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Sizewell Thermal Plume Modelling: Stage 2a review. Selection of preferred SZC cooling water configuration.

Sizewell Thermal Plume Modelling: Stage 2a review. Selection of preferred SZC cooling water configuration.

Liam Fernand, Tiago Silva, Brian Robinson

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Executive summary

In accordance with UK Environment Agency guidelines, two 3D hydrodynamic models have been used to simulate the existing discharge of Sizewell B (SZB) and the proposed discharge of Sizewell C (SZC). The models were built using the GETM and Delft3D systems which have previously been successfully used for modelling of the proposed Hinkley Point C station. The plume modelling methodology uses the following approach:

- Stage 1. Setup and validation of 2 different models against field data (hydrodynamics and thermal plume)
- Stage 2. Use of the validated models to examine different options for the cooling water (CW) configuration for SZC.
- Stage 2a Review (This report). The preferred CW option on environmental, recirculation and other engineering grounds is selected by EDF Energy and then subjected to engineering refinement to produce a proposed design.
- Stage 3. Results from modelling the proposed design both alone and in combination with the discharge from SZB
- Stage 3a Review
- Stage 4. Results of modelling the final configuration after any required model setup refinement following the Stage 3 review. (N.B. This may not be required if no changes to the engineering setup have occurred).

The two models have been successfully set up, validated and calibrated by independent subcontractors, Bolding and Burchard (GETM) and ABPmer (Delft3D). Evaluation and quality assurance of the modelling results is performed by Cefas at each stage of the process before the next stage is undertaken. Both models (and the above subcontractors) were successfully used for modelling of the proposed Hinkley Point C power station. The relative strengths and limitations of these models are well understood by Cefas and the respective model performances were subject to regulatory scrutiny as part of the consultation on the Hinkley Point C planning and permit applications.

Purpose of the Stage 2a Review

During Stage 2 EDF Energy decided that on risk management grounds that the intakes of Sizewell C should be offshore of the Sizewell-Dunwich Bank which has historically been migrating shoreward (BEEMS Technical Report TR105). The purpose of the Stage 2a review then became:

- To determine the accuracy of the excess temperature predictions from the 2 models and which one should be used as the primary tool for assessment purposes
- To determine the preferred SZC cooling water outfall location on environmental, recirculation and engineering grounds in collaboration with EDF Energy engineers.

SZB will be operational until at least 2035 and therefore the modelling undertaken in this study was of the in combination impact of SZB and SZC.

Comparison of the accuracy of the GETM and Delft3D plume temperature predictions

Qualitatively both models described the observed SZB plume features. However, in order to use the models for assessment of thermal recirculation and potential environmental impacts it was important to derive a numerical estimate of the accuracy of the 2 models. The best datasets with which to make such an estimate were the 5 minute inlet temperature record at SZB and the temperature data gathered during the September/October 2009 SZB outage in which we were able to directly follow the thermal impact of SZB from no power to full power in a period of stable weather conditions and to compare these results with modelling.

It was concluded that:

- The predicted Delft3D excess temperatures due to SZB alone were lower than the excess temperatures measured at the station.
- For the Delft3D combined SZB+SZC modelling runs the predicted relative increase in excess temperatures over those predicted due to SZB alone appear reasonable. The predicted values for excess temperatures are, however, significantly under estimated compared with measurements made at the existing SZB station and from considerations of the increase in discharged heat energy.
- The GETM excess temperature predictions for SZB alone were higher than those measured at the station but were closer to the measured values than the Delft3D results. The combined SZB+SZC excess temperature predictions appear reasonable compared with measurements made at the existing SZB station and from considerations of the increase in discharged heat energy.
- It was therefore considered that the GETM model was more suitable as the primary tool for plume modelling at Sizewell and that its use would be conservative but not overly so.

Determination of the preferred SZC cooling water discharge location using the GETM model

The Stage 2 modelling using the Delft3D model suggested that configuration 5 with a SZC discharge inshore of the Sizewell Bank at location O5 in Figure 1 was potentially viable. Subsequent results from the GETM model caused this presumption to be questioned. Both models demonstrated that the impact of recirculation[1] fell predominantly onto SZB and that there was only minor recirculation and consequent elevation of intake temperatures at SZC. In particular, in addition to a generalised increase in mean cooling water intake temperatures throughout the year, the existing recirculation temperature spikes at SZB were predicted to increase in magnitude substantially by the GETM model. The thermal impact on SZB operation from this CW configuration was judged to be unacceptable by EDF Energy.

Three further SZC cooling water configurations (See Figure 1) were compared with the existing SZB and a baseline condition with no power stations at Sizewell:

- Configuration 8 with two offshore intakes at I3 and I4 and an inshore discharge at O8
- Configuration 9 with offshore intakes at I3 and I4 and an outfall offshore of the Bank at O9
- Configuration 10 with offshore intakes at I3 and I4 and an outfall offshore of the Bank at O10 (O10 was not considered likely to be constructible but was modelled to better understand the thermal impact with a range of SZC outfall locations from inshore to offshore of the Sizewell Bank)

The modelling results from BEEMS Technical Report TR230 on SZC outfall locations O5 and O6 were also considered in this study.

[1] For ease of reading recirculation (SZB to SZB) and cross circulation (SZB – SZC) are grouped together

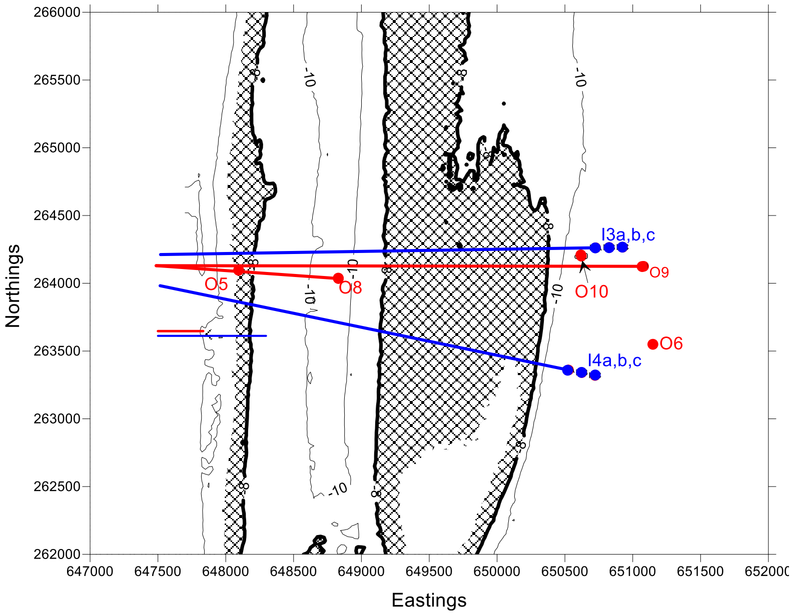

Figure 1 Locations of the modelled SZC cooling water discharges shown in red O5 – O6. Intakes are shown in blue.

Recirculation Impact of the SZC discharge

The thermal impact of the SZC discharge falls predominantly upon SZB as an increase in intake temperatures and in the extent of the SZB discharge plume. For all of the SZC discharge locations studied (O5, O6, O8, O9, O10) the amount of recirculation into SZC is minimal (< 1ºC). The mean and maximum excess temperatures at the SZB intake decreases as the SZC discharge is moved eastwards along the line O5 to O9 with an indication from a study of the now unviable[2] position O6 that this effect continues for at least another 140m further east.

SZC outfall locations inside of the Bank (O5 and O8) produce similar results with much higher mean and maximum intake temperatures at SZB than for outfall locations outside of the Bank. Previously outfall location O5 was considered to produce an unacceptable thermal impact on SZB by EDF Energy; O8 does not produce significantly lower recirculation impacts on SZB.

On the basis of minimizing recirculation at SZB, SZC outfall location O9 offers the best solution and has a minimal impact on recirculation at SZC. O9 is very close to the SZC intake locations and modelling indicates that SZB intake temperatures would decrease further if the SZC outfall were moved further east (subject to the change in water depth).

Environmental Impact of the SZC discharge

From an environmental impact perspective SZC outfall locations offshore of the Sizewell Bank produce a much lower impact than those inshore of the Bank. In particular:

- The area of exceedance of the SPA thermal thresholds at the seabed and surface is least using outfall O9 (270ha at the seabed). Outfall O8, inshore of the Bank, produced the worst results (1660ha at the seabed), closely followed by O5
- The area of intersect with the potentially sensitive coralline crag off Thorpeness is least with O9 (26ha) and worst for O8 (286ha)

[2] This position now lies in the cable corridor or the Galloper windfarm development

- The predicted entrainment temperatures at SZB are lowest for O9 and worst for O5 and O8.

From an environmental impact perspective an offshore SZC outfall location such as O9 is the preferred option but until geotechnical surveys are undertaken it is not known whether such a location is viable. Locations inside of the Bank produce similar environmental impacts but location O8 is worse than O5.

Preferred SZC Cooling Water Outfall Location

On recirculation and environmental impact concerns location O9 is the preferred option for the SZC outfall. O9 is considered the furthest west that an outfall could be built offshore of the Sizewell-Dunwich Bank and depending upon sub sea geology the outfall may have to be built slightly further east. Modelling indicates that locations further to the east would produce slightly lower recirculation and environmental impacts. Location O9 will therefore be taken forward to further environmental assessments as it is considered to bracket the worst case design option.

1 Background

1.1 Overview of the modelling approach

For this project two hydrodynamic models have been applied to the problem of modelling flow dispersion from the proposed SZ C power station. These were:

- General Estuarine Transport Model (GETM)
- Delft3D

The two numerical models, which have very different approaches, were used to quantify the likely uncertainty around the modelling approach and therefore produce a quantified estimate of the likely thermal impact and an associated estimate of error.

The GETM model calculates the effect of the power station by running a reference run (without power station), simulating an entire annual cycle, using a full heat gain and loss implementation. Meteorological data from the ECMWF (European Centre for Medium range Weather Forecasting) reanalysis data is used to force the model, so that incident radiation, cloud cover, humidity, wind speed and long wave radiation are included. A configuration run is then performed over the annual cycle, with the power station's proposed discharge included. The net effect of the power station is derived by subtracting the reference run from the configuration run. The most significant difference between the runs is that the discharge plume will have an increased temperature and therefore the long wave radiation will be greater. It will also potentially have higher evaporative heat loss, which is humidity and wind speed dependant.

The modelling of the heat cycle allows full annual runs to be performed, with winds and other meteorological events, so that realistic estimates can be made of the likely plume variability. In order to perform such long runs, yet still maintain good vertical and horizontal resolution, the runs are performed on a parallel processor.

Draft guidelines on thermal plume modelling produced by the Environment Agency in 2010 require that assessments are made using annual data or simulated data such as model output.

> *"An appropriate time scale is a year, in order to include seasonal variations in air and water temperatures, and other climatic factors, e.g. wind stress, light climate. Other significant variables which show seasonality include river flow, salinity, pH, and tidal range, and the range of variation in these should be defined and considered in any assessment. As the climate varies between years, a representative ('average') year should be defined from a number of years. An appropriate period in this context would be the last 10 years."*

The GETM model has been used to address the requirement of seasonal variability and variability due to climatic factors, wind and river forcing, because inevitably in the course of a year a variety of conditions are experienced. This can be analysed to determine the model (and real) sensitivity to a change in any particular parameter e.g. wind direction. The implications for increased sea temperatures can be understood by investigation of the summer periods.

In contrast the Delft3D model uses an excess temperature model to directly calculate the heat loss from the discharge of the thermal plume. It is a standard approach and has been used in many models such as Telemac. Such models assume that the heat loss from a plume is a function of the temperature of the water and the air speed. These models because they do not seek to emulate "real" from the outset, usually simulate short term conditions and are generally not running on a parallel cluster.

The key question for this Stage 2a review to answer is:
"How accurately is the modelling likely to represent the temperature field of the proposed SZ C development and also that of the SZ B + C combined operation?"

1.2 Modelling Methodology

In accordance with UK Environment Agency guidelines, two 3D hydrodynamic models have been used to simulate the existing discharge of Sizewell B (SZ B) and the proposed discharge of Sizewell C (SZ C). The models were built using the GETM and Delft3D systems which have previously been successfully used for modelling of the proposed Hinkley Point C station. The plume modelling methodology is using the following approach:

- Stage 1. Setup and validation of 2 different models against field data (hydrodynamics and thermal plume)
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The two models have been successfully set up, validated and calibrated by independent subcontractors, Bolding and Burchard (GETM) and ABPmer (Delft3D). Evaluation and quality assurance of the modelling results is performed by Cefas at each stage of the process before the next stage is undertaken. Bolding and Burchard, as the originators of the GETM model, were best placed to implement the GETM model and ABPmer have extensive experience of the Delft3D model on UK applications. Both models (and the above subcontractors) were successfully used for modelling of the proposed Hinkley Point C power station. The relative strengths and limitations of these models are well understood by Cefas and the respective model performances were subject to regulatory scrutiny as part of the consultation on the Hinkley Point C planning and permit applications.

Understanding the sequencing of the modelling work aids understanding of the outputs and completes the picture of the rationale of the approach and how each report links to the other. See Table 1.

Table 1 SZ Thermal Plume Modelling Reports

Model	BEEMS Report Name	Overview of Contents
Delft3D	TR132 Sizewell Thermal Plume Modelling: Delft3D - Stage 1 Model setup, calibration and validation.	Detail of the model grid, setups, validation with observations e.g. Current meters, drifters. Comparison with the thermal plume survey.
Delft3D	TR133 Sizewell Thermal Plume Modelling: Delft3D - Stage 2 Modelling Results including Geomorphology.	Results from the 3 initial CW configuration options for SZ C. Comparison of the relative extent of the plume from a cross shore discharge compared to an offshore one. Meteorological and geomorphological scenarios included. Focus on recirculation estimates.
GETM	TR229 Sizewell Thermal Plume Modelling: GETM - Stage 1 Validation and verification	Details of the setup of the GETM model. Comparison with current meters, drifters and tide gauges. Comparison with the thermal plume surveys.
GETM	TR230 Sizewell Thermal Plume Modelling: GETM Stage 2 Model Results	Results from 2 initial CW configurations. Focus on recirculation estimates.
Combined (This report)	TR301 SZ Thermal Plume Modelling: Stage 2a Review – Selection of the preferred SZC CW configuration	Evaluation of the accuracy of the GETM and Delft3D Sizewell models. Selection of the preferred SZC CW configuration from 5 options based upon recirculation and environmental impact grounds.
Delft3D	TR328 Sizewell Thermal Plume Modelling: Delft3D - Stage 3 Results.	Results from Delft3D runs with the preferred SZC CW configuration. Includes simulations of SZC, SZB and SZB+SZC Also includes results from Geomorphology and Meteorological scenarios.
GETM	TR302 Sizewell Thermal Plume Modelling: GETM Stage 3 results with the preferred SZC cooling water configuration.	Results from GETM runs with the preferred SZC CW configuration. Includes simulations of SZC, SZB and SZB+SZC.

2 Description of the existing SZB thermal environment and previous SZC modelling studies

Figure 2 shows the location of the Sizewell B cooling water intake and outfall which are relatively close to each other and inshore of the Sizewell-Dunwich Bank. SZB already experiences temperatures spikes in intake water temperature due to recirculation from the SZB outfalls to the SZB intakes at certain tidal states.

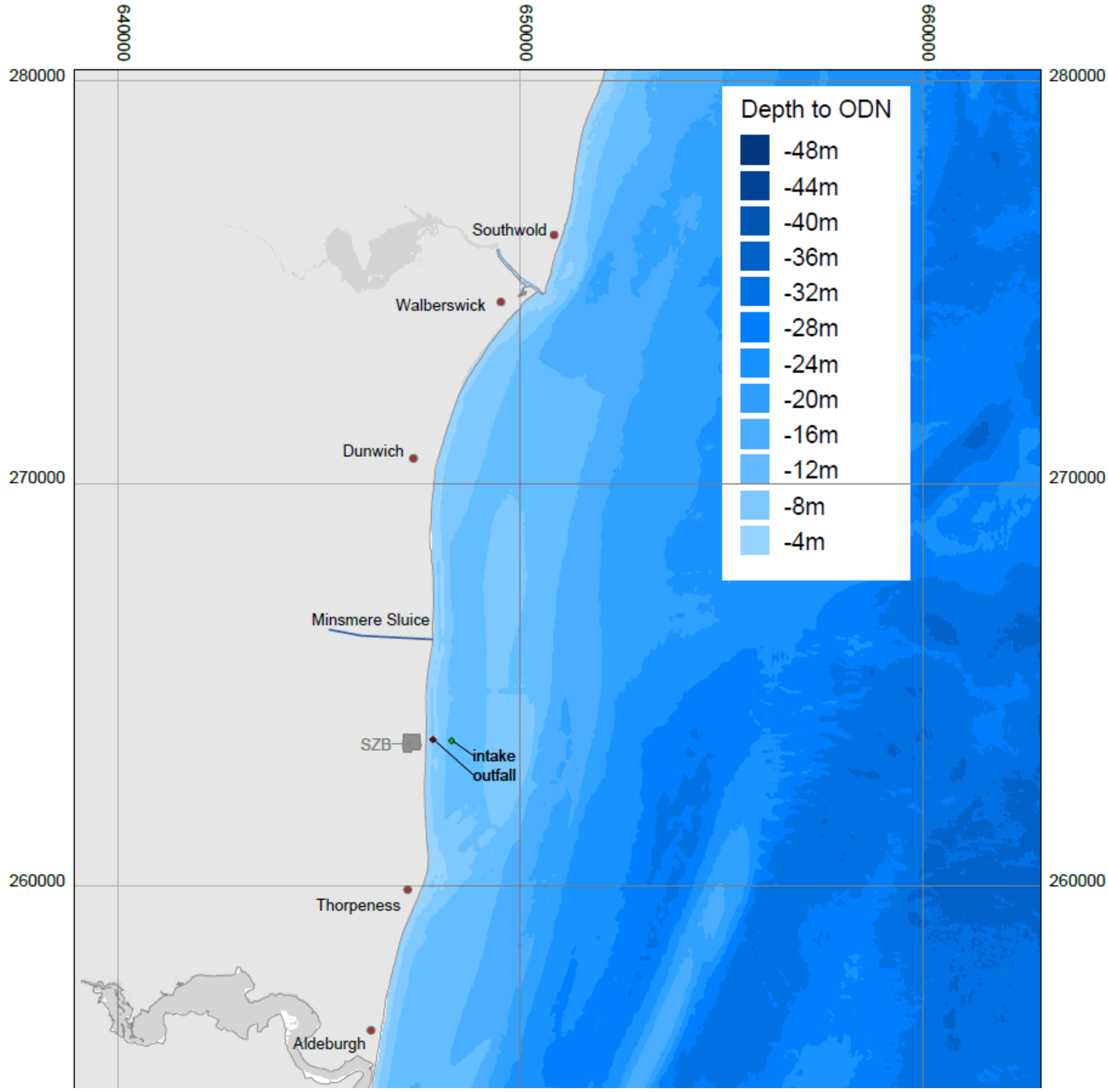

Figure 2 Location of the Sizewell Power station and its cooling water infrastructure (inside of the Sizewell-Dunwich Bank).

2.1 Operation of the present Sizewell B station with intake temperature spikes

Electrical power is generated by the work done by the expansion of steam across turbines. The amount of work being done is directly related to the difference in temperature of the incoming steam and the cooling water. As the incoming steam temperature is mostly fixed by the reactor operating temperature, the efficiency of the plant varies with sea temperature.

The operational control mechanism of Sizewell B station is designed to maintain a constant electrical output, thus if thermal efficiency drops due to a reduction in cooling capacity, then thermal output from the station is increased to generate more steam and produce more electricity i.e. in summer more steam is required than winter for the same electrical output. On a shorter time scale if an intake temperature spike occurs due to recirculation or advection of a warm patch of water past the intake, then the thermal output of the reactor is automatically increased to maintain the electrical load. While this automatic increase is acceptable at low sea temperatures and large temperature spikes can be tolerated, when sea temperatures are high in summer, the extent of spikes that can be tolerated is reduced.

The 2011 stress test for Sizewell B (EDF 2011) outlines the design basis for the control. “*The bounding design basis hazard for high and low seawater temperature is defined as 26°C and 0°C respectively. The probabilities of exceeding these maxima and minima are calculated as 9x10^{-3} p.a. and 3x10^{-2} p.a. respectively*”. The review used a statistical analysis of historic data to estimate the extreme temperature probabilities and concluded. “Conclusion ***SZB 4.3: Based on the above reviews, it is concluded that the extreme design basis hazard level for seawater temperature remains appropriate at the present time. The design basis for seawater temperatures has recently been further reviewed for all sites as part of Climate Change Adaptation and it was identified that the expected increase in extreme seawater temperature may marginally increase within the expected station lifetime. Changes in extreme seawater temperature will be monitored through the safety review process*.”**

2.2 Previous studies on a potential SZC in 1993

Previous studies were conducted in 1993 on the thermal effects of Sizewell A, B and C and brief consideration of this work is useful to compare with BEEMS predictions.

HR Wallingford ltd (Wallingford 1993) used an in house developed model at 100m resolution to study the effect of the then proposed Sizewell C discharge (Twin PWR, cooling water flow of 100 m^3s^{-1}) on Sizewell B (CW flow of 50 m^3s^{-1}). The report considered both onshore and offshore discharge locations over a 14km * 5km area. (In comparison the current proposal for SZC is based upon twin EPRs with a combined CW flow of 125 m^3s^{-1} at a similar Δt to that modelled in Wallingford 1993). The HR modelling and associated observational survey data were subsequently reviewed by an independent consultant (Ken Dixon) in Dixon 1993.

Dixon concluded that on neap tide the total heat content from the combined B + C discharge inside of the bank would lead to possible saturation whereby the heat content would build with each tide. His gave the following explanation of the evolution of the plume “*the cooling water plume spreads around the outfalls at high water slack then streams northward during the ebb. The highest temperatures are found at low water slack when another pool spreads out around the outfalls. The plume then streams south from the outfalls on the flood tide. During the main ebb and flood the plume is quite sharp edged, with the transition from ambient to full plume temperature occupying only two cells laterally (200m)*”.(Dixon 1993).

“*Neap tides generate more pronounced "ponding" effects than Springs and hence a slower dispersal rate for the cooling water discharge. This is due mainly to the lower tidal range which results in (a) slower dilution rates because of the shallower water and slower currents (the exception to this is Low Water Springs when there is less water than at Neaps). (b) slower reversal of the tidal current and hence a tendency to encourage "ponding". (c) slower tidal currents which (i) create less turbulence and hence less "mixing"* *effects than at Springs and (ii)offer less resistance to the concyclic spread of the quite considerable cooling water discharge*." (Dixon, 1993). His view was that on neap tides the heat would not be lost from the system quickly enough so that the seawater temperature would gradually increase resulting in a large rise in the temperature inside of the bank compared to outside of it.

The HR model predictions replicated the ponding features observed by Dixon; Figure 3 shows maximum temperatures occurring at 6 hour intervals with a peak temperature of 6-8°C above ambient at the surface and 3.5 °C at the depth of the intake. Typically these temperatures were predicted over a width of about 300m and up to about 400m north of the 'C' outfall on the ebb and to about 400m south on the flood. The average temperature at the depth of the intakes (model layers 3- 4) was just below 1°C above ambient, however, spikes of up to +3.5 °C were predicted.

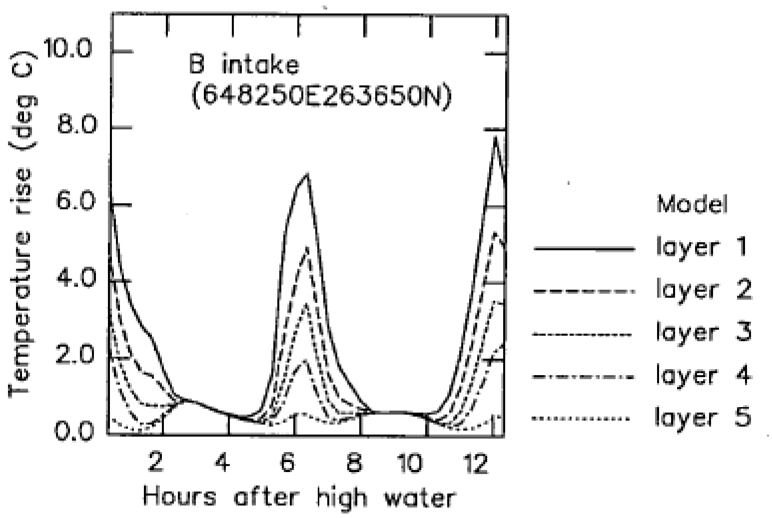

Figure 3 Output from HR Wallingford Model of Sizewell B + C (Twin PWRs) using an inshore discharge for SZC (from HR Wallingford 1993).

Dixon (1993) concluded that in comparison with the observations, that the models under estimated the likely heat content in the system and that the temperatures provided in the HR report should, therefore, be considered as under estimates.

The HR model was relatively limited in spatial extent and did not replicate the residual flow to the south which is important in that it provides a mechanism for heat loss from the system that counters the potential for build up of heat within the trough. The short length of the model runs and the limited duration of the meteorological scenarios were a consequence of the computing resources available at that time. The exchange of water from the Sizewell trough region across Thorpeness and into the greater Sizewell Bay environment is therefore an important issue for the BEEMS modelling to address.

2.3 SZ B intake description and temperature record

At Sizewell B the volume of water extracted is nominally 50 - 52 m^3s^{-1}. The intake structure consists of two intake heads which are connected to a single intake tunnel. Each head is octagonal, approximately 11.5m across and is omni directional. The intake structure sits approximately 3m above the sea bed and extracts water from a 3m high aperture i.e. the intake has a mid point approximately 4.5m above the bed. This is the lower half of the water column and this estimate is critically important to estimates of the likely effect of Sizewell C on Sizewell B. During times of peak tidal flow, when the tidal velocity is approximately $1ms^{-1}$, the entire 11.5m wide streamline is taken into the intake with a small amount of additional flow from around the sides of the intake structure. However, at slack water, water is extracted omni-directionally and draw down from the near surface waters is greatest.

Water extracted from the intakes flows via gravity through the intake tunnel into the forebay. It is then pumped into the condenser system where the temperature is recorded. The time delay from intake to temperature measurement is approximately 7 minutes (Bamber and Seaby 1993). The intake temperatures used in this report come from the station temperature data loggers and are available at up to 5 minute intervals. Inlet temperatures are available for both condensers and these data were checked for consistency in relation to the cooling flow and then averaged if appropriate. The short transit time from the intakes to the condensers, combined with the relatively small volumes of water in the forebay and drum screen area, means that there is limited opportunity for mixing or changing of water temperature during transit and that the station measurements are therefore likely to be reasonably good approximations of the seawater temperatures at the inlets.

2.4 Analysis of existing intake data for Sizewell B

Figure 4 shows the measured SZB inlet temperature from 12 August 2009 to 18 August 2009 plotted against the tidal elevation. Expanded plots of one 24 hour cycle in this period are shown in Figure 5.

