Thermal Plume Model Report for West Offaly Power Station

AUGUST 2018

Report Prepared For

ESB

Report Prepared By

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1. Introduction

This report describes the development of a mathematical model of the River Shannon at Shannonbridge to consider the effects of thermal discharges from West Offaly Power Generating Station on the receiving waters. The model can be used to predict the variations in water temperature and quality.

This report concentrates on investigating the thermal plumes associated with thermal discharges from West Offaly Power (WOP) Generating Station for selected environmental conditions. In particular, the objective is to predict the extent of the thermal plume resulting from the cooling water discharge when West Offaly Power Generating Station is operating on full load when flows in the river Shannon are low. Graphical representation of predicted temperature fields resulting from the continuous operation of West Offaly Power Generating Station are produced.

1.1. The River Shannon to Shannonbridge

The River Shannon is Ireland's largest river and drains a total area of more than 10,400km^2 from its source to Parteen Weir. There are three major lakes along its route, Lough Allen, Lough Ree and Lough Derg. Shannonbridge is situated approximately 25 km south of Lough Ree, the middle lake, see Figure 1.1. Flows in the river are estimated at Athlone the outlet of Lough Ree and from the OPWs hydrometric gauge at Banagher. Banagher is located approximately 12 km downstream of Shannonbridge. The catchment size of the river Shannon upstream of Athlone is 4,601 km^2, upstream of West Offaly Power, it is 6,200 km^2 and upstream of Banagher it is 7,981 km^2. The river Suck, the largest tributary of the river Shannon, flows into the river at Shannonbridge upstream of the cooling water discharge from West Offaly Power. The river Brosna the second largest tributary of the river Shannon flows into the river at Shannon Harbour 8 km downstream of the cooling water discharge from West Offaly Power but 3 km upstream of the OPW gauge at Banagher.

1.1. Cooling Water Discharge

Maximum cooling water discharge from the 150 MW unit at WOP at full load is approximately 5.5 m^3/s. There is no change to the flow in the river Shannon as the cooling water is abstracted and returned. The maximum temperature rise across the condenser is assumed at 8.5^{o}C.

The size and extent of the thermal plume associated with the discharge of cooling water at elevated temperature to the Shannon is mainly determined by the magnitude of flow in the river. The lower the flow the larger the thermal plume.

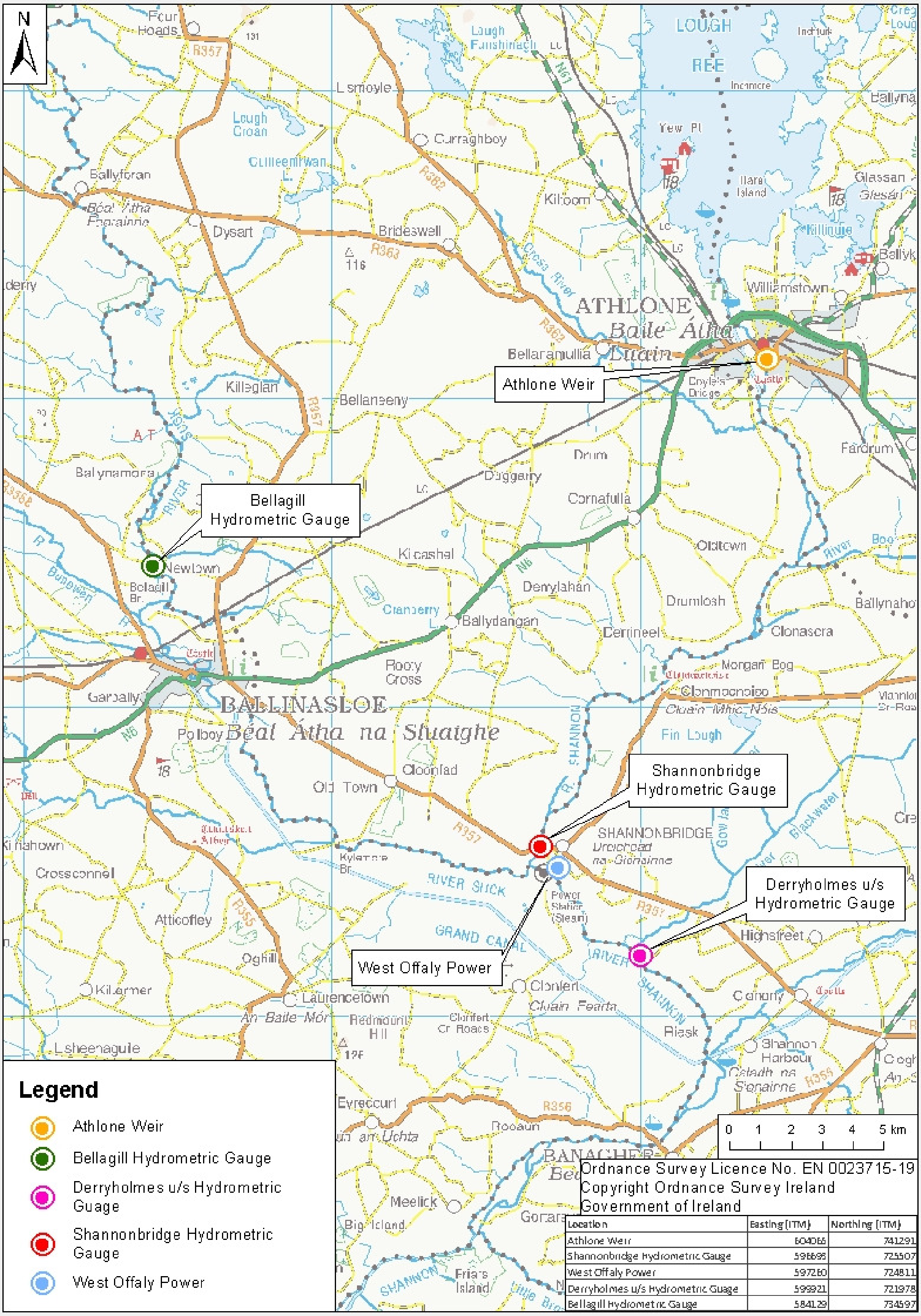

Figure 1.1 Locations of West Offaly Power, Shannonbridge Gauge and Athlone Weir

2. Hydrodynamic Model

The thermal plume model for West Offaly Power was developed using TELEMAC-3D, a three dimensional hydrodynamic modelling software developed by Electricité de France. 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. Model Setup

The model domain is as shown in Figure 3.1. This section of the River Shannon was surveyed bathymetrically by consultants working on behalf of ESB in November 2015 and March 2018.

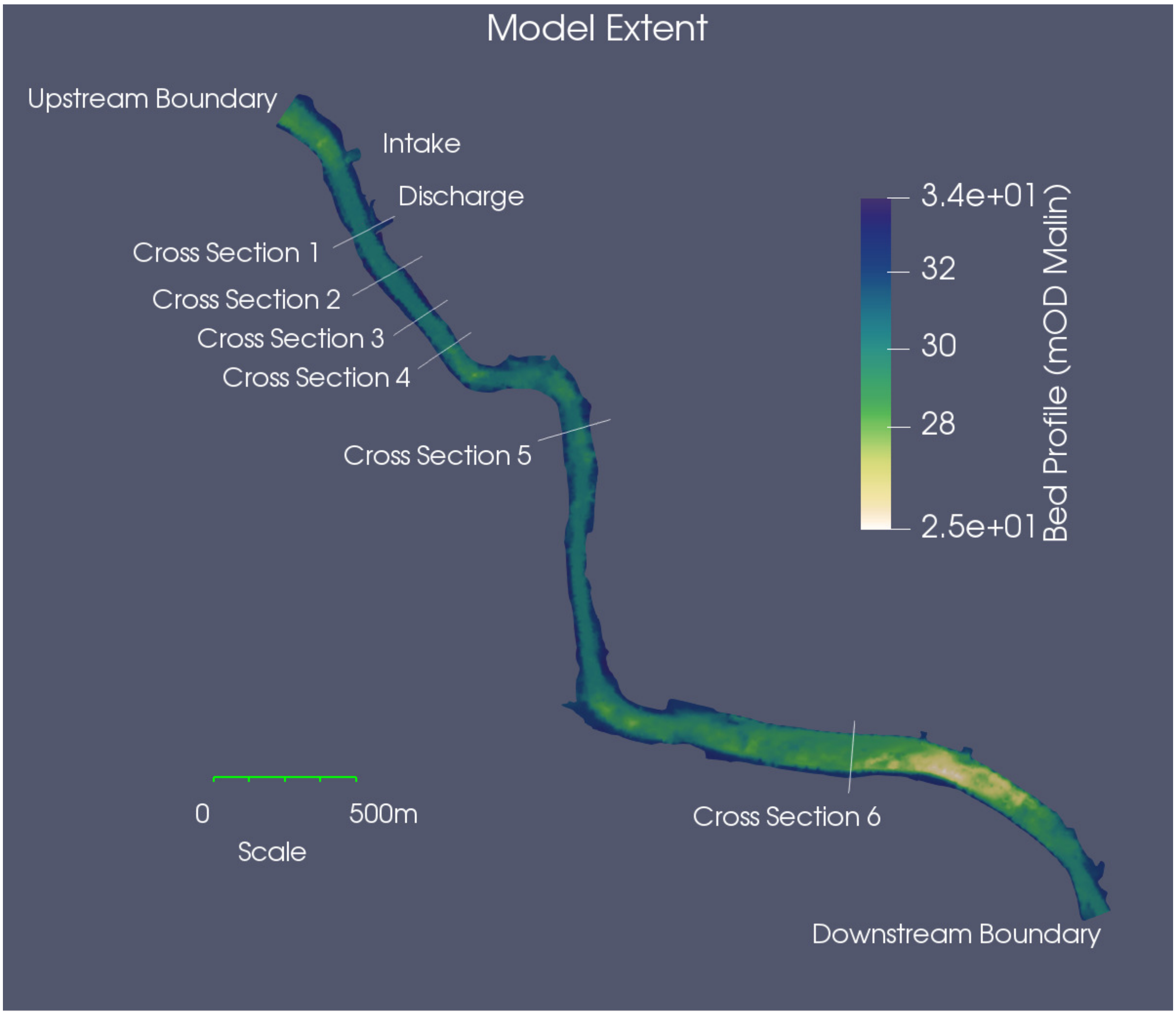

Figure 3.1 - Bed Elevation and cross-section locations along the River Shannon for model domain at Shannonbridge

The model domain has been discretised into an unstructured mesh as shown in Figures 3.2a and 3.2b. A fine mesh was used for the river Shannon from the upstream boundary condition to approximately 900m downstream of the West Offaly Power's cooling water discharge point. This fine mesh was required to accurately model 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.

