ABERDEEN HARBOUR
EXPANSION PROJECT
November 2015

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Technical
Appendices

APPENDIX 7-B WATER QUALITY MODELLING ASSESSMENT

FUGRO EMU LIMITED

ABERDEEN HARBOUR EXPANSION PROJECT

WATER QUALITY ASSESSMENT

Report Reference. P1974_RN3858_Rev3

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SUMMARY

Aberdeen Harbour Board (AHB) is looking at the potential expansion of harbour facilities at Nigg Bay, Aberdeen. Fugro EMU Limited (Fugro) is carrying out an Environmental Impact Assessment (EIA) on behalf of AHB for the proposed expansion. This report has been prepared for Fugro by Intertek Energy and Water Consultancy Services (Intertek) in support of the EIA, assessing modelled water quality impacts of the proposed expansion with respect to the Water Framework Directive (WFD) and other relevant legislation. These investigations include the impacts at identified sensitive sites near the development as given below:

- Nigg Bay Site of Special Scientific Interest (SSSI)
- Cove SSSI
- River Dee Special Area of Conservation (SAC)
- Ythan Estuary and Sands of Forvie draft Special Protection Area (SPA)
- Aberdeen Ballroom Bathing Water (BW)

The aim of this water quality modelling assessment is to understand existing baseline conditions and to predict impacts from the developed harbour over its lifetime. The relative difference between the baseline and developed scenarios was calculated to determine the magnitude of the impacts on the sensitive sites that would result as a consequence of the planned harbour expansion.

METHOD

The pre-existing Aberdeen coastal model was enhanced around Nigg Bay to predict impacts and support the assessment of water quality parameters. This two-dimensional (2D), depth-averaged hydrodynamic model was initially constructed for water quality studies in the Aberdeen area for Scottish Water and accepted as fit for purpose by the Scottish Environment Protection Agency (SEPA). For the harbour expansion assessment, the bathymetry and model grid resolution in the Nigg Bay area were updated and refined so as to accurately represent greater detail of significant features and the proposed harbour structures. Two configurations of the Aberdeen coastal model were created. One represented the existing (baseline) condition; and the other represented the operational phase (i.e. with the proposed harbour expansion in place).

The Aberdeen coastal model was used to represent:

1) The behaviour of discharged plumes using a conservative tracer

2) The residence time of water within Nigg Bay

This modelling was undertaken for the baseline and operational configurations so that comparisons could be made.

RESULTS

TRACER MODELLING

The tracer modelling showed that pollutant concentrations within the proposed harbour expansion were predicted to increase as a consequence of harbour development for the majority of water quality parameters. Dilutions for discharges within and close to the proposed harbour (United Fish Products, East Tullos Burn and Ness Tip Burn) are predicted to decrease following harbour expansion. Dilutions of effluent from the St Fittick's Field Combined Sewer Overflow (CSO) were also predicted to decrease due to the southern breakwater acting as barrier to the transport of discharges from the CSO and redirecting effluent into the harbour under flood tide conditions.

RESIDENCE TIME MODELLING

The residence time modelling results show that the expansion of the harbour is predicted to impact on the flushing of Nigg Bay/Harbour. Under baseline conditions, 90% of initial 'bay' water is predicted to have been flushed from the bay in six hours, while for the post development scenario; only 10% of 'bay' water is predicted to be flushed after this time.

CONCLUSIONS

From the above modelling results, it can be concluded that the water quality impacts of the proposed harbour expansion, in general remain local to the proposed development. With lower dilutions and longer residence times predicted for the developed scenario, discharges into the harbour will have a greater impact than at present. Outside the harbour, the construction of the breakwaters will deflect the tidal streams further offshore, further increasing the residence times of substances near the proposed harbour expansion.

This pattern of water quality impacts is replicated across the tracer and residence time assessments, with failures or deteriorations generally predicted within or adjacent to the proposed harbour, but with low impacts or even slight water quality improvements beyond this area.

The modelling studies demonstrate that in general, detrimental impacts are retained within the proposed harbour. Should the predicted local impacts be unacceptable to regulators, the most effective mitigation measures would be to ensure that discharges are made outwith the new harbour area via rerouted outfalls. This is likely to be the case with the United Fish Products (UFP) outfall, but no alternative location has been decided at the time of completing this report. Further consideration to harbour flushing could also be given at the detailed design stage.

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TABLES

FIGURES

ABBREVIATIONS

2d	Two-dimensional
AA	Annual Average
ACM	Aberdeen Coastal Model
AD	Advection and Dispersion
AHB	Aberdeen Harbour Board
BOD	Biochemical Oxygen Demand
BW	Bathing Water
CSO	Combined Sewer Overflow
D&B	Design and Build
DIA	Drainage Impact Assessment
DIN	Dissolved Inorganic Nitrogen
dl	decilitre
DO	Dissolved Oxygen
EA	Environment Agency
EC	Escherichia coli
EIA	Environmental Impact Assessment
EQS	Environmental Quality Standard
ES	Environmental Statement
FM	Flexible Mesh
FRA	Flood Risk Assessment
FWR	Foundation for Water Research
HD	Hydrodynamic
HDM	Hydrodynamic Modelling
Intertek	Intertek Energy and Water Consultancy Services
LSO	Long Sea Outfall
MAC	Maximum Allowable Concentration
MPS	Minimum Performance Specifications
PAH	Polycyclic Aromatic Hydrocarbon
SAC	Special Area of Conservation
SEPA	Scottish Environment Protection Agency
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UFP	United Fish Products

WFDA	Water Framework Directive Assessment
WQ	Water Quality
WwTW	Wastewater Treatment Works

1 INTRODUCTION

Intertek Energy & Water Consultancy Services (Intertek) was commissioned by Fugro Emu Limited (Fugro) to undertake a range of technical studies that will inform the relevant chapters of an Environmental Impact Assessment (EIA). Fugro are carrying out the EIA work on behalf of Aberdeen Harbour Board (AHB) for the proposed expansion of Aberdeen Harbour at Nigg Bay, Aberdeen. Further details are presented in Section 1.2. This report has been prepared by Intertek, and summarises investigations into the impact that the development would have on water quality compliance with the Water Framework Directive (WFD).

1.1 PROJECT BACKGROUND

Aberdeen Harbour Board has proposed the design and construction of a new harbour facility at Nigg Bay, immediately south of the existing harbour. The purpose of the new facility is to complement and expand the capabilities of the existing harbour, accommodate larger vessels, retain existing custom, and attract increased numbers of vessels and vessel types to Aberdeen.

The new harbour development shall include but is not limited to:

- Dredging the existing bay to accommodate vessels up to 9 m draft with additional dredge depth of 10.5 m to the east quay and entrance channel;
- Construction of new North and South breakwaters to form the harbour;
- Provision of approximately 1,500 m of new quays and associated support infrastructure. The quay will be constructed with solid quay wall construction and suspended decks over open revetment;
- Construction of areas for development by others to facilitate the provision of fuel, bulk commodities and potable water;
- Land reclamation principally through using materials recovered from dredging operations and local sources, where possible;
- Provision of ancillary accommodation for the facility;
- Off-site highway works to the extent necessary to access the facility and to satisfy statutory obligations; and
- Diversions and enabling works necessary to permit the development.

The current proposed option for the Aberdeen Harbour expansion at Nigg Bay is shown in Figure 1-1. The construction of the Aberdeen Harbour Expansion Project will be let under a Design & Build (D&B) contract. AHB has defined Minimum Performance Specifications (MPS) that the completed harbour would need to meet, in respect of a number of aspects such as minimum draft, length of solid-faced quayside and protection from overtopping of the breakwaters (waves breaking over the top of the breakwaters). Under the terms of the contract, D&B contractors are free to employ the methods and technologies of their choosing to meet the MPS, provided they are legal, within the parameters of the assessed Rochdale Envelope and in accordance with any consent conditions. AHB will not appoint a contractor until consent for the development has been granted. For this reason, it is not possible to state with complete certainty at the time of writing what methods the chosen contractor will use. Therefore the assessments in this study have been made employing the Rochdale Envelope approach. This approach makes realistic assumptions about the development, but will tend towards conservatism (in terms of potential impacts) where there is presently uncertainty regarding the precise details of the project.

1.2 Scope of Present Assessment

The technical studies included in Intertek's commission are:

- Hydrodynamic Modelling (HDM). This topic covers currents, waves and sediment dynamics / coastal processes.
- Flood Risk Assessment (FRA). This topic includes coastal flooding.
- Drainage Impact Assessment (DIA).
- Water Quality Assessment (WQA). This topic includes plume dispersion and water quality studies.

This report details the WQA relating to tracer plume dispersion and water quality studies. These plume dispersion and water quality studies provide information to the wider WFDA, which is reported separately [1].

The following designated sites in the immediate vicinity of the proposed expansion have been identified:

- Nigg Bay Site of Special Scientific Interest (SSSI)
- Cove SSSI
- River Dee Special Area of Conservation (SAC)
- Ythan Estuary and Sands of Forvie draft Special Protection Area (SPA)
- Aberdeen Ballroom Bathing Water (BW)

These sites are indicated on Figure 1-1.

1.3 Purpose of Report

This report has been prepared by Intertek on behalf of Fugro. It includes the elements of the WFDA which relate to plume dispersion and water quality. It sets out the method and results of the water quality assessment, reporting the baseline and operational scenarios for the proposed harbour.

1.4 Overview of Approach

The technical studies covered by this report were carried out using a range of supporting data sources and a variety of analysis techniques.

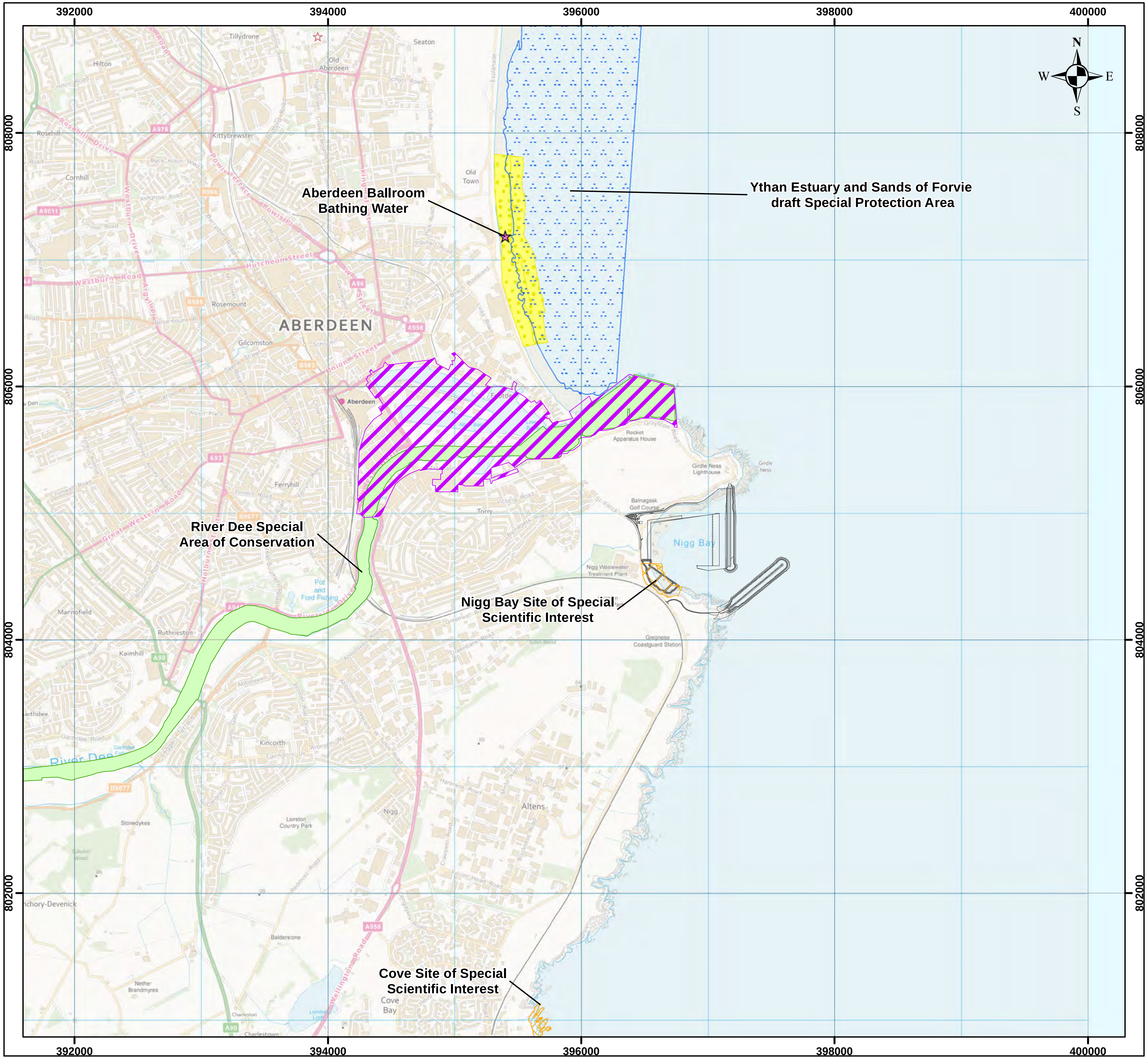
A key component of these studies is the use of complex environmental modelling to aid the following project aims:

- Define existing conditions (baseline scenario).

- Predict impacts due to the proposed development over its lifetime (operational scenario).
- Evaluate the magnitude of these impacts on the local and regional environment, in particular in terms of relative impacts on designated sites.

The key modelling tool used in this work is a coastal modelling system covering Nigg Bay and the surrounding area known as the Aberdeen coastal model.

Figure 1-1 provides a geographic overview of the area of interest.



ABERDEEN HARBOUR EXPANSION PROJECT

Figure 1-1: Geographic overview of the area of interest

Legend

- Aberdeen Harbour Expansion Project area
- Existing Aberdeen Harbour Area
- Special Area of Conservation
- Site of Special Scientific Interest
- Draft Special Protection Area
- Bathing Water Monitoring Location
- Aberdeen Ballroom Bathing Water

NOTE: Not to be used for Navigation

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Created By	Emma Langley
Reviewed By	Ian Charlton
Approved By	Kevin McGovern

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0 0.2 0.4 0.8 1.2 1.6 km

2 NUMERICAL MODELS

2.1 OVERVIEW

This water quality study has been undertaken using a combination of hydrodynamic (HD) and water quality (WQ) models. Together, these models constitute the Aberdeen coastal model.

The Aberdeen coastal model is owned by Scottish Water and was constructed for water quality studies in the Aberdeen area. It was accepted as fit for water quality modelling at the nearby bathing waters by the Scottish Environment Protection Agency (SEPA) following calibration and validation for bathing water studies. For the purposes of the Nigg Bay assessment, the model has been updated with the latest bathymetry data available from AHB. Furthermore, the spatial resolution of the model in the Nigg Bay area has been refined so as to more accurately represent the fine detail of the local environment and the proposed harbour structures.

The Aberdeen coastal model has been built to comply with relevant modelling guidelines and standards including:

- The Foundation for Water Research (FWR) 'Framework for Marine and Estuarine Model Specification in the UK' [2]; and
- SEPA's 'Supporting Guidance WAT-SG-11 – Modelling Coastal and Transitional Discharges', which includes 'SEPA Standards for Models' [3].

The Aberdeen coastal model has been used to assess a range of conditions covering water levels, currents and water quality.

The model is constructed within the MIKE21 modelling software. The software is made up of a number of modules that are designed to address different physical processes, either alone or in combination. Areas of application are wide-ranging and, with reference to the Nigg Bay harbour water quality study, include:

- Hydrodynamics (water levels and currents)
- Water quality

2.2 HYDRODYNAMIC MODEL

The hydrodynamic module of the Aberdeen coastal model supplies the hydrodynamic inputs that drive water quality modelling. The model domain encompasses Nigg Bay, Aberdeen Harbour and the rivers Dee and Don up to their tidal limits. The model has been accepted by SEPA for hydrodynamic and water quality studies, and has been permitted by Scottish Water to be used in this study.

The model calibration and validation used a variety of data sources, some in the public domain and some collected specifically for the model development. These data included water levels, current velocities, drogue tracks, dye patch traces and current velocity vector maps. The model performance against these field data was evaluated statistically and found to exceed the guideline performance criteria published by FWR (1993) [2]. These criteria are used widely throughout the UK for evaluating hydrodynamic models of this type. It was concluded that the model was fit for use in hydrodynamic and water quality studies covering the wide scale (geographically and temporally) required for the EIA.

The coastal hydrodynamic model is a two-dimensional (2D) depth-averaged model constructed using an unstructured, flexible mesh (FM). It uses the MIKE21 FM software package. All hydrodynamic processes relevant to the large scale EIA (water levels, tidal current speeds and direction) can be simulated. As the Nigg Bay area is relatively shallow and well mixed, a 3D model is considered unnecessary.

For the harbour expansion studies, the hydrodynamic model has been updated as follows:

- The latest bathymetry data for the Nigg Bay area has been used. These data have been provided by AHB. For other areas of the model, the existing model bathymetry has been adopted (see Figure 2-1).
- The layout of the proposed development has been based on Option 6, as provided by AHB (see Figure 1-1 for an outline of this option and for a more detailed representation).
- The resolution of the model mesh has been greatly improved in key areas of the model, particularly at Nigg Bay. This allows the proposed development, and the physical processes affected by the development, to be modelled in appropriate spatial detail for an EIA.

Two model meshes have been used to undertake the required water quality impact assessment. The first represents the existing (baseline) condition without the proposed harbour extension in place (Figure 2-1). The second represents the operational phase with the Option 6 development in place, and with accompanying changes to both the Nigg Bay coastline and the local water depths (Figure 2-2).

2.2.1 Tidal conditions

The Nigg Bay area currently has a meso tidal range (spring tidal range is between 2 m and 4 m), with a mean spring tidal range of 3.7 m and a mean neap tidal range of 1.8 m (Aberdeen). The highest astronomical tidal range can reach 4.8 m (Aberdeen). Model results indicate that water levels in Nigg Bay are not significantly different from the water level recorded at Aberdeen.

Figure G-1 shows the peak flood and ebb tidal current predicted under mean spring tide conditions for the baseline. Peak tidal currents under mean neap tide conditions are presented in Figure G-2. Plots in two different spatial scales are given in the figures, to show tidal current in a large extent beyond the development area and detailed current patterns around the development area (Nigg Bay).

Model results indicate that current speeds experience a large variation across the development area due to the presence of the headlands, with speeds up to about 0.6 m/s on both the flooding and ebbing spring tides in the outer bay and 0.1 m/s or lower in the inner bay. On both flooding and ebbing neap tides current speeds in the outer bay are approximately 0.4 m/s and less than 0.1m/s in the inner bay.

Current speeds are more uniform offshore, with speeds of 0.5 m/s on both flooding and ebbing spring tides and 0.4 m/s on both flooding and ebbing neap tides.

A large eddy forms within Nigg Bay as a result of the shear flow around the headlands, the direction of which varies with the tides (clockwise on flood tides, and counter-clockwise on ebb tides). Current strengths are greater on flood tides than ebbing tides, under both spring and neap conditions.

Figure 2-1: Baseline model mesh and bathymetry at the Aberdeen Harbour expansion

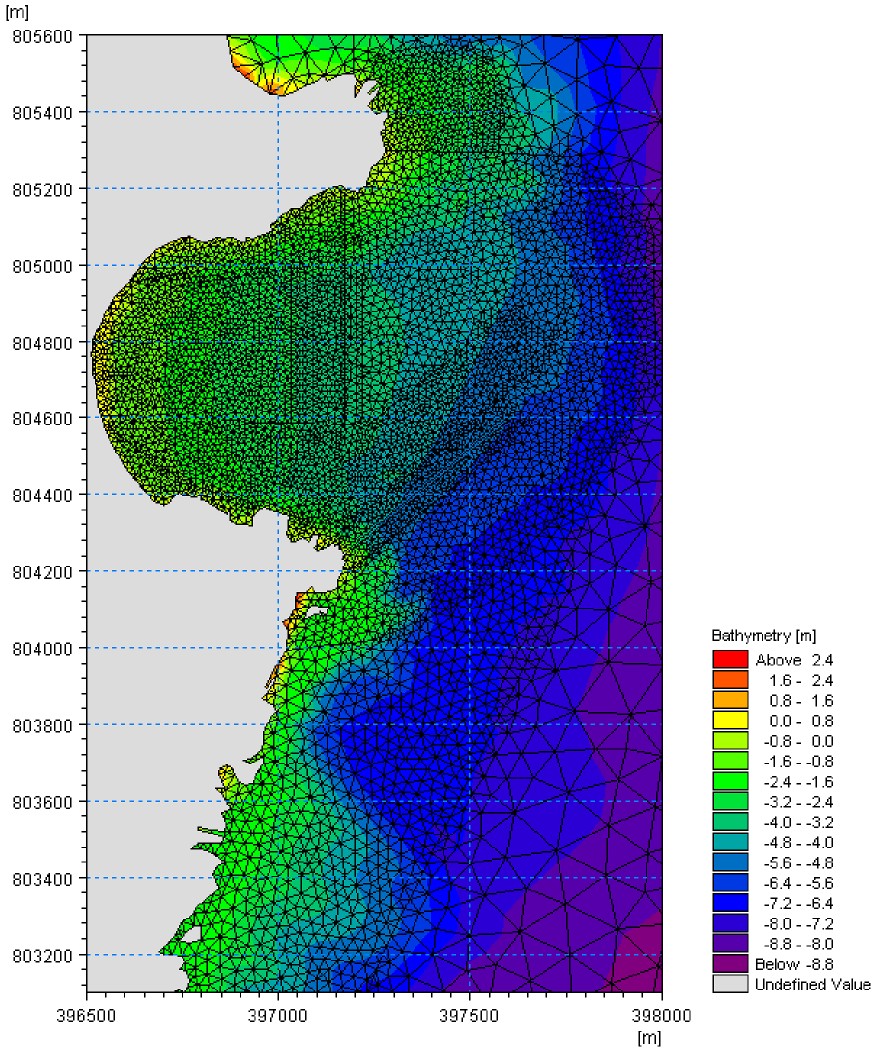
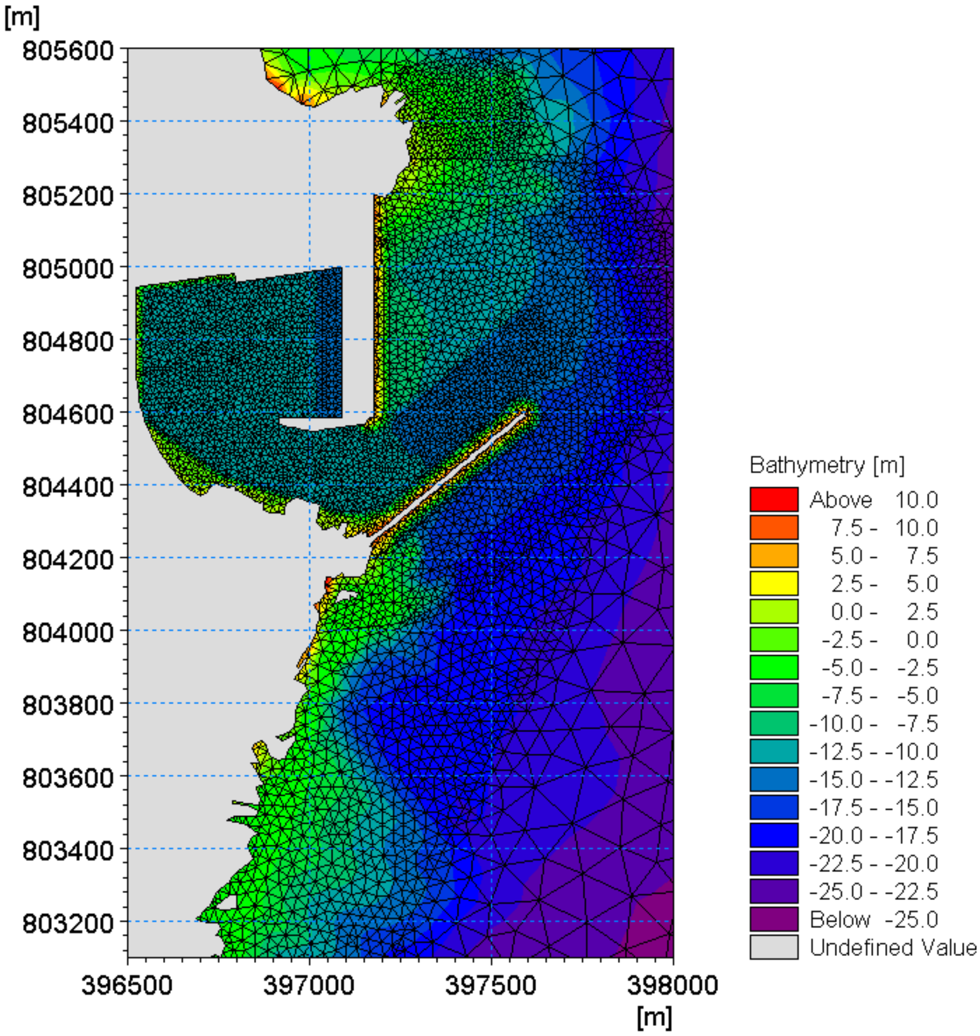


Figure 2-2: ACM showing operational phase mesh and bathymetry



2.3 WATER QUALITY MODEL

The Aberdeen coastal model contains a number of modules that may be used to assess water quality processes and impacts. The advection and dispersion (AD) module has been applied in this study.

The AD approach allows a wide array of water chemistry processes to be simulated. These may range from conservative assessments with no pollutant decay, through simple (exponential) decay, to complex water chemistry cycles (such as for oxygen and nutrients) involving large numbers of determinands governed by multiple dependent interactions.

Dissolved oxygen (DO) concentrations in the receiving waters have been modelled by considering three components:

- DO reduction due to the lower DO concentration of discharges to the water body;

- DO reduction due to the uptake of DO by the biochemical oxygen demand (BOD) component of each discharge; and
- DO reduction due to the uptake of DO by the oxidation of the ammonia component of each discharge.

The DO concentration in the receiving water is calculated by summing these three components of DO reductions. Re-aeration is applied to this calculated DO deficit and the resulting deficit is applied to the background DO water quality to provide an overall DO concentration across the model domain.

3 METHOD

3.1 OVERVIEW

Two methods of water quality assessment have been undertaken. These are:

- Tracer plume modelling, and
- Residence time modelling.

These methods are described in Sections 3.2 and 3.3 respectively.

The assessments have been undertaken to indicate the key changes to the dispersive behaviour of local discharges following the construction of the proposed harbour expansion.

The HD modelling has been carried out over a full spring-neap tidal period.

3.2 TRACER MODELLING

3.2.1 Objectives

The aim of the tracer modelling is to establish the nature (e.g. spatial extents and concentrations) of discharges released from eight selected locations in and around Nigg Bay (see Figure 3-1). The discharges do not represent real discharge events, but are hypothetical discharge events that allow comparisons of plume behaviour under the baseline and operational scenarios to be made. By comparing plume extents and concentrations before and after the development is in place, inferences can be made about potential impacts on water quality resulting from the development.

3.2.2 Tracer Model Processes

The tracer plume study made use of two modules of the Aberdeen coastal model:

- The HD model, which provides water level and current velocity information.
- The AD model, which is driven by the HD model and which tracks the movement and fate of the hypothetical tracer discharges.

The tracer modelling takes account of several key physical processes:

- Advection. This refers to transport by the prevailing currents. Suitable current flows were obtained from the HD model.
- Dispersion. This refers to mixing and spreading of the released tracer due to turbulence within the water column. Appropriate dispersion is specified within the Aberdeen coastal model, based on calibration of this parameter during model construction. In the dispersion calibration, Smagorinsky's formulation for dispersion has been applied with a scaling factor of one. In this formulation, the magnitude of the dispersion is proportional to current shear stress.
- Decay. The tracers have been modelled for four conditions:

a) no decay – appropriate for heavy metals and other conservative determinands

b) decay appropriate for escherichia coli [4](EC) (T90 = 20hr)

c) decay appropriate for biochemical oxygen demand [5](BOD) (0.196 day^{-1}))

d) decay appropriate for ammonia [5](NH4) (0.076 day^{-1})

3.2.3 Tracer Discharge Locations

Tracer plumes were discharged from five locations in and around Nigg Bay and from the three major rivers in the area (see Figure 3-1). These locations reflect discharges which have been identified during initial studies, representing both natural discharges (watercourses) and wastewater outfalls. Table 3-1 gives the location details of these discharges.

Table 3-1: Release locations for tracer plume modelling

Tracer release location	Discharge location (OSGB36)	
	Easting	Northing
East Tullos Burn	396548	804713
Ness Tip Burn	396686	804357
United Fish Products Limited (UFP) outfall*	396677	804700
Scottish Water – Nigg Wastewater Treatment Works (WwTW) Long Sea Outfall (LSO)	398826	804074
Scottish Water – St Fittick's Field Combined Sewer Overflow (CSO)	397357	805382
River Dee	392803	803403
River Don	393740	809226
River Ythan	396934	830324

*The UFP outfall is to be relocated post development. The final location has not as yet been confirmed, but the current location has been used in this assessment.

3.2.4 Plume Model Scenarios

The tracer plume model has been run for two development phases: the baseline condition and the operational condition. For each model configuration, the plume discharges were modelled under typical environmental conditions over a spring-neap tidal cycle. The tracer release locations have been modelled separately as continuous discharges, and these are also modelled over a full spring-neap tidal period.

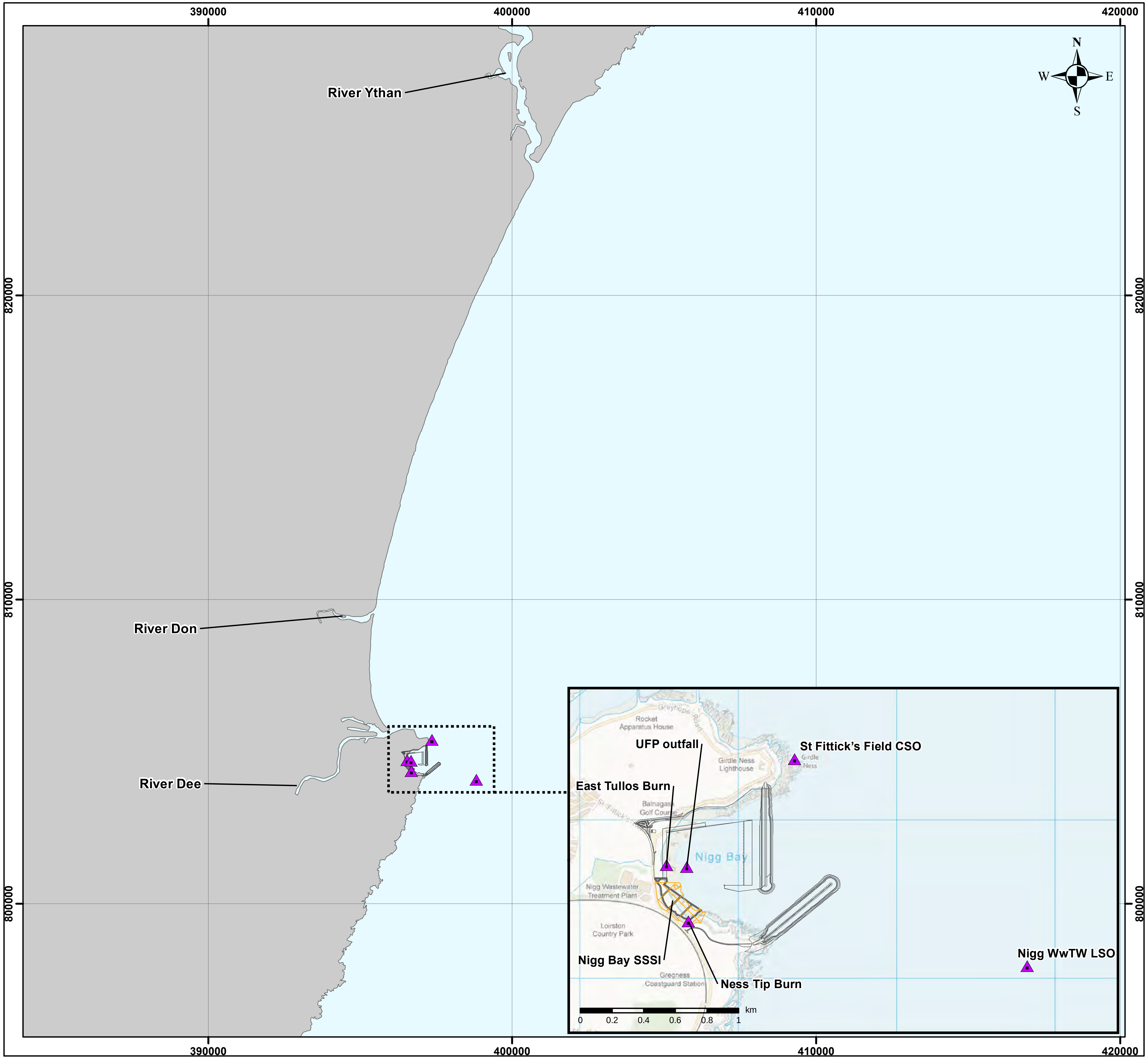


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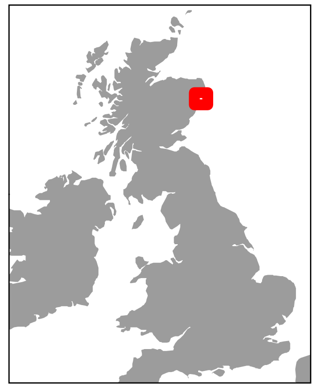
Figure 3-1: Discharge locations for tracer plume modelling

Legend

- Discharge Location
- Aberdeen Harbour Expansion
- SSSI



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Created By	Emma Langley
Reviewed By	Ian Charlton
Approved By	Kevin McGovern

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3.3 RESIDENCE TIME MODELLING

3.3.1 Objectives

The proposed Aberdeen Harbour expansion has the potential to alter residence times within the bay. Residence time describes the typical length of time that a pollutant will remain circulating within the bay before being flushed out by physical processes such as current advection and dispersion.

Long residence times may lead to a build-up of pollutants and a consequent deterioration in water quality. Conversely, they may prevent pollutants from directly impacting sensitive waters outside the bay, allowing an increased level of dispersion or decay prior to impact.

The residence time modelling assesses the typical residence time of the marine waters (and, by implication, substances within these waters) within Nigg Bay, both before and after the proposed development is in place. A comparison of residence times before and after the development allows inferences to be made about potential impacts on water quality resulting from the development.

3.3.2 Residence Time Model Processes

The residence time study used the HD modelling results to drive the AD model. Decay was not included in the residence time modelling to ensure that a conservative assessment is made.

3.3.3 Residence Time Model Scenarios

The residence time model was run for the baseline condition and the operational condition, allowing differences in residence time due to the development to be predicted.

For each model configuration, the plume discharges have been modelled under typical environmental conditions. These were represented by a mean spring-neap tidal cycle and mean river flows.

For each model run, the water held within the boundaries of Nigg Bay was set to a nominal concentration representing “pure” bay water, i.e. a concentration of 1 m^3/m^3 of bay water. All other water in the model domain (the offshore water) was set to have an initial concentration of 0 m^3/m^3 of bay water. As a model run progresses and the bay water mixes with the offshore water, the concentration of bay water within Nigg Bay itself decreases, while the concentration of bay water outside Nigg Bay rises. The rate at which this mixing of waters occurs has been used to generate an estimate for the typical residence time (or, equivalently, the flushing time) of Nigg Bay.

A comparison of residence times between the baseline and operational scenarios allows an assessment of the impact of the proposed development. This was achieved by extracting the percentage of bay water at each location shown on Figure 3-2 for each timestep and for both scenarios.

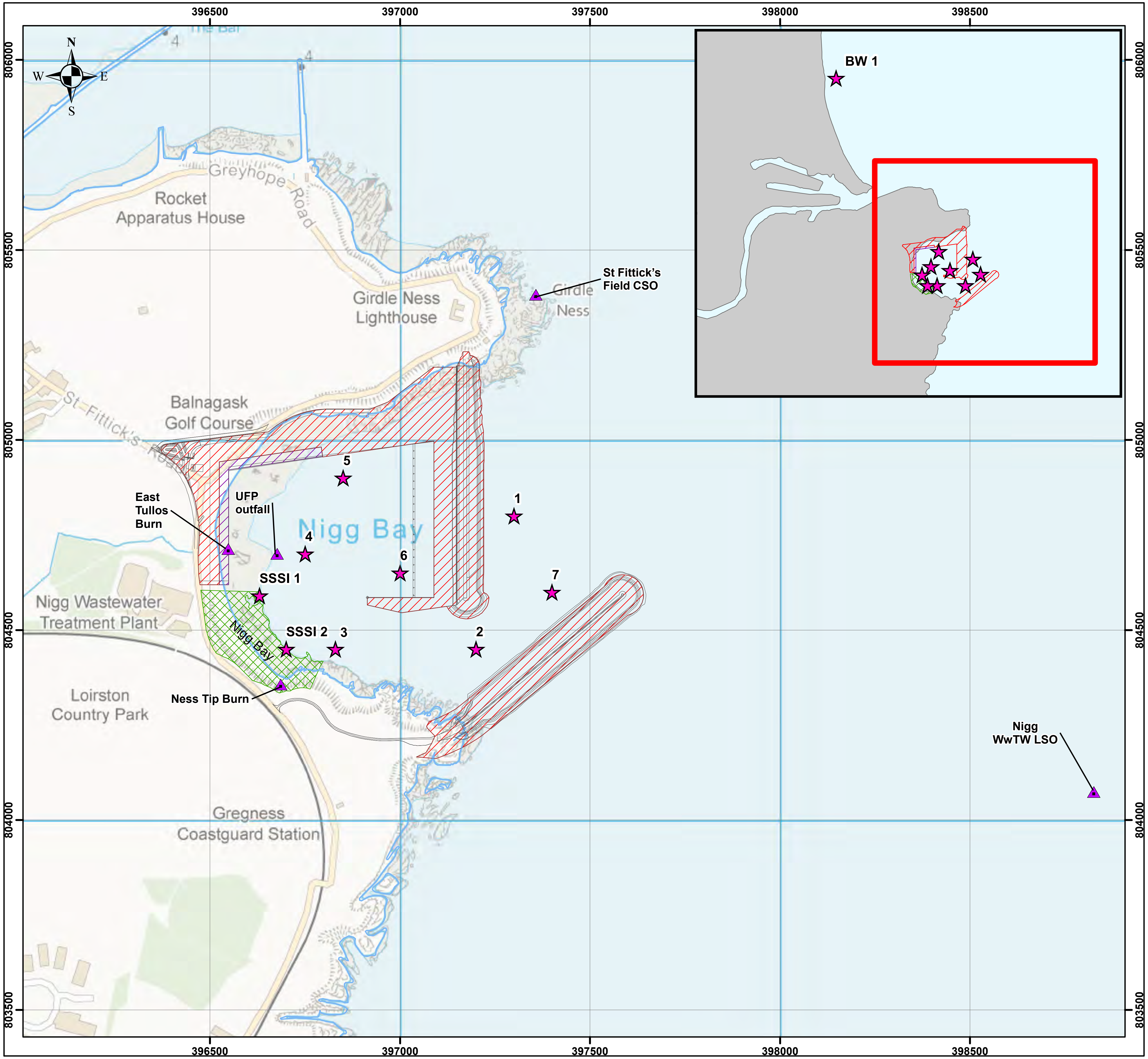

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Figure 3-2: Extraction points for water quality modelling

Legend

- WQ Extraction Locations
- Discharge Location
- Nigg Bay Harbour Layout
- Suspended Deck Structure
- SSSI

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Created By	Ian Charlton
Reviewed By	Emma Langley
Approved By	Paul Taylor

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0 100 200 300 400 m

4 WATER QUALITY STANDARDS

Relevant water quality standards used in the assessment and processing of modelled results are provided in Table 4-1. Some Environmental Quality Standards (EQSs) (for priority hazardous substances and specific other pollutants) were obtained from the relevant SEPA Guidance document [6]. Other water quality standards were obtained from the WFD UK Technical Advisory Group (UKTAG) standards [7] [8] and from Environment Agency (EA) guidance [9].

The water quality standards may be defined as annual average concentrations (AA) and/or maximum allowable concentrations (MAC) or 90%'ile or 95%'ile concentrations, depending on the relevant legislation or guidelines. The applicable method of measurement is given in Table 4-1 below.

Table 4-1: Water quality standards used in assessment

Parameters	SEPA WAT-SG-53 (Marine EQS)	WFD UKTAG Marine standard	WFD UKTAG Freshwater standard	WFD BW	EA	Values	Units
Anthracene	AA					0.1	(µg/l)
Anthracene	MAC					0.4	(µg/l)
Benzo(b/k)Fluoranthene	AA					0.03	(µg/l)
C10-13 Chloroalkanes	AA					0.4	(µg/l)
C10-13 Chloroalkanes	MAC					1.4	(µg/l)
Cadmium	AA					0.2	(µg/l)
Chromium	AA					0.6	(µg/l)
Chromium	95%'ile					32	(µg/l)
Copper	AA					5.09	(µg/l)
Hexachlorobutadiene	AA					0.1	(µg/l)
Hexachlorobutadiene	MAC					0.6	(µg/l)
Lead	AA					7.2	(µg/l)
Mercury	AA					0.05	(µg/l)
Mercury	MAC					0.07	(µg/l)
Phenol	AA					7.7	(µg/l)
Phenol	95%'ile					46	(µg/l)
Zinc	AA					7.9	(µg/l)
Ammonia	AA					1.1	(mg/l)
Ammonia					MAC	8	(mg/l)
BOD			90%'ile			5	(mg/l)
DIN		AA				0.42	(mg/l)
DO		95%'ile				4	(mg/l)
EC - Good				95%'ile		250	(ec/dl)
EC - Excellent				95%'ile		500	(ec/dl)
Unionised ammonia	AA					21	(µg/l)

5 DISCHARGES

The water quality assessment was carried out for the eight release locations presented in Table 3-1. These represent the three principal effluent discharges in the vicinity and five watercourses.

5.1 FLOW

The mean flow for each discharge was determined using the best available data and is provided in Table 5-1.

Table 5-1: Estimated mean flows

Discharge	Flow (m^3/s)	Method of calculation / Data source
East Tullos Burn	0.02	Hydrology calculations from donor catchment
Ness Tip Burn	0.002	Hydrology calculations from donor catchment with assumed catchment area
UFP outfall	0.72	From consent document SEPA variation to consent to discharge [10]
Nigg WwTW LSO	1.4	From SEPA consent document [11]
St Fittick's Field CSO	0.5	Based on the 95%'ile flow in previous study [12]
River Dee	46.99	Mean flow from CEH flow data [13]
River Don	21.14	Mean flow from CEH flow data [14]
River Ythan	8.23	Mean flow from CEH flow data [15]

It should be noted that the flow for St Fittick's Field CSO has been conservatively modelled as a continuous discharge over a spring-neap tidal cycle. In reality, CSO discharges are intermittent in nature; therefore the modelled input represents a worst case scenario.

5.2 WATER QUALITY

The concentrations of water quality parameters were assessed for each of the discharges. The concentrations used in the water quality modelling are presented in Table 5-2. Details of the data sources are provided in Appendix A. Where sufficient data existed, average values were used.

Wherever possible, measured data have been used to represent the pollutant concentrations for each discharge. However, for two determinands estimates have been used:

- Dissolved oxygen (DO). The dissolved oxygen discharge concentrations have been estimated for:

  a) East Tullos Burn (4.5 mg/l) this concentration was selected based on the UKTAG [7] Poor standard for lowland rivers of 45% saturation, taking into account a saturation DO concentration of 10 mg/l.

  b) Ness Tip Burn, UFP outfall, Nigg LSO, St Fittick's Field CSO (0 mg/l). These dissolved oxygen concentrations are conservative.

    - Sampling in the Ness Tip Burn has shown this watercourse to carry a high contaminant load [16]. This has been reflected in this very low estimated DO concentration.

- Sampling at the UFP outfall similarly shows high BOD and ammonia concentrations [16]. This has been reflected in this very low estimated DO concentration.
- No measured data were available for the St Fittick's Field CSO. DO concentrations in CSO discharges, particularly at the beginning of the spill event, are low due to the high ammonia and BOD concentrations and the suspension of bed sediment with its accompanying sediment oxygen demand. This has been reflected in this conservative estimate.
- No measured data were available for Nigg WwTW effluent. DO concentrations in the effluent from wastewater treatment works is typically low and further oxygen will be taken up by BOD and the oxidation of ammonia in the transit of the effluent from the WwTW to the offshore discharge point. This has been reflected in this conservative estimate.

The modelling has assumed a background concentration of 9 mg/l of dissolved oxygen (a typical winter value).

- The EC concentrations have been estimated for all discharges using conservative industry standard concentrations dependent upon the type of discharge. These values have been widely applied and previously agreed with SEPA as acceptable for bathing and shellfish water studies.

The determined concentrations were modelled for both the baseline and post-construction cases, allowing a comparison between the baseline and post-construction cases.

Table 5-2: Modelled concentrations

Parameter	East Tullos Burn	Ness Tip Burn	UFP Outfall	Nigg WwTW LSO	St Fittick's Field CSO	River Dee	River Don	River Ythan
EC (ec/dl)	500	1×10^5	2×10^6	1×10^6	2×10^6	500	500	500
BOD (mg/l)	2.25	3.50	91.10	25	20.7	1.2	3	1.4
Total ammonia (mg/l)	1.07	43.82	20.50	25	2.8	0.025	0.465	0.044
DIN (mg/l)	2	15	100	50	30	5	5	5
DO (mg/l)	4.5	0	0	0	4.5	7.3	8.0	8.3
Cadmium (µg/l*)	0.04	0.045	1.0	0.051	0.102	0.019	0.019	0.019
Chromium (µg/l)*	0.0	0.0	6.57	0.0	0.0	0.243	0.243	0.243
Copper (µg/l)*	13.225	18.5	8.5	7.6	47.5	0.0	0.0	0.0
Mercury (µg/l)*	0.0	0.0	0.242	0.0024	0.01	0.0	0.0	0.0
Lead (µg/l)*	0.95	2.9	0.2	0.55	3.06	0.107	0.107	0.107
Zinc (tot) (µg/l)	13.5	42.5	4.1	34.0	178.9	0.0	0.0	0.0
Phenol (µg/l)	0.5	0.5	29.7	0.0	0.0	0.0	0.0	0.0
Benzo(b/k)Fluoranthene (µg/l)	0.0275	0.0325	0.0	0.07	0.7	6.5	6.5	6.5
Anthracene (µg/l)	0.0375	0.0175	0.0	0.06	2	3.262	1.9	1.92
C10-13 Chloroalkanes (µg/l)	3.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0
Hexachlorobutadiene (µg/l)	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
PAHs (µg/l)	0.095	0.085	3.0	2.039	10.195	3.262	1.9	1.92

* - Note: The metals marked "*" have been measured as total concentrations rather than dissolved metal concentrations. The EQSs have been set in term of dissolved metal concentrations. The solubility of these metals is, in general low, (see Appendix F) and thus the approach taken is conservative. Zinc however is unique among the metals under consideration here, as its EQS is set in terms of its total rather than the dissolved concentration.

In order to understand the proportion of each substance that originates from each source, a table of water quality parameter loads has been prepared. These percentage loads are presented in Table 5-3.

Table 5-3: Modelled Loads

Parameter	East Tullos Burn	Ness Tip Burn	UFP Outfall	Nigg WwTW LSO	St Fittick's Field CSO	River Dee	River Don	River Ythan
EC	0.000%	0.005%	37.129%	36.097%	25.784%	0.606%	0.273%	0.106%
BOD	0.019%	0.003%	27.068%	14.443%	4.271%	23.270%	26.172%	4.755%
Total ammonia	0.034%	0.140%	23.565%	55.878%	2.235%	1.876%	15.694%	0.578%
DIN	0.007%	0.006%	13.361%	12.990%	2.784%	43.600%	19.615%	7.636%
DO Deficit	0.070%	0.014%	5.054%	9.827%	1.755%	62.301%	16.487%	4.493%
Cadmium	0.035%	0.004%	31.384%	3.112%	2.223%	38.917%	17.508%	6.816%
Chromium	0.000%	0.000%	20.314%	0.000%	0.000%	49.036%	22.061%	8.588%
Copper	0.648%	0.091%	14.996%	26.071%	58.194%	0.000%	0.000%	0.000%
Mercury	0.000%	0.000%	95.422%	1.840%	2.738%	0.000%	0.000%	0.000%
Lead	0.179%	0.055%	1.353%	7.237%	14.381%	47.258%	21.261%	8.277%
Zinc (tot)	0.192%	0.061%	2.103%	33.914%	63.730%	0.000%	0.000%	0.000%
Phenol	0.047%	0.005%	99.949%	0.000%	0.000%	0.000%	0.000%	0.000%
Benzo(b/k)Fluoranthene)	0.000%	0.000%	0.000%	0.020%	0.070%	61.482%	27.660%	10.768%
Anthracene (µg/l)	0.000%	0.000%	0.000%	0.040%	0.475%	72.875%	19.096%	7.513%
C10-13 Chloroalkanes	2.695%	0.270%	97.035%	0.000%	0.000%	0.000%	0.000%	0.000%
Hexachlorobutadiene	0.000%	0.000%	100.00%	0.000%	0.000%	0.000%	0.000%	0.000%
PAHs	0.001%	0.000%	0.985%	1.301%	2.324%	69.876%	18.310%	7.203%

6 RESULTS

6.1 TRACER SCENARIOS

The tracer plume modelling has been used to produce a number of graphical and statistical outputs to quantify differences between the baseline and post-construction water quality environments. These outputs include:

- Calculations of maximum concentrations and number of dilutions at selected locations, focusing on designated sites and other points of interest.
- Plots showing the maximum (or minimum in the case of DO) concentration from the entire model run for each point in the model domain.
- Plots and statistical calculations highlighting the predicted differences between the baseline and operational phase scenarios.

6.1.1 Dilutions and maximum concentrations

Time series plots of maximum modelled concentrations at designated sites and other points of interest are provided in Appendix B. The relevant EQSs are also plotted. These time series plots clearly show the higher concentrations which are key to understanding compliance with water quality standards. Tables showing the maximum (minimum for DO) and mean modelled concentration for each water quality parameter, for each scenario are provided in Appendix B. Also provided are tables of percentage differences for the maximum and mean modelled concentrations. These are coloured so a decrease of 100% is dark blue and an increase of 100% is red.

The calculated median dilution of each discharge at each of the designated assessment locations is presented in Table 6-1.

The dilution modelling results show that for discharges within and close to the proposed expansion area (UFP, East Tullos Burn and Ness Tip Burn), dilutions are predicted to decrease. The predicted dilutions for discharges outside the harbour (Nigg WwTW LSO, River Dee and River Don) are predicted to increase marginally. Dilutions of effluent from the St Fittick's Field CSO to locations within and close to the proposed harbour development are predicted to decrease.

The hydrodynamic modelling [17] indicates that the southern breakwater is acting as a barrier to the transport of discharges from St Fittick's Field CSO on the flooding (south flowing) tide. Discharges from the CSO are predicted to be redirected into the harbour under these conditions.

The dilutions of discharges from Nigg WwTW LSO experienced at Aberdeen Ballroom Bathing Water are predicted to be very high for both the baseline and post development cases. However, dilutions from both this source and St Fittick's Field CSO are predicted to be reduced following harbour expansion. The hydrodynamic modelling [12] indicates that on the ebbing (north flowing) tide discharges from the LSO and CSO are directed closer to the coast, thus leading to decreased dilution from these sources at the bathing water. However, these changes are comparatively small and are unlikely to affect bathing water classification or increase the risk to bathers.

Table 6-1: Predicted dilution at assessment sites for baseline and post harbour expansion scenarios

Assessment Location	Baseline Dilutions						
	Nigg WwTW LSO	St Fittick's Field CSO	Ness Tip Burn	UFP outfall	East Tullos Burn	River Dee	River Don
1	2,002	937	1,565,619	1,570	4,432	7	32
2	1,570	841	823,934	1,211	3,747	8	26
3	1,522	733	58,058	34	121	10	25
4	1,486	693	562,620	348	1,506	10	27
5	1,357	866	622,991	1,028	3,166	11	29
6	1,455	971	966,473	1,461	5,064	10	29
7	1,339	899	856,494	1,454	4,478	9	39
BW	10,457	3491	7,391,147	7,942	39,005	30	4
SSSI 1	1,756	1046	163,075	19	8	11	33
SSSI 2	1,517	932	10,882	16	15	10	34
Assessment Location	Post Harbour Expansion Dilutions						
	Nigg WwTW LSO	St Fittick's Field CSO	Ness Tip Burn	UFP outfall	East Tullos Burn	River Dee	River Don
1	1,029	281	291,238	916	3,226	5	21
2	1,421	323	58,066	137	456	5	29
3	2,039	569	3,739	6	19	12	35
4	2,022	577	8,317	5	17	12	37
5	2,622	714	8,748	4	15	14	45
6	2,548	697	8,524	4	14	14	44
7	1,183	289	242,637	774	2,680	4	22
BW	3,791	1079	1,034,330	2,185	8,356	13	4
SSSI 1	2,407	650	7,167	6	9	13	43
SSSI 2	2,235	611	963	6	14	13	40

6.1.2 Maximum concentration contour plots

Plots of maximum (or minimum in the case of DO) modelled concentration are provided in Appendix C. The plots are provided for each water quality parameter (see Table 5-2) and show the maximum impacts across the model domain over the entire model simulation. The plots showing EC concentrations have the Aberdeen Ballroom Bathing Water shown as a black rectangle north of the harbour. For green and red colour scales, yellow to red show where the determinands' concentrations are greater than the relevant EQS. Where there was no directly applicable EQS a wider range of colours were used to show more detail. The plots showing EC concentrations have colour scales based on boundaries from the revised Bathing Water Directive [18].

For substances which have both an AA EQS and a MAC or high percentile EQS (see Table 4-1), the area which is predicted to exceed the AA EQS is shown in orange and the area which is predicted to exceed the MAC or high percentile EQS is shown in red. For substances which only have an AA EQS (see Table 4-1), the area which is predicted to exceed that EQS is shown in red.

The modelling results show that concentrations within the proposed harbour expansion are predicted to increase following harbour construction for most water quality parameters. The exceptions to this are anthracene (Figure C-1, Figure C-32), benzo(b/k)fluoranthene (Figure C-2, Figure C-33) and PAHs (Figure C-24, Figure C-55). Lead has no area of EQS failure under either scenario (Figure C-18, Figure C-50). Where the highest proportion of the load near the harbour is from watercourses outside the harbour, the concentrations decrease due to the breakwaters protecting the bay; but where the majority of the load is from sources inside the harbour, such as East Tullos Burn, Ness Tip Burn and the UFP outfall, the substance concentrations increase.

For C10-13 chloroalkanes (Figure C-6, Figure C-38), copper (Figure C-10, Figure C-41) and zinc (Figure C-30, Figure C-61), there are reduced areas of EQS failure inside the harbour together with reduced BOD concentrations (Figure C-3, Figure C-34). These decreases in concentration are believed to be a result of increased depth in the area around the UFP outfall as a result of dredging post development.

Around Girdle Ness, zinc has an area of EQS failure principally resulting from discharges from St. Fittick's Field CSO. The shape of this area of EQS failure changes from the baseline to post construction conditions due to the deflection of tidal currents off the northern breakwater.

Cadmium (Figure C-4, Figure C-36), Chromium (Figure C-8, Figure C-40) and unionised ammonia (10°C and 15°C) (Figure C-28, Figure C-59, Figure C-29, Figure C-60) all have an increased area of EQS failure within the harbour post-construction. DO concentrations are lower within the harbour post-construction (Figure C-13, Figure C-44).

Mercury (Figure C-20, Figure C-51), hexachlorobutadiene (Figure C-16, Figure C-47) and ammonium (Figure C-22, Figure C-53) all have a larger area of failure of the AA EQS within the harbour post-development but a smaller area of MAC EQS failure. This is believed to be a result of two competing factors:

- Deeper water around the UFP outfall post construction which provides some additional dilution.
- Reduced exchange due to the construction of the harbour.

Exceedances of MAC EQS are likely to occur around a low water slack period. In this period, the additional dilution provided by dredging post-construction is less pronounced, leading to exceedances of the MAC EQS over a more restricted area. Over the longer term, the reduced exchange due to the construction of the harbour leads to an increased area of failure of the AA EQSs for these substances.

Phenol, however, has a similar area of AA EQS failure along the western shore of bay for both scenarios (Figure C-26, Figure C-57).

There is very little change in EC concentrations within the harbour or near the Bathing Water (Figure C-15, Figure C-46). However, the southern breakwater acts as a barrier to the southwards transport of EC bacteria, reducing the impacts south of the bay.

6.1.3 Percentage difference plots

Plots of the percentage difference in maximum modelled concentration between the baseline and development scenarios are provided in Appendix D. The plots are provided for each water quality parameter in Table 5-2. The colour scales have reds for increases in maximum concentrations after construction of the harbour and blues for decreases.

The percentage difference plots do not depict any specific moment in time, i.e. not a snapshot, but represent the impacts across the model domain over the entire model simulation. The percentage differences have been calculated for each grid cell by a four step process:

1) Subtracting the maximum baseline concentration from the maximum post development concentration.

2) Finding the maximum baseline concentration across the whole grid.

3) Dividing the concentration difference (step 1) by the maximum baseline concentration (step 2).

4) Expressing this concentration difference as a percentage.

For anthracene (Figure D-1), benzo(b/k)fluoranthene (Figure D-3) and PAHs (Figure D-17), there are reductions in substance concentrations between the two scenarios immediately north and south of the bay, due to a decrease in tidal currents flushing the bay. There are increases further offshore and near Aberdeen Harbour due to changes in hydrodynamics as a result of the breakwater construction.

For BOD (Figure D-3), cadmium (Figure D-6), C10-13 chloroalkanes (Figure D-7), chromium (Figure D-8), copper (Figure D-9), DIN (Figure D-10), EC (Figure D-12), hexachlorobutadiene (Figure D-13), lead (Figure D-14), mercury (Figure D-15), phenol (Figure D-19), ammonium (Figure D-16) and unionised ammonia (at 10°C and at 15°C) (Figure D-20, Figure D-21), there are reductions in substance concentrations in the inshore area of Nigg Bay and increases in the eastern part of the harbour as the tidal streams no longer flow parallel to the pre-construction coastline. Post-construction, EC (Figure D-12) and zinc (Figure D-22) concentrations are predicted to increase north of St. Fittick's Field CSO and reduce to the south and east due to weakened north-going (ebb) tidal current being deflected to the north-west by the southern breakwater.

The DO percentage difference plot is provided in Appendix D (Figure D-11). This has been plotted as the percentage difference in DO deficit rather than the percentage difference in DO concentrations. DO is unusual among water quality parameters, in that low, rather than high, DO concentrations are detrimental to the environment. Every temperature and salinity combination has a DO saturation concentration; which is the maximum DO concentration that this combination of temperature and salinity combination can accommodate. The DO deficit is a measure the concentration of DO below this saturation concentration:

$$DO_{deficit} = DO_{saturation} - DO_{water}$$

The DO deficit provides an understanding of the impact on the environment in an analogous way to concentrations of other water quality parameters and is useful as it is directly related to the ability of aquatic life to survive.

The DO deficit increases within the whole proposed harbour area due to the increased containment of the discharge from the UFP outfall.

6.2 RESIDENCE TIME MODELLING

The residence time modelling produced a number of graphical and statistical outputs that help to quantify differences between the baseline and post-construction water quality environments. These outputs, in Appendix E, include:

- Figure E-1 to E-10 show the percentage of Bay water around the study area at different times for both scenarios after the beginning of the model simulation.
- Figure E-11 to E-20 show timeseries of the percentage of Bay water at that point at each timestep for both scenarios at the designated points; For the assessment points within the Bay, Points 3 to 6, these plots indicate the percentage of 'Bay' water remaining.
- Table E-1 to E-6 show the percentage of Bay water at the assessment points at selected times after the model run start.
- Table E-7 shows e-folding times for assessment points within the proposed harbour breakwaters.

The percentage and timeseries plots both show that the development of the harbour is predicted to have a notable impact on the flushing of Nigg Bay. Under baseline conditions, the bay is flushed relatively quickly with only 10% of 'Bay' water remaining after six hours. Post development, the bay is in comparison flushed more slowly with up to 90% of 'Bay' water remaining within the harbour after six hours. This is also reflected in the e-folding time increasing from 0.25 to 14 days within the proposed harbour development.

7 CONCLUSIONS

The model used in the analysis is deemed fit for the purpose of a wide scale water quality study and has been accepted as such by SEPA. Measured average input data have been used where data were available in sufficient quantities. Where data were not available, realistic conservative estimates or licenced maximum values were used to ensure that realistic but conservative modelling results were achieved.

The model results show that the construction of the proposed harbour expansion will lead to less exchange with offshore water and thus less long-term dilution and longer residence times. However, dredging of the new harbour will provide increased dilution at some phases of the tide. Over the longer-term, substances discharged into the bay will have a greater impact on local water quality in the operational phase of the harbour than at present. However, exceedance of MAC EQSs may be decreased due to the short-term increase in dilution around low water provided by the increased depth within the harbour. Outside the harbour, the construction of the breakwaters will deflect the tidal streams further offshore, further increasing the residence times of substances near the proposed harbour development.

7.1 MAXIMUM CONCENTRATION AND PERCENTAGE DIFFERENCE PLOTS

The modelling results show that most water quality parameters are predicted to increase in concentration within the harbour following its construction. The exceptions are anthracene, benzo(b/k)fluoranthene, lead, BOD and PAHs, which reduce and also have reductions in concentration immediately north and south of the bay due to the tidal currents no longer flowing parallel to the original coast. Furthermore, lead does not fail its EQS under either scenario and reduces in concentration within the harbour during its operational phase.

Most water quality parameters show an increase in their area of EQS failure between the two scenarios. However, for C10-13 chloroalkanes, copper and zinc, the areas of EQS failure inside the harbour. These decreases in concentration are believed to be a result of increased depth in the area around the UFP outfall as a result of dredging to deepen the bay.

Zinc and phenol have areas of EQS failure; these are located off Girdle Ness for zinc and inside the harbour for phenol. The areas of failure change in shape following harbour construction due to the deflection of tidal currents by the northern breakwater.

Cadmium, chromium, DO and unionised ammonia (10°C and 15°C) all have an increased area of EQS failure within the harbour post-construction. Mercury, hexachlorobutadiene and ammonium both have a larger area of failure of the AA EQS within the harbour but a smaller area of MAC EQS failure. The increases in concentration and spatial area of failures are a result of increased containment of the discharge from the UFP outfall, within the harbour. There is very little change in EC concentrations within the harbour or near the designated bathing water.

Off Girdle Ness, the ebb (north flowing) tide is weakened and deflected to the north-west by the presence of the southern breakwater. The ebb tide flows over St. Fittick's Field CSO outfall and transports its discharge to the north-west. This change in tidal flow has the effect of increasing the concentrations of hazardous substances relative to the baseline scenario around the CSO and towards the north-west.

7.2 DILUTIONS AND MAXIMUM CONCENTRATIONS

The dilution modelling results show that for the discharges to the harbour (UFP, East Tullos Burn and Ness Tip Burn), dilutions are predicted to decrease following harbour expansion. The predicted dilutions from discharges outside the harbour (Nigg WwTW LSO, River Dee and River Don) are predicted to increase marginally. Dilutions of effluent from the St Fittick's Field CSO at locations within and close to the proposed harbour development are predicted to decrease, as the southern breakwater acts as a barrier on the flooding (south flowing) tide. Discharges from the CSO are predicted to be redirected into the harbour under these conditions.

Around Aberdeen Ballroom bathing water, dilutions from Nigg WwTW LSO and St Fittick's Field CSO are predicted to be reduced during the operational phase of the new harbour due to the ebbing (north flowing) tide directing discharges closer to the coast. However, these changes are comparatively small and are unlikely to affect bathing water classification or increase the risk to bathers.

7.3 RESIDENCE TIME MODELLING

The residence time modelling results show that the development of the harbour is predicted to have a significant impact on the flushing of Nigg Bay. Under baseline conditions, the bay is flushed relatively quickly with only 10% of 'bay' water remaining after six hours. Post development, the bay is in comparison flushed more slowly with up to 90% of 'bay' water remaining after six hours.

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Appendix A Summary of Water Quality Parameter Data Sources

Parameters		Nigg WwTW LSO	St Fittick's Field CSO	UFP outfall	Ness Tip Burn	East Tullos Burn	River Dee	River Don	River Ythan
Anthracene		Literature[21]	Literature- based on [21]	Survey on 15/04/2013. Samples taken at inlet and outlet for processing site.	Water quality surveys undertaken by Arch Henderson LLP for EIA- 2 samples on 4 dates - (30/11/2014, 06/01/2015, 25/02/2015, 31/03/2015)		SEPA[23]		
Benzo(b/k)Fluoranthene									
C10-13 Chloroalkanes		Not modelled*					Not modelled*		
Cadmium		Literature[21]	Literature- based on [21]				SEPA[23]		
Chromium		Not modelled*							
Copper		Literature[21]	Literature- based on [21]				Not modelled*		
Hexachlorobutadiene		Not modelled*							
Lead		Literature[21]	Literature- based on [21]				SEPA[23]		
Mercury							Not modelled*		
PAHs		Not modelled*					SEPA[23]		
Phenol							Not modelled*		
Zinc		Literature[21]	Literature- based on [21]						
BOD		Literature [23]					SEPA[23]		
DIN		Calculated from total ammonia, nitrites and nitrates							
	Nitrite	Literature[24]		Survey as above	Using total oxidised nitrogen		SEPA[23]		
	Nitrate			Literature[22]					
DO		Estimated from typical values†							
EC		Estimated from typical values†					Estimated from 'clean' river sampling data		
Total ammonia		Literature[24]		Survey as above	Survey as above		SEPA[23]		
Unionised ammonia	Calculated from total ammonia using EA algorithm								

Notes: *Where water quality parameters are designated as not modelled, laboratory analysis for the particular water quality parameter was not carried out for that discharge.

†See section 5.2

[19] [20] [21] [22]

Appendix B Designated points time series

TABLES

FIGURES

Table B-1: Baseline – Max. modelled concentrations at designated sites

Assessment Location	Baseline										Units
	1	2	3	4	5	6	7	BW	SSSI 1	SSSI 2	
Anthracene	2.390	2.230	0.933	0.972	0.999	2.190	2.310	1.470	0.786	0.732	µg/l
Benzo(b/k)Fluoranthene	4.870	4.570	2.020	2.070	2.130	4.480	4.710	5.020	1.660	1.570	µg/l
C10-13 Chloroalkanes	0.024	0.022	1.160	2.280	0.028	0.022	0.027	0.001	2.230	1.110	µg/l
Cadmium	0.015	0.224	0.224	0.542	0.010	0.014	0.014	0.015	0.580	0.197	µg/l
Chromium	0.183	0.173	1.440	3.510	0.087	0.171	0.178	0.188	3.770	1.260	µg/l
Copper	0.832	0.231	4.180	7.550	0.171	0.243	0.266	0.025	7.130	4.030	µg/l
Hexachlorobutadiene	0.007	0.007	0.215	0.532	0.006	0.006	0.008	0.000	0.573	0.188	µg/l
Lead	0.124	0.078	0.229	0.374	0.044	0.076	0.086	0.083	0.478	0.236	µg/l
Mercury	0.002	0.002	0.052	0.129	0.001	0.001	0.002	0.000	0.139	0.045	µg/l
Phenol	0.222	0.193	6.480	15.900	0.180	0.178	0.240	0.006	17.100	5.660	µg/l
Polycyclic Aromatic Hydrocarbons (PAHs)	2.410	2.240	1.070	1.730	1.020	2.200	2.310	1.470	1.850	0.952	µg/l
Zinc (Total)	3.110	0.849	3.460	5.780	0.607	0.858	0.985	0.089	6.850	3.510	µg/l
Ammonia	0.172	0.156	4.520	11.100	0.148	0.134	0.183	0.306	11.800	3.950	mg/l
BOD	1.050	0.714	19.100	48.500	0.611	0.706	0.764	1.630	51.400	16.400	mg/l
DIN	4.000	3.580	22.400	53.900	1.820	3.520	3.660	3.870	57.800	19.600	mg/l
EC	30300	8440	322000	1010000	7170	6930	10800	122	996000	253000	EC/dl
Unionised ammonia (at 10°C)	2.500	2.270	65.600	162.000	2.160	1.940	2.650	4.450	172.000	57.400	µg/l
Unionised ammonia (at 15°C)	3.690	3.350	96.700	238.000	3.180	2.860	3.910	6.560	253.000	84.600	µg/l

Intertek

Table B-2: Development – Max. modelled concentrations at designated sites

Assessment Location	Post construction										Units
	1	2	3	4	5	6	7	BW	SSSI 1	SSSI 2	
Anthracene	2.330	2.300	0.953	0.477	0.316	0.304	2.380	1.490	0.346	0.365	µg/l
Benzo(b/k)Fluoranthene	4.810	4.770	2.070	1.070	0.693	0.665	4.920	5.030	0.756	0.796	µg/l
C10-13 Chloroalkanes	0.068	0.853	0.904	0.988	1.280	1.160	0.654	0.003	1.220	0.935	µg/l
Cadmium	0.022	0.244	0.244	0.264	0.372	0.324	0.178	0.015	0.227	0.228	µg/l
Chromium	0.181	1.480	1.600	1.730	2.440	2.120	1.170	0.188	1.490	1.490	µg/l
Copper	0.529	2.810	2.940	3.230	3.960	3.680	2.150	0.079	4.900	3.270	µg/l
Hexachlorobutadiene	0.018	0.221	0.239	0.259	0.369	0.319	0.174	0.001	0.222	0.223	µg/l
Lead	0.094	0.124	0.127	0.143	0.150	0.162	0.100	0.083	0.309	0.182	µg/l
Mercury	0.004	0.054	0.058	0.063	0.089	0.077	0.042	0.000	0.054	0.054	µg/l
Phenol	0.526	6.600	7.140	7.730	11.000	9.520	5.190	0.022	6.640	6.660	µg/l
Polycyclic Aromatic Hydrocarbons (PAHs)	2.360	2.310	1.150	1.090	1.350	1.230	2.400	1.490	0.994	1.010	µg/l
Zinc (Total)	1.960	2.120	2.170	2.400	2.520	2.670	2.130	0.276	4.600	2.850	µg/l
Ammonia	0.249	2.330	2.840	3.080	5.510	4.170	2.230	0.299	2.420	2.420	mg/l
BOD	0.772	5.670	7.010	8.070	18.700	12.400	5.700	1.590	5.400	4.580	mg/l
DIN	3.810	22.900	24.700	26.600	37.400	32.600	18.100	3.870	23.000	23.100	mg/l
EC	15400	15700	45600	25600	202000	48600	18200	121	32700	11000	EC/dl
Unionised ammonia (at 10°C)	3.610	33.900	41.300	44.800	80.000	60.700	32.400	4.340	35.100	35.200	µg/l
Unionised ammonia (at 15°C)	5.330	50.000	60.900	66.000	118.000	89.400	47.700	6.400	51.800	51.800	µg/l

Table B-3: Min. modelled concentrations at designated sites

Assessment Location	Baseline										Units
	1	2	3	4	5	6	7	BW	SSSI 1	SSSI 2	
DO - Baseline	7.64	7.75	4.86	2.51	8.26	7.77	7.71	7.55	1.55	4.59	mg/l
DO - Development	6.70	0.00	0.00	0.00	0.00	0.00	0.00	7.52	0.00	2.69	mg/l

Table B-4: Baseline – Mean modelled concentrations at designated sites

Assessment Location	Baseline										Units
	1	2	3	4	5	6	7	BW	SSSI 1	SSSI 2	
Anthracene	8.67E-01	6.26E-01	4.24E-01	4.17E-01	3.73E-01	5.56E-01	6.04E-01	6.04E-01	3.31E-01	3.61E-01	µg/l
Benzo(b/k)Fluoranthene	1.80E+00	1.33E+00	9.13E-01	9.01E-01	8.10E-01	1.18E+00	1.27E+00	1.97E+00	7.10E-01	7.76E-01	µg/l
C10-13 Chloroalkanes	5.21E-03	4.23E-03	2.10E-01	1.27E-01	5.88E-03	3.56E-03	3.84E-03	2.62E-04	6.48E-01	4.17E-01	µg/l
Cadmium	6.85E-03	5.14E-03	4.29E-02	2.99E-02	4.02E-03	4.53E-03	4.89E-03	5.84E-03	7.46E-02	6.94E-02	µg/l
Chromium	7.60E-02	5.67E-02	2.89E-01	2.08E-01	3.99E-02	5.00E-02	5.39E-02	7.40E-02	4.63E-01	4.50E-01	µg/l
Copper	1.23E-01	8.22E-02	8.12E-01	5.06E-01	8.34E-02	7.79E-02	8.44E-02	8.97E-03	2.59E+00	1.59E+00	µg/l
Hexachlorobutadiene	1.32E-03	1.08E-03	3.88E-02	2.65E-02	1.48E-03	9.17E-04	1.00E-03	7.18E-05	6.65E-02	6.40E-02	µg/l
Lead	3.72E-02	2.68E-02	5.70E-02	3.98E-02	1.83E-02	2.41E-02	2.60E-02	3.29E-02	1.70E-01	1.00E-01	µg/l
Mercury	3.42E-04	2.76E-04	9.42E-03	6.42E-03	3.71E-04	2.36E-04	2.59E-04	1.91E-05	1.61E-02	1.55E-02	µg/l
Phenol	3.94E-02	3.22E-02	1.17E+00	7.94E-01	4.41E-02	2.74E-02	3.00E-02	2.14E-03	2.05E+00	1.94E+00	µg/l
Polycyclic Aromatic Hydrocarbons (PAHs)	8.89E-01	6.42E-01	5.55E-01	5.11E-01	3.89E-01	5.70E-01	6.19E-01	6.06E-01	5.48E-01	5.67E-01	µg/l
Zinc (Total)	4.14E-01	2.70E-01	8.49E-01	5.99E-01	2.59E-01	2.61E-01	2.83E-01	3.15E-02	2.48E+00	1.48E+00	µg/l
Ammonia	5.03E-02	4.10E-02	8.26E-01	5.66E-01	4.66E-02	3.69E-02	4.04E-02	1.00E-01	1.48E+00	1.35E+00	mg/l
BOD	3.88E-01	2.70E-01	3.47E+00	2.44E+00	2.13E-01	2.33E-01	2.63E-01	4.57E-01	5.92E+00	5.38E+00	mg/l
DIN	1.61E+00	1.19E+00	4.71E+00	3.44E+00	8.38E-01	1.06E+00	1.15E+00	1.53E+00	7.54E+00	7.20E+00	mg/l
EC	3.61E+03	1.87E+03	5.20E+04	4.08E+04	1.78E+03	1.64E+03	2.06E+03	2.46E+01	7.91E+04	6.10E+04	EC/dl
Unionised ammonia (at 10°C)	7.32E-01	5.96E-01	1.20E+01	8.23E+00	6.78E-01	5.36E-01	5.87E-01	1.46E+00	2.15E+01	1.96E+01	µg/l
Unionised ammonia (at 15°C)	1.08E+00	8.79E-01	1.77E+01	1.21E+01	9.99E-01	7.90E-01	8.65E-01	2.15E+00	3.18E+01	2.88E+01	µg/l
DO	8.41E+00	8.54E+00	7.87E+00	8.21E+00	8.65E+00	8.58E+00	8.56E+00	8.29E+00	6.81E+00	6.95E+00	mg/l

Table B-5: Development – Mean modelled concentrations at designated sites

Assessment Location	Post construction										Units
	1	2	3	4	5	6	7	BW	SSSI 1	SSSI 2	
Anthracene	7.00E-01	7.89E-01	2.28E-01	2.19E-01	1.49E-01	1.47E-01	8.01E-01	7.48E-01	1.56E-01	1.81E-01	µg/l
Benzo(b/k)Fluoranthene	1.47E+00	1.63E+00	4.84E-01	4.67E-01	3.16E-01	3.10E-01	1.67E+00	2.19E+00	3.27E-01	3.84E-01	µg/l
C10-13 Chloroalkanes	3.66E-03	1.29E-01	4.98E-01	5.22E-01	7.50E-01	6.88E-01	2.70E-02	7.12E-04	6.44E-01	5.22E-01	µg/l
Cadmium	5.68E-03	4.04E-02	1.38E-01	1.44E-01	2.10E-01	1.84E-01	1.25E-02	6.65E-03	1.23E-01	1.30E-01	µg/l
Chromium	6.13E-02	2.91E-01	9.06E-01	9.44E-01	1.37E+00	1.20E+00	1.09E-01	8.30E-02	7.90E-01	8.50E-01	µg/l
Copper	1.87E-01	5.48E-01	1.63E+00	1.70E+00	2.37E+00	2.22E+00	2.64E-01	3.36E-02	2.33E+00	1.77E+00	µg/l
Hexachlorobutadiene	9.80E-04	3.50E-02	1.35E-01	1.41E-01	2.07E-01	1.81E-01	7.15E-03	1.90E-04	1.18E-01	1.27E-01	µg/l
Lead	3.59E-02	5.09E-02	6.93E-02	7.16E-02	9.01E-02	9.01E-02	4.22E-02	3.81E-02	1.24E-01	8.30E-02	µg/l
Mercury	2.75E-04	8.51E-03	3.27E-02	3.41E-02	5.02E-02	4.39E-02	1.77E-03	5.28E-05	2.87E-02	3.08E-02	µg/l
Phenol	2.92E-02	1.04E+00	4.03E+00	4.20E+00	6.18E+00	5.41E+00	2.13E-01	5.68E-03	3.56E+00	3.80E+00	µg/l
Polycyclic Aromatic Hydrocarbons (PAHs)	7.34E-01	9.20E-01	6.46E-01	6.56E-01	7.82E-01	7.01E-01	8.54E-01	7.54E-01	5.25E-01	5.76E-01	µg/l
Zinc (Total)	6.74E-01	7.99E-01	1.23E+00	1.28E+00	1.60E+00	1.56E+00	7.32E-01	1.20E-01	1.97E+00	1.41E+00	µg/l
Ammonia	4.06E-02	4.60E-01	1.71E+00	1.85E+00	3.14E+00	2.50E+00	1.17E-01	9.11E-02	1.41E+00	1.55E+00	mg/l
BOD	2.65E-01	1.30E+00	4.19E+00	4.89E+00	1.02E+01	7.13E+00	4.87E-01	4.27E-01	3.07E+00	3.26E+00	mg/l
DIN	1.37E+00	4.89E+00	1.40E+01	1.46E+01	2.11E+01	1.85E+01	2.14E+00	1.73E+00	1.23E+01	1.32E+01	mg/l
EC	3.69E+03	3.73E+03	5.37E+03	9.03E+03	7.54E+04	2.19E+04	4.03E+03	4.30E+01	2.74E+03	1.96E+03	EC/dl
Unionised ammonia (at 10°C)	5.91E-01	6.68E+00	2.49E+01	2.69E+01	4.56E+01	3.64E+01	1.71E+00	1.32E+00	2.05E+01	2.26E+01	µg/l
Unionised ammonia (at 15°C)	8.70E-01	9.84E+00	3.67E+01	3.97E+01	6.73E+01	5.36E+01	2.51E+00	1.95E+00	3.02E+01	3.33E+01	µg/l
DO	8.41E+00	6.04E+00	1.62E+00	1.56E+00	1.20E+00	1.20E+00	7.90E+00	8.20E+00	1.83E+00	1.69E+00	mg/l

Table B-6: Percentage difference in maximum concentrations between scenarios at designated sites

Assessment Location	Percentage difference (maximum concentrations; minimum for DO)									
	1	2	3	4	5	6	7	BW	SSSI 1	SSSI 2
Anthracene	-3	3	2	-51	-68	-86	3	1	-56	-50
Benzo(b/k)Fluoranthene	-1	4	3	-48	-68	-85	5	0	-54	-49
C10-13 Chloroalkanes	178	3,865	-22	-57	4,418	5,164	2,306	303	-45	-15
Cadmium	46	9	9	-51	3,651	2,269	1,158	0	-61	16
Chromium	-2	753	11	-51	2,692	1,141	559	0	-61	19
Copper	-36	1,116	-30	-57	2,217	1,417	708	214	-31	-19
Hexachlorobutadiene	137	3,304	11	-51	6,008	5,256	2,054	281	-61	19
Lead	-24	58	-44	-62	242	114	17	0	-35	-23
Mercury	137	3,281	11	-51	5,943	5,198	2,042	271	-61	19
Phenol	138	3,315	10	-51	5,981	5,254	2,058	282	-61	18
Polycyclic Aromatic Hydrocarbons (PAHs)	-2	3	8	-37	32	-44	4	1	-46	6
Zinc (Total)	-37	150	-37	-58	316	211	116	209	-33	-19
Ammonia	44	1,392	-37	-72	3,610	3,023	1,121	-2	-80	-39
BOD	-26	694	-63	-83	2,963	1,661	646	-3	-90	-72
DIN	-5	540	10	-51	1,956	824	395	0	-60	18
EC	-49	87	-86	-97	2,710	600	69	-1	-97	-96
Unionised ammonia (at 10°C)	44	1,392	-37	-72	3,610	3,023	1,121	-2	-80	-39
Unionised ammonia (at 15°C)	44	1,392	-37	-72	3,610	3,023	1,121	-2	-80	-39
DO	-12	-100	-100	-100	-100	-100	-100	0	-100	486

Table B-7: Percentage difference in mean concentrations between scenarios at designated sites

Assessment Location	Percentage difference (mean concentrations)									
	1	2	3	4	5	6	7	BW	SSSI 1	SSSI 2
Anthracene	-19	26	-46	-47	-60	-74	33	24	-53	-50
Benzo(b/k)Fluoranthene	-18	23	-47	-48	-61	-74	32	11	-54	-50
C10-13 Chloroalkanes	-30	2,953	137	312	12,661	19,222	605	172	-1	25
Cadmium	-17	687	221	381	5,130	3,966	156	14	65	88
Chromium	-19	413	213	354	3,341	2,303	103	12	71	89
Copper	52	566	100	236	2,743	2,752	213	274	-10	11
Hexachlorobutadiene	-26	3,147	248	432	13,962	19,665	612	165	78	99
Lead	-3	89	22	80	393	273	62	16	-27	-17
Mercury	-20	2,984	247	431	13,432	18,462	584	176	78	99
Phenol	-26	3,143	244	429	13,933	19,655	612	165	74	96
Polycyclic Aromatic Hydrocarbons (PAHs)	-17	43	17	28	101	23	38	25	-4	2
Zinc (Total)	63	196	45	113	518	499	159	282	-21	-5
Ammonia	-19	1,020	107	227	6,635	6,682	191	-9	-5	15
BOD	-32	381	21	101	4,701	2,961	85	-6	-48	-39
DIN	-15	309	197	324	2,419	1,640	87	13	63	83
EC	2	99	-90	-78	4,145	1,232	96	75	-97	-97
Unionised ammonia (at 10°C)	-19	1,020	107	227	6,636	6,683	191	-9	-5	15
Unionised ammonia (at 15°C)	-19	1,020	107	227	6,636	6,683	191	-9	-5	15
DO	0	-29	-79	-81	-86	-86	-8	-1	-73	-76