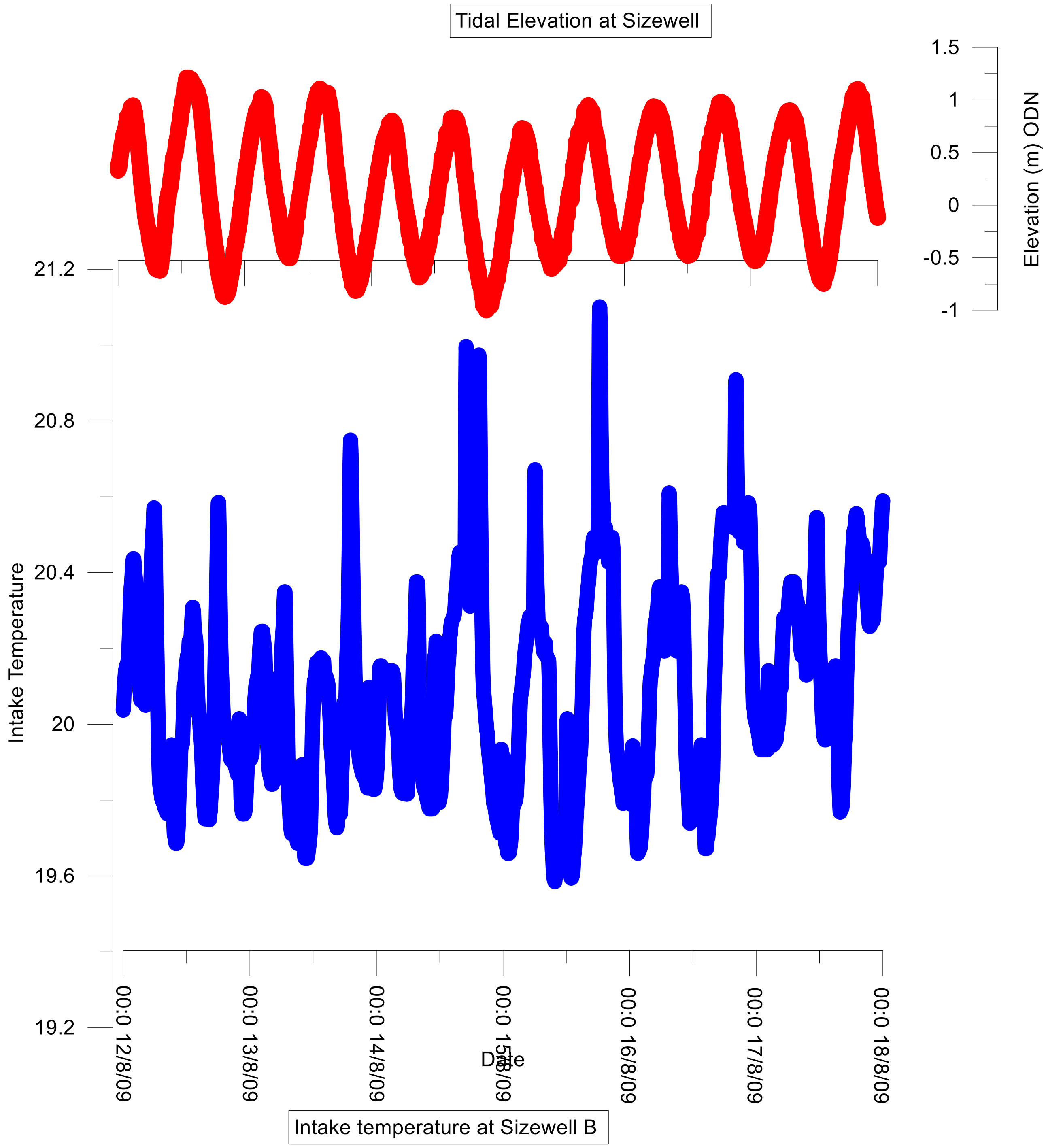

Figure 4 SZB Intake temperature (blue) during Neap tides in August 2009 and tidal elevation (red).

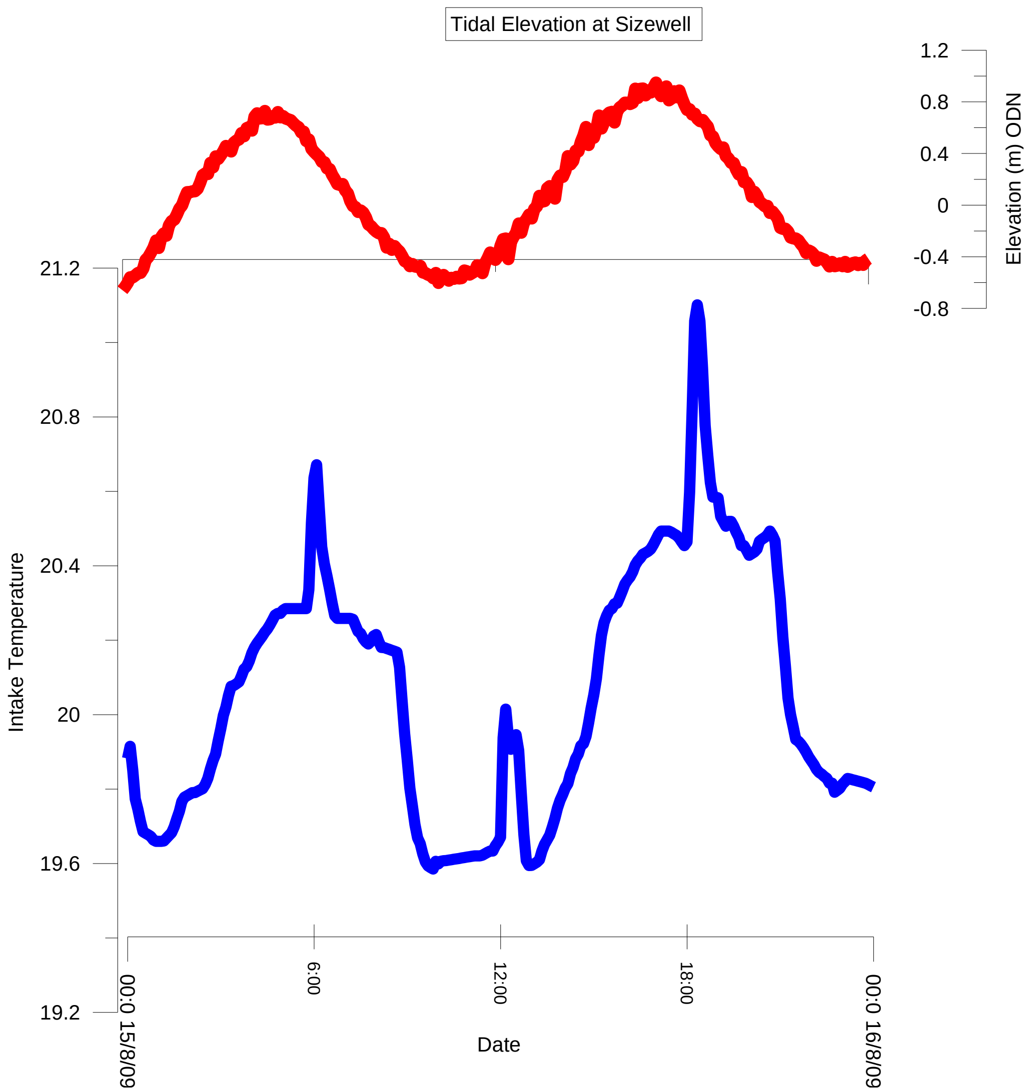

Figure 5 High resolution detail of SZB measured intake temperature in summer. Temp profile in (blue) and red shows the elevation data at Sizewell.

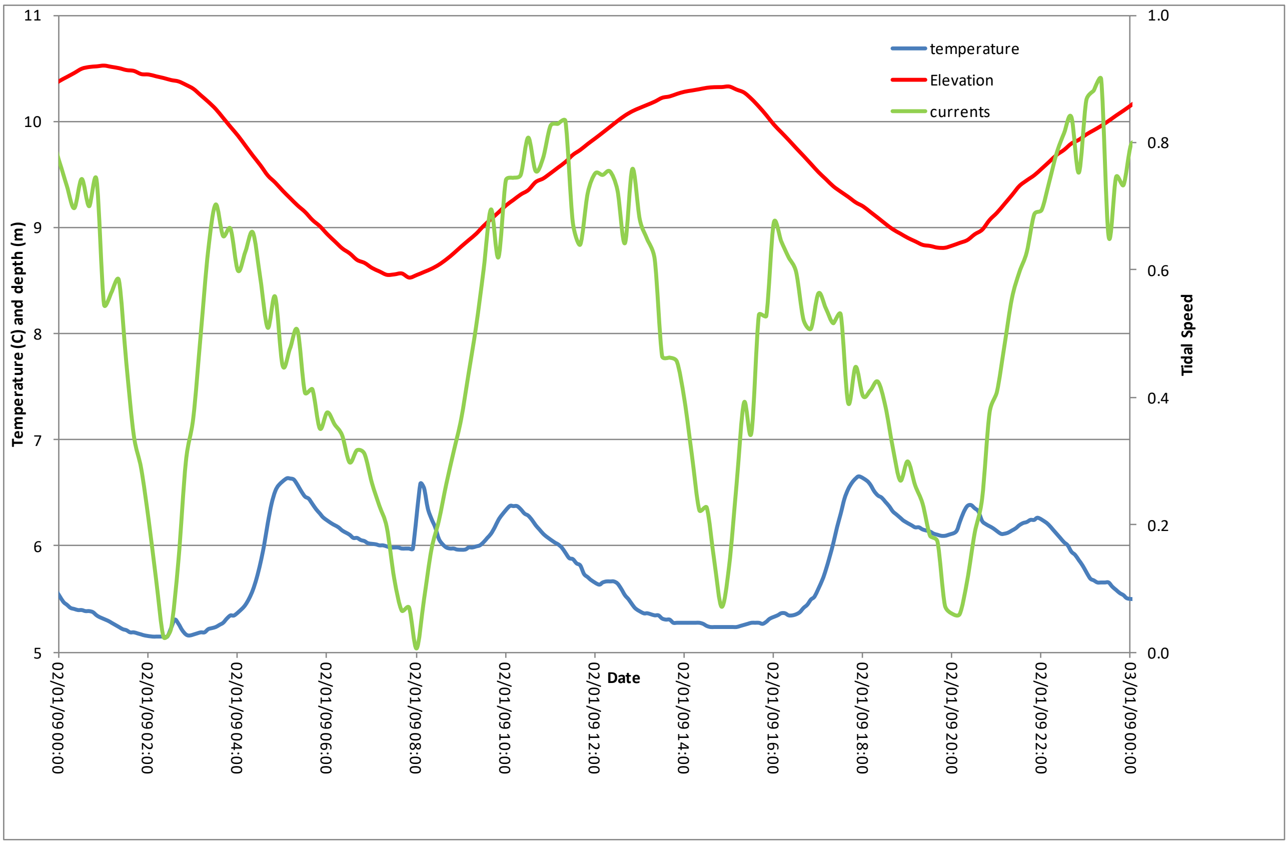

Figure 6 High resolution of temperature profile in winter (blue) neap tides, elevation at a sea bed lander site (near the Sizewell B intake) and mid water current speed (green) at the sea bed lander.

Key points to note from Figures 4 to 6 are:

i. The temperature cycle is related to the tidal excursion and mixing, rather than linked to the daily solar cycle. During summer maximum temperatures are associated with high water, where warmer water from relatively shallow areas in the Sizewell trough has been advected south on the flood tide. In contrast in winter (Figure 6) the flood tide brings cooler water from these regions.

ii. In summer temperature spikes of approximately 45 minutes duration occur near high and low water.. These spikes are typically +0.5°C to + 0.8°C above the daily diurnal variation. The contribution these spikes make to the mean is considered below.

iii. The monthly average of the daily difference between observed maximum and minimum temperatures at the SZB inlets in 2009 ranged between 0.9 and 1.5°C; with a mean of 1.2°C (See Annex B.2 for an analysis of the 1 hourly SZB temperature record). There is also a mean temperature uplift of the entire environment which is difficult to estimate from observations, but modelling indicates that it is approximately 0.2 – 0.35°C

iv. High and low water are slightly decoupled from slack tide, with both occurring slightly before slack. The period of slack water is short and the corresponding temperature spikes are short, it is during this time that the intakes are most likely to be drawing water from the surface regions.

v. Apparent from Figure 6 is that under some conditions rather than a temperature spike at high water, another spike occurs when the tide mixes the hot surface waters down, into the intake region. Thus producing spikes associated with peak velocity or a combination of peak velocity and tidal elevation. These spikes tend to occur over a longer time scale than the short spikes due to the periods of slack water. It is perfectly possible to have 4 temperature spikes per tide, 2 at slack water and 2 at peak flow, although this is relatively rare and 2 spikes per tide are more usual.

vi. The results of harmonic analysis of the SZB intake temperatures over 2007 – 2009 are presented in Appendix A along with analysis of August 2009 data. The analysis of data from August 2009 showed that the maximum daily variation around the mean due to tidal advection (i.e. excluding high frequency spikes) is ±0.46 °C. i.e. element i above.

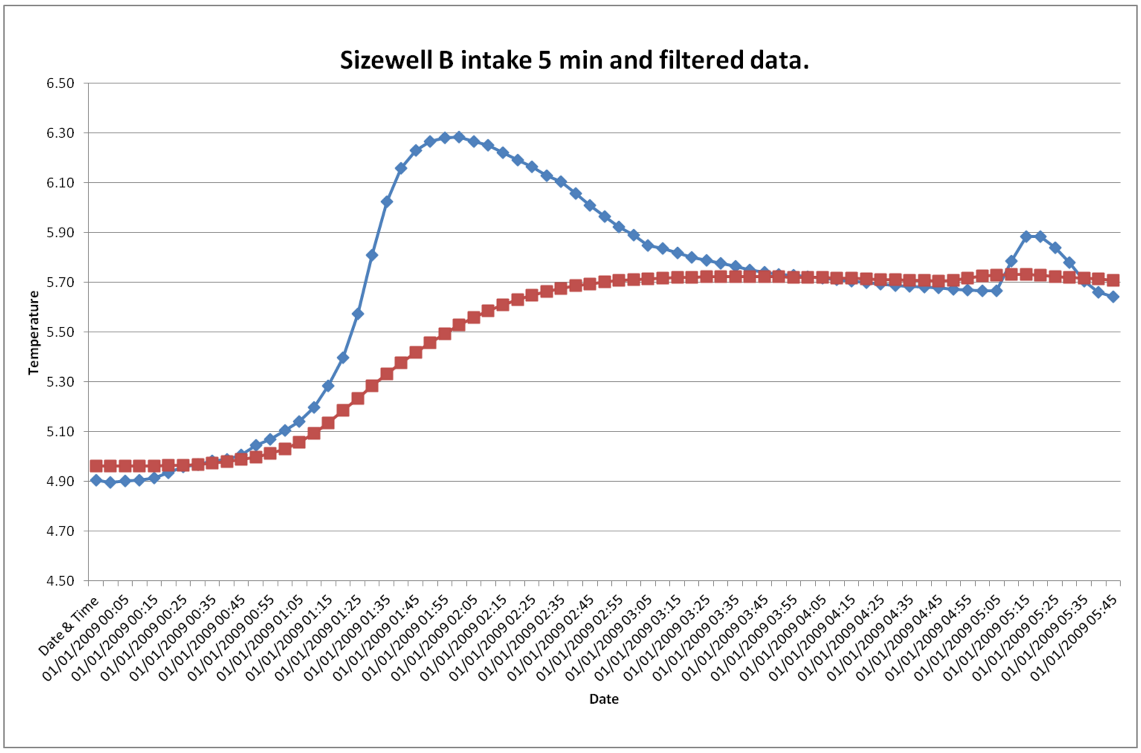

Figure 7 Sizewell Intake data at 5min interval (blue) and filtered data

A year long data set at high frequency (5 min) resolution for 2009 was used to estimate the contribution that the spikes make to the longterm mean. The raw data was filtered to remove the spikes using a exponential filter (0.1) (see red line in Figure 7). As spikes are only positive this filter was adapted to allow for this and generate a mean which excluded the spikes. Averaged over the whole of the year the mean excluding the spikes was 0.1 ºC lower than that which included the spikes. There is no way of estimating from the observations the general uplift effect of the power station inside of the Sizewell Bank. The uplift element can be estimated from models.

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2.5 Comparison and cross validation of temperature records

The longest and highest resolution seawater temperature dataset at Sizewell is that from the SZB cooling water pumps. However, the absolute accuracy of the SZB sensors is not known. A mooring with a calibrated ESM2 logger was deployed as close as practical to the Sizewell B intake from Nov 2008 – March 2009 and the logger data were used to calibrate the SZB sensors. The comparison was performed using the minimum daily temperatures, as the maximum or mean temperatures are most likely to suffer from recirculation or surface effects. This intercalibration demonstrated that the SZB sensors recorded inlet temperatures 0.3 °C too high and all temperatures from these sensors were therefore reduced by this value.

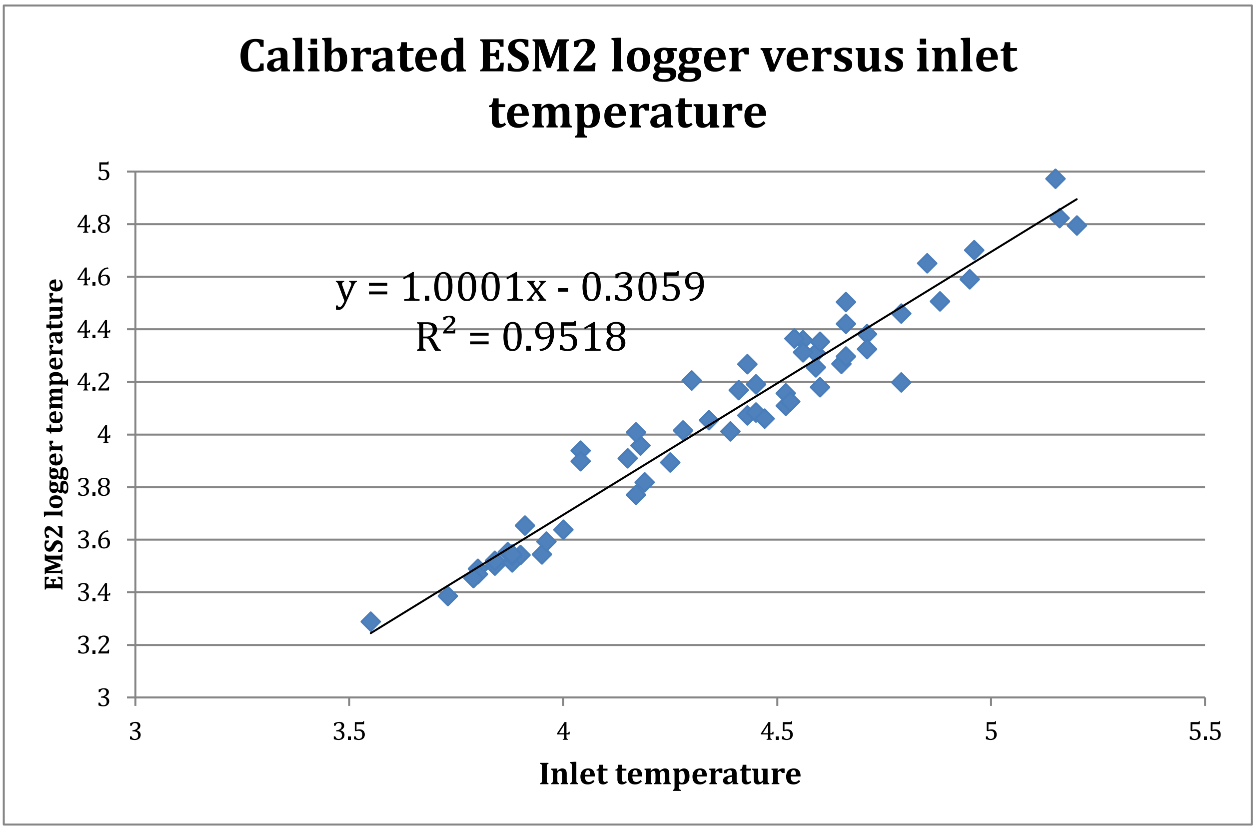

Figure 8 Calibration of SZB inlet temperature sensors

The seawater temperatures at the proposed Sizewell C intake have been estimated by comparing records from the BEEMS DWR wave recorder, which is slightly further offshore from the proposed Sizewell C intakes, with the calibrated SZB inlet temperatures. Analysis of the 2008 - 2009 datasets indicated that the offshore waters are cooler in the summer months by approximately 0.4 °C as a monthly mean and in the winter months by approximately 0.15 °C, see Table 2. (The data from the SZB intakes used for this calculation were filtered to remove the large spikes due to recirculation). The tables in this document relating to the Sizewell C intake have used the minimum value for each month from

Table 2 as a correction factor.

Table 2 Monthly comparison of offshore and inshore temperatures at Sizewell.

	Offshore SZC (intake) – Inshore B intake as monthly value (ºC)		
	Mean	Max	Minimum
Jan	0.0	-0.6	0.1
Feb	-0.5	-1.3	0.2
Mar	-0.3	-0.8	0.1
Apr	-0.6	-1.0	-0.4
May	-0.8	-1.7	-0.3
Jun	-0.7	-0.5	-0.8
Jul	-0.5	-0.8	-0.5
Aug	-0.2	-1.0	0.0
Sep	-0.2	-0.5	0.1
Oct	0.0	0.0	0.3
Nov	0.1	-0.1	0.2
Dec	-0.1	-0.3	0.0

Temperature estimates for the Sizewell C intake have been corrected for the effect of being offshore by using the monthly minimum difference as above. i.e. SZC is slightly warmer in winter but colder in summer than SZB. As can be seen from Figure 9 the differences are greatest when the rate of sea temperature change is greatest, but reduce when maximum sea temperatures are reached.

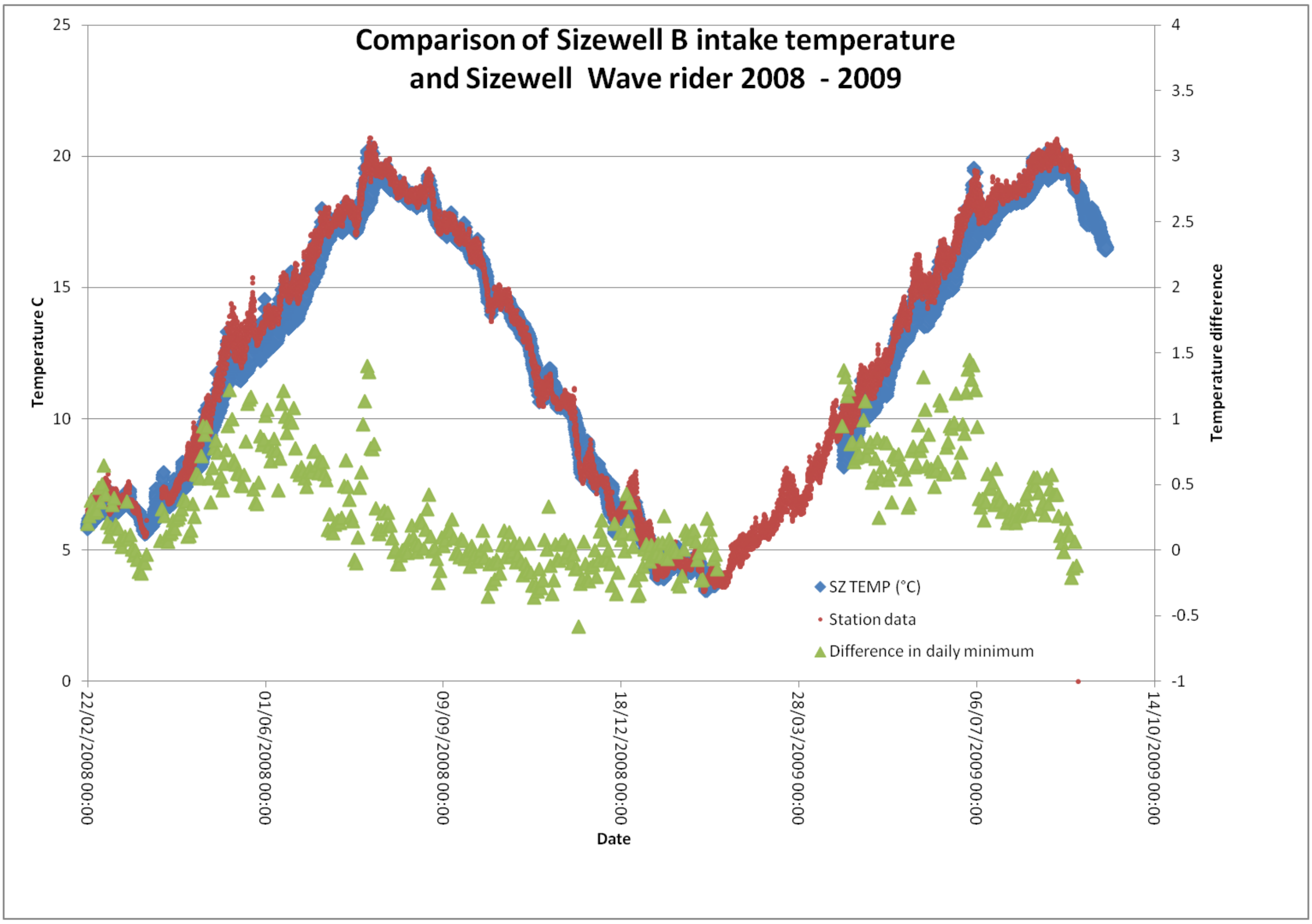

Figure 9 Corrected SZB intake temperatures and surface offshore temperature (blue) at proposed SZC intakes. The green is the difference in the daily minimum (right hand scale). There is a slight (+0.46 C) general uplift of the inshore temperature compared to offshore.

3 Summary of the Stage 2 Sizewell C modelling results

The details of the Stage 1 Delft3D and the GETM model setup, current validation and thermal comparison results can be found in BEEMS Technical Reports TR132 and TR229 respectively. The Stage 2 results are in BEEMS Technical Reports TR133 and TR230 respectively.

The Delft3D model was ready for use before the GETM model. An initial list of six potential intake/outfall configurations was considered by EDF Energy for Sizewell C (See Figure 10 and Table 3). This list was narrowed down after a consideration of engineering constraints and coastal hazards to 3 priority configurations for modelling in Delft3D that represented the range of possible system designs:

- Configuration 1 (C1): Onshore intakes (I1 and I2) and discharge O1;
- Configuration 4 (C4): Onshore intakes (positions as C1), offshore discharge O4;
- Configuration 5 (C5): Offshore intakes (I3 and I4), onshore discharge (O5).

(where offshore means offshore of the Sizewell-Dunwich Bank).