A flow boundary condition with a fixed temperature value is used for the upstream boundary condition as shown in Figure 3.1. It has been assumed that the water flowing into the domain is at ambient temperature. The downstream boundary as shown in Figure 3.1 is a fixed water level with a free temperature value. At this boundary, the temperature is governed by water temperature in the model domain and is allowed to vary.

Figure 3.2a Unstructured Mesh used in the Model - top

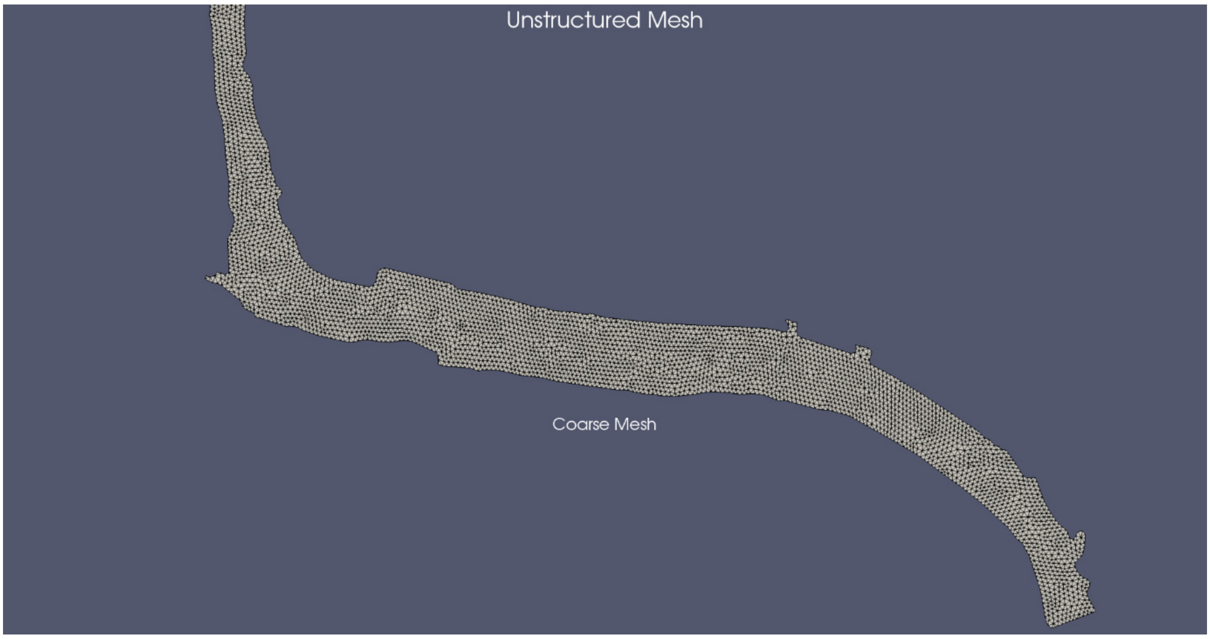

Figure 3.2b Unstructured Mesh used in the Model - bottom

4. River Flows and Levels

The mathematical model of the river Shannon at Shannonbridge is being used to simulate the areal extent and depth of the thermal plume from West Offaly Power for low flows conditions. At high flows, there is significant overbank flow and the thermal plume is small when compared to the higher flow levels.

Flow values in this reach of the river Shannon are readily available only at Athlone (the outlet of Lough Ree) and Banagher. Generally, there is likely to be a strong correlation between the flow at Athlone and the flow at Shannonbridge.

The model's upstream boundary is a flow boundary condition with a fixed temperature. The fixed temperature is set as ambient temperature.

The flow at Shannonbridge consists of the discharge from Athlone, the flow in the River Suck and the flow from the catchment of the river Shannon between Athlone and Shannonbridge. There is no rated hydrometric gauge at Shannonbridge and therefore in the absence of local flow data, it is difficult to estimate accurately the River Shannon flow at Shannonbridge. However, two methods have been used both of which based on professional judgement and give reasonable results.

Method 1 - Flows at Shannonbridge can also be estimated from the values at Athlone using ratios of relative upstream catchment area as outlined in the table below.

Shannon Catchment	Upstream Catchment Area km^2	Ratio to Athlone
Athlone	4,601	1
Shannonbridge	6,200	1.35

Table 4.1 Upstream Catchment Areas

Method 2 - The OPW operates hydrometric gauge 26007 on the river Suck at Bellagill upstream of Ballinasloe. This is a rated gauge so flow can be estimated from the water level. The flow at Shannonbridge can be estimated by adding the discharge from Athlone to the flow at Bellagill.

Both methodologies give approximate values only but are sufficiently accurate for use in the mathematical model.

Data from the rated OPW gauge 25017 Banagher was not considered as the OPW states that it cannot be used to estimate flows in the river Shannon when levels are medium to low.

The downstream boundary is a fixed water level with a free temperature. The temperature at this boundary is dependent on the temperature in the model domain.

There are four OPW water level only hydrometric gauges on the river Shannon in the vicinity of Shannonbridge.

- OPW Gauge 26028 Shannonbridge located upstream of the road bridge at Shannonbridge,
- OPW Gauge 26353 W.O.P.S Rail Bridge located just downstream of Bord Na Mona's railway bridge and West Offaly Power's outfall,
- OPW Gauge 26351 Derryholmes u/s located approximately 4 km downstream of West Offaly Power's outfall and
- Gauge 26352 Derryholmes d/s located approximately 4.5 km downstream of West Offaly Power's outfall.

None of the gauges are rated, so it is not possible to estimate flow from water level.

OPW Gauge 26028 has been in existence since 1983 whereas the other 3 gauges were installed in late 2016.

The model's downstream boundary is located at the location of OPW Gauge 26351 Derryholmes u/s.

5. Model Simulations

The model was run for the following scenarios:

- Conditions on 31st July 2014
- Conditions on 29th April 2016
- the 95 percentile flow in the River Shannon (based on the flow record at Athlone)
- the 75 percentile flow in the River Shannon (based on the flow record at Athlone)

Thermal Plume surveys of the River Shannon at Shannonbridge were carried out for ESB by Irish Hydrodata Ltd. on the 31st July 2014 and the 29th of April 2016. The results of these surveys are used for model calibration and verification. The 95 and 75 percentile flows represent a range of low to medium flow conditions in the River Shannon.

The model results have also been compared to the temperature data recorded by the programme of continuous temperature monitoring ongoing at Shannonbridge since 2016. The model results are in good agreement with this data.

Cross-sections of the River Shannon presenting the model results have been produced at locations 100m, 250m, 450m, 600m, 1.2 km and 3km downstream of the discharge.

The thermal plume is defined as where the temperature rise with respect to ambient is greater than 1.5 ^{o}C in line with condition 5.5 of the Industrial Emissions Licence for the WOP station.

5.1. Calibration and Verification

Two thermal plume surveys were carried out, during low to medium flow conditions, on 31st July 2014 and 29th of April 2016 respectively. The model has been calibrated against these surveys.

5.1.1. Conditions on 31st July 2014

The thermal Plume survey on the 31st of July 2014 was carried out during a period of low flow and low water levels in the River Shannon.

A key input to the TELEMAC-3D model is flow in the River Shannon. As discussed above, in the absence of a rated hydrometric gauge at Shannonbridge it is necessary to undertake estimates of flow based at hydrometric conditions at neighbouring sites as set out below.

- **Method 1 -** The calculated flow at Athlone on 31st of July 2014 was 16.69 m^3/s. This equates to the 96.8 percentile flow for the period 1957 to 2017. Using the relative catchment ratio methodology gives an estimated flow of 22.53 m^3/s at Shannonbridge.
- **Method 2 -** The estimated flow at Bellagill near Ballinasloe on the river Suck on 31st of July 2014 was 5.8 m^3/s. The OPW flow statistics puts this flow between 75 and 90 percentile flow for Bellagill. The associated water level at Bellagill was 40.7 m OD Poolbeg and this is between the 90 and 95 percentile level for Bellagill. Combining the estimated discharge from Athlone and estimated flow at Bellagill gives a Shannonbridge flow of 22.49 m^3/s.

Both methodologies give very similar values for Shannonbridge.

The TELEMAC-3D model was used to simulate the thermal plume behaviour on 31st of July 2014 with these estimated flow conditions as inputs. From a comparison of the thermal plume survey and the results of the mathematical model, it was found that the model gives the best representation of the surveyed thermal plume when a slightly lower flow of 19 m^3/s is used as the upstream boundary condition. This figure is close enough to the estimated flows to be acceptable.

The water level on the 31st of July 2014 at OPW Gauge 26028 Shannonbridge was 32.669 mOD Malin. This corresponds to a gauge level of 2.141m. The 3 other OPW Gauges listed in Section 4 above were not in operation at this time but a comparison of levels when all four gauges were in operation gives an estimated level of 32.49 mOD Malin for this date for the location of OPW Gauge 26351 Derryholmes u/s which is also the downstream boundary of the model.

The average wind speed and direction recorded at the nearest representative Met Éireann meteorological station, Gurteen, Co. Tipperary, on 31st of July 2014 was approximately 11.3 knots and from a west south west direction and this was included in the model simulation.

The station was at or near full load for the previous two months.

In summary, the following parameters were used for the 31st of July 2014 model scenario:

Parameter	**Value**	**Unit**
Station Load	150	MW
Cooling Water Discharge	5.5	m^3/s
Temperature rise across the condenser	8.5	^oC
Wind speed	11.3	knots
Wind direction	west south west	
Upstream boundary condition - River Shannon Flow	19	m^3/s
Downstream boundary condition - Water level at Derryholmes	32.49	m OD

Table 5.1 Model Scenario of 31st of July 2014 – Input Parameters

The results of the model and the thermal plume survey are in good agreement. The river Shannon was surveyed from just upstream of the intake to 1.5 km approximately downstream of the discharge whereas the model extends to approximately 4 km downstream.

Both show that the thermal plume took up the entire cross-sectional area of the river Shannon. The survey showed at 1.5 km downstream of the discharge point the temperature rise in the thermal plume was over 2 ^oC which is consistent with the model results. The model shows that the thermal plume on the 31st of July 2014 extended to approximately 4 km downstream of the discharge point.

Model Results

Figure 5.1 shows that the simulated thermal plume flows directly out from the WOP discharge channel to the west bank of the river. It extends approximately 4 km downstream of the discharge point and is spread over the entire water channel from approximately 200 m downstream. The highest temperatures, as expected, occur close to the discharge point and gradually dissipate with distance. Because the thermal plume flows across the river channel, higher temperatures occur at the west bank of the river. Simulated conditions at selected cross-sections downstream are summarised below.

