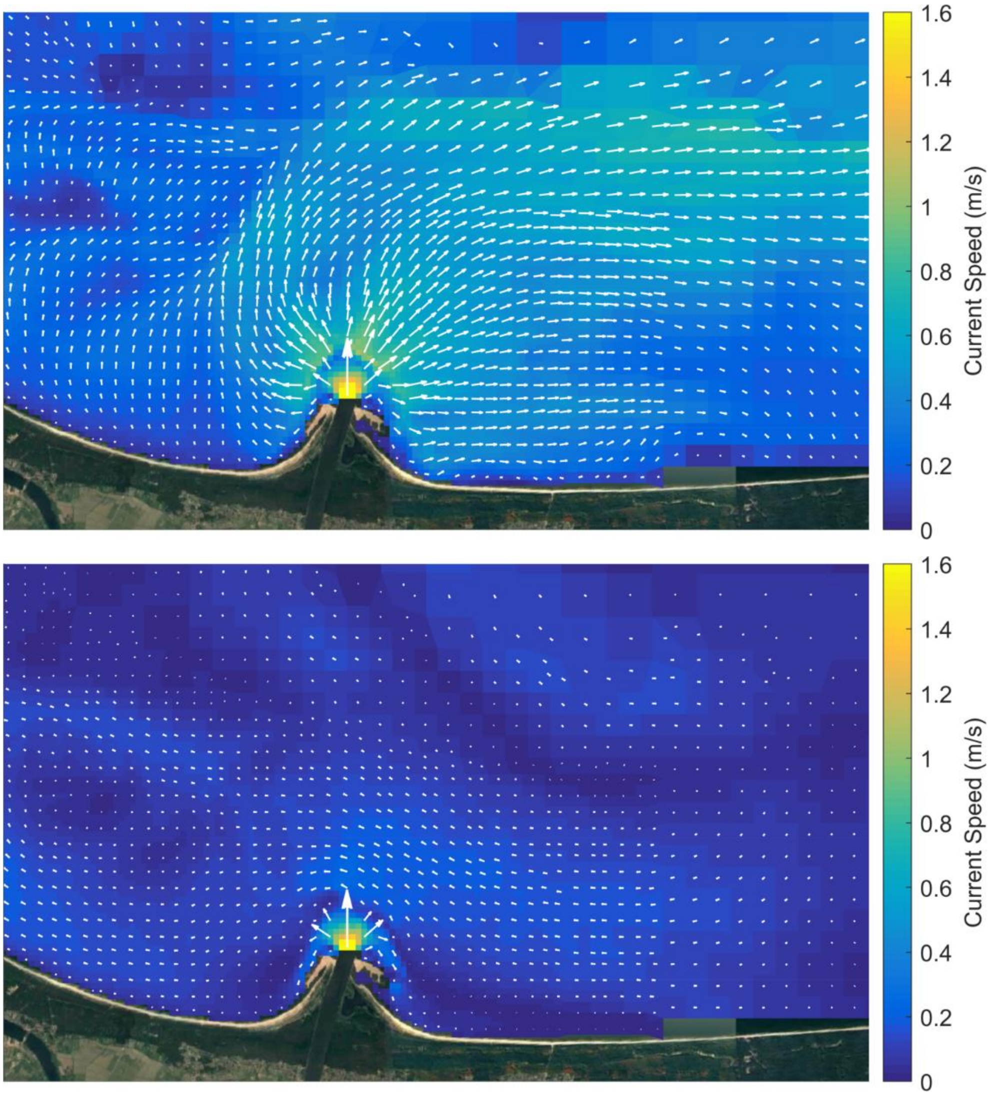

Figure 6.8: Surface (top) and depth averaged(bottom) currents at the mouth of the Vistula River during a peak flow (2,490 m3 /s) event at 1 Jul 2020 17:00.

6.2.2 Flushing

For this project, flushing is defined as the rate at which a conservative tracer is replaced by ambient water in the T3 shadow zone. Timeseries of flushing over the course of the model runs in the T3 shadow zone are shown over time in Figure 6.9 with and without the T3 terminal in place. In these plots the quantity of remaining tracer is presented as a percentage of the released tracer load. The time until 80% and 95% flushing occurs for each scenario is presented in Table 6.1. In all cases, flushing occurs most rapidly directly after the tracer release and increases tangentially towards 100%. In all cases, the flushing progresses more rapidly for the *Present* scenario than for the *Future* scenario. The mean 80% flushing time is 0.31 days for the *Present* scenario and 2.25 days for the *Future* scenario. The mean 95% flushing time is 0.70 days for the *Present* scenario and 4.68 days for the *Future* scenario. In the *Future* scenario, the most efficient flushing occurs under W winds and the least efficient occurs under NE winds. In the *Present* scenario the most efficient flushing occurs under SE winds and the least efficient occurs under NE and SW winds. The steady state surface and depth-averaged current speeds are presented for each scenario in Appendix C. Overall, with the T3 development in place, flushing in the enclosed area between the T3 terminal and Stogi Beach is reduced in all scenarios by a factor of 7 on average.

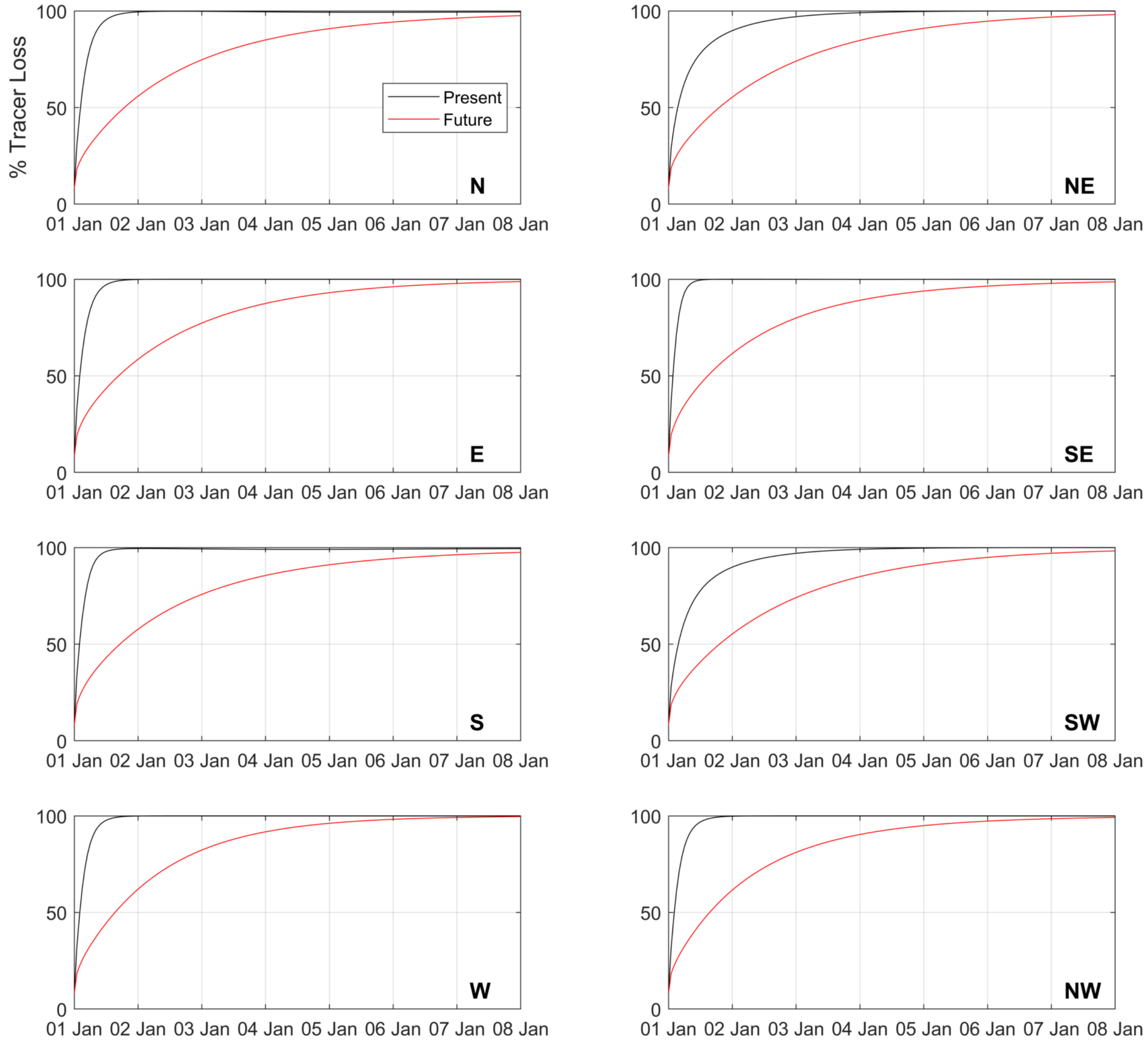

Figure 6.9: Flushing of conservative tracer form the area enclosed by the T3 enclosed area with and without the T3 development in place.

Table 6.1: Flushing times for the T3 enclosed area with and without the T3 development.

