3FMProject

Bringing
Dublin Port
To 2040

Environmental Impact Assessment Report

Appendix 13.3

Volume 3 Part 7

COMHLACHT CHALAFORT
ÁTHA CLIATH
DUBLIN PORT COMPANY

rps
A TETRA TECH COMPANY

Third & Final
Masterplan
Project

DUBLIN PORT 3FM

Thermal Plume Validation Report

IBE2022
29 May 2024

rpsgroup.com

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
Rev 00	Draft	NRS	KC	AKB	21/03/2024
Rev01	Updated modelling	NRS	KC	AKB	30/04/2024
Rev02	Final	NRS	KC	AKB	29/05/2024

Approval for issue

A. Bell	Adrian K. Bell	31/05/2024

Prepared by:

RPS

Dr Naomi Shannon
Principal Engineer - Water Environment and Flood Risk Management

Elmwood House
74 Boucher Road, Belfast
Co. Antrim BT12 6RZ

E naomi.shannon@rps.tetratech.com

Prepared for:

Dublin Port Company

Máiréad Rushe
Project Manager,
Programme Management Office

Port Centre, Alexandra Rd,
North Dock, Dublin, D01 H4C6,
Ireland

T +353 (0) 1 8876075

Contents

1 THERMAL PLUME MODELLING VALIDATION 1
1.1 Purpose of this Report 1
1.2 Model Structure 1
1.3 Hydrodynamic Model Verification 4
1.4 Thermal Plume Modelling Results 6
1.4.1 Initial Modelling 7
1.4.2 Further Modelling 13
1.4.3 Thermal Plume Modelling Discussion 15
1.4.4 Additional Modelling 32
1.4.5 Assessing Model Performance 44
1.5 Summary 45

Tables

Table 1.1: River Discharge Rates [cumecs] 1
Table 1.2: Background Temperature 1
Table 1.3: Thermal discharges active during each survey period. 7
Table 1.4: Recorded thermal plume data for the Spring tides as reported by 2018 survey 39
Table 1.5: Modelled thermal plume data for the Spring tides *(note difference in daylight savings)* 39
Table 1.6: Recorded thermal plume data for the Neap tides as reported by 2018 survey 39
Table 1.7: Modelled thermal plume data for the Neap tides *(note difference in daylight savings)* 39

Figures

Figure 1.1: Outer model bathymetry and mesh (right). 2
Figure 1.2: Inner model bathymetry and mesh (top). 3
Figure 1.3: Verification of predicted tidal heights for the 2016 survey period. 4
Figure 1.4: Verification of predicted tidal heights for the 2018 survey period. 5
Figure 1.5: Verification of predicted tidal heights for the 2019 survey period. 5
Figure 1.6: Drying out within the vicinity of Poolbeg CCGT outfall location. 6
Figure 1.7: Thermal plume outfall locations. 7
Figure 1.8: Location of section to illustrate sigma layer definition. 8
Figure 1.9: Initial thermal modelling equidistant sigma layers. 8
Figure 1.10: Preliminary model output: Temperature of surface layer mid-flood spring tide. 9
Figure 1.11: Survey contour: Excess temperature of surface layer mid-flood spring tide. 9
Figure 1.12: Preliminary model output: Temperature of surface layer high water spring tide. 10
Figure 1.13: Survey contour: Excess temperature of surface layer high water spring tide. 10
Figure 1.14: Preliminary model output: Temperature of surface layer mid-ebb spring tide. 11
Figure 1.15: Survey contour: Excess temperature of surface layer mid-ebb spring tide. 11
Figure 1.16: Preliminary model output: Temperature of surface layer low water spring tide. 12
Figure 1.17: Survey contour: Excess temperature of surface layer low water spring tide. 12
Figure 1.18: Further thermal modelling sigma layers variation through water column. 13
Figure 1.19: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 0.3m depth. 16
Figure 1.20: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 1m depth. 16
Figure 1.21: Survey contour 20th April 2018 – excess temperature at mid-flood 0.3m depth. 17
Figure 1.22: Survey contour 20th April 2018 – excess temperature at mid-flood 1m depth. 17
Figure 1.23: Thermal plume 20th April 2018 – excess temperature at high water circa 0.3m depth. 18
Figure 1.24: Thermal plume 20th April 2018 – excess temperature at high water circa 1m depth. 18
Figure 1.25: Survey contour 20th April 2018 – excess temperature at high water 0.3m depth. 19

Figure 1.26: Survey contour 20th April 2018 – excess temperature at high water 1m depth. 19
Figure 1.27: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 0.3m depth. 20
Figure 1.28: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 1m depth. 20
Figure 1.29: Survey contour 20th April 2018 – excess temperature at mid-ebb 0.3m depth. 21
Figure 1.30: Survey contour 20th April 2018 – excess temperature at mid-ebb 1m depth. 21
Figure 1.31: Thermal plume 20th April 2018 – excess temperature at low water circa 0.3m depth. 22
Figure 1.32: Thermal plume 20th April 2018 – excess temperature at low water circa 1m depth. 22
Figure 1.33: Survey contour 20th April 2018 – excess temperature at low water 0.3m depth. 23
Figure 1.34: Survey contour 20th April 2018 – excess temperature at low water 1m depth. 23
Figure 1.35: Survey contour 24th April 2018 – excess temperature at mid-flood 0.3m depth. 24
Figure 1.36: Survey contour 24th April 2018 – excess temperature at mid-flood 1m depth. 24
Figure 1.37: Survey contour 24th April 2018 – excess temperature at mid-flood 2m depth. 25
Figure 1.38: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 0.3m depth. 25
Figure 1.39: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 1m depth. 26
Figure 1.40: Thermal plume 20th April 2018 – excess temperature at low water circa 2m depth. 26
Figure 1.41: Approximate Locations of Vertical Dips 27
Figure 1.42: Surveyed vertical profile – 24th April 2018 high water plus 47mins 28
Figure 1.43: Modelled vertical profile – 24th April 2018 high water plus 47mins 28
Figure 1.44: Surveyed vertical profile – 24th April 2018 high water plus 4hrs 29
Figure 1.45: Modelled vertical profile – 24th April 2018 high water plus 4hrs 29
Figure 1.46: Surveyed vertical profile – 24th April 2018 low water plus 36mins 30
Figure 1.47: Modelled vertical profile – 24th April 2018 low water plus 36mins 30
Figure 1.48: Surveyed vertical profile – 24th April 2018 high water minus 2hrs 31
Figure 1.49: Modelled vertical profile – 24th April 2018 high water minus 2hrs 31
Figure 1.50: Spillway discharges 2020, 2021 & 2024 (Source: Google Earth) 32
Figure 1.51: Ringsend Generating Station – C.W. Culvert Outfall Preliminary Drawing 25-05-1965 33
Figure 1.52: Survey contour 24th April 2018 – excess temperature at mid-flood 1m depth. 34
Figure 1.53: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 1m depth (layer 5). 34
Figure 1.54: Surveyed vertical profile – 24th April 2018 high water plus 47mins 35
Figure 1.55: Modelled vertical profile – 24th April 2018 high water plus 47mins 35
Figure 1.56: Surveyed vertical profile – 24th April 2018 high water plus 4hrs 36
Figure 1.57: Modelled vertical profile – 24th April 2018 high water plus 4hrs 36
Figure 1.58: Surveyed vertical profile – 24th April 2018 low water plus 36mins 37
Figure 1.59: Modelled vertical profile – 24th April 2018 low water plus 36mins 37
Figure 1.60: Surveyed vertical profile – 24th April 2018 high water minus 2hrs 38
Figure 1.61: Modelled vertical profile – 24th April 2018 high water minus 2hrs 38
Figure 1.62: Survey contour 9th April 2019 – excess temperature at low water 0.3m depth. 40
Figure 1.63: Thermal plume 9th April 2019 – excess temperature at low water circa 0.3m depth (layer 6). 41
Figure 1.64: Bathymetry to mean sea level Dublin Port 41
Figure 1.65: Survey contour 9th April 2019 – excess temperature at mid-ebb 0.3m depth. 42
Figure 1.66: Thermal plume 9th April 2019 – excess temperature at mid-ebb layer 6. 42
Figure 1.67: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa layer 3. 43
Figure 1.68: Poolbeg CCGT discharge pier 43
Figure 1.69: Thermal plume 9th April 2019 – excess temperature at mid-ebb profile. 44
Figure 1.70: Thermal plume 12th August 2016 – excess temperature at high water circa 0.3m depth layer 6 48
Figure 1.71: Thermal plume 12th August 2016 – excess temperature at high water circa 1m depth layer 5 49
Figure 1.72: Thermal plume 12th August 2016 – excess temperature at high water circa 2m depth layer 4 50

Figure 1.73: Thermal plume 12th August 2016 – excess temperature at mid-ebb circa 0.3m depth layer 6 51
Figure 1.74: Thermal plume 12th August 2016 – excess temperature at mid-ebb circa 1m depth layer 5....52
Figure 1.75: Thermal plume 12th August 2016 – excess temperature at mid-ebb circa 2m depth layer 4....53
Figure 1.76: Thermal plume 12th August 2016 – excess temperature at low water circa 0.3m depth layer 6....54
Figure 1.77: Thermal plume 12th August 2016 – excess temperature at low water circa 1m depth layer 5 55
Figure 1.78: Thermal plume 12th August 2016 – excess temperature at low water circa 2m depth layer 3 56
Figure 1.79: Thermal plume 12th August 2016 – excess temperature at mid-flood circa 0.3m depth layer 6....57
Figure 1.80: Thermal plume 12th August 2016 – excess temperature at mid-flood circa 1m depth layer 5 58
Figure 1.81: Thermal plume 12th August 2016 – excess temperature at mid-flood circa 2m depth layer 4 59
Figure 1.82: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 0.3m depth layer 6....62
Figure 1.83: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 1m depth layer 5....63
Figure 1.84: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 2m depth layer 4....64
Figure 1.85: Thermal plume 20th April 2018 – excess temperature at high water circa 0.3m depth layer 6 65
Figure 1.86: Thermal plume 20th April 2018 – excess temperature at high water circa 1m depth layer 5....66
Figure 1.87: Thermal plume 20th April 2018 – excess temperature at high water circa 2m depth layer 4....67
Figure 1.88: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 0.3m depth layer 6....68
Figure 1.89: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 1m depth layer 5....69
Figure 1.90: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 2m depth layer 4....70
Figure 1.91: Thermal plume 20th April 2018 – excess temperature at low water circa 0.3m depth layer 6 71
Figure 1.92: Thermal plume 20th April 2018 – excess temperature at low water circa 1m depth layer 5 72
Figure 1.93: Thermal plume 20th April 2018 – excess temperature at low water circa 2m depth layer 4 73
Figure 1.94: Thermal profile 1 - 20th April 2018 – high water minus 2.25 hours 74
Figure 1.95: Thermal profile 2 - 20th April 2018 – high water plus 1 hour 74
Figure 1.96: Thermal profile 3 - 20th April 2018 – low water....75
Figure 1.97: Thermal plume 24th April 2018 – excess temperature at high water circa 0.3m depth layer 6 77
Figure 1.98: Thermal plume 24th April 2018 – excess temperature at high water circa 1m depth layer 5....78
Figure 1.99: Thermal plume 24th April 2018 – excess temperature at high water circa 2m depth layer 4....79
Figure 1.100: Thermal plume 24th April 2018 – excess temperature at mid-ebb circa 0.3m depth layer 6 80
Figure 1.101: Thermal plume 24th April 2018 – excess temperature at mid-ebb circa 1m depth layer 5....81
Figure 1.102: Thermal plume 24th April 2018 – excess temperature at mid-ebb circa 2m depth layer 4....82
Figure 1.103: Thermal plume 24th April 2018 – excess temperature at low water circa 0.3m depth layer 6 83
Figure 1.104: Thermal plume 24th April 2018 – excess temperature at low water circa 1m depth layer 5 84
Figure 1.105: Thermal plume 24th April 2018 – excess temperature at low water circa 2m depth layer 4 85
Figure 1.106: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 0.3m depth layer 6 86
Figure 1.107: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 1m depth layer 5....87
Figure 1.108: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 2m depth layer 4....88
Figure 1.109: Thermal profile 1 - 24th April 2018 – high water plus 47 minutes....89
Figure 1.110: Thermal profile 2 - 24th April 2018 – high water plus 4 hours 89
Figure 1.111: Thermal profile 3 - 24th April 2018 – low water plus 36 minutes 90
Figure 1.112: Thermal profile 4 - 24th April 2018 – high water minus 2 hours 90

Figure 1.113: Thermal plume 9th April 2019 – excess temperature at low water circa 0.3m depth layer 6 93
Figure 1.114: Thermal plume 9th April 2019 – excess temperature at low water circa 0.9m depth layer 5 94
Figure 1.115: Thermal plume 9th April 2019 – excess temperature at low water circa 1.8m depth 95
Figure 1.116: Thermal plume 9th April 2019 – excess temperature at mid-flood circa 0.3m depth layer 6.....96
Figure 1.117: Thermal plume 9th April 2019 – excess temperature at mid-flood circa 0.9m depth layer 5.....97
Figure 1.118: Thermal plume 9th April 2019 – excess temperature at mid-flood circa 1.8m depth layer 4.....98
Figure 1.119: Thermal plume 9th April 2019 – excess temperature at high water circa 0.3m depth layer 6 99
Figure 1.120: Thermal plume 9th April 2019 – excess temperature at high water circa 0.9m depth layer 5 100
Figure 1.121: Thermal plume 9th April 2019 – excess temperature at high water circa 1.8m depth layer 3 101
Figure 1.122: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa 0.3m depth layer 6.....102
Figure 1.123: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa 0.9m depth layer 4.....103
Figure 1.124: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa 1.8m depth layer 3.....104

Appendices

Appendix A 46
A.1 Thermal Survey August 2016.....47

Appendix B 60
B.1 Thermal Survey Spring Tide 20th April 2018.....61
B.1.1 Thermal Survey – Contours of Excess Temperature 61
B.1.2 Thermal Survey – Vertical profiles.....74
B.2 Thermal Survey Neap Tide 24th April 2018.....76
B.2.1 Thermal Survey – Contours of Excess Temperature 76
B.2.2 Thermal Survey – Vertical Profiles 89

Appendix C 91
C.1 Thermal Survey 9th April 2019.....92

1 THERMAL PLUME MODELLING VALIDATION

1.1 Purpose of this Report

A numerical modelling study is being undertaken to quantify the potential impact of the proposed Dublin Port 3FM development on the existing tidal flows and thermal stratification due to both freshwater river inflows and outfall discharges and intakes. Prior to assessing the potential impact of the 3FM development it was critical to first calibrate the thermal plume model based on the present-day scenario. To assist with this work package, ESB supplied three thermal plume survey reports to enable model verification and therefore increase confidence in the outcomes of the numerical modelling studies.

This report details phases of development, the most recent of which occurred in April 2024 following additional feedback from ESB, and the validation between the thermal plume modelling and surveys.

1.2 Model Structure

The modelling was undertaken using the DHI MIKE modelling software suite. The model was implemented using a three dimensional (3D) model domain and included density driven flow – both in terms of salinity and temperature. It was of particular importance to establish accurate tidal flows in Dublin Port given the complex interaction of multiple freshwater rivers that flow into Dublin Port which contributes to dynamic temporally and spatially varying pycnocline throughout much of the Port area. To achieve this, RPS developed two individual numerical models using the Hydrodynamic (HD) module within MIKE 21 to simulate water level variations and flows into Dublin Port, for each of the following timeframes to correspond with the survey periods:

- 10th August – 13th August 2016
- 19th April – 25th April 2018
- 5th April – 11th April 2019

The first "outer tidal" model was developed for the purpose of deriving a suitable tidal boundary condition to apply to the mode detailed "inner" model of Dublin Bay and Dublin Port. The "outer" model (shown in Figure 1.1) uses mesh sizes varying from 250,000 m^2 (equivalent to 500m x 500m squares) at the outer boundary of the model down to a finer 225 m^2 (equivalent to 15m x 15m squares). The outer tidal hydrodynamic model was run using boundary conditions extracted from RPS' in-house storm surge forecast model.

Figure 1.2 illustrates the second inner model bathymetry and Dublin Bay boundary and was developed with a finer mesh resolution in Dublin Port around the thermal plume and freshwater outfalls.

The rate of discharge from the rivers Liffey, Tolka and Dodder were initially defined as constant discharges based on the average rates summarised in Table 1.1. However, these rates were subsequently updated to utilise timeseries information as provided by ESB for the additional modelling described in Section 1.4.4.

Table 1.1: River Discharge Rates [cumecs]

	2016	2018	2019
Liffey	17.99	16.41	7.79
Dodder	0.76	2.17	2.40
Tolka	0.22	1.13	1.80

The background temperatures used in the model simulations are shown in Table 1.2 below, alongside the background temperatures measured.

Table 1.2: Background Temperature

	2016	2018	2019
Background Temperature	**°C**	**°C**	**°C**
2016 Survey	15.57 - 16.45		
2018 Survey Spring		9.2°C - 12.42	
2018 Survey Neap		9.28 – 10.81	
2019 Survey			8.6 – 9.6
RPS models	16.0	9.5	9.5

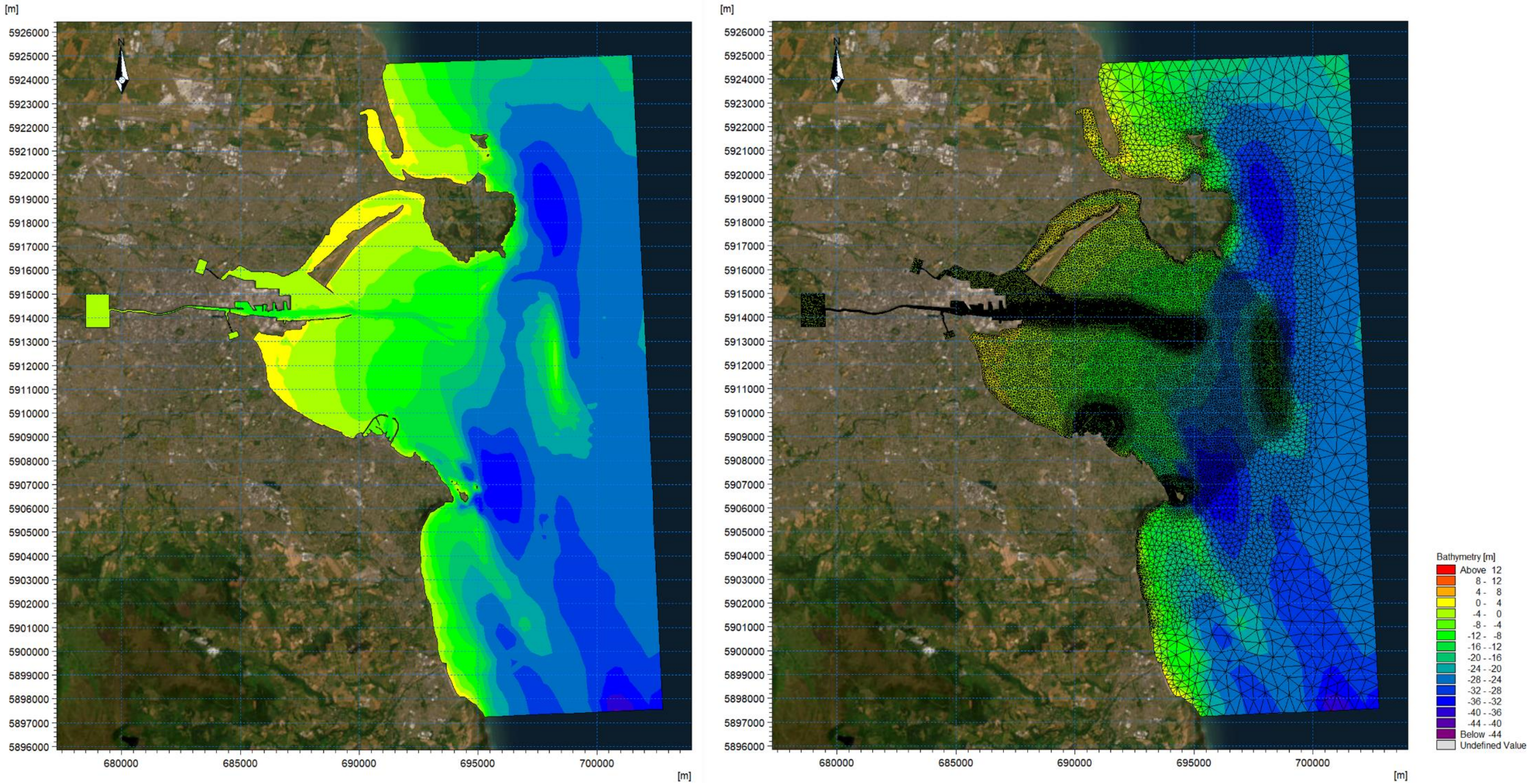

Figure 1.1: Outer model bathymetry and mesh (right).

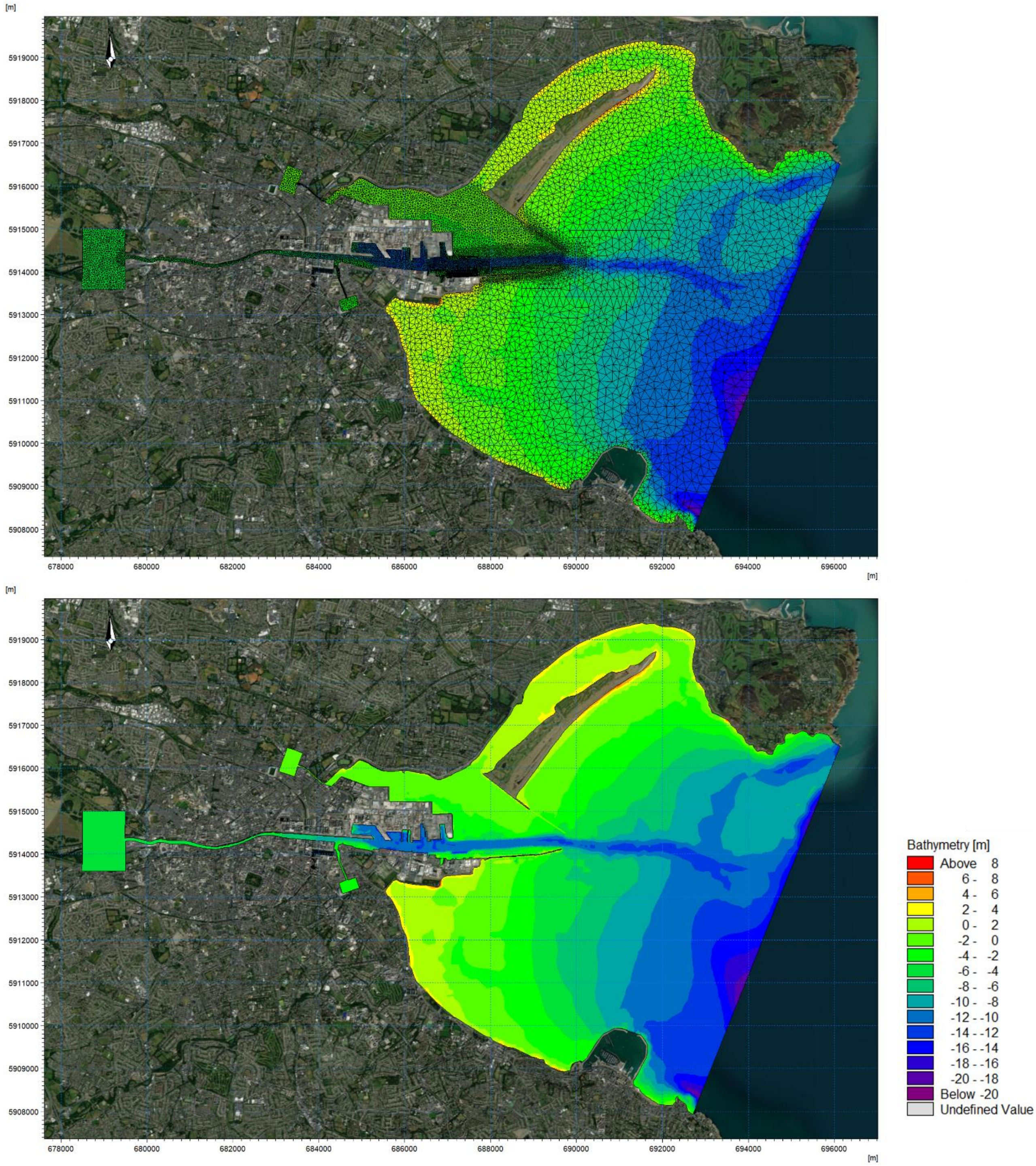

Figure 1.2: Inner model bathymetry and mesh (top).

1.3 Hydrodynamic Model Verification

No project specific Acoustic Doppler Current Profiler (ADCP) information for the survey periods described in Section 1.2 was made available for this study. RPS therefore validated the hydrodynamic accuracy of the models, described in the previous section, by comparing simulated surface elevations within Dublin Port with measured levels from the Dublin Port tidal gauge from the National Tide Gauge Network.

It should be noted that the hydrodynamic model had previously been calibrated and determined fit for purpose as part of the Alexandra Basin Re-development (ABR) and Masterplan 2 (MP2) projects using ADCP data for different periods. This calibration process was considered acceptable by Dublin Port Company, the Marine Institute and An Bord Pleanála. For the purposes of brevity, the extensive calibration process has not been repeated in this document which instead focuses on the thermal plume survey dates.

Figure 1.3 to Figure 1.5 represent the modelled tide levels (blue trace) plotted against the Dublin Port tide gauge levels (black trace) for each period with the survey periods being indicated in red. It can be seen that the surface elevations from the hydrodynamic model (HD) correlate well both in terms of tidal excursion and phase with the measured data. On occasion there is some deviation from the measured data, however this is likely to be as a result of temporally varying river flows and/or localised meteorological influences; as the wind recorded at Dublin airport was applied across the entire model extent and therefore forms a simplified wind field.

Notwithstanding this, the model was found to correspond with the recorded tidal elevations and particularly well on the day of each thermal plume survey that the model was verified against (indicated in red). It was therefore concluded that the numerical models developed for this study were fit for purpose.

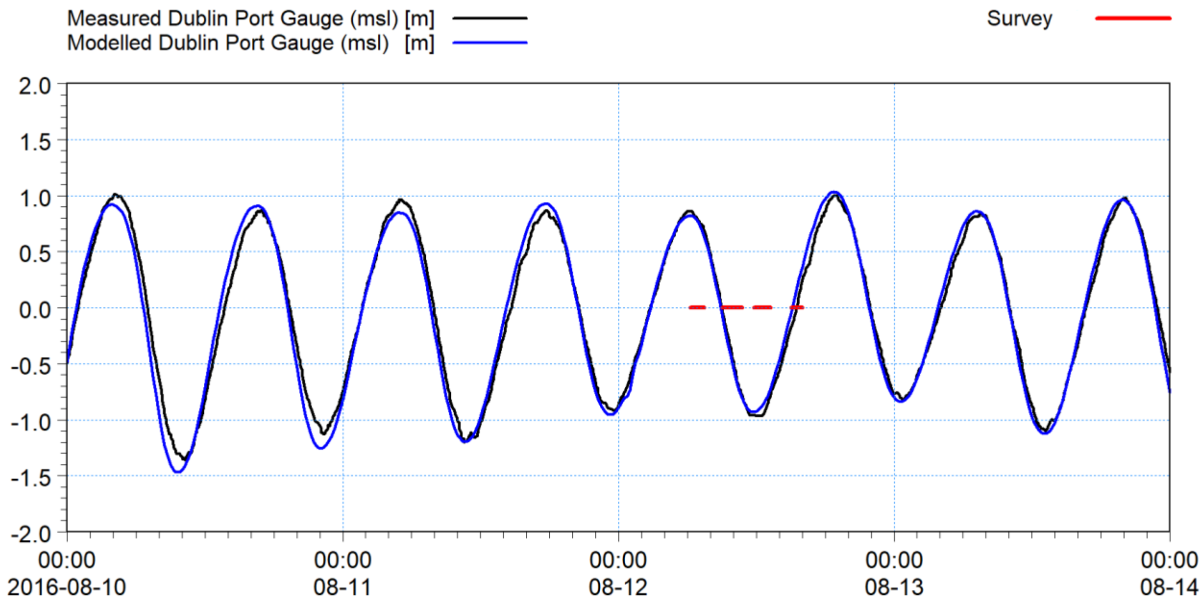

Figure 1.3: Verification of predicted tidal heights for the 2016 survey period.

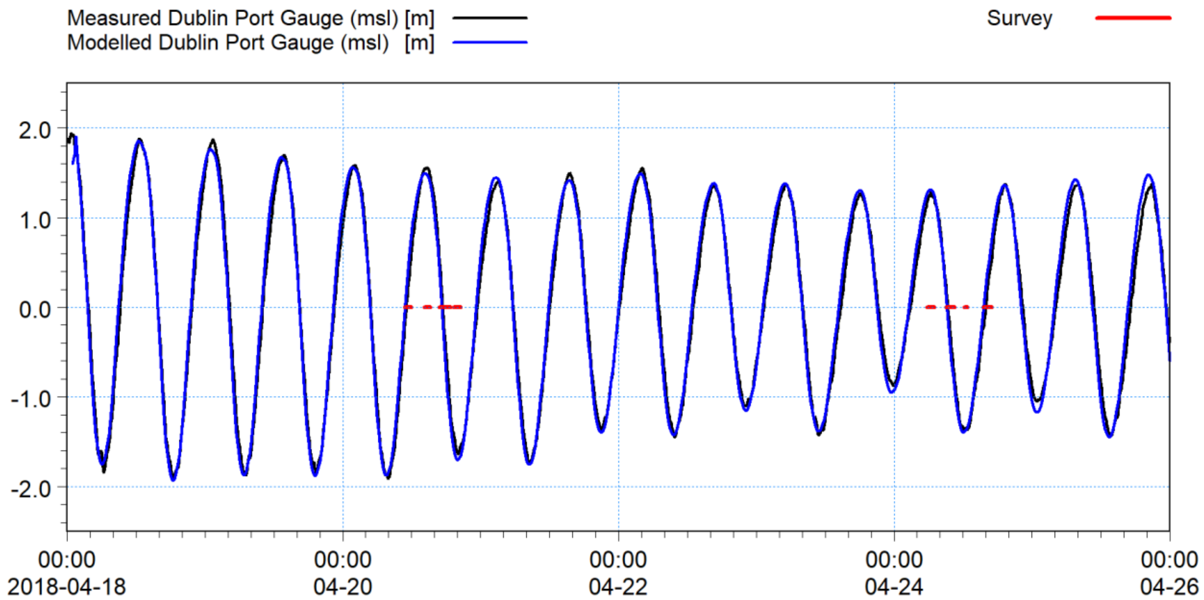

Figure 1.4: Verification of predicted tidal heights for the 2018 survey period.

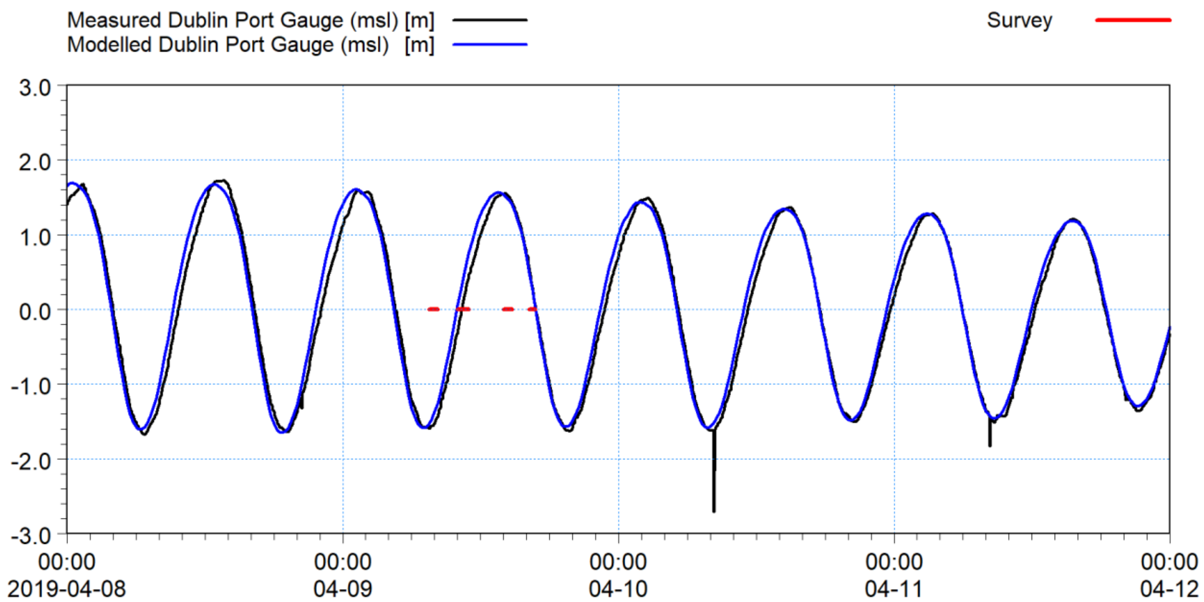

Figure 1.5: Verification of predicted tidal heights for the 2019 survey period.

1.4 Thermal Plume Modelling Results

This section of the document will examine the model performance relating to thermal plumes surveys presented in the following three reports:

- Survey reports:
  - ESB International (2017) Dublin Bay Power Plant: Thermal Plume Survey.
  - Irish Hydrodata (2018) Covanta Dublin Wate to Energy Facility: Thermal Plume Surveys of April 20th and 24th 2018.
  - Irish Hydrodata (2019) Poolbeg CCGT: Thermal Plume Survey of April 9th, 2019.

Figure 1.7 below shows the location of each facilities thermal/freshwater discharge and Table 1.3 outlines which facilities were actively discharging during each of the survey periods reported. The Dublin Bay Power Station, Dublin Waste to Energy and Poolbeg CCGT are all saline thermal discharges whilst Ringsend WWTP is a freshwater discharge. Time series data relating to flow rates and temperature for the various discharges during the survey periods was supplied by ESB and was utilised in the modelling[1].

There were two thermal discharges active during the 2016 survey: ESB's Dublin Bay Power facility and Irish Water's Waste Water Treatment Plant (WWTP). The full set of the final model output corresponding to the survey data is presented in Appendix A.

There were three facilities discharging during the 2018 survey times: ESB's Dublin Bay Power facility, Irish Water's WWTP and the Dublin Waste to Energy facility. The full set of the final model output corresponding to the survey data is presented in Appendix B. This includes both thermal contour plots and dip profiles collected during spring and neap surveys.

There were three facilities discharging during the 2019 survey times: Poolbeg CCGT, Irish Water's WWTP and the Dublin Waste to Energy facility. Appendix C presents final model output corresponding approximately to the survey contours, noting that the model layers will vary in depth from the surface depending on the bathymetry (still water depth) and tidal state (instantaneous water depth). It should also be noted that the plotting scale used in the figures corresponds with that implemented in the survey report (which varies from the preceding survey reports).

The model bathymetry was derived from a number of data sources which included survey data in the vicinity of the Poolbeg CCGT discharge. Bed levels are higher in this region and this area frequently dries out depending on phase of tide, as illustrated in Figure 1.6.

Figure 1.6: Drying out within the vicinity of Poolbeg CCGT outfall location.

[1] Limited measured flow data for the Rivers Liffey, Dodder and Tolka were also provided and used for relevant periods of simulations. The river discharge rates summarised in Table 1.1 were used for periods without specific data.

Figure 1.7: Thermal plume outfall locations.

Table 1.3: Thermal discharges active during each survey period.

	2016	2018	2019
WWTP	✓	✓	✓
Dublin Waste to Energy		✓	✓
Dublin Bay Power	✓	✓	
Poolbeg CCGT			✓

1.4.1 Initial Modelling

Modelling was undertaken for the three survey periods using the model discretisation as described in Section 1.2. The MIKE 3D modelling system utilises a layered vertical mesh to describe the flow and dispersion in the water column. Initial modelling was undertaken with six sigma layers of equal weighting, i.e. the water column was divided into six equal layers which depended on bed level and varied in depth as changes in water level due to tidal flow occurred. Figure 1.8 shows the location of section A-B which the sigma layers are presented in Figure 1.9 to illustrate the vertical mesh discretisation.

Varying wind data as recorded at Dublin Airport was applied to each model simulation presented in this report.

The initial modelling provided a good representation of the behaviour of the stratified flow as illustrated in the following figures. These figures present the modelled output in the surface layer for mid-flood tide, high water, mid-ebb tide and low water during the spring tide survey undertaken in April 2018. Each figure is accompanied by the corresponding survey contour plot for the surface layer. It should be noted that surveys were recoded to Greenwich Mean Time (GMT) whilst modelling was undertaken for Universal Time (UT) and, as the survey was undertaken during summer time, there is a one hour difference in the timing of records.

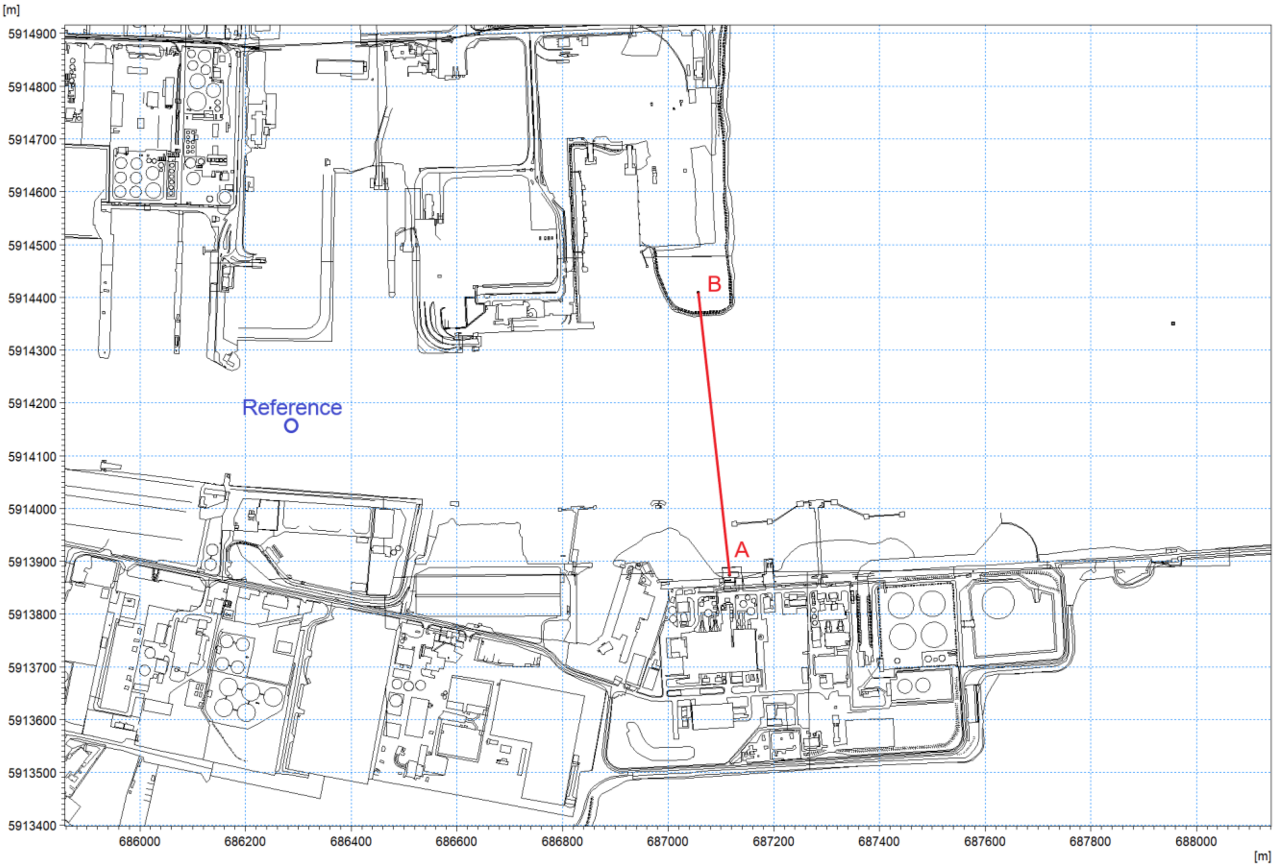

Figure 1.8: Location of section to illustrate sigma layer definition.

