Dublin Port Thermal Plume Model

Final Report

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Report Prepared For

ESB

Report Prepared By

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Contents

Executive Summary

Telemac 3D has been used to develop a three dimensional mathematical model of Dublin Bay and Dublin Port to simulate the thermal discharges from Dublin Bay Power, Waste to Energy, Poolbeg CCGT and Ringsend Wastewater Treatment Plant for a variety of tidal, atmospheric and thermal discharge conditions.

The model was used to simulate the thermal plume when all four facilities were discharging the maximum thermal load continuously over a 14 day period, a complete spring neap tidal cycle. It is highly unlikely that the four facilities would be discharging the maximum measured thermal load continuously for 14 days. Historically this has not happened. The output from power generating stations tend to be vary over the course of a day and they are often at minimum load during the night period.

For all model scenarios the maximum cross sectional area occupied by the thermal discharges from all sources occurs at the combined outfall of Dublin Bay Power and the Waste to Energy facility.

The maximum cross sectional area occupied by the thermal discharges for all stages of the tide is less than 25% with one exception. At low water spring tide under dry weather conditions the model estimates that the cross sectional area occupied by the thermal discharge at Dublin Bay Power's and Waste to Energy outfall will be 26% with the future proposed discharge from Ringsend Wastewater Treatment Plant and the other 3 facilities operating simultaneously at maximum capacity for a sustained period of time. This only occurs for a short period of time. The average cross sectional area over the tidal cycle is 12%. See Appendix G for further detail.

The maximum cross sectional area occupied by the thermal discharges at Poolbeg CCGT and Ringsend Wastewater Treatment Plant outfall is 10%.

1. Introduction

This Report describes the development of a mathematical model of Dublin Port as part of a study of the effects of thermal discharges from several sources on the receiving waters. The thermal discharges are from ESB's Dublin Bay Power and Poolbeg Stations and Covanta's Waste to Energy facility. Sewage effluent from Irish Water's wastewater treatment plant at Ringsend is mixed with Poolbeg's cooling water prior to its discharge into the estuary. The model can be used to predict the variations in water temperature and quality.

This report concentrates on predicting the effect of the thermal discharge from all sources for selected environmental conditions. In particular, the objective is to predict the extent of the thermal plume resulting when all sources of thermal discharge are working at full production. Graphical Representation of Temperature Fields resulting from the current maximum thermal discharges are produced.

1.1. Dublin Port

The Liffey enters Dublin Bay between Clontarf and Ringsend in the channel formed by the North Bull Wall and the Great South Wall. (Figure 1.) The long term mean inflow to the estuary from the combined Liffey and Dodder is of the order of 25m^3/s. The long term mean inflow from the Tolka, to the northern part of the Port, is approximately 3m^3/s.

The North Bull Wall, a natural bank reinforced by a stone embankment, is only inundated at half tide and therefore holds back the water flowing out of the harbour at and after half ebb. A deep narrow channel, which runs close to the South Wall, extends from the Port area through the mouth of the harbour. This access channel is maintained at a depth of 7 to 8 metres by dredging and natural scouring. To the north of this channel are extensive areas which dry out at low water. These mudflats extend from the mouth of the River Tolka almost to the end of the Bull Wall and north-eastwards to the Bull Island Causeway at St. Anne's.

Dublin Bay is shallow with water depths not greater than 20m at low tide at its outer limit between Sorrento Point and Baily. This water depth decreases towards the harbour with depths of less than 5m occurring in the inner half of the Bay. North of the harbour at Bull Island and south around Sandymount extensive areas dry out at low tide.

The tidal characteristics of Dublin Bay reflect the tidal regime in the Irish Sea. On the flood tide, the tidal stream enters from the south of the bay past Dalkey Island and runs north creating a clockwise flow. On the ebb the tidal stream flows south past Howth Head towards the shore at Dalkey Island. The resulting dominant feature is therefore a clockwise tidal circulation giving a strong eastwards net flow. The mean tidal range in the Bay is approximately 3.4m for spring tides and 1.9m for neap tides. Tide levels, relative to Malin Head, are listed in Table 1.1.

Lowest Astronomical Tide	-2.61 m O.D.
Mean Low Water Spring	-1.81 m O.D.
Mean Low Water Neap	-1.01 m O.D.
Mean Sea Level	-0.11 m O.D.
Mean High Water Neap	0.89 m O.D.
Mean High Water Spring	1.59 m O.D.
Highest Astronomical Tide	1.99 m O.D.

Table 1.1 - Dublin Port Tidal Levels (rel. Malin Hd.)

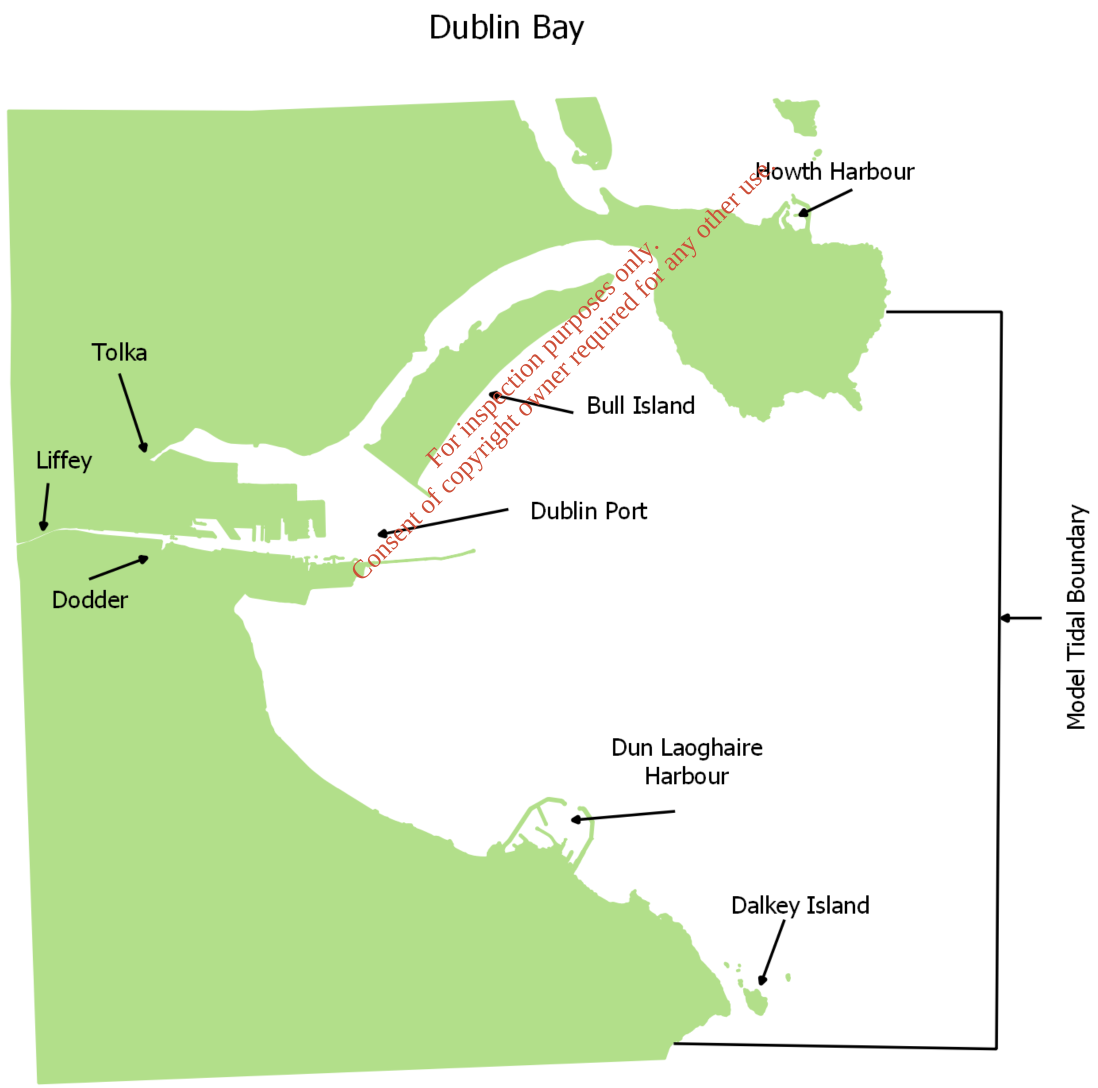

Figure 1.1 Outline of Dublin Bay

1.2. Thermal Discharges to Dublin Port

There are four thermal discharges discharging into Dublin Port

- Dublin Bay Power generating station.
- Waste to Energy facility at Ringsend
- Poolbeg CCGT power generating station
- Wastewater treatment plant at Ringsend.

The temperature rise for all facilities was obtained from an analysis of facility data. Previous studies used the maximum design temperature rise supplied by the design teams.

Tables 1.2 and 1.3 provide relevant flow and temperature information for each discharge source.

• Facility	Flow m^3/s	Temperature Rise ^oC
Dublin Bay Power	6.4	7.60
Waste to Energy	3.9	8.72
Poolbeg CCGT	9	6.96
Waste water Treatment	4.28 to 8.04	3

Table 1.2 Measured Maximum Discharge

Facility	Flow m^3/s		Temperature Rise ^oC		Thermal Discharge MW_{TH}	
	Normal	**Max**	**Normal**	**Max**	**Normal**	**Max**
Dublin Bay Power	8.4	8.4	9	9.5	240	250
Waste to Energy	3.9	6.6	9	9.5	N/A	N/A
Poolbeg Power Station	12	12	10	14	338	555
Wastewater Treatment	4.91	8.04	3	N/A	N/A	N/A

Table 1.3 Licenced Maximum Discharge

There are only two thermal discharge outfalls into Dublin Port. The thermal discharge of Dublin Bay Power and the Waste to Energy facility discharge into Dublin Port at a single location and the thermal discharge of Poolbeg CCGT and the Wastewater treatment plant discharge into Dublin Port at the other location.

The intakes for Dublin Bay Power, Waste to Energy facility and Poolbeg CCGT are located upstream (west) of their applicable discharge locations. The intakes take water from the bottom of the water column to minimise the risk of recirculation of thermal discharge. The Wastewater treatment plant has no intake.

Figure 1.2 shows the location of the discharges and intakes.

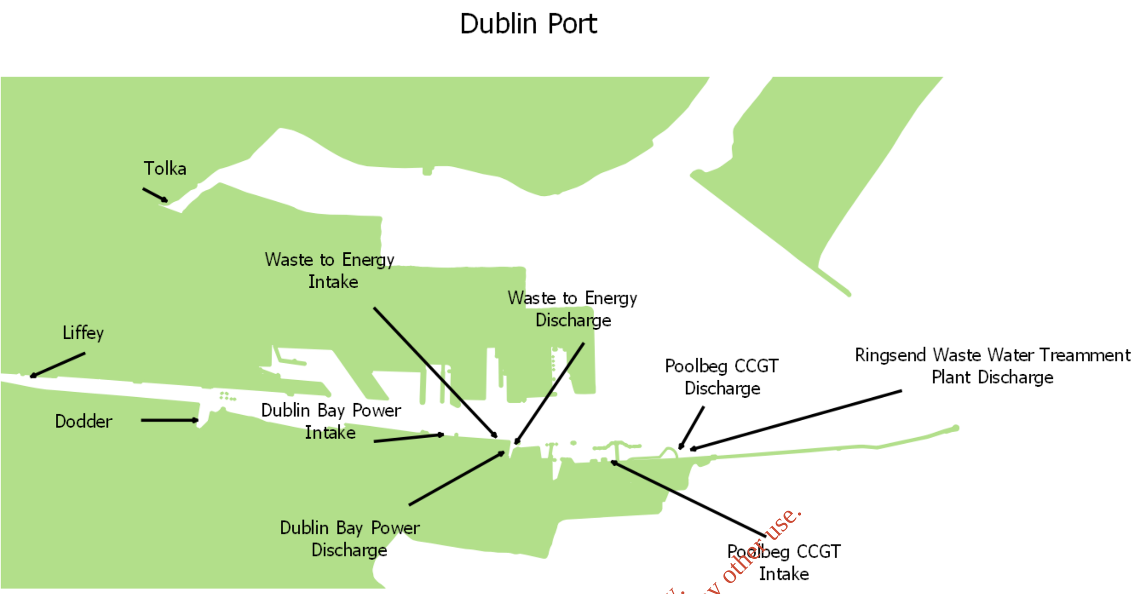

Figure 1.2 Dublin Port

1.3. Scope of Report

The key elements of the study presented in the report are set out below

- Summary information on recent relevant thermal plume surveys in Dublin Port/Dublin Bay
- A mathematical model of Dublin Bay and Dublin Port was constructed to simulate the behaviour of thermal discharges under various operational, tidal, hydrological and meteorological conditions
- Mathematical modelling techniques were used to simulate plume behaviour recorded during the measurement events.
- Mathematical modelling techniques were used to simulate plume behaviour under a range of hypothetical scenarios of varying operational, tidal, hydrological and meteorological conditions

2. Hydrodynamic Model

The thermal plume model of Dublin Port was developed using Telemac-3D, a three dimensional hydrodynamic modelling software. It solves the Navier-Stokes equations using finite-element / finite-volume numerical method. The horizontal domain is discretised into an unstructured mesh of triangular elements. The vertical domain is discretised into a series of model planes between the bed and the water surface.

Flexibility in the placement of these planes permits the use of a sigma grid (each plane at a given proportion of the spacing between bed and surface) or a number of other strategies for intermediate plane location. One useful example is to include some planes which are at a fixed distance below the water surface, or above the bed. In the presence of a near surface thermocline or halocline, this is advantageous in so far as mixing water between the near surface planes, where the greatest density gradients are located, can be avoided. The wave formulation for the updating of the free surface is used for efficiency.

The modelling software is written primarily to solve the shallow water equations in 3D format, but an option is also available to solve the governing equations including dynamic pressure so allowing shorter waves than those in a shallow water context (where wavelengths are required to be at least twenty times the water depth). This non-hydrostatic model formulation may also be important when modelling flows over trenches or on steep slopes.

TELEMAC-3D can take into account the following phenomena:

- Propagation of long waves, taking into account non-linear effects
- Bed friction
- Influence of Coriolis force
- Influence of meteorological factors: atmospheric pressure and wind
- Turbulence Torrent and river flows
- Influence of temperature and/or salinity gradients on density
- Cartesian or spherical coordinates for large domains
- Dry areas in the computational domain: intertidal flats and flood plains
- Current entrainment and diffusion of a tracer, with source and sink terms Monitoring of floats and Lagrangian drifts
- Treatment of singular points: sills, dikes, pipes.

3. Available Data

The following data is available for Dublin Bay and Dublin Port.

- Dublin Port maintains a tide gauge at Alexandra Basin West.
- Dublin Port undertook a hydrographic survey of the Tolka Estuary and Dublin Port in December 2017.
- The Marine Institute's and the Geological Survey of Ireland INFOMAR (Integrated Mapping for the Sustainable Development of Ireland's Marine Resource) programme. Various bathymetric surveys have taken place since 2006.
- Irish Water undertook extensive measures in Dublin Port in 2015 as part of the Ringsend Wastewater Treatment Plant Upgrade Project. The following data was measured
    - Continuous current measurements from the 23rd of September to the 27th of October 2015 were at 2 locations in Dublin Port and 1 location in Dublin Bay.
    - Current, Salinity and temperature measurements were carried out at 6 locations in Dublin Port between the 19th and 23rd of October 2015
- ESB undertook a thermal plume survey of the thermal discharge from Dublin Bay Power on the 12th August 2016
- Covanta undertook a thermal plume survey of the thermal discharge from their Waste to Energy facility at Ringsend and ESB's Dublin Bay Power on the 2oth and 24th of April 2018.
- ESB undertook a thermal plume survey of the thermal discharge from Poolbeg Combined Cycle Gas Turbine on the 9th of April 2019.
- Meteorological data from Met Eireann's weather station at Dublin Airport.

4. Model Setup

The model domain is as shown in Figure 4.1.

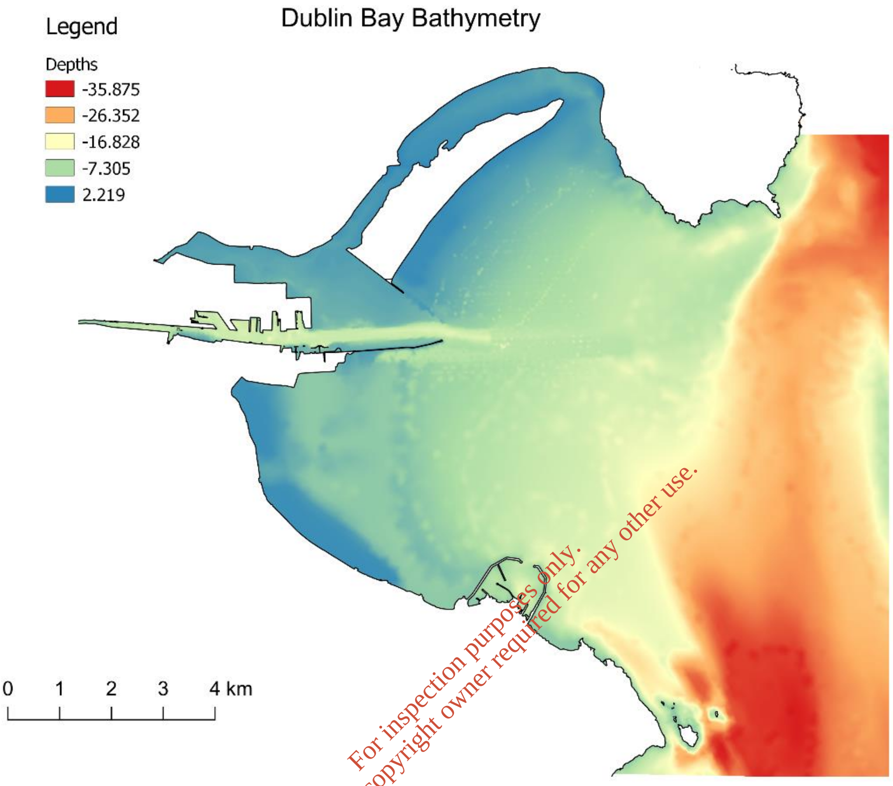

Figure 4.1 - Dublin Bay Bed Elevation and model domain.

Bathymetric data was obtained from the following sources

- INFOMAR (Geological Survey of Ireland & The Marine Institute)
- Dublin Port
- Irish Water

The model domain has been discretised into an unstructured mesh as shown in Figure 3.2. A fine mesh was used for Dublin Port as shown in Figure 3.3. This fine mesh was required to model accurately the flows in the complicated topology of Dublin Port. It is also required to model accurately the near field thermal plume where thermal gradients are highest. A coarser mesh was then used for the remainder of the model domain. The domain was vertically discretised into 6 planes using a sigma grid.

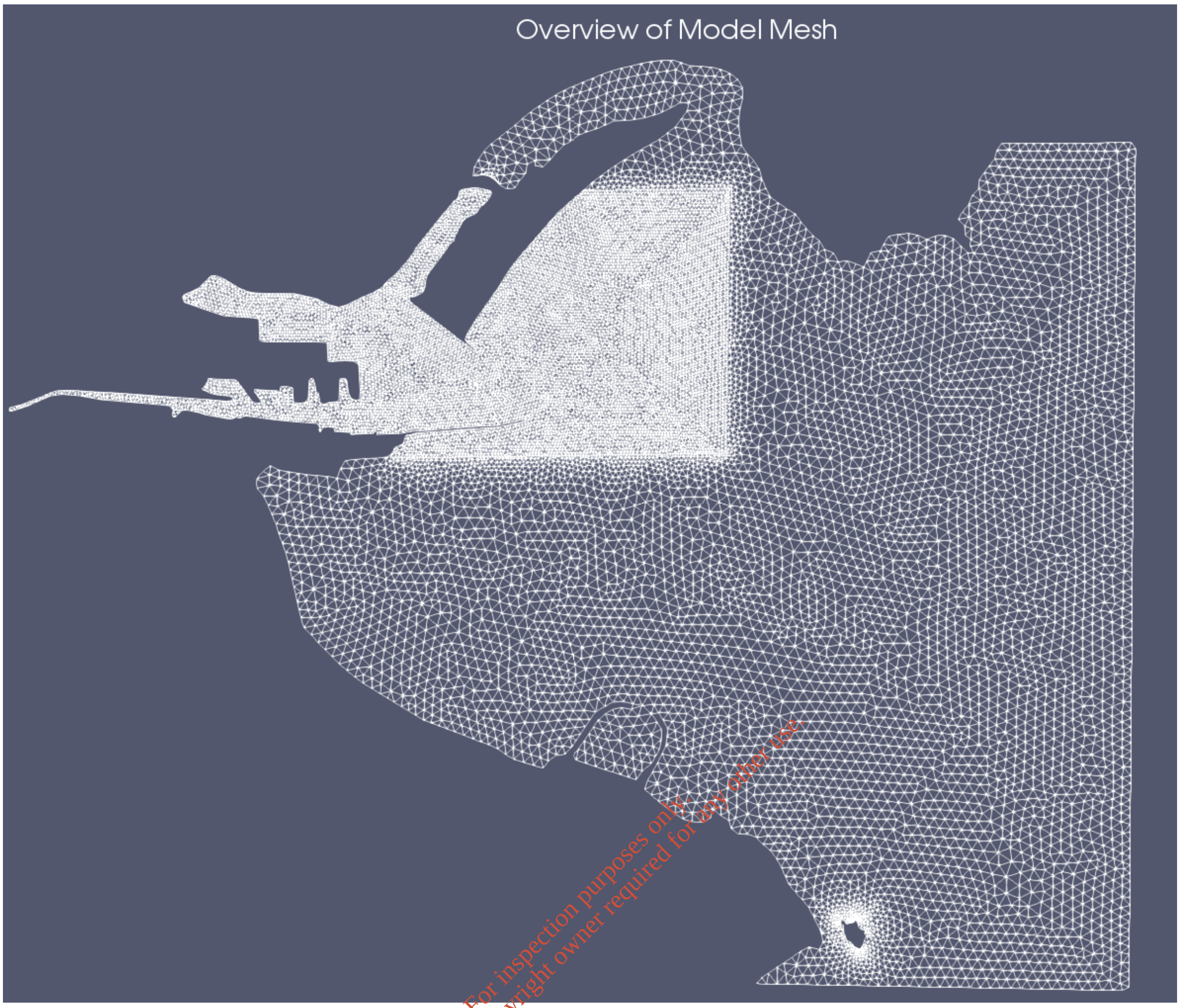

Figure 4.2 Unstructured Mesh used in the Model

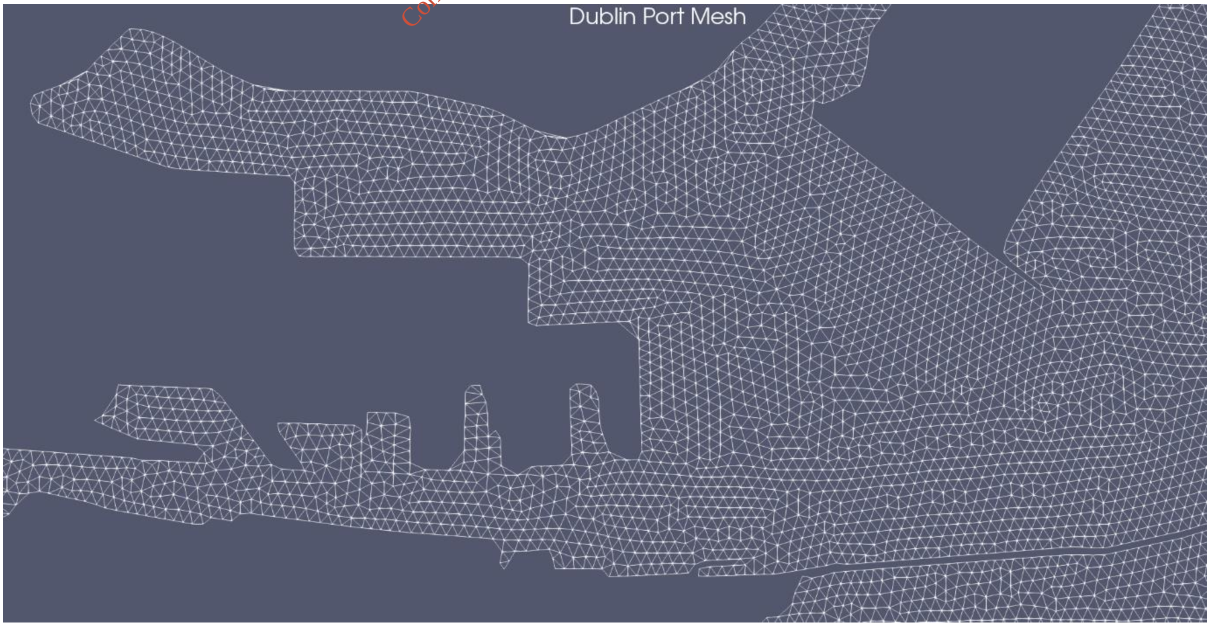

Figure 4.3 Fine Mesh of Dublin Port

4.1. Boundary Conditions

The model has the following 4 boundaries

- Boundary with the Irish Sea
- River Dodder at the Grand Canal Dock
- River Liffey at O'Connell Bridge
- River Tolka at Fairview

4.1.1. Irish Sea Boundary

The Irish Sea boundary is a tidal boundary. The tidal boundary conditions for the velocities and surface elevations were obtained from the Oregon State University's (OSU) TPXO European Shelf 1/30^{o} regional model (11 tidal constituents: M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4 and MN4). Temperature and salinity were kept constant in space and time along the boundary. Salinity was taken as 34 ppt and the temperature was dependent on the time of year.

4.1.2. River Boundaries

The River boundaries are treated as sources. Hourly time series flow data was used at all 3 boundaries. The flow used were

- River Dodder – The estimated flow of the Dodder at Waldron's Bridge was used as the Dodder Flow boundary condition
- River Liffey – The combined flow from the ESB Discharge data from Leixlip Dam and the estimated flow of the Ryewater at Leixlip was used as the Liffey Flow boundary condition
- River Tolka – The estimated flow of the Tolka at the Botanic Gardens was used as the Tolka Flow boundary condition

Temperature and salinity were kept constant in space and time at all 3 boundaries. Salinity was taken as 0 ppt and the temperature was dependent on the time of year.

5. Model Simulations

The model was run for the following scenarios:

- 12th August 2016
- 20th to 24th April 2018
- 9th April 2019
- Spring-neap tidal cycle.

The thermal plume is defined as where the temperature rise with respect to ambient is greater than 1.5 ^oC.

5.1. Calibration and Verification

The model has been calibrated against the following data

- Thermal Plume Survey on the 12th August 2016
- Thermal Plume Survey on the 20th April 2018
- Thermal Plume Survey on the 24th April 2018
- Thermal Plume Survey on the 9th April 2019

5.1.1. Thermal Plume Survey on the 12th August 2016

A thermal plume survey of Dublin Bay Power thermal discharge was carried out on the 12th of August 2016. The survey was undertaken during a neap tide and the wind was from a south westerly direction at an average speed of 37 km/hr approximately (Force 5 on the beaufort scale). The discharge from Leixlip varied between 2 and 4 m^3/s. The flow in the Ryewater was estimated at 0.4 m^3/s, the Dodder was estimated at 0.75 m^3/s and the Tolka was estimated to 0.22 m^3/s. Poolbeg CCCGT was not on load and the Covanta Waste Energy's facility was not operational.

The report entitled "Dublin Bay Power – Thermal Plume Survey. Report Number QS-000196-01-R001-001" presents the results of the survey. The thermal plume survey found no thermal stratification in the water column.

On the 12th of August 2016 the thermal plume survey showed that the thermal plume from Dublin Bay Power was mainly on the water surface. The thickness of the thermal plume was less than 2 metres except at the outfall. It was situated mainly to the east of the outfall on the southern side of the main channel.

Plots of the measured thermal plume at 0.3, 1 and 2 metres below the water surface for High Water, Half Ebb, Low Water and Half flood were produced using different ambient temperatures in each plot. The following can be observed:

- The thermal plume is predominantly situated east of the cooling water discharge for all stages of the tide.
- The thermal plume is predominantly situated on the southern side of the main channel of the cooling water discharge for all stages of the tide.
- The thermal plume is mainly a surface phenomenon.
- No thermal stratification of the water column in Dublin Port was observed during the survey.

The model simulated the thermal discharges into Dublin Port from 10/08/2016 00:00:00.

Model Parameters

The boundary conditions are described in section 4.

There were 2 thermal discharges into Dublin Port during this period. These were ESB's Dublin Bay Power and Irish Water's Waste Water Treatment Plant at Ringsend. ESB's Poolbeg CCGT was not on load during this period. Dublin Bay Power's hourly temperature rise, and flow were used to simulate its thermal discharge. A constant temperature rise of 3 ^{o}C and a flow of 4.91 m^3/s were used to simulate the Waste Water Treatment Plant thermal discharge.

Ambient Sea Temperature was taken as 16 ^{o}C.

The salinity of Dublin Bay Power's discharge was taken as the model salinity at the location of the intake. The salinity of the Waste Water Treatment Plant is taken as 0 ppt. The salinity of the open sea water is taken as 34 ppt.

Hourly wind speed and direction from Met Eireann's weather station at Dublin Airport were used for the model's meteorological conditions.

The results of the thermal plume model are shown in Appendix A and the thermal plume survey is in references 5 and 6. The key findings were:

- The model gives a good representation of the surveyed plume for all stages of the tide.
- The maximum cross section taken up by the simulated thermal plume was 6 % and this occurred at section 1 at Low Water and Half Flood stages of the tide. Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall.

See Appendix A for full results of the model simulation and location of cross sections.

5.1.2. Thermal Plume Survey on the 20th April 2018

A thermal plume survey of Covanta's Waste to Energy and ESB's Dublin Bay Power thermal discharges was carried out on the 20th of April 2018 during a spring tide. The survey was undertaken by Irish Hydrodata Limited on behalf of Covanta. The wind speed varied from 20 km/hr (Force 3 to 4 on the beaufort scale) at the start of the survey to 5 km/hr (Force 2 on the beaufort scale) at the end of the survey. The wind direction varied from a westerly direction at the start of the survey to a south easterly at the end of the survey.

The discharge from Leixlip varied between 2 and 31 m^3/s. The flow in the Ryewater was estimated at 1.8 m^3/s, the Dodder was estimated at 2.0 m^3/s and the Tolka was estimated to 1.0 m^3/s. Poolbeg CCCGT was not on load.

The report entitled "Covanta Dublin Waste to Energy Facility – Thermal Plume Surveys of April 20th and April 24th 2018" presents the results of the survey. The thermal plume survey found that there was a significant thermal stratification in the water column. The survey found that the surface water was up to 3 °C warmer than the temperature of the water at a depth of 2 metres in the vicinity of Covanta's Waste to Energy facility and ESB's Dublin Bay Power outfall. There was significant variation in the surface water temperature in a north south direction but less in an east west. It is likely that the stratification is as a result of the river water being warmer then the sea water and the variation in the north south direction due to shipping.

Because of the thermal stratification it is impossible to estimate the horizontal extent and vertical thickness of thermal plume.

Plots of the measured thermal plume at 0.3, 1 and 2 metres below the water surface for High Water, Half Ebb, Low Water and Half flood were produced using different ambient temperatures in each plot. The following can be observed:

- The thermal plume is predominantly situated east of the cooling water discharge for all stages of the tide.
- The thermal plume is predominantly situated on the southern side of the main channel of the cooling water discharge for all stages of the tide.
- The thermal plume is not a surface phenomenon and at certain stages of the tide it can be seen to be approximately 1 to 2 metres below the surface.
- Thermal stratification of the water column in Dublin Port was observed during the survey.

The model simulated the thermal discharges into Dublin Port from 19/04/2018 00:00:00.

Model Parameters

The boundary conditions are described in section 4.

There were 3 thermal discharges into Dublin Port during this period. These were ESB's Dublin Bay Power, Covanta's Waste to Energy facility at Ringsend and Irish Waters Waste Water Treatment Plant at Ringsend. ESB's Poolbeg CCGT was not on load during this period. Dublin Bay Power's and the Waste to Energy hourly temperature rise and flow were used to simulate their thermal discharge. A constant temperature rise of 3 °C and a flow of 4.91 m^3/s were used to simulate the Waste Water Treatment Plant thermal discharge.

Ambient Sea Temperature was taken as 9.5 °C.

The salinity of Dublin Bay Power's and the Waste to Energy's discharges were taken as the model salinity at the location of their intake. The salinity of the Waste Water Treatment Plant is taken as 0 ppt. The salinity of the open sea water is taken as 34 ppt.

Hourly wind speed and direction from Met Eireann's weather station at Dublin Airport were used for the model's meteorological conditions.

The results of the thermal plume model are shown in Appendix B and the thermal plume survey is in reference 7.

- The thermal stratification of the water has made it difficult to determine the precise location of the thermal plume due to the discharges from Dublin Bay Power and the Waste to Energy facility. However, the model gives a reasonable representation of the surveyed plume for all stages of the tide.
- For certain stages of the tide the model shows that the thermal plume is below the water surface.
- The maximum cross section taken up by the simulated thermal plume was 14 % and this occurred at section 1 at Low Water stage of the tide. Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall.

See Appendix B for full results of the model simulation and location of cross sections.

5.1.3. Thermal Plume Survey on the 24th April 2018

A thermal plume survey of Covanta's Waste to Energy and ESB's Dublin Bay Power thermal discharges was carried out on the 24th of April 2018 during a neap tide. The survey was undertaken by Irish Hydrodata Limited on behalf of Covanta. The wind speed varied from 22 km/hr (Force 3 to 4 on the beaufort scale) at the start of the survey to 12 km/hr (Force 3 on the beaufort scale) during the middle of the survey. It increased to 26 km/hr (Force 4 on the beaufort scale) at the end of the survey. The wind direction was from a south westerly direction at the start of the survey veered towards the north during the middle of the survey to a south westerly at the end of the survey.

The discharge from Leixlip varied between 2 and 31 m^3/s. The flow in the Ryewater was estimated at 1.8 m^3/s, the Dodder was estimated at 2.0 m^3/s and the Tolka was estimated to 1.0 m^3/s. Poolbeg CCCGT was not on load.

The report entitled "Covanta Dublin Waste to Energy Facility – Thermal Plume Surveys of April 20th and April 24th 2018" presents the results of the survey. The thermal plume survey found that there was a significant thermal stratification in the water column. The survey found that the surface water was up to 3 ^oC warmer than the temperature of the water at a depth of 2 metres in the vicinity of Covanta's Waste to Energy facility and ESB's Dublin Bay Power outfall. There was significant variation in the surface water temperature in a north south direction but less in an east west. It is likely that the stratification is as a result of the river water being warmer then the sea water and the variation in the north south direction due to shipping.

Because of the thermal stratification it is impossible to estimate the horizontal extent and vertical thickness of thermal plume.

Plots of the measured thermal plume at 0.3, 1 and 2 metres below the water surface for High Water, Half Ebb, Low Water and Half flood were produced using different ambient temperatures in each plot. The following can be observed:

- The thermal plume is predominantly situated east of the cooling water discharge for all stages of the tide.
- The thermal plume is predominantly situated on the southern side of the main channel of the cooling water discharge for all stages of the tide.
- The thermal plume is not a surface phenomenon and at certain stages of the tide it can be seen to be approximately 1 to 2 metres below the surface.
- Thermal stratification of the water column in Dublin Port was observed during the survey.

The model simulated the thermal discharges into Dublin Port from 19/04/2018 00:00:00.

Model Parameters

The boundary conditions are described in section 4.

There were 3 thermal discharges into Dublin Port during this period. These were ESB's Dublin Bay Power, Covanta's Waste to Energy facility at Ringsend and Irish Waters Waste Water Treatment Plant at Ringsend. ESB's Poolbeg CCGT was not on load during this period. Dublin Bay Power's and the Waste to Energy hourly temperature rise and flow were used to simulate their thermal discharge. A constant temperature rise of 3 °C and a flow of 4.91 m^3/s to were used to simulate the Waste Water Treatment Plant thermal discharge.

Ambient Sea Temperature was taken as 9.5 °C.

The salinity of Poolbeg CCGT and the Waste to Energy's discharges were taken as the model salinity at the location of their intake. The salinity of the Waste Water Treatment Plant is taken as 0 ppt. The salinity of the open sea water is taken as 34 ppt.

Hourly wind speed and direction from Met Eireann's weather station at Dublin Airport were used for the model's meteorological conditions.

The results of the thermal plume model are shown in Appendix C and the thermal plume survey is in reference 7.

- The thermal stratification of the water has made it difficult to determine the precise location of the thermal plume due to the discharges from Dublin Bay Power and the Waste to Energy facility. However, the model gives a reasonable representation of the surveyed plume for all stages of the tide.
- For certain stages of the tide the model shows that the thermal plume is below the water surface.
- The maximum cross section taken up by the simulated thermal plume was 13 % and this occurred at section 1 at Low Water stage of the tide. Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall.

See Appendix C for full results of the model simulation and location of cross sections.

5.1.4. Thermal Plume Survey on the 9th April 2019

A thermal plume survey of Poolbeg CCCGT thermal discharge was carried out on the 9th of April 2019. The survey was undertaken during an average tide and the wind was from an easterly direction. The wind speed varied between 15 km/hr (Force 3 on the beaufort scale) and 31 km/hr (Force 5 on the beaufort scale). The discharge from Leixlip varied between 3 and 13 m^3/s. The flow in the Ryewater was estimated at 1.0 m^3/s, the Dodder was estimated at 2 m^3/s and the Tolka was estimated to 1.5 m^3/s. Dublin Bay Power was not on load and the Covanta Waste Energy's facility was not operational.

The report entitled "Poolbeg CCGT, Pigeon House Road, Dublin 4 (IEL No. P0577-03) Thermal Plume Survey of April 9th 2019" presents the results of the survey. The thermal plume survey found no thermal stratification in the water column. Plots of the thermal plume at 0.3, 1 and 2 metres below the water surface for High Water, Half Ebb, Low Water and Half flood.

On the 9th of April 2019 the thermal plume survey showed that the thermal plume from Poolbeg CCGT was mainly on the water surface. The thickness of the thermal plume was less than 2 metres. It was situated mainly to the west of the outfall at Low Water, Half Flood and High Water and to the east of the outfall at Half Ebb. It was situated mainly on the southern side of the main channel.

Plots of the measured thermal plume at 0.3, 1 and 2 metres below the water surface for High Water, Half Ebb, Low Water and Half flood were produced using different ambient temperatures in each plot. The following can be observed:

- The thermal plume is predominantly situated to the west of the cooling water discharge for Low Water, Half Flood, and High Water of the tide and to the east of the cooling water discharge for Half Ebb.
- The thermal plume is predominantly situated on the southern side of the main channel of the cooling water discharge for all stages of the tide.
- The thermal plume from the Poolbeg CCGT is a surface phenomenon.
- No thermal stratification of the water column in Dublin Port was observed during the survey.

The model simulated the thermal discharges into Dublin Port from 05/04/2019 00:00:00.

Model Parameters

The boundary conditions are described in section 4.

There were 3 thermal discharges into Dublin Port during this period. These were Covanta's Waste to Energy facility at Ringsend, ESB's Poolbeg CCGT and Irish Waters Waste Water Treatment Plant at Ringsend. ESB's Dublin Bay Power was not on load during this period. Dublin Bay Power's and the Waste to Energy hourly temperature rise and flow were used to simulate their thermal discharge. A constant temperature rise of 3 ^{o}C and a flow of 4.91 m^3/s were used to simulate the Waste Water Treatment Plant thermal discharge.