	80% flushing		95% flushing	
Wind Direction	**Present**	**Future**	**Present**	**Future**
N	0.25	2.46	0.50	5.33
NE	0.58	2.50	1.58	5.13
E	0.25	2.25	0.42	4.58
SE	0.17	2.04	0.29	4.38
S	0.21	2.38	0.38	5.29
SW	0.58	2.50	1.58	5.04
W	0.21	1.88	0.42	3.67
NW	0.25	1.96	0.46	4.04
Mean	**0.31**	**2.25**	**0.70**	**4.68**

6.3 Conclusions

The modelling results indicate that the freshwater plume from the Vistula River disperses widely over the southern Gulf of Gdańsk and reaches the Port of Gdańsk particularly under high flow conditions and easterly wind conditions. The intrusion of the river water in the marine area between the T3 terminal and Stogi Beach is reduced with the T3 development in place due to its effect on ambient current patterns. River water is likely to be one of the largest contributors of bacterial loads to the marine environment. Construction of the T3 development is unlikely to lead to higher bacterial or river borne pollutant concentrations at the western end of Stogi Beach.

The modelling also shows that in the same area, while there is some variability in current patterns under different wind conditions, flushing in this area is on average 7 times slower with the T3 development in place. While Vistula River water is less likely to enter the region between the T3 terminal and Stogi beach with the T3 terminal in place, once waterborne pollutants enter this area, they will take on average 7 times as long to be removed under natural influences. There is consequently a strong likelihood that this region will become a sink for litter and debris.

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Appendix A. Additional Satellite Imagery

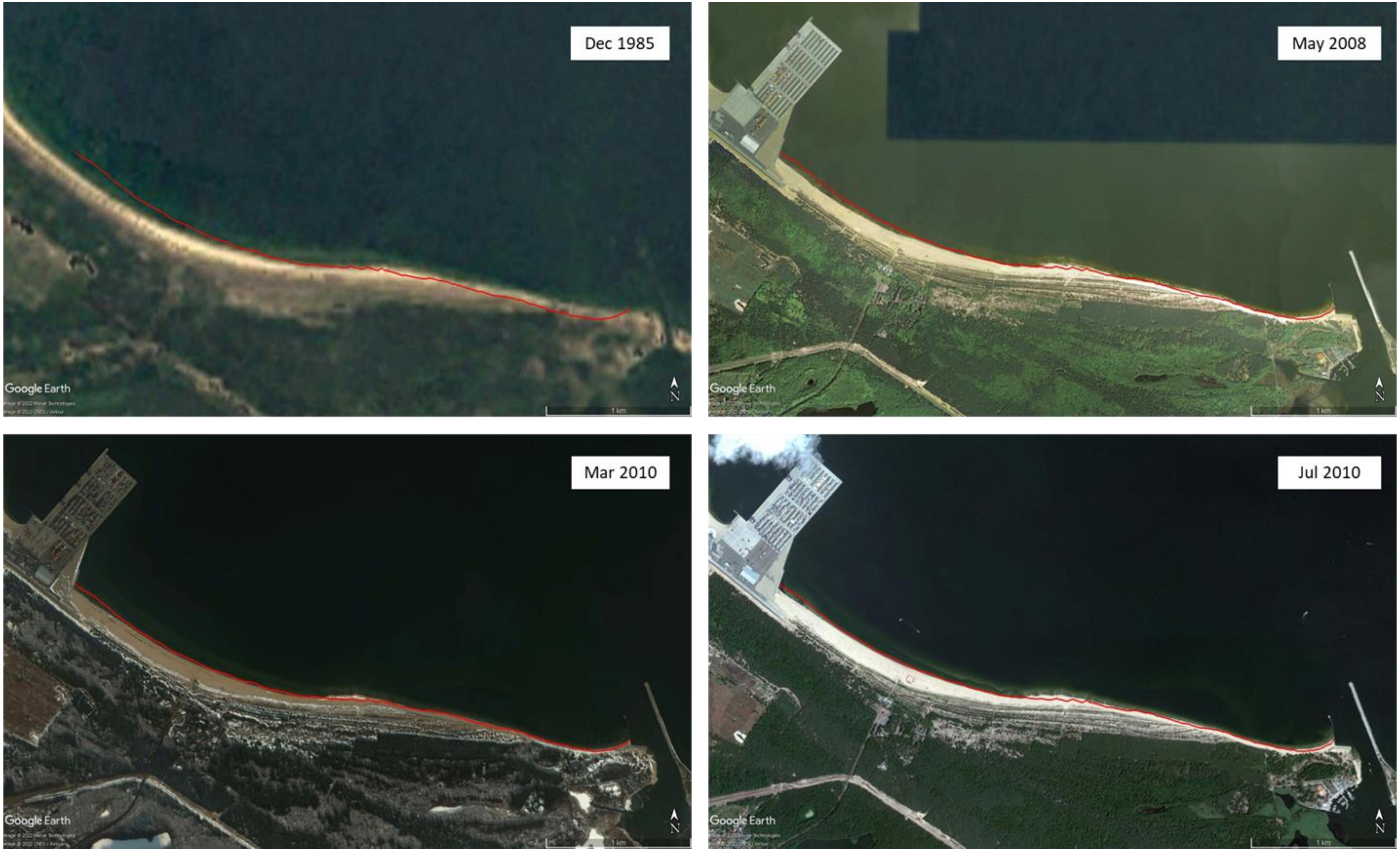


Figure 7.1: The evolution of the Stogi Beach shoreline. The red line indicates the shoreline in May 2018 for comparison. Source: Google Earth.

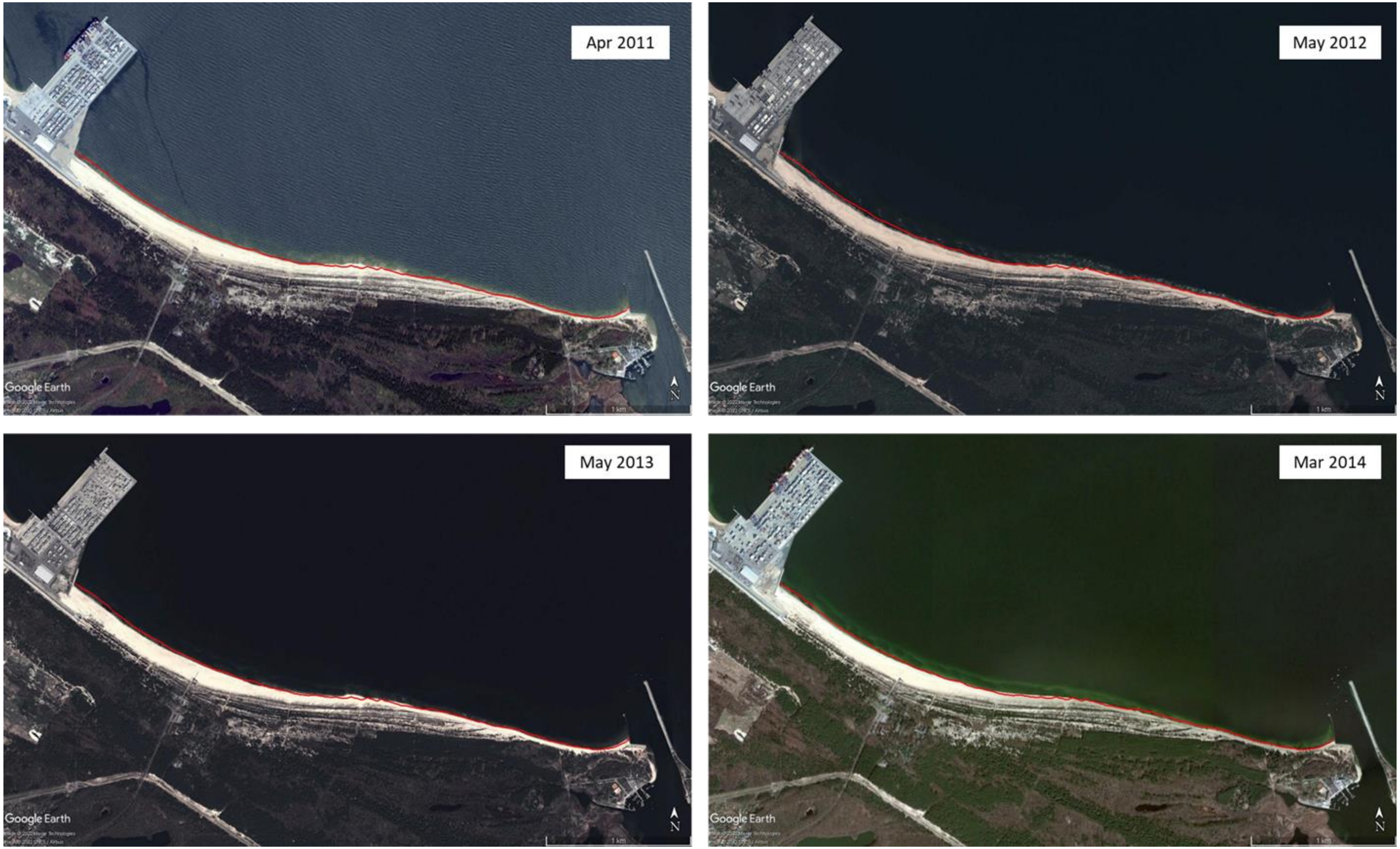
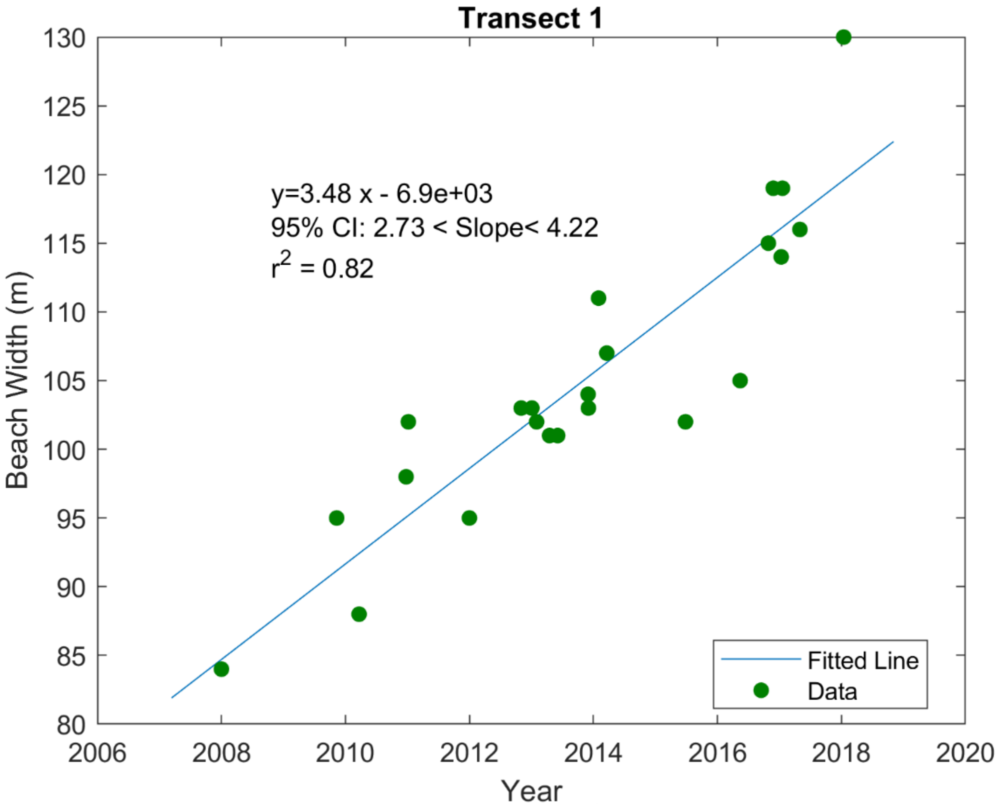