Table 3. Locations of the Sizewell B and modelled Sizewell C intakes and outfalls

Intake/ Outfall	Location		Depth (mODN)
	Easting (mBNG)	Northing (mBNG)	
Intake SZ B	648297	263612	8.95
Outfall SZ B	647834	263647	5.10
Proposed SZ C			
Intake C1a (and C4a)	648577	264524	9.13
Intake C1b (and C4b)	648619	264026	10.08
Outfall O1	647974	264172	5.11
Outfall O4	651293	264715	14.55
Intake C5a	650650	264150	12.26
Intake C5b	650536	263156	14.12
Outfall C5 (O5)	648071	264050	6.12
Outfall C6 (O6)	651217	263582	16.8
Note. Depths are positive below datum, BNG British National Grid, ODN Ordnance Datum Newlyn			

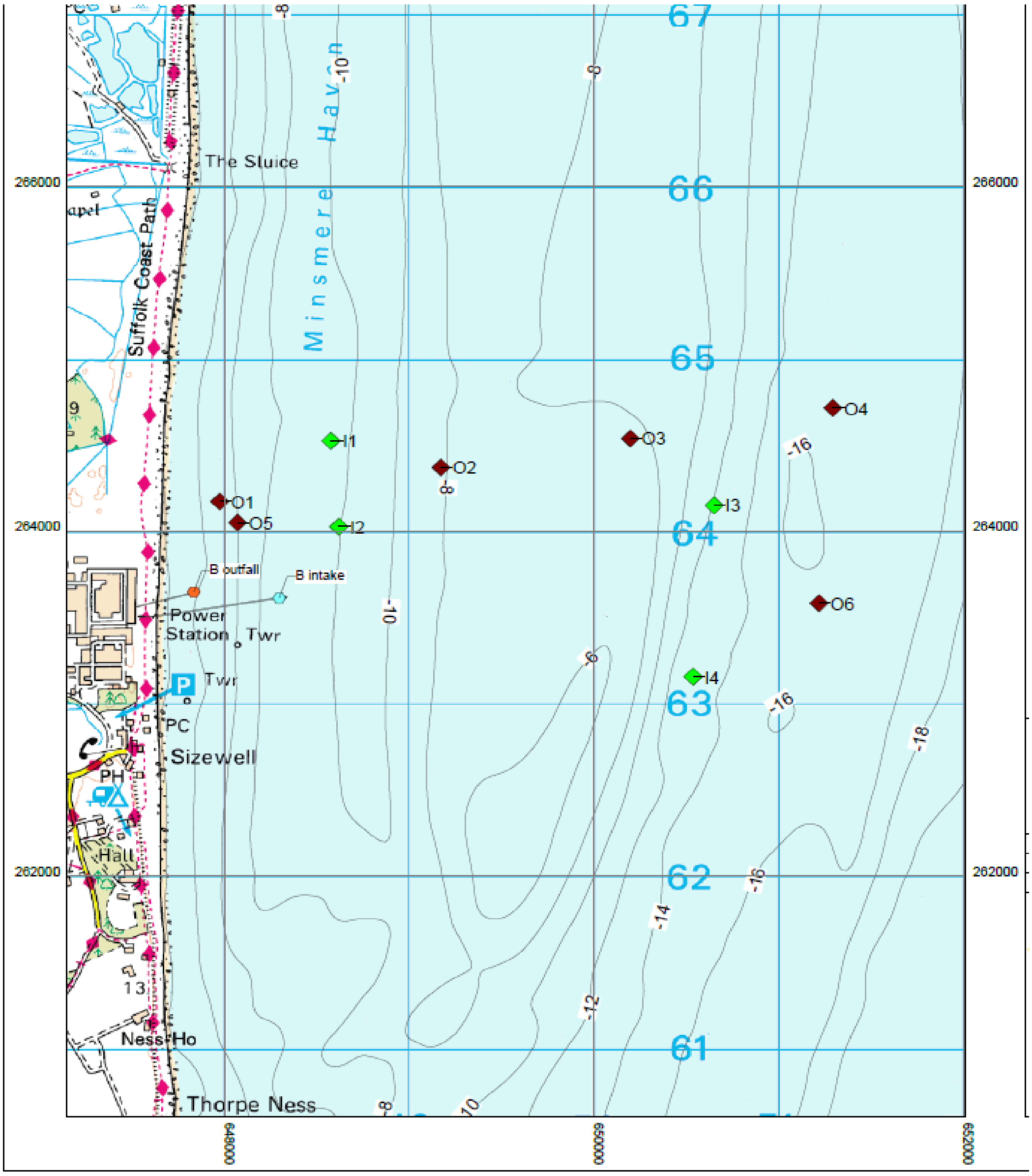

Figure 10. Locations of the SZB and initial SZC intakes (green) and outfalls (purple) in relation to the site bathymetry

The results of modelling these 3 configurations using the Delft3D model are described for in BEEMS Technical Report TR133 which concluded that:

- Configuration 5 resulted in the lowest mean excess temperatures at the SZC inlets (0.1°C) with mean excess temperatures of 1.3°C at the SZB intakes (over a spring-neaps cycle)
- Configuration 4 produced the lowest mean excess temperatures at the SZB inlets (0.3°C) with mean excess temperatures at SZC inlets of 0.2°C (over a spring-neaps cycle)

After a consideration of coastal hazards, EDF Energy decided on risk management grounds that the intakes of SZC should be offshore of the Sizewell-Dunwich Bank which has historically been migrating shoreward (BEEMS Technical Report TR105).

For engineering reasons EDF Energy also provisionally decided that, subject to further studies, that the SZC outfall should be onshore (EDF Configuration 5). The existing SZB station has an onshore discharge with an intake in the trough between the shore and the Sizewell-Dunwich Bank. Using Configuration 5 for the design of the SZC CW system the recirculation between the SZC outfall and intakes would be negligible but there would be increased temperatures at the SZB intakes due to the SZC discharge that could affect the operation of SZB. SZB is planned to operate until at least 2035 and so the purpose of continuing studies was to estimate the magnitude of the potential impact of the SZC discharge upon SZB both in 2020 (the earliest estimate of SZC becoming operational at that time) and throughout the life of SZB if Configuration 5 were adopted for the SZC cooling water system.

Further modelling was conducted in GETM of:

- Configuration 5 (C5): Offshore intakes (I3 and I4), onshore discharge (O5).
- Configuration 6 (C6): Offshore intakes (I3 and I4), offshore discharge (O6, south of O4 modelled in Delft3d).

It was concluded that the increase in mean excess temperatures at the seabed offshore of the Bank at the SZC intakes would be similar for both configurations (approximately +0.5 to +0.8°C). Inshore of the Bank Configuration 5 had a much more substantial thermal impact both in terms of the size of the area affected and the increase in temperatures (approximately +2°C increase in annual mean excess temperatures at the seabed). These predicted excess temperatures at the Sizewell B intakes and in particular the predicted maximum excess temperatures caused some concern over the future operation of SZB and it was therefore important to understand the relative confidence that could be placed in the predictions from the 2 different models.

4 Comparison of the accuracy of thermal predictions from the 2 models

Qualitatively both models described the observed SZB plume features (Appendix C and BEEMS Technical Reports TR132 and TR229). However, in order to use the models for assessment of thermal recirculation and potential environmental impacts it is important to derive a numerical estimate of the accuracy of the 2 models. The best datasets with which to make such an estimate were the 5 minute inlet temperature record at SZB and the temperature data gathered during the September/October 2009 SZB outage in which we were able to directly follow the thermal impact of SZB from no power to full power in a period of stable weather conditions and to compare these results with modelling.

4.1 Delft3D and GETM modelling of excess temperatures at SZB inlets due to SZB alone

In BEEMS Technical Report TR132 a comparison was presented of modelled excess temperatures at the SZB inlet against measured temperatures with SZB at full power output. The comparison was done for the 23rd June 2009 Spring tide and 1 July 2009 Neap tide. The input parameters to the Delft3D model were a measure wind speed of $3ms^{-1}$ from NE and a background sea temp of 17°C. The model spin up time in order to achieve thermal equilibrium was 7 days.

The modelled excess temperatures at SZB inlets due to SZB were 0.25°C Springs and 0.4°C Neaps i.e. a mean excess temperature of approximately 0.33°C

An estimate of the actual excess temperature of 0.5°C was calculated by subtracting the minimum recorded temperatures at the intake from the observational temperature during the spring and neap survey periods. TR132 acknowledged that this calculation assumed that there was no general uplift in local seawater temperatures due to SZB and that this was unlikely to be correct. It is not possible to estimate the temperature uplift from the available temperature record but from modelling it has been estimated to be approximately 0.27°C. i.e. the actual excess temperature in the period 23rd June to 1 July compared to a situation with no power station operating was approximately 0.77°C, indicating a Delft3D error of -0.44°C

The same two 24hour periods were extracted from the GETM model results for runs with both SZB operating and with no power station. The modelled excess temperatures were 0.77°C and 0.79°C with a mean 0.78°C i.e. 0.01°C too high.

From this limited analysis it could be concluded that the 2 models produce similar predictions of excess temperatures. The Delft3D model does not use real meteorology and has limited parameterisation i.e. wind speed and water temperature which are given one set of values for the duration of each model run (usually a spring-neap cycle) and the calculated excess temperatures are then used for any time during the year. This was the approach adopted in BEEMS Technical Report TR133 to calculate excess temperatures at the SZB inlets due to SZC+SZB operating together. A water temperature of 11.6°C and a wind speed of 5 ms^{-1} were applied; representing annual mean values at Sizewell. The question that then arises is how much confidence can be placed in the calculated Delft3D results.

Figure 11 shows modelled excess temperatures at the SZB inlets from the GETM model for SZC (configuration 5) + SZB and SZB only. Both charts show that the predicted excess temperatures vary seasonally with lowest values in July and highest in winter. This is likely to be due to stronger winds in winter causing greater mixing of the buoyant thermal plumes down into the water column where they are more likely to be abstracted by the intakes and/or to the lower heat loss associated with low winter temperatures due to long wave radiation. If this predicted seasonal cycle is realistic then the comparison described above was undertaken when the expected excess temperatures were at a minimum.

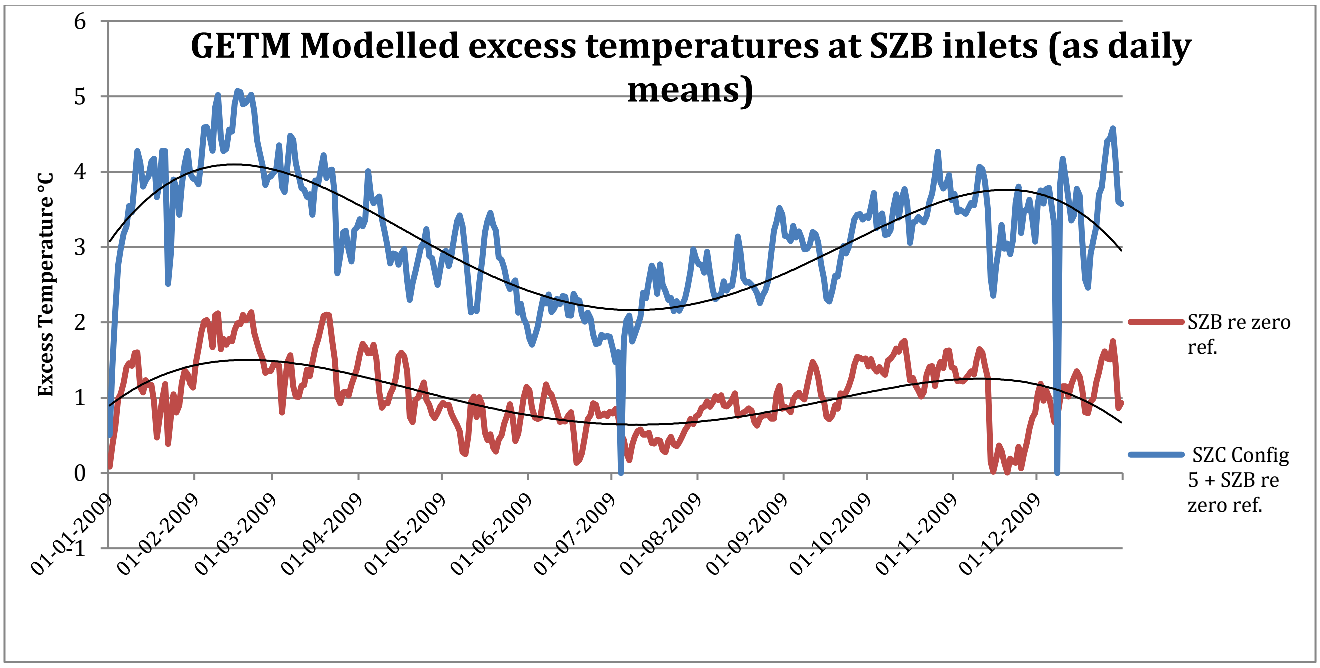

Figure 11 GETM predictions of daily mean excess temperatures at the SZB inlets for SZB and Configuration 5 (SZB+SZC)

In the period 18/9/2009 to 28/10/2009 there was a SZB outage which has provided further validation data. In particular from 18 September to 22nd October the reactor was operating at zero power output which would have provided ample time for any generalised uplift in water temperatures due to SZB to have been eliminated from the environment and temperatures measured when the cooling water flow was at 100% could reliably be considered as pristine background temperatures. The period 21/10/2009 to 1/11/2009 is of particular interest because prior to and after this period water temperatures were predicted and measured to be declining but during that period, the GETM zero reference run (with no power station) indicated that meteorological conditions and, in particular water temperatures, were stable. Inspection of Figure 12 shows that period E represents a period when water temperatures had stabilised after SZB had ramped its power output to 100%. The measured temperature difference between period A in Table 4 and period E therefore represents an estimate of the true excess temperature due to SZB.

Table 4 SZB power output by date during the 2009 outage

Period	Date	% of rated power output	CW Flow
A	15:00 21/10/09 -14:00 22/10/09	0.28%	100%
B	15:00 22/10/09 – 17:00 22/10/09	Power ramped up to 8.6%.	100%
C	21:00 24/10/09 – 11:00 25/10/09	Power increased to 51%	100%
D	16:00 27/10/09 – 16:00 28/10/09	Power increased to 100%	100%
E	21:00 30/10/09 – 12:00 1/11/09	101%	100%

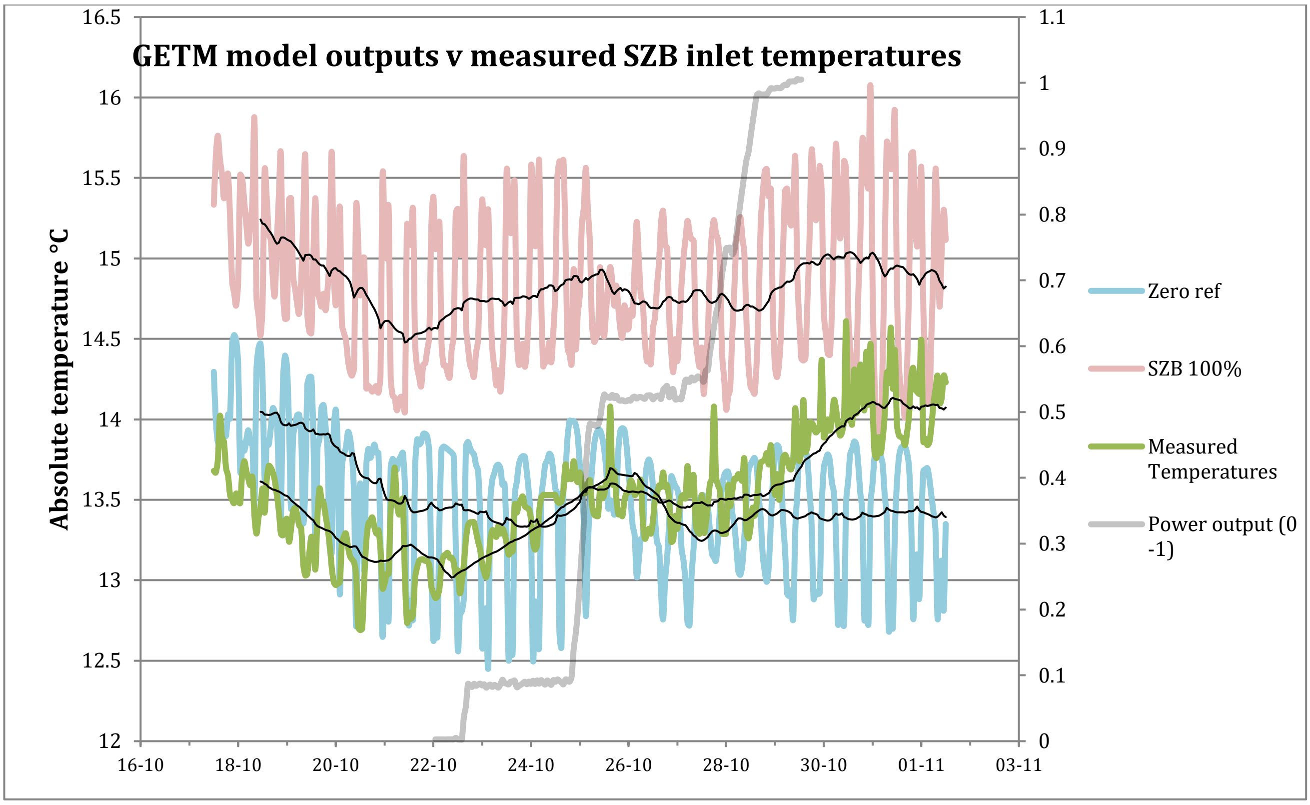

Figure 12. GETM model outputs (SZB and Zero reference at 1 hr resolution) and measured SZB inlet temperatures during the 2009 SZB outage. The black lines represent a 24 hour running mean through each temperature series.

Analysis of the outage data showed that:

- The measured excess temperature rise at the SZB inlets due to SZB was 1.04°C in the period 21/10/09 to 1/11/09

- The modelled excess temperature (SZB-zero reference) was 1.4°C; i.e. the GETM error was +0.36C compared to the measured value
- Both the GETM zero reference and SZB models consistently over predicted absolute temperatures; during the outage period by approximately +0.5°C and +0.8°C respectively.
- Inspection of the annual SZB inlet temperature record showed that the predicted absolute temperatures when SZB was operational exceeded the measured values during all of 2009. The largest over predictions of absolute temperatures occurred in period June- mid July (+1.5 to +2.5°C)

Table 5 Summary of calculated errors in modelling excess temperatures at SZB inlets due to SZB alone.

Date	**Delft3D Predicted excess temp. °C**	**GETM Predicted excess temp. °C**	**Estimated actual excess temp. °C**	**Delft3D error °C**	**GETM Error °C**
23/6/09 & 1/7/09	0.33	0.78	0.77	-0.44	+0.01
21/10/09- 1/11/09	0.33	1.4	1.04	-0.71	+0.36

Note: The Delft3D predicted excess temperature is a mean over a spring-neap cycle. Based upon previous studies the Delft3D excess temperature predictions are assumed to be mostly independent of seasonal variation.

Based upon the results of SZB modelling Table 5 indicates that:

a. the GETM excess temperatures predictions are greater than measured values and the Delft3D excess temperatures are lower than those measured

b. the GETM excess temperature predictions are more accurate than those from Delft3D

4.2 Delft3D and GETM modelling of excess temperatures at SZB inlets due to SZC+ SZB

This study considered the modelling results from SZB+SZC Configuration 5 with both stations discharging inshore of the Sizewell-Dunwich Bank. The ratio of the dissipated power in the marine environment between Configuration 5 and SZB alone is 3.7:1. However, whilst such a ratio might be generally indicative of expected temperature increases, the ratio of the excess temperatures at the SZB inlets would not expected to be linearly related to the ratio of dissipated power because of seasonally varying mixing and heat loss to the atmosphere. The SZB and SZC plumes are discharged from different locations but both outfalls were inshore of the Sizewell-Dunwich Bank and the 2 plumes would be expected to be additive but with considerable variability depending upon prevailing meteorology at the time.

For the configuration 5 runs the Delft3D model was parameterised with a heat exchange coefficient of 26.2 Wm^{-2} $(°C)^{-1}$ based upon a mean water temperature of 11.6°C and a wind speed of $5ms^{-1}$. These numbers were derived from a 37y water temperature record at Sizewell and the median wind speed from a 30y record at Walton-on-Naze (60km south of Sizewell). The water temperatures correspond with those measured in late May and early November. It is not known whether the mean wind speed was appropriate for these periods.

Table 6 Delft3D estimates of excess temperatures at SZB inlets

Month	**SZB only °C**	**SZC (Config 5) + SZB °C**	**Ratio of excess temperatures**
23/6 – 1/7	0.33	1.3	3.9

Note: the 2 Delft3D estimates were derived from models with slightly different heat exchange coefficients

Table 7 GETM estimates of excess temperatures at the SZB inlets

Month	SZB only °C	SZC (Config 5) + SZB °C	Ratio of excess temperatures
January	1.03	3.49	3.4
February	1.8	4.6	2.5
March	1.38	3.71	2.7
April	1.18	3.15	2.7
May	0.68	2.75	4.1
June	0.75	2.13	2.8
July	0.5	2.18	4.4
August	0.86	2.68	3.1
September	1.11	3.18	2.8
October	1.4	3.54	2.5
November	0.75	3.49	4.7
December	1.13	3.51	3.1
Mean			3.23

The GETM results predict that the Configuration 5 excess temperatures at the SZB inlets would be approximately 3.25 times those due to SZB alone. The limited equivalent estimates from Delft3D suggest an excess temperature multiplier of 3.9 times those due to SZB alone. The measured excess temperature at the SZB inlets due to SZB alone was 0.77°C in June and 1.04°C in late October. The Delft3D predicted excess temperature of 1.3°C at the SZB inlets due to Configuration 5 is, therefore, not credible given comparable measured excess temperatures with SZB alone.

4.3 Selection of model to use for excess temperature estimates

The predictions of excess temperatures from the two models show large differences dependent upon the comparisons that are made. The model validation work has demonstrated that the 2 models produce similar estimates for the mean excess temperatures at the SZB intakes with only SZB operating and with light winds. However, sensitivity tests with the Delft3D model have demonstrated that the results are sensitive to the wind direction and it is to be expected that the Delft3D predictions will also be sensitive to wind speed which will create different amounts of down mixing of the plume than that produced by the light winds simulated to date.

The predicted excess temperatures during the annual cycle from the GETM model of SZB+C show a clear seasonal trend with lowest values in the summer months. This may be due to the greater heat loss associated with high temperatures due to long wave radiation and/or to reduced mixing with lower wind speeds in summer. The GETM results are only from one year of meteorological data and whilst it is considered likely that there will be a seasonal variation in excess temperatures, we only have limited evidence to determine whether the predicted magnitude of the seasonal effect is correct. Nevertheless, given the effect of meteorological variation on model predictions, we consider it important to model cooling water systems over an entire 12month cycle with real meteorology.

Given the predicted seasonal change in excess temperatures at the SZB intakes it is not appropriate to compare Delft3D estimates from one Spring-Neap tidal cycle and fixed, low wind speeds with estimates from an entire 12 month GETM run with real meteorology. Indeed estimates of annual means and maximums of excess temperatures are not particularly useful for predicting SZB intake temperatures given the expected seasonality in excess temperatures. Both models are sensitive to the winds, with winds from the South and Southwest producing the greatest excess temperatures. The GETM model gives predicted excess temperatures that are higher than those from Delft3D. However, GETM is able to more fully represent the dynamic winds observed at Sizewell and the model outputs are therefore considered to be most appropriate for predictive purposes in this report and likely to represent upper limits.

In conclusion:

- The predicted Delft3D excess temperatures due to SZB alone were lower than the excess temperatures measured at the station.
- For the Delft3D combined SZB+SZC modelling runs the predicted relative increase in excess temperatures over those predicted due to SZB alone appear reasonable. The predicted values for excess temperatures are, however, significantly under estimated compared with measurements made at the existing SZB station and from considerations of the increase in discharged heat energy.
- The GETM excess temperature predictions for SZB alone were higher than those measured at the station but were closer to the measured values than the Delft3D results. The combined SZB+SZC excess temperature predictions appear reasonable compared with measurements made at the existing SZB station and from considerations of the increase in discharged heat energy.
- It was therefore considered that the GETM model was more suitable as the primary tool for plume modelling at Sizewell and that its use would be conservative but not overly so.

5 GETM modelling of additional options for the SZC outfall position.

Having decided that the GETM results were more reliable for predictive purposes, the temperature regime at the intakes of SZB and SZC were considered in detail for a SZC discharge inshore of the Sizewell Bank at location O5 in Figure 13 (configuration 5). These analyses demonstrated that the impact of recirculation fell predominantly onto SZB and that there was only minor recirculation and consequent elevation of intake temperatures at SZC. In particular, in addition to a generalised increase in mean cooling water intake temperatures throughout the year, the existing recirculation temperature spikes at SZB were predicted to increase in magnitude substantially. The thermal impact on SZB operation from this CW configuration was judged to be unacceptable by EDF Energy.

BEEMS Technical Report TR230 presented the initial results of modelling 2 CW options that encompassed what was considered to represent a realistic range of SZC discharge locations

- Configuration 5 with two offshore intakes at I3 and I4 and an inshore discharge at O5
- Configuration 6 with offshore intakes at I3 and I4 and an outfall offshore of the Bank at O6.

The results showed a substantial reduction in the thermal impact of recirculation on SZB with configuration 6. However, it subsequently became clear that Configuration 6 could not be built as it was in the agreed development zone of the Galloper wind farm cable corridor (delineated by the thick purple lines shown in Figure13.

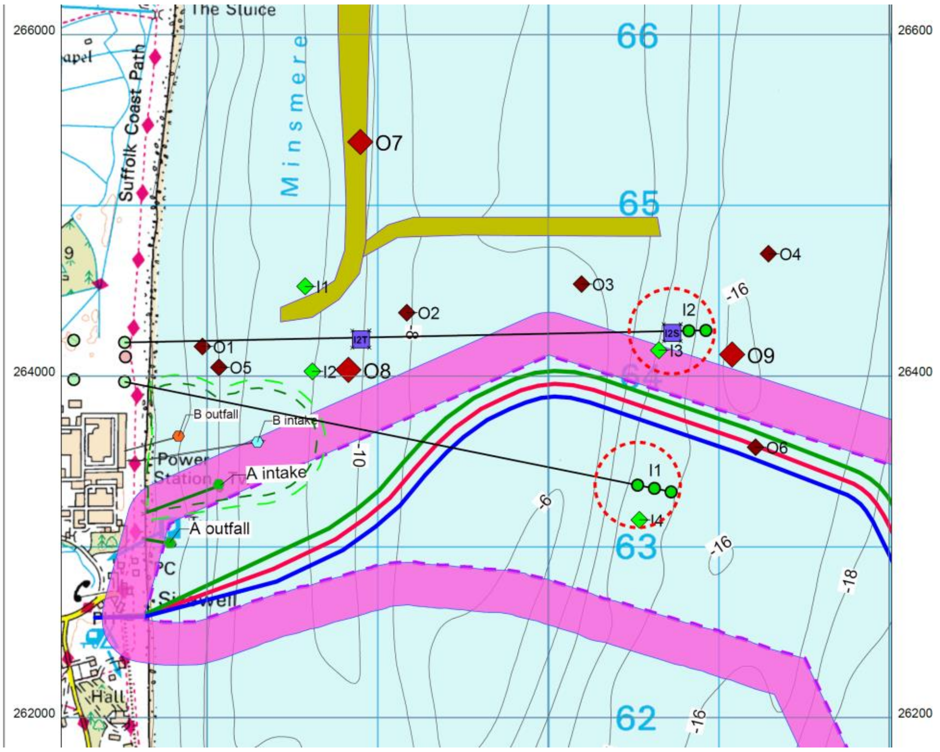

Figure 13 Sizewell cooling water system locations shown against the Galloper development zone (inside purple lines).