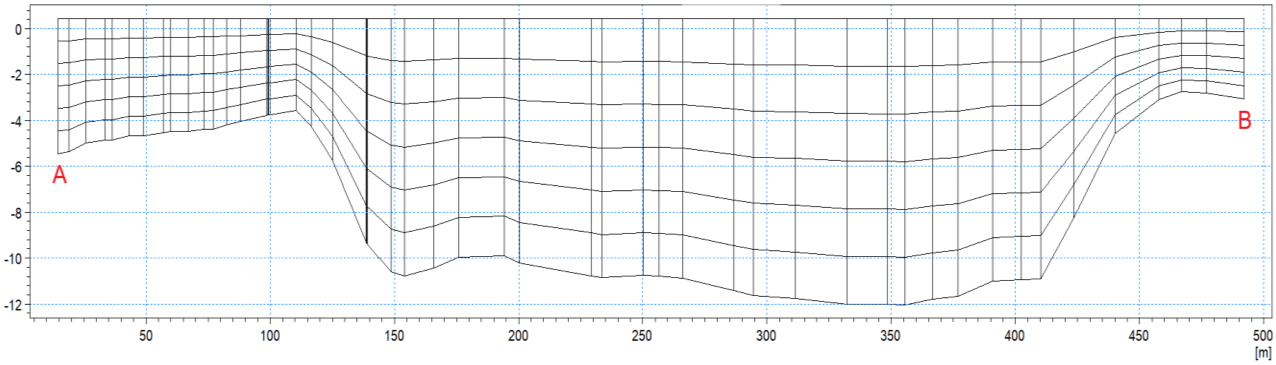

Figure 1.9: Initial thermal modelling equidistant sigma layers.

It was noted from the survey reports that there was a variation in the thermal characteristics of the plume across the top 2m surveyed water depth.

With the application of the equal sigma layers, when the plume is dispersed towards the deeper water in the navigation channel all survey layers effectively lie within one model layer therefore further discretisation was applied to the model domain to provide an improved approximation of plume behaviour.

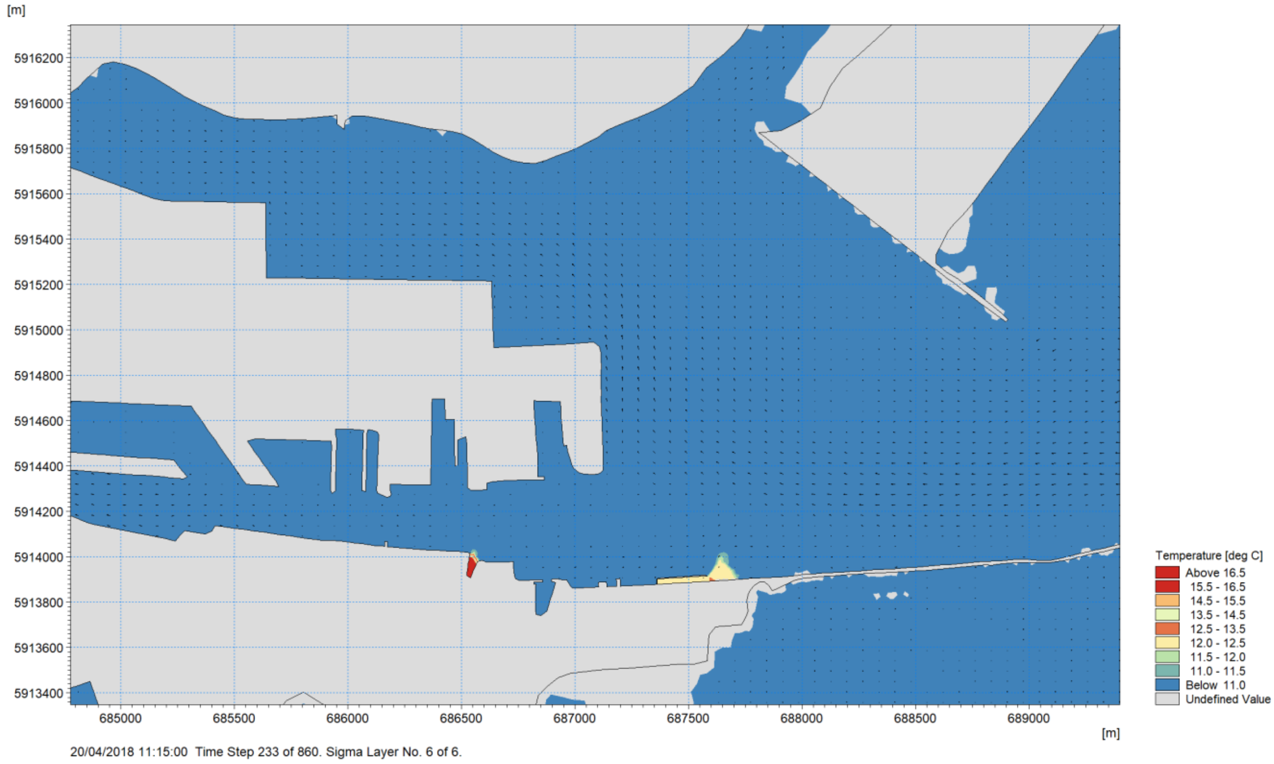

Figure 1.10: Preliminary model output: Temperature of surface layer mid-flood spring tide.

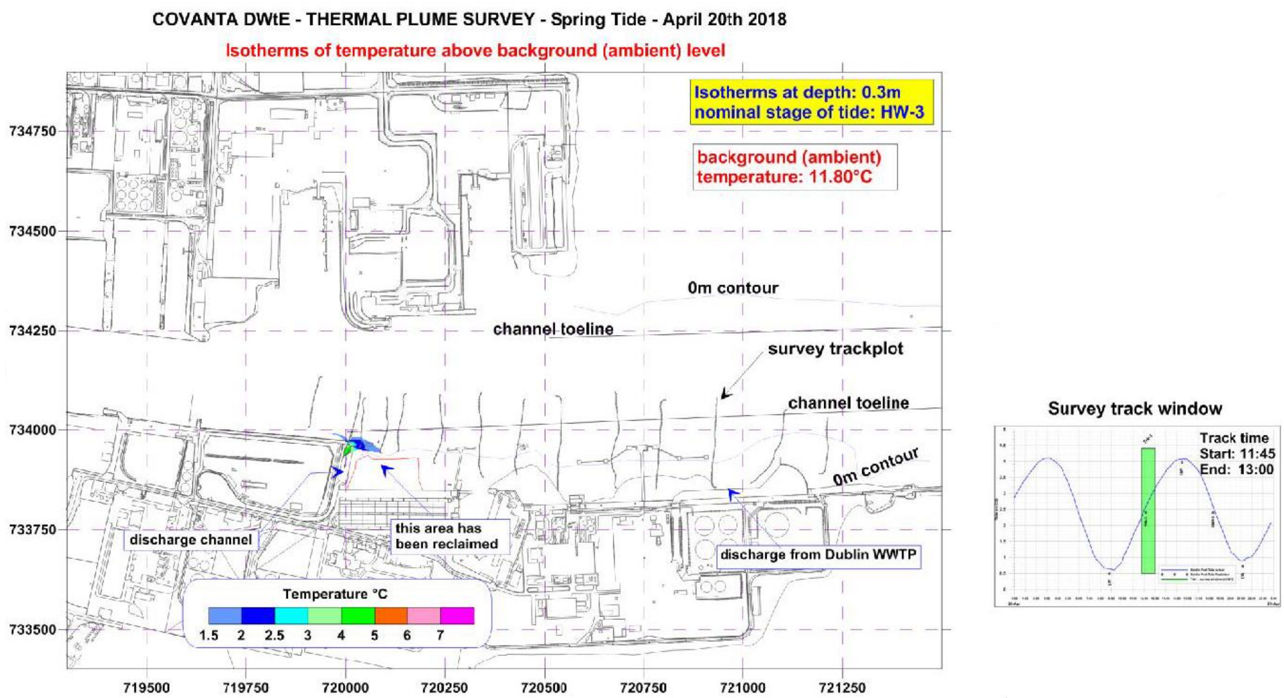

Figure 1.11: Survey contour: Excess temperature of surface layer mid-flood spring tide.

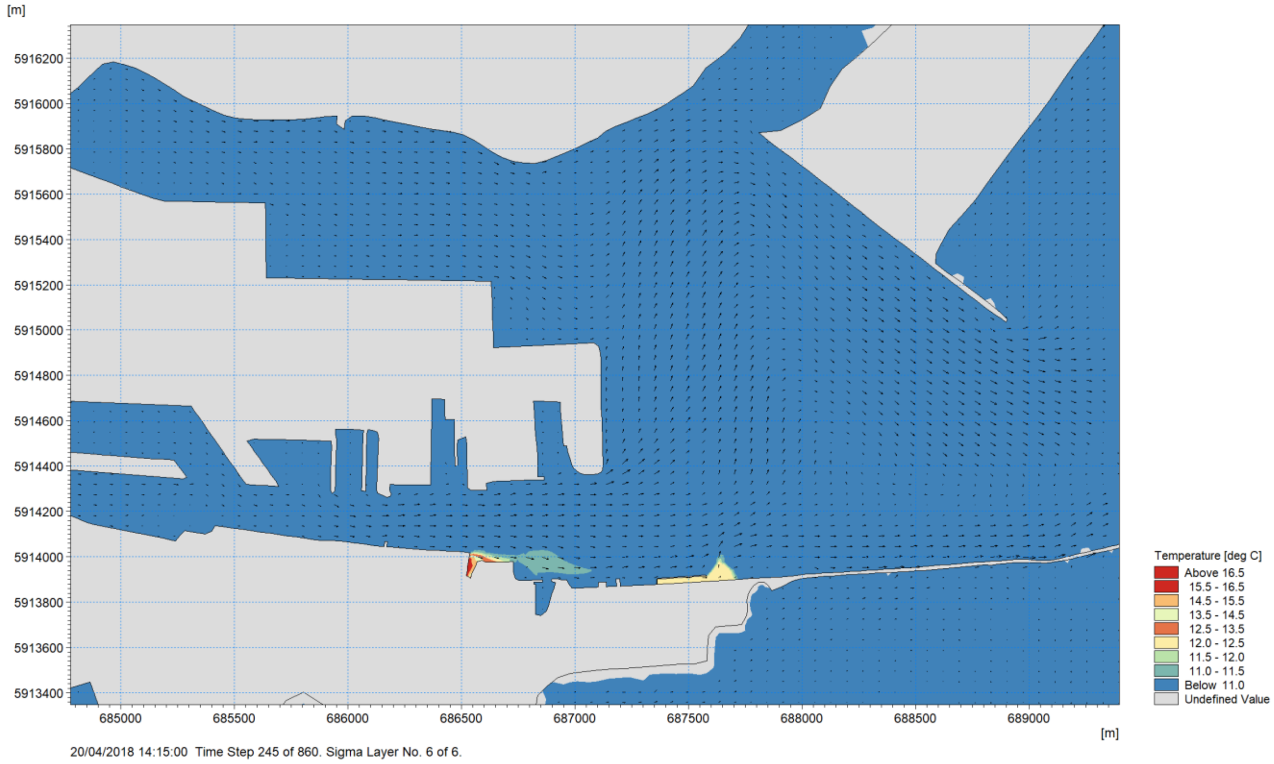

Figure 1.12: Preliminary model output: Temperature of surface layer high water spring tide.

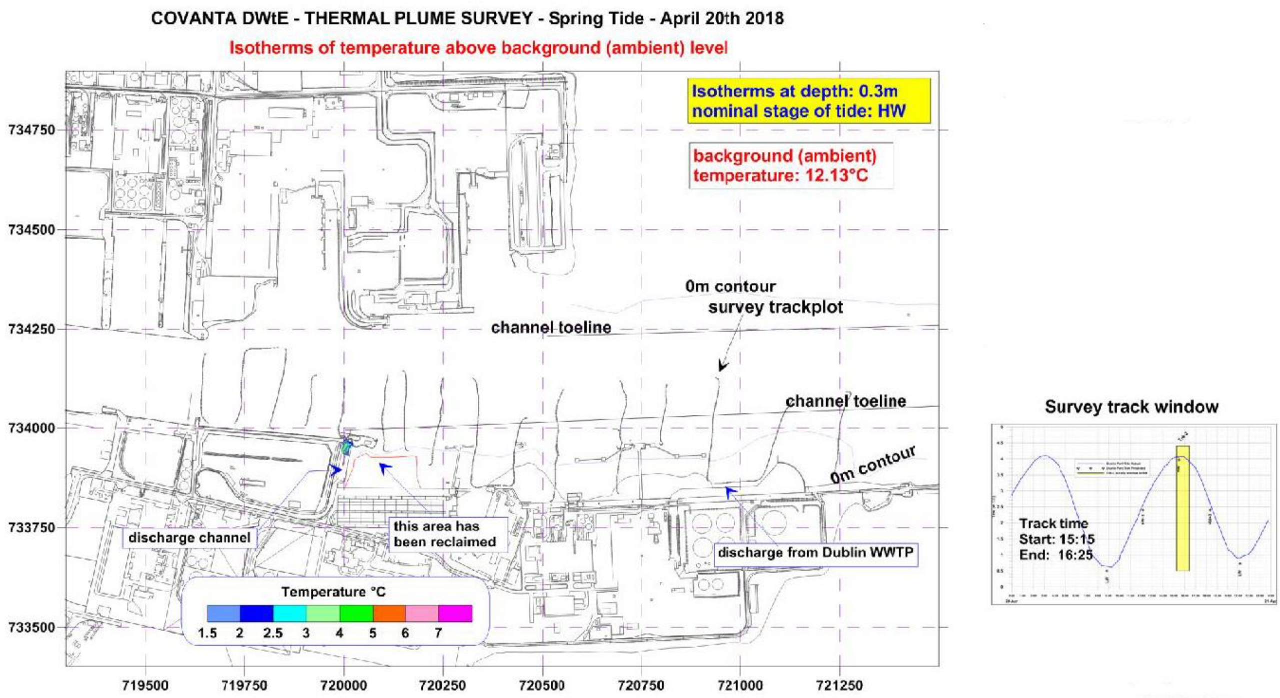

Figure 1.13: Survey contour: Excess temperature of surface layer high water spring tide.

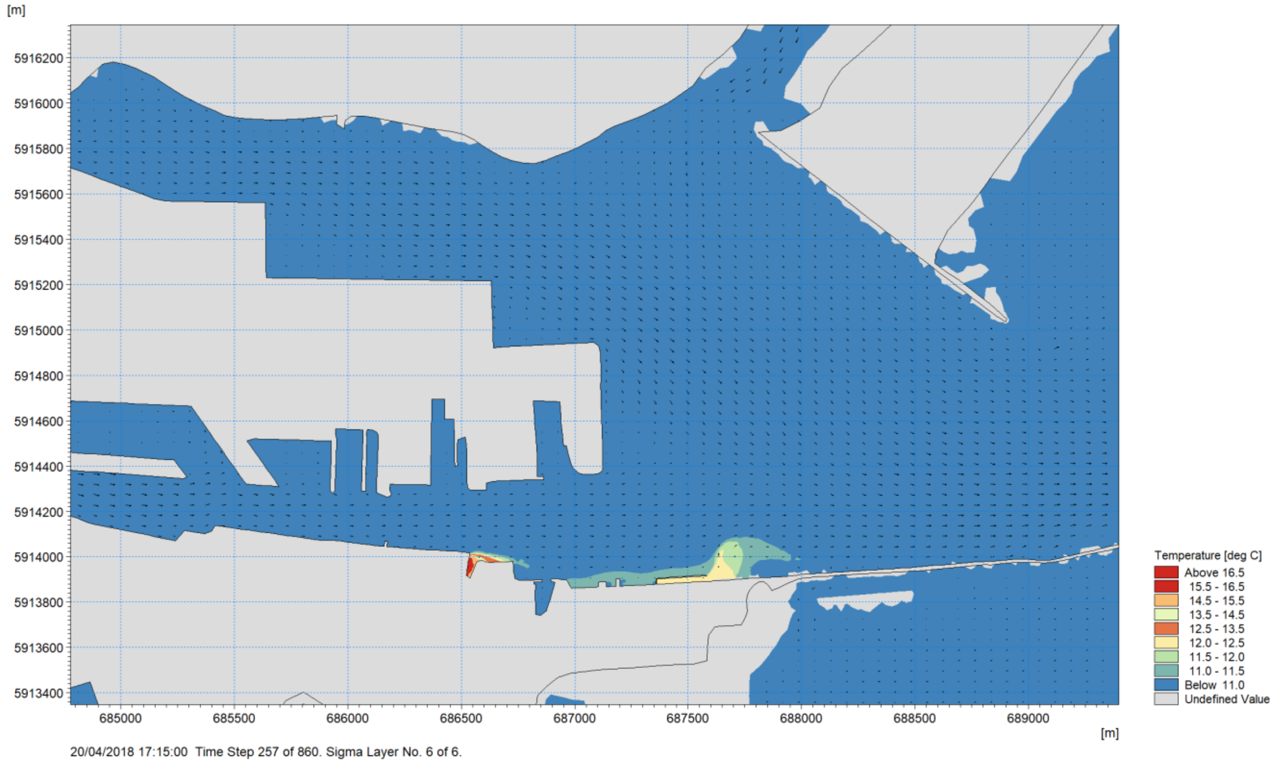

Figure 1.14: Preliminary model output: Temperature of surface layer mid-ebb spring tide.

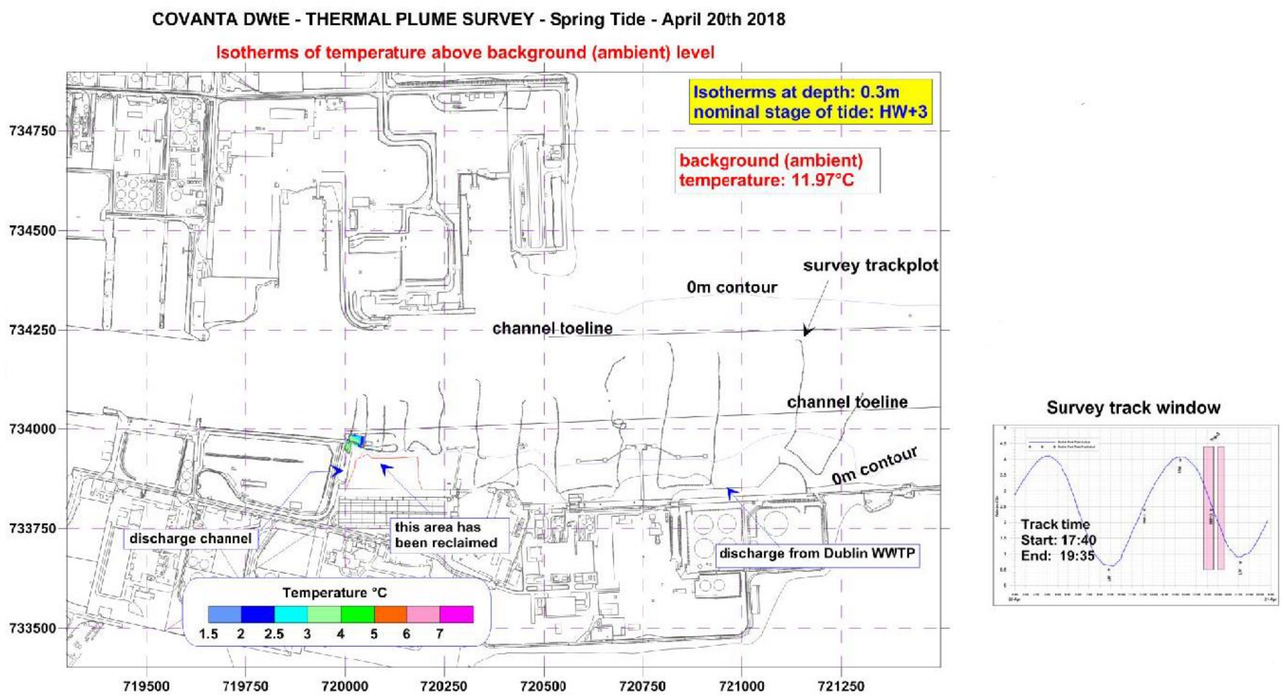

Figure 1.15: Survey contour: Excess temperature of surface layer mid-ebb spring tide.

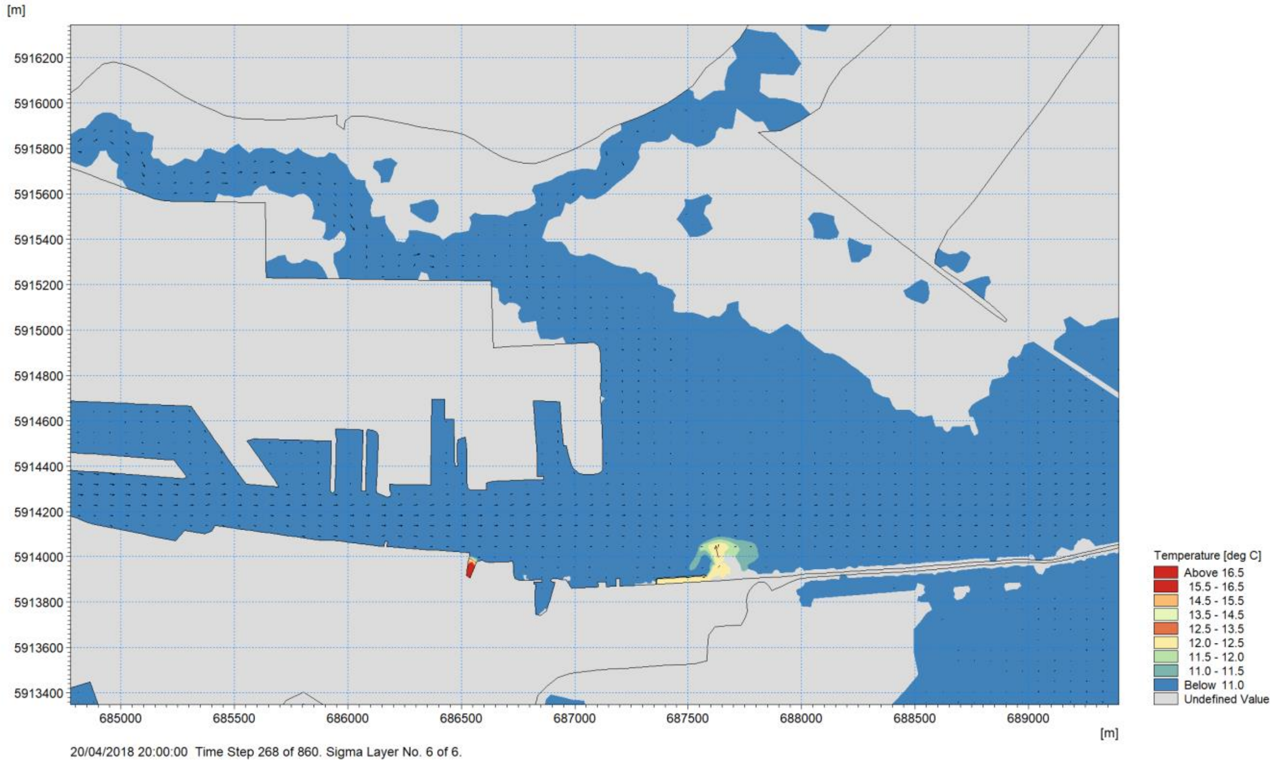

Figure 1.16: Preliminary model output: Temperature of surface layer low water spring tide.

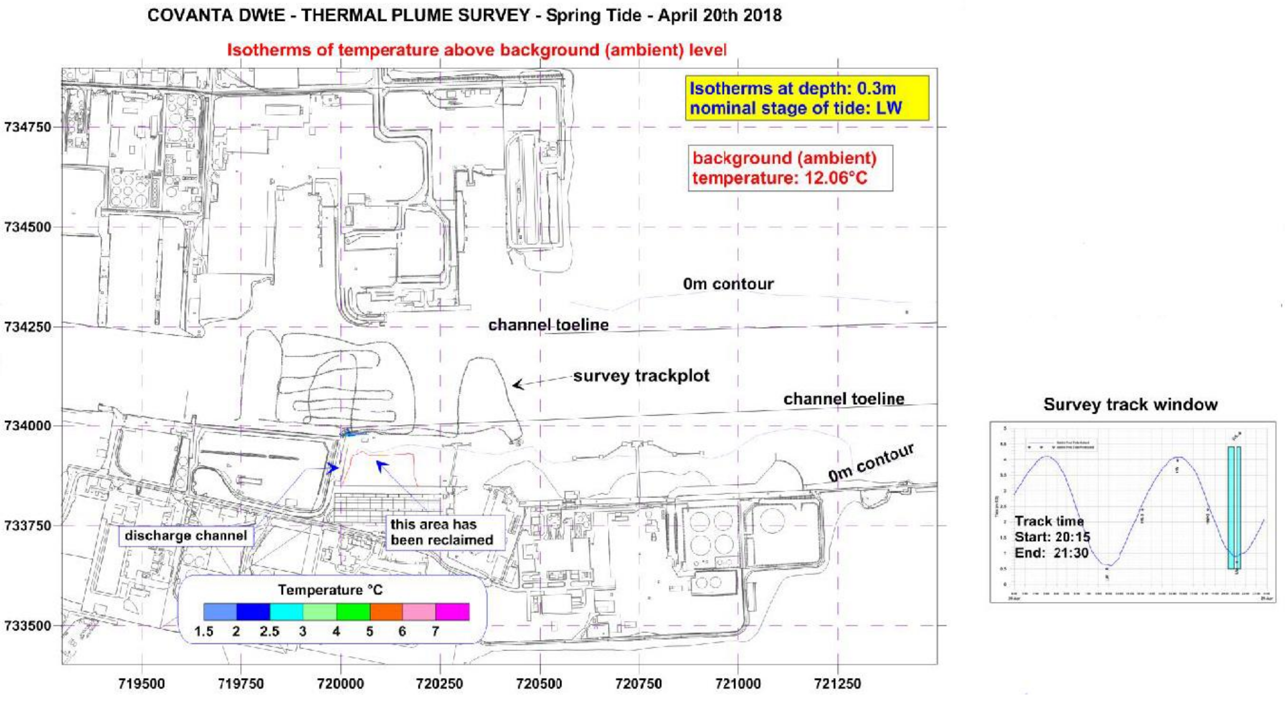

Figure 1.17: Survey contour: Excess temperature of surface layer low water spring tide.

1.4.2 Further Modelling

Having liaised with ESB regarding initial thermal plume modelling results, queries were raised regarding the ability of six equally spaced vertical layers being able to accurately resolve the vertical dispersion and stratifying effects observed within Dublin Port. To examine this, initial model simulations were further refined and updated to better represent density driven processes within Dublin Port.

The survey reports provided data typically at 0.3m, 1m and 2m levels from the surface so, although it was not possible to fix model layers relative to the water surface, the sigma layers were adjusted to provide information more comparable to that recorded. The same number of layers was implemented as in the preliminary modelling; however layers were concentrated near the surface.

As the discretisation determines the resolution of hydrodynamics as well as the thermal characteristics, the bed layer was maintained at the previous setting to preserve model accuracy in terms of flow and baseline stratification within the Liffey. As previously, the layer thicknesses varied through the tidal cycle but the proportions of the water column occupied by each layer remained consistent. Figure 1.18 illustrates the same channel cross-section, at the same stage of the tide, as shown in Figure 1.8 but with the revised sigma layer distribution (with the original equidistant vertical structure illustrated in Figure 1.9).

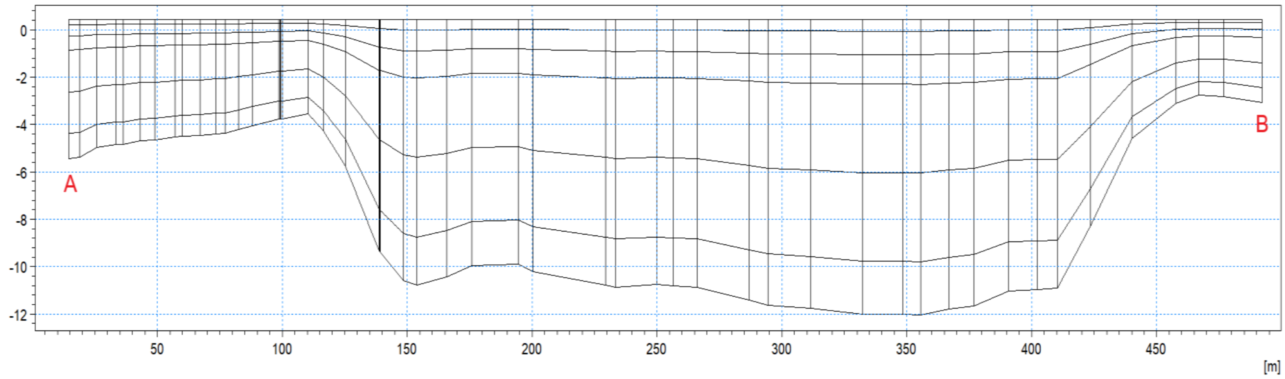

Figure 1.18: Further thermal modelling sigma layers variation through water column.

In order to verify the model against the survey data presented in the reports a similar data processing exercise was undertaken to the measured data. This had the benefit of taking some account of the variations in background temperature experienced in the receiving water which would not be replicated within the model without detailed information on both sea and river temperatures and salinities in the period prior to and during the survey.

As temperature is not a neutral tracer, a reference temperature profile was extracted from the model at the location indicated in Figure 1.8 (a similar location to the survey dip sections in the 2016 and 2018 surveys) at the timestep immediately prior to each individual survey period. The resulting model data was then adjusted to provide 'excess temperature' i.e. that above the background reference value. As with the measured data, this was undertaken for each survey pass for each stage of the tide. The data was then plotted for layer six (surface), five and typically four which corresponded most closely to the surveyed levels. The figures use the same output area, colour palette and mapping data for ease of comparison as only the reported data was available.

When making comparisons between the modelled and measured datasets it is recognised that survey data supplied to RPS is limited to survey trackplots owing to constraints associated with working within a busy port area and in some cases surveys were undertaken over prolonged periods (up to 1.5 hours). It is therefore important to acknowledge that the instantaneous nature of the model output means that model outputs will may not *fully* correspond with the extent of the survey. This is particularly evident during slack water surveys where underlying flow conditions are in a state of fluctuation and those where thermal plumes may be disrupted by marine traffic which is not reflected in the models. Where plumes are concentrated in shallower areas the model layer most representative of the survey level at the location of the plume is presented; this is particularly significant during low water.

1.4.2.1 2016 Survey Report

The thermal plume survey for the ESB (2017) Report, was conducted on 12th August 2016 to measure the thermal discharge from the Dublin Bay Power facility, during a neap tide and during the following tide conditions:

- High water
- Mid-Ebb (high water plus 3 hours)
- Low water
- Mid-Flood (high water minus 3 hours)

The survey was conducted during neap tides as they are considered a worst-case scenario in terms of thermal plumes as spring tides would provide greater dispersion potential. The survey track for each tidal condition lasted between 60 and 100 minutes, with the thermistor string attached at three fixed depths (0.3m, 1.0m and 2.0m). Background temperature levels were measured upstream of the plume prior to each track commencing and ranged from 15.57°C to 16.45°C.

There were two thermal discharges active during this survey: ESB's Dublin Bay Power facility and Irish Water's Waste Water Treatment Plant (WWTP).

1.4.2.2 2018 Survey Report

Irish Hydrodata Ltd. conducted a thermal plume survey for Covanta Dublin Waste to Energy on the 20th April 2018 during a spring tide and on the 24th April 2018 during a neap tide, at the following four phases of the tide:

- Low water
- Mid-Flood (high water minus 3 hours)
- High water
- Mid-Ebb (high water plus 3 hours)

There were three facilities discharging during these survey times: ESB's Dublin Bay Power facility, Irish Water's WWTP and the Dublin Waste to Energy facility. Three thermistors were attached 0.3m, 1.0m and 2.0m and one track run for each tidal condition which lasted between 70 and 115 minutes. Background temperature levels were measured upstream of the plume prior to each track commencing and ranged from 9.2°C to 12.42°C. The survey report included both thermal contour plots and dip profiles collected during spring and neap surveys.

1.4.2.3 2019 Survey Report

Irish Hydrodata Ltd. conducted a thermal plume survey for ESB Generation and Wholesale Markets (ESB GWM) of the Poolbeg Combined Cycle Gas Turbine (CCGT) power station, on the 9th of April 2019 over the following four stages of a single tidal cycle:

- Low water
- Mid-Flood (high water minus 3 hours)
- High water
- Mid-Ebb (high water plus 3 hours)

Three facilities were discharging during these survey times: Poolbeg CCGT, Irish Water's WWTP and the Dublin Waste to Energy facility. Four thermistors were used at depths of 0.3m, 0.6m, 0.9m, 1.2m and 1.8m, one track run for each tidal condition which lasted between 30 and 60 minutes. The background temperature levels measured ranged from 8.6°C to 9.6°C.

Appendix C presents model output corresponding approximately to the 0.3m, 0.9m and 1.8m survey contours, again noting that the model layers will vary in depth from the surface depending on the bathymetry (still water depth) and tidal state (instantaneous water depth). It should also be noted that the plotting scale used in the figures corresponds with that implemented in the survey report (which varies from the preceding survey reports).

1.4.3 Thermal Plume Modelling Discussion

Over the course of the three surveys a significant volume of data was collected and reproduction of the survey reports *en masse* would not be conducive to clear assessment as the datasets were only available as an electronic document of limited resolution therefore a sample of the model output is discussed here. The appendices of this document may be compared with those relating to the three survey report documents.

It was noted that the use of the shallow surface sigma layer was beneficial in identifying where, even though the thermal discharges are buoyant due to temperature, they do not necessarily dominate the surface layer. This is particularly relevant with regards to the Dublin Bay Waste to Energy and Power Station discharge; where the saline thermal discharge from cooling is discharged into a stratified flow where freshwater river discharges are present. Freshwater being significantly less dense than saline water, even with an increased temperature than the receiving water body. Therefore the freshwater discharge from Ringsend WWTP may exhibit different characteristics to those from the saline cooling water discharges.

The following series of figures are presented for the thermal plume survey undertaken for the spring tide during April 2018. For each tidal stage two pairs of plots are presented; first, the modelled surface and near surface layers which approximately correspond with the 0.3m and 1m survey are presented, the corresponding survey contours are presented in the second pair of plots.

It can be seen in each case that the thermal plume from the Dublin Bay Waste to Energy and Power Station is more extensive below the initial surface layer. Whereas for the WWTP, as the discharge is a freshwater source, it exhibits a greater plume extent on the surface layer. It also appears that the excess temperatures >1.5°C from the WWTP do not fall within the survey tracks.

Figure 1.19: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 0.3m depth.

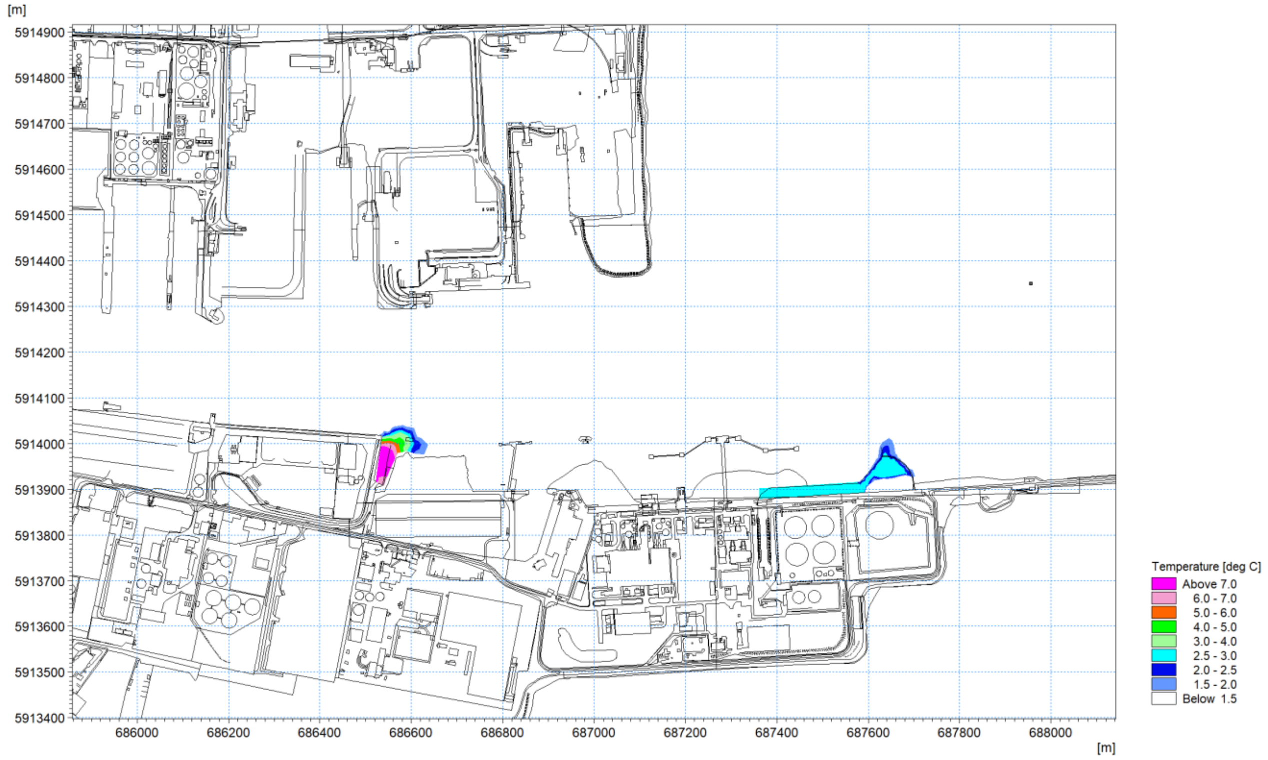

Figure 1.20: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 1m depth.