- At cross-section 1, (Figure 5.2) 100 m downstream of the discharge point, the simulated thermal plume is confined mainly to the eastern half of the river channel. The maximum simulated temperature rise is approximately 7.3°C.
- At cross-section 2, (Figure 5.3) 250 m downstream of the discharge point, the simulated thermal plume covers the entire cross-section of the river channel with higher temperatures on the western side of the channel. The maximum simulated temperature rise is approximately 3.2°C.
- The simulated thermal plume at cross-sections 3, (Figure 5.4) 450 m and cross-section 4, (Figure 5.5) 650 m downstream of the discharge show the same features. The maximum simulated temperature rises are approximately 2.7°C and 2.6°C respectively.
- At cross-section 5, (Figure 5.6) 1.2 km and cross-section 6, (Figure 5.7) 3 km downstream of the discharge point, the thermal plume is more uniform. The maximum simulated temperature rises are approximately 2.3°C and 1.9°C respectively.

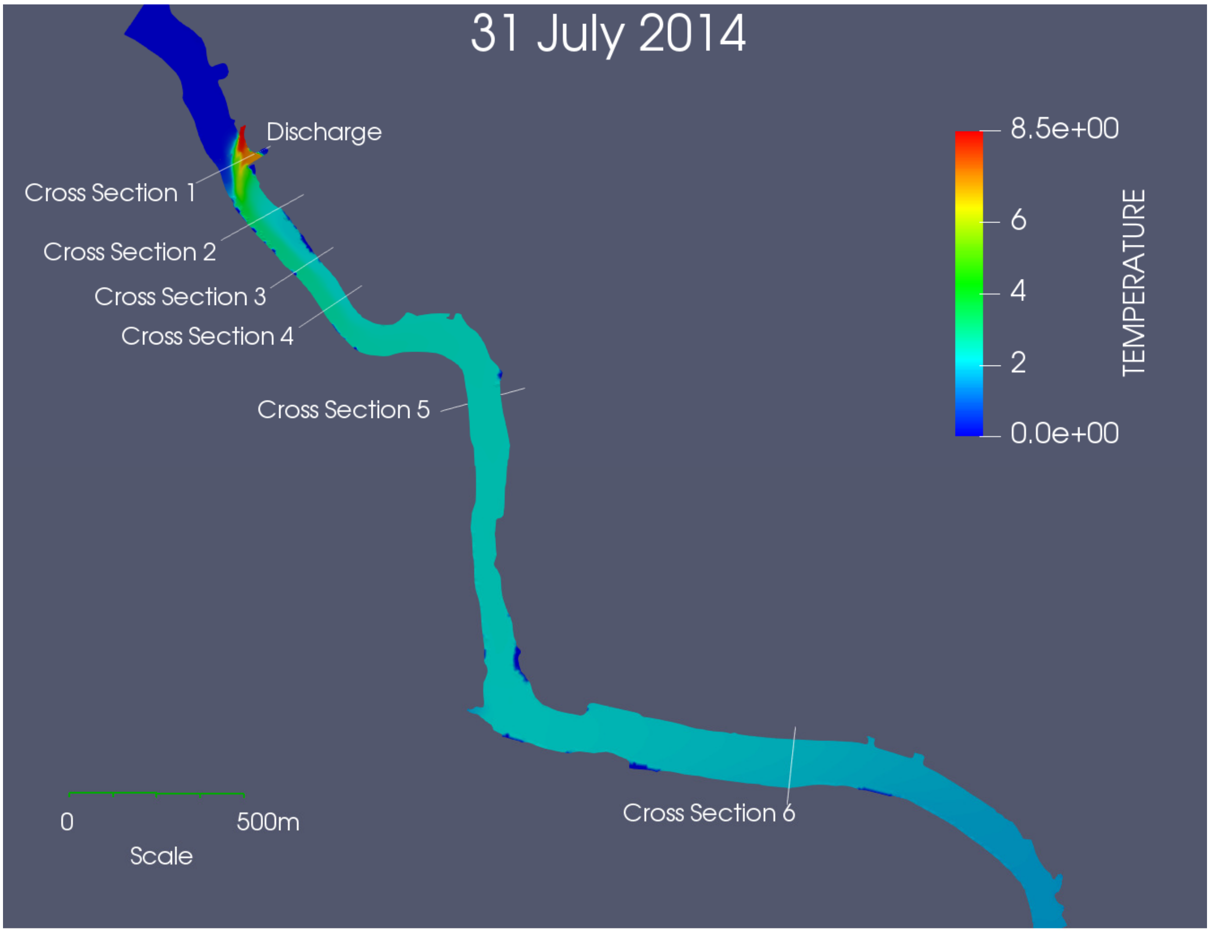

Figure 5.1 Plan of thermal Plume

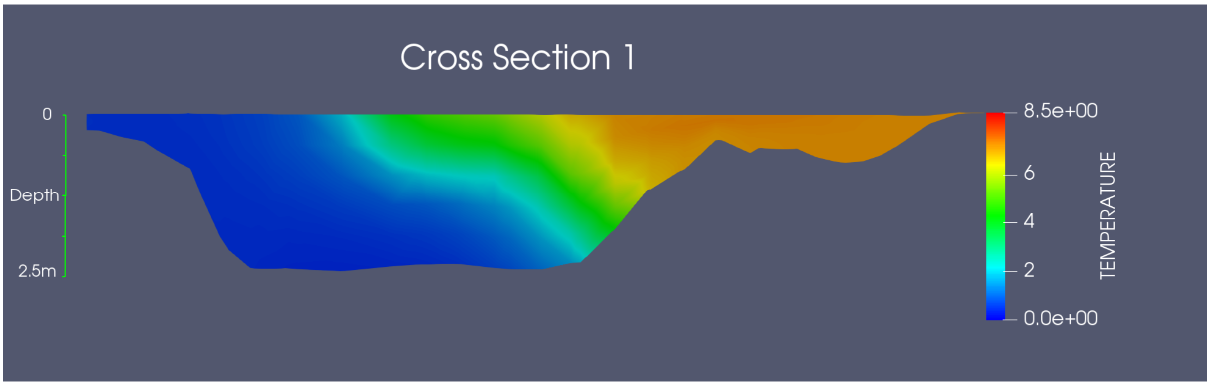

Figure 5.2 Cross-section 1 of thermal Plume *(100m downstream)*

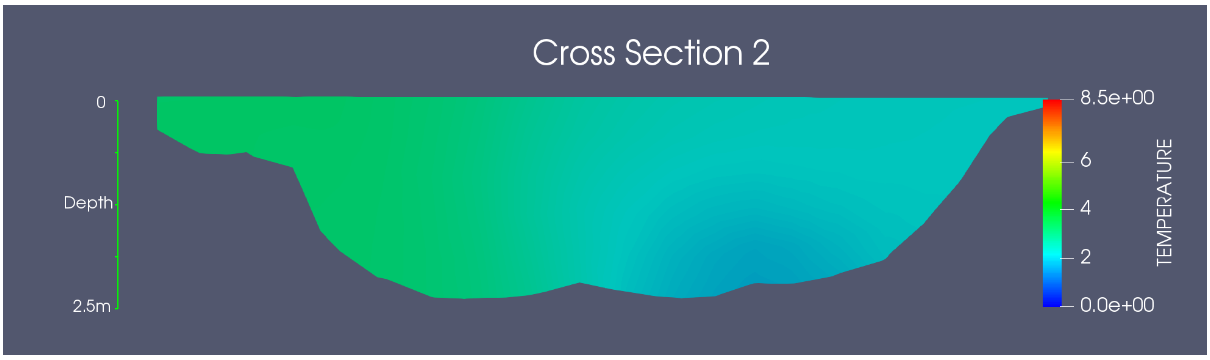

Figure 5.3 Cross-section 2 of thermal Plume (250m downstream)

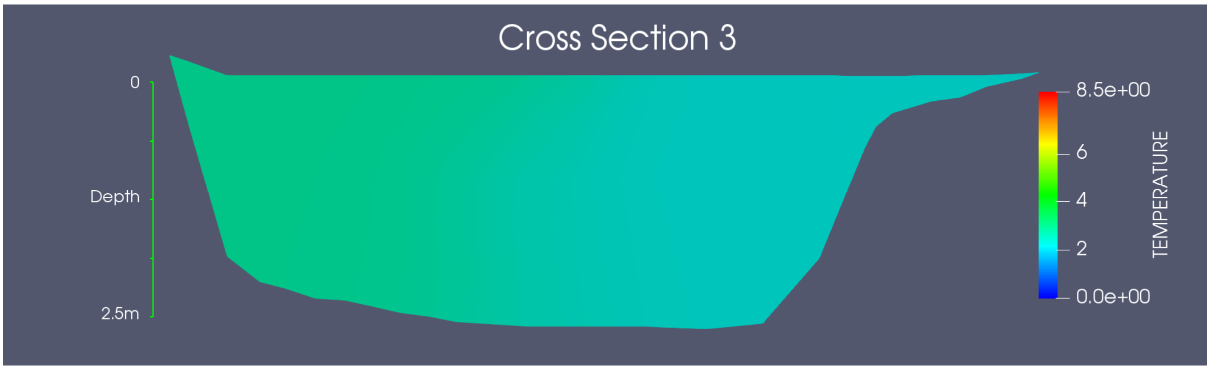

Figure 5.4 Cross-section 3 of thermal Plume (450m downstream)

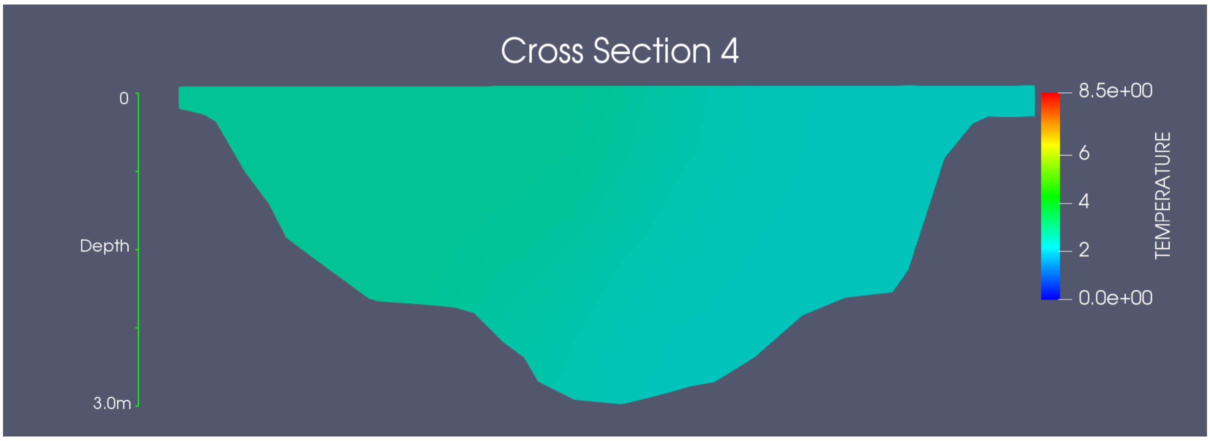

Figure 5.5 Cross-section 4 of thermal Plume (650m downstream)