It was decided that BEEMS should investigate three additional locations for the SZC discharge (See Figure 13):

- Outfall locations O7, O8 inside of the Sizewell Bank (located as far offshore as possible inside of the bank)
- Outfall location 09 outside of the Bank (located as close to shore as possible without entering the construction zone of SZC intake I2).

To enable the impacts of the different locations to be rapidly screened the model was run for each location for the hottest month in the reference year (August 2009). As would be expected from hydrodynamic considerations, an outfall location offshore of the Bank produced lower increases in intake temperatures at SZB than either of the discharge locations inshore of the Bank. The results from SZC discharge locations 07 and 08 were essentially the same. However, O7 would be complex to build and would require a reengineering of the SZC site plot plan. The location was also in the likely navigation route for vessels using the proposed Beach Landing Facility and jetty (MOLF). Location O7 was, therefore, discounted and it was decided that further studies would be focussed on locations O8 and O9 only. It is known that the modelling results are substantially affected by the prevailing meteorology and therefore before environmental impacts of the different SZC CW configurations could be assessed it was essential to produce annual model runs.

It was expected from prior modelling results that the thermal impacts of different SZC discharge locations would be ranked on a gradient from west to east and in order to better understand the model outputs it was decided to include an additional SZC discharge location, O10, offshore of the Bank but to the west of the SZC intakes (fully understanding that this position could probably not be built). In addition, to understand the impact of going east of O9 into deeper water, a further analysis of previous modelling results from configuration 6 was undertaken (previously reported in BEEMS Technical Report TR230). The full range of SZC discharge locations that were tested with annual model runs are shown in Figure 14 and Table 8.

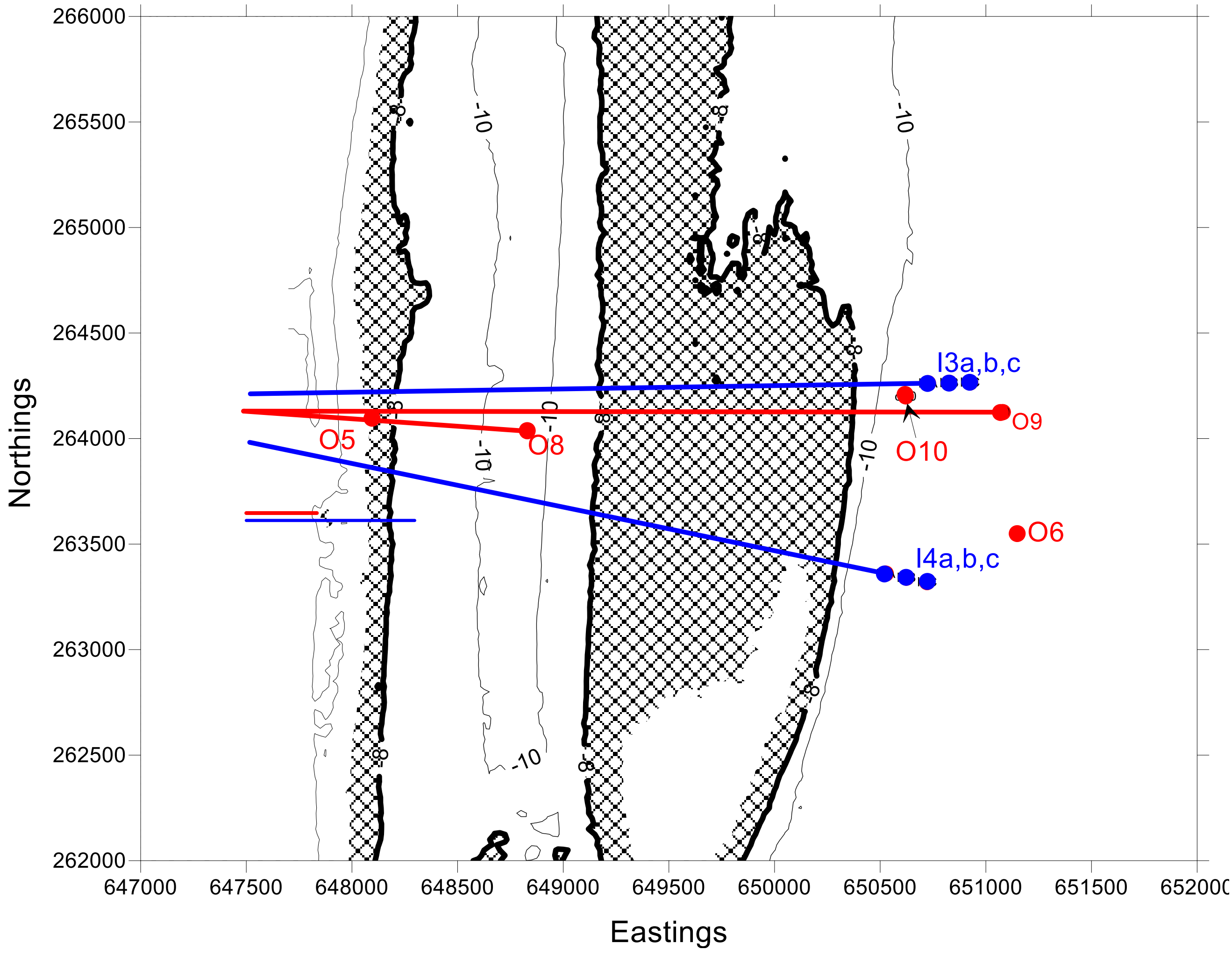

Figure 14 Layout of Intake and Outfalls for SZ B and the proposed SZ C. Intakes are marked in blue, outfalls in red. New modelled outfalls at O8, O10, O9. Also marked are previous locations O5 and O6.

Table 8 Location of the SZB and SZC cooling system components

Intake/Outfall	Location		Depth below (mODN)
	Easting (mBNG)	**Northing (mBNG)**	
IB Intake SZ B	648297	263612	8.95
OB Outfall SZ B	647834	263647	5.10
Proposed SZ C			
I3a Intake	650726	264262	11.6
I3b	650826	264264	
I3c	650925	264266	
I4a Intake	650526	263360	12.1
I4b	650624	263341	
I4c	650722	263320	
Outfall O5	648071	264050	6.3
Outfall O8	648830	264035	10.4
Outfall O10	650621	264200	11.9
Outfall O9	651080	264125	16.2
Outfall O6	651217	263582	16.8
Note. Depths are positive below datum, BNG British National Grid, ODN Ordnance Datum Newlyn			

Table 9 shows the model runs that were performed during this study together with the cooling water discharge parameters used. Figure 15 shows the Sizewell model domain.

Table 9 GETM Model runs undertaken

Run ID	Description	Intake location	Discharge location	Discharge flow and delta T m^3s^{-1} @ °C
SZ B	SZ B	IB	OB	51.5 @ 11.0
Zero Reference	No power stations, no CW flow			
Configuration 5	SZ C (inshore discharge) + SZ B	I3, I4 + IB	O5 + OB	125 @ 11.6 and 51.5 @11.0
Configuration 6	SZ C (offshore discharge) + SZ B	I3, I4 + IB	O6 + OB	125 @ 11.6 and 51.5 @ 11.0
Configuration 8	SZ C (inshore discharge) + SZ B	I3b,c, I4b,c + IB	O8 + OB	125 @ 11.6 and 51.5 @ 11.0
Configuration 9	SZ C (offshore discharge) + SZ B	I3b,c, I4b,c + IB	O9 + OB	125 @ 11.6 and 51.5 @ 11.0
Configuration 10	SZ C (offshore discharge) + SZ B	I3b,c, I4b,c + IB	O10 + OB	125 @ 11.6 and 51.5 @ 11.0

6 Predicted increase in temperature at SZB intake due to SZC (recirculation)

6.1 Methodology for deriving annual plume temperatures

All the model runs covered the period from 1/12/2008 to 31/12/2009. December 2008 was used only as a spin-up period for the meteorological and boundary forcing and the twelve months of 2009 were used to calculate the mean and maximum temperatures presented in this report. The area around the Sizewell area was simulated on a curvilinear grid of 25 m resolution at its finest and with 20 layers in the vertical. All model results were obtained from GETM version 2.1.0.

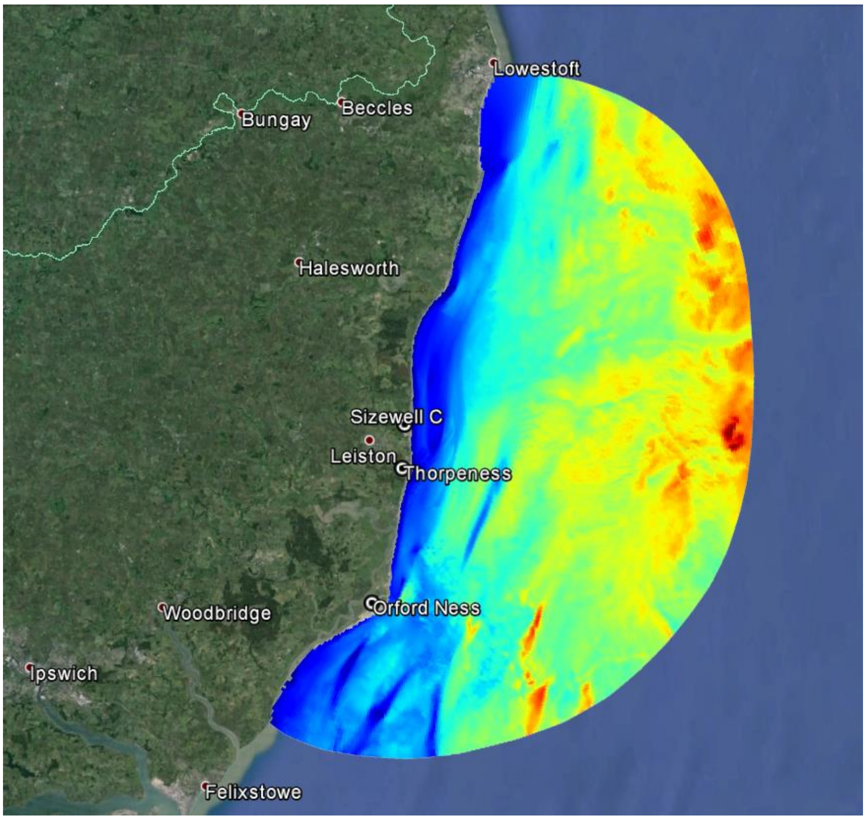

Figure 15 Model Domain showing bathymetry and the curvilinear boundary.

The data were output at 1 hour intervals and created approximately 925 GB per model run per annual cycle. Each annual model run took approximately 20 elapsed days. The models outputted a selected set of variables every hour into NetCDF (Network Common Data Form) files that were used to produce time series, mean and maximum temperatures.

Two sets of excess temperature are presented, those that are referenced to a zero situation where no power stations operate and those which are referenced to the thermal conditions created by the existing Sizewell B.

6.2 Annual intake temperatures at SZB and SZC compared with existing situation

Figures 16 -19 show the predicted excess temperatures at the intakes of SZB or SZC (over existing temperatures due to the SZB discharge) with different SZC outfall locations.

Figure 16 shows the effect of moving the SZC outfall offshore (at positions O5, O8, O10, O9 and O6) in terms of the annual mean and 95%ile excess temperatures at the SZB intake. Mean excess temperatures reduce from +1.8°C at O5 to +0.54°C at O6 i.e. temperatures fall at a rate of approximately 0.4°C/km. The 95%ile temperatures fall at a slightly faster rate of 0.48°C/km from O5 to O9 or 0.7°C/km if the predicted impact at O6 is included.

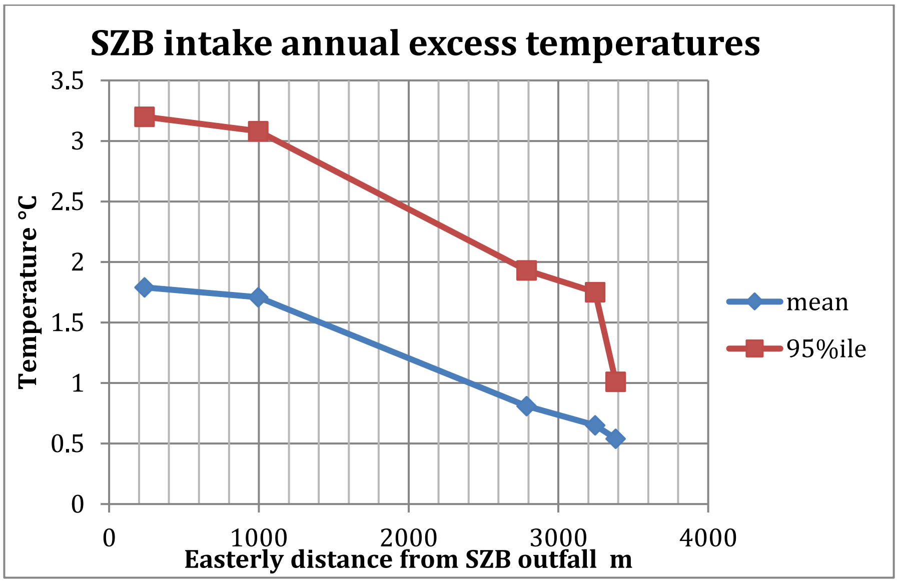

Figure 16 Impact on SZB intake temperatures of SZC discharge location. (SZB+SZC referenced to SZB).

The corresponding impact on recirculation at SZC is shown in Figure 17. There is a slight increase in mean and 95%ile excess temperatures from O5 to O9 with a predicted drop in both temperatures at O6.

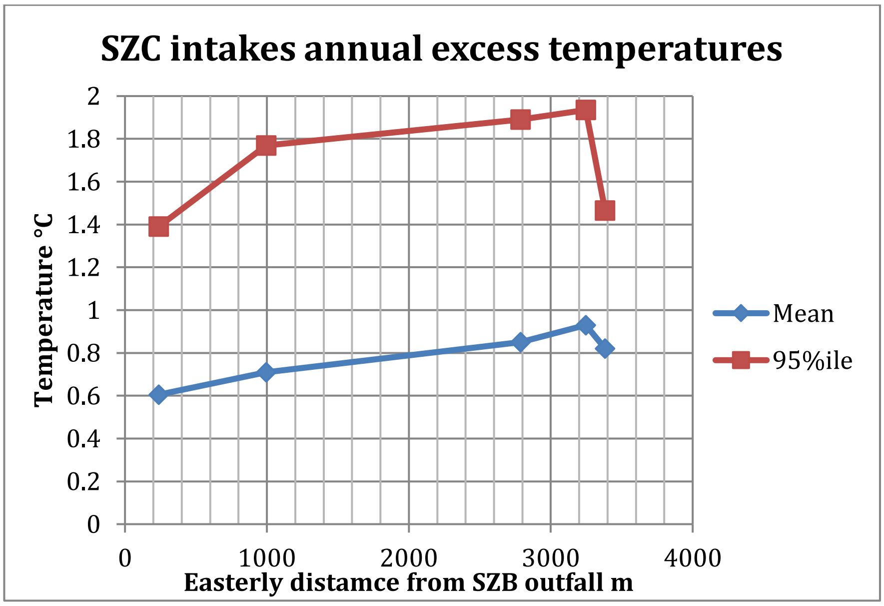

Figure 17 Impact on SZC intake temperatures of SZC discharge location. (SZB+SZC referenced to SZB).

Modelling undertaken for this study has demonstrated that the amount of recirculation depends upon meteorological conditions and there is a distinct seasonal cycle with higher excess temperatures in winter and lower in summer. It would, therefore, be expected that whilst the trend of reduced recirculation with easterly location of the SZC discharge would be replicated throughout the year, the magnitude and variability of the impact would vary in different months. This is illustrated in Figures 18 and 19 which show calculated excess temperatures in the hottest month of the year, August.

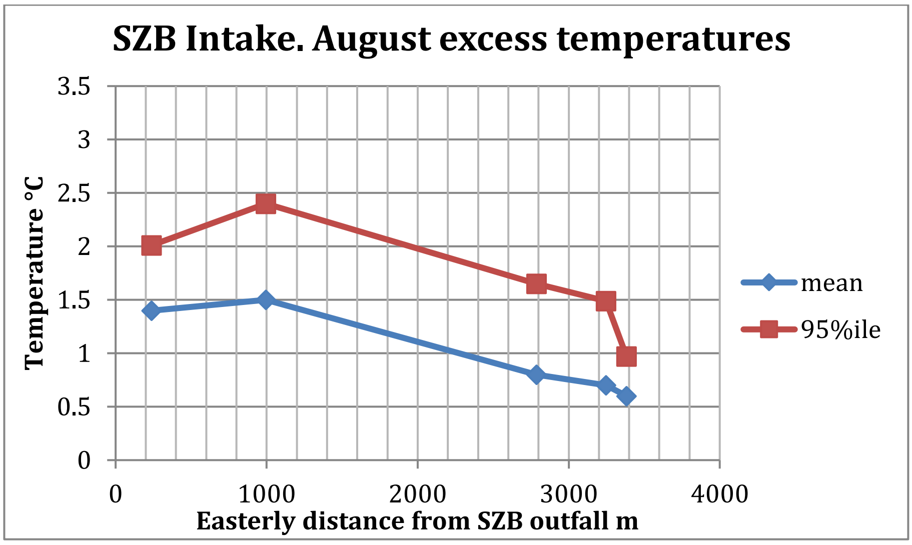

Figure 18 Impact on SZB intake temperatures in August with different SZC discharge locations.

In August, there is much less meteorological variability and hence 95%ile temperatures are close to the means. The modelling results show that mean excess temperatures at the SZB intake fall at a predicted rate of 0.25°C/km, compared with 0.4°C/km derived from annual model runs.

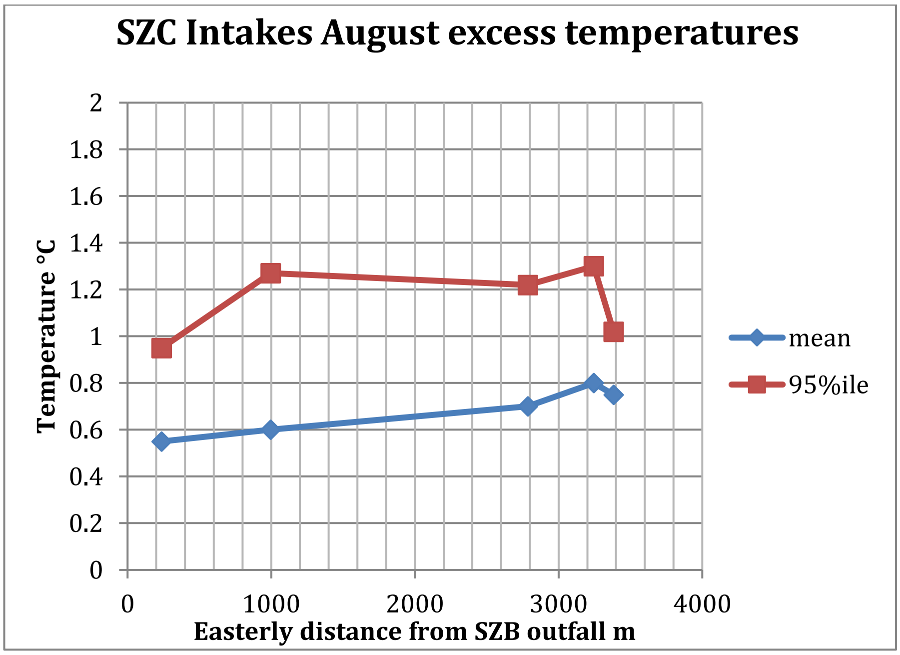

Figure 19 Impact on SZC intake temperatures in August with different SZC discharge locations.

Table 10 shows the tabulated annual results for each SZC discharge location derived from subtraction of either the Sizewell B run or the zero reference run. For each SZC intake tunnel, three positions I3a,b,c and I4a,b,c were considered. Examination of the data indicates that results are very similar for each of the 3 intake locations and thus only one set of each (I3a, I4a) are shown below. More detailed information has been included in Appendix A.

Table 10 Predicted annual excess temperatures for Configurations 5, 6, 8,9,10 compared to SZ B only and Zero Reference

	Annual Excess Temperature °C		
Conf5 – SZB	**SZC intake I3**	**SZC intake I4**	**SZB**
Average	0.61	0.60	1.79
95th Percentile	1.38	1.40	3.20
Max	2.96	2.75	5.48
Conf5 – Zero Ref			
Average	0.80	0.80	2.89
95th Percentile	1.89	1.91	5.15
Max	3.71	3.57	7.99
Conf6 – SZB			
Average	0.84	0.80	0.54
95th Percentile	1.50	1.43	1.01
Max	2.44	2.45	1.78
Conf6 – Zero Ref			
Average	1.03	1.00	1.64
95th Percentile	1.86	1.81	2.98
Max	3.07	3.05	5.00
Conf8 – SZB			
Average	0.66	0.76	1.70
95th Percentile	1.71	1.83	3.08
Max	2.72	2.99	4.98
Conf8 – Zero Ref			
Average	0.86	0.95	2.79
95th Percentile	2.04	2.22	4.76
Max	3.63	3.79	6.35
Conf9 – SZB			
Average	0.91	0.95	0.65
95th Percentile	1.88	1.99	1.75
Max	3.26	3.39	3.45
Conf9 – Zero Ref			
Average	1.11	1.15	1.74
95th Percentile	2.20	2.27	3.17
Max	3.48	3.51	4.68
Conf10 – SZB			
Average	0.78	0.92	0.81

95th Percentile	1.79	1.99	1.93
Max	3.45	3.74	3.60
Conf10 – Zero Ref			
Average	0.97	1.12	1.91
95th Percentile	2.15	2.37	3.41
Max	3.48	3.73	4.92

Evident from above is that Conf 5 and 8 give very similar maximum and 95%ile temperatures at the SZB intake and also at the SZC (I3 and I4) intakes. Conf 9 and 10 give lower temperatures at the SZB intake by 1.2 °C and 0.8 °C for maximum and 95%ile temperatures respectively. Conf 9 and 10 have slightly higher temperatures at the I3, I4 intakes than with Conf 5 (but by less than 0.25 °C).

Table 11 Predicted absolute temperatures at SZB and SZC intakes for annual runs of Configuration 5, 8, 9, and 10. SZB and Zero reference

	Absolute Temperature °C		
Conf 5	**SZC intake I3**	**SZC intake I4**	**SZB**
Minimum	3.49	3.49	4.20
5th Percentile	4.54	4.55	6.51
Average	12.53	12.51	14.80
95th Percentile	20.21	20.14	22.43
Max	21.88	21.75	24.45
Sizewell B only			
Minimum	3.41	3.42	3.24
5th Percentile	4.04	4.06	4.66
Average	11.92	11.91	13.01
95th Percentile	19.60	19.59	21.05
Max	21.11	21.00	22.57
Zero Reference			
Minimum	2.61	2.67	2.33
5th Percentile	3.86	3.86	3.35
Average	11.73	11.71	11.91
95th Percentile	19.49	19.46	20.11
Max	20.36	20.38	21.20
Conf8			
Minimum	3.54	3.59	4.07
5th Percentile	4.60	4.67	6.57
Average	12.59	12.67	14.71
95th Percentile	20.22	20.25	22.47
Max	21.97	21.91	24.17
Conf9			
Minimum	3.96	3.89	3.92
5th Percentile	5.12	5.09	5.38
Average	12.84	12.86	13.65
95th Percentile	20.35	20.37	21.70
Max	21.84	21.85	23.22
Conf10			
Minimum	3.54	3.67	3.91
5th Percentile	4.87	5.03	5.55
Average	12.70	12.83	13.82
95th Percentile	20.24	20.34	21.82
Max	21.81	22.05	23.36

*SZ B intake is from mid depth layer, SZC intakes I3 & I4 are from 0.85m depth layer

6.3 Monthly intake temperatures at SZB and SZC

The predicted monthly mean and 95%ile temperatures at the intakes of SZB and SZC (I3a, I4a) are shown in Table 12 and graphically in Appendix B.

Table 12 Monthly means for SZB intake, SZ C intakes I3 and I4 for Conf 5,8,9,10 SZB and zero ref

	Conf5			Conf8			Conf10			Conf9			SZB			Zero_ref		
date	**IB**	**I3**	**I4**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**
Jan	6.9	4.9	4.9	7.0	5.3	5.3	6.0	5.7	5.8	5.8	5.9	5.8	5.2	4.6	4.6	4.2	4.5	4.5
Feb	7.7	5.0	5.0	7.6	5.1	5.3	6.4	5.2	5.4	6.2	5.4	5.4	5.2	4.1	4.1	3.4	3.8	3.8
Mar	9.2	6.4	6.4	9.1	6.5	6.6	8.2	6.5	6.7	8.0	6.7	6.8	7.2	5.7	5.7	5.8	5.4	5.4
Apr	12.2	9.1	9.1	12.3	9.2	9.4	11.5	9.3	9.5	11.3	9.4	9.5	10.4	8.4	8.4	9.0	8.1	8.1
May	14.9	12.5	12.5	15.0	12.6	12.7	14.3	12.6	12.7	14.2	12.7	12.8	13.6	11.9	11.9	12.7	11.7	11.6
Jun	19.2	16.6	16.6	19.4	16.7	16.8	18.8	16.6	16.8	18.7	16.7	16.8	18.0	16.0	15.9	17.1	15.7	15.7
Jul	21.2	19.2	19.2	21.4	19.2	19.3	20.8	19.3	19.4	20.7	19.4	19.4	20.1	18.7	18.6	19.3	18.5	18.4
Aug	22.2	20.3	20.2	22.3	20.3	20.3	21.6	20.4	20.4	21.5	20.5	20.5	20.8	19.7	19.7	19.8	19.5	19.5
Sep	20.2	18.7	18.7	20.3	18.7	18.8	19.4	18.9	19.0	19.2	19.0	19.0	18.7	18.2	18.2	17.7	18.0	18.0
Oct	17.9	16.0	16.0	18.0	16.1	16.2	16.9	16.2	16.3	16.7	16.3	16.3	16.0	15.4	15.3	14.7	15.1	15.1
Nov	14.7	12.3	12.2	13.3	12.1	12.1	12.5	12.3	12.3	12.3	12.4	12.3	12.0	11.8	11.7	11.2	11.7	11.7
Dec	10.9	8.9	8.9	10.3	8.8	8.9	9.0	9.1	9.2	8.8	9.3	9.2	8.4	8.3	8.3	7.5	8.3	8.2

Table 13 Monthly 95%iles for SZB Intake, SZC intakes I3 and I4 for Conf 5,8,9,10, SZB and zero ref. Derived from hourly model output

	Conf5			Conf8			Conf10			Conf9			SZB			Zero_ref		
date	**IB**	**I3**	**I4**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**	**IB**	**I3a**	**I4a**
Jan	8.9	5.7	5.7	9.1	6.9	7.1	7.5	7.7	7.9	7.2	7.6	7.6	6.3	5.6	5.6	5.4	5.6	5.6
Feb	9.4	6.5	6.6	9.4	6.7	6.9	7.9	6.9	7.1	7.7	7.0	7.2	6.7	5.1	5.1	4.8	4.5	4.5
Mar	11.1	7.9	7.8	11.1	8.0	8.1	10.0	7.9	8.1	9.7	8.0	8.1	8.9	6.9	6.9	6.6	6.4	6.4
Apr	14.6	10.9	11.0	14.4	11.1	11.3	13.5	11.1	11.3	13.4	11.1	11.3	12.6	10.1	10.1	10.8	9.8	9.8
May	17.9	15.0	14.9	17.9	15.1	15.2	17.1	14.9	15.2	16.9	15.0	15.1	16.3	14.3	14.2	15.3	13.9	13.8
Jun	21.7	18.7	18.6	21.9	18.8	18.9	21.0	18.7	18.8	20.9	18.7	18.8	20.2	18.0	17.9	19.3	17.7	17.6
Jul	22.8	20.0	20.0	22.9	20.1	20.2	22.2	20.0	20.2	22.1	20.2	20.2	21.5	19.5	19.5	20.7	19.2	19.2
Aug	23.9	21.3	21.3	23.7	21.4	21.5	22.9	21.3	21.4	22.7	21.4	21.5	22.1	20.6	20.6	20.6	20.1	20.1
Sep	21.9	19.9	19.8	21.8	19.9	20.0	20.3	20.0	20.0	20.2	19.9	19.9	19.7	19.2	19.2	18.9	19.1	19.1
Oct	20.1	18.1	18.1	19.8	18.2	18.3	19.0	18.1	18.3	18.8	18.2	18.3	18.1	17.2	17.1	16.6	16.8	16.9
Nov	17.0	14.2	14.2	16.1	14.2	14.1	15.3	14.2	14.2	15.1	14.3	14.3	14.4	13.5	13.6	13.1	13.4	13.4
Dec	13.5	10.8	10.8	12.4	10.5	10.7	10.7	10.6	10.7	10.5	10.9	10.9	10.2	10.2	10.2	9.4	10.4	10.3

The monthly 95%ile values are derived from an analysis of the hourly data within a month and as such they represent inter daily temperature spikes due to the power station and diurnal variation. What is not included is inter-annual variance; Modelling has showed this to be about 1°C. These results show that for 95%ile temperatures (there will be 36 values at 1hr intervals higher than this each month) for Conf 9 are 1.2°C less than Configuration 5 (or Configuration 8) and 0.6 °C above the present SZB situation.