Figure B-1: Anthracene conc. timeseries – points 4, 5, 6

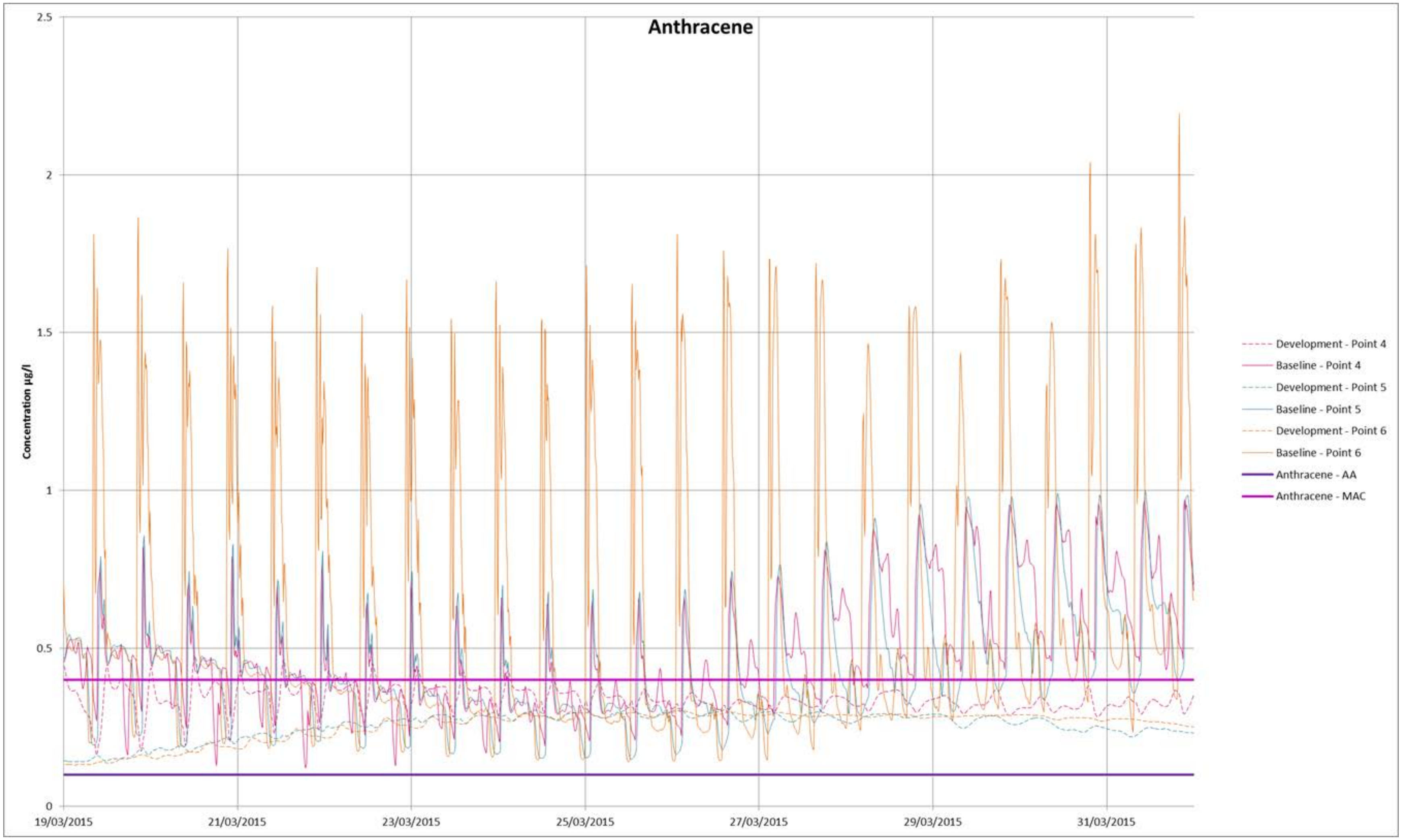


Figure B-2: Anthracene conc. timeseries – points 1, 2, 7

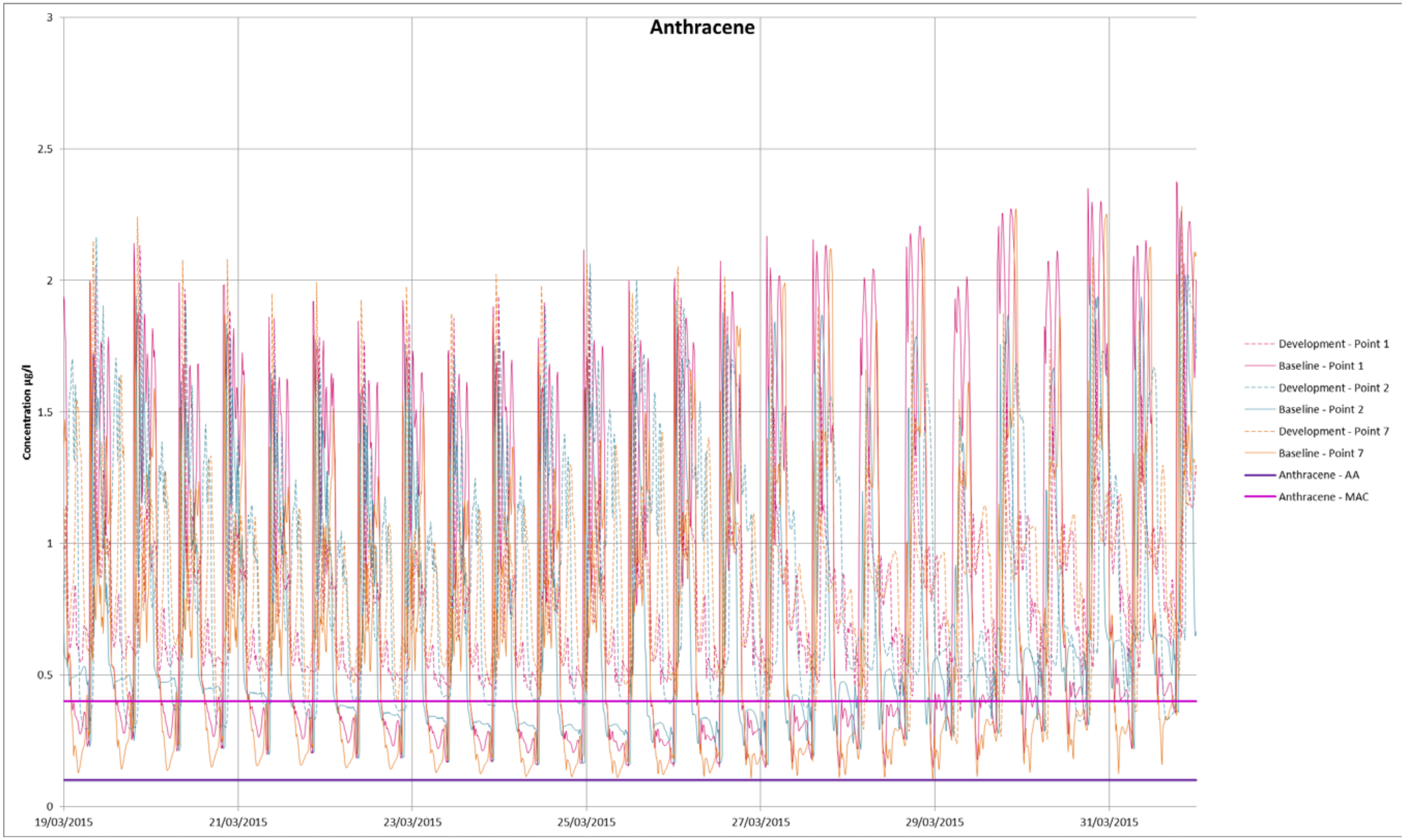


Figure B-3: Anthracene conc. timeseries – point 3, SSSI 1, SSSI 2

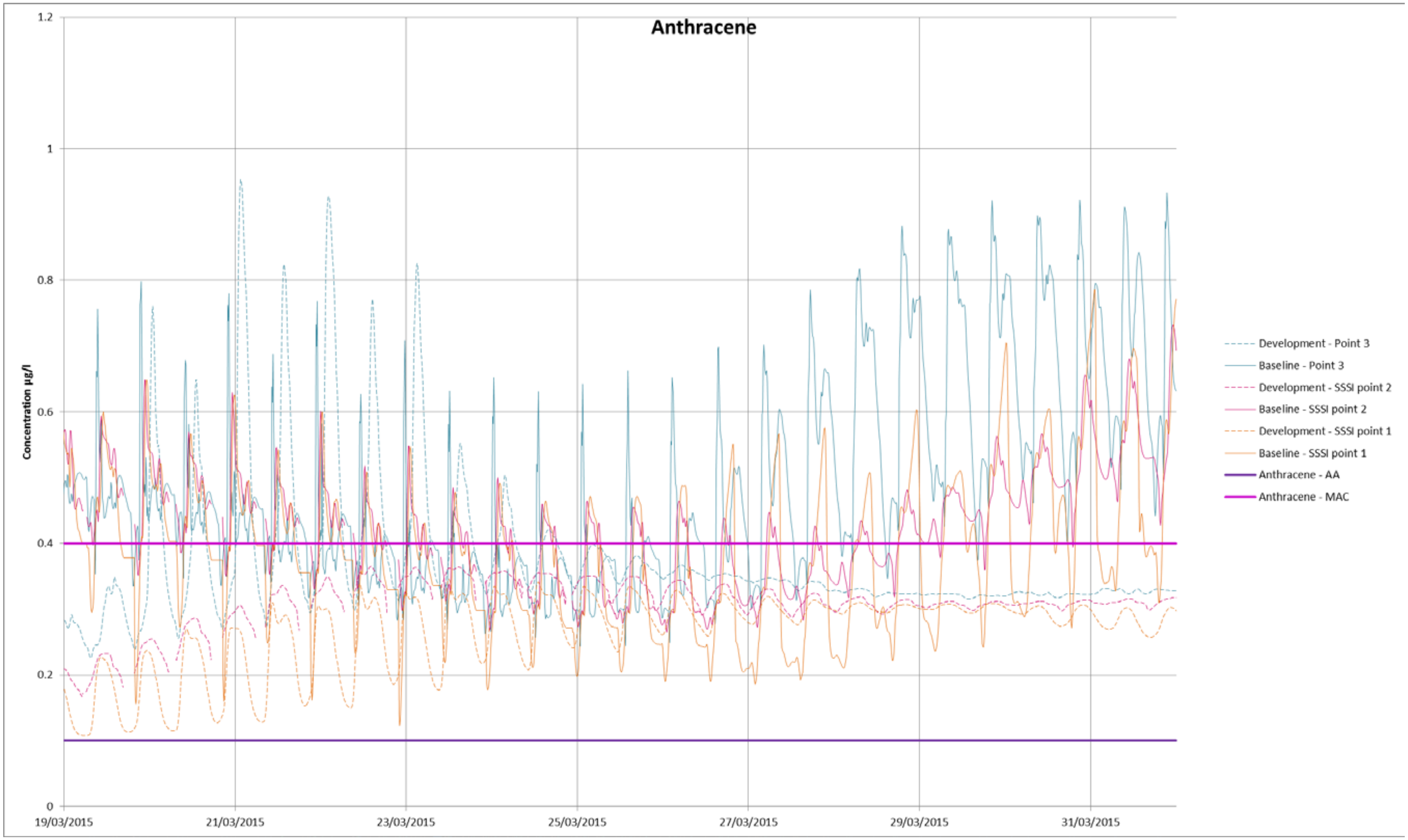


Figure B-4: Benzo(b\k)fluoranthene conc. timeseries – points 4, 5, 6

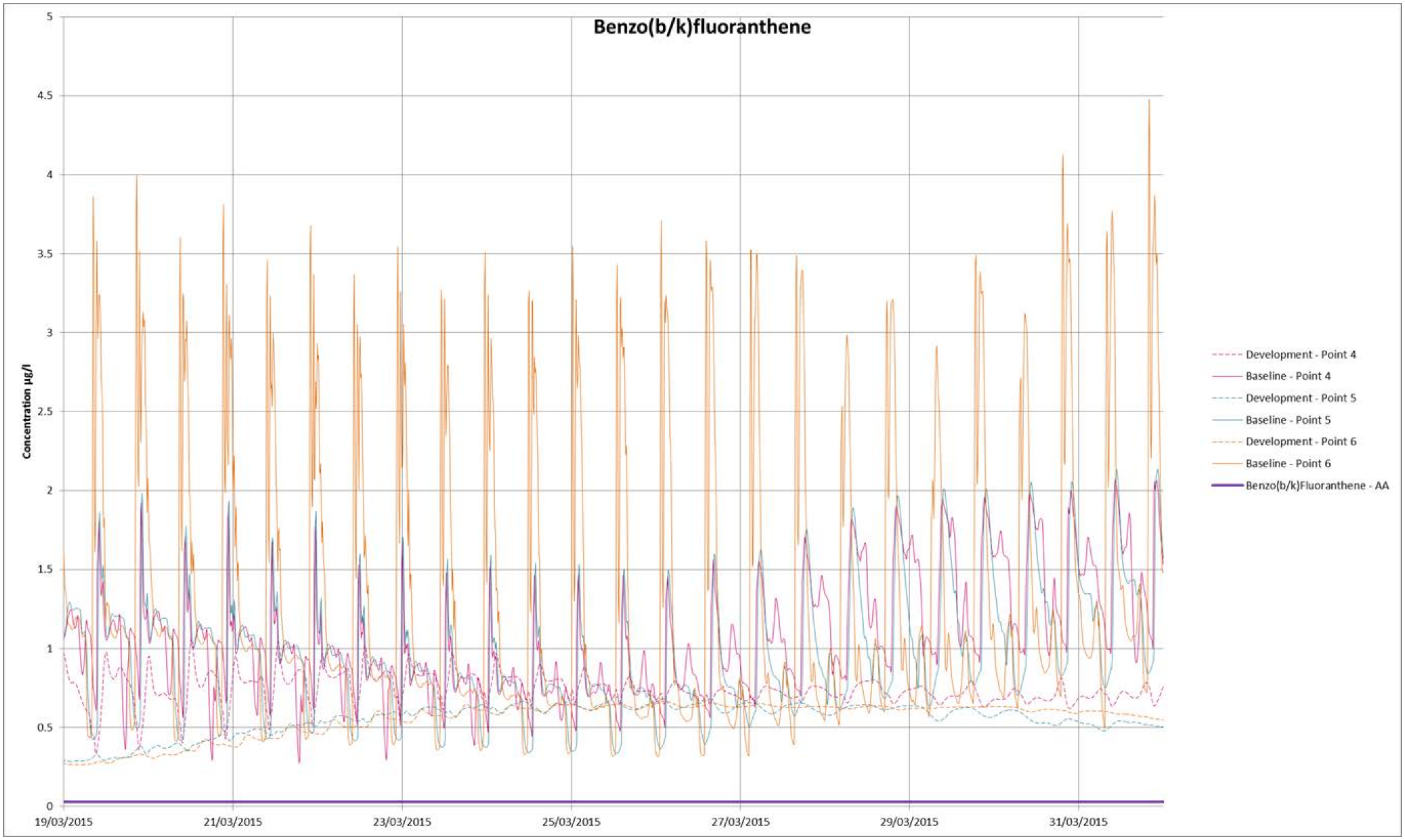


Figure B-5: Benzo(b\k)fluoranthene conc. timeseries – points 1, 2, 7

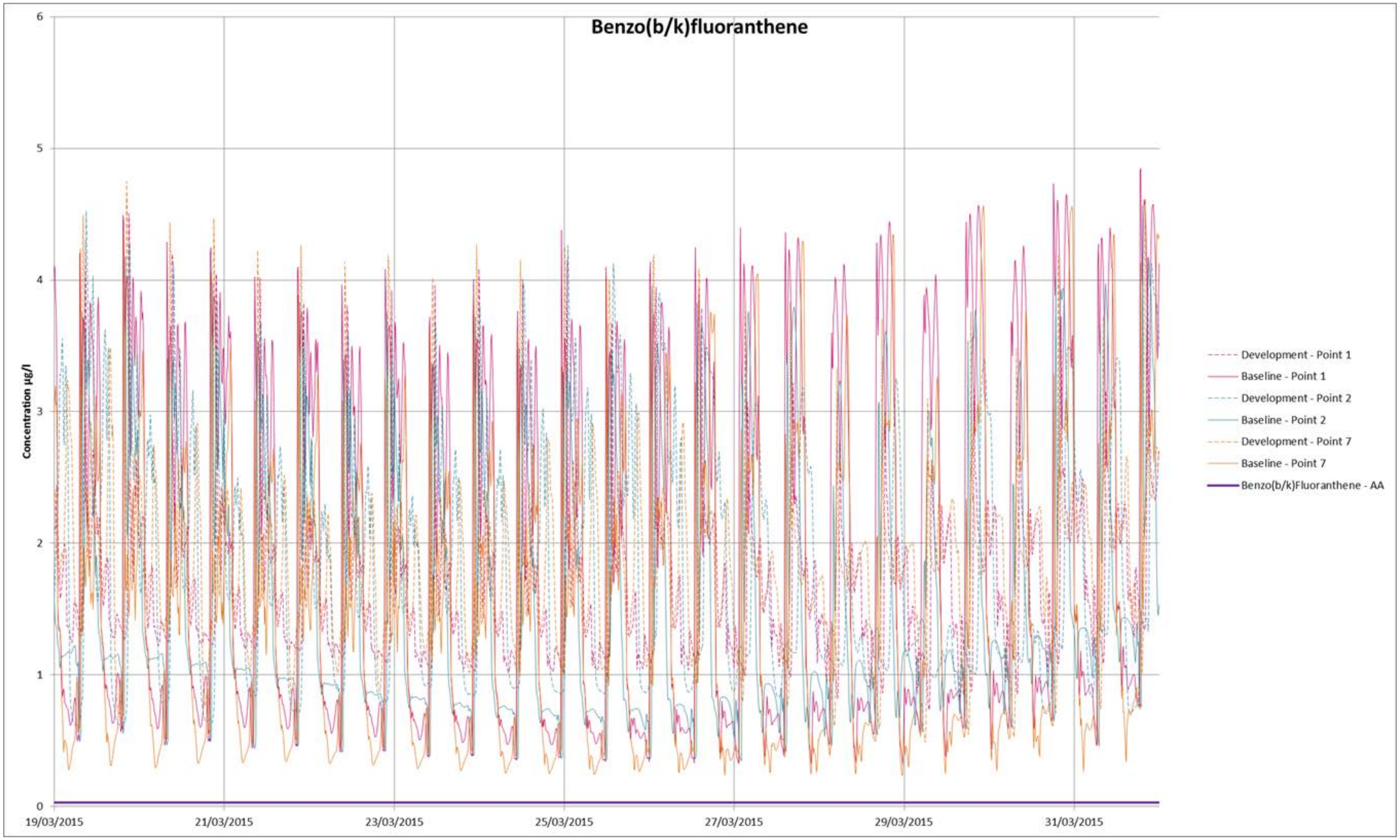


Figure B-6: Benzo(b\k)fluoranthene conc. timeseries – point 3, SSSI 1, SSSI 2

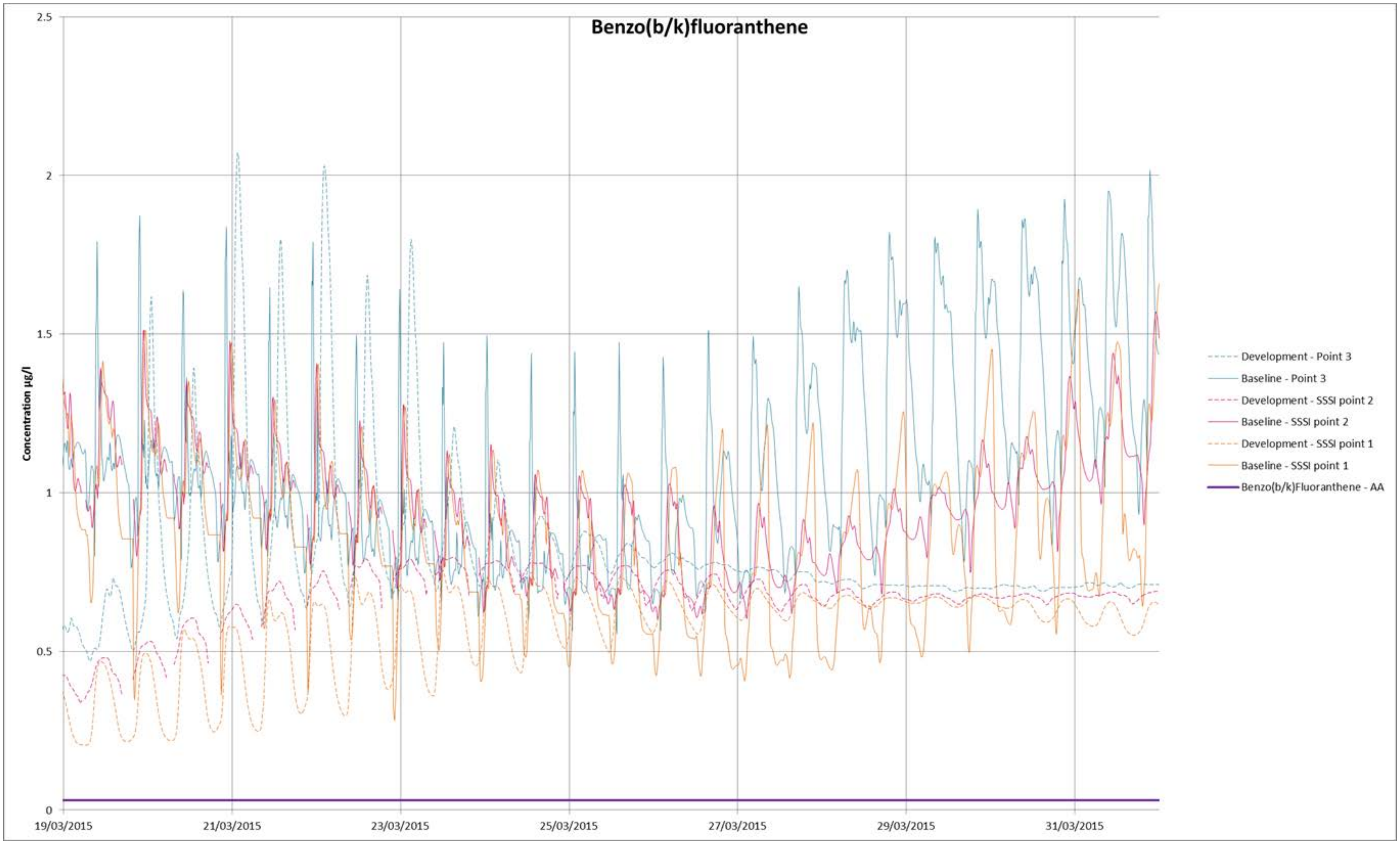


Figure B-7: BOD conc. timeseries – points 4, 5, 6

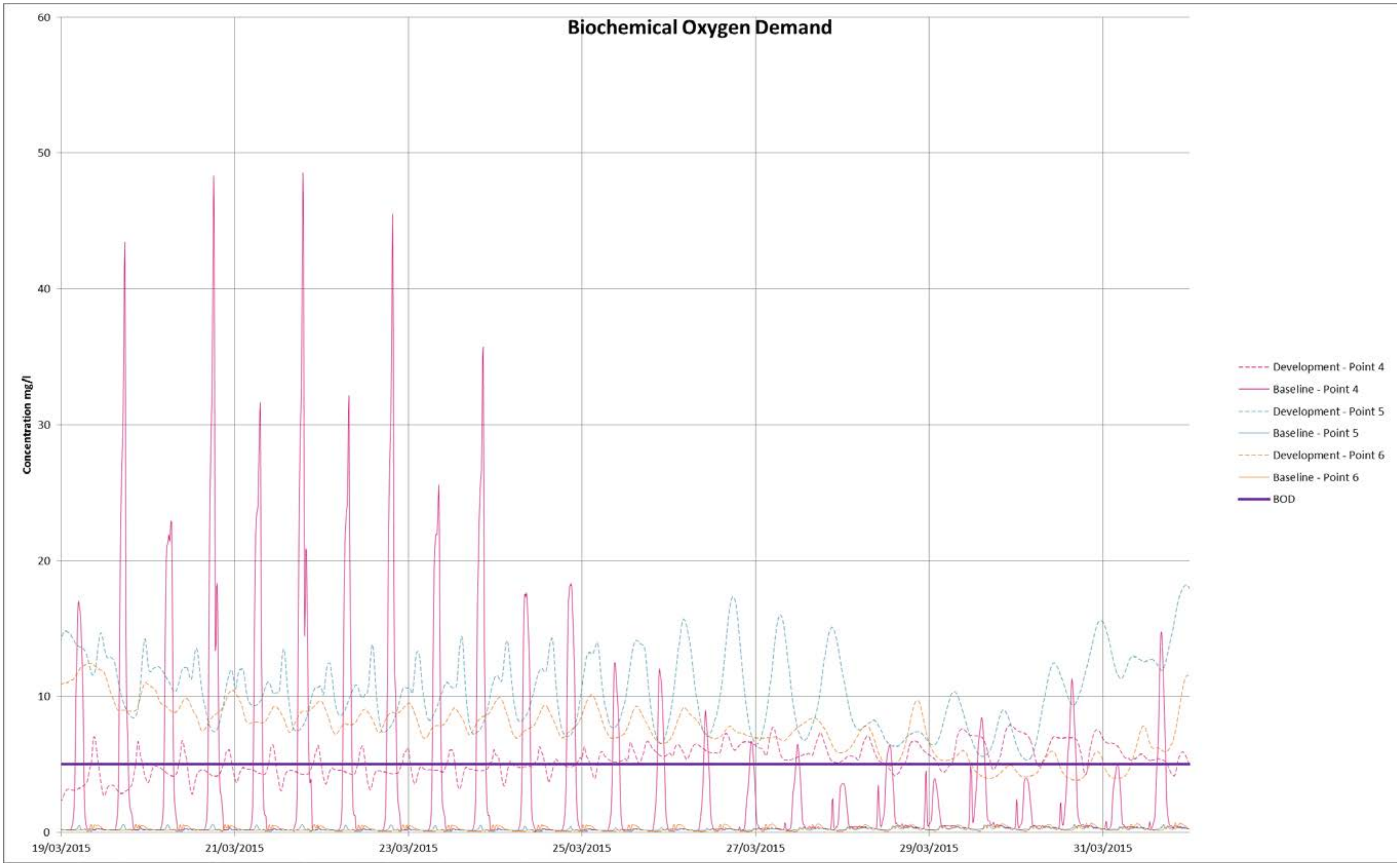


Figure B-8: BOD conc. timeseries – points 1, 2, 7

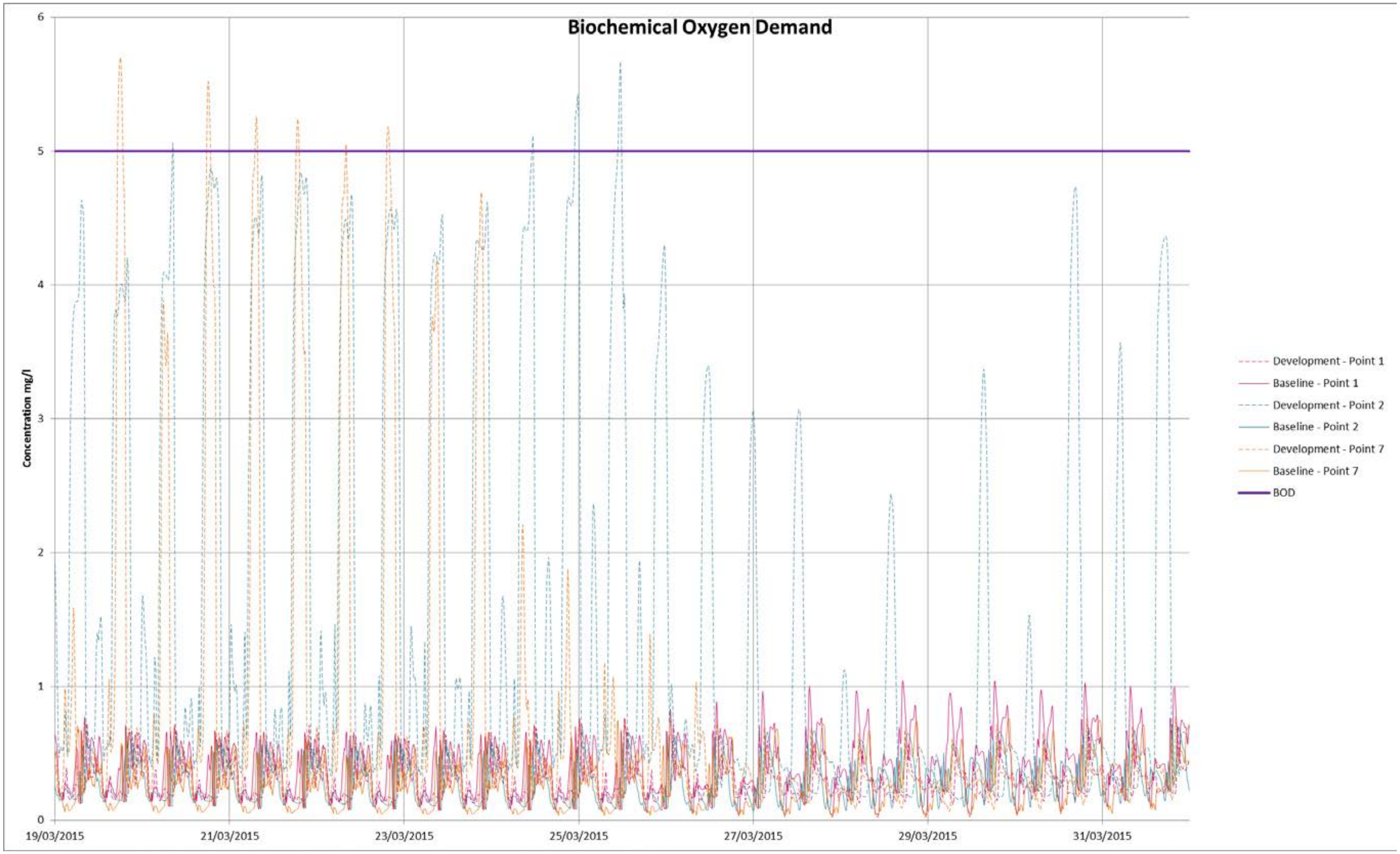


Figure B-9: BOD conc. timeseries – point 3, SSSI 1, SSSI 2

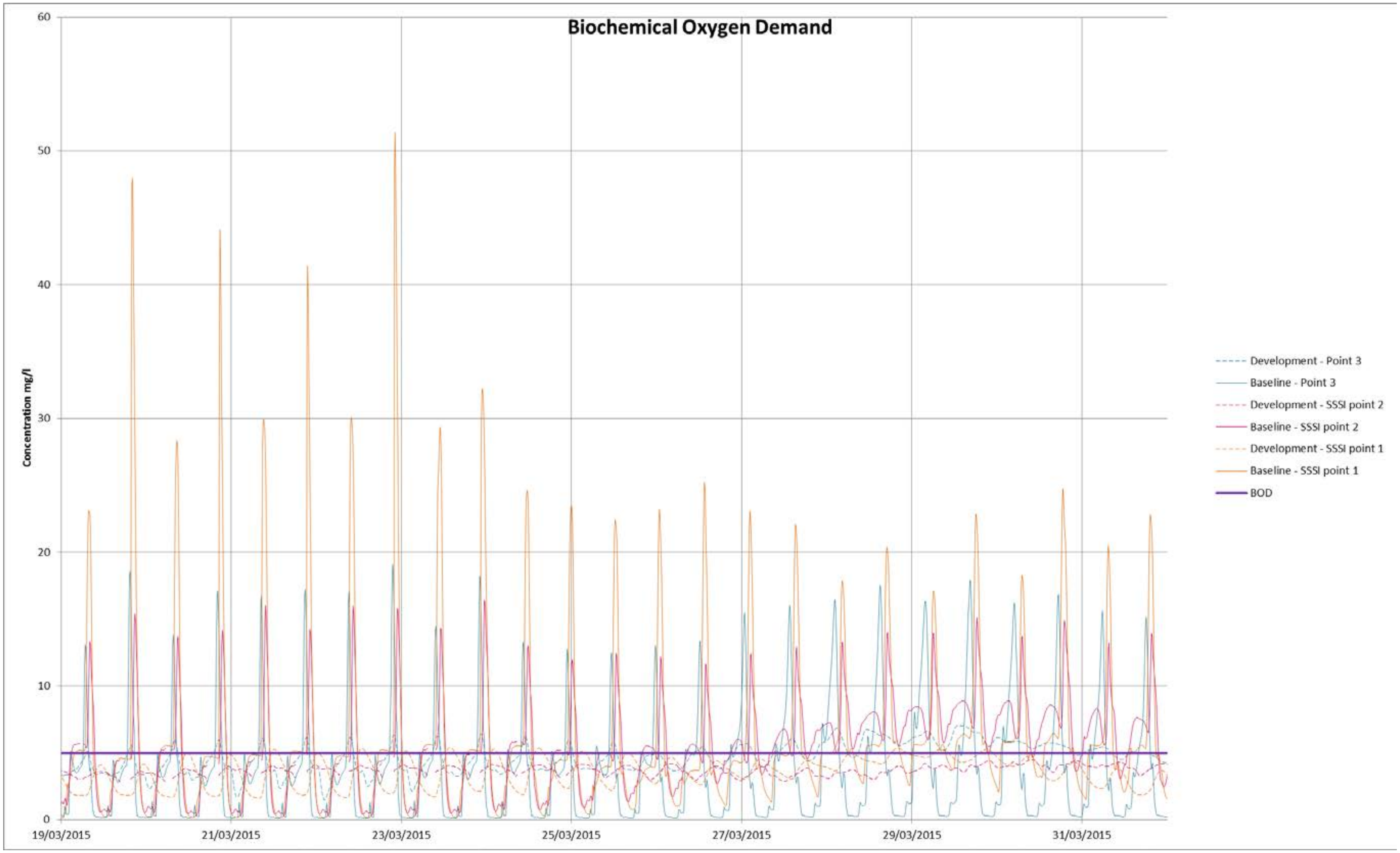


Figure B-10: C10-13 Chloroalkanes conc. timeseries – points 4, 5, 6

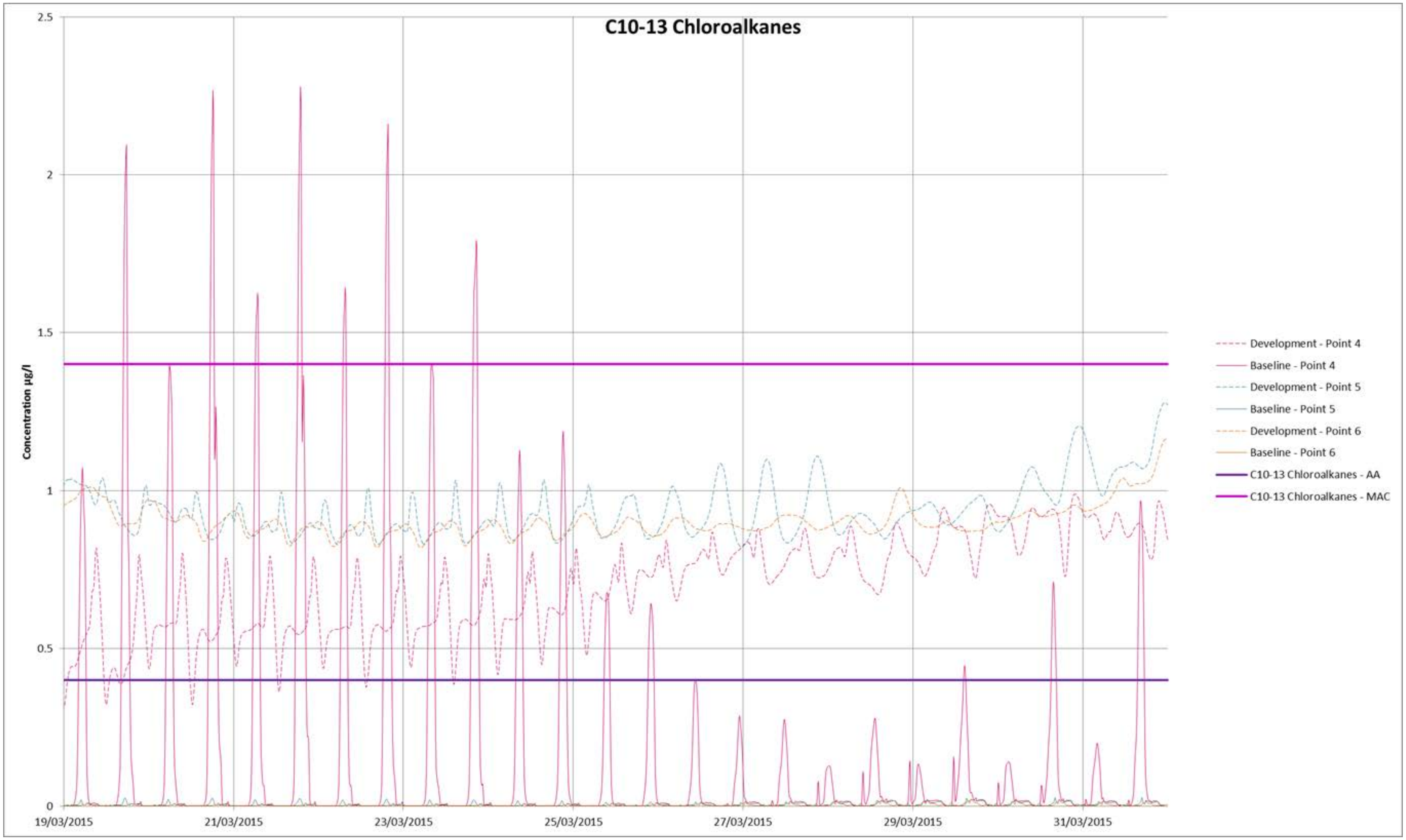


Figure B-11: C10-13 Chloroalkanes conc. timeseries – points 1, 2, 7

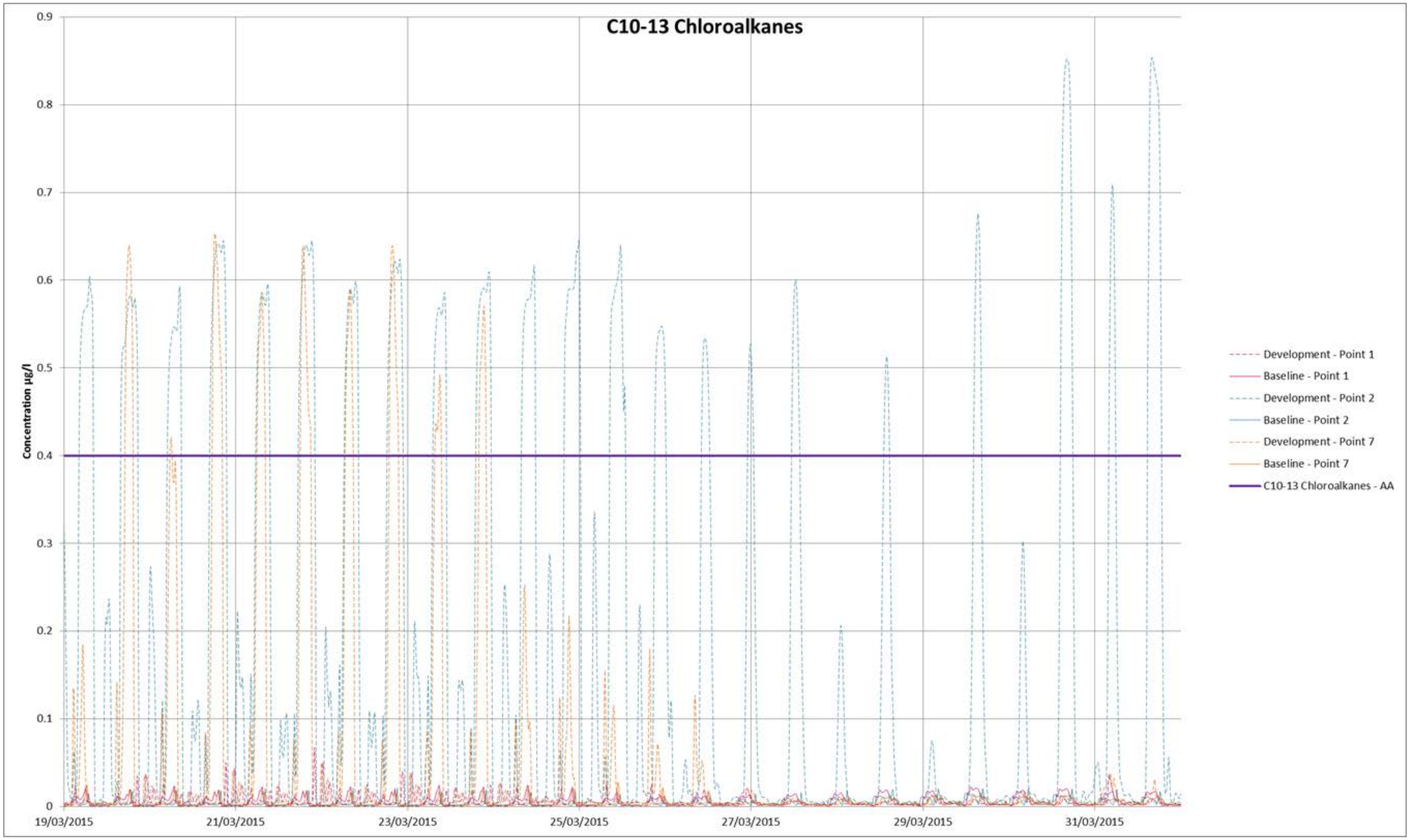


Figure B-12: C10-13 Chloroalkanes conc. timeseries – point 3, SSSI 1, SSSI 2

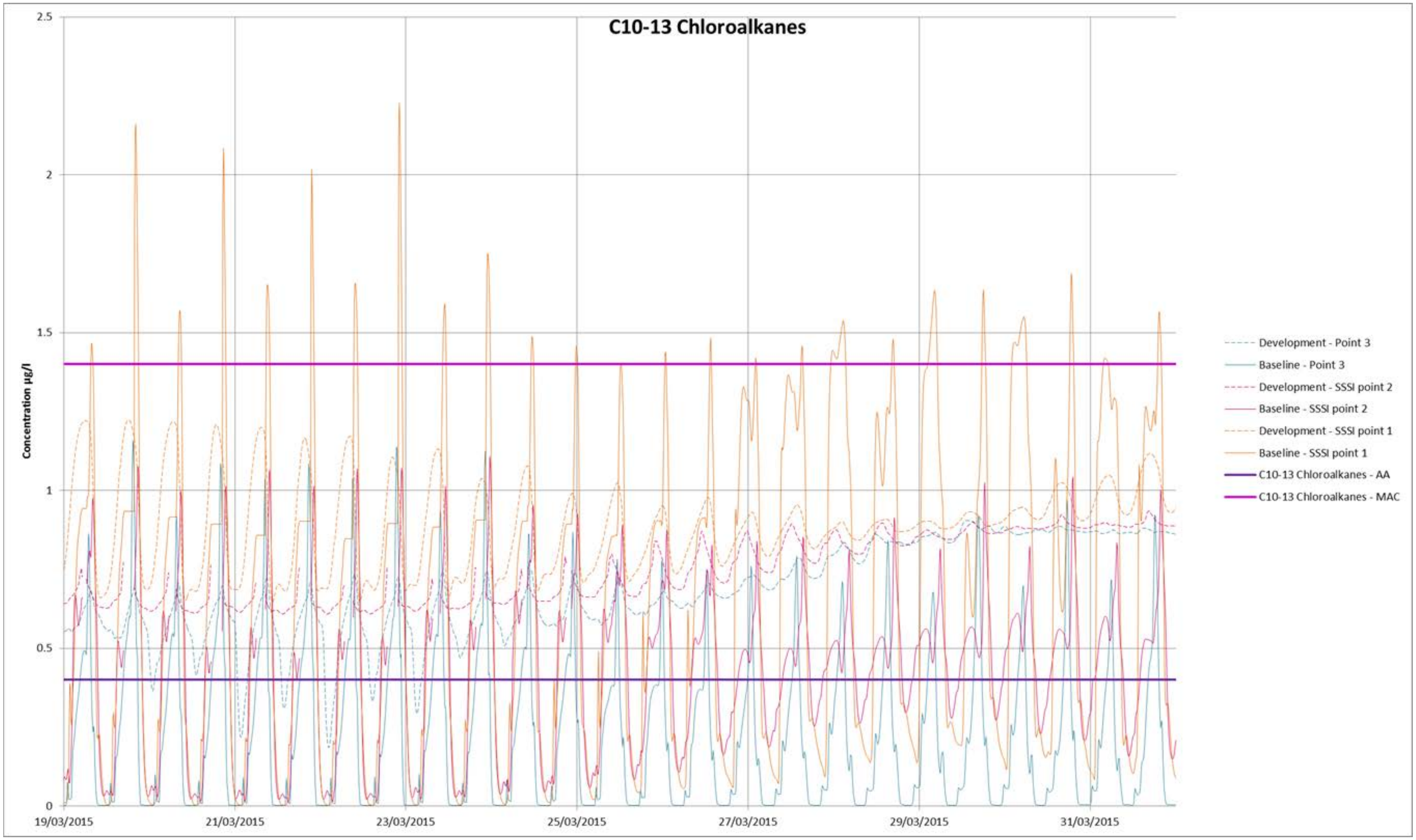


Figure B-13: Cadmium conc. timeseries – points 4,5,6

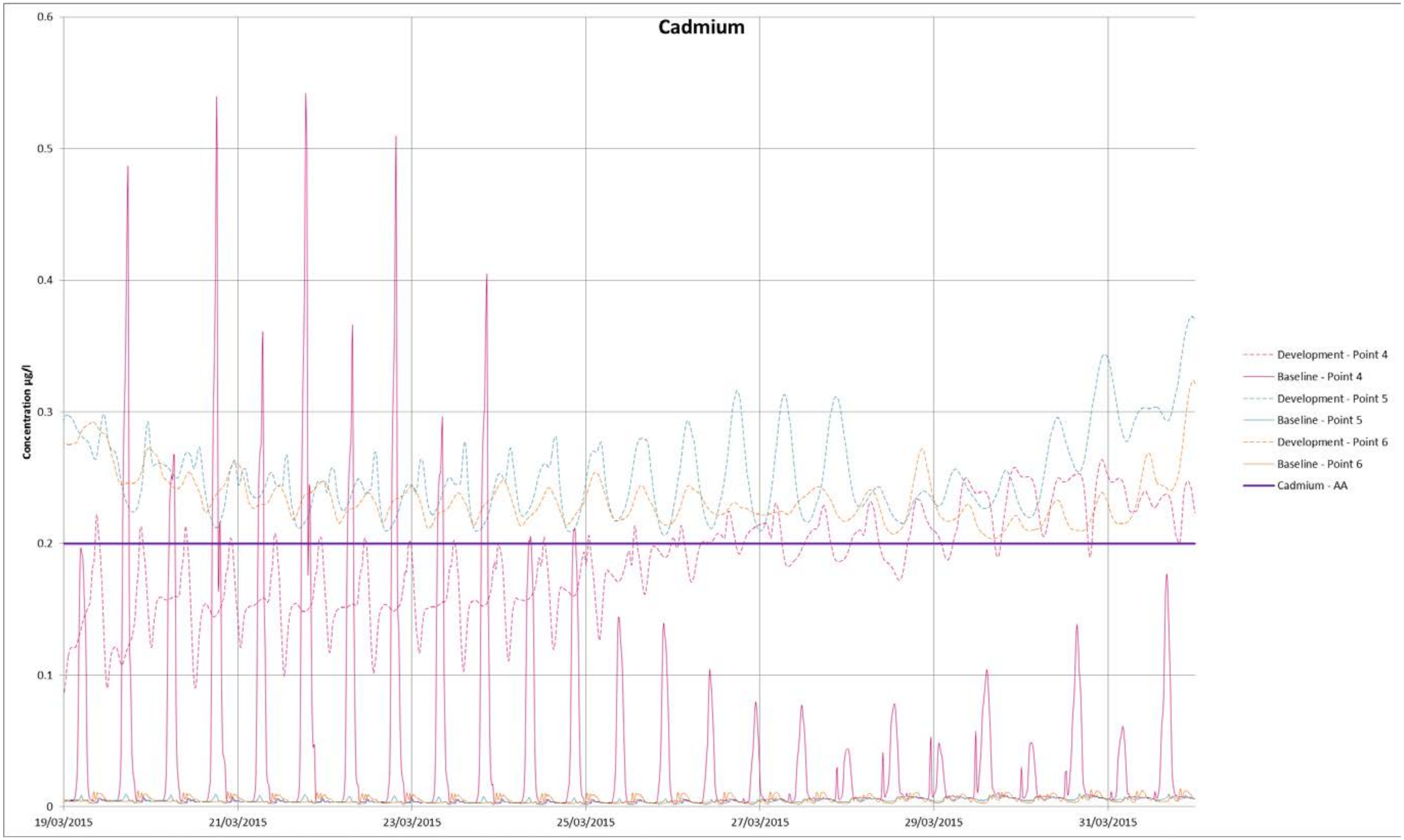


Figure B-14: Cadmium conc. timeseries – points 1, 2, 7

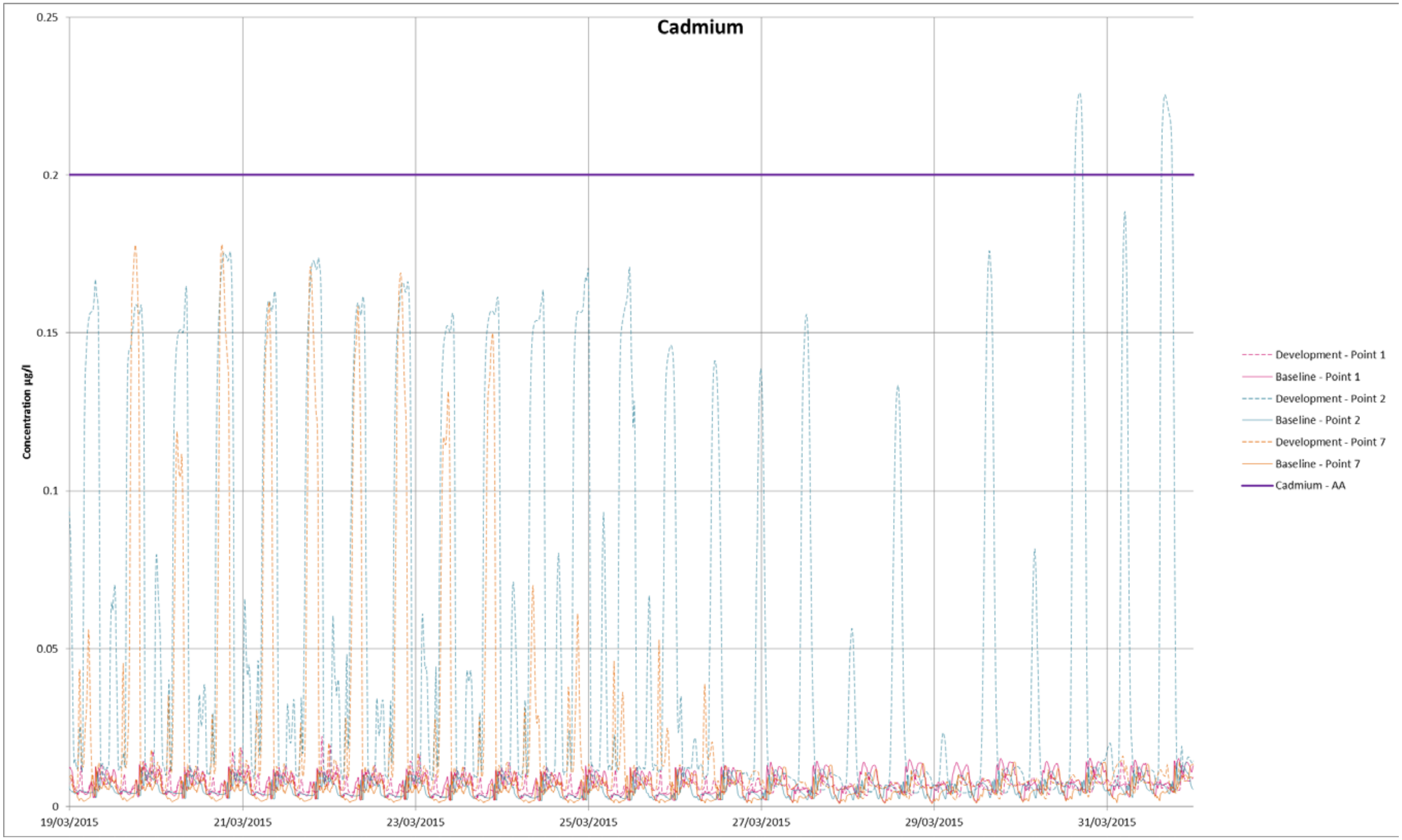


Figure B-15: Cadmium conc. timeseries – point 3, SSSI 1, SSSI 2

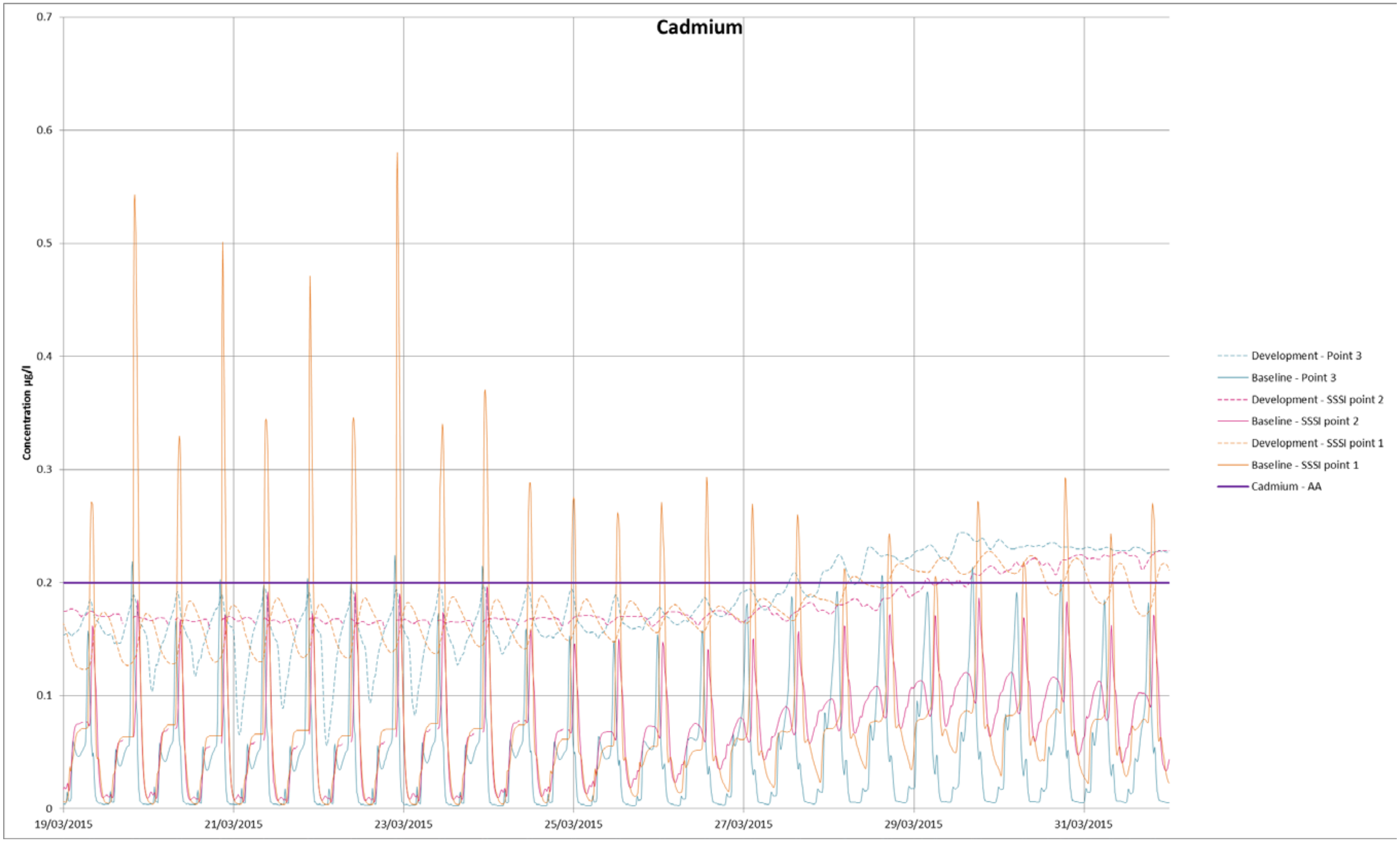


Figure B-16: Chromium conc. timeseries – points 4, 5, 6

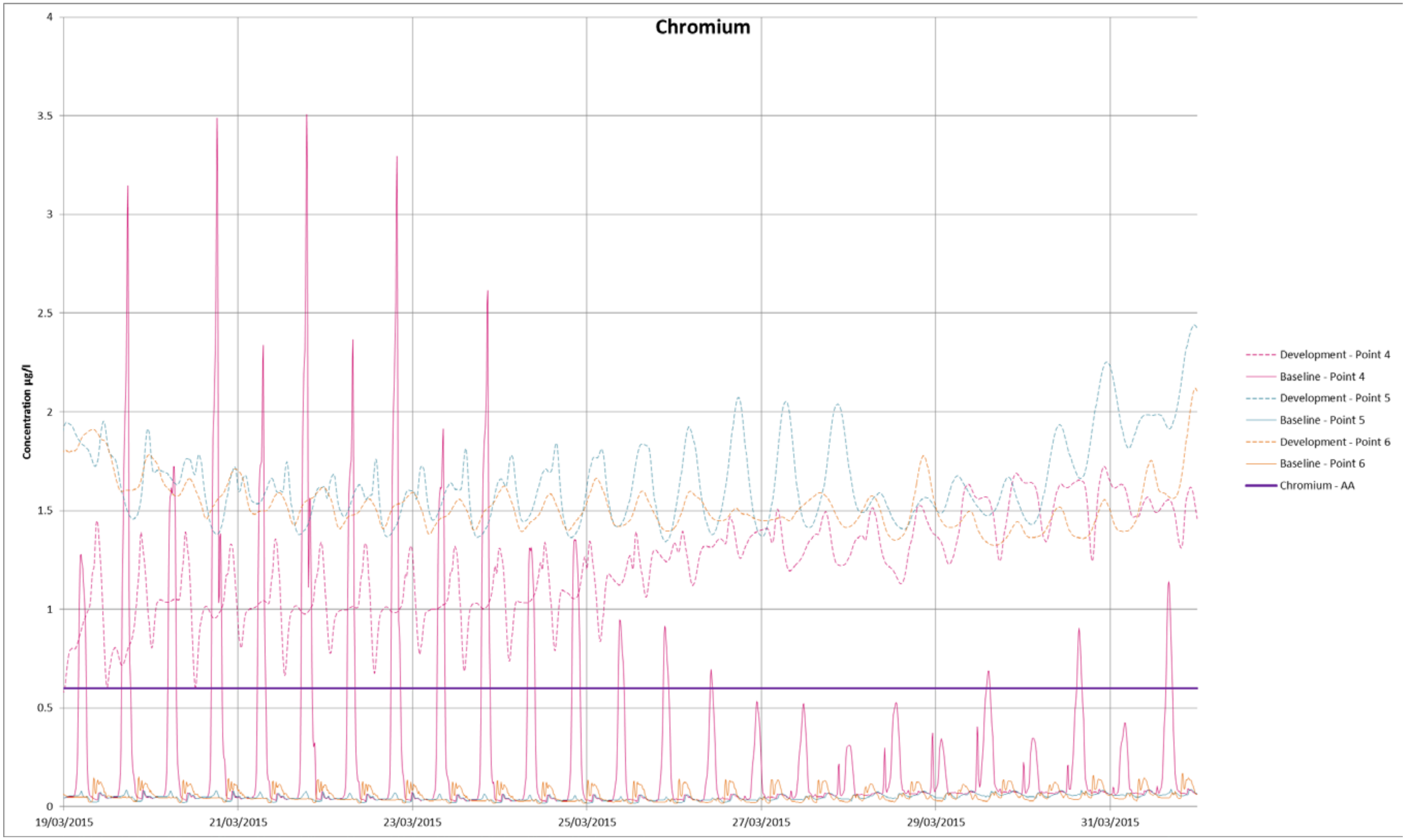


Figure B-17: Chromium conc. timeseries – points 1, 2, 7

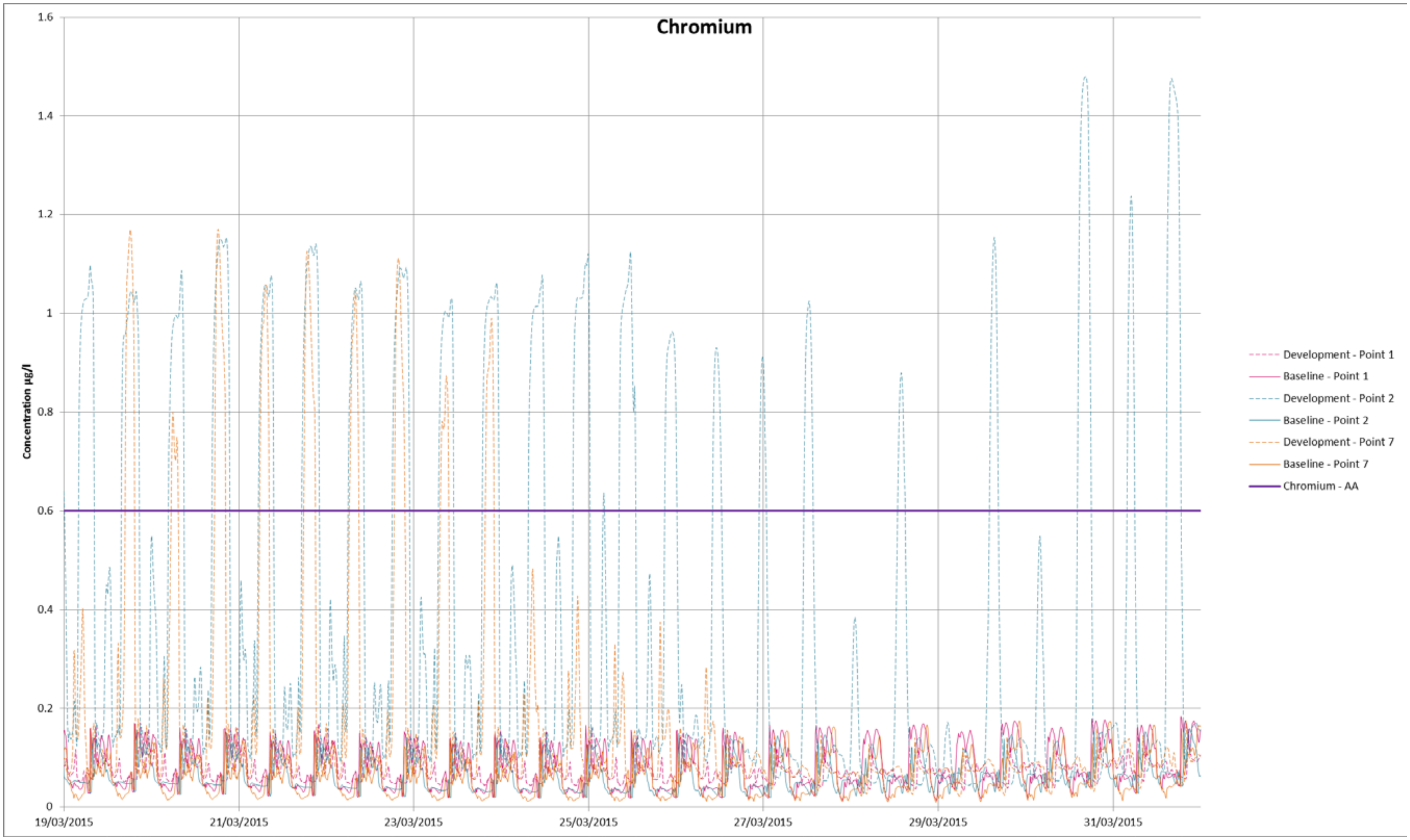


Figure B-18: Chromium conc. timeseries – point 3, SSSI 1, SSSI 2

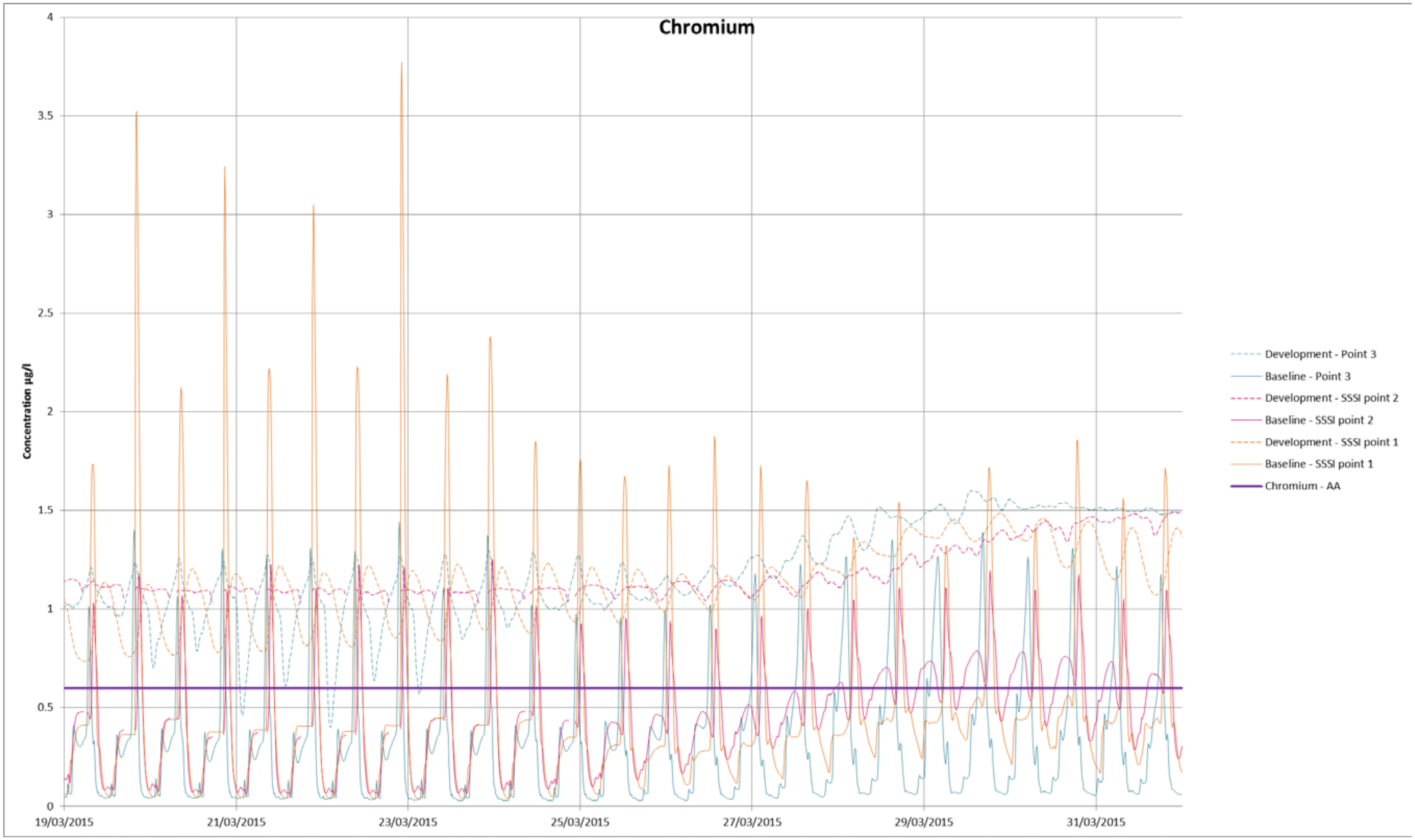


Figure B-19: Copper conc. timeseries – points 4, 5, 6

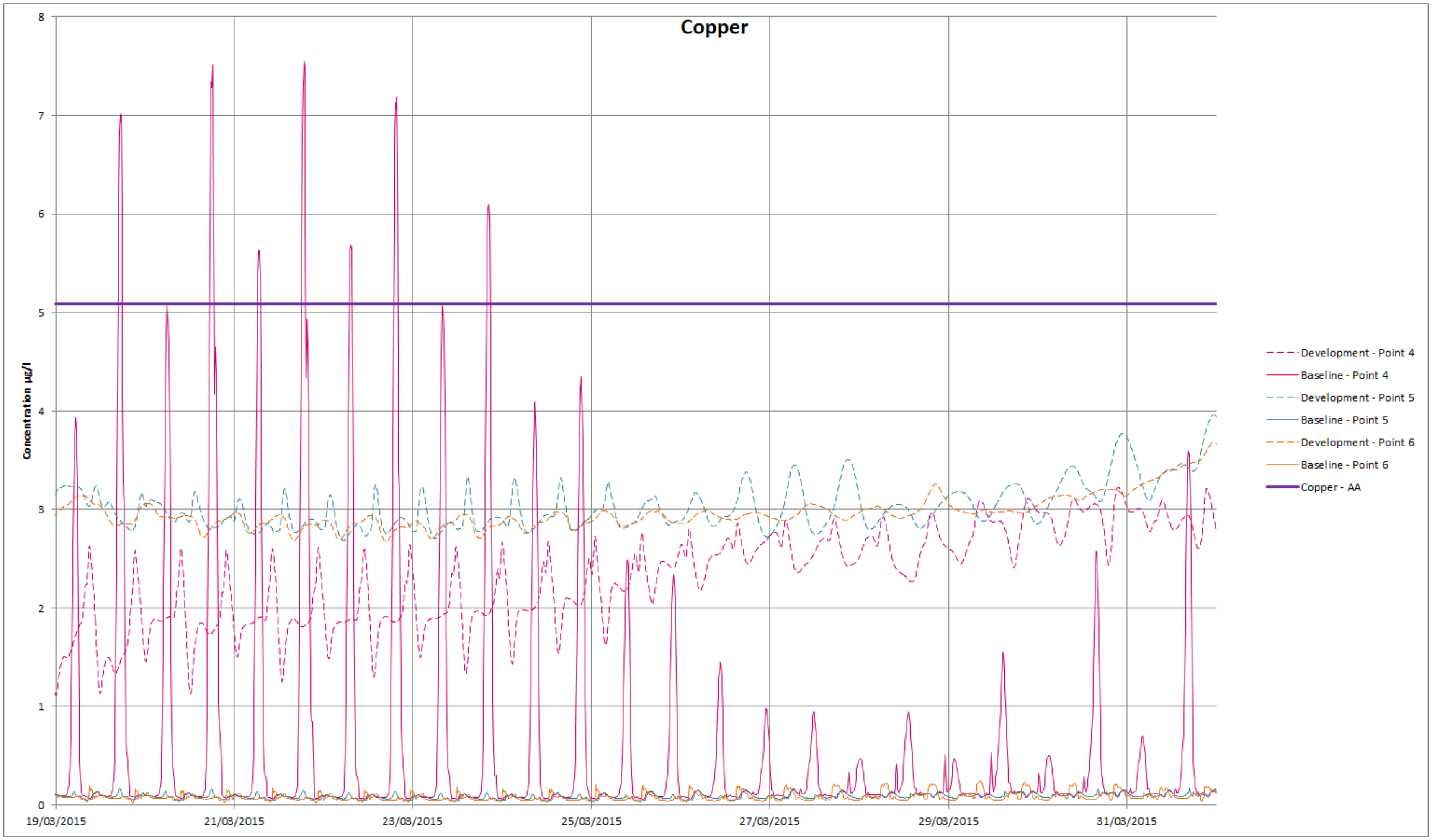


Figure B-20: Copper conc. timeseries – points 1, 2, 7

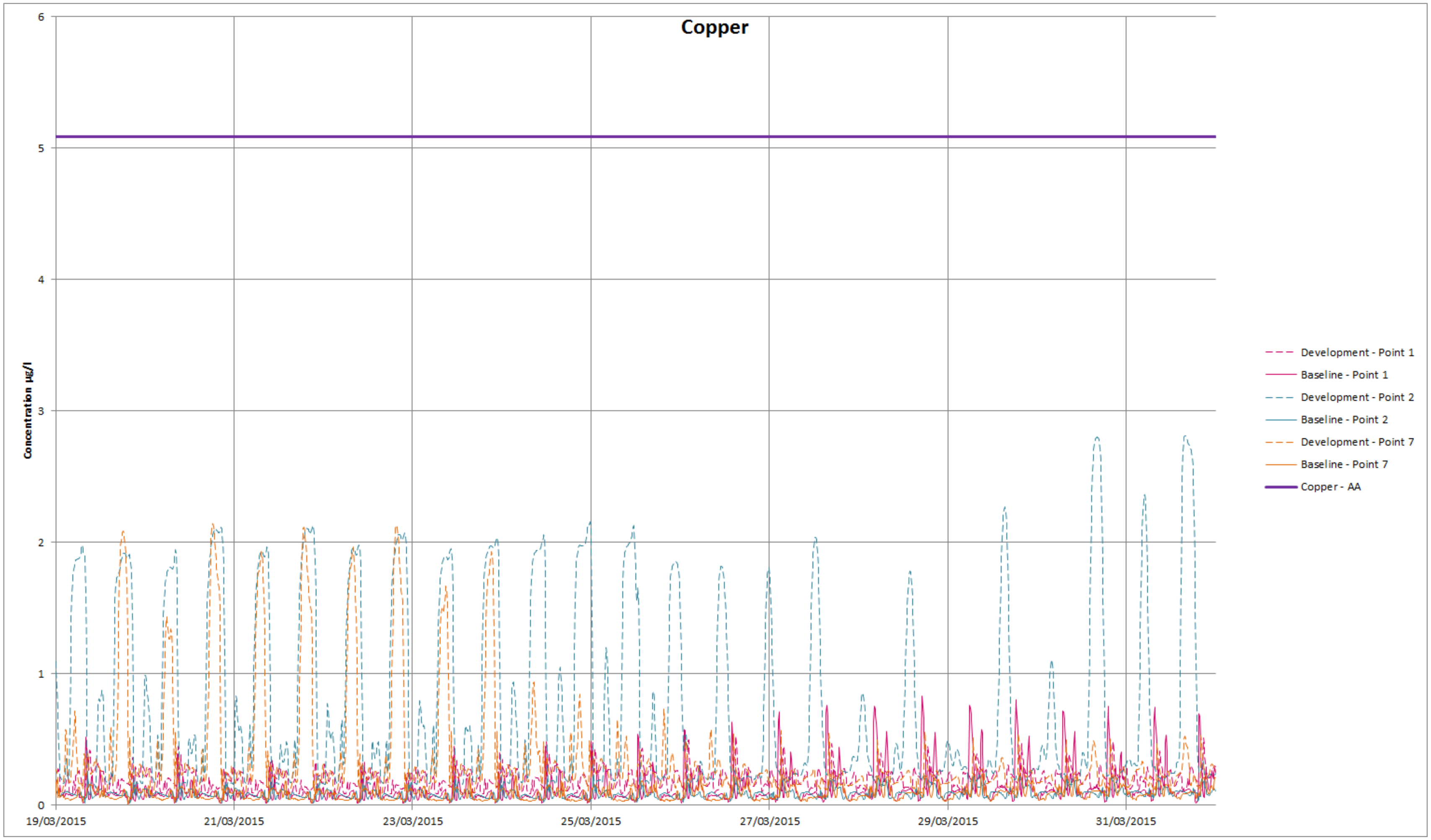


Figure B-21: Copper conc. timeseries – point 3, SSSI 1, SSSI 2

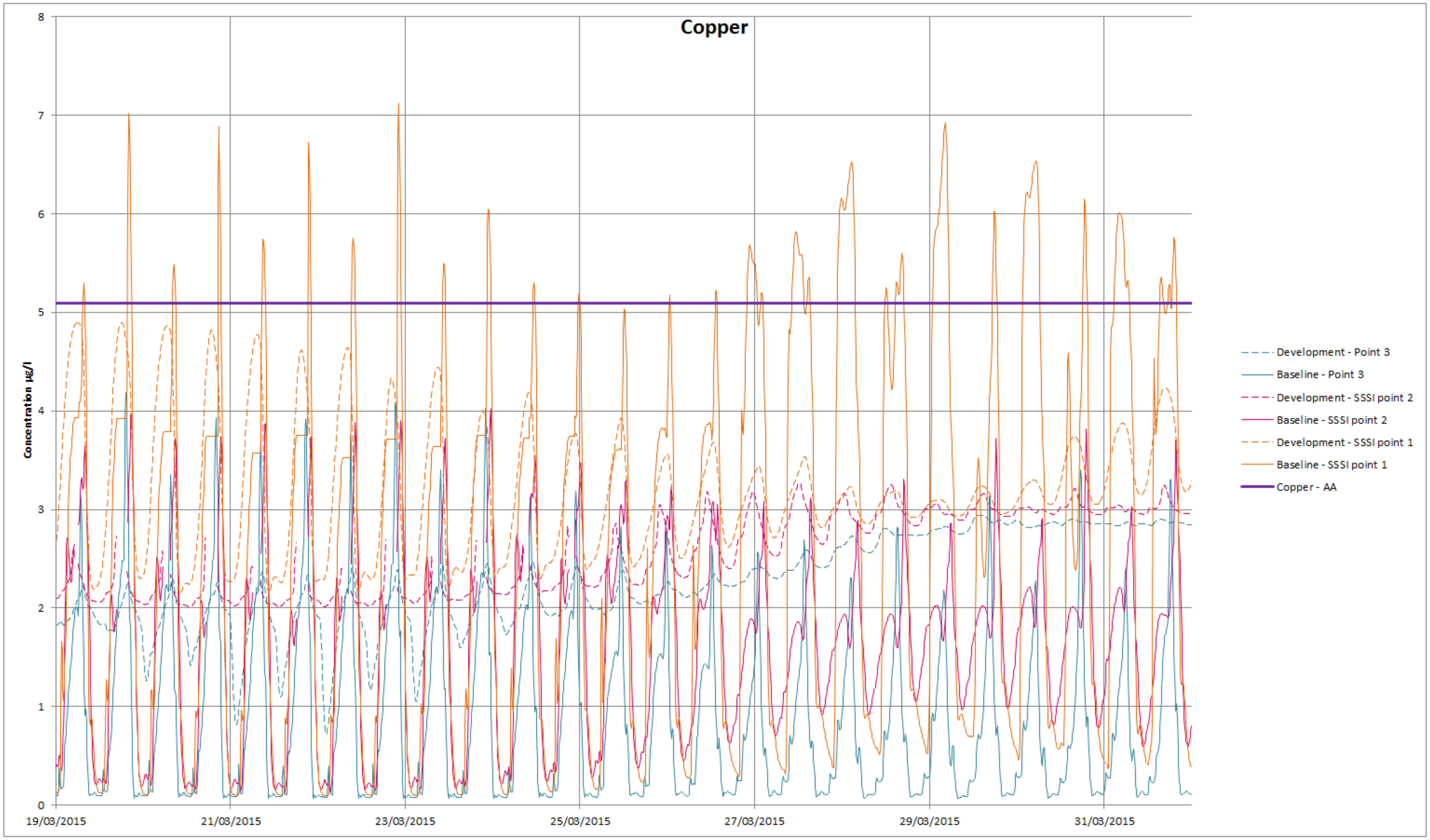


Figure B-22: DIN conc. timeseries – points 4, 5, 6

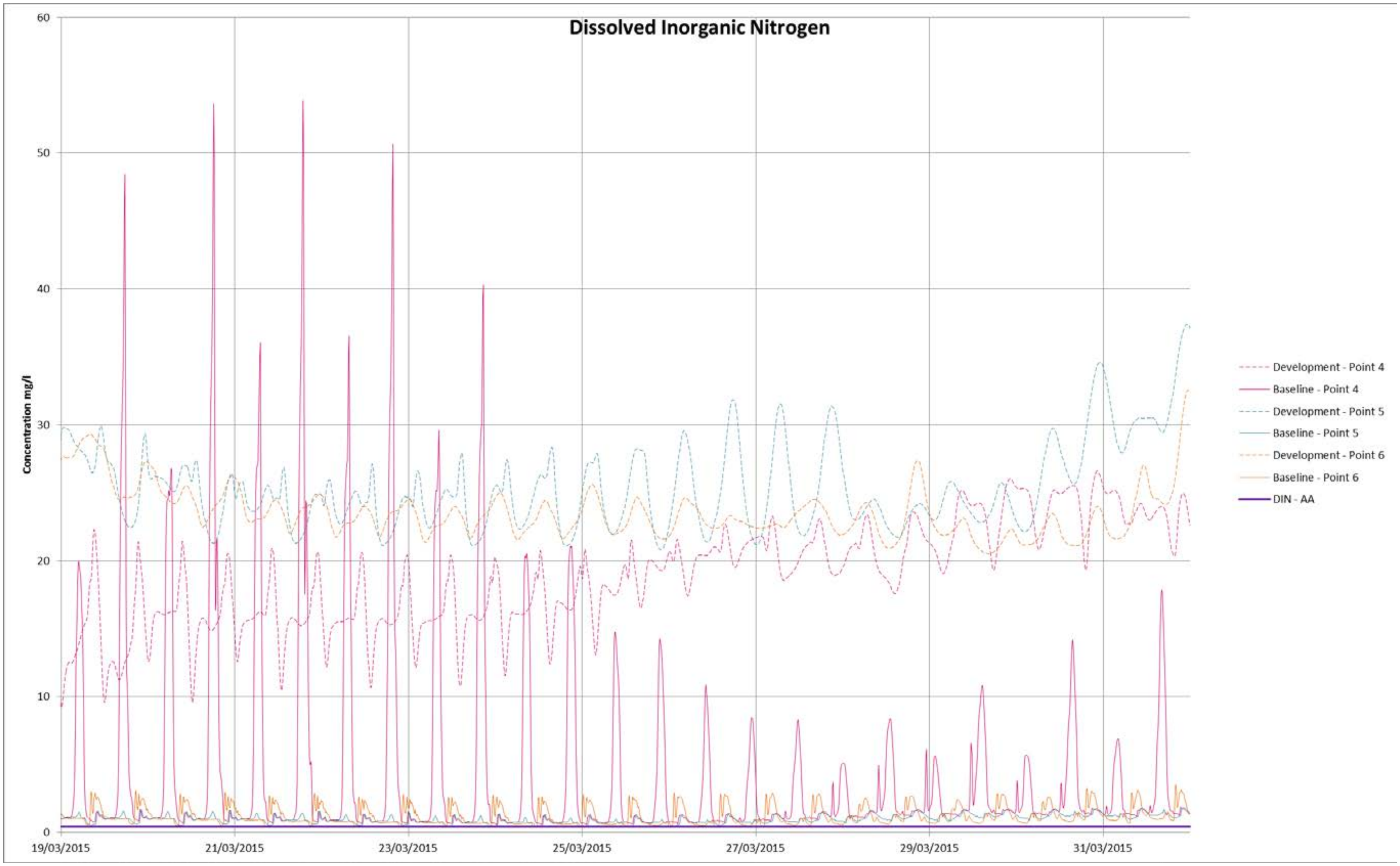


Figure B-23: DIN conc. timeseries – points 1, 2, 7

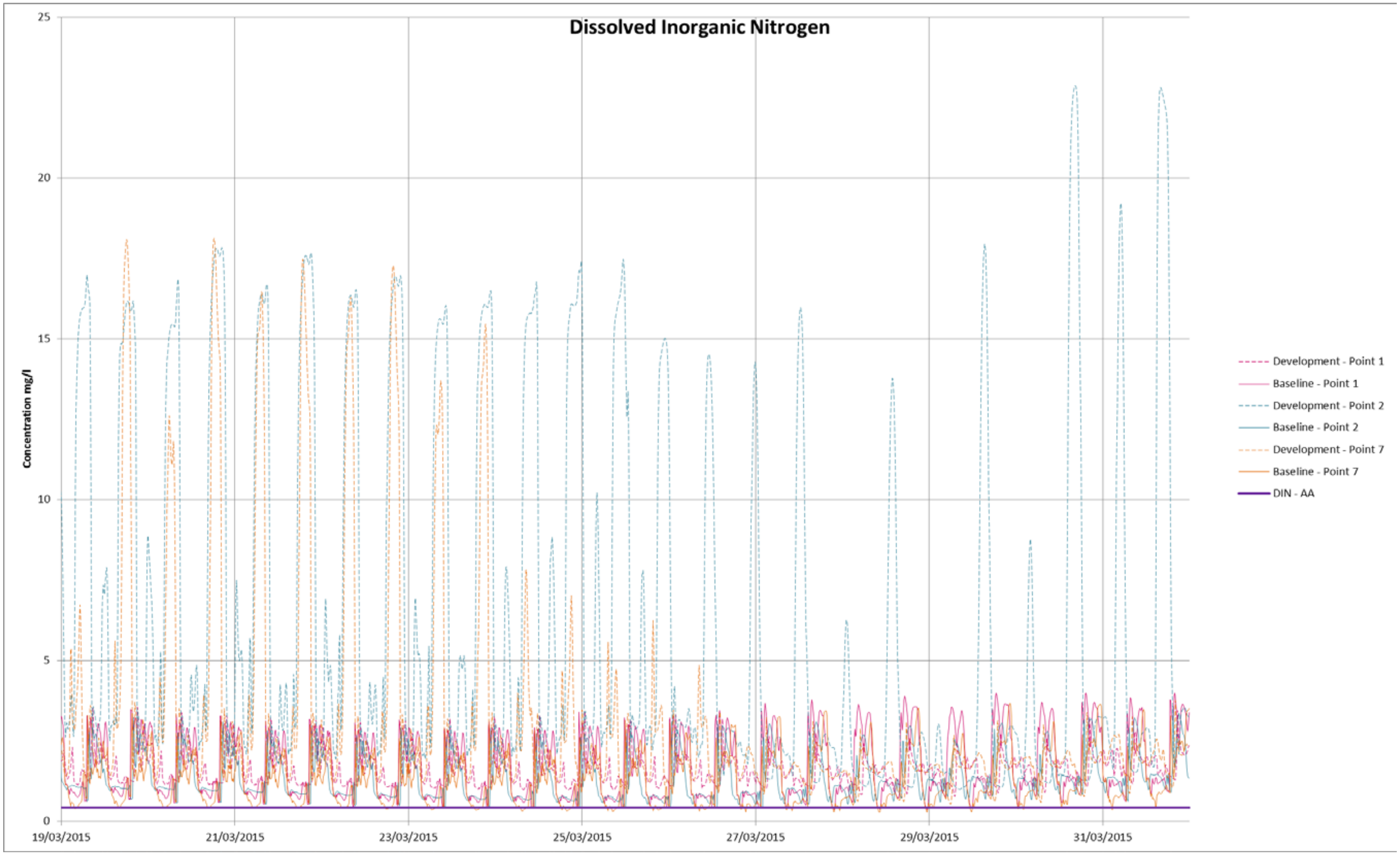


Figure B-24: DIN conc. timeseries – point 3, SSSI 1, SSSI 2

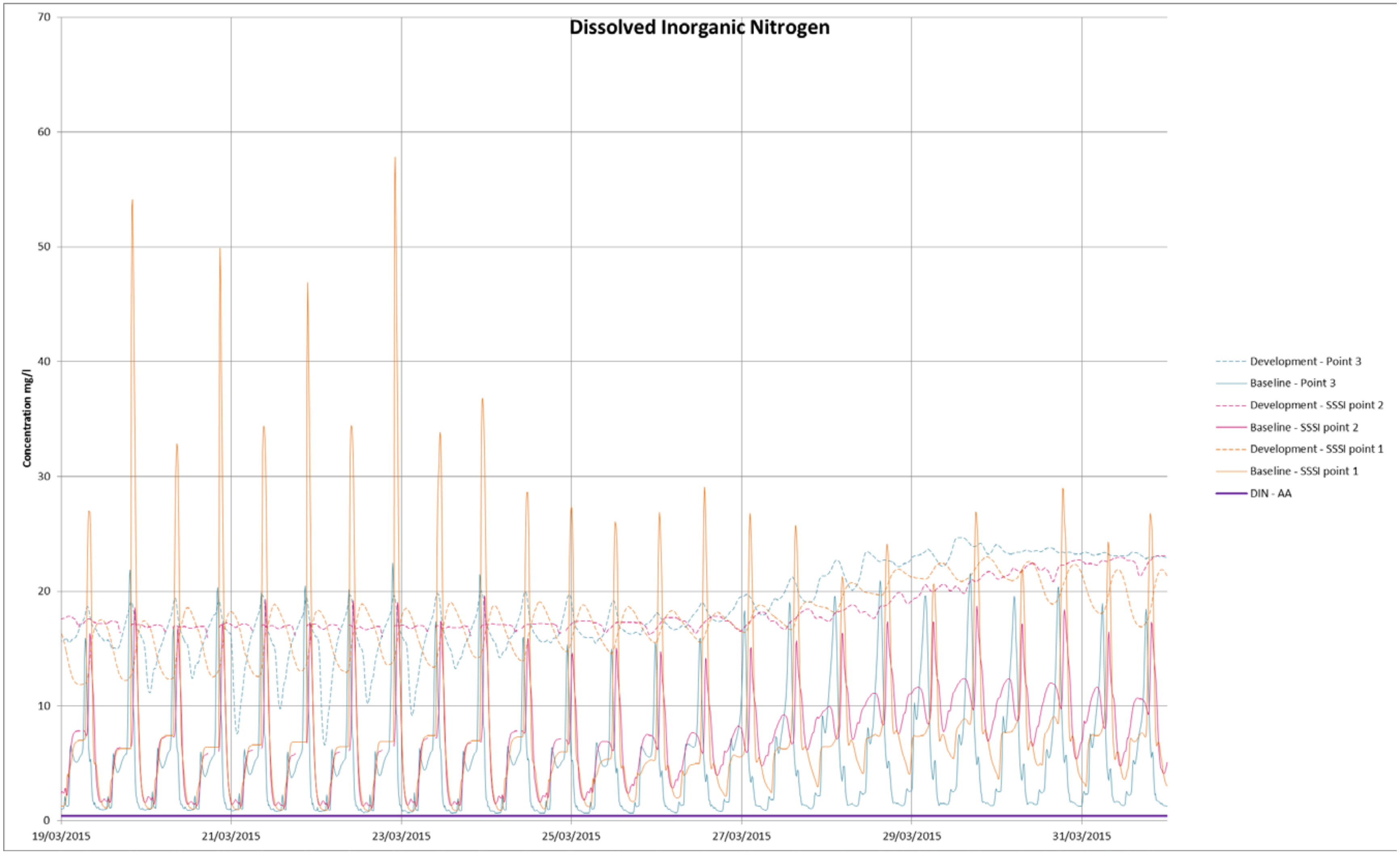


Figure B-25: Dissolved Oxygen (DO) conc. timeseries – points 4, 5, 6

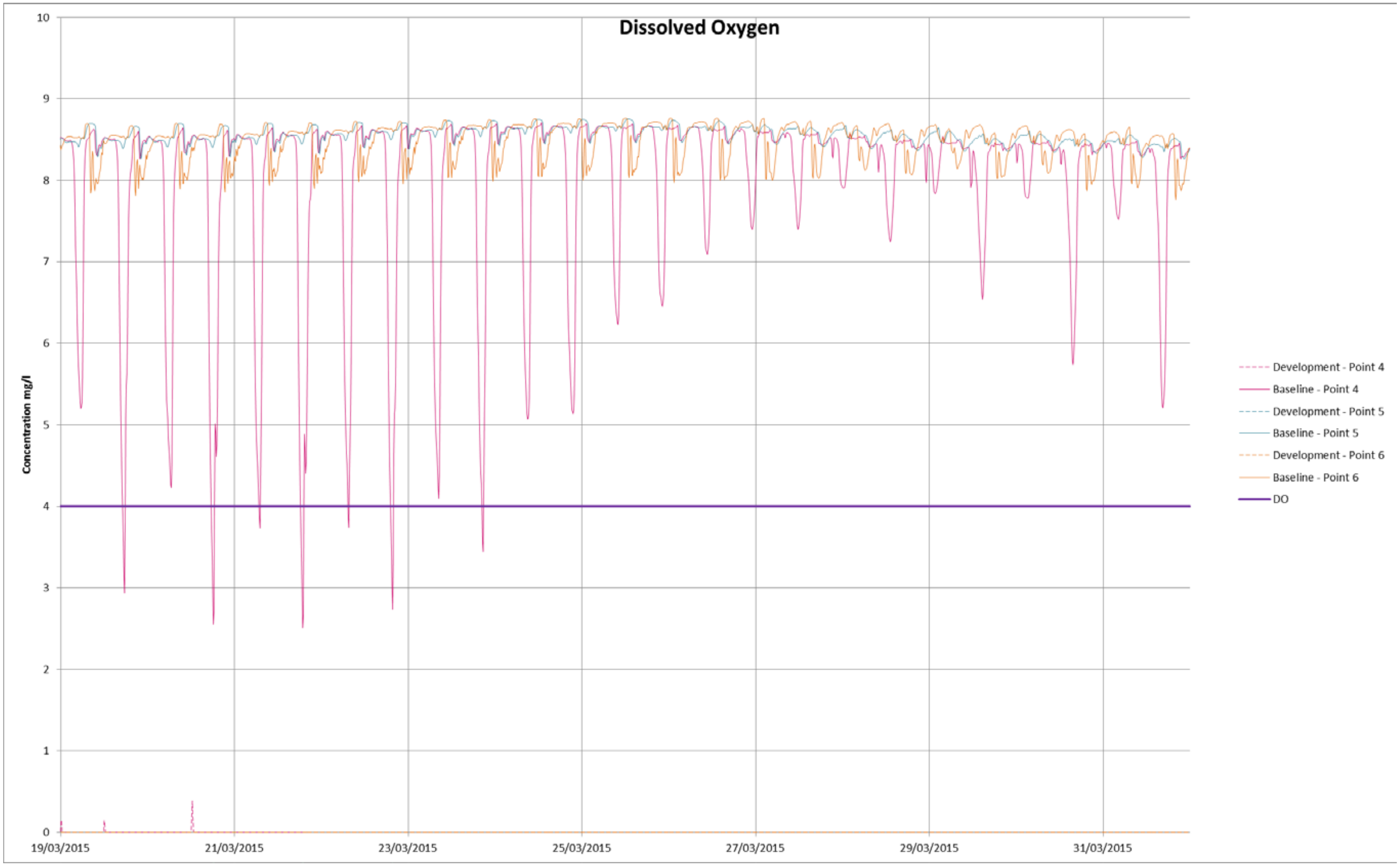


Figure B-26: Dissolved Oxygen (DO) conc. timeseries – points 1, 2, 7

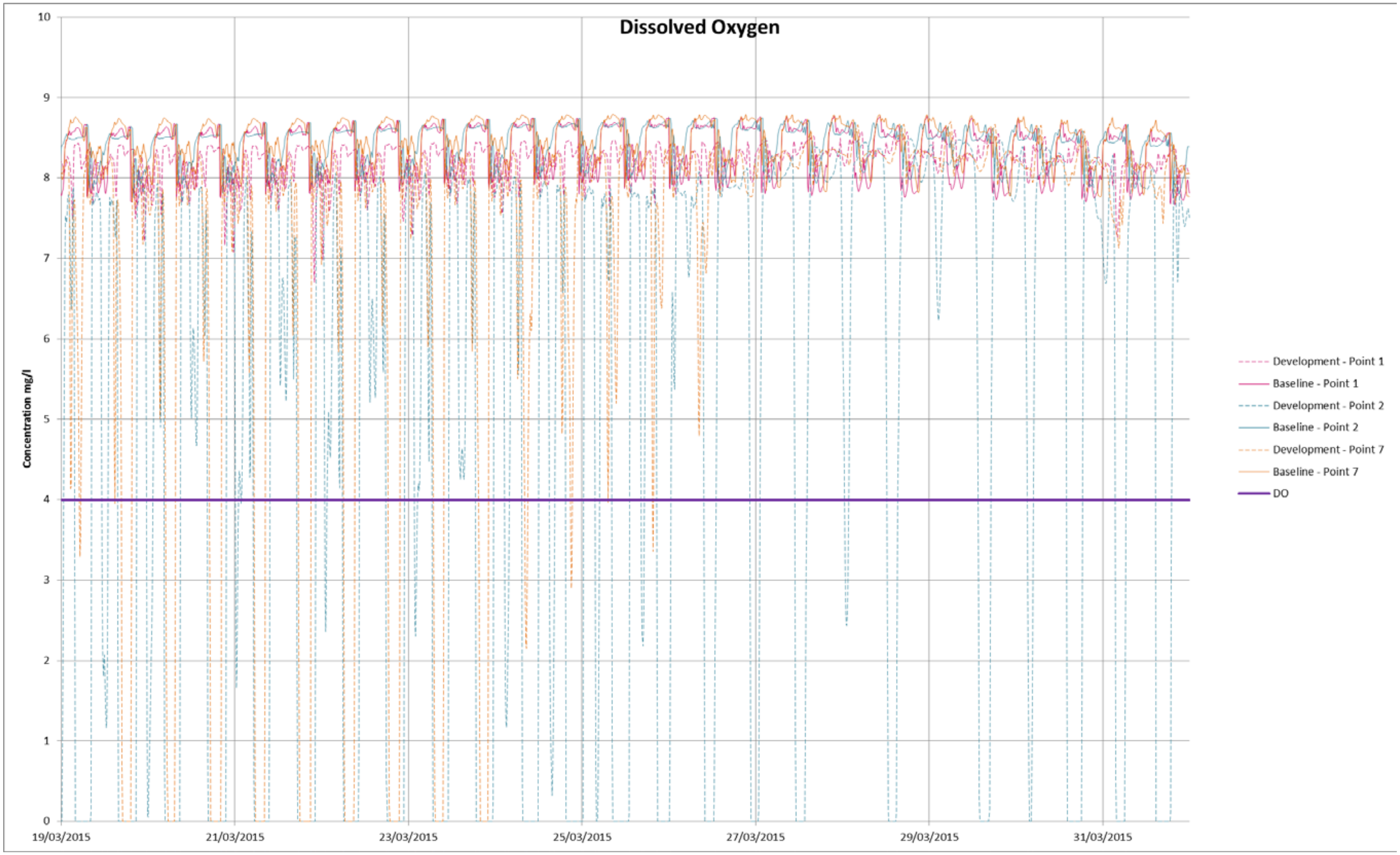