Ambient Sea Temperature was taken as 9.5 ^{o}C.

The salinity of Dublin Bay Power's discharge was taken as the model salinity at the location of the intake. The salinity of the Waste Water Treatment Plant is taken as 0 ppt. The salinity of the open sea water is taken as 34 ppt.

Hourly wind speed and direction from Met Eireann's weather station at Dublin Airport were used for the model's meteorological conditions.

The results of the thermal plume model are shown in Appendix D and the thermal plume survey is in reference 8. The model gives a good representation of the surveyed plume for all stages of the tide.

The maximum cross section taken up by the simulated thermal plume was 6 % and this occurred at section 1 at Low Water stage of the tide Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall. See Appendix D for full results of the model simulation and location of cross sections.

5.2. Model Results

The model was run for the following scenarios

1. All facilities operating at maximum capacity with dry weather conditions
2. All facilities operating at maximum capacity with wet weather conditions
3. All facilities operating at maximum capacity with future flows at Irish Water's Waste Water Treatment Plant with dry weather conditions
4. All facilities operating at maximum capacity future flows at Irish Water's Waste Water Treatment Plant with wet weather conditions

The model was used to simulate the thermal plume when all four facilities were discharging the maximum thermal load continuously over a 14 day period, a complete spring neap tidal cycle. This is the worst case scenario and has never occurred. It is highly unlikely that the four facilities would be discharging the maximum measured thermal load continuously for 14 days. The output from power generating stations tend to be vary over the course of a day and they are often at minimum load during the night period.

The start date for the tidal model was the 5th of April 2019. The spring tide plots are for the 7th of April 2019 and the tidal range is 3.44 metres approximately. The neap tide plots are for the 13th of April 2019 and the tidal range is 2.25 metres approximately.

Dry weather conditions mean that there are low river flows and the flow from Ringsend wastewater treatment plant is low. Wet weather conditions mean that there are high river flows and the flow from Ringsend wastewater treatment plant is high.

5.2.1. All facilities operating at current maximum capacity with dry weather conditions

The river boundaries have the following parameters

- Combined Liffey/Ryewater discharge was set at 2 m^3/s
- Dodder discharge was set at 0.5 m^3/s
- Tolka discharge was set at 0.5 m^3/s

The thermal discharges are

Facility	Flow (m^3/s)	Temperature rise (^oC)
Dublin Bay Power	6.4	7.6
Waste to Energy	3.9	8.72
Poolbeg CCGT	9.0	6.96
Waste Water Treatment Plant	4.28	3.0

Ambient Sea Temperature is 12.0 ^oC.

The salinity of Dublin Bay Power's, Waste to Energy and Poolbeg CCGT discharges were taken as the model salinity at the location of the intake. The salinity of the Waste Water Treatment Plant is 0 ppt. The salinity of the open sea water is 34 ppt.

The key findings were:

- During dry weather conditions the thermal plume is a surface phenomenon as the thermal discharge for all four facilities is less dense than the receiving waters. It is predominantly on the southern side of the main channel. It is also predominantly to the east of the discharge points although at certain stages of the tide it is pushed westward. The thermal plume is at its largest at low water.
- The maximum cross section taken up by the simulated thermal plume was 24 % and this occurred at section 1 at Low Water Spring Tide. The average cross section taken up by the simulated thermal plume is 13%. Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall.

See Appendix E for full results of the model simulation and location of cross sections.

5.2.2. All facilities operating at current maximum capacity with wet weather conditions

The river boundaries have the following parameters

- Combined Liffey/Ryewater discharge was set at 25 m^3/s
- Dodder discharge was set at 4 m^3/s
- Tolka discharge was set at 3 m^3/s

The thermal discharges are

Facility	Flow (m^3/s)	Temperature rise (^oC)
Dublin Bay Power	6.4	7.6
Waste to Energy	3.9	8.72
Poolbeg CCGT	9.0	6.96
Waste Water Treatment Plant	8.04	3.0

Ambient Sea Temperature was taken as 12.0 °C.

The salinity of Dublin Bay Power's, Waste to Energy and Poolbeg CCGT discharges were taken as the model salinity at the location of the intake. The salinity of the Waste Water Treatment Plant is 0 ppt. The salinity of the open sea water is 34 ppt.

The key findings were:

- During wet weather conditions the thermal plume from Poolbeg CCGT and the Waste water treatment plant is a surface phenomenon as the thermal discharge is significantly less dense than the receiving waters as the discharge from the Waste water treatment plant has zero salinity.
- At certain stages of the tide the thermal plume from Dublin Bay Power and the Waste to Energy is not a surface phenomenon. The reason for this is that at certain stages of the tide the salinity of the thermal discharge is greater than the salinity of the receiving waters.
- The thermal plume is predominantly on the southern side of the main channel. It is also predominantly to the east of the discharge points.
- The thermal plume is at its largest at low water.
- The maximum cross section taken up by the simulated thermal plume was 22 % and this occurred at section 1 at Low Water Spring Tide. The average cross section taken up by the simulated thermal plume is 12%. Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall.

See Appendix F for full results of the model simulation and location of cross sections.

5.2.3. All facilities operating at future maximum capacity with future flows at Irish Water's Waste Water Treatment Plant with dry weather conditions

The river boundaries have the following parameters

- Combined Liffey/Ryewater discharge was set at 2 m^3/s
- Dodder discharge was set at 0.5 m^3/s
- Tolka discharge was set at 0.5 m^3/s

The thermal discharges are

Facility	Flow (m^3/s)	Temperature rise (°C)
Dublin Bay Power	6.4	7.6
Waste to Energy	3.9	8.72
Poolbeg CCGT	9.0	6.96
Waste Water Treatment Plant	6.05	3.0

Ambient Sea Temperature was taken as 12.0 °C.

The salinity of Dublin Bay Power's, Waste to Energy and Poolbeg CCGT discharges were taken as the model salinity at the location of the intake. The salinity of the Waste Water Treatment Plant is 0 ppt. The salinity of the open sea water is 34 ppt.

The description of the thermal plume is the same as section 5.2.1. Additional key findings were:

- The maximum cross section taken up by the simulated thermal plume was 26 % and this occurred at section 1 at Low Water Spring Tide.
- The average cross section taken up by the simulated thermal plume is 13%.

Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall. See Appendix G for full results of the model simulation and location of cross sections.

5.2.4. All facilities operating at future maximum capacity with wet weather conditions

The river boundaries have the following parameters

- Combined Liffey/Ryewater discharge was set at 25 m^3/s
- Dodder discharge was set at 4 m^3/s
- Tolka discharge was set at 3 m^3/s

The thermal discharges are

Facility	Flow (m^3/s)	Temperature rise (^oC)
Dublin Bay Power	6.4	7.6
Waste to Energy	3.9	8.72
Poolbeg CCGT	9.0	6.96
Waste Water Treatment Plant	11.1	3.0

Ambient Sea Temperature was taken as 12.0 ^oC.

The description of the thermal plume is the same as section 5.2.1

The salinity of Dublin Bay Power's, Waste to Energy and Poolbeg CCGT discharges were taken as the model salinity at the location of the intake. The salinity of the Waste Water Treatment Plant is 0 ppt. The salinity of the open sea water is 34 ppt.

The description of the thermal plume is the same as section 5.2.1. Additional key findings were:

- The maximum cross section taken up by the simulated thermal plume was 23 % and this occurred at section 1 at Low Water Spring Tide.
- The average cross section taken up by the simulated thermal plume is 12%.

Section 1 is located at Dublin Bay Power and Waste to Energy thermal discharge outfall. See Appendix H for full results of the model simulation and location of cross sections.

6. Conclusions

From the results of this modelling process, the following can be concluded:

- The tide in Dublin Port has the largest impact on the thermal discharges and the location of the thermal plume.
- The flow in the River Liffey also has a significant on the currents in Dublin Port and on the thermal discharges.
    - During periods of high flows there is a strong eastward flow in the surface waters in Dublin Port for most stages of the tide. This results in the thermal plumes from all sources being situated east of the outfalls and keeping to the southern side of the main channel for most stages of the tide.
    - High river flows also creates a significant density gradient where the surface waters are less dense than the deeper water. River water is less dense than sea water as it contains very little salt. This causes the thermal discharge from Dublin Bay Power and Waste to Energy to sink even though it's warmer than the ambient water.
    - During periods of low flows there is less of a pronounced eastward flow in the surface waters in Dublin. This results in the thermal plumes from all sources moving eastwards and westwards with the stages of the tide. It also covers more of the main channel.
- Wind also has a significant impact on the location of the thermal plumes. The strong easterly wind that occurred on the 9th of April 2019 resulted in thermal plume from Poolbeg CCGT being located westward of the outfall for more stages of the tide than under normal conditions
- The thermal plume from Poolbeg CCGT is mainly a surface phenomenon because it is mixed with the fresh water discharge from Ringsend Waste Water Treatment Plant before it enters Dublin Port.
- For all model scenarios the maximum cross sectional area occupied by the thermal discharges occurs at the location of the combined outfall of Dublin Bay Power and the Waste to Energy facility.
- The maximum predicted cross sectional area of the thermal plume for all stages of the tide is less than 25% with one exception. At low water spring tide under dry weather conditions the model estimates that the cross sectional area occupied by the thermal discharge at the location of the combined outfall of Dublin Bay Power and Waste to Energy facility will be 26% if the future proposed discharge from Ringsend Waste Water Treatment Plant and the other 3 facilities operating at maximum capacity for a sustained period of time. This only occurs for a short period of time within the tidal cycle. The average cross sectional area over the tidal cycle is 12%. See Appendix G for further detail.
- The maximum cross sectional area occupied by the thermal discharges at Poolbeg CCGT and Ringsend Waste Water Treatment Plant outfall is 10%.