For the mean values the difference is smaller with Configuration 9 increasing the temperature at the Sizewell B intake by 0.7°C compared to present and Configuration 5 by 1.4 °C.

Overall it can be seen that Configuration 5 and Configuration 8 produce similar results and have a greater thermal impact on SZB than the 2 offshore locations, Configurations 9 and 10. Configuration 9 produces the lowest thermal impact on SZB.

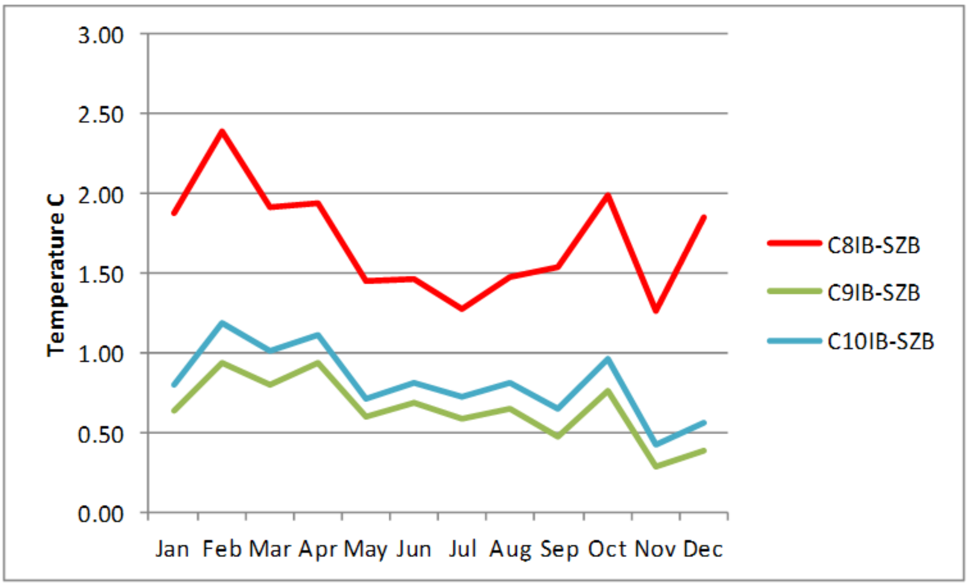

Figure 20 Monthly mean excess temperatures at SZB intake due to Confs 8,9,10 referenced to SZB.

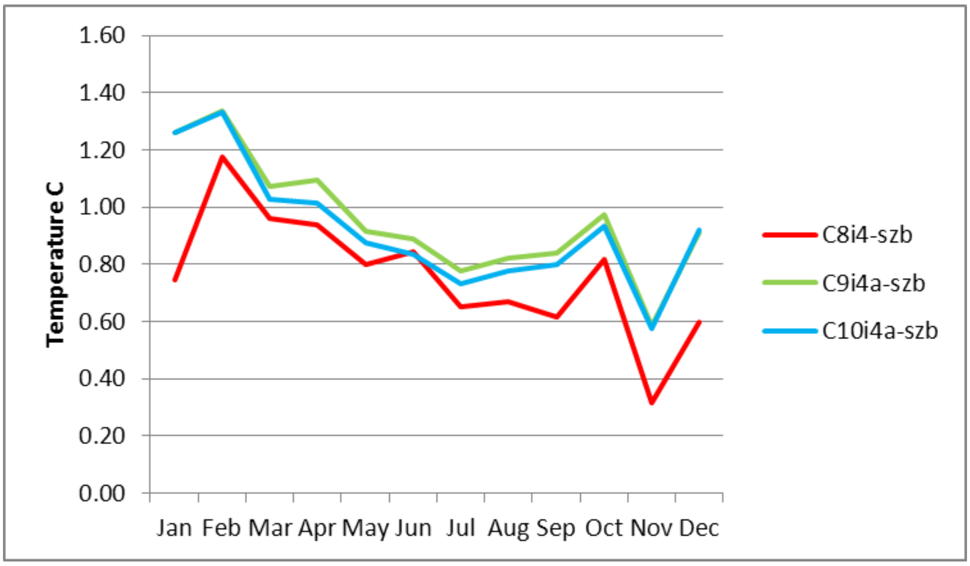

Figure 21 Monthly mean excess temperatures at SZ C intake I4 due to Confs 8,9,10 referenced to SZB.

The monthly mean excess temperatures indicate that at the Sizewell B intake Configurations 9 and 10 increase the temperature by approximately 0.7 °C compared to the present situation, whereas Configuration 8 increases it by 1.75 °C. There does appear to be a seasonal bias with the winter months producing higher recirculation. This has yet to be fully investigated but is most likely due to storms leading to increased mixing.

7 Spatial Analysis of Plume Temperatures

Figures 22 to 26 show the predicted thermal plumes as annual mean excess temperatures greater than 1°C and 2°C compared with a baseline with no power station operating (the zero reference). Plots are provided at the surface and seabed for the existing Sizewell B (Figure 22) and for the plumes resulting from SZC outfall locations O5, O8, O10 and O9 in combination with SZB (Figures 23-26).

For all SZC outfall locations the impact of SZC at the seabed is to increase the apparent size of the SZB inshore plume. Surface plumes are only apparent as small features greater than 2°C for outfall locations O10 and O9.It can be seen that the largest plumes are with SZC outfall locations inshore of the Bank (O5, O10). For these plumes in the well mixed inshore waters, the size of the surface plume is only marginally bigger than the seabed plume.

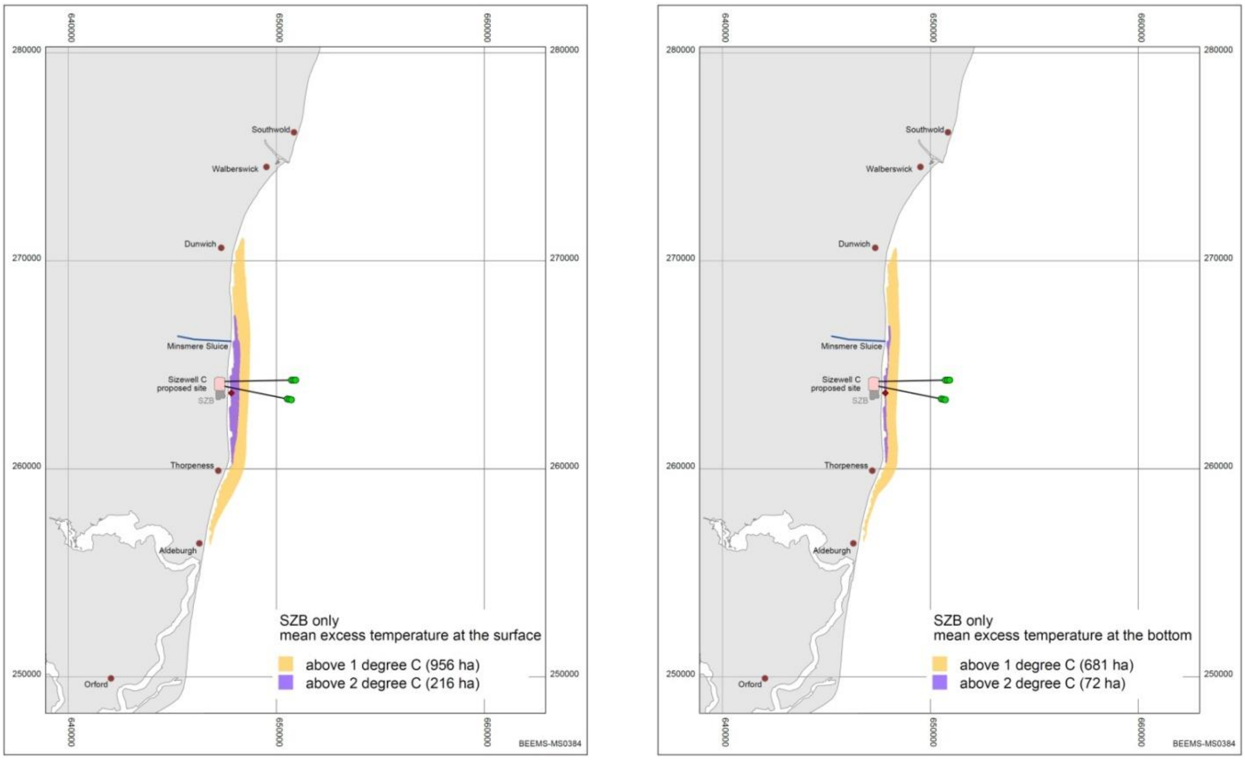

Figure 22 SZB alone: Annual mean excess temperatures compared to Zero ref. The left panel shows the surface layer in the model and the right panel show the near bottom layer.

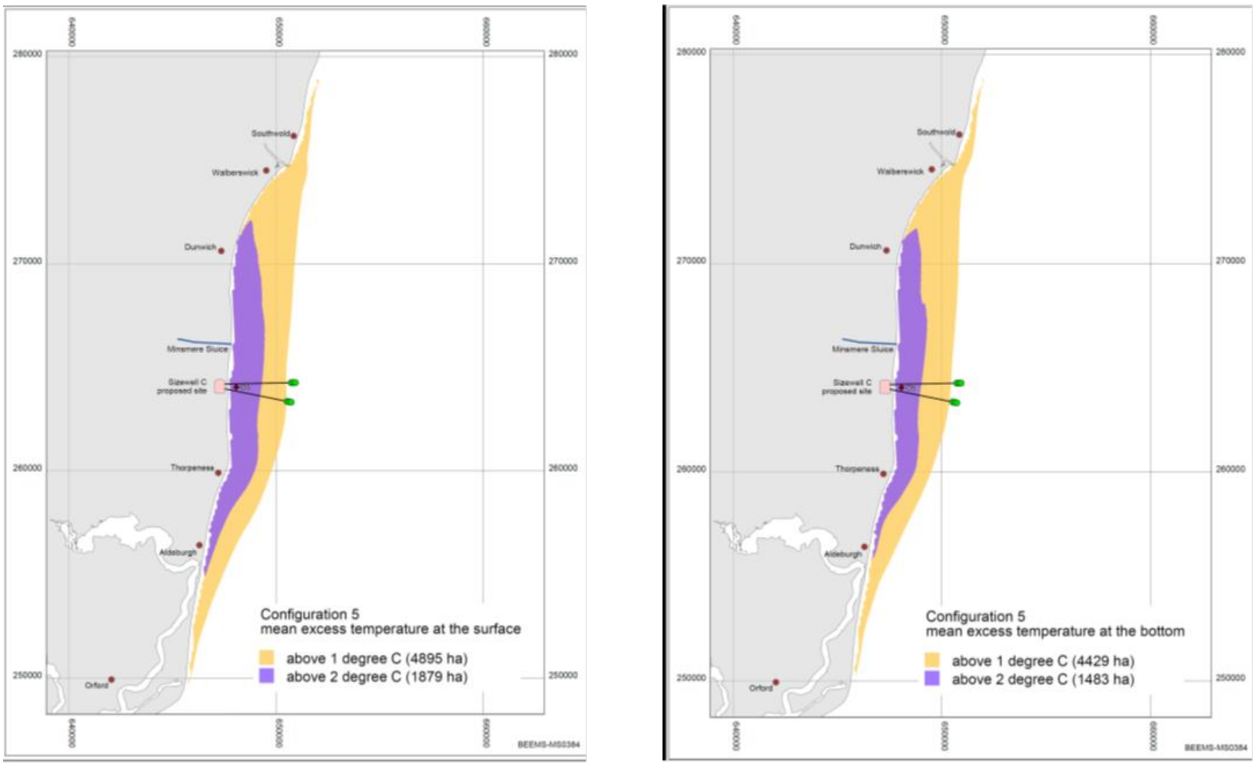

Figure 23 SZB+ SZC Configuration 5 Mean annual excess temperatures compared to zero reference. The two panels on the left show the surface layer in the model and the right panels show the near bottom layer.

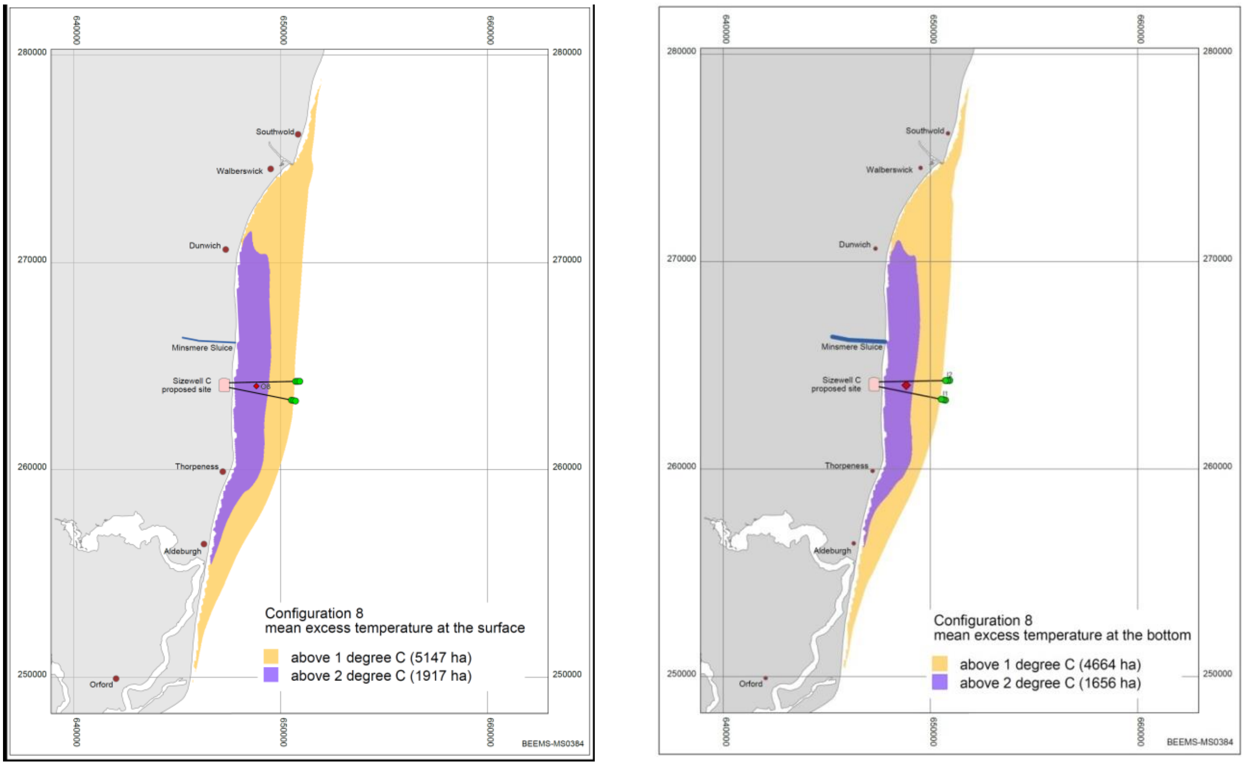

Figure 24 SZB+SZC Configuration 8 Mean annual excess temperatures compared to zero reference. The two panels on the left show the surface layer in the model and the right panels show the near bottom layer.

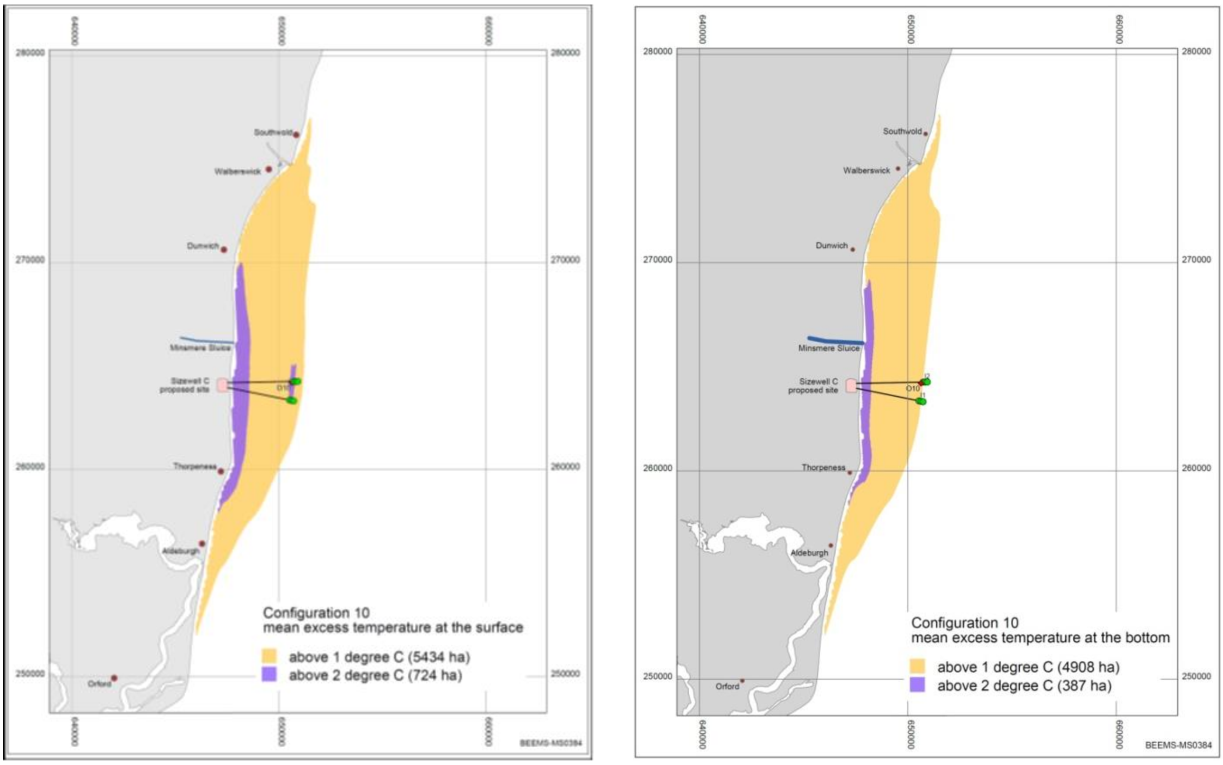

Figure 25 SZB+SZC Configuration 10: Annual mean excess temperatures compared to Zero ref. The left panel shows the surface layer in the model and the right panel show the near bottom layer.

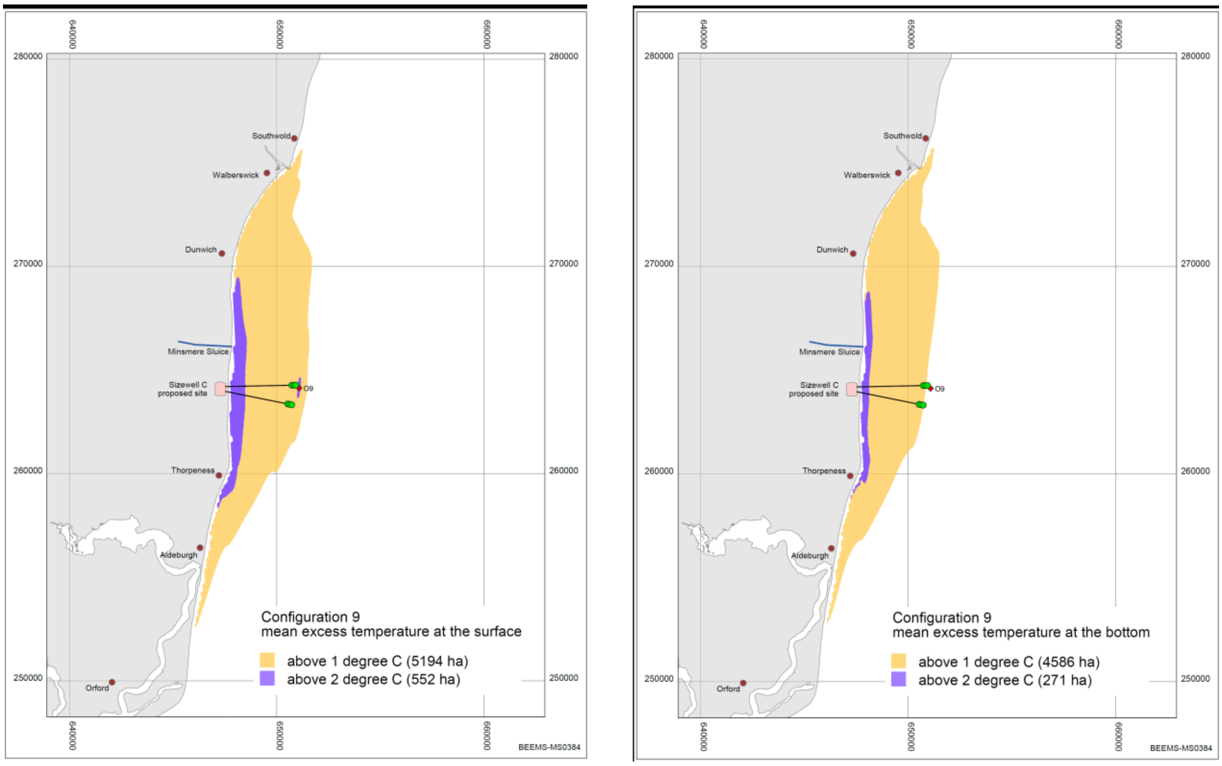

Figure 26 SZB+SZC Configuration 9: Annual mean excess temperatures compared to Zero ref. The left panel shows the surface layer in the model and the right panel show the near bottom layer.

The predicted plume areas in ha are listed in Table 14.

Table 14 Area in Hectares of each configuration above 1 and 2 degrees compared to zero reference

Layer	Temp Threshold	SZB	Conf 5	Conf 8	Conf 10	Conf 9
Bottom	>1 °C	681	4,429	4,664	4,908	4,586
	>2°C	72	1,483	1,656	387	271
Surface	>1 °C	956	4,895	5,147	5,434	5,194
	>2 °C	216	1,879	1,917	724	552

Where Conf 5 to Conf 9 represent SZB + SZC plume areas

8 Environmental Impacts of different SZC discharge locations

To assess the relative environmental impact of the different SZC outfall locations 3 different criteria have been used:

a. The plume areas exceeding HRA thermal standards for an SPA
b. The area of seabed plume intersecting with the potentially environmentally sensitive exposed bedrock at Thorpeness
c. The entrainment temperatures at SZB and SZC and the consequent impacts on plankton and larval mortality

8.1 Thermal standards

Under the Habitats Directive thermal boundaries have to be established to protect the most sensitive taxa. Existing thermal guidelines have mostly been derived from data on fish. The Habitats Directive has no specific temperature requirements but requires that European protected habitats and species be maintained or restored with strict protection of Annex IV species.

In 2006 WQTAG 160,"Guidance on assessing the impact of thermal discharges on European Marine Sites" cited in Turnpenny and Liney, 2006 recommended interim thermal standards for assessing SAC/SPA sites in estuarine and coastal sites under the Habitats Regulations based upon standards contained within the Freshwater Fish Directive. For an SPA these guidelines state that the annual mean water temperature uplift should not exceed 2°C at the edge of the mixing zone.

The modelling undertaken in this study has demonstrated that the main impact of the SZC discharge is to increase the extent and temperatures of the SZB plume inshore of the Sizewell Bank.

Table 15 Area (hectares) at the surface and bed above the 2°C annual mean uplift threshold (SZB+SZC)

Layer	Excess Temp Threshold	SZB Only	Conf 5	Conf 8	Conf 10	Conf 9
Bottom	>2°C	72	1483	1,656	387	271
Surface	>2°C	216	1,879	1,917	724 (of which 42ha are outside of the Bank)	552 (of which 13ha are outside of the Bank

Note: These areas will be recalculated using simulations of the final CW configuration for HRA and EIA purposes.

Table 15 shows that the total plume area above 2°C annual mean uplift from the combined SZB and SZC discharge decreases as the SZC outfall is moved eastwards both at the surface and the seabed. Configurations 5 and 8 produce similar plume areas of approximately 1400 – 1600ha greater area than that of the existing SZB plume at the seabed. Configurations 10 and 9 produce substantially smaller plume areas with the most easterly site, configuration 9, producing the smallest plume, 200ha greater than the existing SZB plume.

8.2 Plume Intercept with Thorpeness bedrock

The main impact from power station discharge plumes is normally upon any sensitive benthic organisms that are unable to avoid the plume. With the exception of the coralline crag off Thorpeness, the Sizewell Bay area has been extensively surveyed by BEEMS and the subtidal benthos does not contain populations of sensitive species. However, it has not proved possible to date to adequately characterise the exposed bedrock off Thorpeness using trawls, grabs or several different optical cameras. There remains a risk that this relatively undisturbed area might provide a habitat for sensitive and/or protected species. Attempts will be made to survey the area in 2014 using alternative approaches but it is not guaranteed that these surveys will be successful and as a precautionary measure it would therefore be advisable to limit the area of the bottom plume intersecting with the bedrock. Modelling has shown that the existing SZB plume barely touches the area off Thorpeness (Table 16). The area of intersect decreases with an increasing easterly position for the SZC outfall with configuration 9 produced the smallest intersect area of 26ha. Configurations 5 and 8 produced similar results but with Configuration 8 producing the largest potential impact.