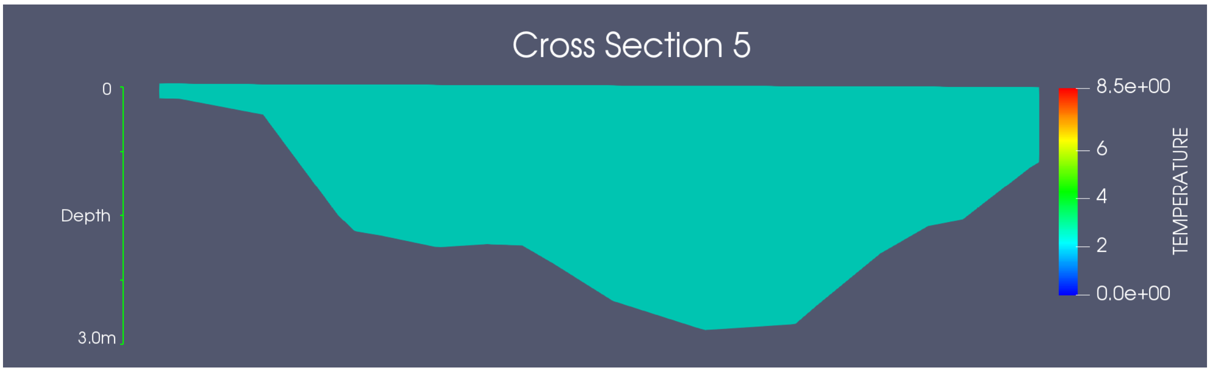

Figure 5.6 Cross-section 5 of thermal Plume (1.2km downstream)

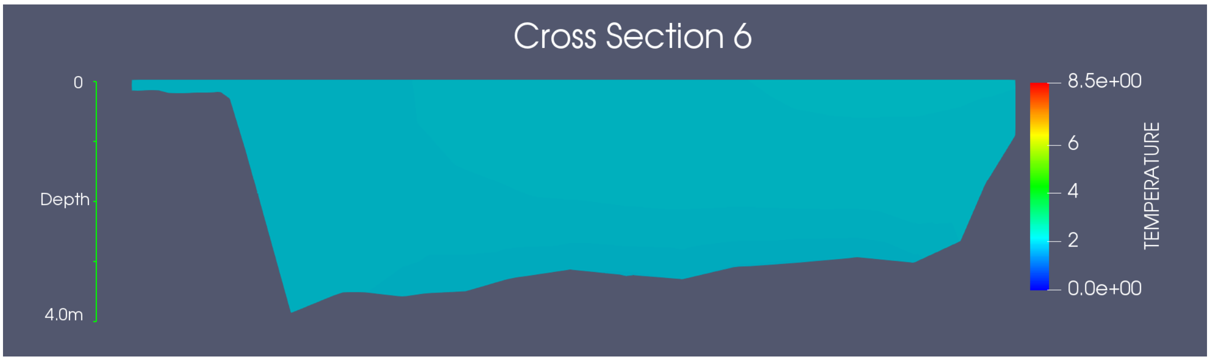

Figure 5.7 Cross-section 6 of thermal Plume (3.0km downstream)

5.1.2. Conditions on 29th of April 2016

The thermal Plume survey on the 29th of April 2016 was carried out during conditions of medium flow and water levels in the River Shannon. Flow values at Shannonbridge on this date were estimated as set out below.

- **Method 1 -** The calculated flow at Athlone was 71.49 m^3/s. This equates to the 52.4 percentile flow for the period 1957 to 2017. Using the catchment ratio methodology gives an estimated flow of 96.51 m^3/s at Shannonbridge.
- **Method 2 -** The estimated flow on the 29th of April 2016 at Bellagill near Ballinasloe on the river Suck was 10.7 m^3/s. The flow statistics puts this flow between the 50 and 75 percentile flow for Bellagill. The equivalent water level at Bellagill was 40.88 m OD Poolbeg and this is between the 50 and 75 percentile level for Bellagill. Combining the discharge from Athlone and estimated flow at Bellagill gives an estimated flow of 82.19 m^3/s at Shannonbridge.

The model give the best representation of the surveyed thermal plume when a flow of 88 m^3/s is used as the upstream boundary condition. This flow is between the calculated flows from Method 1 and Method 2 and is acceptable.

The water level at OPW Gauge 26028 Shannonbridge on this date was 33.294 mOD Malin. This corresponds to a gauge level of 2.776 m. The 3 other OPW Gauges were not in operation at this time but a comparison of levels when all four gauges were in operation gives an estimated expected level of 32.90 mOD for the location of OPW Gauge 26351 Derryholmes u/s which is also the downstream boundary.

The average wind speed and direction on the 29th of April 2016 recorded at Gurteen was approximately 11.3 knots and from a north west direction and this was included in the model simulation.

The station was on load from the 26th of April and at or near full load from the 28th April.

In summary, the following parameters were used for the 29th of April 2016 model scenario:

Parameter	Value	Unit
Station Load	150	MW
Cooling Water Discharge	5.5	m^3/s
Temperature rise across the condenser	8.5	°C
Wind speed	11.3	knots
Wind direction	North-west	
Upstream boundary condition - River Shannon Flow	88	m^3/s
Downstream boundary condition - Water level at Derryholmes	32.90	m OD

Table 5.2 Model Scenario of 29th of April 2016 – *Input Parameters*

The results of the model and the thermal plume survey are in good agreement. The river Shannon was surveyed from just upstream of the intake to 1.5 km approximately downstream of the discharge where as the model extends to approximately 4 km downstream.

The model predictions and the surveyed data both show that the thermal plume is confined to the eastern bank of the river Shannon and extends approximately 400 m to 500 m downstream of the discharge point.

Model Results

Figure 5.8 shows the simulated thermal plume is very small and is confined to the eastern bank of the river channel. It extends approximately 400 m to 500 m downstream of the discharge. The highest temperatures, as expected, occur close to the discharge point and dissipate quickly with distance. Simulated conditions at selected cross-sections downstream are summarised below.

- At cross-section 1 (Figure 5.9) 100 m downstream of the discharge point, the simulated thermal plume is confined mainly to the eastern half of the river channel. The cross-sectional area of the simulated thermal plume is largest at this cross-section. The maximum simulated temperature rise is 6.8 ^{o}C.
- At cross-section 2, (Figure 5.10) 250 m downstream of the discharge point, the simulated thermal plume is confined the eastern quarter of the river channel. The maximum simulated temperature rise is 2.6^{o}C.
- The simulated thermal plume has dissipated at cross-sections 3, (Figure 5.11) 450 m, cross-section 4, (Figure 5.12) 650 m, cross-section 5 (Figure 5.13) 1.2 km and cross-section 6 (Figure 5.14) 3 km downstream respectively of the discharge point.

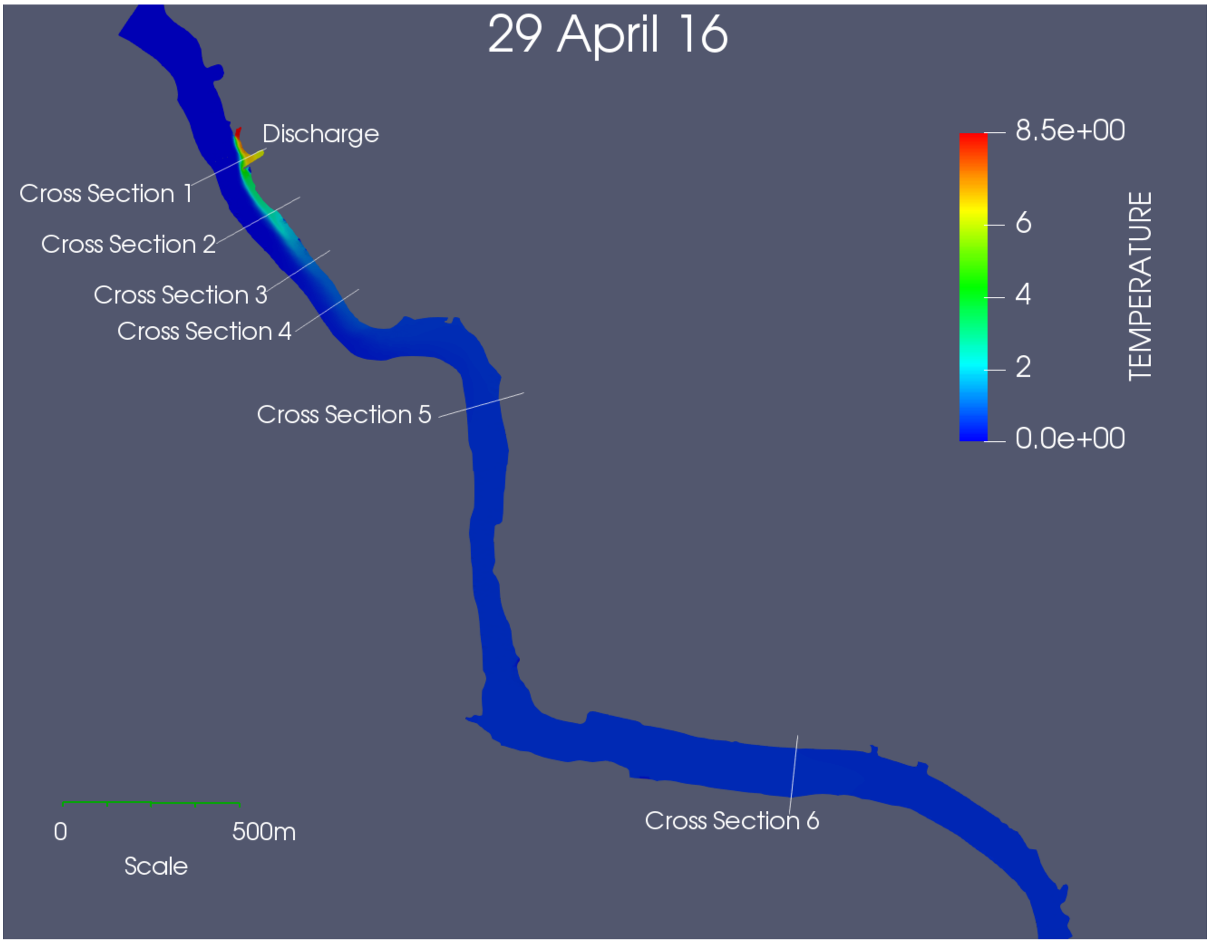

Figure 5.8 Plan of thermal Plume

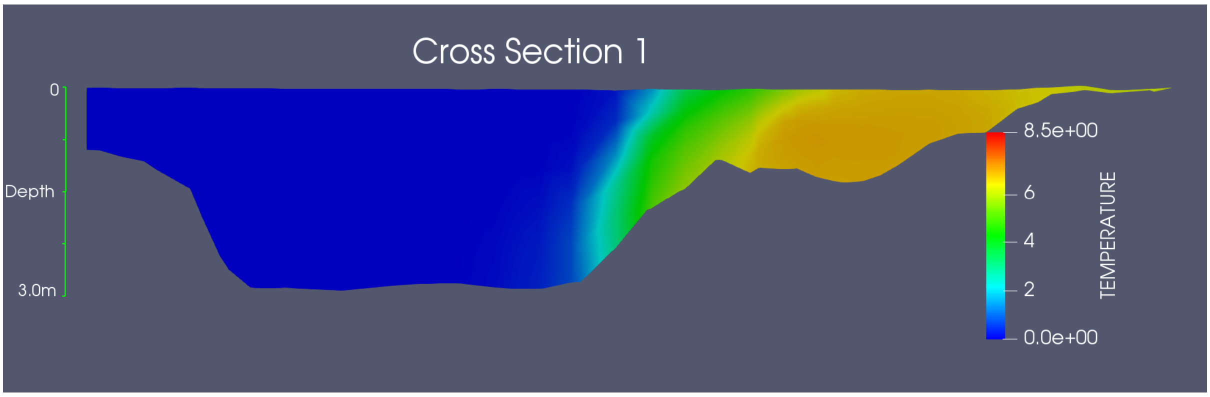

Figure 5.9 Cross-section 1 of thermal Plume (100m downstream)