Figure 7.2: The evolution of the Stogi Beach shoreline. The red line indicates the shoreline in May 2018 for comparison. Source: Google Earth.

Figure 7.3: The evolution of the Stogi Beach shoreline. The red line indicates the shoreline in May 2018 for comparison. Source: Google Earth.

Appendix B. Stogi Beach Width Evolution



Transect 1

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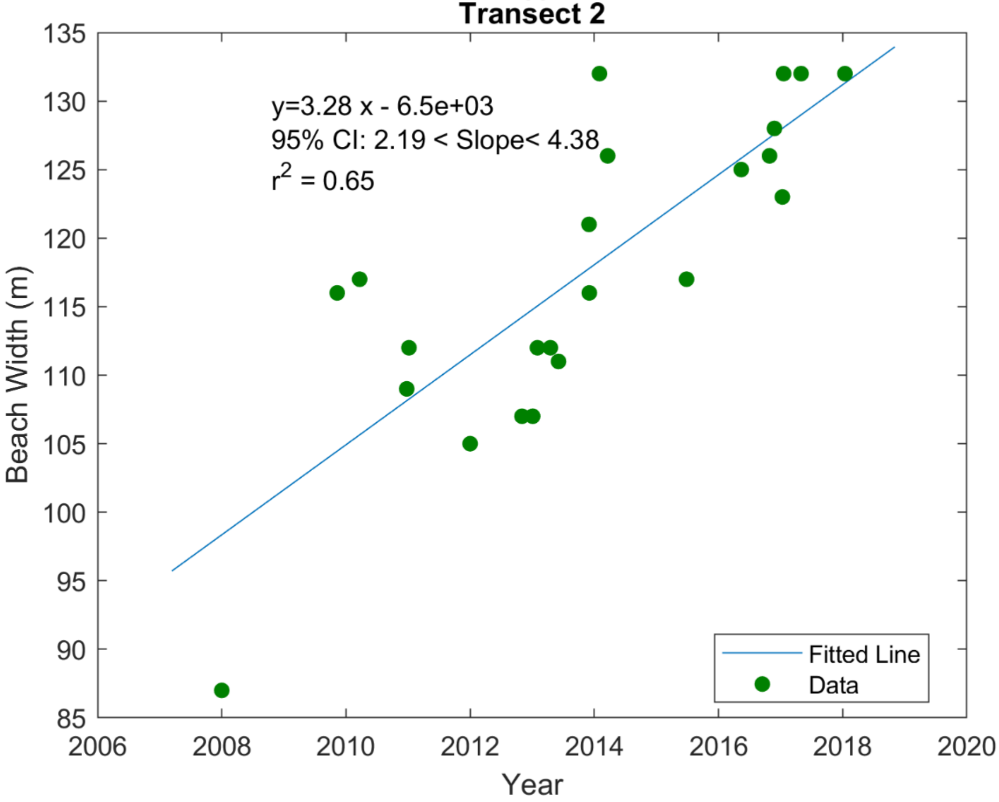
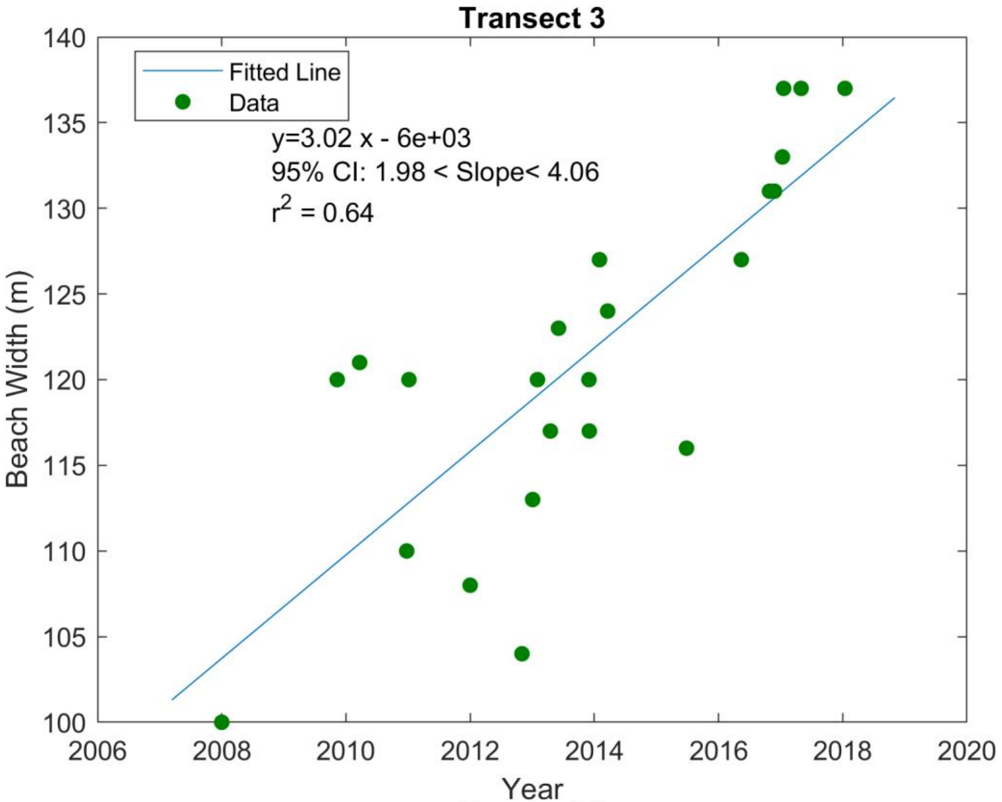
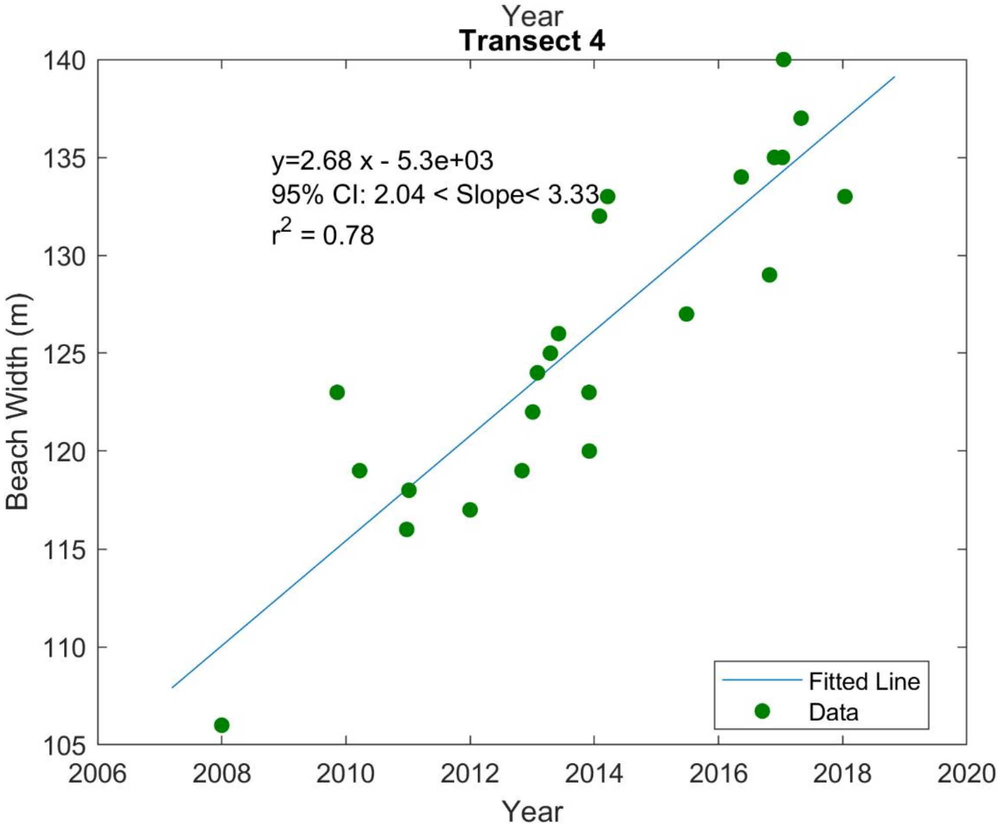
95% CI: 2.73 < Slope< 4.22
$r^2 = 0.82$