Table 16 Area (hectares) of Thorpeness bedrock is exposed to >2°C excess mean temperature (SZB+SZC)

		Area in ha				
Layer	**Temp Threshold**	**SZB Only**	**Conf 5**	**Conf 8**	**Conf 10**	**Conf 9**
Bottom	>2°C	2	250	286	44	26

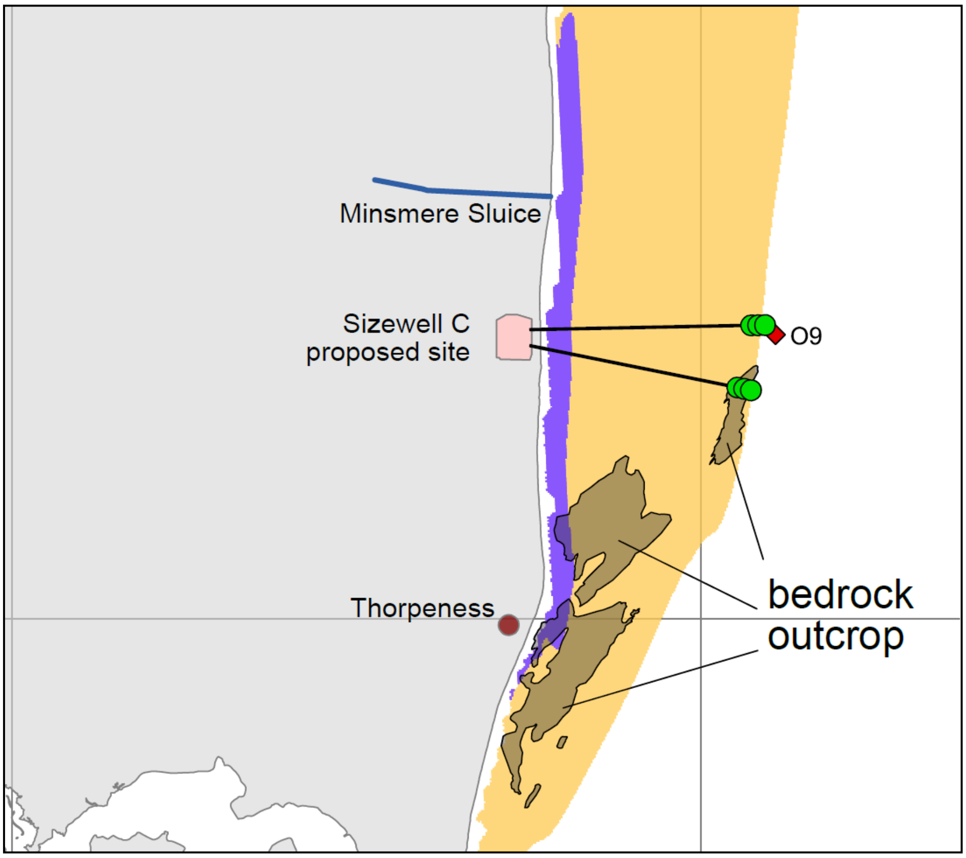

Figure 27 SZB+ SZC discharge at O9: Intersect of the >2°C plume (in purple) with bedrock outcrop at Thorpeness.

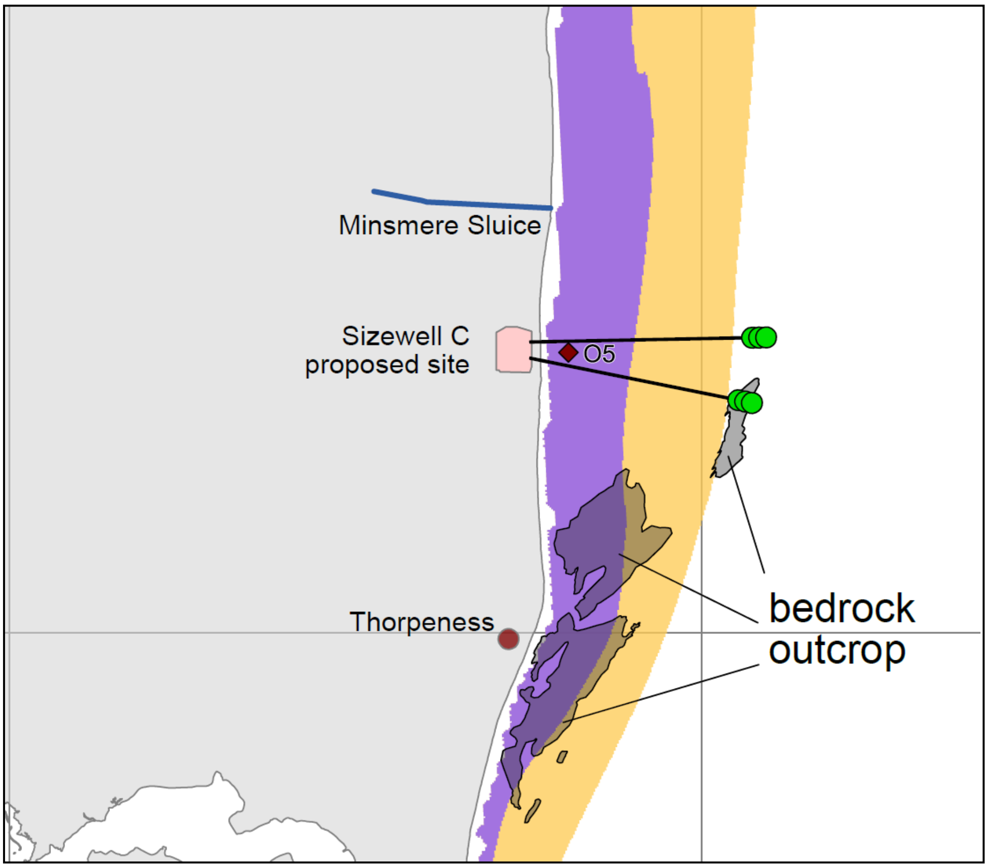

Figure 28 SZB+SZC discharge at O5: Intersect of the >2°C plume (in purple) with bedrock outcrop at Thorpeness.

8.3 Entrainment temperatures at SZB and SZC

The environmental impact of increasing the intake temperatures of SZB and SZC due to recirculation is to increase the cooling water temperature inside of the condensers. When entrainment temperatures exceed 30°C many, but not all, egg and larval life stages of fish and zooplankton species are at risk of increased mortality due to temperature shock. (See BEEMS Technical Report TR081). Temperatures greater than 33-35°C are expected to cause 100% mortality for almost any organism entrained in the power station. The relationship between survival and temperature is not simple. For example for some species it is not the maximum temperatures that are important but the temperature change that organisms can tolerate in a short period of time.

The environmental impact of entrainment temperatures depends upon the time of the year. It is not the summer period of July to September that is of the most importance but the period in the spring when the eggs and larvae of most fish species will be present in the water column i.e. March to June.

Section 6 of this report has already demonstrated that the impact of moving the SZC outfall eastwards is very small (+0.25°C increase in mean intake temperatures at SZC in August). Figure 29 shows that the entrainment temperatures at SZC are essentially the same for the SZC outfall at the two extreme locations considered in this report of O5 and O9. Mean SZC entrainment temperatures for both SZC locations are approximately 28°C in June; well below that known to cause large increases in mortality for fish eggs and larvae.

Inshore water temperatures are already higher inshore than at the SZC intake positions due to a generalized water temperature uplift caused by SZB and the fact that water temperatures are naturally higher in the shallow inshore waters. With only SZB operating mean entrainment temperatures reach 29C in June (Figure

30). The impact of SZC discharges was to increase SZB entrainment temperatures for all outfall locations modelled; the impact being least with outfall location O9 which would produce SZB entrainment temperatures of 29.7°C in June. The difference between O9 and O5 is a reduction in mean entrainment temperatures of 0.7C which, whilst apparently not very great, provides a buffer against future temperature rises due to climate change.

The beneficial impact of O9 compared with O5 is increased when 95%ile entrainment temperatures are considered (Figure 31).

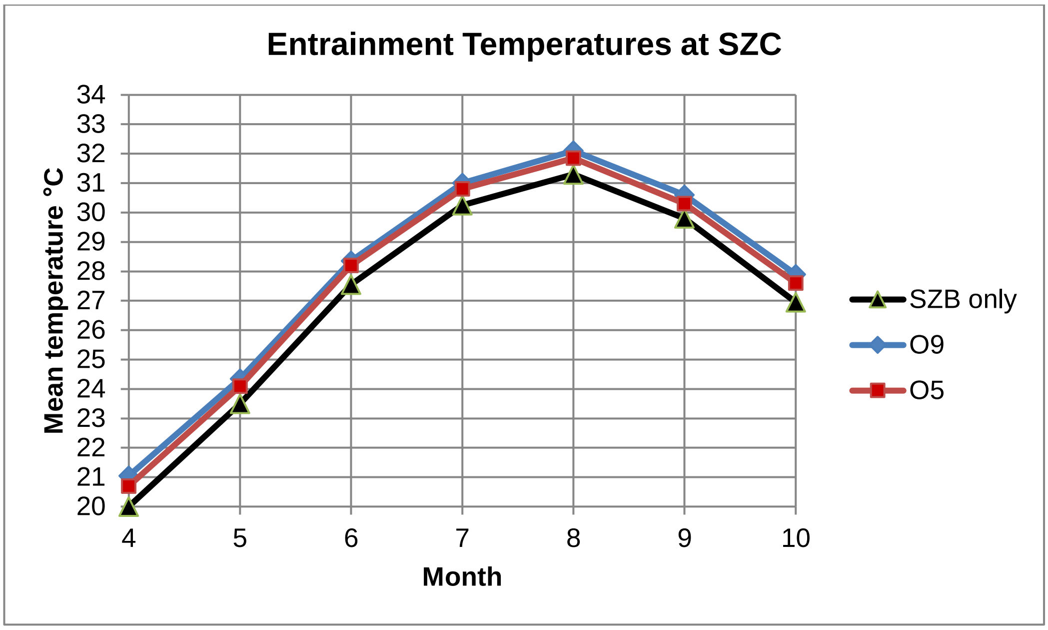

Figure 29 Monthly mean entrainment temperatures at SZC with SZB only and SZC outfalls O5 and O9.

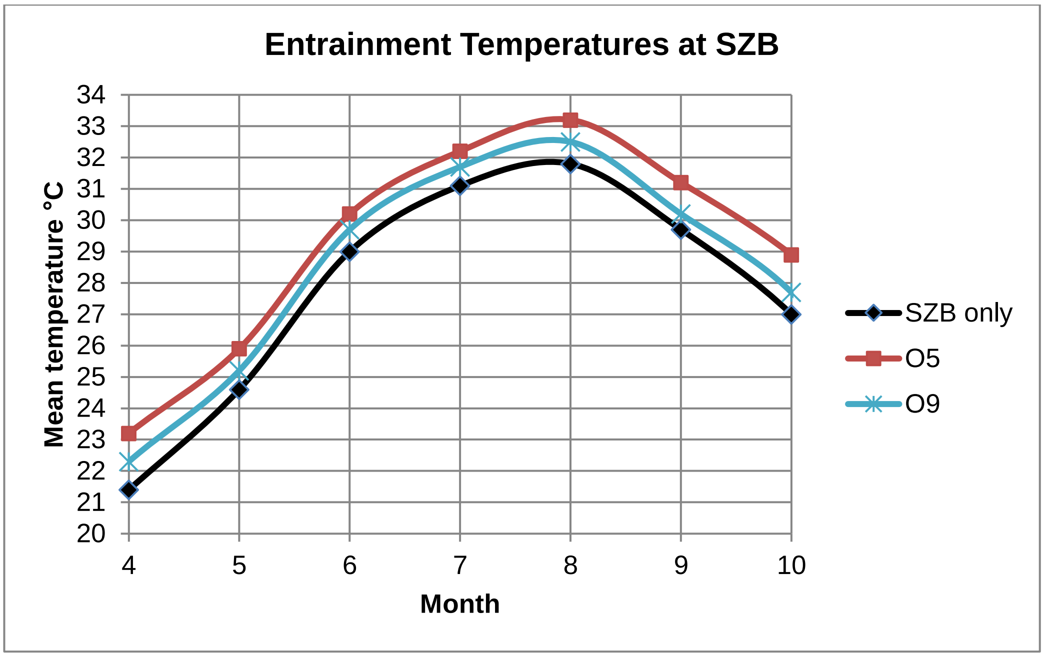

Figure 30 Monthly mean entrainment temperatures at SZB with SZB only and SZC outfalls O5 and O9.

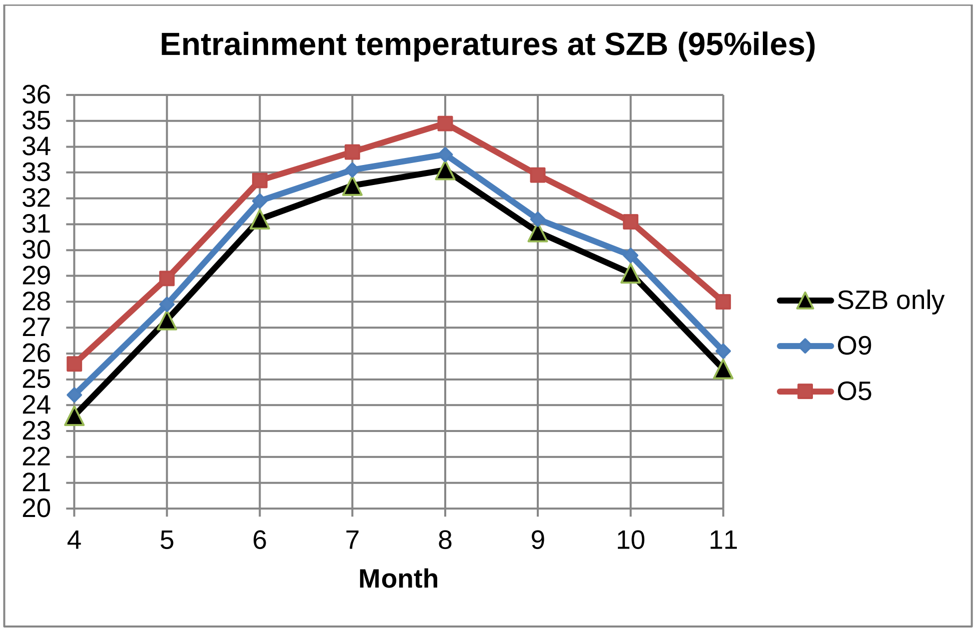

Figure 31 95%ile entrainment temperatures at SZB with SZB only and SZC outfalls O5 and O9.

9 Conclusions

There are a number of constraints on the location of the SZC outfall including engineering feasibility, sufficient water depth, suitable geology for construction and seismic qualification, impact on the marine environment and the operational impact on SZB. This report provides information on the recirculation temperatures at Sizewell B and C and the consequent potential environmental impacts.

9.1 Recirculation

The thermal impact of the SZC discharge falls predominantly upon SZB as an increase in intake temperatures and in the extent of the SZB discharge plume. For any of the SZC discharge locations studied from O5 to O6 the amount of recirculation into SZC is minimal. The mean and maximum excess temperatures at the SZB intake decreases as the SZC discharge is moved eastwards along the line O5 to O9 with an indication from a study of the now unviable position O6 that this effect continues for at least another 140m further east.

SZC outfall locations inside of the Bank (O5 and O8) produce similar results with much higher mean and maximum intake temperatures at SZB than for outfall locations outside of the Bank. Previously outfall location O5 was considered to produce an unacceptable thermal impact on SZB by EDF Energy; O8 does not produce significantly lower recirculation impacts on SZB.

On the basis of minimizing recirculation at SZB, SZC outfall location O9 offers the best solution and has minimal impact on recirculation at SZC. O9 is very close to the SZC intake locations and modelling indicates that SZB intake temperatures would decrease further if the SZC outfall were moved further east (subject to the change in water depth).

Table 17 Recirculation – increase in annual intake temperatures compared to current situation with SZB operating

	Excess Temperature °C		
Conf5 – SZB	**SZC intake I3**	**SZC intake I4**	**SZB**
Mean	0.61	0.60	1.79
95th Percentile	1.38	1.40	3.20
Max	2.96	2.75	5.48
Conf6 – SZB			
Mean	0.66	0.76	1.70
95th Percentile	1.71	1.83	3.08
Max	2.72	2.99	4.98
Conf8 – SZB			
Mean	0.78	0.92	0.81
95th Percentile	1.79	1.99	1.93
Max	3.45	3.74	3.60
Conf9 – SZB			
Mean	0.91	0.95	0.65
95th Percentile	1.88	1.99	1.75
Max	3.26	3.39	3.45

9.2 Environmental Impacts

From an environmental impact perspective SZC outfall locations offshore of the Sizewell Bank produce a much lower impact than those inshore of the Bank. In particular:

- The area of exceedance of the SPA thermal thresholds at the seabed and surface is least using outfall O9 (270ha at the seabed). Outfall O8, inshore of the Bank, produced the worst results (1660ha at the seabed), closely followed by O5
- The area of intersect with the potentially sensitive coralline crag off Thorpeness is least with O9 (26ha) and worst for 08 (286ha)
- The predicted entrainment temperatures at SZB are lowest for O9 and worst for O5 and O8.

From an environmental impact perspective an offshore SZC outfall location such as O9 is the preferred option but until geotechnical surveys are undertaken it is not known whether such a location is viable. Locations inside of the Bank produce similar environmental impacts but location O8 is worse than O5.

9.3 Preferred SZC Cooling Water Outfall Location

On recirculation and environmental impact concerns location O9 is the preferred option for the SZC outfall. O9 is considered the furthest west that an outfall could be built offshore of the Sizewell-Dunwich Bank and depending upon sub sea geology the outfall may have to be built slightly further east. Modelling indicates that locations further to the east would produce slightly lower recirculation and environmental impacts. Location O9 will therefore be taken forward to further environmental assessments as it is considered to bracket the worst case design option.

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Appendix A Temperatures at different SZC intake locations

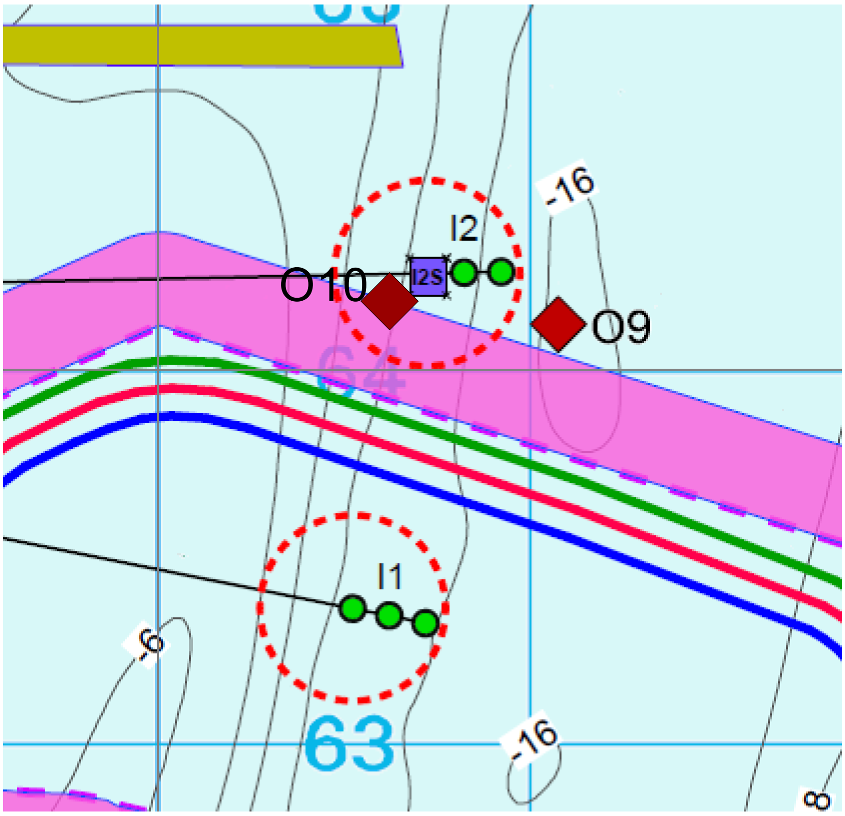

Figure A. 1 Expanded map of SZC intake and outfalls. The red, green and blue lines mark cable routes and the dotted lines a 250m buffer zone. The purple band shows the 250m buffer zone around the agreed Galloper development zone.

Table 18 Monthly mean, 95%ile and 98%ile temperatures for each SZC intake position

	Conf9 Monthly Mean						Conf9 95%						Conf9 98%					
	I3a	I3b	I3c	I4a	I4b	I4c	I3a	I3b	I3c	I4a	I4b	I4c	I3a	I3b	I3c	I4a	I4b	I4c
Jan	5.6	5.5	5.5	5.5	5.5	5.5	7.6	7.6	7.6	7.6	7.6	7.6	8.0	7.9	7.8	7.9	8.0	7.9
Feb	5.4	5.3	5.2	5.3	5.3	5.3	7.0	6.9	6.8	7.2	7.1	7.0	7.2	7.1	7.0	7.4	7.3	7.1
Mar	6.7	6.6	6.5	6.8	6.7	6.6	8.0	7.9	7.7	8.1	8.0	7.9	8.1	8.0	7.9	8.2	8.1	8.0
Apr	9.5	9.4	9.2	9.7	9.5	9.4	11.1	11.0	10.8	11.3	11.1	11.0	11.4	11.3	11.1	11.5	11.3	11.3
May	12.6	12.5	12.3	12.6	12.5	12.4	15.0	14.9	14.7	15.1	14.9	14.8	15.5	15.4	15.2	15.8	15.5	15.4
Jun	16.6	16.5	16.3	16.7	16.5	16.4	18.7	18.6	18.4	18.8	18.6	18.5	19.1	19.0	18.8	19.3	19.1	19.0
July	19.4	19.3	19.2	19.4	19.3	19.2	20.2	20.1	19.9	20.2	20.1	20.0	20.3	20.1	19.9	20.3	20.2	20.1
Aug	20.4	20.4	20.3	20.5	20.4	20.3	21.4	21.3	21.2	21.5	21.4	21.3	21.6	21.4	21.3	21.7	21.6	21.5
Sep	19.0	18.9	18.8	19.0	18.9	18.9	19.9	19.9	19.9	19.9	19.9	19.9	20.2	20.2	20.2	20.1	20.1	20.1
Oct	16.4	16.3	16.2	16.4	16.3	16.3	18.2	18.1	18.1	18.3	18.2	18.1	18.6	18.5	18.4	18.7	18.6	18.5
Nov	12.3	12.3	12.2	12.2	12.2	12.2	14.3	14.3	14.1	14.3	14.2	14.2	14.8	14.7	14.7	14.7	14.7	14.7

Evident from the table above is that the months of Jan, Feb and March are much more variable than the summer months. For example for I3a in January the 98% is 2.4 °C above the mean, while in August it is 1.2 °C above the mean. Also clear is the relatively small difference between each intake.

Table 19 Excess temperature at I3a,b,c, I4a,b,c compared to SZB as monthly values

	Conf9 Monthly Mean						Conf9 95%						Conf9 98%					
	I3a	I3b	I3c	I4a	I4b	I4c	I3a	I3b	I3c	I4a	I4b	I4c	I3a	I3b	I3c	I4a	I4b	I4c
Jan	1.1	1.1	1.0	1.0	1.1	1.0	2.8	2.8	2.8	2.7	2.8	2.8	3.0	3.0	3.0	3.0	3.0	3.0
Feb	1.4	1.3	1.2	1.3	1.3	1.3	2.3	2.2	2.0	2.4	2.3	2.2	2.5	2.4	2.2	2.6	2.5	2.4
Mar	0.9	0.9	0.7	1.0	1.0	0.9	1.9	1.8	1.6	2.0	2.0	1.8	2.2	2.0	1.8	2.2	2.2	2.0
Apr	0.9	0.8	0.6	1.0	0.9	0.8	1.9	1.8	1.5	2.1	1.9	1.7	2.2	2.0	1.7	2.4	2.2	2.0
May	0.8	0.7	0.5	0.9	0.7	0.6	1.8	1.6	1.3	2.0	1.7	1.5	1.9	1.7	1.5	2.2	2.0	1.8
Jun	0.7	0.6	0.4	0.8	0.7	0.6	1.5	1.3	1.1	1.7	1.5	1.3	1.6	1.5	1.2	1.9	1.6	1.4
July	0.7	0.6	0.5	0.7	0.6	0.6	1.3	1.2	1.0	1.5	1.3	1.2	1.4	1.3	1.2	1.7	1.5	1.3
Aug	0.7	0.7	0.6	0.8	0.7	0.7	1.3	1.2	1.1	1.5	1.3	1.2	1.5	1.3	1.2	1.7	1.5	1.3
Sep	0.8	0.7	0.7	0.8	0.8	0.7	1.4	1.4	1.3	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5
Oct	0.9	0.9	0.8	0.9	0.9	0.8	1.7	1.6	1.5	1.6	1.6	1.6	1.7	1.7	1.6	1.8	1.7	1.7
Nov	0.6	0.6	0.5	0.6	0.6	0.6	1.2	1.2	1.2	1.1	1.1	1.1	1.4	1.3	1.3	1.3	1.3	1.3

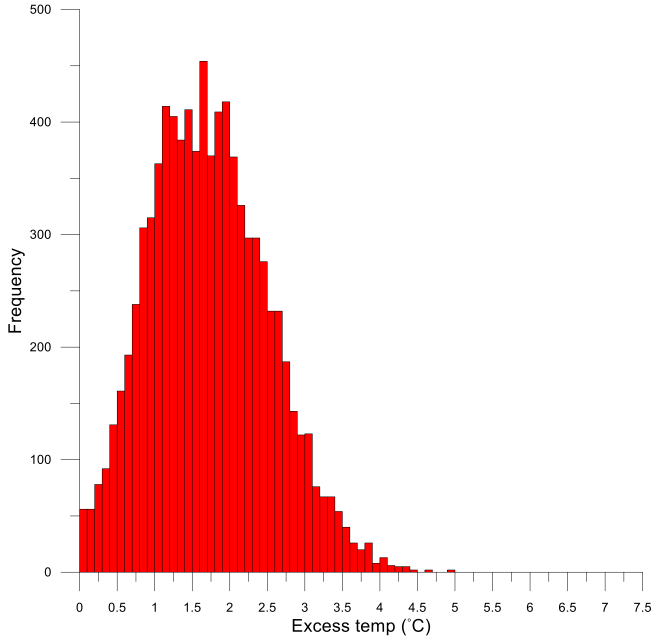

Figure 32 Config 8: Excess temperatures at SZB intake compared to SZB only.