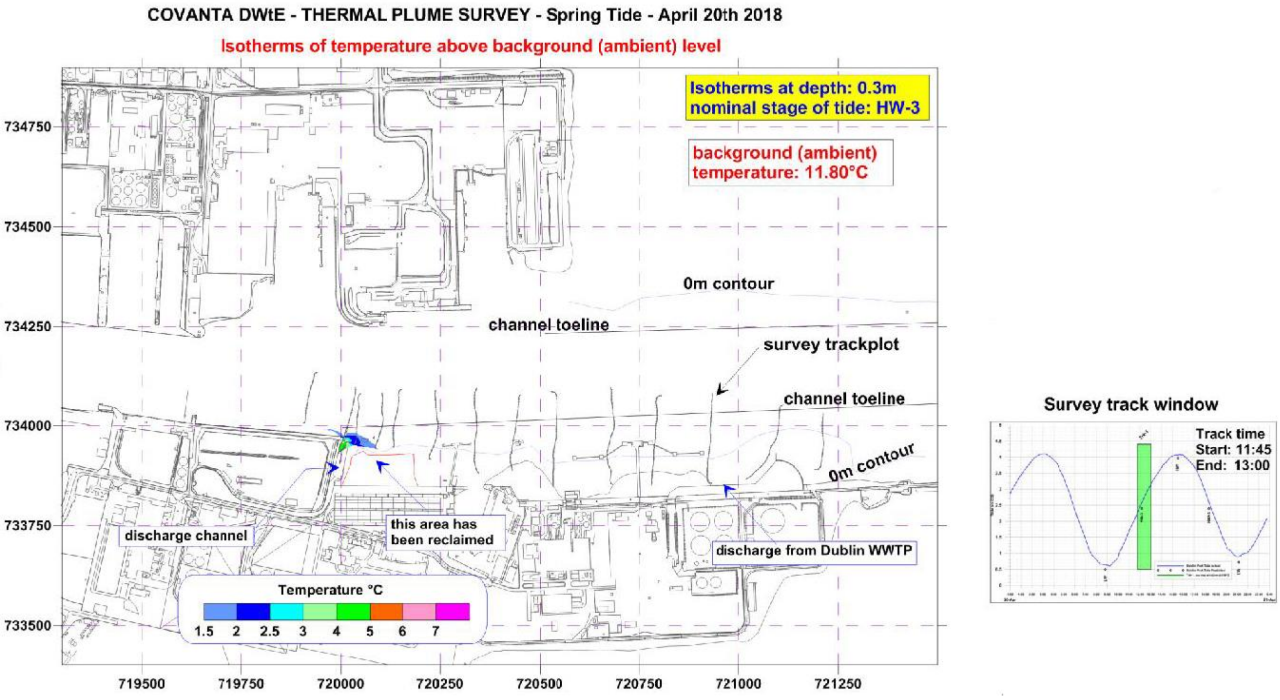

Figure 1.21: Survey contour 20th April 2018 – excess temperature at mid-flood 0.3m depth.

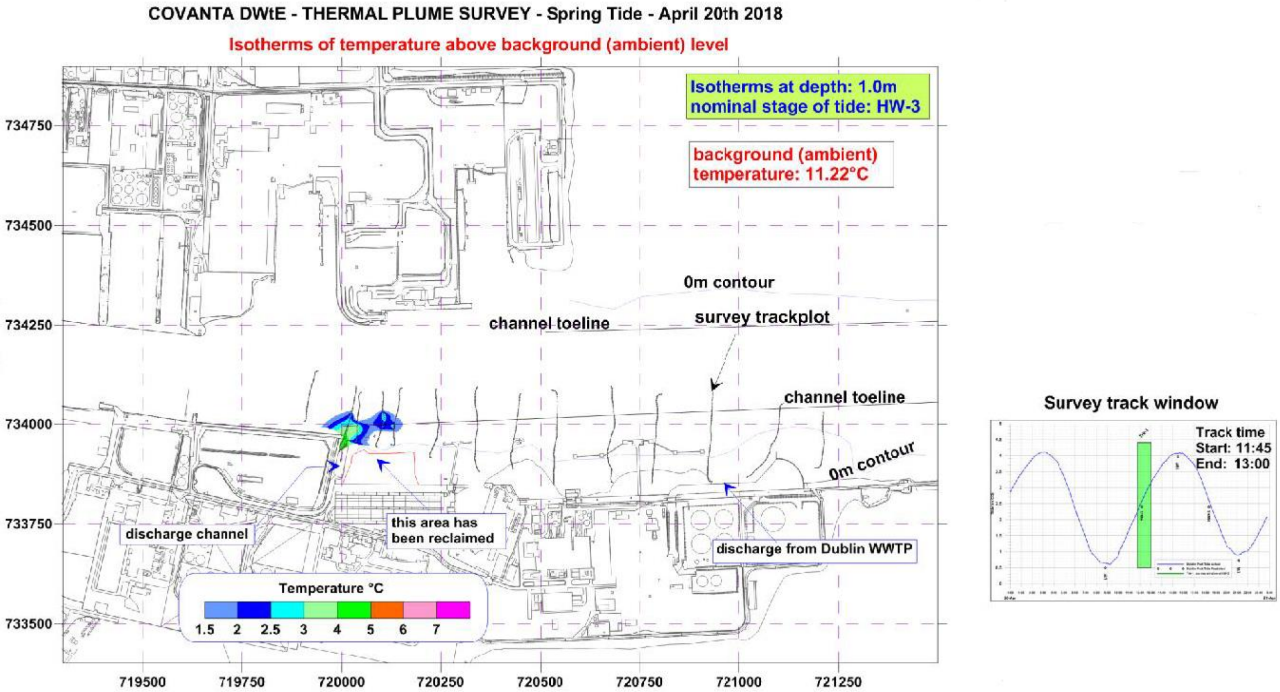

Figure 1.22: Survey contour 20th April 2018 – excess temperature at mid-flood 1m depth.

Figure 1.23: Thermal plume 20th April 2018 – excess temperature at high water circa 0.3m depth.

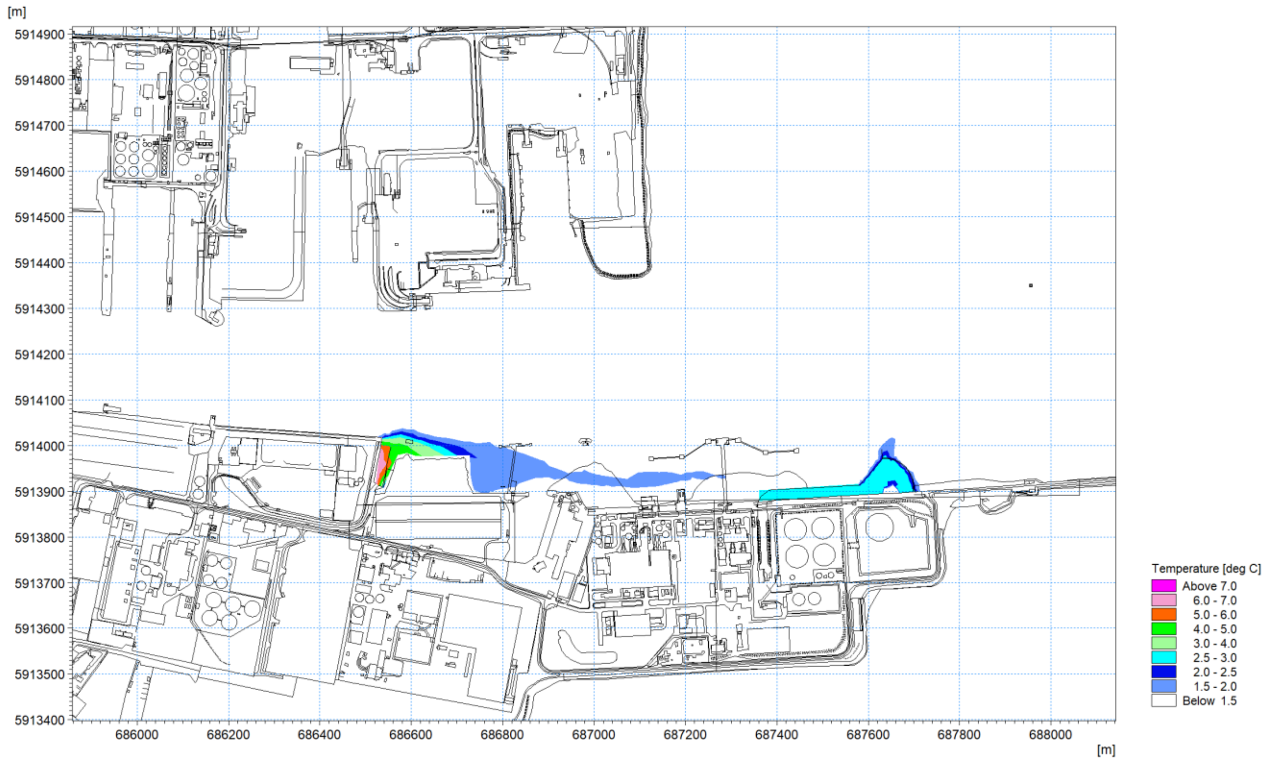

Figure 1.24: Thermal plume 20th April 2018 – excess temperature at high water circa 1m depth.

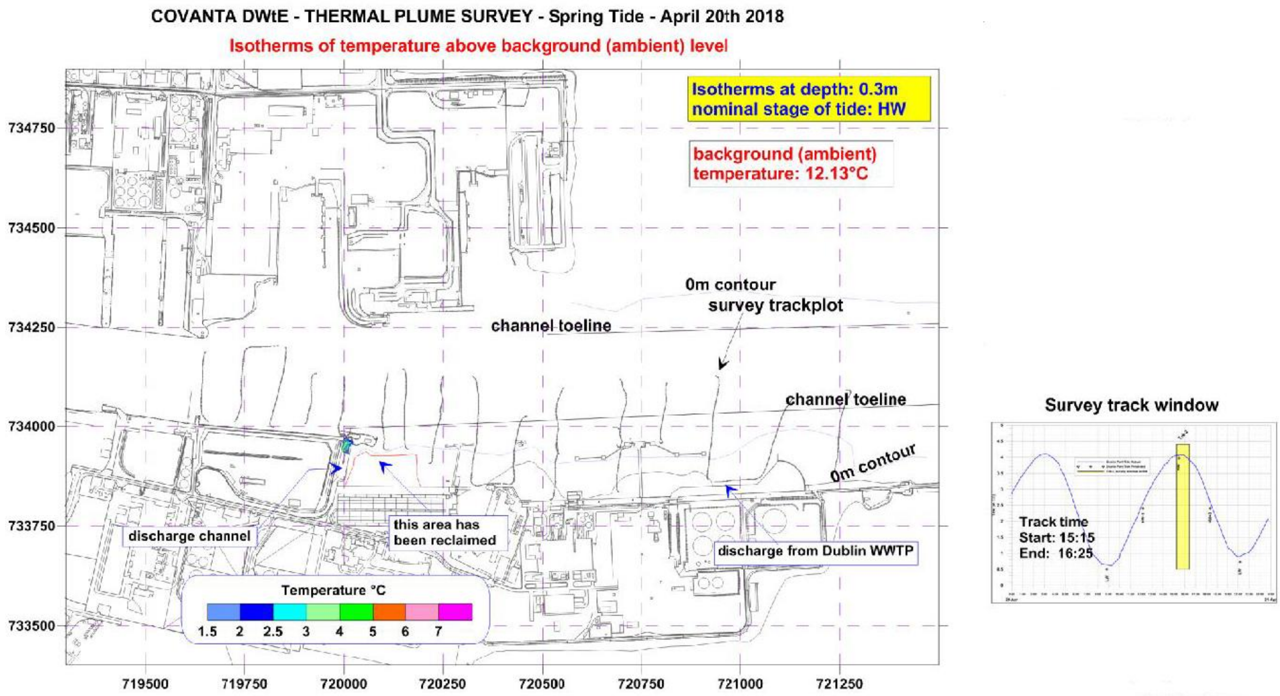

Figure 1.25: Survey contour 20th April 2018 – excess temperature at high water 0.3m depth.

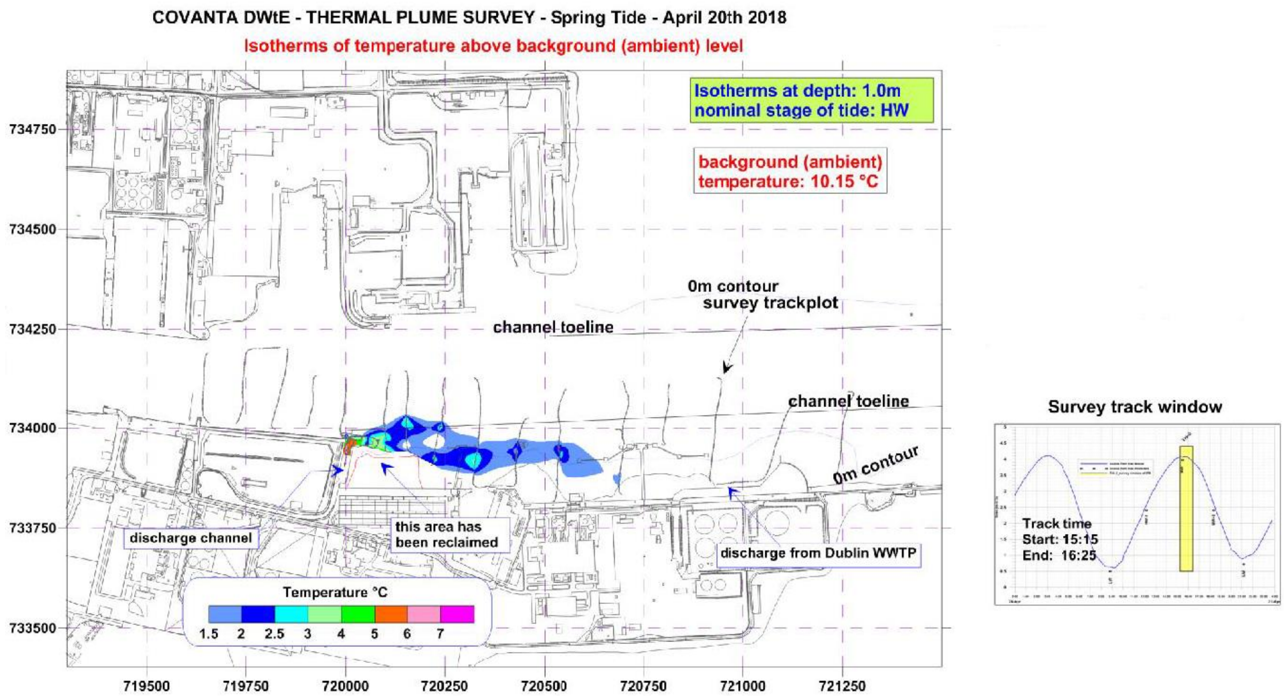

Figure 1.26: Survey contour 20th April 2018 – excess temperature at high water 1m depth.

Figure 1.27: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 0.3m depth.

Figure 1.28: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 1m depth.

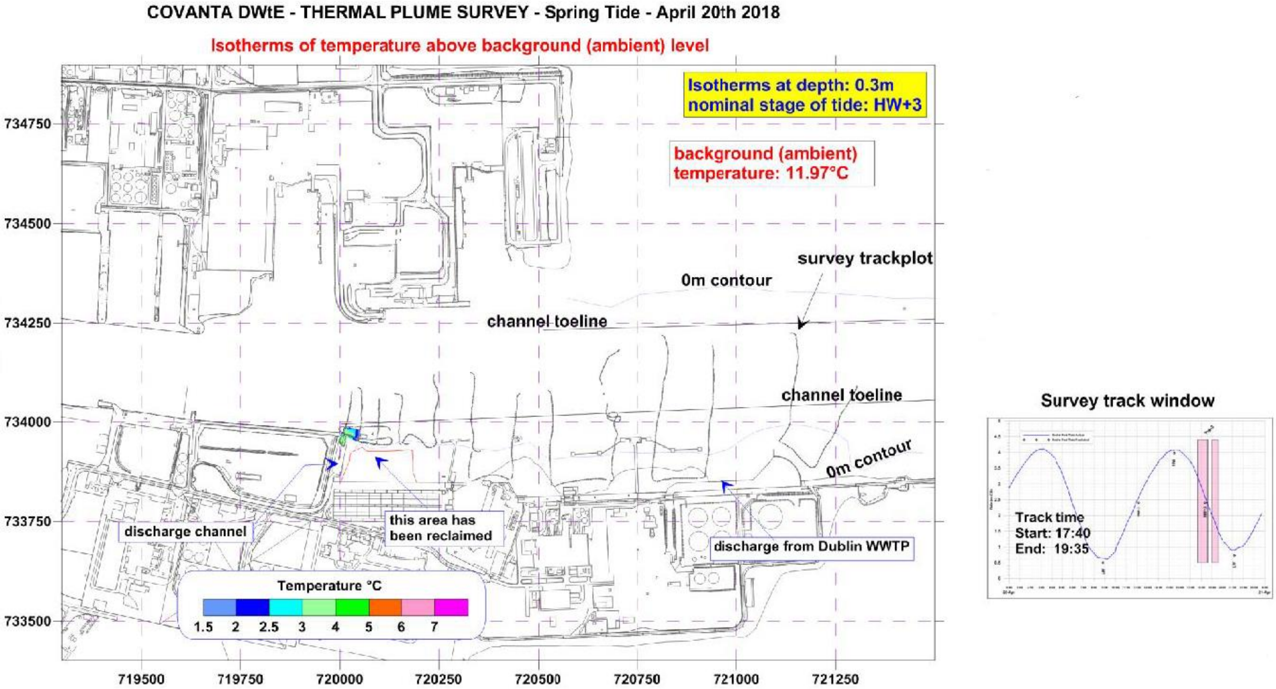

Figure 1.29: Survey contour 20th April 2018 – excess temperature at mid-ebb 0.3m depth.

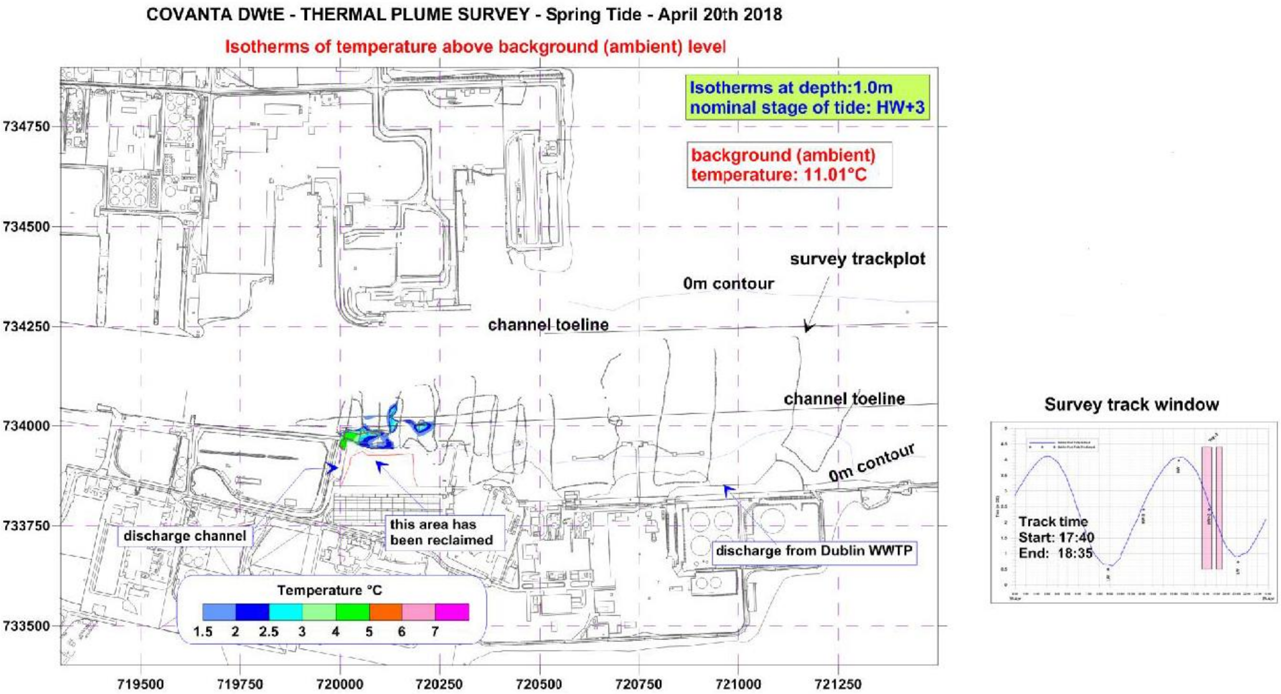

Figure 1.30: Survey contour 20th April 2018 – excess temperature at mid-ebb 1m depth.

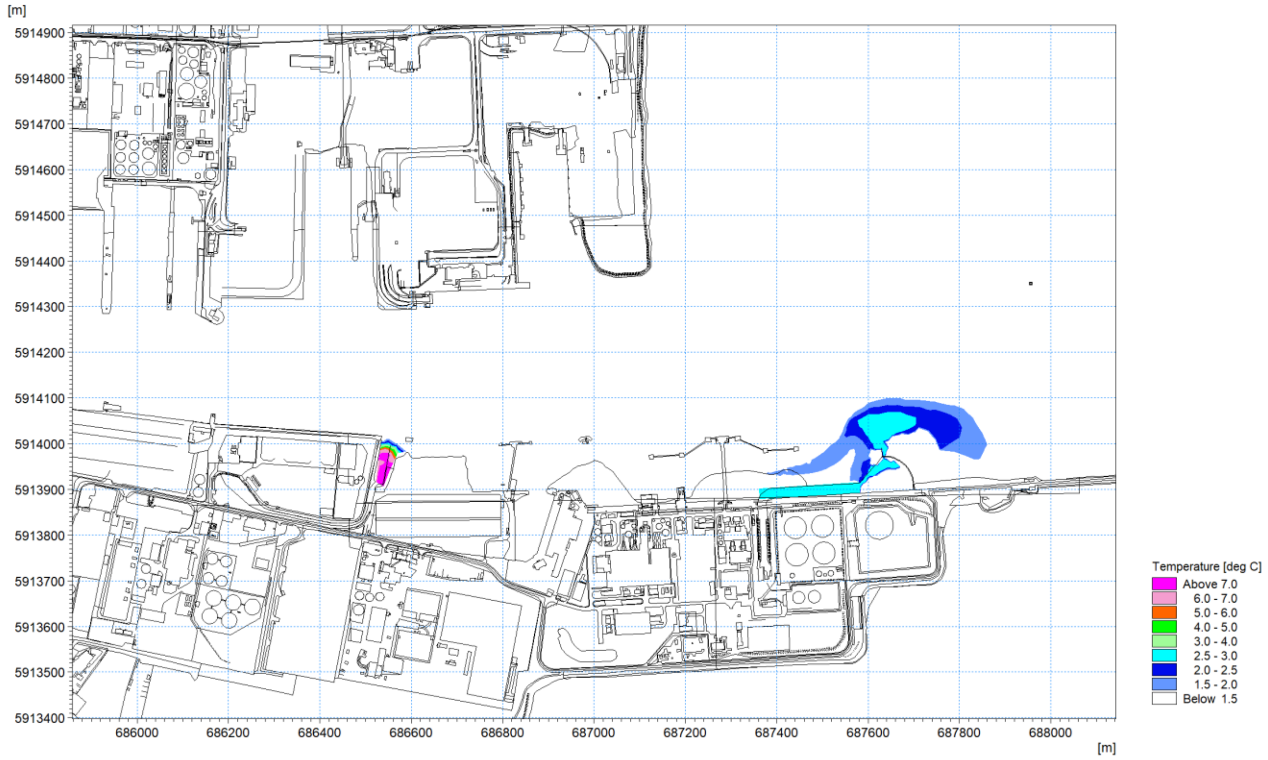

Figure 1.31: Thermal plume 20th April 2018 – excess temperature at low water circa 0.3m depth.

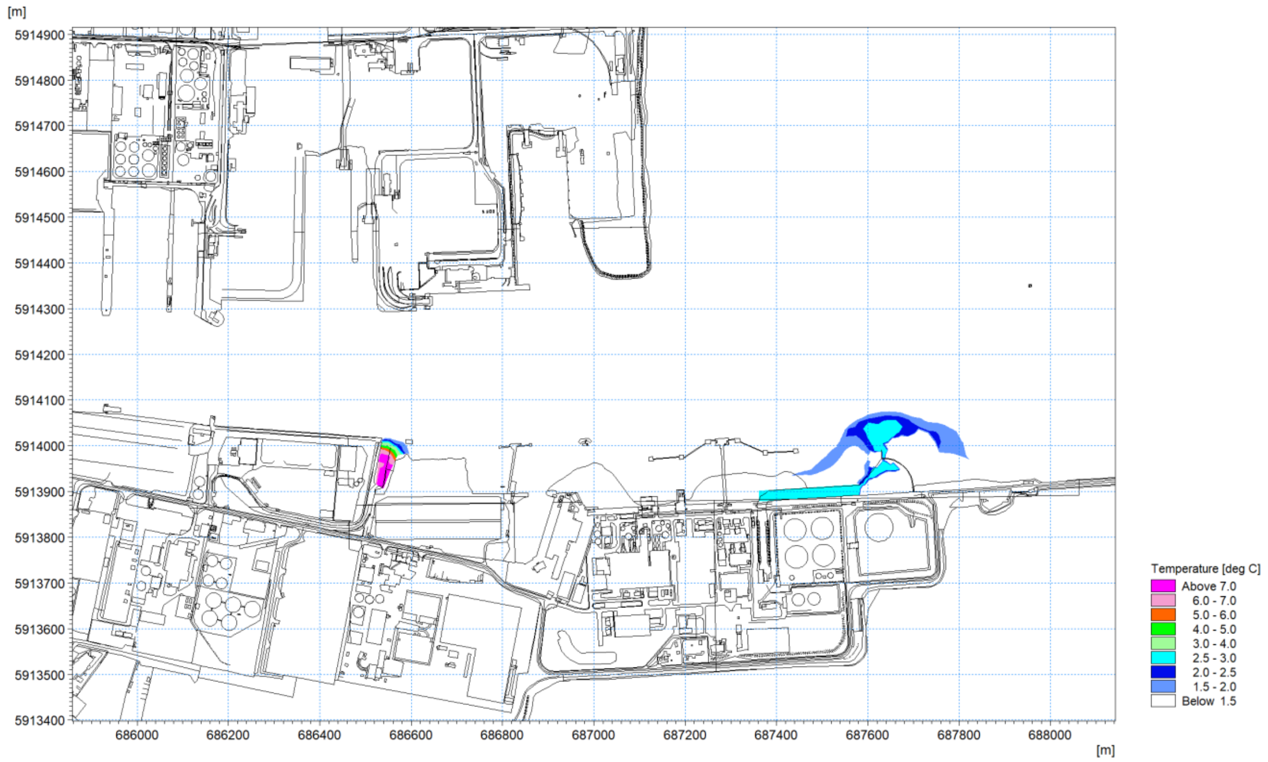

Figure 1.32: Thermal plume 20th April 2018 – excess temperature at low water circa 1m depth.

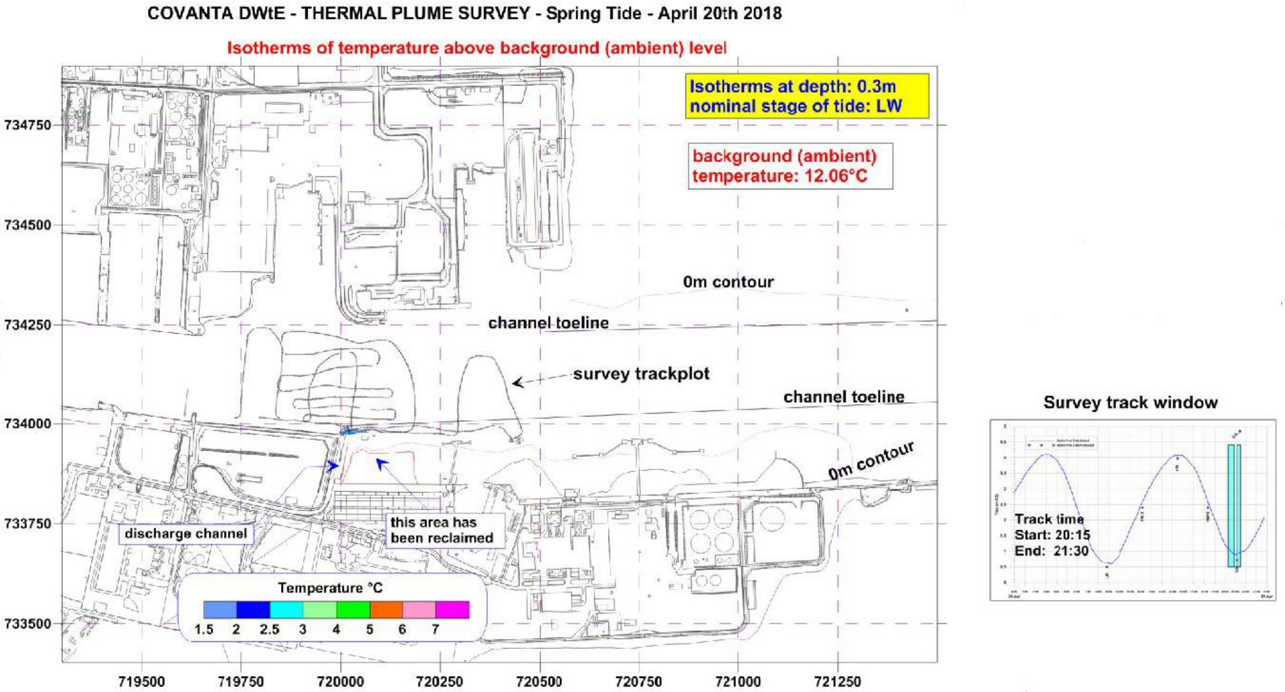

Figure 1.33: Survey contour 20th April 2018 – excess temperature at low water 0.3m depth.

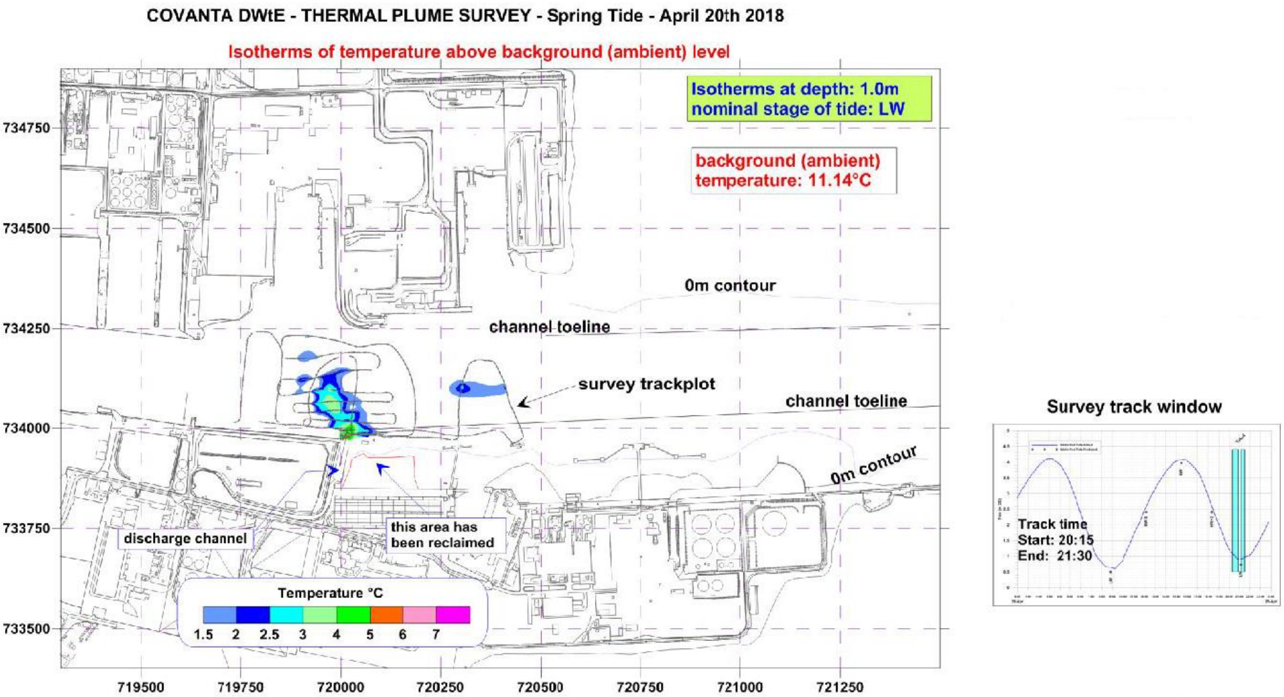

Figure 1.34: Survey contour 20th April 2018 – excess temperature at low water 1m depth.

In addition to the plume dispersion which is driven by a temperature differential there are also more complex flows driven by density stratification. An example of this is demonstrated during the thermal plume survey undertaken during the neap tide during April 2018. During the flood tide, when tidal flow occurs in a westerly direction the thermal plume from the Dublin Waste to Energy and Power Station is seen to be advected to the east at the surface with a much less marked dispersion pattern at lower levels, as illustrated in Figure 1.35 to Figure 1.37. It is noted however that during this period there was heavy traffic which may have influenced the survey (a process which would not have been represented in the numerical simulations).

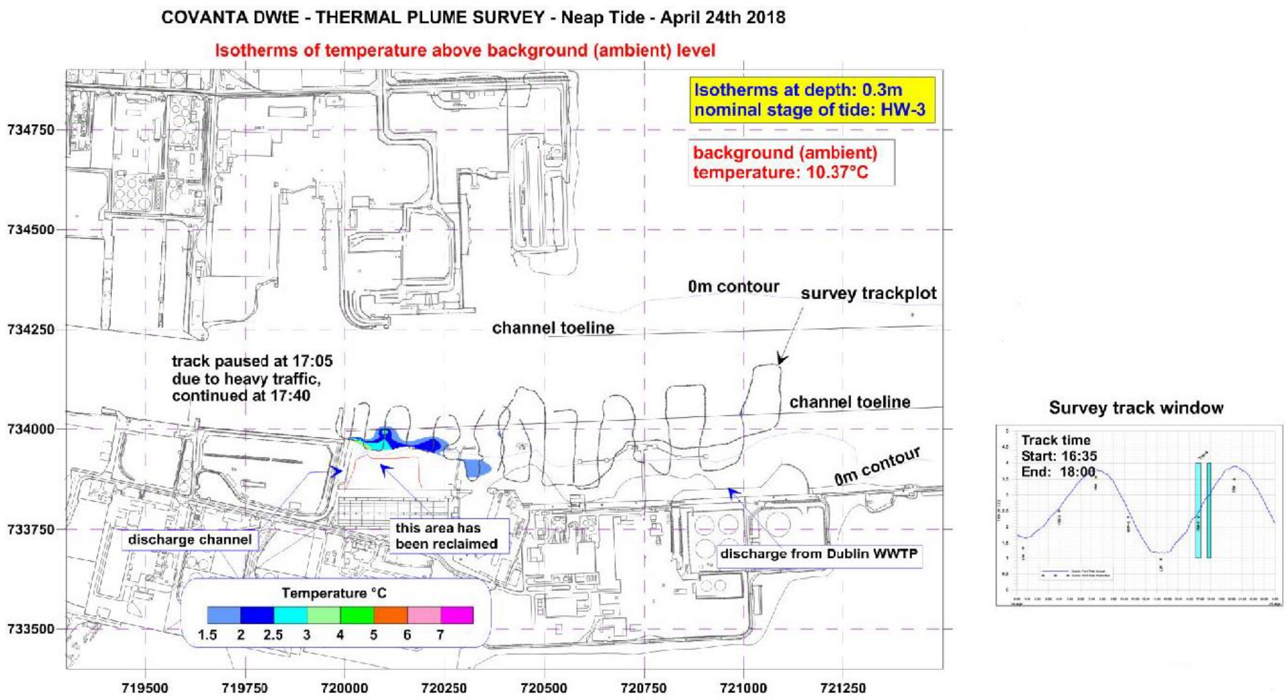

Figure 1.35: Survey contour 24th April 2018 – excess temperature at mid-flood 0.3m depth.

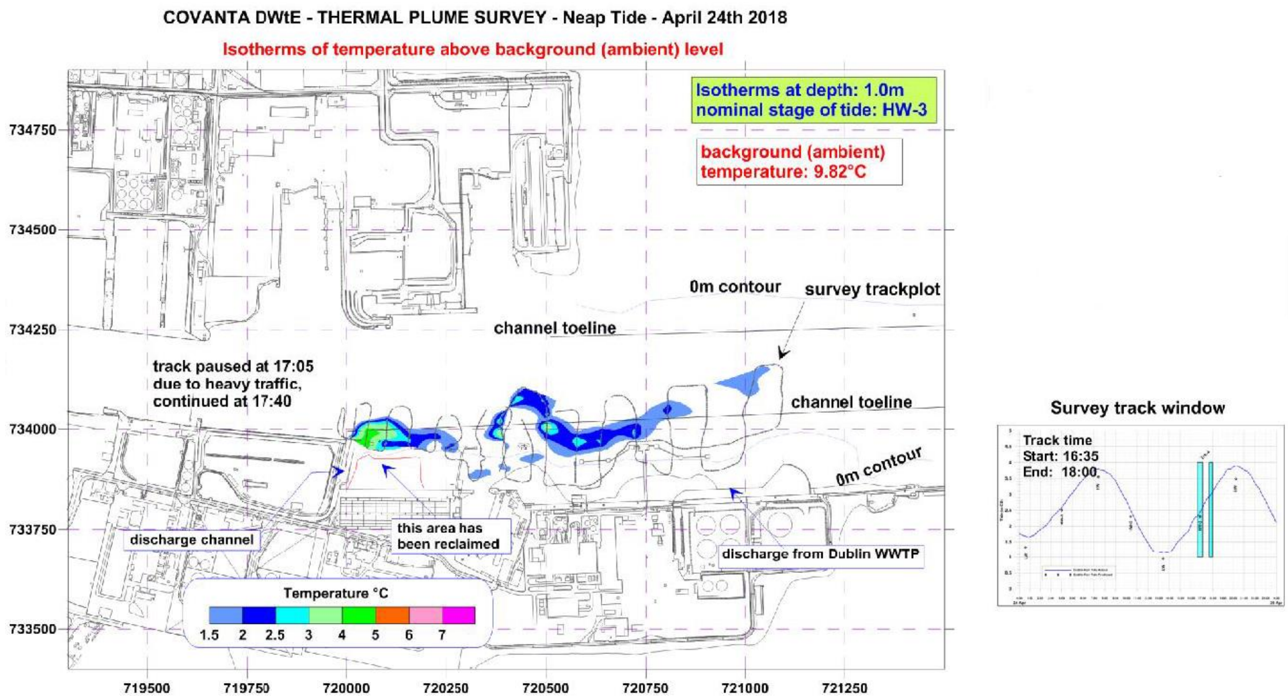

Figure 1.36: Survey contour 24th April 2018 – excess temperature at mid-flood 1m depth.