Figure B-27: Dissolved Oxygen (DO) conc. timeseries – point 3, SSSI 1, SSSI 2

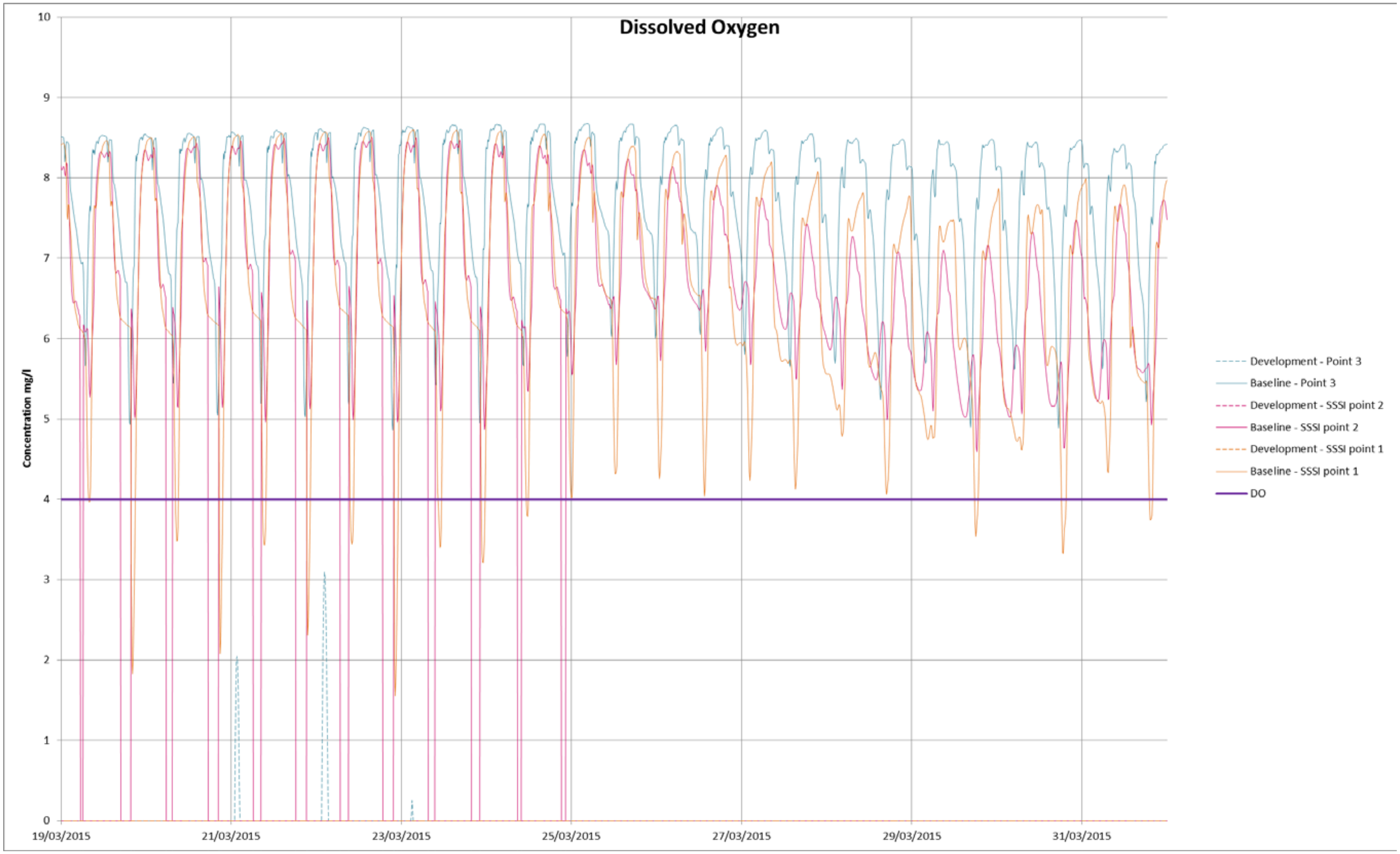


Figure B-28: Escherichia coli (EC) conc. timeseries – points 4, 5, 6

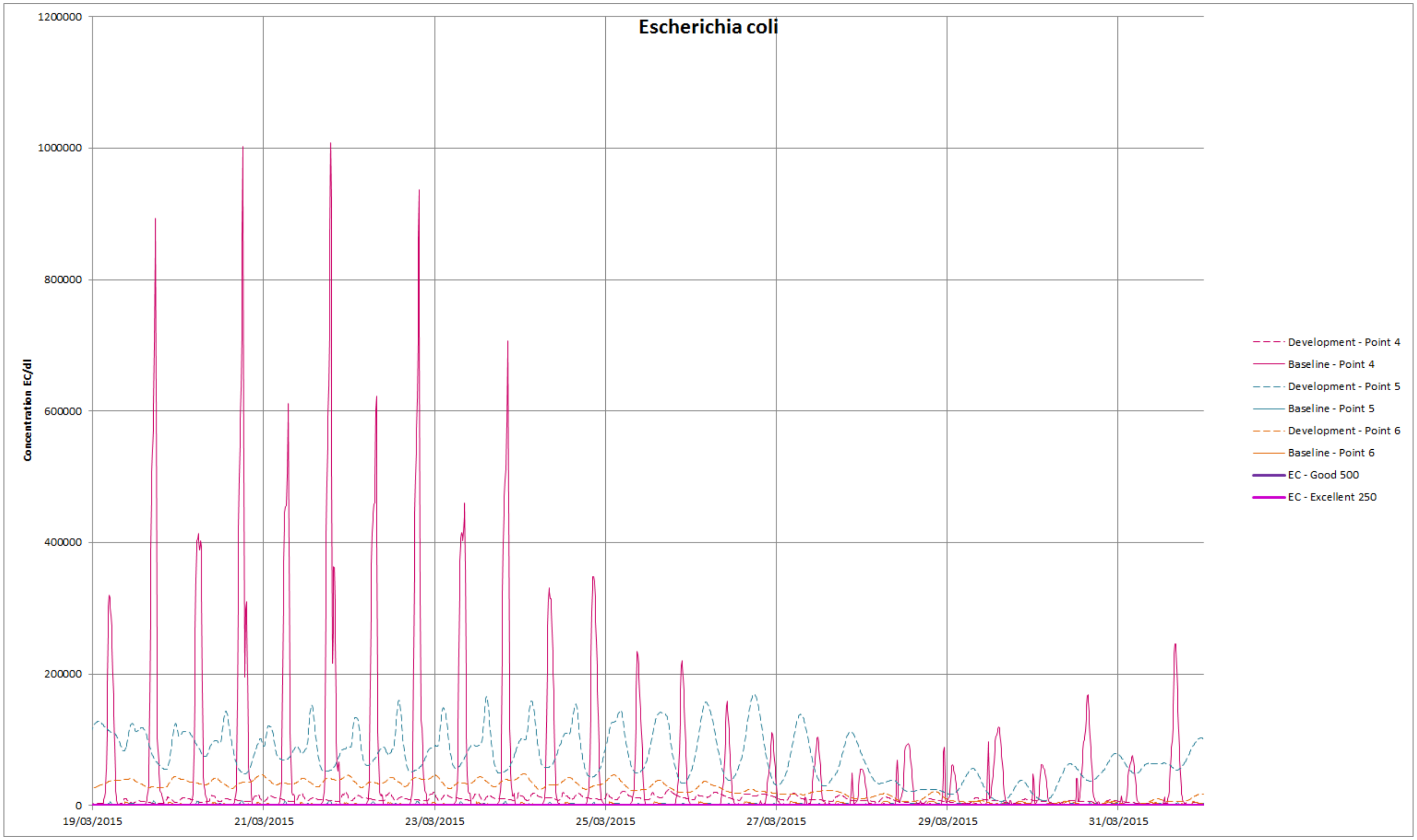


Figure B-29: Escherichia coli (EC) conc. timeseries – points 1, 2, 7

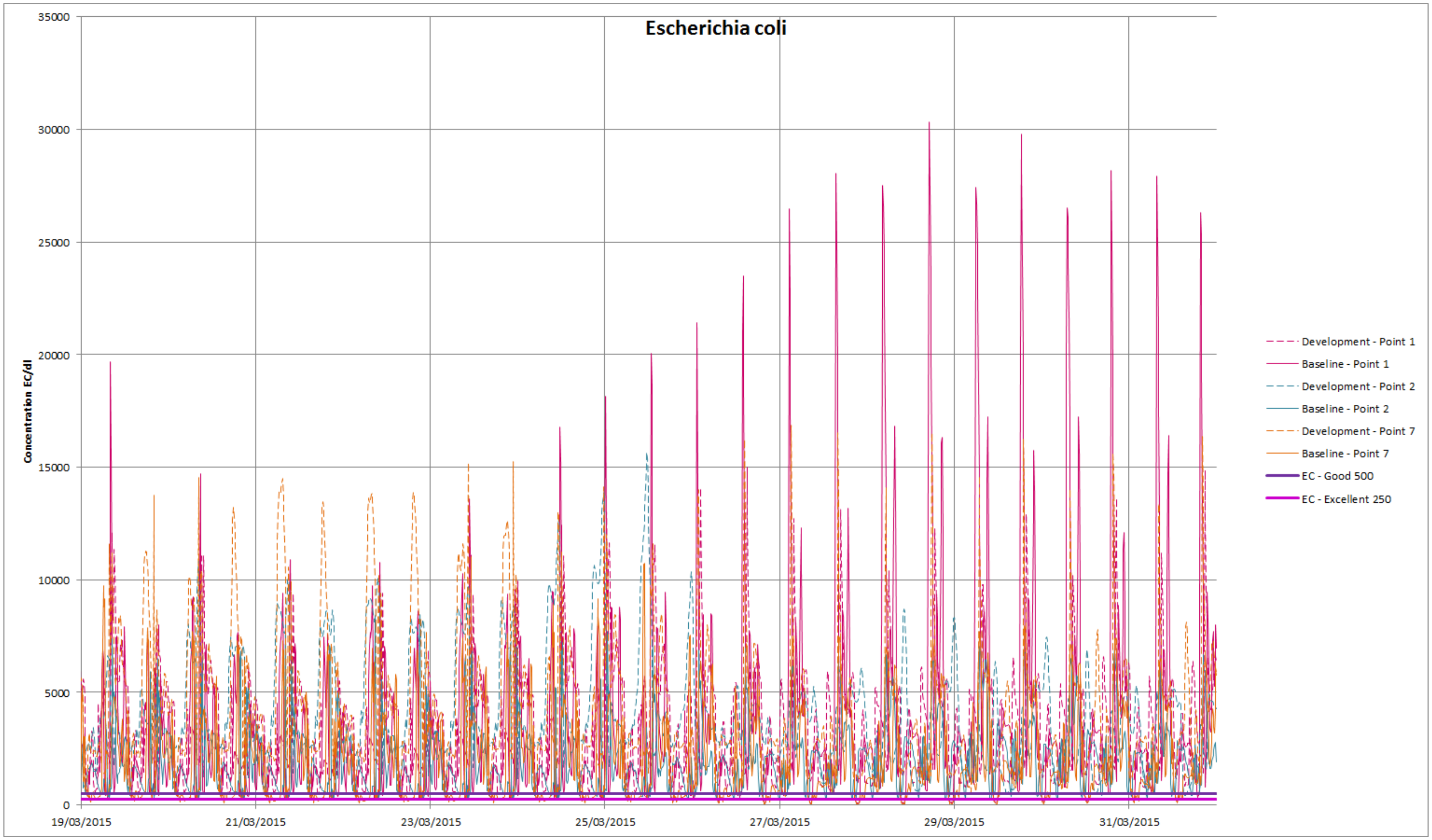


Figure B-30: Escherichia coli (EC) conc. timeseries – point 3, SSSI 1, SSSI 2

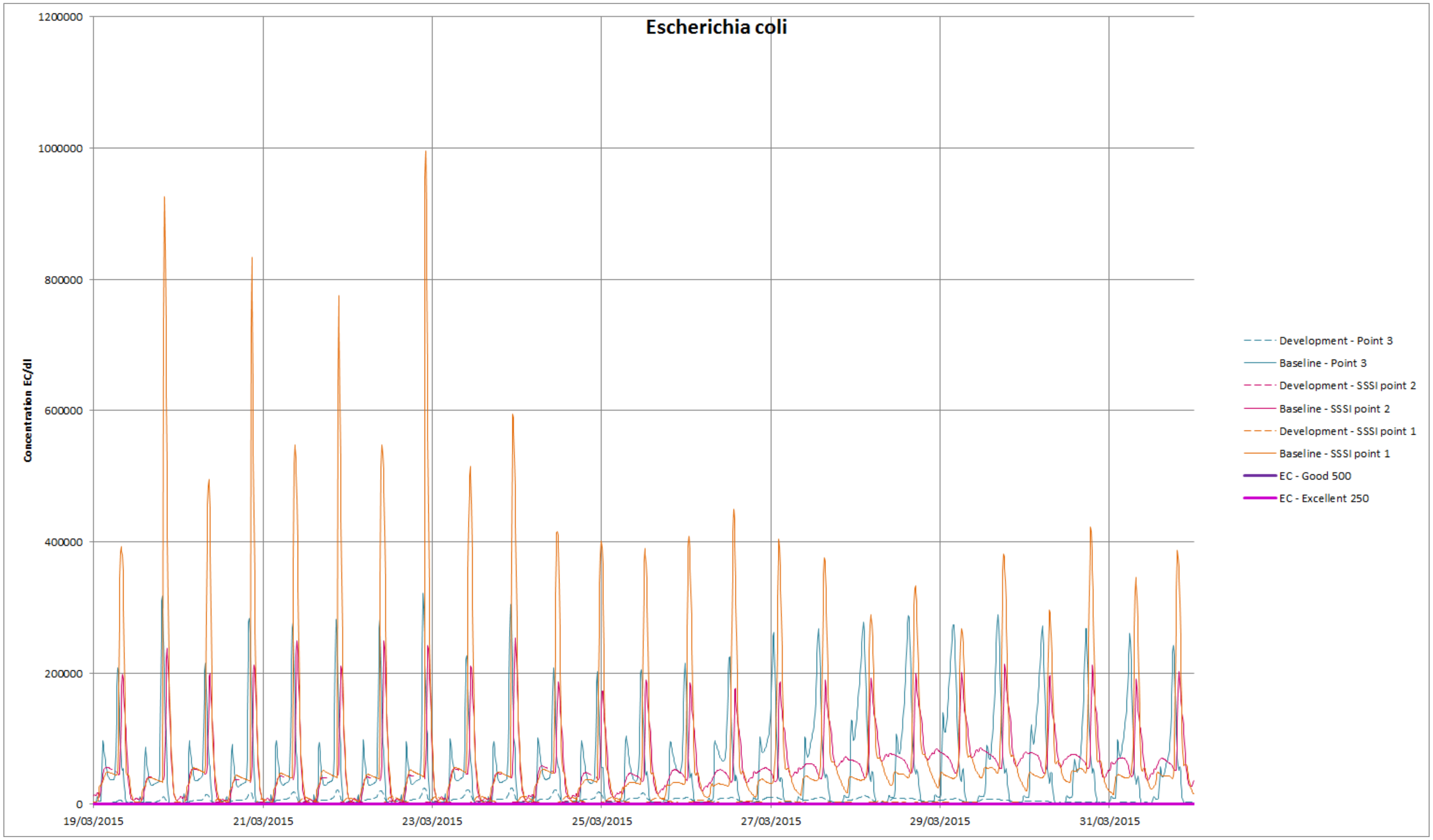


Figure B-31: Hexachlorobutadiene conc. timeseries – points 4, 5, 6

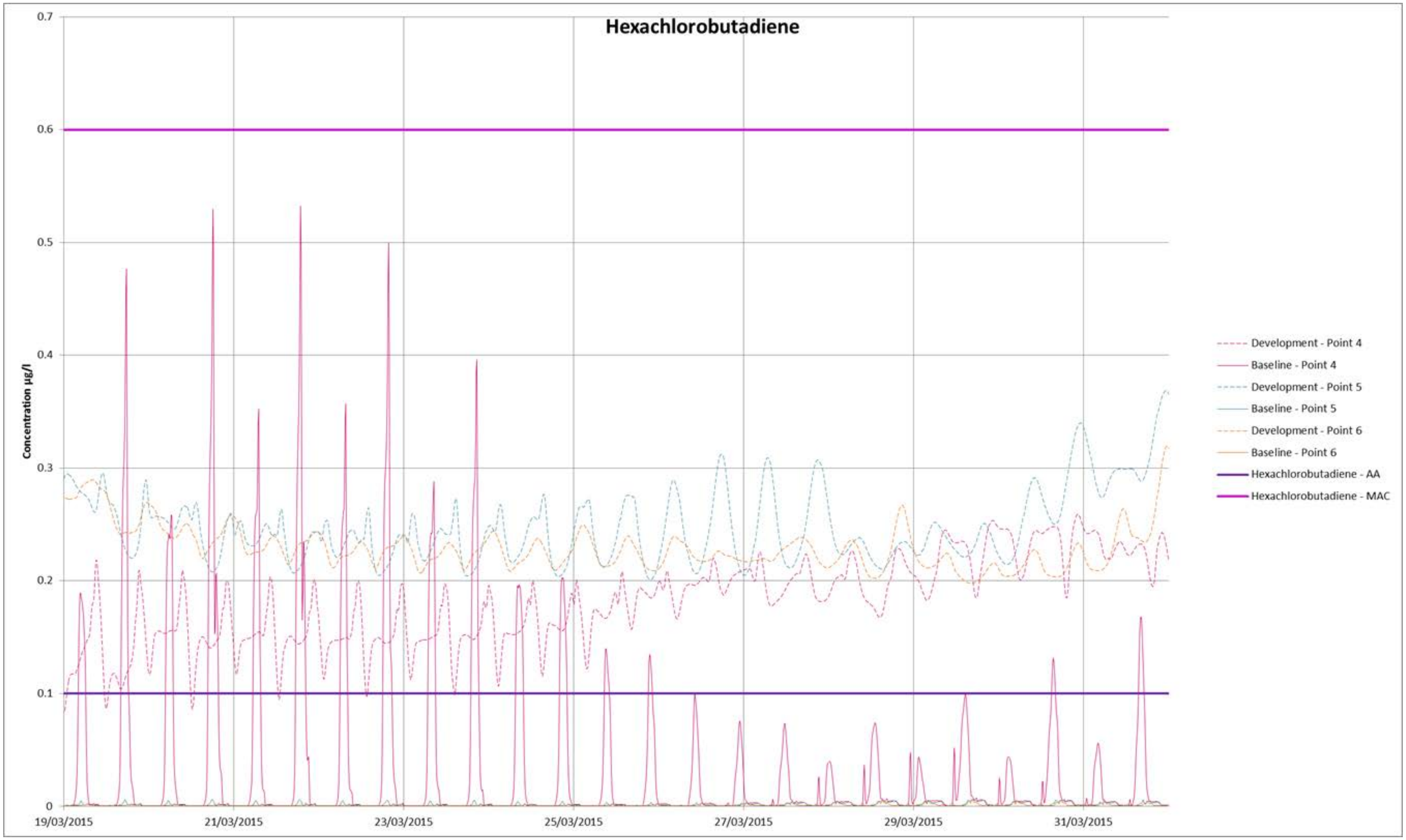


Figure B-32: Hexachlorobutadiene conc. timeseries – points 1, 2, 7

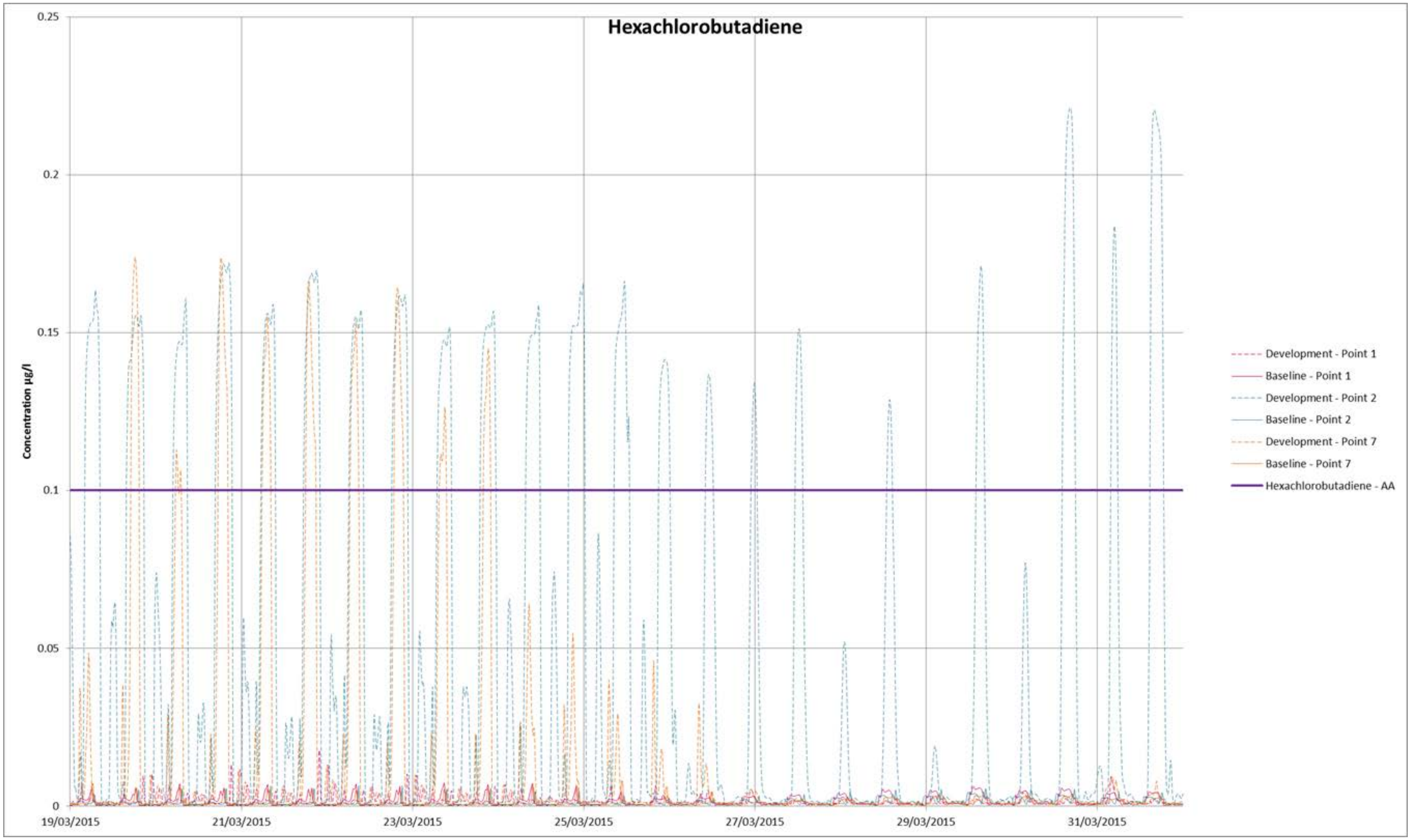


Figure B-33: Hexachlorobutadiene conc. timeseries – point 3, SSSI 1, SSSI 2

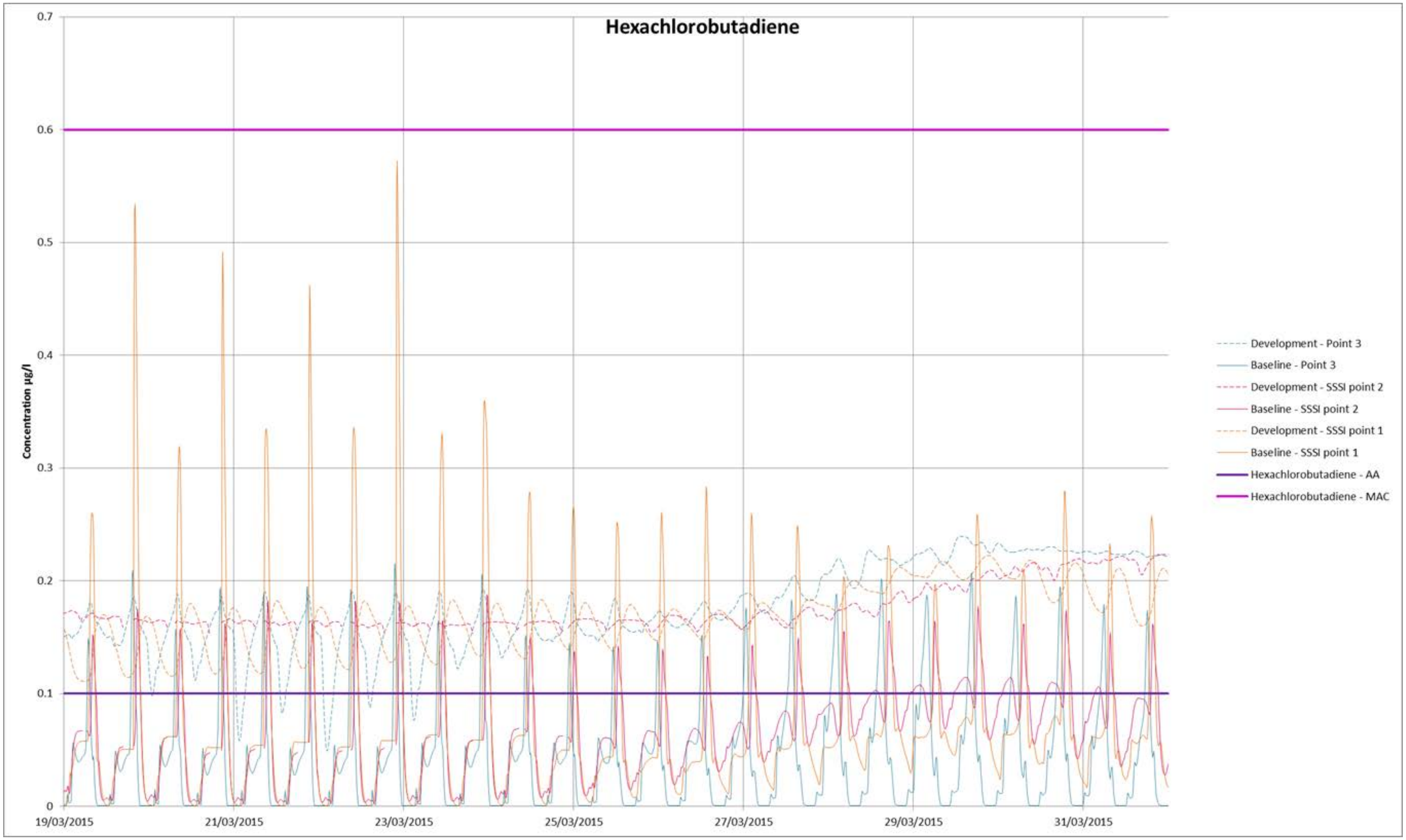


Figure B-34: Lead conc. timeseries – points 4, 5, 6

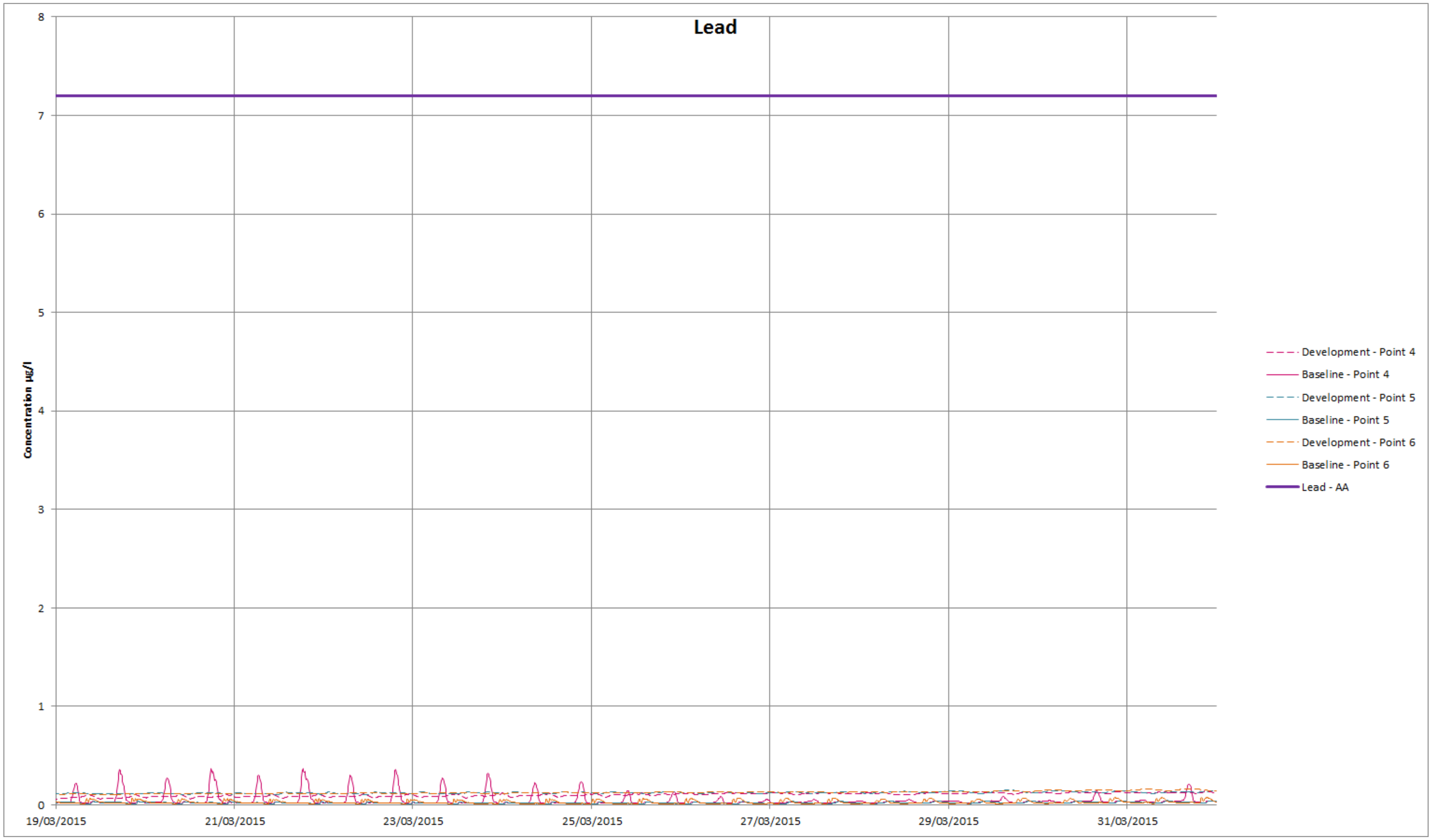


Figure B-35: Lead conc. timeseries – points 1, 2, 7

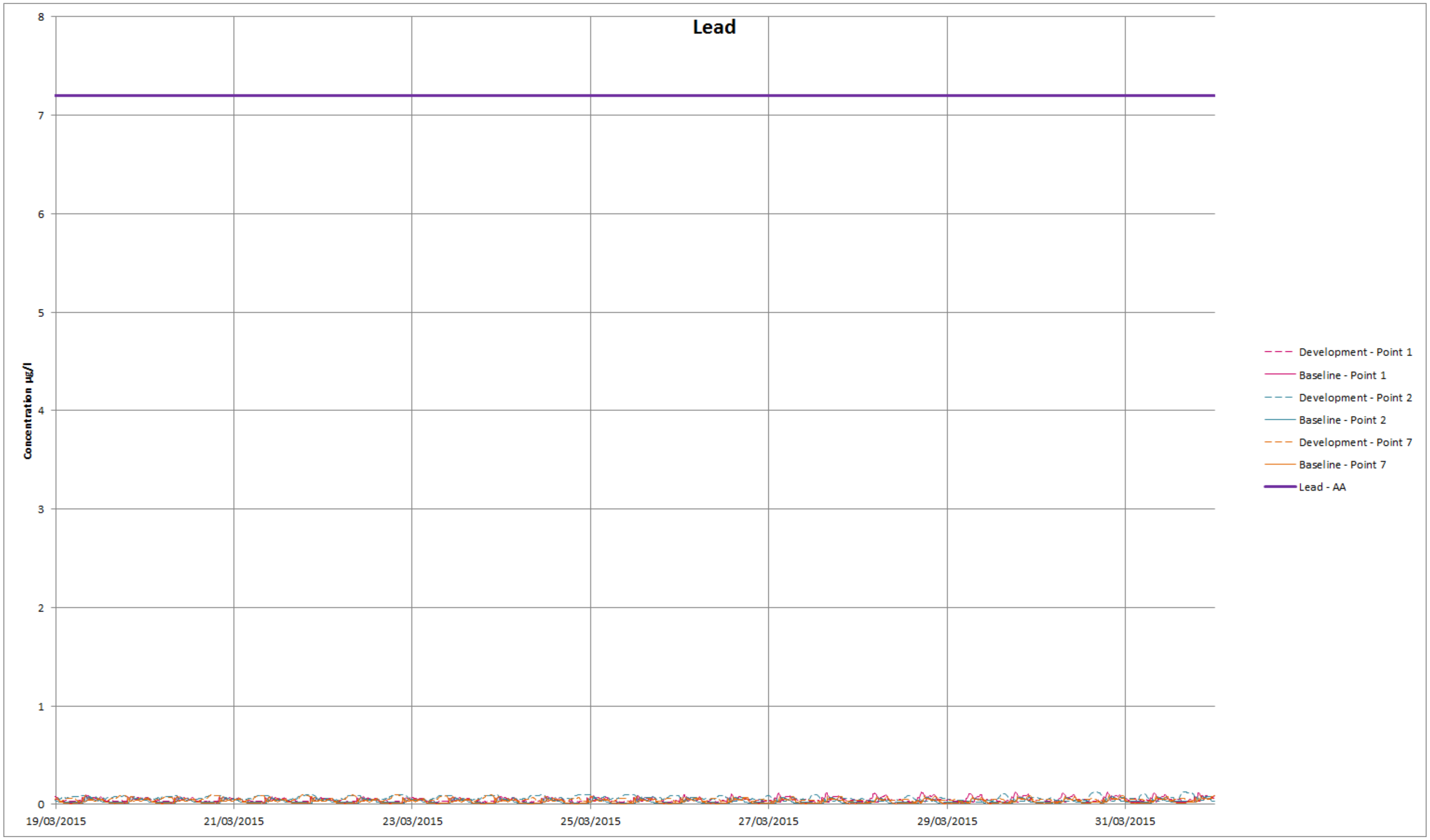


Figure B-36: Lead conc. timeseries – point 3, SSSI 1, SSSI 2

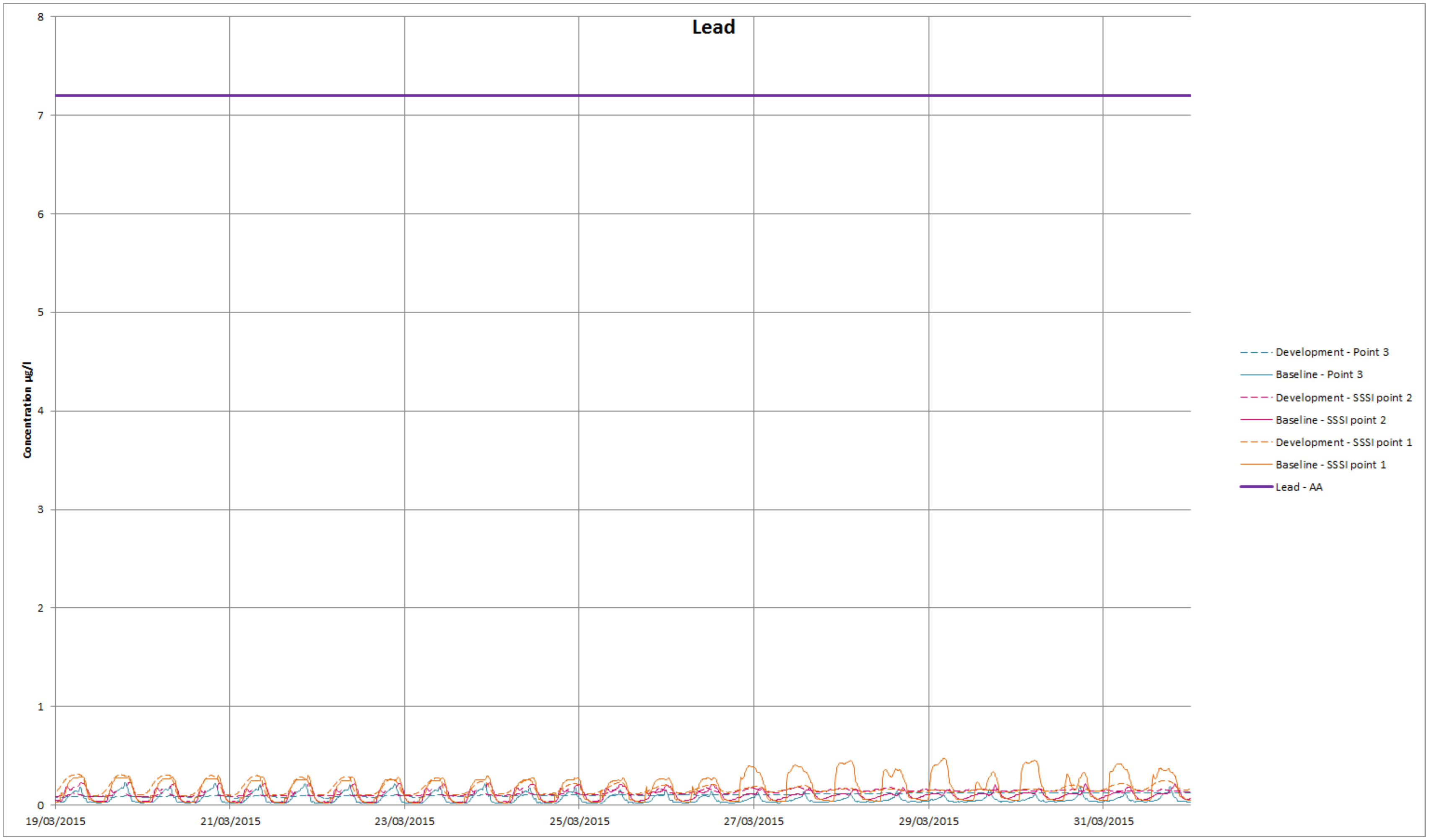


Figure B-37: Mercury conc. timeseries – points 4, 5, 6

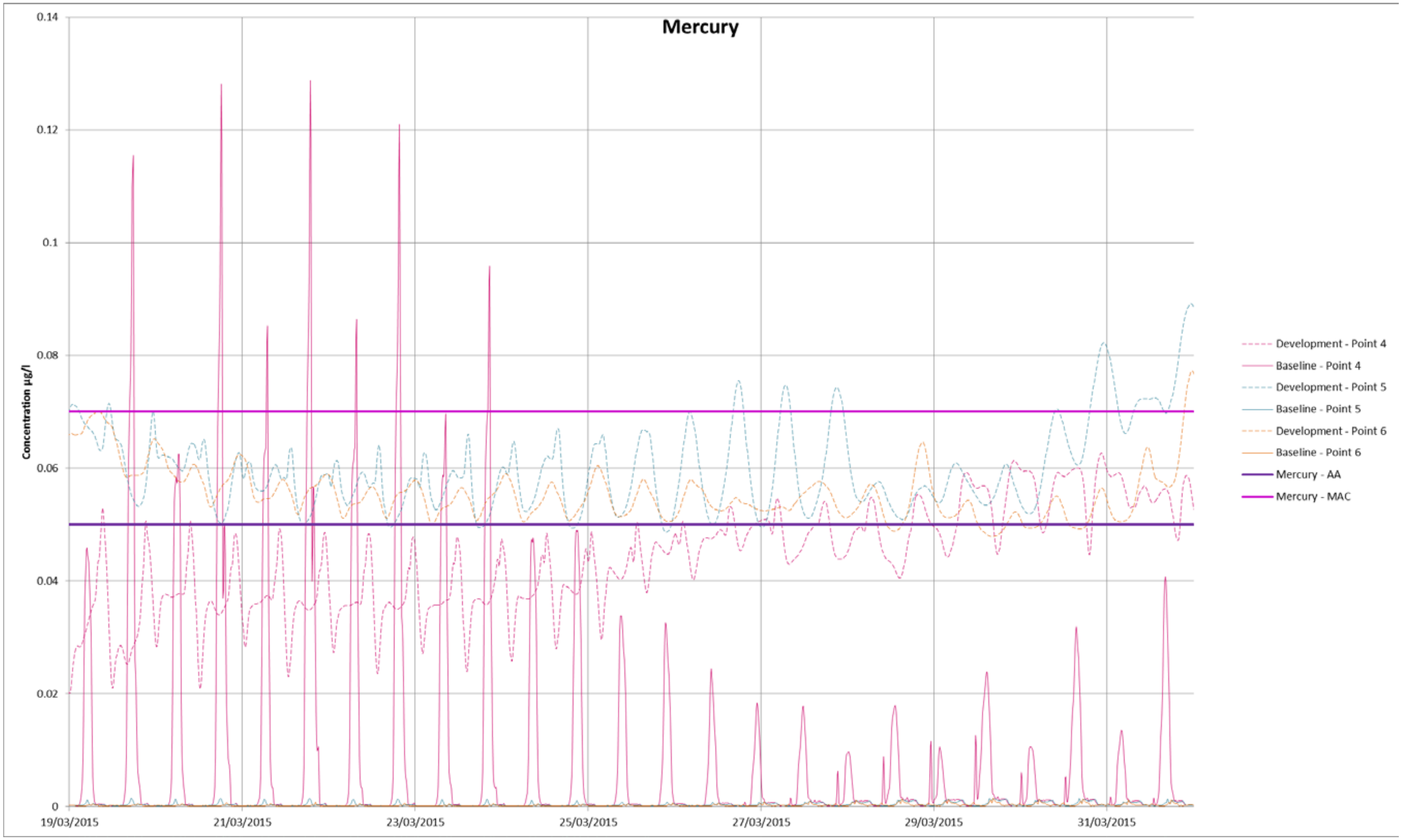


Figure B-38: Mercury conc. timeseries – points 1, 2, 7

Figure B-39: Mercury conc. timeseries – point 3, SSSI 1, SSSI 2

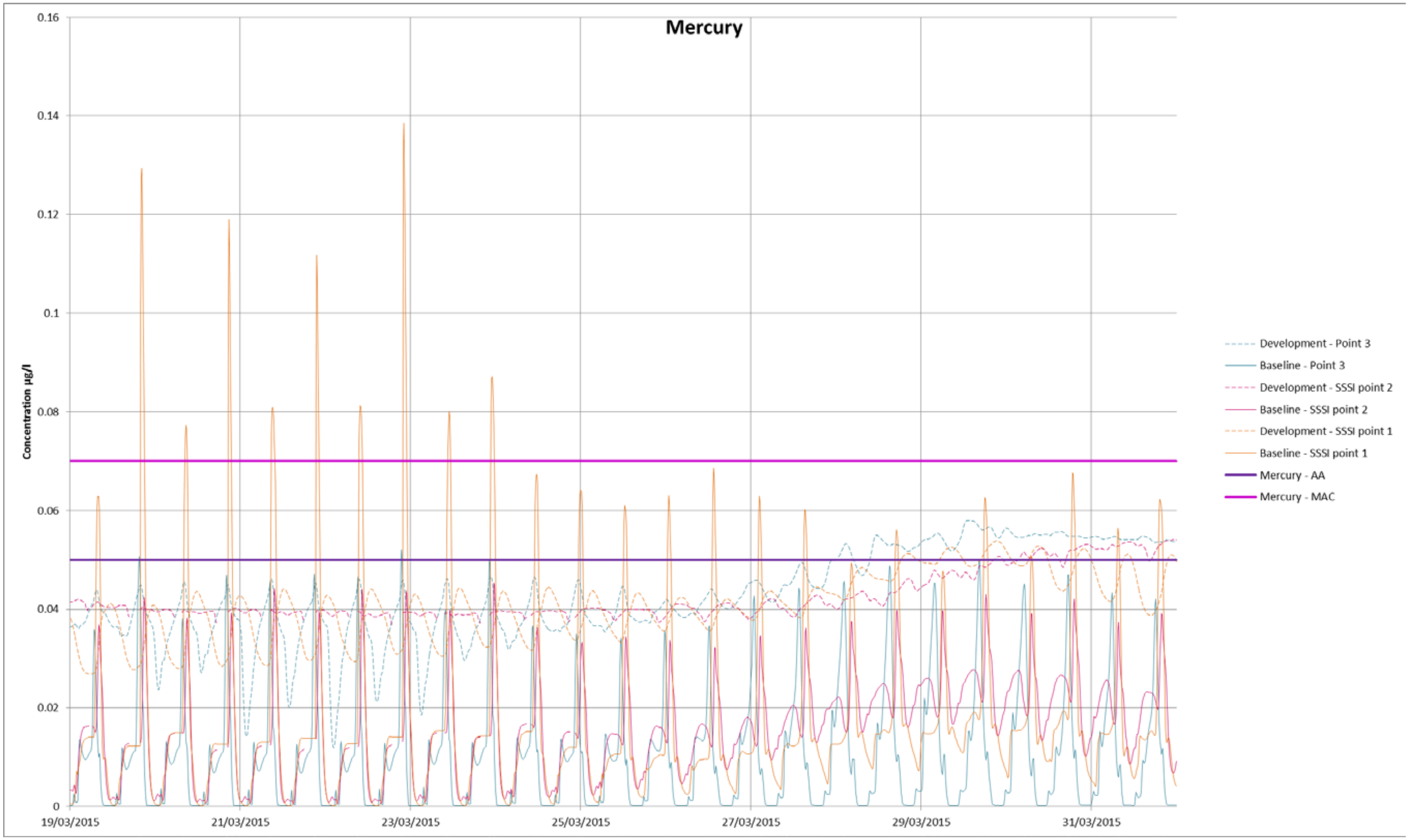


Figure B-40: Phenol conc. timeseries – points 4, 5, 6

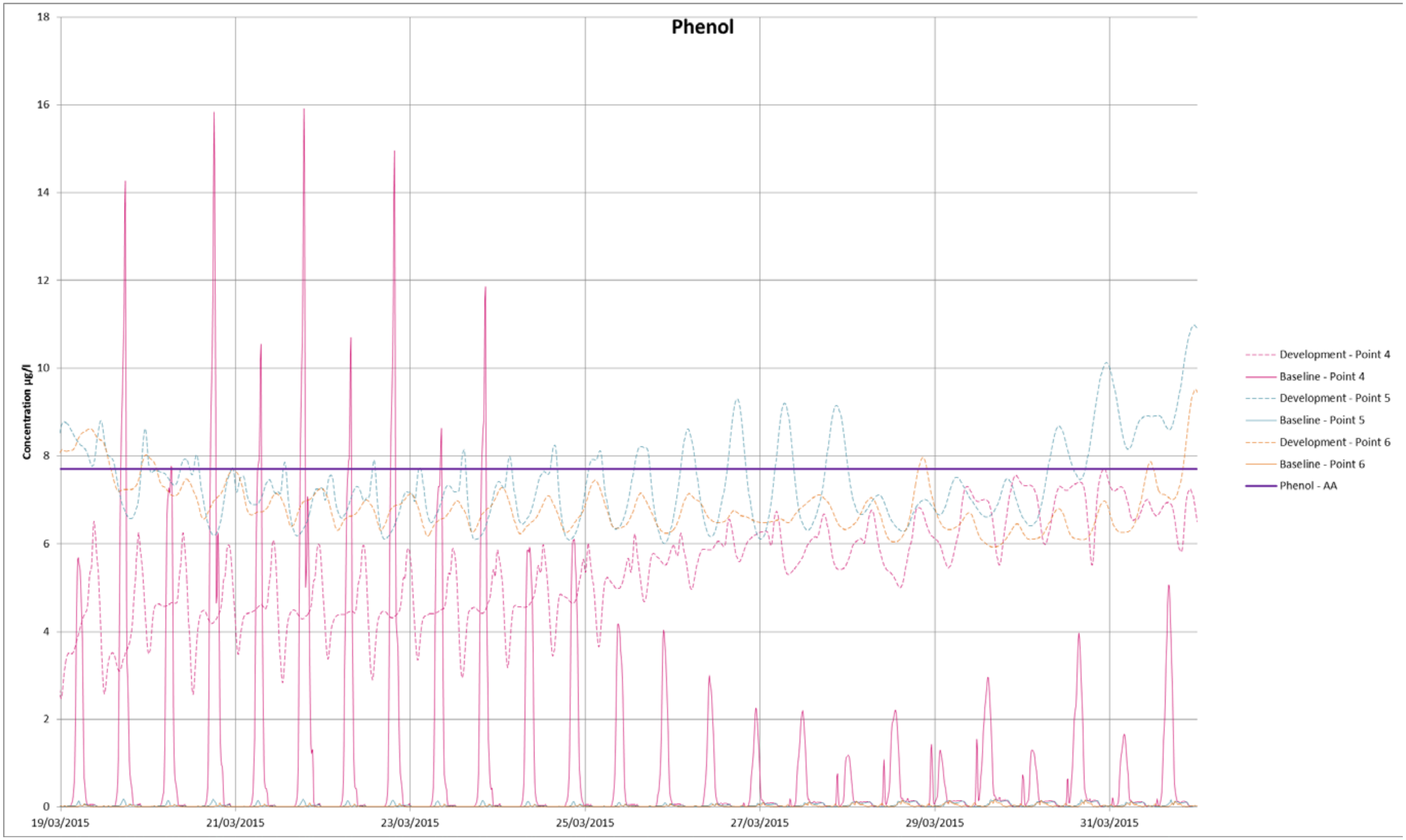


Figure B-41: Phenol conc. timeseries – points 1, 2, 7

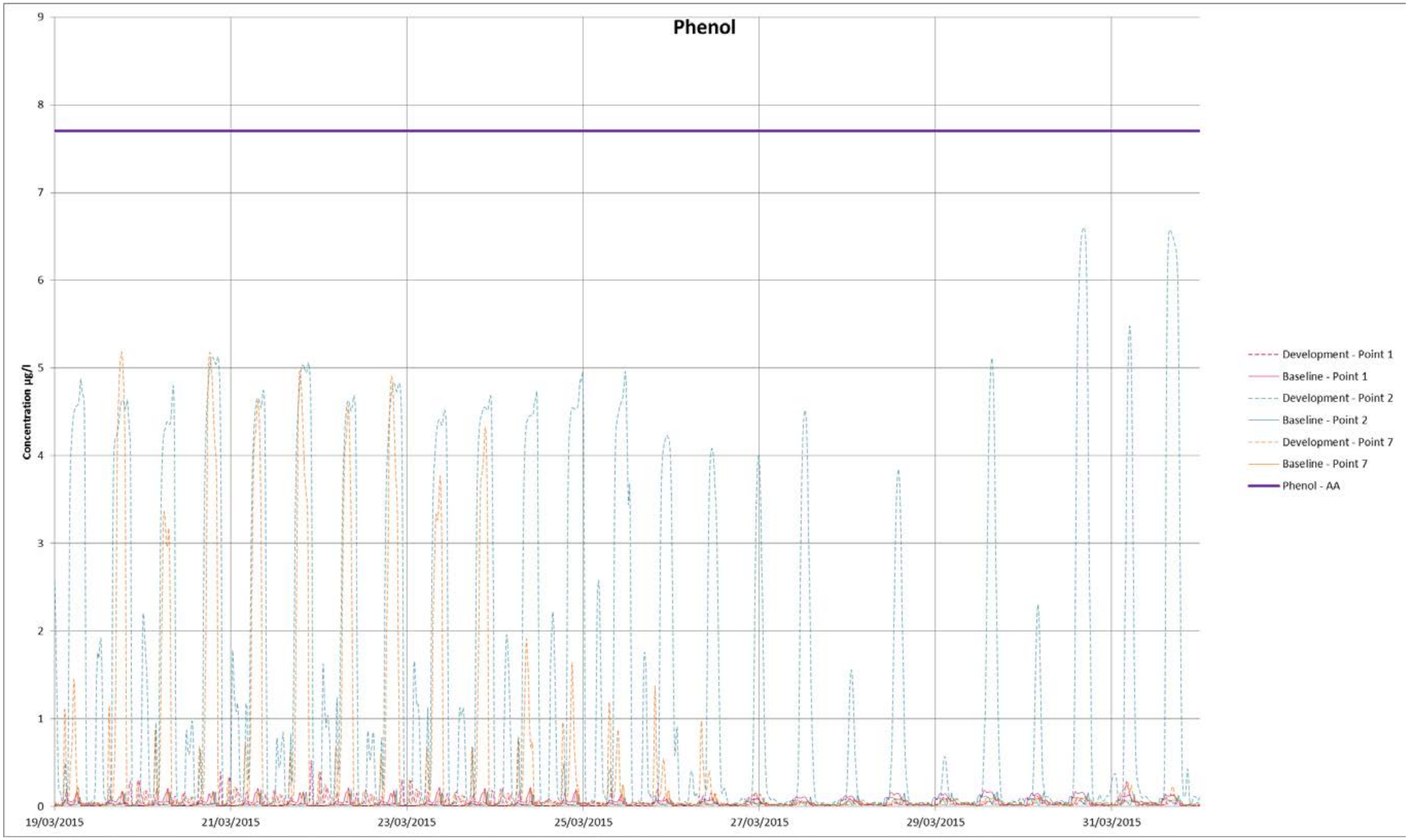


Figure B-42: Phenol conc. timeseries – point 3, SSSI 1, SSSI 2

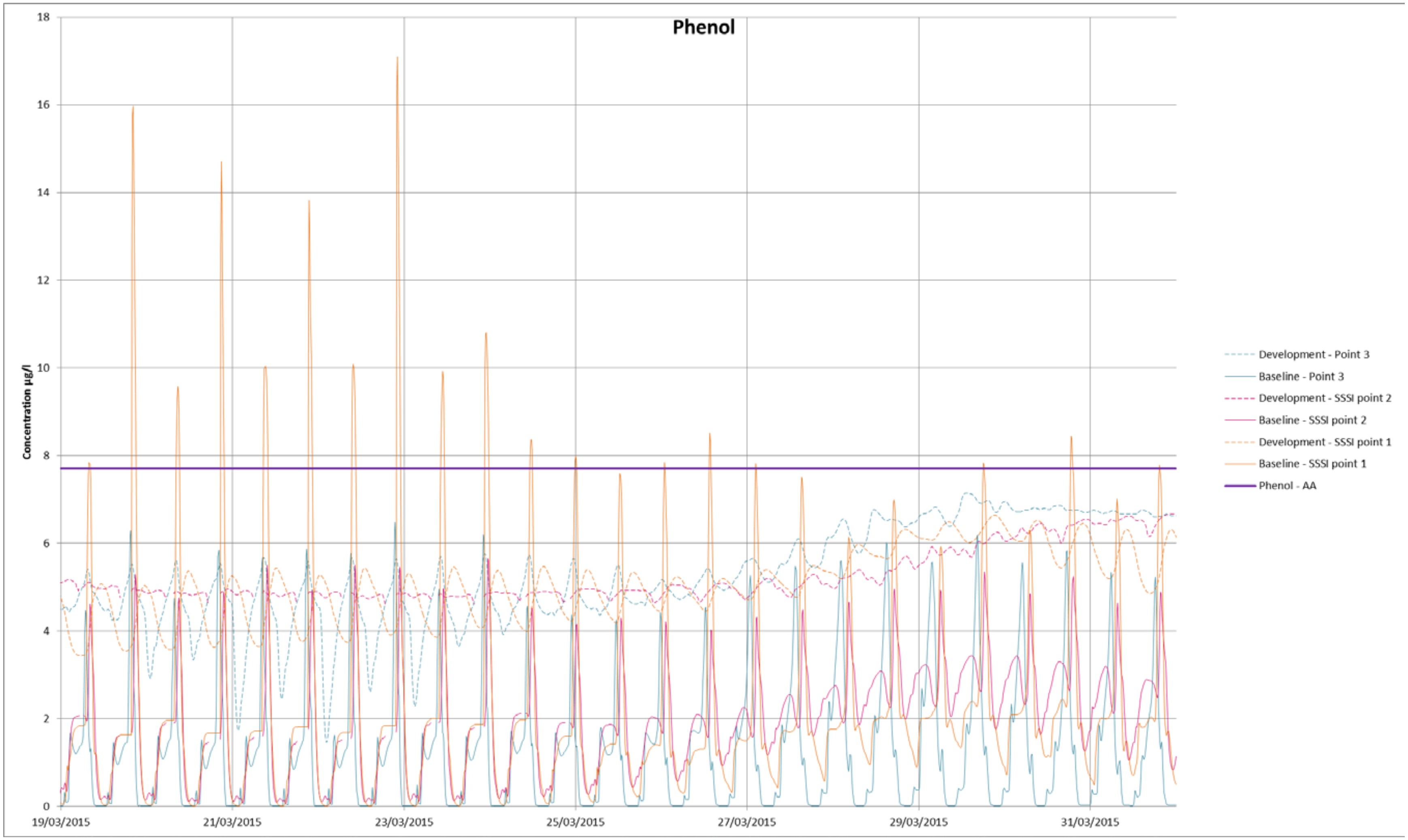


Figure B-43: Polycyclic aromatic hydrocarbons conc. timeseries – points 4, 5, 6

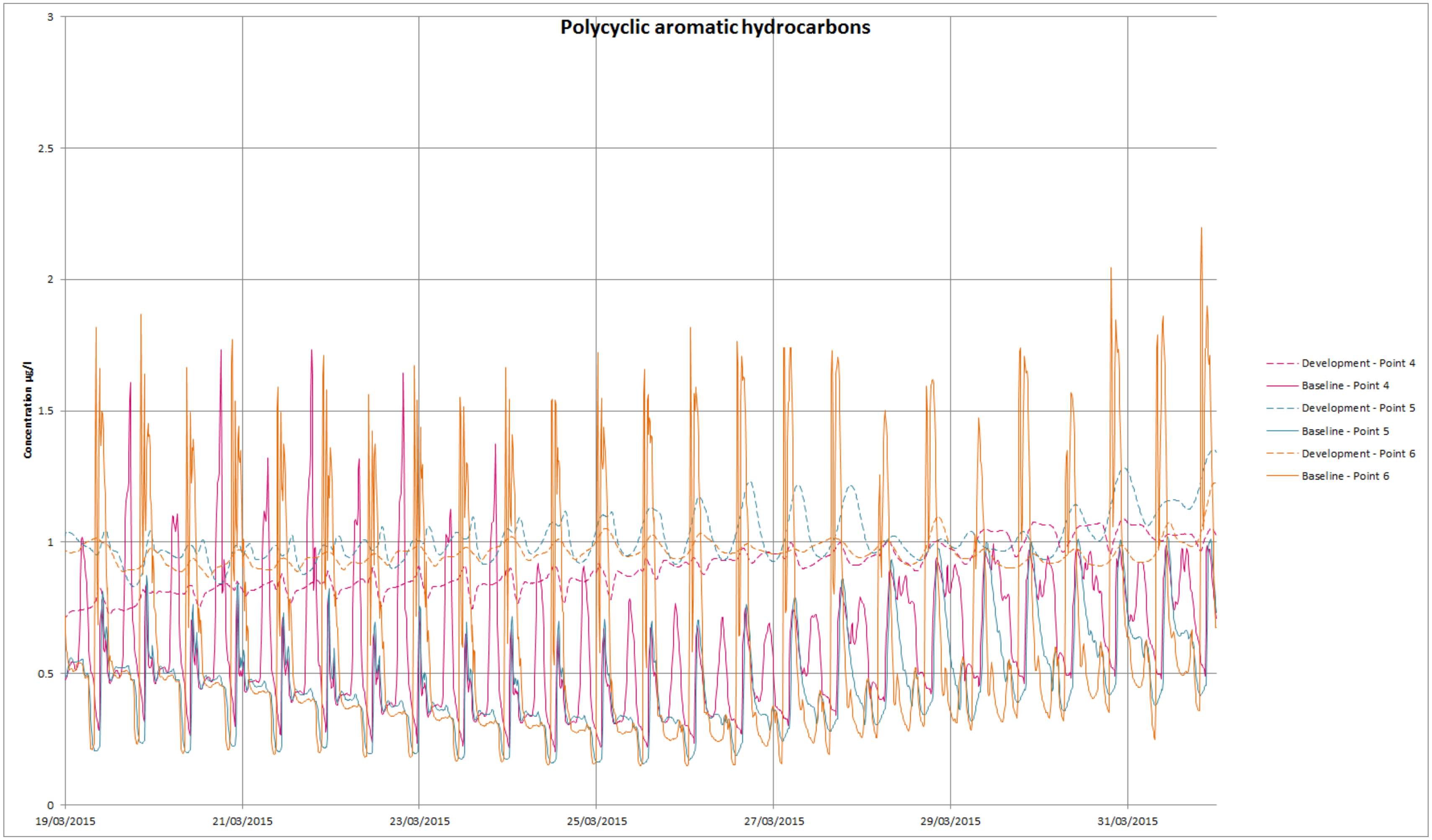


Figure B-44: Polycyclic aromatic hydrocarbons conc. timeseries – points 1, 2, 7

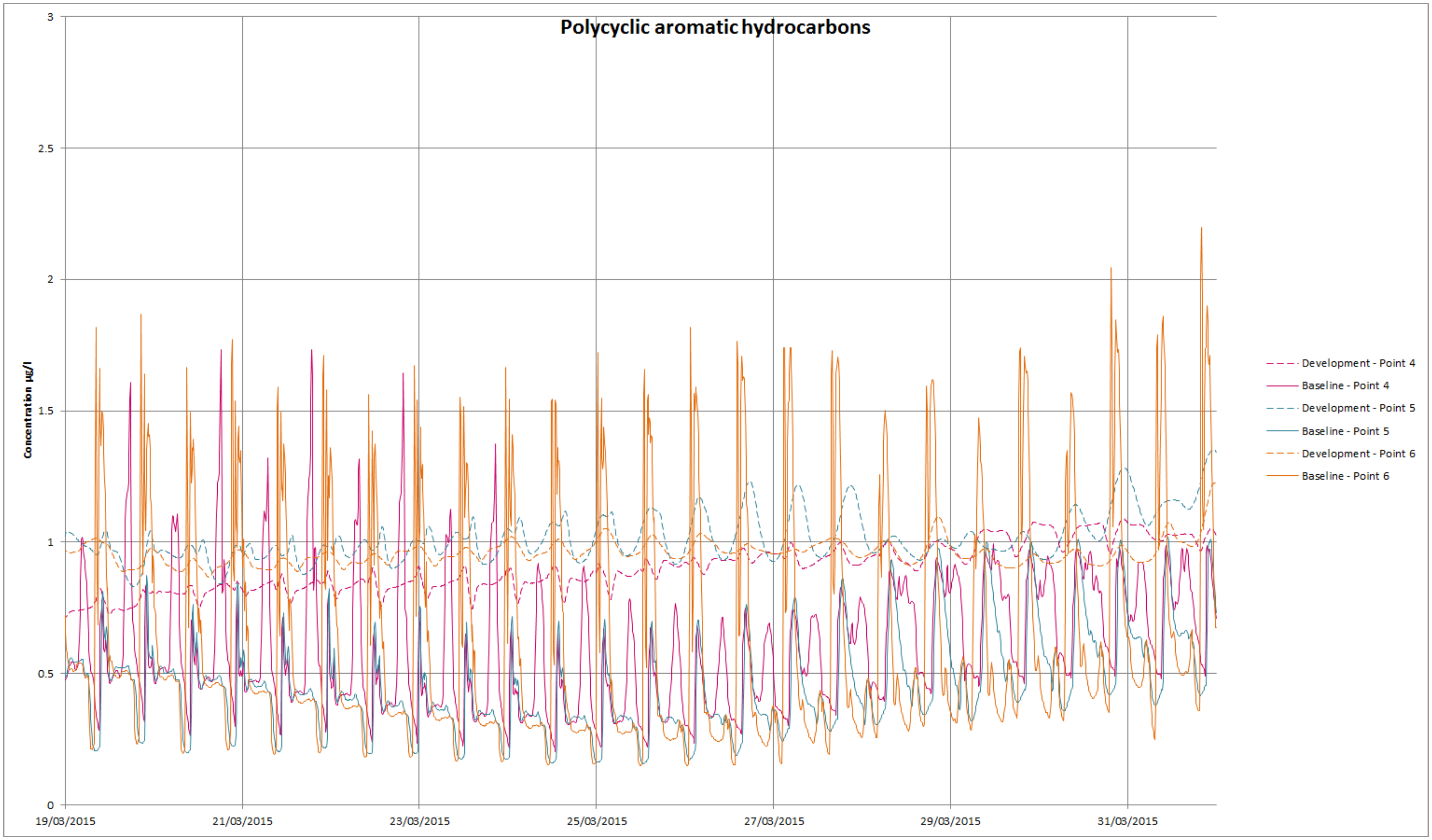


Figure B-45: Polycyclic aromatic hydrocarbons conc. timeseries – point 3, SSSI 1, SSSI 2

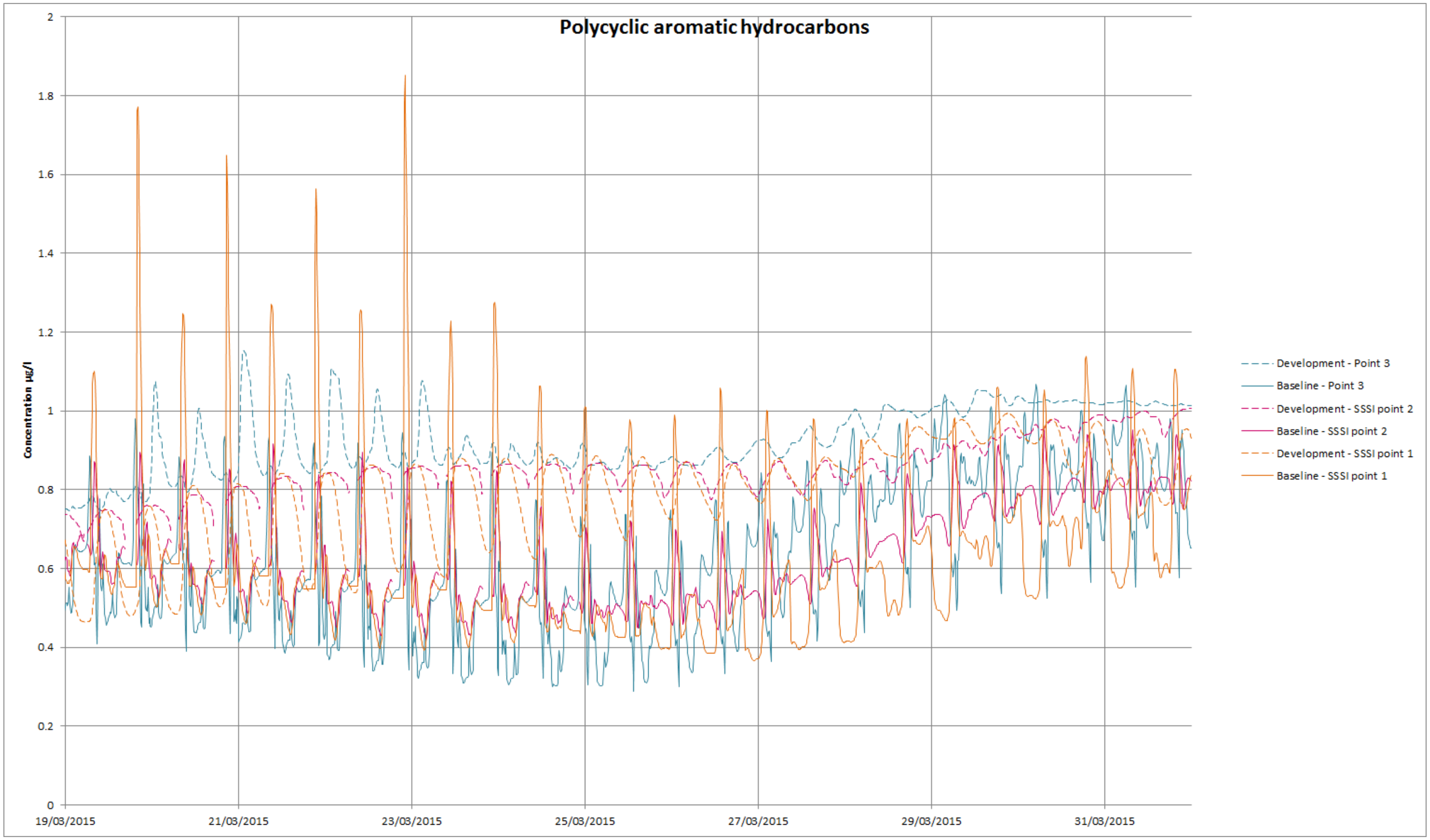


Figure B-46: Total ammonia conc. timeseries – points, 4, 5, 6

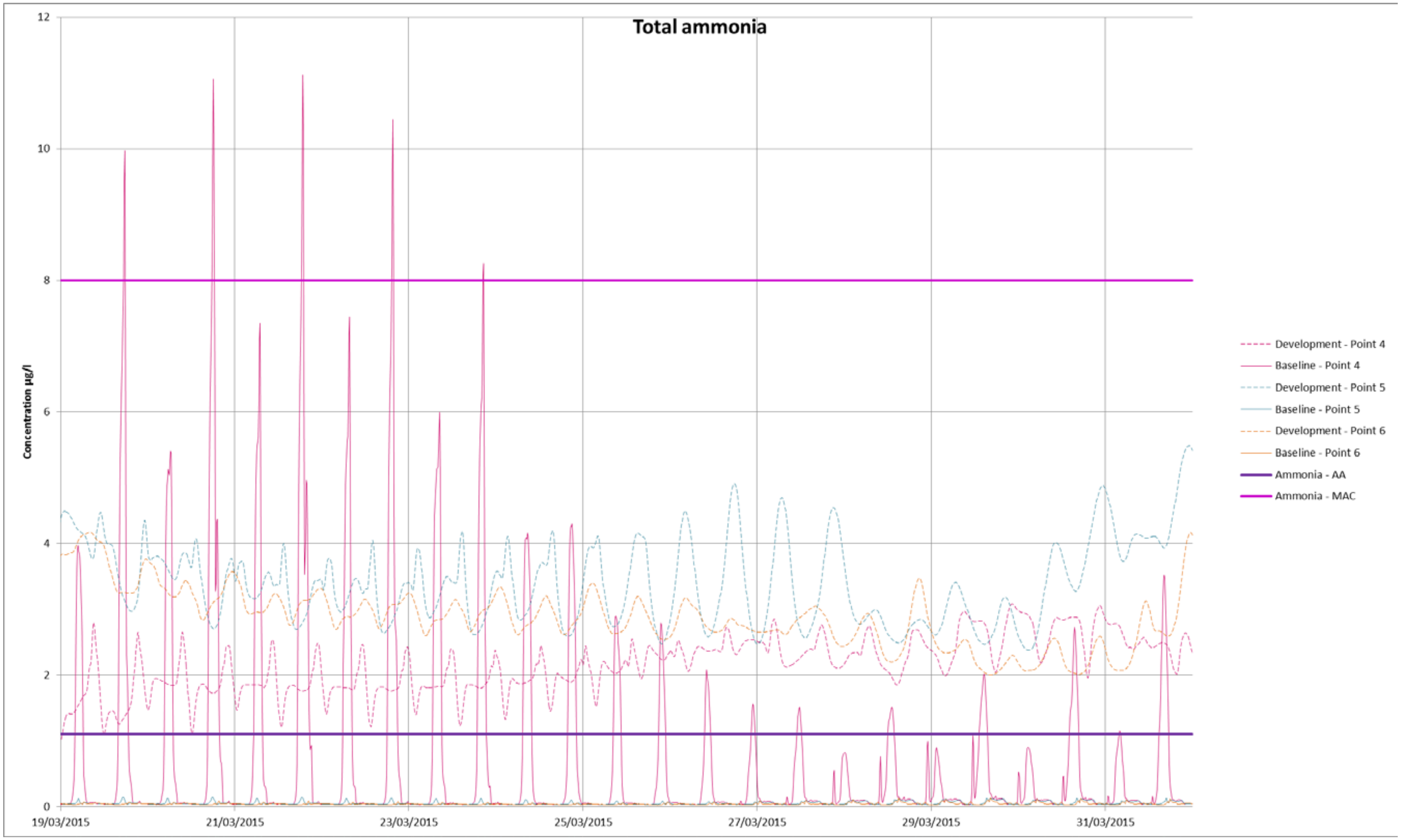


Figure B-47: Total ammonia conc. timeseries – points 1, 2, 7

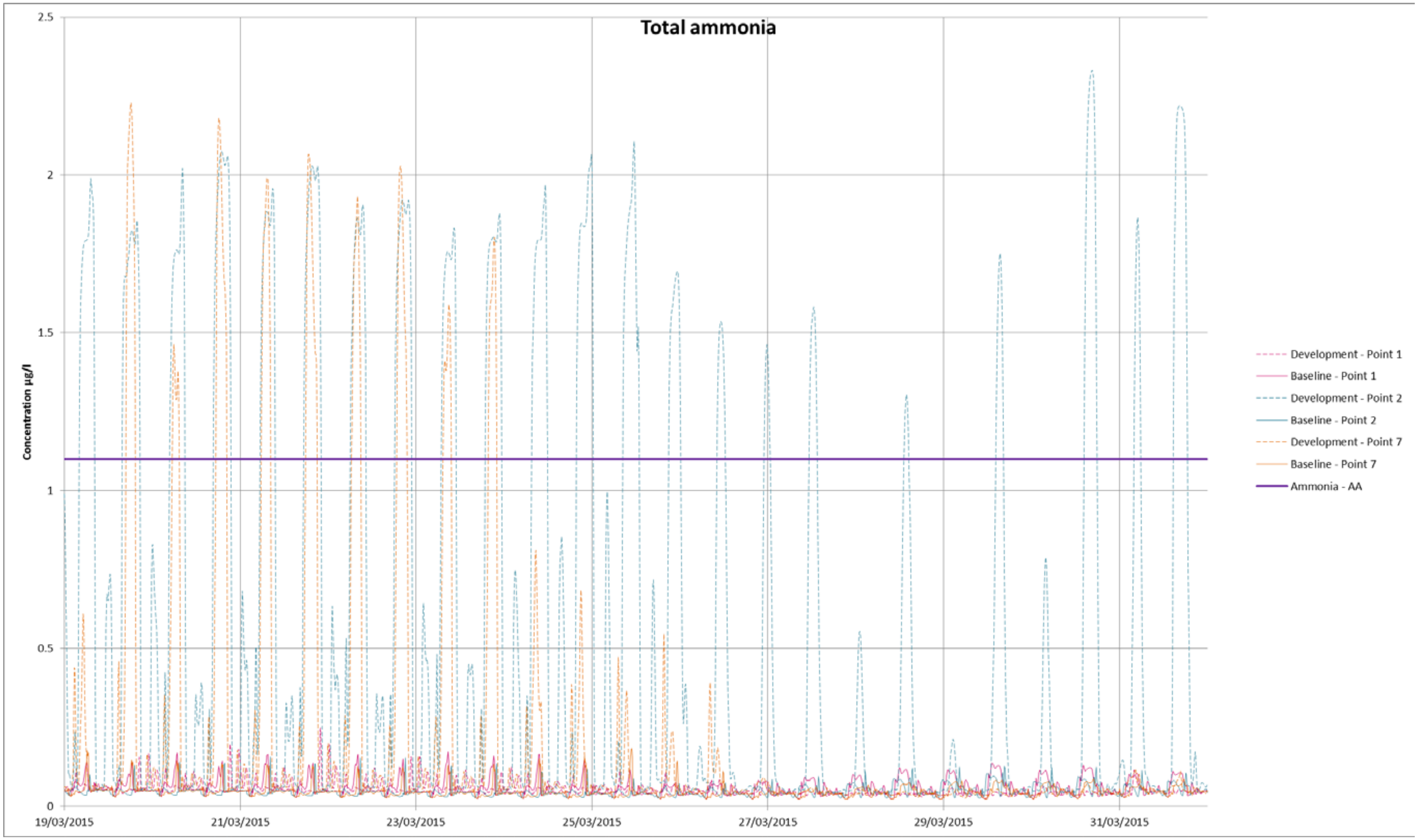


Figure B-48: Total ammonia conc. timeseries – point 3, SSSI 1, SSSI 2

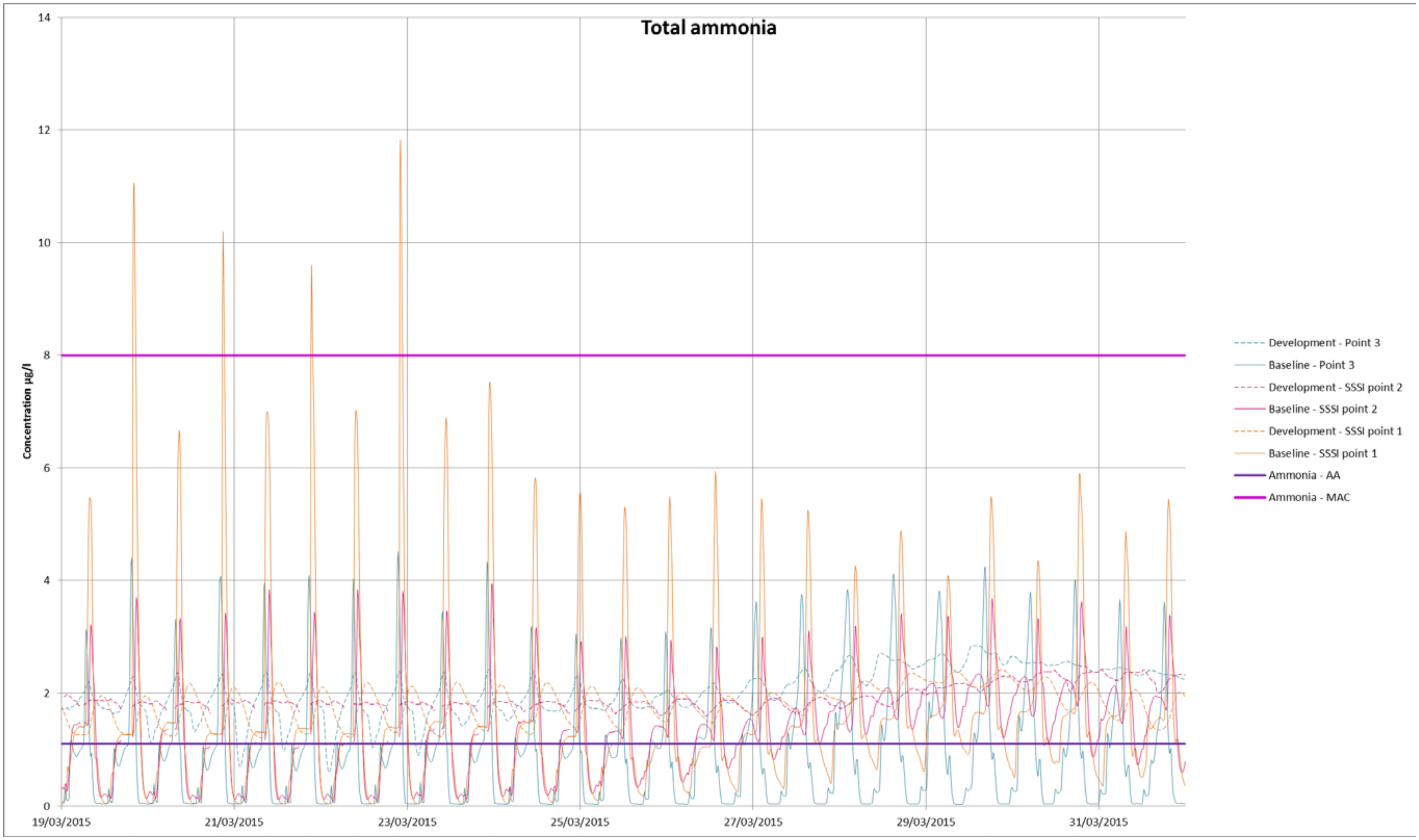


Figure B-49: Unionised ammonia (at 10°C) conc. timeseries – points 4, 5, 6

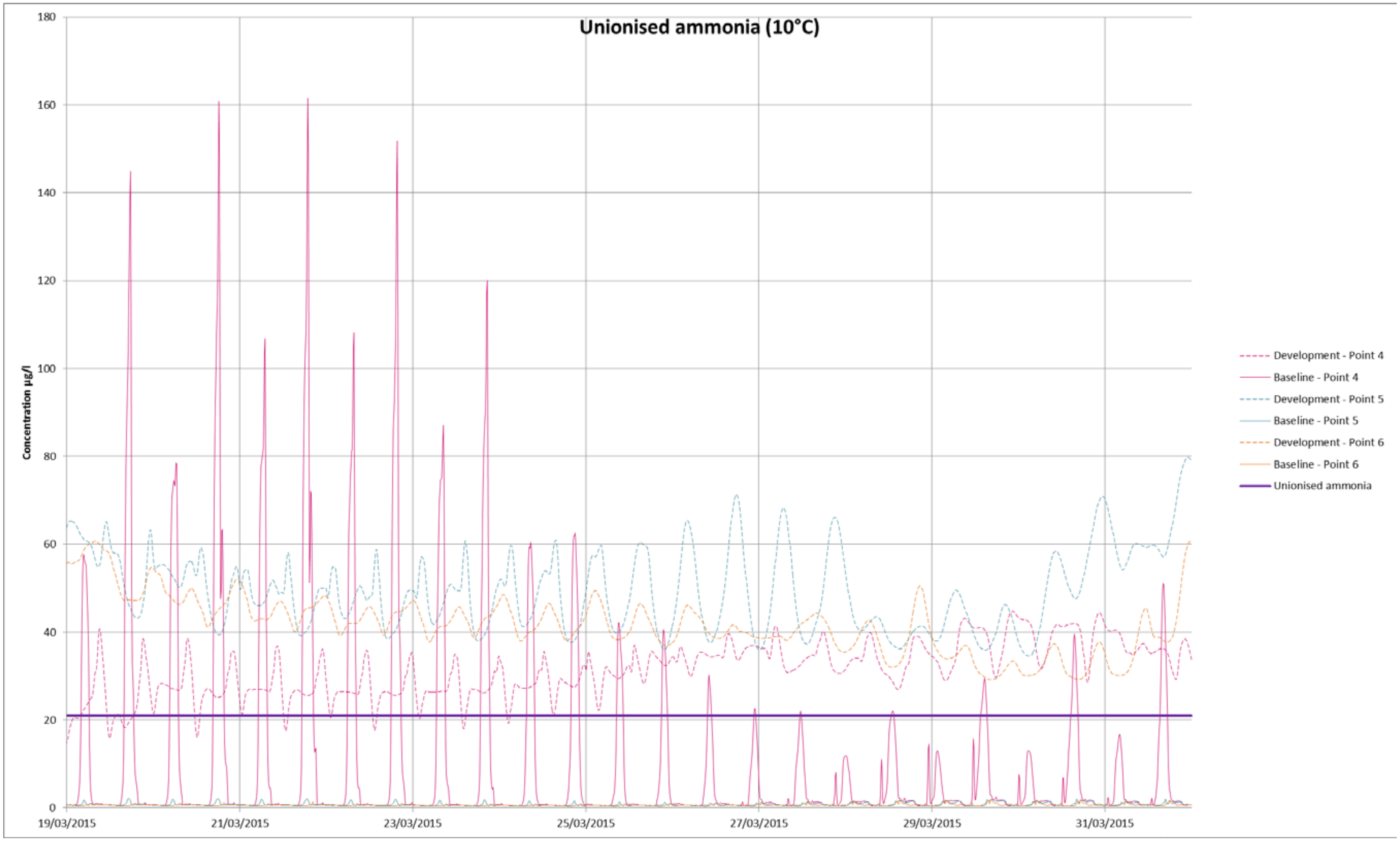


Figure B-50: Unionised ammonia (at 10°C) conc. timeseries – points 1, 2, 7

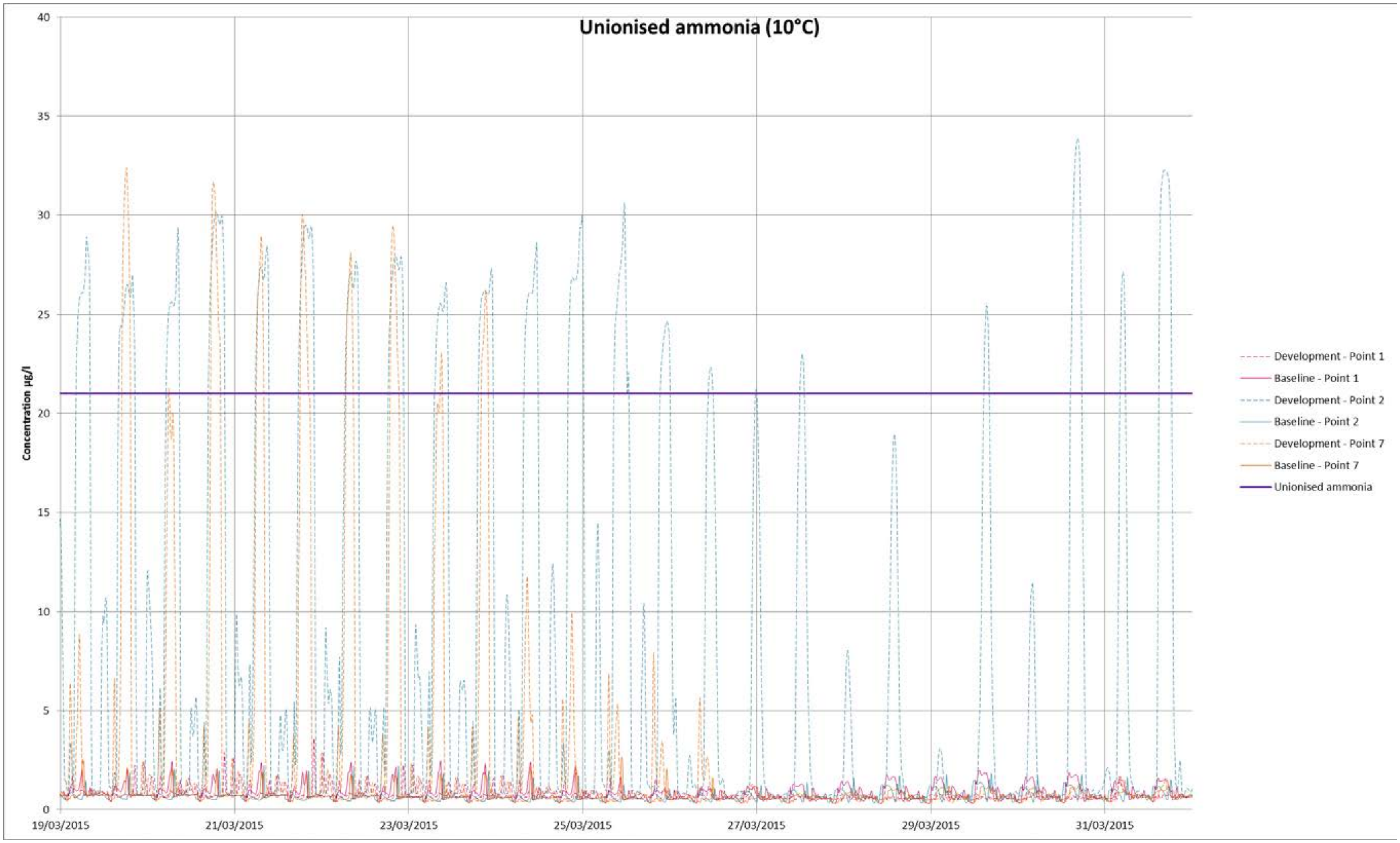


Figure B-51: Unionised ammonia (at 10°C) conc. timeseries – point 3, SSSI 1, SSSI 2