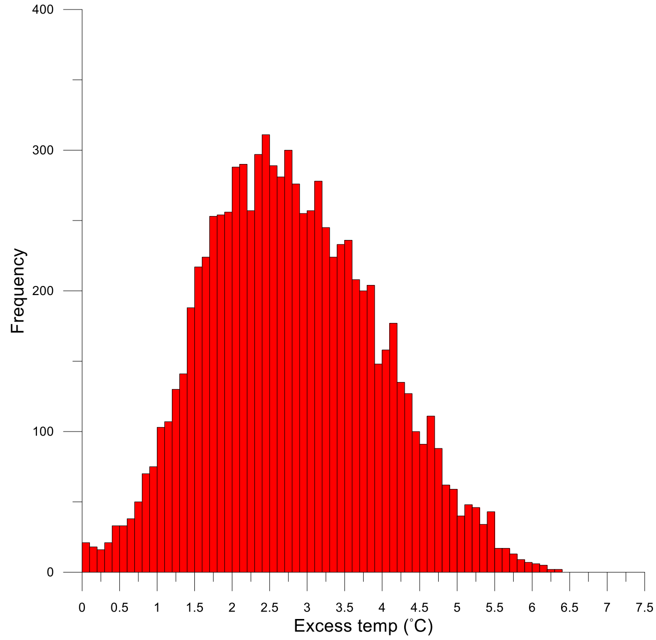

Figure 33 Config 8: Excess temperatures at SZB intake compared to Zero reference.

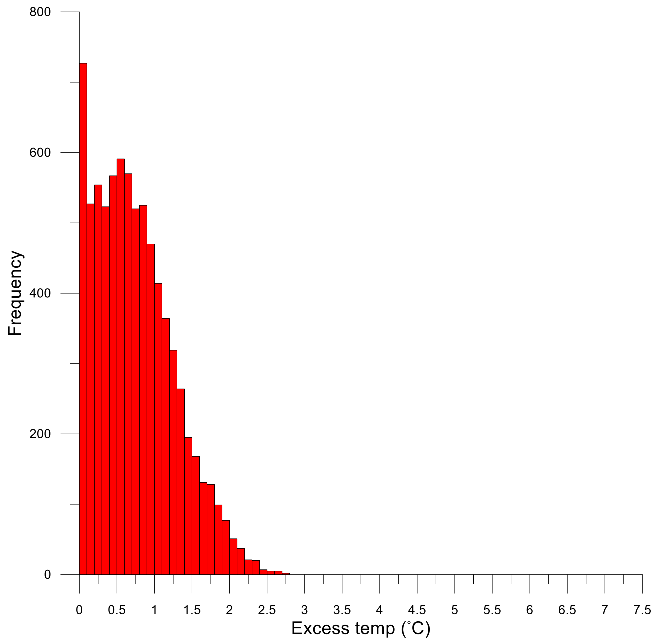

Figure 34 Config 8: Excess temperatures at SZC I3 Intake compared to SZ B only.

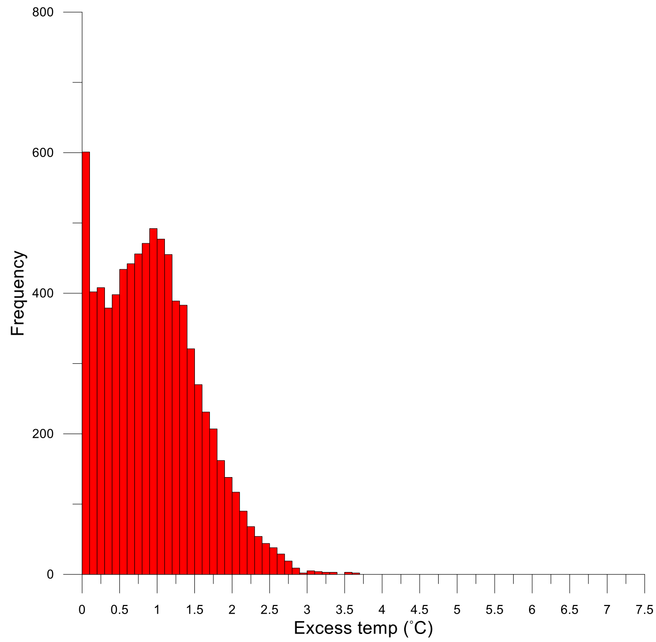

Figure 35 Config 6: Excess temperatures at SZC I3a Intake compared to Zero reference.

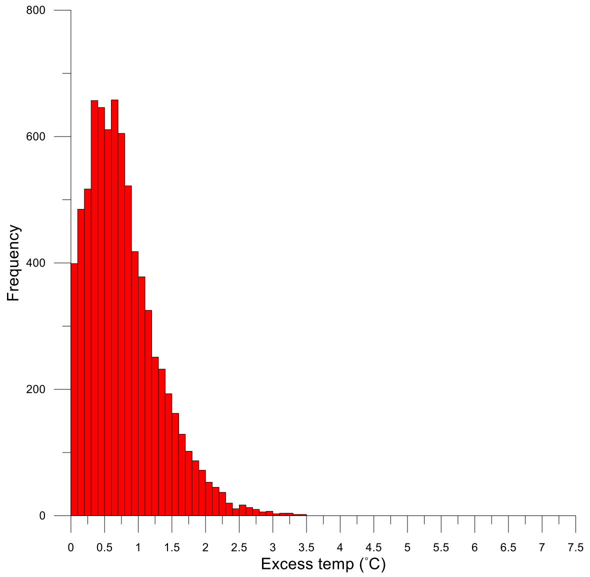

Figure 36 Config 9: Excess temperatures at SZB intake compared to SZB only.

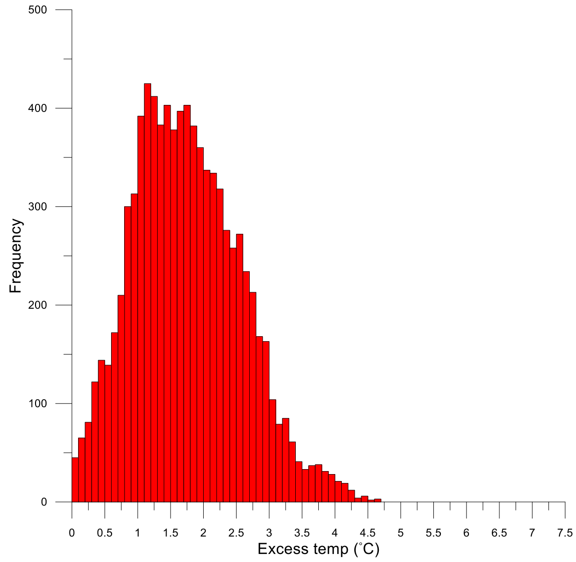

Figure 37 Config 9: Excess temperatures at SZB intake compared to Zero reference.

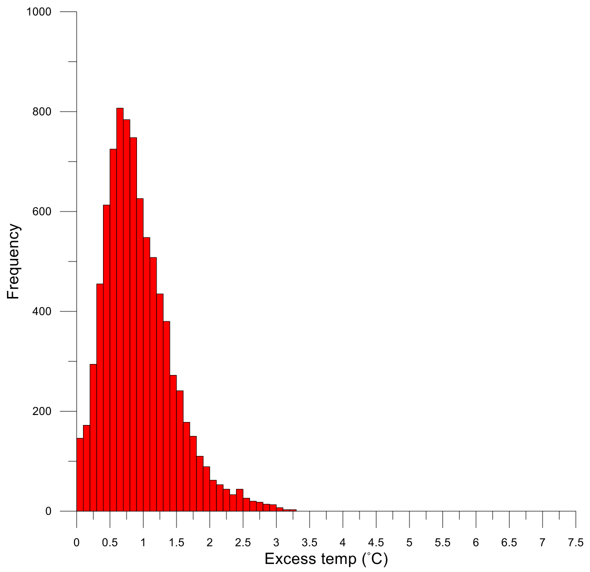

Figure 38 Config 9: Excess temperatures at SZC I3a Intake compared to SZ B only.

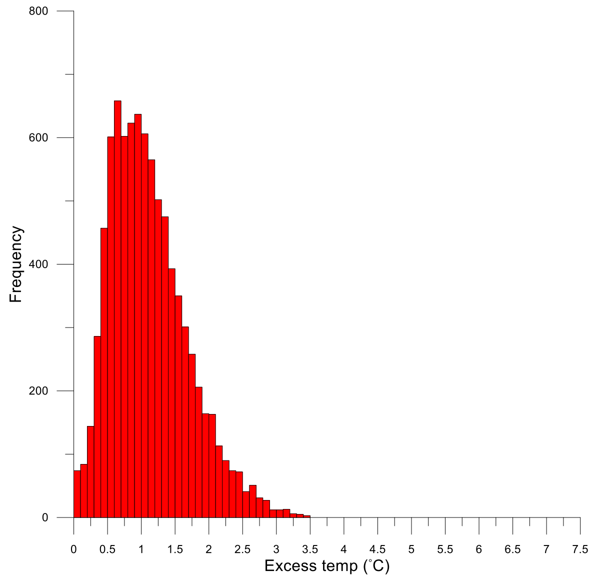

Figure 39 Config 9: Excess temperatures at SZC I3a Intake compared to Zero reference.

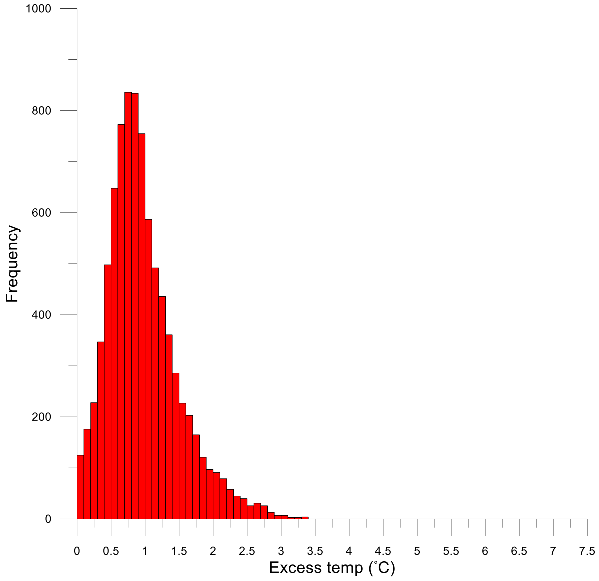

Figure 40 Config 9: Excess temperatures at SZC I4a Intake compared to SZ B only.

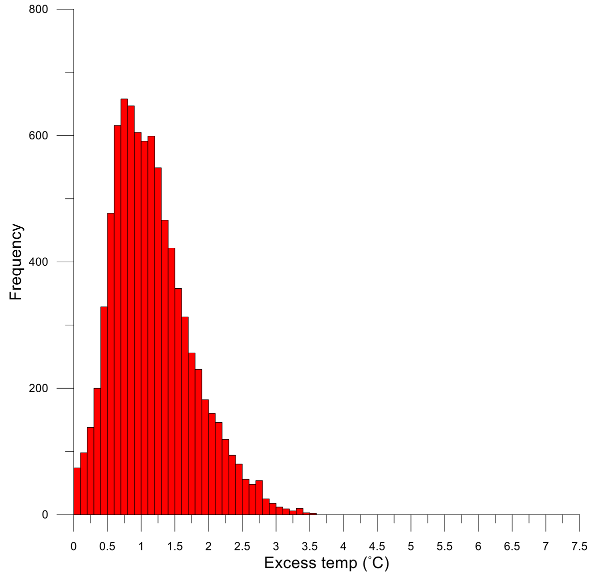

Figure 41 Config 9: Excess temperatures at SZC I4a Intake compared to Zero reference.

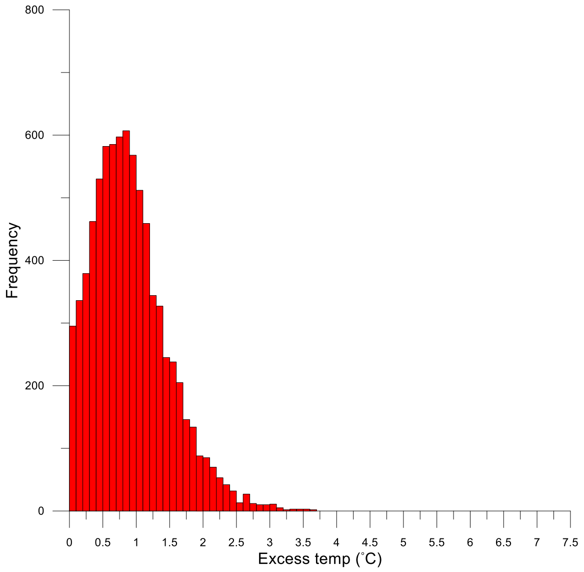

Figure 42 Config 10: Excess temperatures at SZB intake compared to SZB only.

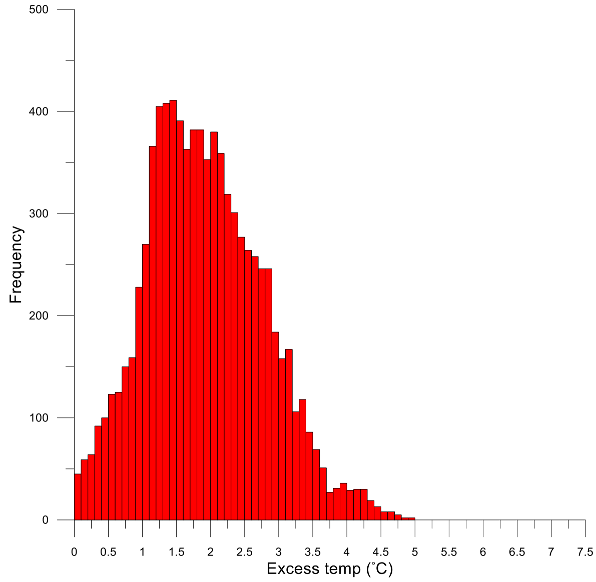

Figure 43 Config 10: Excess temperatures at SZB intake compared to Zero reference.

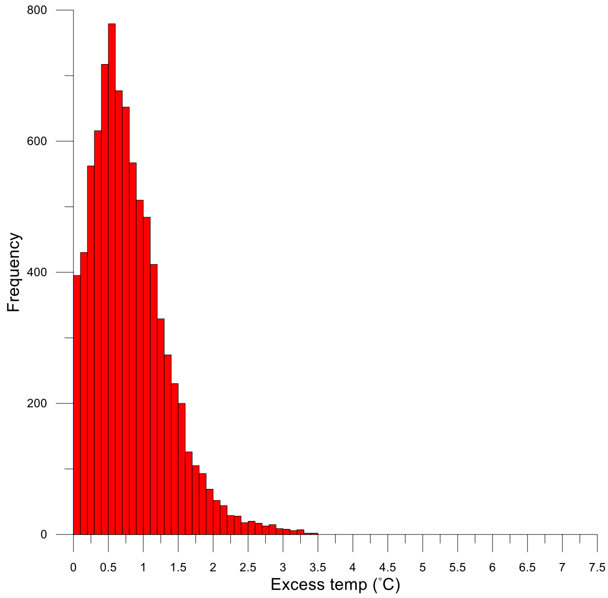

Figure 44 Config 10: Excess temperatures at SZC I3a Intake compared to SZ B only.

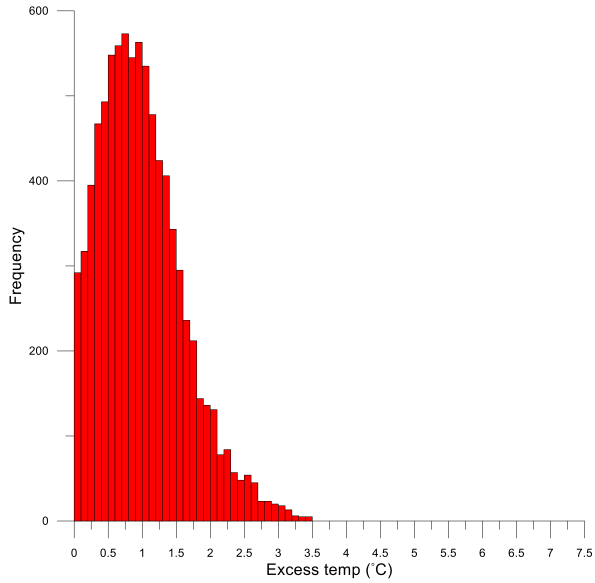

Figure 45 Config 10: Excess temperatures at SZC I3a Intake compared to Zero reference.

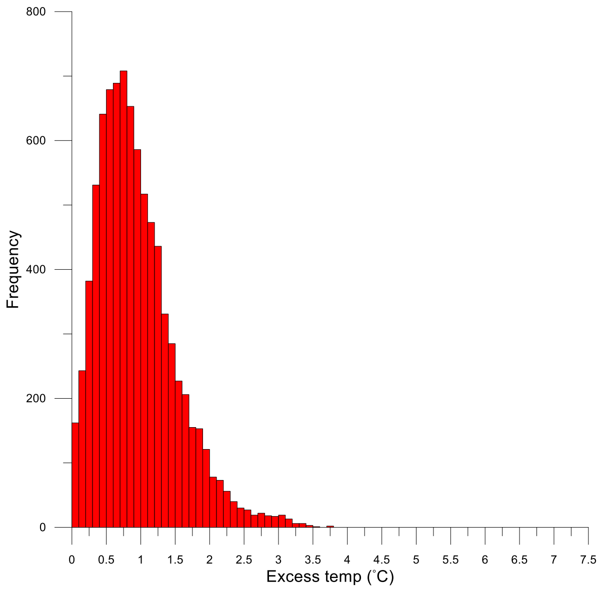

Figure 46 Config 10: Excess temperatures at SZC I4a Intake compared to SZ B only.

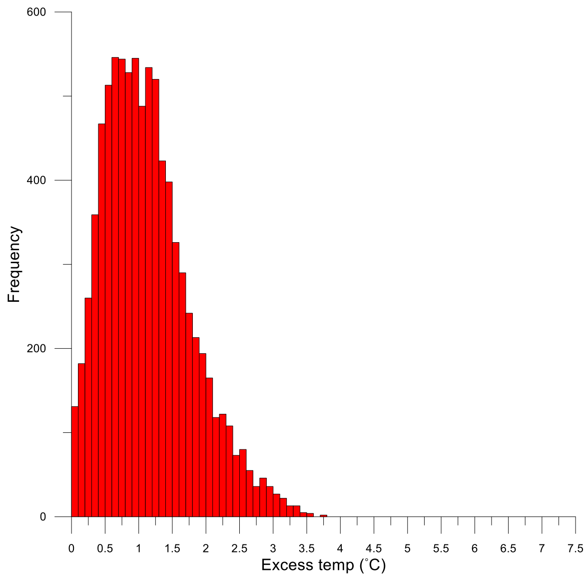

Figure 47 Config 10: Excess temperatures at SZC I4a Intake compared to Zero reference.

Appendix B Absolute temperatures for SZB and SZC intakes with different SZC discharge locations

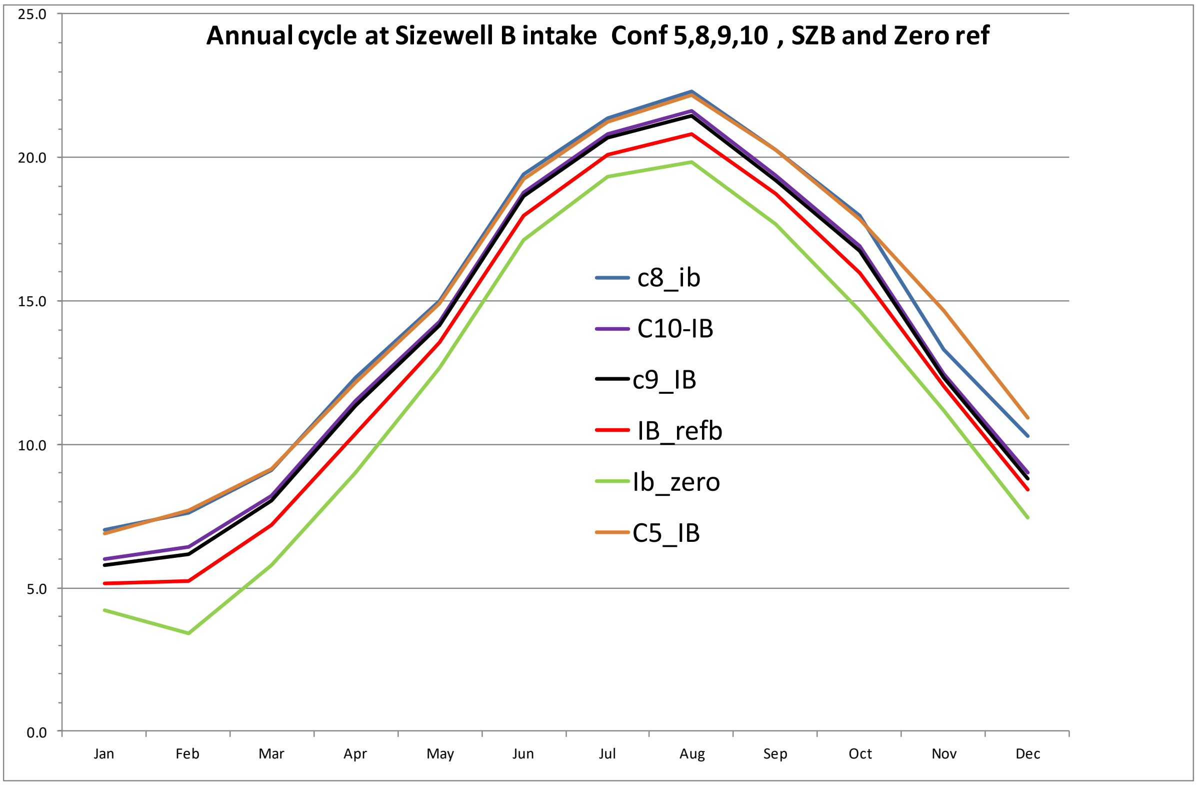

Figure 48 Monthly mean temperatures at SZB intake.

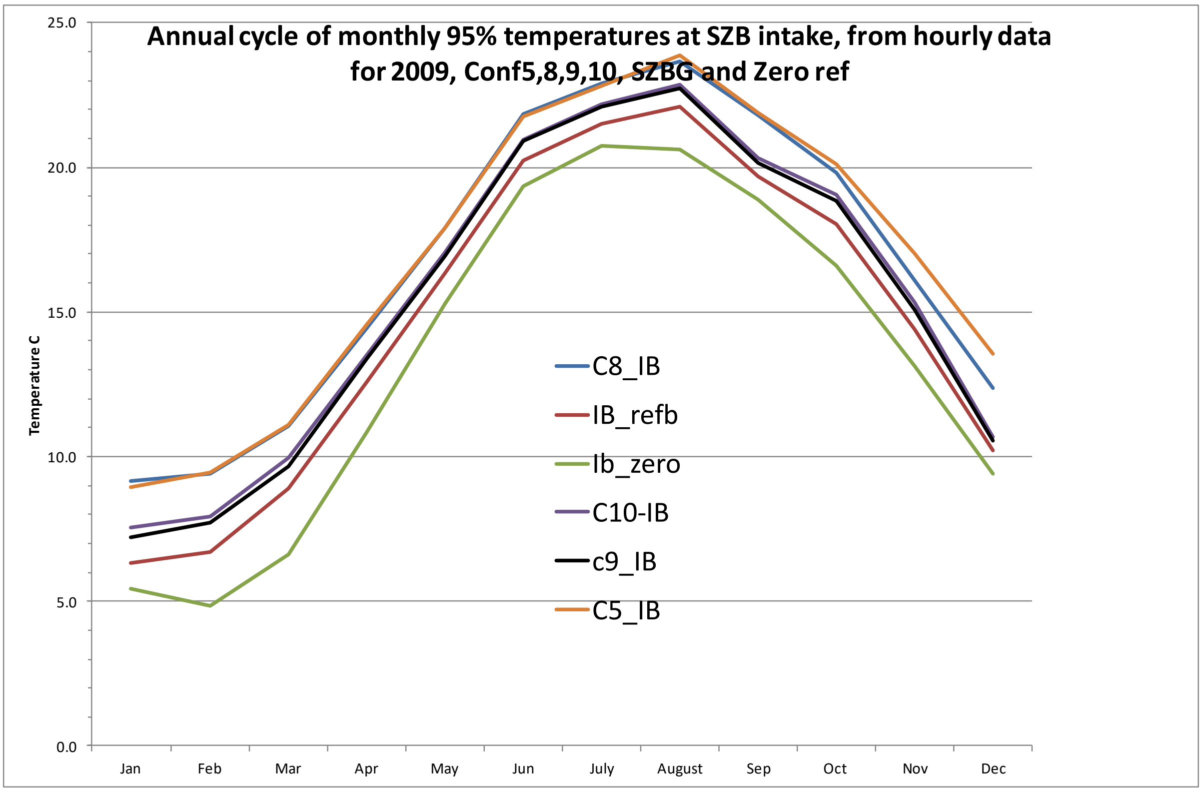

Figure 49 Monthly 95%ile temperatures at SZB intake from hourly output for 2009.

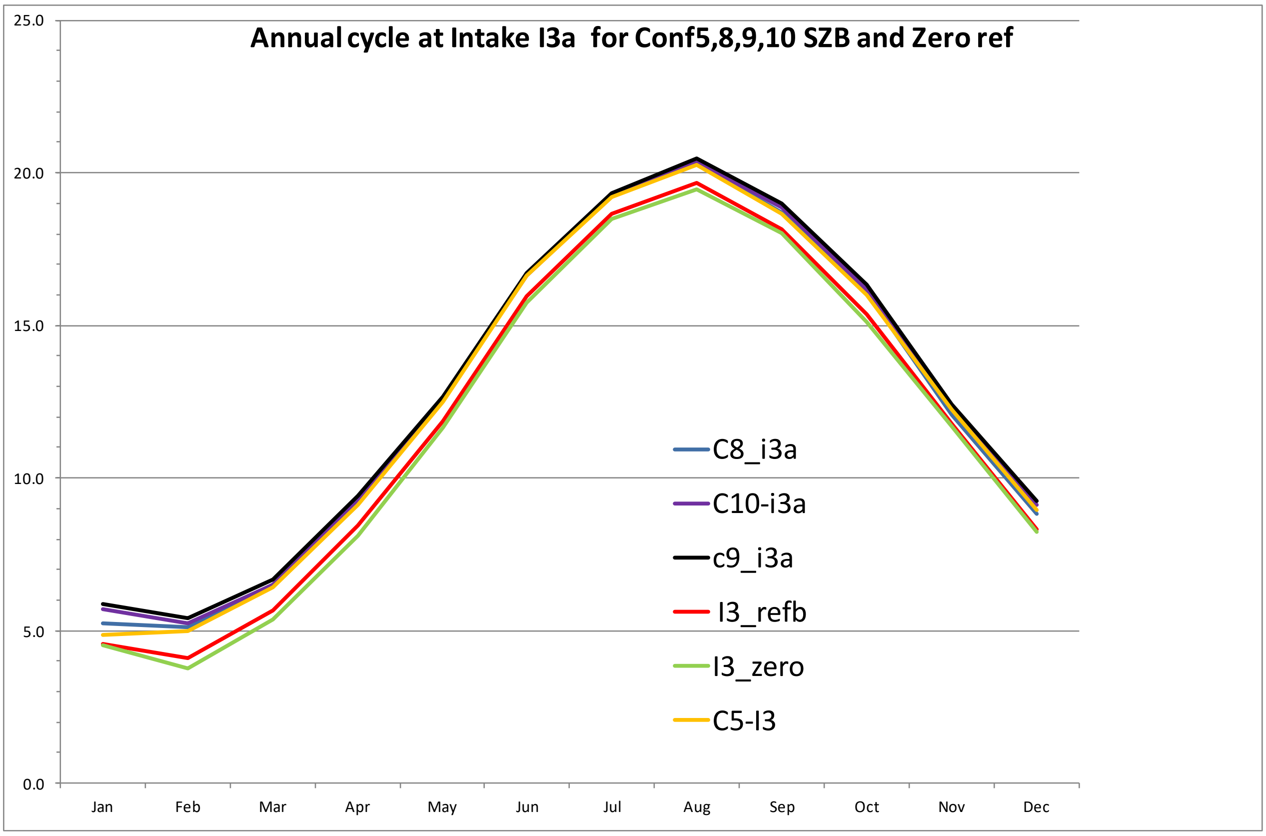

Figure 50 Annual mean temperature cycle at SZC intake I3a (I4 intake is similar at this resolution).