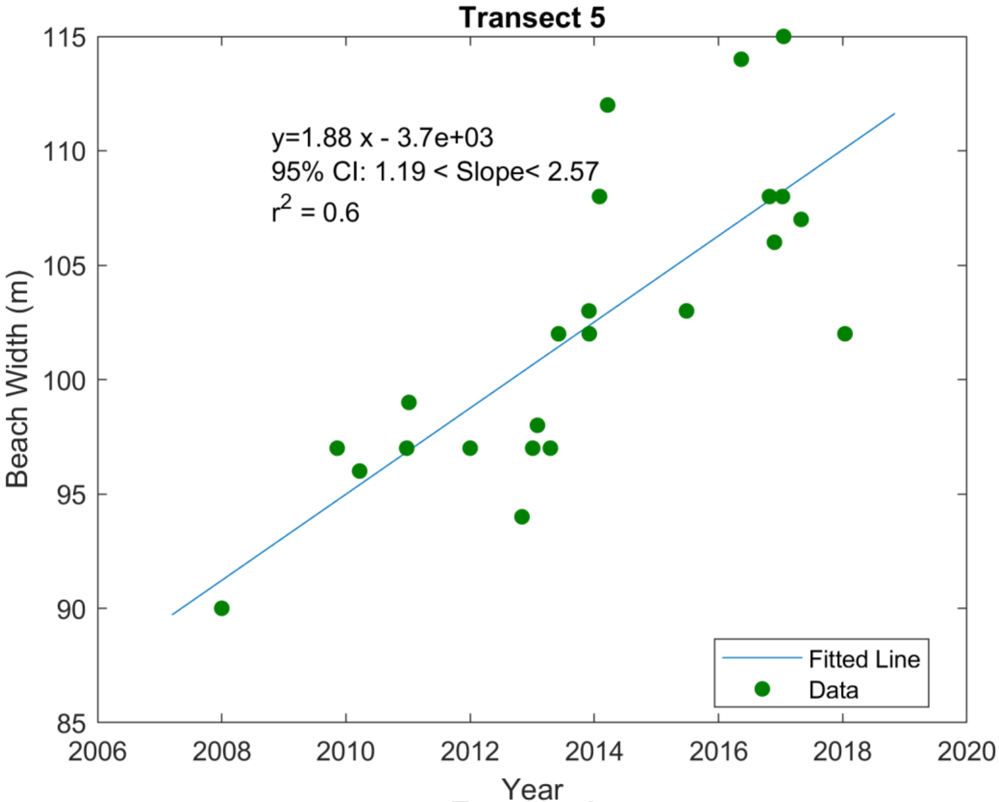


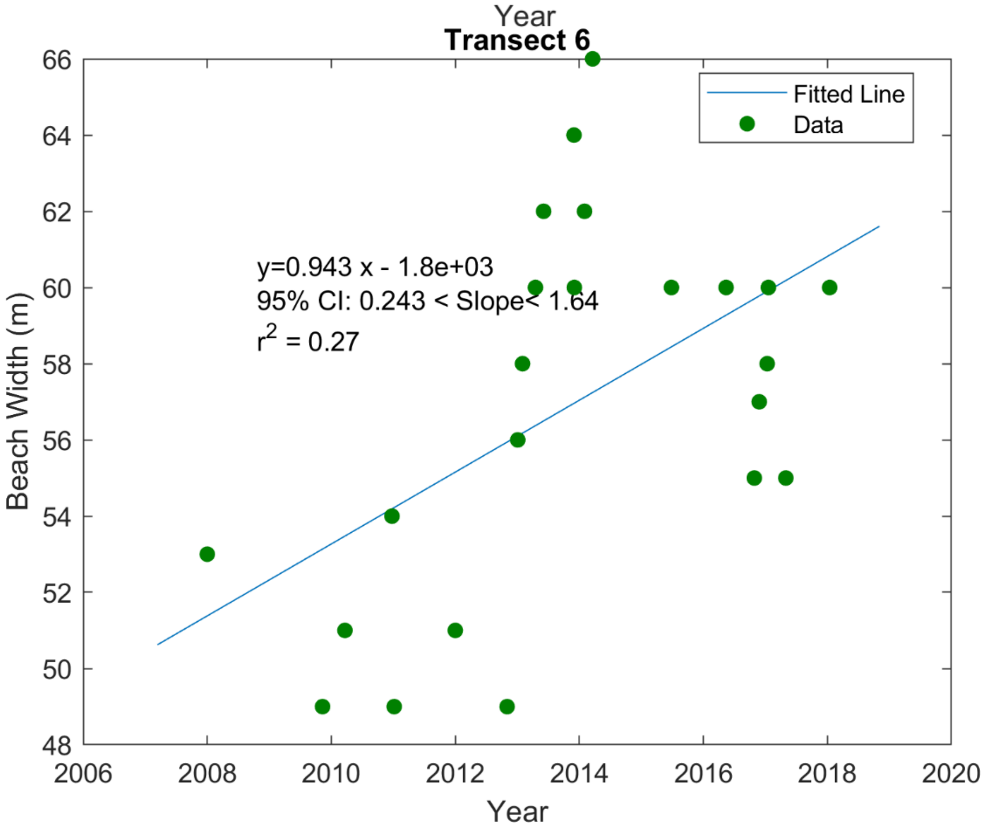
Transect 2

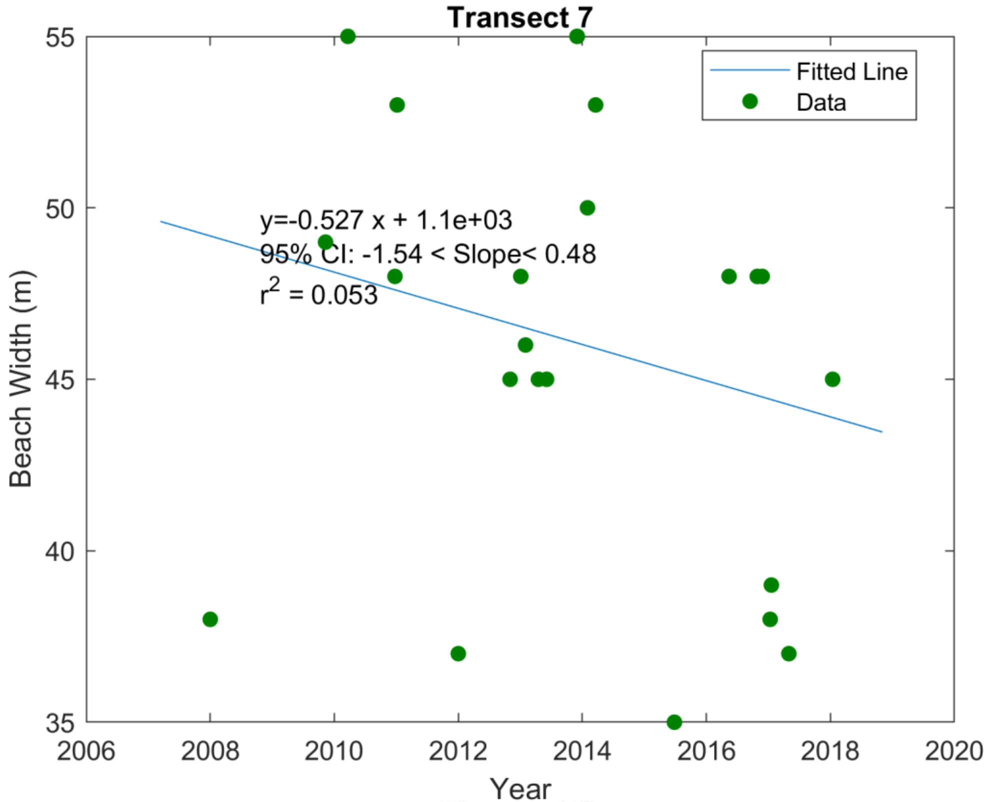
y=3.28 x - 6.5e+03
95% CI: 2.19 < Slope< 4.38
$r^2 = 0.65$