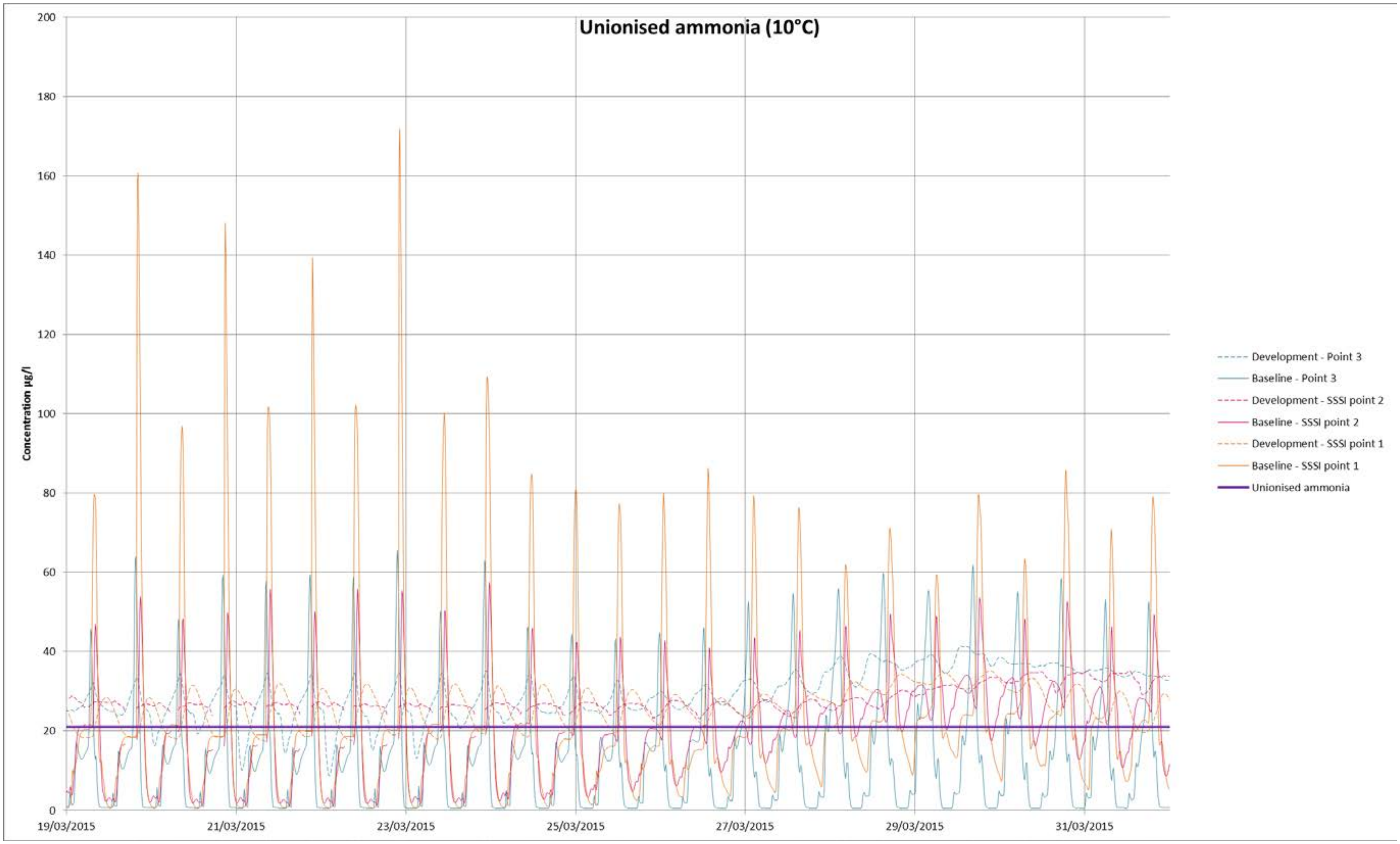


Figure B-52: Unionised ammonia (at 15°C) conc. timeseries – points 4, 5, 6

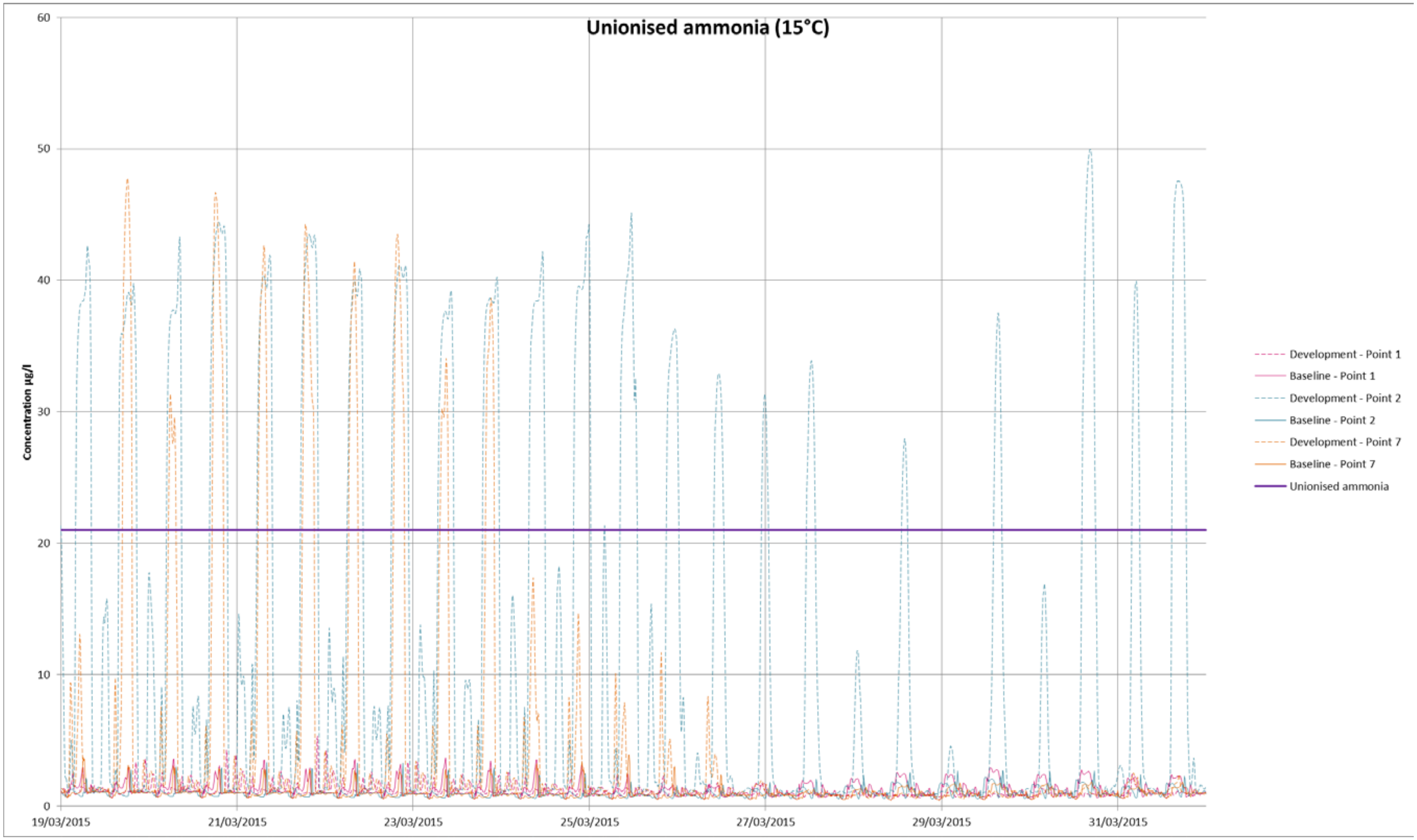


Figure B-53: Unionised ammonia (at 15°C) conc. timeseries – points 1, 2, 7

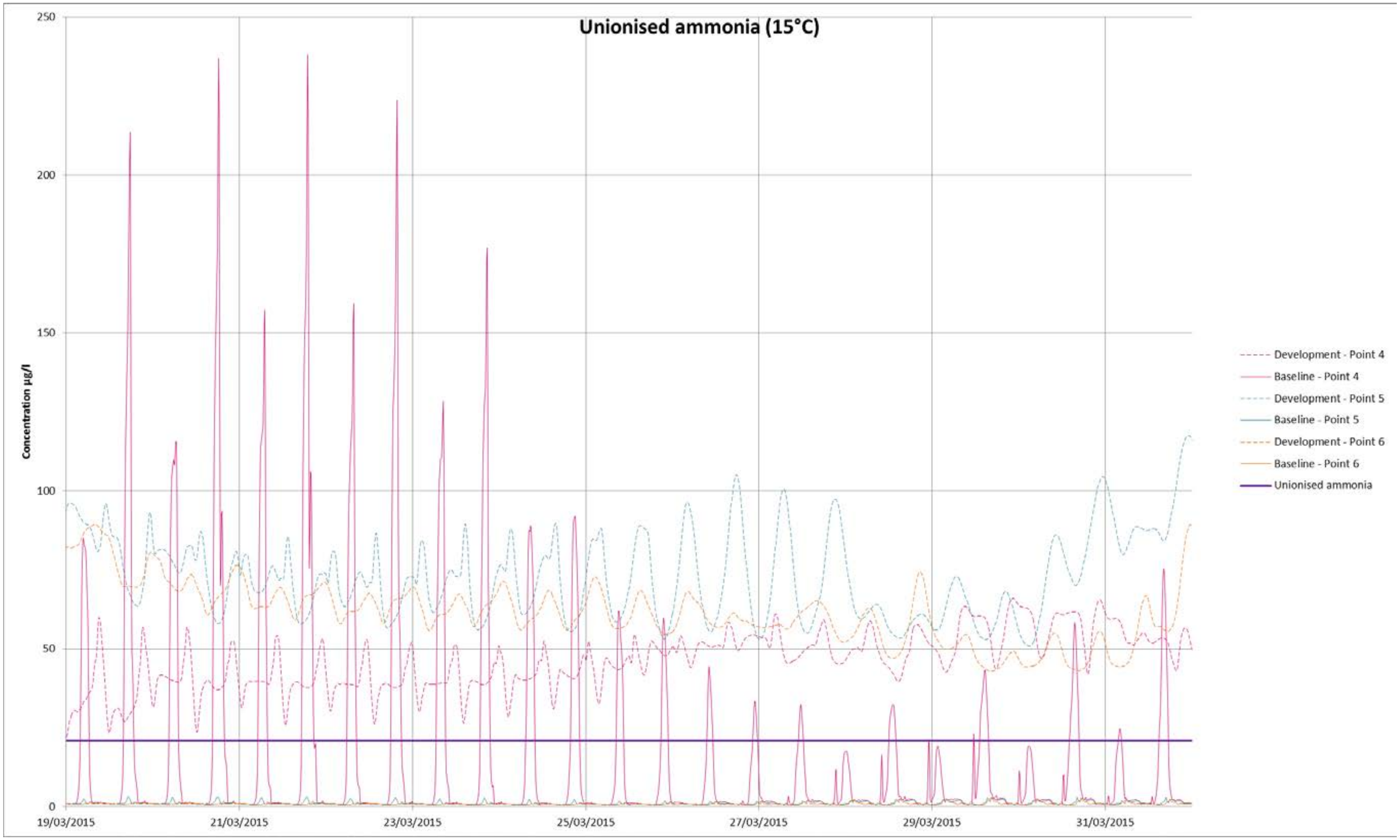


Figure B-54: Unionised ammonia (at 15°C) conc. timeseries – point 3, SSSI 1, SSSI 2

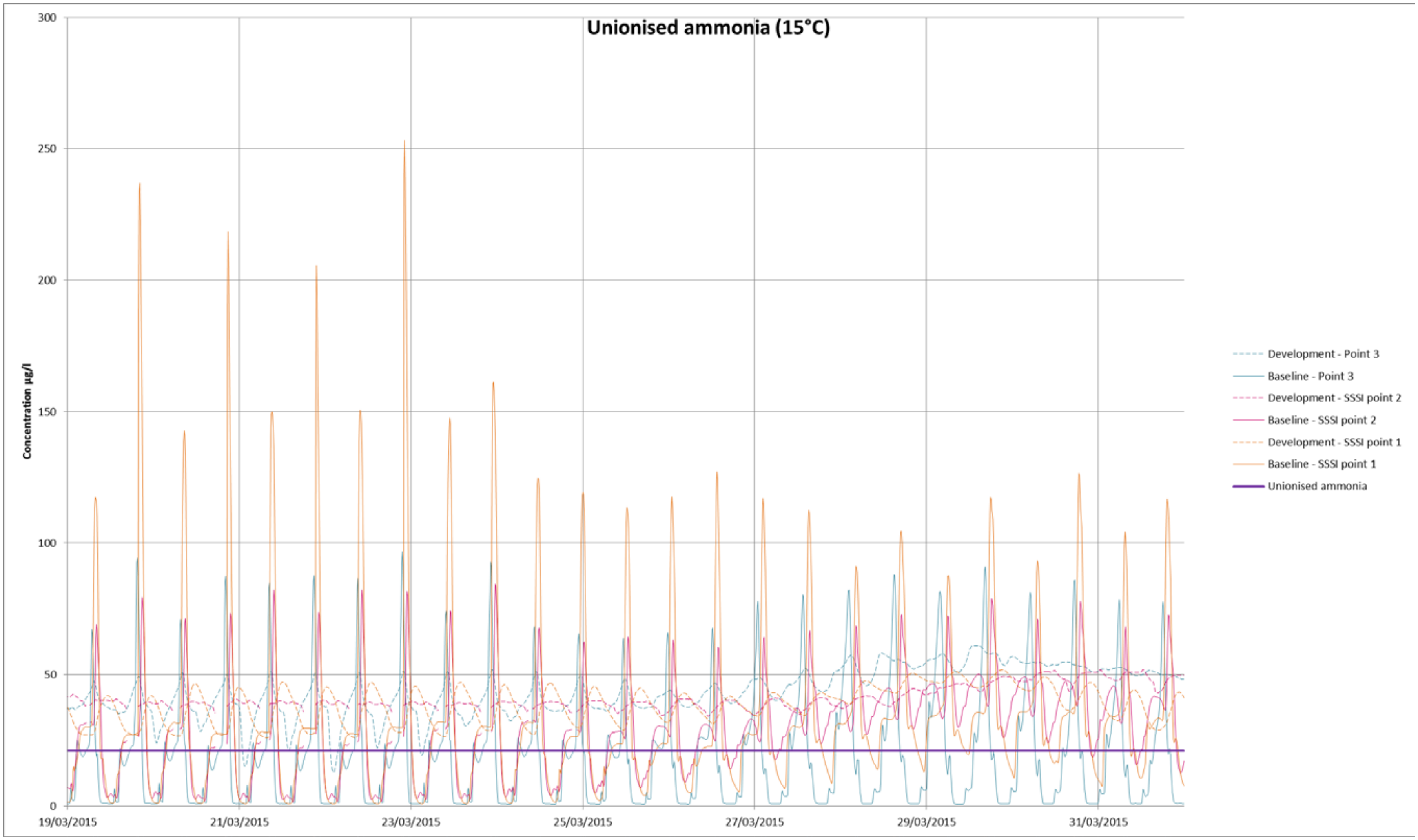


Figure B-55: Zinc conc. timeseries – points 4, 5, 6

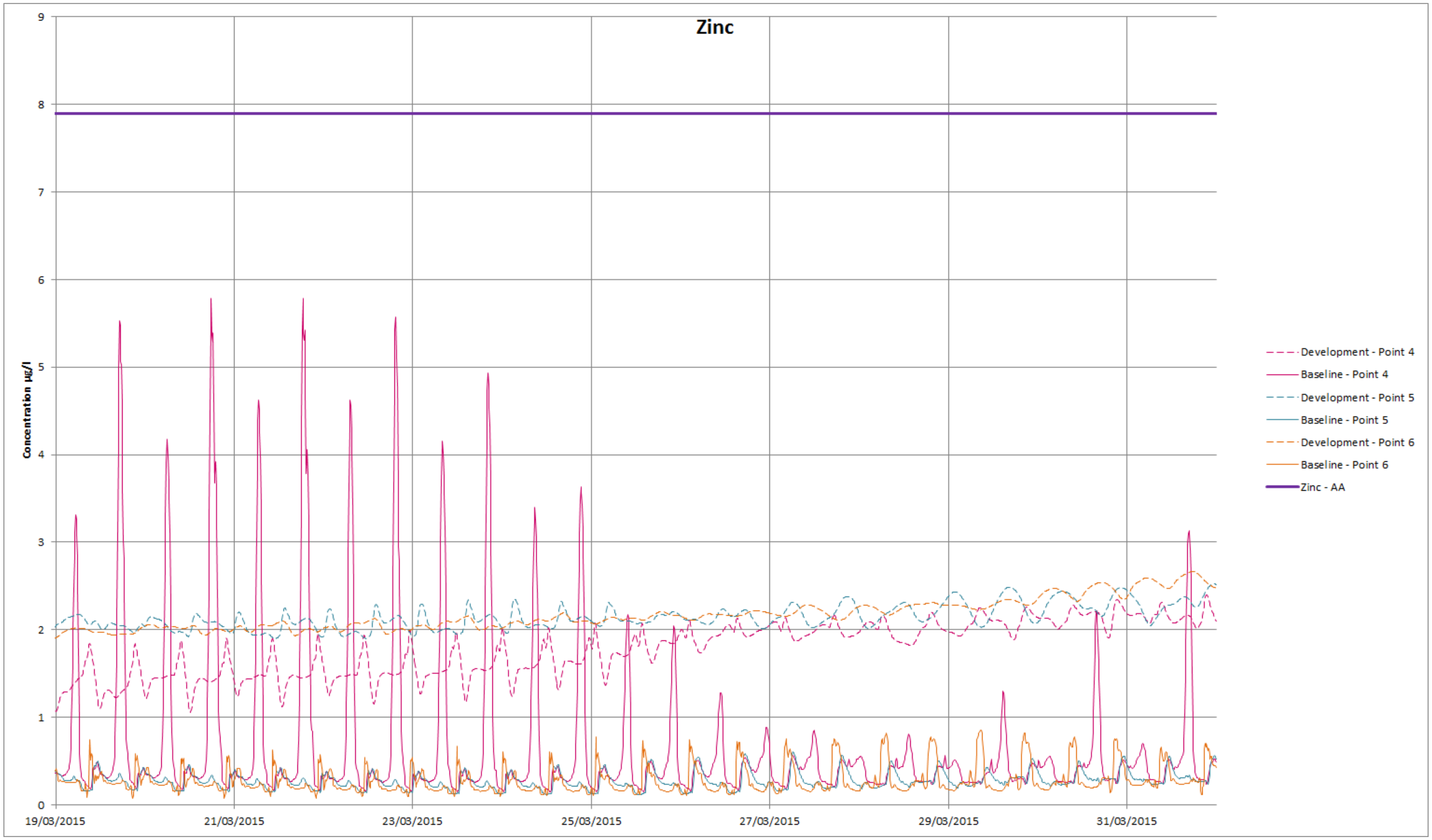


Figure B-56: Zinc conc. timeseries – points 1, 2, 7

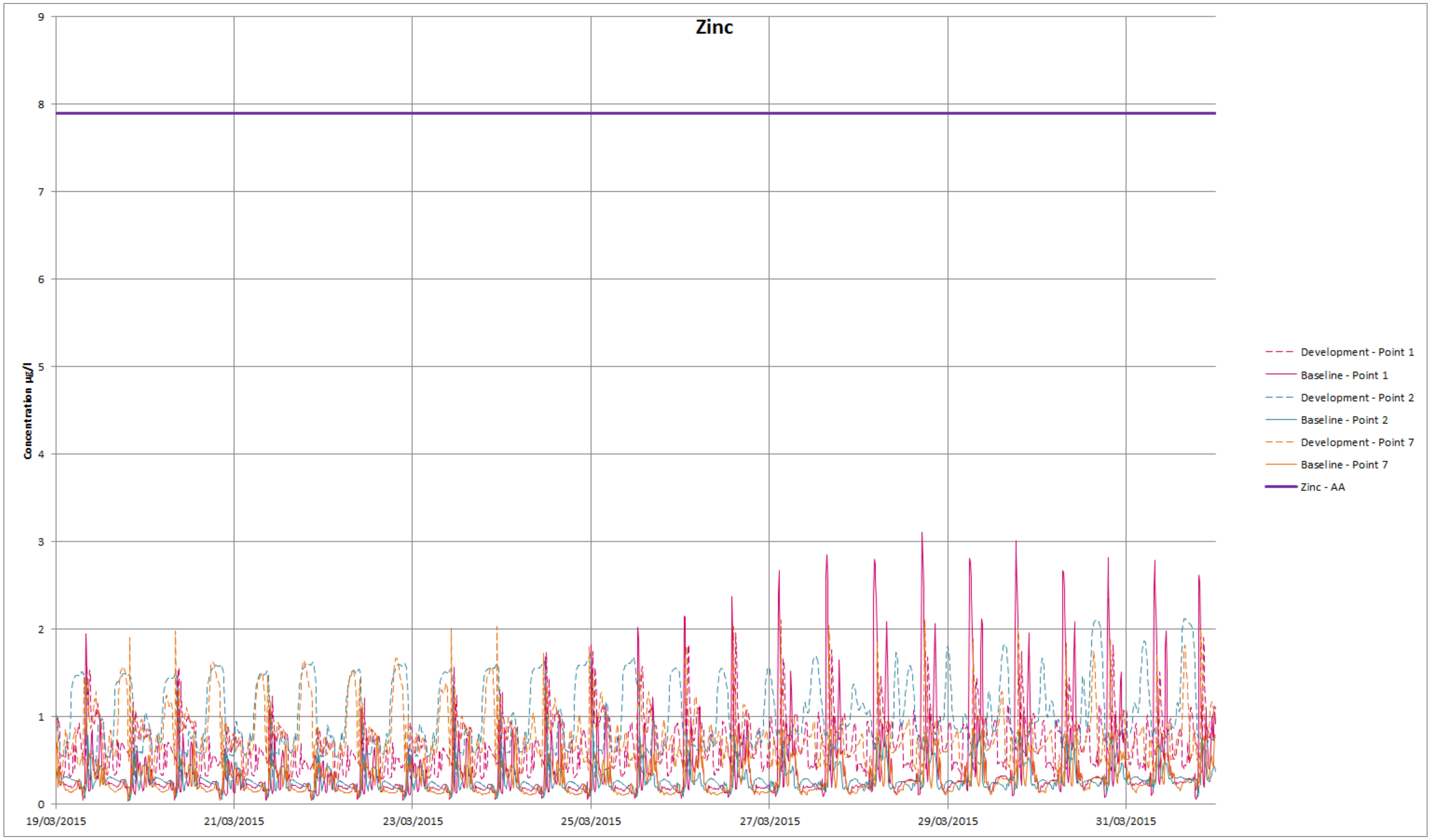
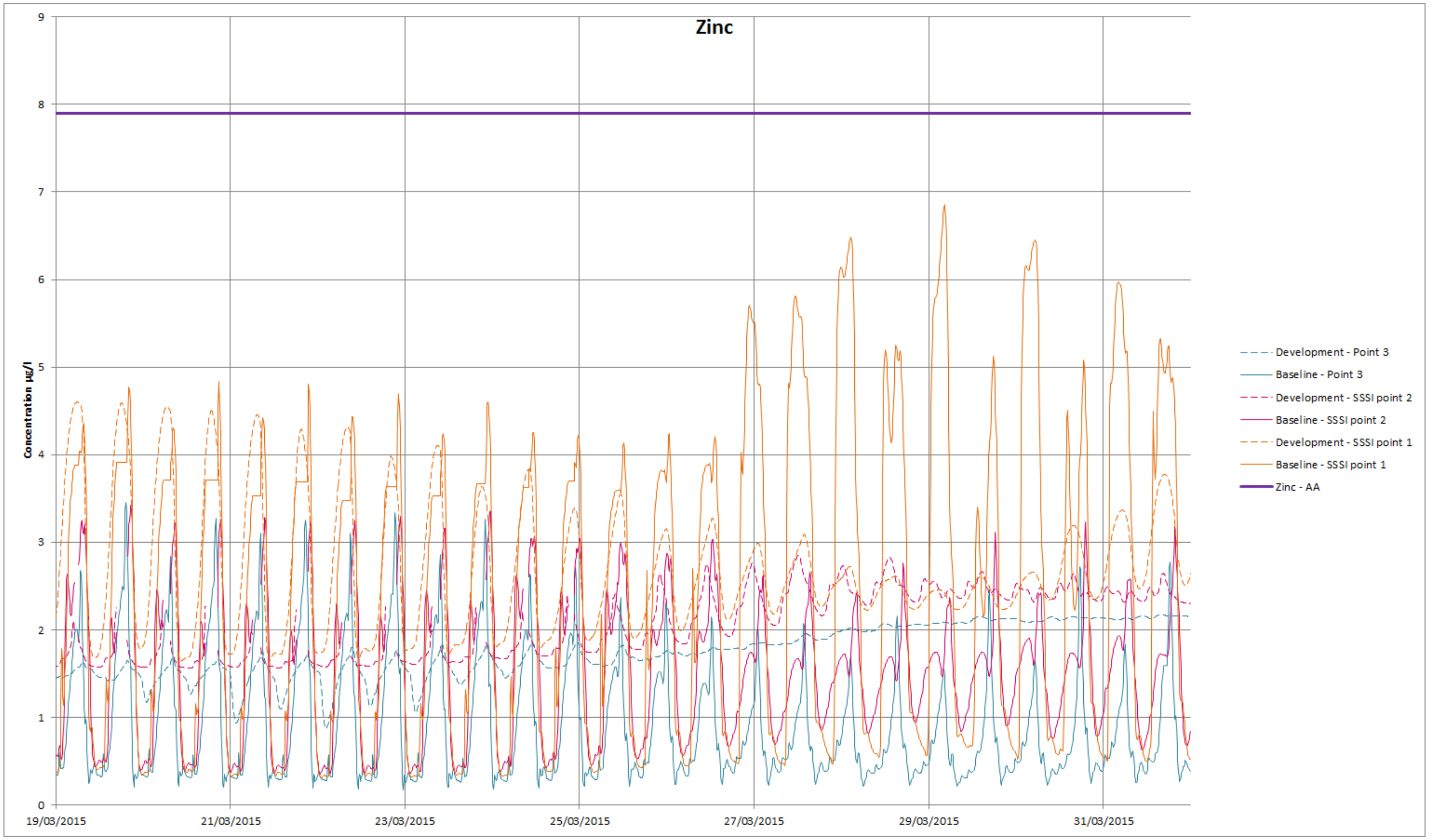


Figure B-57: Zinc conc. timeseries – point 3, SSSI 1, SSSI 2



Appendix C Maximum modelled concentration plots

FIGURES

Figure C-1: Baseline - Anthracene max. modelled conc. (overview and close-up) - (AA = 0.1 µg/l, MAC = 0.4 µg/l)

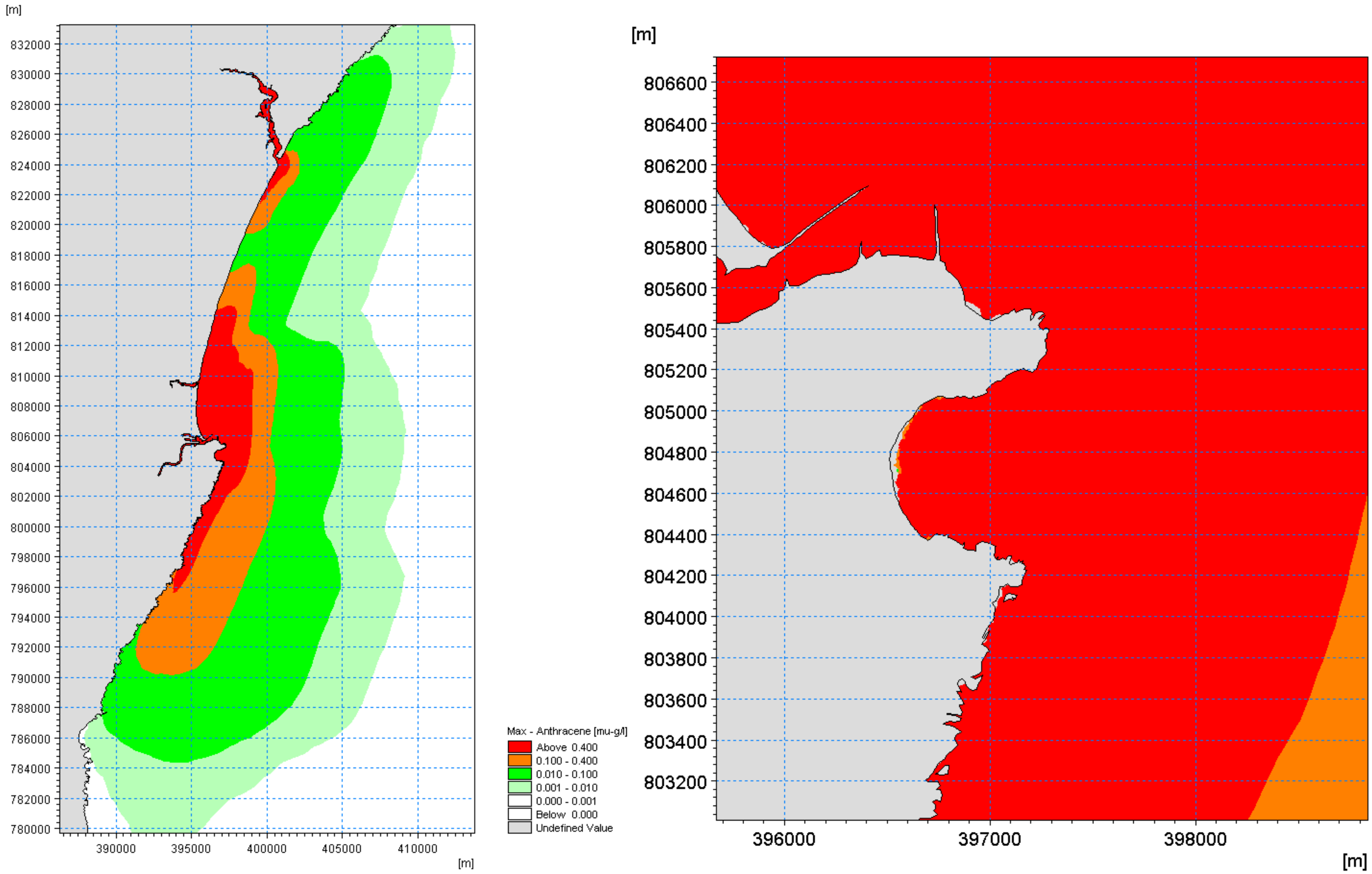


Figure C-2: Baseline - Benzo(b\k)fluoranthene max. modelled conc.(overview and close-up) - (AA = 0.03 µg/l)

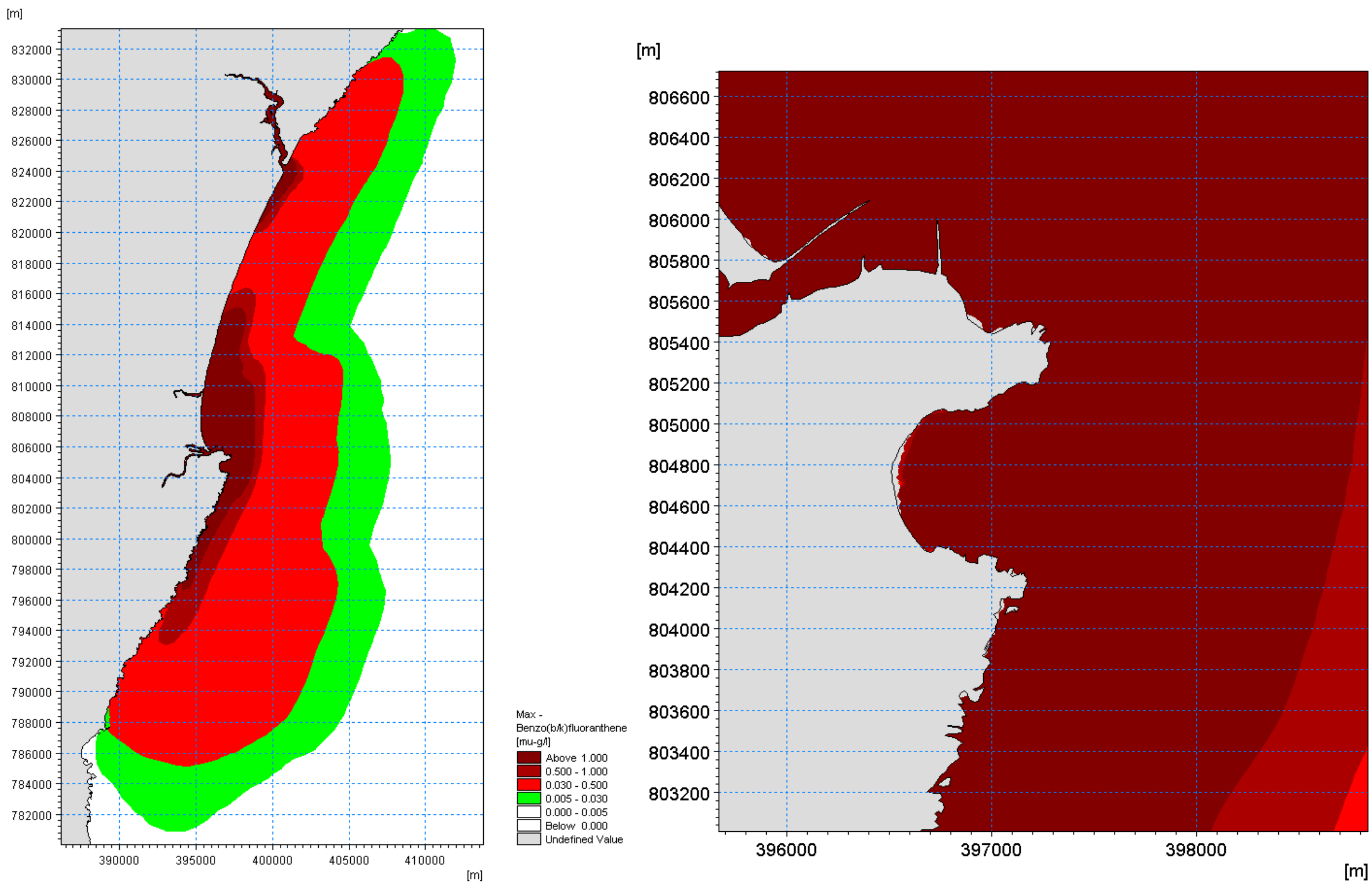


Figure C-3: Baseline - BOD max. modelled conc. (overview and close-up) - (90%'ile = 5 mg/l)

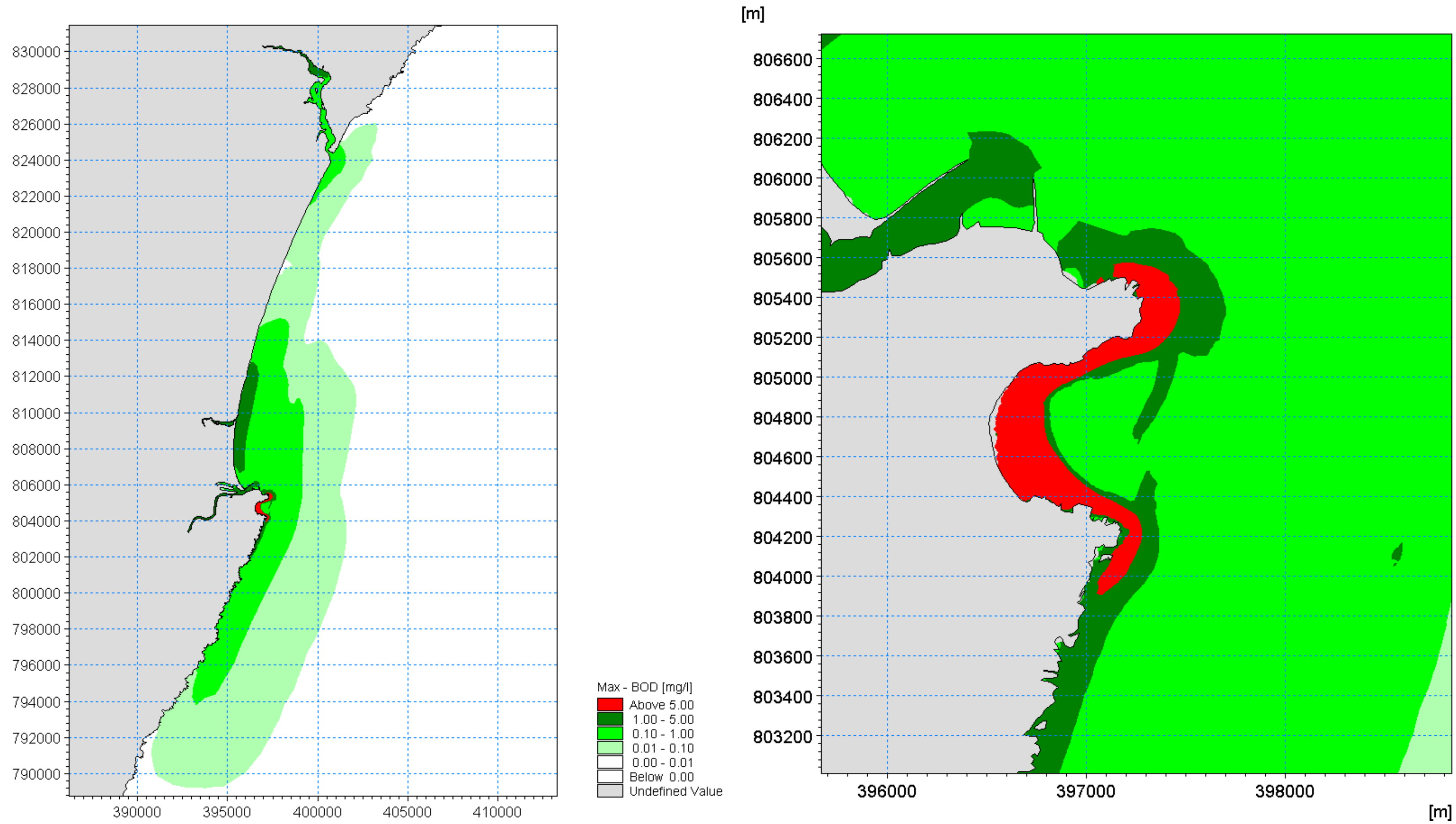


Figure C-4: Baseline - Cadmium max. modelled concentration (overview) - (AA = 0.2 µg/l)

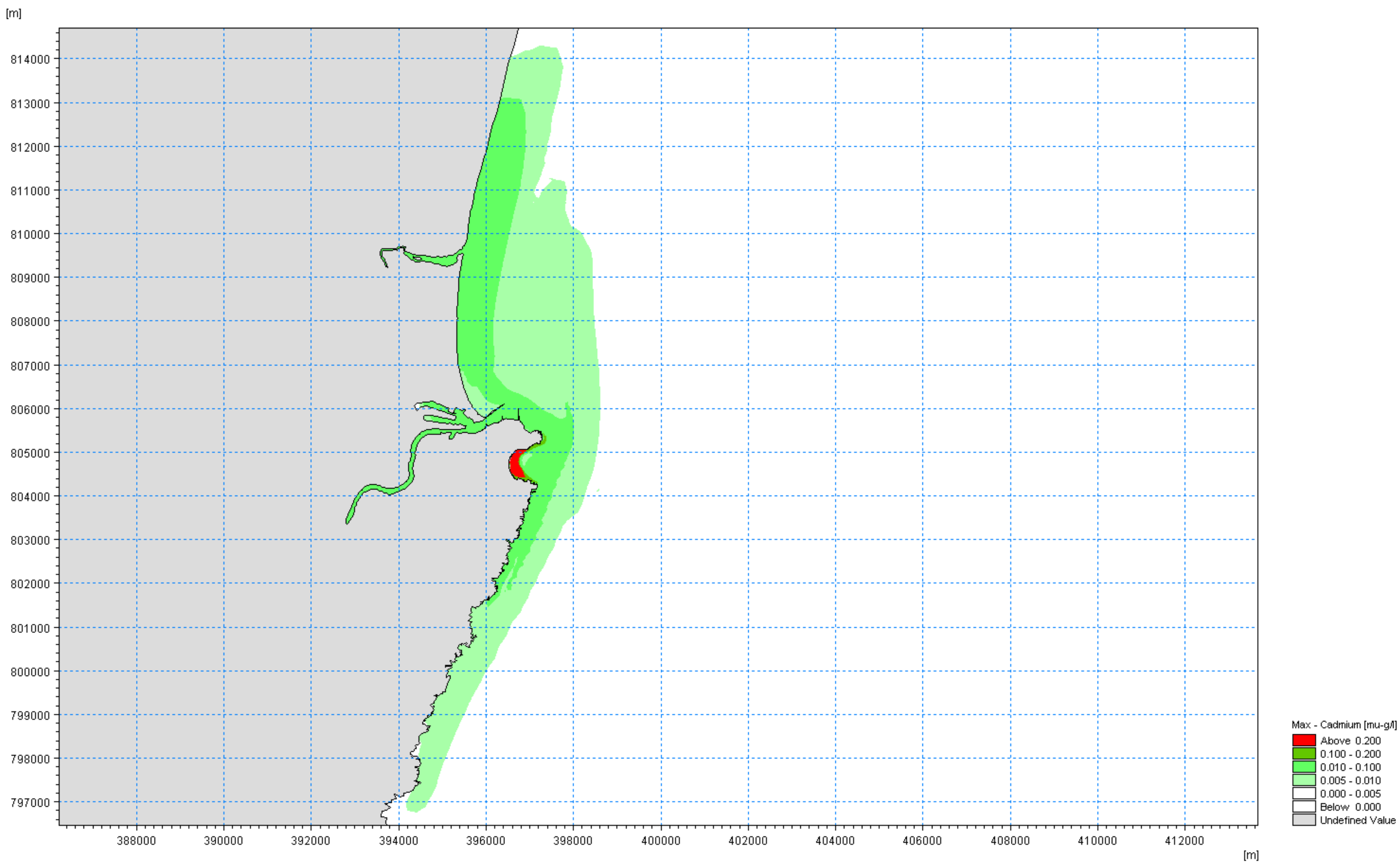


Figure C-5: Baseline - Cadmium max. modelled concentration (close-up) - (AA = 0.2 µg/l)

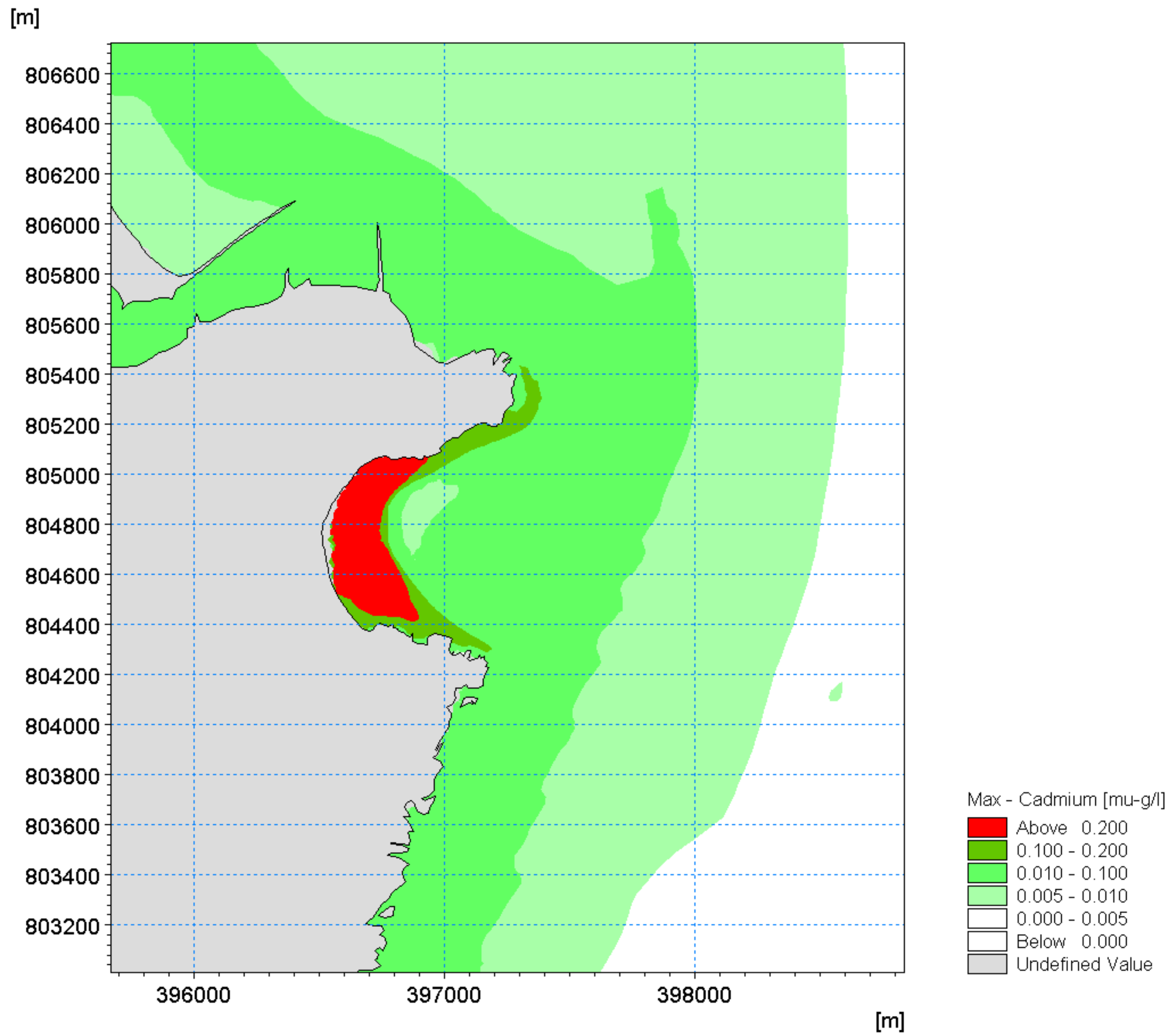


Figure C-6: Baseline - C10-13 Chloroalkanes max. modelled conc. (overview) - (AA = 0.4 µg/l, MAC = 1.4 µg/l)

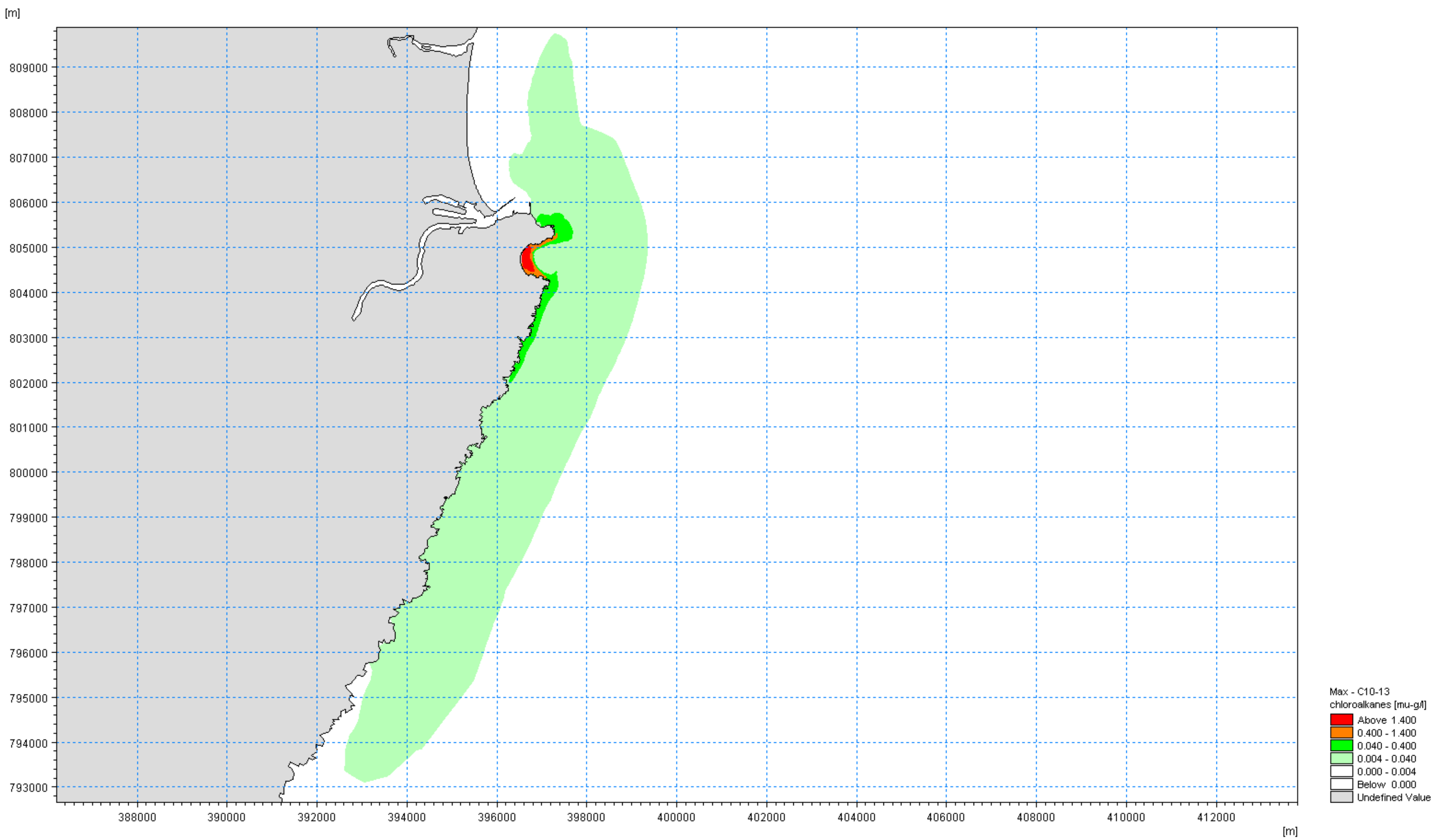


Figure C-7: Baseline - C10-13 Chloroalkanes max. modelled conc. (close-up) - (AA = 0.4 µg/l, MAC = 1.4 µg/l)

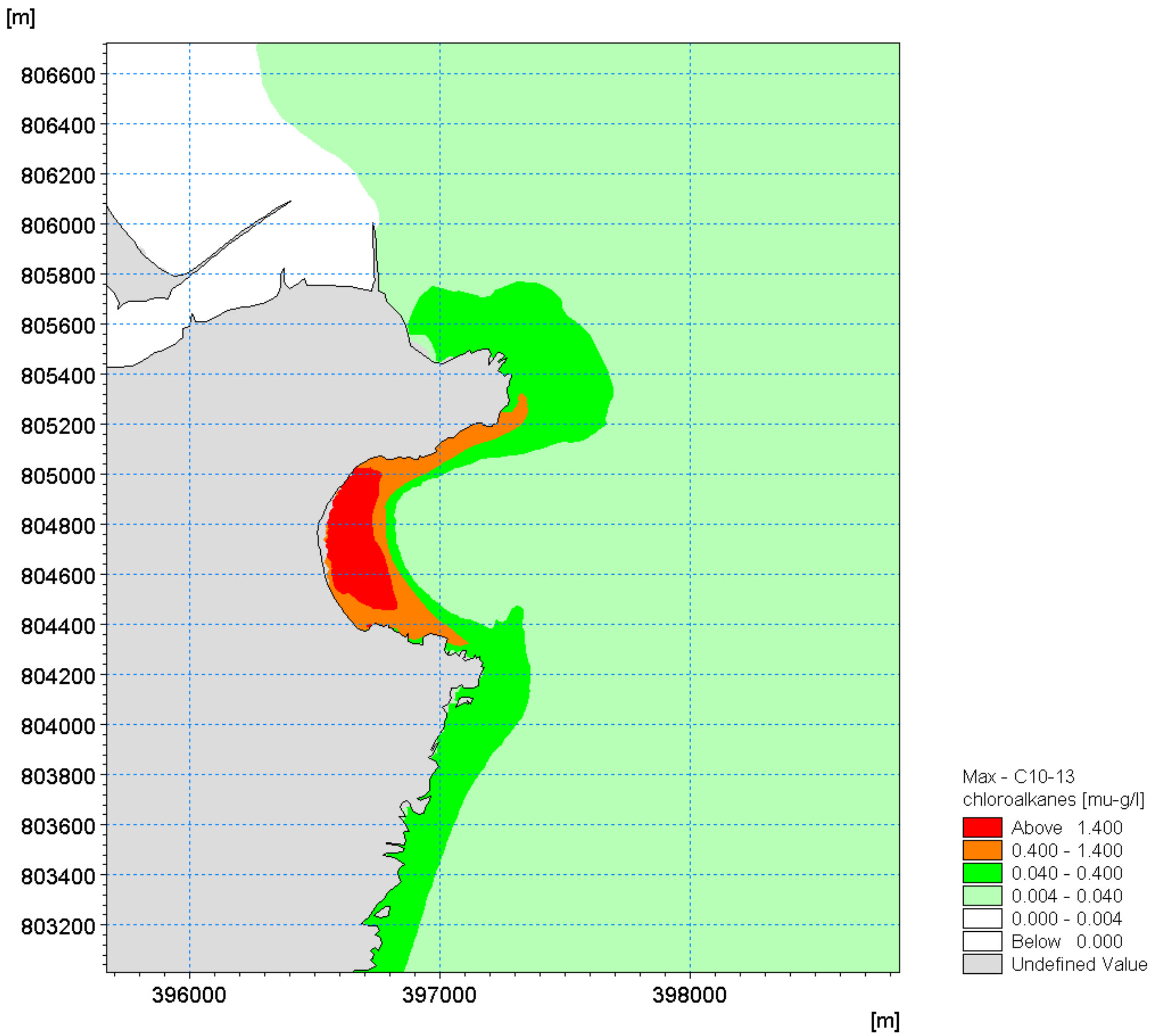


Figure C-8: Baseline - Chromium max. modelled conc. (overview) - (AA = 0.6 µg/l, 95%'ile = 32 µg/l)

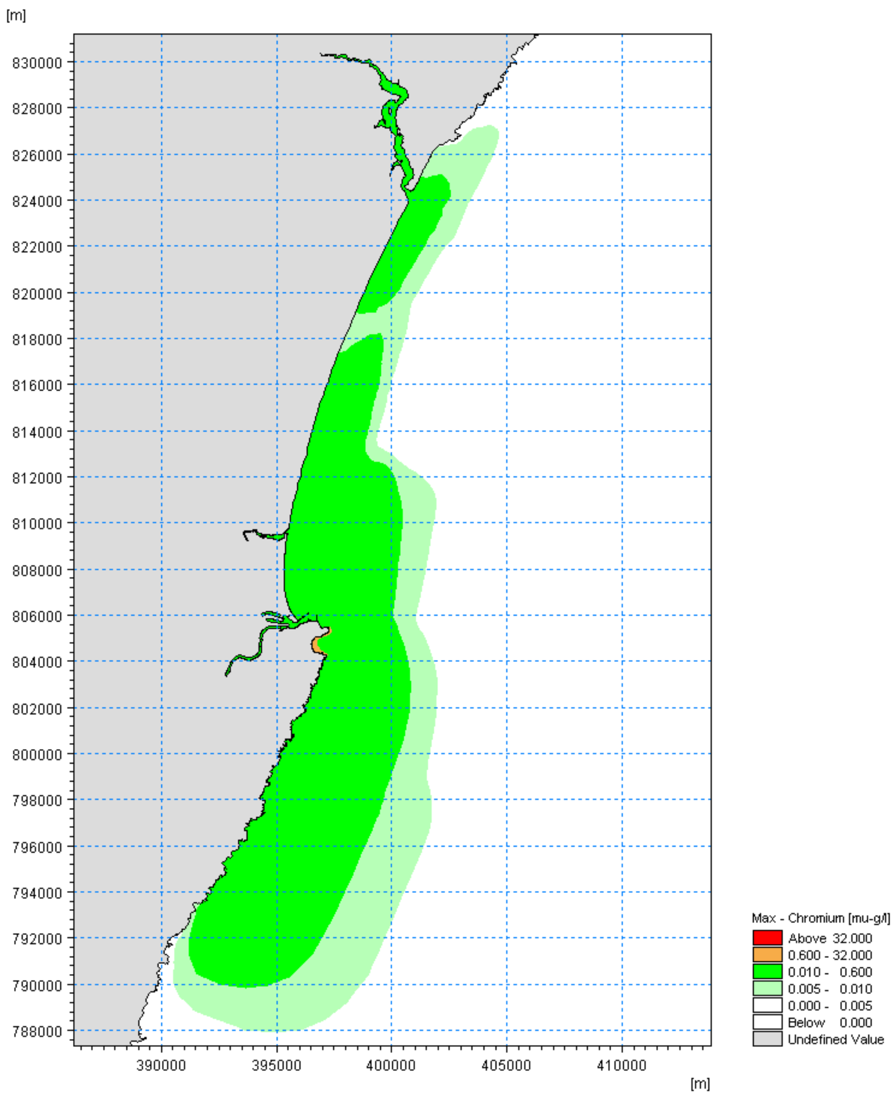


Figure C-9: Baseline - Chromium max. modelled conc. (close-up) - (AA = 0.6 µg/l, 95%'ile = 32 µg/l)

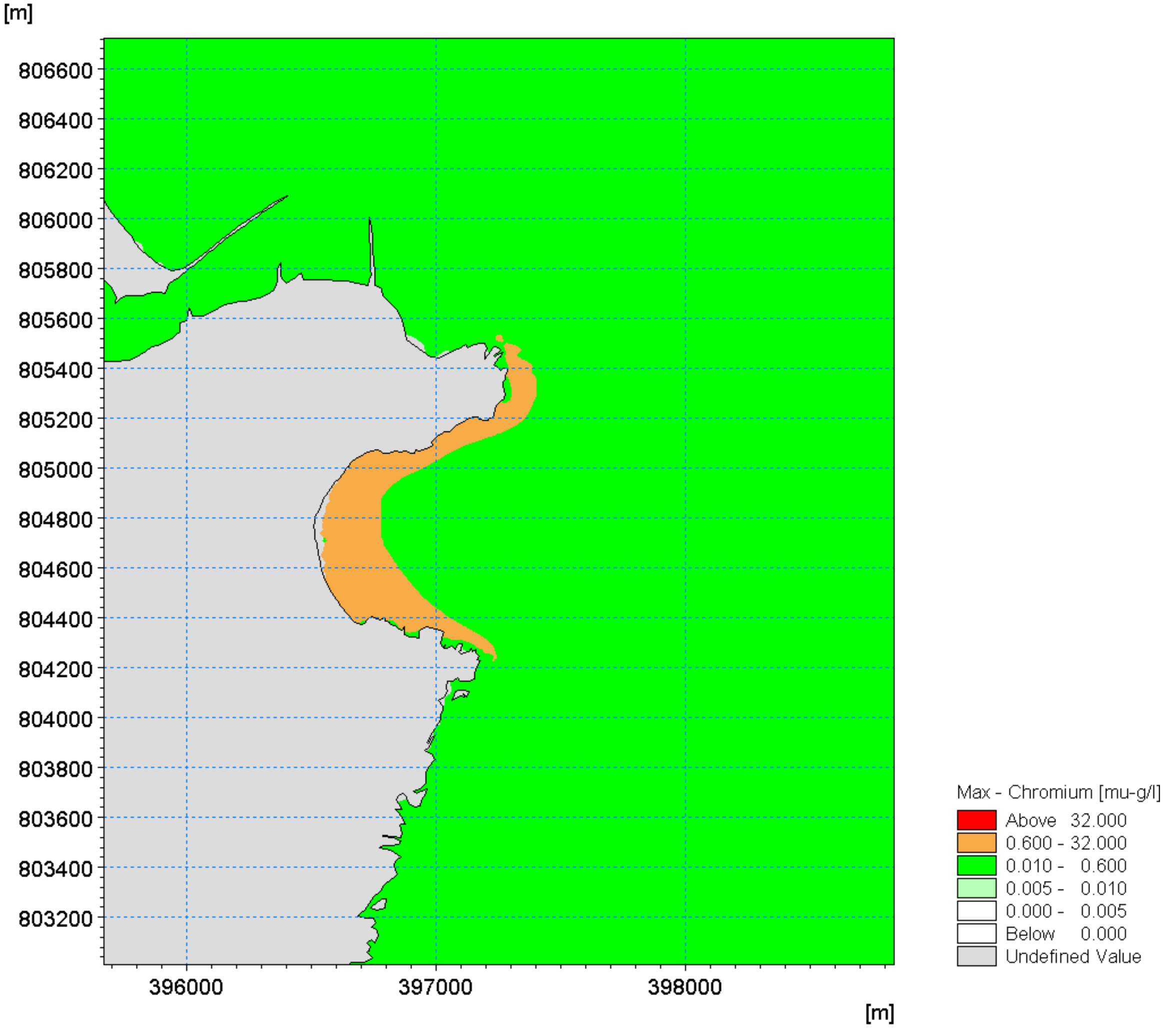


Figure C-10: Baseline - Copper max. modelled conc. (overview) - (AA = 5.09 µg/l)

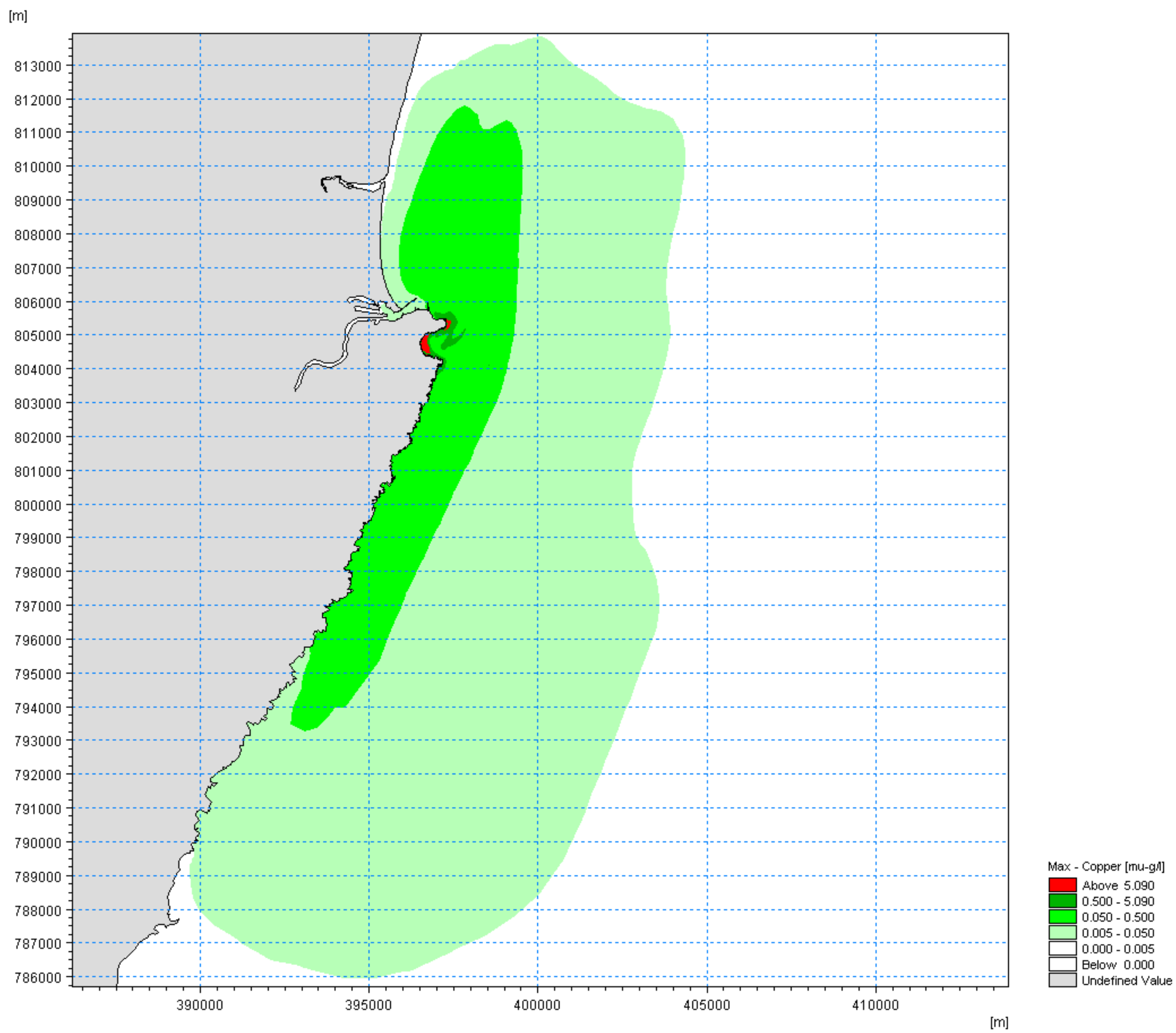


Figure C-11: Baseline - Copper max. modelled conc. (close-up) - (AA = 5.09 µg/l)

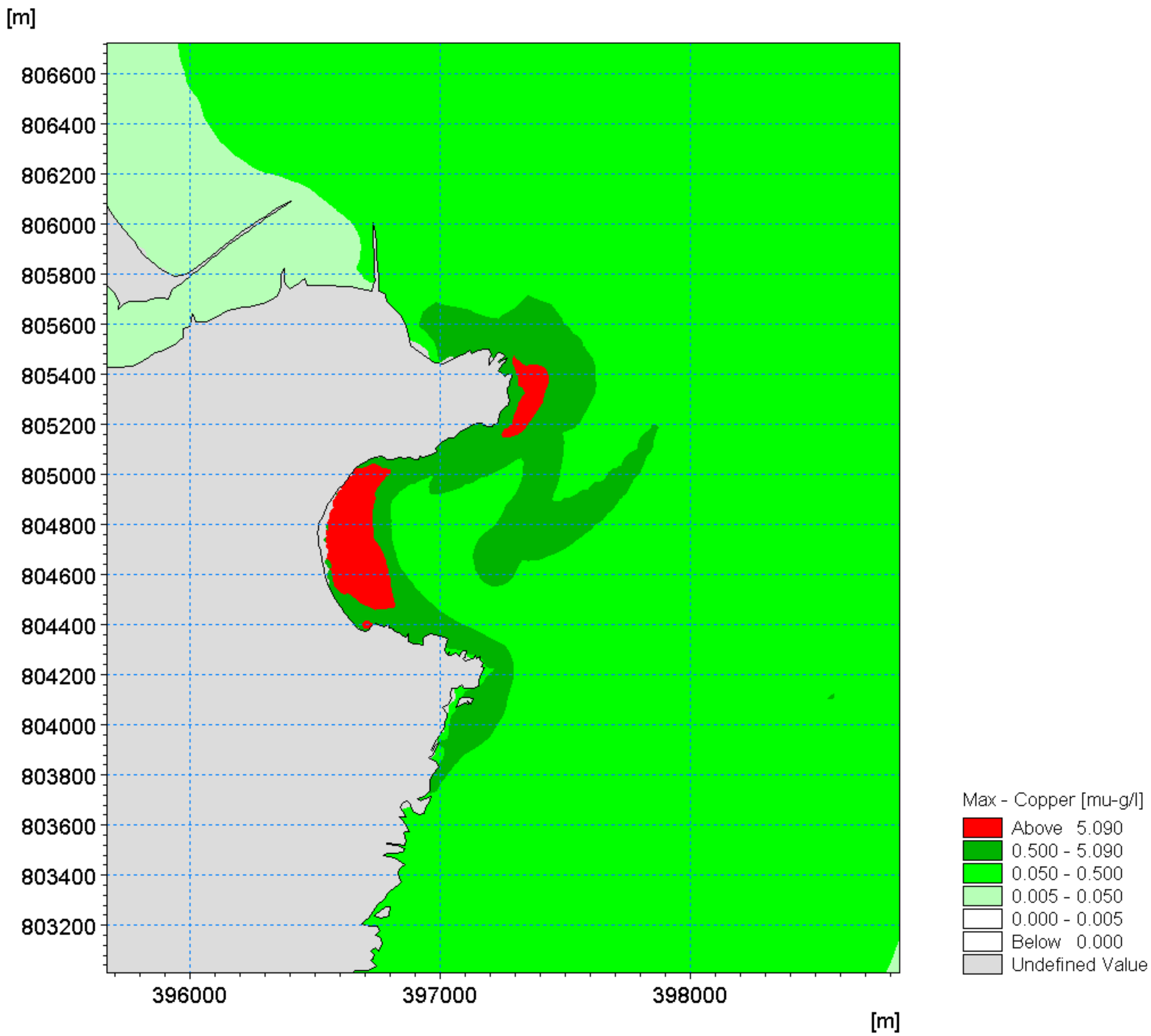


Figure C-12: Baseline – DIN max. modelled conc. (overview and close-up) - (AA = 0.42 mg/l)

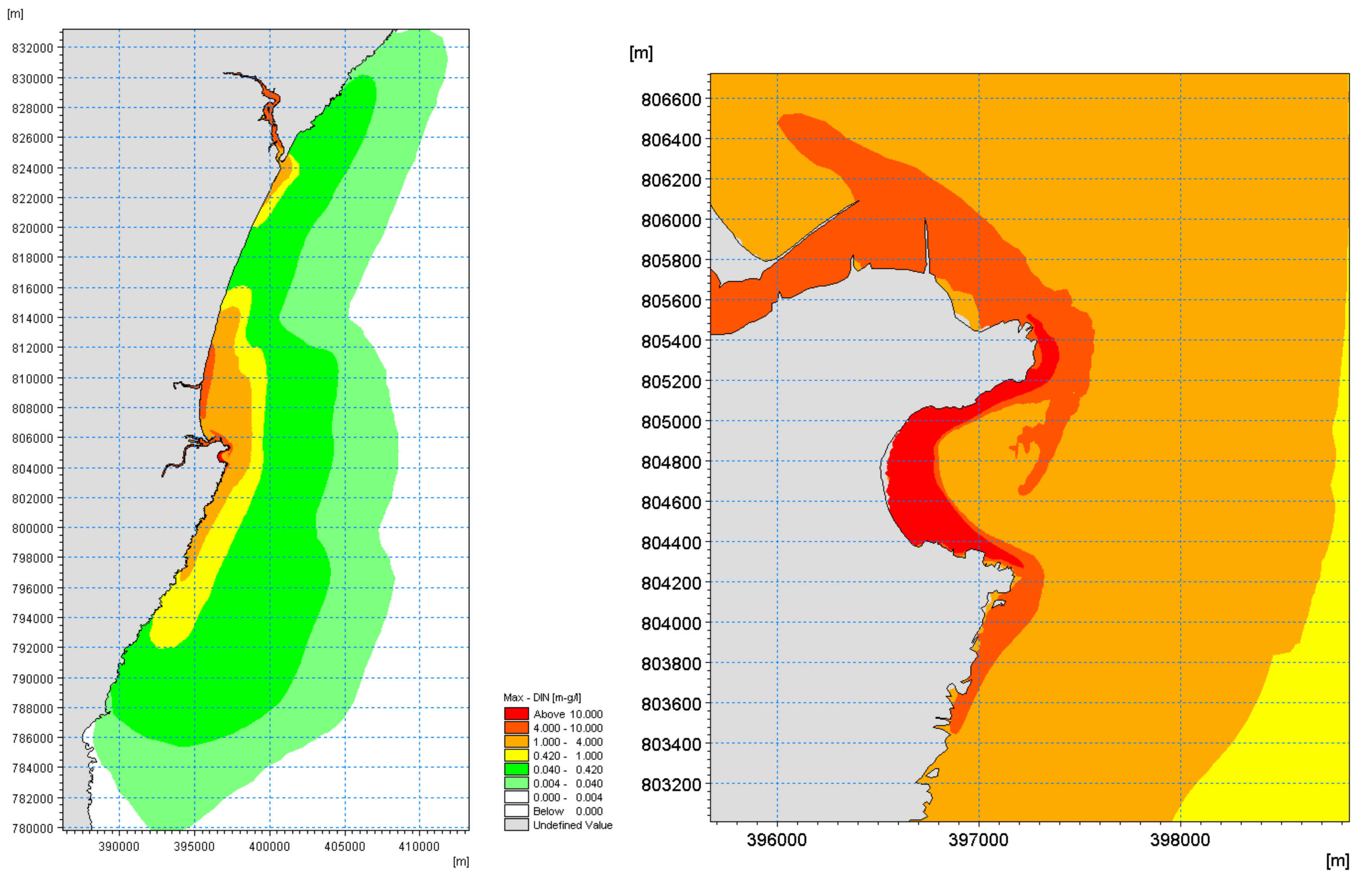


Figure C-13: Baseline - DO minimum modelled conc. (overview and close-up) - (95%'ile = 4 mg/l)

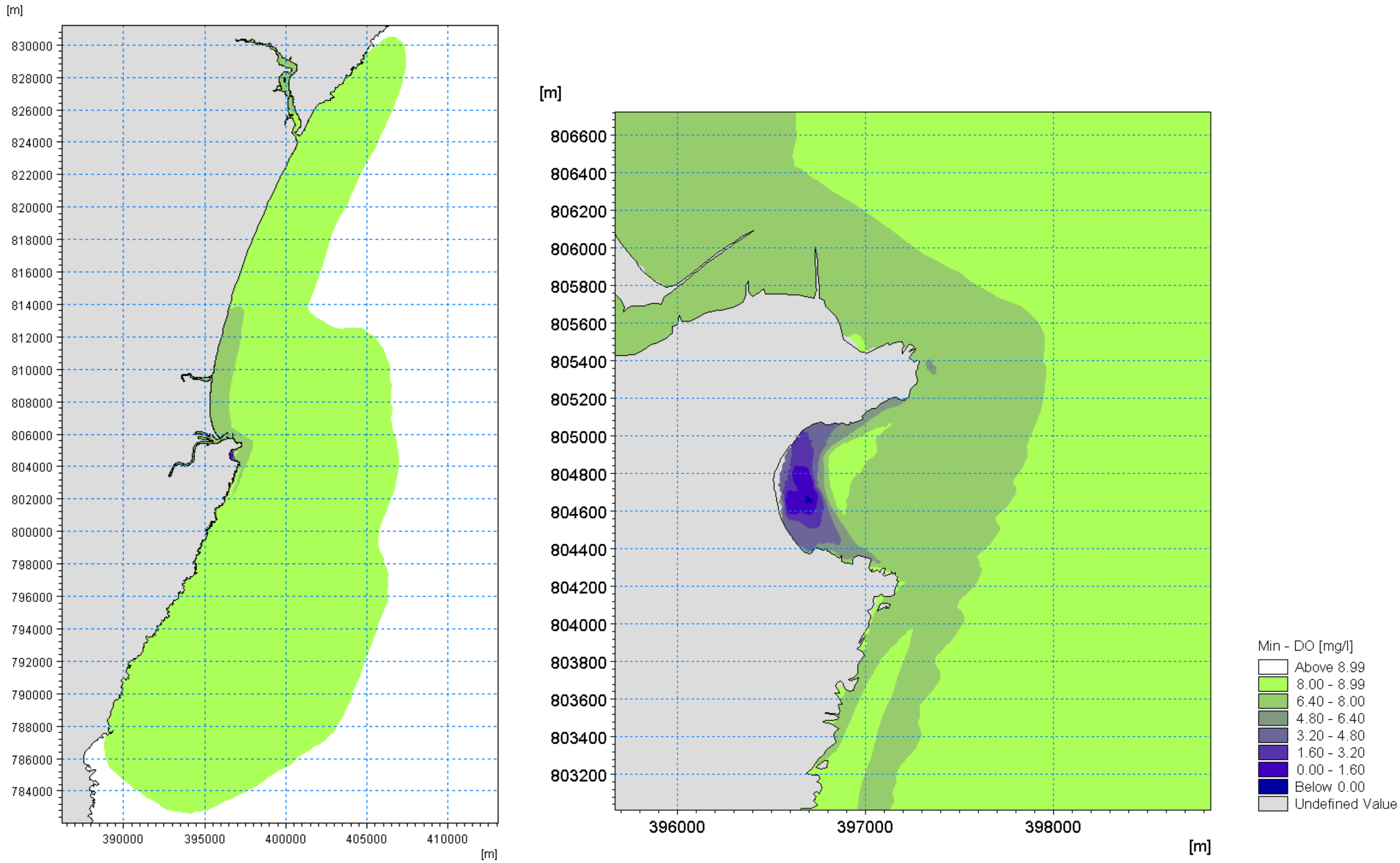


Figure C-14: Baseline - EC max. modelled conc. (overview) - (95%'ile = 250 ec/dl, 95%'ile = 500 ec/dl)