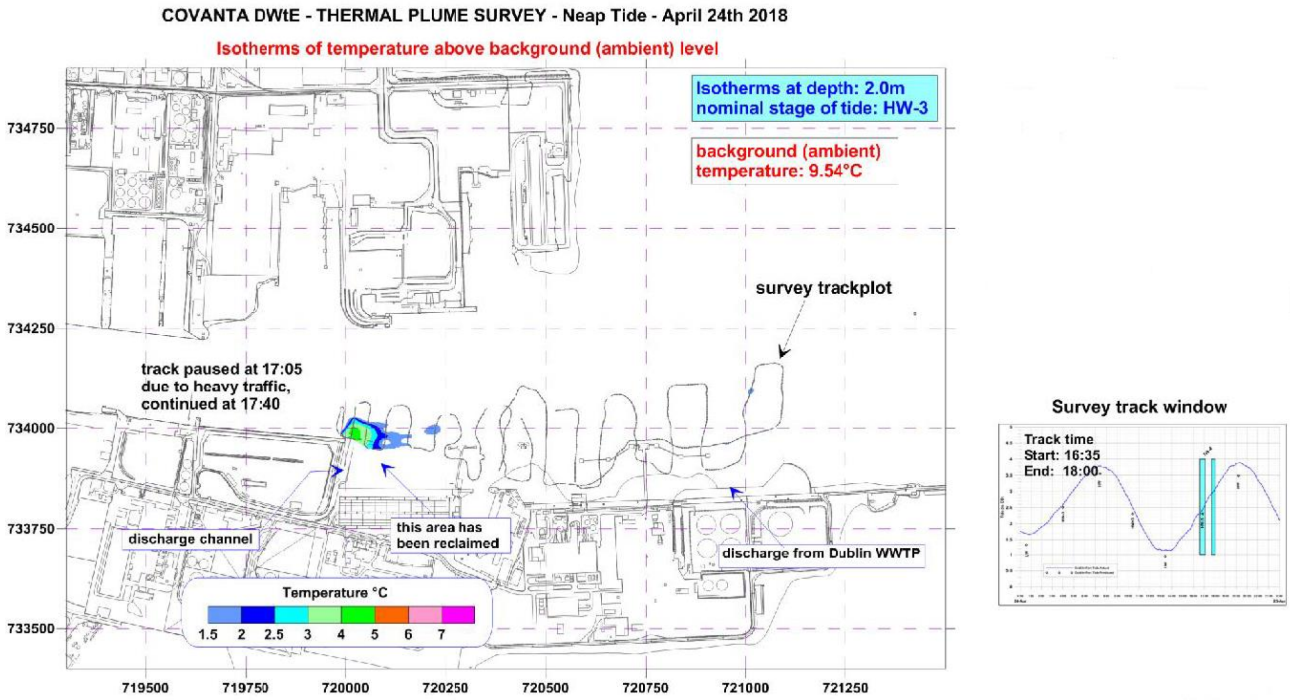

Figure 1.37: Survey contour 24th April 2018 – excess temperature at mid-flood 2m depth.

The numerical model for the same period also demonstrates the stratified flow. The following figures illustrate the thermal plumes with the flow vectors superimposed. Figure 1.38 and Figure 1.39 show the surface and near surface model output respectively. These are characterised by with flow vectors to the east with a larger plume extent below the surface. Whilst Figure 1.40 shows the lower layer with tidal flow entering from the east advecting the plume.

Figure 1.38: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 0.3m depth.

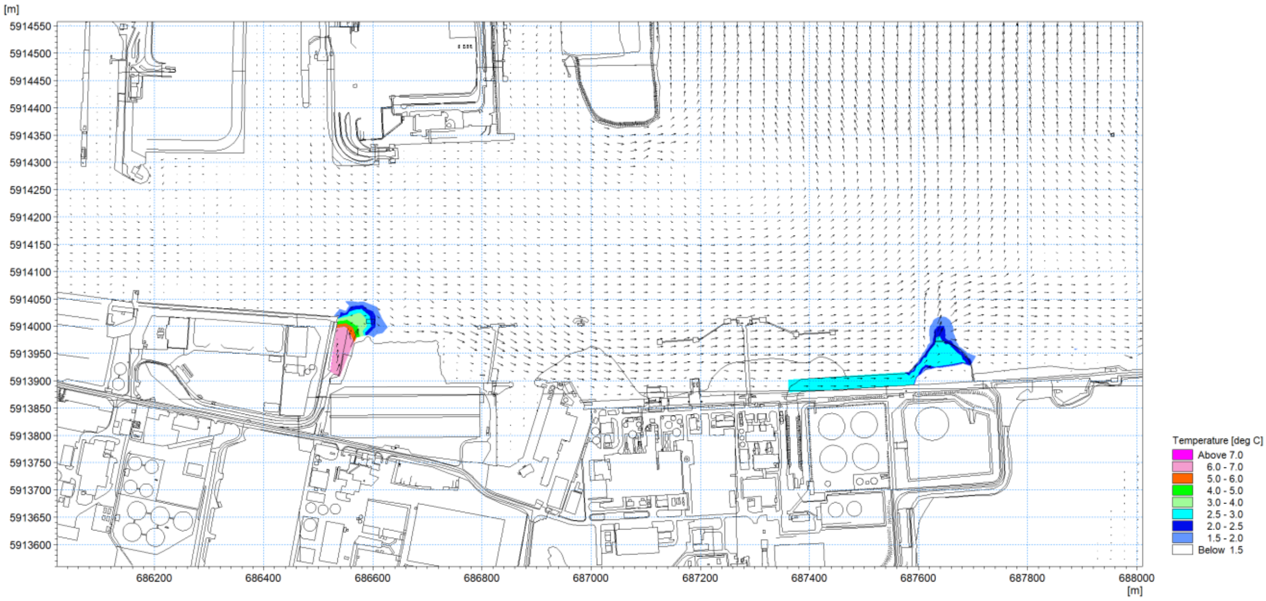

Figure 1.39: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 1m depth.

Figure 1.40: Thermal plume 20th April 2018 – excess temperature at low water circa 2m depth.

In addition to the thermal plume plan surveys, which were undertaken at fixed depths to determine the thermal contours during the 2018 Dublin Waste to Energy surveys, a series of dip surveys were undertaken to prepare vertical profiles. These extended from within the outfall discharge canal and across the river channel as illustrated in Figure 1.41. This exercise was carried out during both spring and neap surveys. The comparison between the surveyed and modelled profiles during the neap survey are presented here.

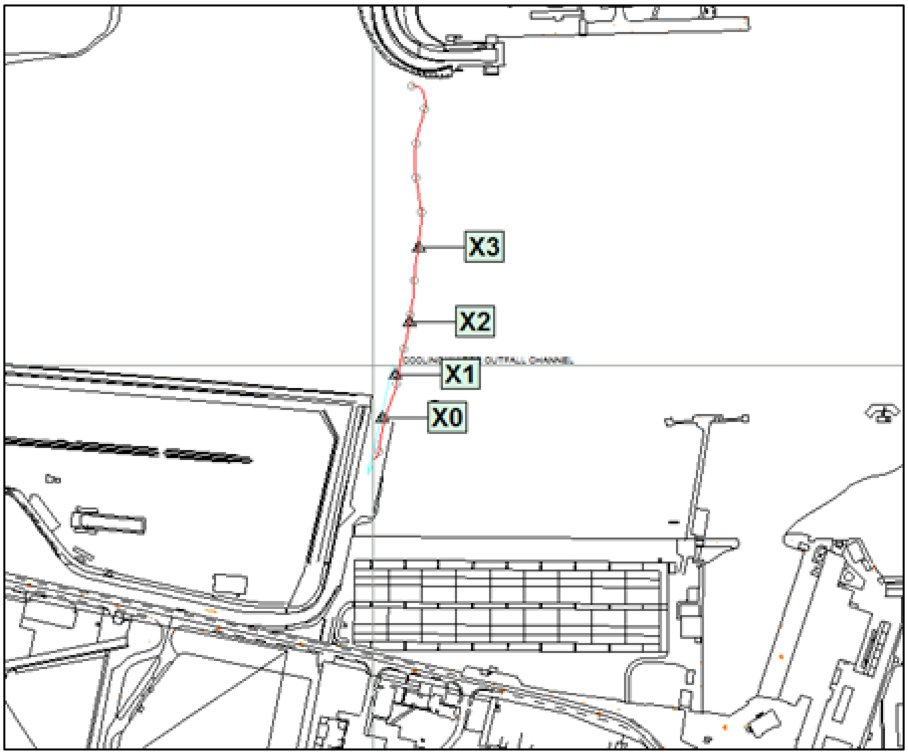

Figure 1.41: Approximate Locations of Vertical Dips

During the neap survey in April 2018 a series of four vertical profiles were taken. These occurred shortly following high water, during ebb tide, shortly following low water and during the flood tide. It was noted that the extraction of the dip profiles is sensitive both in terms of alignment and timing when undertaken near slack water and only an approximate overarching location was provided. The following figures present the surveyed profile followed by the equivalent profile from the modelled data. i.e. at the same approximate location, time and using the same contour palette, for each of the four tidal states.

Figure 1.42 and Figure 1.43 show the measured and modelled profiles shortly following high water. The form of the modelled data correlates with the measured data however it is apparent that a greater amount of mixing may have occurred within the discharge canal as the model bed levels differ from those in the survey plot in this area. This can be attributed to a lack of detailed bathymetric data in this localised area.

During the ebb tide approaching low water the plume is somewhat truncated in the model data indicating that the alignment of the plume may be differ between the modelled and surveyed locations. The two remaining modelled profiles correlate well with the surveyed data. They demonstrate the more buoyant river flows at the surface within the river channel, with the thermal saline plume residing just below this. The modelled plume is not quite as well defined as the surveyed values which extend further into the river channel. This may be due to the limitations of the mesh resolution (i.e. the layers becoming deeper with increasing water depth) and the lack of detailed bathymetry within the discharge canal. However, in general terms, the nature and form of the plume are well represented within the model.

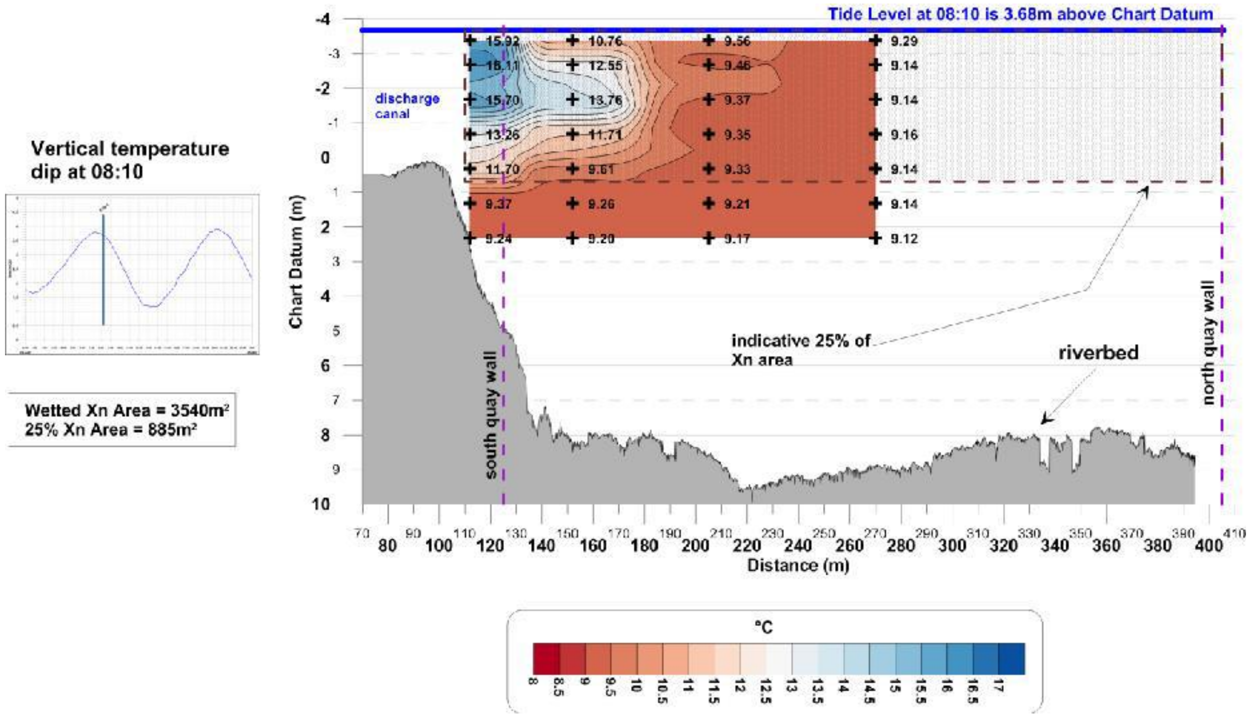

Figure 1.42: Surveyed vertical profile – 24th April 2018 high water plus 47mins

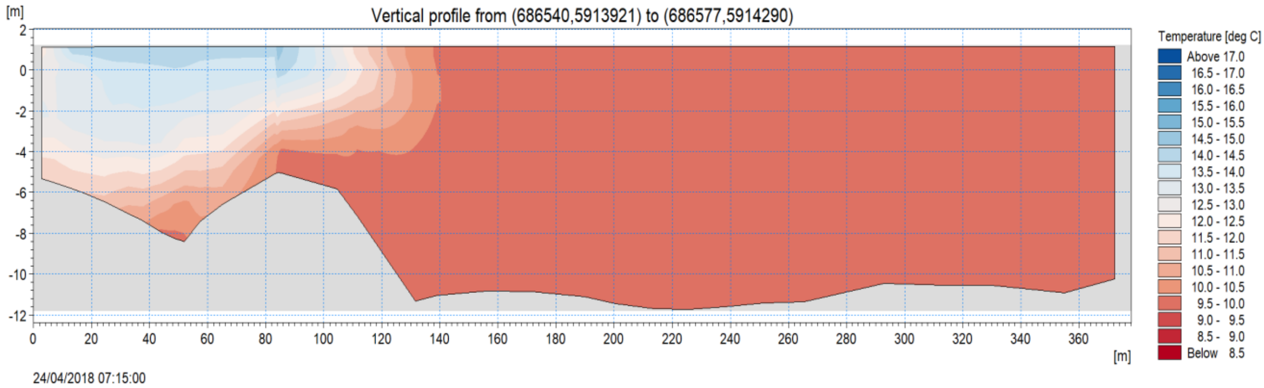

Figure 1.43: Modelled vertical profile – 24th April 2018 high water plus 47mins

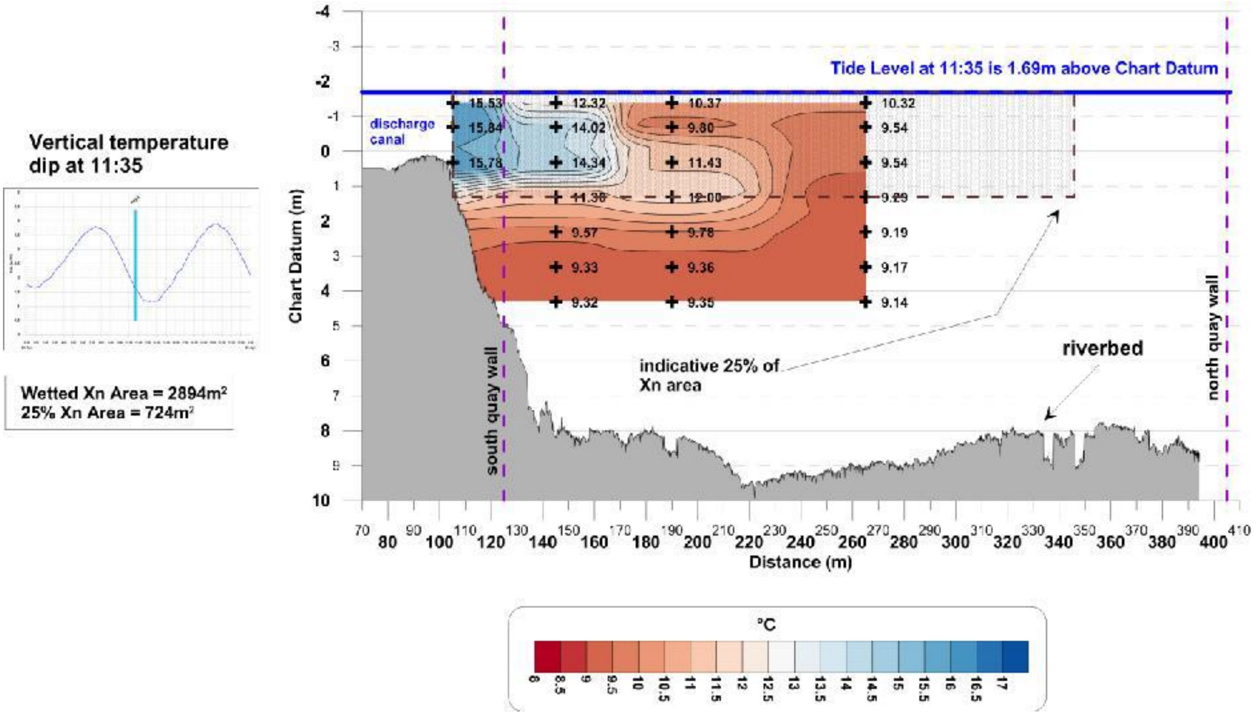

Figure 1.44: Surveyed vertical profile – 24th April 2018 high water plus 4hrs

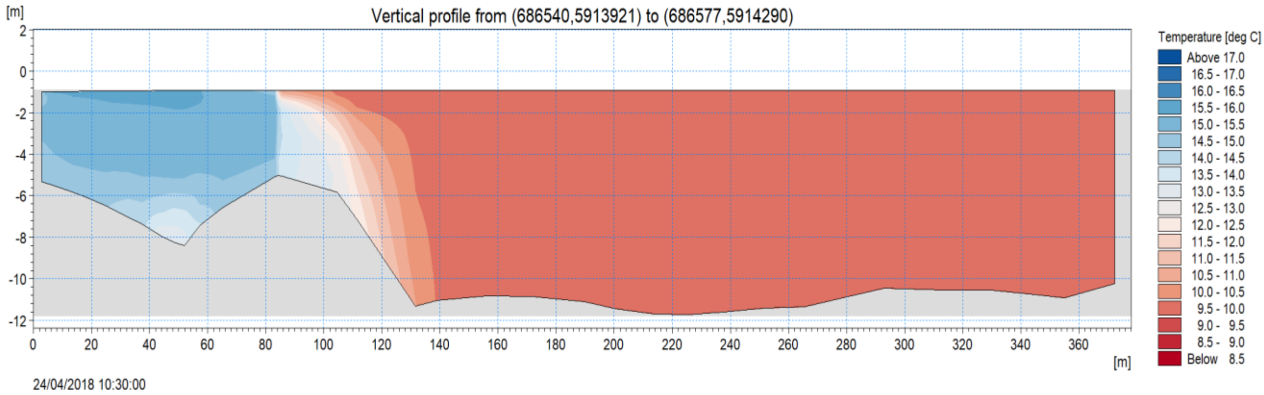

Figure 1.45: Modelled vertical profile – 24th April 2018 high water plus 4hrs

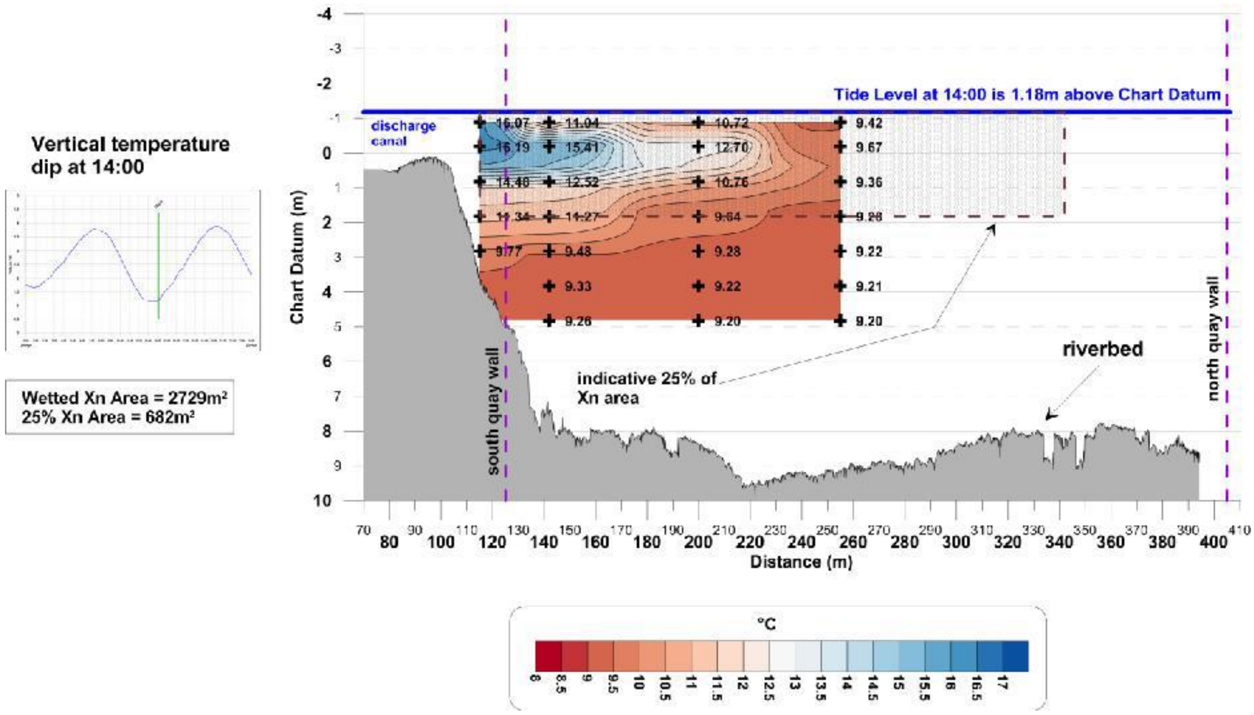

Figure 1.46: Surveyed vertical profile – 24th April 2018 low water plus 36mins

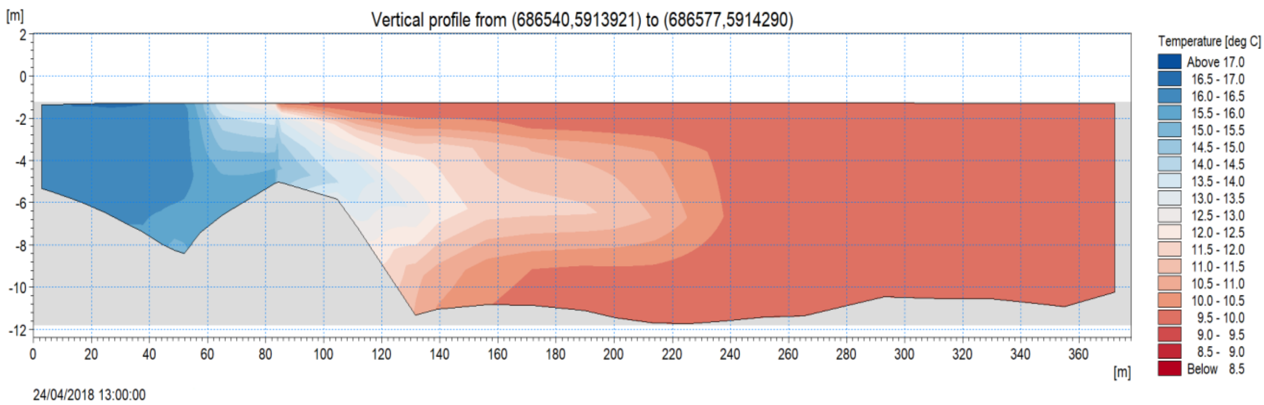

Figure 1.47: Modelled vertical profile – 24th April 2018 low water plus 36mins

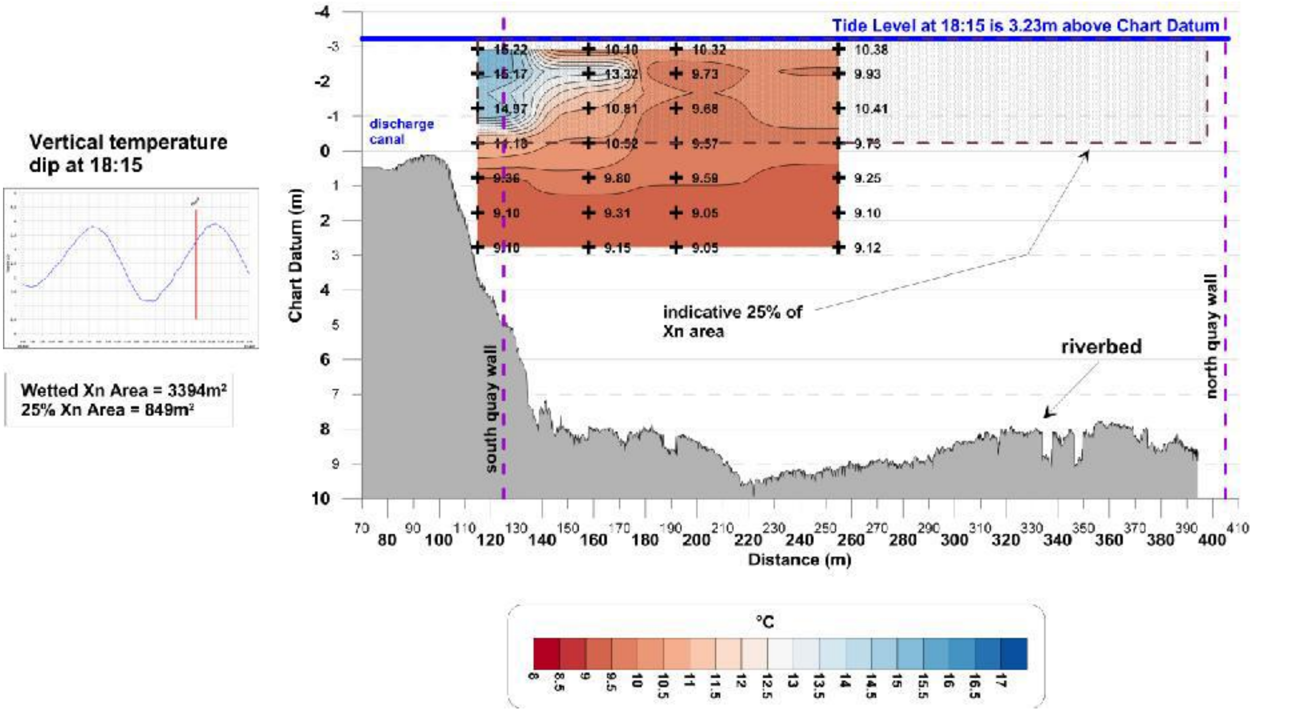

Figure 1.48: Surveyed vertical profile – 24th April 2018 high water minus 2hrs

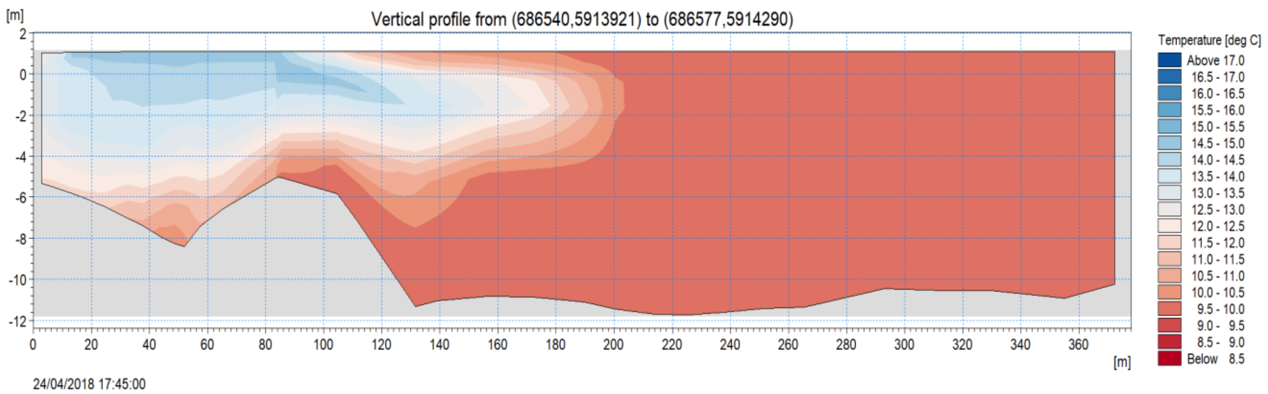

Figure 1.49: Modelled vertical profile – 24th April 2018 high water minus 2hrs

1.4.4 Additional Modelling

Having issued a report which described the findings of the Further Modelling described in Sections 1.4.2 and 1.4.3 in March 2024, RPS received additional comments from ESB which generally related to the simulated extent of thermal plumes generated at particular phases of different tides over the 2016, 2018 and 2019 periods. Recognising these comments and the importance of developing a suitable model to address potential concerns within this area, RPS undertook additional model developments and simulations to improve the overall accuracy and performance of the model.

The modelling results presented in the previous section indicates that the model developed was capable of simulating the stratified flow associated with the thermal discharges at Dublin Port. External feedback on the modelling study noted that model predictions from the Dublin Bay Power Station and Waste to Energy Plant are over-predicted along the south wall and do not extend sufficiently into the main channel.

In this respect it is important to note that the intended use of the model is to undertake a comparative study in relation to the Dublin Port 3FM development, which is proposed at this location, therefore use of this model to quantify potential impacts would provide a conservative prediction. It was also noted that the Poolbeg thermal discharge plume differed from that anticipated. It was therefore considered prudent to revisit the modelling and identify areas which may provide potential improvements.

It was noted that the thermal stratification and plume dispersion within Dublin Port is a result of numerous inter-rated factors some of which may be clearly prescribed within the models, such as discharge rates and temperatures, whilst others, such as ambient conditions are influenced by longer terms flow patterns and marine traffic. Two areas were considered for further investigation; namely river discharge and the mechanisms by which discharges are released. In the first instance models were re-run using the varying river flows provided by ESB for the duration of the simulations for which they were available and average flow for the periods when this data was not available. The resulting model output showed some variation from the previous scenario, however the plume extent along the south wall remained largely unaffected.

The second area identified for further consideration related to the discharge mechanisms. These concentrated on the canal which acts as a spillway for the Dublin Bay Power and Dublin Waste to Energy discharges and the discharge weir associated with the Ringsend WWTP and Poolbeg CCGT. The latter discharge being most apparent in the 2019 monitoring program where both discharges are operating and the threshold for excess temperature is lowest in the survey data presented.

1.4.4.1 Dublin Bay Power and Dublin Waste to Energy spillway

Examination of satellite data relating to discharge from the spillway indicates that the mechanism by which the discharge is released into the channel may influence how the subsequent plume is formed. This is illustrated in Figure 1.50 which shows images from Google Earth for a variety of tidal states and discharge volumes.

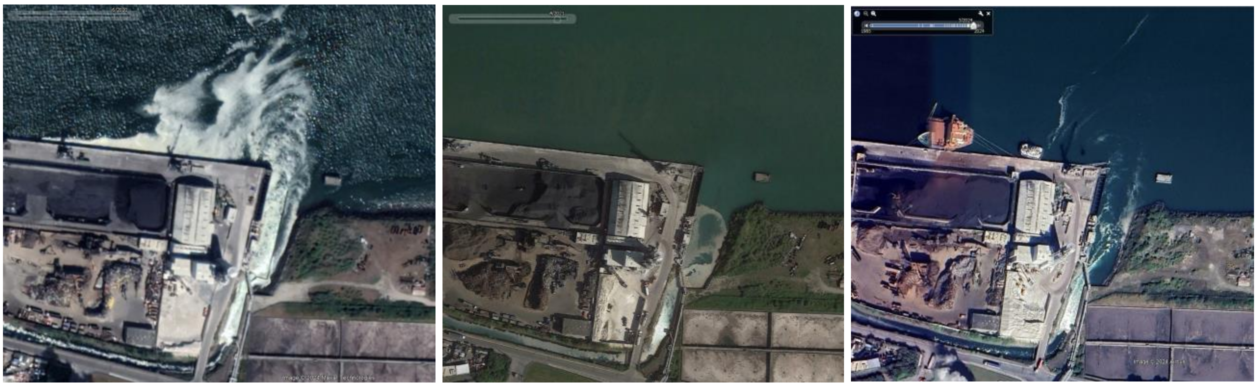

Figure 1.50: Spillway discharges 2020, 2021 & 2024 (Source: Google Earth)

The way in which the plume develops within the channel may be influenced by the discharge volume and also the spillway geometry. For the development of the preliminary model there was no recently surveyed bathymetric data for the spillway available. To update the model and test this sensitivity the original spillway extension construction drawing from the ESB archive was used to approximate the bathymetry within the spillway, a section of which is presented in Figure 1.51.

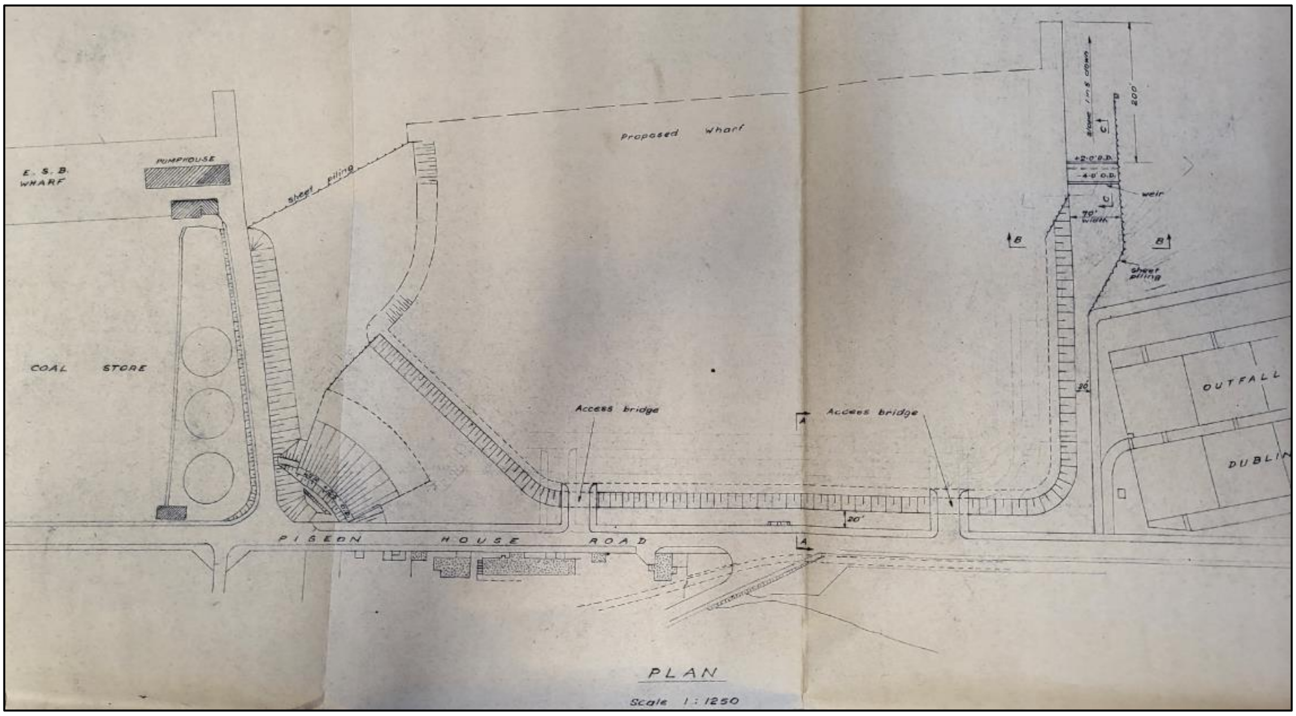

Figure 1.51: Ringsend Generating Station – C.W. Culvert Outfall Preliminary Drawing 25-05-1965

The model bathymetry was accordingly updated and then re-calibrated for the 2018 simulation period, which covered both spring and neap monitoring periods. Calibration involved introducing the discharge in all model layers at the head of the spillway and adjusting vertical dispersion parameters.

It was further noted that the spillway flow was also influenced by the tidal phase and the weir at the head of the spillway which is outside the model domain. The use of the modified spillway and revised calibration parameters gave rise to a general improvement in that the plume was moved into the channel and away from the south wall as is illustrated in Figure 1.52 and Figure 1.53 for the measured and modelled plume for mid-flood neap tide.

It was noted that the revised spillway bathymetry and parameters showed varying degrees of improvement across the range of tidal states and survey periods further indicating the sensitivity of both the discharge parameters and the receiving environment.

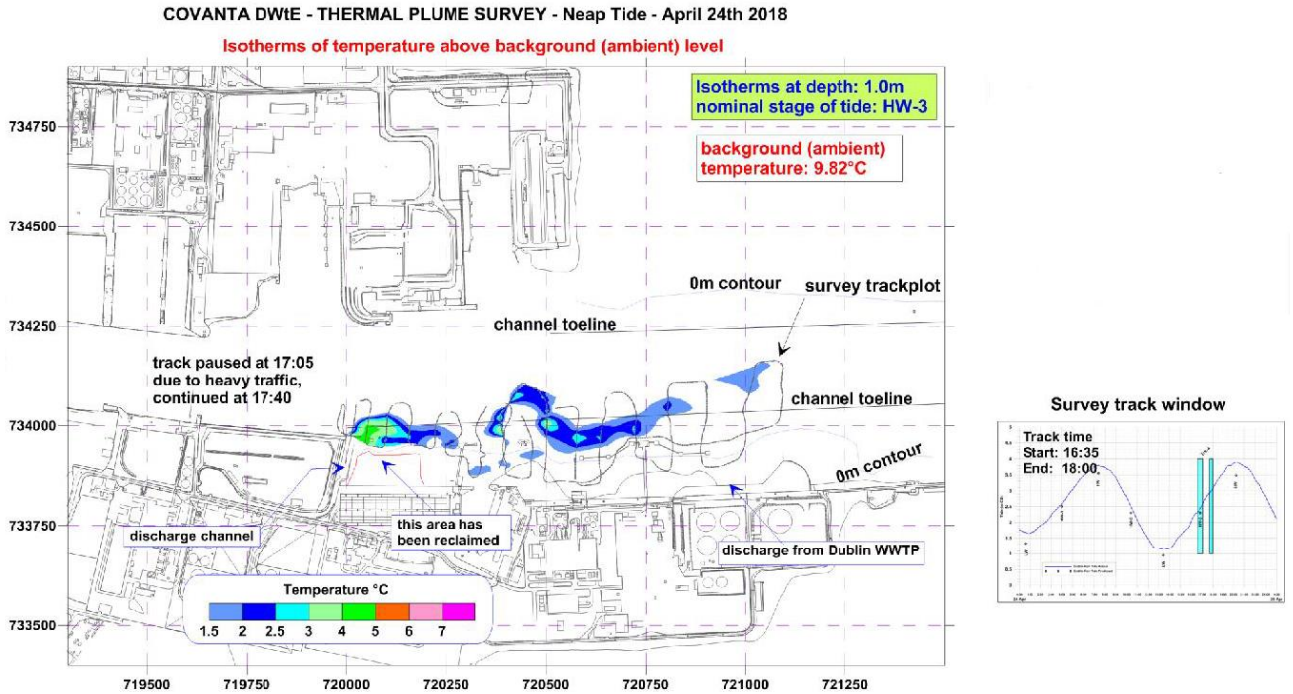

Figure 1.52: Survey contour 24th April 2018 – excess temperature at mid-flood 1m depth.