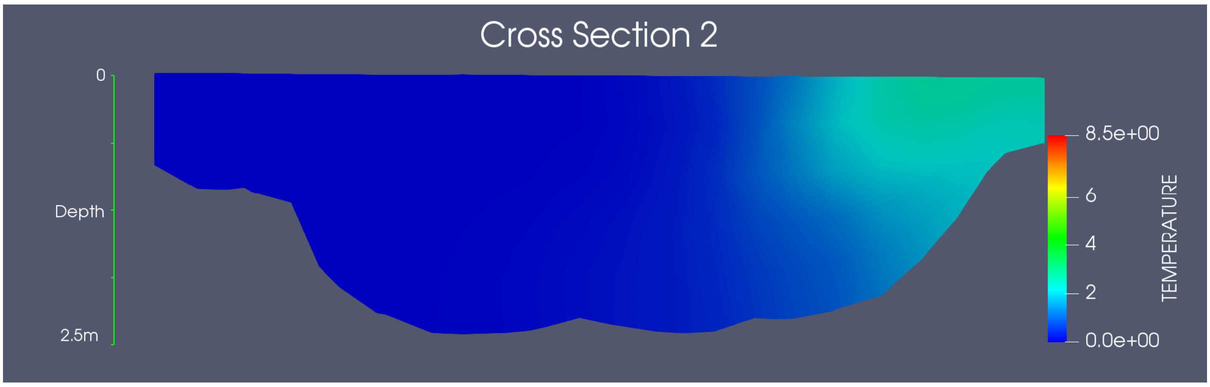

Figure 5.10 Cross-section 2 of thermal Plume (250m downstream)

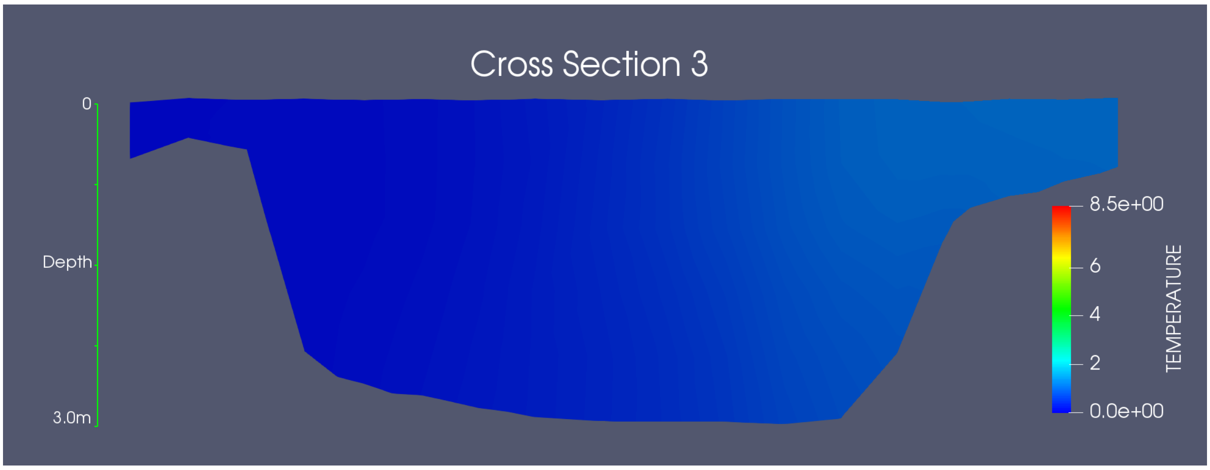

Figure 5.11 Cross-section 3 of thermal Plume (450m downstream)

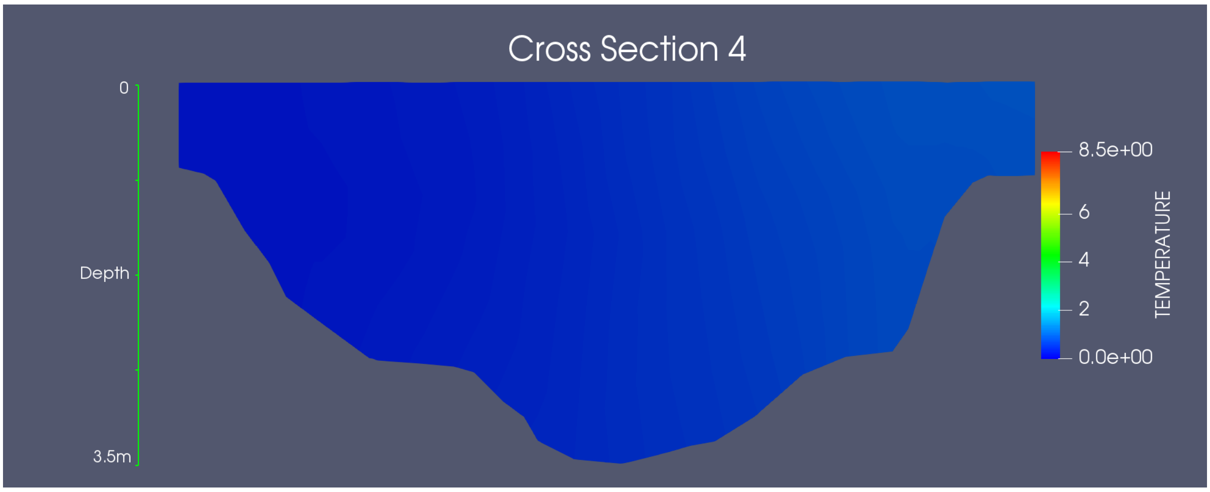

Figure 5.12 Cross-section 4 of thermal Plume (650m downstream)

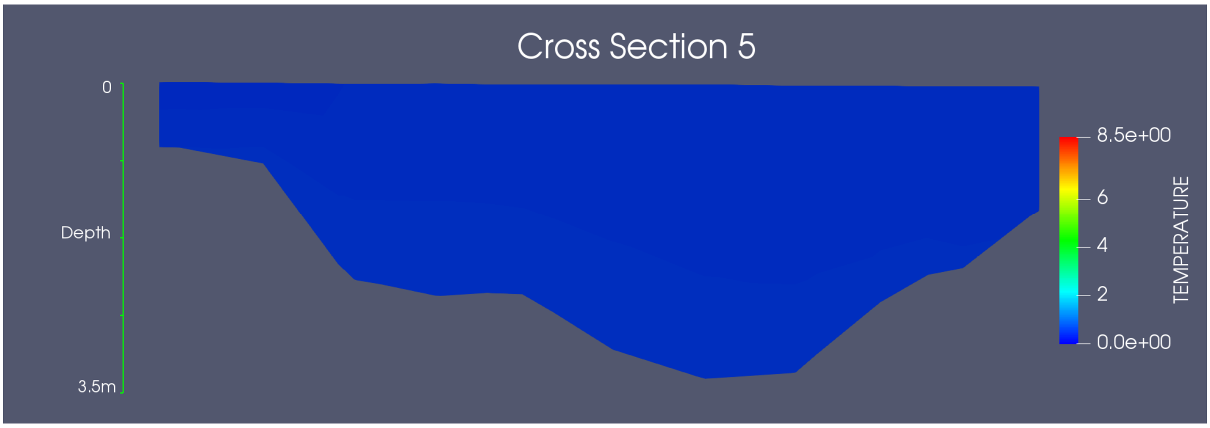

Figure 5.13 Cross-section 5 of thermal Plume (1.2km downstream)

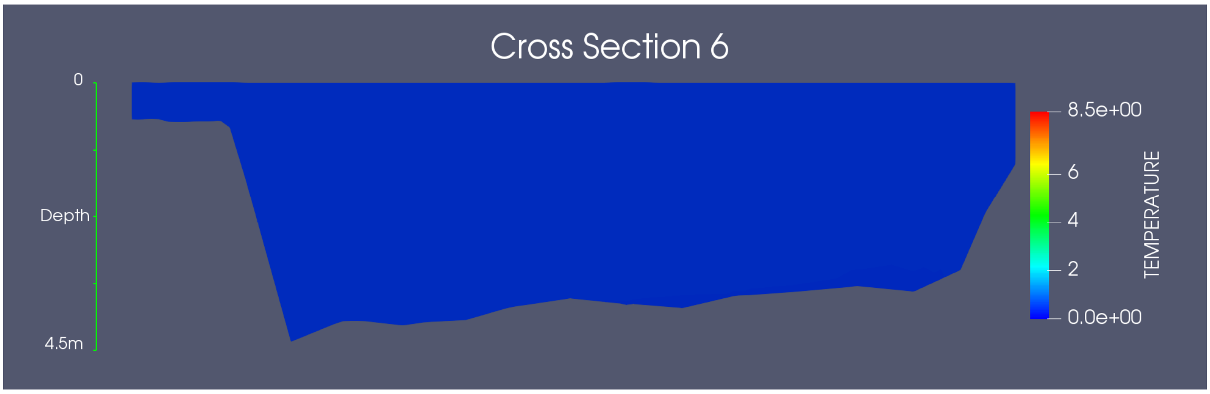

Figure 5.14 Cross-section 6 of thermal Plume (3.0km downstream)

5.2. Low to medium flow conditions

The flow record for the Shannon at Athlone for the period 1957 to 2017 and Method 1 in Section 5.1 have been used to estimate the values of 95 and 75 percentile flows at Shannonbridge to be used as model inputs. Method 2 was not used as the record at Athlone is significantly longer and the flow estimates better (weir rather than a rating curve) than at Bellagill.