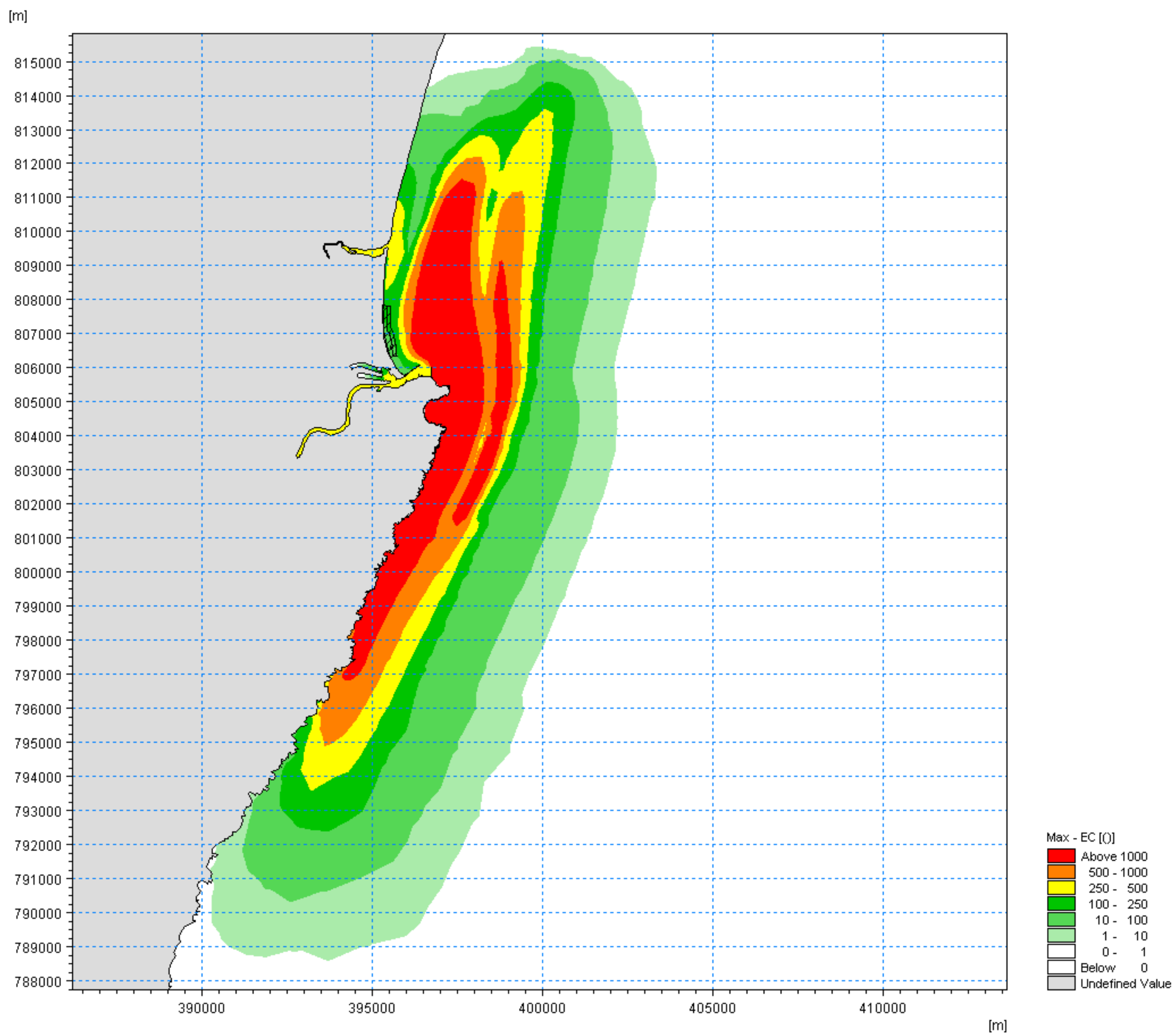


Figure C-15: Baseline - EC max. modelled conc. (close-up) - (95%'ile = 250 ec/dl, 95%'ile = 500 ec/dl)

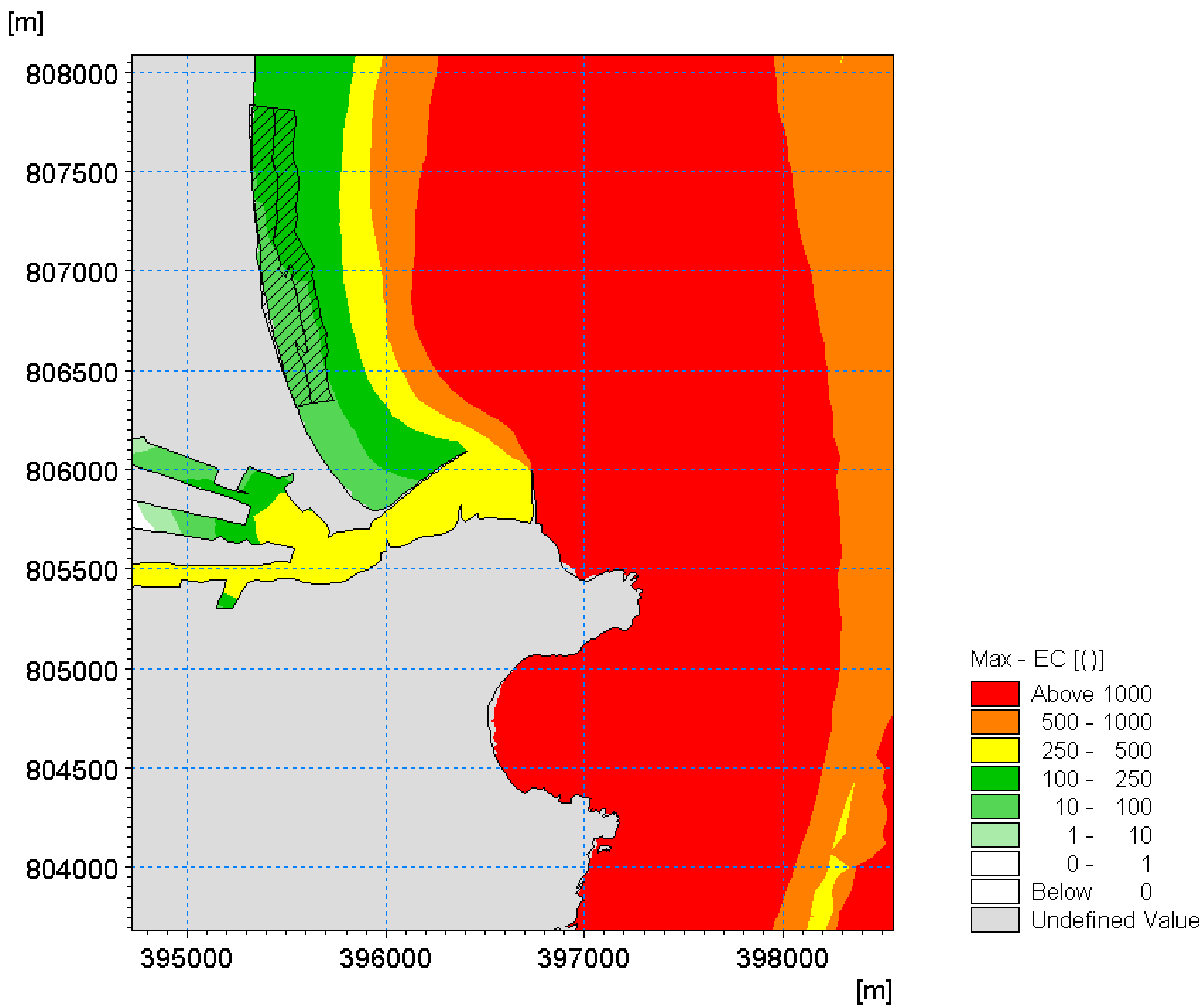


Figure C-16: Baseline - Hexachlorobutadiene max. modelled conc. (overview) - (AA = 0.1 µg/l, MAC = 0.6 µg/l)

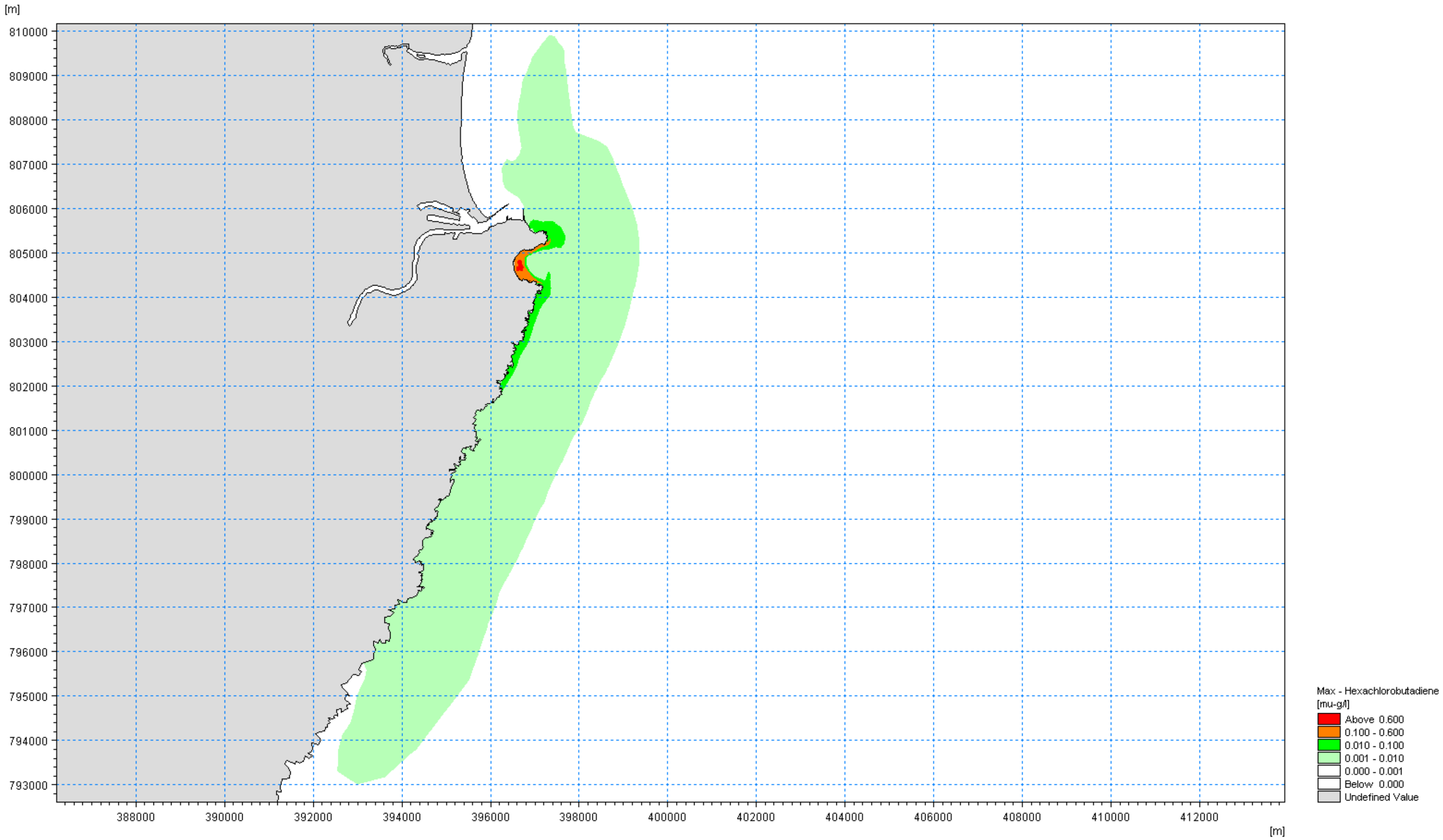


Figure C-17: Baseline - Hexachlorobutadiene max. modelled conc. (close-up) - (AA = 0.1 µg/l, MAC = 0.6 µg/l)

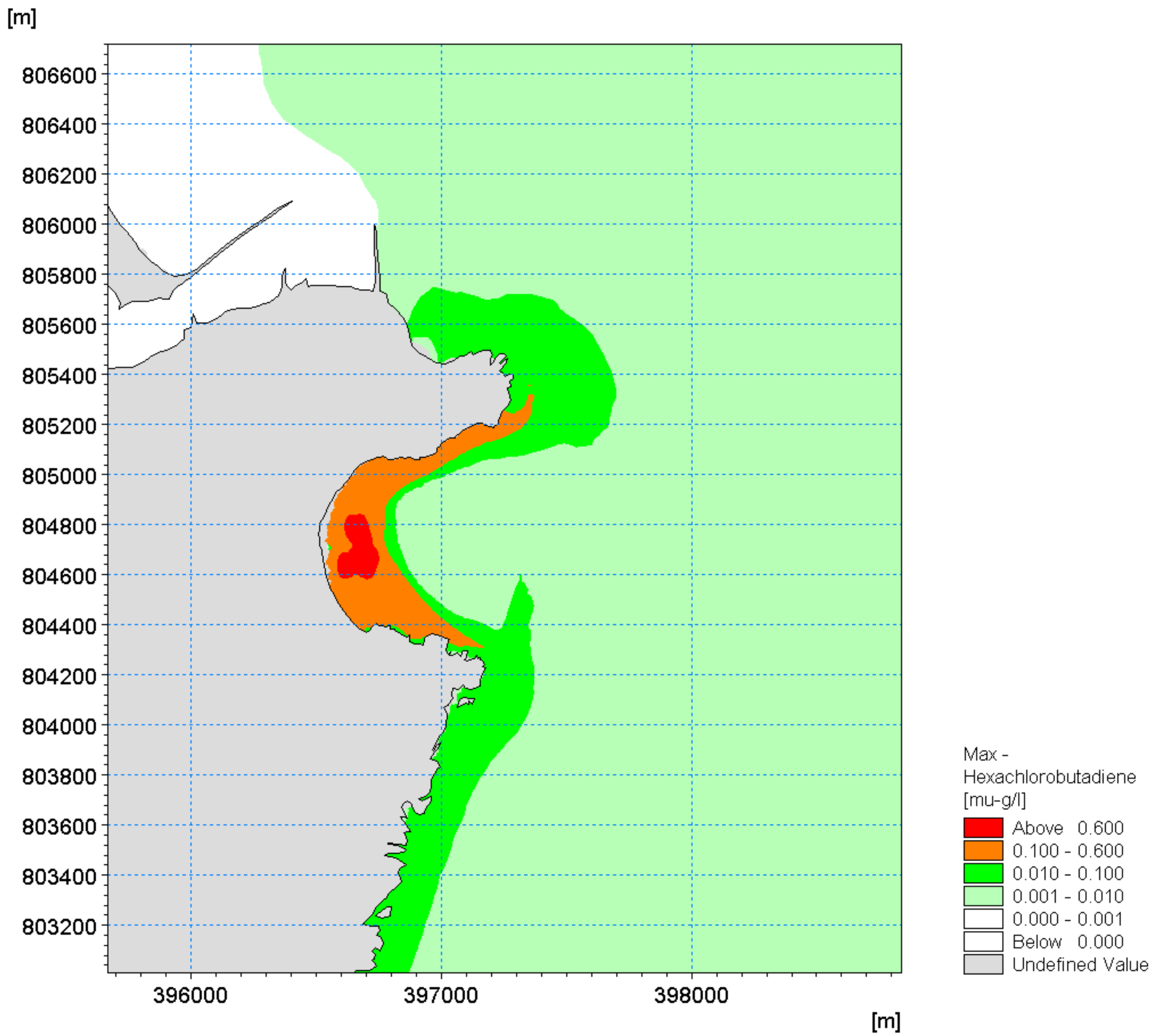


Figure C-18: Baseline - Lead max. modelled conc. (overview) - (AA = 7.2 µg/l)

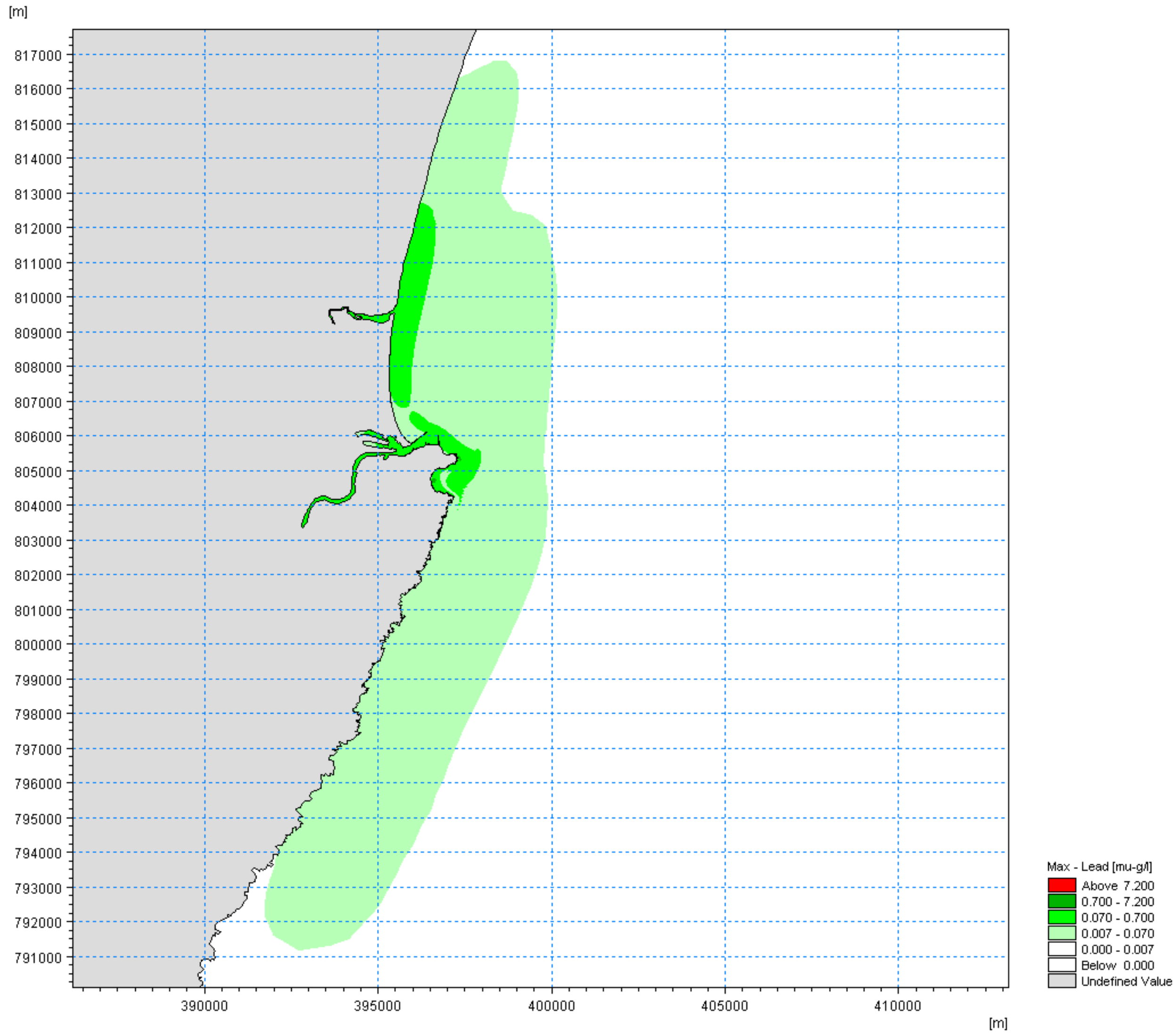


Figure C-19: Baseline - Lead max. modelled conc. (close-up) - (AA = 7.2 µg/l)

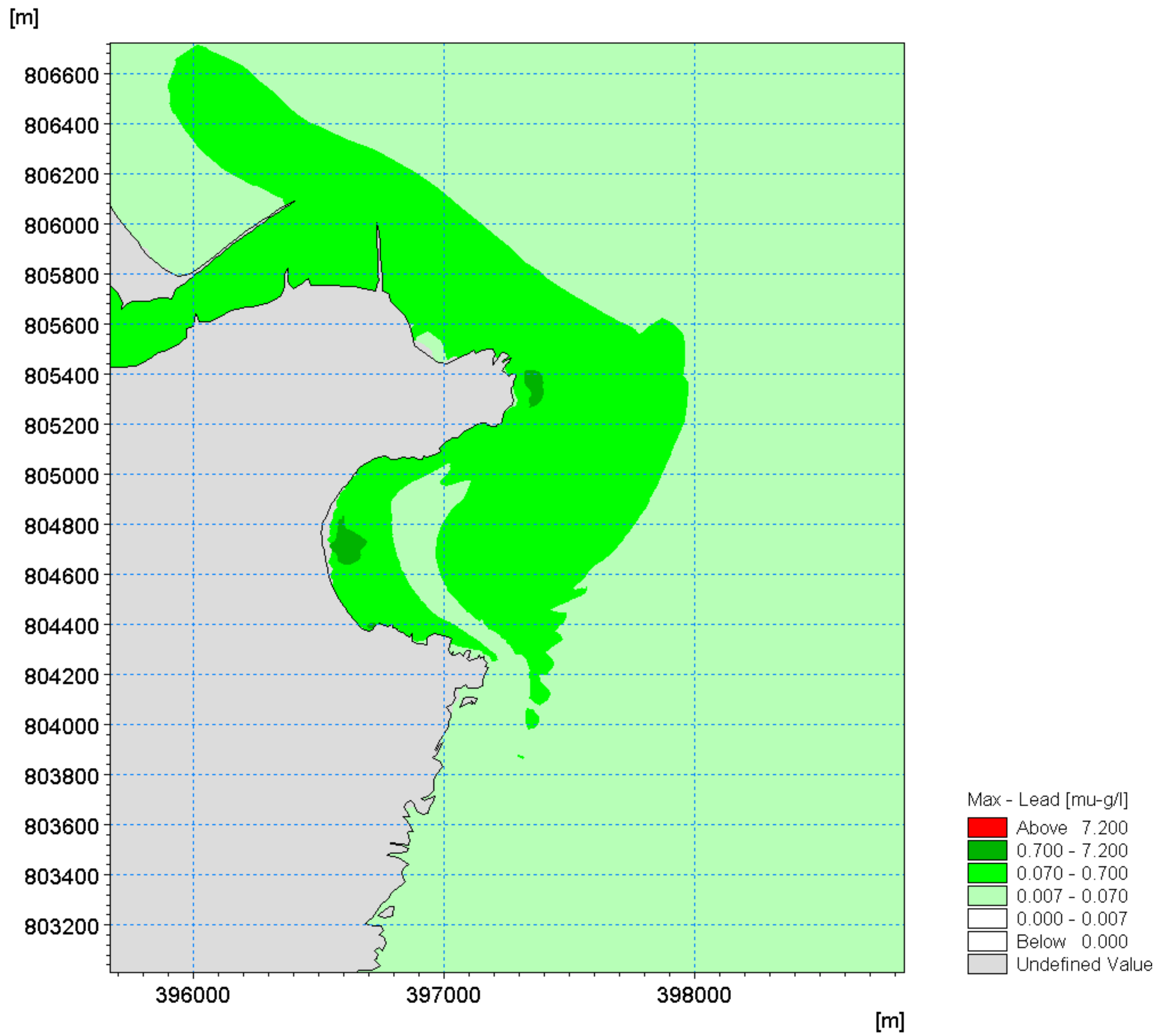


Figure C-20: Baseline - Mercury max. modelled conc. (overview) - (AA = 0.05 µg/l, MAC = 0.07 µg/l)

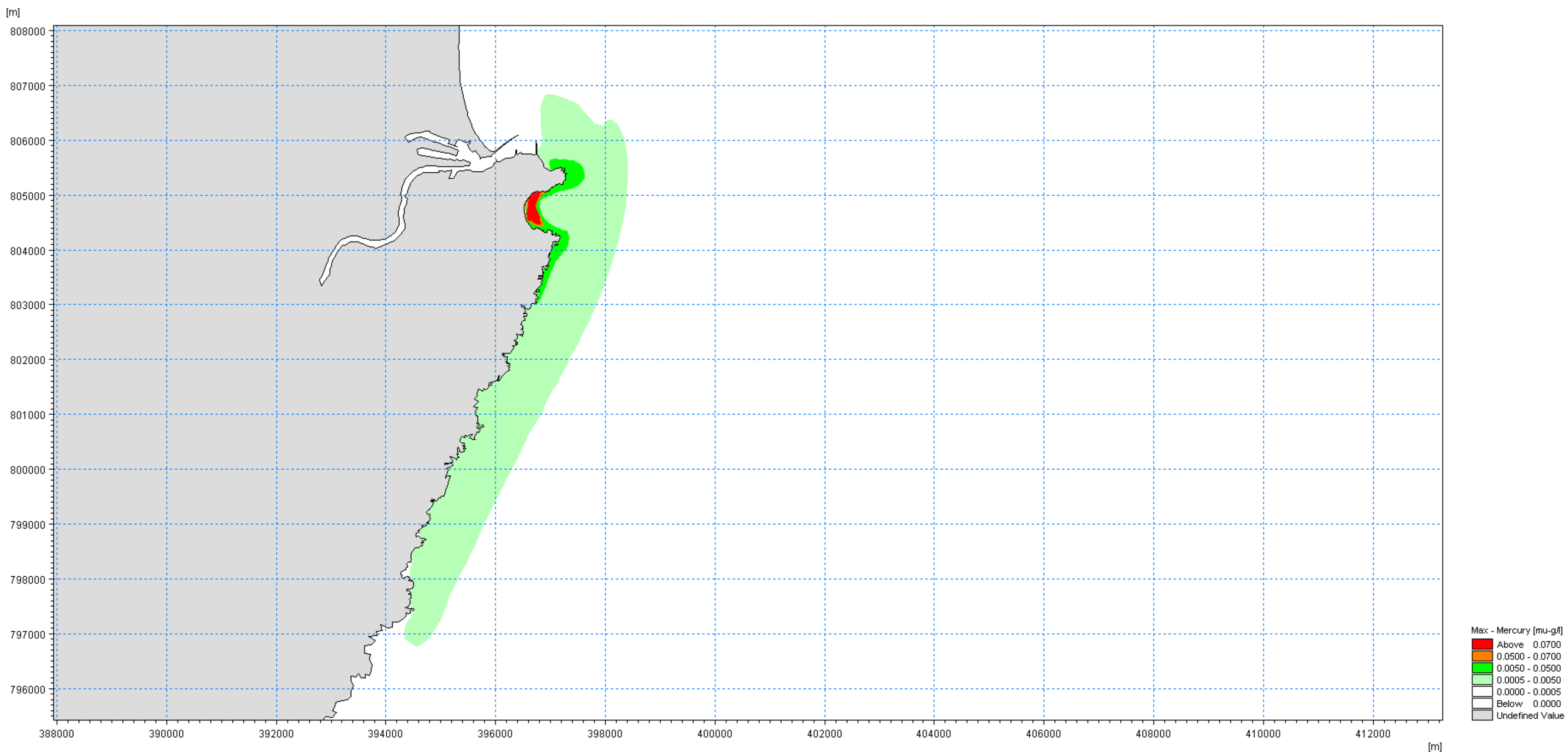


Figure C-21: Baseline - Mercury max. modelled conc. (close-up) - (AA = 0.05 µg/l, MAC = 0.07 µg/l)

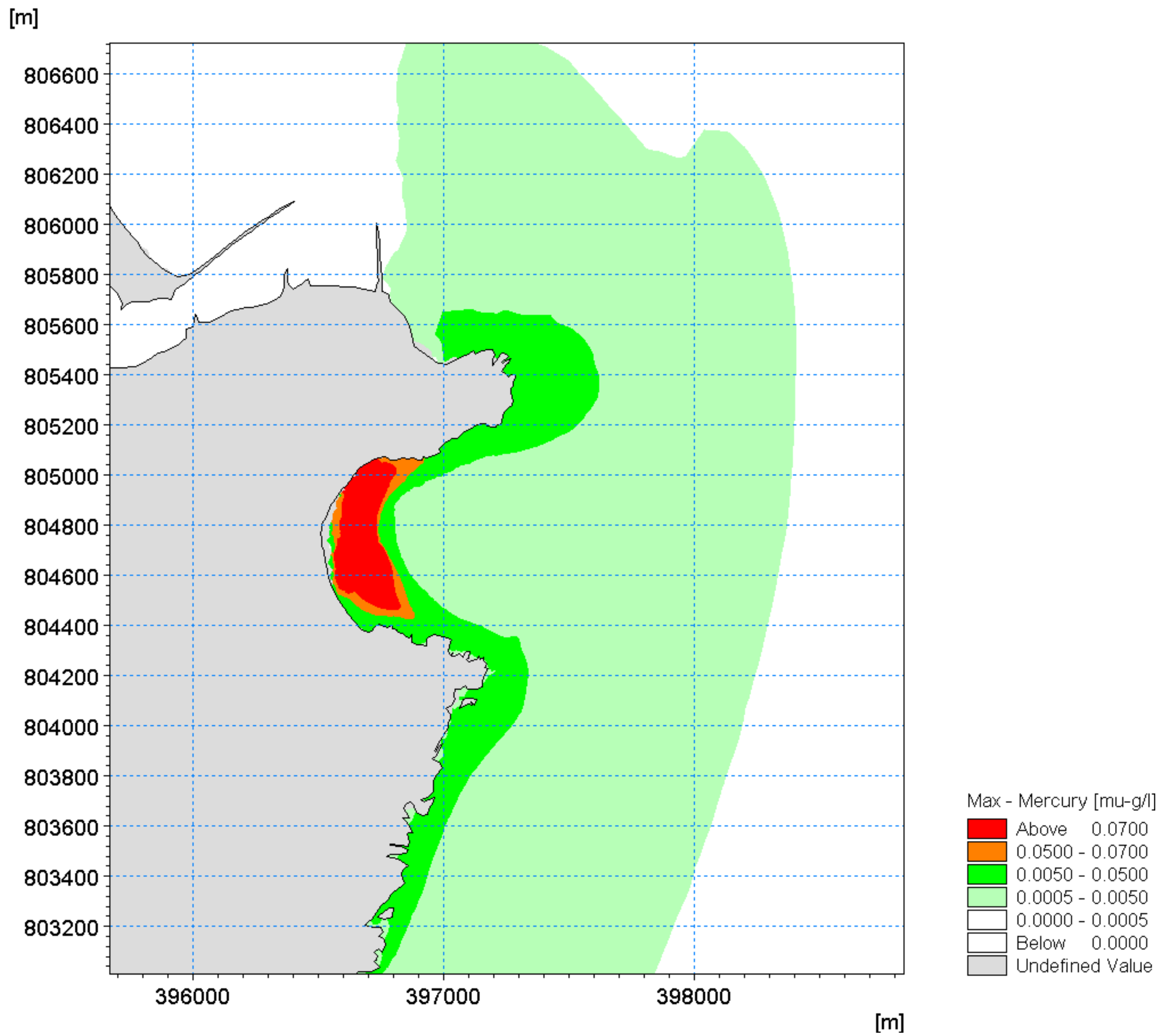


Figure C-22: Baseline - Total ammonia max. modelled conc. (overview) - (AA = 1.1 mg/l, MAC = 8 mg/l)

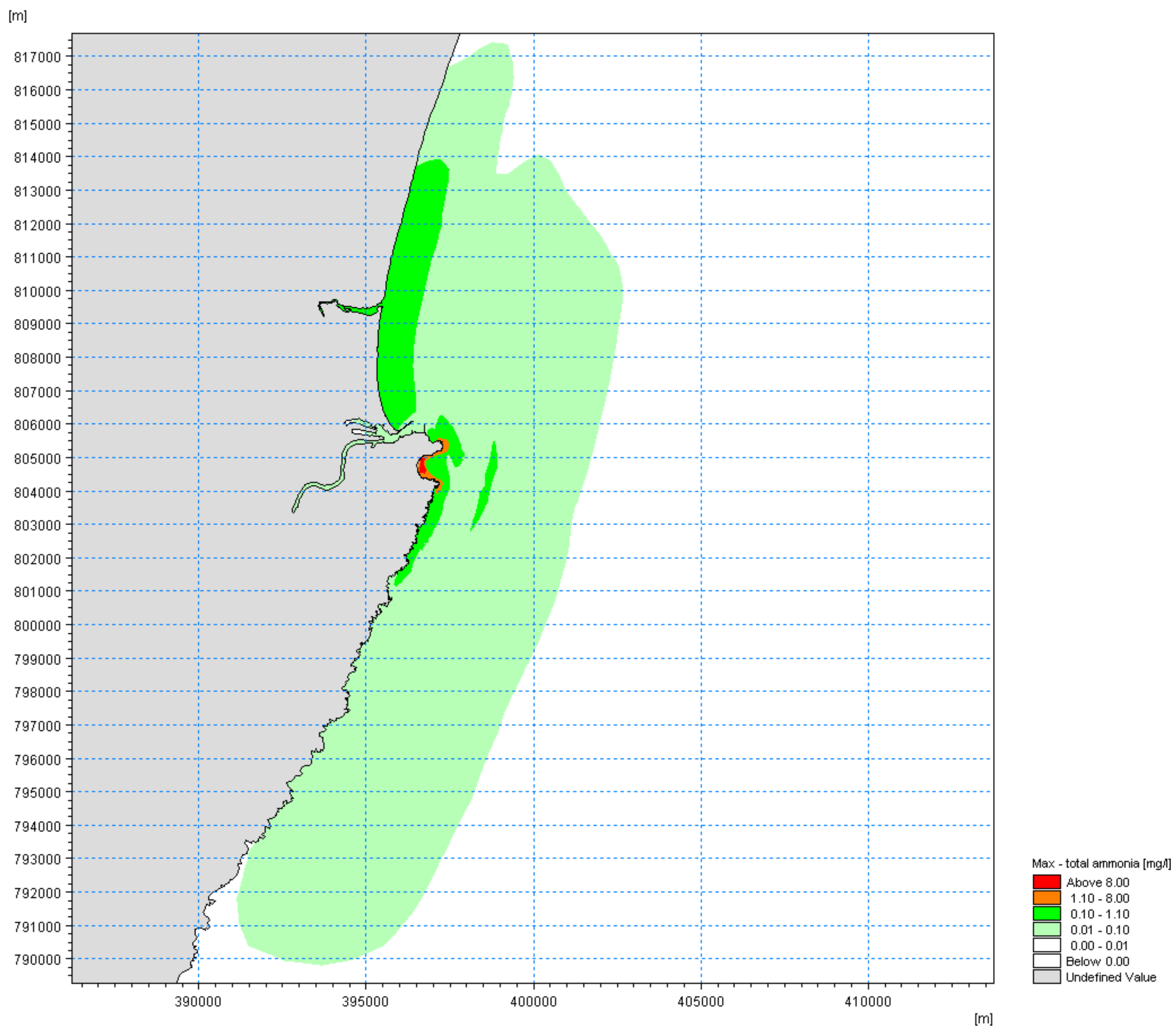


Figure C-23: Baseline - Total ammonia max. modelled conc. (close-up) - (AA = 1.1 mg/l, MAC = 8 mg/l)

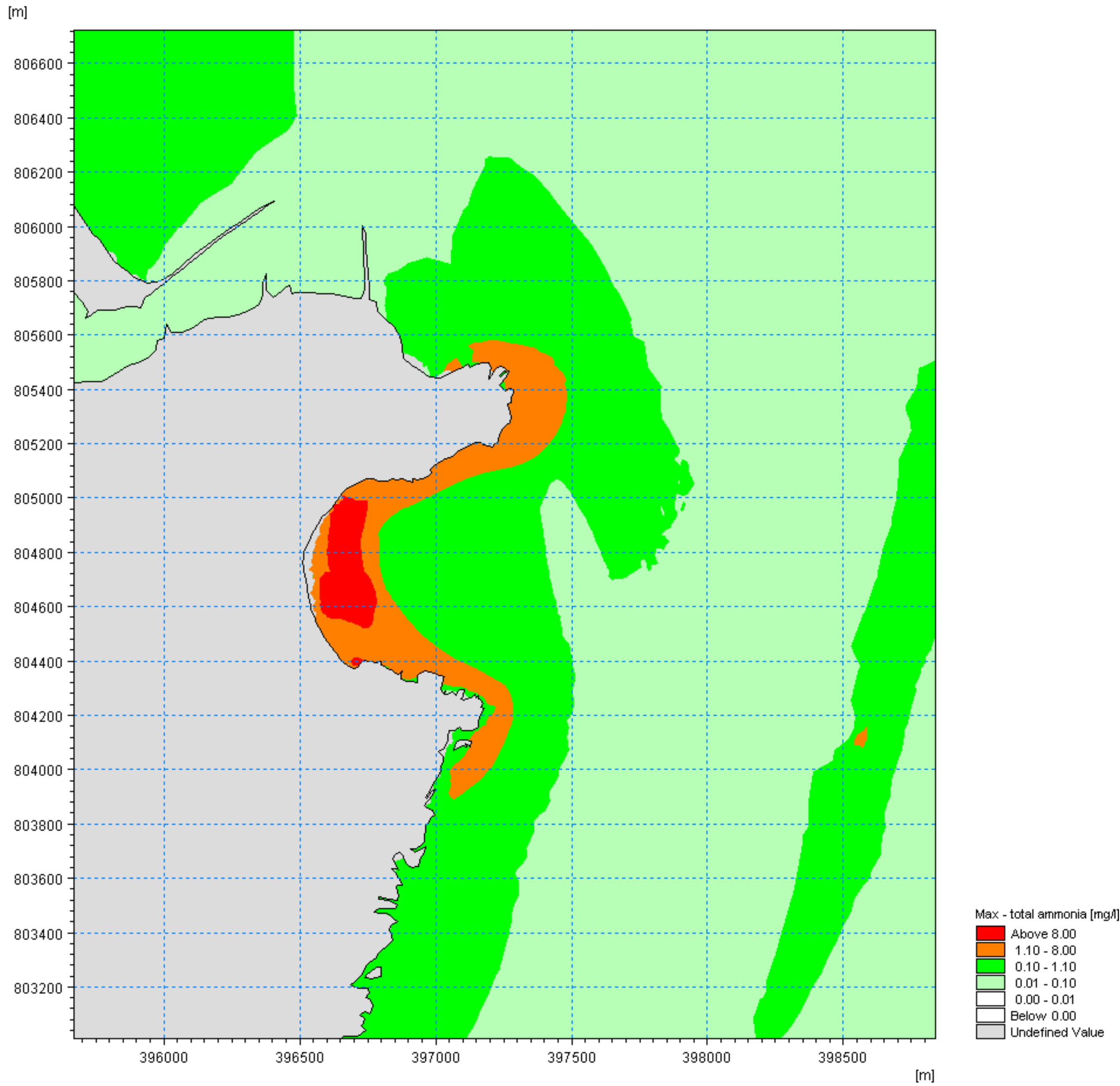


Figure C-24: Baseline - PAHs max. modelled conc. (overview)

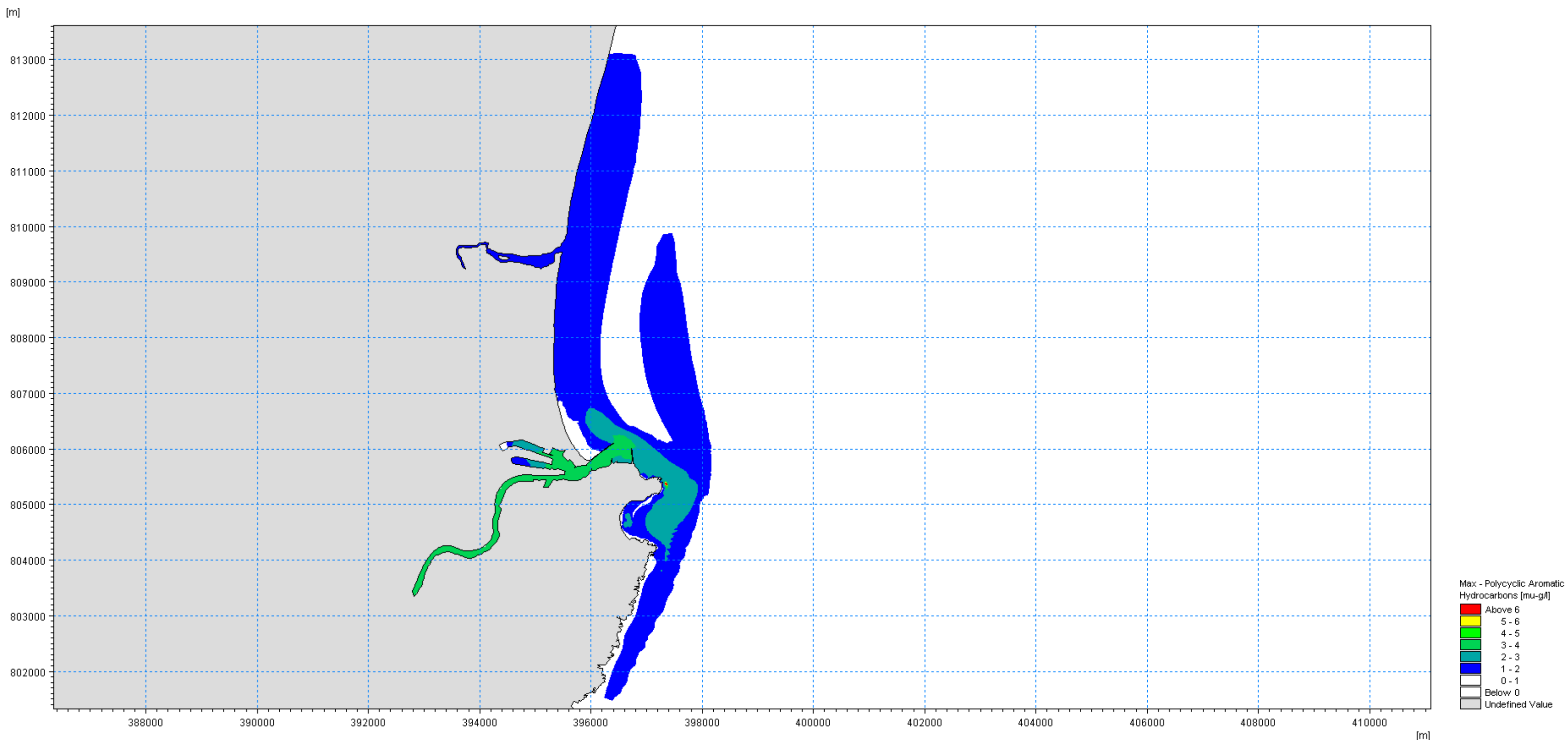


Figure C-25: Baseline - PAHs max. modelled conc. (close-up)

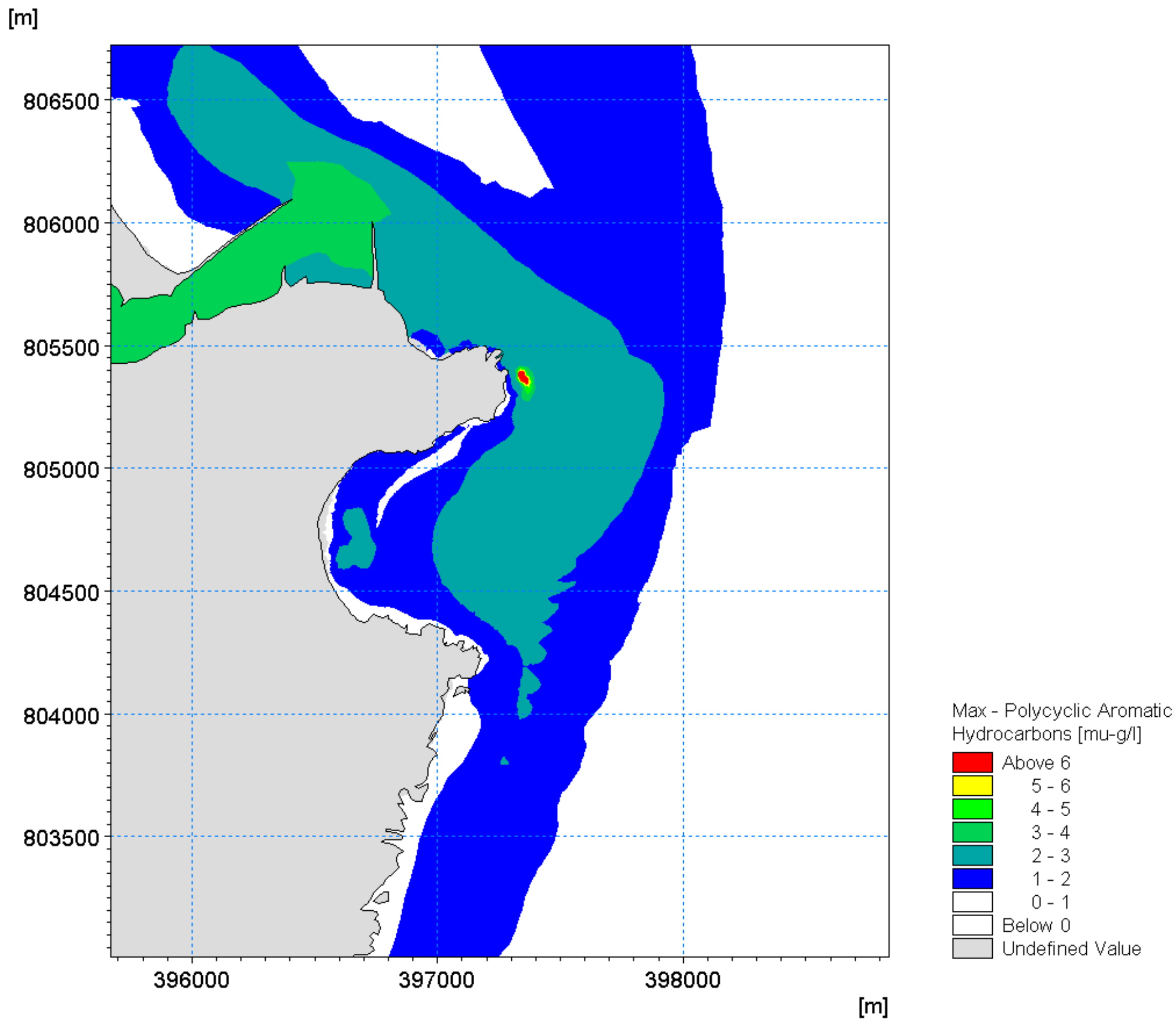


Figure C-26: Baseline - Phenol max. modelled conc. (overview) - (AA = 7.7 µg/l, 95%'ile = 46 µg/l)

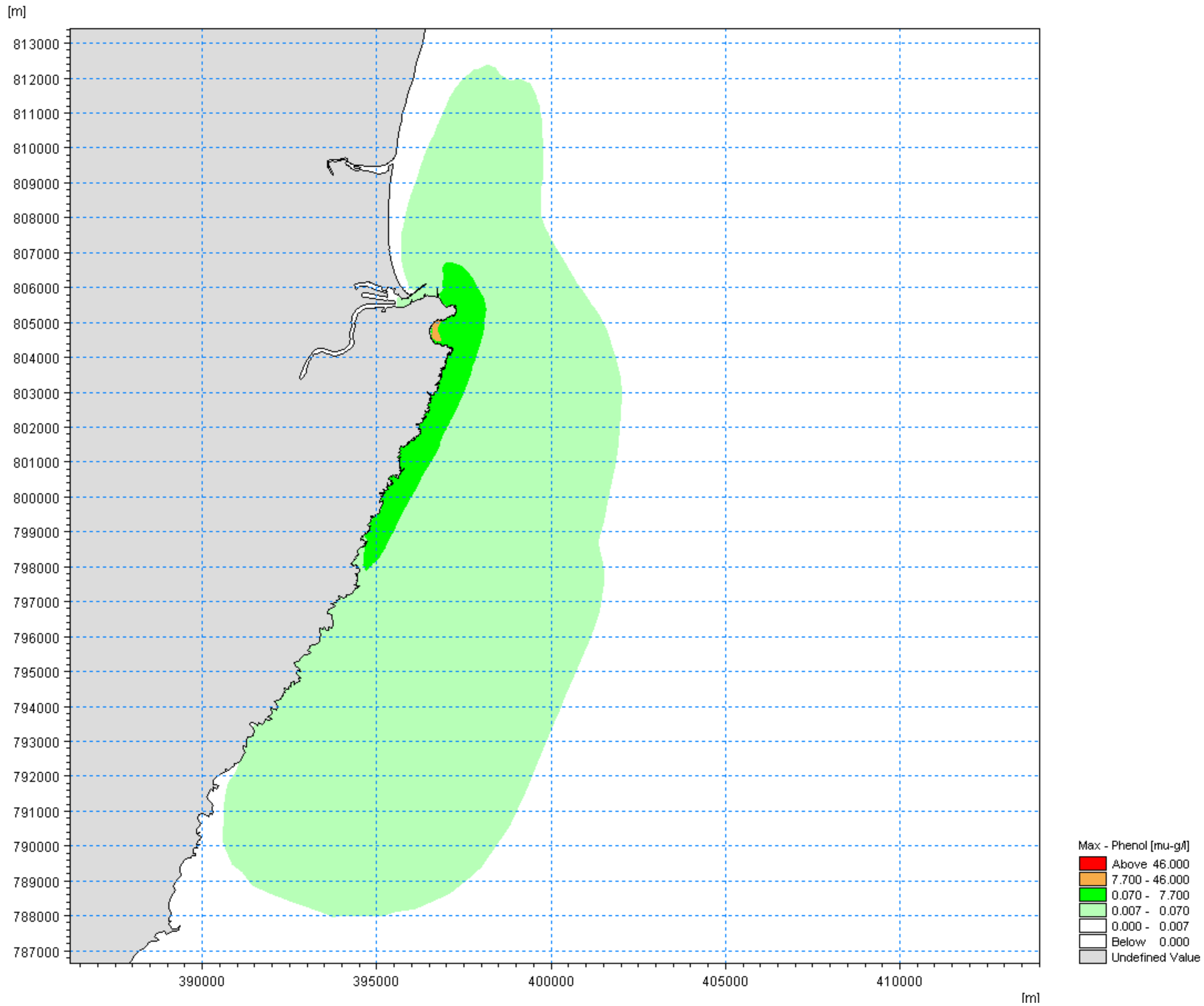


Figure C-27: Baseline - Phenol max. modelled conc. (close-up) - (AA = 7.7 µg/l, 95%'ile = 46 µg/l)

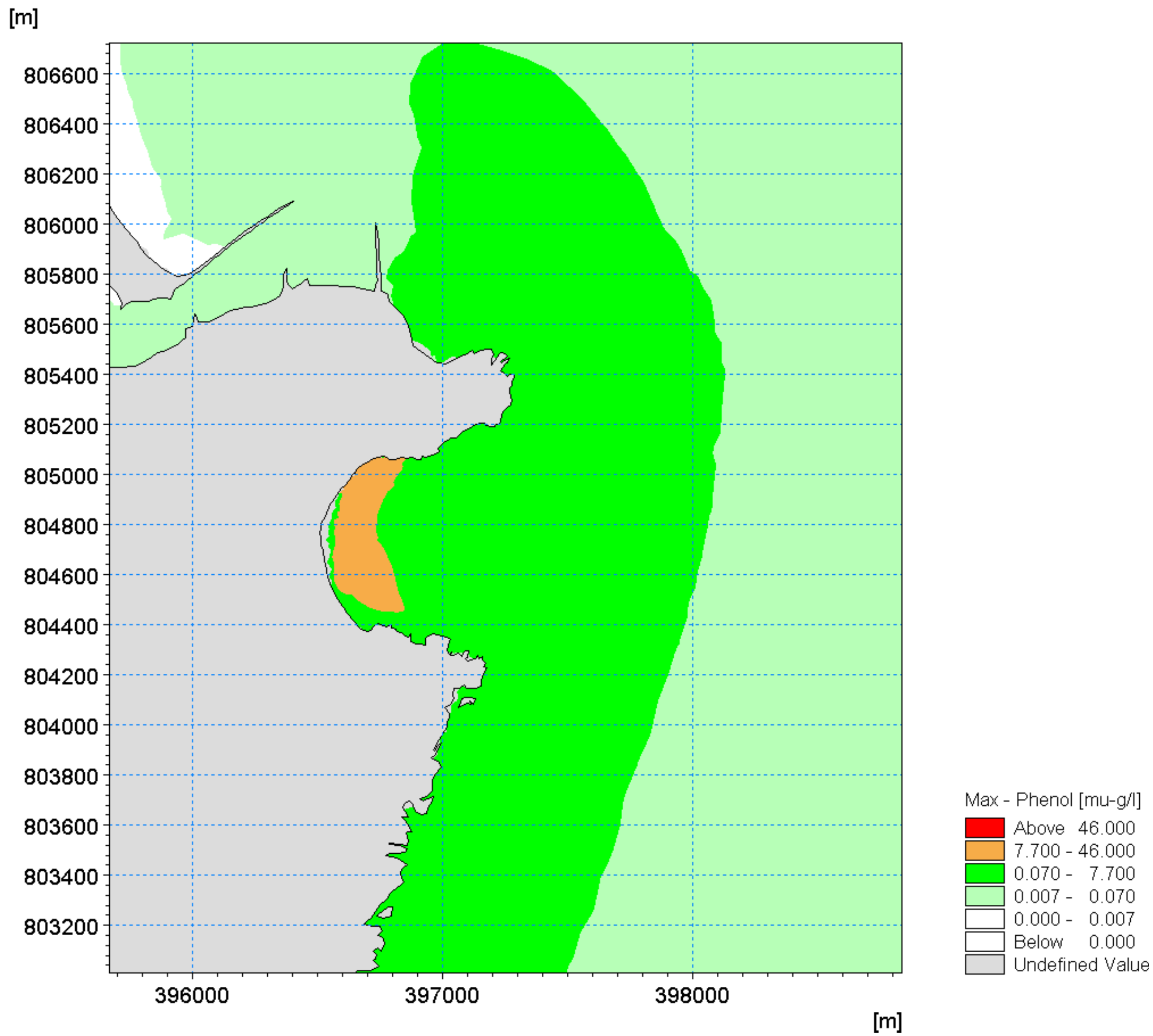


Figure C-28: Baseline - Unionised ammonia (at 10°C) max. modelled conc. (overview and close-up) - (AA = 21 µg/l)

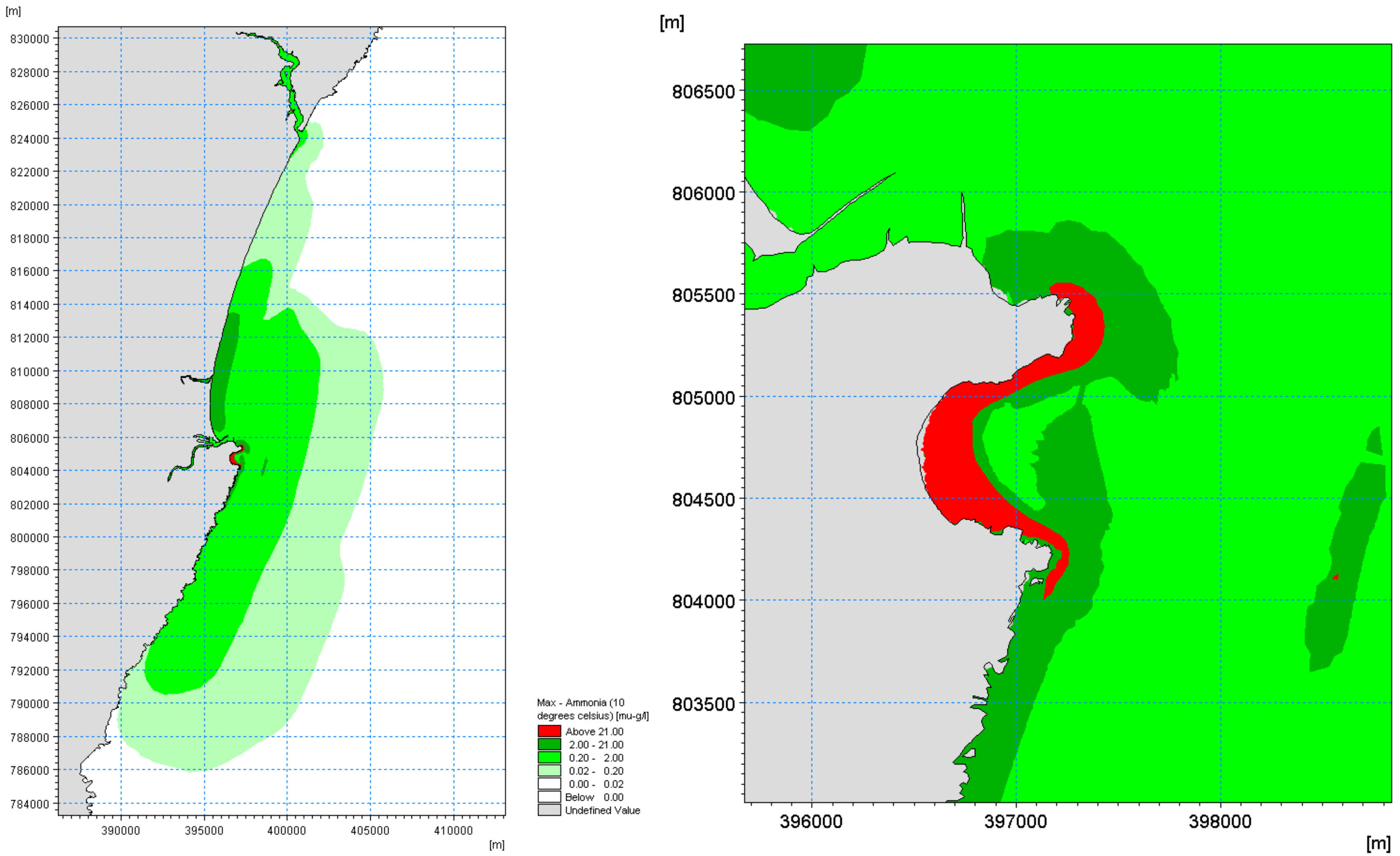


Figure C-29: Baseline - Unionised ammonia (at 15°C) max. modelled conc. (overview and close-up) - (AA = 21 µg/l)

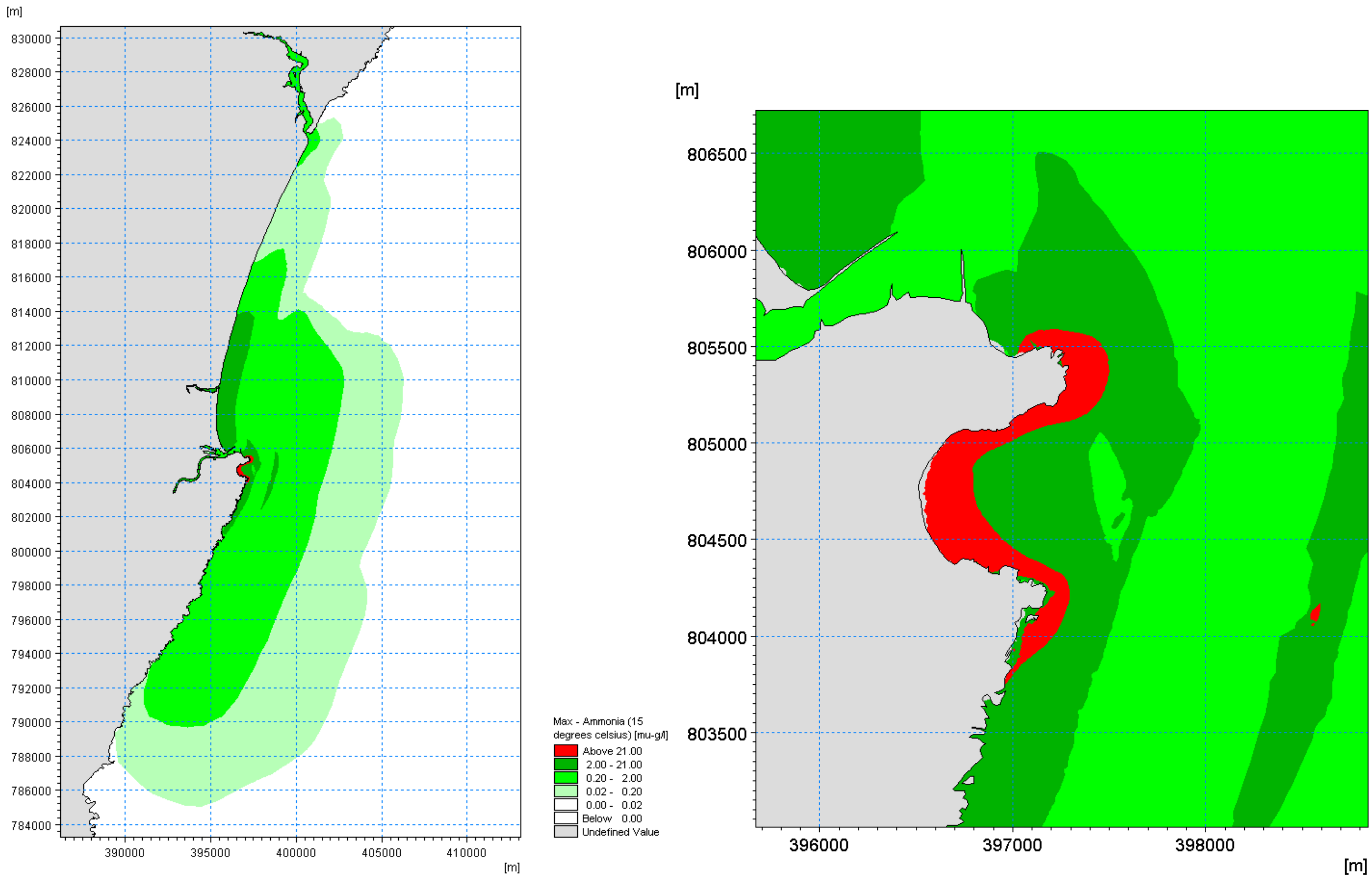


Figure C-30: Baseline - Zinc max. modelled conc. (overview) - (AA = 7.9 µg/l)

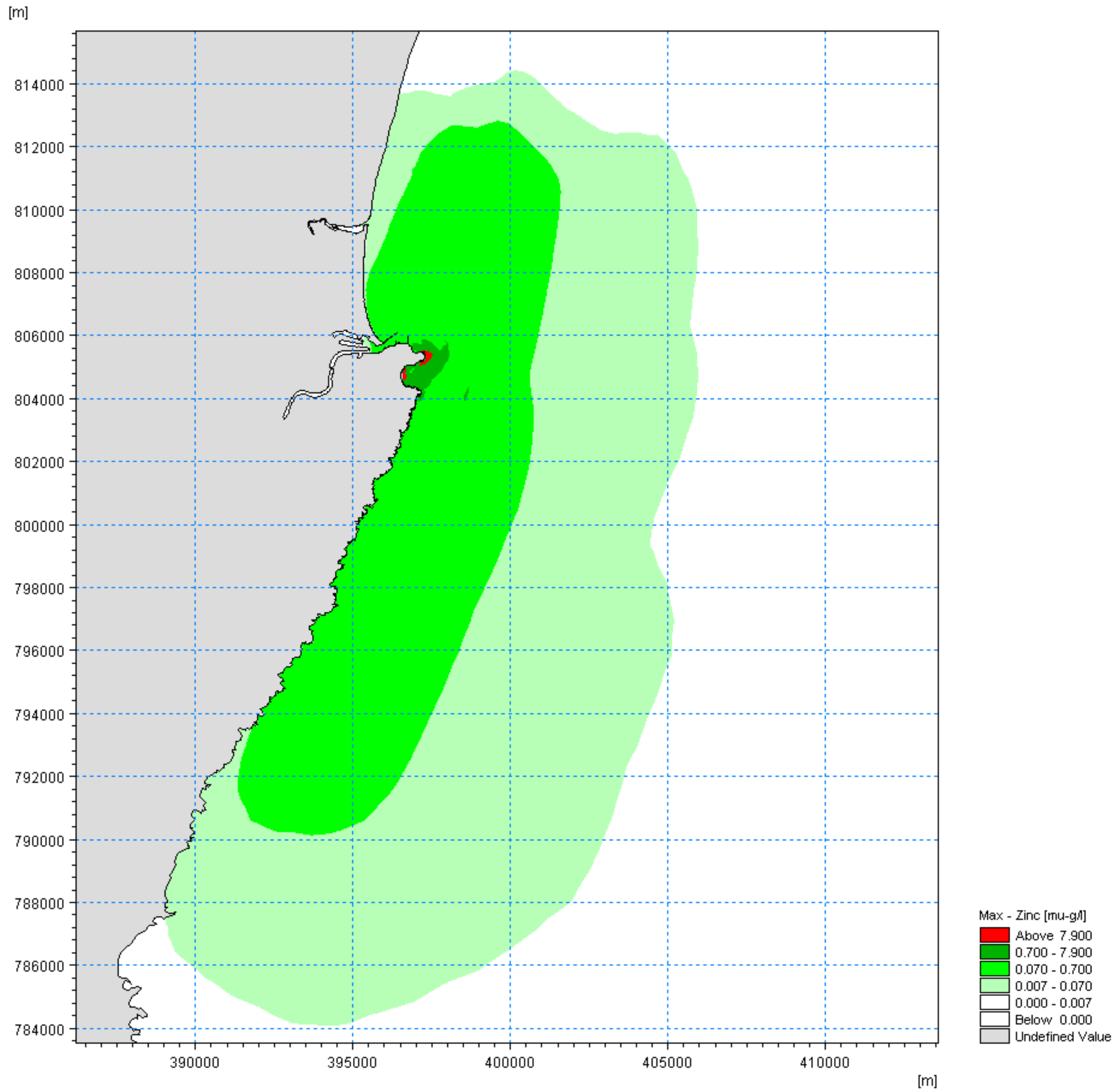


Figure C-31: Baseline - Zinc max. modelled conc. (close-up) - (AA = 7.9 µg/l)

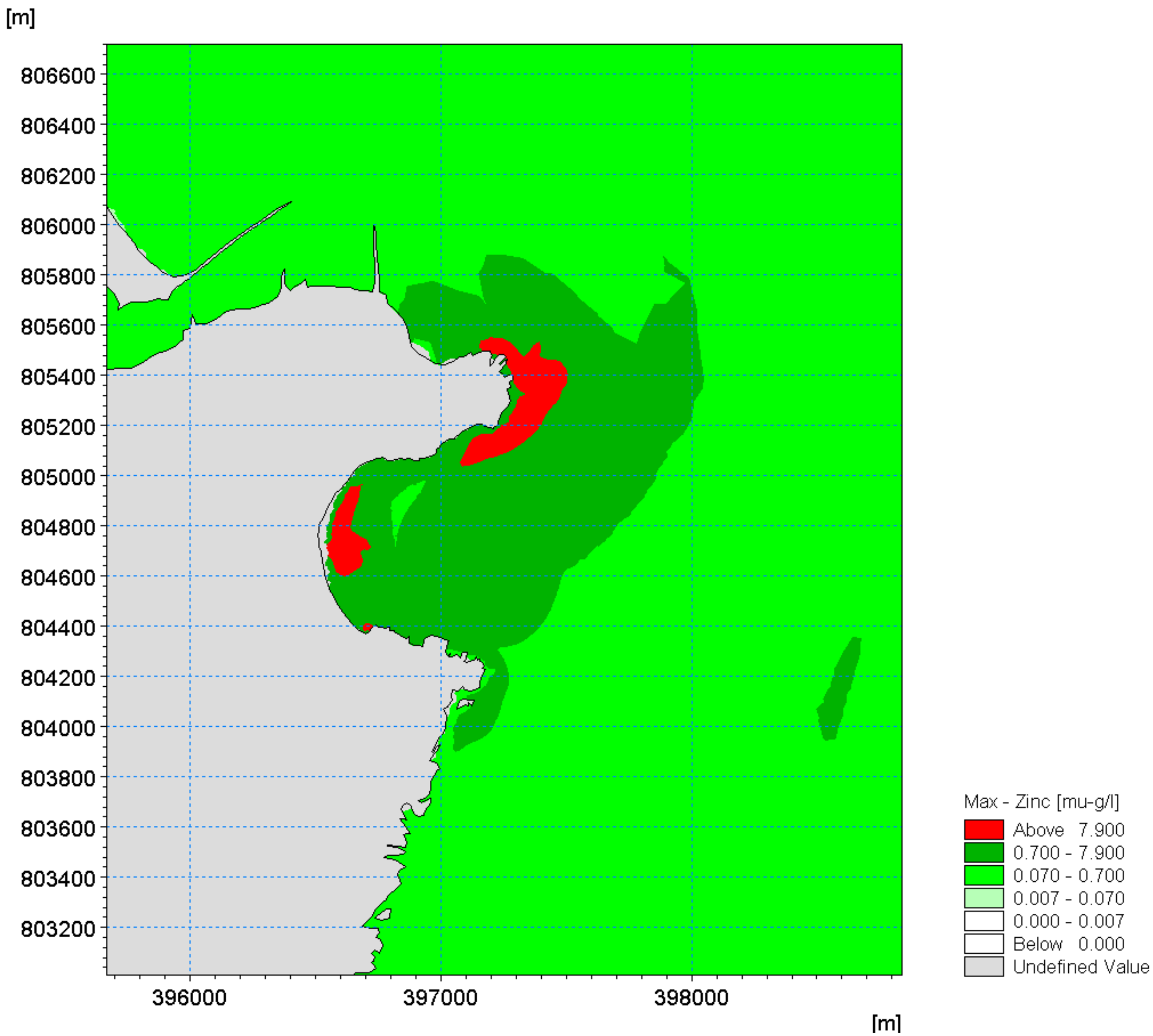


Figure C-32: Development - Anthracene max. modelled conc. (overview and close-up) - (AA = 0.1 µg/l, MAC = 0.4 µg/l)

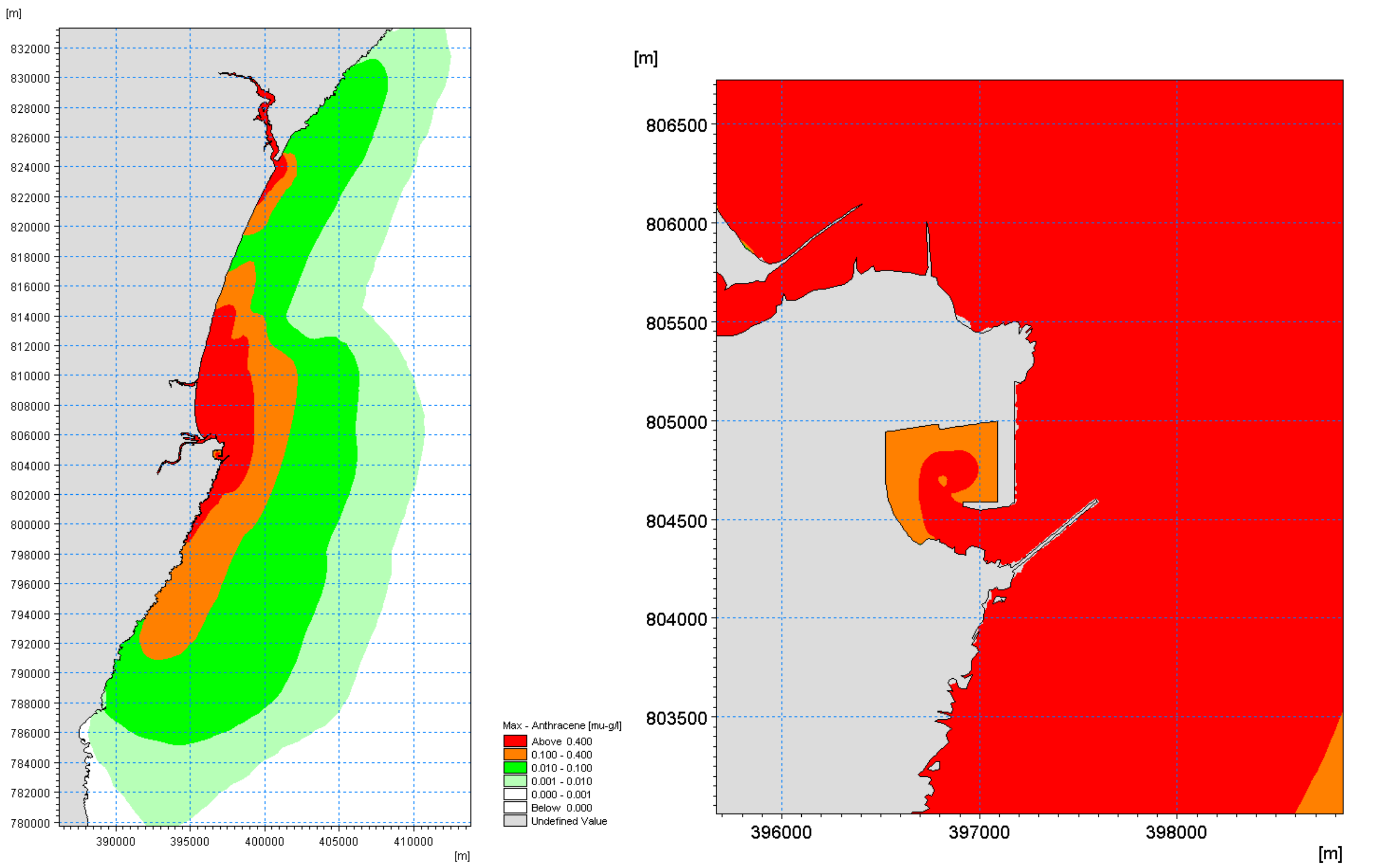


Figure C-33: Development - Benzo(b\k)fluoranthene max. modelled conc. (overview and close-up) - (AA = 0.03 µg/l)

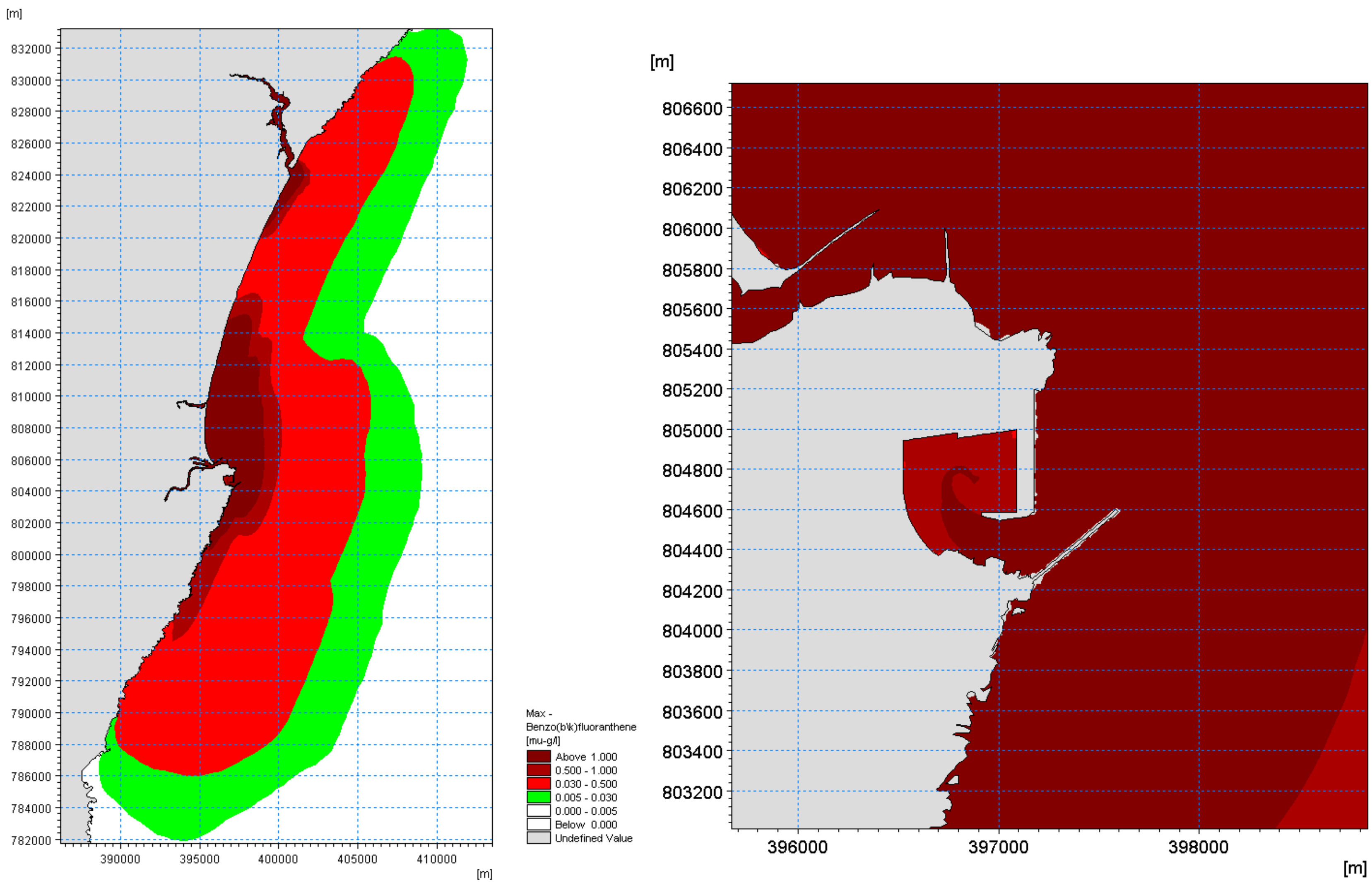


Figure C-34: Development - BOD max. modelled conc. (overview) - (90%'ile = 5 mg/l)

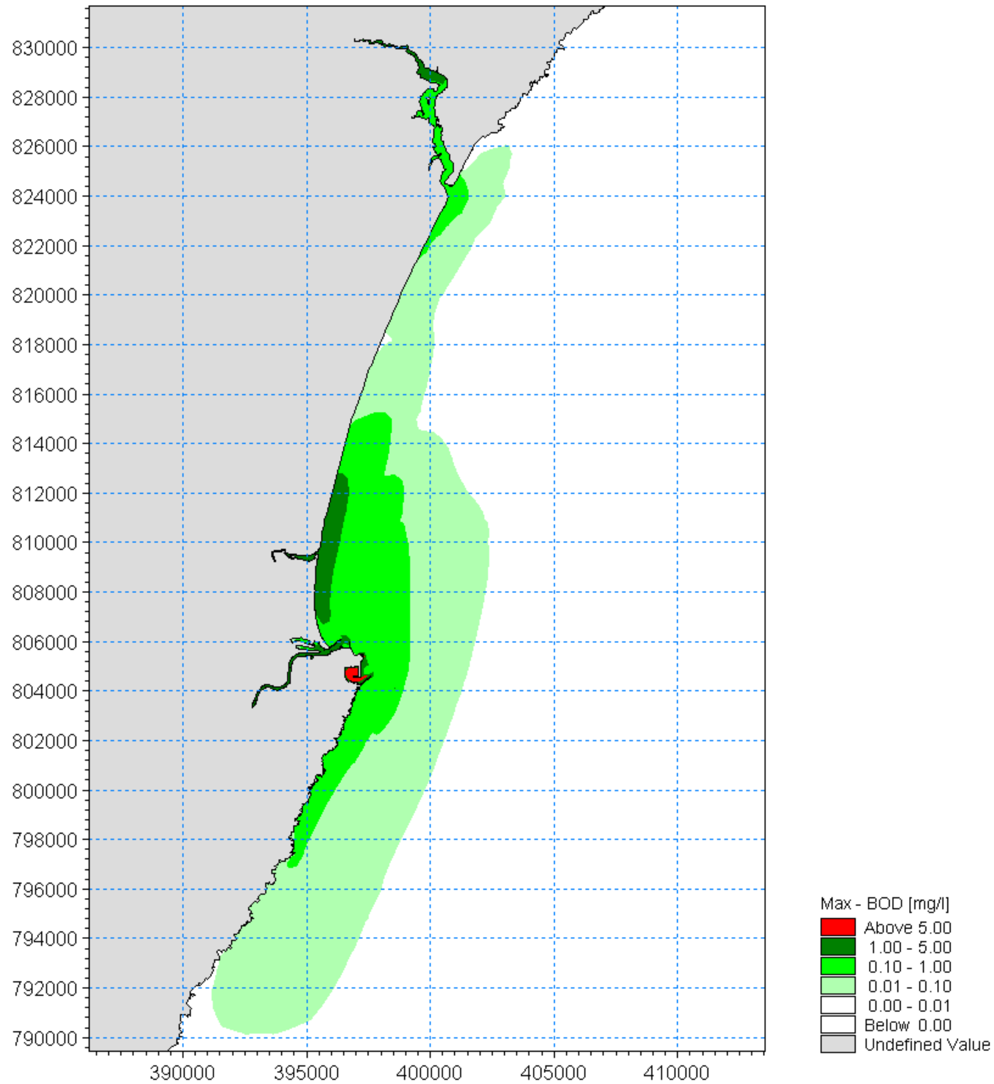


Figure C-35: Development - BOD max. modelled conc. (close-up) - (90%'ile = 5 mg/l)

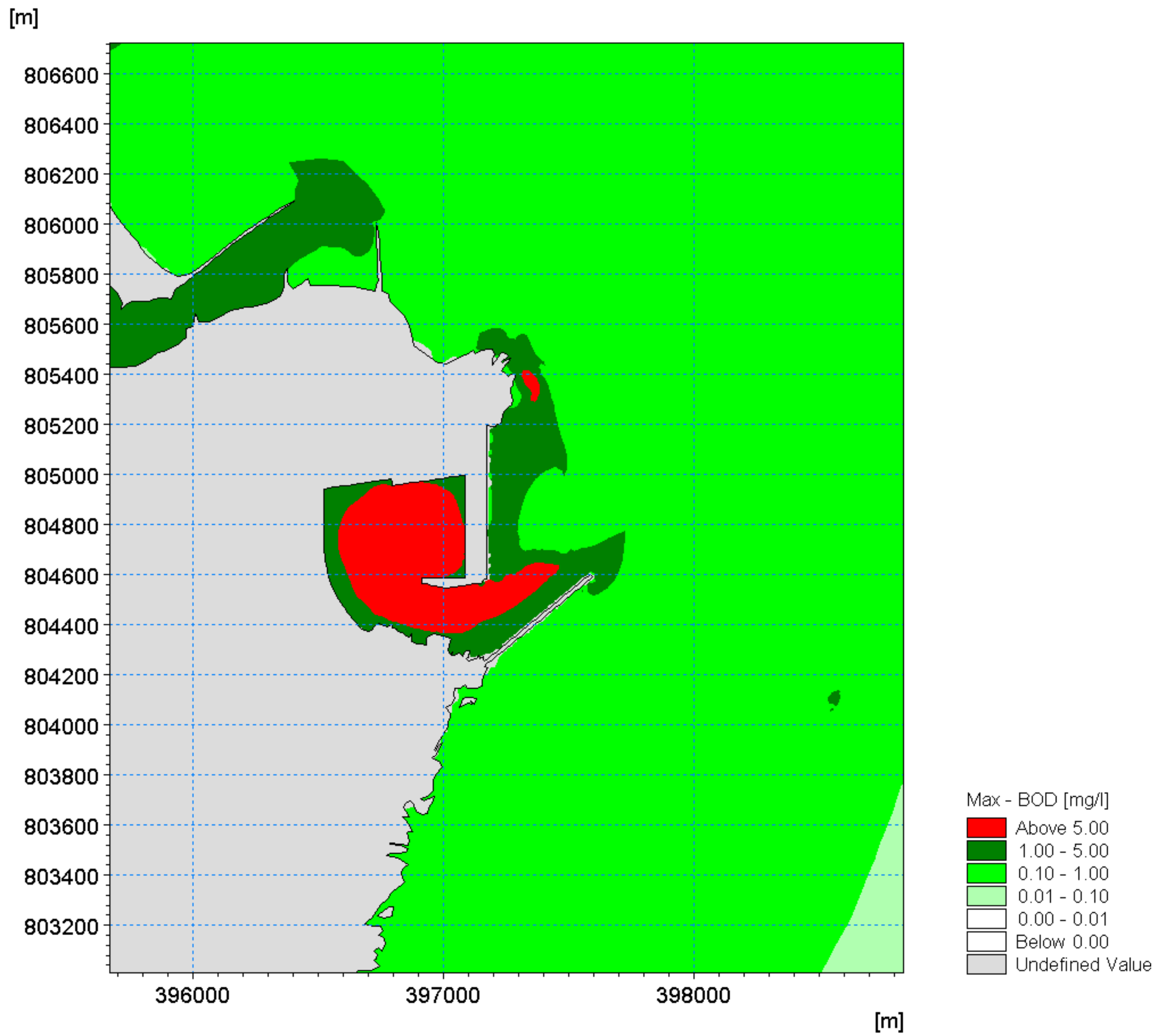


Figure C-36: Development - Cadmium max. modelled conc. (overview) - (AA = 0.2 µg/l)