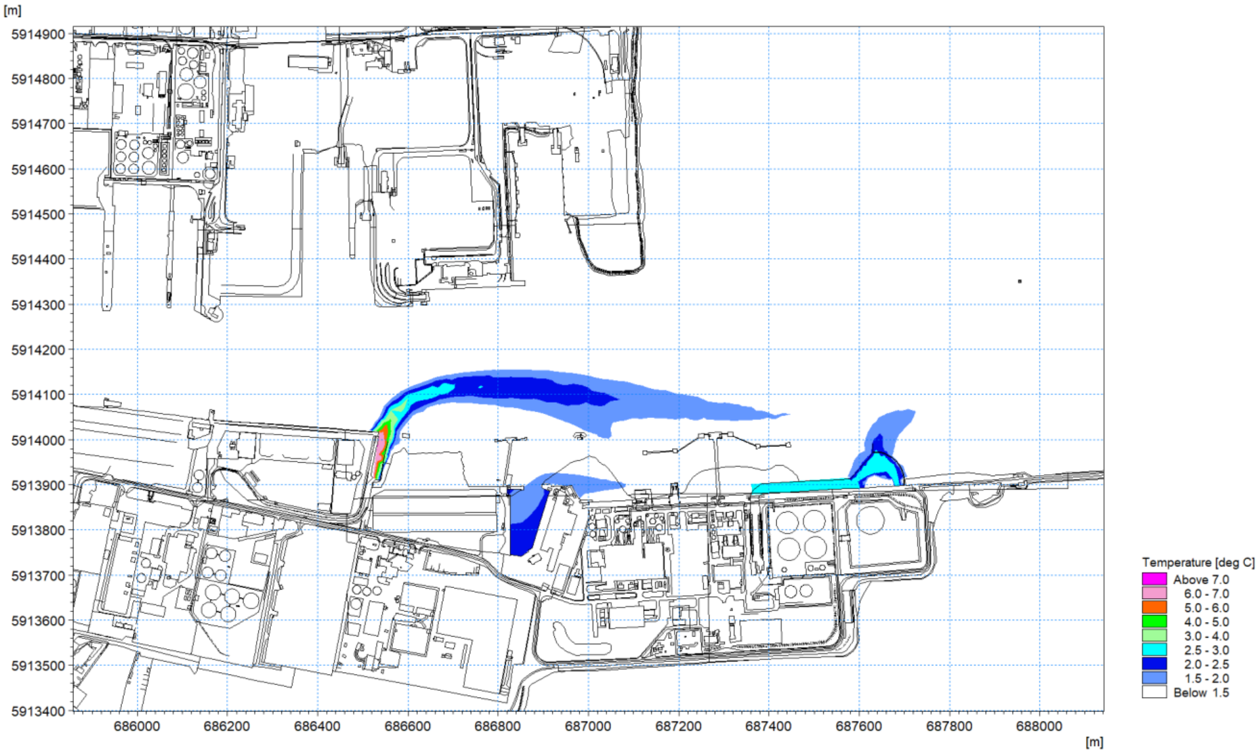

Figure 1.53: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 1m depth (layer 5).

To demonstrate the improvements to the model, the dip profiles presented in the previous section (Figure 1.42 to Figure 1.49) are recreated here from the revised model. In each case the plume extends further into the channel comparing more closely with the monitored data –a distinct improvement for high water plus four hours. The revised model plume is more concentrated towards the surface at the exit of the spillway channel than in the previous simulations however the river flows are seen to still overlay the plume further into the channel. This is particularly evident in Figure 1.61 during the flood tide where counter flow occurs. Noting that the revised scenarios include time varying river flow from the ESB dataset.

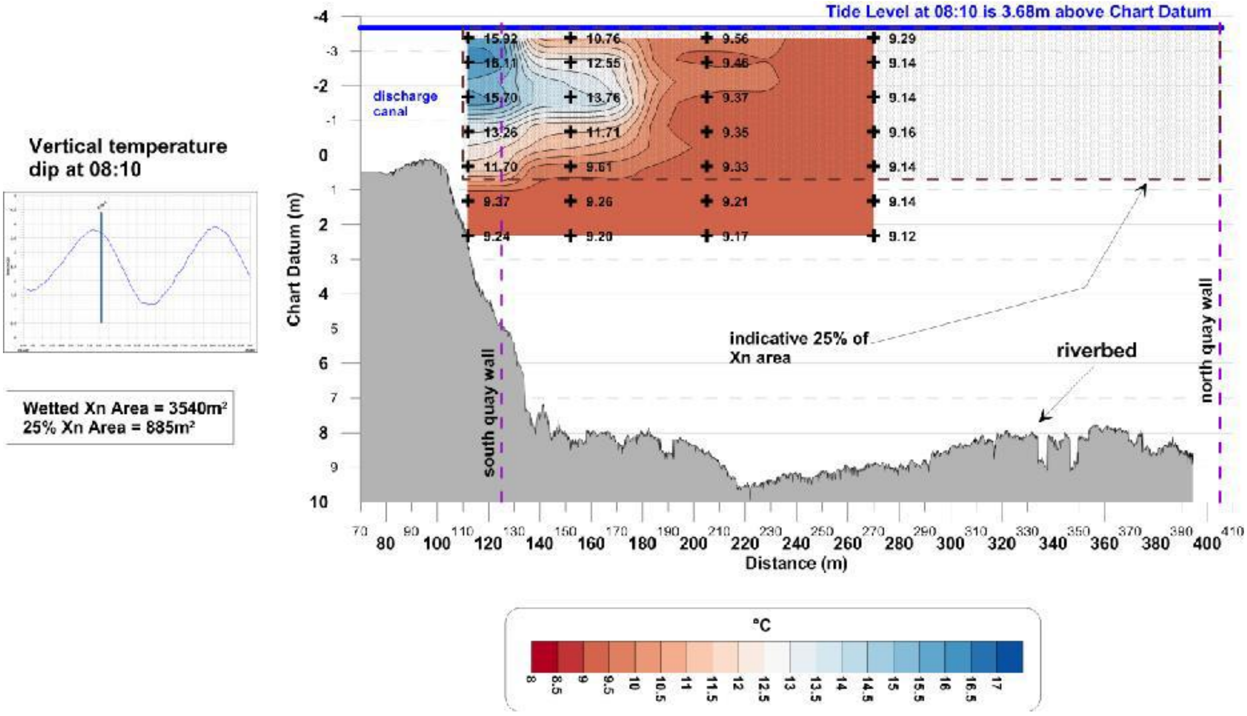

Figure 1.54: Surveyed vertical profile – 24th April 2018 high water plus 47mins

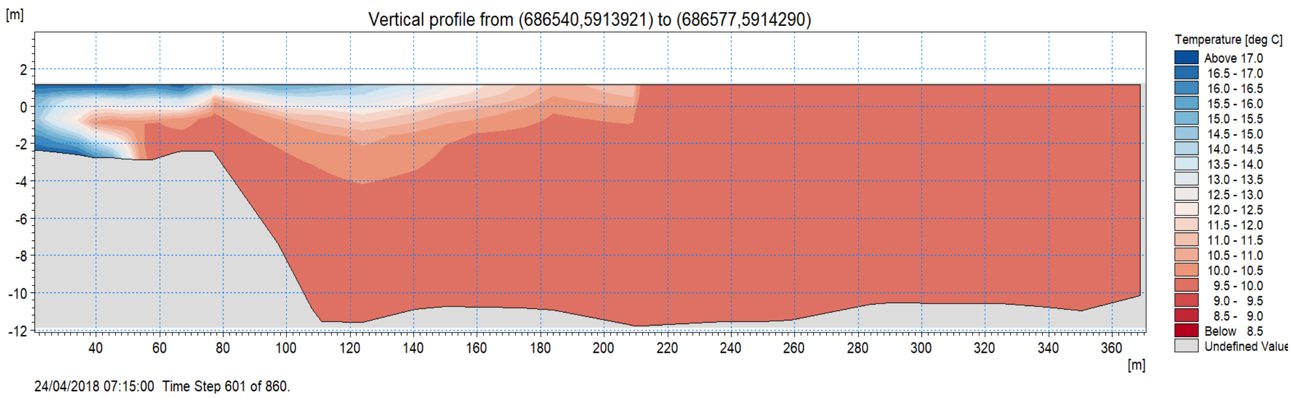

Figure 1.55: Modelled vertical profile – 24th April 2018 high water plus 47mins

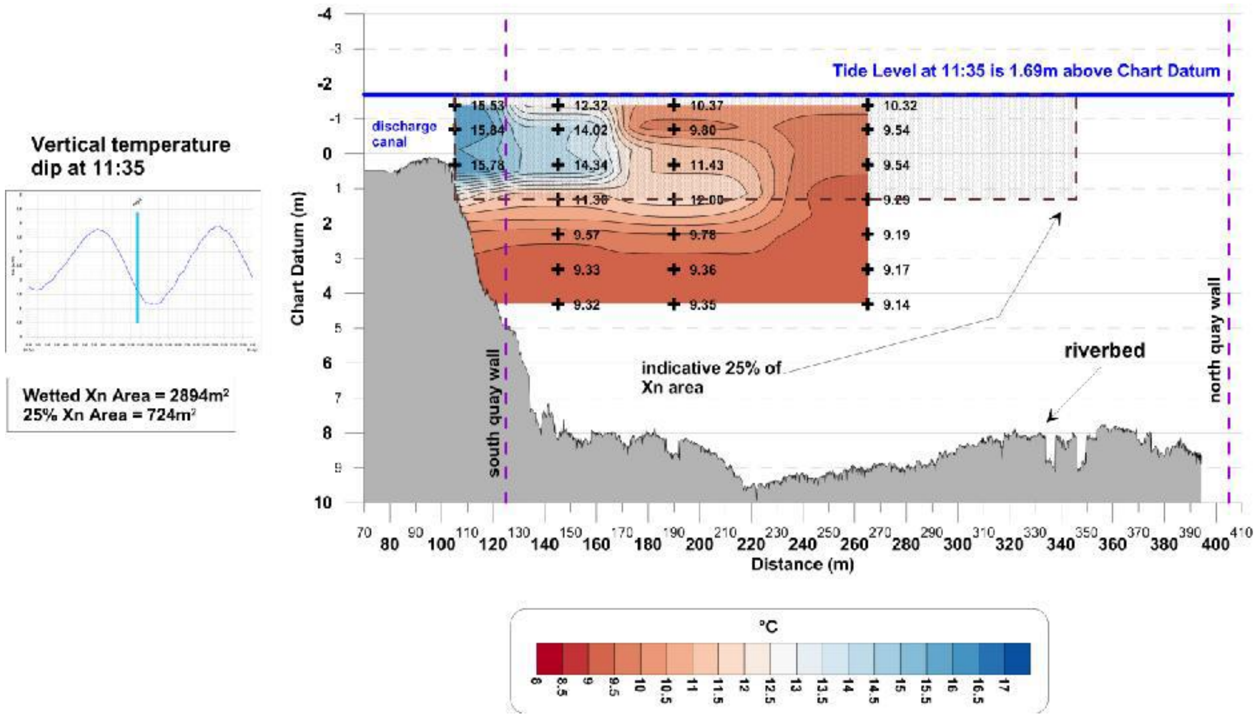

Figure 1.56: Surveyed vertical profile – 24th April 2018 high water plus 4hrs

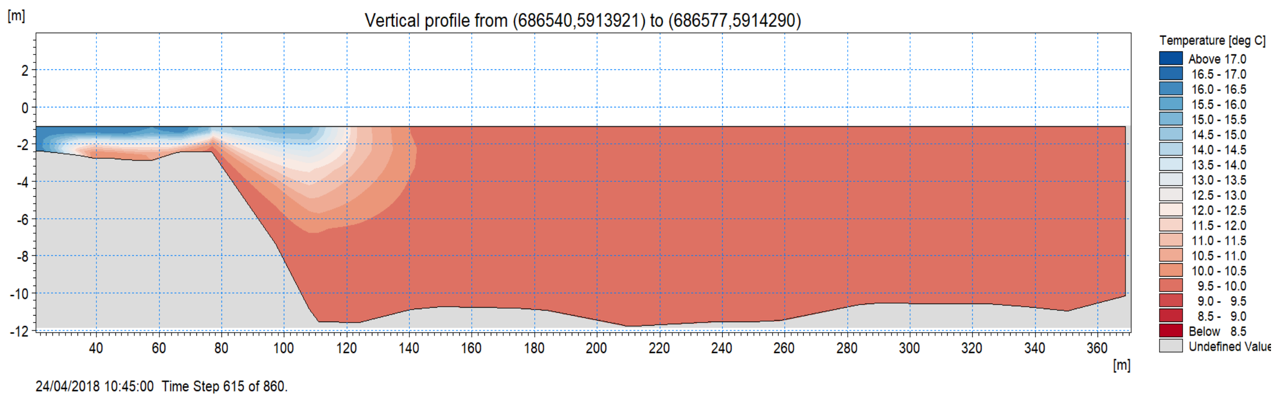

Figure 1.57: Modelled vertical profile – 24th April 2018 high water plus 4hrs

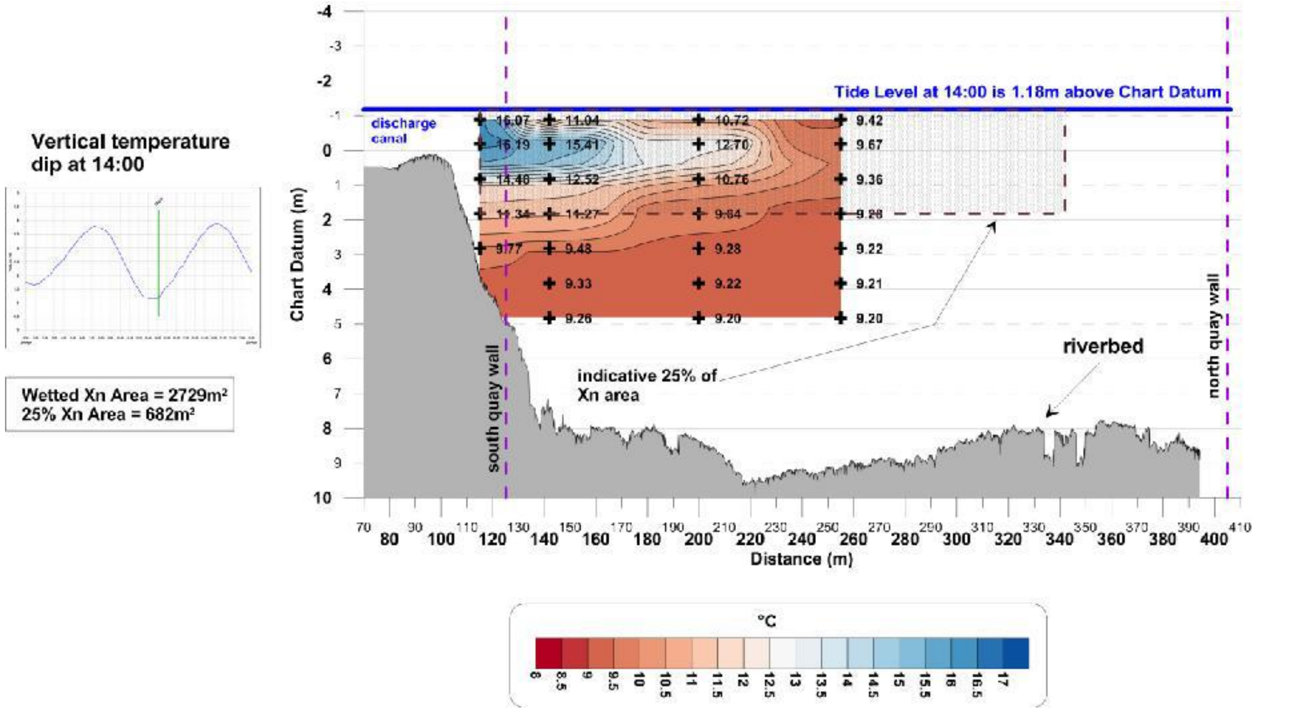

Figure 1.58: Surveyed vertical profile – 24th April 2018 low water plus 36mins

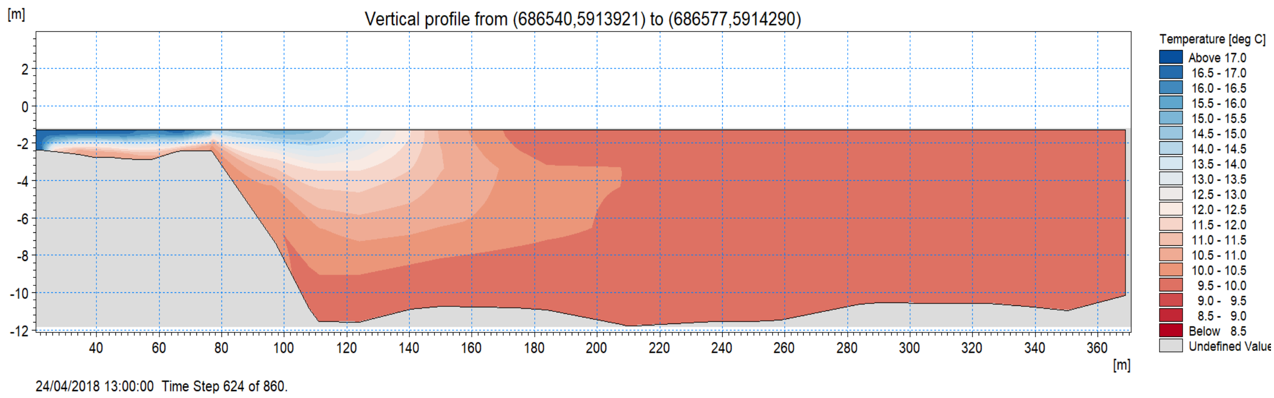

Figure 1.59: Modelled vertical profile – 24th April 2018 low water plus 36mins

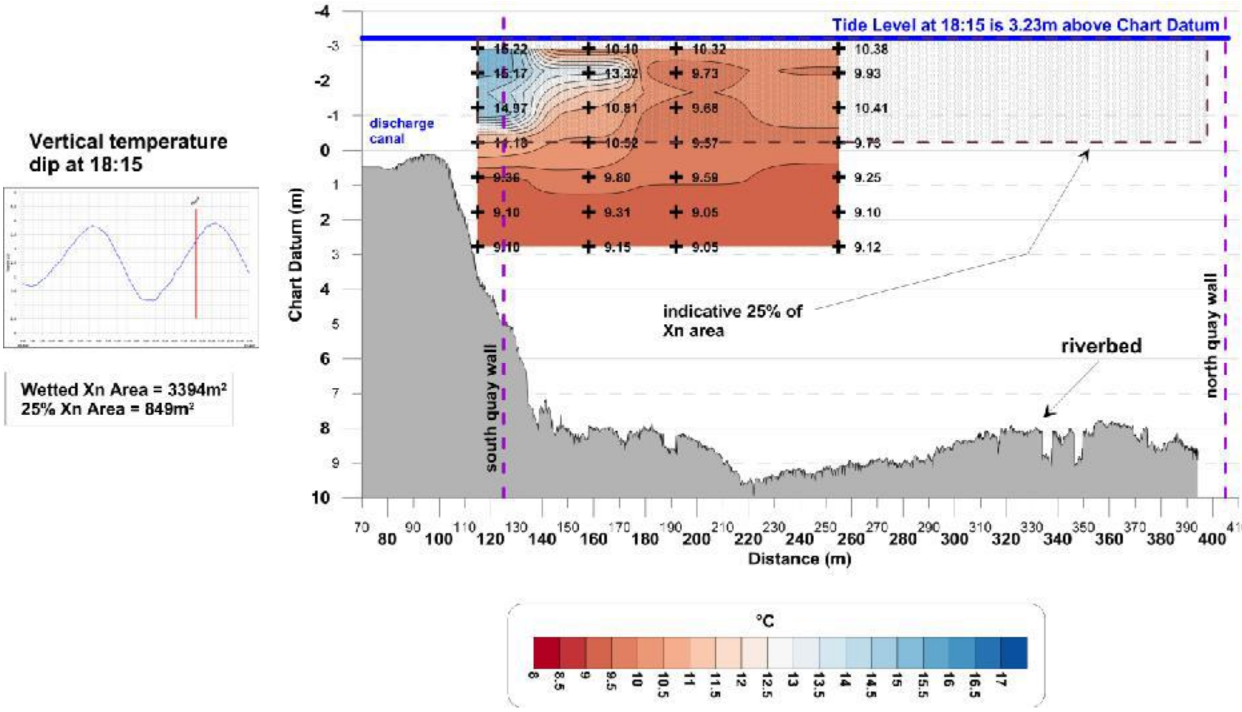

Figure 1.60: Surveyed vertical profile – 24th April 2018 high water minus 2hrs

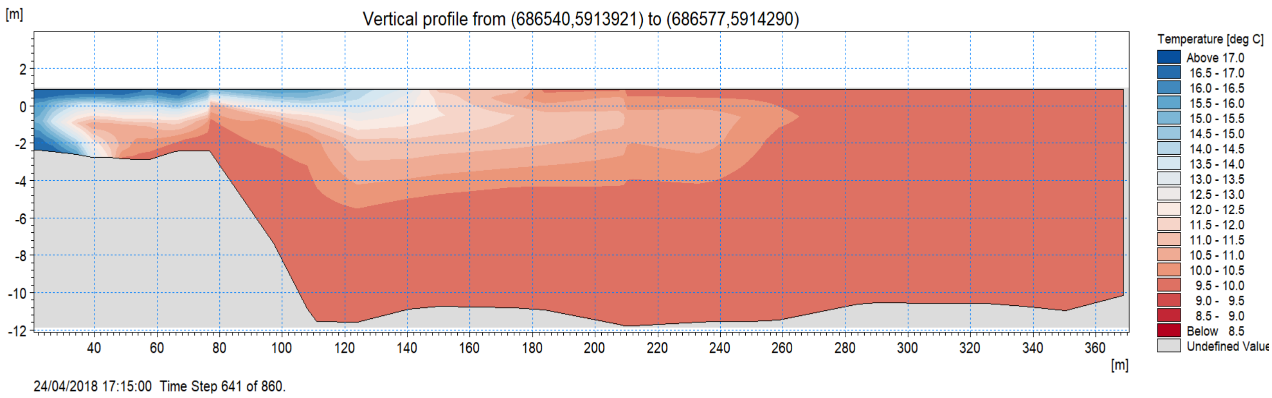

Figure 1.61: Modelled vertical profile – 24th April 2018 high water minus 2hrs

1.4.4.2 Vertical profile extent near Dublin Bay Power

It is recognised that the maximum cross-sectional area of any thermal plume envelope produced by the assets which discharge into Dublin Port are of partiuclar interest to a range of stakeholders for the purposes of licensing consents. Given the importance of ensuring model accuracy in this context, RPS compared the relevant modelled vertical profiles described in the previous Section with measurements as reported by the 2018 thermal plume survey report across the section illustrated in Figure 1.41.

Using a geographic information system, the wetted cross-sectional area of the navigation channel was calculated which in-turn was used to derive the 25% area relative to the water level at that time. Similarly, the cross-sectional area of the channel occupied by a thermal plume which exceeded 1.5ºC above background levels was calculated (*with background levels between c. 9.5 – 10ºC*). This process was undertaken for both the spring and neap thermistor surveys described in the 2018 thermal plume survey report.

It will be seen by comparing Table 1.6 and Table 1.7 that the area occupied by a thermal plume which exceeded 1.5ºC ranged between 7 - 12% and 8 – 12% for measured and modelled results respectively. For spring conditions, the equivalent ranges were 8 to 12% and 8 to 13% for measured and modelled respectively.

These results demonstrate that the numerical model successfully represents the dispersion of thermal plume envelopes within Dublin Port. The slight discrepancies maybe accounted for by localised model performance or minor spatial and temporal differences between modelled and surveyed data.

Table 1.4: Recorded thermal plume data for the Spring tides as reported by 2018 survey

Vertical Profile No.	Time	Stage of Tide	Tide Level (m above CD)	X^n Area (m^2)	25% of X^n area (m^2)	Plume area (m^2)	%
1	13:15	HW-2.25hr	3.31	3420	855	400	11
2	16:35	HW+1hr	3.86	3598	900	300	8
3	21:00	LW	0.90	2638	660	320	12

Table 1.5: Modelled thermal plume data for the Spring tides *(note difference in daylight savings)*

Time relative to 20/04/2018	Channel Area [m^2]	25% of Channel Area [m^2]	Plume Area [m^2]	%
12:15	3890	959	510	13%
15:30	3948	987	320	8%
20:00	2760	708	263	10%

Table 1.6: Recorded thermal plume data for the Neap tides as reported by 2018 survey

Vertical Profile No.	Time	Stage of Tide	Tide Level (m above CD)	X^n Area (m^2)	25% of X^n area (m^2)	Plume area m^2	%
1	08:10	HW+47mins	3.68	3540	885	220	7
2	11:35	HW+4hrs	1.69	2894	724	310	11
3	14:00	LW+36mins	1.18	2729	682	330	12
4	18:15	HW-2hrs	3.23	3394	849	230	7

Table 1.7: Modelled thermal plume data for the Neap tides *(note difference in daylight savings)*

Time relative to 24/04/2018	Channel Area [m^2]	25% of Channel Area [m^2]	Plume Area [m^2]	%
07:15	4691	1173	413	9%
10:45	3075	769	239	8%
13:00	2992	748	330	11%
17:15	3847	962	476	12%

1.4.4.3 Ringsend WWTP and Poolbeg CCGT discharge pier

On review of the model setup it was noted that during the previous 2019 simulations the Poolbeg CCGT discharge had been incorrectly specified. This was therefore corrected and the model was re-run using the parameters defined during the calibration process defined in the previous section.

For the comparison of survey data and modelled data the process described in section 1.4.1 was applied to the model output to derive excess temperature. However, it is noted that within the survey a different parameter was used, whereby selection of the minimum temperature close to the edge of the surveyed extents was applied. This may result in a variation in the background temperature applied although the contour palette applied, in both survey and modelling output, is reduced from the previous surveys to 0.5°C minimum excess temperature which aids in comparisons. Figure 1.62 and Figure 1.63 illustrate the surface plume at low water during the 2019 survey for measured and modelled data respectively. For reference, it should be noted that the natural variation in background temperatures during this period was reported as varying between 8.6°C to 9.6°C. This is important even very minor changes in the background temperature used to create the plume envelopes could change considerably depending on what reference value is used.

The model layers will vary in depth from the surface depending on the bathymetry (still water depth) and tidal state (instantaneous water depth) this is particularly relevant to plumes along the south wall where the bed levels vary significantly as illustrated in Figure 1.64, where for example in the vicinity of the wall the 1m survey may be located in layer 2 whereas further offshore the same survey level is present in layer 5.

This is illustrated by comparison of the mid-ebb survey undertaken in 2019 shown in Figure 1.65 and the modelled data for the surface layer 6 in Figure 1.66 and the mid-depth layer 4 in Figure 1.67. As the profile approaches the drying areas the lower model layers link with the survey data.

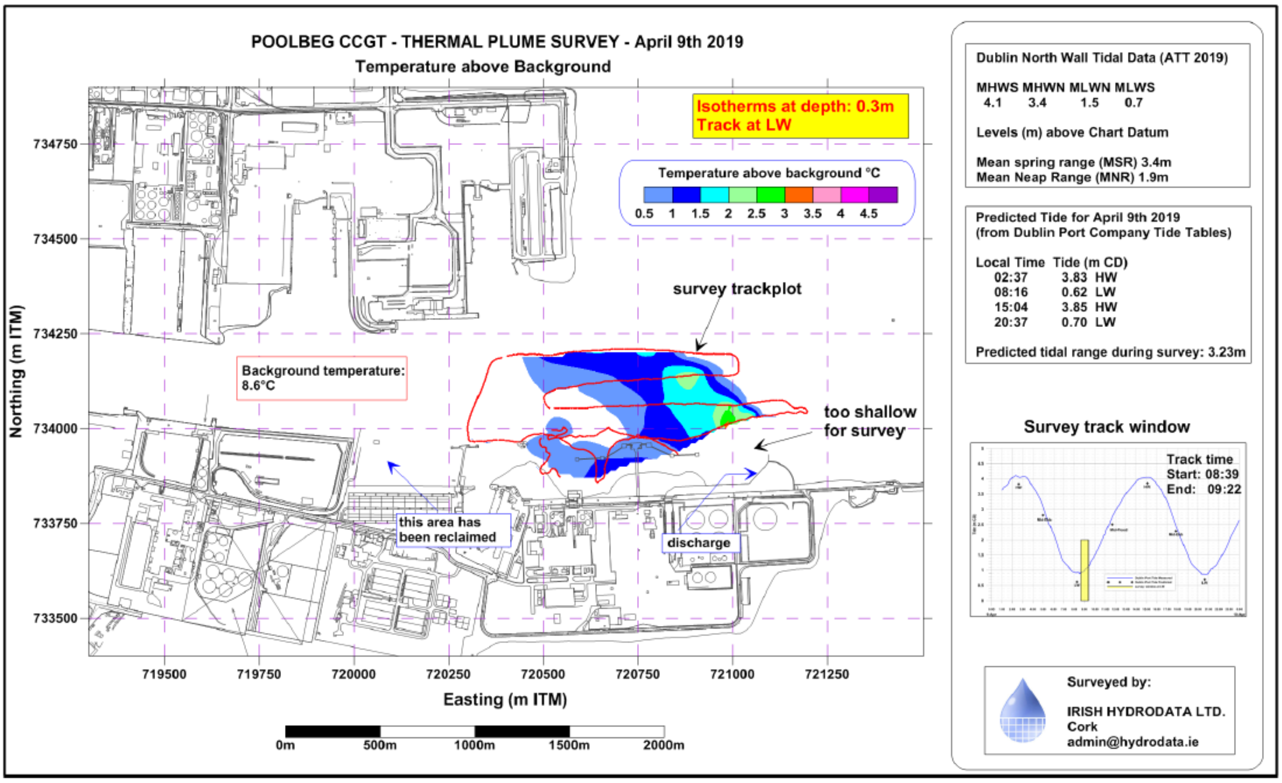

Figure 1.62: Survey contour 9th April 2019 – excess temperature at low water 0.3m depth.

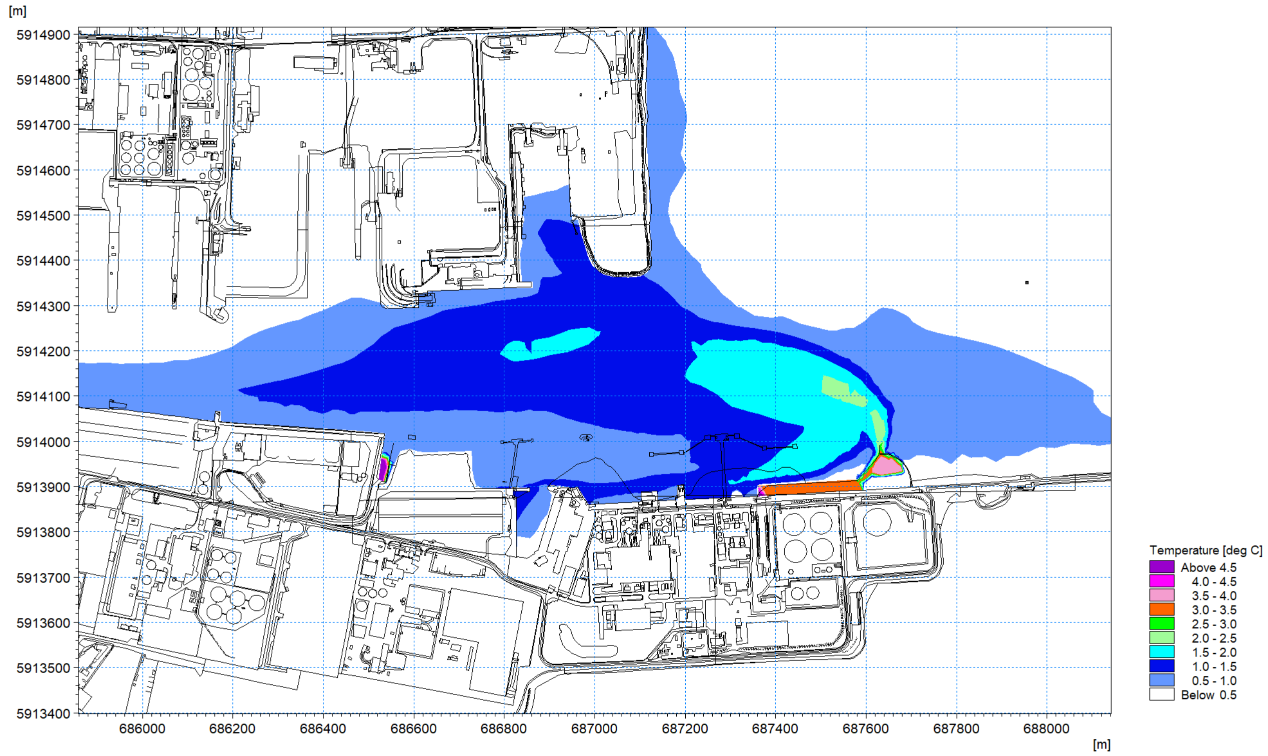

Figure 1.63: Thermal plume 9th April 2019 – excess temperature at low water circa 0.3m depth (layer 6).

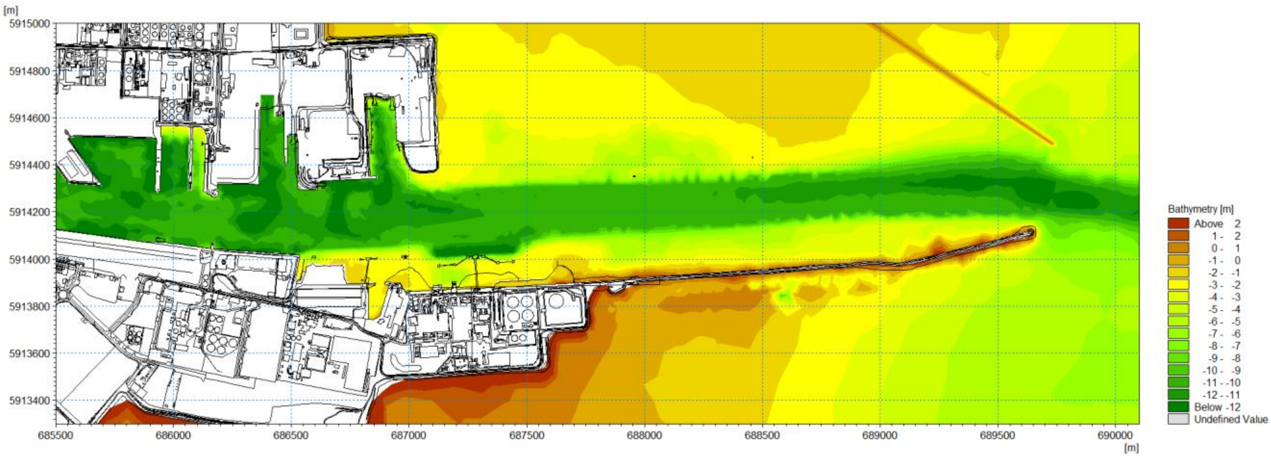

Figure 1.64: Bathymetry to mean sea level Dublin Port

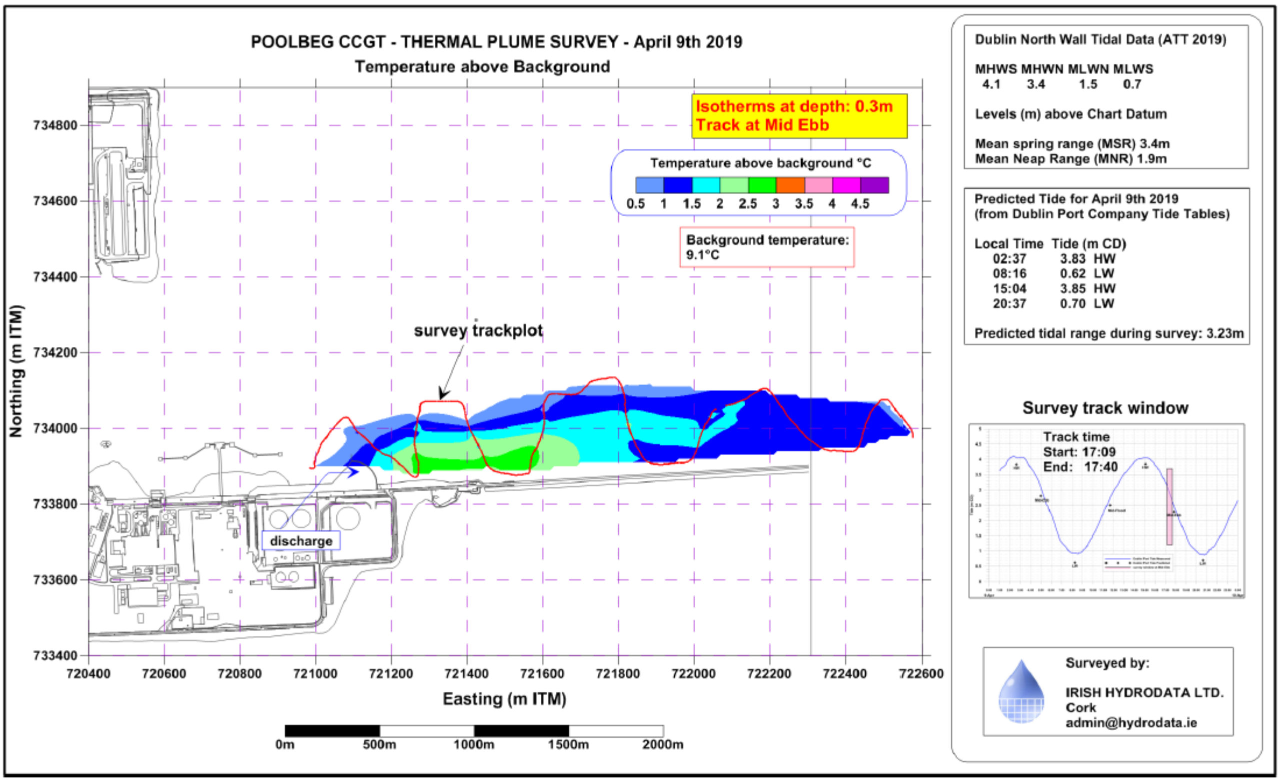

Figure 1.65: Survey contour 9th April 2019 – excess temperature at mid-ebb 0.3m depth.