A. Appendix A - Results of 12th of August 2016

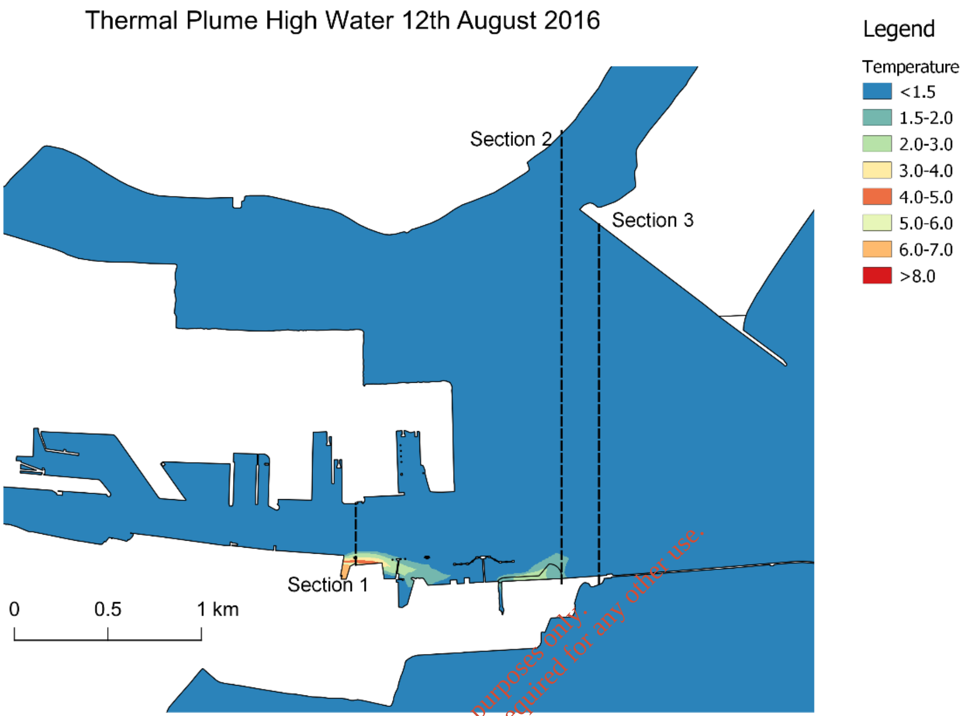

Figure A.1 Surface Water Thermal Plume at High Water

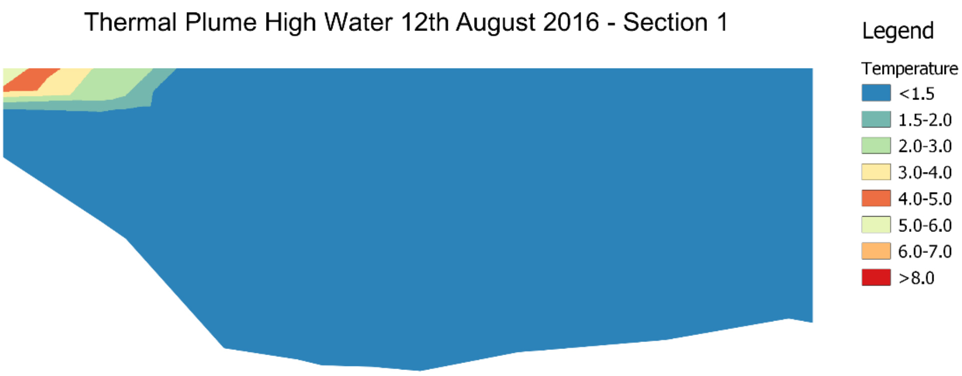

Figure A.2 Section 1 - Thermal Plume at High Water

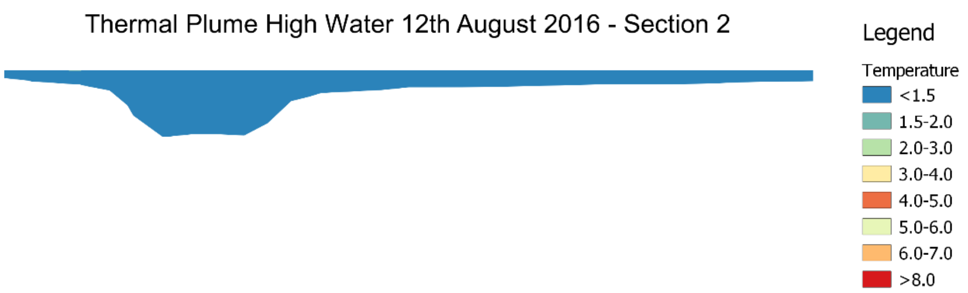

Figure A.3 Section 2 - Thermal Plume at High Water

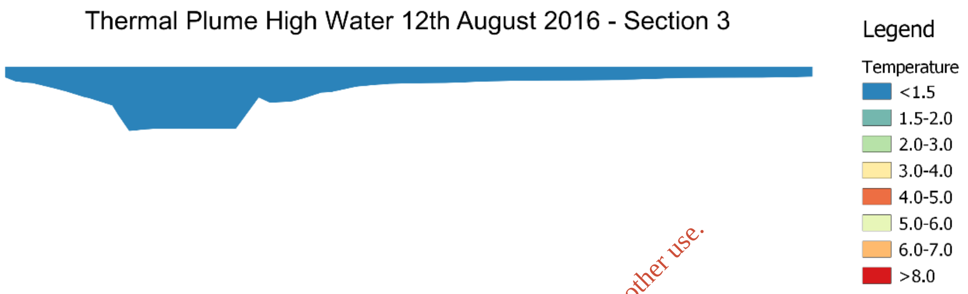

Figure A.4 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	3
2	0
3	0

Table A.1 Thermal Plume Percentage Cross Section

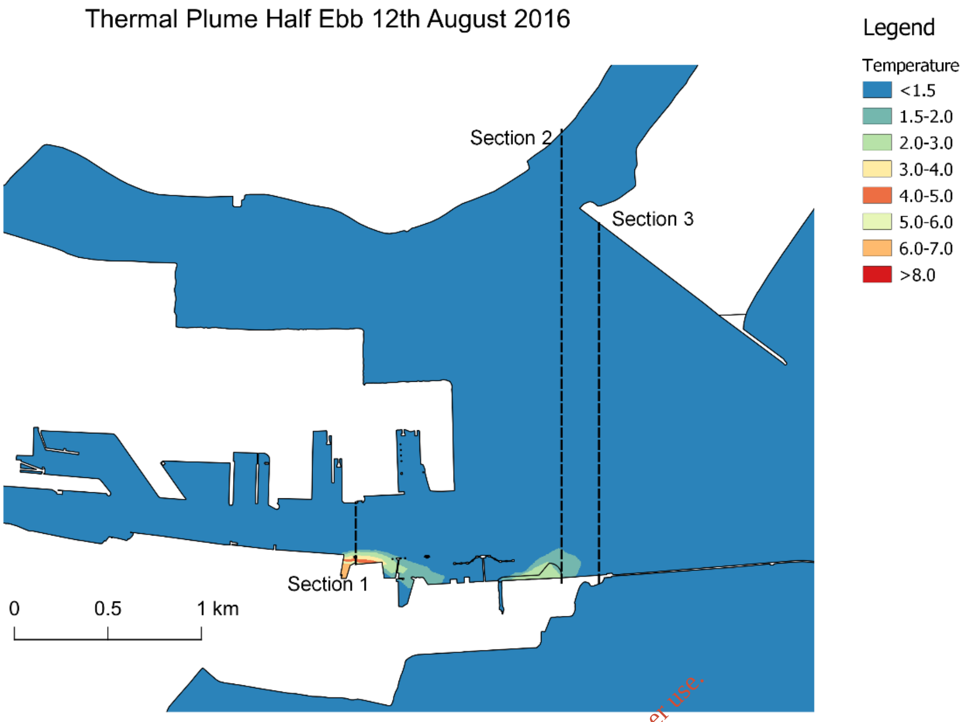

Figure A.5 Surface Water Thermal Plume at Half Ebb

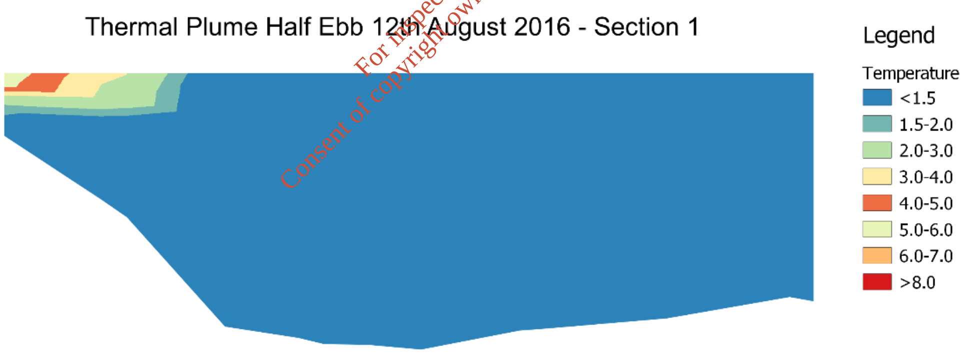

Figure A.6 Section 1 - Thermal Plume at Half Ebb

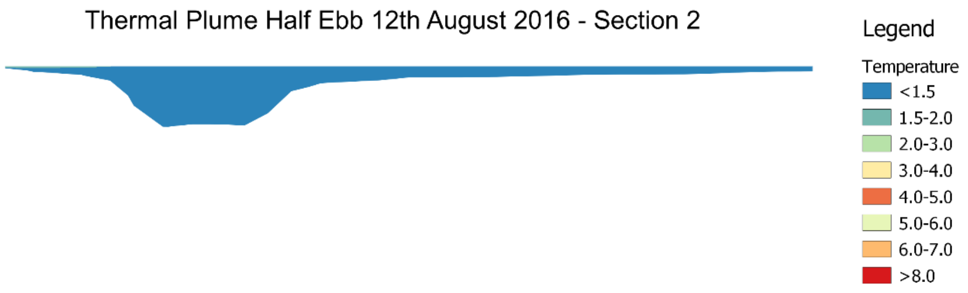

Figure A.7 Section 2 - Thermal Plume at Half Ebb

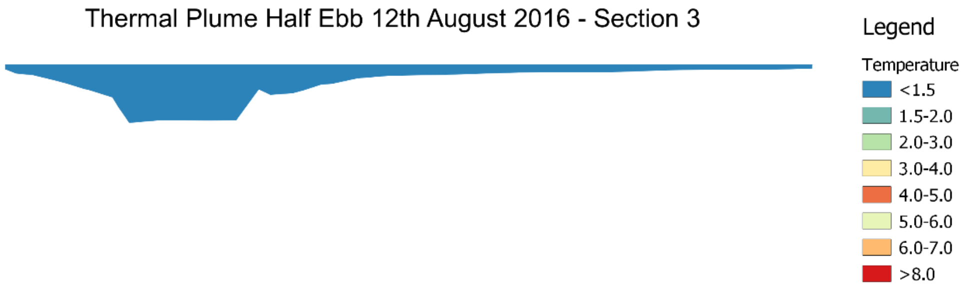

Figure A.8 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	4
2	1
3	0

Table A.2 Thermal Plume Percentage Cross Section

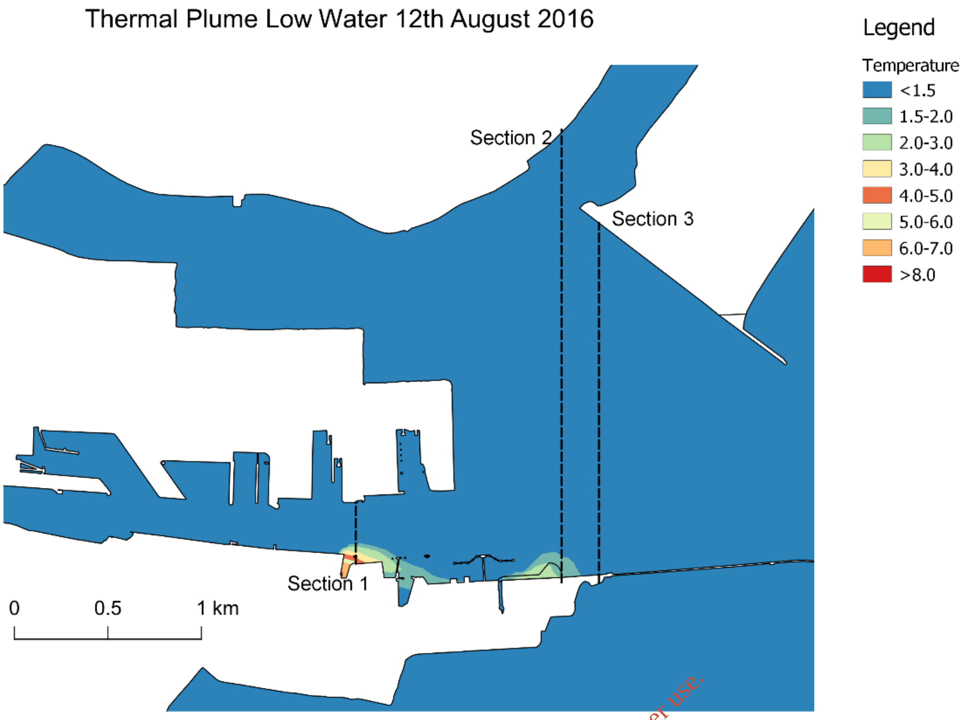

Figure A.9 Surface Water Thermal Plume at Low Water

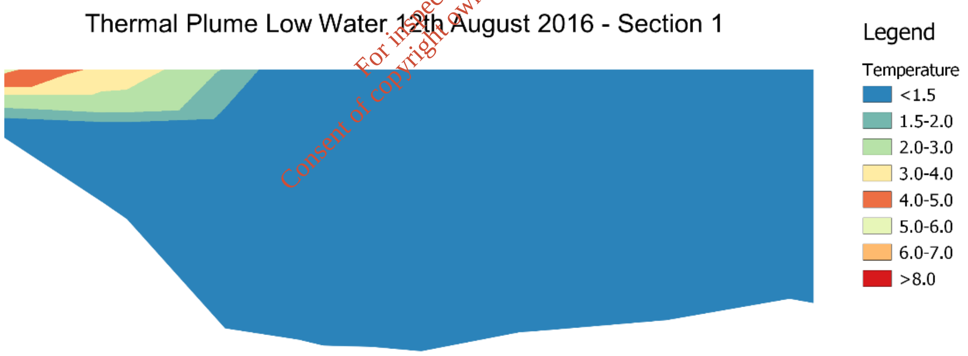

Figure A.10 Section 1 - Thermal Plume at Low Water

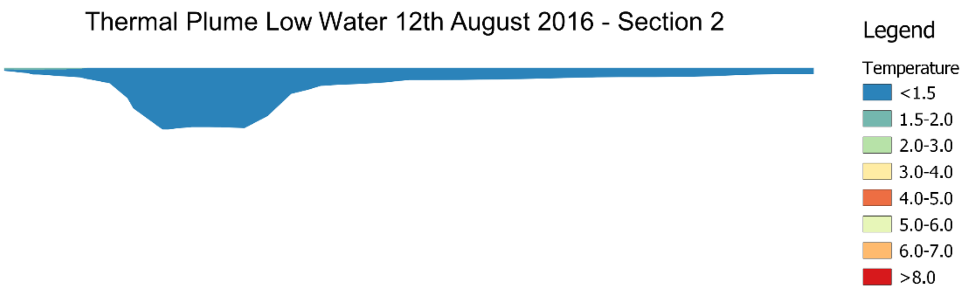

Figure A.11 Section 2 - Thermal Plume at Low Water

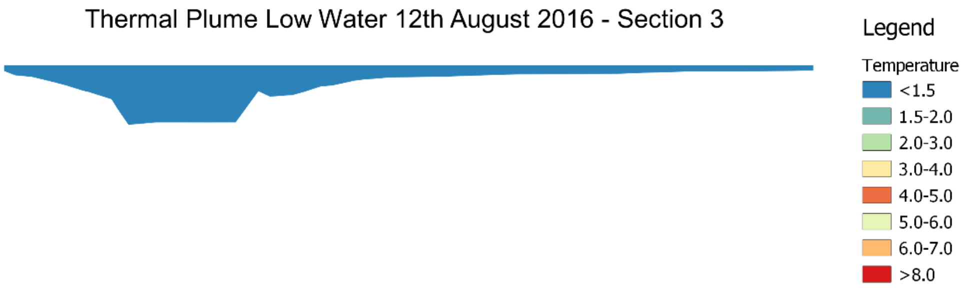

Figure A.12 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	6
2	1
3	0

Table A.3 Thermal Plume Percentage Cross Section

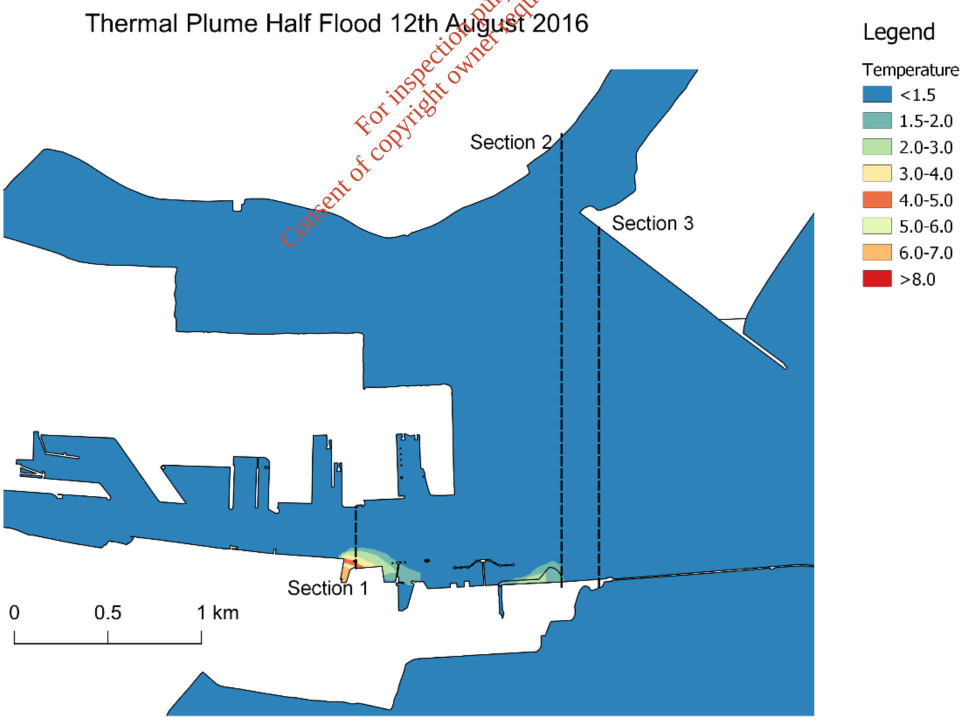

Figure A.13 Surface Water Thermal Plume at Half Flood

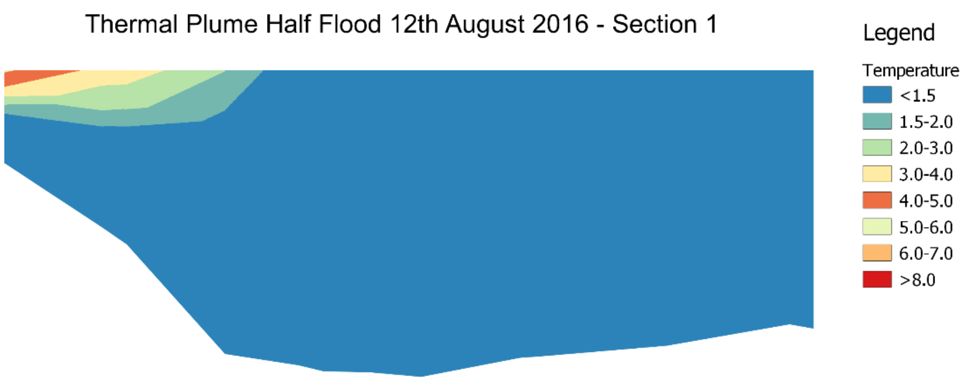

Figure A.14 Section 1 - Thermal Plume at Half Flood

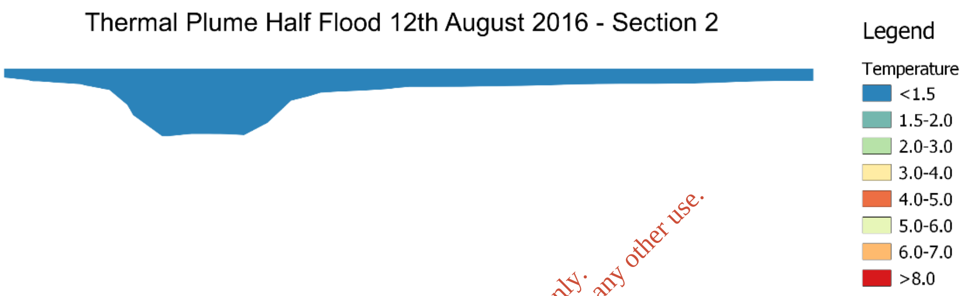

Figure A.15 Section 2 - Thermal Plume at Half Flood

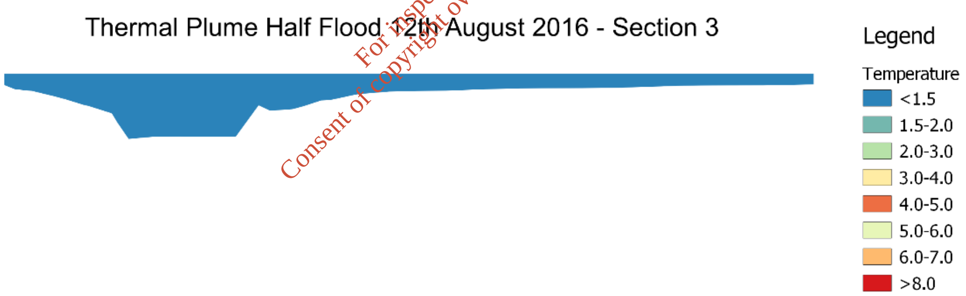

Figure A.16 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	6
2	0
3	0

Table A.4 Thermal Plume Percentage Cross Section

B. Appendix B - Results of 20th of April 2018

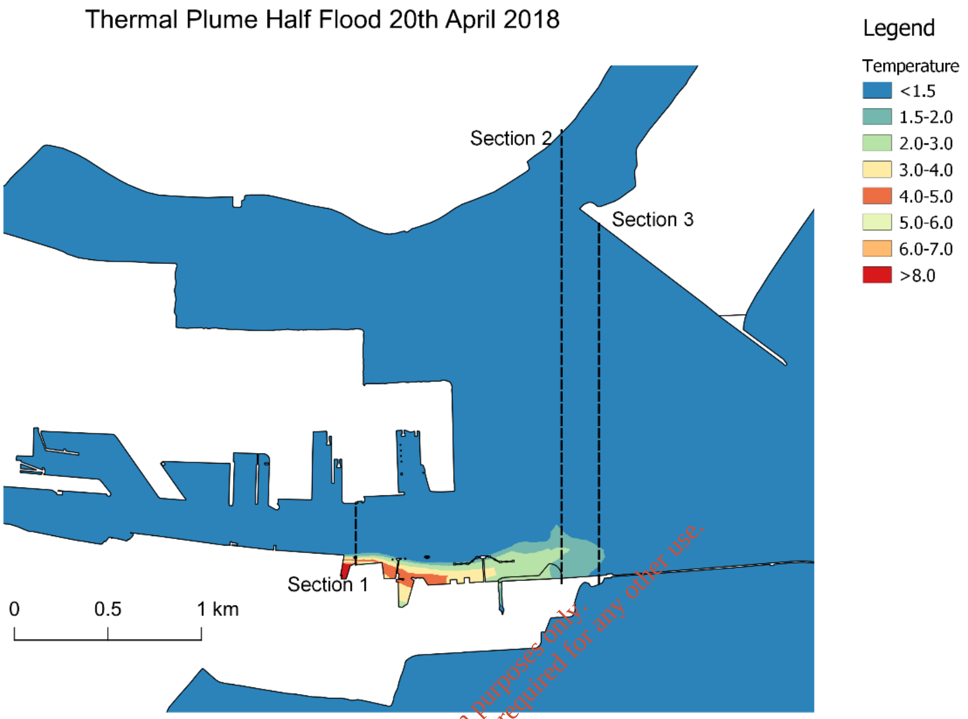

Figure B.1 Surface Water Thermal Plume at Half Flood

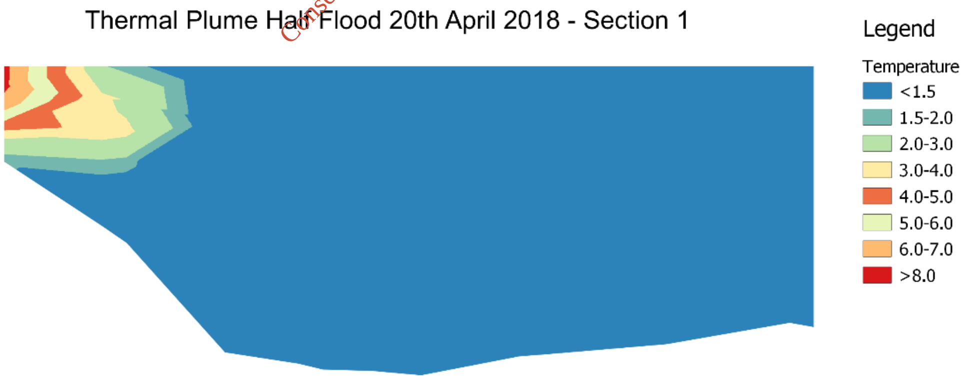

Figure B.2 Section 1 - Thermal Plume at Half Flood

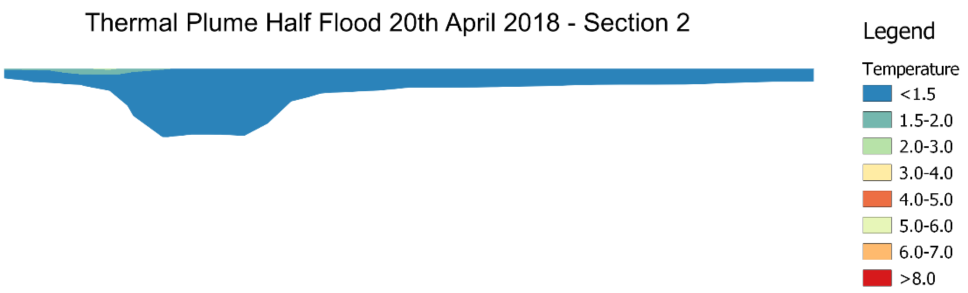

Figure B.3 Section 2 - Thermal Plume at Half Flood

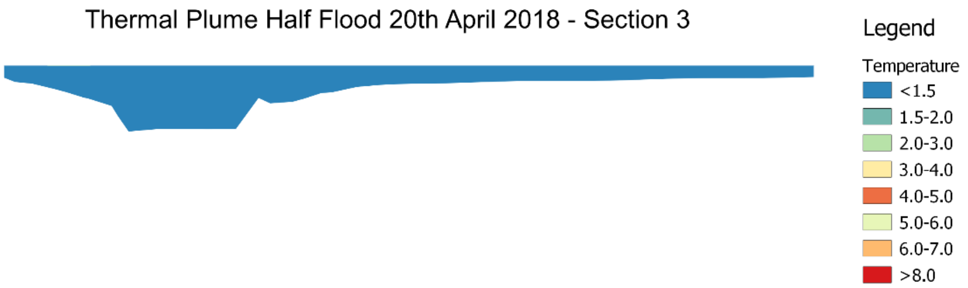

Figure B.4 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	8
2	2
3	0

Table B.1 Thermal Plume Percentage Cross Section

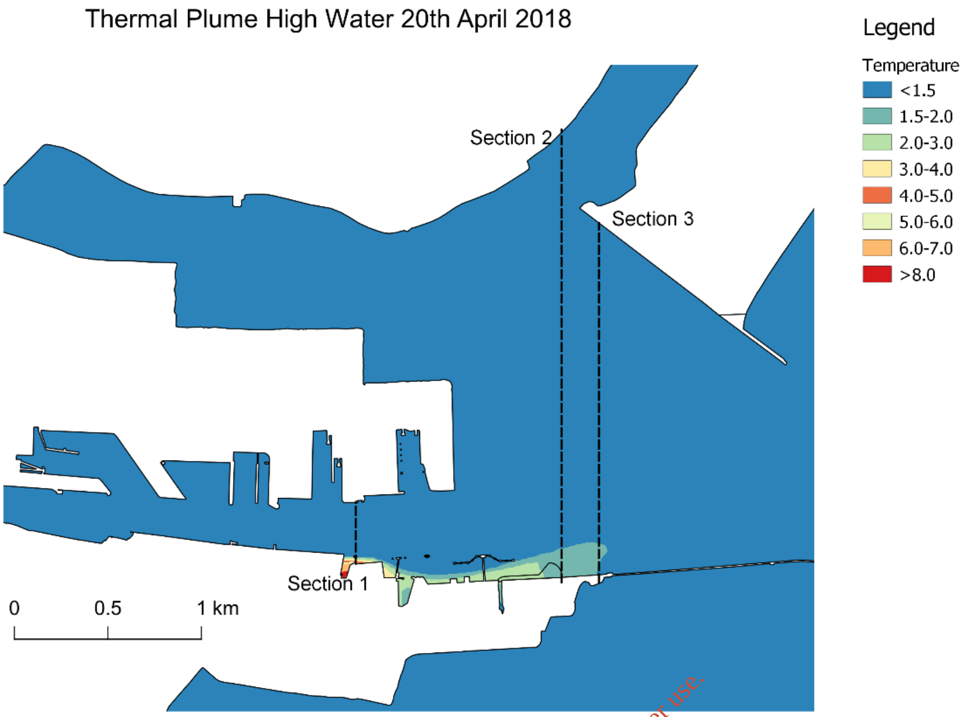

Figure B.5 Surface Water Thermal Plume at High Water

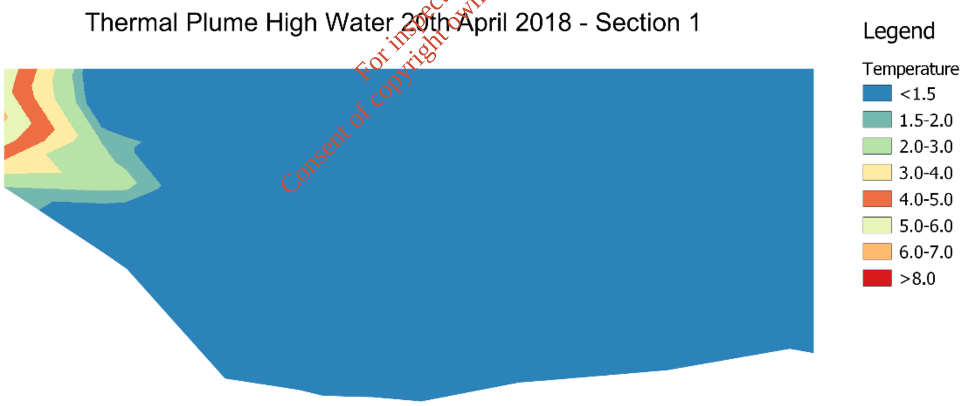

Figure B.6 Section 1 - Thermal Plume at High Water

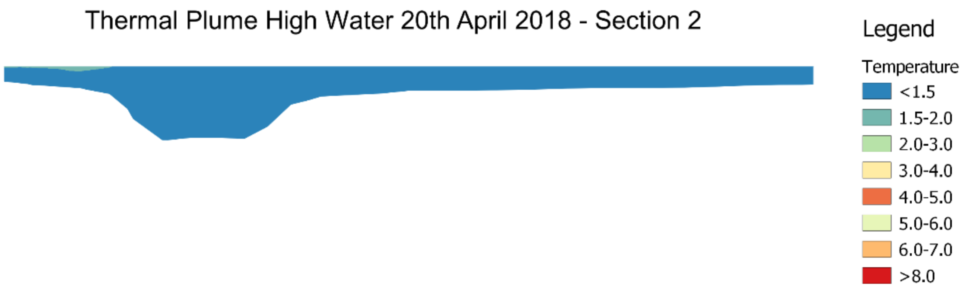

Figure B.7 Section 2 - Thermal Plume at High Water

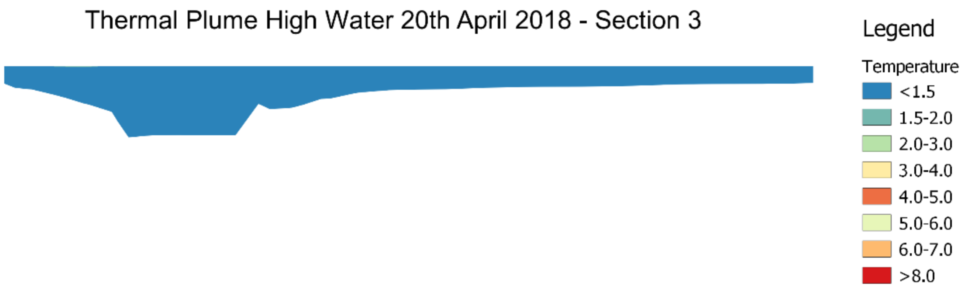

Figure B.8 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	7
2	1
3	0

Table B.2 Thermal Plume Percentage Cross Section

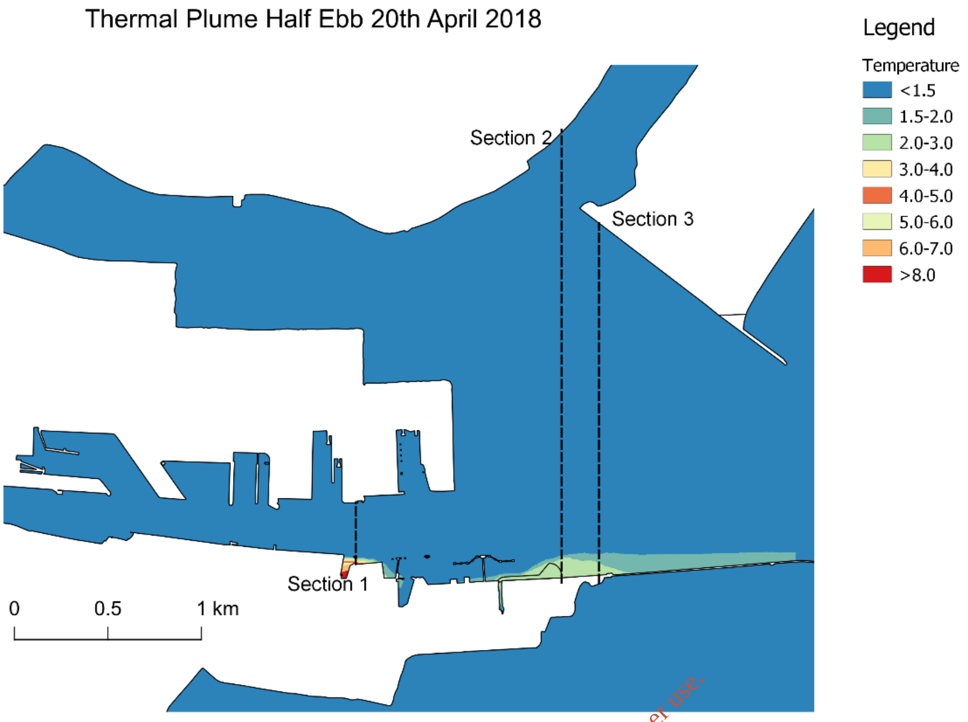

Figure B.9 Surface Water Thermal Plume at Half Ebb

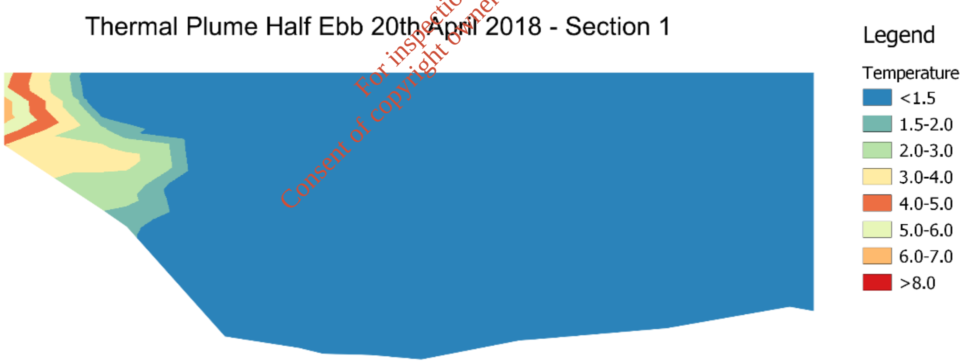

Figure B.10 Section 1 - Thermal Plume at Half Ebb

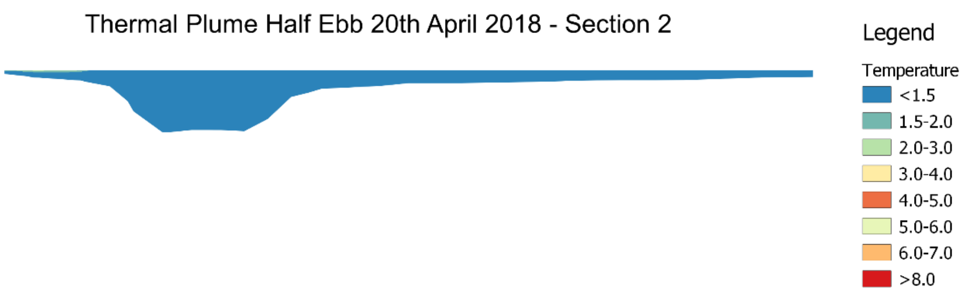

Figure B.11 Section 2 - Thermal Plume at Half Ebb

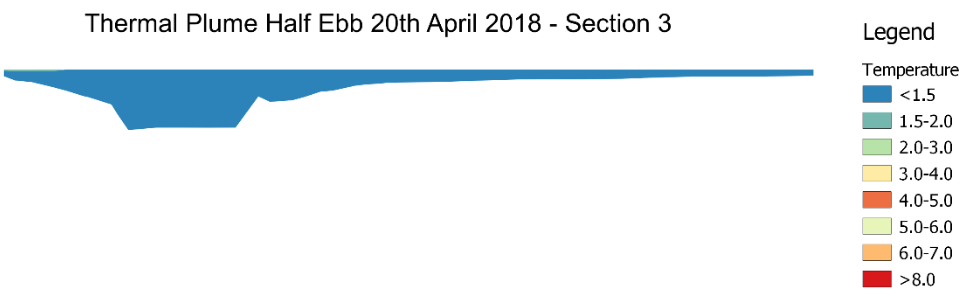

Figure B.12 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	9
2	1
3	1

Table B.3 Thermal Plume Percentage Cross Section

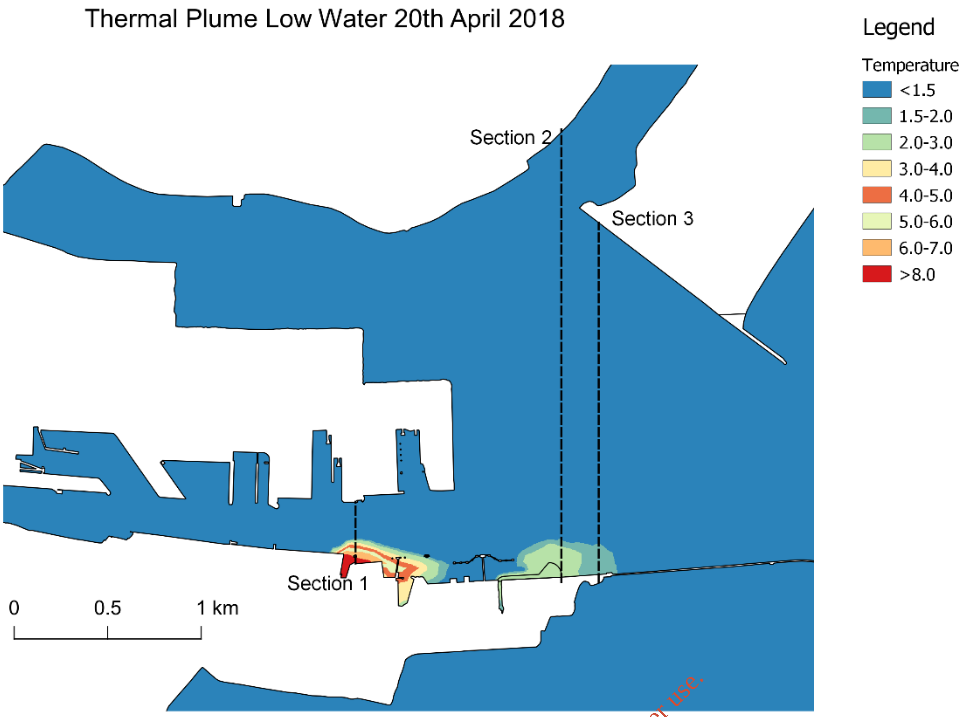

Figure B.13 Surface Water Thermal Plume at Low Water

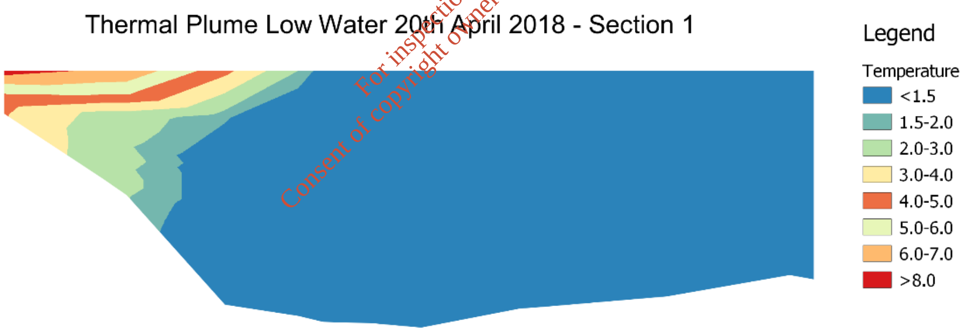

Figure B.14 Section 1 - Thermal Plume at Low Water

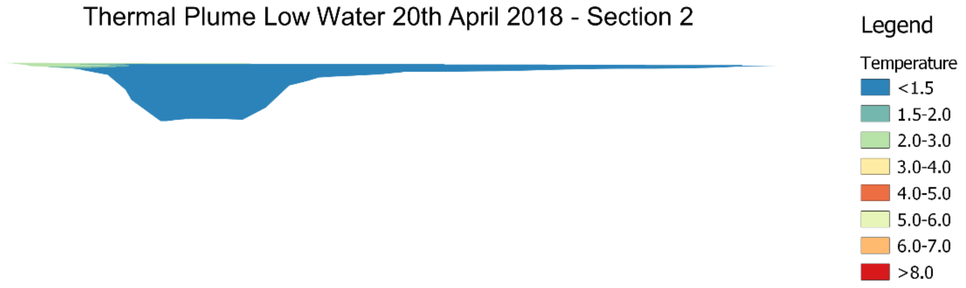

Figure B.15 Section 2 - Thermal Plume at Low Water

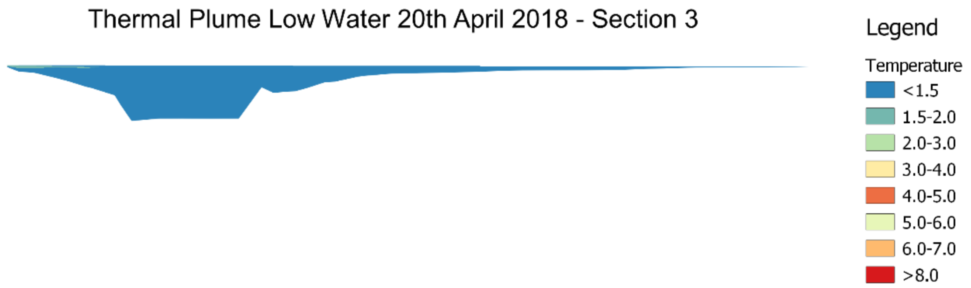

Figure B.16 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	14
2	2
3	1

Table B.4 Thermal Plume Percentage Cross Section

C. Appendix C - Results of 24th of April 2018

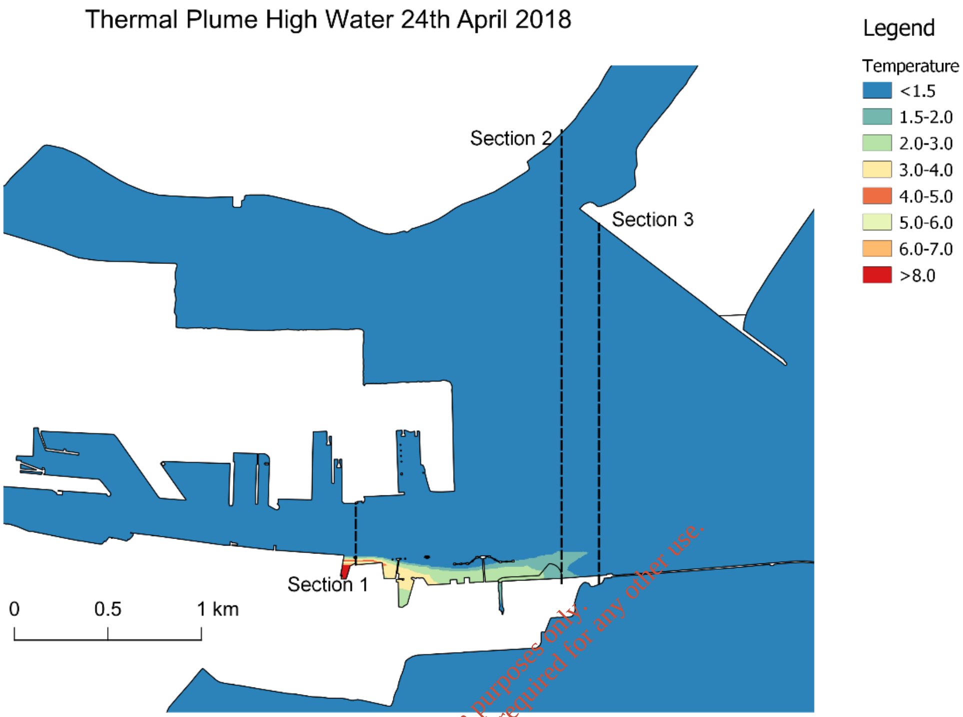