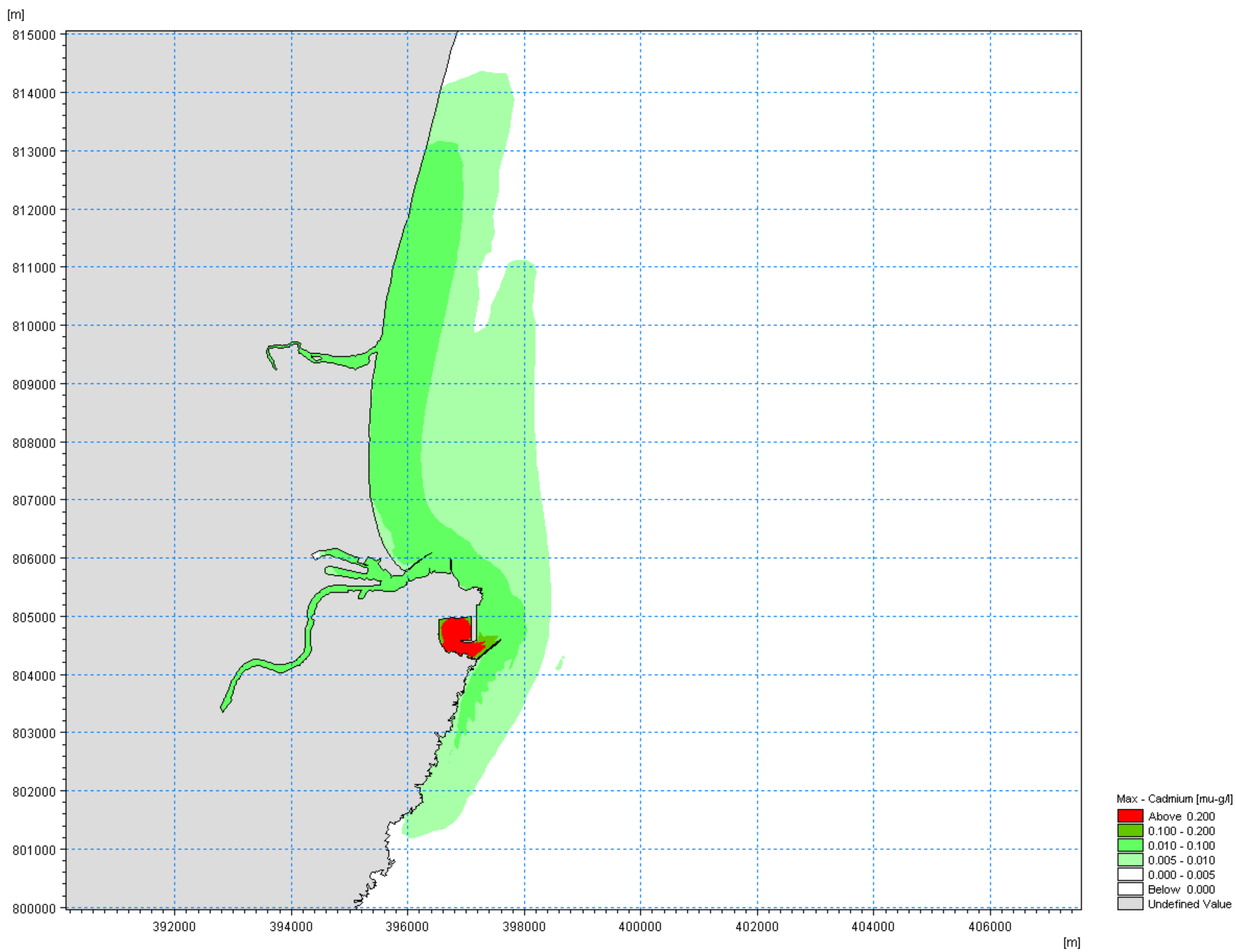


Figure C-37: Development - Cadmium max. modelled conc. (close-up) - (AA = 0.2 µg/l)

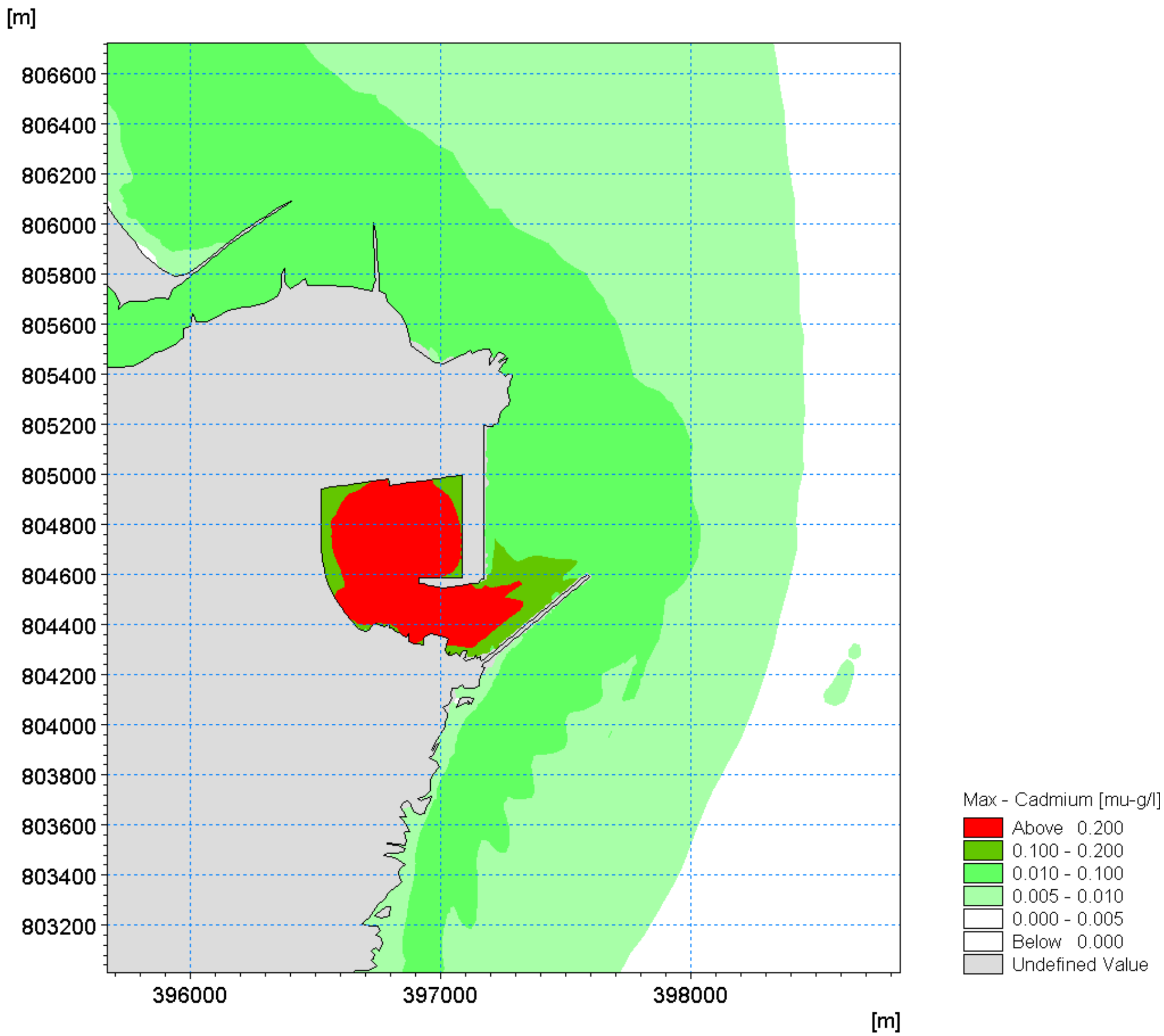


Figure C-38: Development - C10-13 Chloroalkanes max. modelled conc. (overview) - (AA = 0.4 µg/l, MAC = 1.4 µg/l)

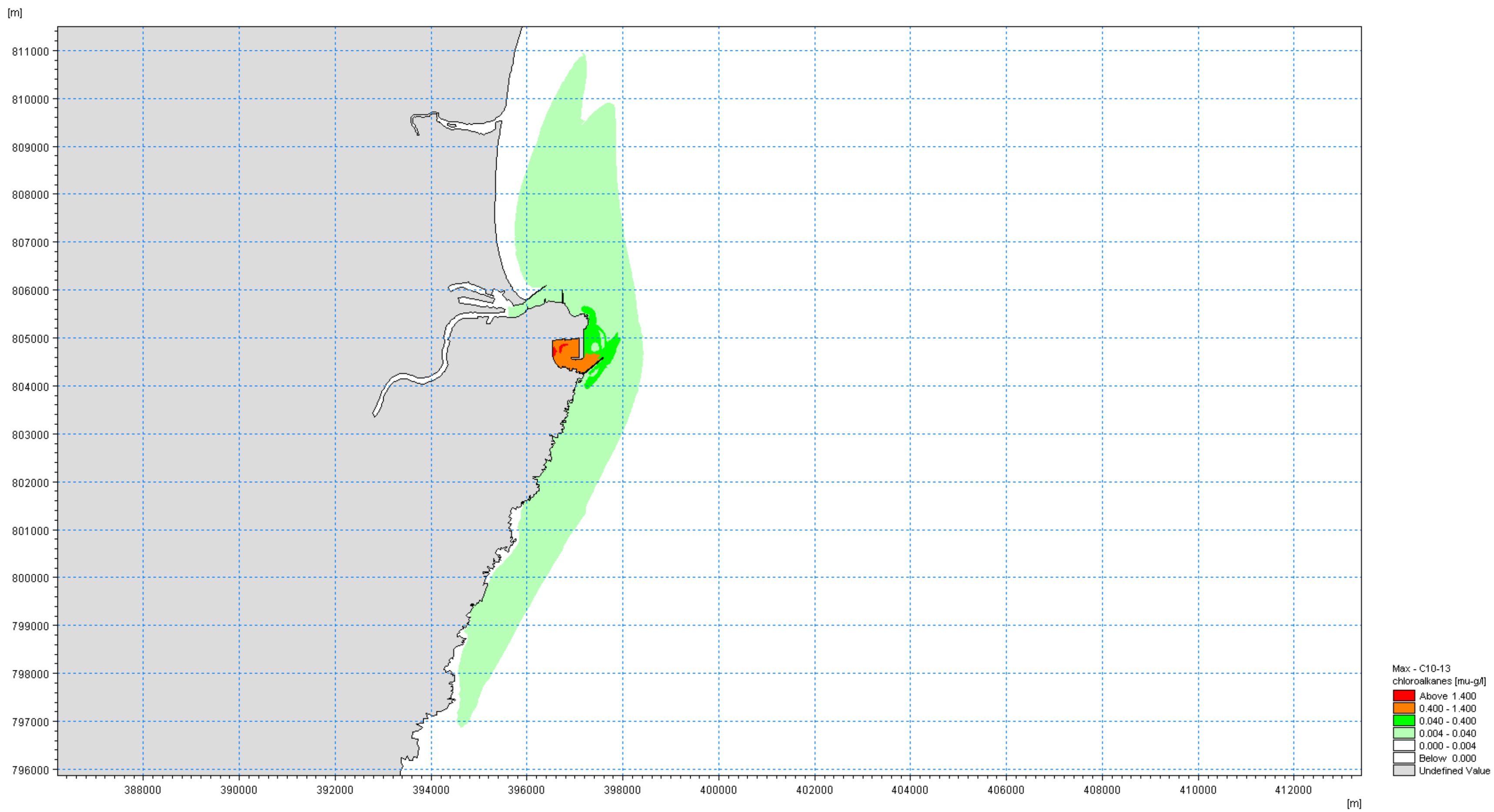


Figure C-39: Development - C10-13 Chloroalkanes max. modelled conc. (close-up) - (AA = 0.4 µg/l, MAC = 1.4 µg/l)

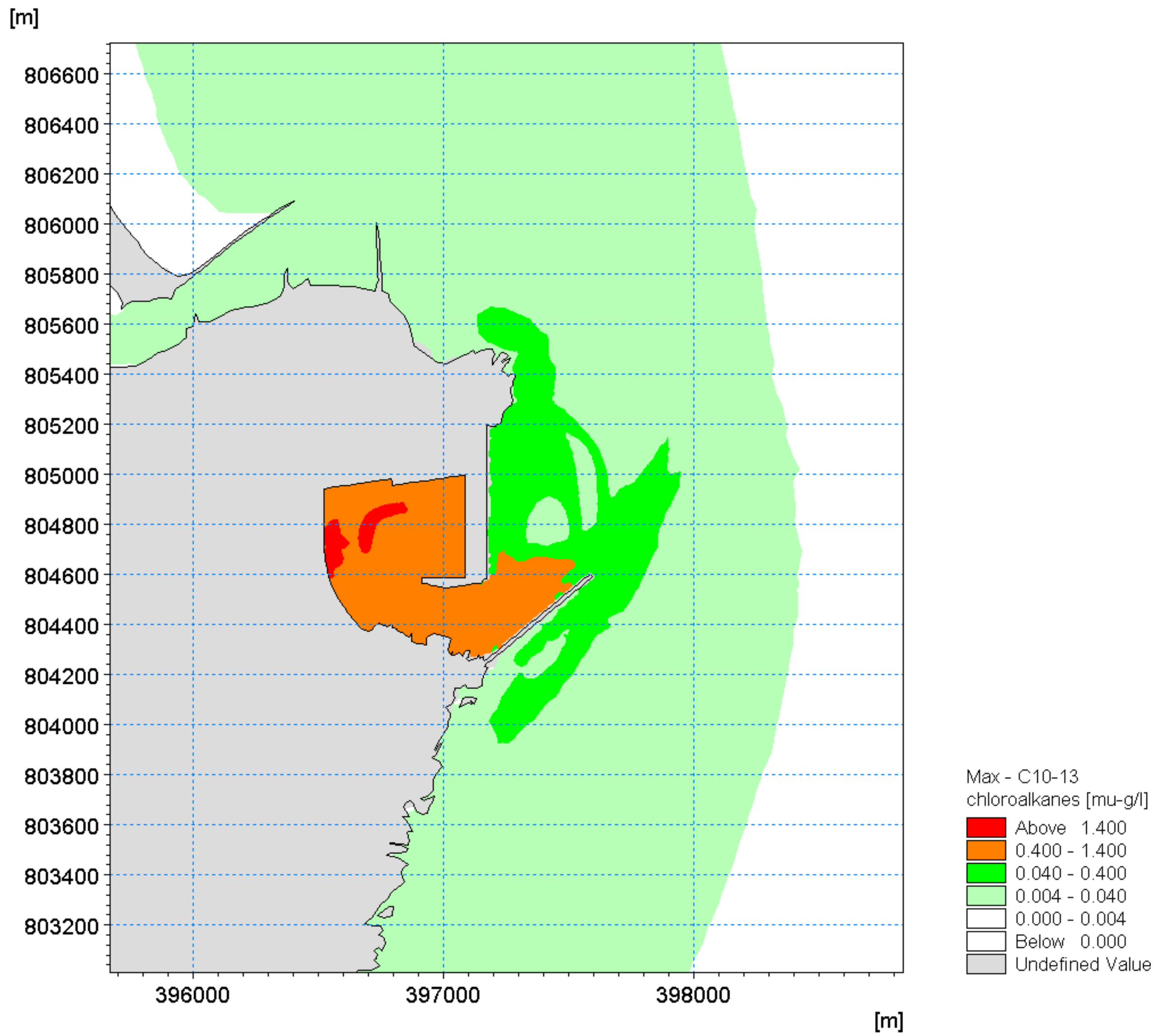


Figure C-40: Development - Chromium max. modelled conc. (overview and close-up) - (AA = 0.6 µg/l, 95%'ile = 32 µg/l)

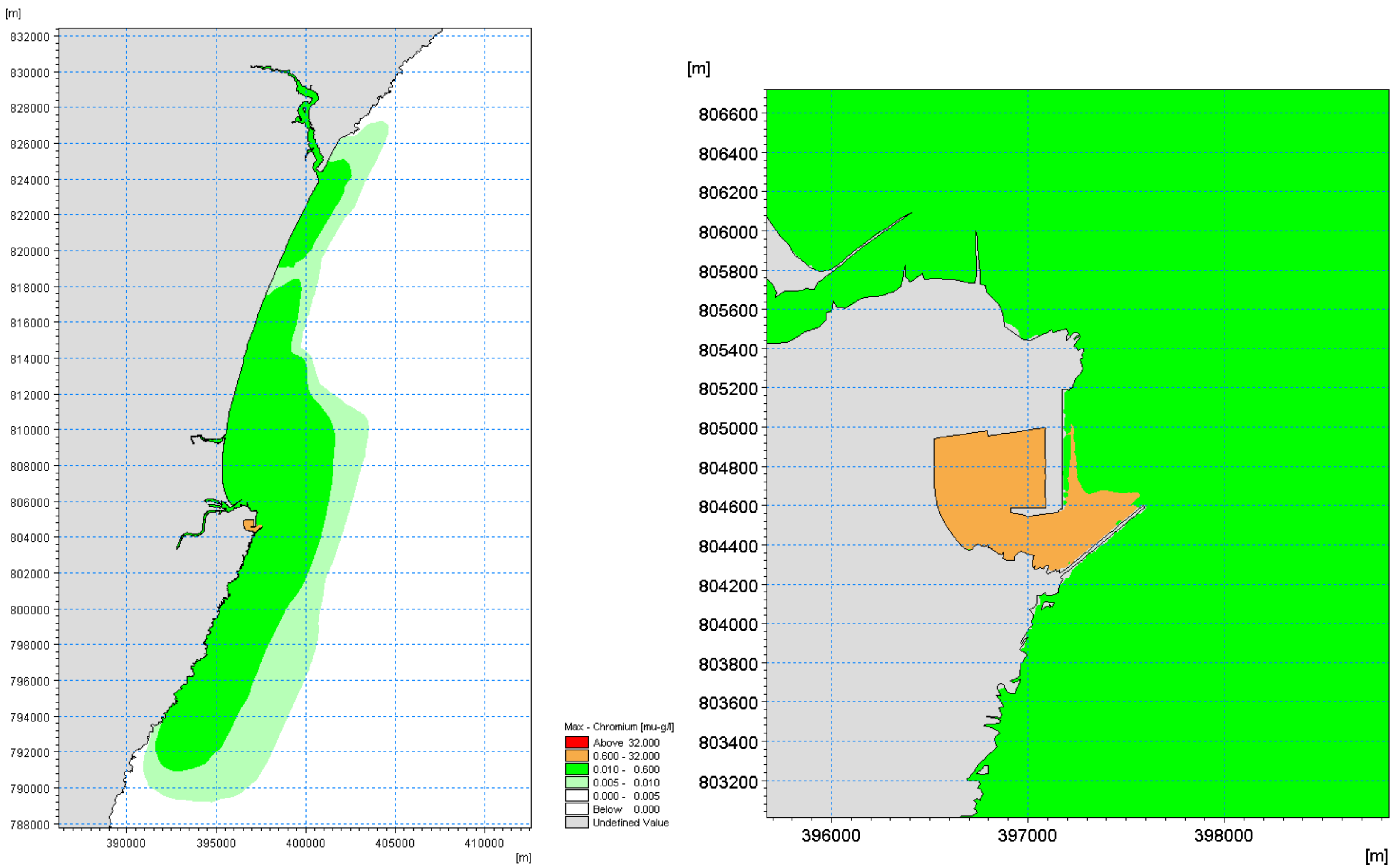


Figure C-41: Development - Copper max. modelled conc. (overview) - (AA = 5.09 µg/l)

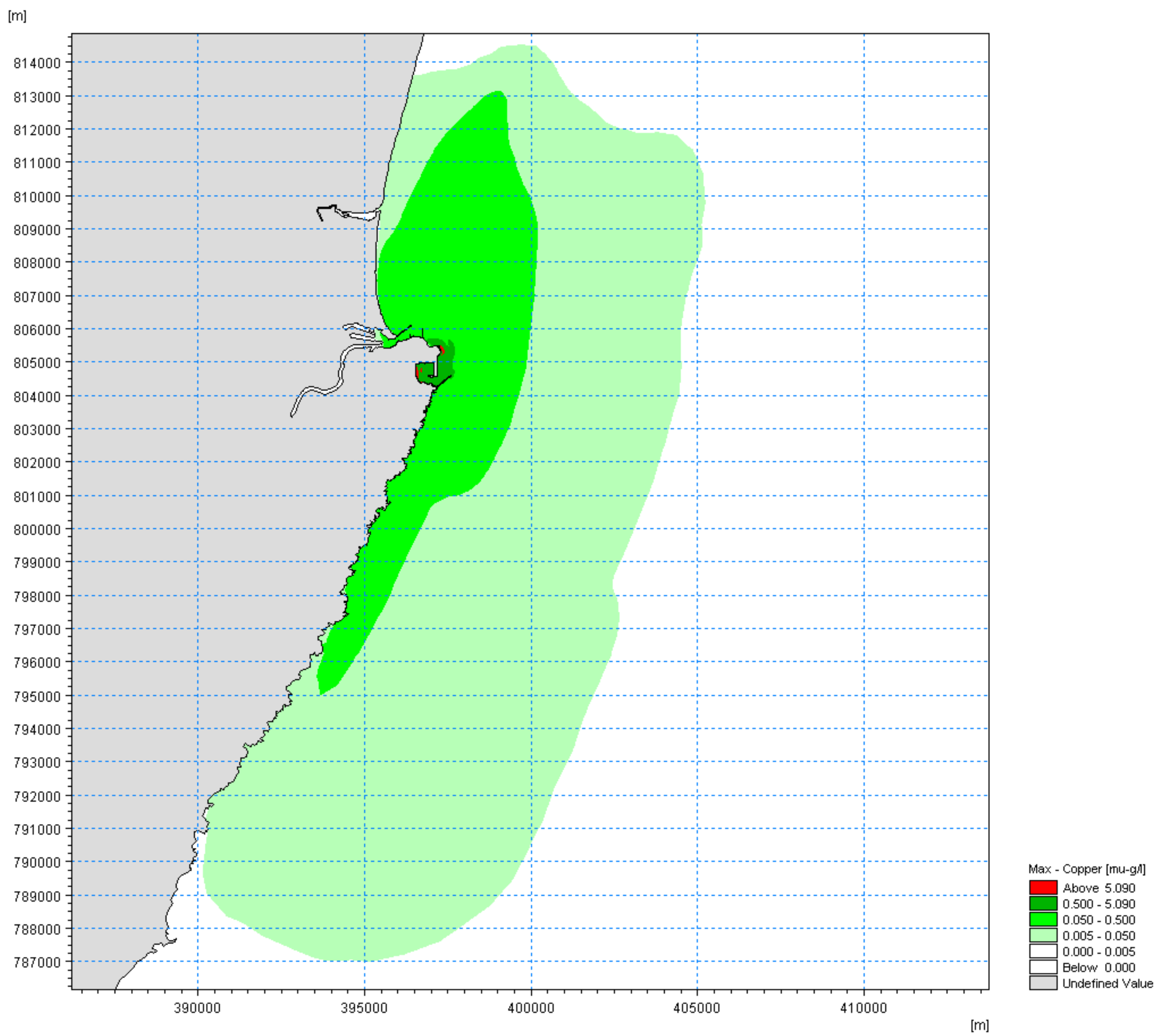


Figure C-42: Development - Copper max. modelled conc. (close-up) - (AA = 5.09 µg/l)

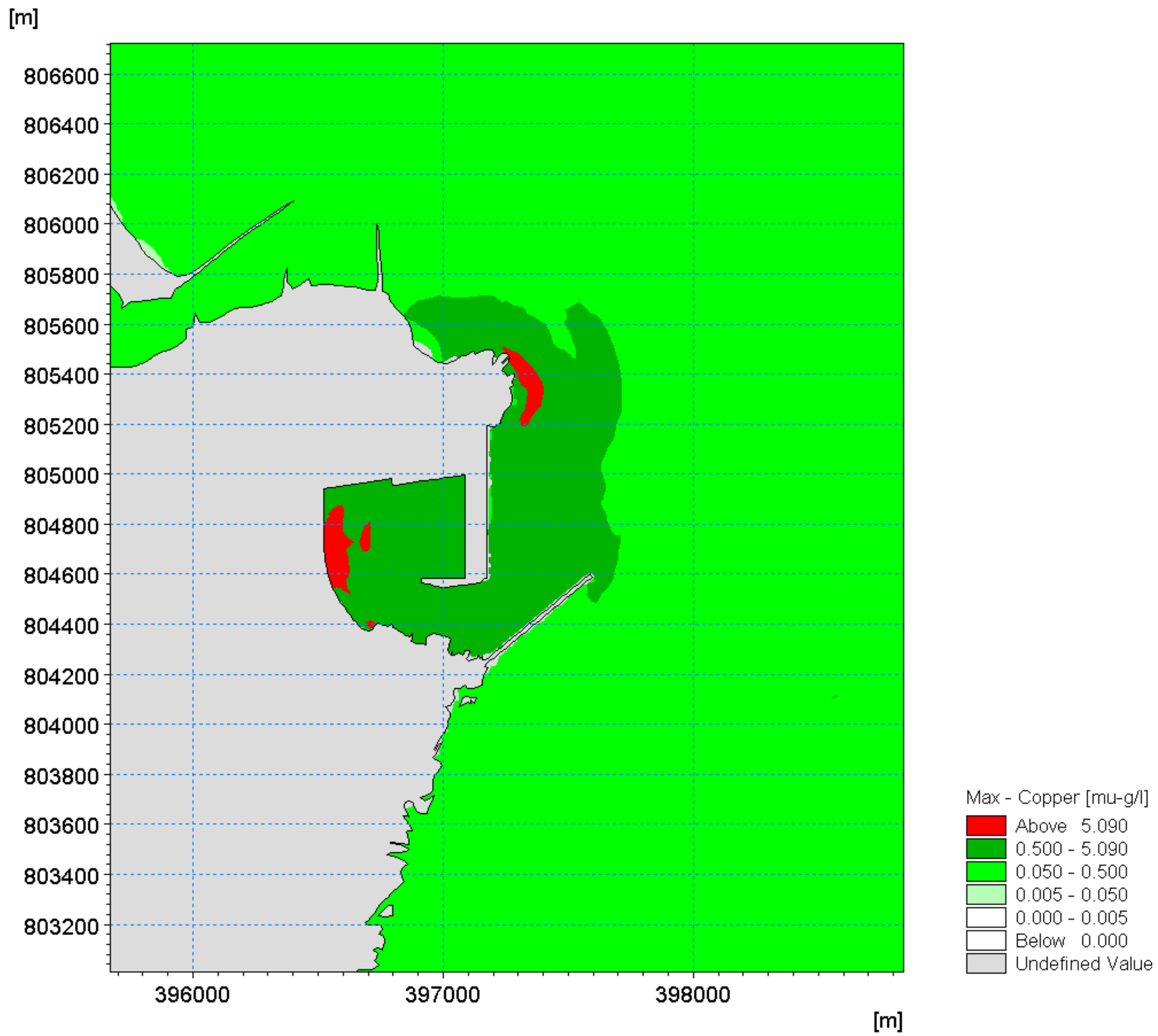


Figure C-43: Development - DIN max. modelled conc. (overview and close-up) - (AA = 0.42 mg/l)

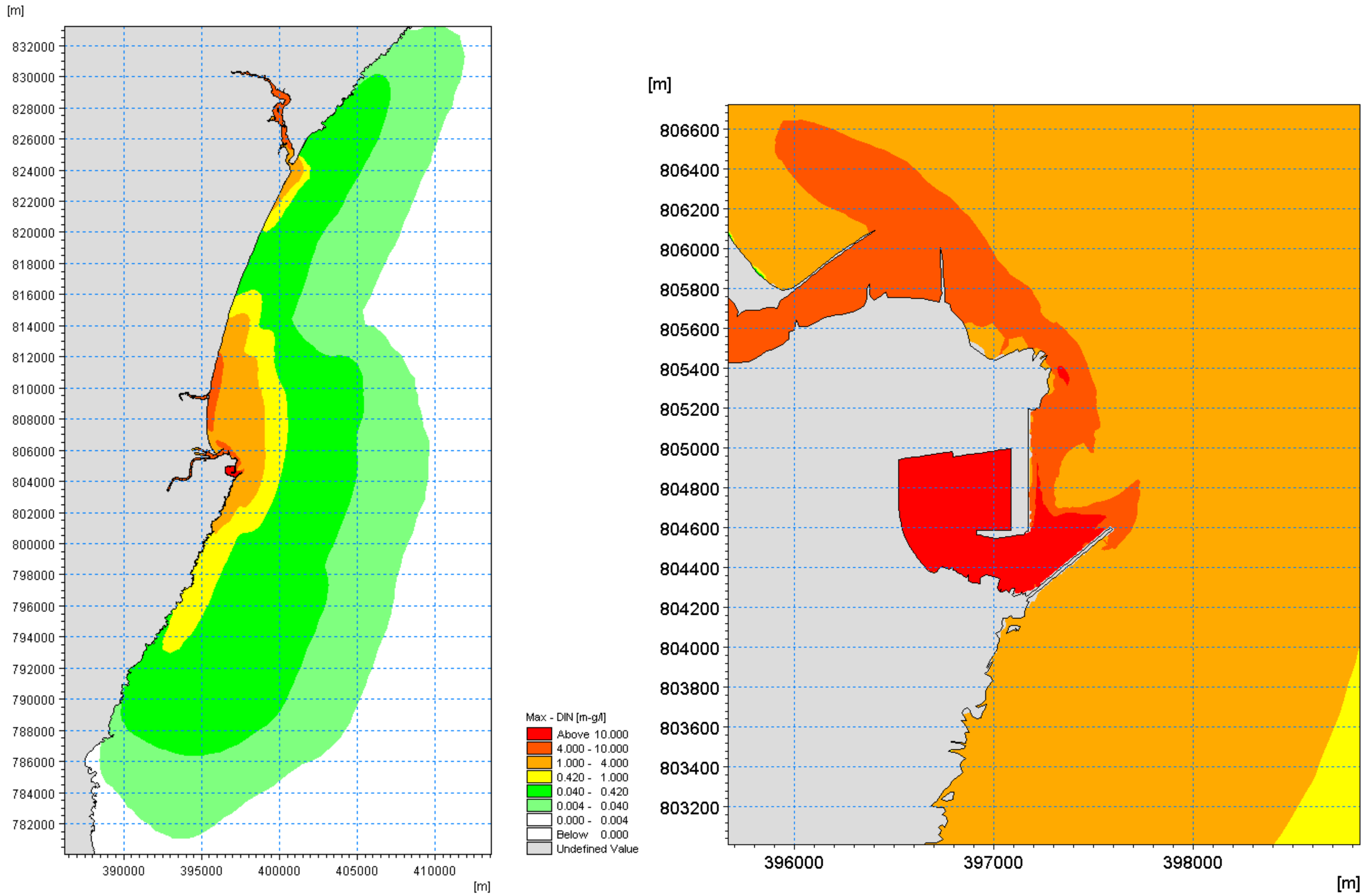


Figure C-44: Development - DO minimum modelled conc. (overview and close-up) - (95%'ile = 4 mg/l)

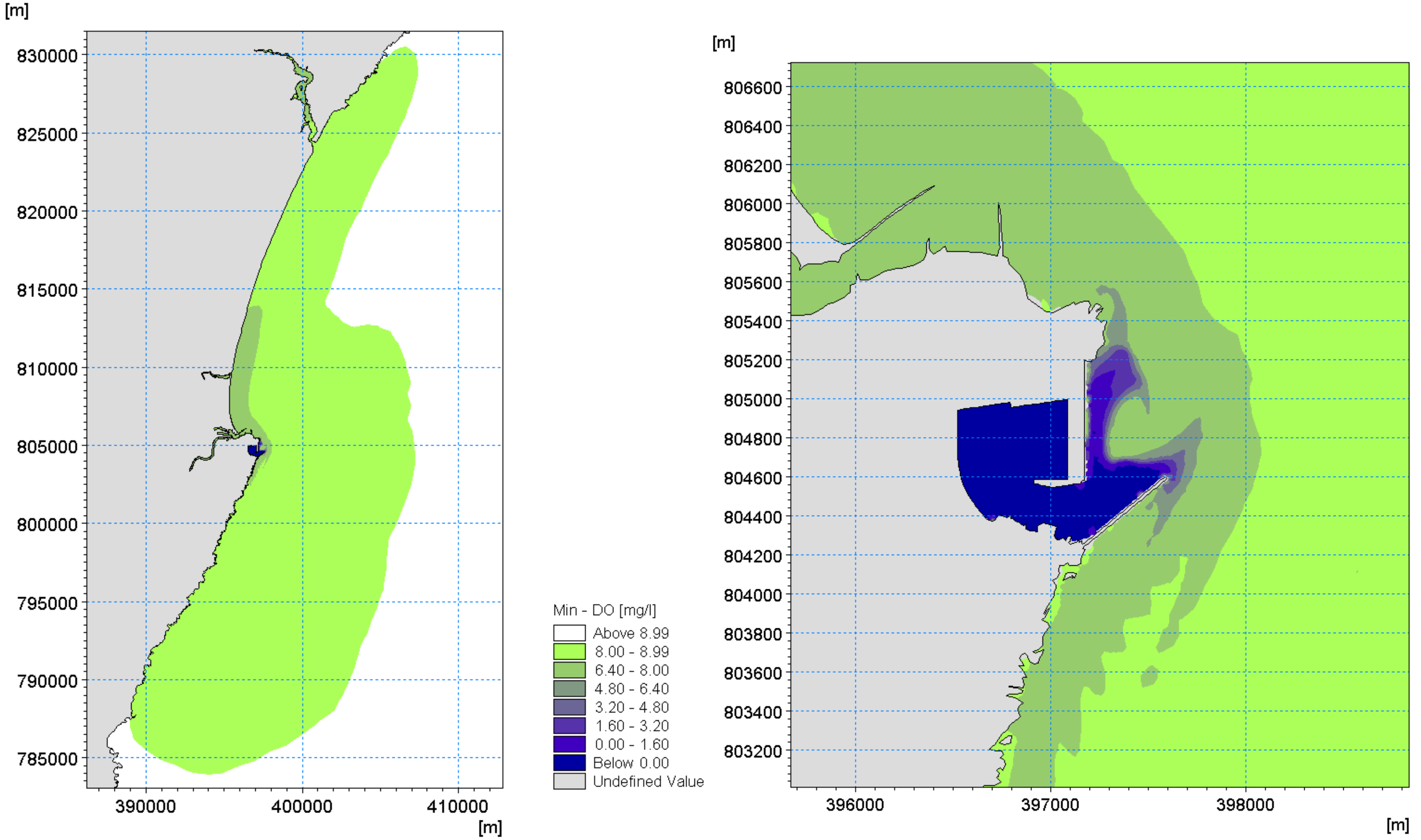


Figure C-45: Development - EC max. modelled conc. (overview) - (95%'ile = 250 ec/dl, 95%'ile = 500 ec/dl)

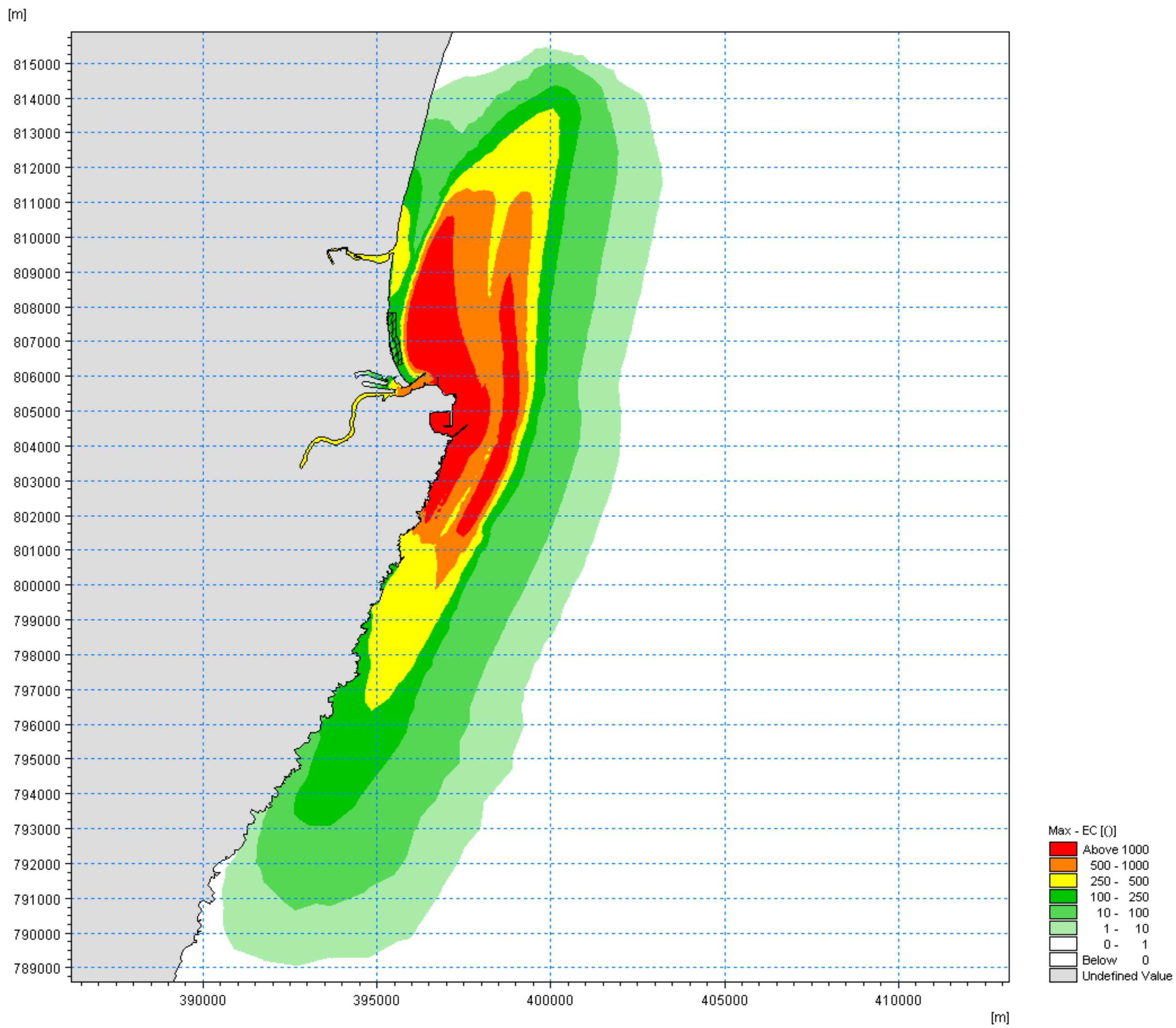


Figure C-46: Development - EC max. modelled conc. (close-up) - (95%'ile = 250 ec/dl, 95%'ile = 500 ec/dl)

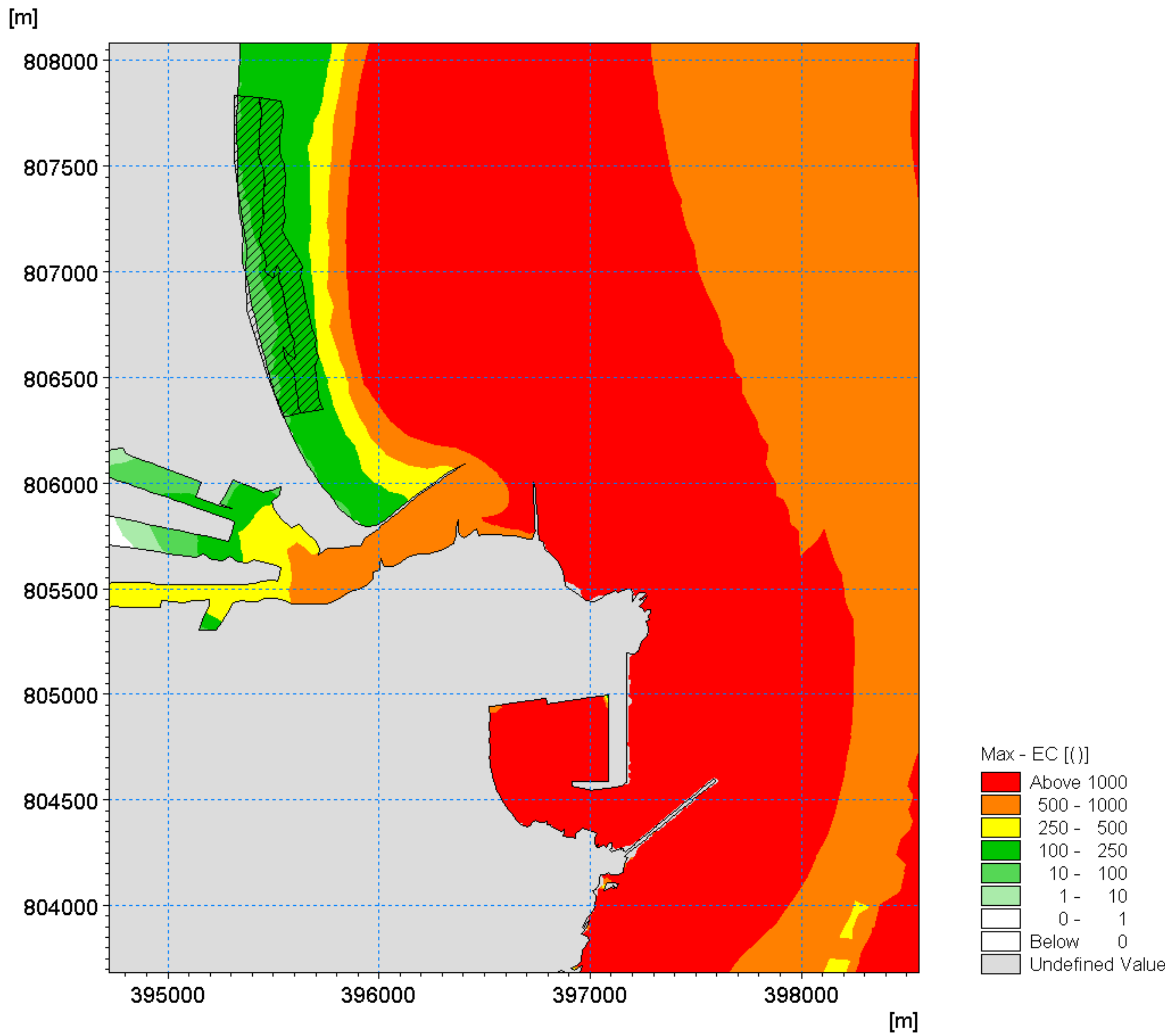


Figure C-47: Development - Hexachlorobutadiene max. modelled conc. (overview) - (AA = 0.1 µg/l, MAC = 0.6 µg/l)

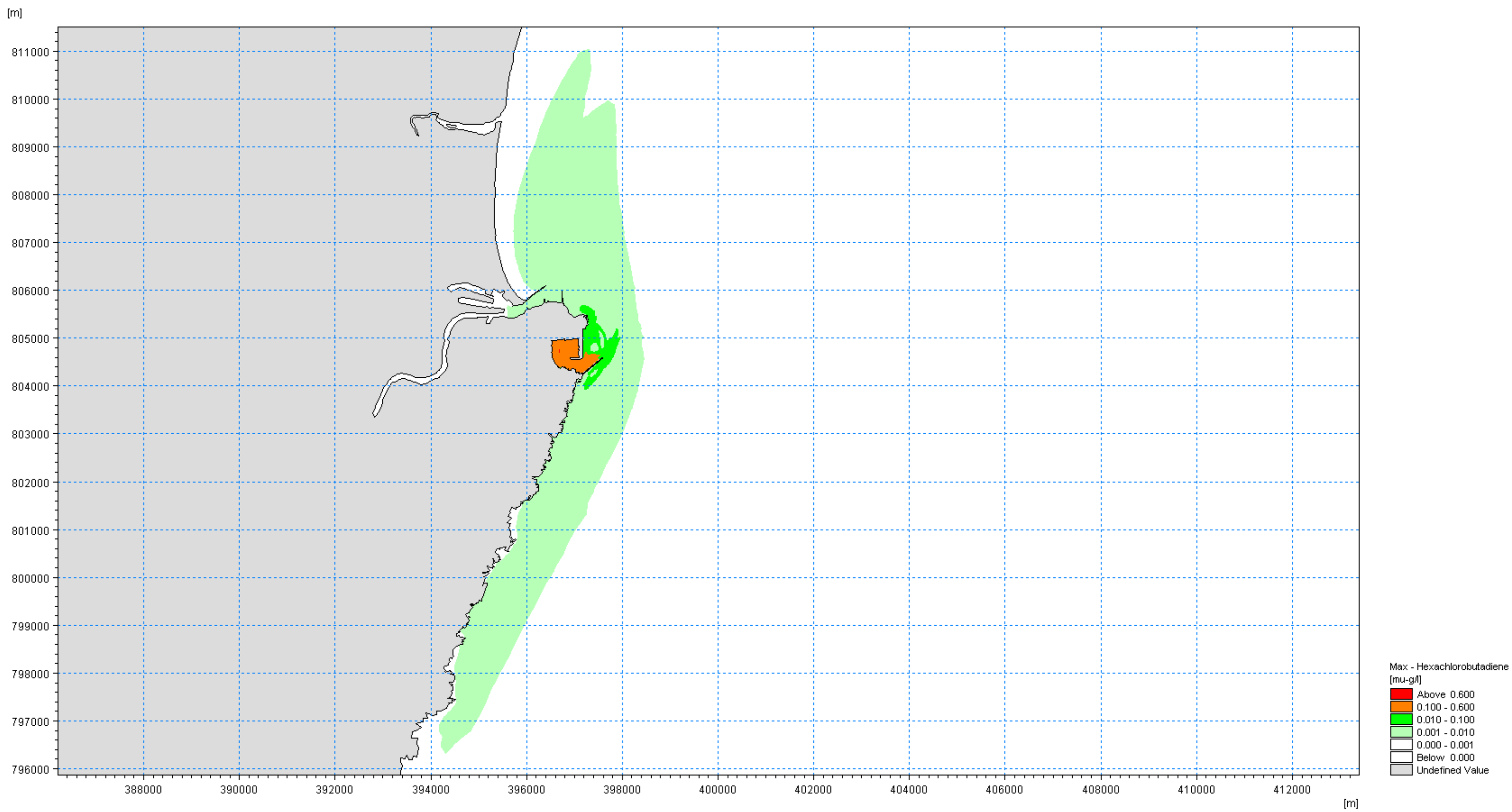


Figure C-48: Development - Hexachlorobutadiene max. modelled conc. (close-up) - (AA = 0.1 µg/l, MAC = 0.6 µg/l)

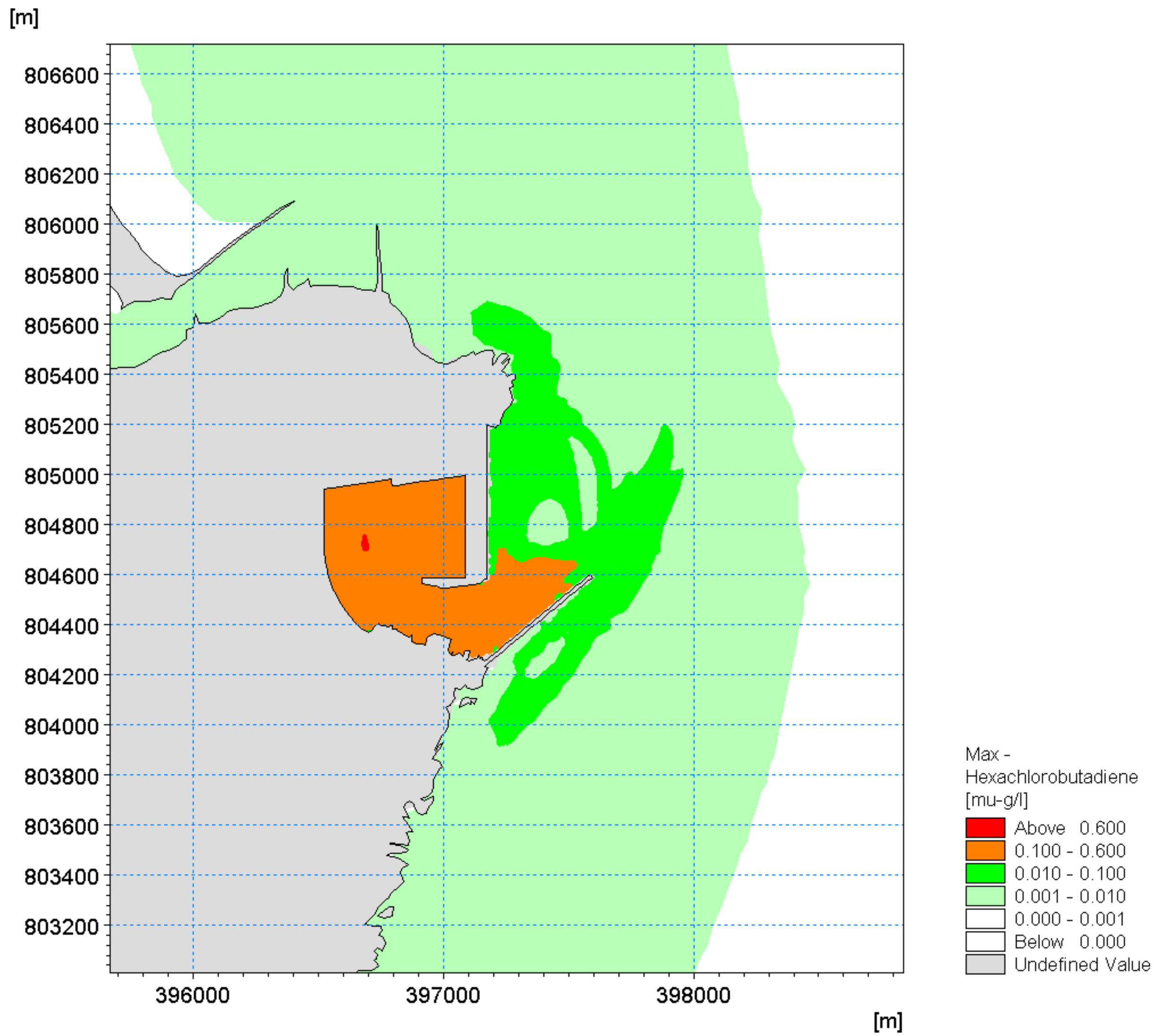


Figure C-49: Development - Lead max. modelled conc. (overview) - (AA = 7.2 µg/l)

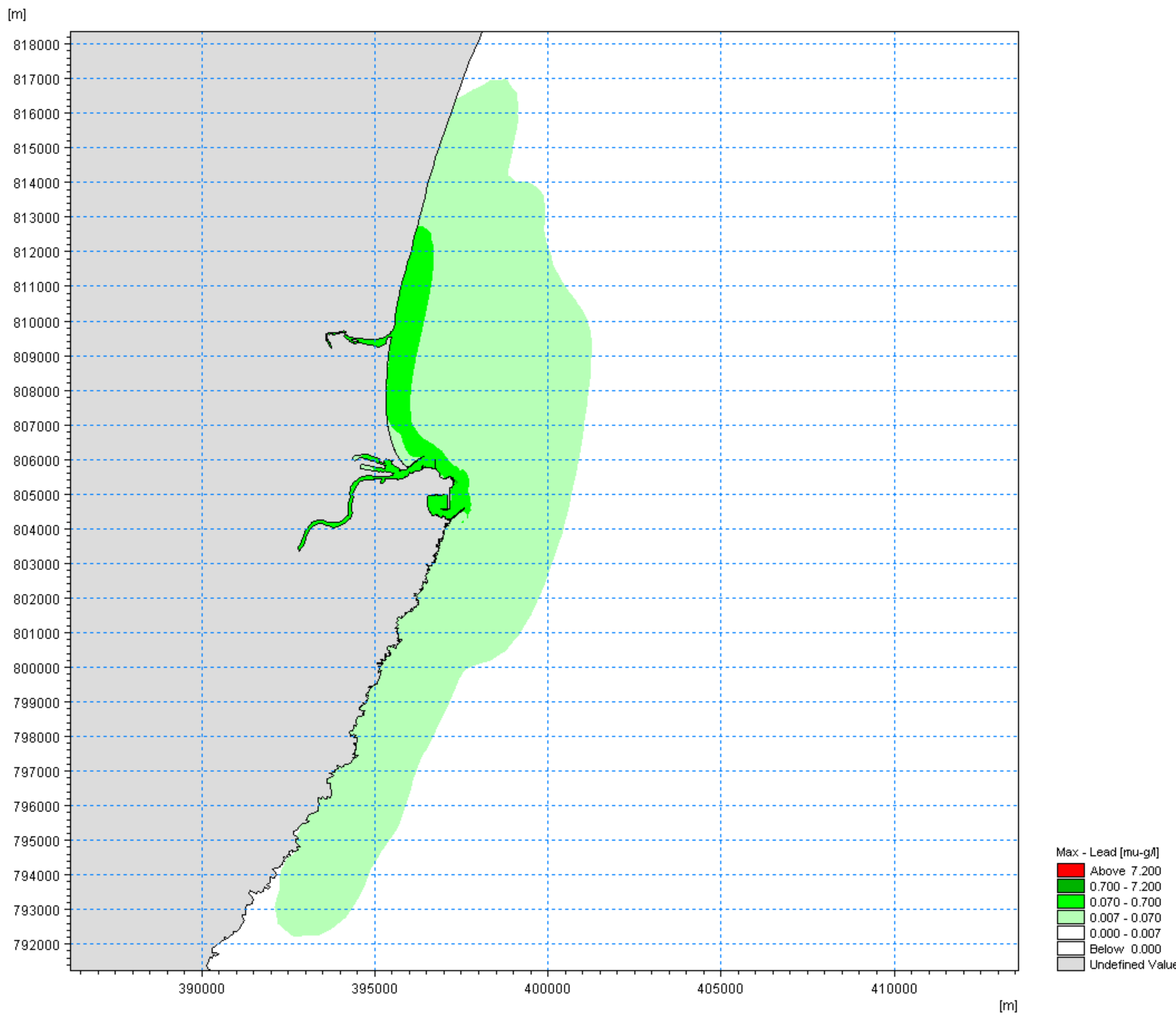


Figure C-50: Development - Lead max. modelled conc. (close-up) - (AA = 7.2 µg/l)

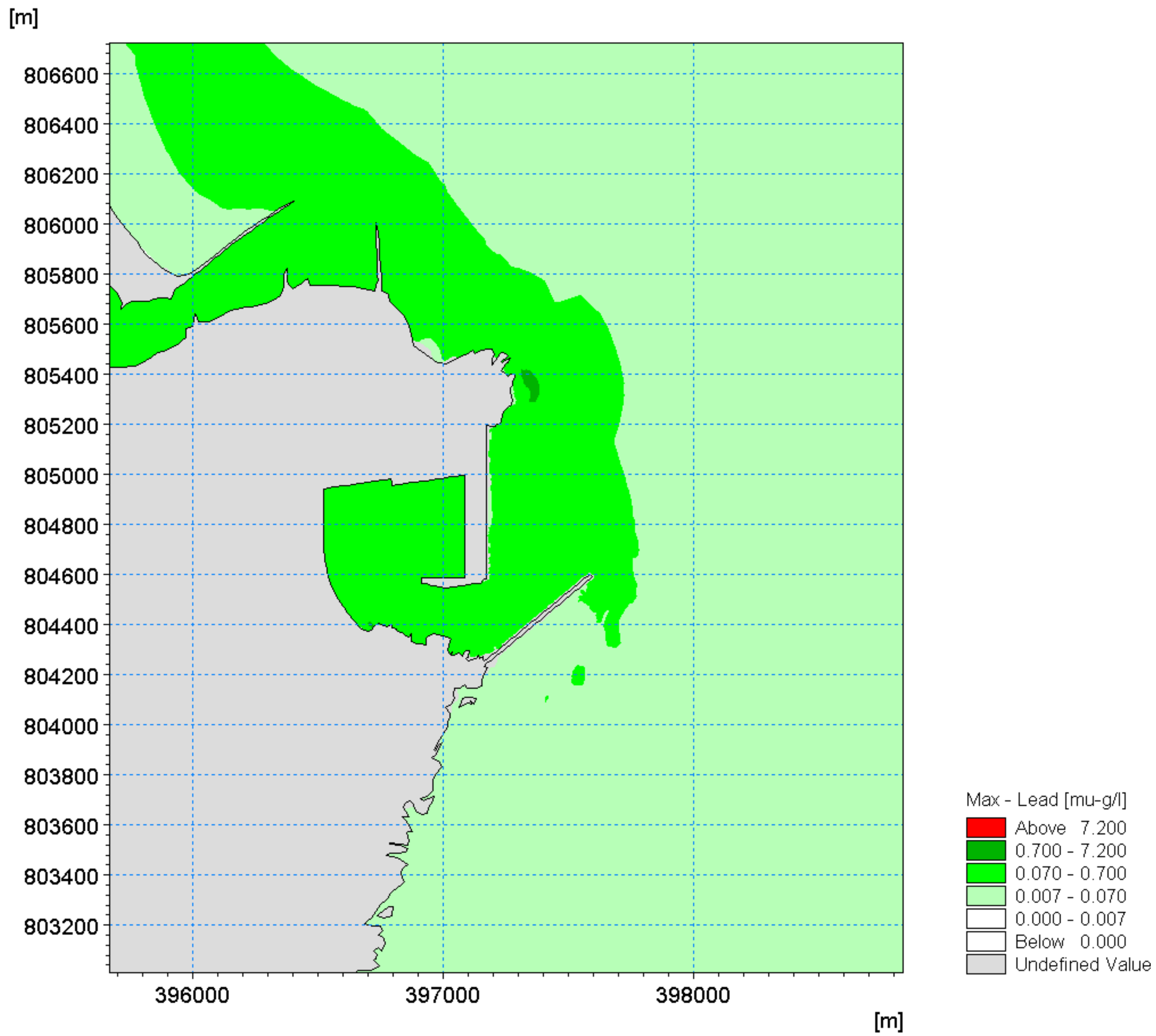


Figure C-51: Development - Mercury max. modelled conc. (overview) - (AA = 0.05 µg/l, MAC = 0.07 µg/l)

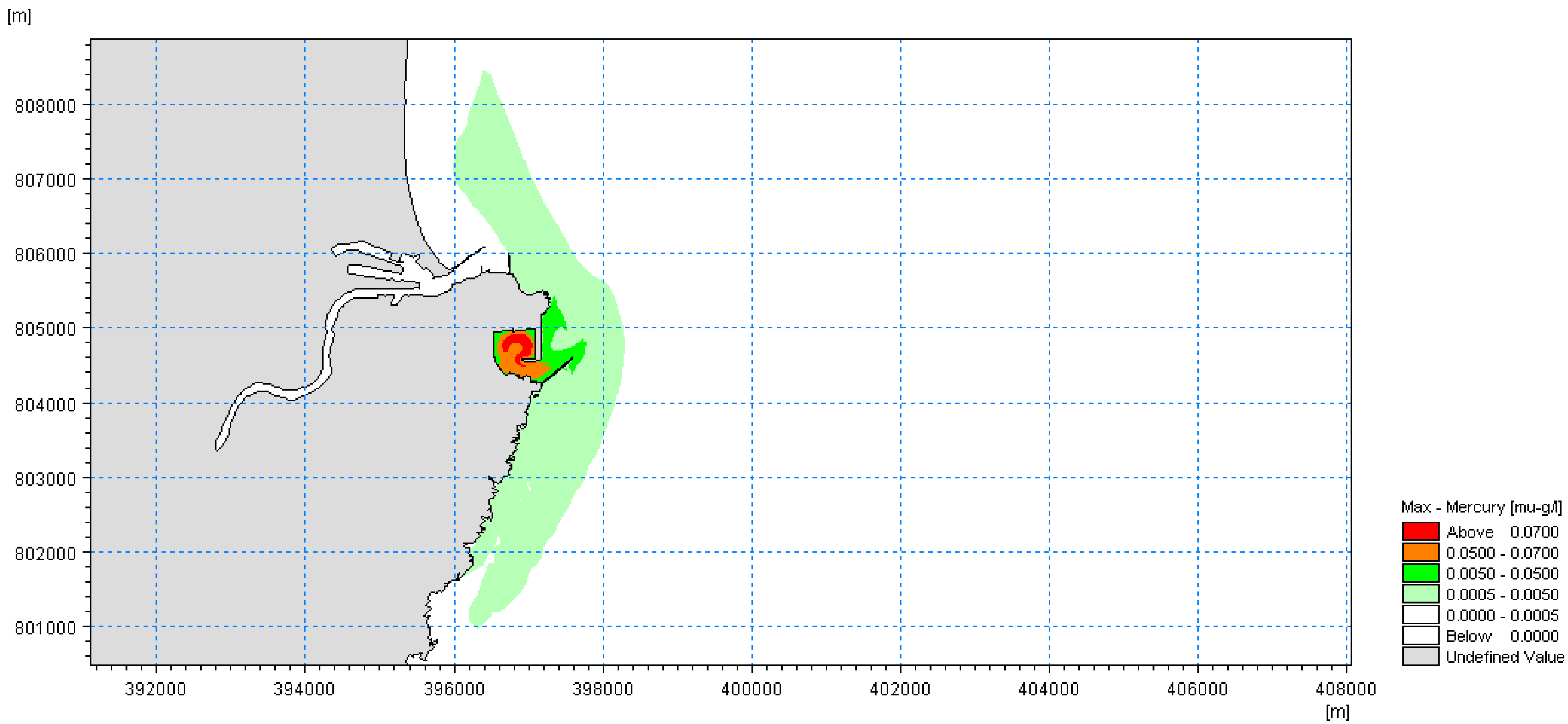


Figure C-52: Development - Mercury max. modelled conc. (close-up) - (AA = 0.05 µg/l, MAC = 0.07 µg/l)

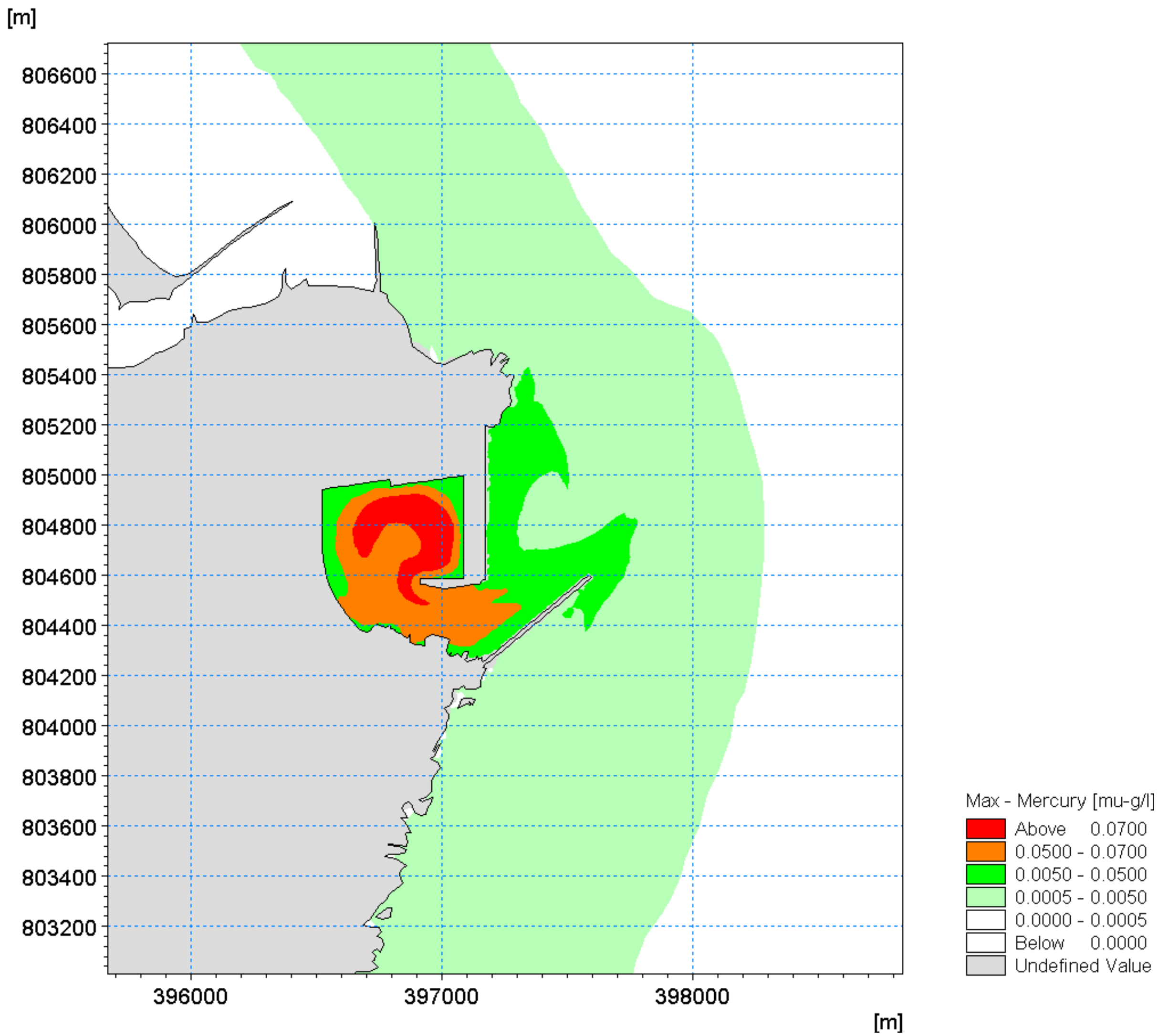


Figure C-53: Development – Total ammonia max. modelled conc. (overview) - (AA = 1.1 mg/l, MAC = 8 mg/l)

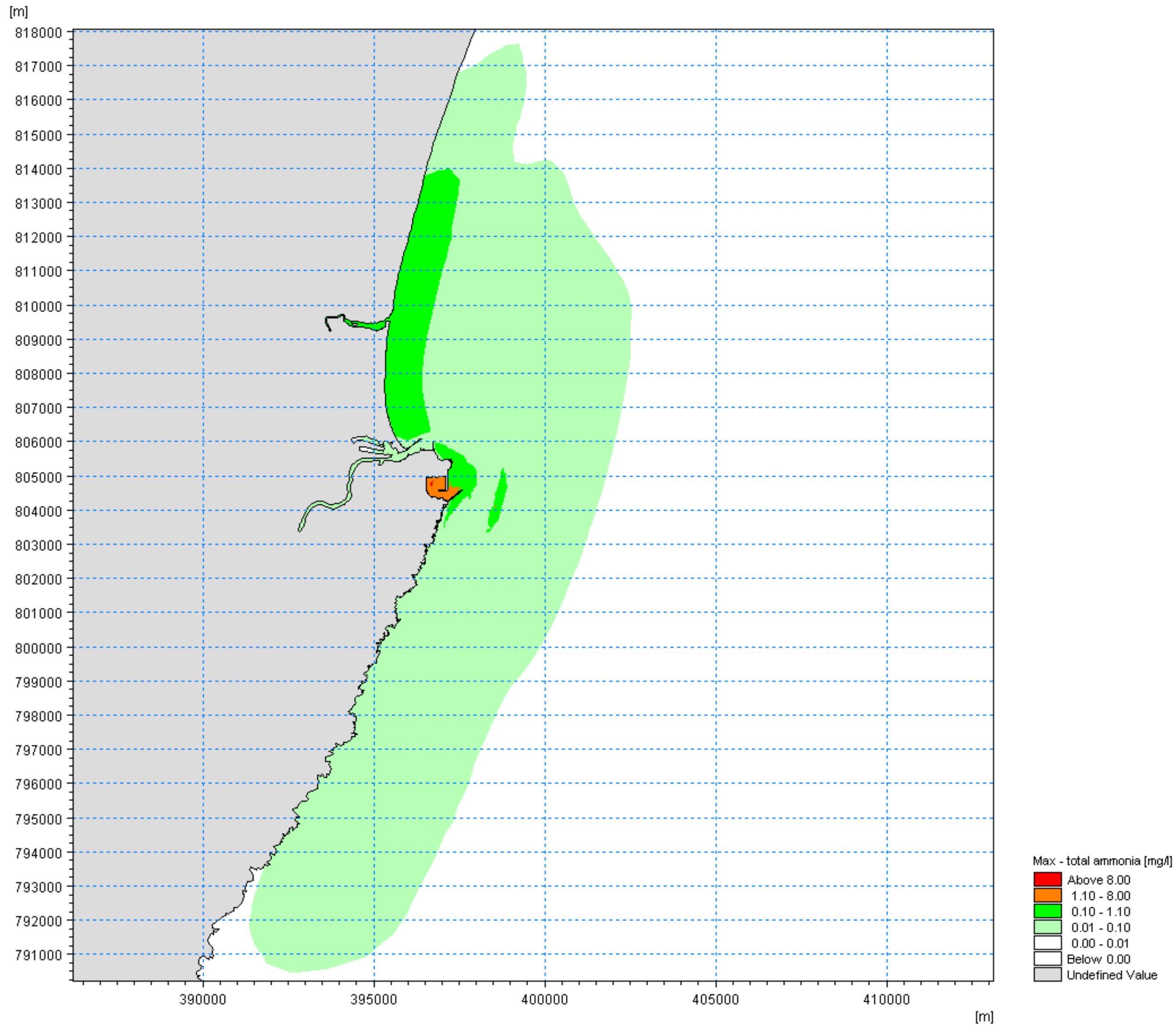


Figure C-54: Development – Total ammonia max. modelled conc. (close-up) - (AA = 1.1 mg/l, MAC = 8 mg/l)

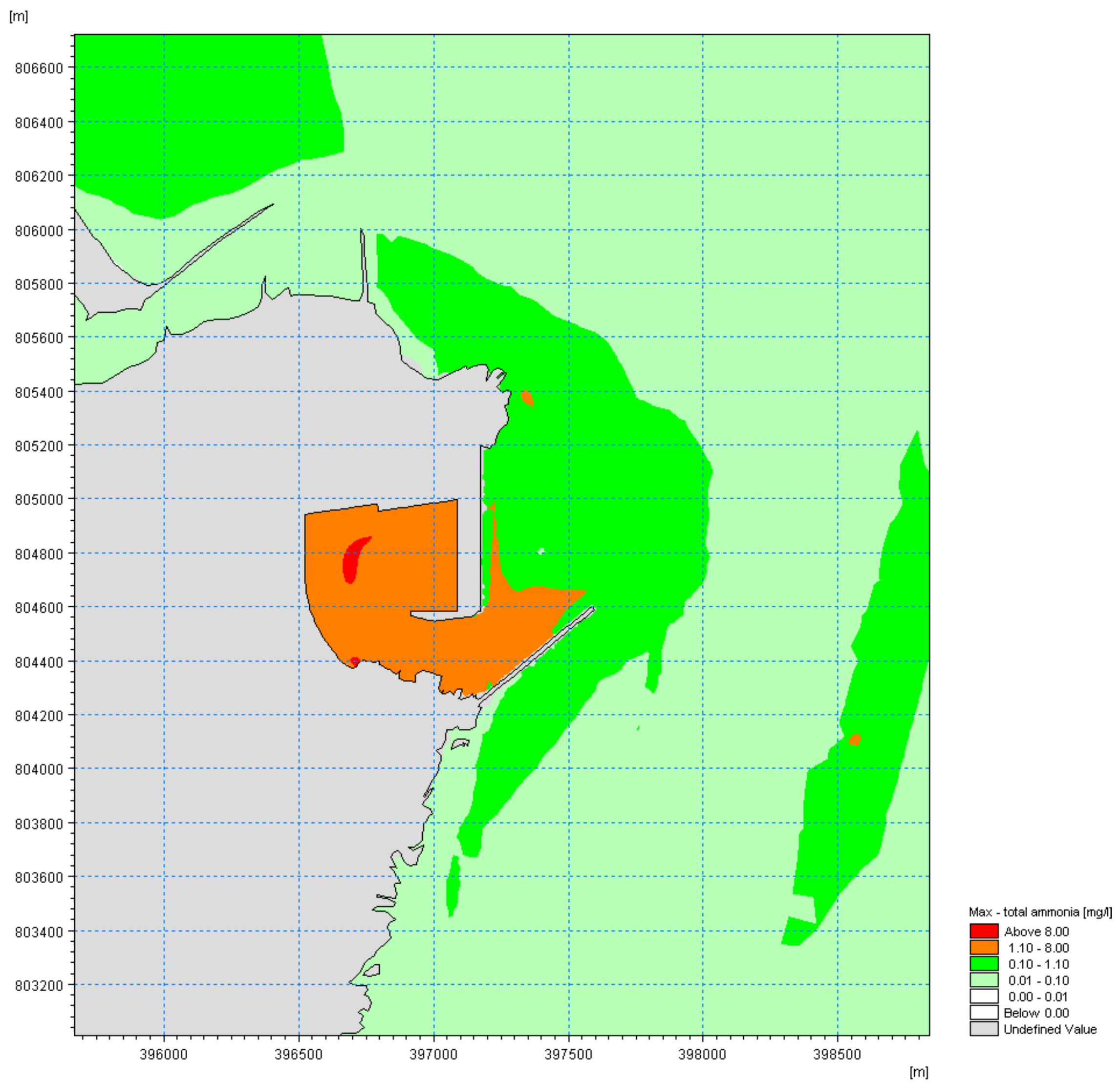


Figure C-55: Development - PAHs max. modelled conc. (overview)

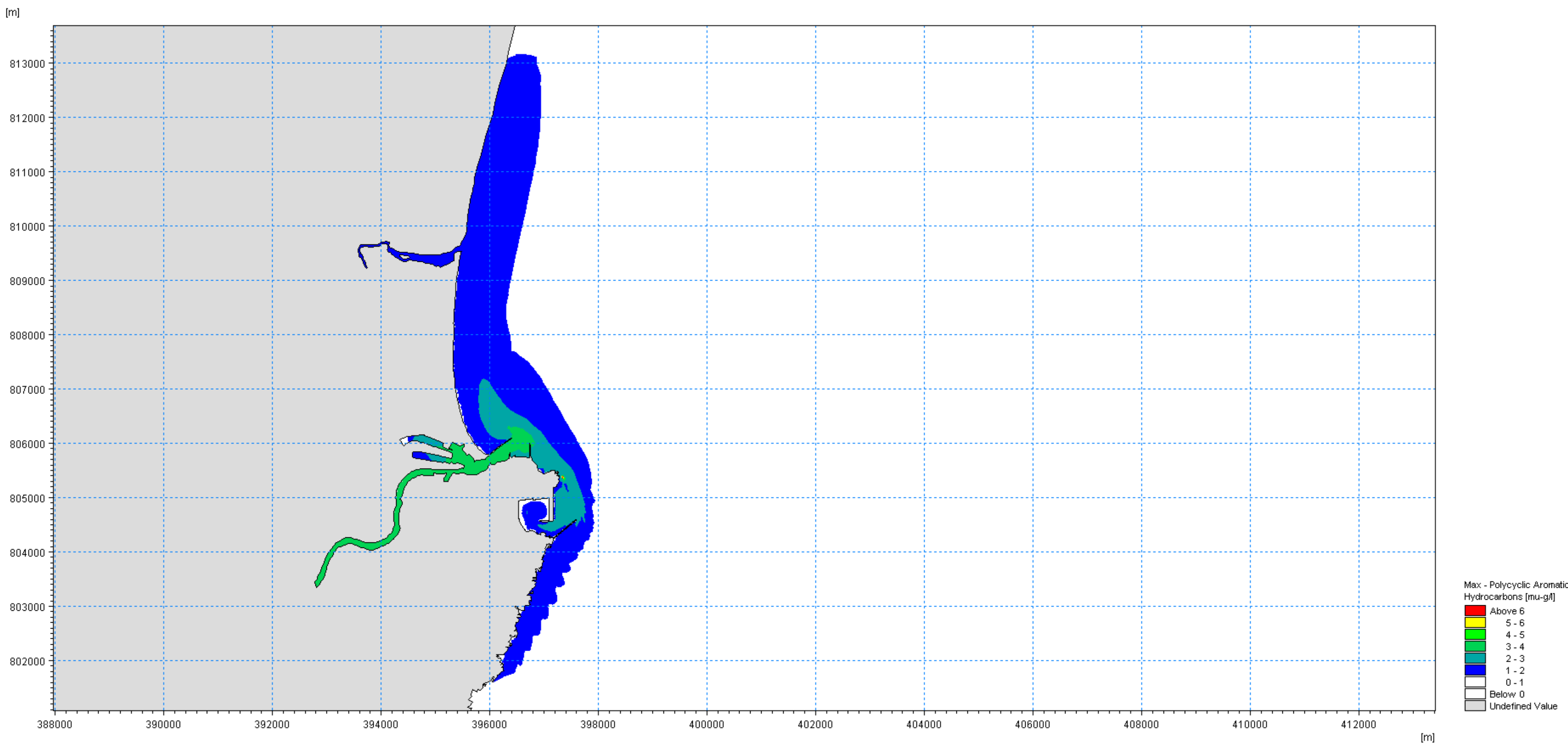


Figure C-56: Development - PAHs max. modelled conc. (close-up)

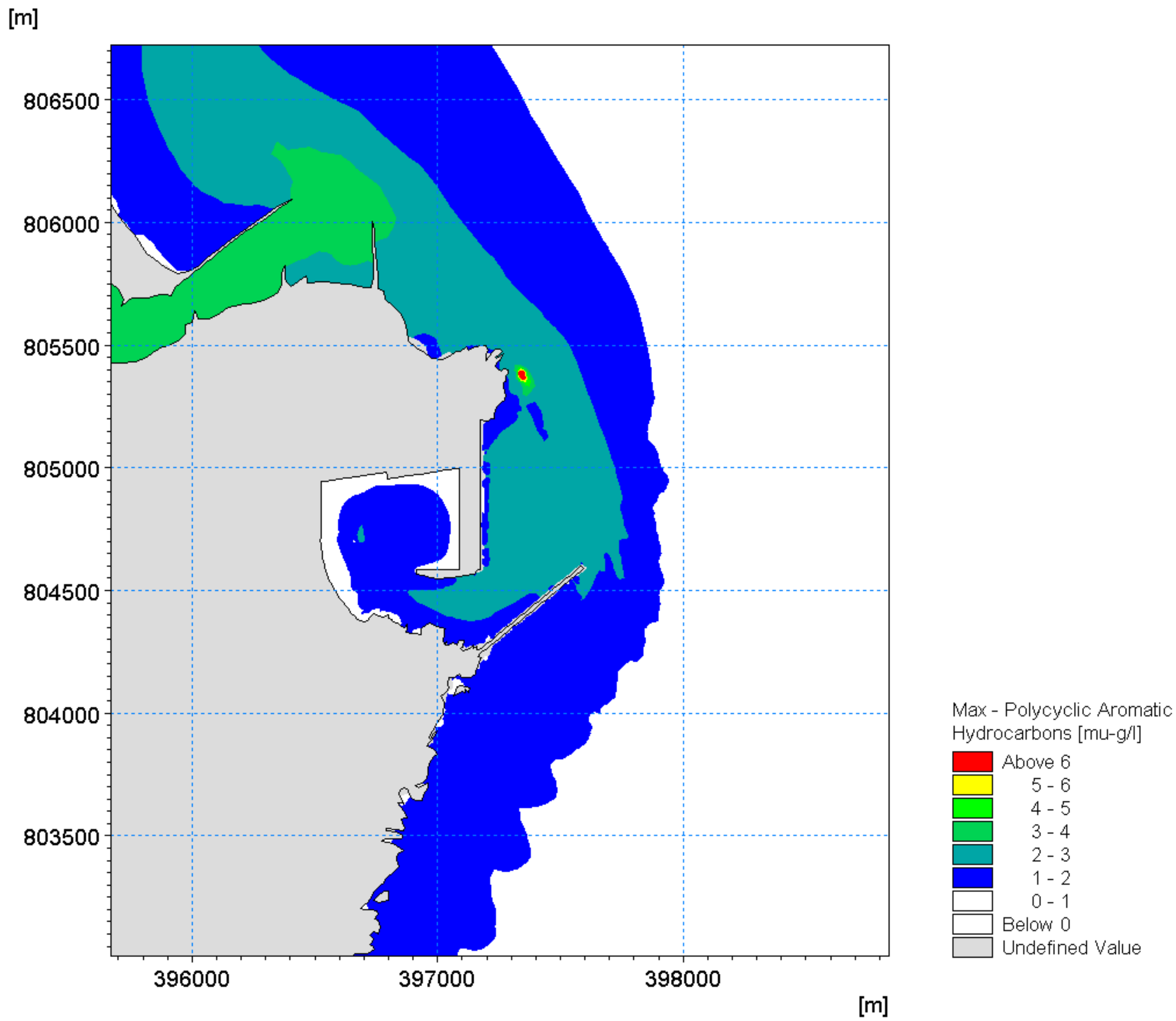


Figure C-57: Development - Phenol max. modelled conc. (overview) - (AA = 7.7 µg/l, 95%'ile = 46 µg/l)

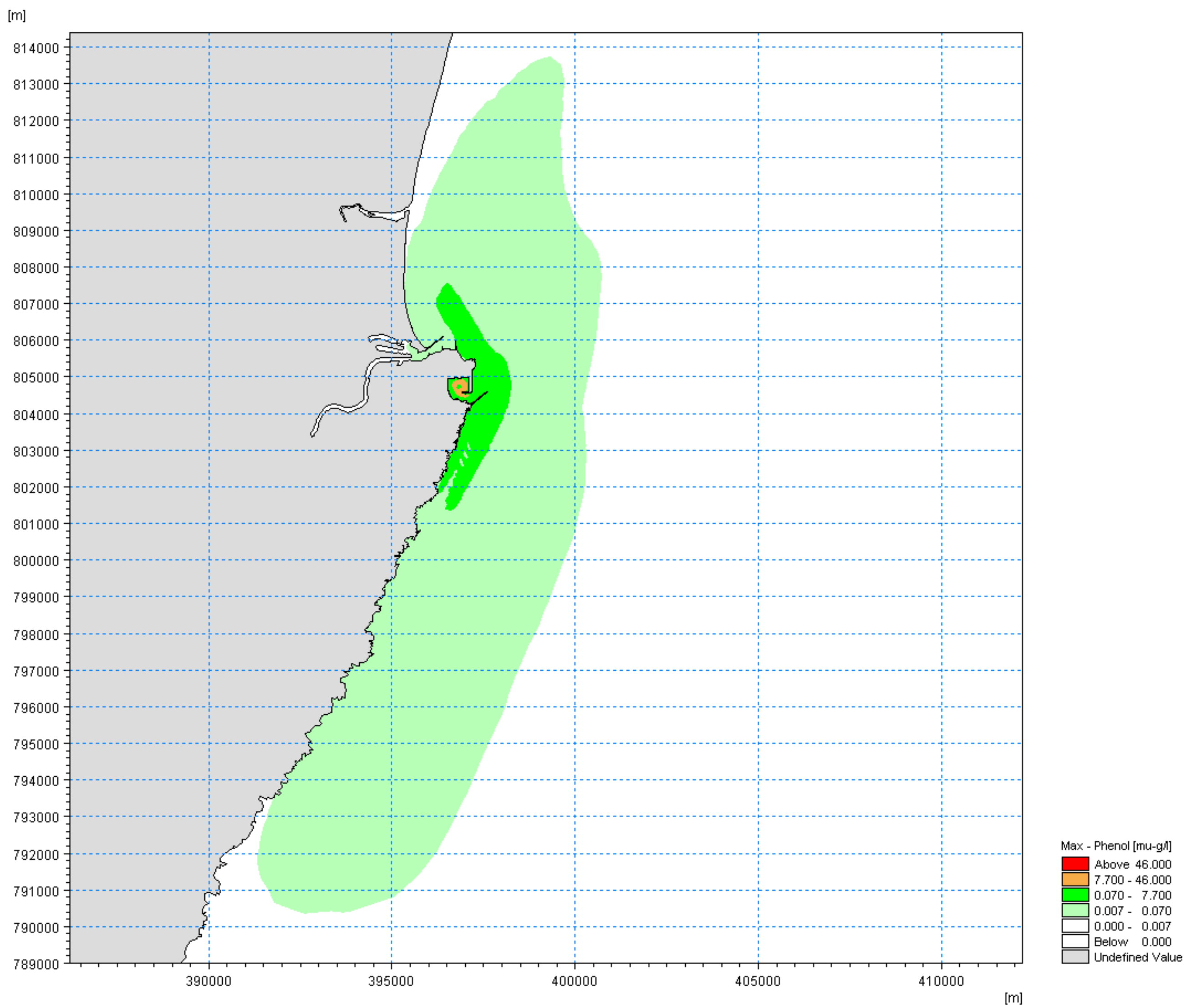


Figure C-58: Development - Phenol max. modelled conc. (close-up) - (AA = 7.7 µg/l, 95%'ile = 46 µg/l)