Transect 3
Fitted Line
Data
y=3.02 x - 6e+03
95% CI: 1.98 < Slope< 4.06
r2 = 0.64
Beach Width (m)
140
135
130
125
120
115
110
105
100
2006
2008
2010
2012
2014
2016
2018
2020
Year


Transect 4
y=2.68 x - 5.3e+03
95% CI: 2.04 < Slope< 3.33
r2 = 0.78
Fitted Line
Data
Beach Width (m)
140
135
130
125
120
115
110
105
2006
2008
2010
2012
2014
2016
2018
2020
Year


Transect 5
y=1.88 x - 3.7e+03
95% CI: 1.19 < Slope< 2.57
r2 = 0.6
Fitted Line
Data
Beach Width (m)
Year
115
110
105
100
95
90
85
2006
2008
2010
2012
2014
2016
2018
2020


Transect 6
y=0.943 x - 1.8e+03
95% CI: 0.243 < Slope< 1.64
r2 = 0.27
Fitted Line
Data
Beach Width (m)
Year
66
64
62
60
58
56
54
52
50
48
2006
2008
2010
2012
2014
2016
2018
2020


Transect 7
Fitted Line
Data
y=-0.527 x + 1.1e+03
95% CI: -1.54 < Slope< 0.48
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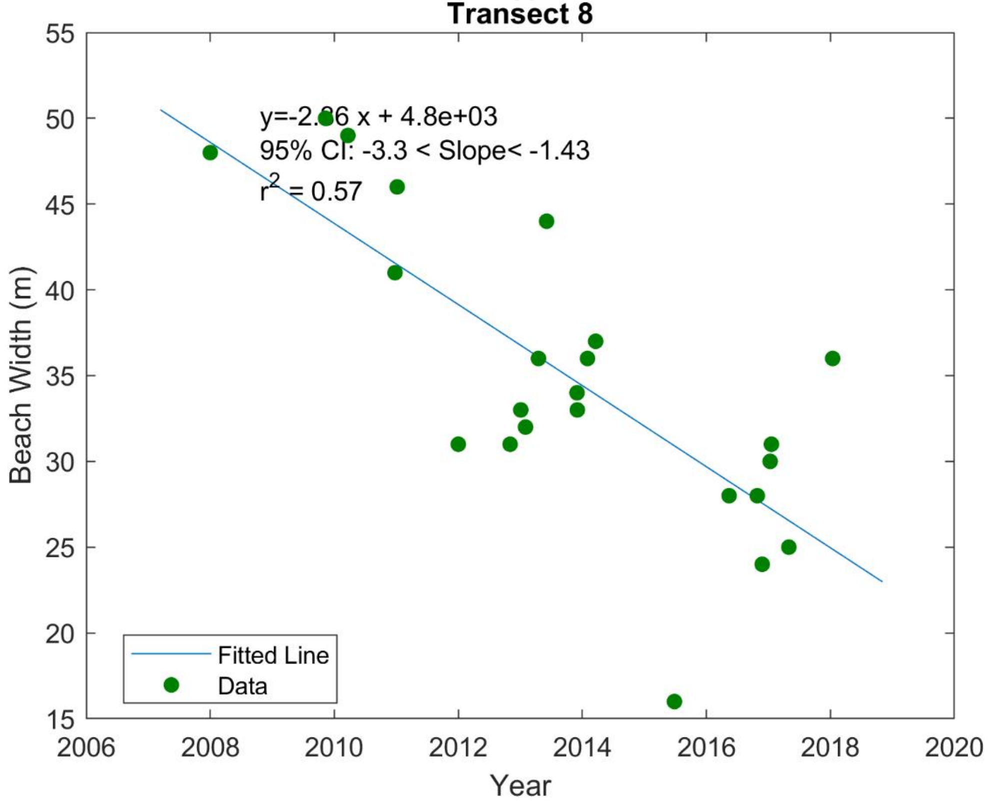
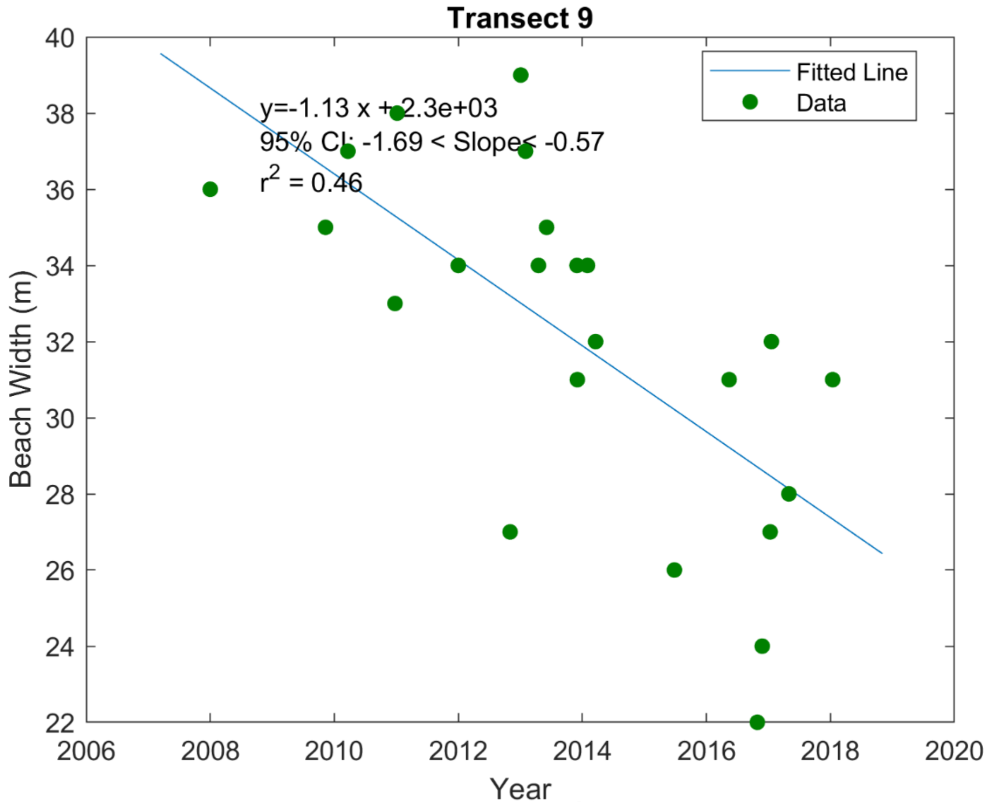
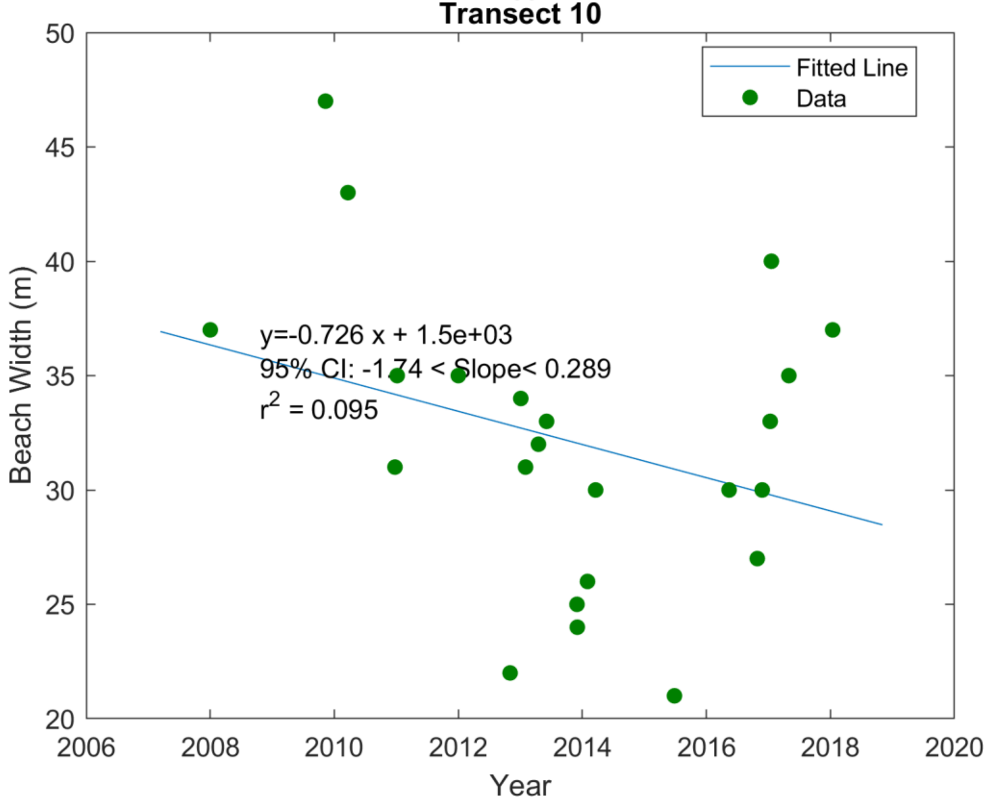
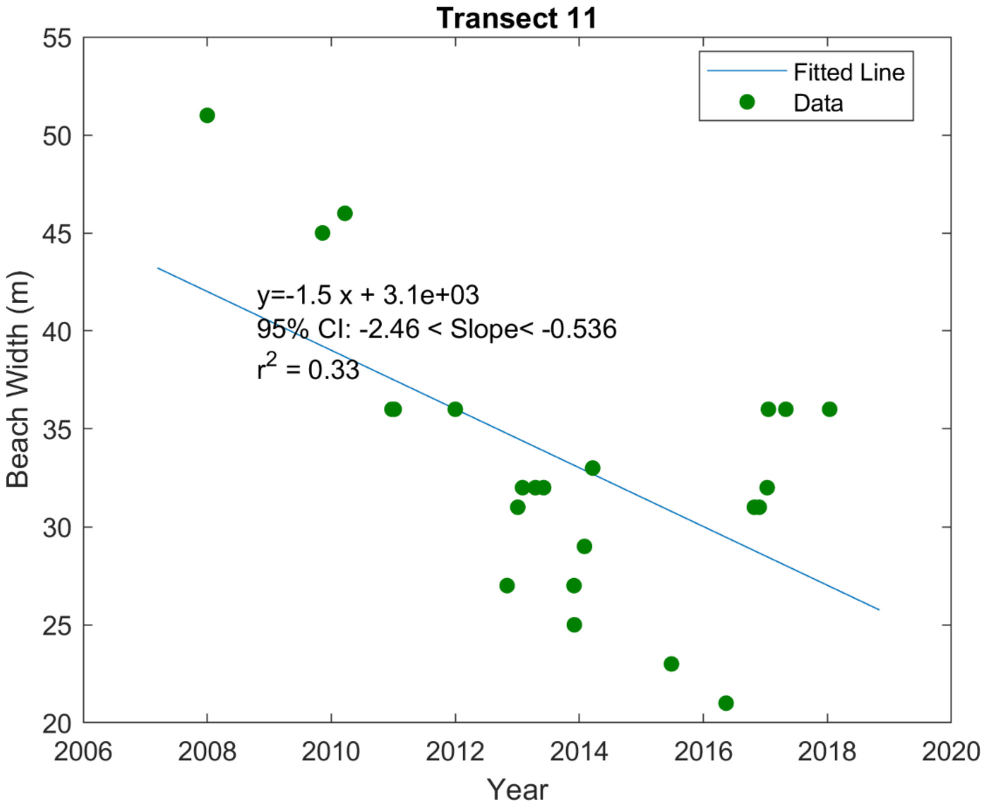
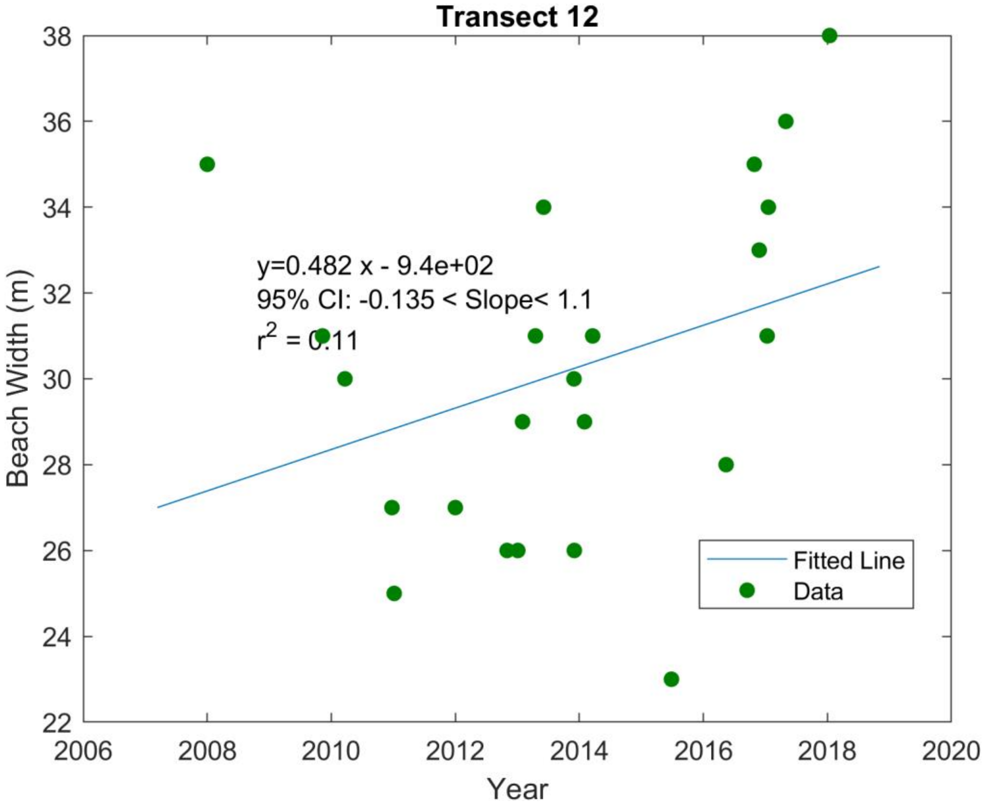
Beach Width (m)
55
50
45
40
35
2006
2008
2010
2012
2014
2016
2018
2020
Year