Figure C.1 Surface Water Thermal Plume at High Water

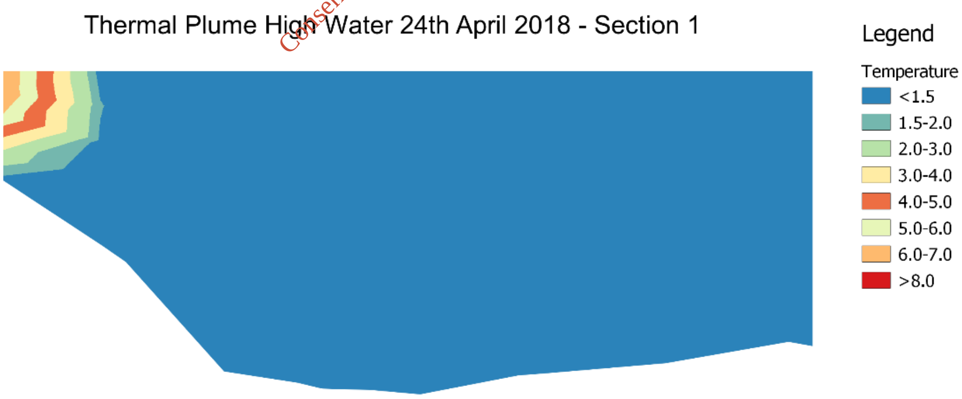

Figure C.2 Section 1 - Thermal Plume at High Water

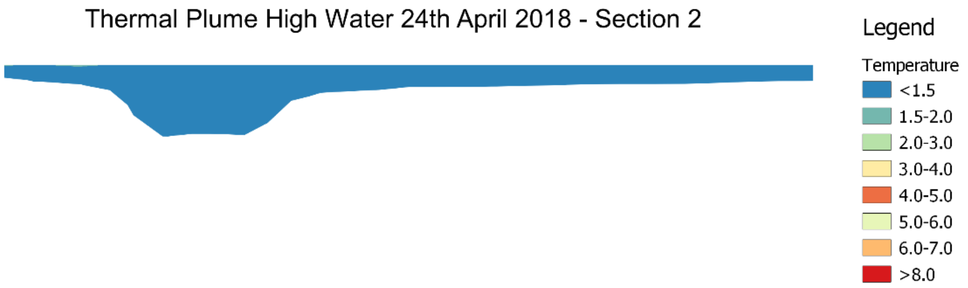

Figure C.3 Section 2 - Thermal Plume at High Water

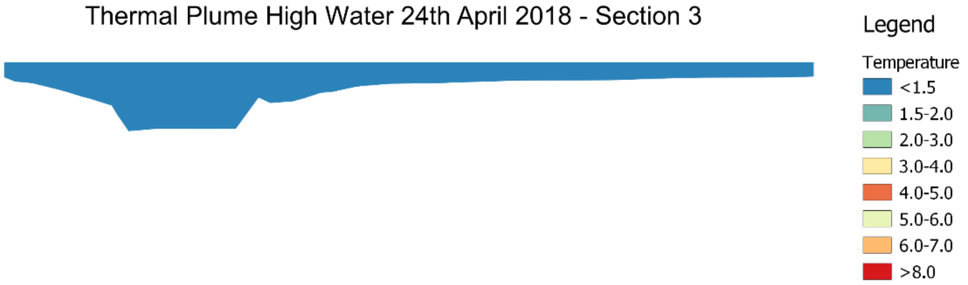

Figure C.4 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	4
2	0
3	0

Table C.1 Thermal Plume Percentage Cross Section

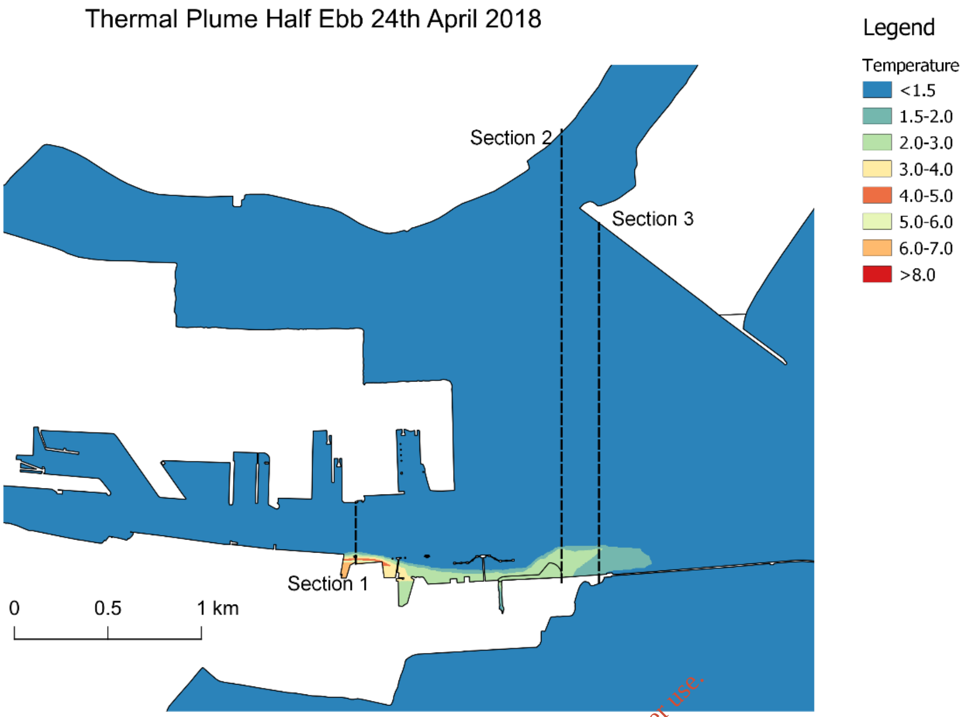

Figure C.5 Surface Water Thermal Plume at Half Ebb

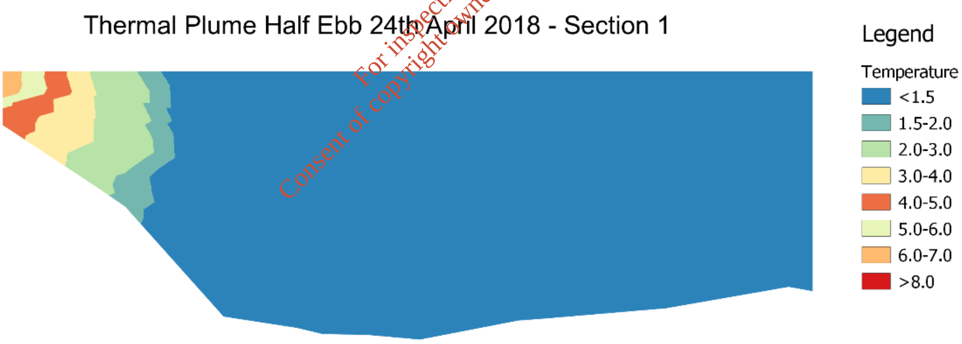

Figure C.6 Section 1 - Thermal Plume at Half Ebb

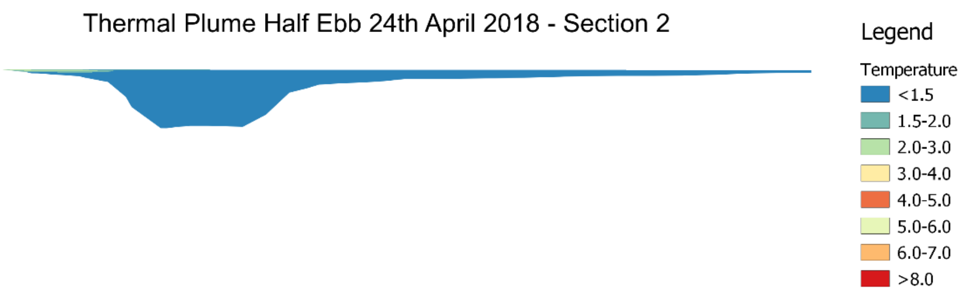

Figure C.7 Section 2 - Thermal Plume at Half Ebb

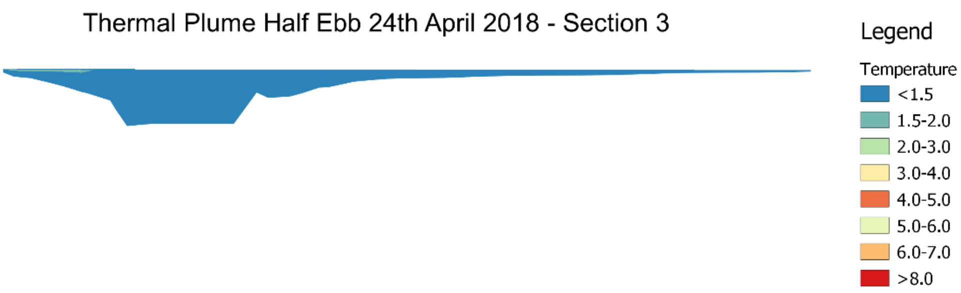

Figure C.8 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	9
2	2
3	1

Table C.2 Thermal Plume Percentage Cross Section

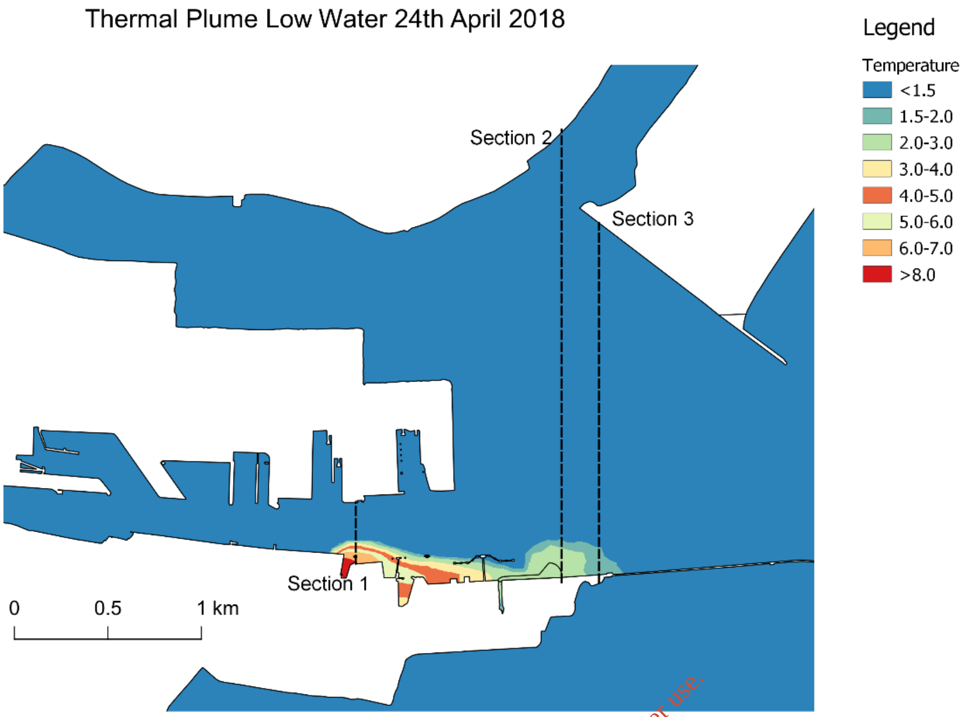

Figure C.9 Surface Water Thermal Plume at Low Water

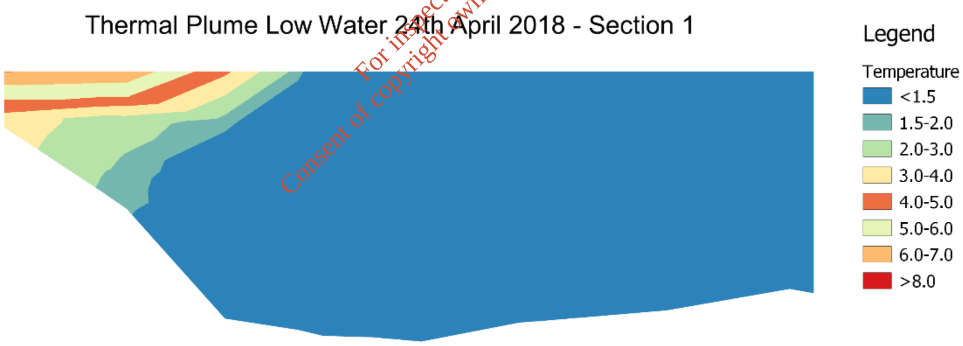

Figure C.10 Section 1 - Thermal Plume at Low Water

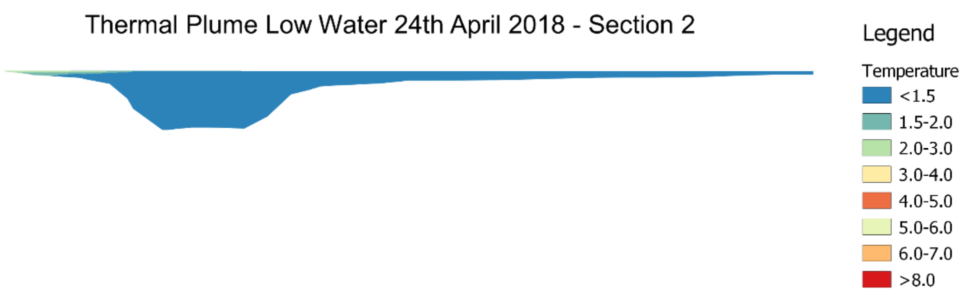

Figure C.11 Section 2 - Thermal Plume at Low Water

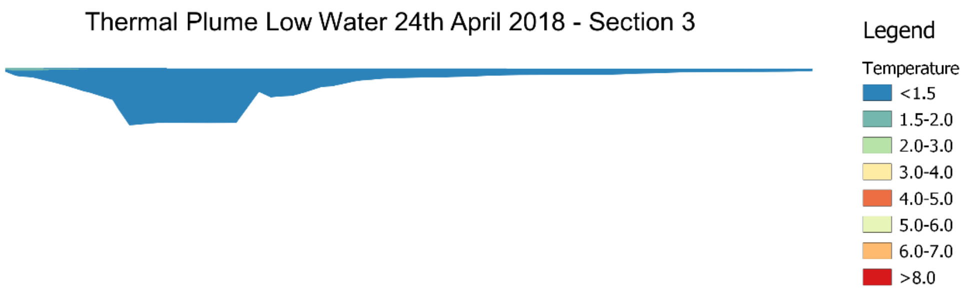

Figure C.12 Section 3 - Thermal Plume at Low Water

Section No	**% Cross-section**
1	13
2	2
3	1

Table C.3 Thermal Plume Percentage Cross Section

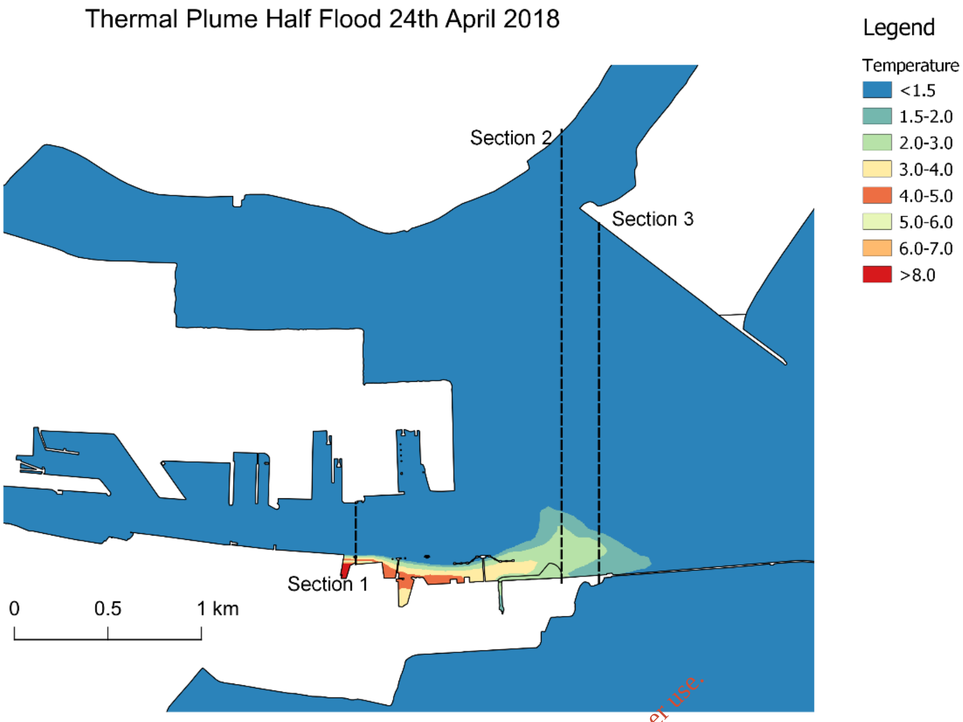

Figure C.13 Surface Water Thermal Plume at Half Flood

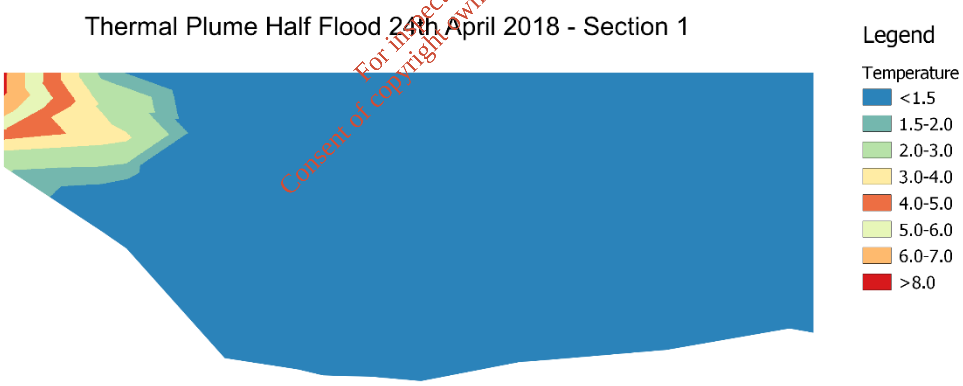

Figure C.14 Section 1 - Thermal Plume at Half Flood

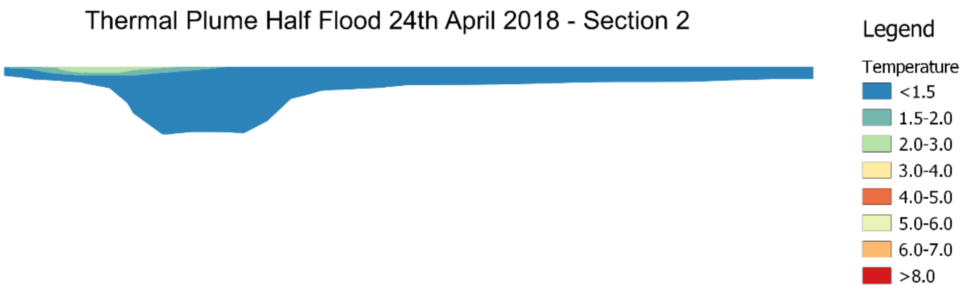

Figure C.15 Section 2 - Thermal Plume at Half Flood

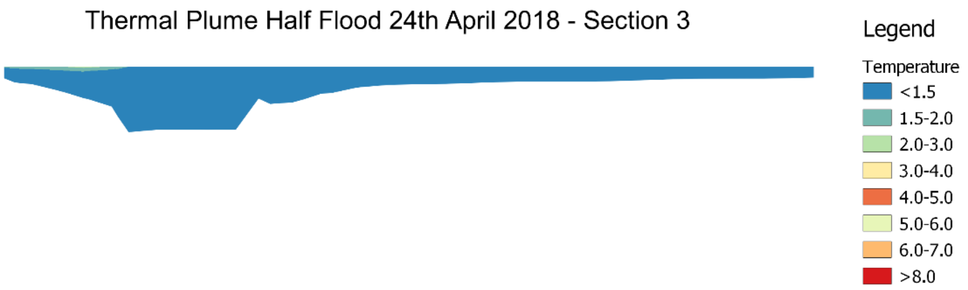

Figure C.16 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	8
2	6
3	2

Table C.4 Thermal Plume Percentage Cross Section

D. Appendix D - Results of 9th of April 2019

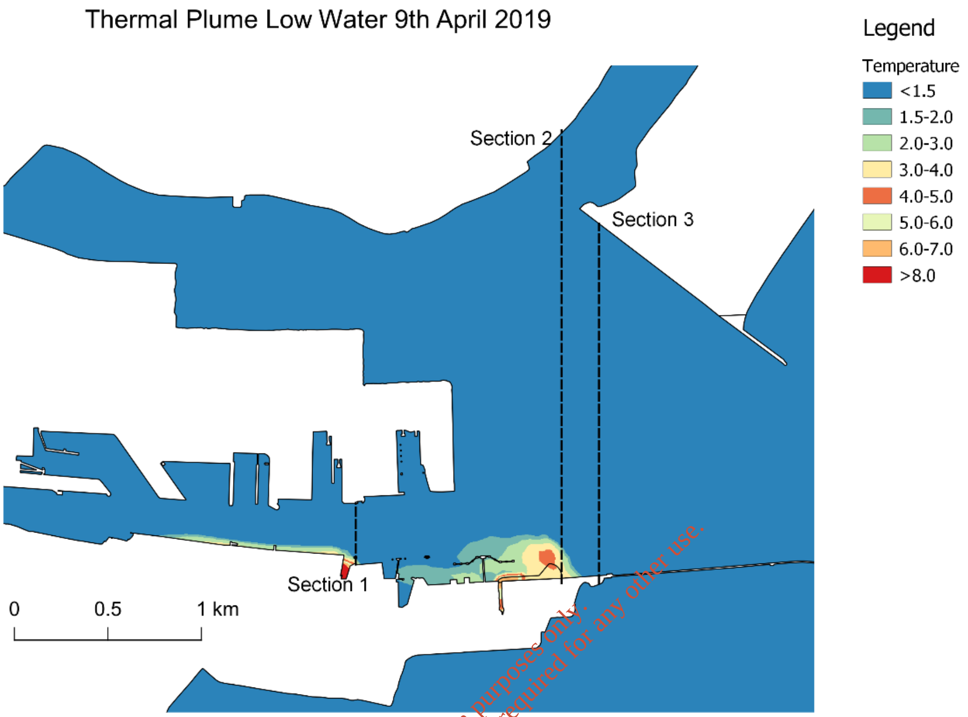

Figure D.1 Surface Water Thermal Plume at Low Water

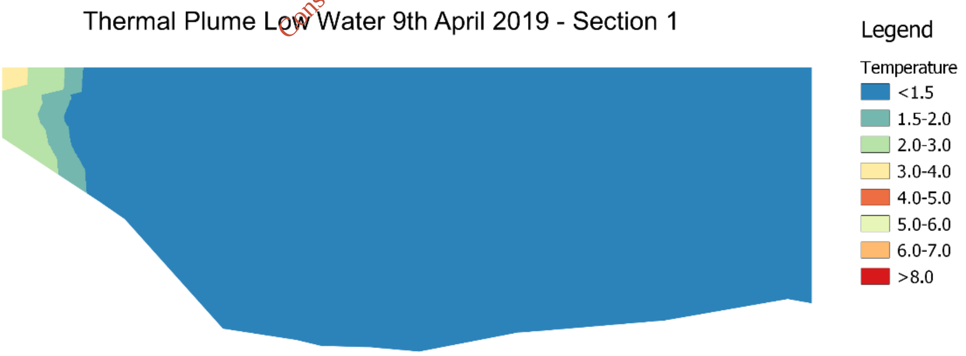

Figure D.2 Section 1 - Thermal Plume at Low Water

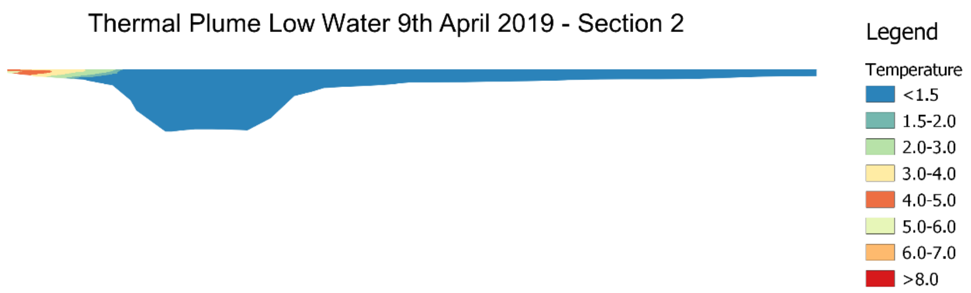

Figure D.3 Section 2 - Thermal Plume at Low Water

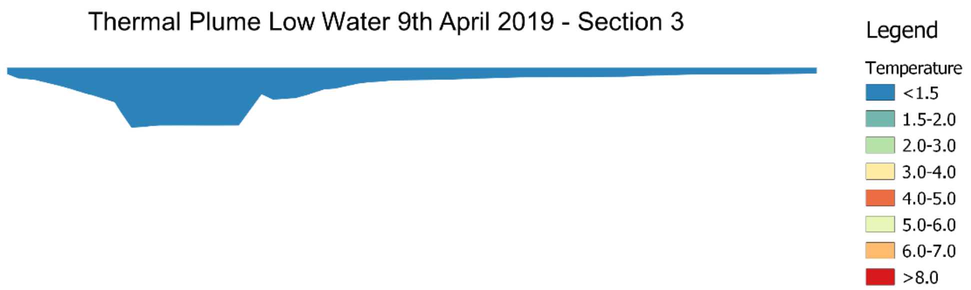

Figure D.4 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	4
2	5
3	0

Table D.1 Thermal Plume Percentage Cross Section

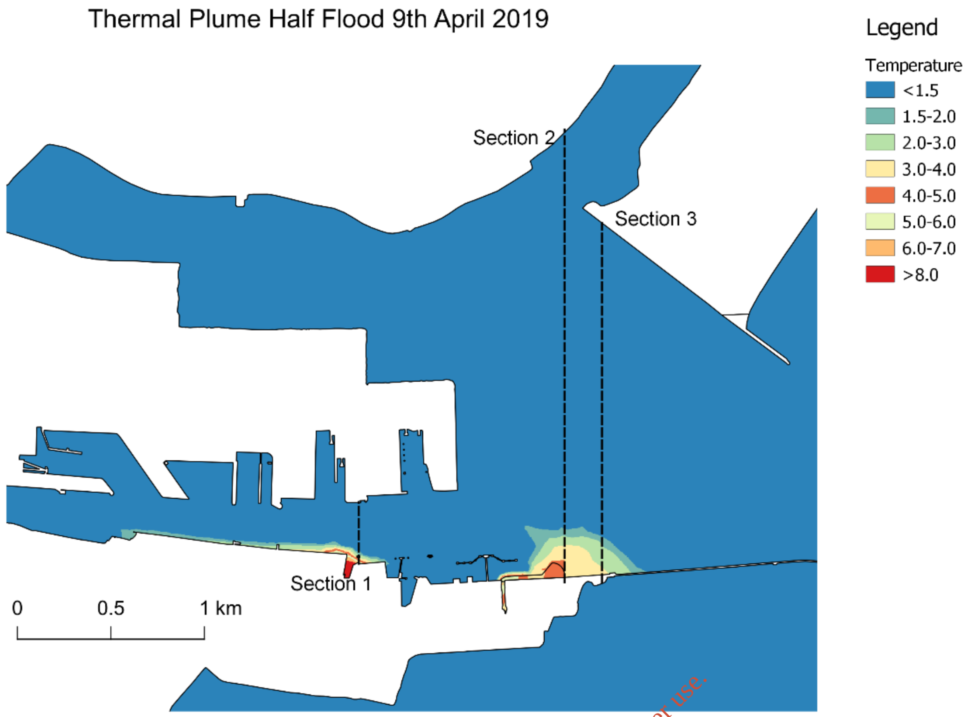

Figure D.5 Surface Water Thermal Plume at Half Flood

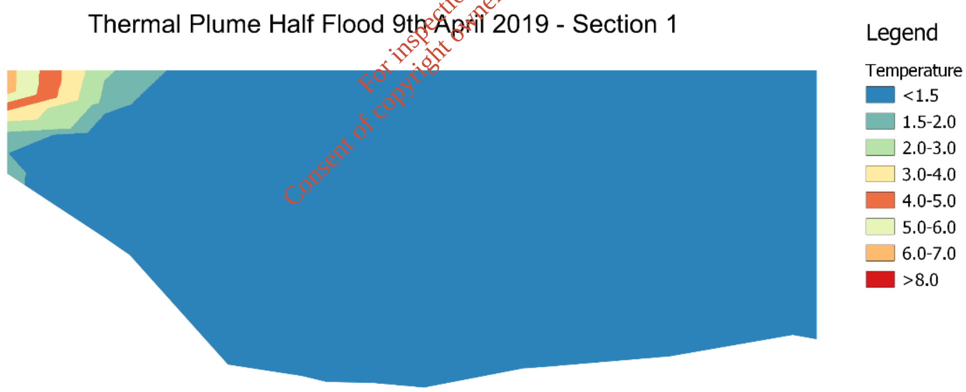

Figure D.6 Section 1 - Thermal Plume at Half Flood

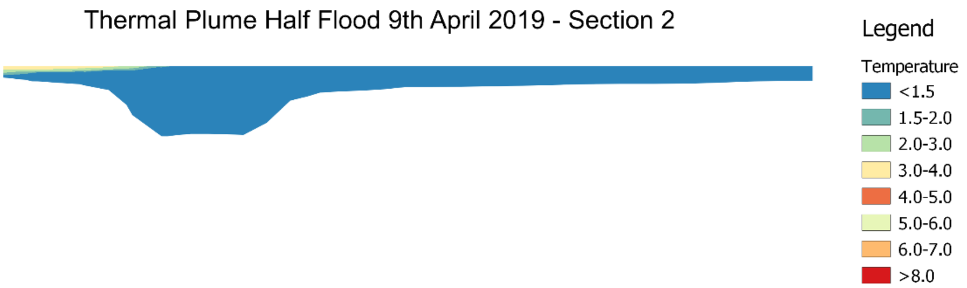

Figure D.7 Section 2 - Thermal Plume at Half Flood

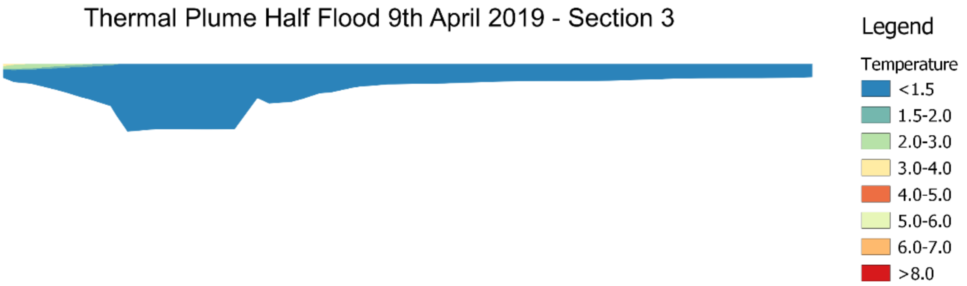

Figure D.8 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	4
2	4
3	2

Table D.2 Thermal Plume Percentage Cross Section

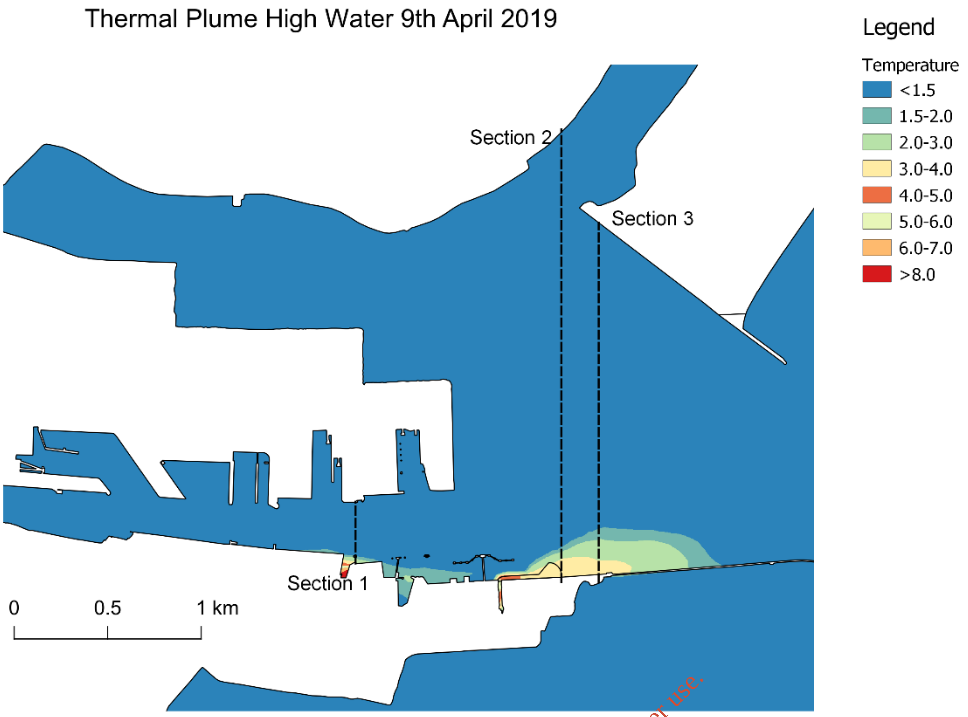

Figure D.9 Surface Water Thermal Plume at High Water

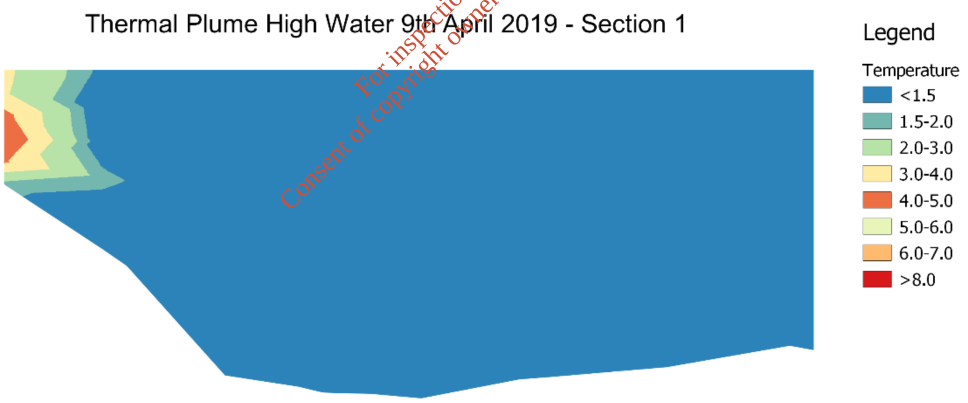

Figure D.10 Section 1 - Thermal Plume at High Water

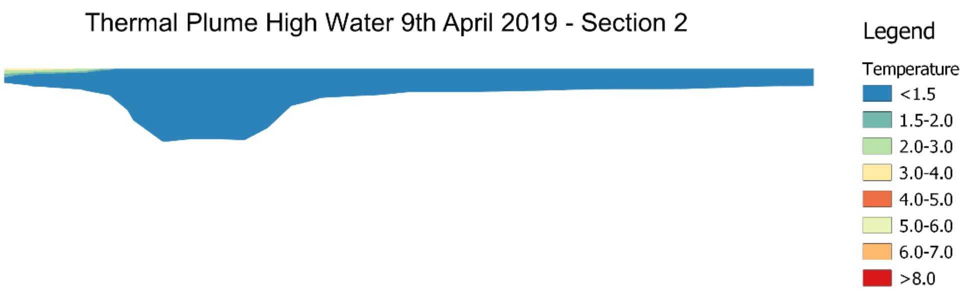

Figure D.11 Section 2 - Thermal Plume at High Water

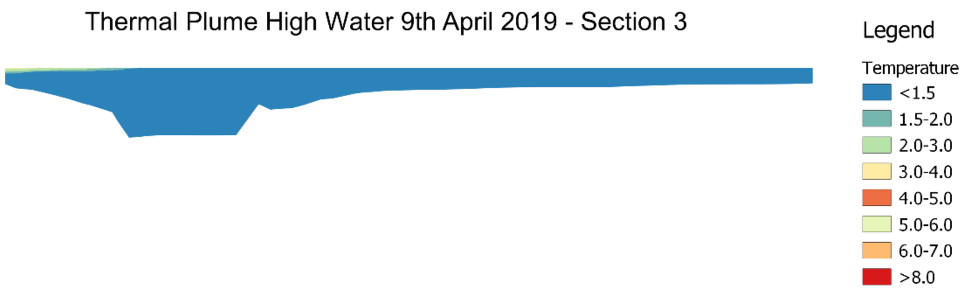

Figure D.12 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	5
2	2
3	2

Table D.3 Thermal Plume Percentage Cross Section

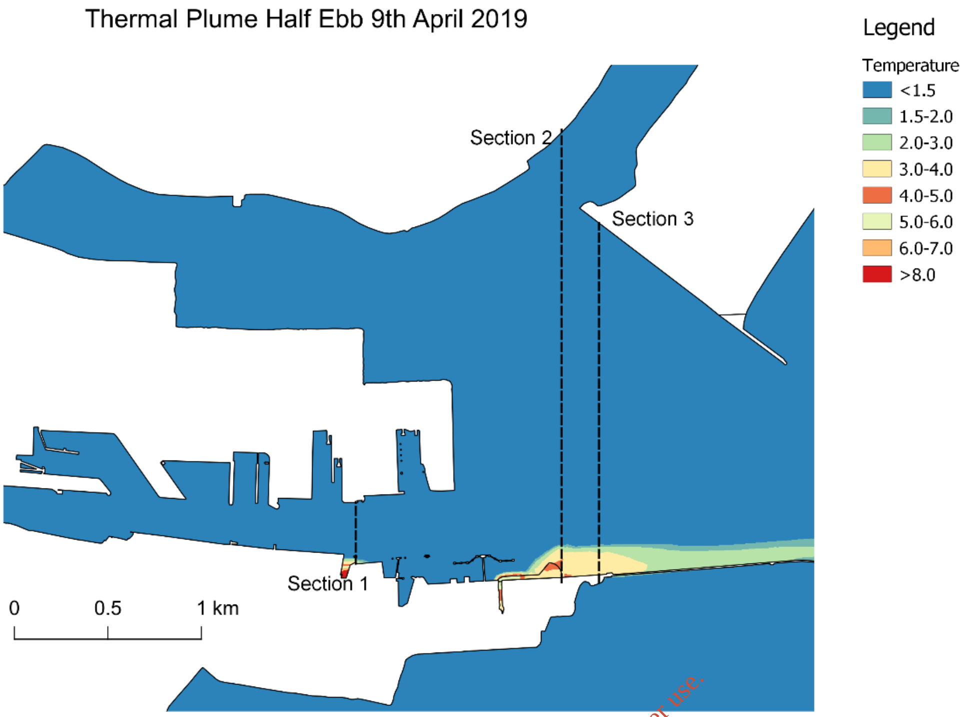

Figure D.13 Surface Water Thermal Plume at Half Ebb

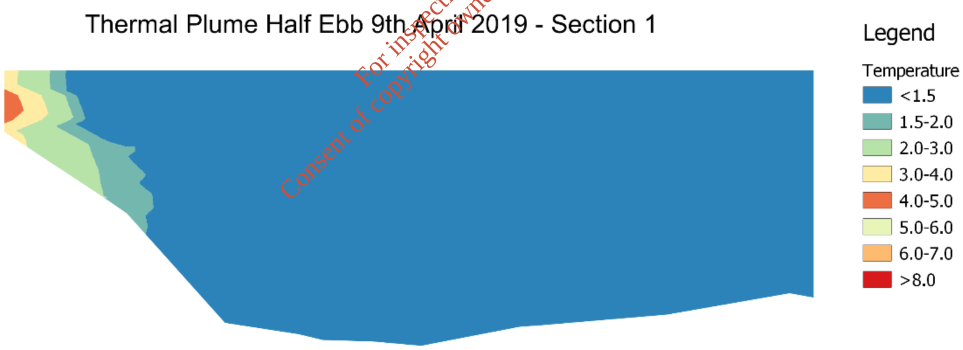

Figure D.14 Section 1 - Thermal Plume at Half Ebb

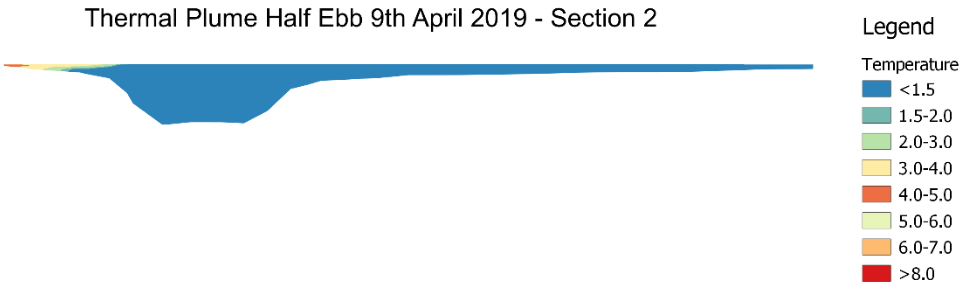

Figure D.15 Section 2 - Thermal Plume at Half Ebb

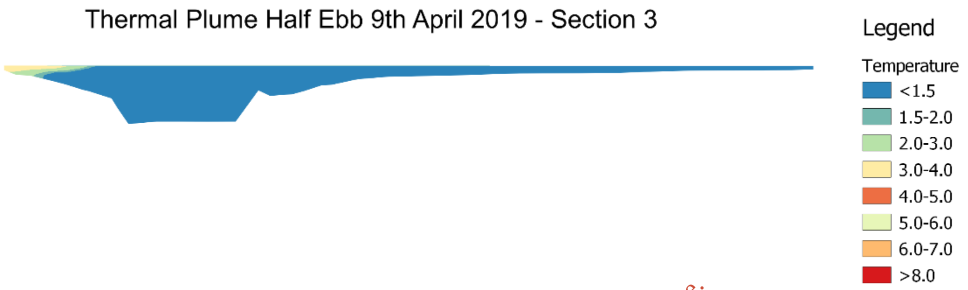

Figure D.16 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	6
2	3
3	4

Table D.4 Thermal Plume Percentage Cross Section

E. Appendix E - Results of All facilities operating at current maximum capacity with dry weather conditions

E.1. Spring Tide