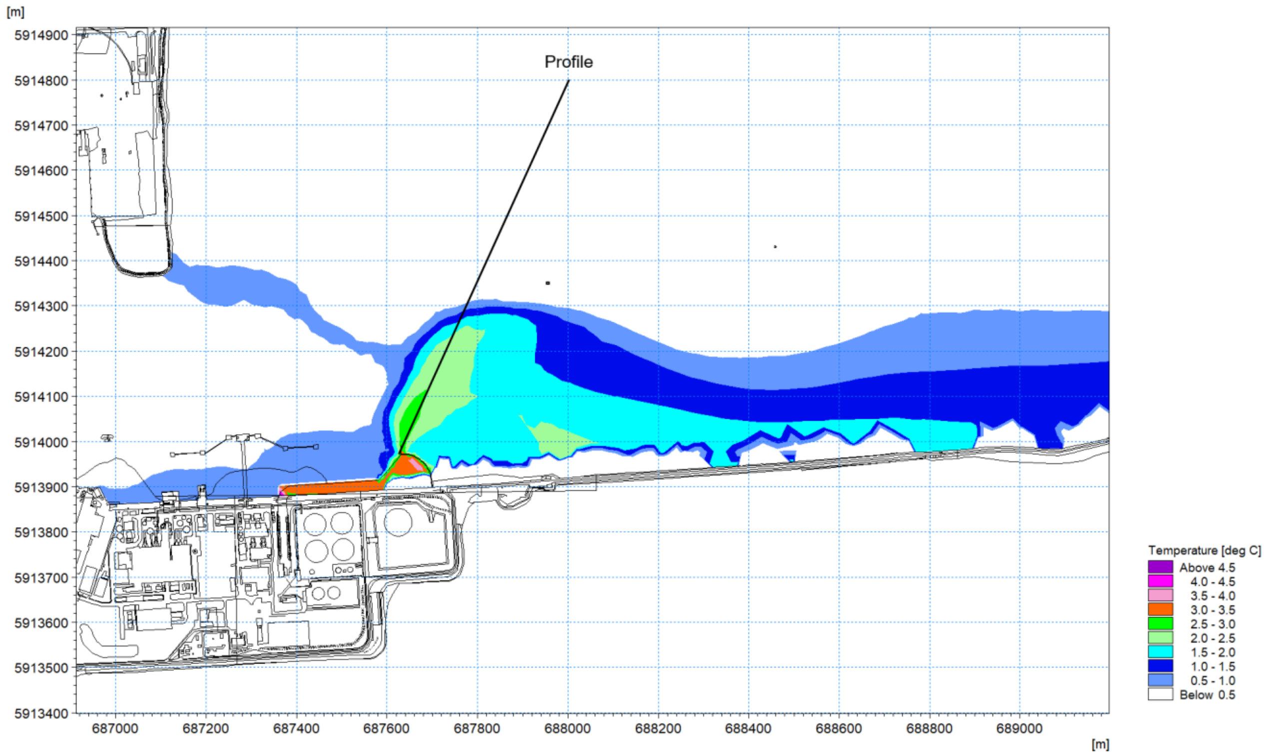

Figure 1.66: Thermal plume 9th April 2019 – excess temperature at mid-ebb layer 6.

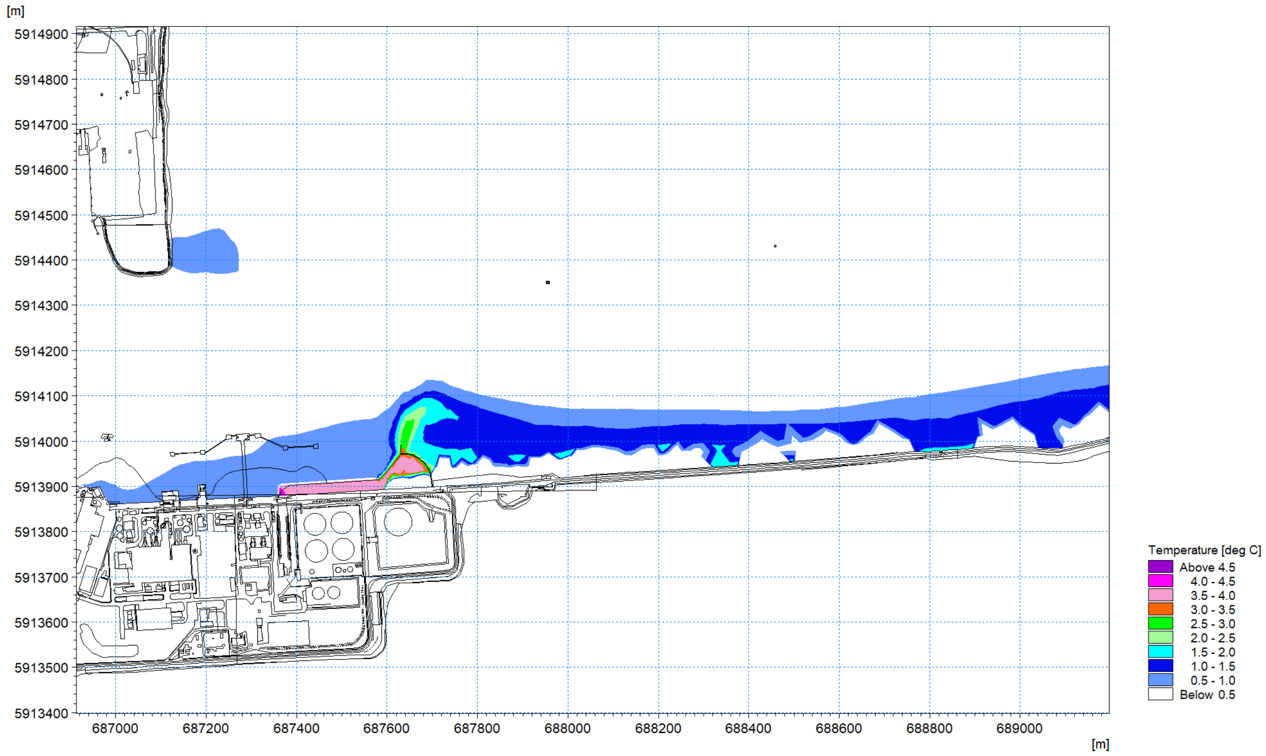

Figure 1.67: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa layer 3.

There is a clear disparity between the surveyed and modelled data where the discharge is released at the eastern end of the impoundment. Within the model this is represented by a series of weirs, the curved section with a level set to mean sea level, whilst the adjacent section is set 1m lower which effectively forms the discharge plume. This arrangement was used to represent the structures in place, as shown in Figure 1.68 on the right, however in reality due to the condition of the structures the discharge is more diffuse, as illustrated on the left of this figure. This would be difficult to recreate in the existing model without either detailed survey information to describe the condition of the structure at the time of thermal plume survey or decreased resolution to diffuse the influx numerically.

Figure 1.68: Poolbeg CCGT discharge pier

However, once the discharge is released from the immediate vicinity of the impoundment the plume spreads out and forms a surface layer circa 1m in depth with an excess temperature of 1.5°C. This is illustrated in Figure 1.69 which is a profile taken at mid-ebb during the 2019 survey at the location shown in Figure 1.66. This is in accordance with the observed behaviour of the plume from the Ringsend WWTP and Poolbeg CCGT discharges.

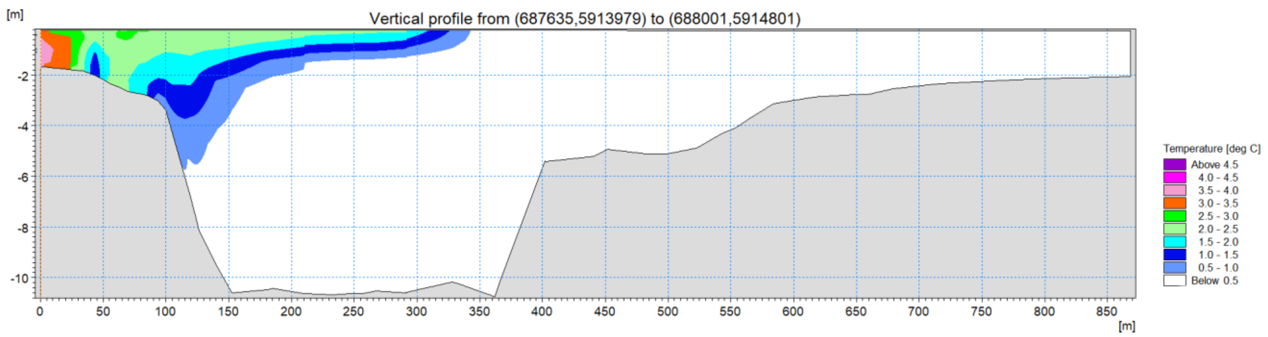

Figure 1.69: Thermal plume 9th April 2019 – excess temperature at mid-ebb profile.

1.4.5 Assessing Model Performance

This document has discussed the model performance relating to thermal plumes surveys presented in the following three reports:

- Survey reports:
  - ESB International (2017) Dublin Bay Power Plant: Thermal Plume Survey.
  - Irish Hydrodata (2018) Covanta Dublin Wate to Energy Facility: Thermal Plume Surveys of April 20th and 24th 2018.
  - Irish Hydrodata (2019) Poolbeg CCGT: Thermal Plume Survey of April 9th, 2019.
- The full set of the final model output corresponding to each survey is provided in the Appendices of this document as flows:
  - 2016 survey: Discharge from ESB's Dublin Bay Power facility and Irish Water's Waste Water Treatment Plant (WWTP) in Appendix A.
  - 2018 survey: Discharge from ESB's Dublin Bay Power facility, Irish Water's WWTP and the Dublin Waste to Energy facility in Appendix B. This includes both thermal contour plots and dip profiles collected during spring and neap surveys.
  - 2019 survey: Discharge from Poolbeg CCGT, Irish Water's WWTP and the Dublin Waste to Energy facility in Appendix C.

The stratified flow and thermal plume dispersion within Dublin Port is a complex process which is influenced by various factors which act on a range of temporal scales, Such factors include longer term hydrological conditions which develop background conditions and short term direct influences such as outfall discharges, current meteorological conditions and vessel activity within the Port. The purpose of this study was to characterise the primary hydraulic processes that govern the dispersive behaviour of the thermal discharges in order that the parameters derived may be applied in a comparative thermal plume study undertaken to inform the environmental assessment.

The numerical model provides instantaneous output based on the model discretisation described in sections 1.2 and 1.4.4, with thermal plumes presented from specific model layers. The use of layers relative to water depth is the most effective way to accurately simulate the behaviour of stratified flow. As previously noted, the use of sigma layers means that the information presented is relative to the location within the water column, as opposed to a fixed location relative to the water surface (as is the case with the surveyed data). The relative depth and thickness of the layers will vary spatially (i.e. are shallower in shallow water) and also temporally (i.e. with the changing water level associated with tidal flows). This is because the sigma layers used represent a fix percentage of the water column, the depth of which changes with tides and location.

It was therefore important when comparing modelled output with surveyed data to apply a holistic approach. In the case of comparing model layers it is noted that for a specific surveyed depth more than one model layer may be relevant to those measured values. For example, a depth of 1m below the surface would be in layer 5 (one below the surface layer) within the main channel but within layer 2 (one above the bed) in intertidal areas. Similarly, the surveys were undertaken over a period of time which in many cases exhibited a wide range of conditions such as turning tides and marine traffic therefore a single model step could not be expected to recreate the data presented within a single survey plot.

The conditions across the four surveys, covered by the three monitoring campaigns, varied in terms of background conditions, tidal flows and thermal discharges however a single set of parameters were required to best simulate the behaviour of the thermal plumes across all three survey periods.

> The thermal plume model development and calibration process was independently audited by DHI and determined to be fit for the purpose of undertaking a comparative study to evaluate the impacts of the proposed development of 3FM on existing thermal discharges and intakes in Dublin Port.

Therefore, when undertaking the comparison, rather than comparing each individual survey plot with a single model output, it is often necessary to assess the behaviour of the thermal plumes through the water column and across the survey period and compare with the simulated behaviour. That is to say, the reader may have to review modelled outputs in more than one layer when comparing with an equivalent survey reading.

1.5 Summary

Numerical models were developed to simulate the hydrodynamic conditions in Dublin Port. The models included freshwater input from river sources and saline tidal flow from the Irish Sea through Dublin Bay. The modelled tidal levels were shown to correlate well with those recoded at Dublin Port under the same meteorological conditions. A three dimensional modelling scheme was used to simulate thermal plumes from both saline sources from the Dublin Waste to Energy, Dublin Power Station and Poolbeg CCGT cooling water outfalls and buoyant freshwater discharge from Ringsend WWTP.

Based on constructive feedback from ESB, models were developed to include a series of improvement. Based upon these improvements, the model was ultimately found to recreate the mechanisms of stratified flow; with a profile of increasing salinity with depth persisting throughout the ebb tide upstream of Dublin Port. Additionally, on occasion, the modelled surface flow out of Dublin Port was observed when tidal flow entered below the stratified layer during flood tides.

The use of sigma layers with varied thicknesses within the model was able to distinguish between the saline thermal plume layers and freshwater surface plumes. The model was compared with survey reports presenting excess temperature during three survey campaigns. Whilst it can be challenging to directly compare this data with model outputs, due to the phased nature of the surveys and method of assessing background temperatures coupled with the modelled discretisation the model was found to generally perform well and represented key processes relating to thermal dispersion and stratification to degree considered suitable by RPS.

In conclusion, the model was found to recreate the plume behaviour across all three survey periods with sufficient accuracy. The models were considered fit for the purpose of undertaking a comparative study to examine the impact of the proposed 3FM development in an independent audit by DHI.

Appendix A

A.1 Thermal Survey August 2016

Figure 1.70: Thermal plume 12th August 2016 – excess temperature at high water circa 0.3m depth layer 6

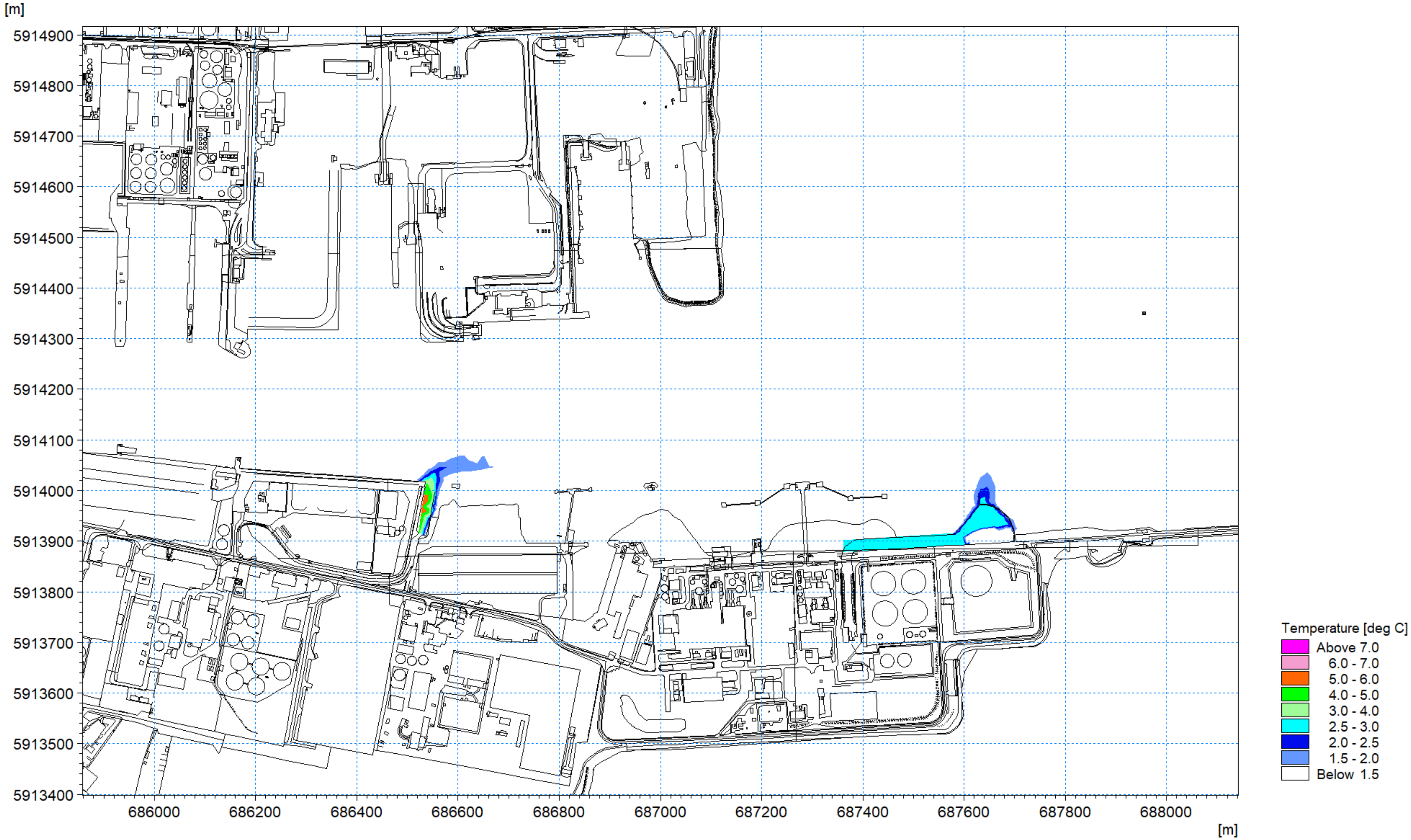

Figure 1.71: Thermal plume 12th August 2016 – excess temperature at high water circa 1m depth layer 5

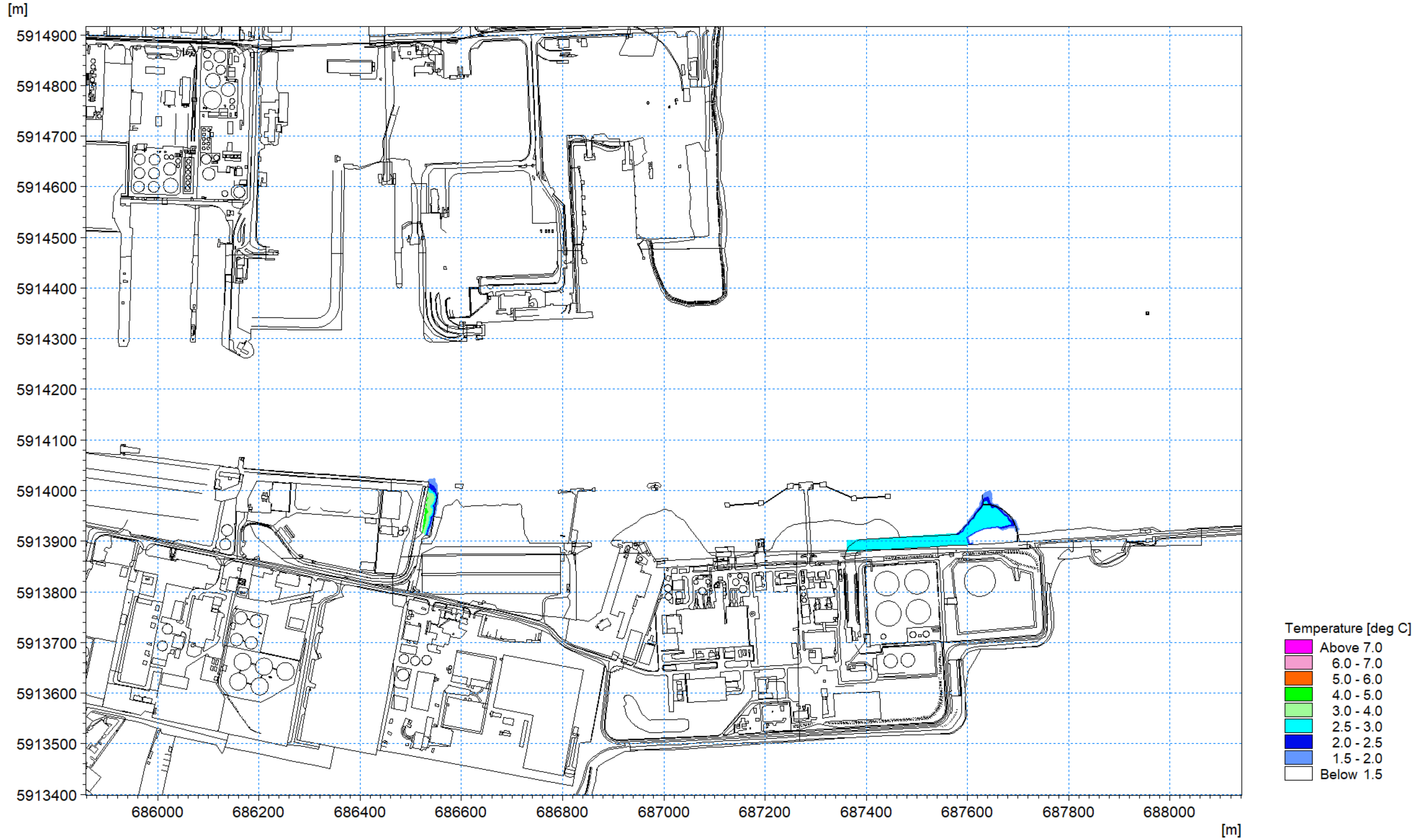

Figure 1.72: Thermal plume 12th August 2016 – excess temperature at high water circa 2m depth layer 4

Figure 1.73: Thermal plume 12th August 2016 – excess temperature at mid-ebb circa 0.3m depth layer 6

Figure 1.74: Thermal plume 12th August 2016 – excess temperature at mid-ebb circa 1m depth layer 5

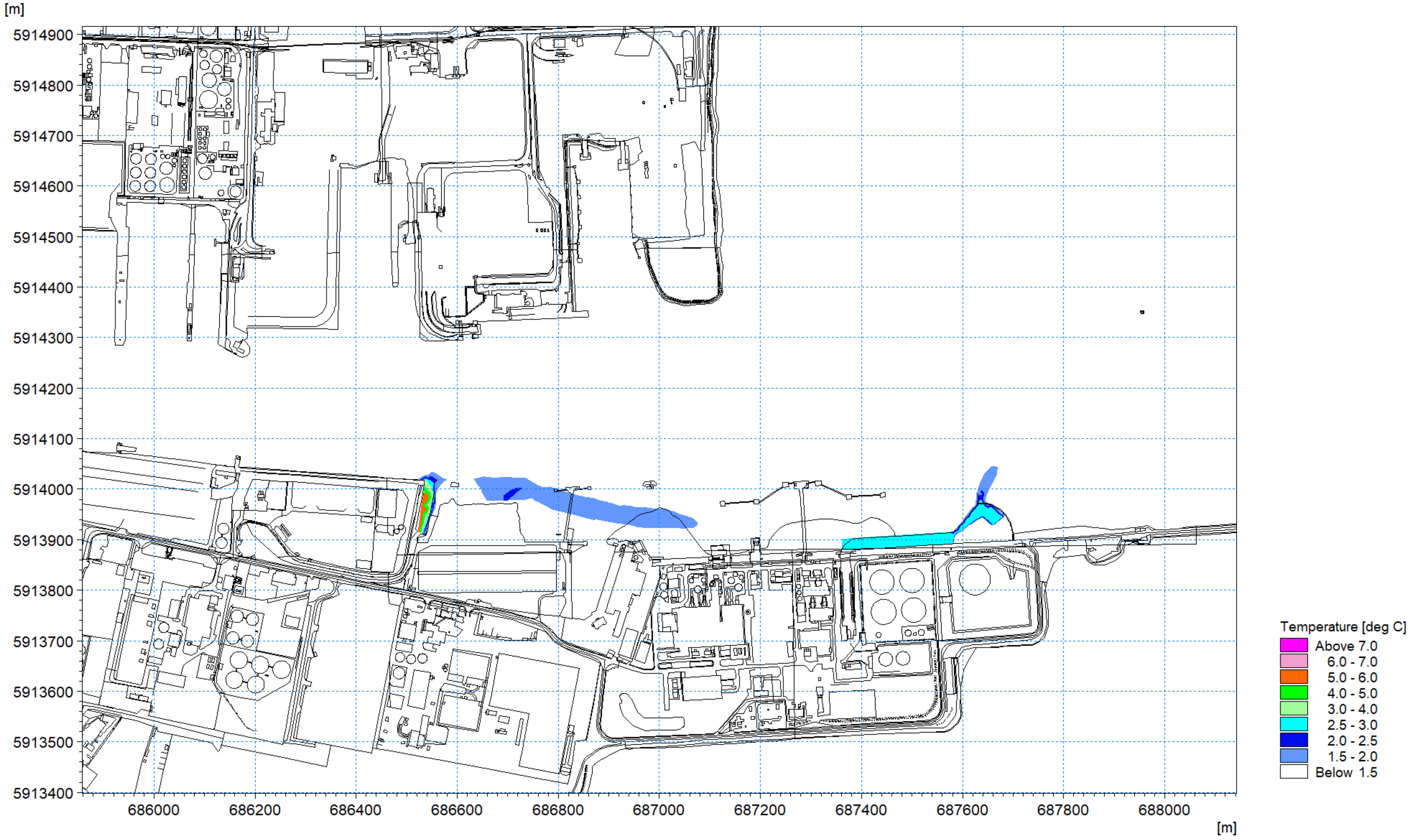

Figure 1.75: Thermal plume 12th August 2016 – excess temperature at mid-ebb circa 2m depth layer 4

Figure 1.76: Thermal plume 12th August 2016 – excess temperature at low water circa 0.3m depth layer 6

Figure 1.77: Thermal plume 12th August 2016 – excess temperature at low water circa 1m depth layer 5

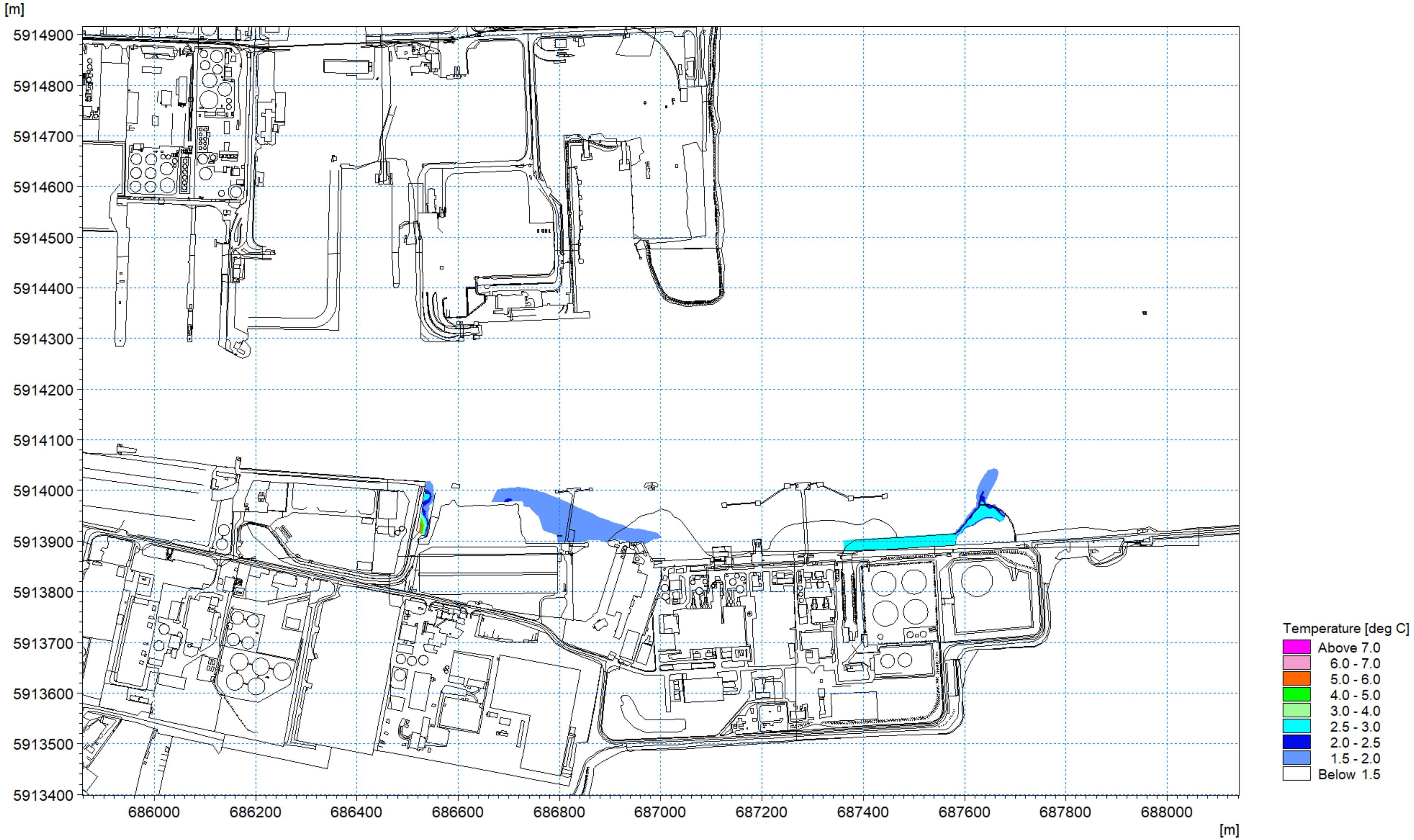

Figure 1.78: Thermal plume 12th August 2016 – excess temperature at low water circa 2m depth layer 3

Figure 1.79: Thermal plume 12th August 2016 – excess temperature at mid-flood circa 0.3m depth layer 6

Figure 1.80: Thermal plume 12th August 2016 – excess temperature at mid-flood circa 1m depth layer 5

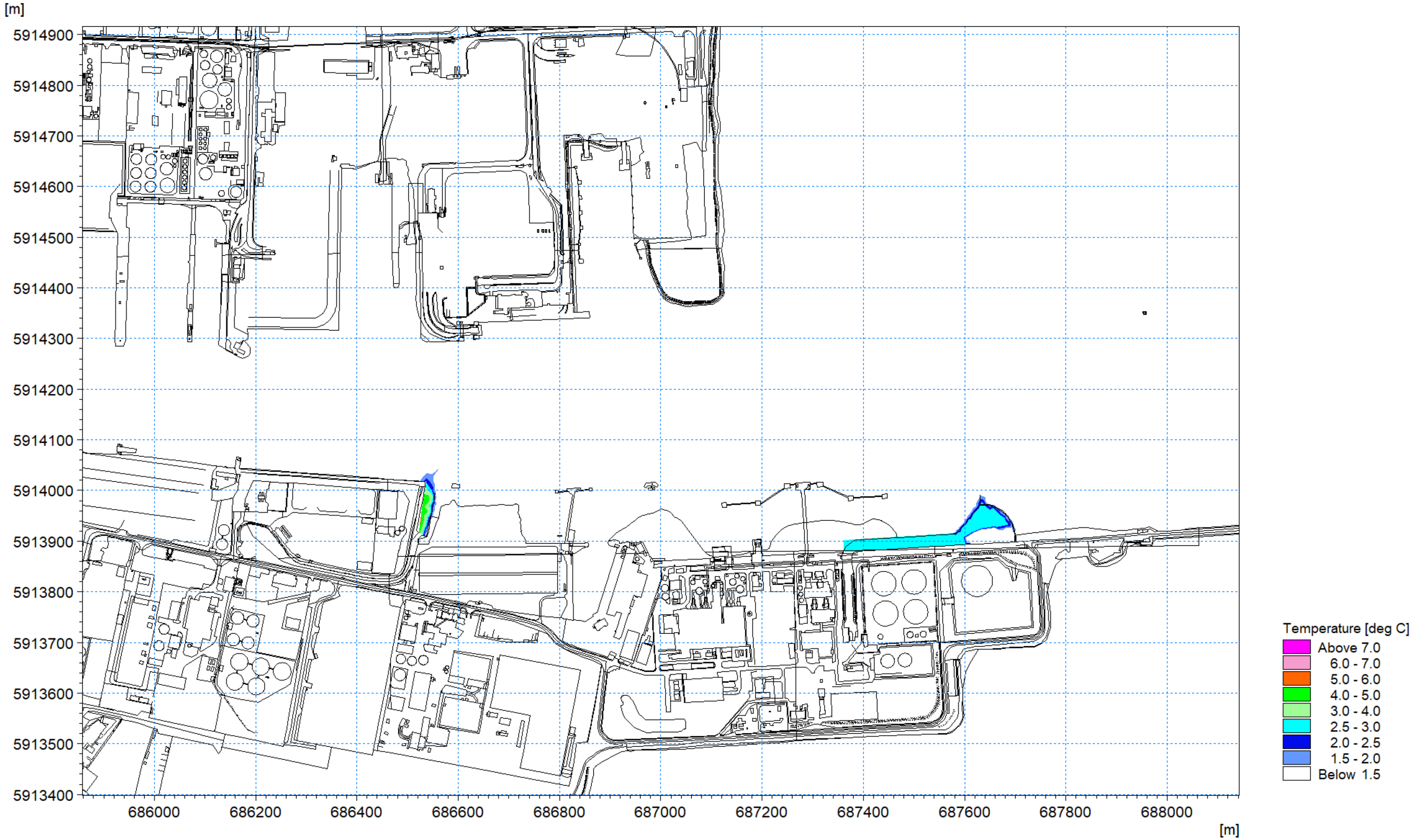

Figure 1.81: Thermal plume 12th August 2016 – excess temperature at mid-flood circa 2m depth layer 4

Appendix B

B.1 Thermal Survey Spring Tide 20th April 2018

B.1.1 Thermal Survey – Contours of Excess Temperature

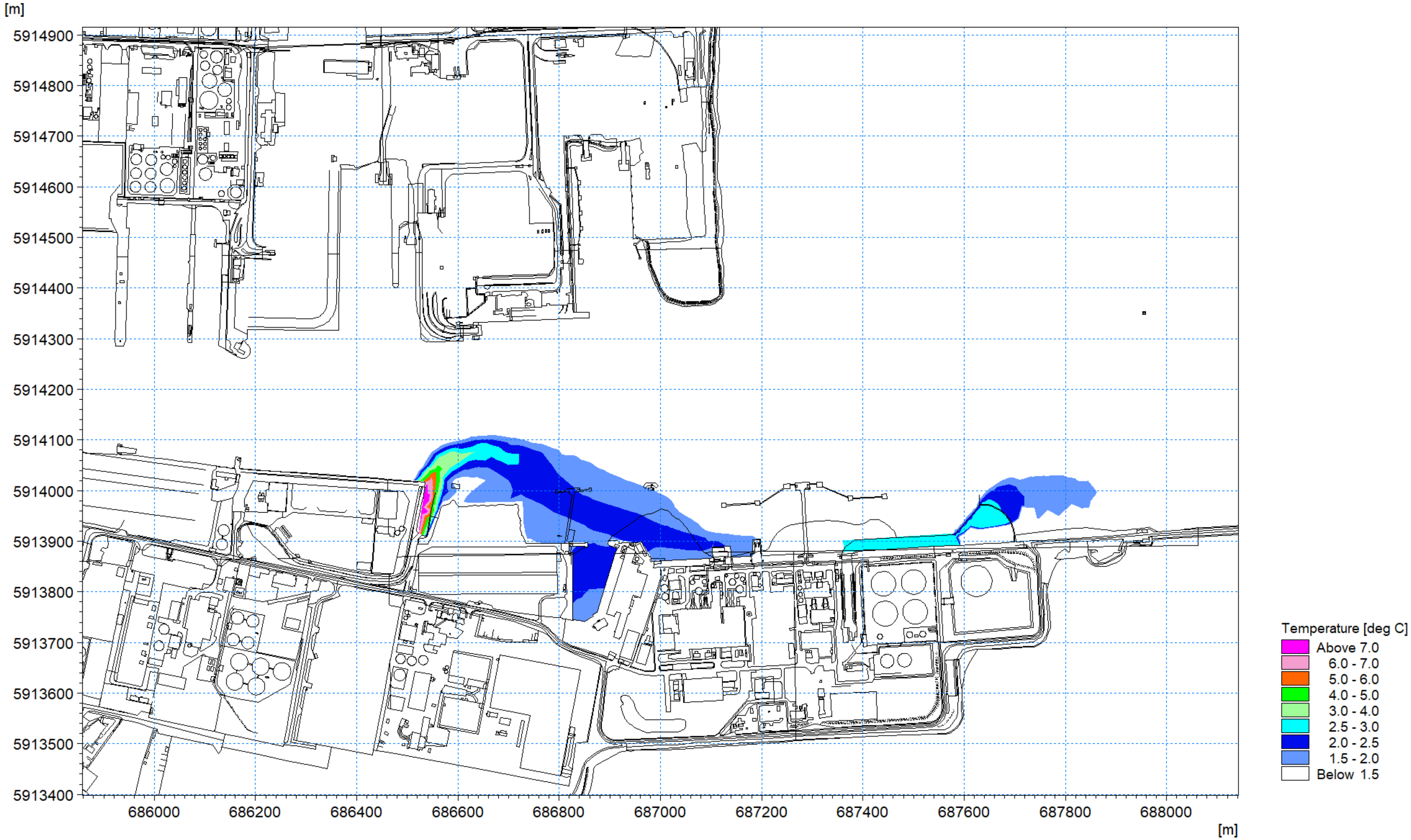

Figure 1.82: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 0.3m depth layer 6

Figure 1.83: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 1m depth layer 5

Figure 1.84: Thermal plume 20th April 2018 – excess temperature at mid-flood circa 2m depth layer 4

Figure 1.85: Thermal plume 20th April 2018 – excess temperature at high water circa 0.3m depth layer 6

Figure 1.86: Thermal plume 20th April 2018 – excess temperature at high water circa 1m depth layer 5