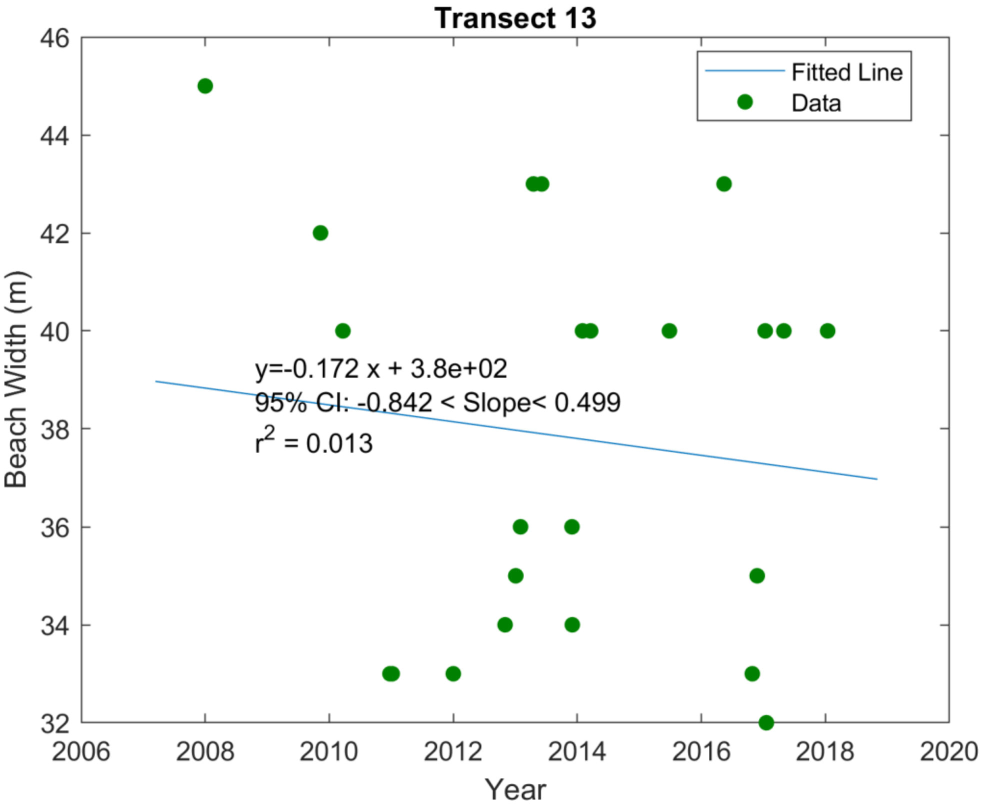

Transect 8
y=-2.36 x + 4.8e+03
95% CI: -3.3 < Slope< -1.43
r2 = 0.57
Fitted Line
Data
Beach Width (m)
55
50
45
40
35
30
25
20
15
2006
2008
2010
2012
2014
2016
2018
2020
Year