5.2.1. 95 Percentile flow

The 95 percentile flow in the Shannon at Athlone for the period 1957 to 2017 is approximately 19.65 m^3/s (i.e. the flow which is equalled or exceeded for 95% of the time of record). Using the catchment ratio methodology gives an estimated 95 percentile flow in the Shannon at Shannonbridge of 26.53 m^3/s and this is used as the upstream boundary condition. The 95 percentile flow value is greater than the estimated flow that occurred on 31st of July 2014.

From an examination of flow and water level data, the water level chosen for the downstream boundary condition is 32.5 m OD Malin.

In summary, the following parameters were used for the 95 percentile flow model scenario:

Parameter	Value	Unit
Station Load	150	MW
Cooling Water Discharge	5.5	m^3/s
Temperature rise across the condenser	8.5	^oC
Wind speed	0	knots
Wind direction	No wind	
Upstream boundary condition - River Shannon Flow	26.53	m^3/s
Downstream boundary condition - Water level at Derryholmes	32.50	m OD

Table 5.3 Model Scenario – 95 percentile flow – Input Parameters

Model Results

Figure 5.15 shows that the simulated thermal plume flows directly out from the discharge channel to the west bank of the river. It extends for approximately 3 km downstream of the discharge and is spread over the entire water channel from approximately 200 m downstream. The highest temperatures, as expected, occur close to the discharge point and gradually dissipate with distance. Because the thermal plume flows across the river channel, higher temperatures occur at the west bank of the river. Simulated conditions at selected cross-sections downstream are summarised below.

- At cross-section 1, (Figure 5.16) 100 m downstream of the discharge the simulated thermal plume is confined mainly to the eastern half of the river channel. The maximum simulated temperature rise is approximately 7.1 ^oC.
- At cross-section 2, (Figure 5.17) 250 m downstream of the discharge point, the simulated thermal plume covers the entire surface of the river channel with higher temperatures at the water surface in the centre of the river channel. The simulated thermal plume is mainly confined to the upper half of the cross-section. The maximum simulated temperature rise is approximately 4.9 ^oC.

- The simulated thermal plume at cross-section 3, (Figure 5.18) 450 m downstream of the discharge point, is mainly confined to the western two-thirds of the river channel. The maximum simulated temperature rise is approximately 2.9 ^{o}C.
- The simulated thermal plume at cross-section 4, (Figure 5.19) 650 m downstream of the discharge point, is mainly confined to the western three-quarters of the river channel. The maximum simulated temperature rise is approximately 2.5 ^{o}C.
- However, at cross-section 5, (Figure 5.20) 1.2 km of the discharge point, the thermal plume is more uniform and covers the entire cross-section. The maximum simulated temperature rise is approximately 1.7 ^{o}C.
- At cross-section 6, (Figure 5.21) 3 km downstream of the discharge point, the simulated thermal plume has dissipated.

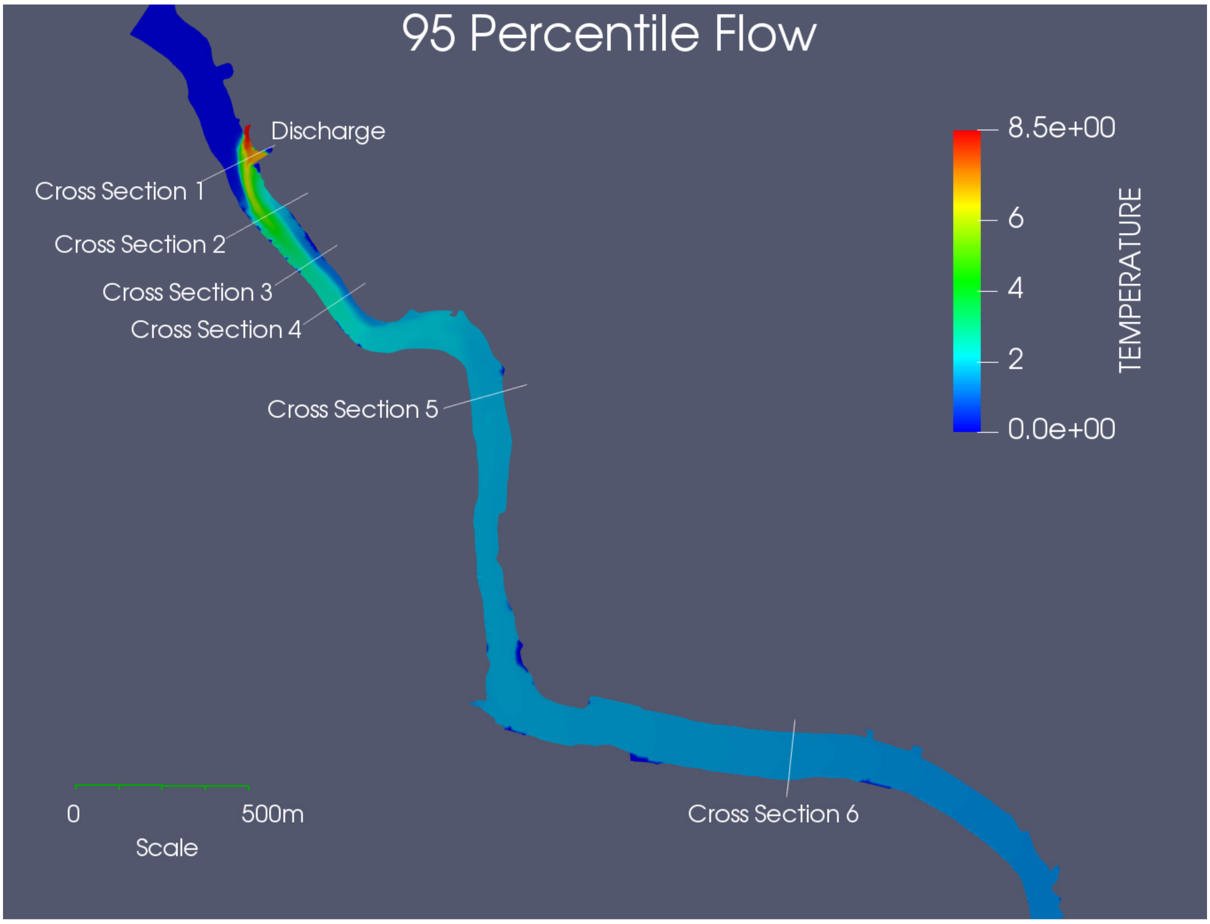

Figure 5.15 Plan of thermal Plume

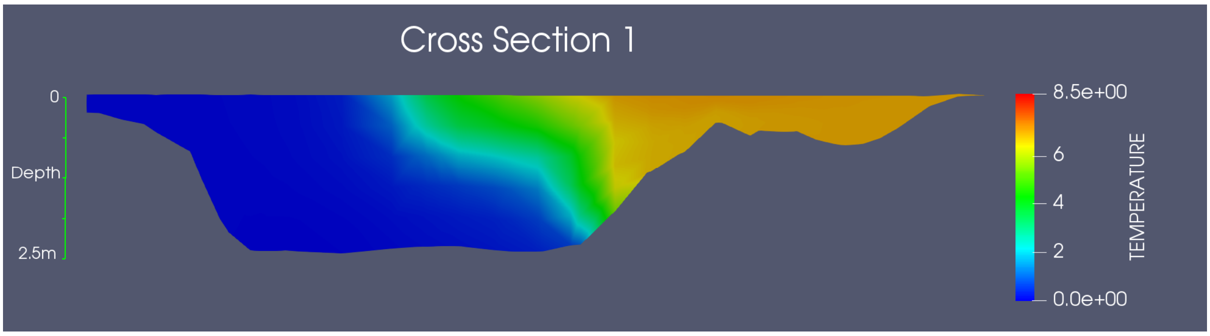

Figure 5.16 Cross-section 1 of thermal Plume (100m downstream)

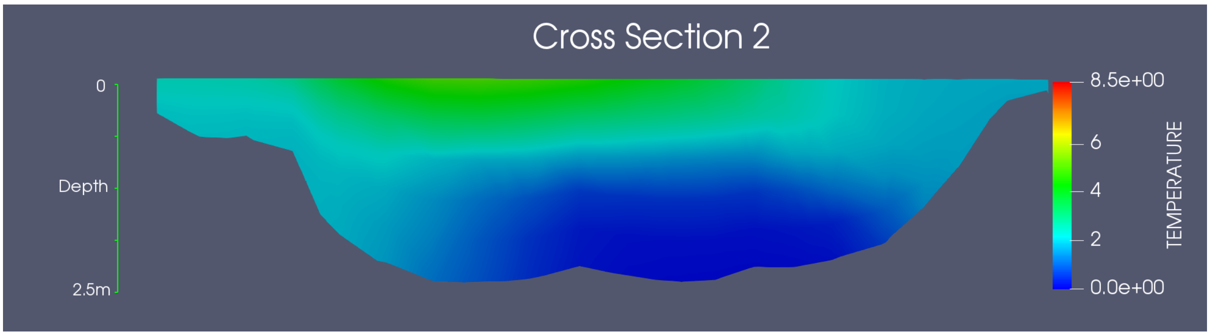

Figure 5.17 Cross-section 2 of thermal Plume (250m downstream)

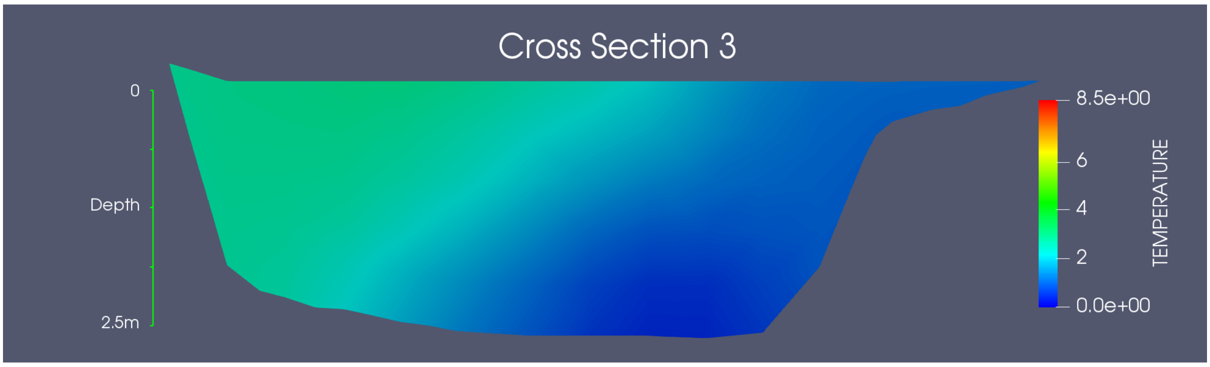

Figure 5.18 Cross-section 3 of thermal Plume (450m downstream)