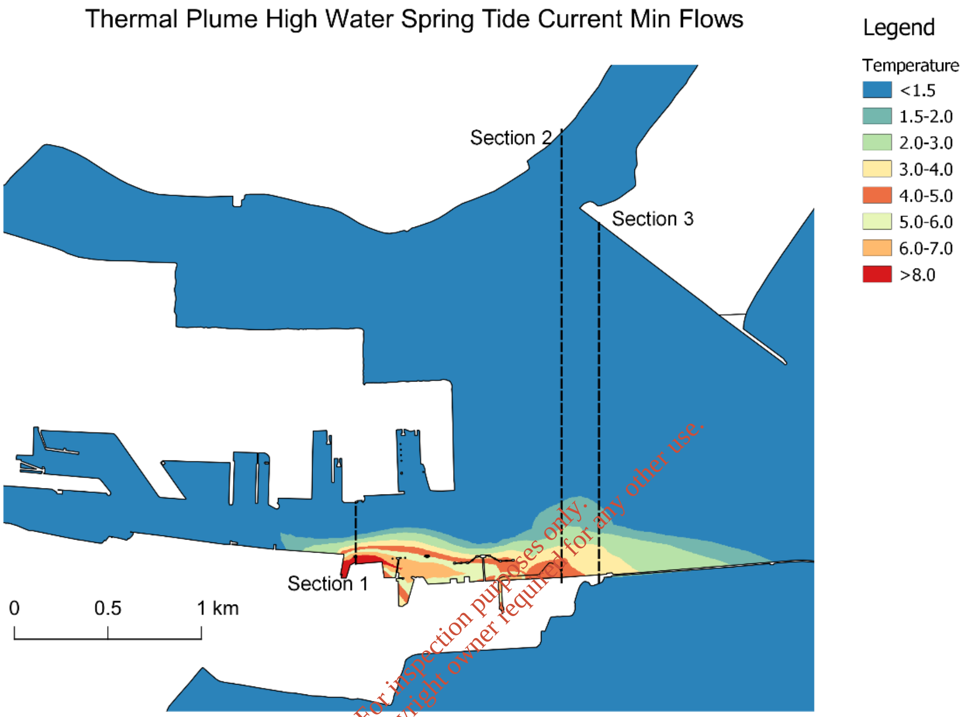

Figure E.1 Surface Water Thermal Plume at High Water

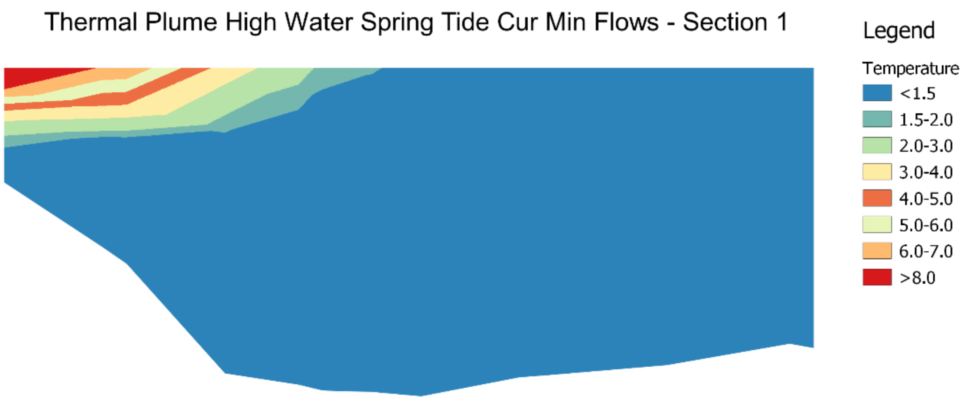

Figure E.2 Section 1 - Thermal Plume at High Water

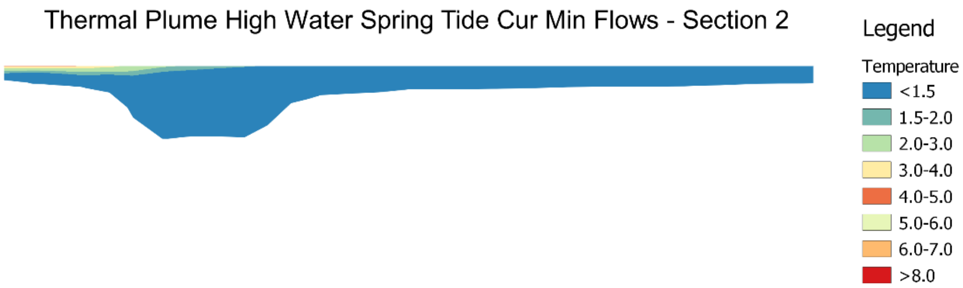

Figure E.3 Section 2 - Thermal Plume at High Water

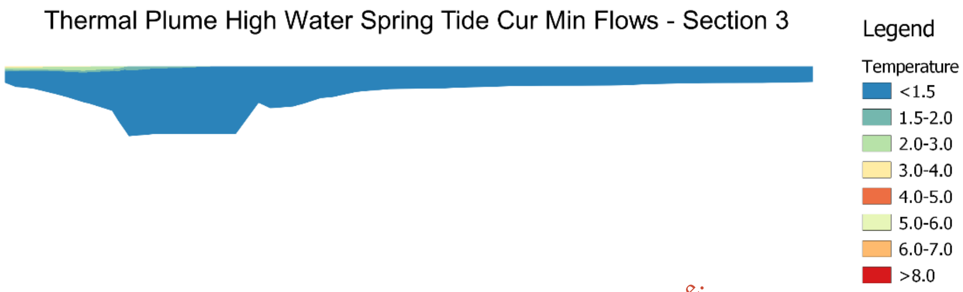

Figure E.4 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	9
2	5
3	3

Table E.1 Thermal Plume Percentage Cross Section

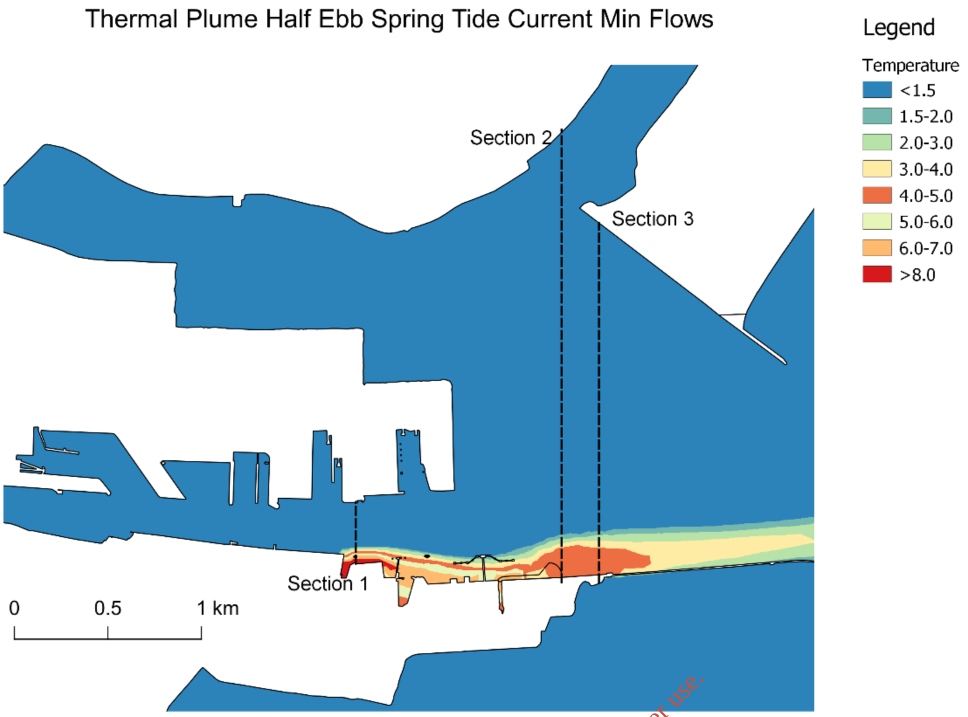

Figure E.5 Surface Water Thermal Plume at Half Ebb

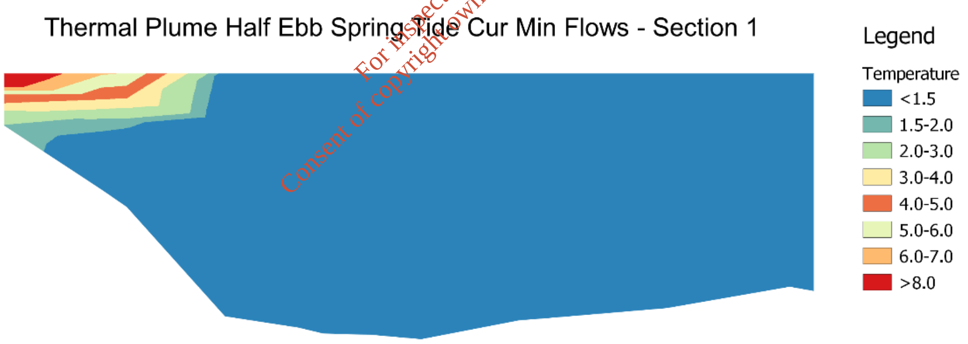

Figure E.6 Section 1 - Thermal Plume at Half Ebb

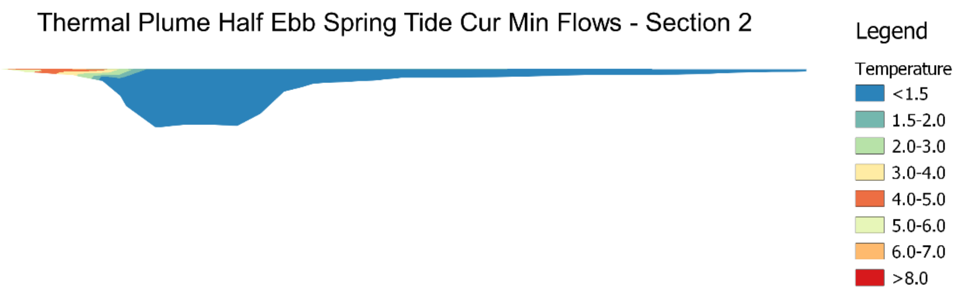

Figure E.7 Section 2 - Thermal Plume at Half Ebb

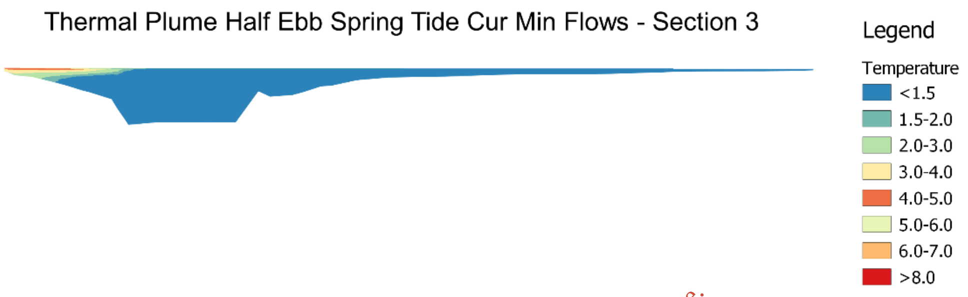

Figure E.8 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	7
2	6
3	7

Table E.2 Thermal Plume Percentage Cross Section

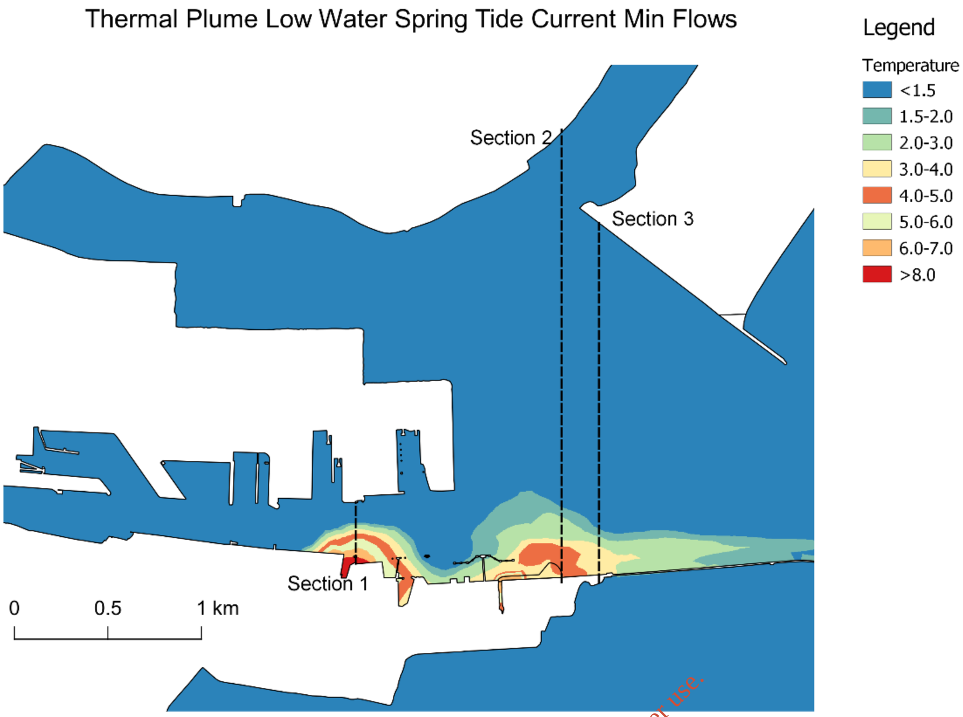

Figure E.9 Surface Water Thermal Plume at Low Water

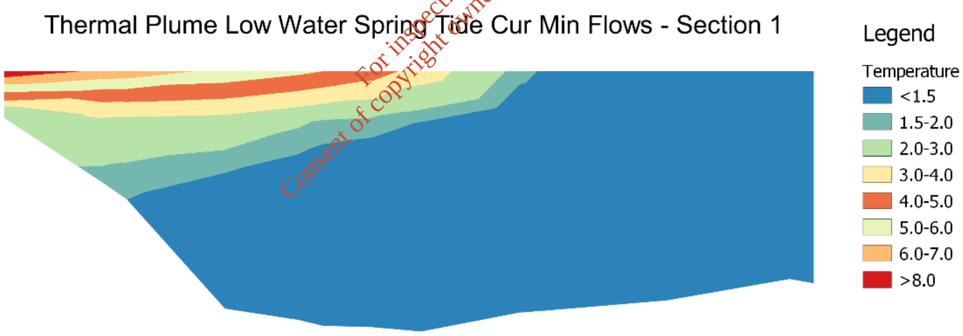

Figure E.10 Section 1 - Thermal Plume at Low Water

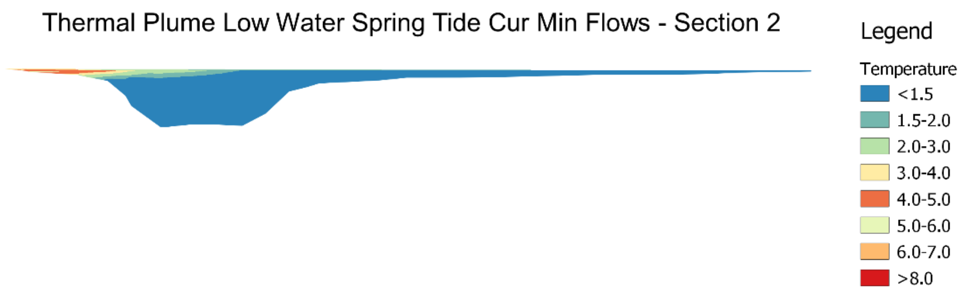

Figure E.11 Section 2 - Thermal Plume at Low Water

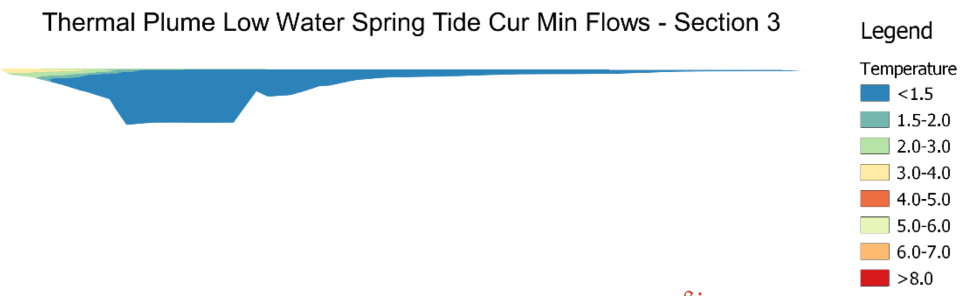

Figure E.12 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	24
2	10
3	6

Table E.3 Thermal Plume Percentage Cross Section

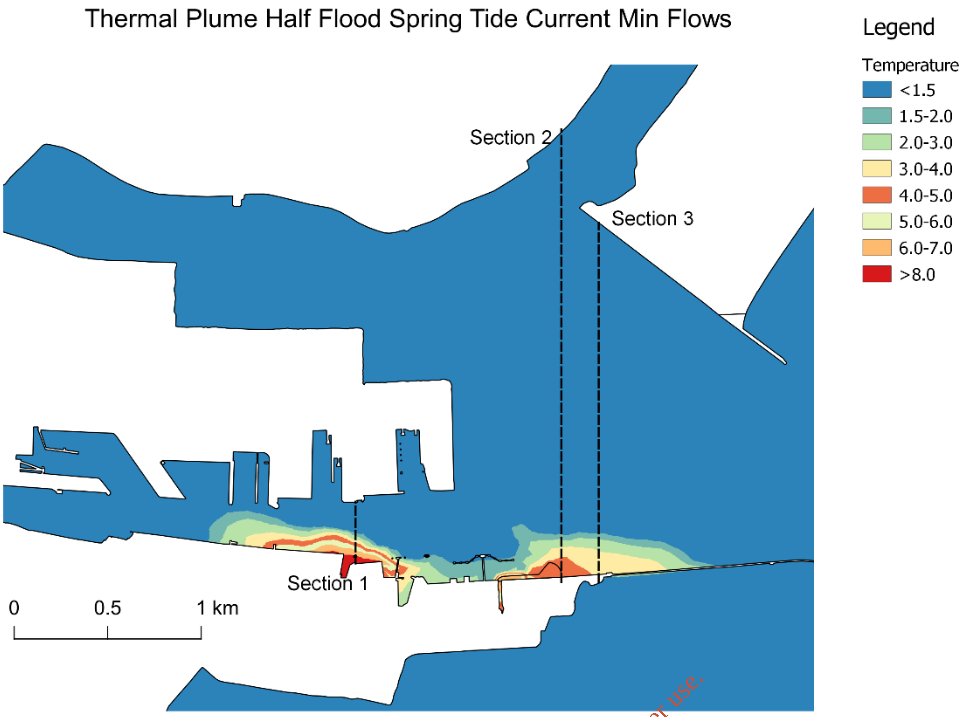

Figure E.13 Surface Water Thermal Plume at Half Flood

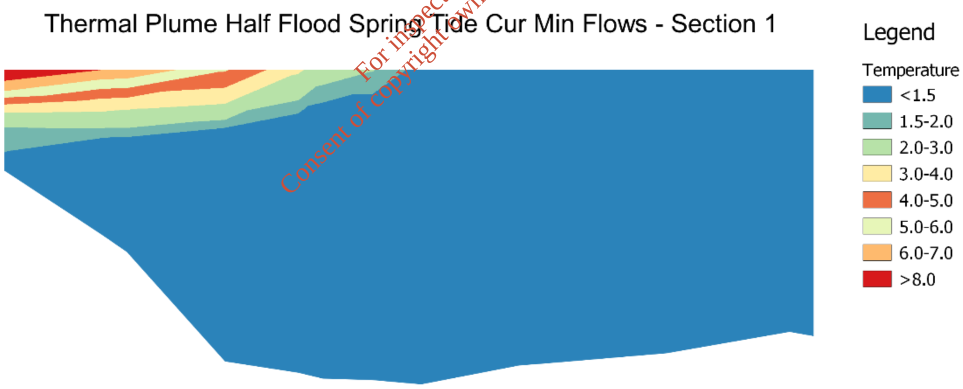

Figure E.14 Section 1 - Thermal Plume at Half Flood

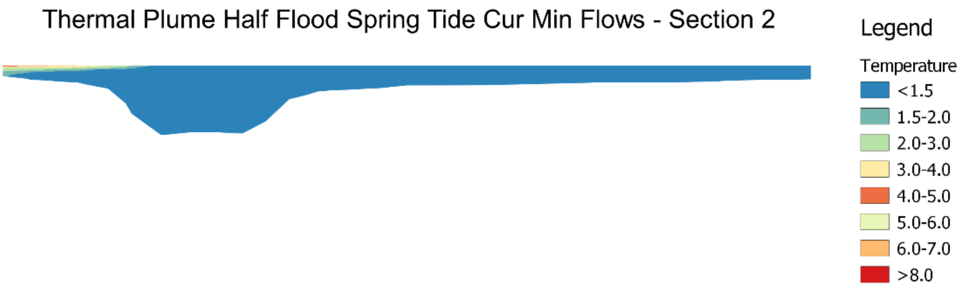

Figure E.15 Section 2 - Thermal Plume at Half Flood

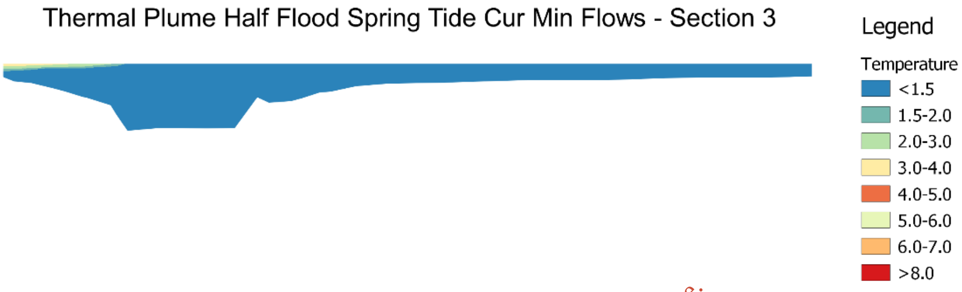

Figure E.16 Section 3 - Thermal Plume at Half Flood

Section No	**% Cross-section**
1	10
2	4
3	2

Table E.4 Thermal Plume Percentage Cross Section

E.2. Neap Tide

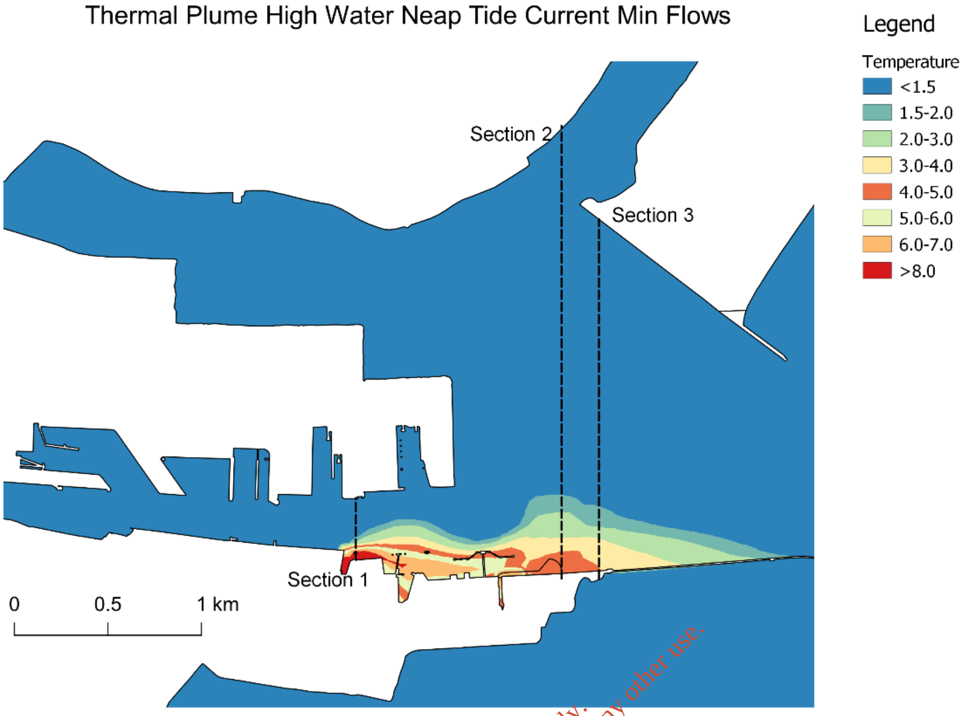

Figure E.17 Surface Water Thermal Plume at High Water

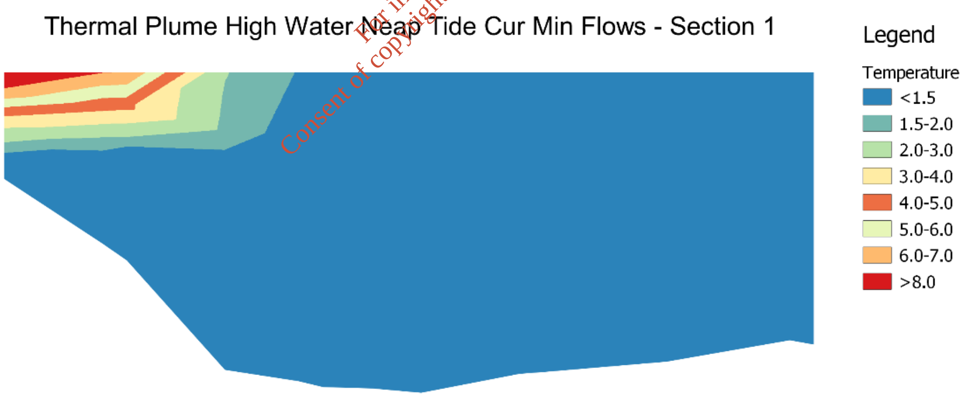

Figure E.18 Section 1 - Thermal Plume at High Water

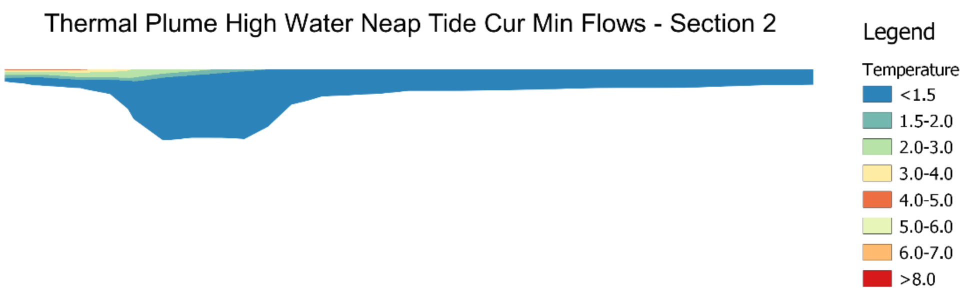

Figure E.19 Section 2 - Thermal Plume at High Water

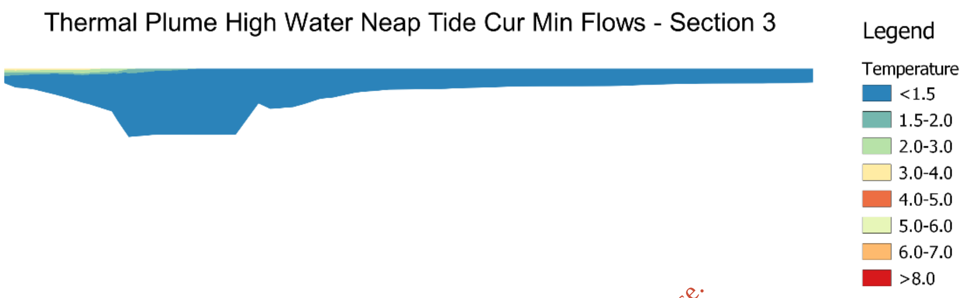

Figure E.20 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	9
2	8
3	4

Table E.5 Thermal Plume Percentage Cross Section

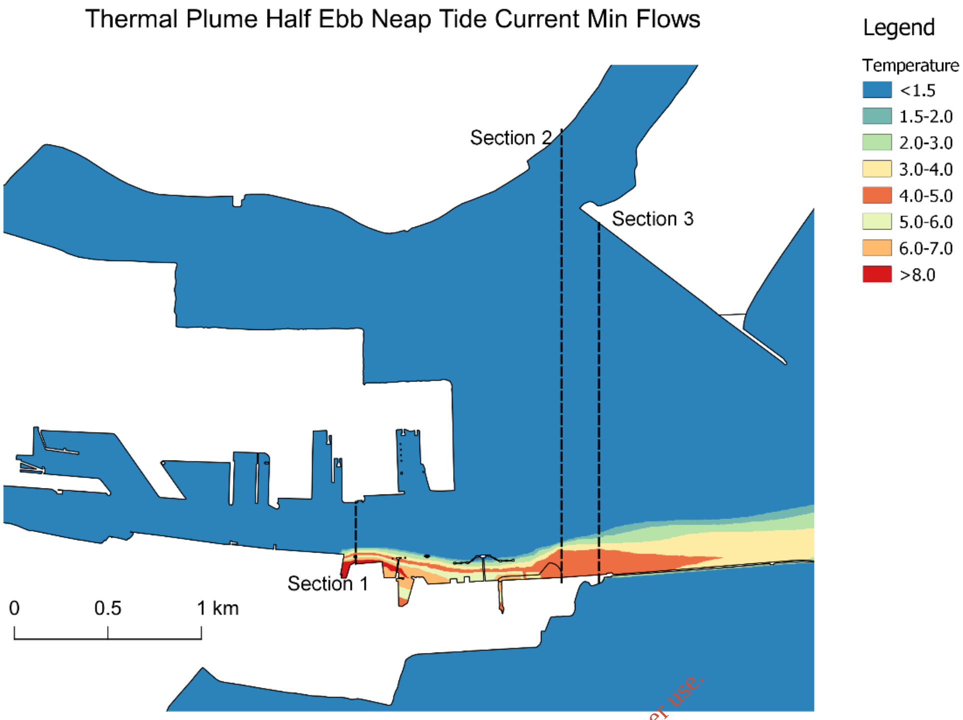

Figure E.21 Surface Water Thermal Plume at Half Ebb

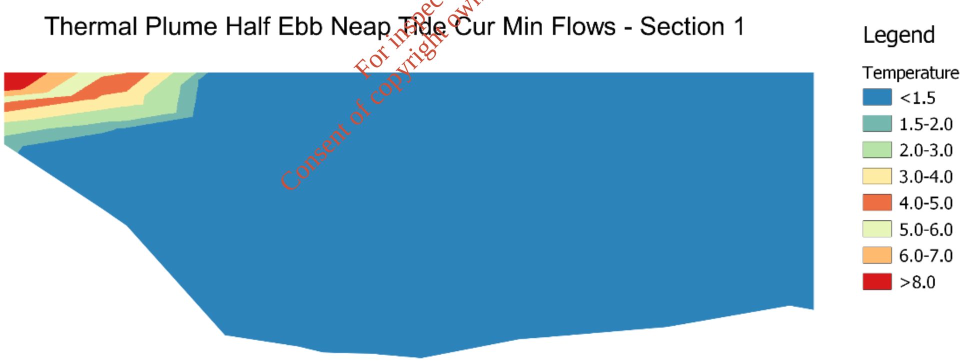

Figure E.22 Section 1 - Thermal Plume at Half Ebb

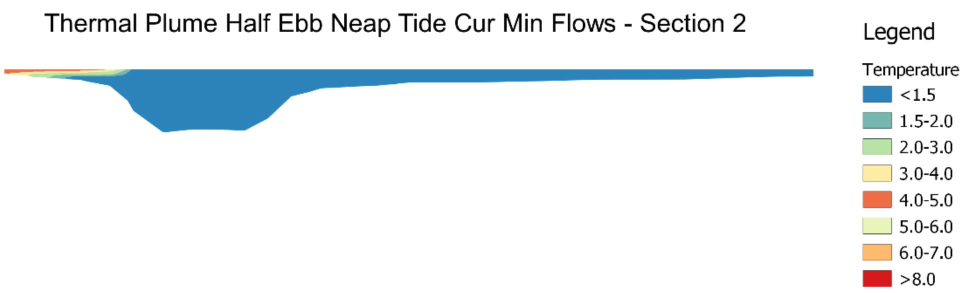

Figure E.23 Section 2 - Thermal Plume at Half Ebb

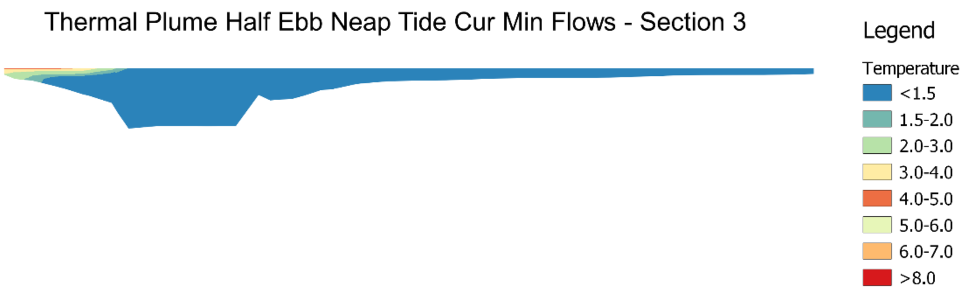

Figure E.24 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	6
2	5
3	6

Table E.6 Thermal Plume Percentage Cross Section

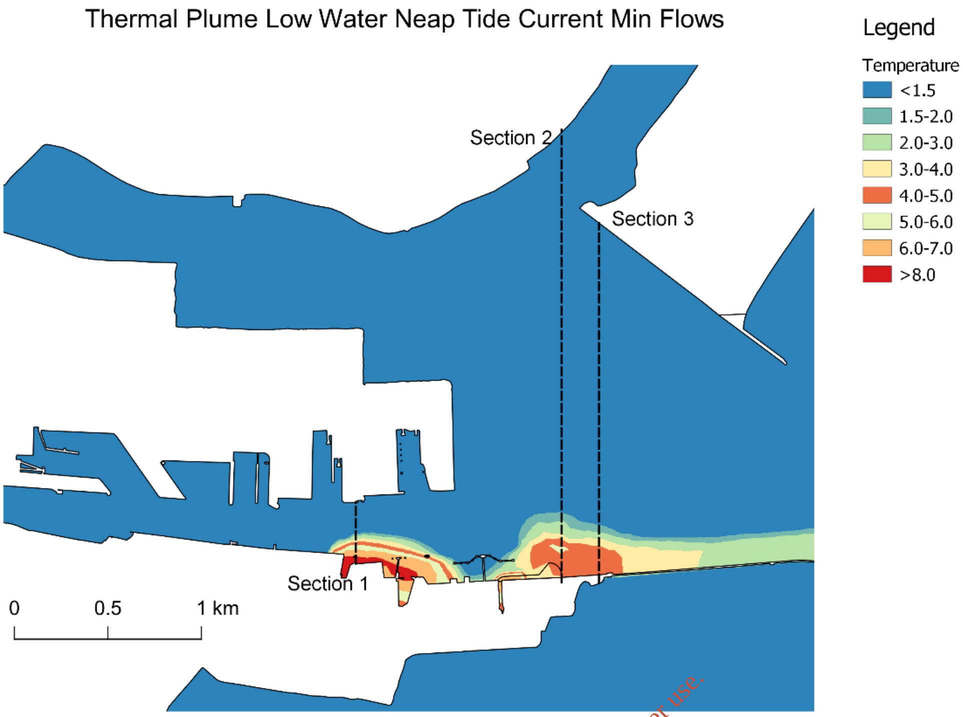

Figure E.25 Surface Water Thermal Plume at Low Water

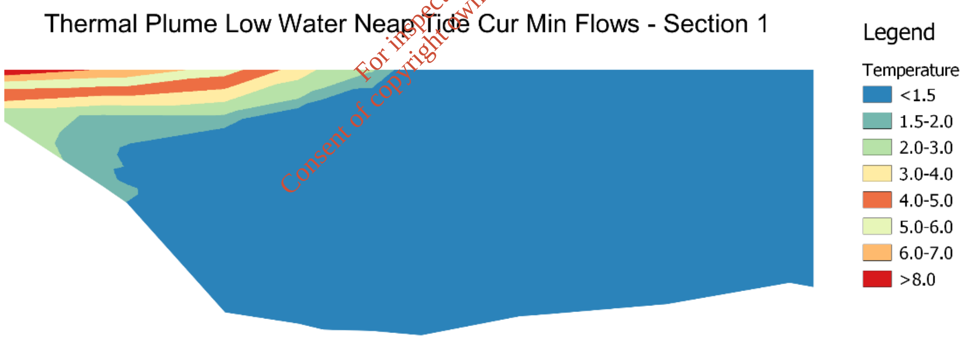

Figure E.26 Section 1 - Thermal Plume at Low Water

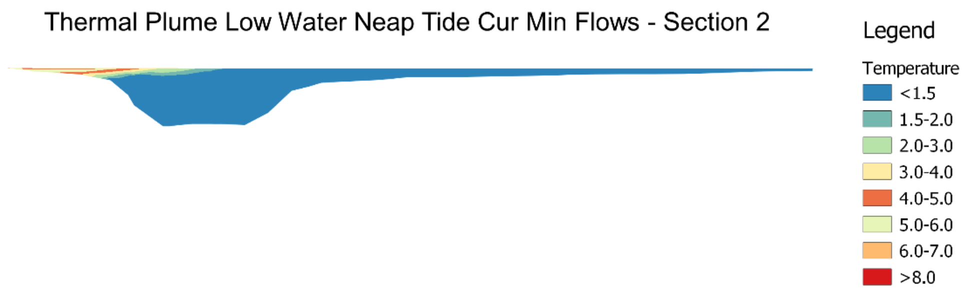

Figure E.27 Section 2 - Thermal Plume at Low Water

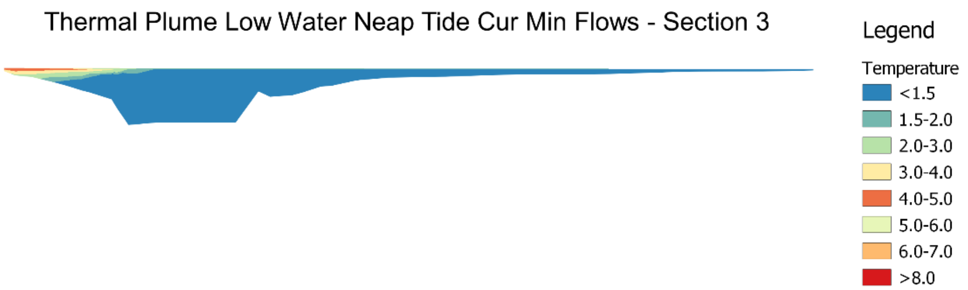

Figure E.28 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	13
2	9
3	8

Table E.7 Thermal Plume Percentage Cross Section

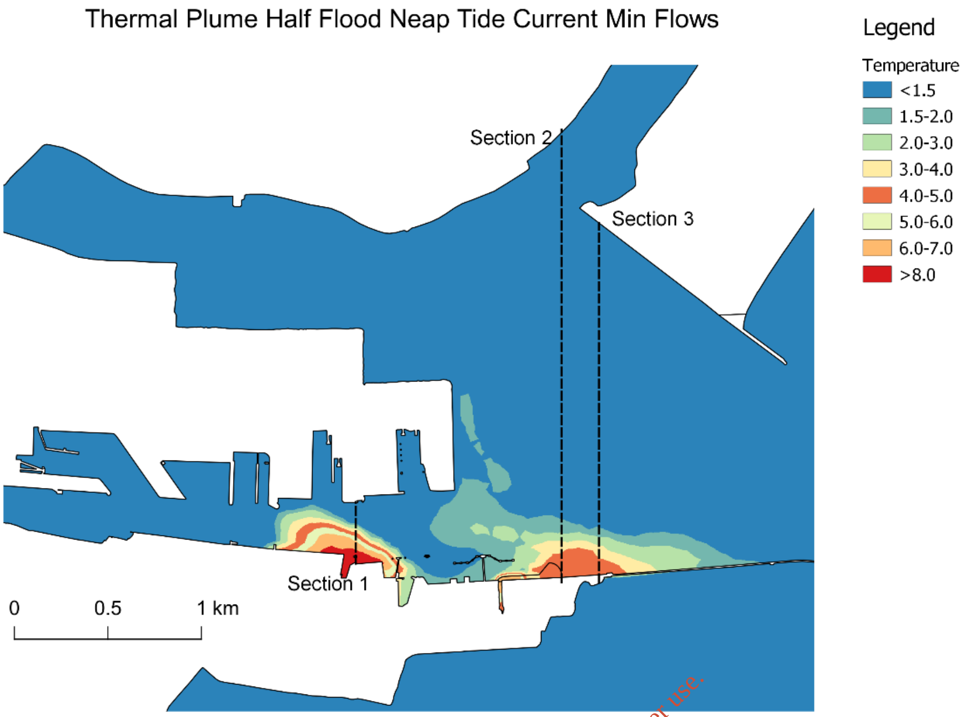

Figure E.29 Surface Water Thermal Plume at Half Flood

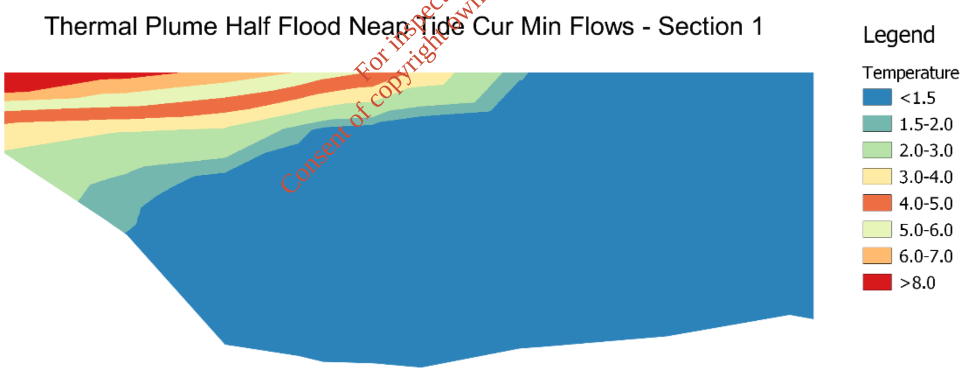

Figure E.30 Section 1 - Thermal Plume at Half Flood

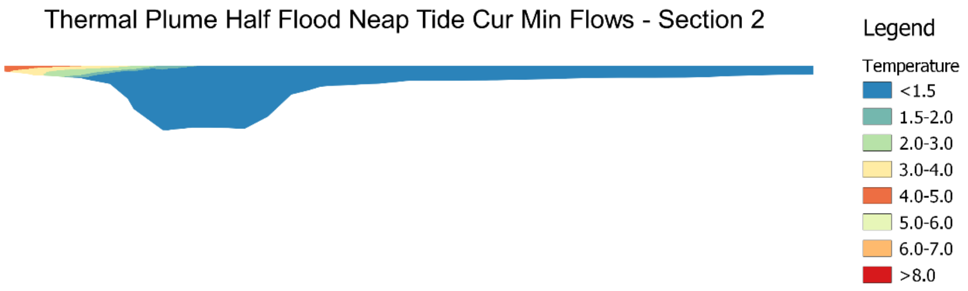

Figure E.31 Section 2 - Thermal Plume at Half Flood

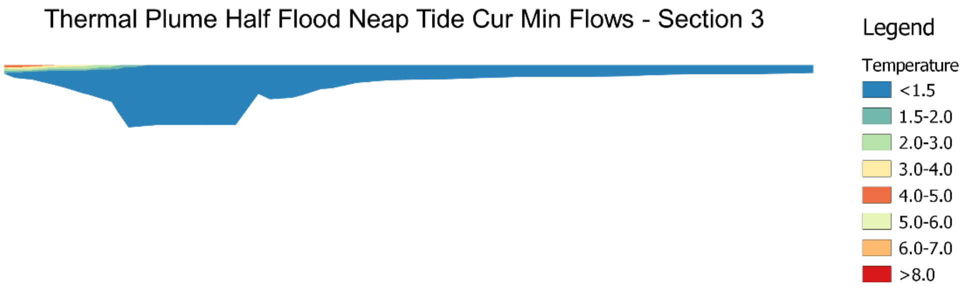

Figure E.32 Section 3 - Thermal Plume at Half Flood

Section No	**% Cross-section**
1	22
2	7
3	4

Table E.8 Thermal Plume Percentage Cross Section

F. Appendix F - Results of All facilities operating at current maximum capacity with wet weather conditions