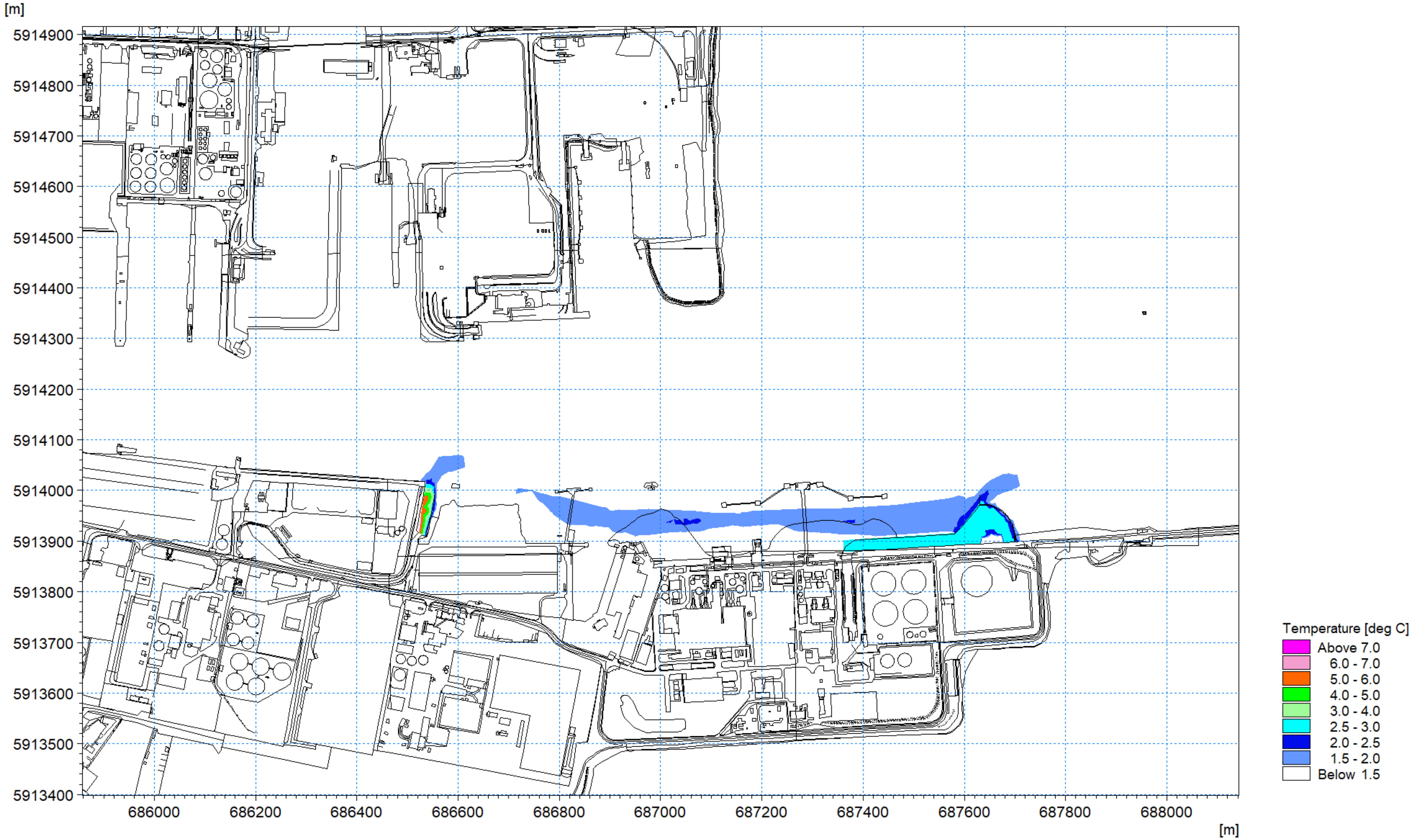

Figure 1.87: Thermal plume 20th April 2018 – excess temperature at high water circa 2m depth layer 4

Figure 1.88: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 0.3m depth layer 6

Figure 1.89: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 1m depth layer 5

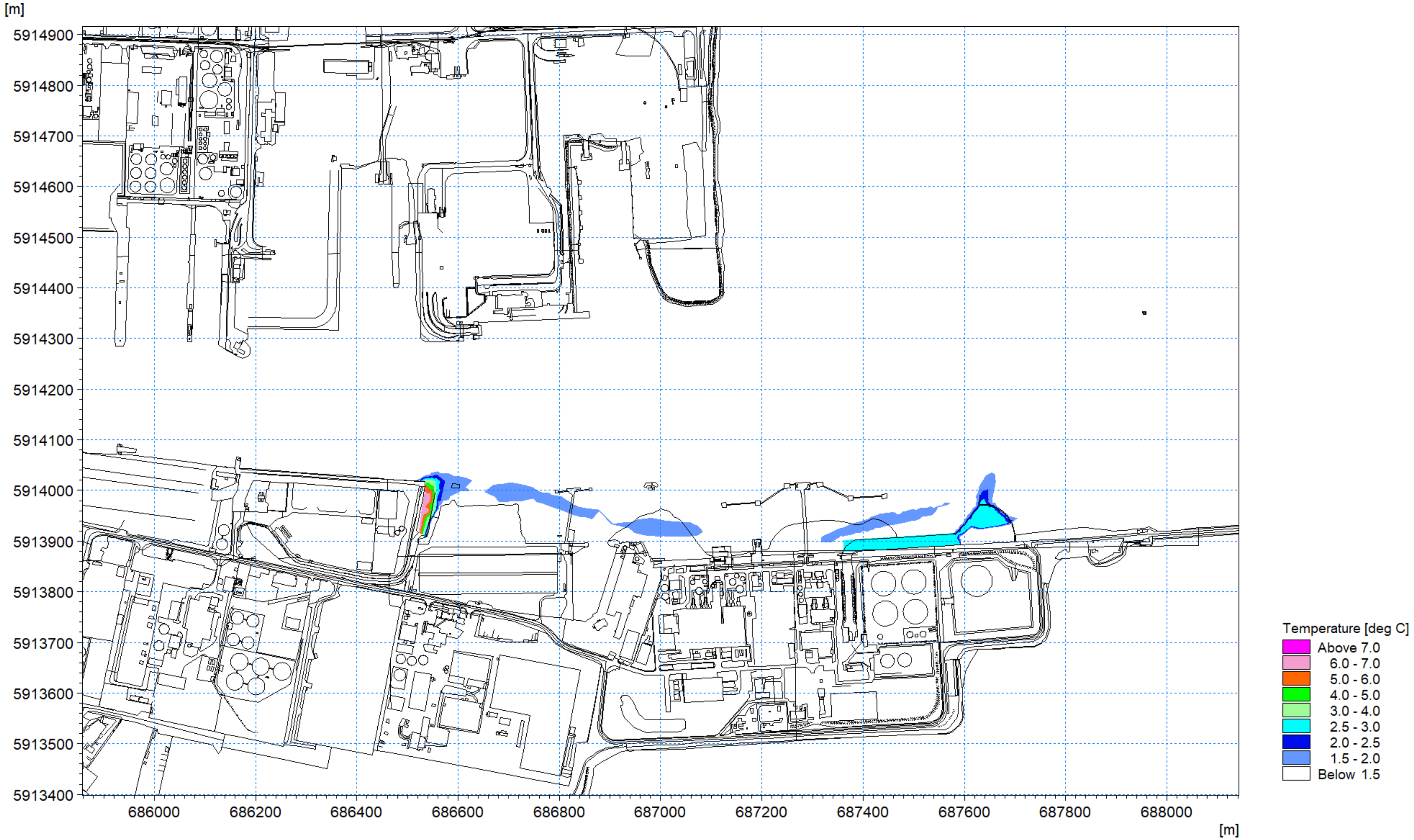

Figure 1.90: Thermal plume 20th April 2018 – excess temperature at mid-ebb circa 2m depth layer 4

Figure 1.91: Thermal plume 20th April 2018 – excess temperature at low water circa 0.3m depth layer 6

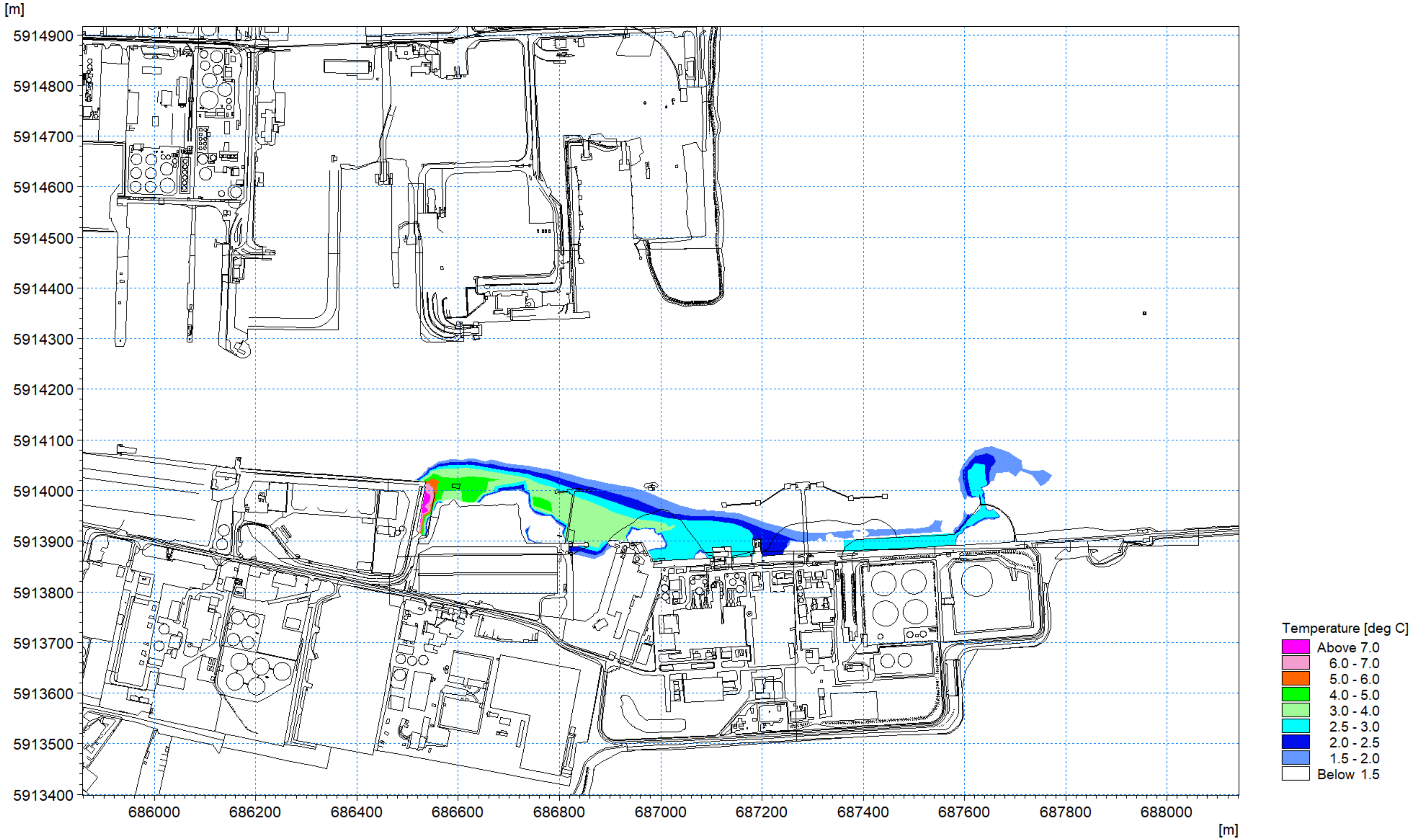

Figure 1.92: Thermal plume 20th April 2018 – excess temperature at low water circa 1m depth layer 5

Figure 1.93: Thermal plume 20th April 2018 – excess temperature at low water circa 2m depth layer 4

B.1.2 Thermal Survey – Vertical profiles

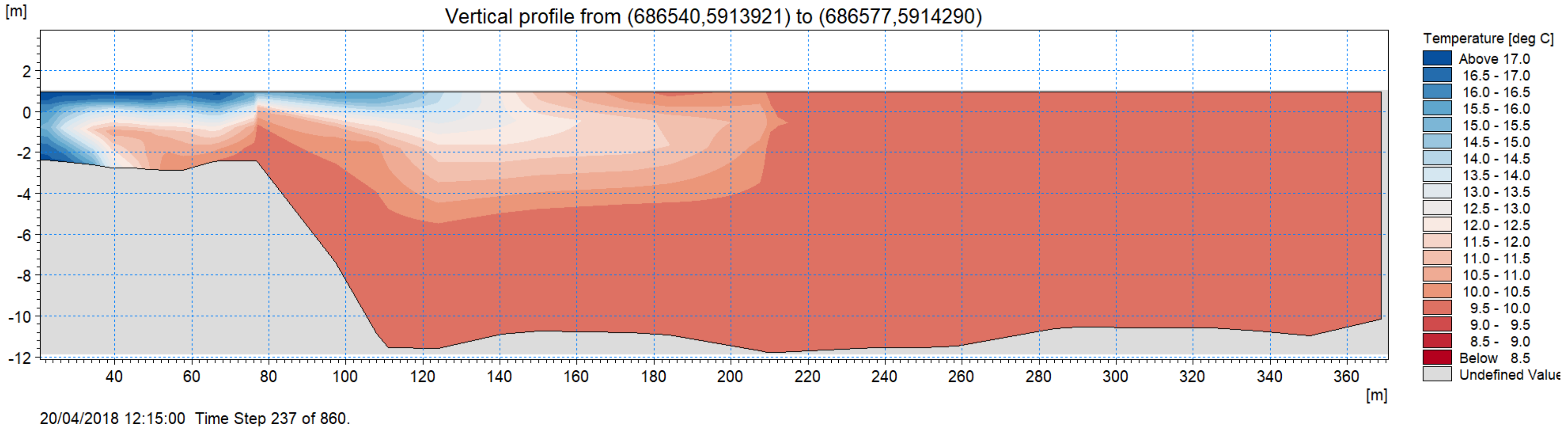

Figure 1.94: Thermal profile 1 - 20th April 2018 – high water minus 2.25 hours

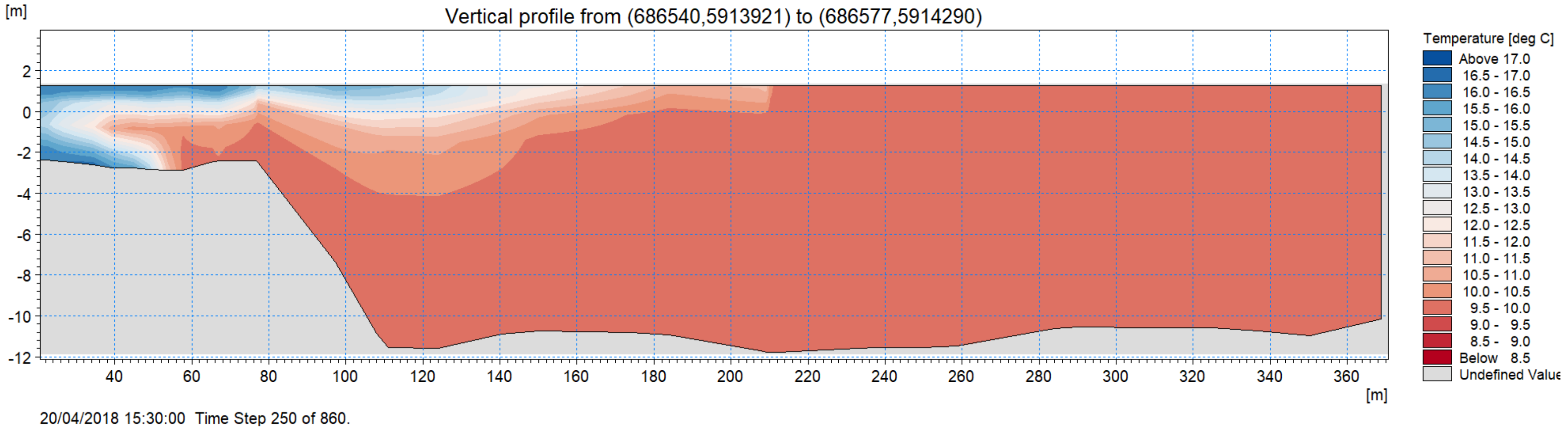

Figure 1.95: Thermal profile 2 - 20th April 2018 – high water plus 1 hour

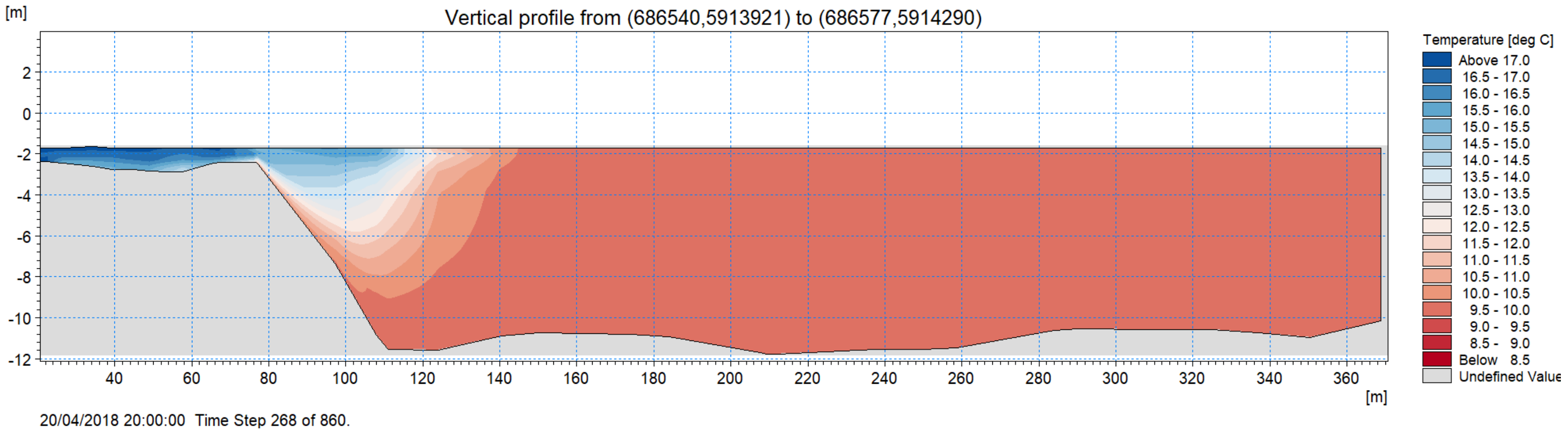

Figure 1.96: Thermal profile 3 - 20th April 2018 – low water

B.2 Thermal Survey Neap Tide 24th April 2018

B.2.1 Thermal Survey – Contours of Excess Temperature

Figure 1.97: Thermal plume 24th April 2018 – excess temperature at high water circa 0.3m depth layer 6

Figure 1.98: Thermal plume 24th April 2018 – excess temperature at high water circa 1m depth layer 5

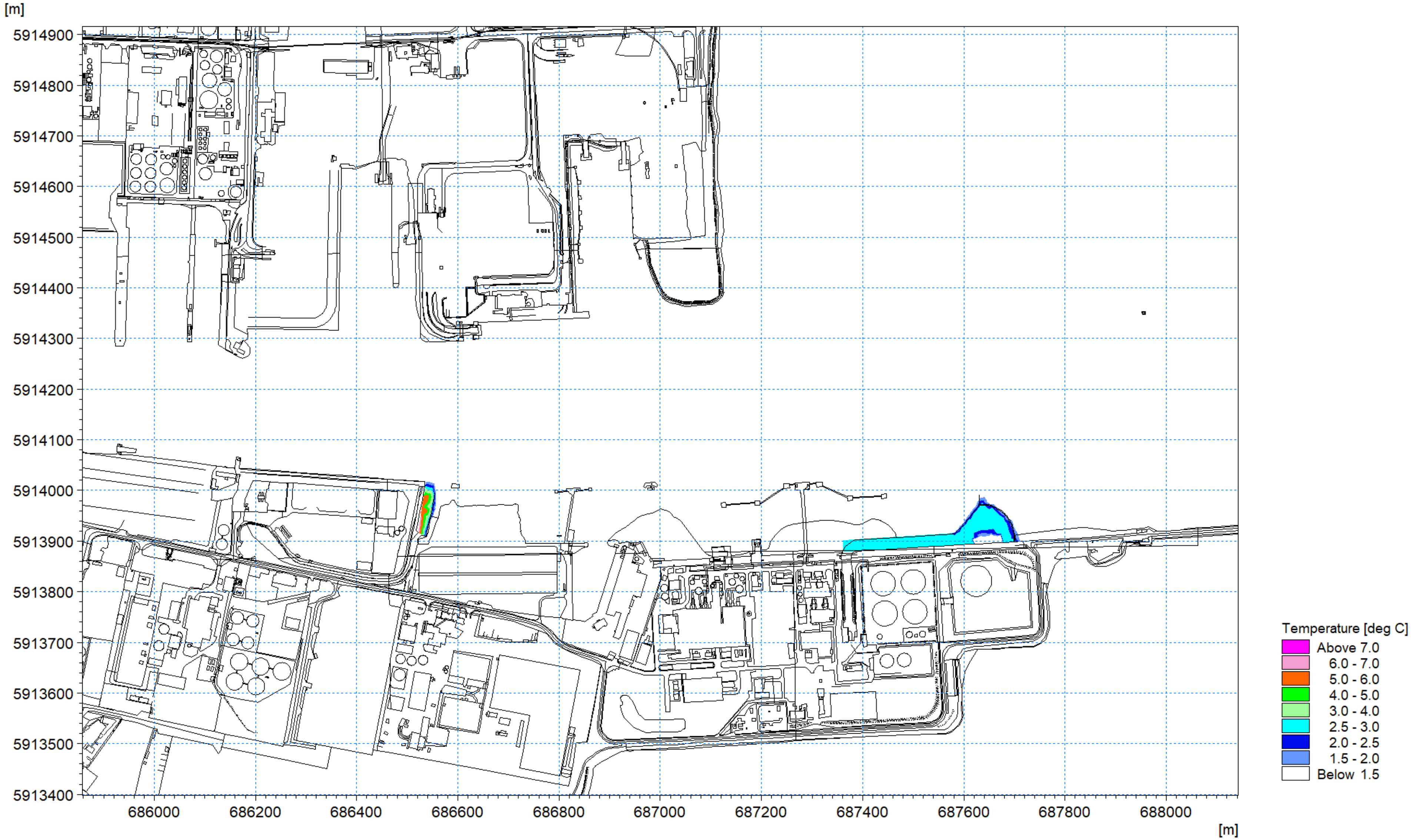

Figure 1.99: Thermal plume 24th April 2018 – excess temperature at high water circa 2m depth layer 4

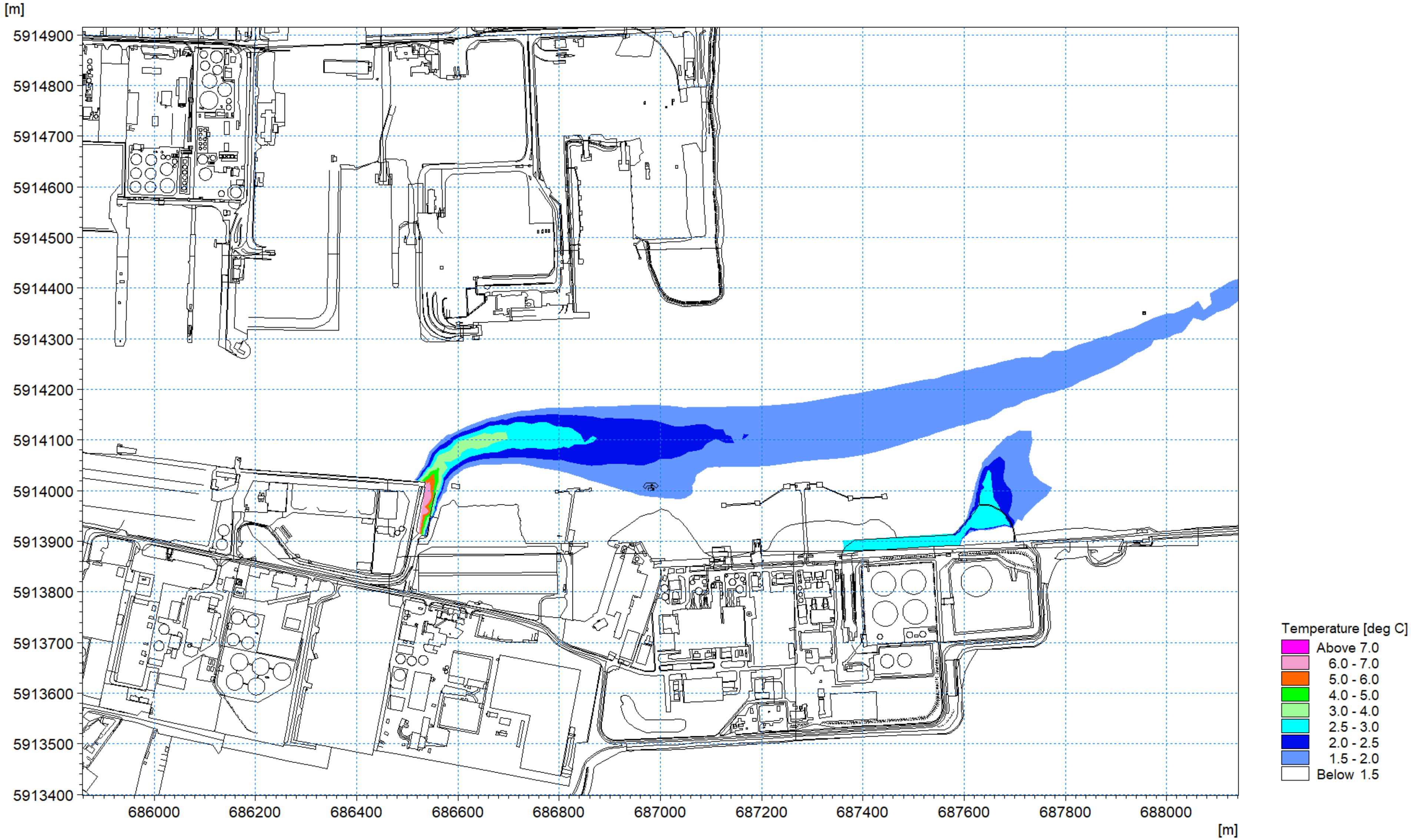

Figure 1.100: Thermal plume 24th April 2018 – excess temperature at mid-ebb circa 0.3m depth layer 6

Figure 1.101: Thermal plume 24th April 2018 – excess temperature at mid-ebb circa 1m depth layer 5

Figure 1.102: Thermal plume 24th April 2018 – excess temperature at mid-ebb circa 2m depth layer 4

Figure 1.103: Thermal plume 24th April 2018 – excess temperature at low water circa 0.3m depth layer 6

Figure 1.104: Thermal plume 24th April 2018 – excess temperature at low water circa 1m depth layer 5

Figure 1.105: Thermal plume 24th April 2018 – excess temperature at low water circa 2m depth layer 4

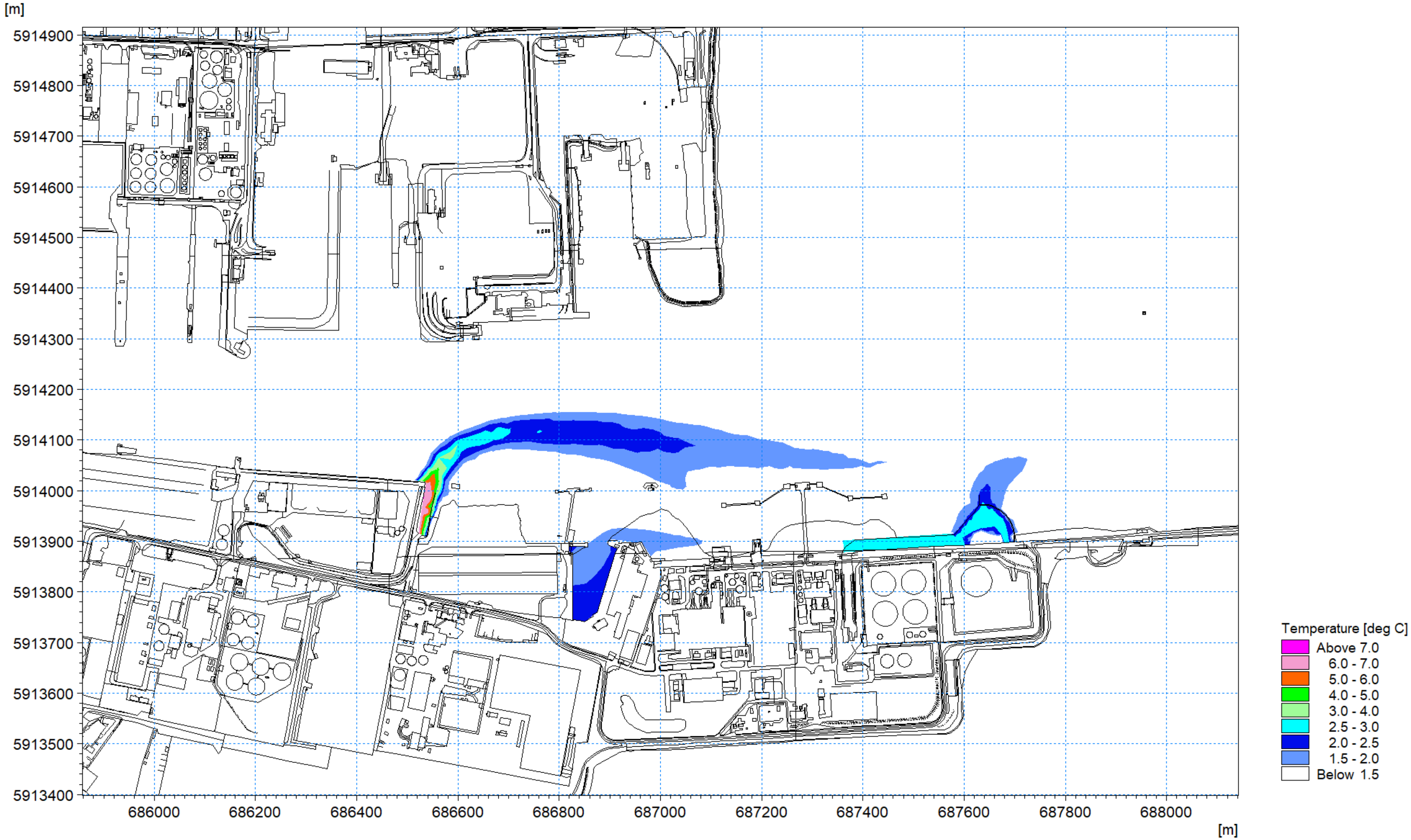

Figure 1.106: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 0.3m depth layer 6

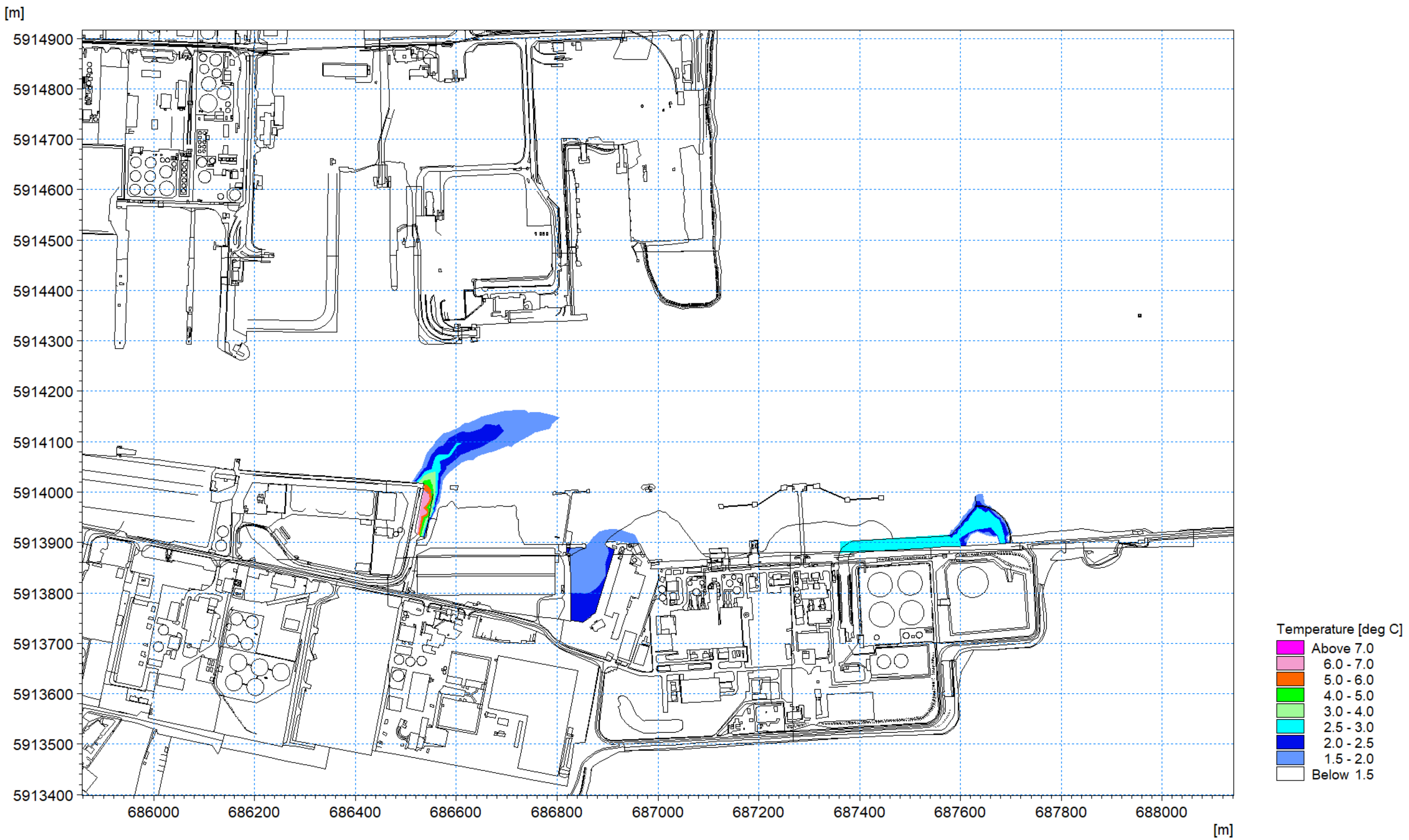

Figure 1.107: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 1m depth layer 5

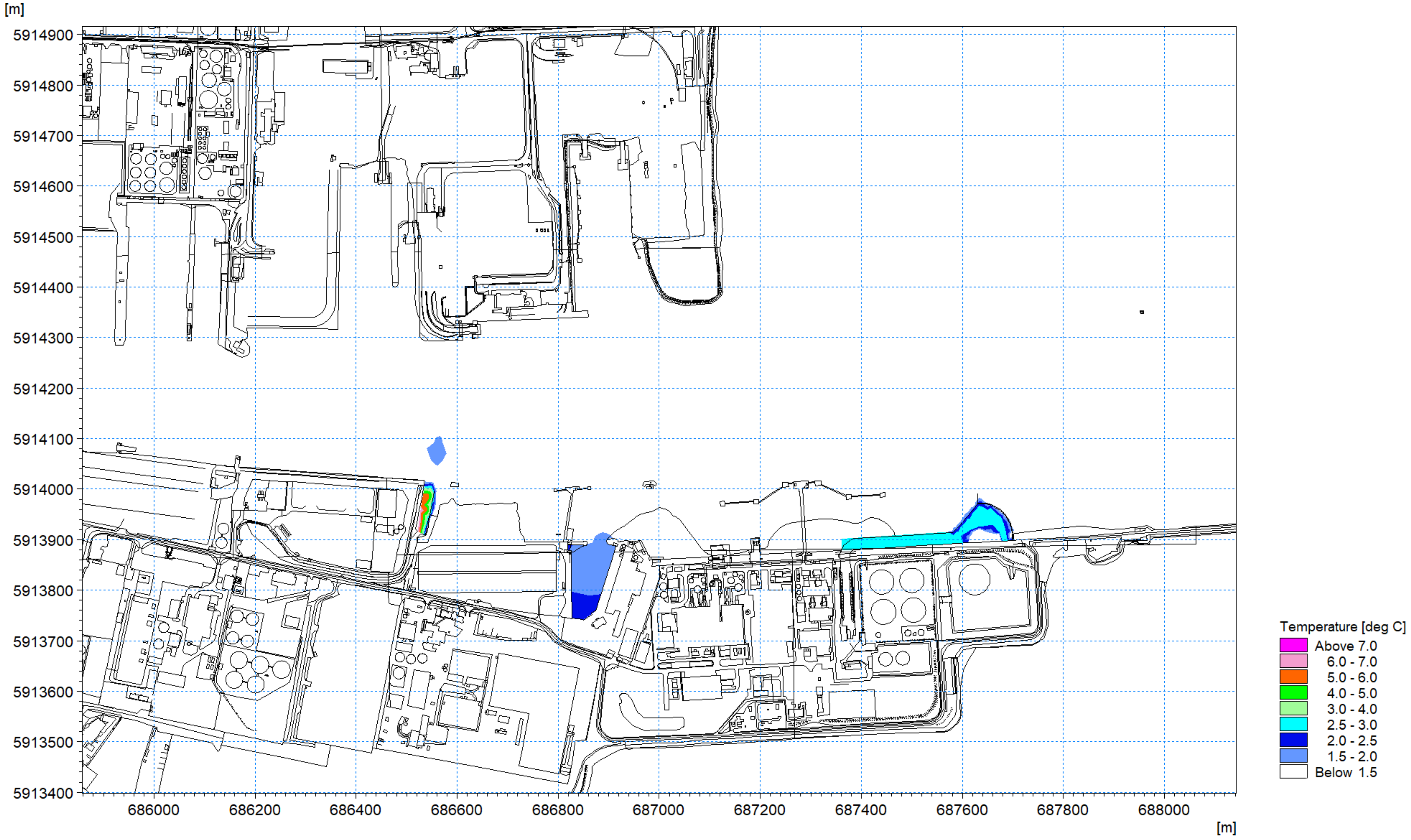

Figure 1.108: Thermal plume 24th April 2018 – excess temperature at mid-flood circa 2m depth layer 4