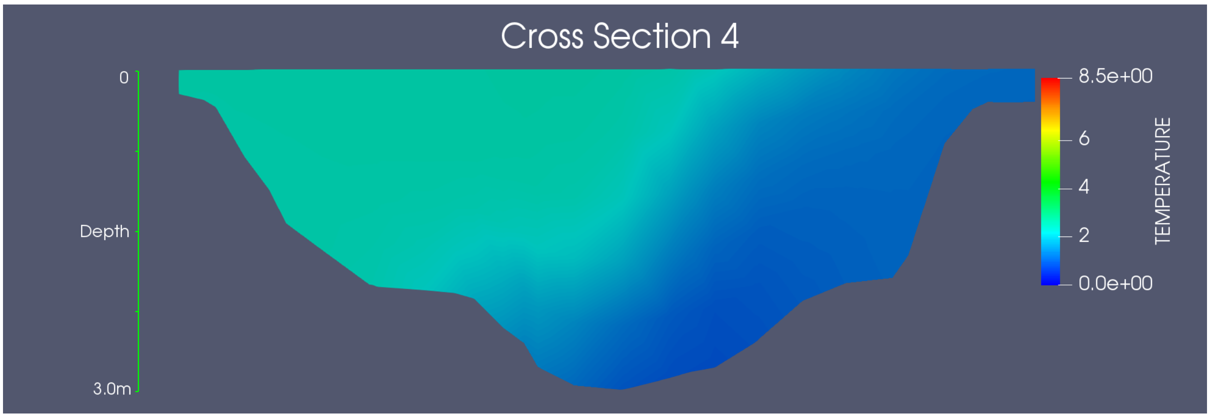

Figure 5.19 Cross-section 4 of thermal Plume (650m downstream)

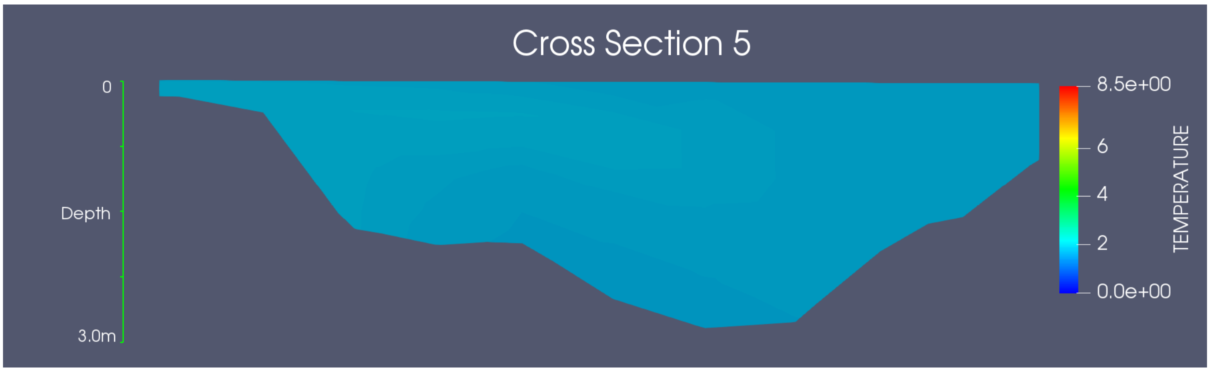

Figure 5.20 Cross-section 5 of thermal Plume (1.2km downstream)

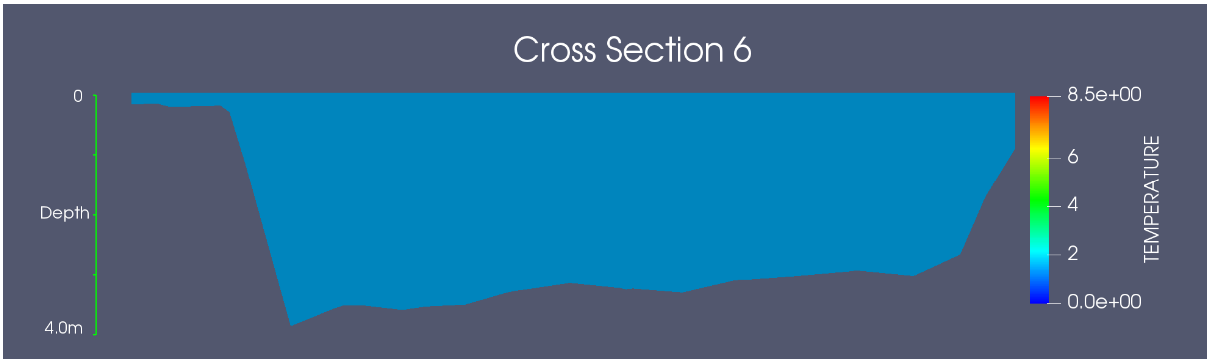

Figure 5.21 Cross-section 6 of thermal Plume (3.0km downstream)

5.2.2. 75 Percentile flow

The 75 percentile flow at Athlone for the period 1957 to 2017 is approximately 43.4 m^3/s (i.e. the flow which is equalled or exceeded for 75% of the time of record). Using the catchment ratio methodology gives an estimated 75 percentile flow in the Shannon at Shannonbridge of 58.59 m^3/s.

From an examination of flow and water level data, the water level chosen for the downstream boundary condition is 32.6 m OD Malin.

In summary, the following parameters were used for the 75 percentile flow model scenario:

Parameter	Value	Unit
Station Load	150	MW
Cooling Water Discharge	5.5	m^3/s
Temperature rise across the condenser	8.5	^oC
Wind speed	0	knots
Wind direction	No wind	
Upstream boundary condition - River Shannon Flow	58.59	m^3/s
Downstream boundary condition - Water level at Derryholmes	32.60	m OD

Table 5.4 Model Scenario – 75 percentile flow – Input Parameters

Model Results

Figure 5.22 shows the simulated thermal plume is very small and is confined to the eastern bank of the river channel. It extends for approximately 400 m to 500 m downstream of the discharge. The highest temperatures, as expected, occur close to the discharge point and dissipate quickly with distance. Simulated conditions at selected cross-sections downstream are summarised below.

- At cross-section 1, (Figure 5.23) 100 m downstream of the discharge point, the simulated thermal plume is confined mainly to the eastern half of the river channel. The cross-sectional area of the simulated thermal plume is largest at this cross-section. The maximum simulated temperature rise is 6.9 ^oC.
- At cross-section 2, (Figure 5.24) 250 m downstream of the discharge point, the simulated thermal plume is confined the eastern quarter of the river channel. The maximum simulated temperature rise is 4.2 ^oC.
- At cross-section 3, (Figure 5.25) 450 m downstream of the discharge point, the simulated thermal plume is confined to the top half of eastern half of the river channel. The maximum simulated temperature rise is 2.3 ^oC.
- The simulated thermal plume has dissipated at cross-section 4, (Figure 5.26) 650 m, cross-section 5, (Figure 5.27) 1.2 km and cross-section 6, (Figure 5.28) 3 km downstream respectively of the discharge point.

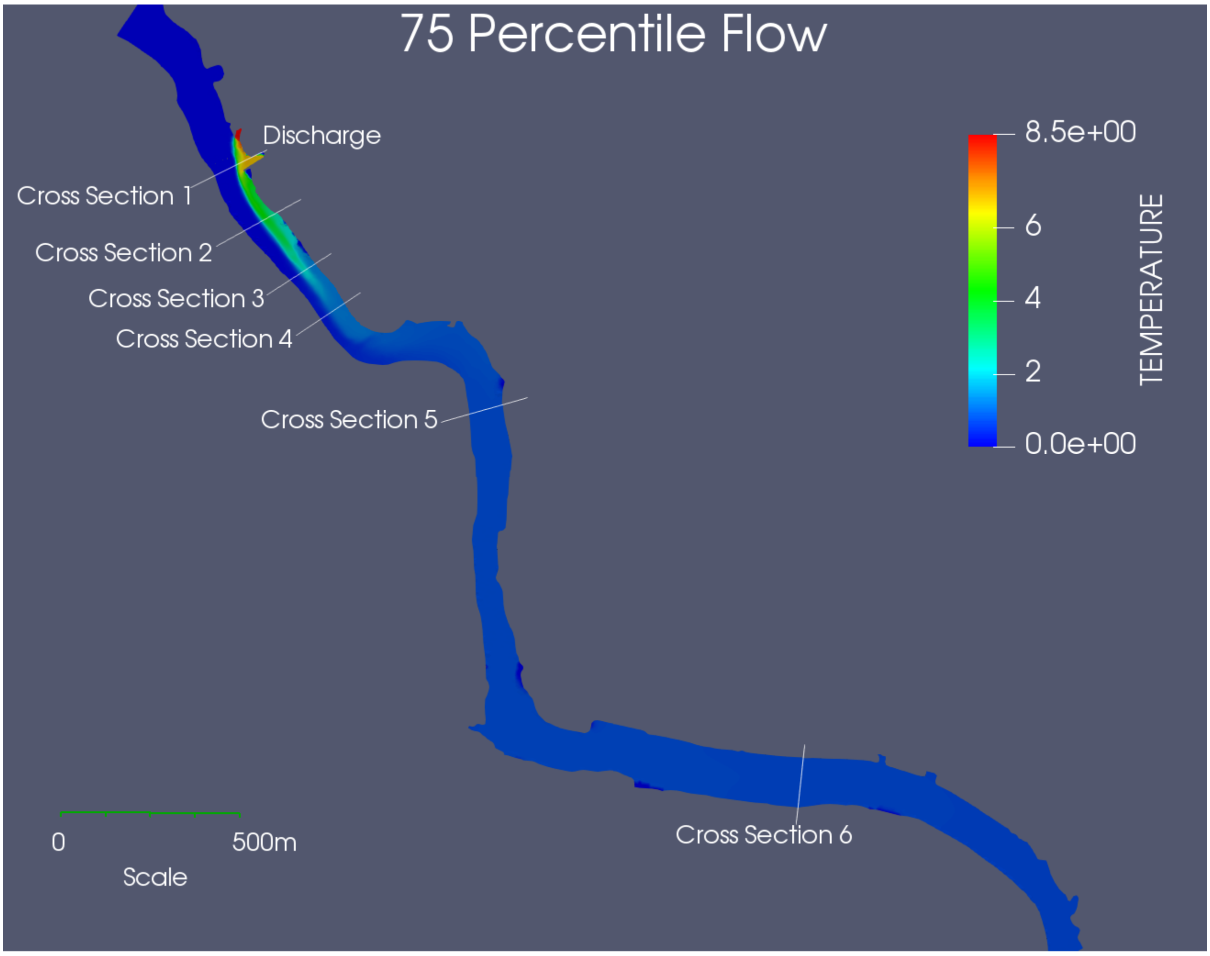

Figure 5.22 Plan of thermal Plume

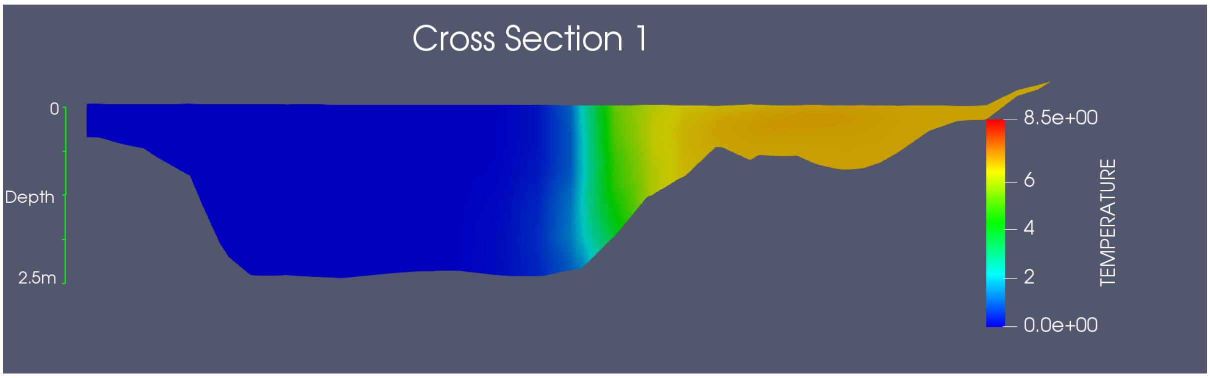

Figure 5.23 Cross-section 1 of thermal Plume (100m downstream)