F.1. Spring Tide

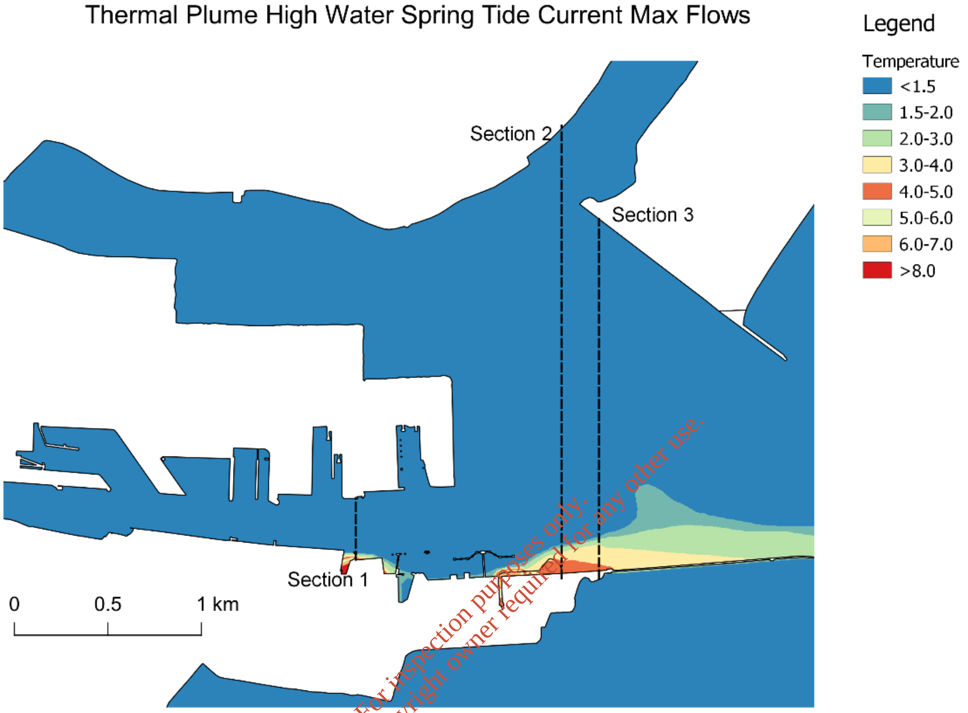

Figure F.1 Surface Water Thermal Plume at High Water

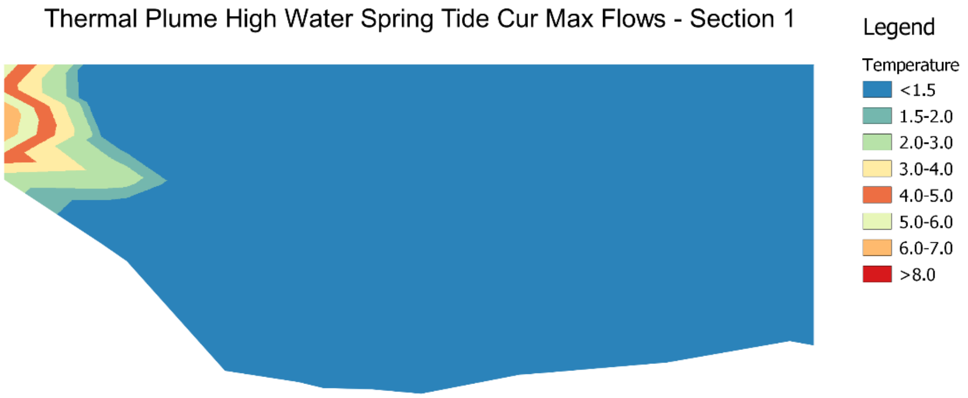

Figure F.2 Section 1 - Thermal Plume at High Water

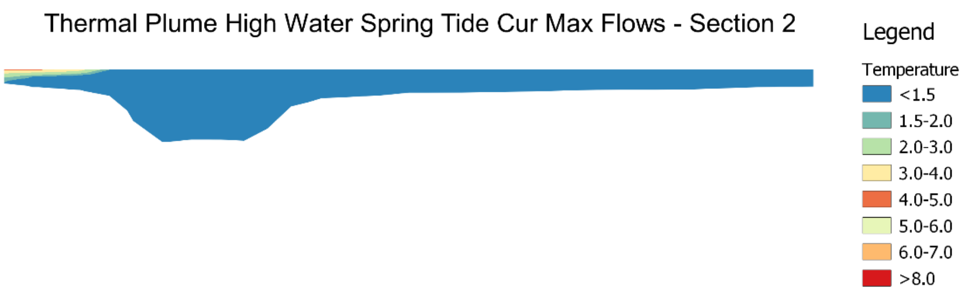

Figure F.3 Section 2 - Thermal Plume at High Water

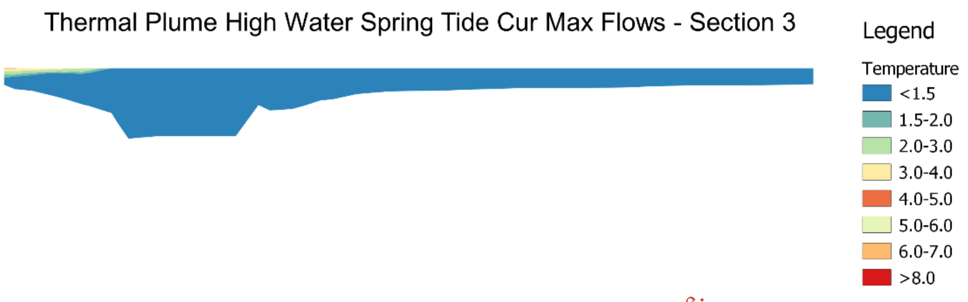

Figure F.4 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	6
2	3
3	2

Table F.1 Thermal Plume Percentage Cross Section

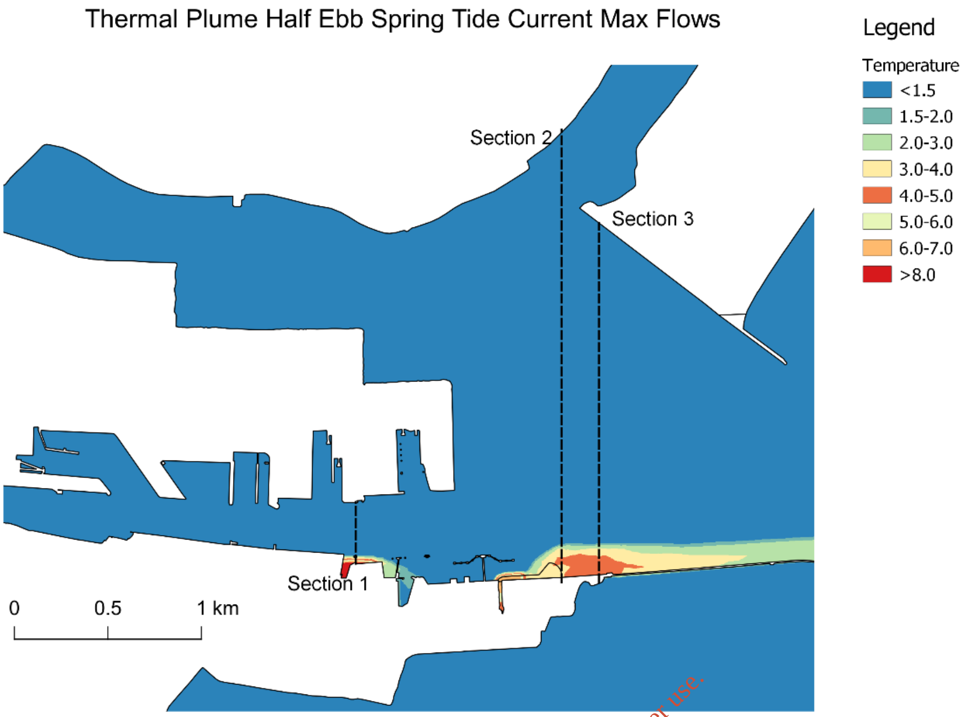

Figure F.5 Surface Water Thermal Plume at Half Ebb

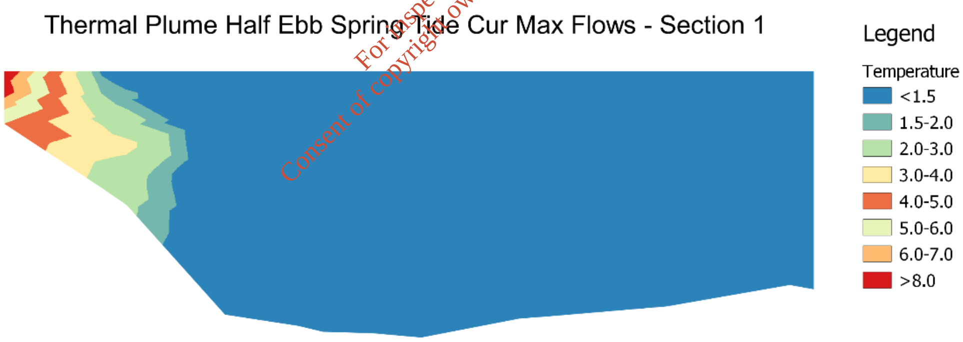

Figure F.6 Section 1 - Thermal Plume at Half Ebb

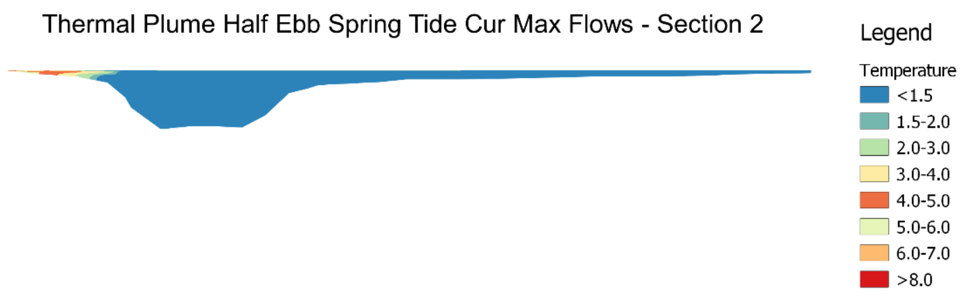

Figure F.7 Section 2 - Thermal Plume at Half Ebb

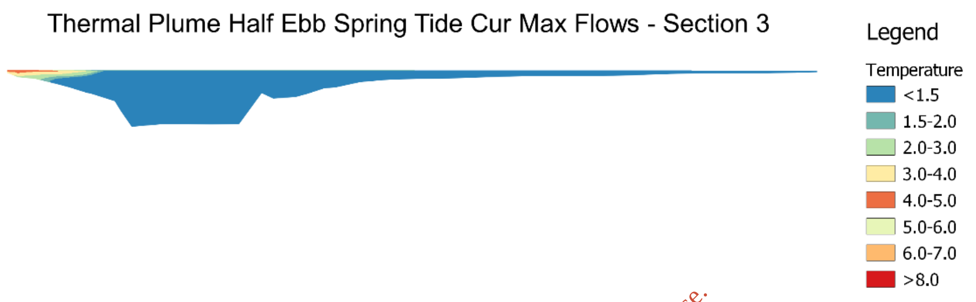

Figure F.8 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	10
2	4
3	5

Table F.2 Thermal Plume Percentage Cross Section

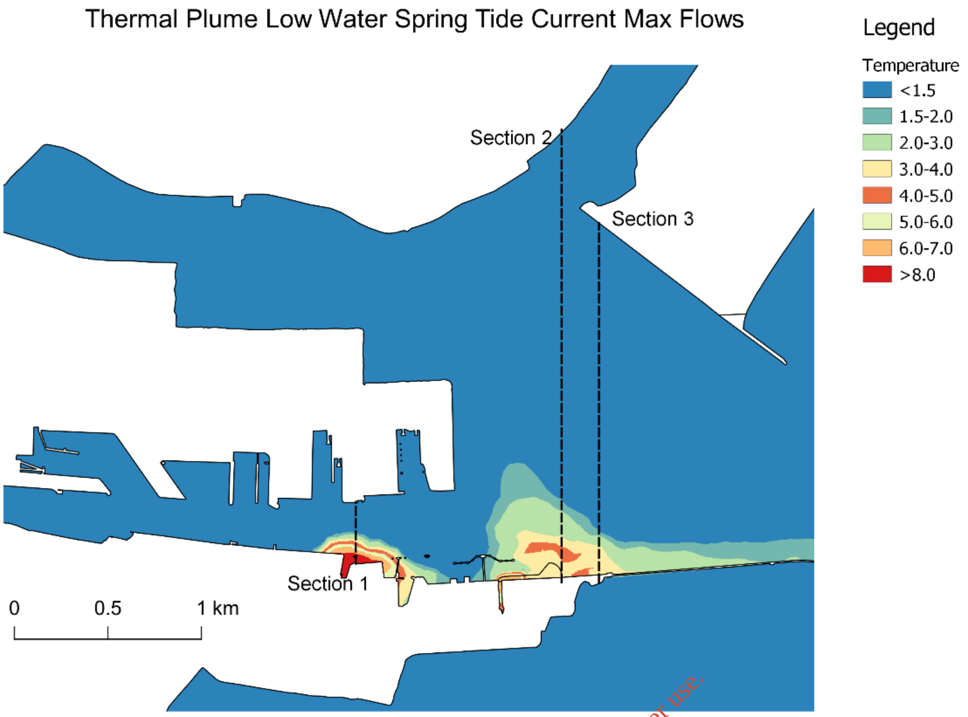

Figure F.9 Surface Water Thermal Plume at Low Water

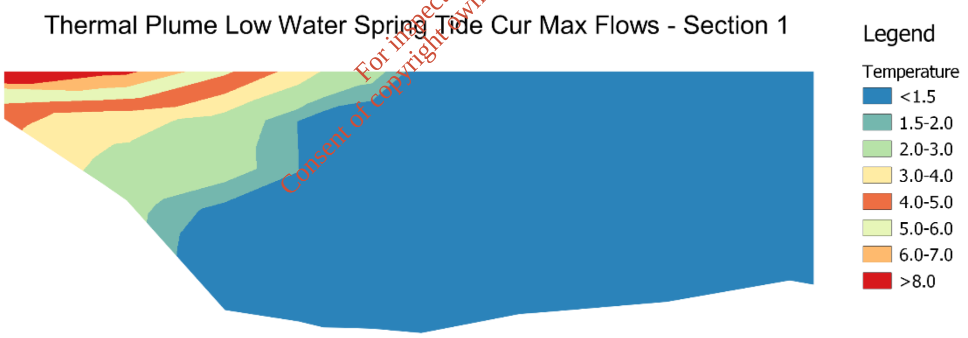

Figure F.10 Section 1 - Thermal Plume at Low Water

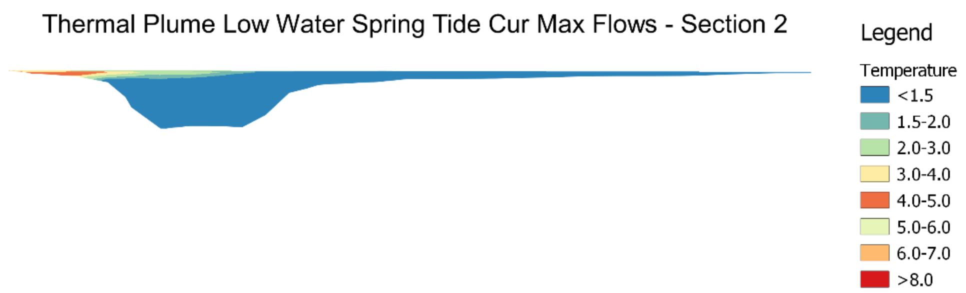

Figure F.11 Section 2 - Thermal Plume at Low Water

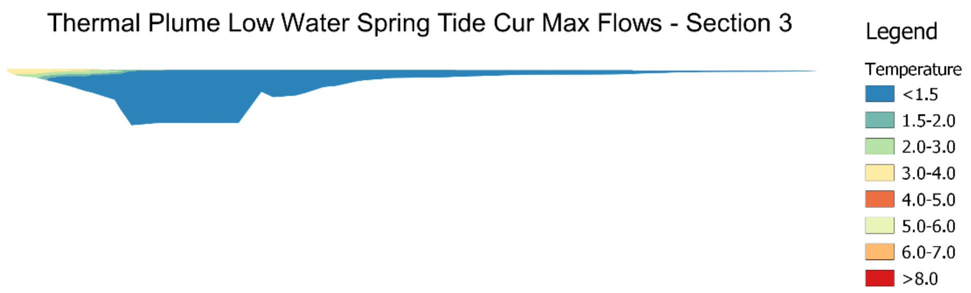

Figure F.12 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	22
2	10
3	5

Table F.3 Thermal Plume Percentage Cross Section

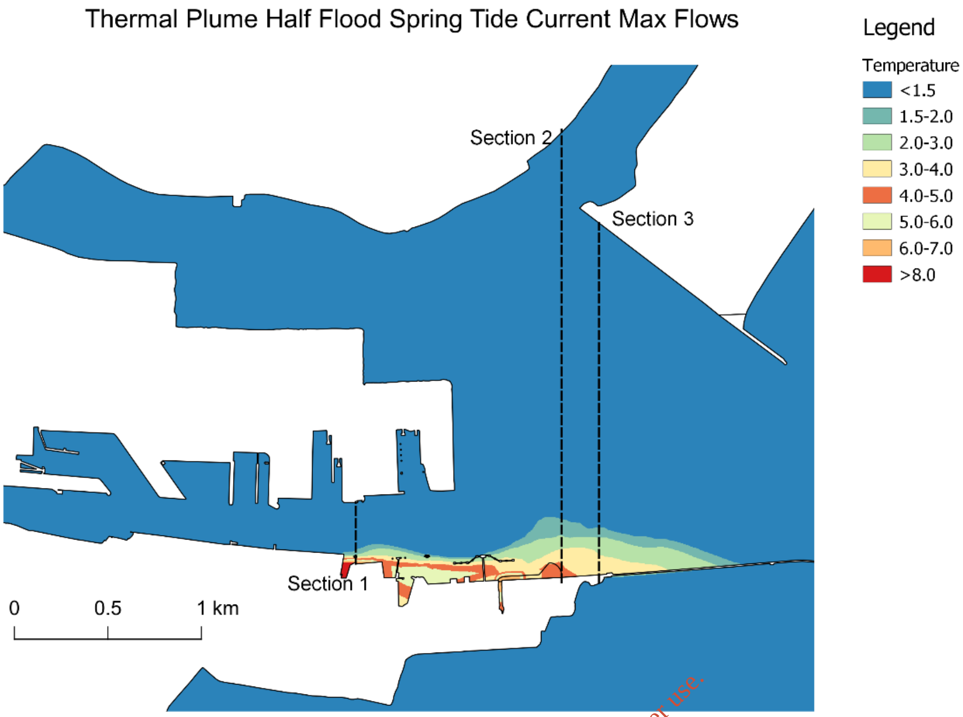

Figure F.13 Surface Water Thermal Plume at Half Flood

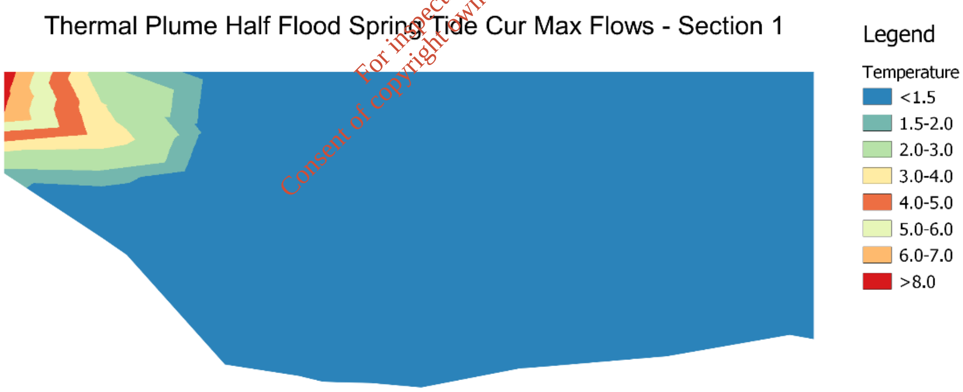

Figure F.14 Section 1 - Thermal Plume at Half Flood

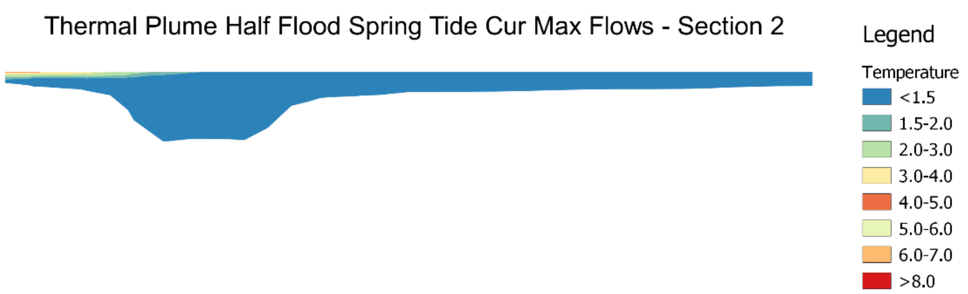

Figure F.15 Section 2 - Thermal Plume at Half Flood

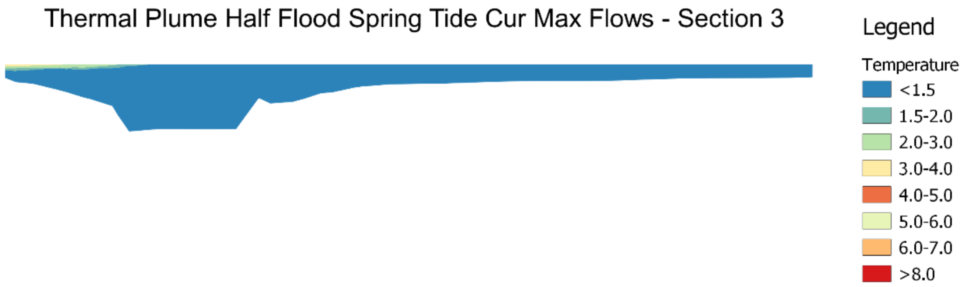

Figure F.16 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	10
2	4
3	3

Table F.4 Thermal Plume Percentage Cross Section

F.2. Neap Tide

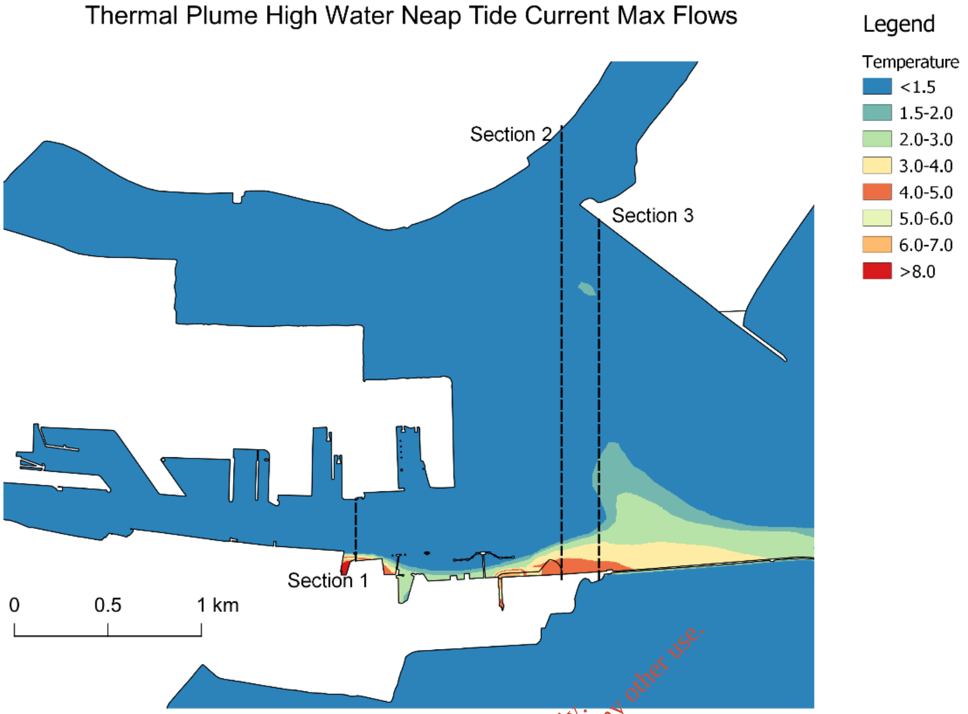

Figure F.17 Surface Water Thermal Plume at High Water

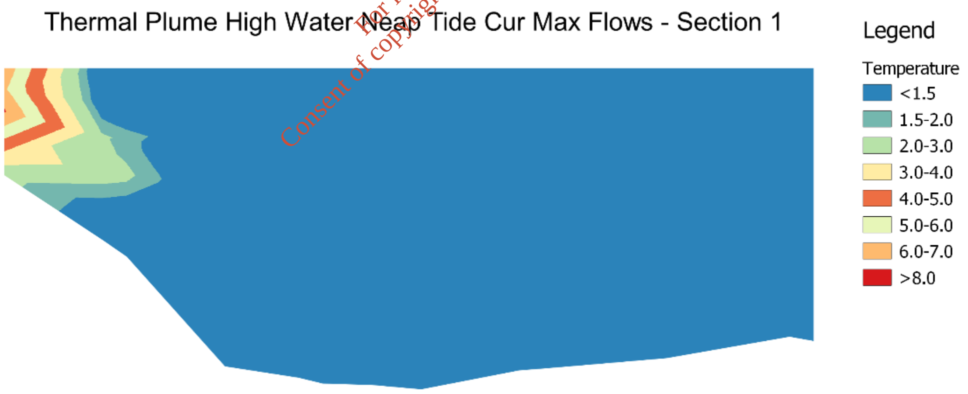

Figure F.18 Section 1 - Thermal Plume at High Water

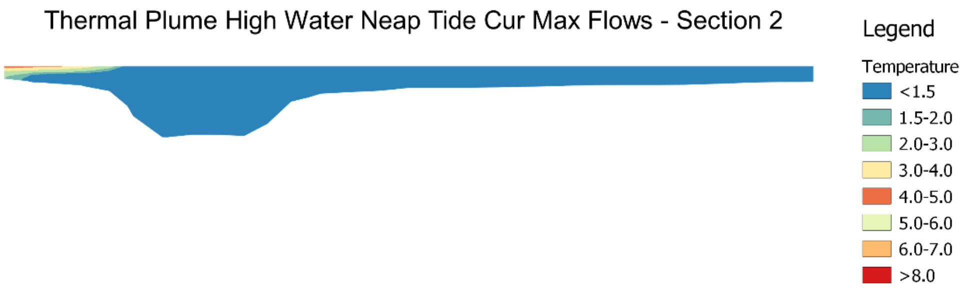

Figure F.19 Section 2 - Thermal Plume at High Water

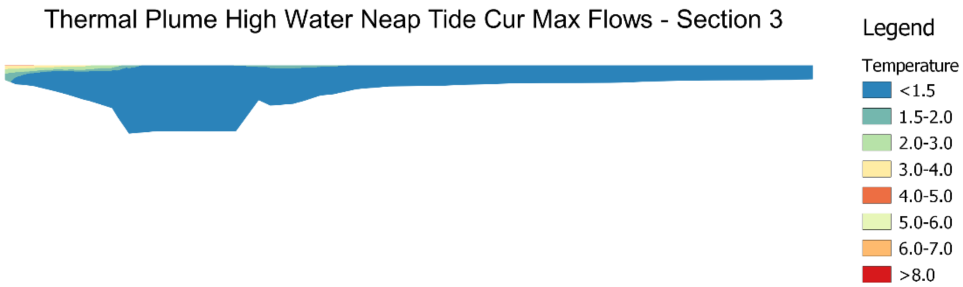

Figure F.20 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	7
2	4
3	5

Table F.5 Thermal Plume Percentage Cross Section

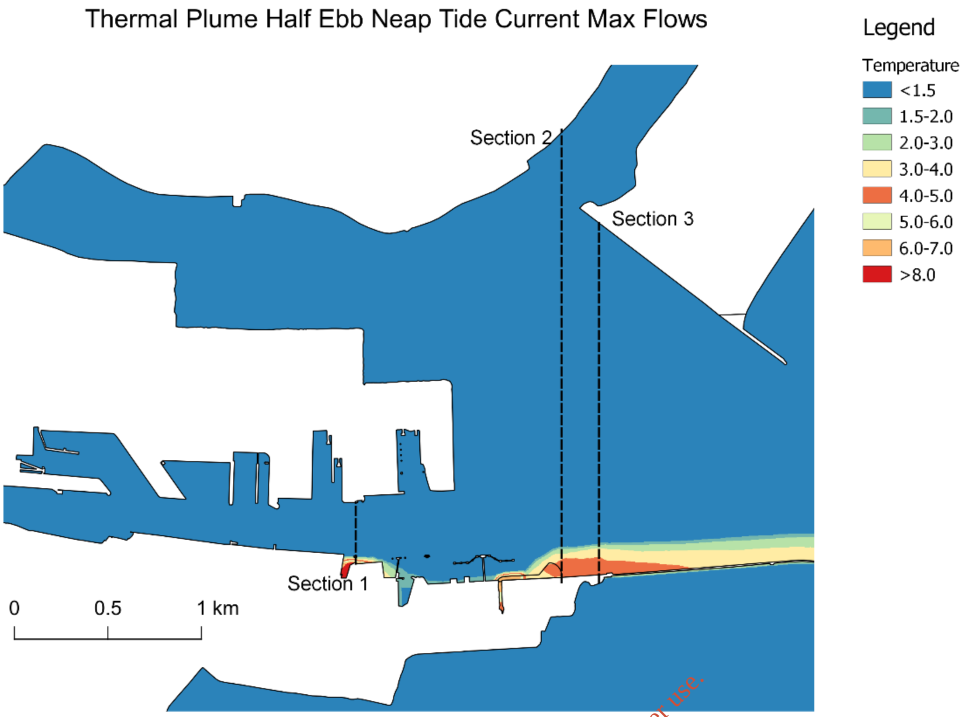

Figure F.21 Surface Water Thermal Plume at Half Ebb

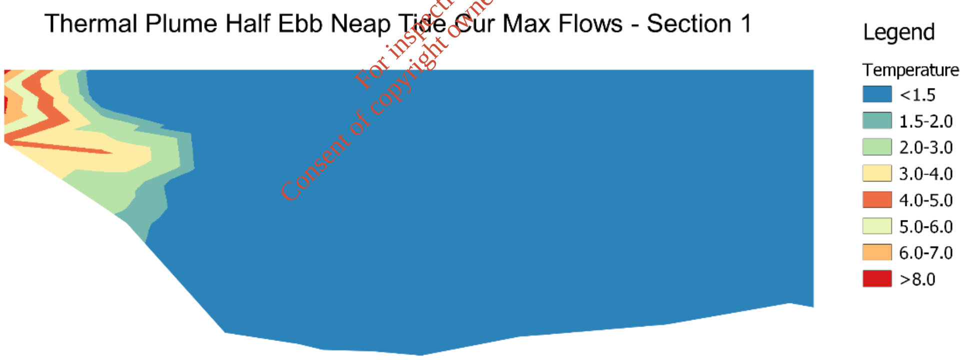

Figure F.22 Section 1 - Thermal Plume at Half Ebb

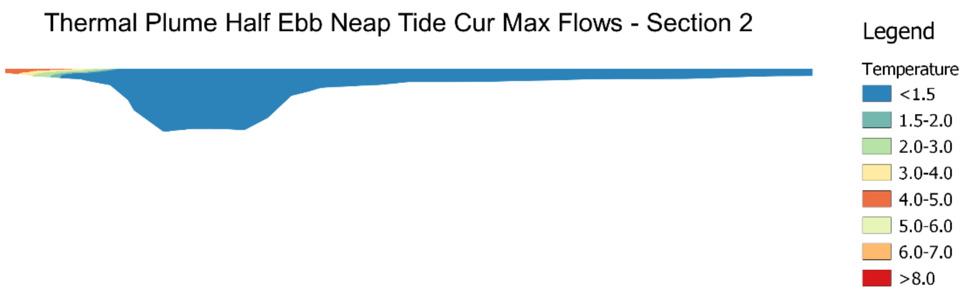

Figure F.23 Section 2 - Thermal Plume at Half Ebb

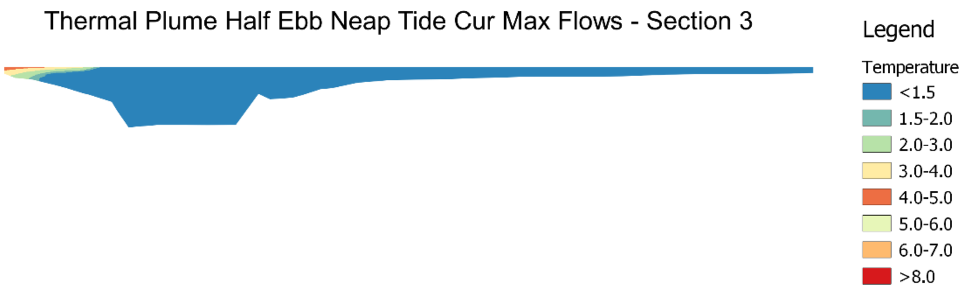

Figure F.24 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	9
2	4
3	4

Table F.6 Thermal Plume Percentage Cross Section

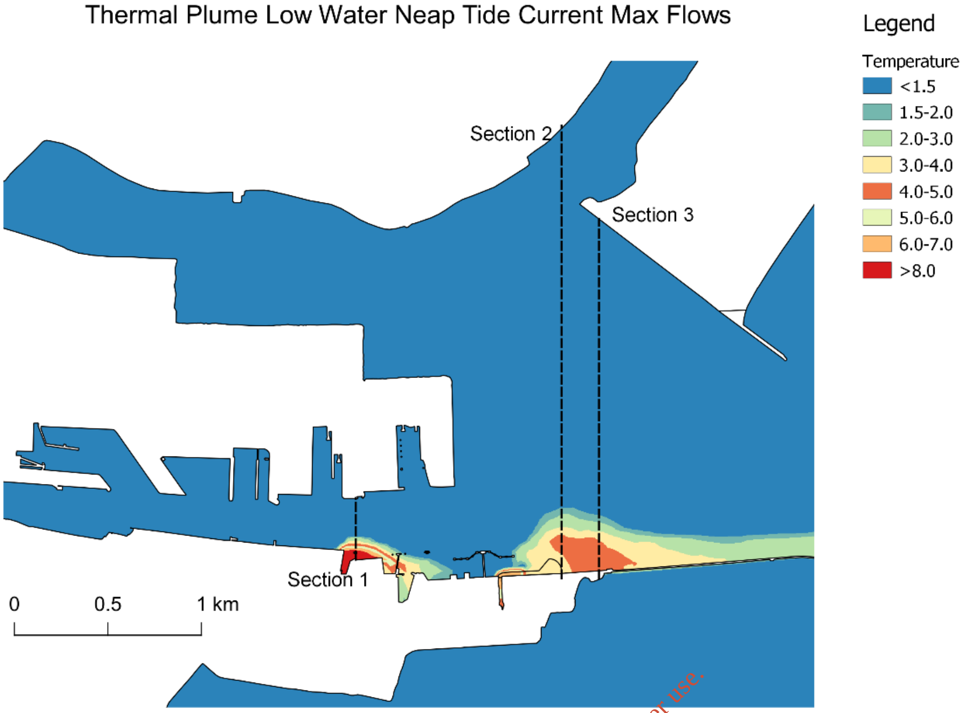

Figure F.25 Surface Water Thermal Plume at Low Water

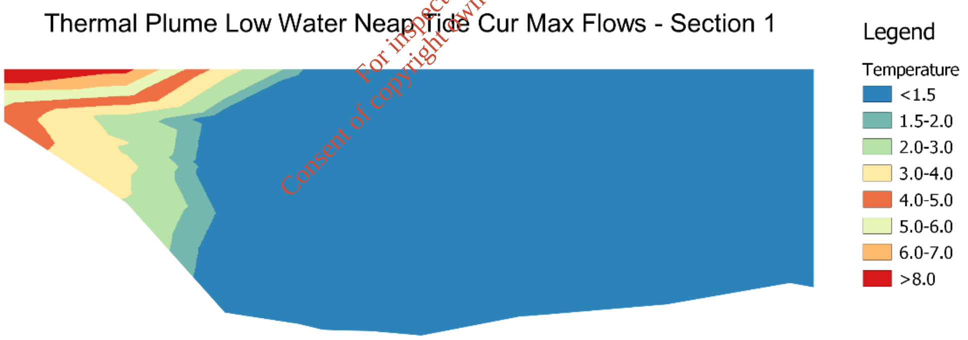

Figure F.26 Section 1 - Thermal Plume at Low Water

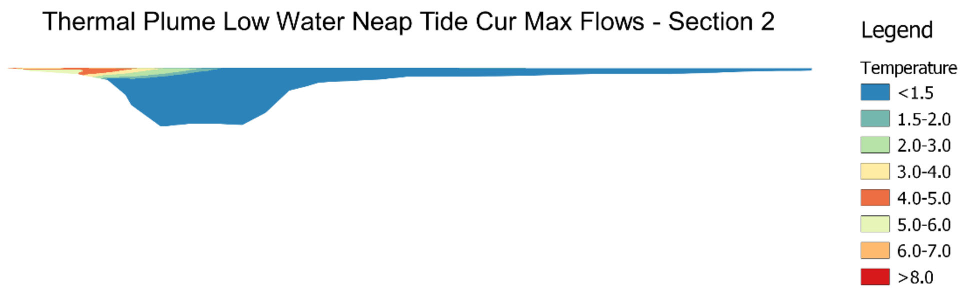

Figure F.27 Section 2 - Thermal Plume at Low Water

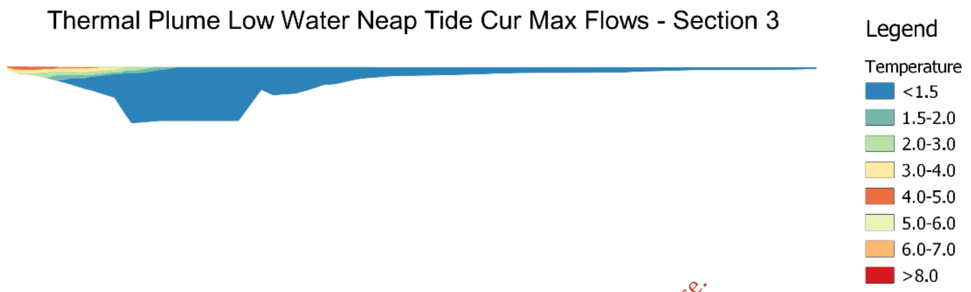

Figure F.28 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	16
2	10
3	9

Table F.7 Thermal Plume Percentage Cross Section

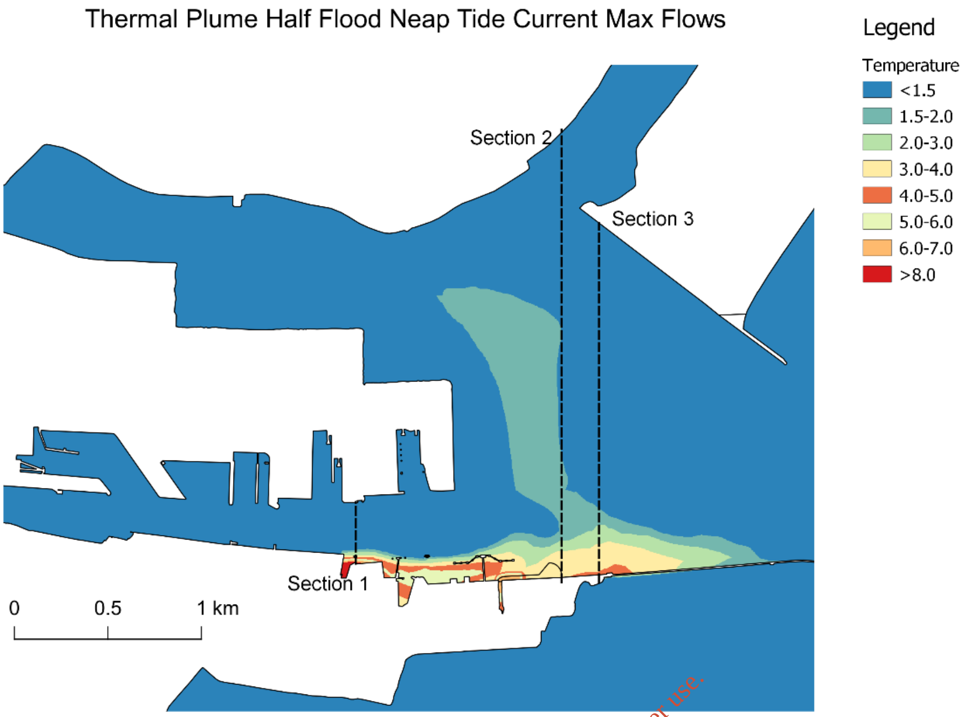

Figure F.29 Surface Water Thermal Plume at Half Flood

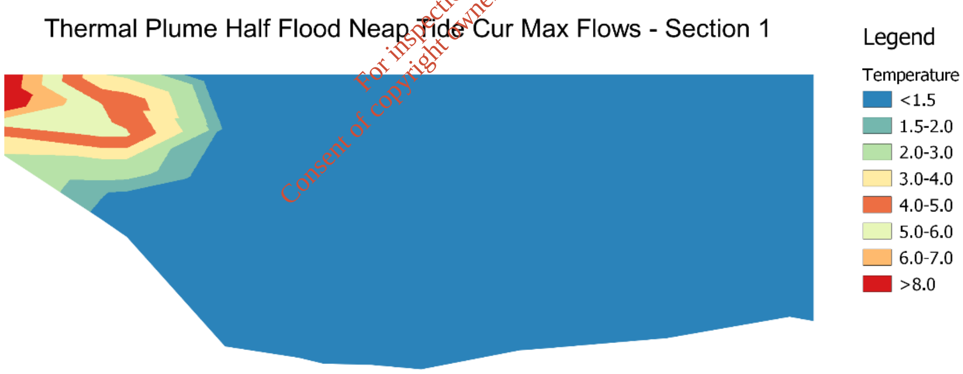

Figure F.30 Section 1 - Thermal Plume at Half Flood

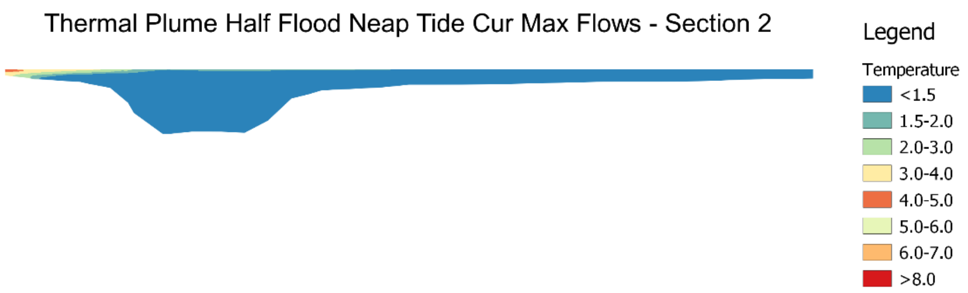

Figure F.31 Section 2 - Thermal Plume at Half Flood

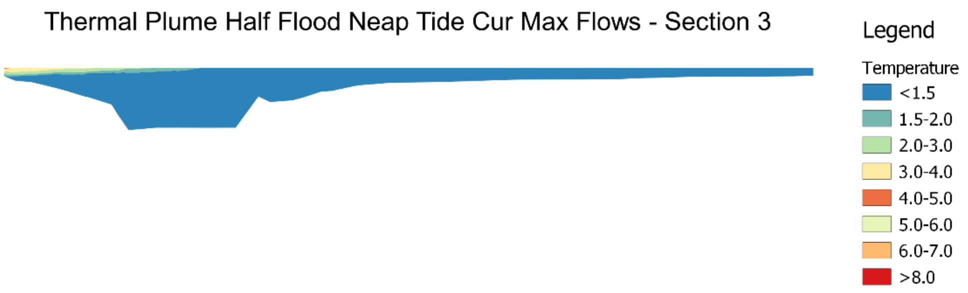

Figure F.32 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	12
2	5
3	6

Table F.8 Thermal Plume Percentage Cross Section

G. Appendix G - Results of All facilities operating at future maximum capacity with dry weather conditions

G.1. Spring Tide