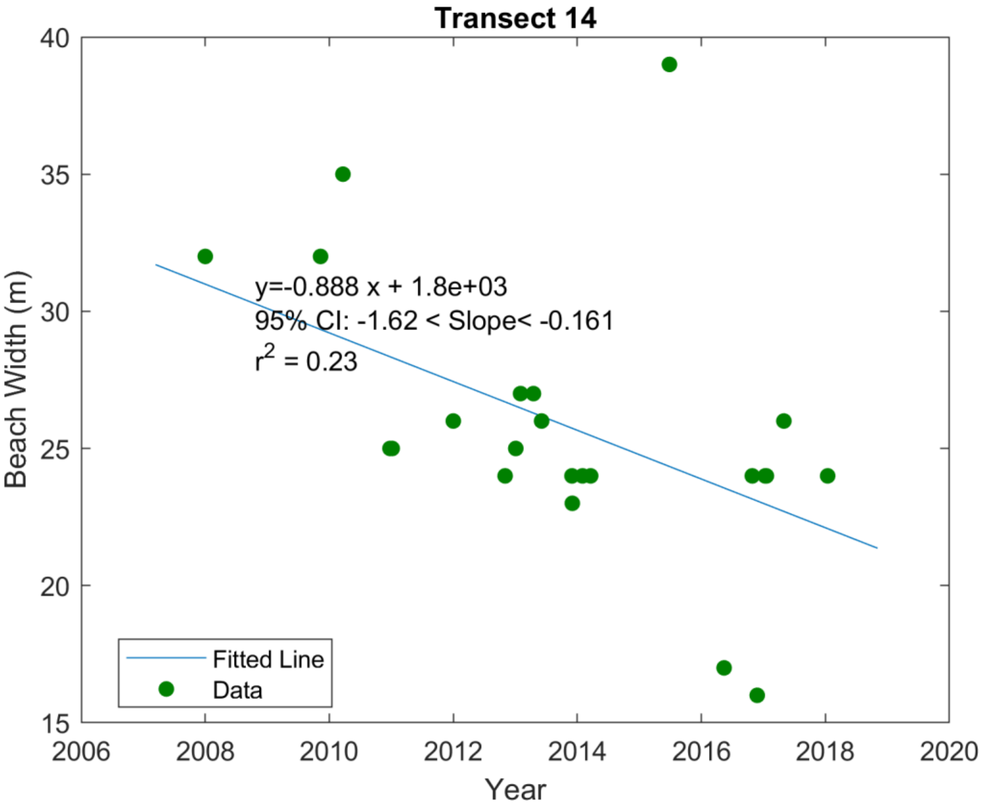

Transect 9


Transect 10


Transect 11
Fitted Line
Data
y=-1.5 x + 3.1e+03
95% CI: -2.46 < Slope< -0.536
r2 = 0.33
Beach Width (m)
55
50
45
40
35
30
25
20
2006
2008
2010
2012
2014
2016
2018
2020
Year

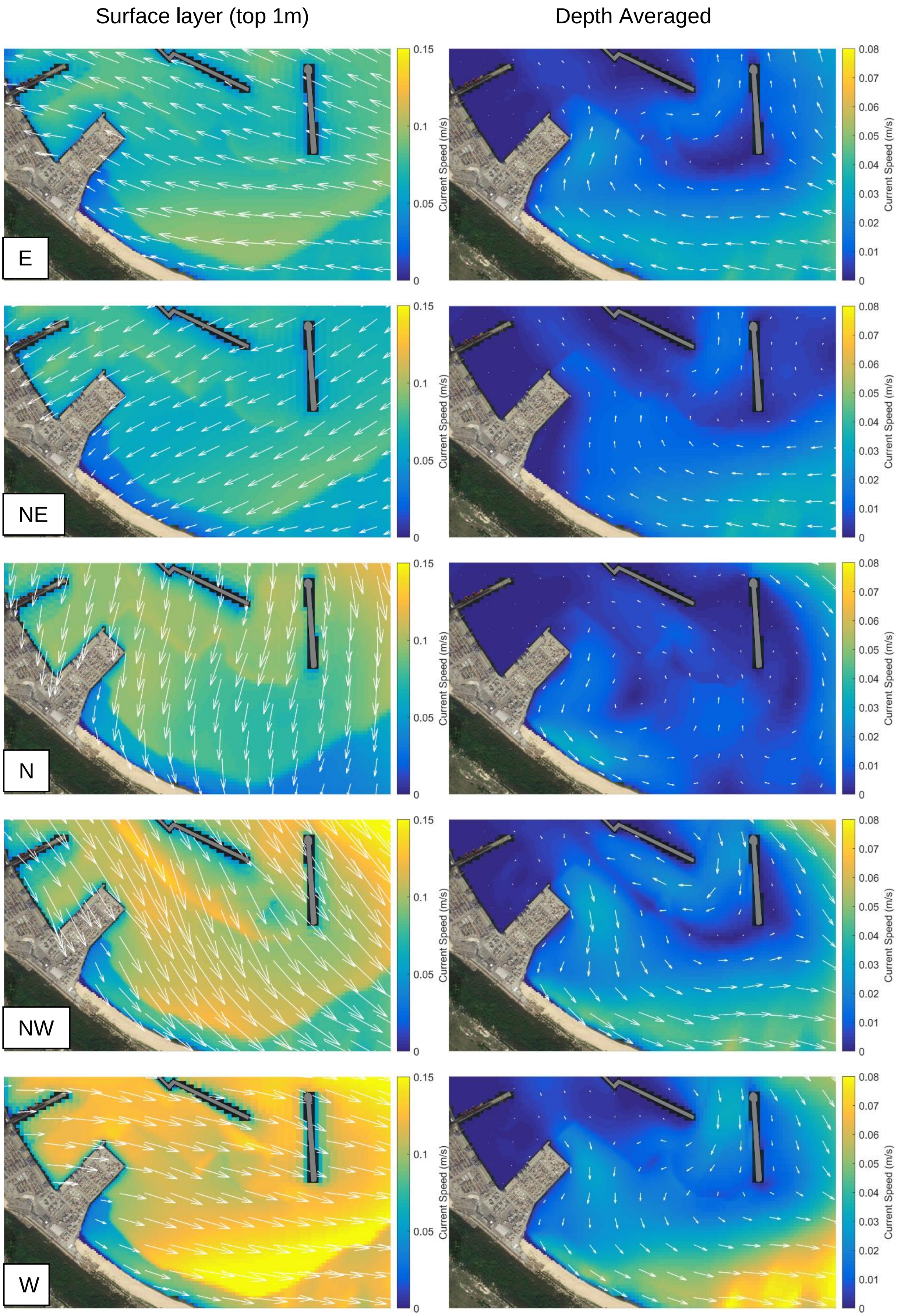

Transect 12
y=0.482 x - 9.4e+02
95% CI: -0.135 < Slope< 1.1
r2 = 0.11
Fitted Line
Data
Beach Width (m)
38
36
34
32
30
28
26
24
22
2006
2008
2010
2012
2014
2016
2018
2020
Year

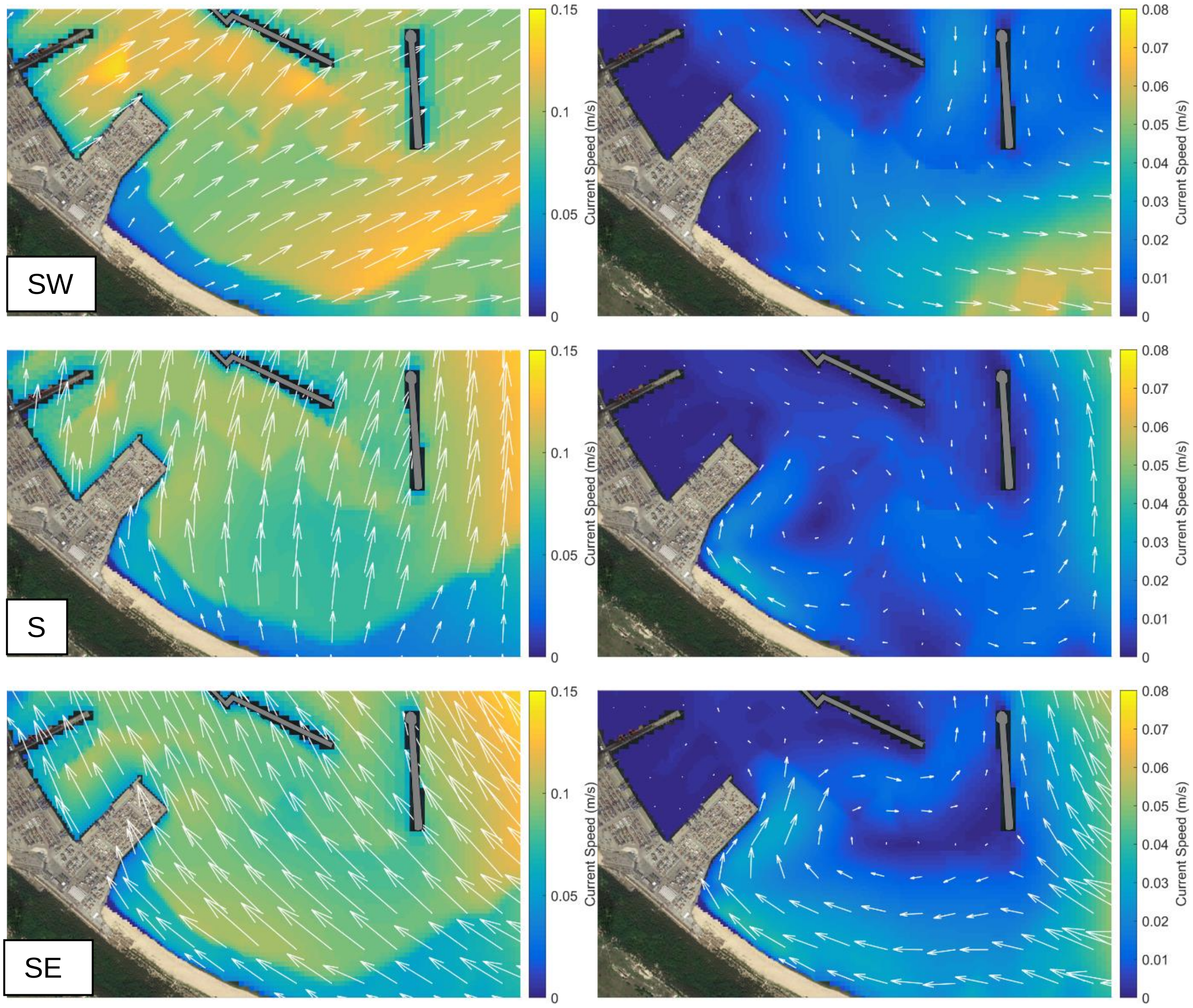

Transect 13
Fitted Line
Data
y=-0.172 x + 3.8e+02
95% CI: -0.842 < Slope< 0.499
r2 = 0.013
Beach Width (m)
Year
46
44
42
40
38
36
34
32
2006
2008
2010
2012
2014
2016
2018
2020