B.2.2 Thermal Survey – Vertical Profiles

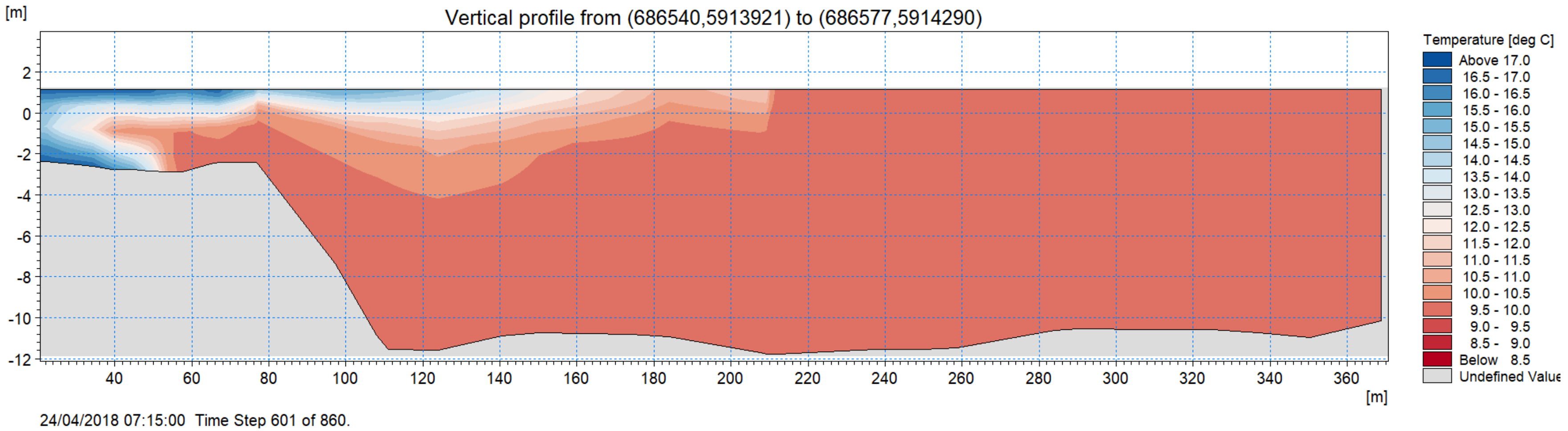

Figure 1.109: Thermal profile 1 - 24th April 2018 – high water plus 47 minutes

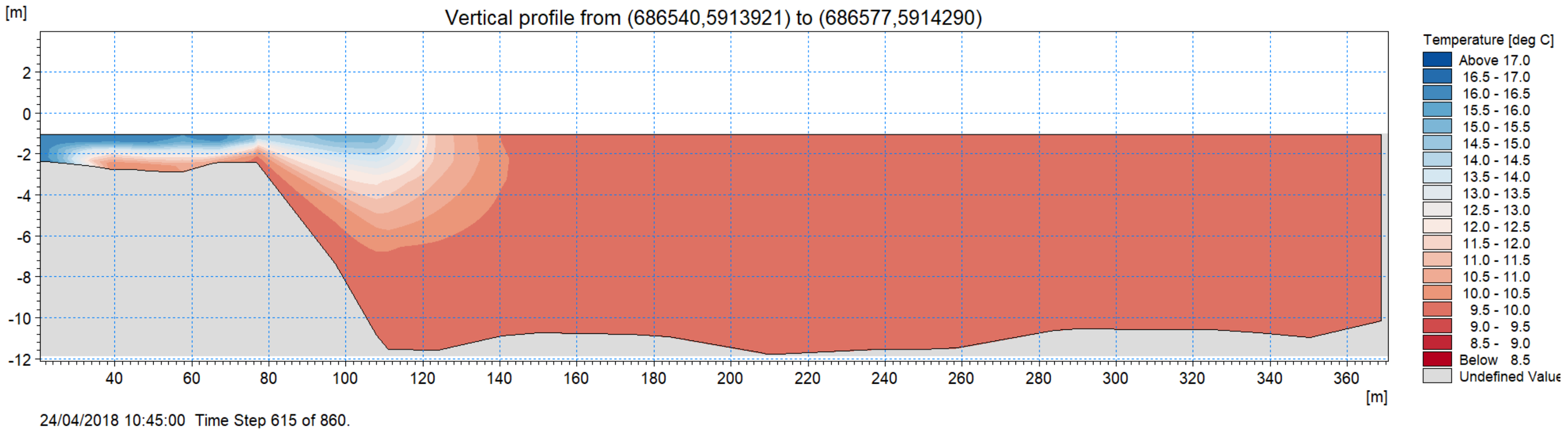

Figure 1.110: Thermal profile 2 - 24th April 2018 – high water plus 4 hours

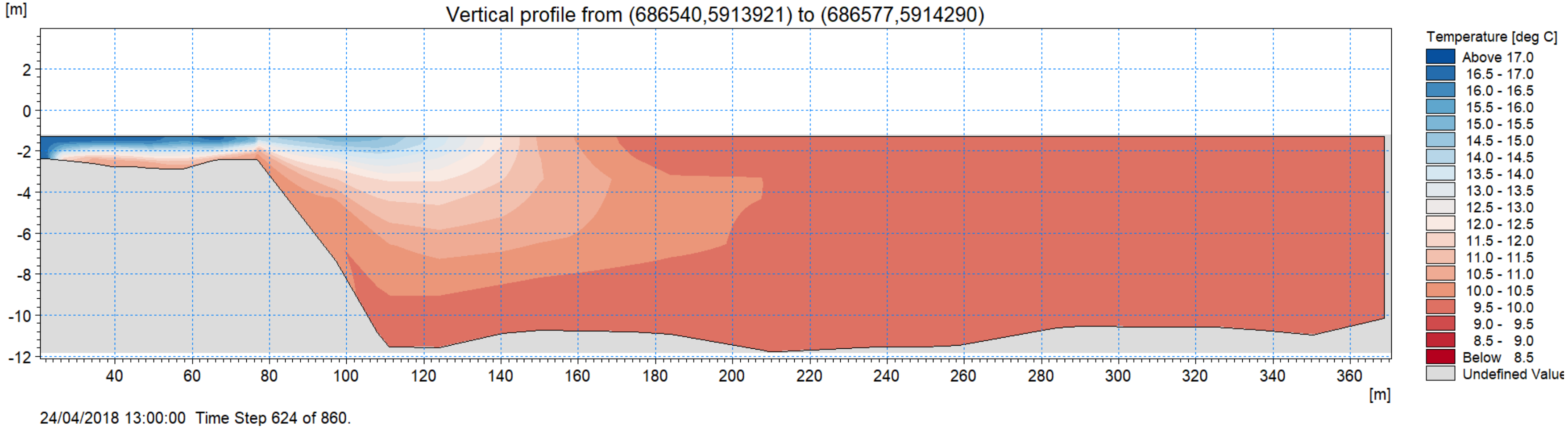

Figure 1.111: Thermal profile 3 - 24th April 2018 – low water plus 36 minutes

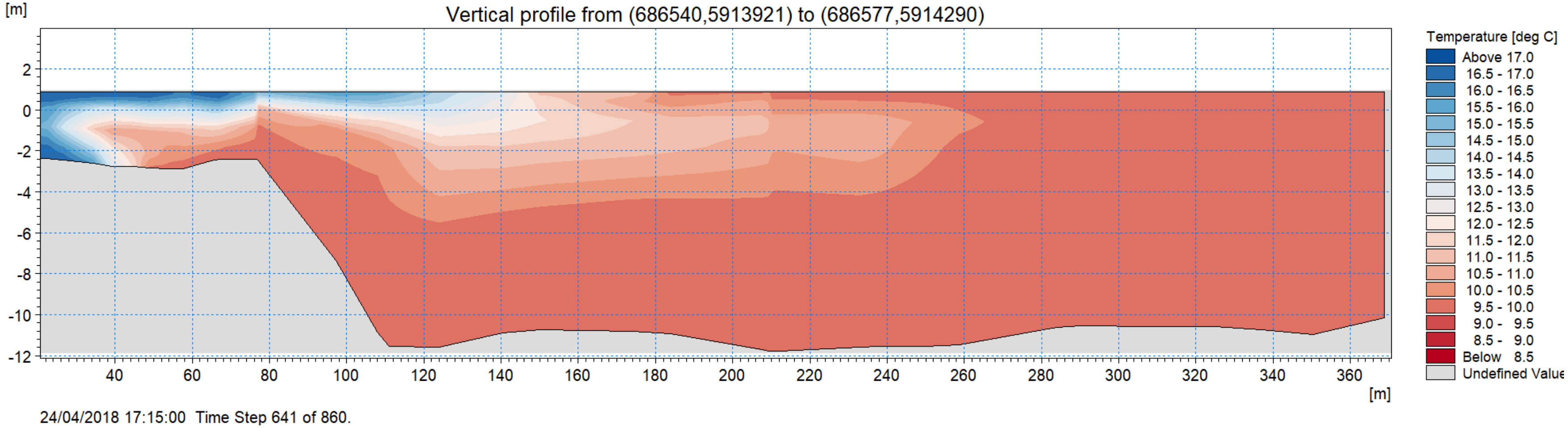

Figure 1.112: Thermal profile 4 - 24th April 2018 – high water minus 2 hours

Appendix C

C.1 Thermal Survey 9th April 2019

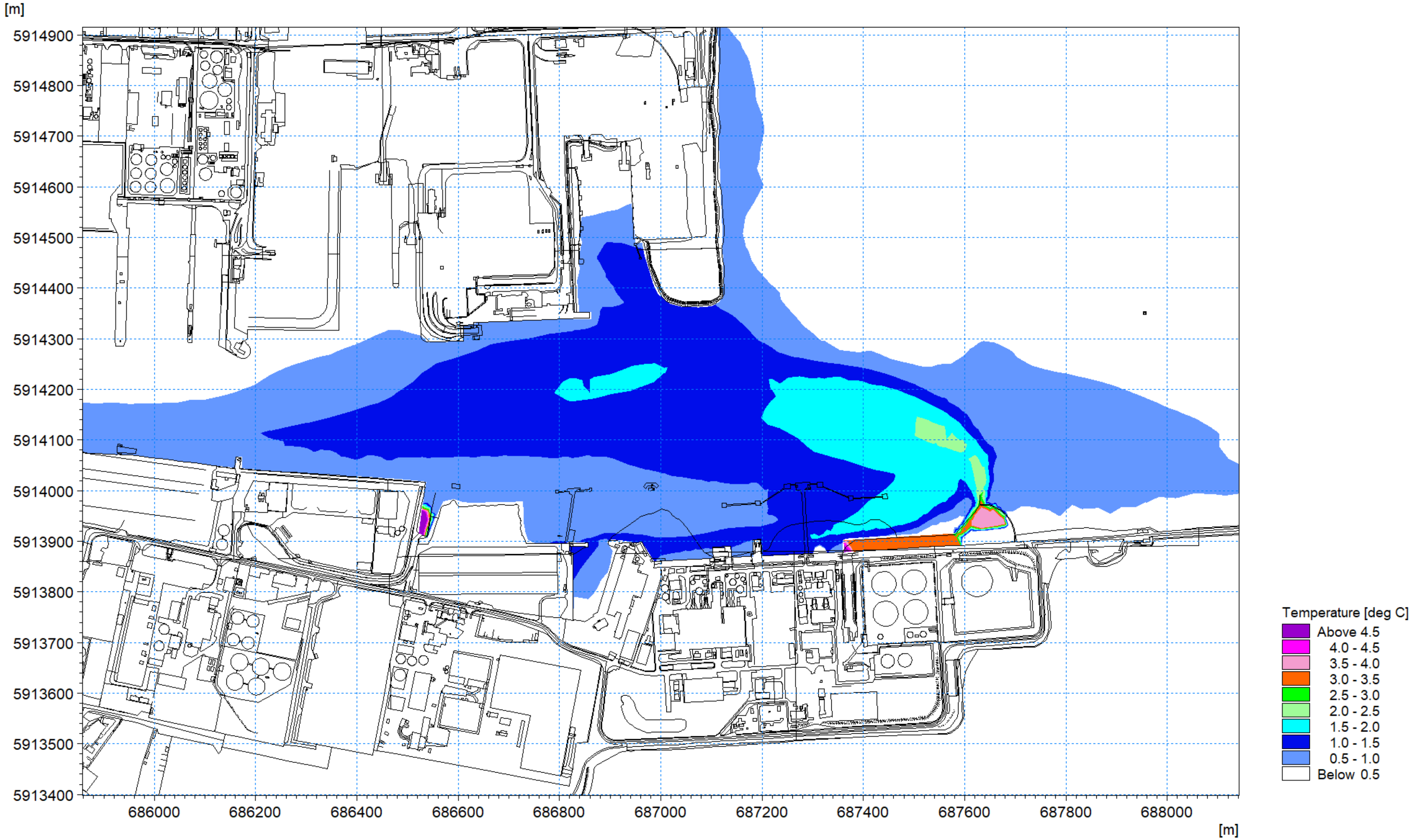

Figure 1.113: Thermal plume 9th April 2019 – excess temperature at low water circa 0.3m depth layer 6

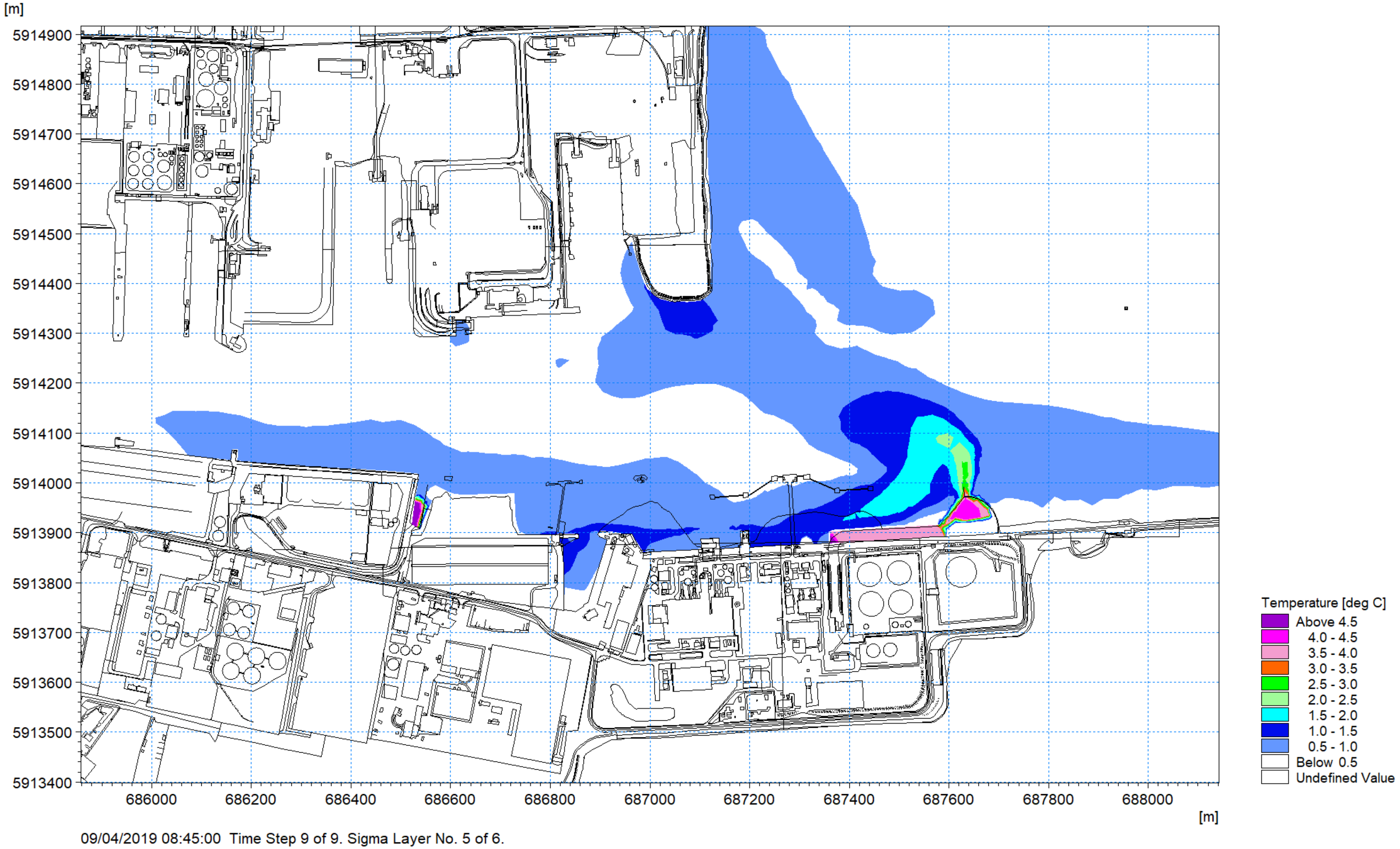

Figure 1.114: Thermal plume 9th April 2019 – excess temperature at low water circa 0.9m depth layer 5

Figure 1.115: Thermal plume 9th April 2019 – excess temperature at low water circa 1.8m depth

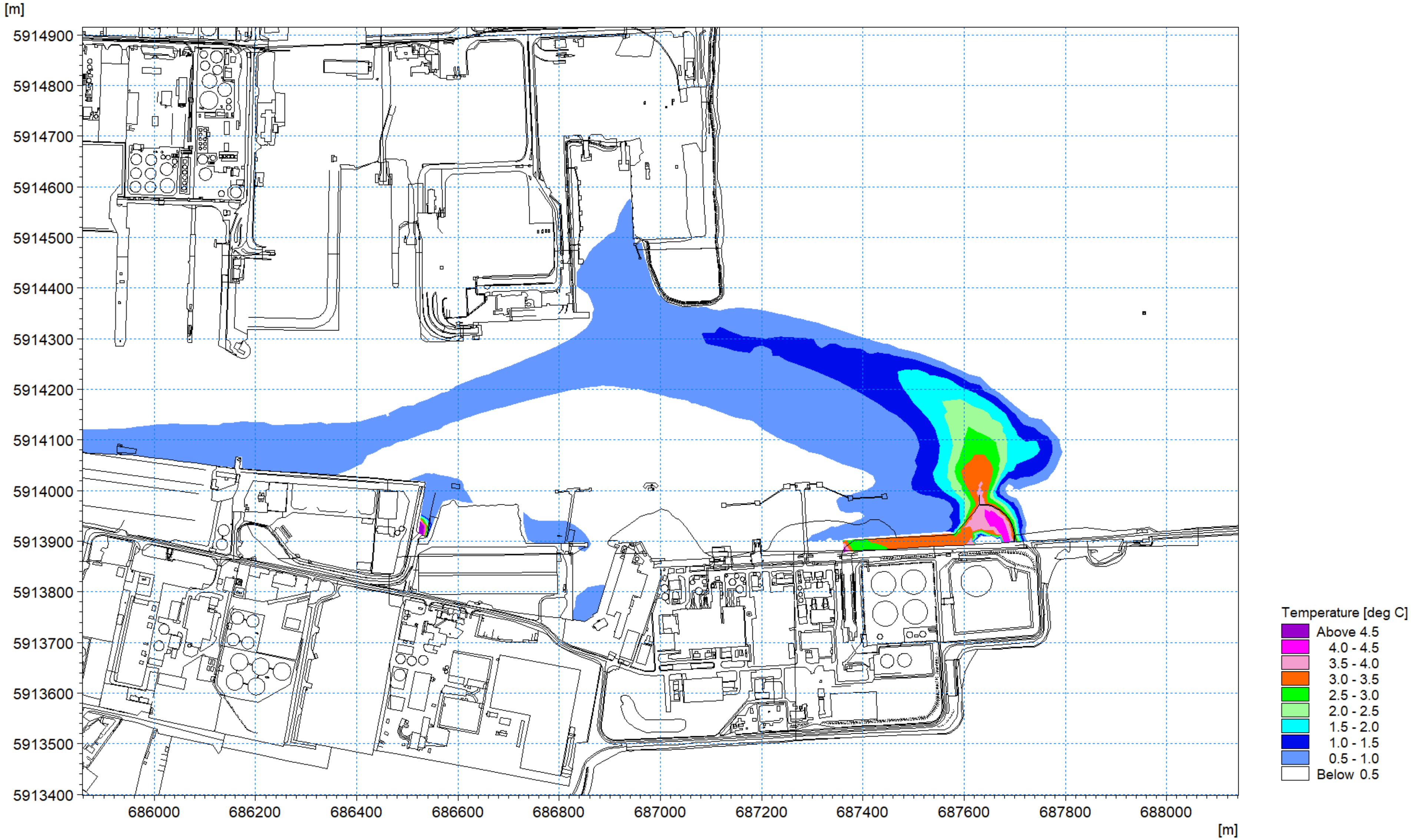

Figure 1.116: Thermal plume 9th April 2019 – excess temperature at mid-flood circa 0.3m depth layer 6

Figure 1.117: Thermal plume 9th April 2019 – excess temperature at mid-flood circa 0.9m depth layer 5

Figure 1.118: Thermal plume 9th April 2019 – excess temperature at mid-flood circa 1.8m depth layer 4

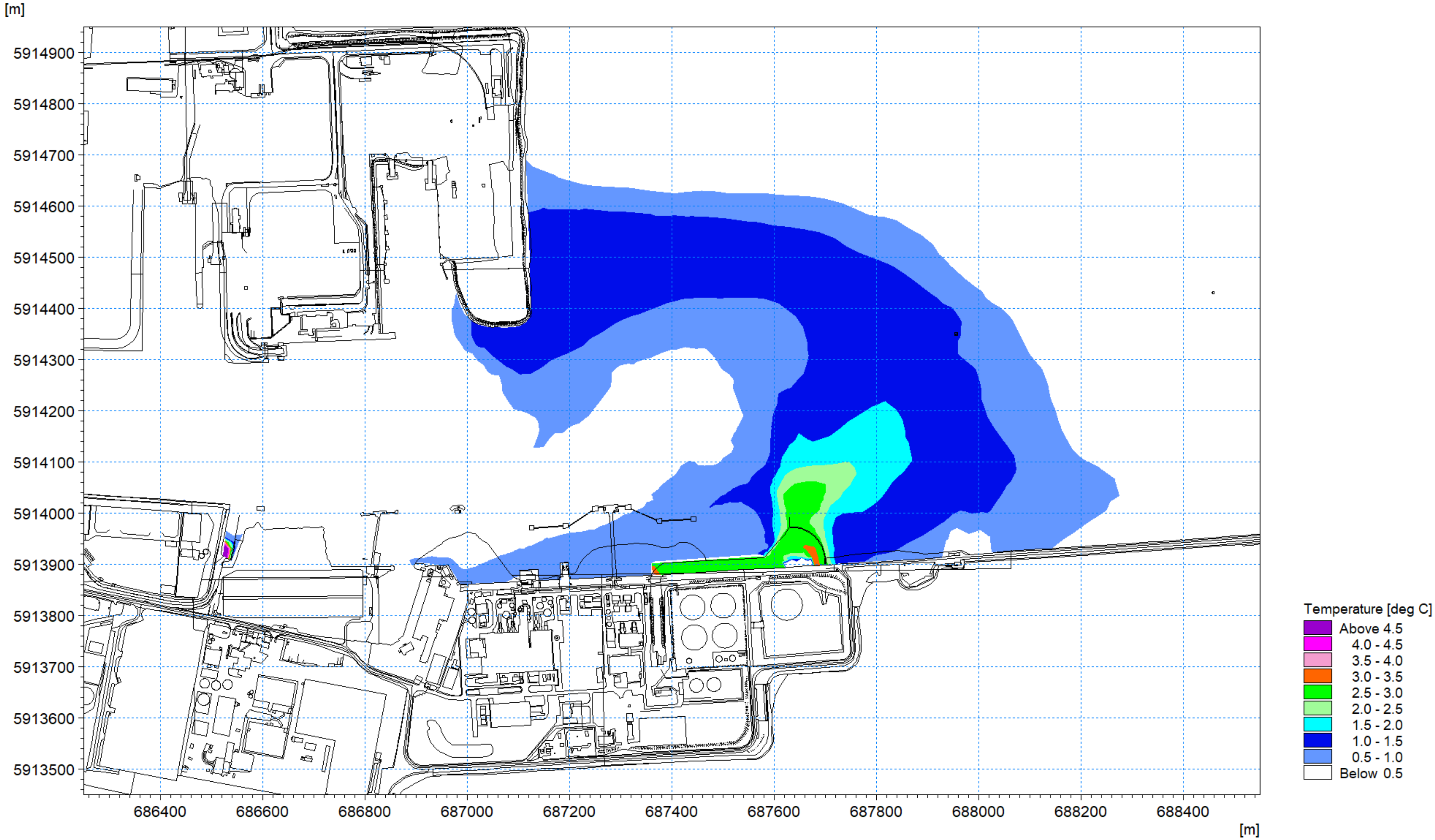

Figure 1.119: Thermal plume 9th April 2019 – excess temperature at high water circa 0.3m depth layer 6

Figure 1.120: Thermal plume 9th April 2019 – excess temperature at high water circa 0.9m depth layer 5

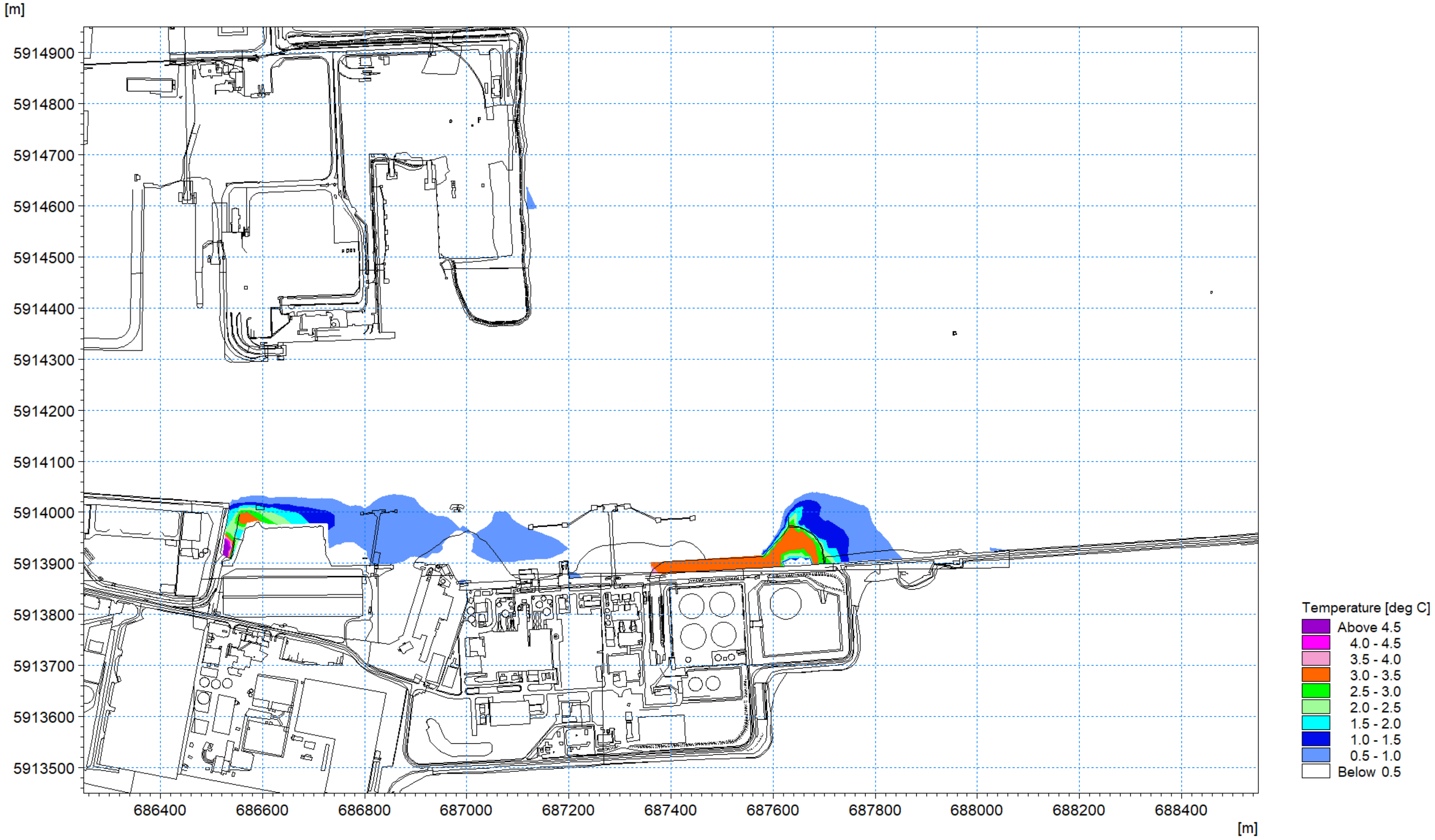

Figure 1.121: Thermal plume 9th April 2019 – excess temperature at high water circa 1.8m depth layer 3

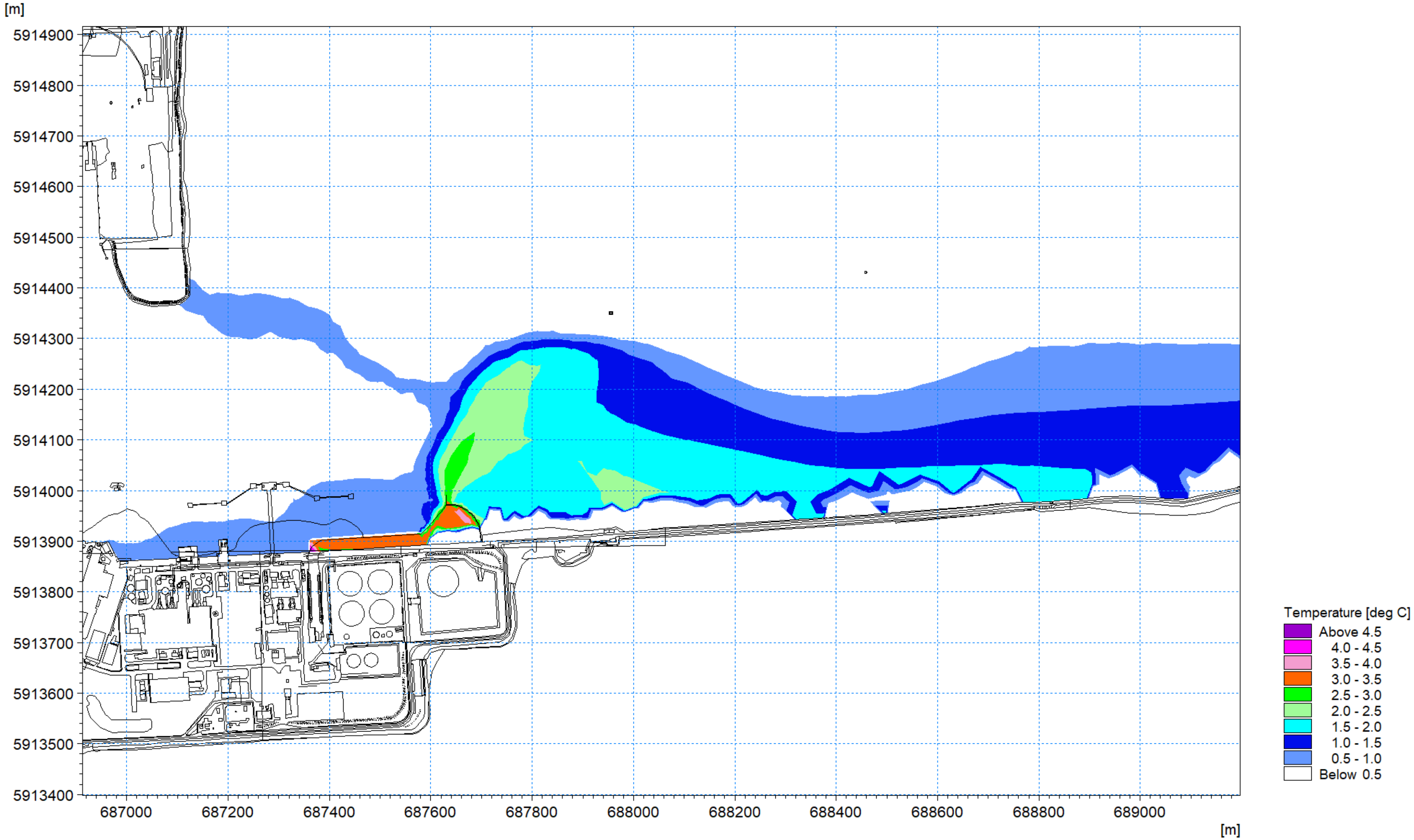

Figure 1.122: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa 0.3m depth layer 6

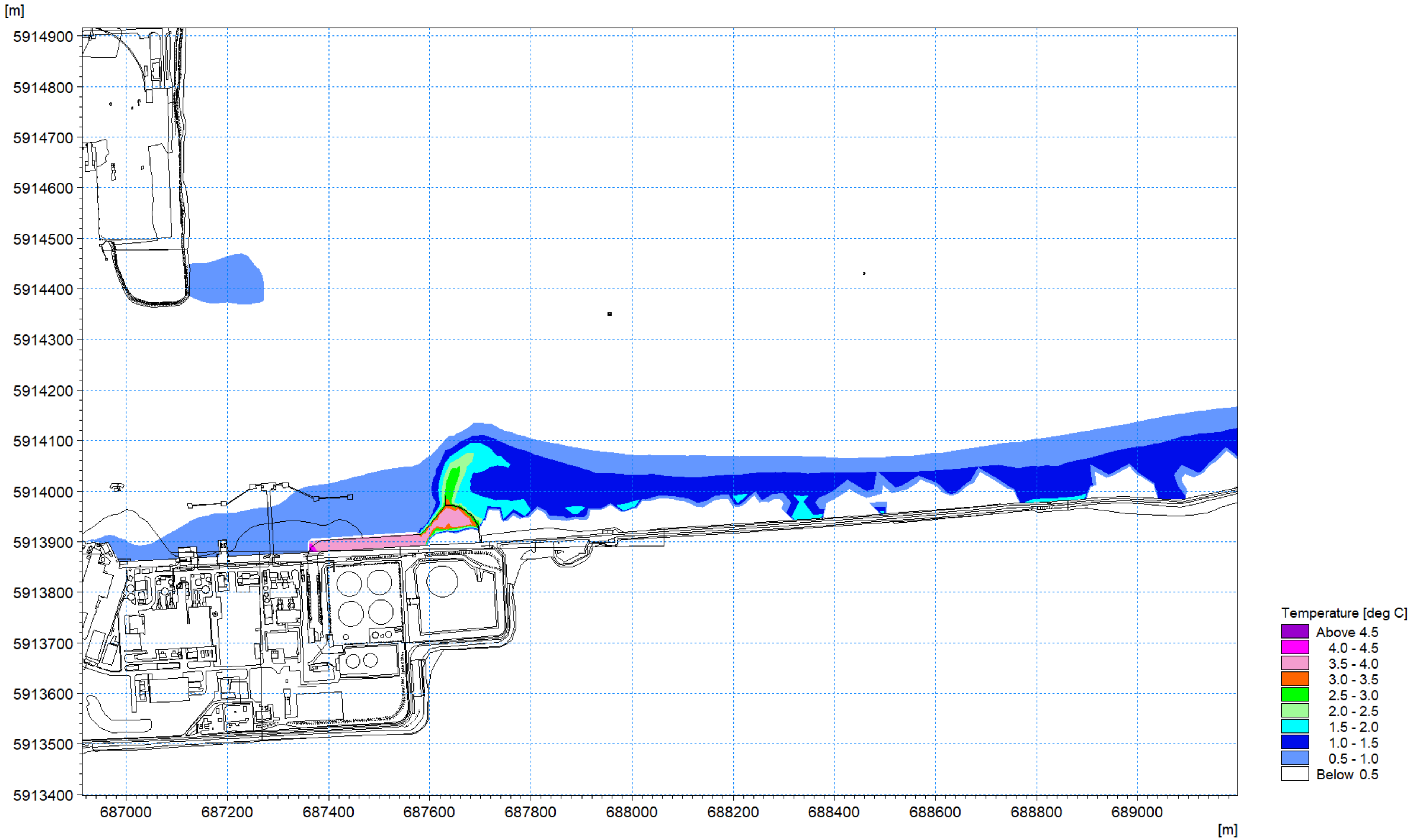

Figure 1.123: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa 0.9m depth layer 4

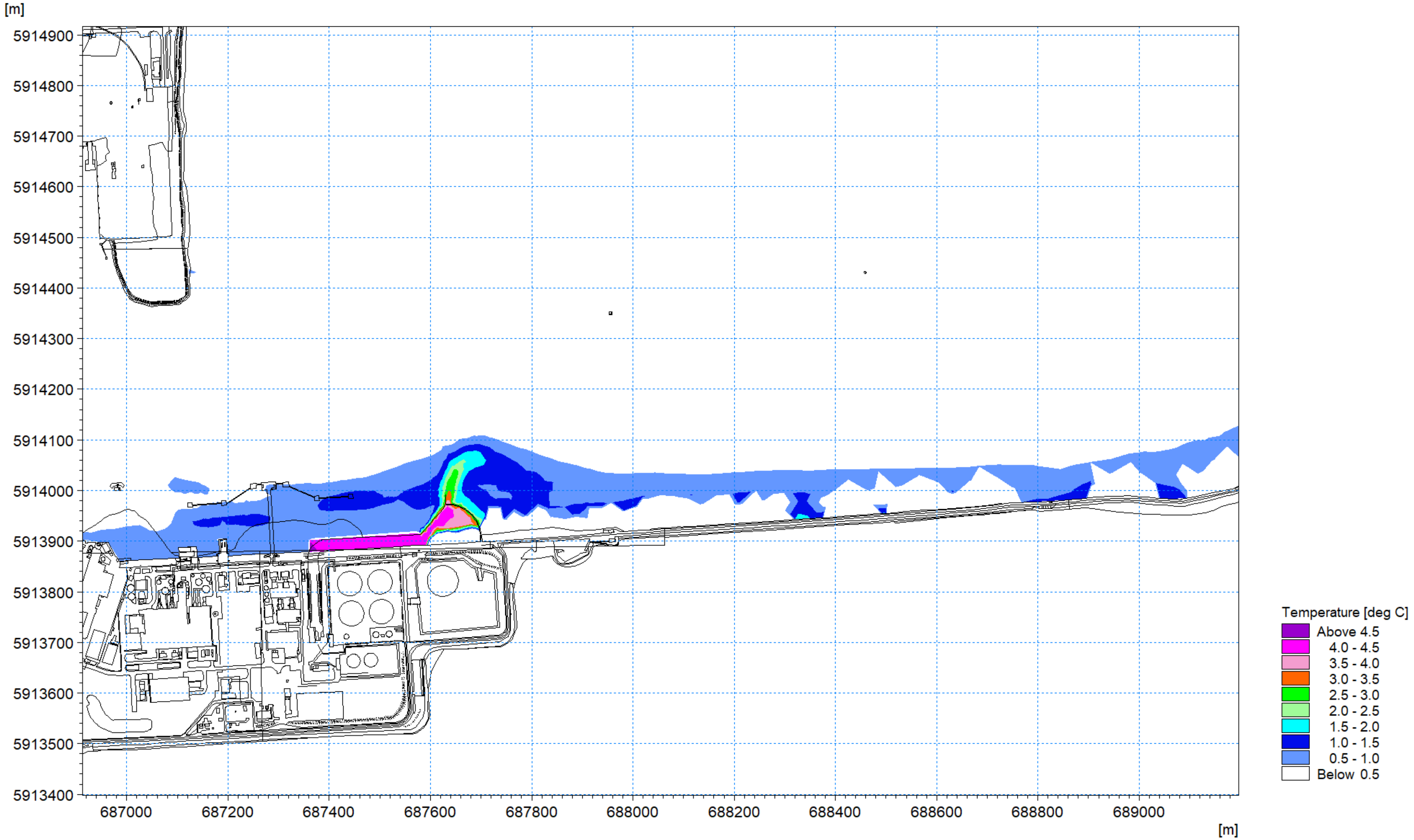

Figure 1.124: Thermal plume 9th April 2019 – excess temperature at mid-ebb circa 1.8m depth layer 3