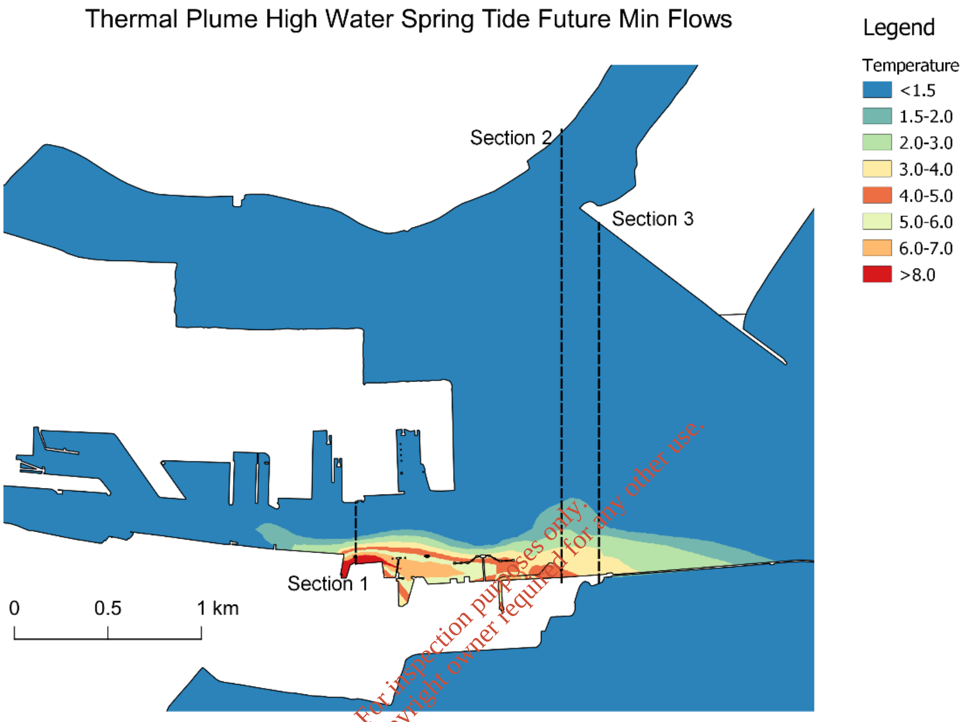

Figure G.1 Surface Water Thermal Plume at High Water

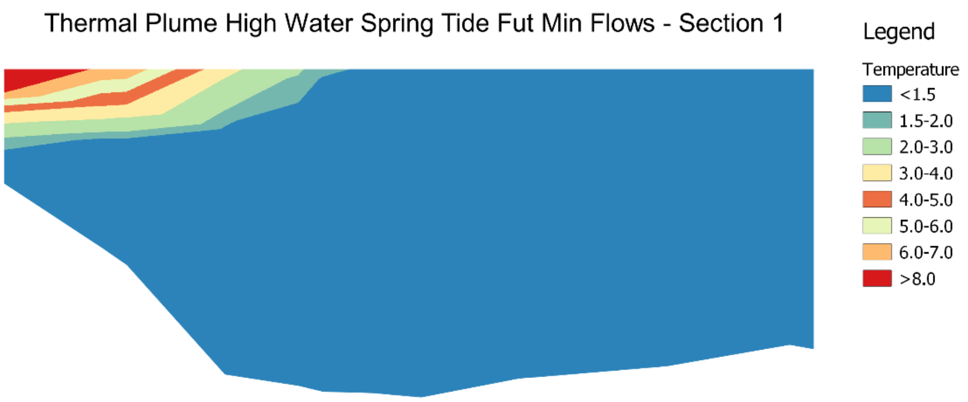

Figure G.2 Section 1 - Thermal Plume at High Water

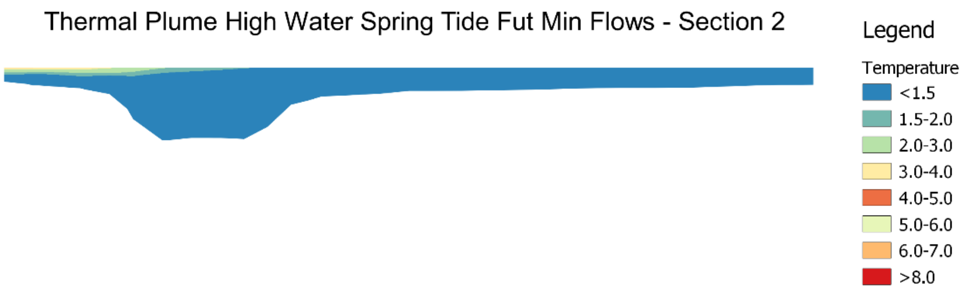

Figure G.3 Section 2 - Thermal Plume at High Water

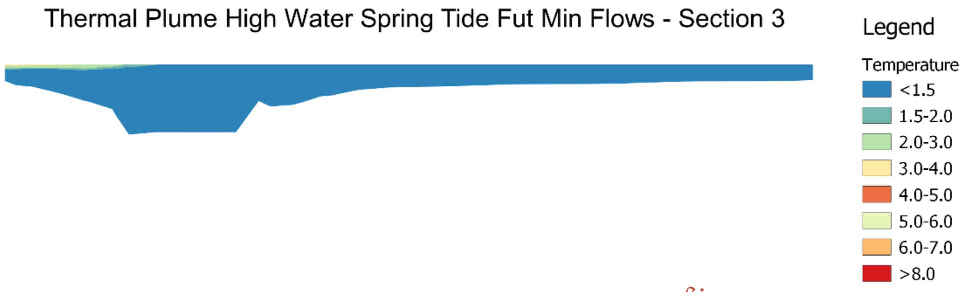

Figure G.4 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	9
2	6
3	3

Table G.1 Thermal Plume Percentage Cross Section

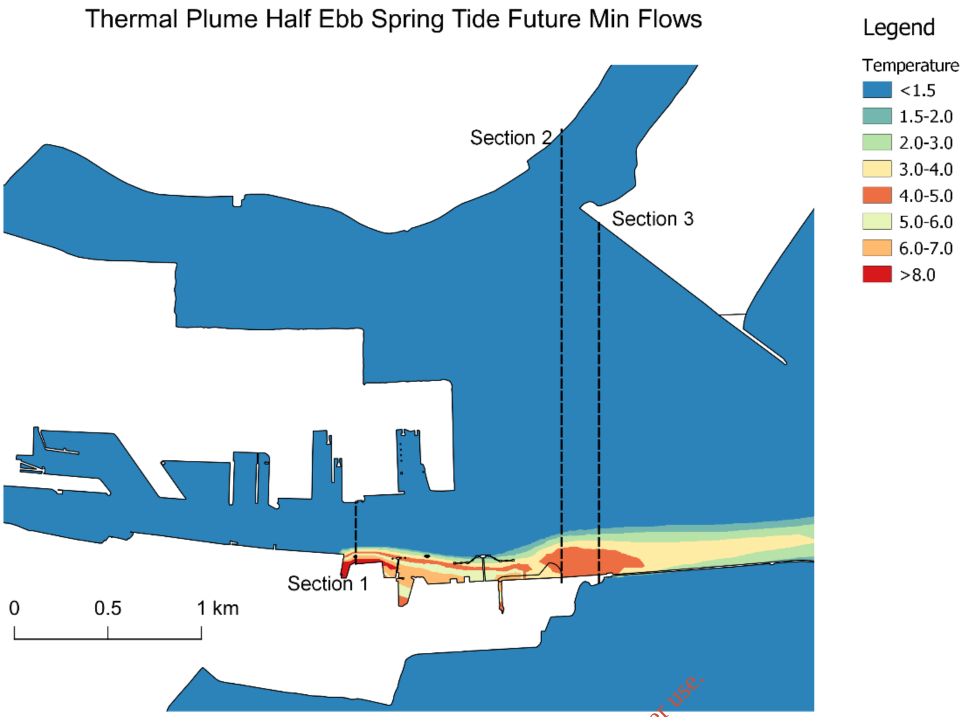

Figure G.5 Surface Water Thermal Plume at Half Ebb

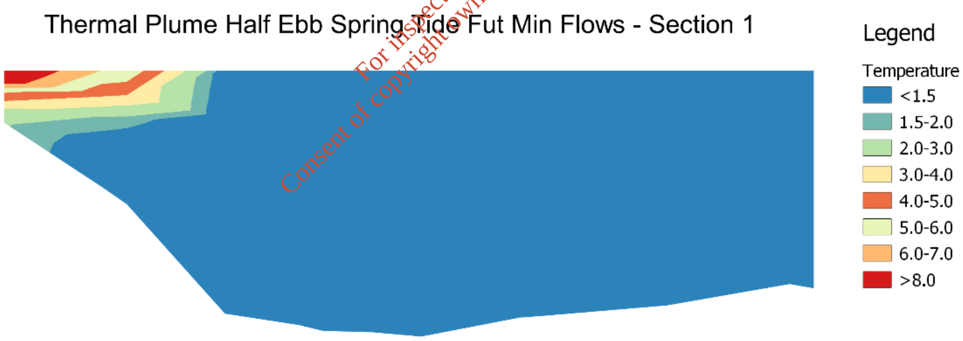

Figure G.6 Section 1 - Thermal Plume at Half Ebb

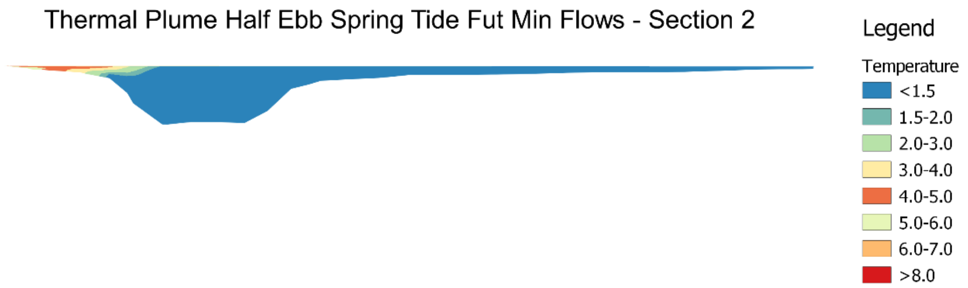

Figure G.7 Section 2 - Thermal Plume at Half Ebb

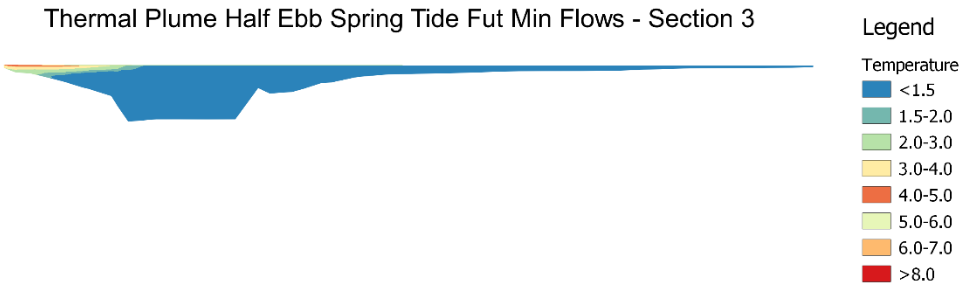

Figure G.8 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	7
2	6
3	8

Table G.2 Thermal Plume Percentage Cross Section

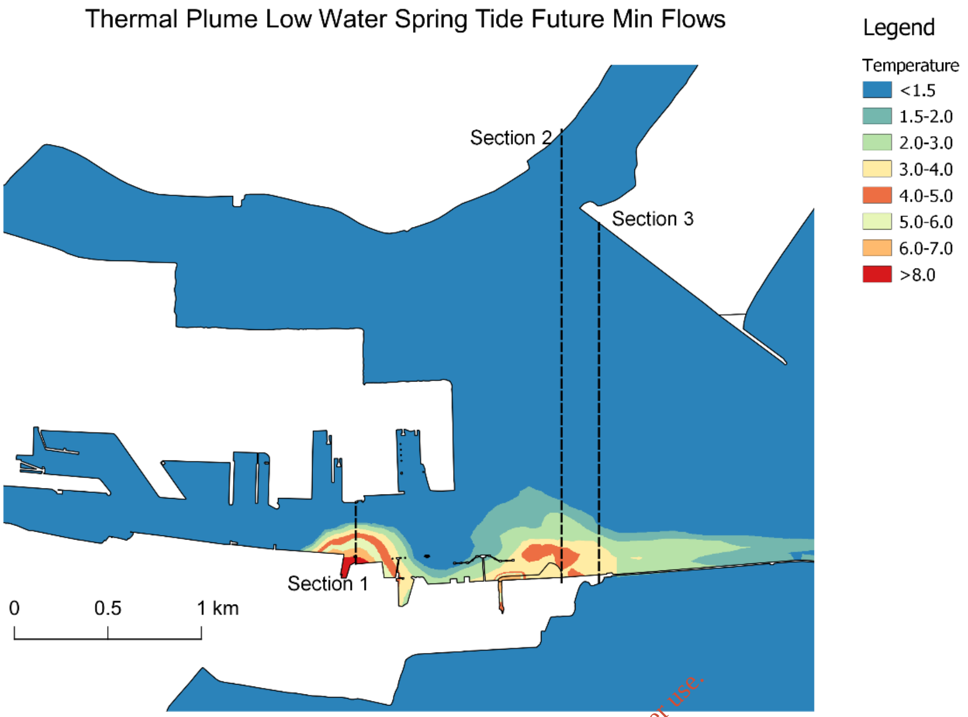

Figure G.9 Surface Water Thermal Plume at Low Water

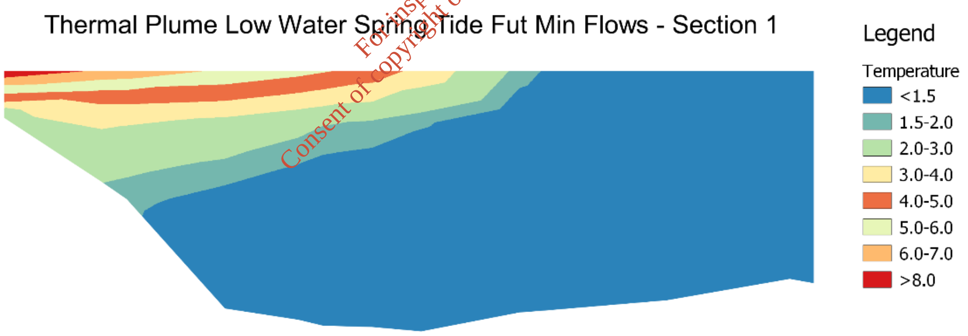

Figure G.10 Section 1 - Thermal Plume at Low Water

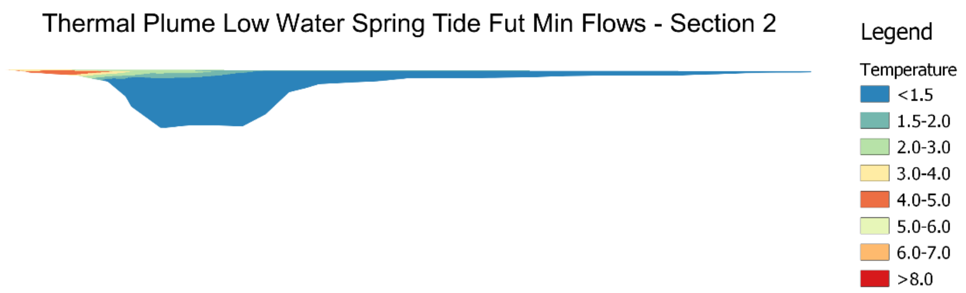

Figure G.11 Section 2 - Thermal Plume at Low Water

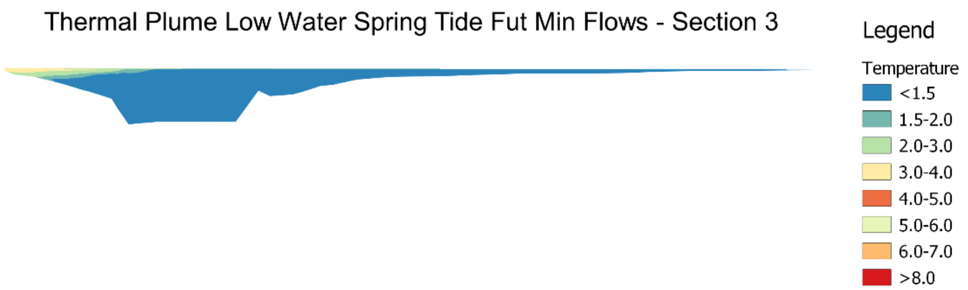

Figure G.12 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	26
2	10
3	7

Table G.3 Thermal Plume Percentage Cross Section

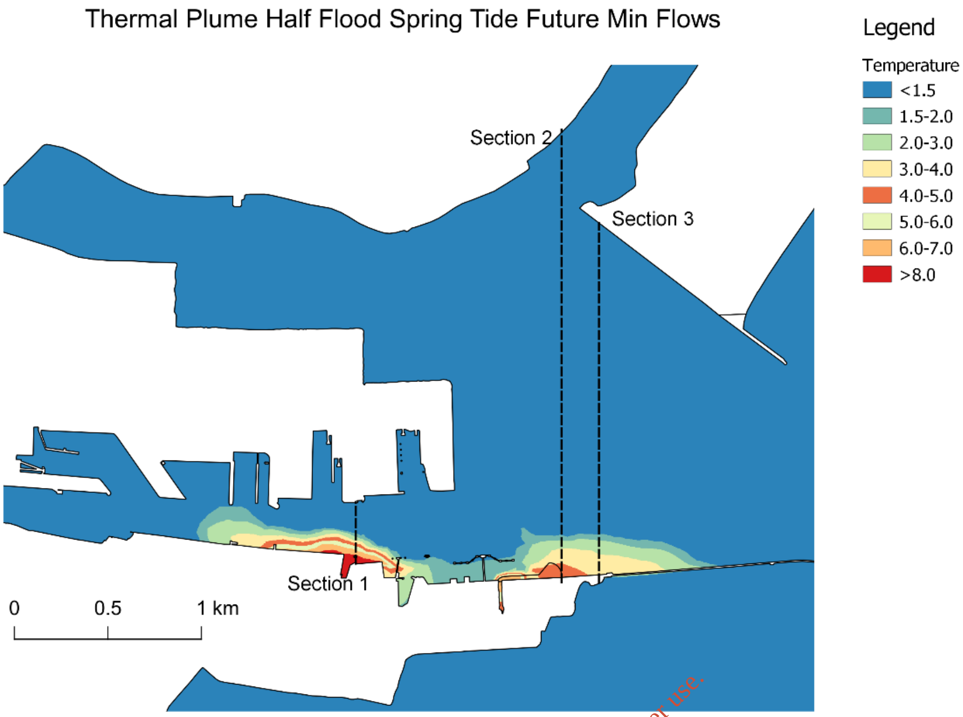

Figure G.13 Surface Water Thermal Plume at Half Flood

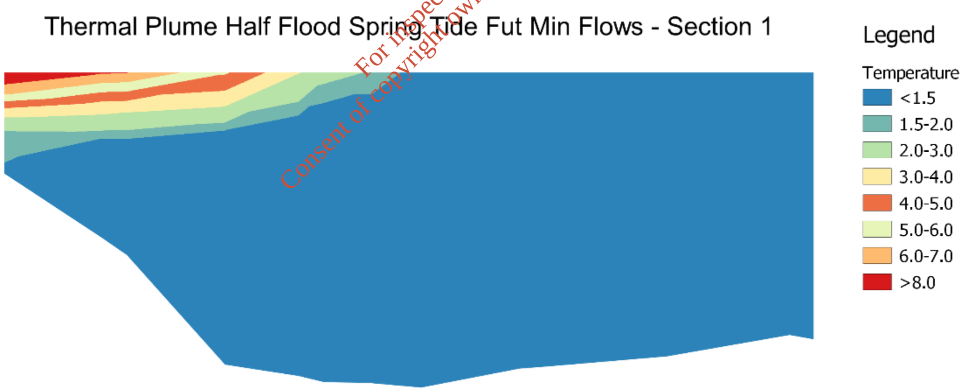

Figure G.14 Section 1 - Thermal Plume at Half Flood

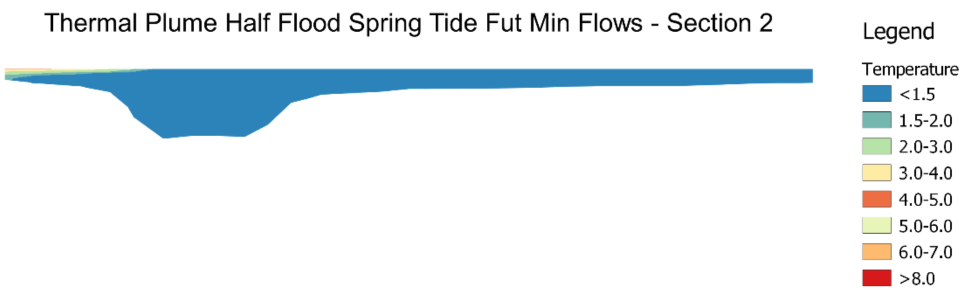

Figure G.15 Section 2 - Thermal Plume at Half Flood

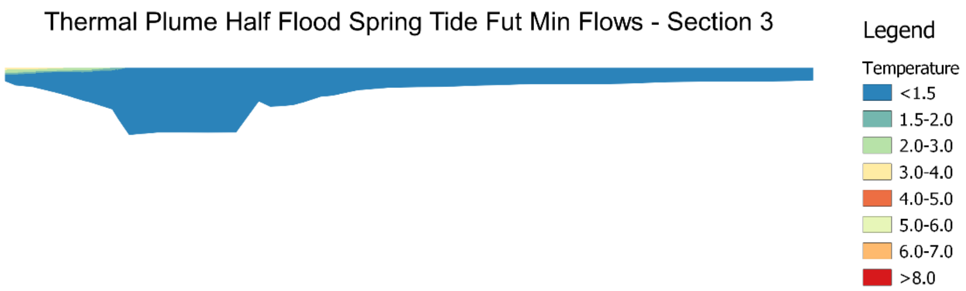

Figure G.16 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	10
2	3
3	2

Table G.4 Thermal Plume Percentage Cross Section

G.2.Neap Tide

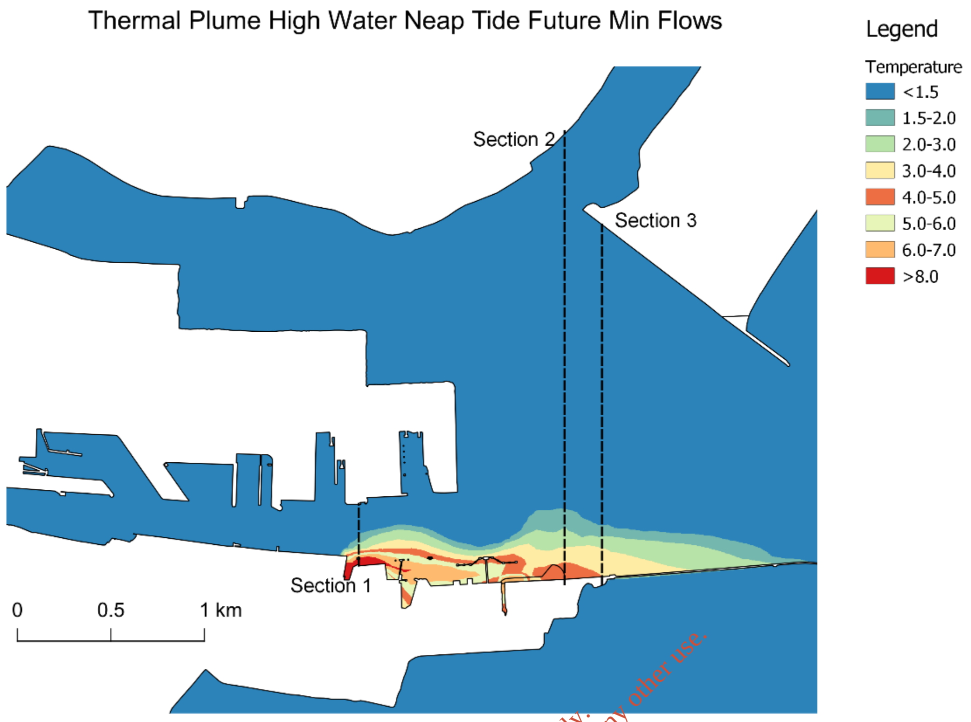

Figure G.17 Surface Water Thermal Plume at High Water

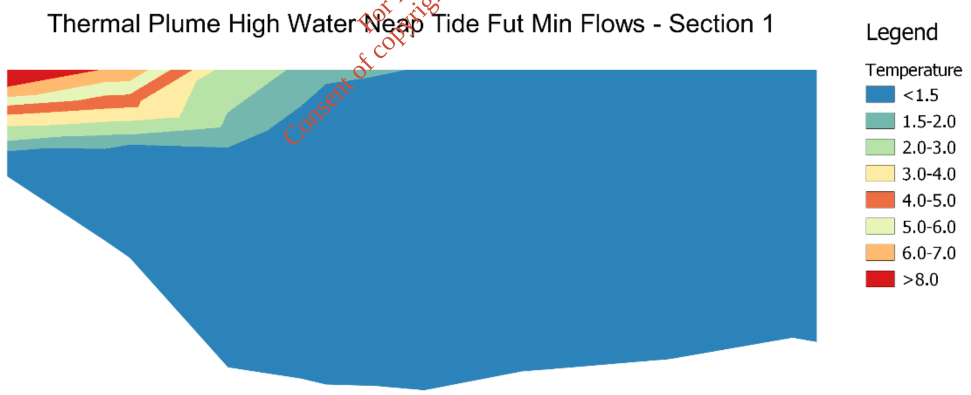

Figure G.18 Section 1 - Thermal Plume at High Water

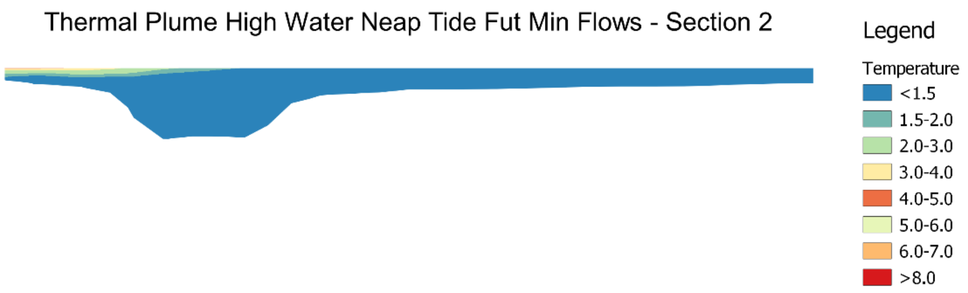

Figure G.19 Section 2 - Thermal Plume at High Water

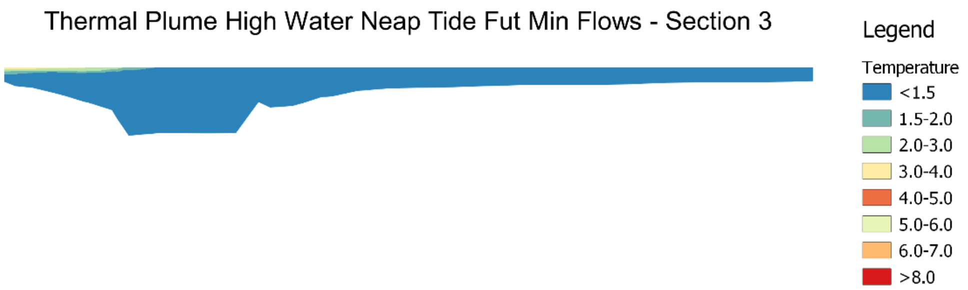

Figure G.20 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	10
2	6
3	3

Table G.5 Thermal Plume Percentage Cross Section

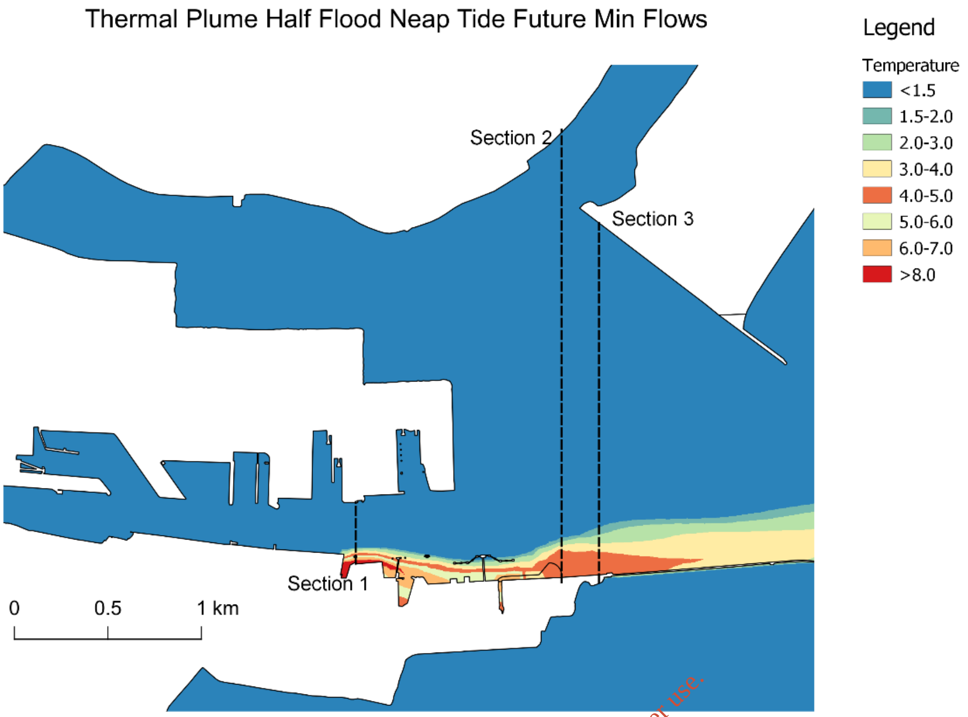

Figure G.21 Surface Water Thermal Plume at Half Ebb

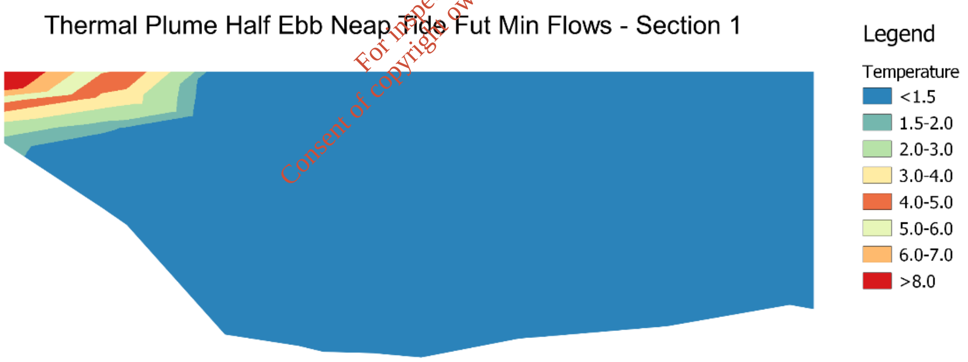

Figure G.22 Section 1 - Thermal Plume at Half Ebb

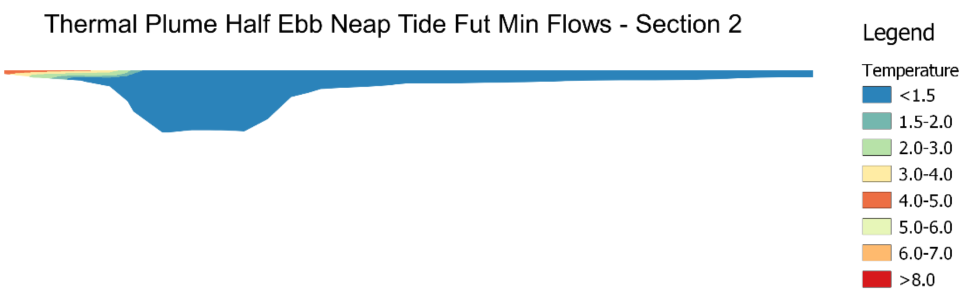

Figure G.23 Section 2 - Thermal Plume at Half Ebb

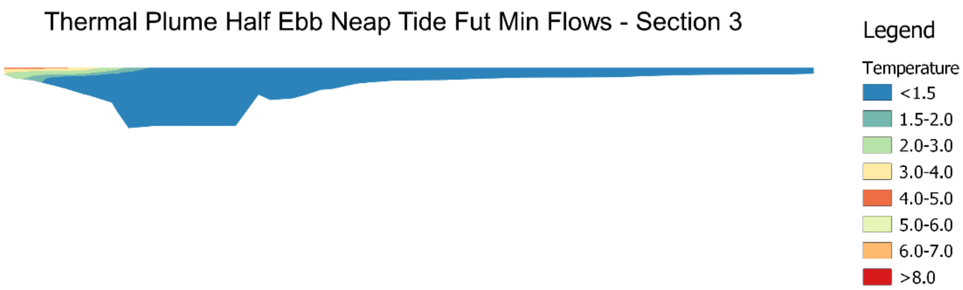

Figure G.24 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	6
2	6
3	7

Table G.6 Thermal Plume Percentage Cross Section

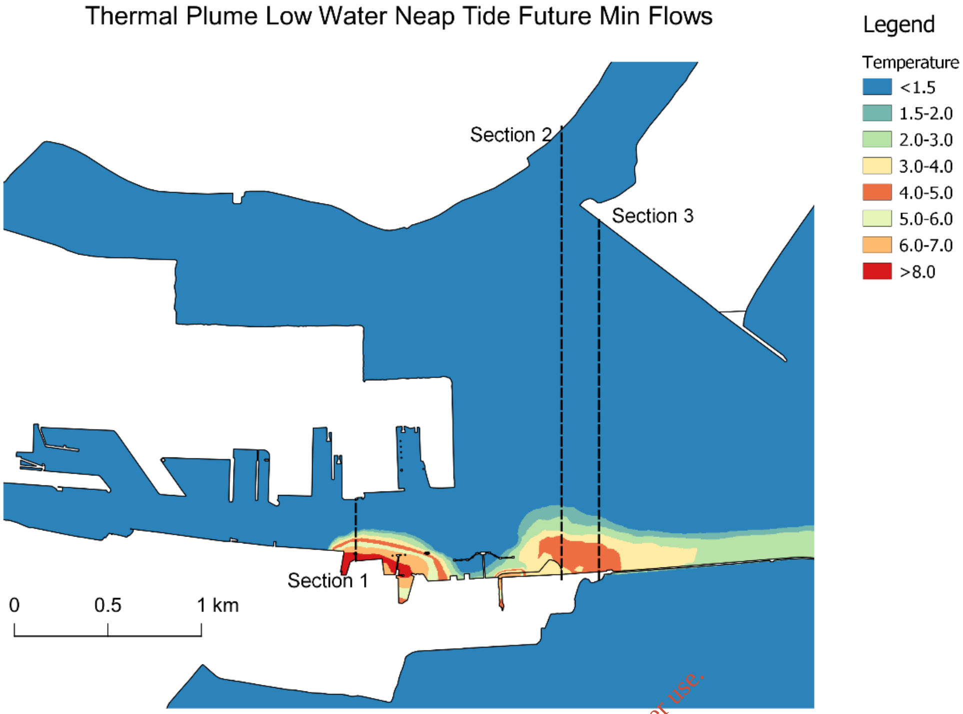

Figure G.25 Surface Water Thermal Plume at Low Water

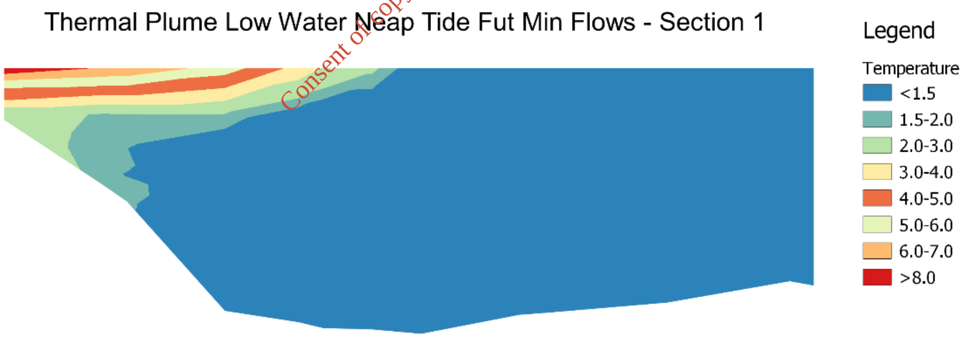

Figure G.26 Section 1 - Thermal Plume at Low Water

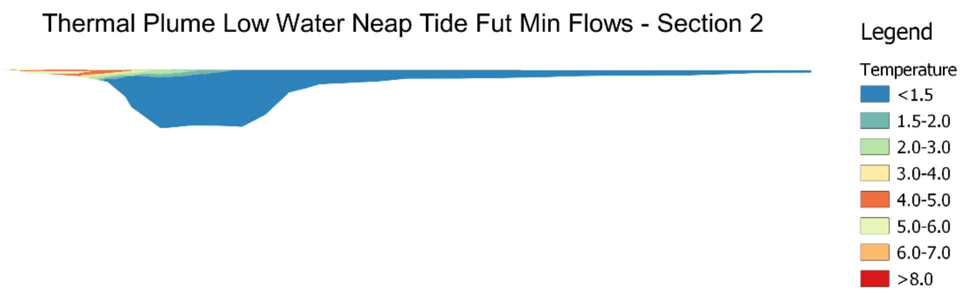

Figure G.27 Section 2 - Thermal Plume at Low Water

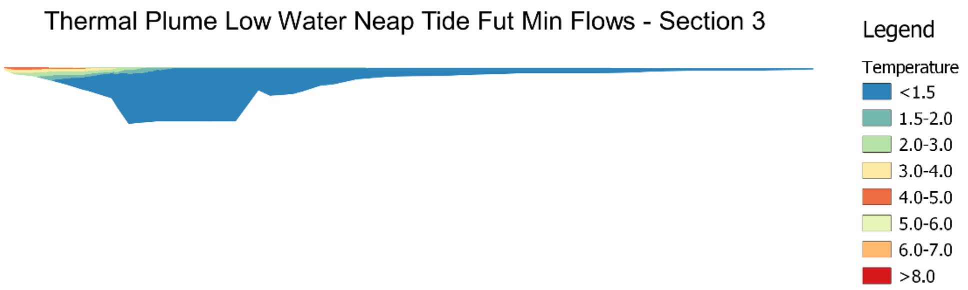

Figure G.28 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	14
2	9
3	9

Table G.7 Thermal Plume Percentage Cross Section

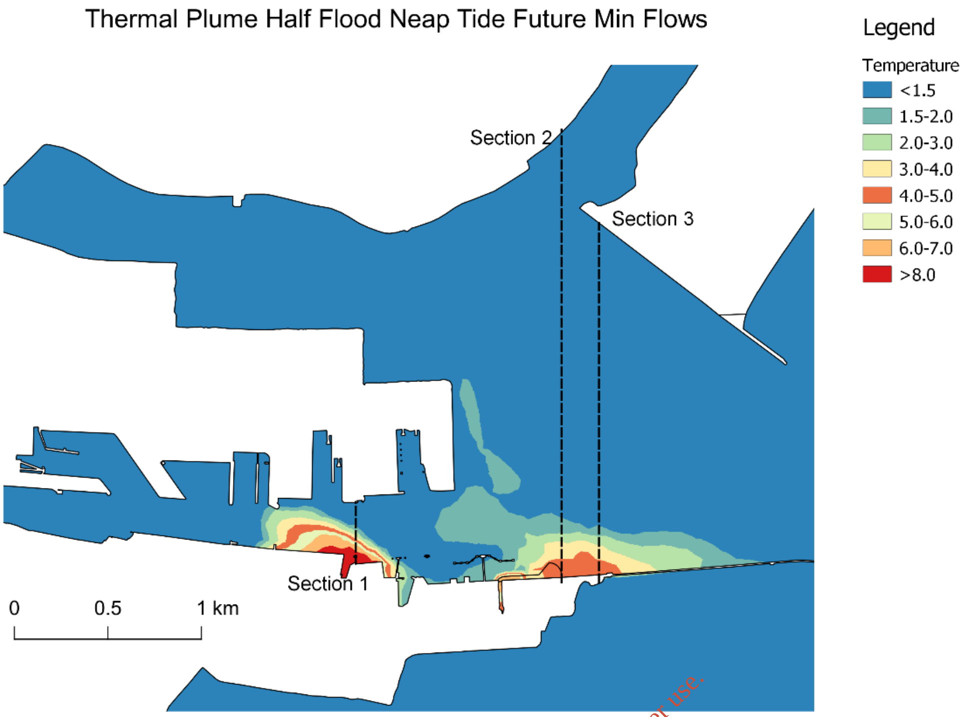

Figure G.29 Surface Water Thermal Plume at Half Flood

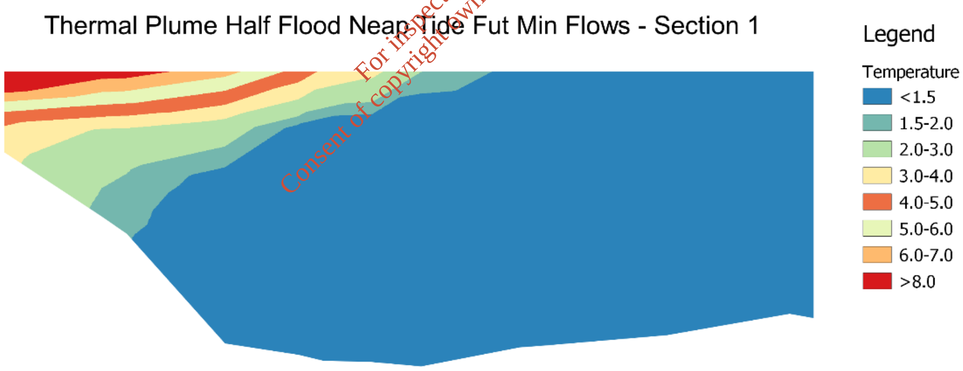

Figure G.30 Section 1 - Thermal Plume at Half Flood

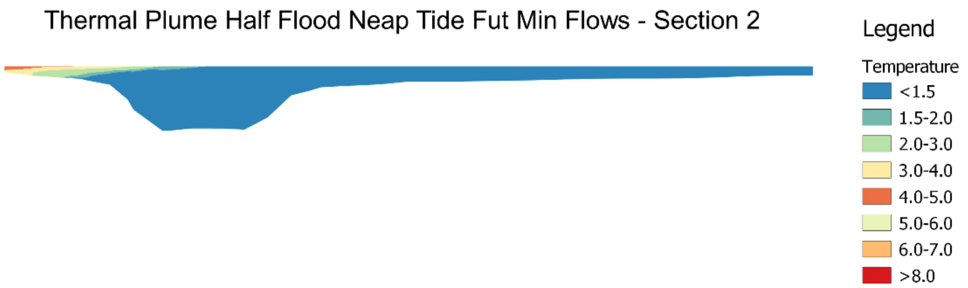

Figure G.31 Section 2 - Thermal Plume at Half Flood

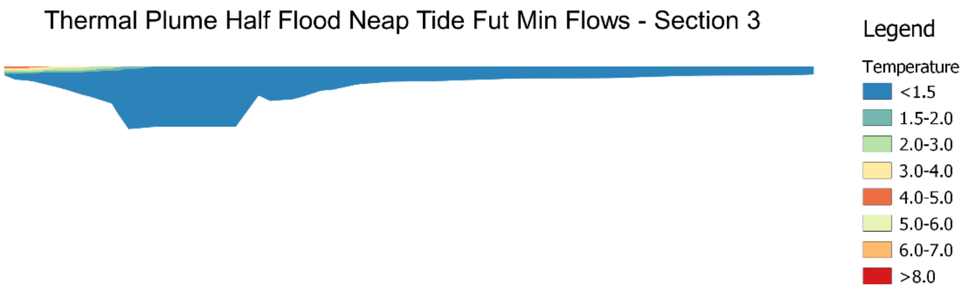

Figure G.32 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	19
2	7
3	4

Table G.8 Thermal Plume Percentage Cross Section

H. Appendix H - Results of All facilities operating at future maximum capacity with wet weather conditions

H.1. Spring Tide