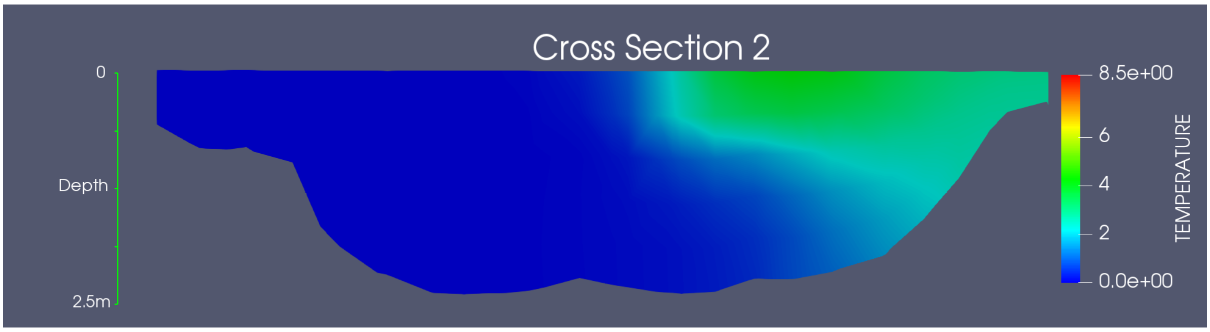

Figure 5.24 Cross-section 2 of thermal Plume (250m downstream)

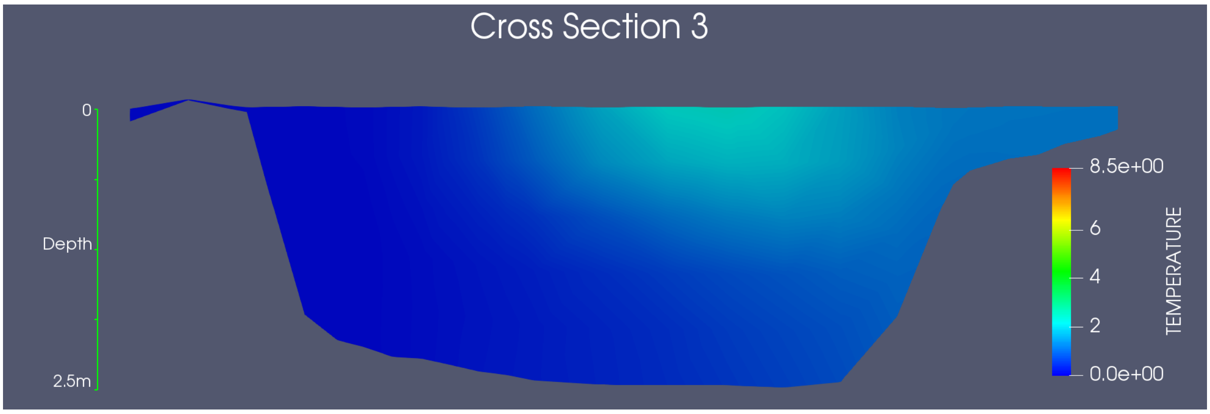

Figure 5.25 Cross-section 3 of thermal Plume (450m downstream)

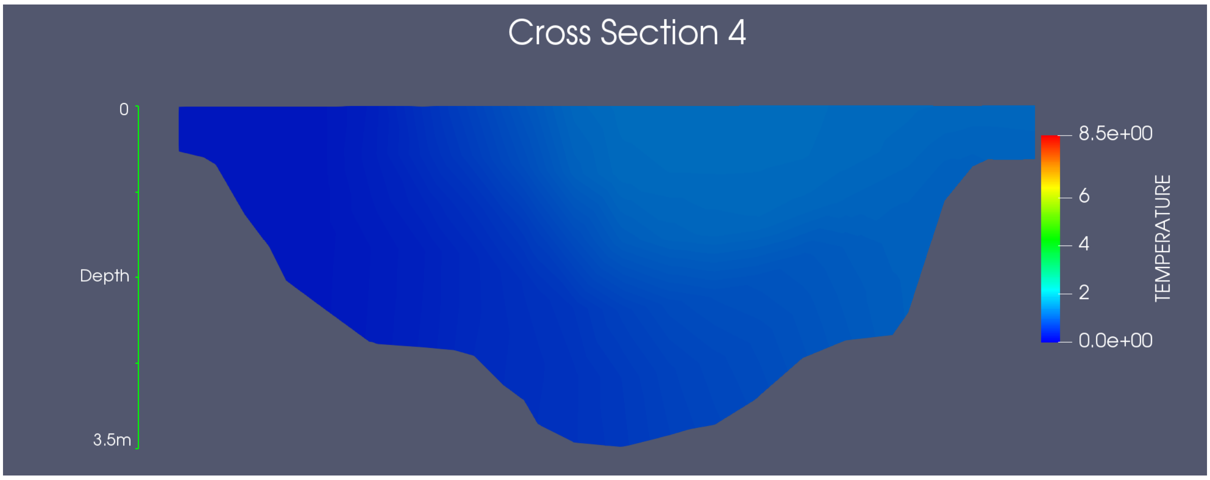

Figure 5.26 Cross-section 4 of thermal Plume (650m downstream)

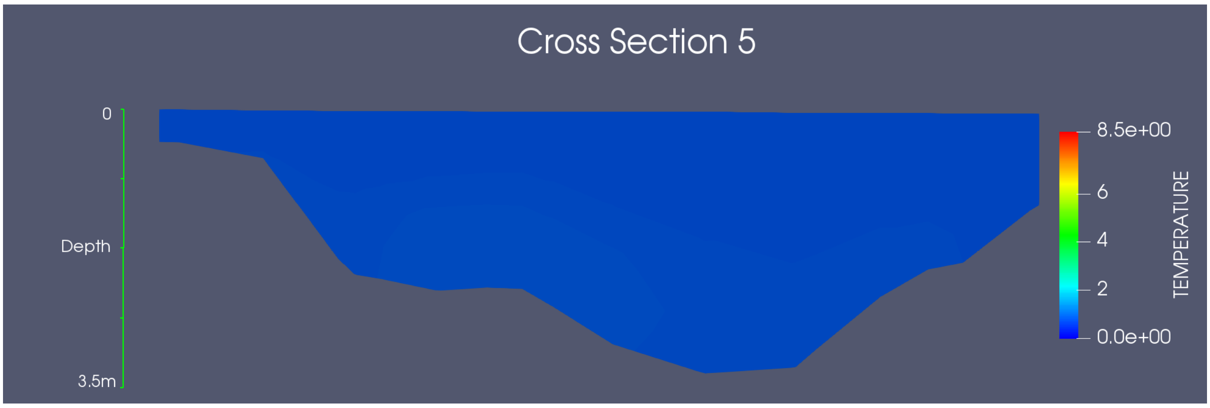

Figure 5.27 Cross-section 5 of thermal Plume (1.2km downstream)

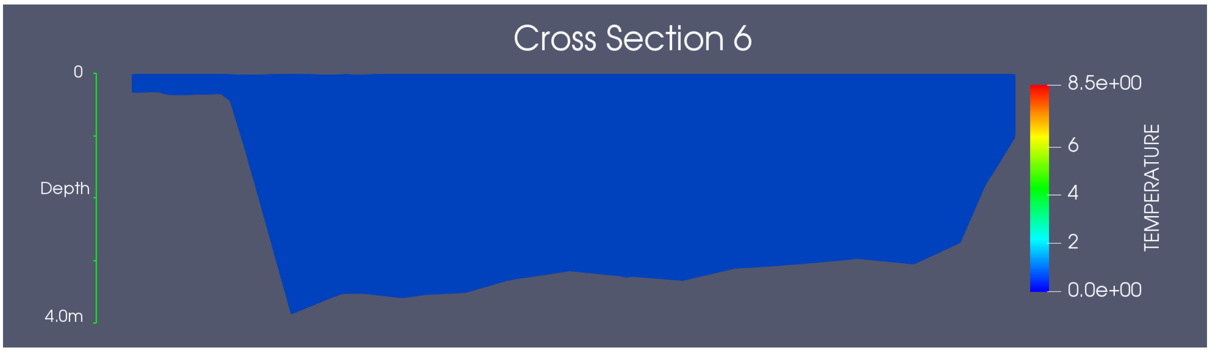

Figure 5.28 Cross-section 6 of thermal Plume (3.0km downstream)

6. Conclusions

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

- The size and extent of the thermal plume is mainly determined by the flow in the River Shannon.
- Highest temperature rises occur closest to the discharge point and decrease with distance downstream. The rate of temperature decrease is related to the percentile flow in the river at Shannonbridge.
- As expected, there is no evidence of the thermal plume upstream of the discharge.
- At low flows, the thermal plume will cover the entire river channel for a significant distance downstream of the discharge point and the thermal plume flows across the river channel.
- At medium flows the thermal plume is not very large and is mainly confined to the east bank of the river.

7. References

1. http://www.opentelemac.org – Modelling Software
2. http://waterlevel.ie/ - OPW gauge data
3. ESB OIS Hydro Database – ESB Shannon Data
4. Irish Hydrodata -West Offaly Power Station, Shannonbridge County Offaly, Thermal Plume Survey July 2014. Report for ESB
5. Irish Hydrodata -West Offaly Power Station, Shannonbridge County Offaly, Thermal Plume Survey April 2016. Report for ESB