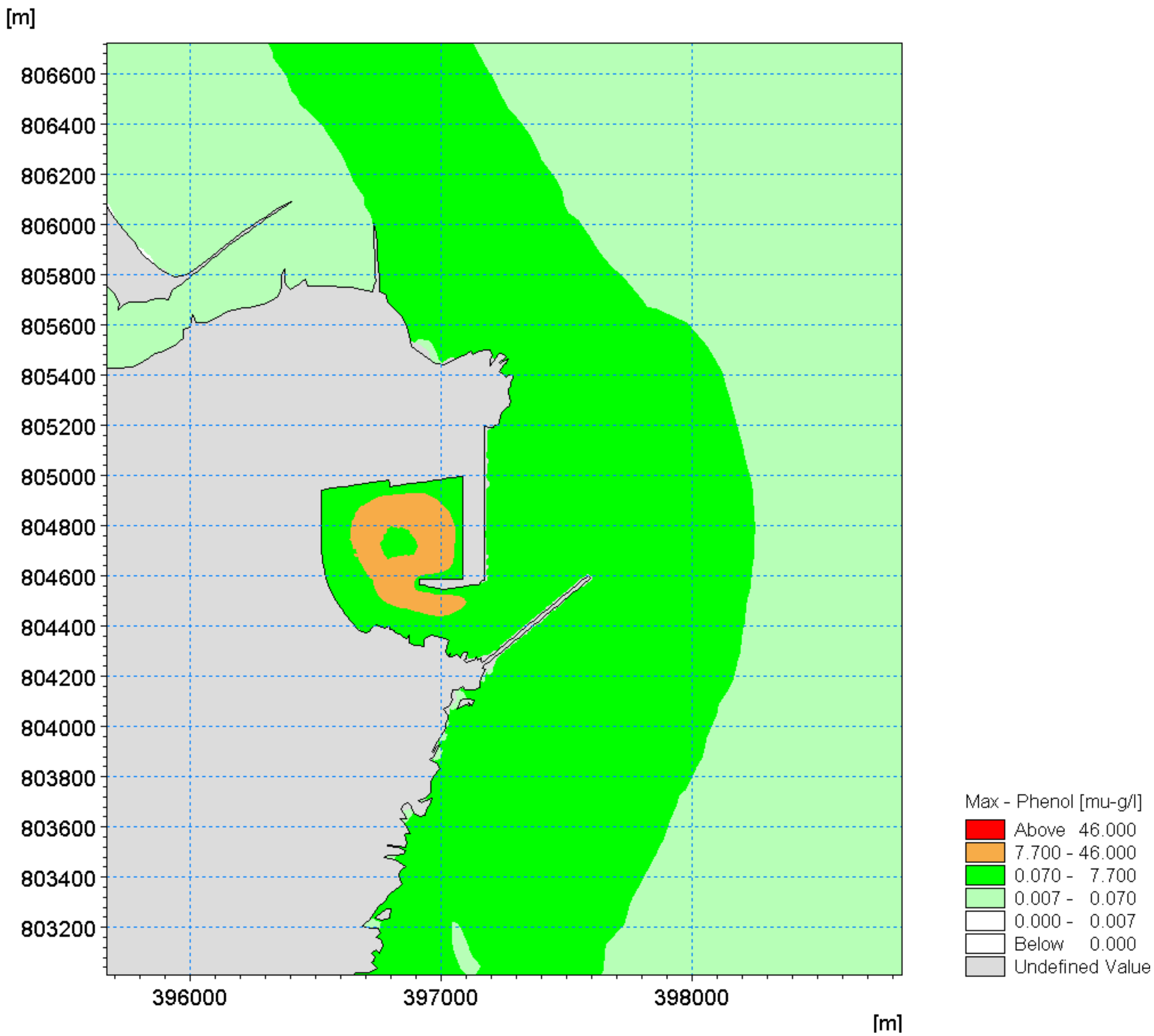


Figure C-59: Development - Unionised ammonia (at 10°C) max. modelled conc. (overview and close-up) - (AA = 21 µg/l)

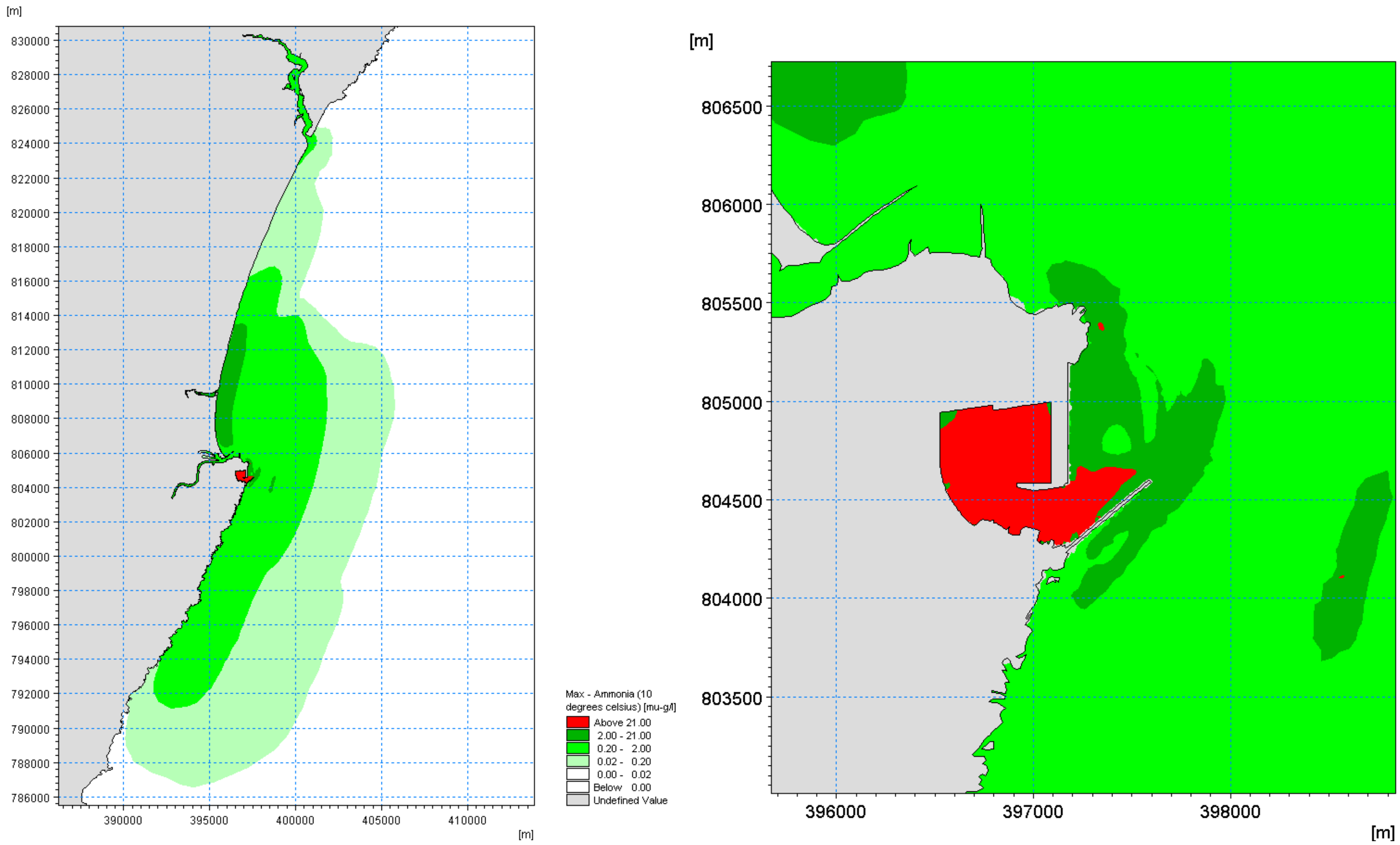
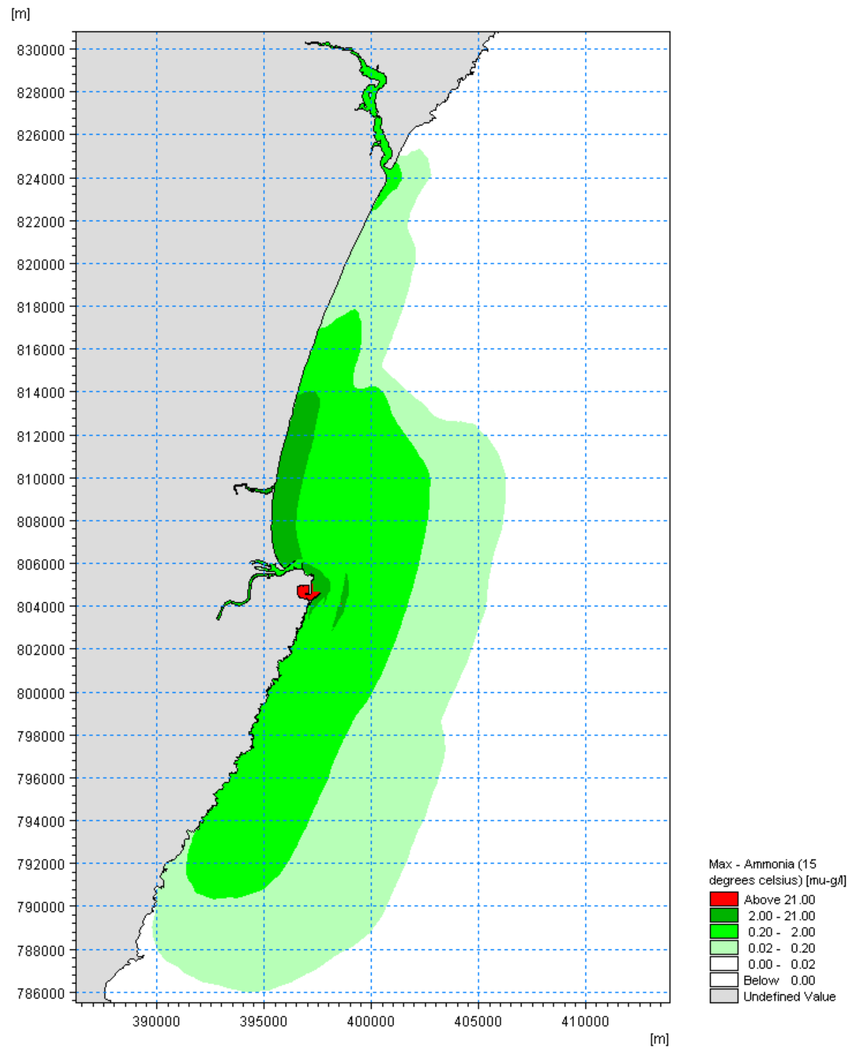


Figure C-60: Development - Unionised ammonia (at 15°C) max. modelled conc. (overview and close-up) - (AA = 21 µg/l)



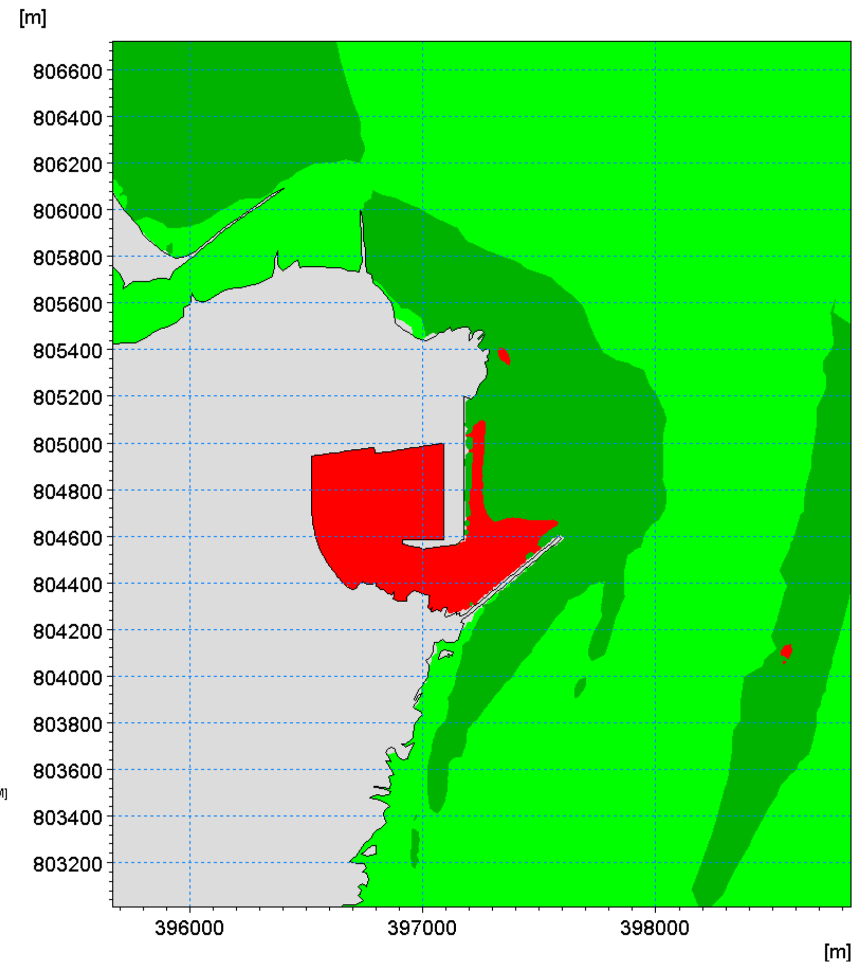


Figure C-61: Development - Zinc max. modelled conc. (overview) - (AA = 7.9 µg/l)

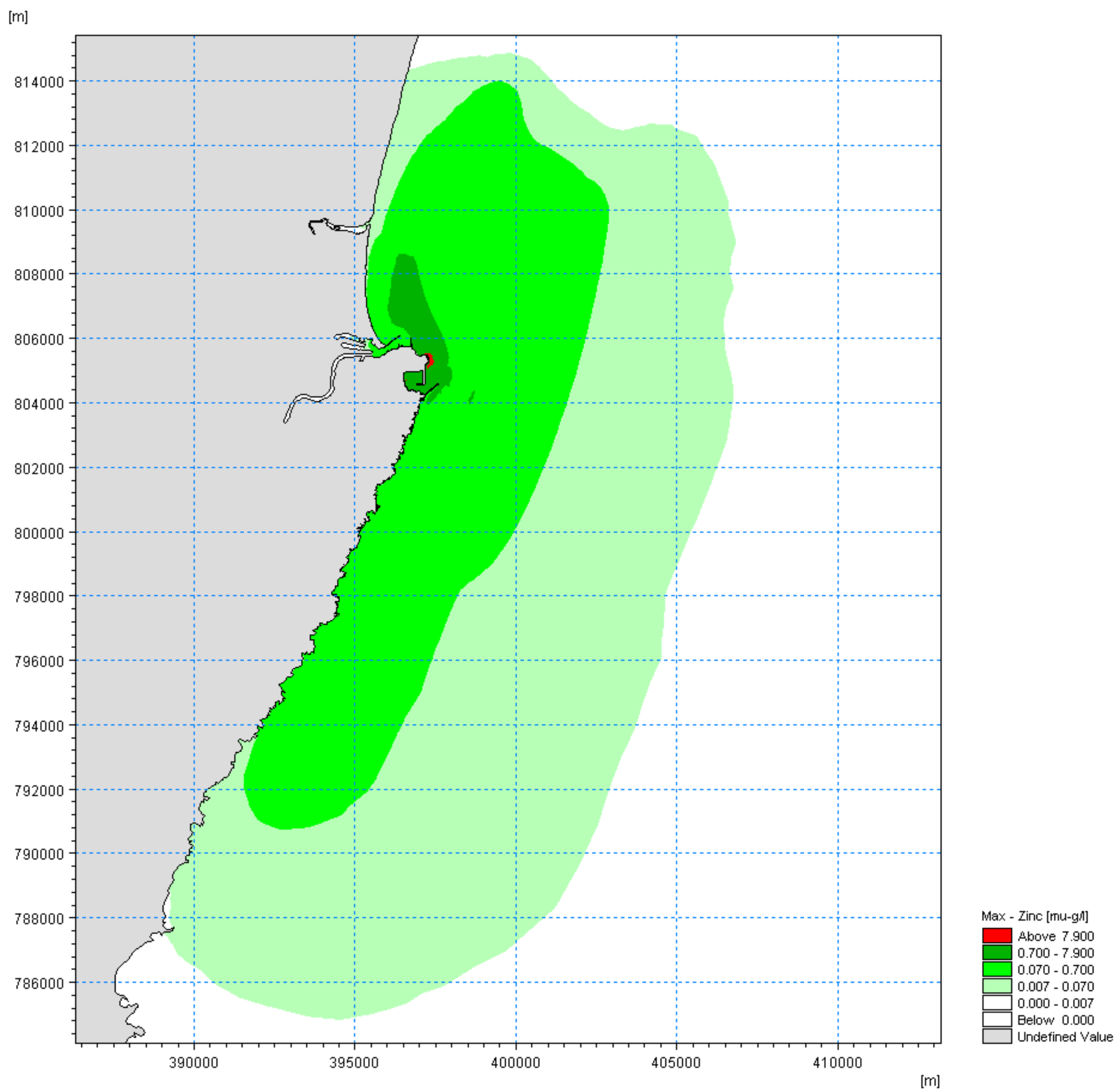
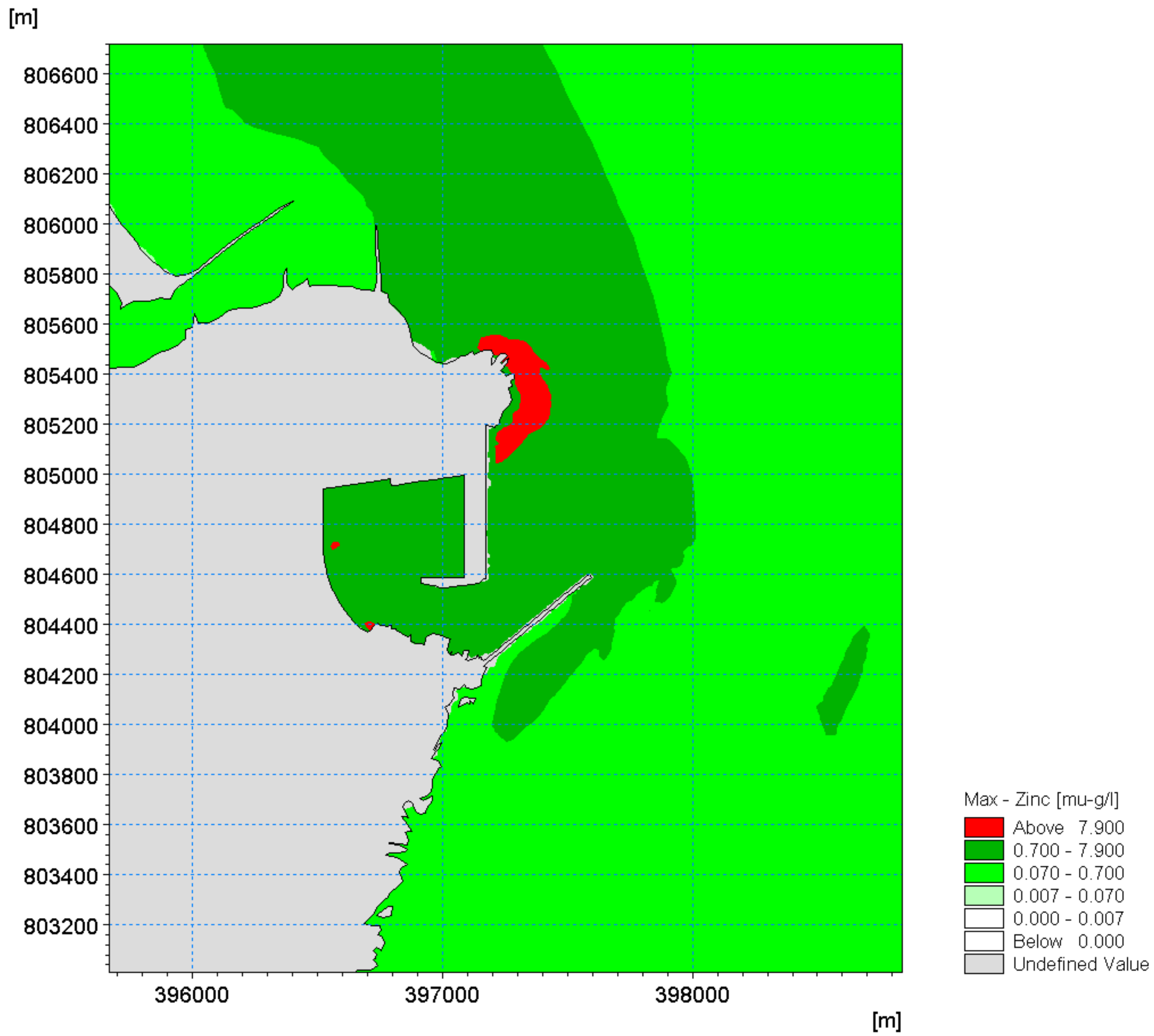


Figure C-62: Development - Zinc max. modelled conc. (close-up) - (AA = 7.9 µg/l)