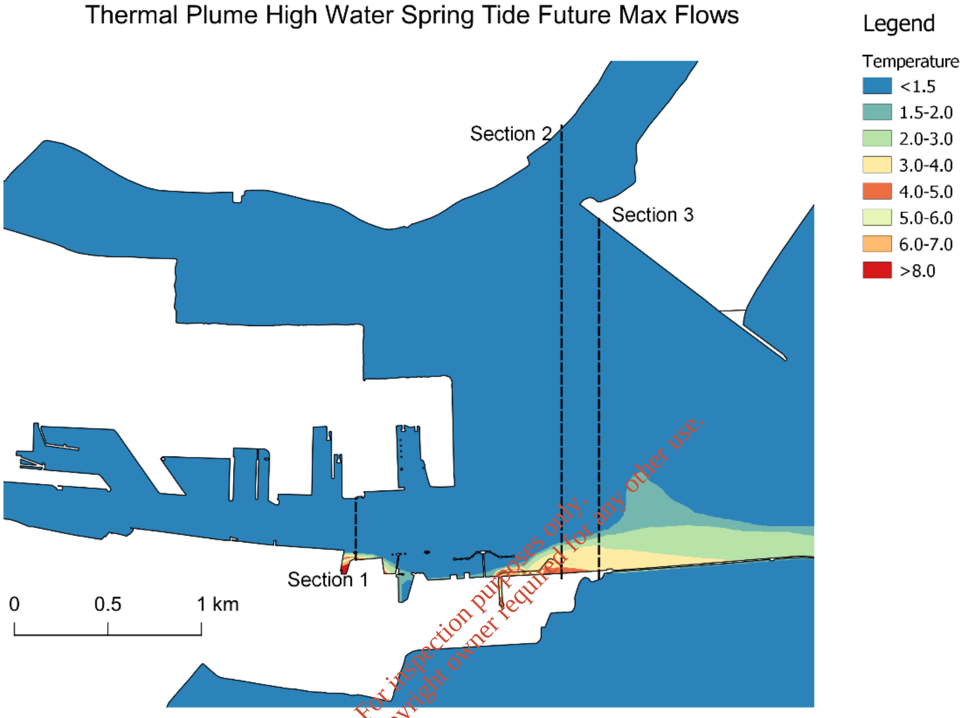

Figure H.1 Surface Water Thermal Plume at High Water

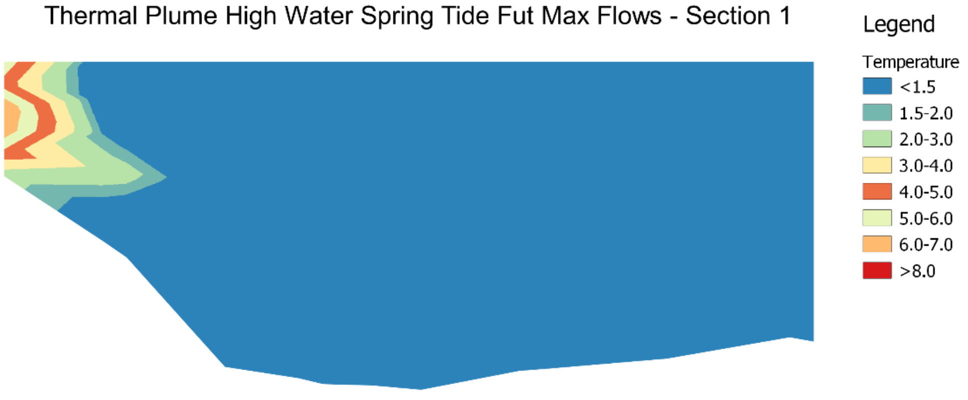

Figure H.2 Section 1 - Thermal Plume at High Water

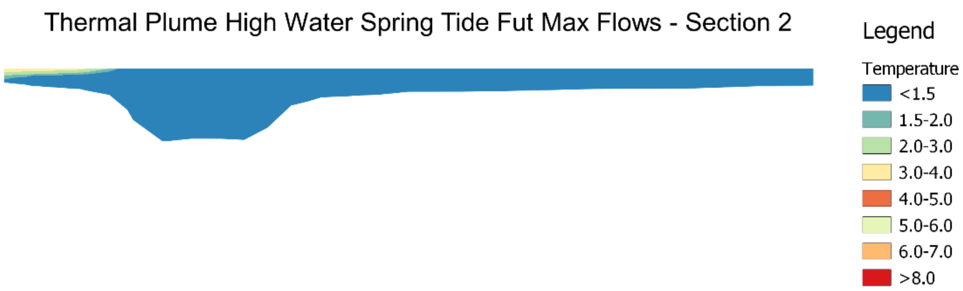

Figure H.3 Section 2 - Thermal Plume at High Water

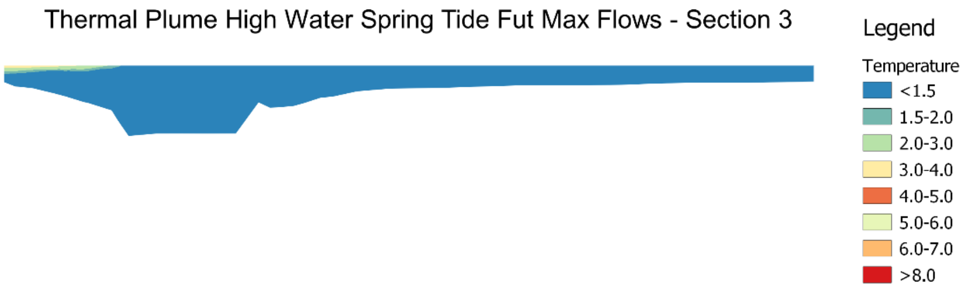

Figure H.4 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	6
2	3
3	3

Table H.1 Thermal Plume Percentage Cross Section

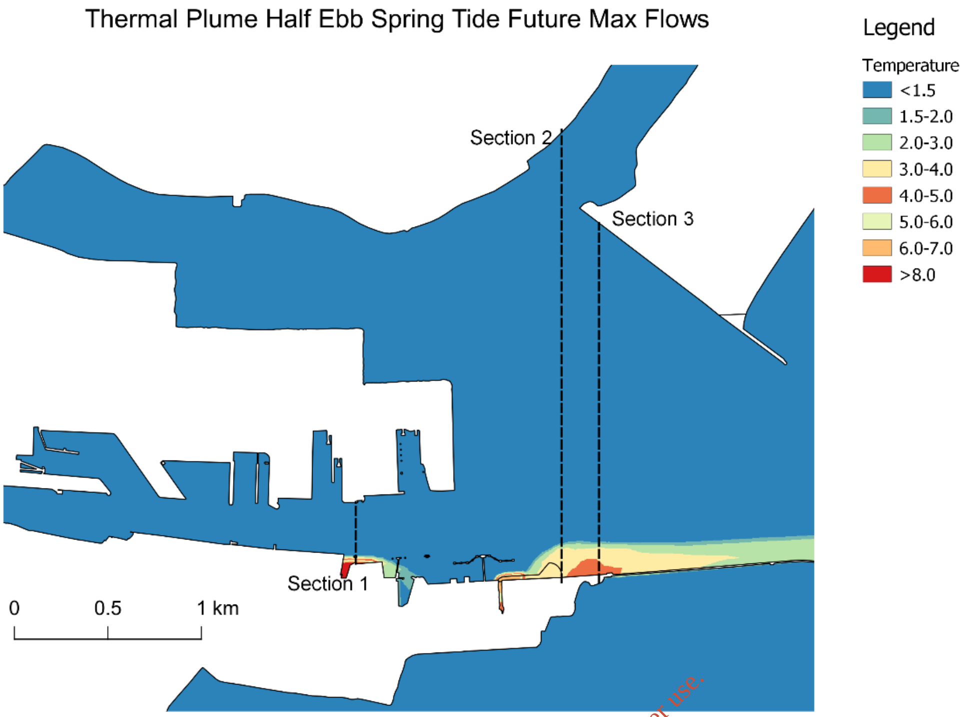

Figure H.5 Surface Water Thermal Plume at Half Ebb

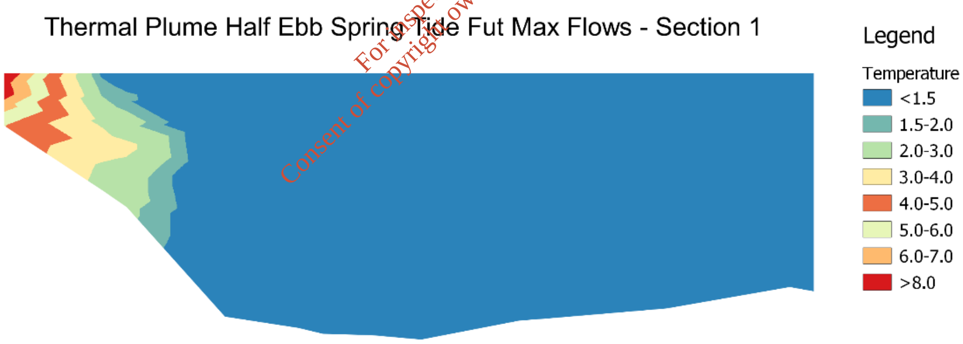

Figure H.6 Section 1 - Thermal Plume at Half Ebb

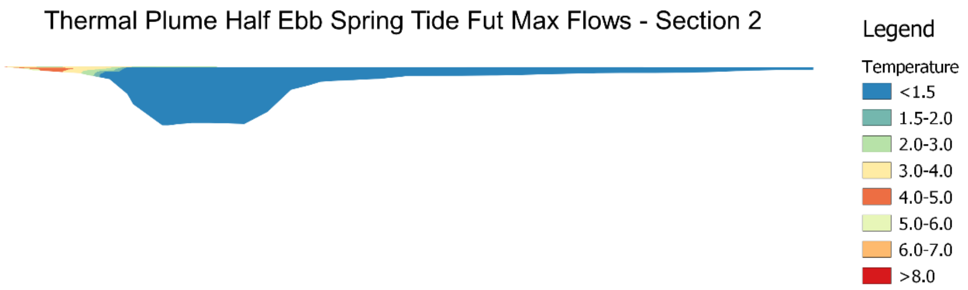

Figure H.7 Section 2 - Thermal Plume at Half Ebb

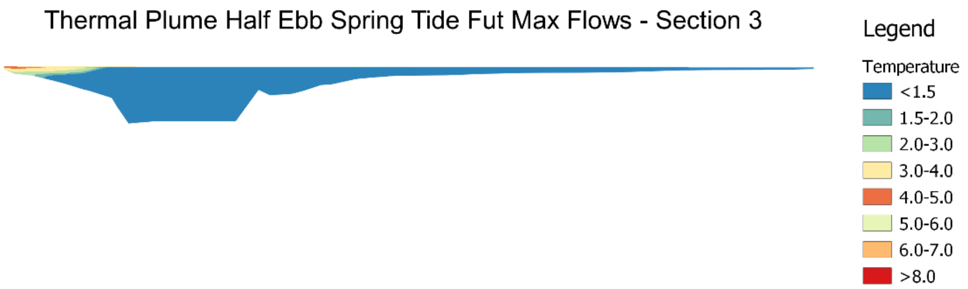

Figure H.8 Section 3 - Thermal Plume at Half Ebb

Section No	**% Cross-section**
1	10
2	4
3	5

Table H.2 Thermal Plume Percentage Cross Section

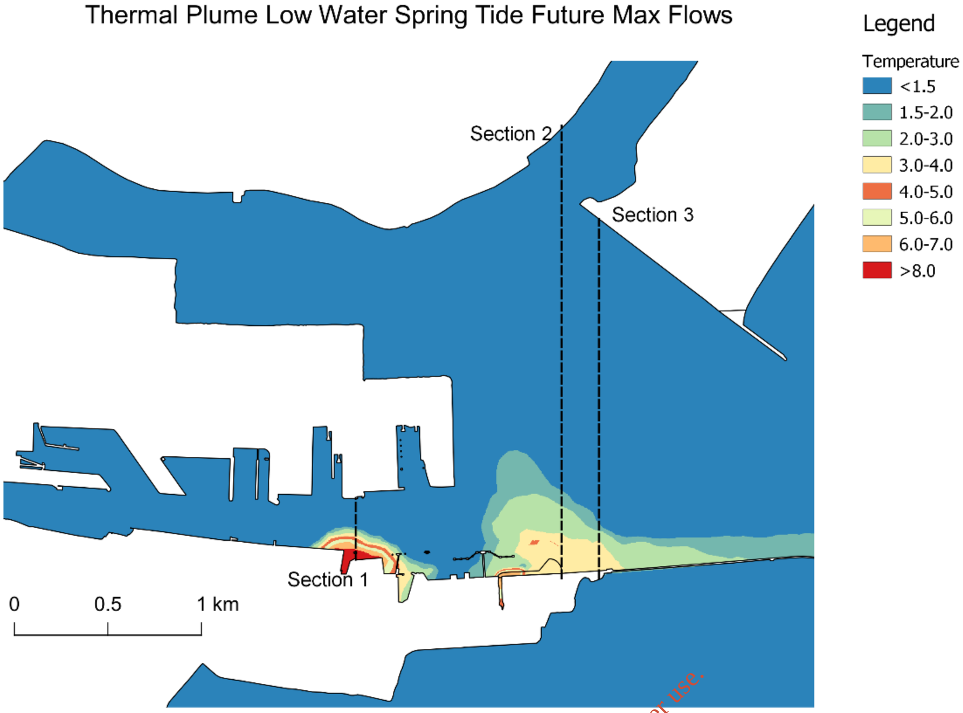

Figure H.9 Surface Water Thermal Plume at Low Water

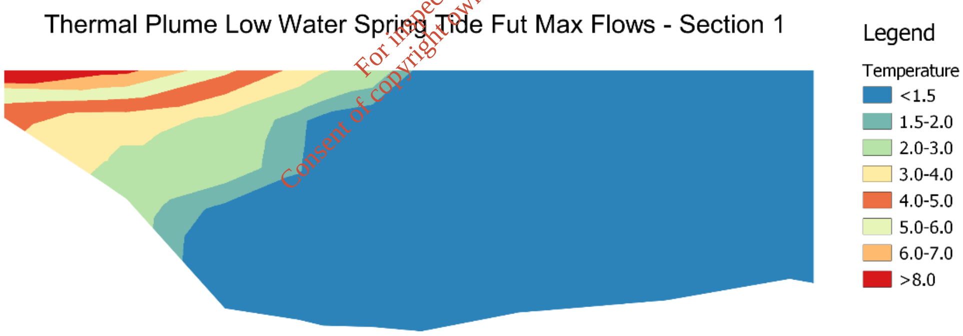

Figure H.10 Section 1 - Thermal Plume at Low Water

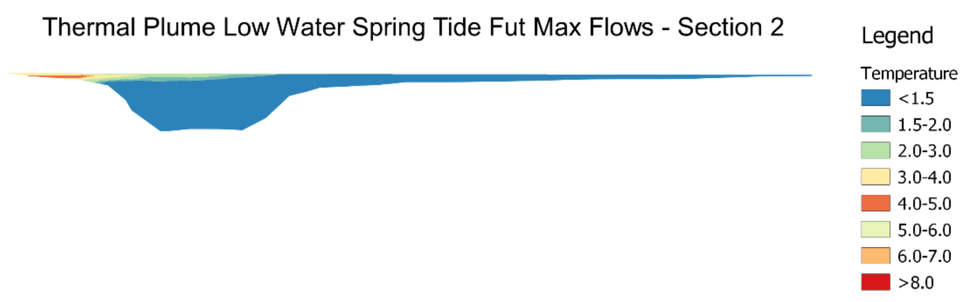

Figure H.11 Section 2 - Thermal Plume at Low Water

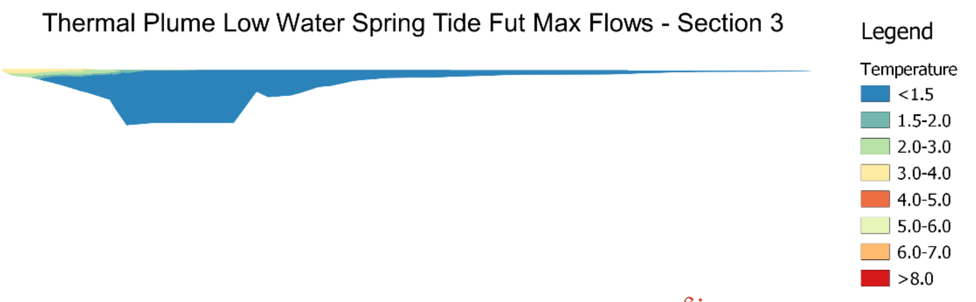

Figure H.12 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	23
2	10
3	6

Table H.3 Thermal Plume Percentage Cross Section

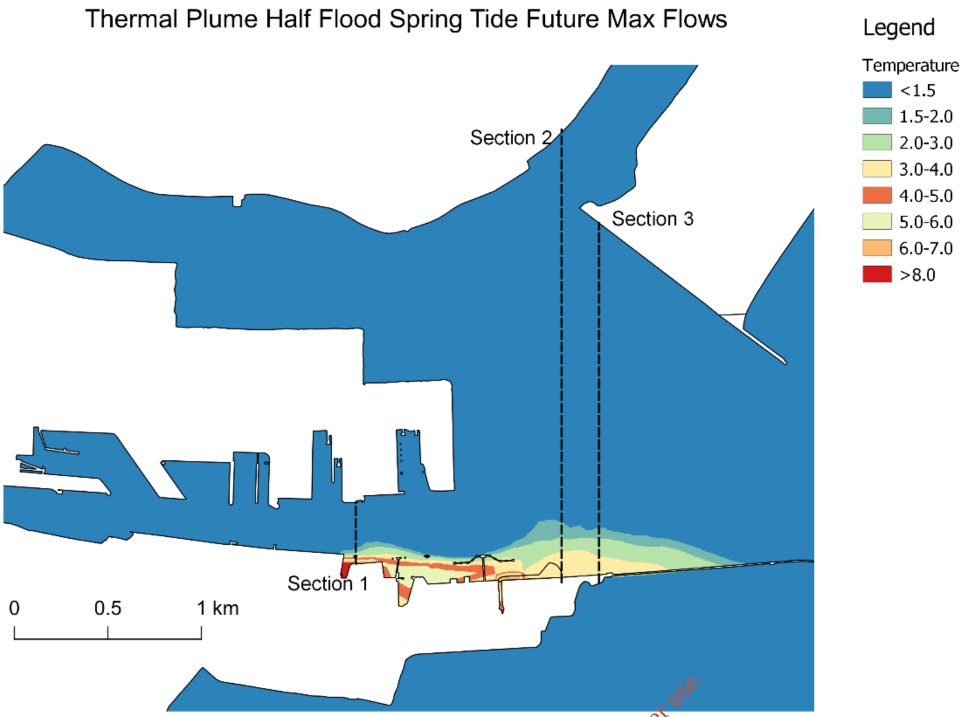

Figure H.13 Surface Water Thermal Plume at Half Flood

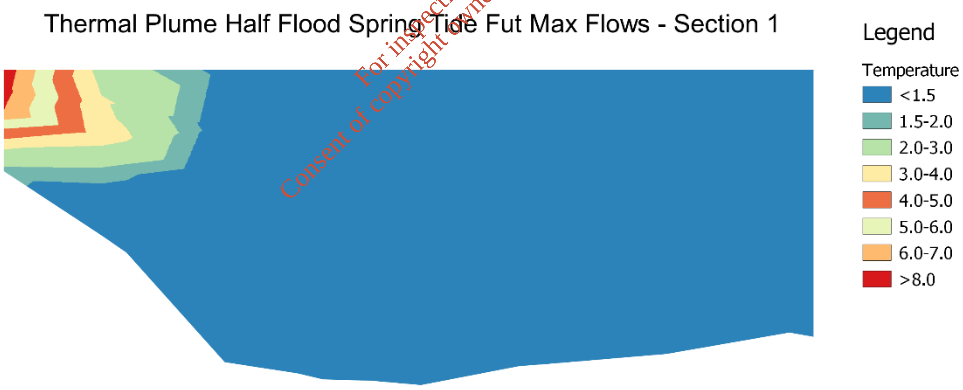

Figure H.14 Section 1 - Thermal Plume at Half Flood

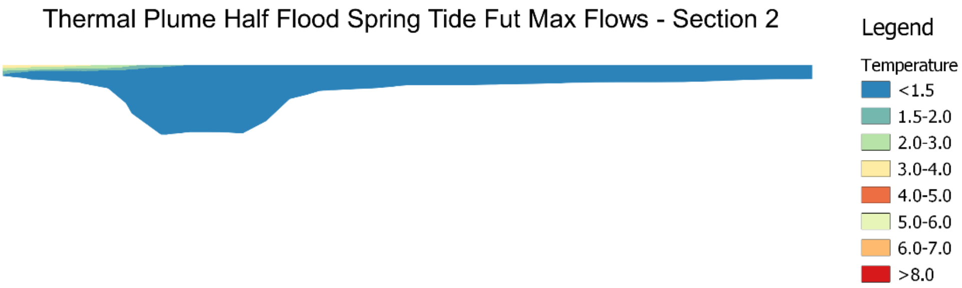

Figure H.15 Section 2 - Thermal Plume at Half Flood

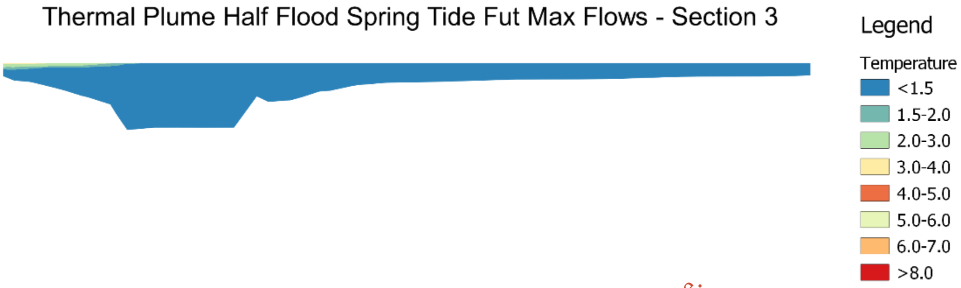

Figure H.16 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	10
2	4
3	3

Table H.4 Thermal Plume Percentage Cross Section

H.2. Neap Tide

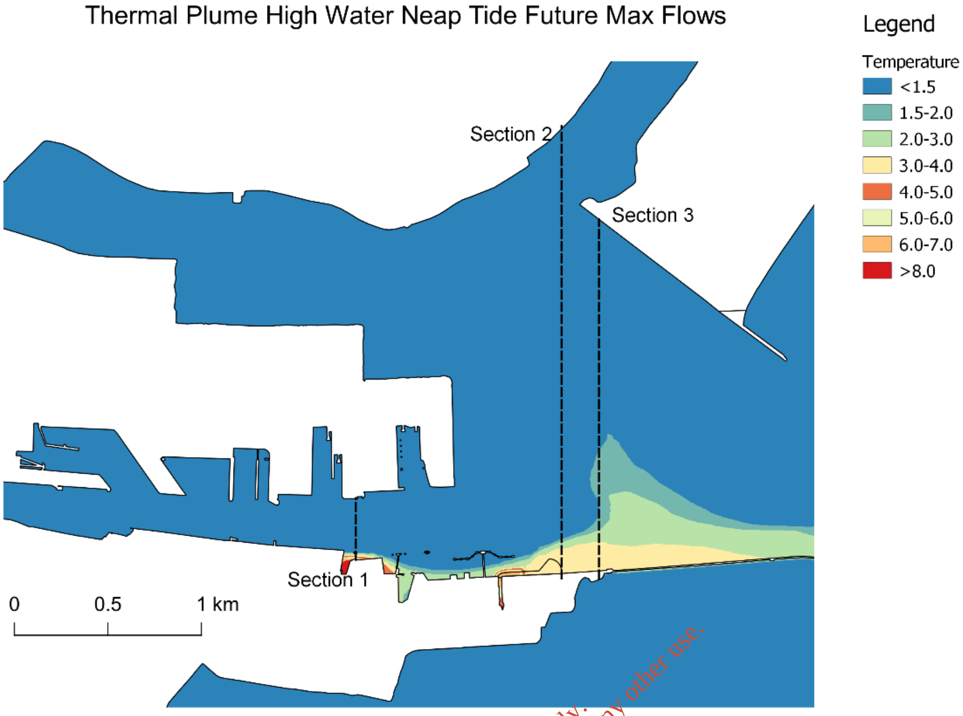

Figure H.17 Surface Water Thermal Plume at High Water

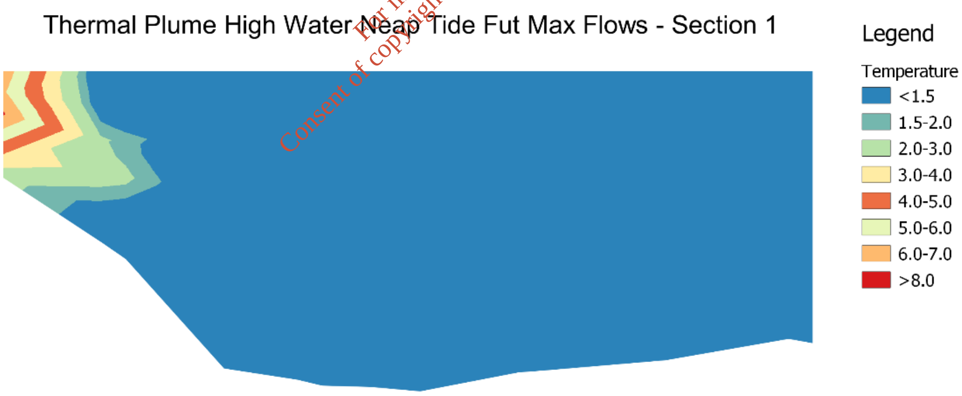

Figure H.18 Section 1 - Thermal Plume at High Water

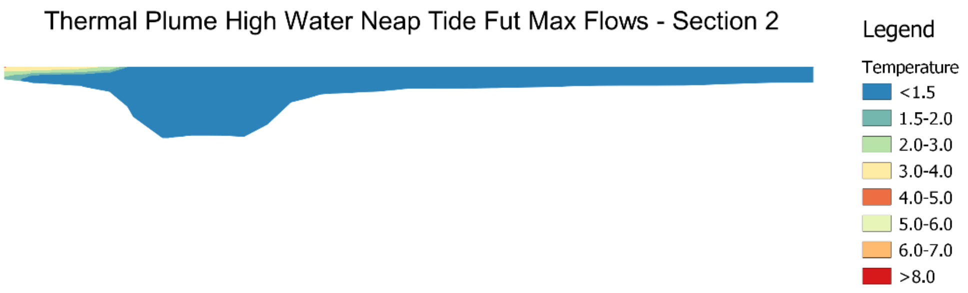

Figure H.19 Section 2 - Thermal Plume at High Water

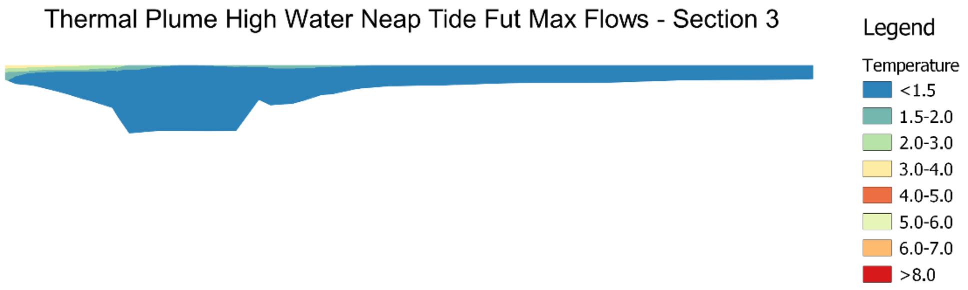

Figure H.20 Section 3 - Thermal Plume at High Water

Section No	% Cross-section
1	7
2	4
3	6

Table H.5 Thermal Plume Percentage Cross Section

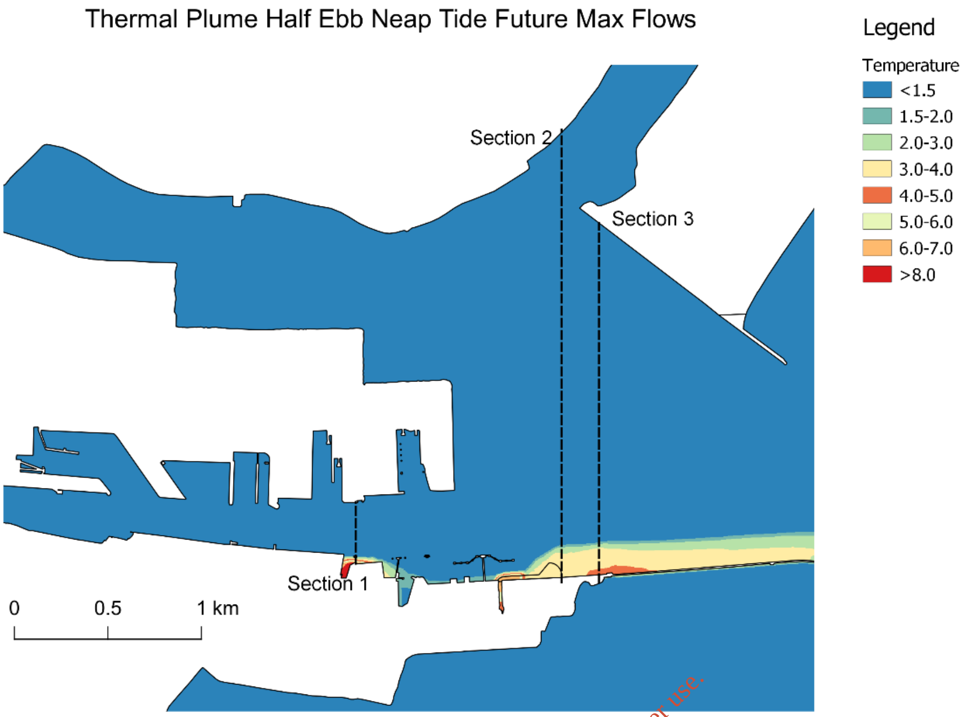

Figure H.21 Surface Water Thermal Plume at Half Ebb

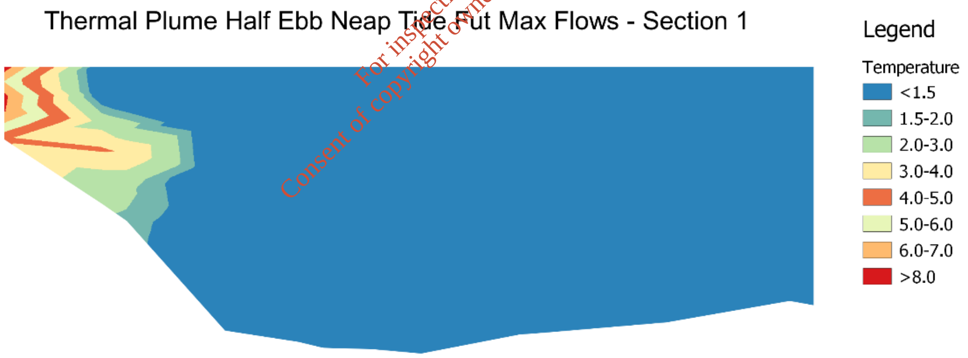

Figure H.22 Section 1 - Thermal Plume at Half Ebb

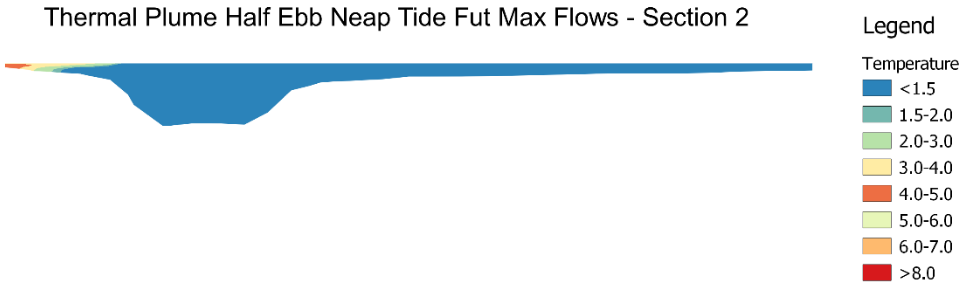

Figure H.23 Section 2 - Thermal Plume at Half Ebb

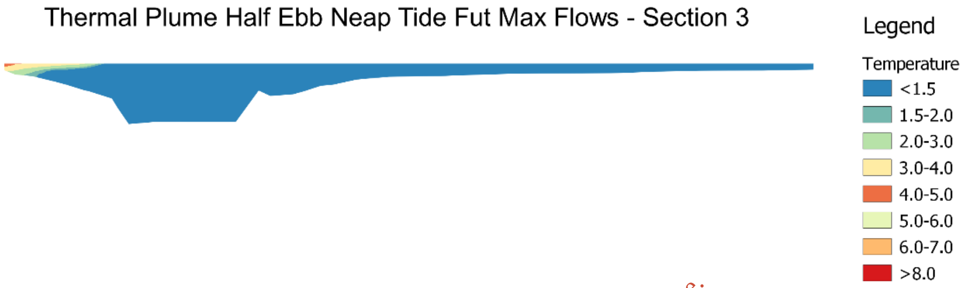

Figure H.24 Section 3 - Thermal Plume at Half Ebb

Section No	% Cross-section
1	9
2	4
3	4

Table H.6 Thermal Plume Percentage Cross Section

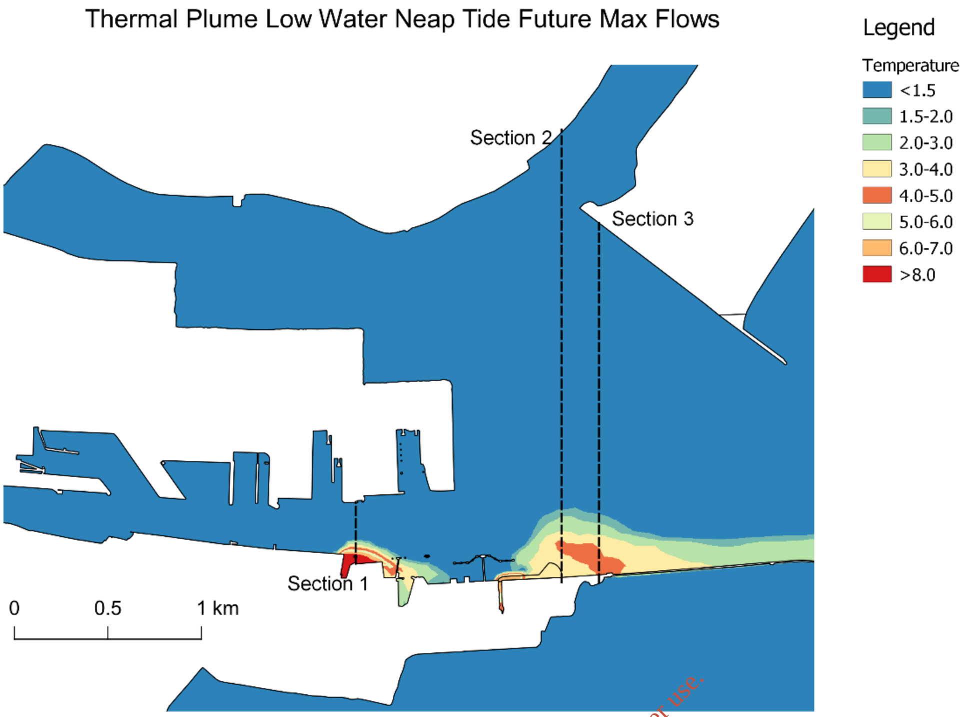

Figure H.25 Surface Water Thermal Plume at Low Water

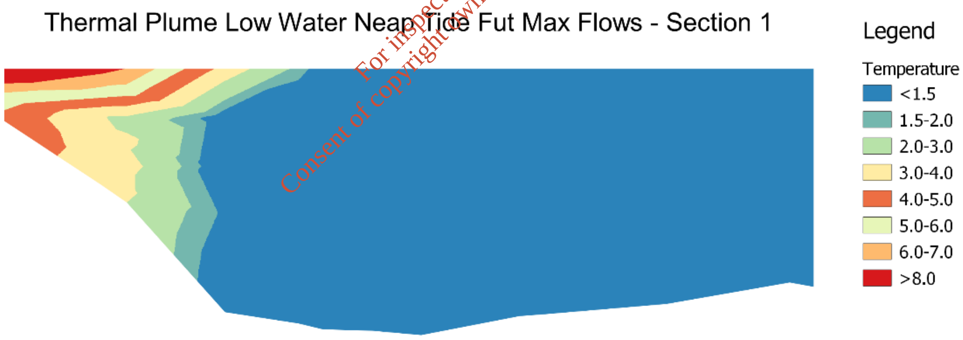

Figure H.26 Section 1 - Thermal Plume at Low Water

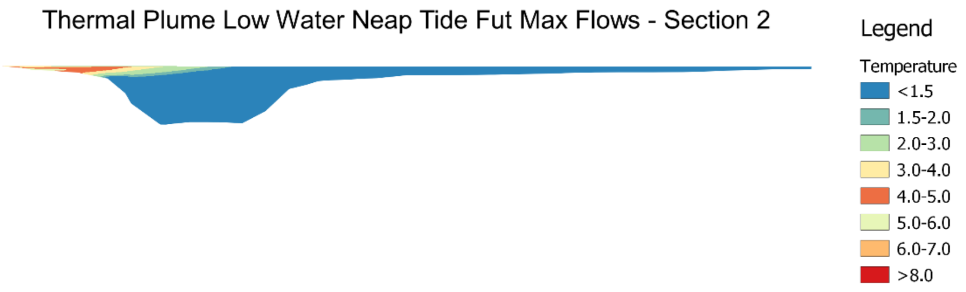

Figure H.27 Section 2 - Thermal Plume at Low Water

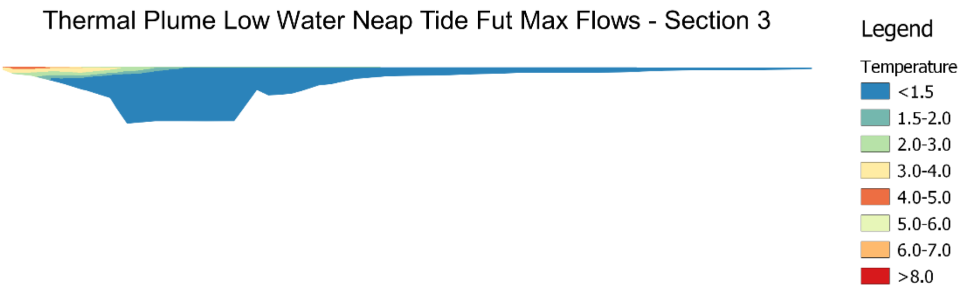

Figure H.28 Section 3 - Thermal Plume at Low Water

Section No	% Cross-section
1	16
2	10
3	10

Table H.7 Thermal Plume Percentage Cross Section

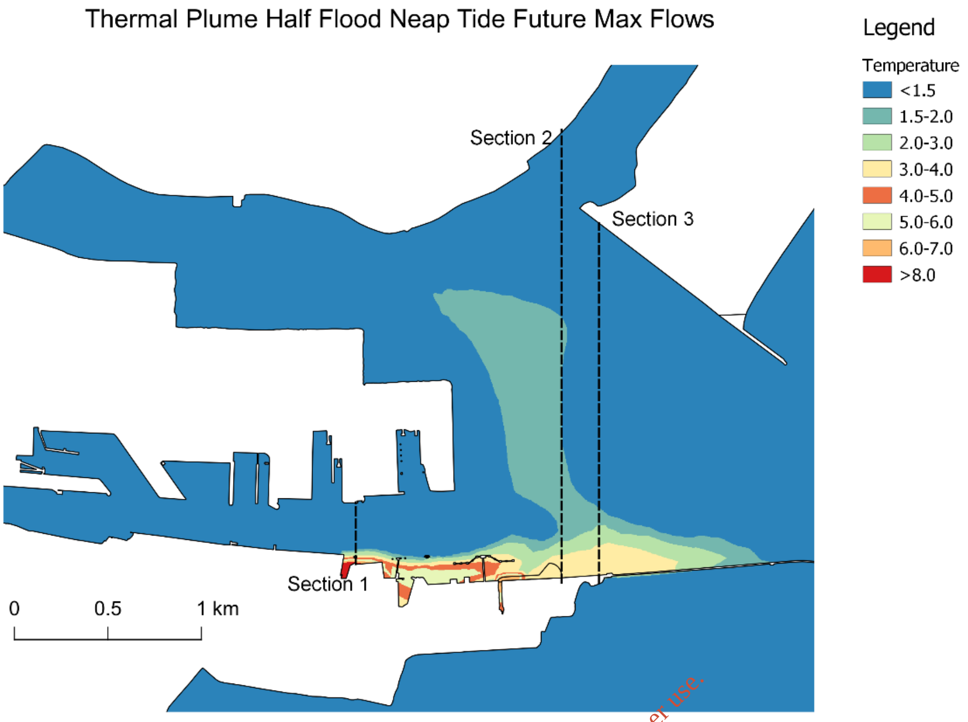

Figure H.29 Surface Water Thermal Plume at Half Flood

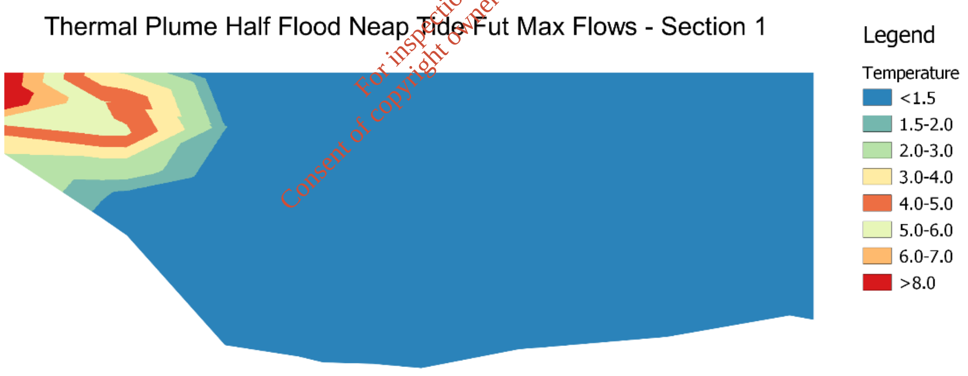

Figure H.30 Section 1 - Thermal Plume at Half Flood

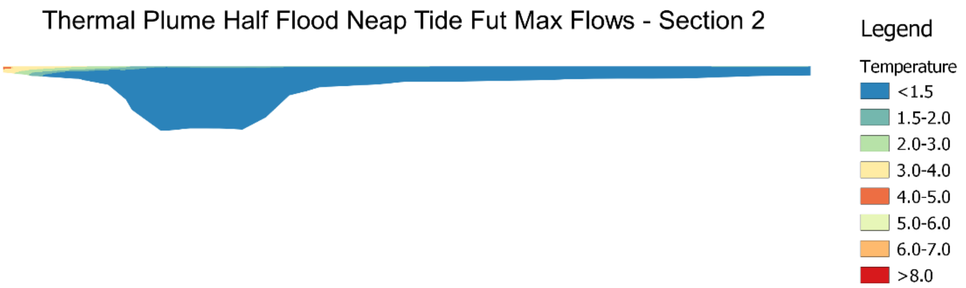

Figure H.31 Section 2 - Thermal Plume at Half Flood

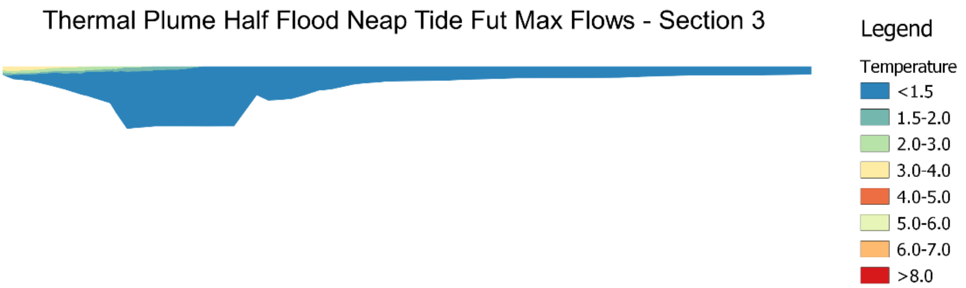

Figure H.32 Section 3 - Thermal Plume at Half Flood

Section No	% Cross-section
1	12
2	6
3	6

Table H.8 Thermal Plume Percentage Cross Section

I. References

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