Transect 14
Fitted Line
Data
y=-0.888 x + 1.8e+03
95% CI: -1.62 < Slope< -0.161
r2 = 0.23
Beach Width (m)
Year
40
35
30
25
20
15
2006
2008
2010
2012
2014
2016
2018
2020

Appendix C. Currents at the T3 Terminal

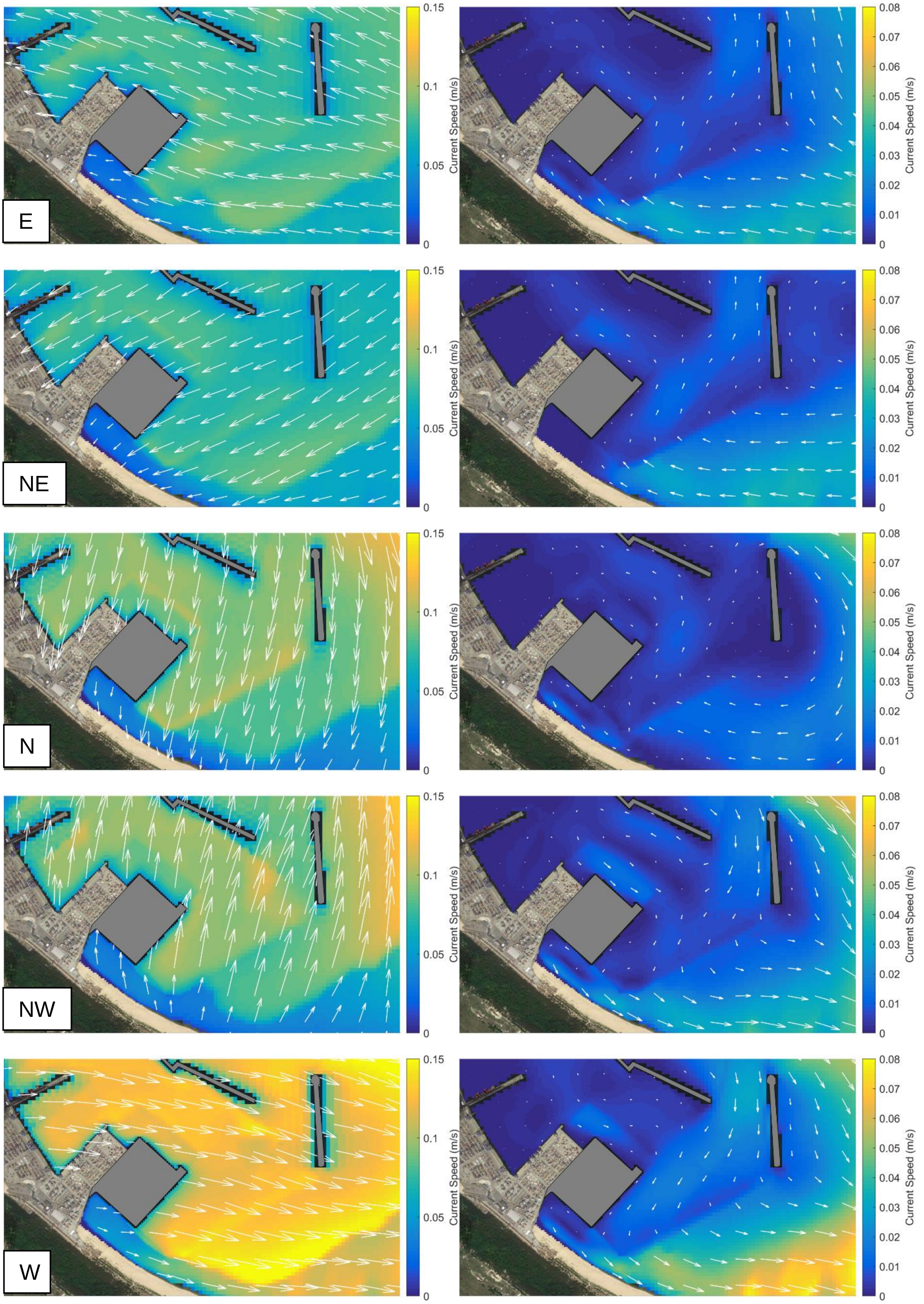
Present Scenario

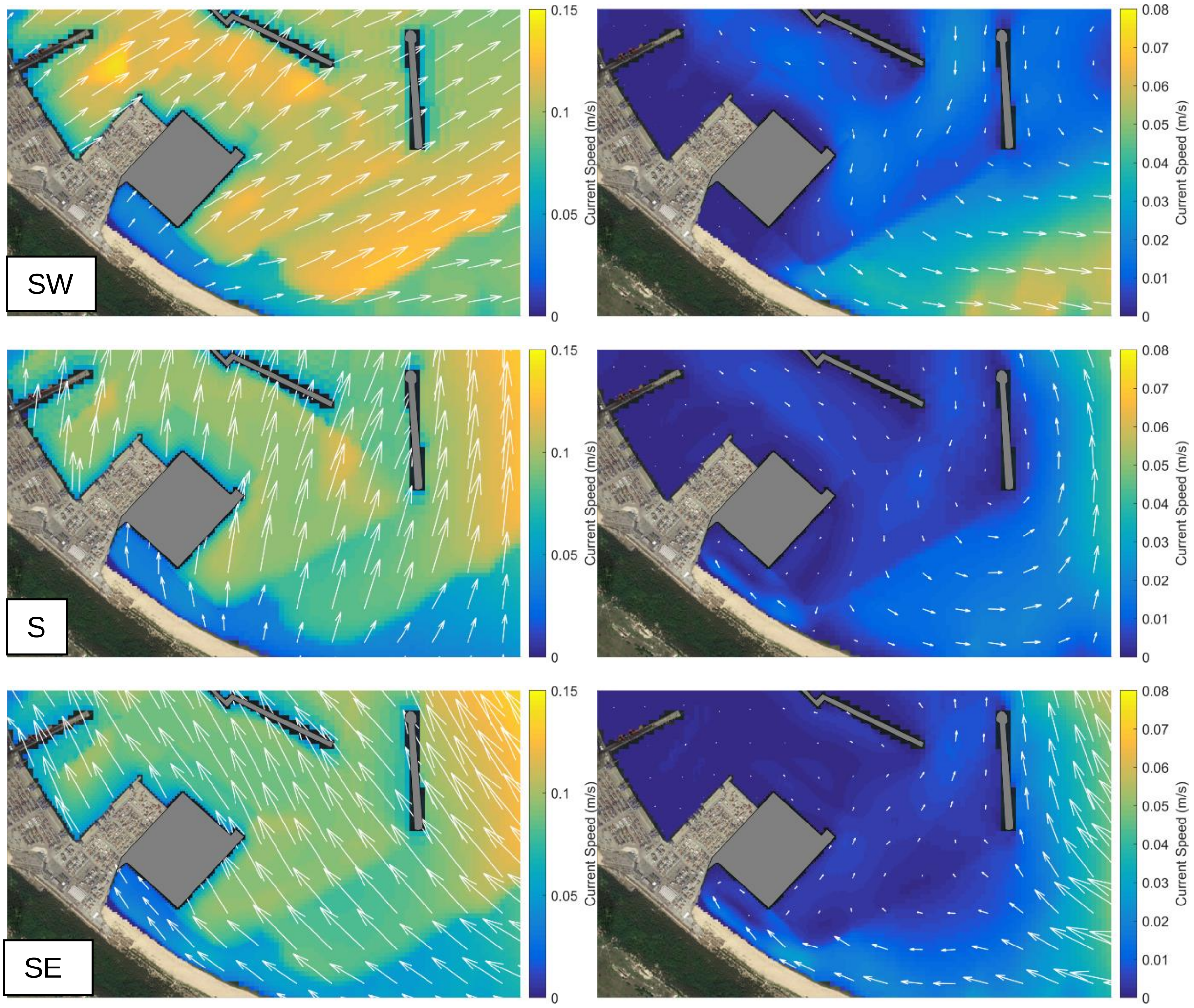



SW
S
SE
0.15
0.1
0.05
0
Current Speed (m/s)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Current Speed (m/s)

Future Scenario

Surface layer (top 1m) Depth Averaged




SW
S
SE
Current Speed (m/s)
0.15
0.1
0.05
0
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0