Appendix D Percentage difference plots

FIGURE

Figure D-1: Anthracene percentage difference plot

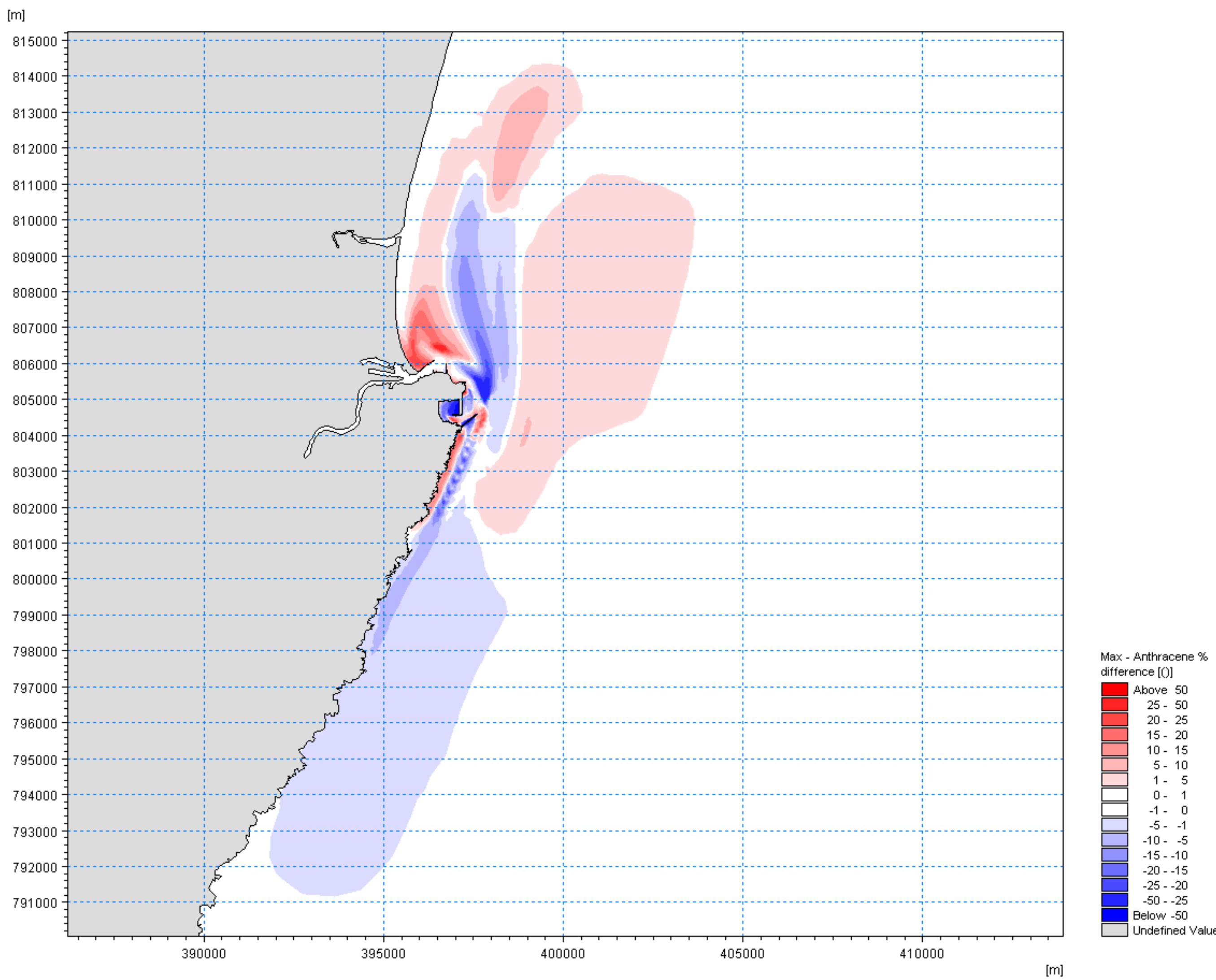


Figure D-2: Anthracene percentage difference plot close-up

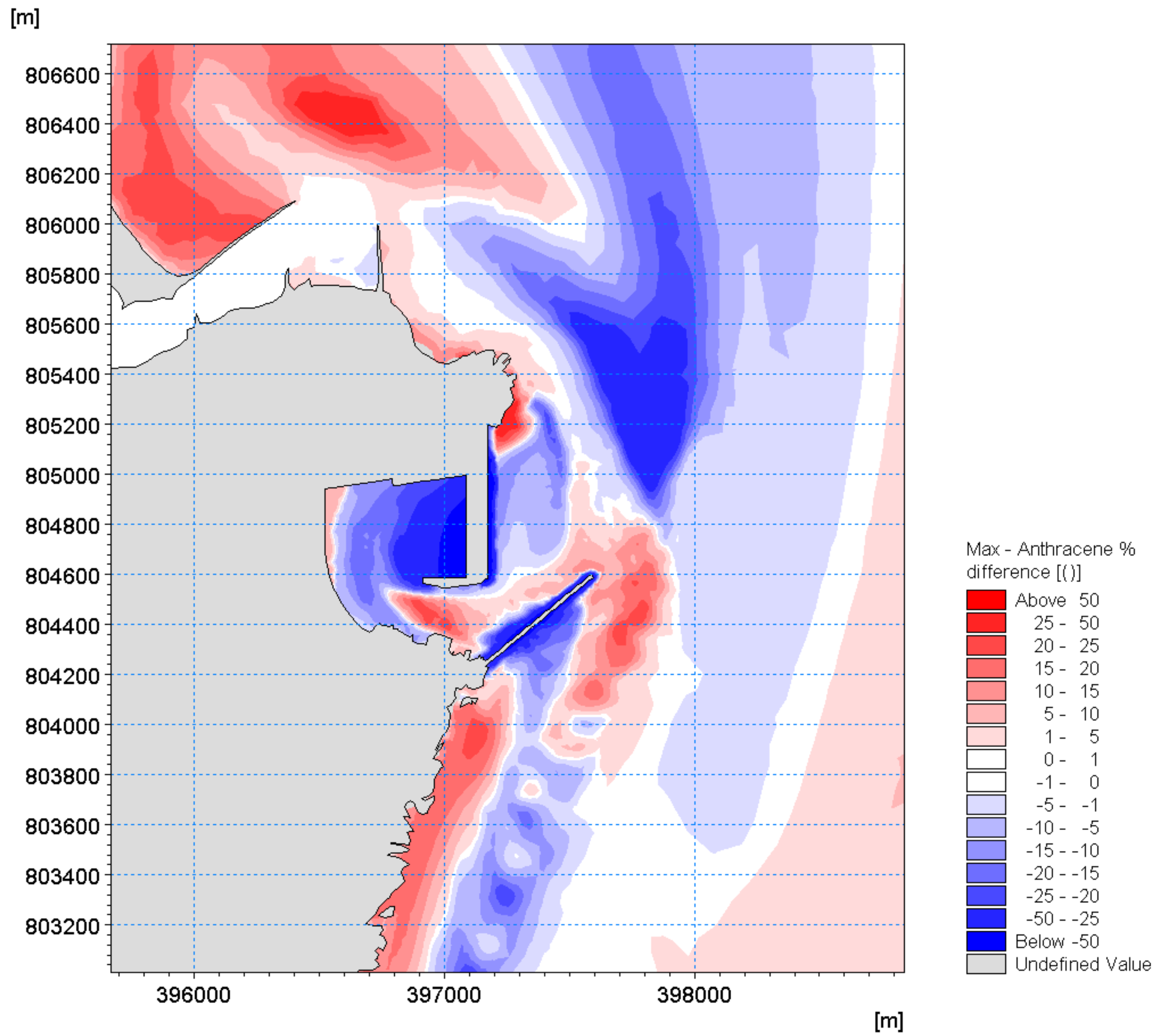


Figure D-3: Benzo(b\k)fluoranthene percentage difference plot

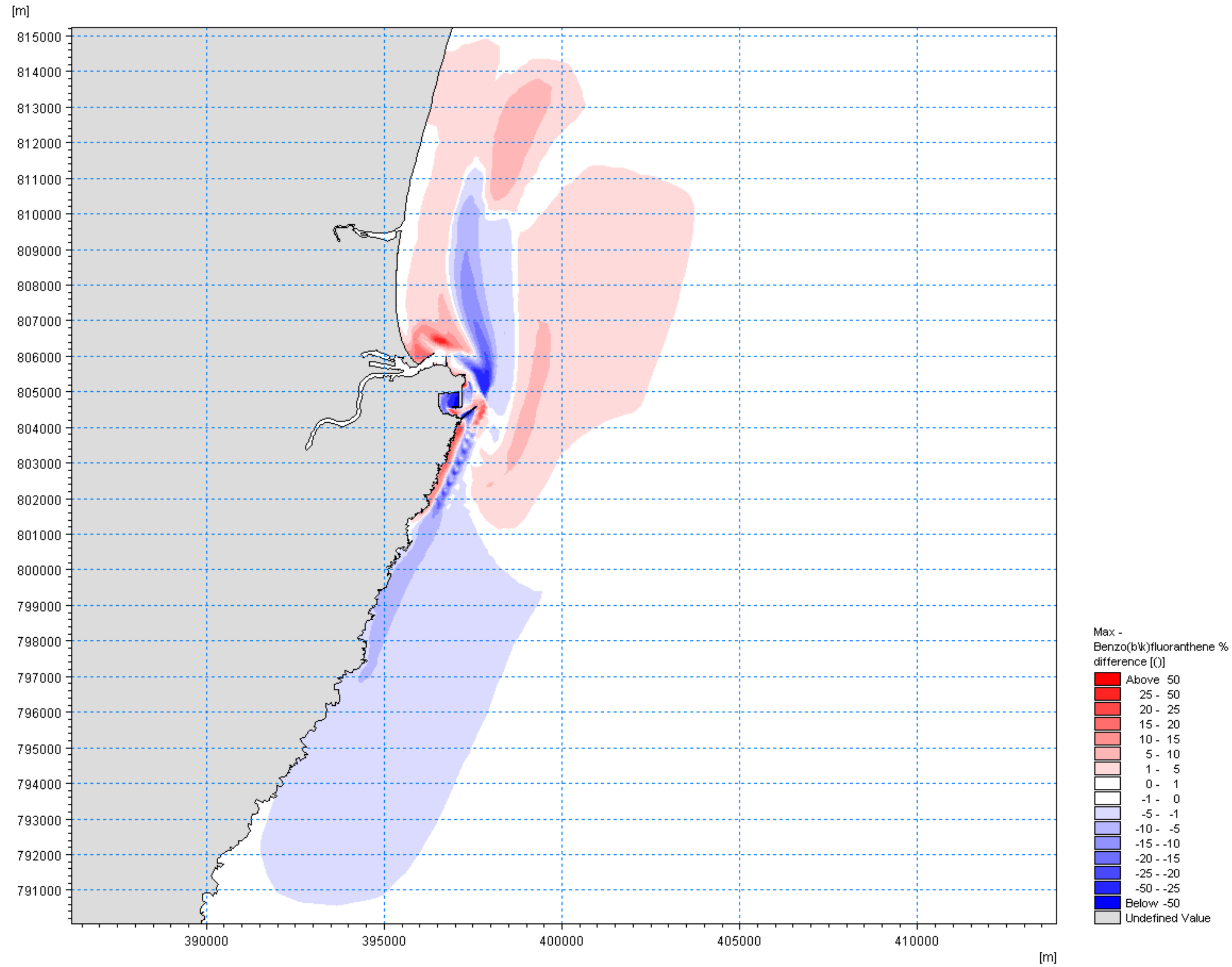


Figure D-4 : Benzo(b\k)fluoranthene percentage difference plot close-up

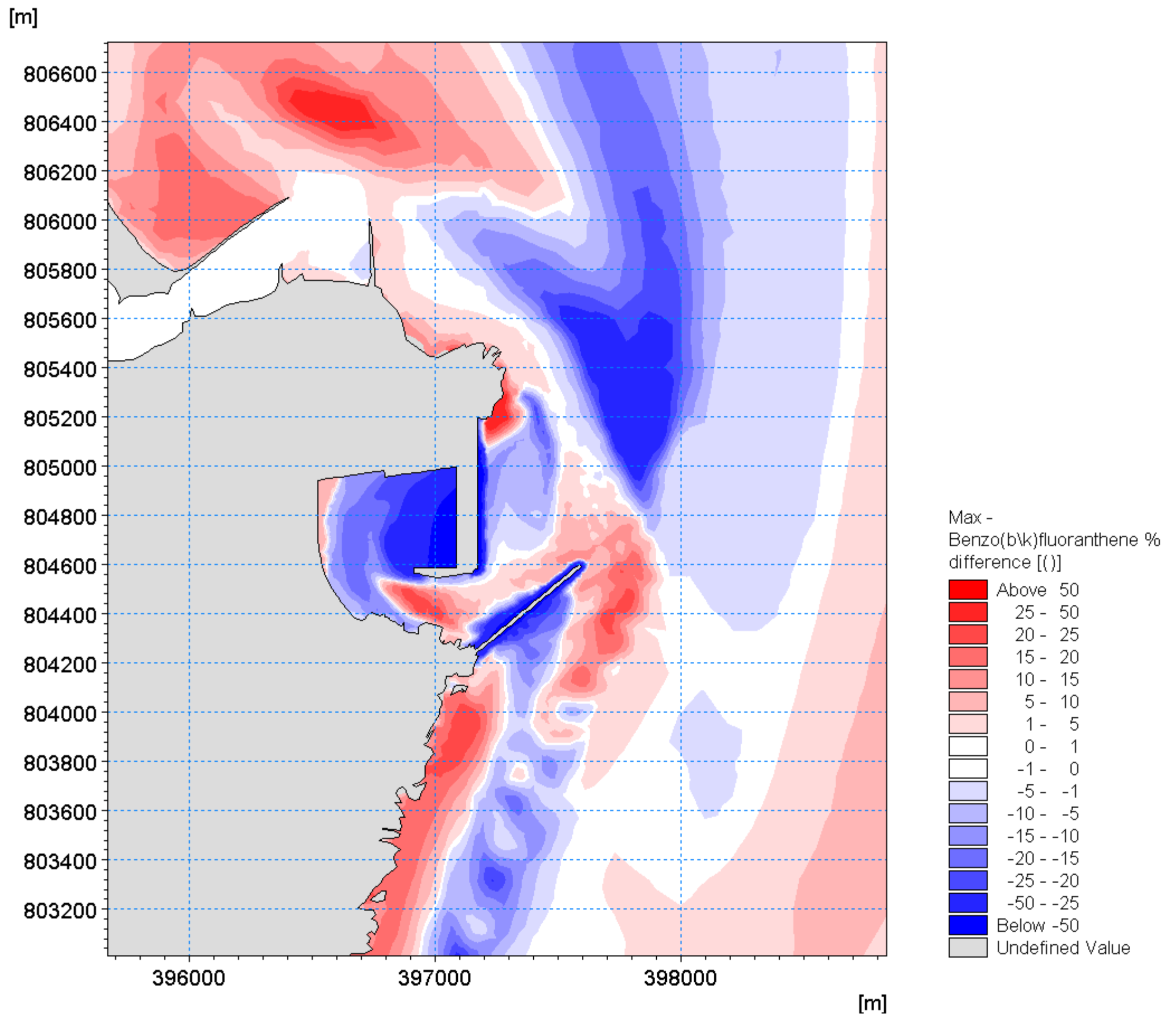


Figure D-5: Biochemical Oxygen Demand (BOD) percentage difference plot

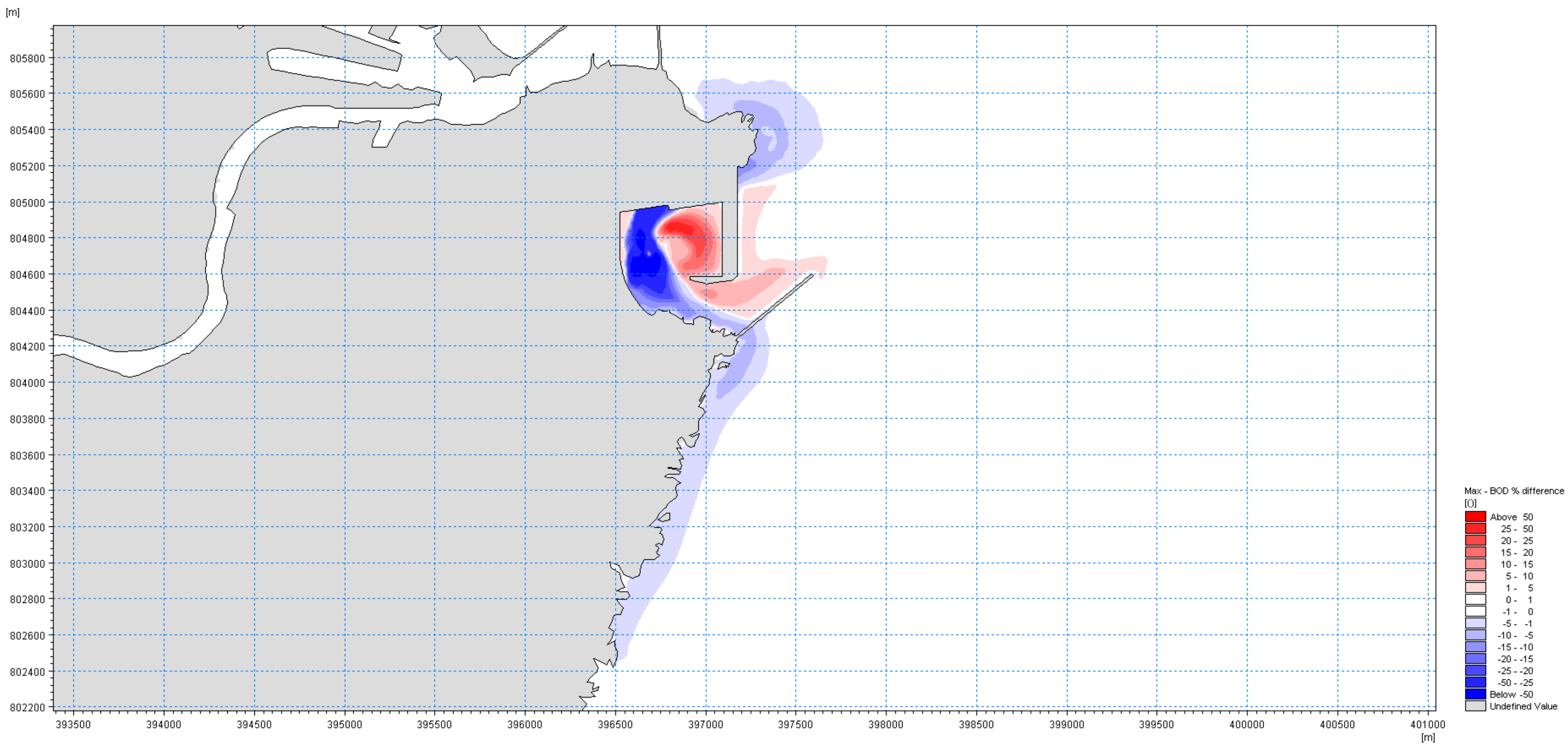


Figure D-6: Cadmium percentage difference plot

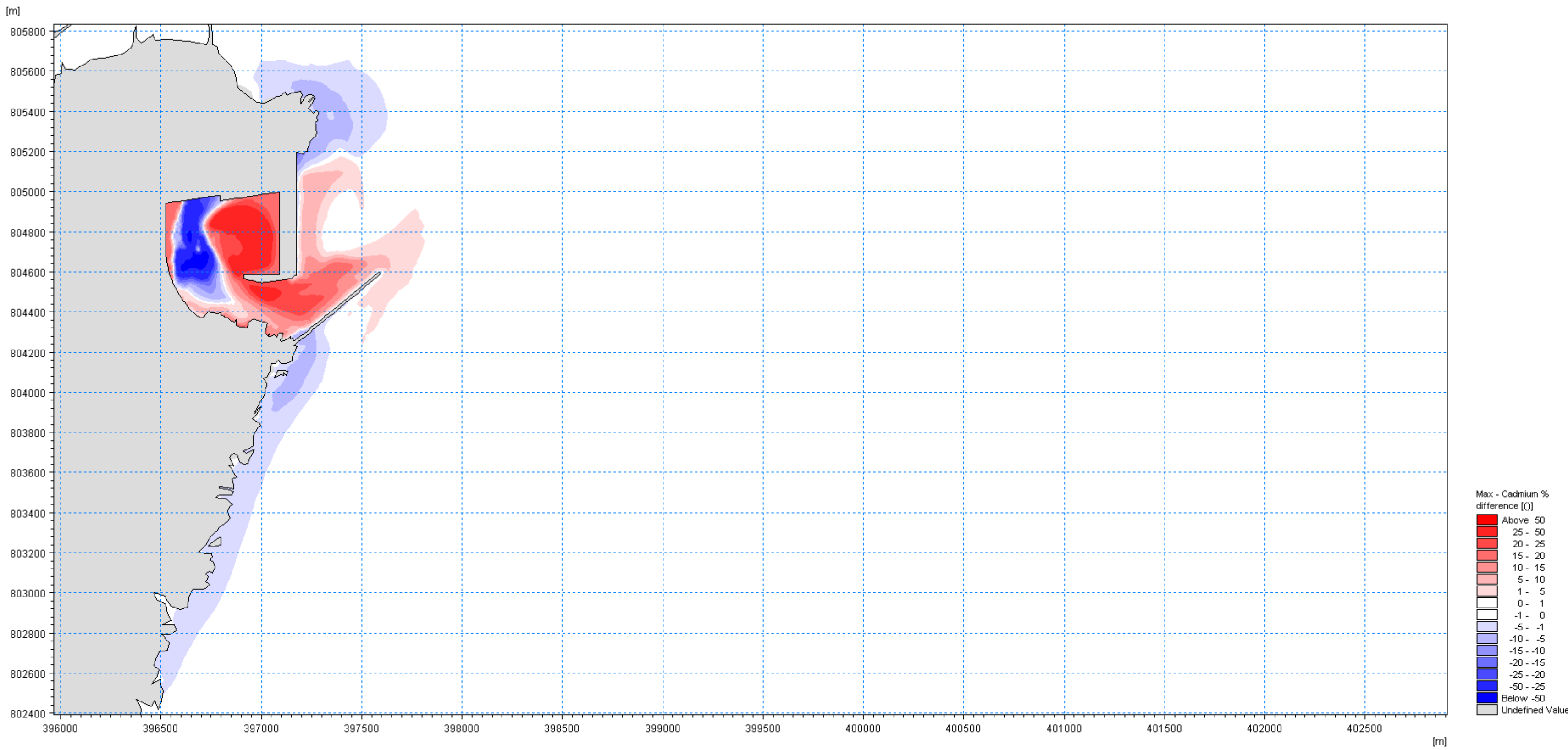


Figure D-7: C10-13 Chloroalkanes percentage difference plot

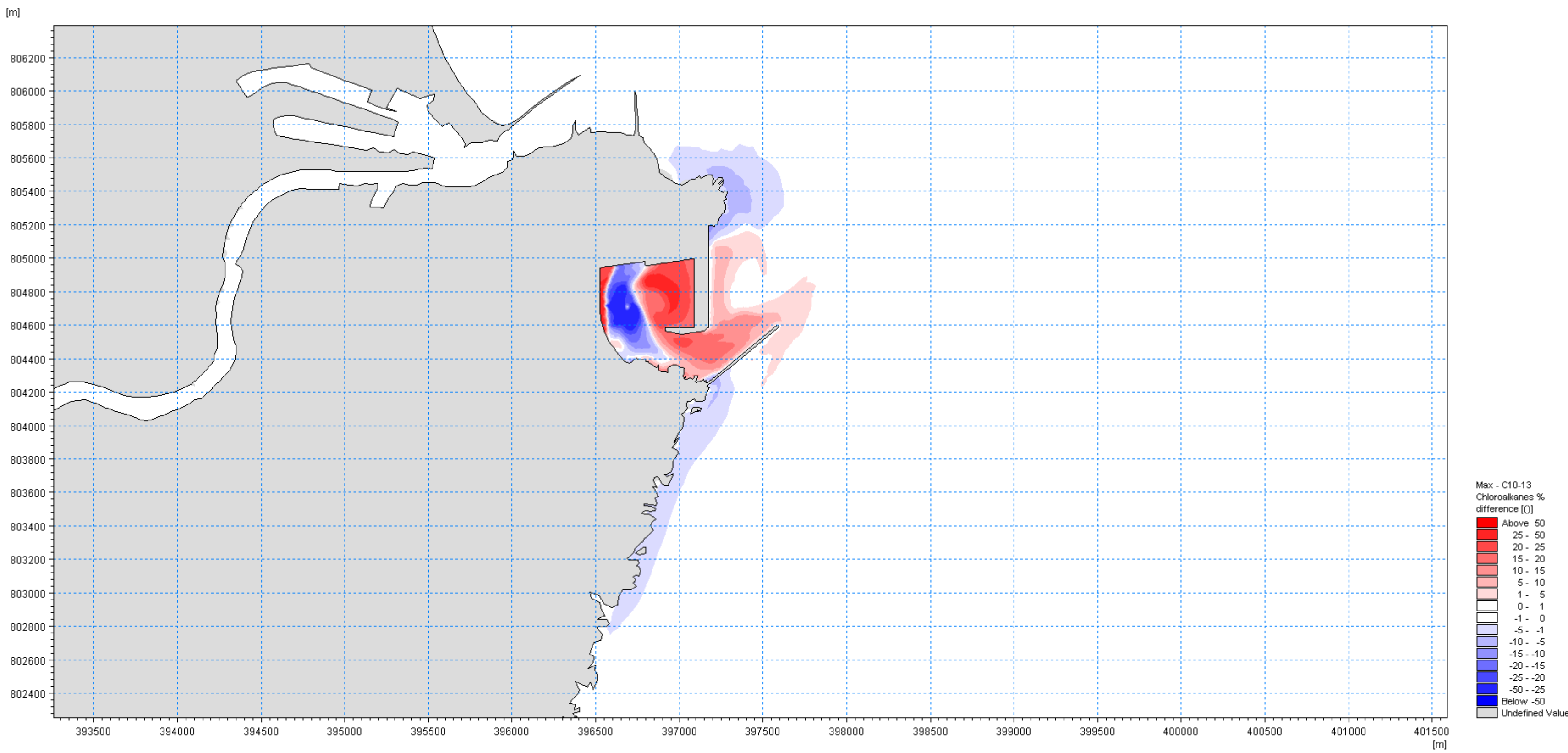


Figure D-8: Chromium percentage difference plot

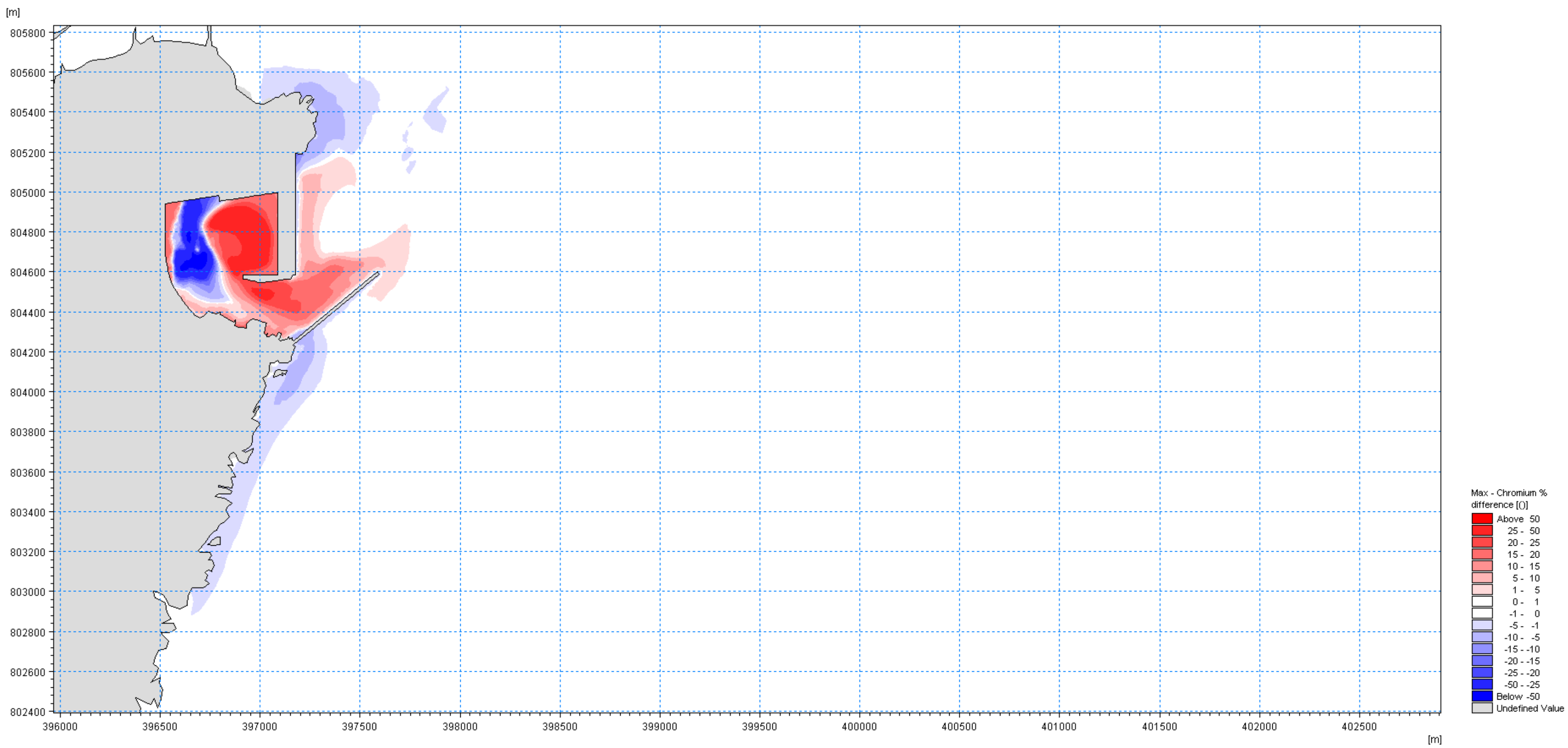


Figure D-9: Copper percentage difference plot

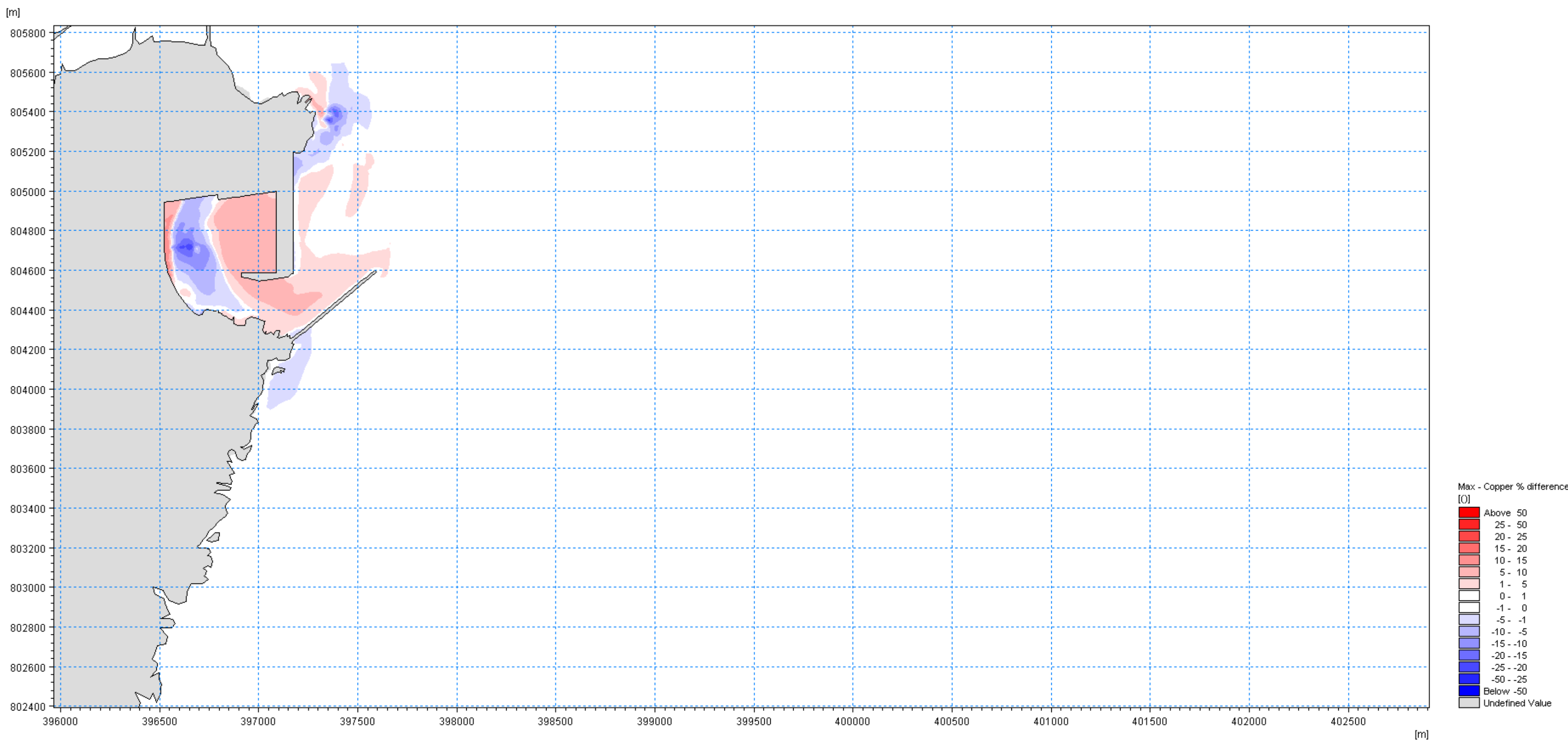


Figure D-10: DIN percentage difference plot

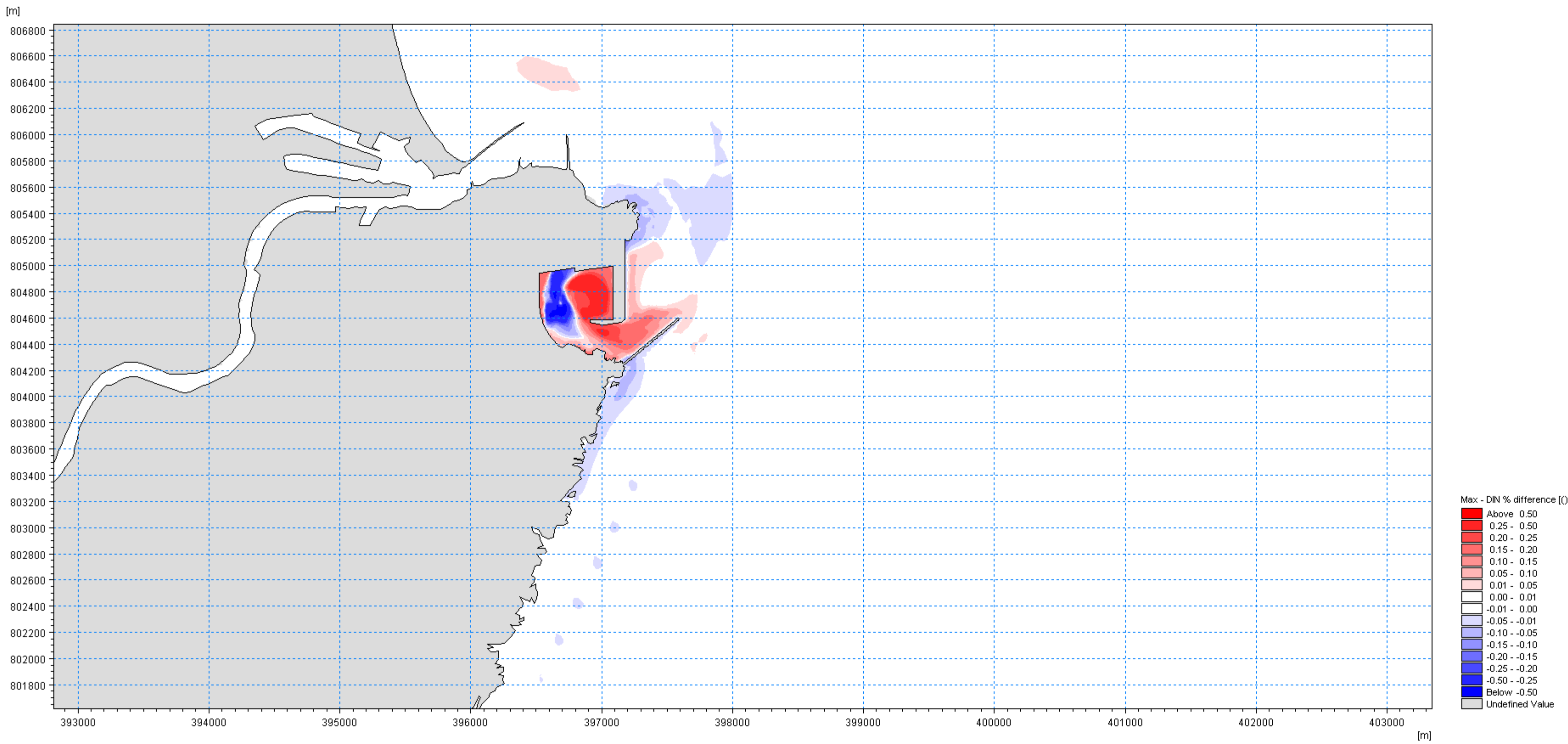


Figure D-11: DO deficit percentage difference plot

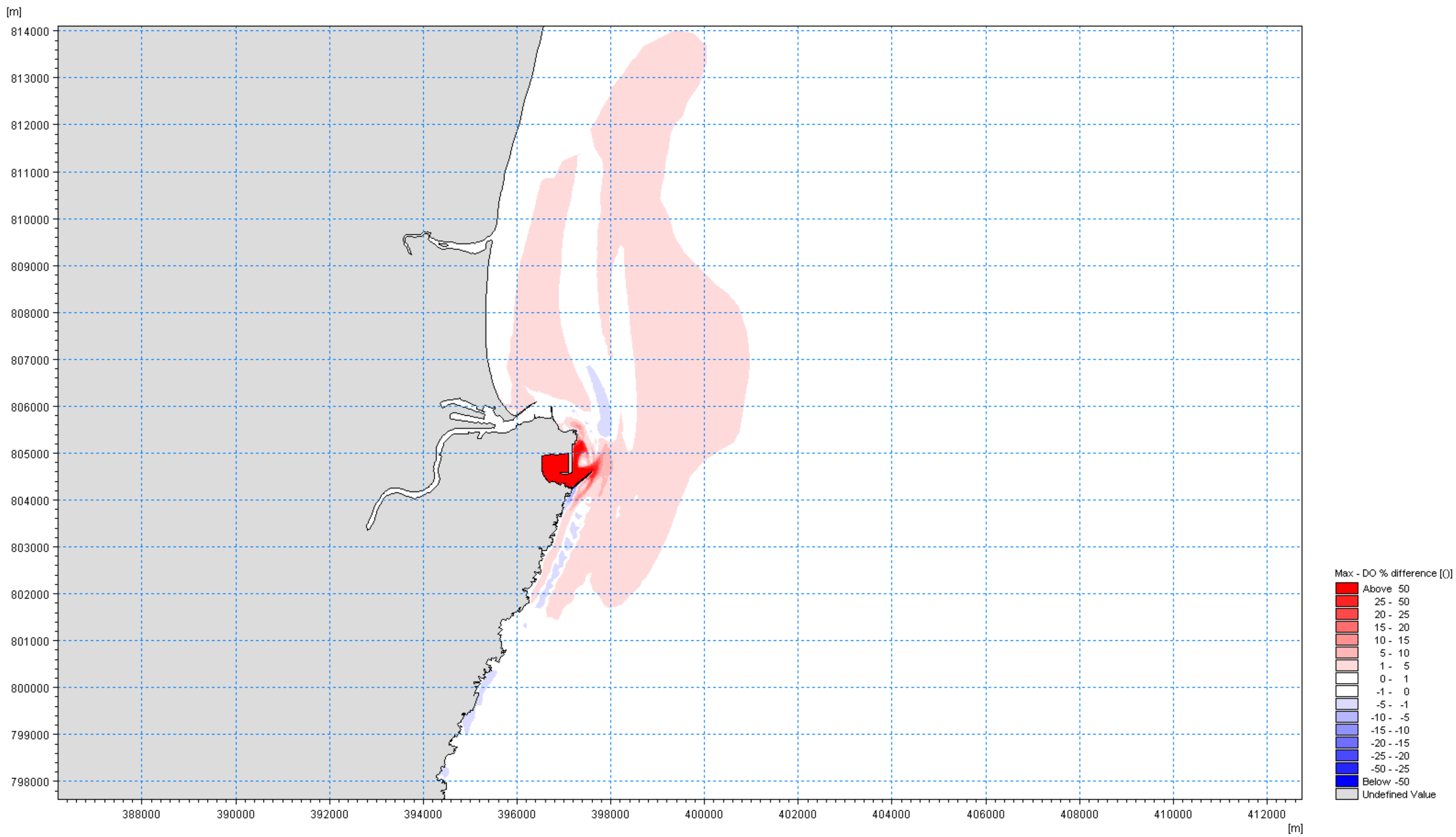


Figure D-12: EC percentage difference plot

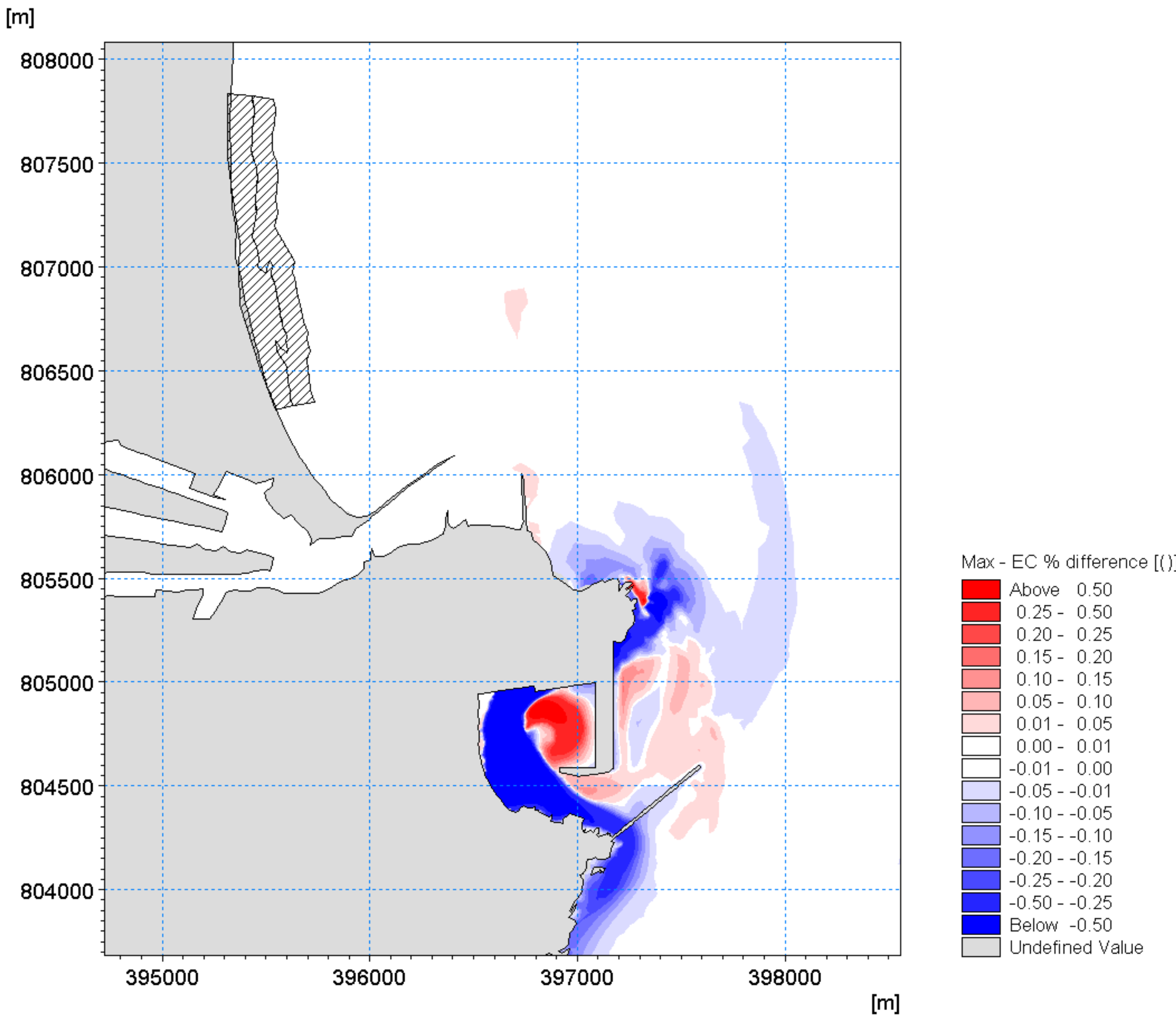


Figure D-13: Hexachlorobutadiene percentage difference plot

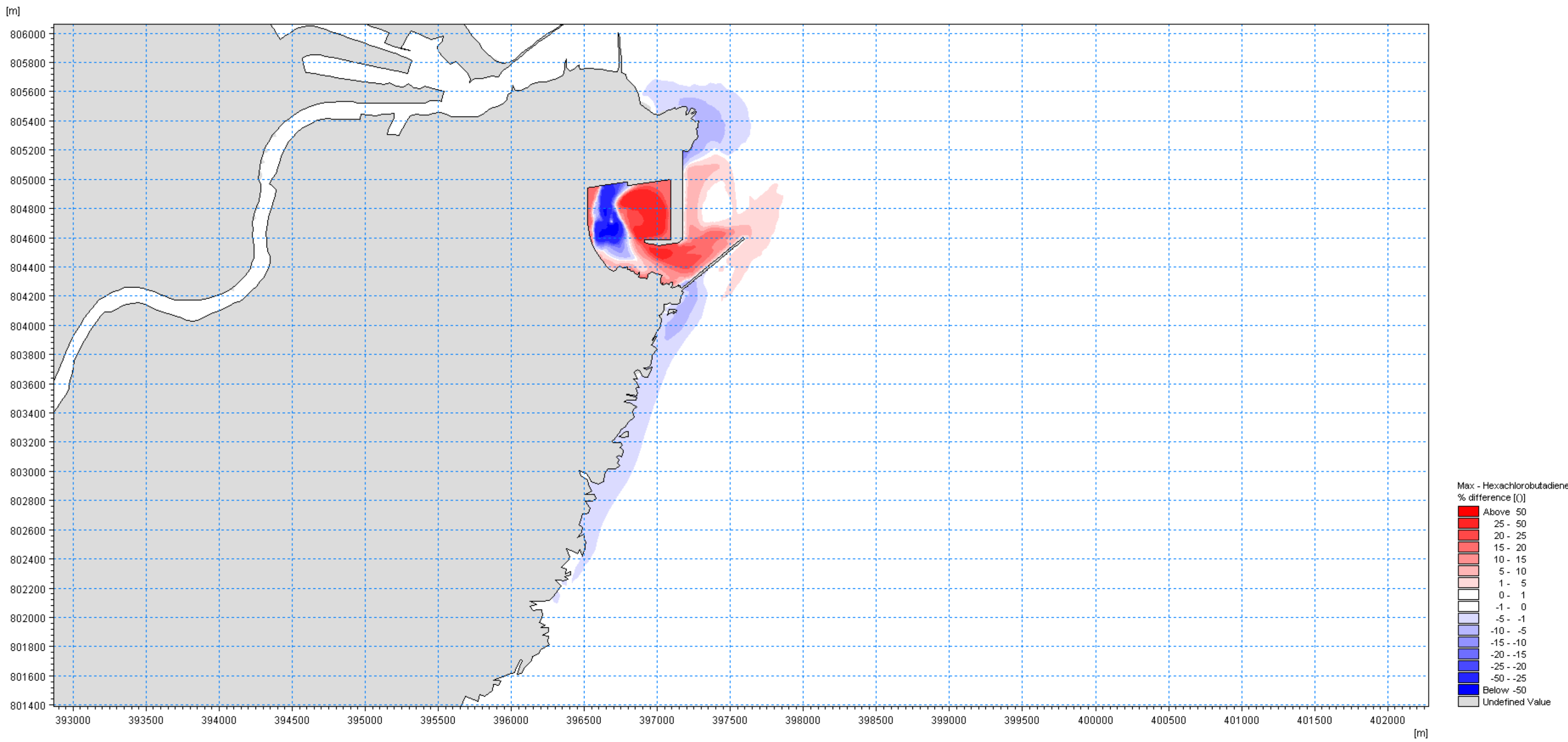


Figure D-14: Lead percentage difference plot

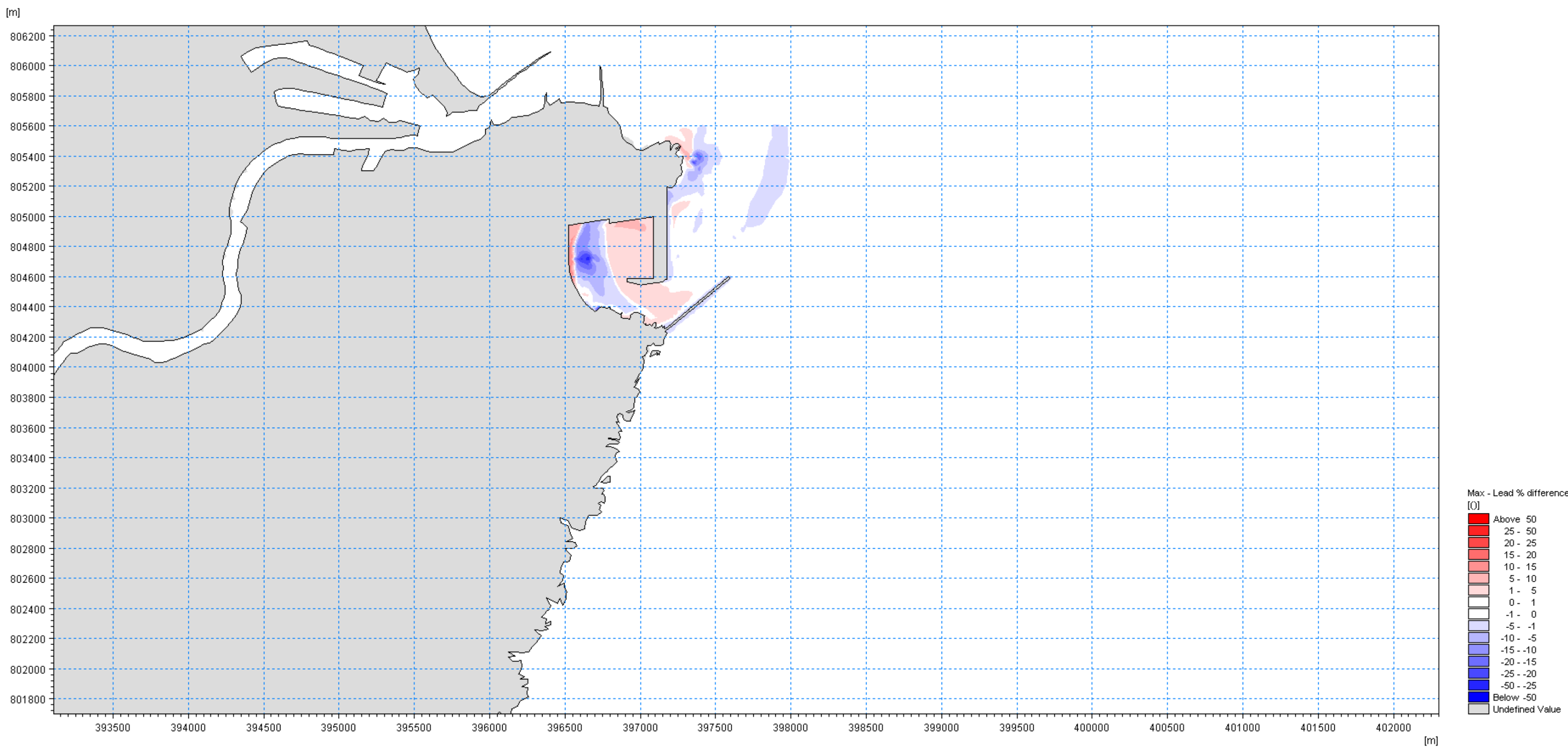


Figure D-15: Mercury percentage difference plot

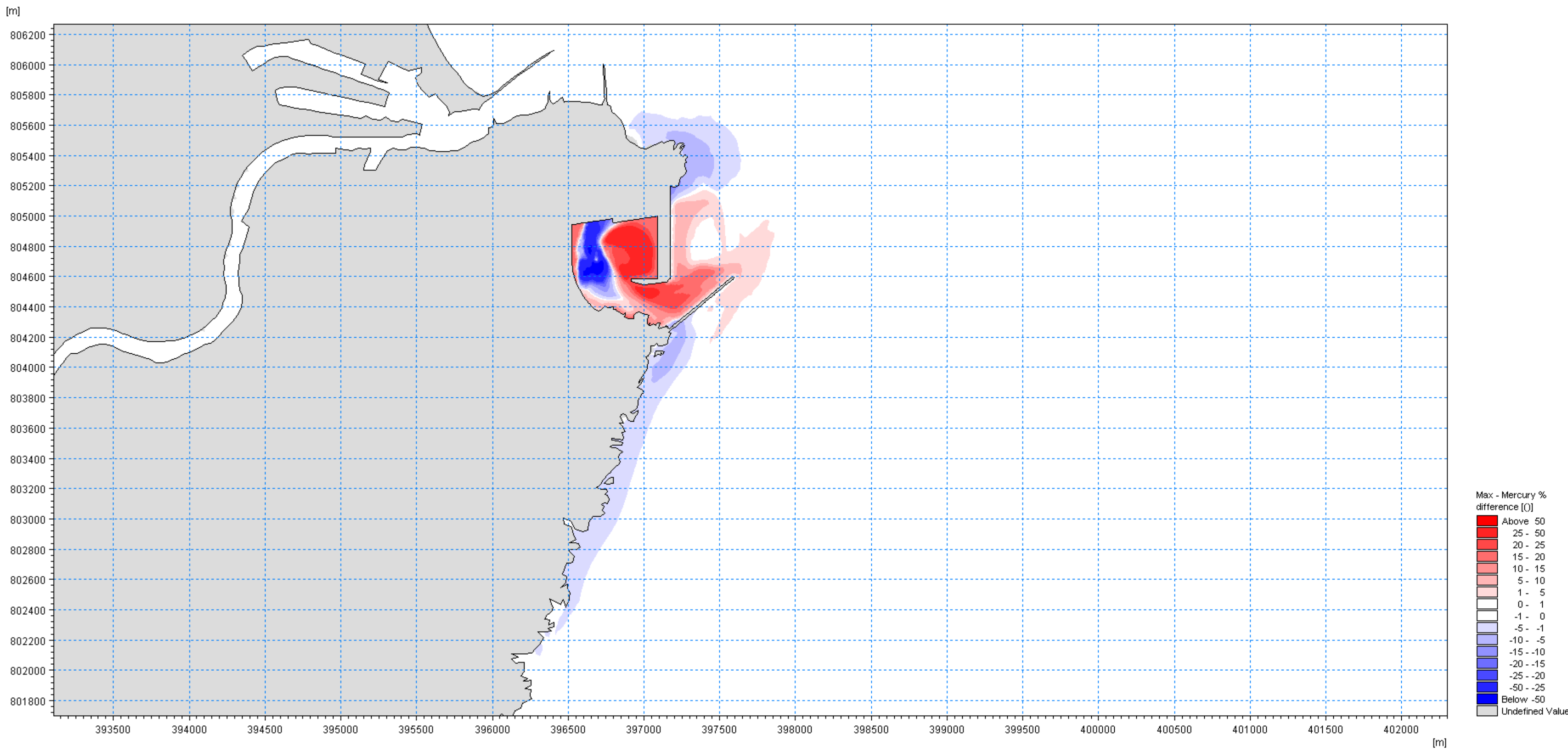


Figure D-16: Total ammonia percentage difference plot

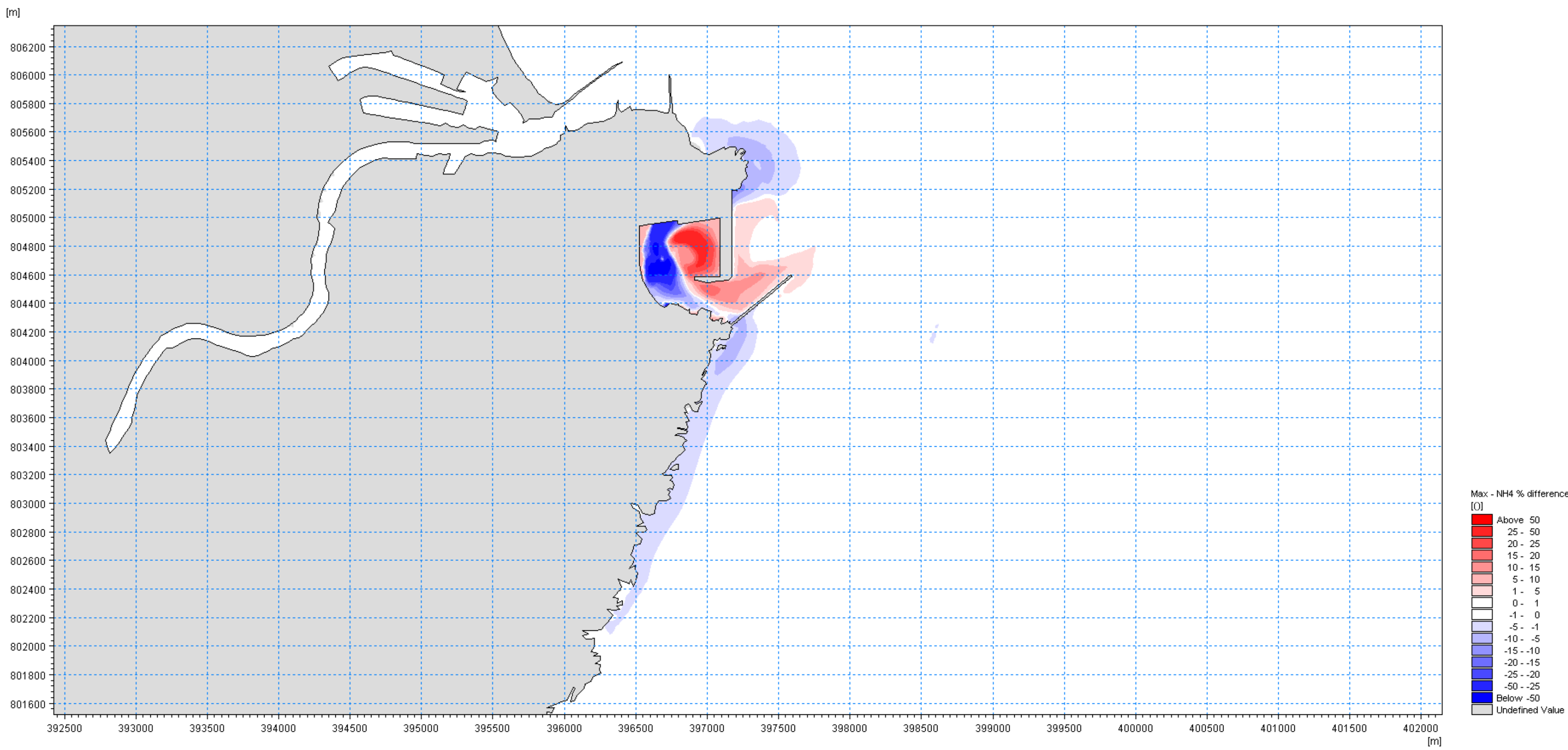


Figure D-17: PAHs percentage difference plot

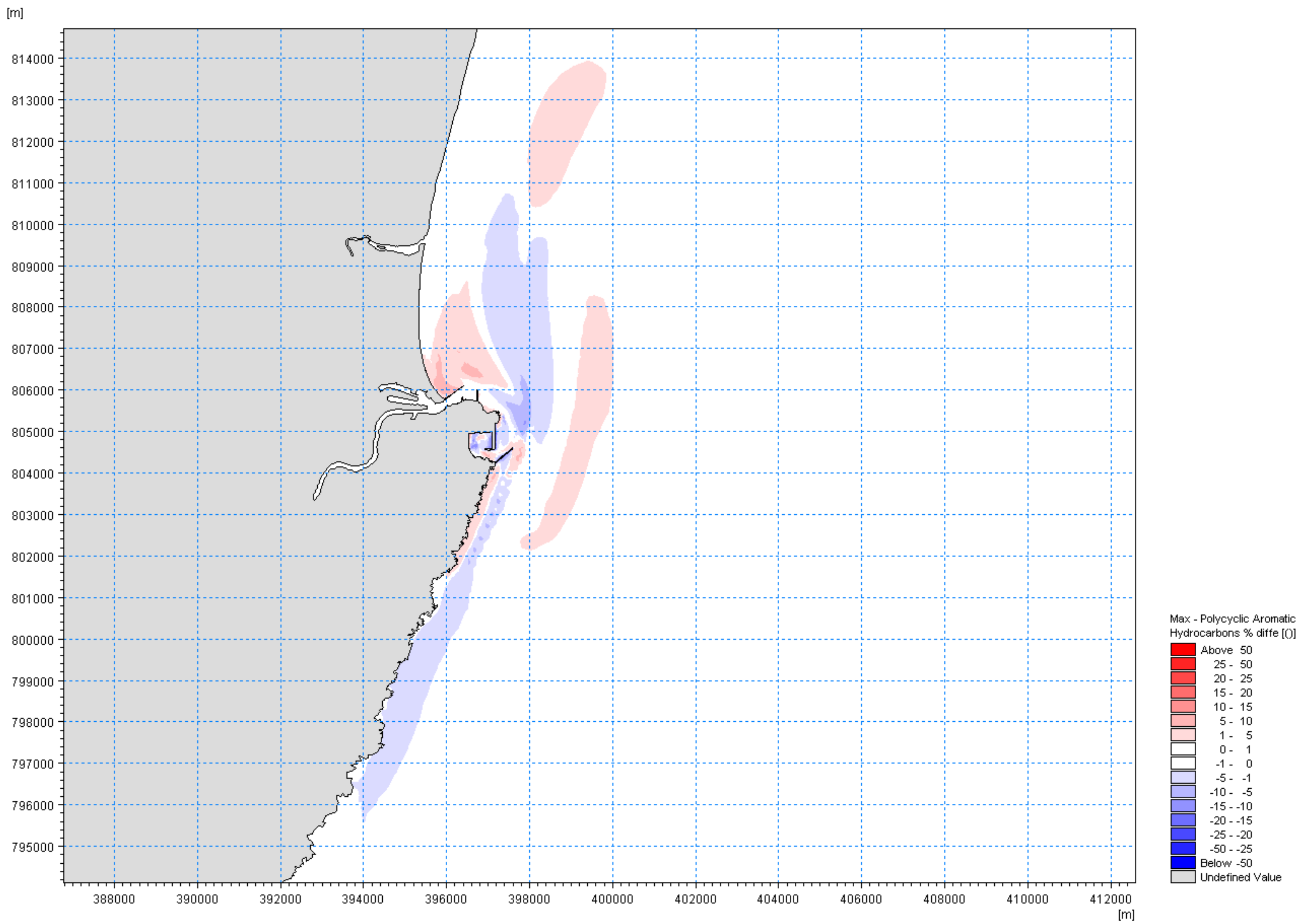


Figure D-18: PAHs percentage difference plot close up

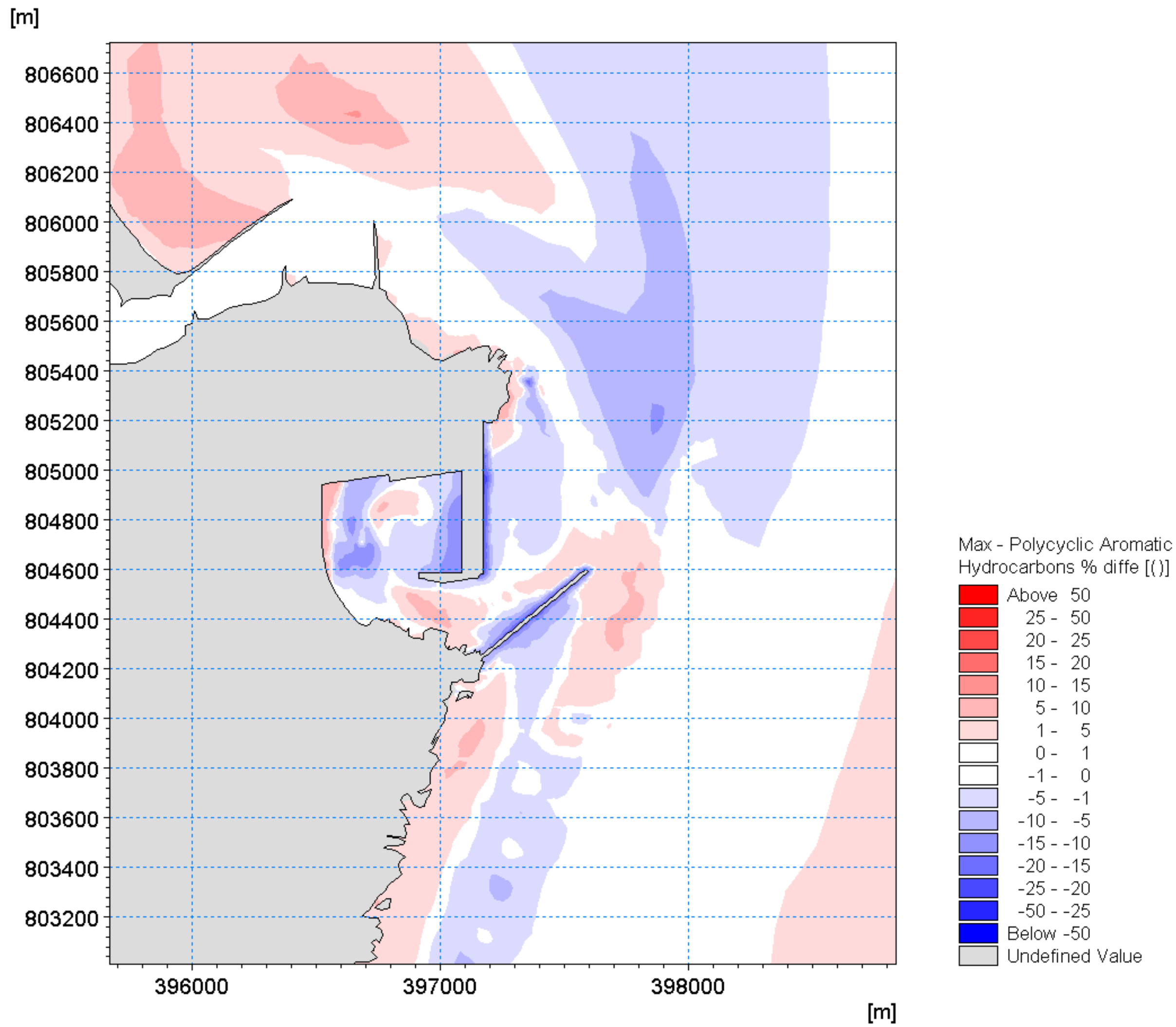


Figure D-19: Phenol percentage difference plot

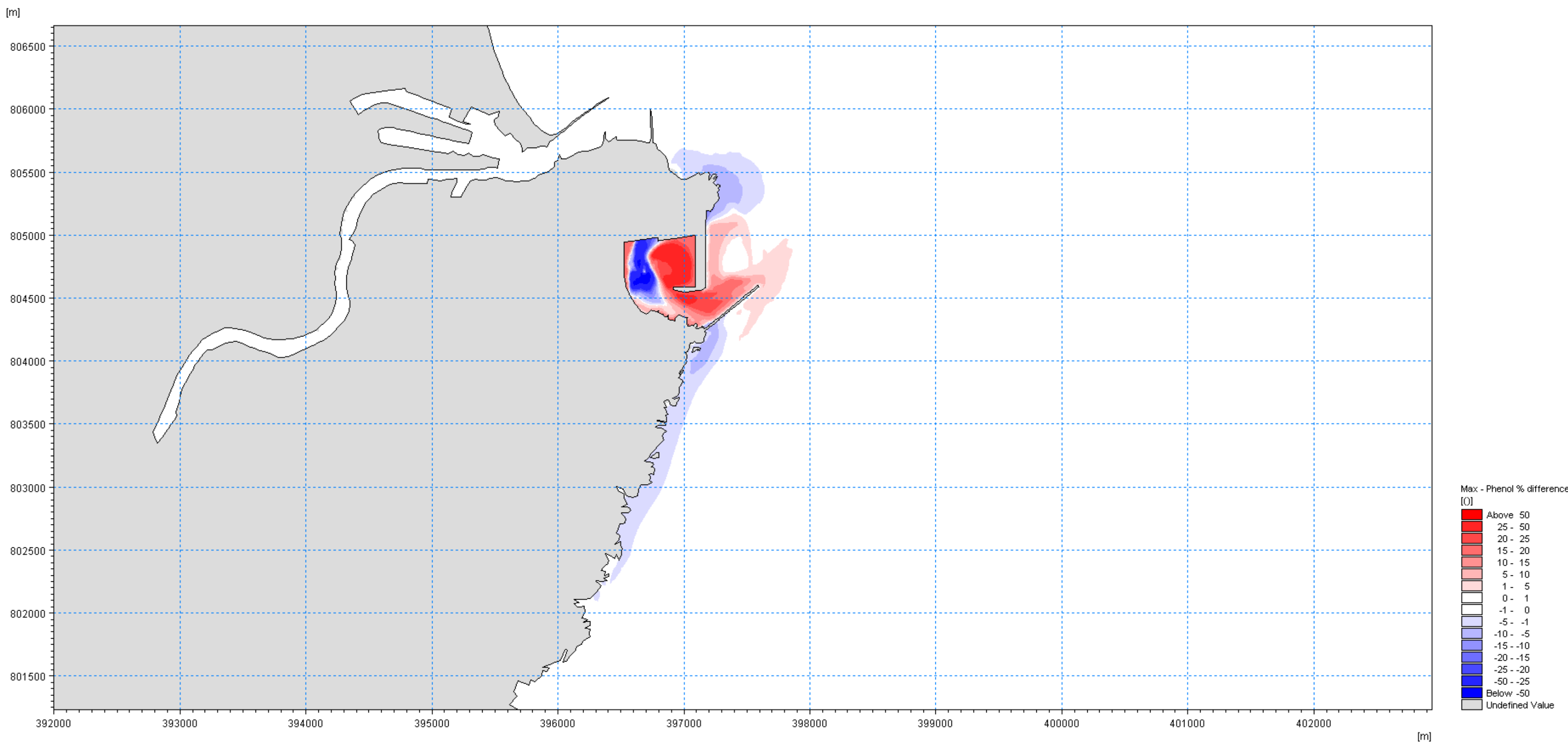


Figure D-20: Unionised ammonia (at 10°C) percentage difference plot

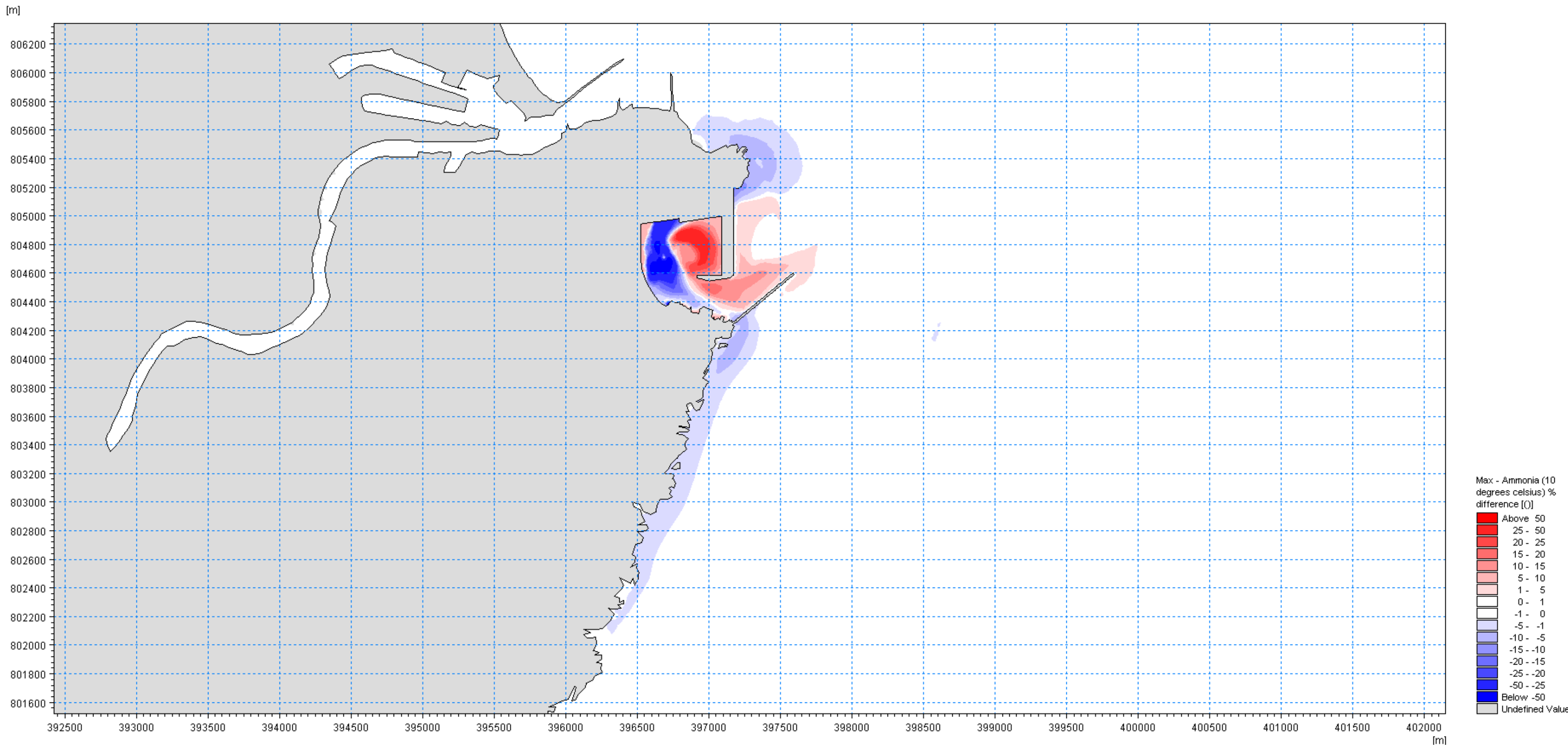
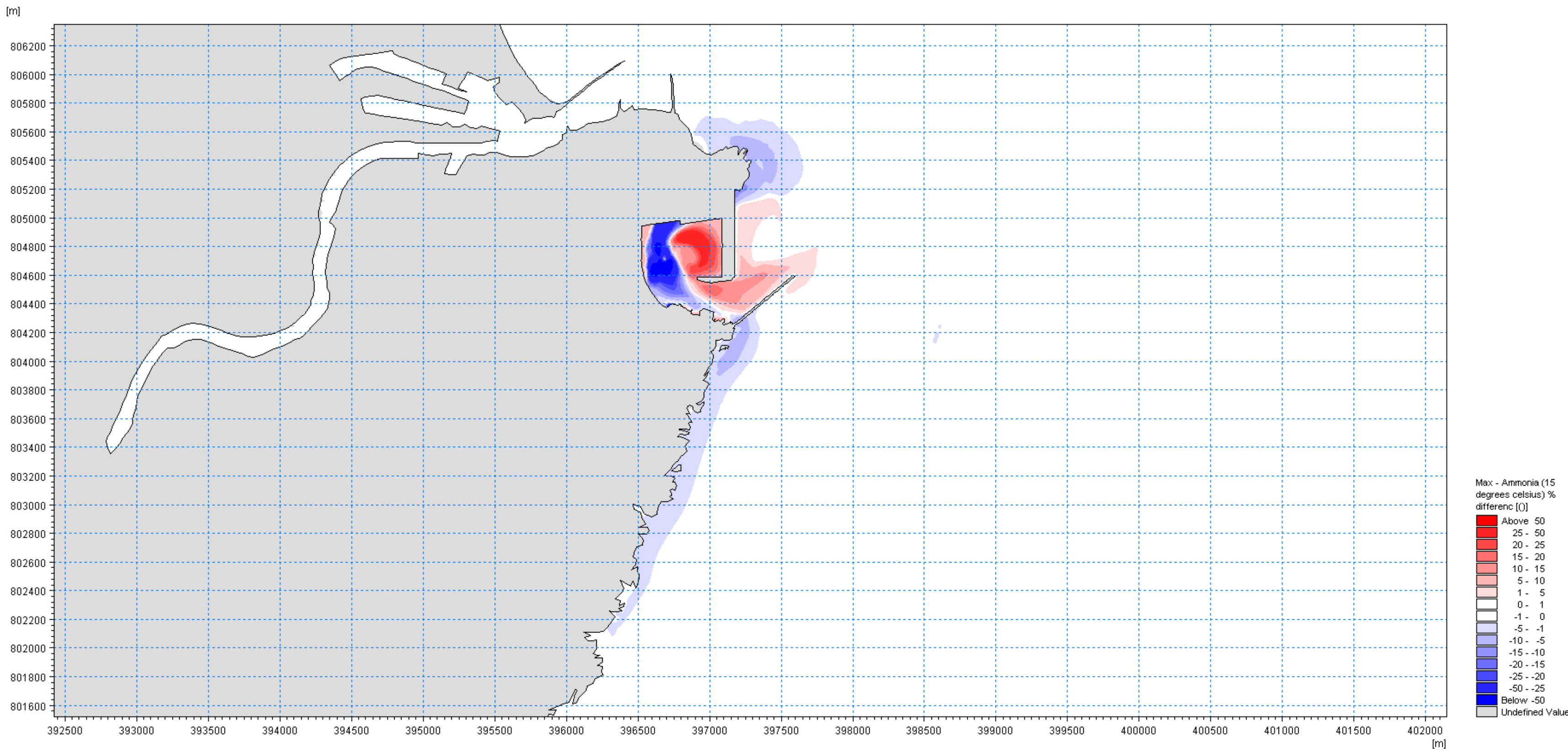
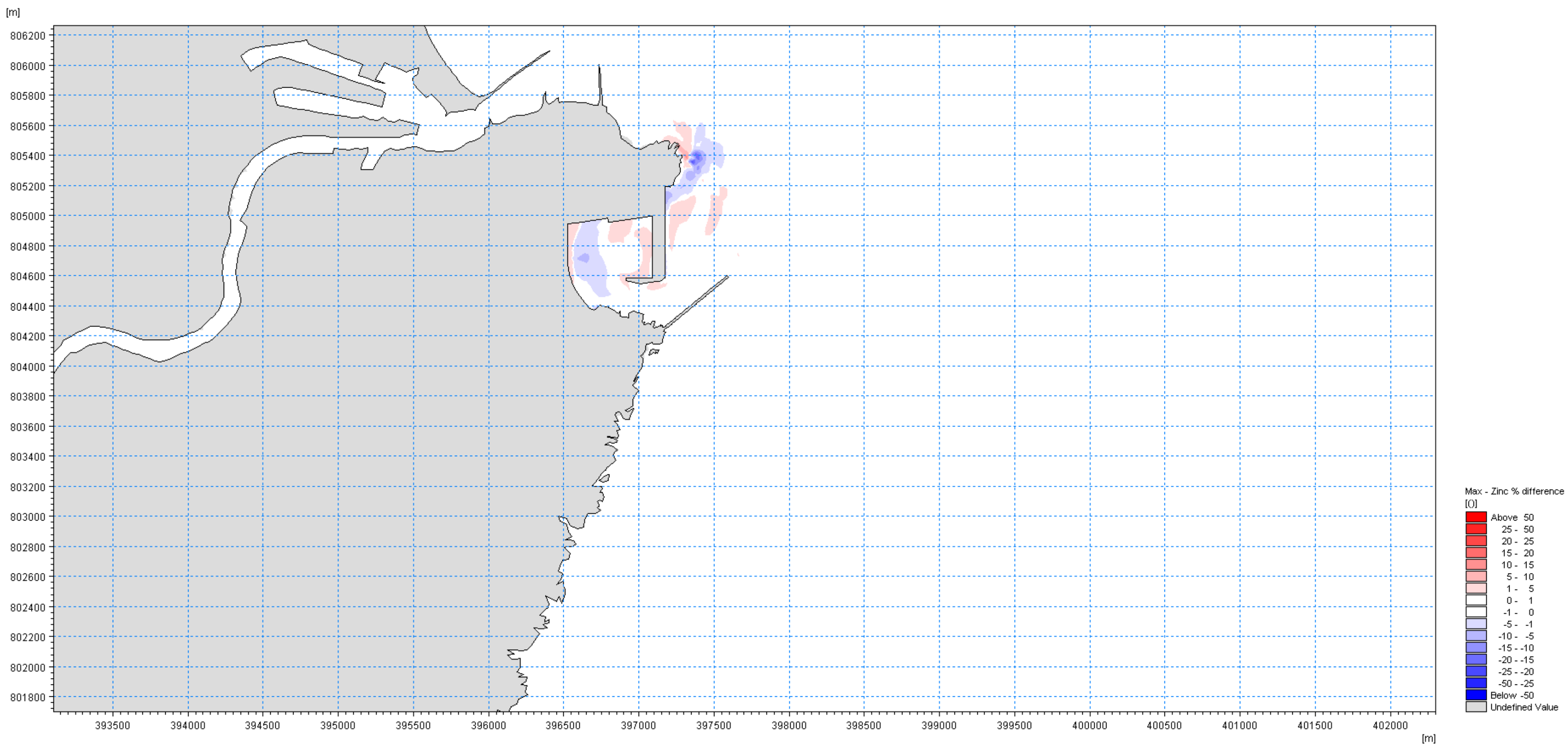


Figure D-21: Unionised ammonia (at 15°C) percentage difference plot



Intertek

Figure D-22: Zinc percentage difference plot



Appendix E Retention time plots

FIGURES

TABLES

Figure E-1: Baseline - % Bay water at 0 hours after start

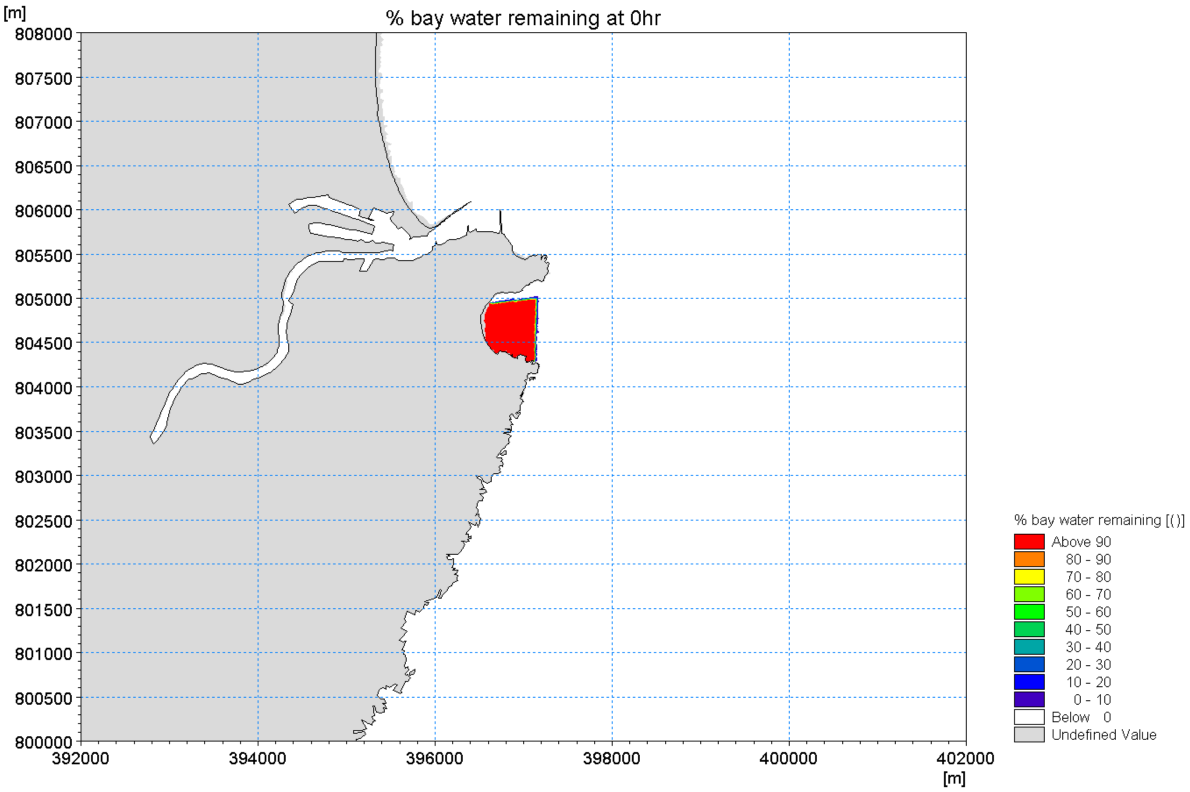


Figure E-2: Baseline - % Bay water at 6 hours after start

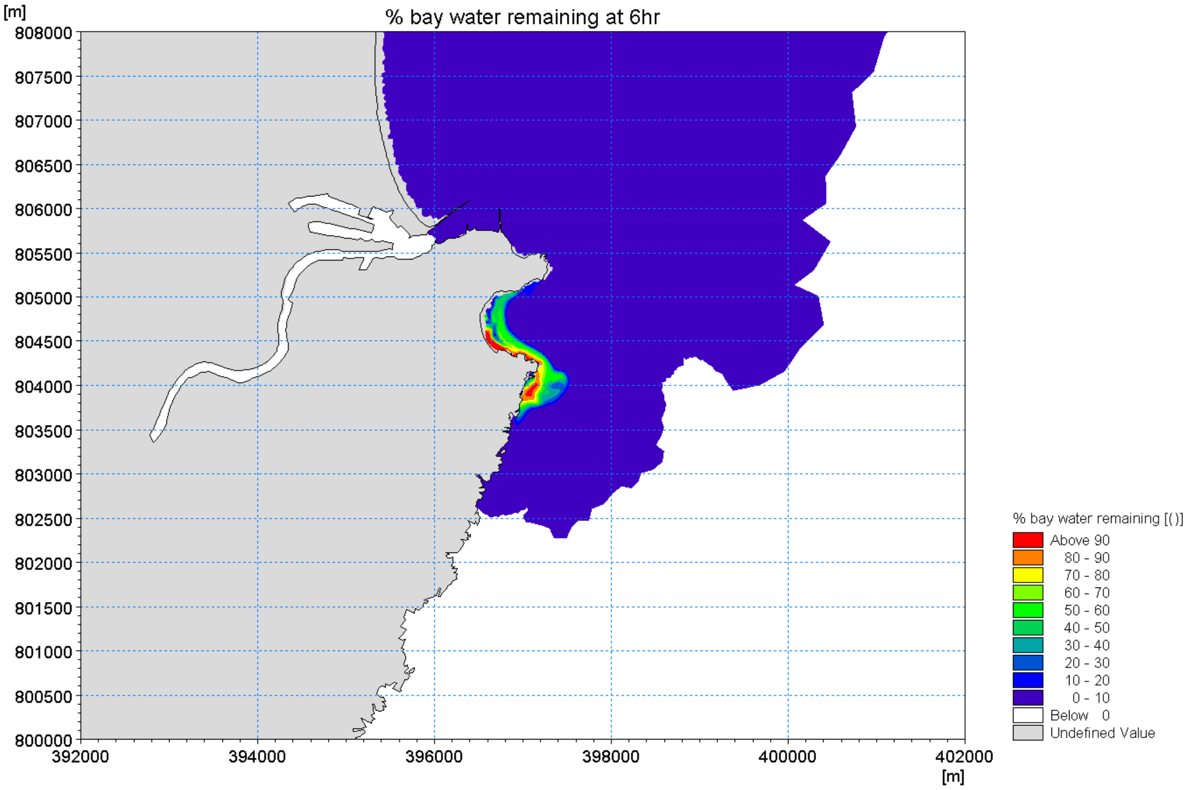


Figure E-3: Baseline - % Bay water at 12 hours after start

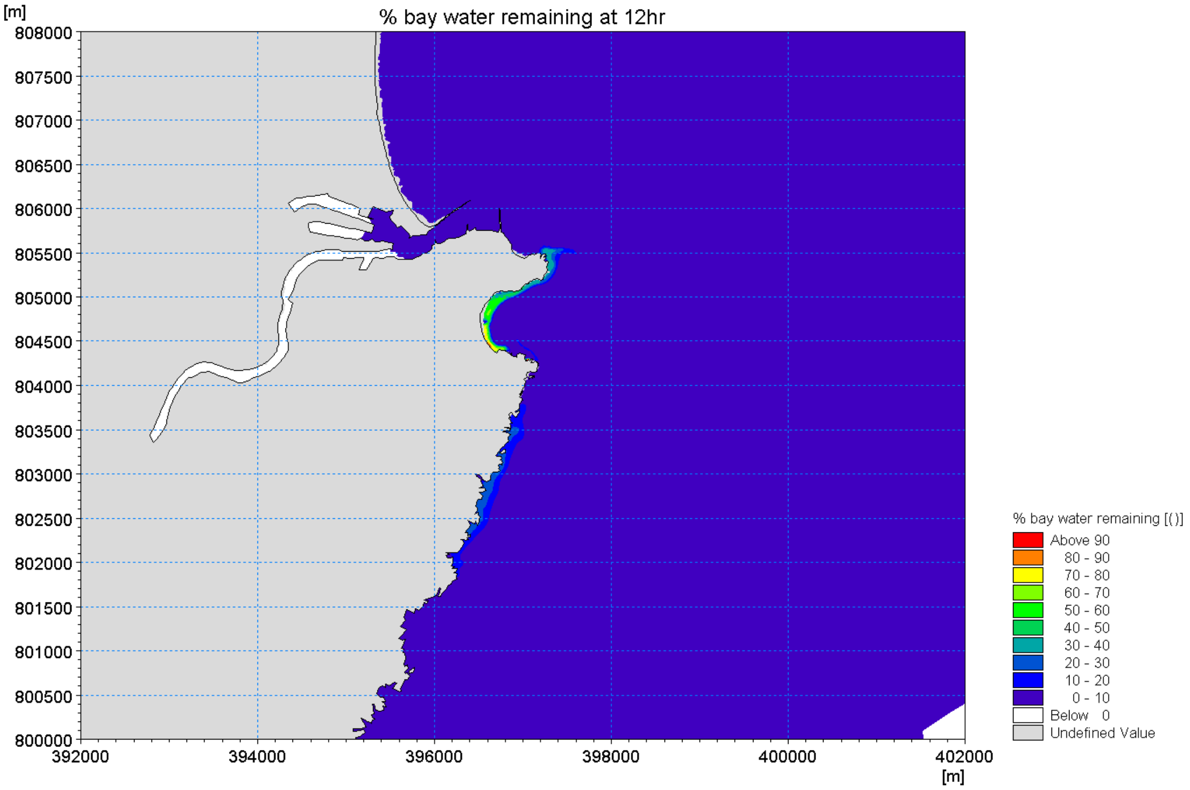


Figure E-4: Baseline - % Bay water at 24 hours after start

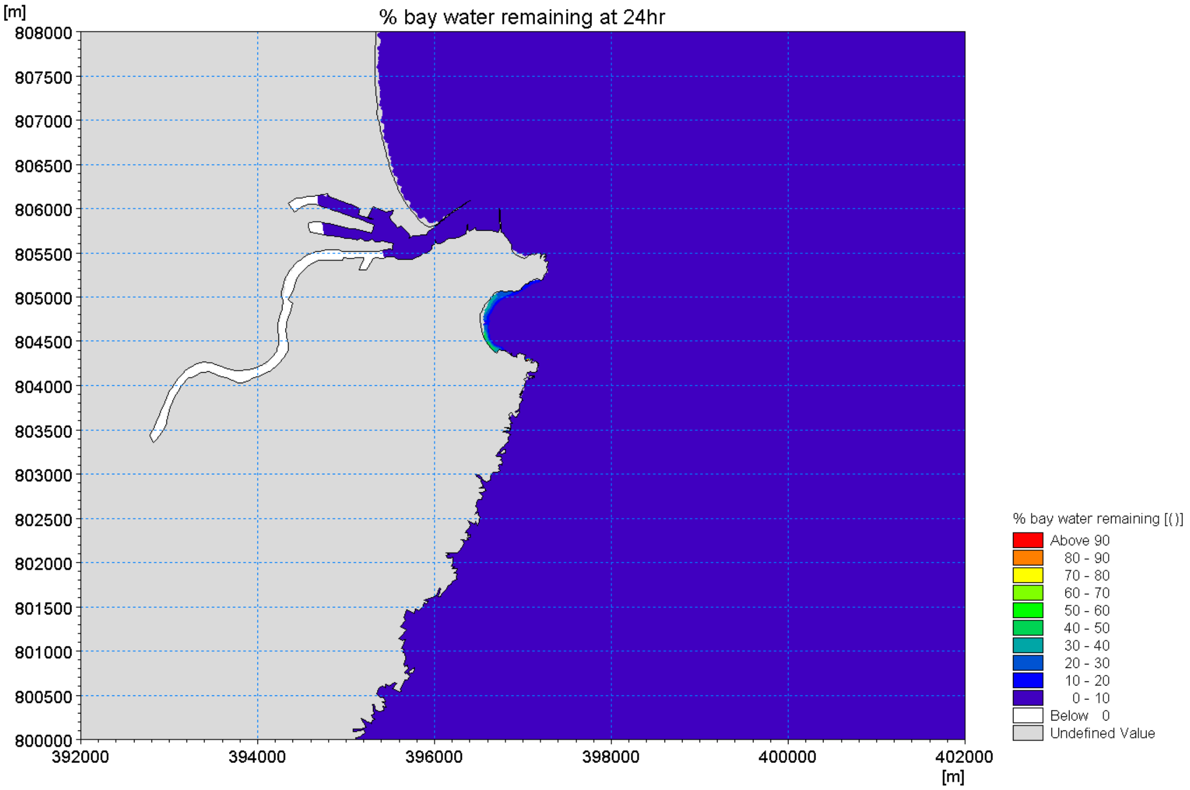


Figure E-5: Baseline - % Bay water at 10 days (240 hours) after start

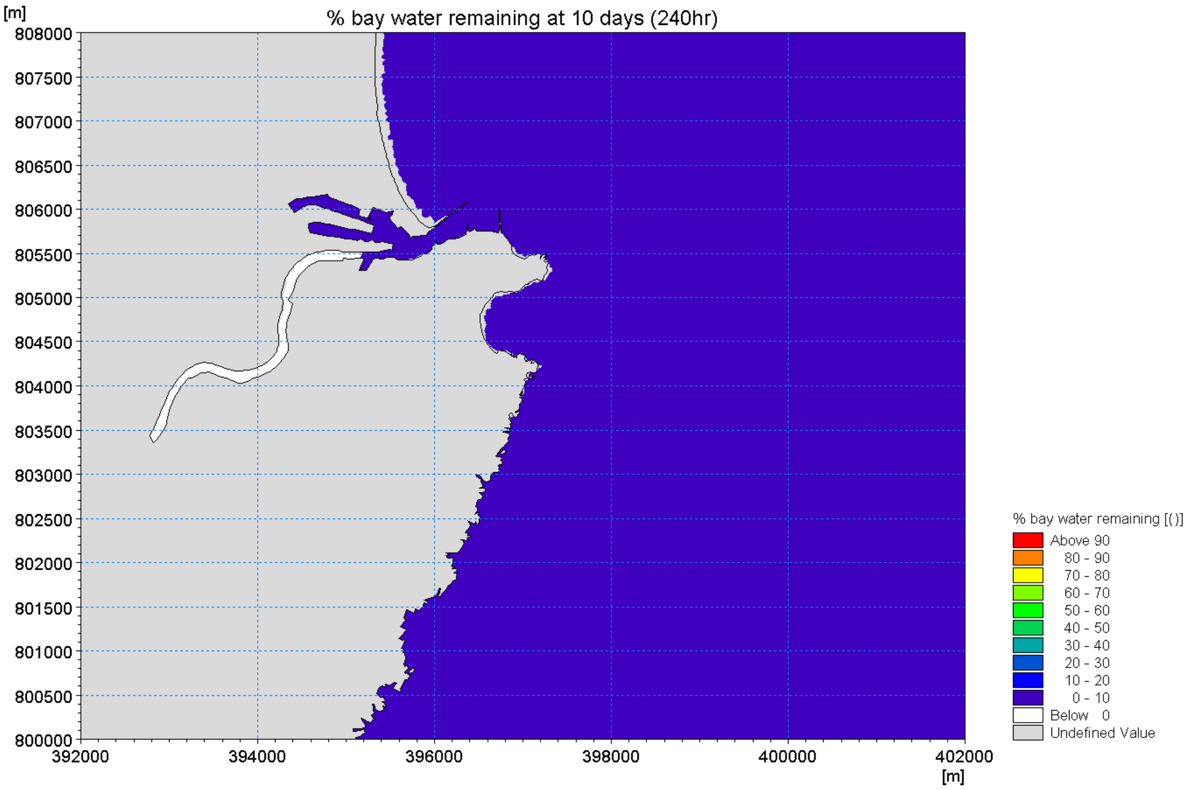


Figure E-6: Development - % Bay water at 0 hours after start

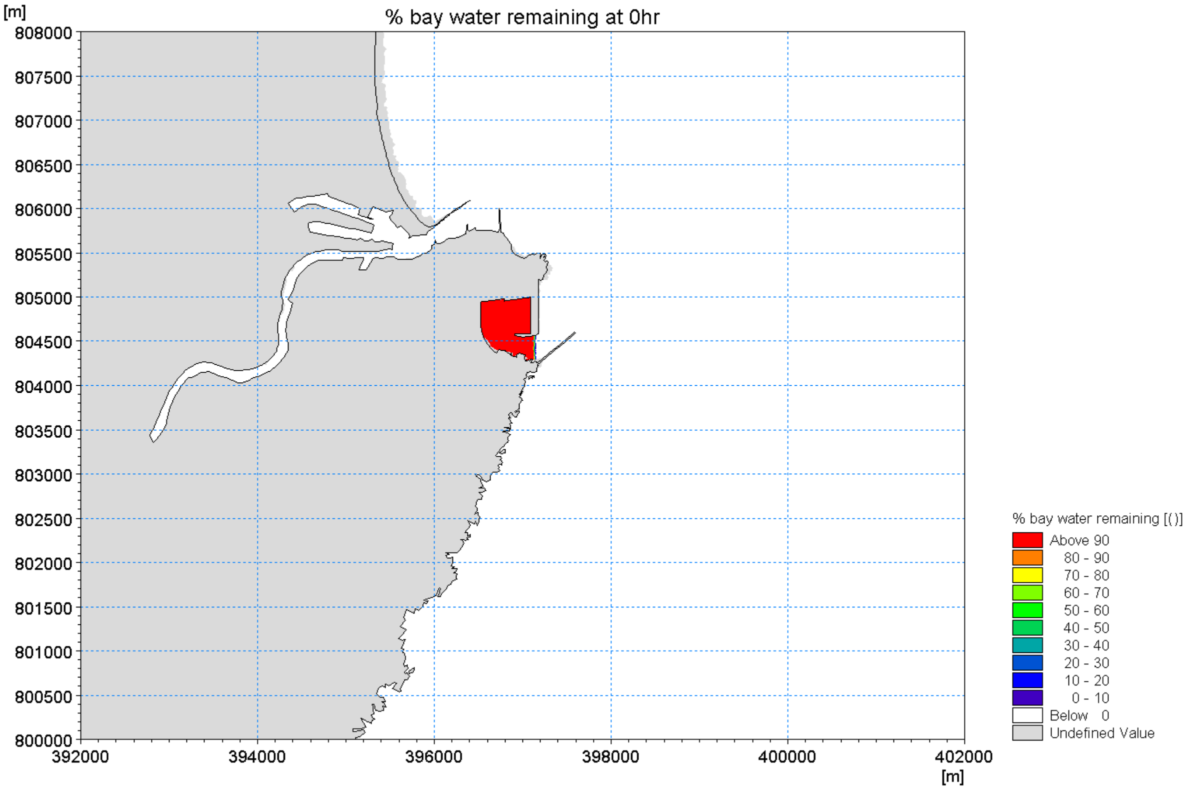


Figure E-7: Development - % Bay water at 6 hours after start

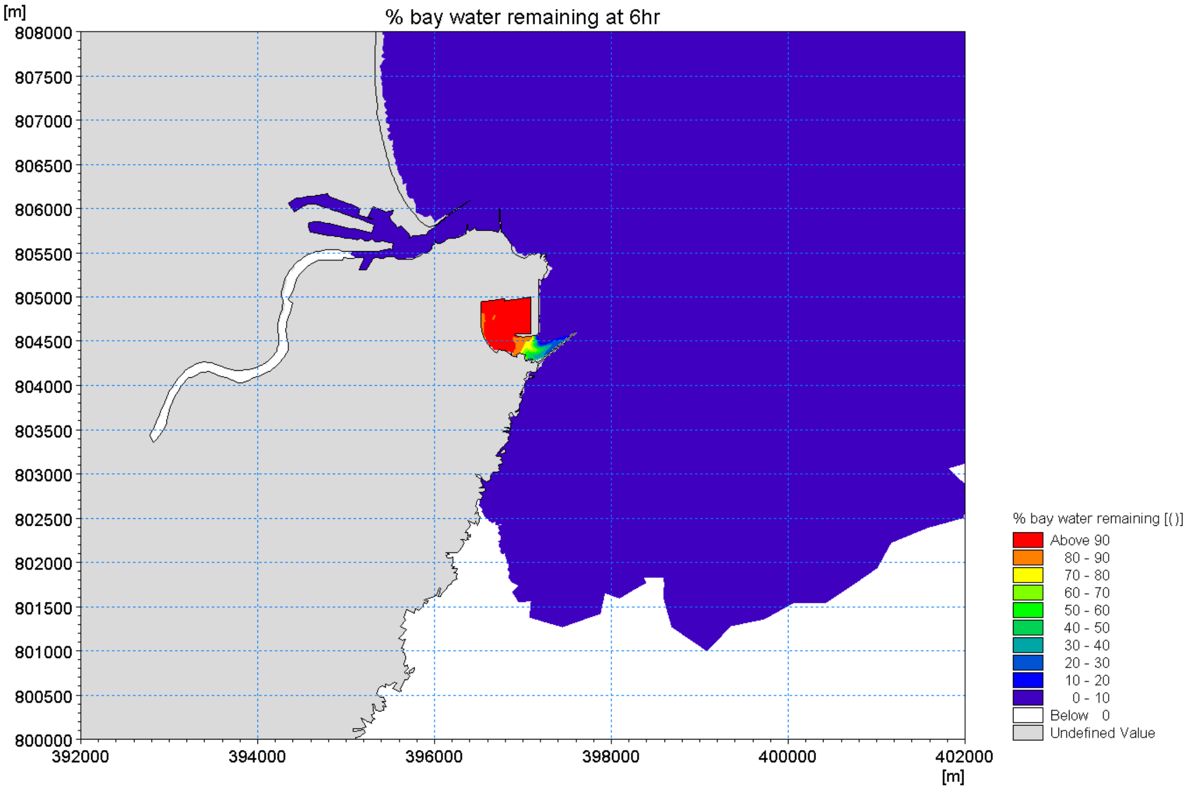


Figure E-8: Development - % Bay water at 12 hours after start

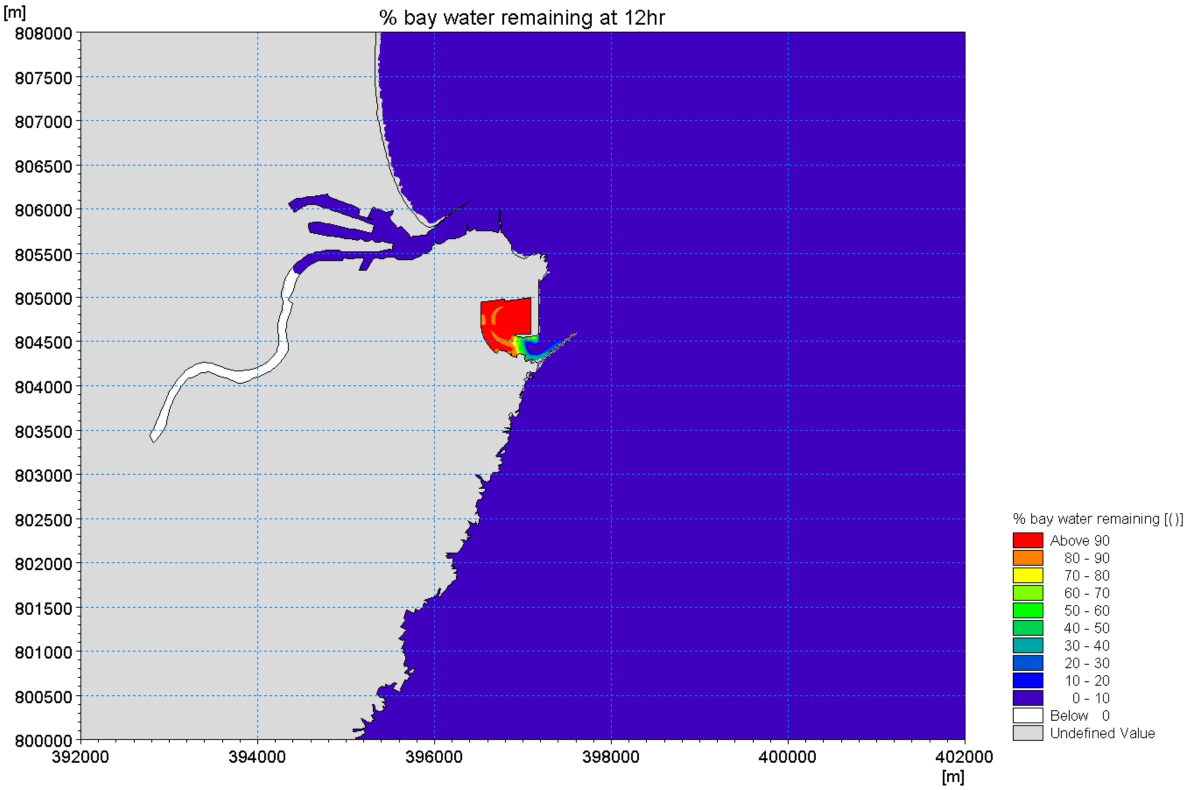


Figure E-9: Development - % Bay water at 24 hours after start

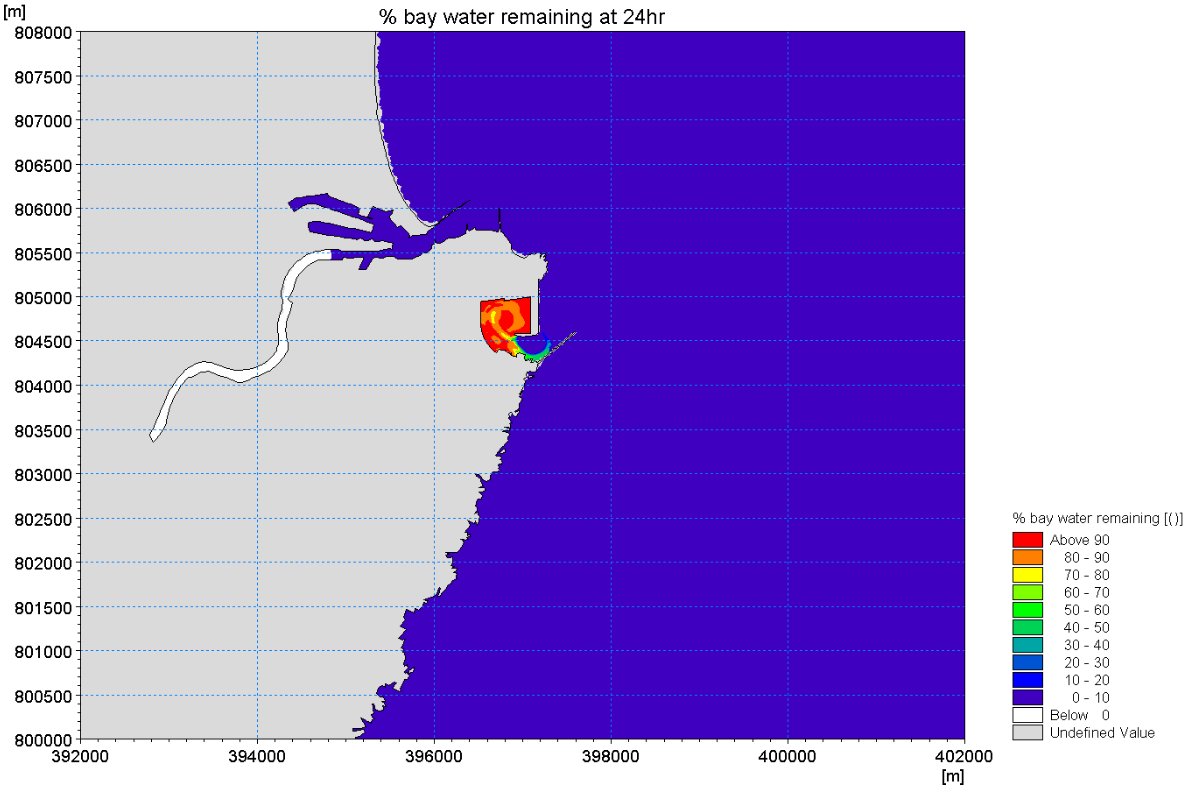


Figure E-10: Development - % Bay water at 10 days (240 hours) after start

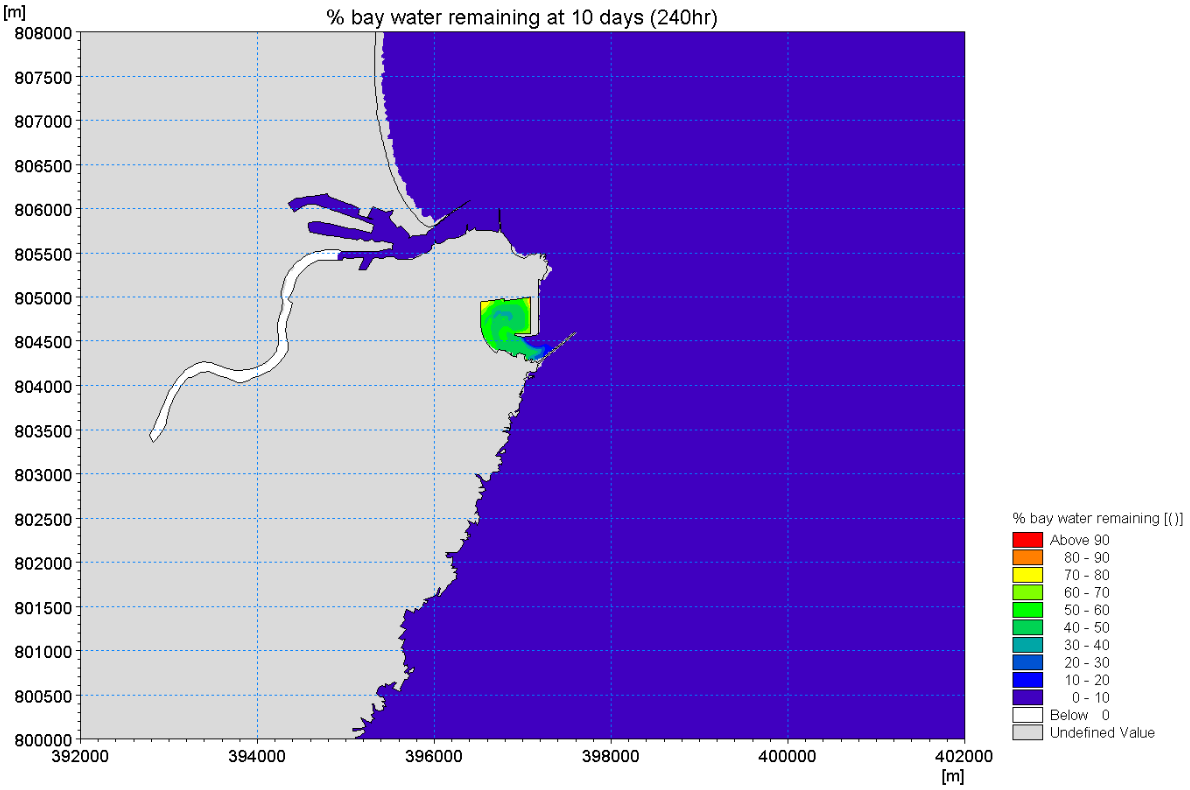


Figure E-11: Time series of Bay water concentration at Point 1

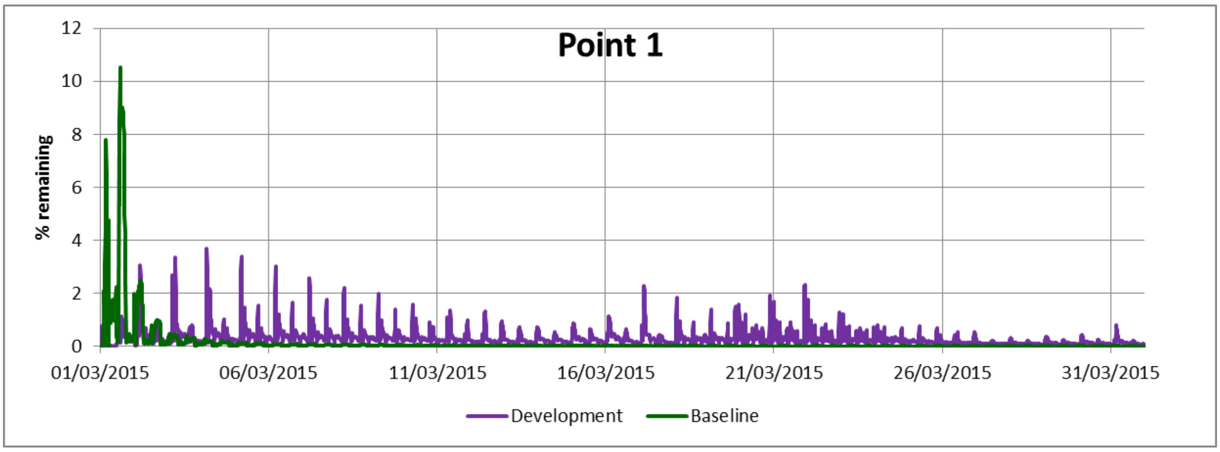


Figure E-12: Time series of Bay water concentration at Point 2

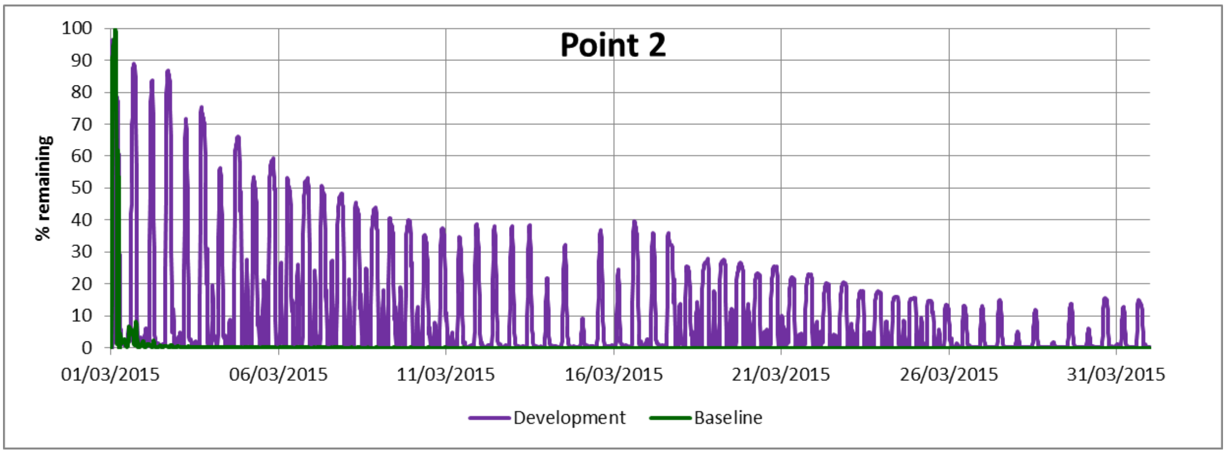


Figure E-13: Time series of Bay water concentration at Point 3

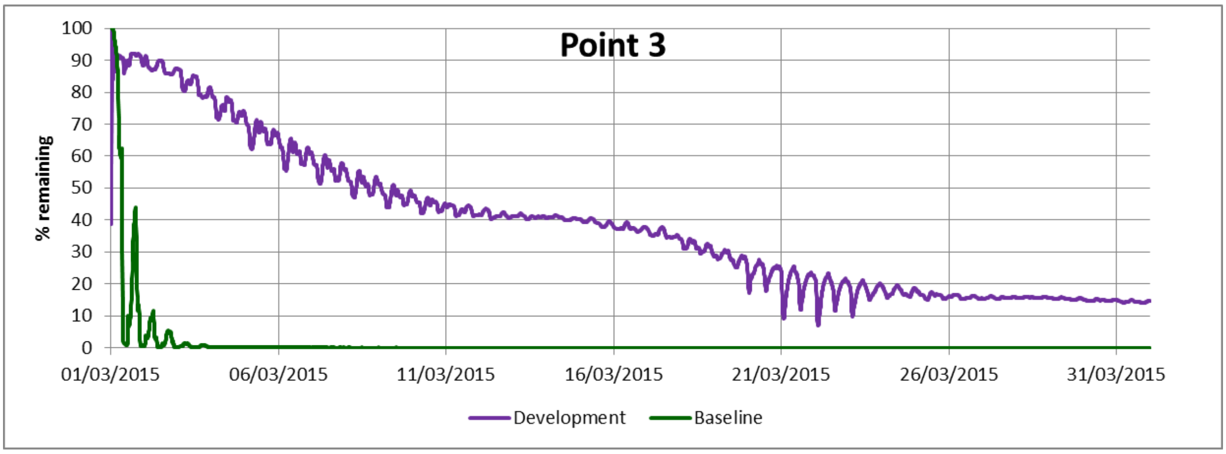


Figure E-14: Time series of Bay water concentration at Point 4

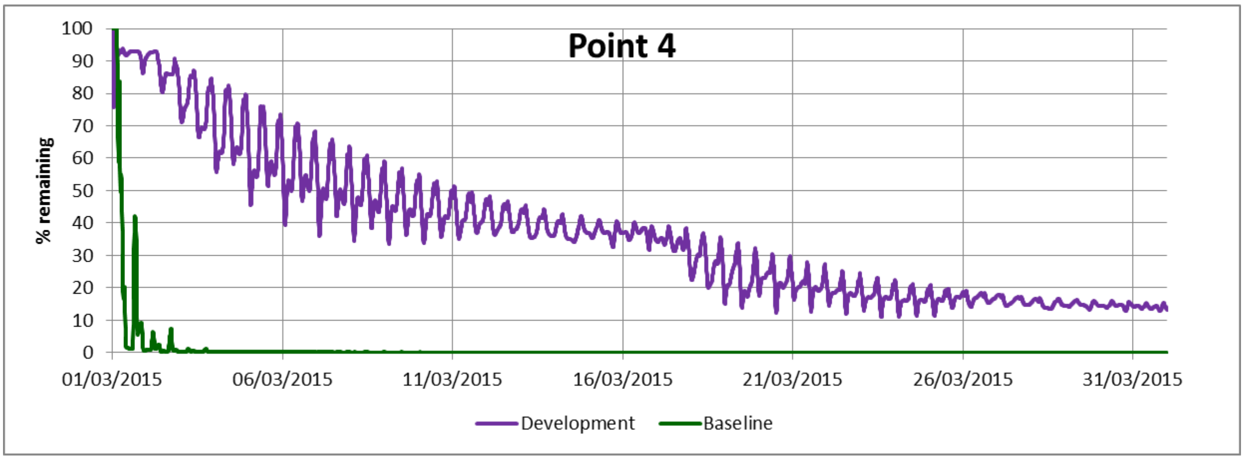


Figure E-15: Time series of Bay water concentration at Point 5

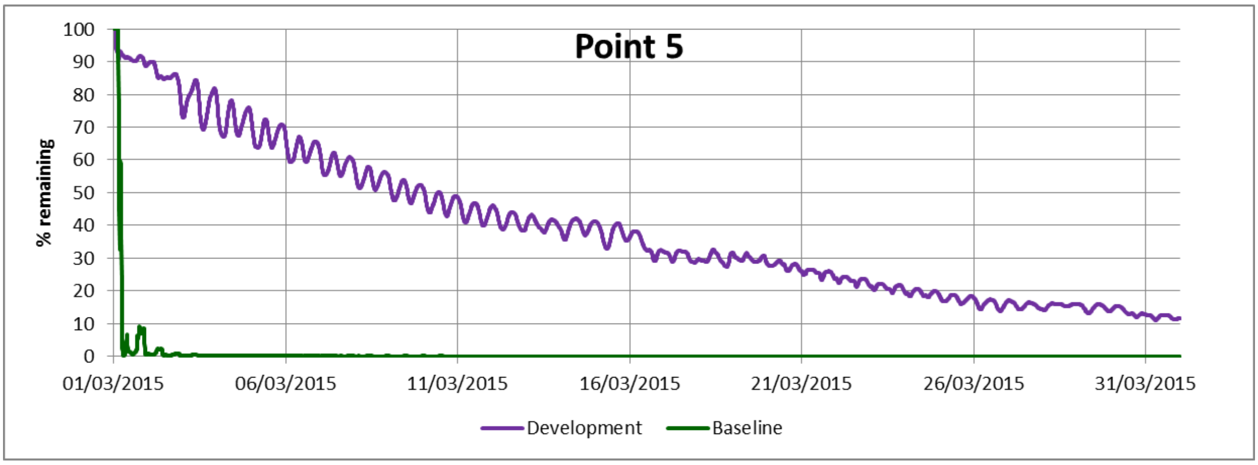


Figure E-16: Time series of Bay water concentration at Point 6

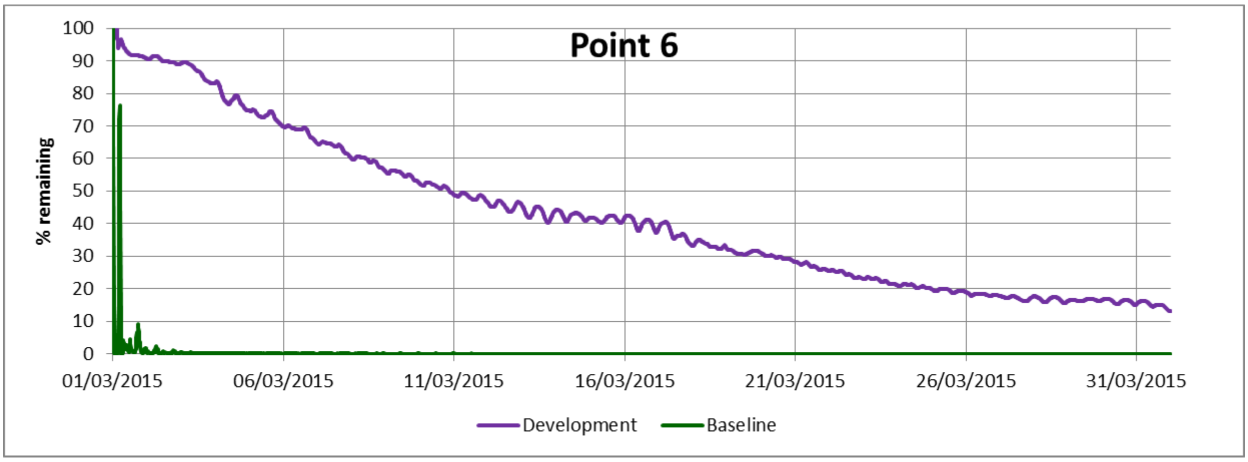


Figure E-17: Time series of Bay water concentration at Point 7

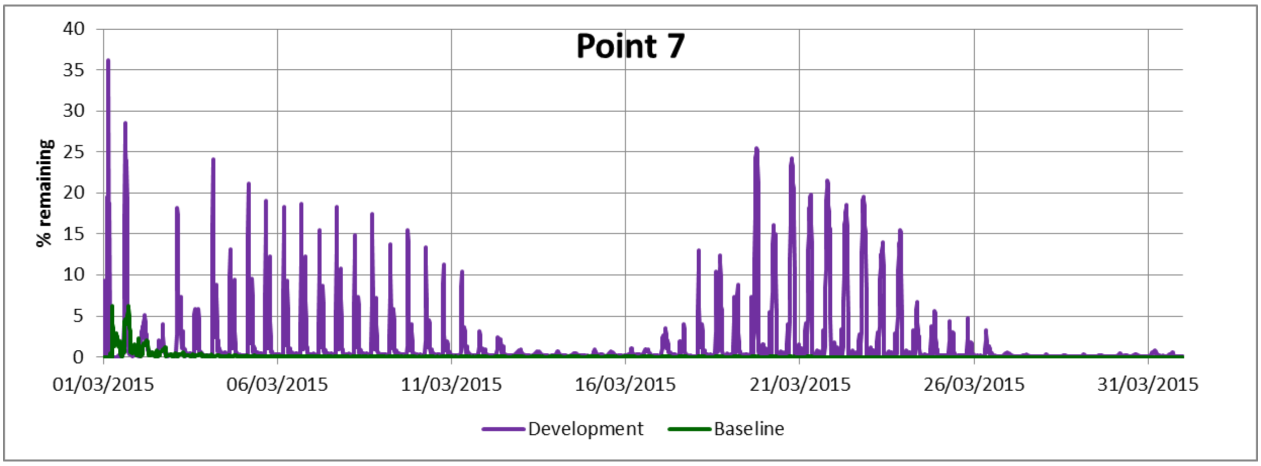


Figure E-18: Time series of Bay water concentration at SSSI point 1

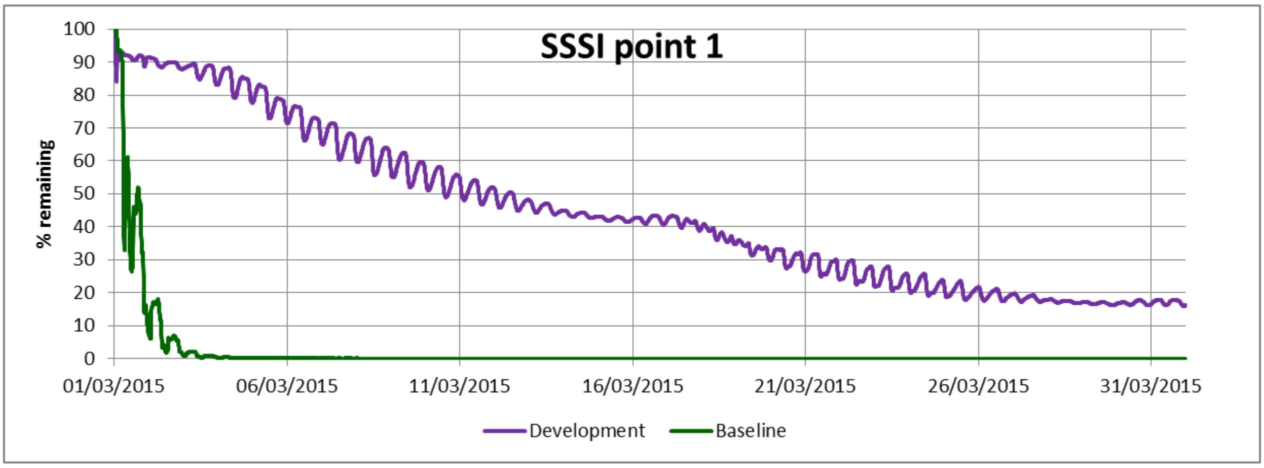


Figure E-19: Time series of Bay water concentration at SSSI point 2

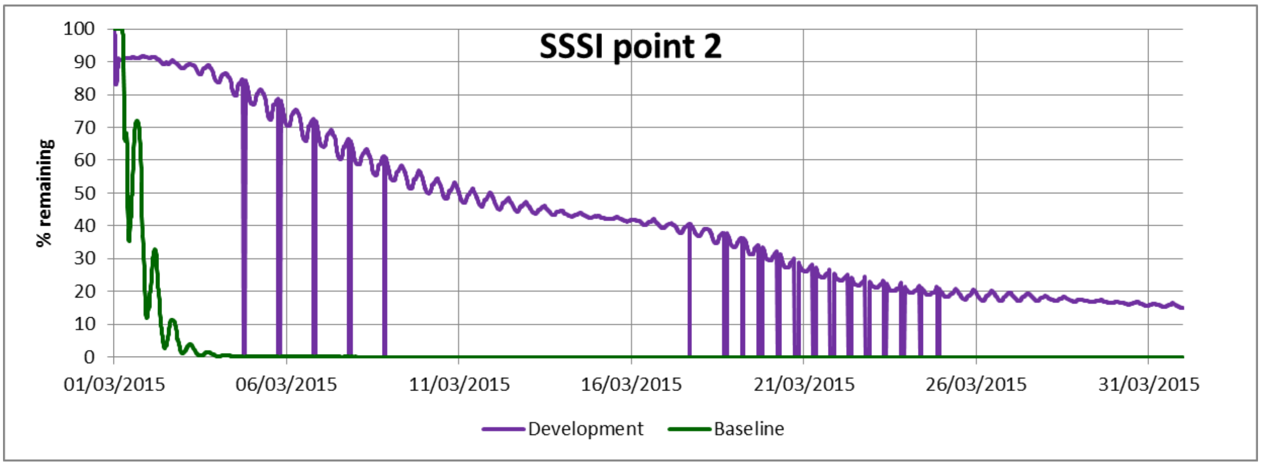


Figure E-20: Time series of Bay water concentration at Bathing Water point

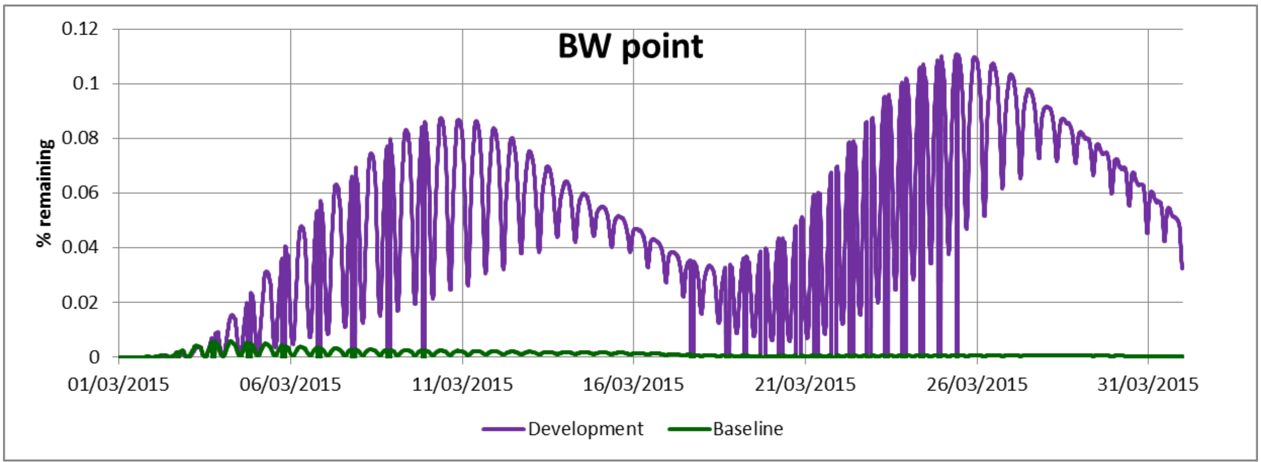


Table E-1: % of Bay water remaining at points 1 & 2

Point 1			Point 2		
Time / hrs	% 'Bay' water		Time / hrs	% 'Bay' water	
	baseline	development		baseline	development
0	0.00	0.00	0	0.00	0.00
3	1.89	0.01	3	98.77	77.50
6	3.24	0.01	6	0.15	23.57
9	1.35	0.00	9	2.17	0.97
12	0.36	0.05	12	2.21	0.88
24	0.41	0.19	24	0.22	2.35
48	0.14	0.16	48	0.48	2.21
120	0.02	0.29	120	0.03	1.05
240	0.00	0.23	240	0.01	8.61
480	0.00	1.05	480	0.00	1.19
720	0.00	0.08	720	0.00	0.75

Table E-2: % of Bay water remaining at points 3 & 4

Point 3			Point 4		
Time / hrs	% 'Bay' water		Time / hrs	% 'Bay' water	
	baseline	development		baseline	development
0	100.00	100.00	0	100.00	100.00
3	95.38	86.34	3	99.34	92.38
6	62.74	91.27	6	55.05	93.02
9	1.50	88.08	9	7.37	91.96
12	4.48	89.53	12	1.10	92.71
24	0.61	89.45	24	0.81	91.27
48	0.28	87.26	48	0.27	74.44
120	0.06	66.01	120	0.06	61.58
240	0.02	44.39	240	0.03	48.12
480	0.01	23.46	480	0.01	20.37
720	0.00	14.98	720	0.00	14.27

Table E-3: % of Bay water remaining at points 5 & 6

Point 5			Point 6		
Time / hrs	% 'Bay' water		Time / hrs	% 'Bay' water	
	baseline	development		baseline	development
0	100.00	100.00	0	100.00	100.00
3	98.65	95.24	3	0.01	99.20
6	4.69	92.12	6	0.02	96.30
9	5.45	91.31	9	1.81	93.36
12	1.01	90.68	12	3.32	91.98
24	0.94	89.35	24	0.31	90.64
48	0.28	73.34	48	0.43	89.23
120	0.05	67.20	120	0.03	69.76
240	0.04	48.47	240	0.04	48.89
480	0.01	26.14	480	0.01	28.21
720	0.00	12.73	720	0.00	15.22

Table E-4: % of Bay water remaining at point 7

Point 7		
Time / hrs	% 'Bay' water	
	baseline	development
0	0.00	0.00
3	0.00	16.25
6	0.00	0.02
9	2.85	0.00
12	0.31	0.06
24	0.25	0.12
48	0.09	0.16
120	0.08	0.31
240	0.06	0.09
480	0.02	0.37
720	0.00	0.07

Table E-5: % of Bay water remaining at SSSI points 1 & 2

SSSI point 1			SSSI point 2		
Time / hrs	% 'Bay' water		Time / hrs	% 'Bay' water	
	baseline	development		baseline	development
0	100.00	100.00	0	100.00	100.00
3	92.90	91.22	3	100.00	90.40
6	82.67	92.78	6	99.24	90.83
9	60.07	92.01	9	64.79	91.24
12	26.34	91.28	12	42.79	91.24
24	7.33	91.43	24	15.07	91.13
48	0.88	87.95	48	1.30	88.08
120	0.08	71.33	120	0.07	70.71
240	0.02	54.34	240	0.02	50.12
480	0.01	26.52	480	0.01	26.22
720	0.00	16.57	720	0.00	15.76

Table E-6: % of Bay water remaining at the bathing water point

Bathing Water point		
Time / hrs	% 'Bay' water	
	baseline	development
0	0.00	0.00
3	0.00	0.00
6	0.00	0.00
9	0.00	0.00
12	0.00	0.00
24	0.00	0.00
48	0.00	0.00
120	0.00	0.01
240	0.00	0.08
480	0.00	0.01
720	0.00	0.05

Table E-7: e-folding time for points within the proposed harbour development

	e-folding time / hr	
	baseline	development
point 3	8.2	375.7
point 4	7.2	145.8
point 5	4.2	313.3
point 6	0.7	393.0
SSSI_1	6.8	417.3
SSSI_2	10.2	406.5
Mean	6.2	342

Appendix F Metal Solubility

F.1 Cadmium

The solubility of cadmium in water is affected by pH [23]. Studies have shown that suspended or sediment-bound cadmium may dissolve when acidity increases. In natural waters, cadmium is found mainly in bottom sediments and suspended particles.

Although it unlikely that a significant proportion of the total cadmium will be available in the dissolved form, it has been assumed that all of the cadmium becomes dissolved for the purposes of the water column investigation. This assumption is very conservative.

F.2 Chromium

Many chromium compounds are relatively water insoluble. Chromium (III) compounds are water insoluble because they are largely bound to floating particles in water. Chromium (III) oxide and chromium (III) hydroxide are the only water soluble chromium (III) compounds [24]. Chromium (VI) oxide is water soluble, but chromium is only found in this form under highly alkaline conditions.

Although it unlikely that any significant proportion of the total chromium will be available in the dissolved form, it has been assumed that that all of the chromium becomes dissolved for the purposes of the water column investigation. This assumption is very conservative.

F.3 Copper

Copper metal is insoluble in water, while copper (II) (divalent) compounds such as acetate, chloride, nitrate and sulphate salts are soluble in water, whereas the oxide, carbonate and cyanide salts are insoluble [25].

It has been assumed that the dissolved copper concentration is equal to the available copper concentration. This assumption is conservative.

F.4 Lead

Elementary lead does not dissolve in water [26] however lead carbonate (Pb(II) CO_3) and lead chloride (PB(II)Cl) are soluble in water [27]. Lead hydroxide (Pb(II)OH) is also soluble and lead frequently binds to sulphur in sulphide form (S^{2-}), or to phosphor in phosphate form (PO_4^{3-}). In these forms lead is extremely insoluble, and is present as immobile compounds in the environment. It has been estimated that in the marine environment around 13% of lead is insoluble and 87% is soluble [27].

It has been assumed that the dissolved lead concentration is equal to the total lead concentration. This assumption is conservative.

F.5 Mercury

Inorganic mercury can be converted to methylmercury by anaerobic organisms in rivers and esturaries [28]. However, these biological processes cannot account for all of the methylmercury that is formed and it is likely that chemical reactions represent another route for mercury methylation in the aquatic environment [29].

Based on this evidence, it has been assumed that all of the mercury becomes dissolved for the purposes of the water column investigation. This assumption is very conservative.

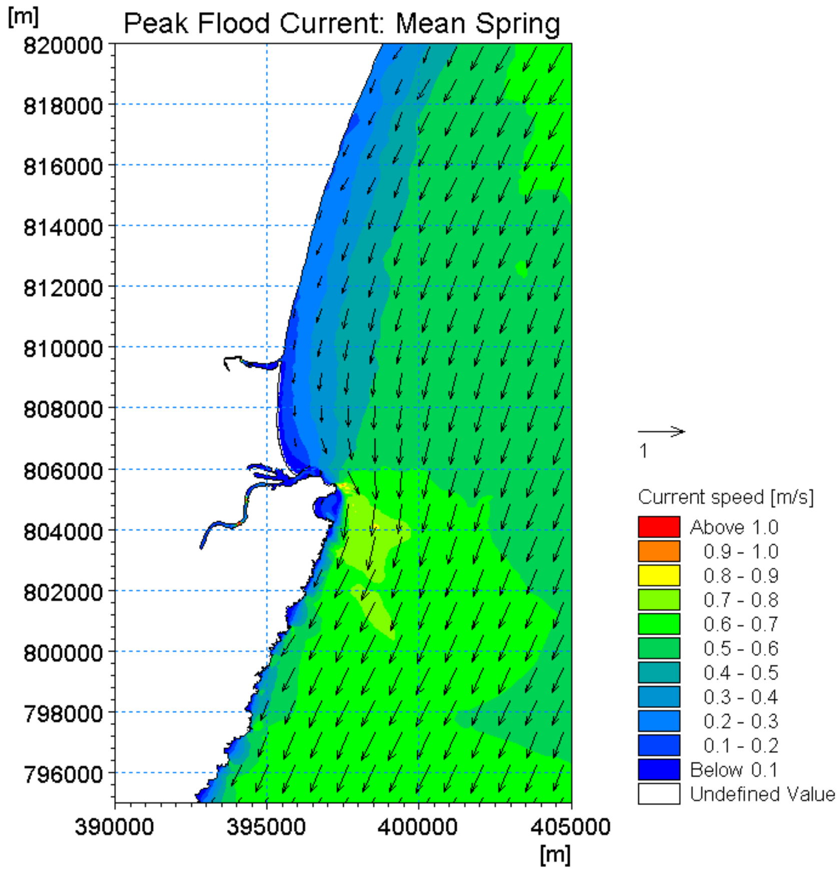
Appendix G Tidal Conditions

FIGURES

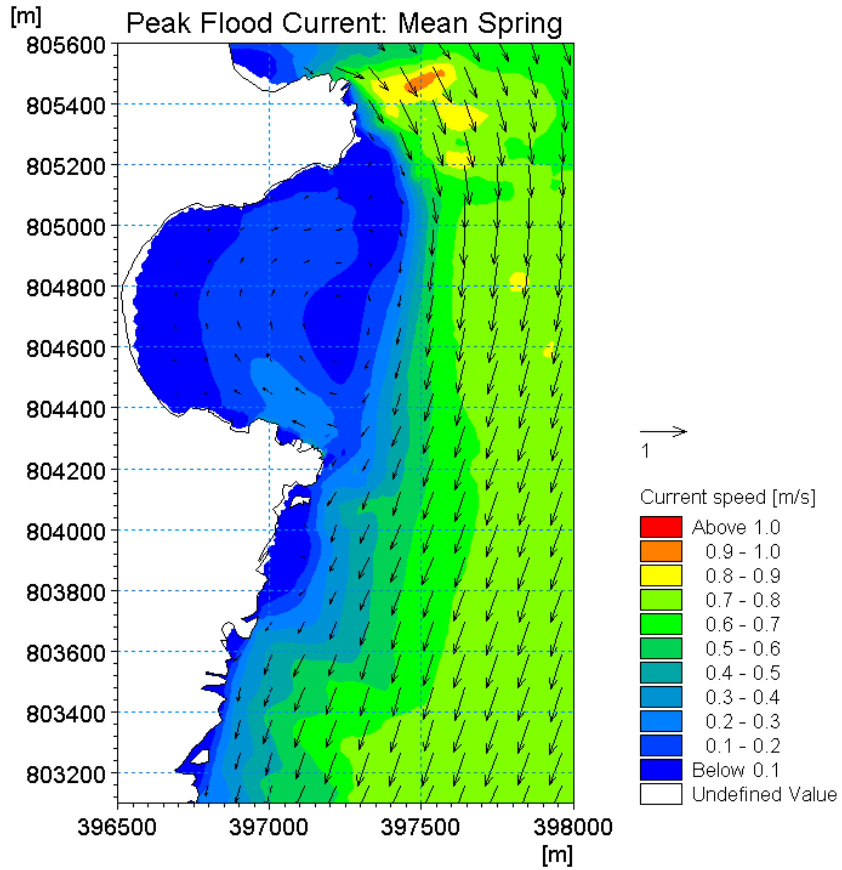
Figure G-1: Tidal current speed and direction on a mean spring tide

Flood Tide

Over a Large Extent



Local to the Development



Ebb Tide

Over a Large Extent

Local to the Development

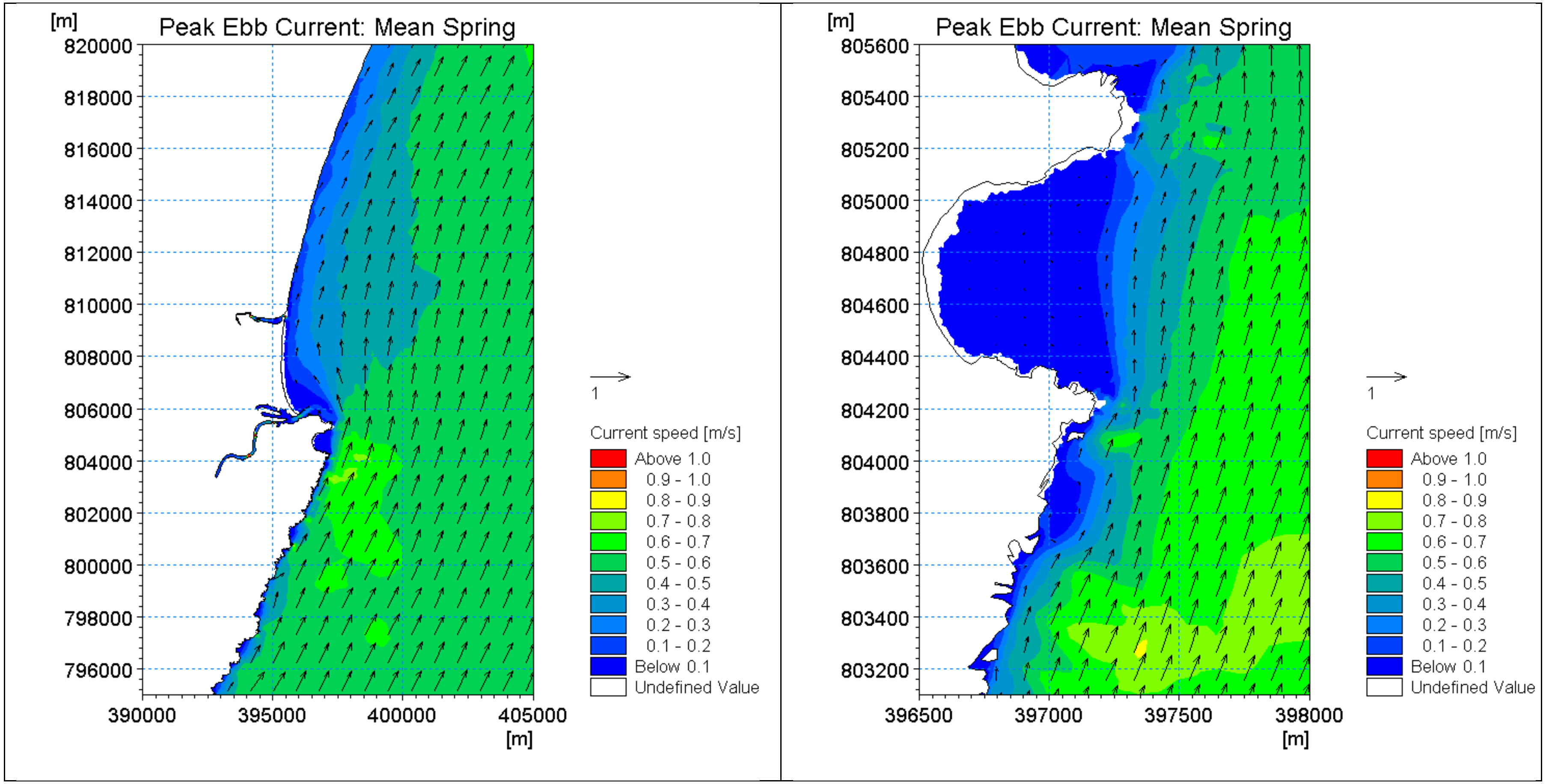
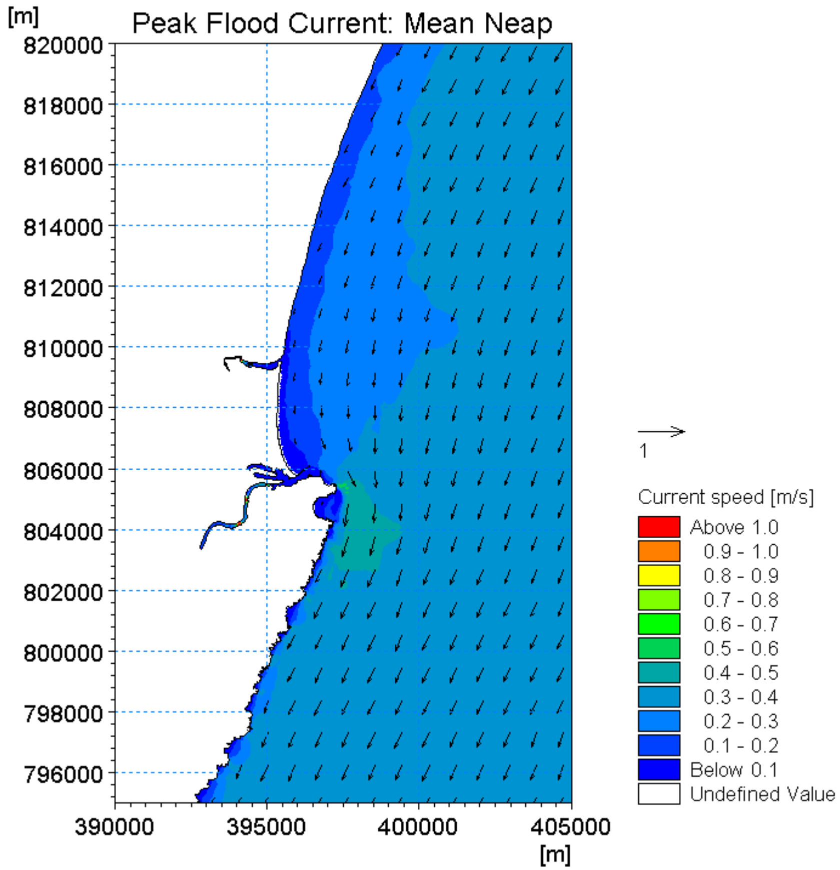

Peak Ebb Current: Mean Spring
[m]
820000
818000
816000
814000
812000
810000
808000
806000
804000
802000
800000
798000
796000
390000
395000
400000
405000
[m]
1
Current speed [m/s]
Above 1.0
0.9 - 1.0
0.8 - 0.9
0.7 - 0.8
0.6 - 0.7
0.5 - 0.6
0.4 - 0.5
0.3 - 0.4
0.2 - 0.3
0.1 - 0.2
Below 0.1
Undefined Value
Peak Ebb Current: Mean Spring
[m]
805600
805400
805200
805000
804800
804600
804400
804200
804000
803800
803600
803400
803200
396500
397000
397500
398000
[m]
1
Current speed [m/s]
Above 1.0
0.9 - 1.0
0.8 - 0.9
0.7 - 0.8
0.6 - 0.7
0.5 - 0.6
0.4 - 0.5
0.3 - 0.4
0.2 - 0.3
0.1 - 0.2
Below 0.1
Undefined Value

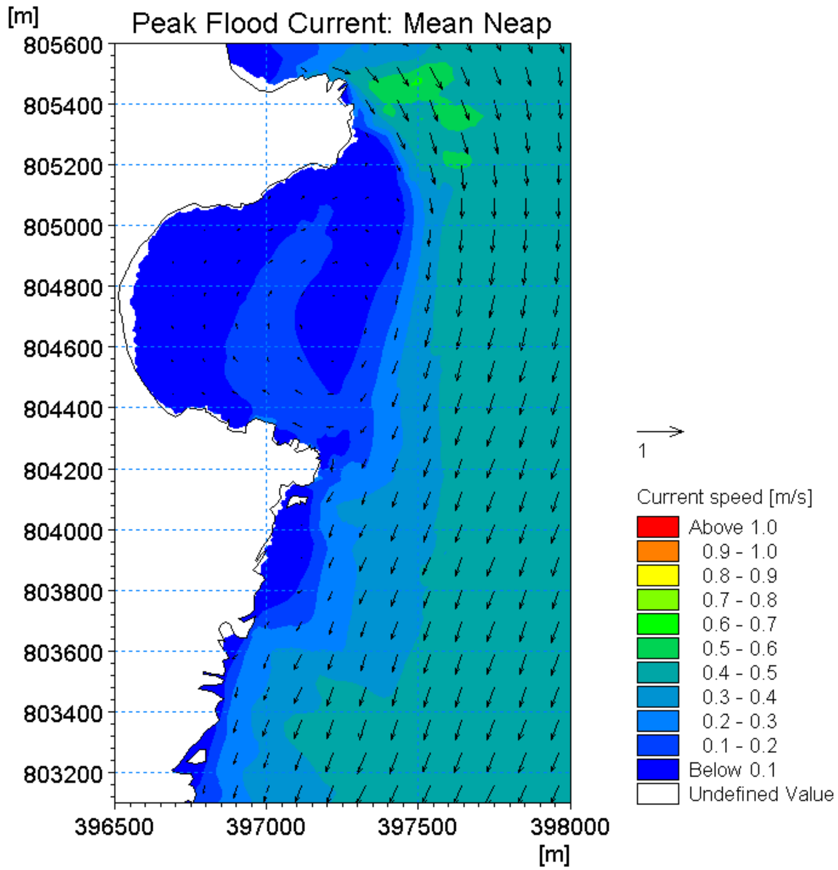
Figure G-2: Tidal current speed and direction on a mean neap tide

Flood Tide

Over a Large Extent



Local to the Development



Ebb Tide	
Over a Large Extent	Local to the Development