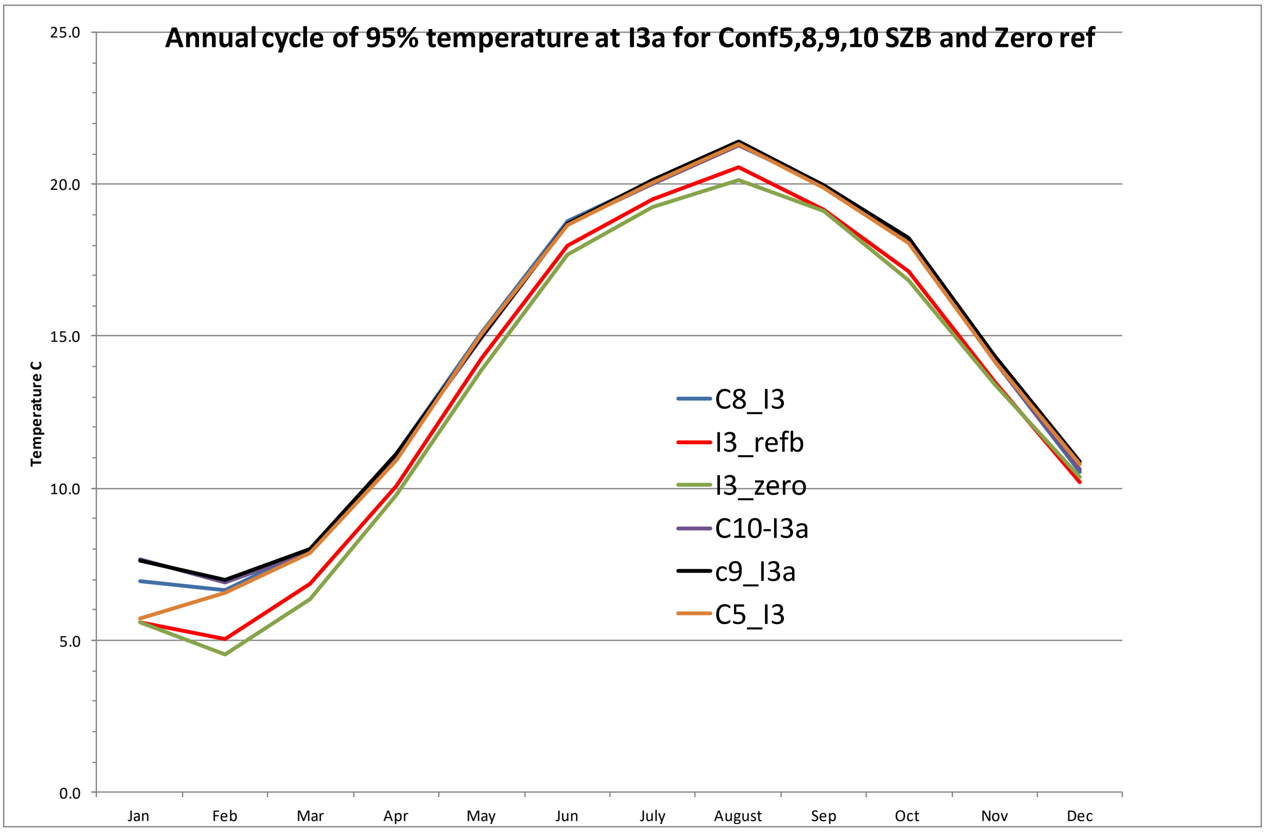

Figure 51 Annual cycle of 95%ile temperatures at SZC intake I3 for Confs 5, 8,9,10, SZB and Zero ref. Hourly output for 2009

Appendix C Comparison of the thermal plume model outputs

Delft3D Model

BEEMS Technical Report TR132 reported comparisons of the Delft3D SZB model predictions against thermal plume observations and the SZB intake temperature record. The model generally reproduced the shape of the observed plume, both in longitudinal and latitudinal extent and vertical structure. The modelled temperatures under-estimated the plume survey observations on Spring tides, but did a much better job on Neap tides when the predicted values were higher. On Neap tides there did not appear to be a significant bias with only slight under- estimates of the observations in 2 – 3 ºC excess temperature range.

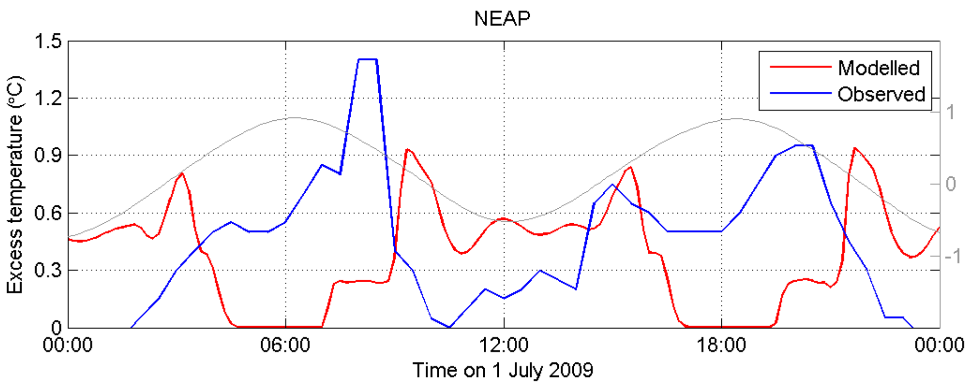

Figure 52 Comparison of observed and model excess temperatures at the SZ B intake (only SZ B operating) from the Delft 3D model. Note that the peaks are under represented by +0.5 ºC.

GETM Model

The GETM model is an absolute temperature model that predicts actual temperatures. To calculate excess temperatures the results from a reference run with no power station are subtracted from the modelled power station run. Comparisons of the SZB modelled data against thermal plume observations obtained near to the SZB discharge (BEEMS SZB anchor station data) have been performed and are reported in BEEMS Technical Report TR229 and illustrated in Figure 53. The figures for the Delft3D and GETM model outputs have been extracted from the respective subcontractor’s report and are not displayed on consistent scales. Nevertheless they do show that the timing and duration of the plume were replicated, as was the vertical thermal structure.

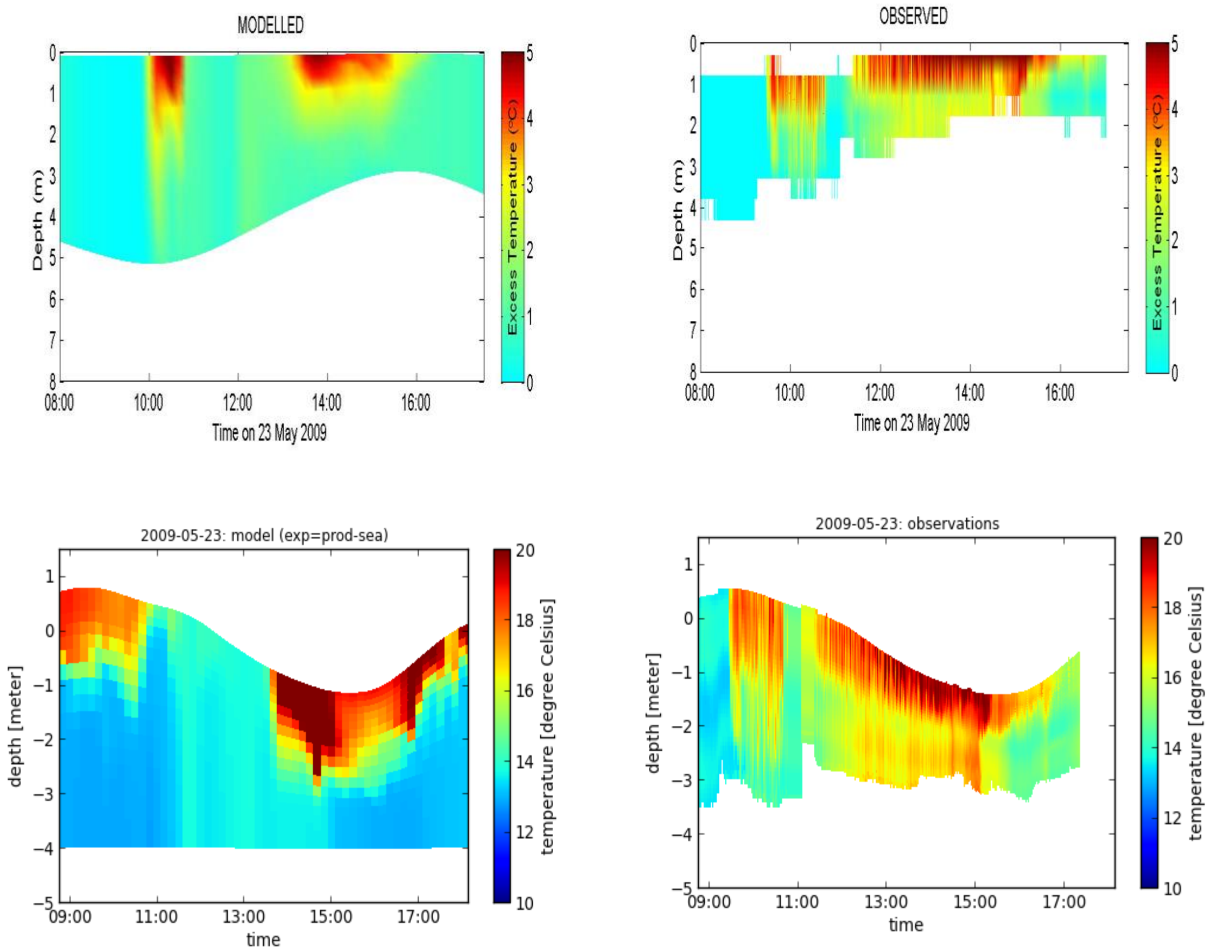

Figure 53 Comparison of Delft (upper) and GETM model result (lower) against observations at an anchor station just to the south of the outfall on 23rd May for High water – low water.

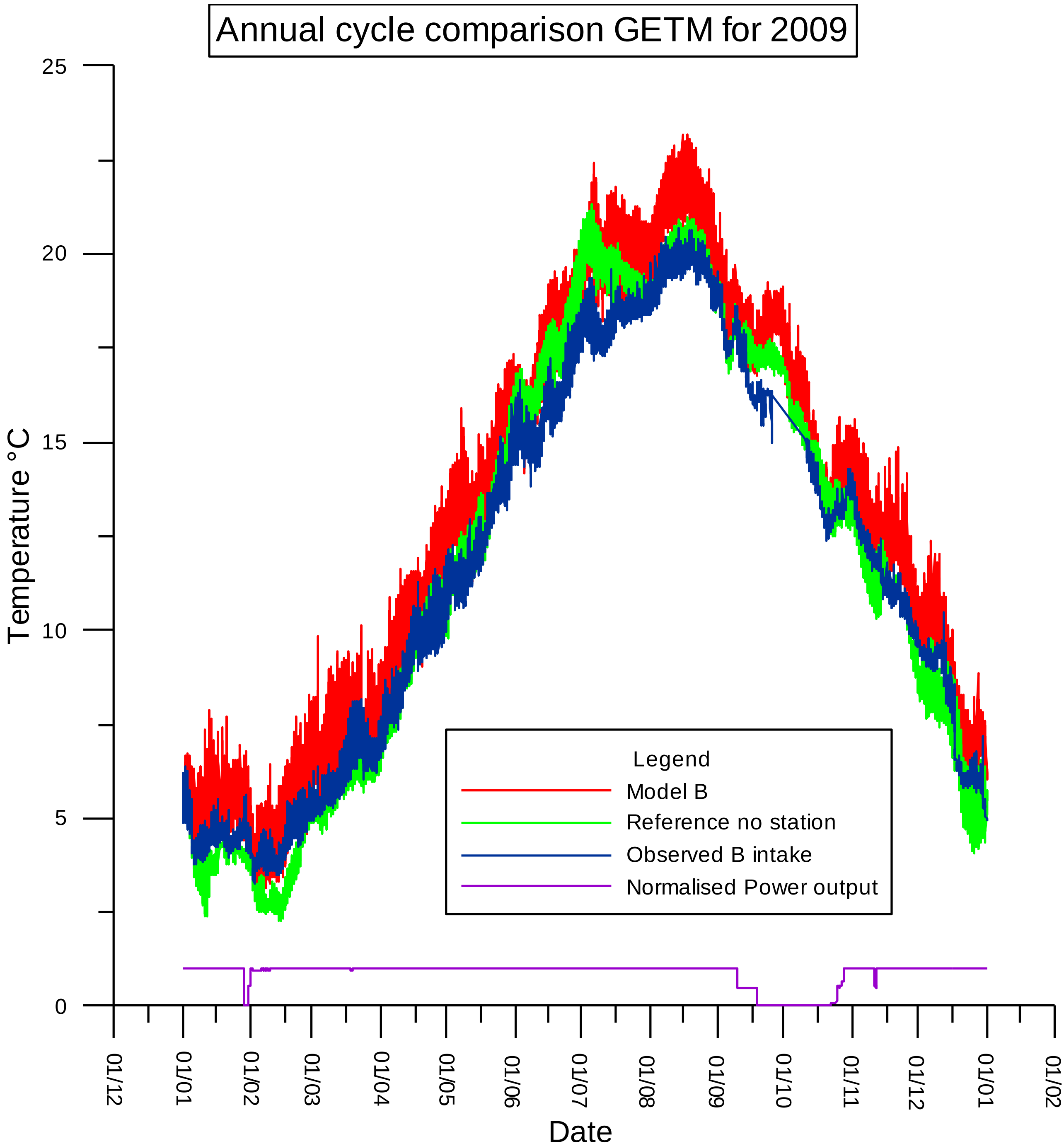

Figure 54 Annual comparison of GETM model, B only, reference and observed data

A number of features are evident in the annual cycle comparison in Figure 54:

- The reference run temperatures (model with no power station) and the observed SZB intake temperature data lie close together indicating that the GETM reference model slightly over predicts temperature. The model was initiated in December 2008 and is then forced by six hourly data from meteorological forcing and time varying boundary conditions provided from another wide scale model. It is therefore not surprising that there will be periods of difference between the observed and modelled data at the inshore position. (The subtraction of the reference run from the modelled station runs should, in principle, allow such errors to be removed).
- Overall the match between the SZB modelled and observed intake temperatures is very good with similar features being observed. The most notable exception to this is the period in mid July where the model predicts an increase in temperature which was not observed. The period of maximum observed sea temperatures in late August/September is well replicated.

The lower line in Figure 54 is the normalised SZ B station power output, indicating that the power station was not operating from September 19th to 24th October. The temperature sensors in the station only give reliable sea temperature information when there is flow through the station. Fortunately there was a period, 10/10 - 24/10, when the cooling pumps were running, ensuring reliable temperatures and when there was no thermal output, enabling a comparison to be made to the model reference run.

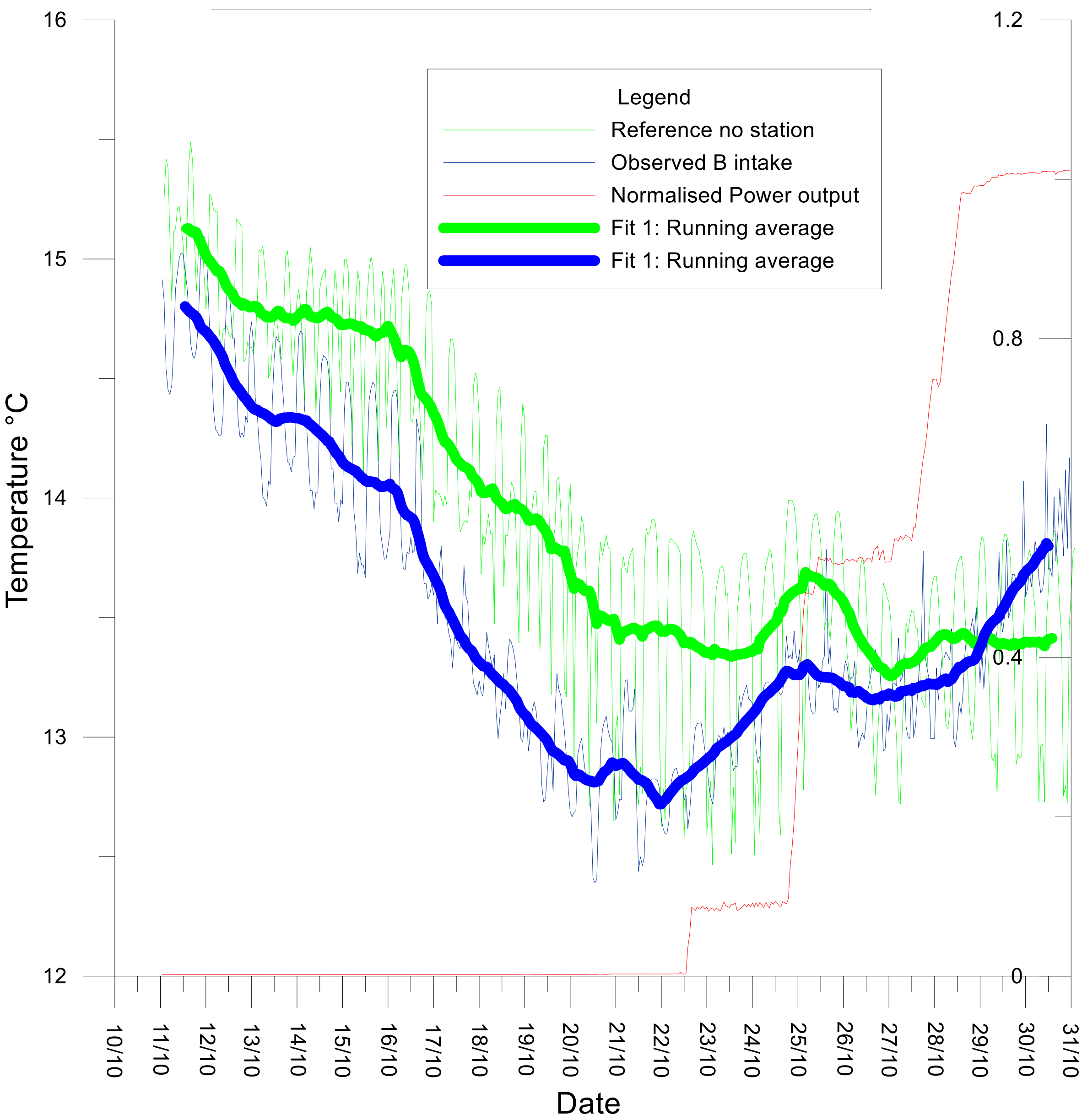

Figure 55 Time series at Intake B comparison with GETM model reference for period when station is not operating. Blue are the observed values, green is the model reference. Thick lines are the averages over 25 hours. The red line is the power station output where a value of 1 represents full power.

Figure 55 shows the comparison between the observed intake temperatures and the predictions from the GETM reference model (with no power station) in October 2009 when the power station was not operating; the GETM model replicates the tidal features well and the subtle trends in atmospheric forcing e.g. on 14-15/10. However, the GETM absolute temperatures are approximately +0.5 ºC too high, and the model does indicate greater variability than the observed values. However, the model results are instantaneous values at hourly intervals; whereas the observations, although hourly, are partially integrated by virtue of the volume of water in the fore bay. Once the power station resumes power output after 22/10 the effect of SZB is evident, with the observed temperatures increasing above the model reference predictions.

Model predictions of the Sizewell C and Sizewell B combined discharge

Figure 56 shows the predicted annual cycle of SZB intake temperatures from the GETM model. The figure shows a clear seasonal cycle in the excess temperatures with maxima in the winter months and minima in the summer time. This is likely to be due to stronger winds in winter causing greater mixing of the buoyant thermal plumes down into the water column where they are more likely to be abstracted by the intakes. Increased temperatures at the intake occur due to two mechanisms, the advection of vertical well mixed water ponded at slack tide, which is then advected across on the intake, or the mixing down of stratified water by the combination of wind, waves and tidal current.

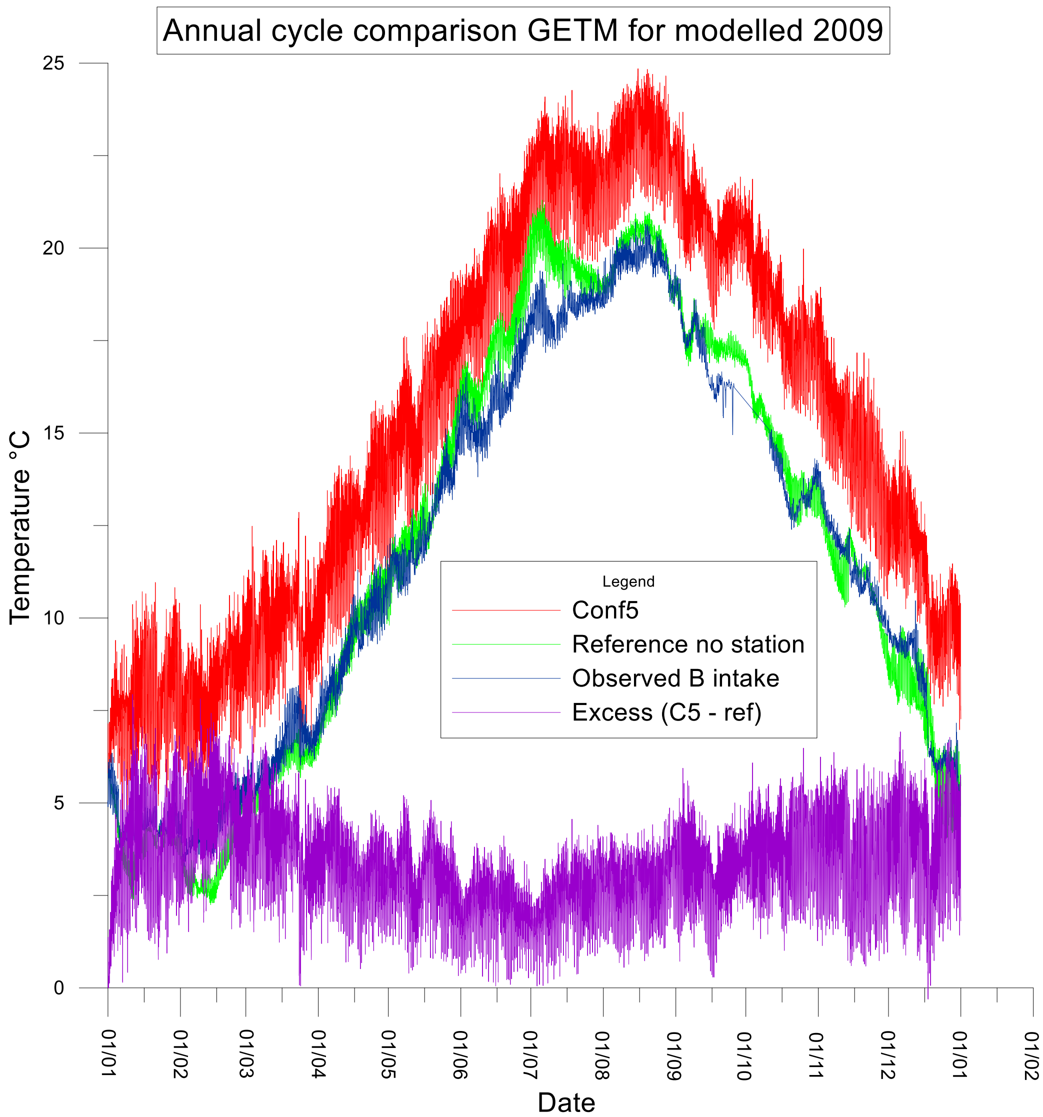

Figure 56 GETM annual cycle of temperature for SZC Configuration 5, reference with no power station and the observed values "intake B". The excess temperature is the difference between the Configuration 5 and reference model runs

Figures 57 and 58 attempt to compare the Delft3D and GETM outputs during similar tidal and meteorological conditions. These data suggest that the two models give similar excess temperature predictions for periods when wind speeds are low, however, overall the GETM model shows greater variability and on average gives higher values of excess temperature than the Delft3D model. One of the major causes of intake temperature variability is the positioning of the SZB intakes. These are well positioned to extract water from the cool bottom water, but as can be seen from Figure 57 there are strong vertical temperature gradients in winter so that different strengths in surface mixing, due to waves or winds, can lead to different predicted intake temperatures.

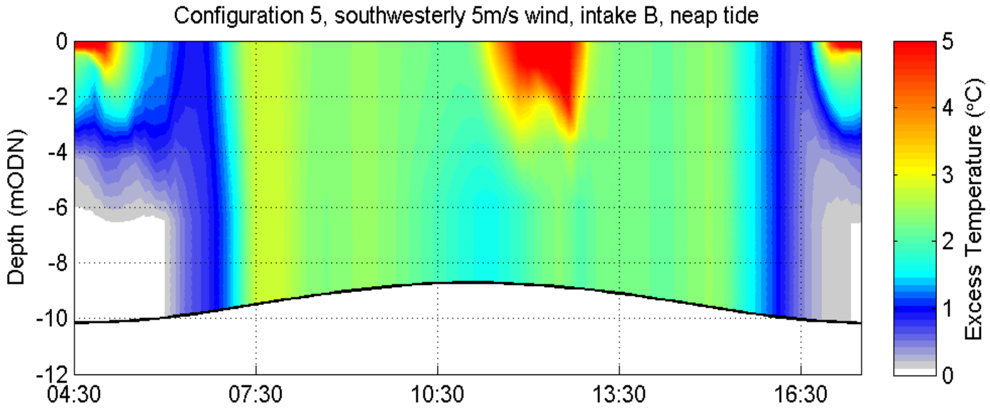

Figure 57 Simulation of the temperature time series at the Sizewell B intake using the Delft 3d model for Sizewell B + C. Low water (10:30) (15 min output). The generic neap run mean excess temperature with low winds was1.70°C i.e. no specific timings.

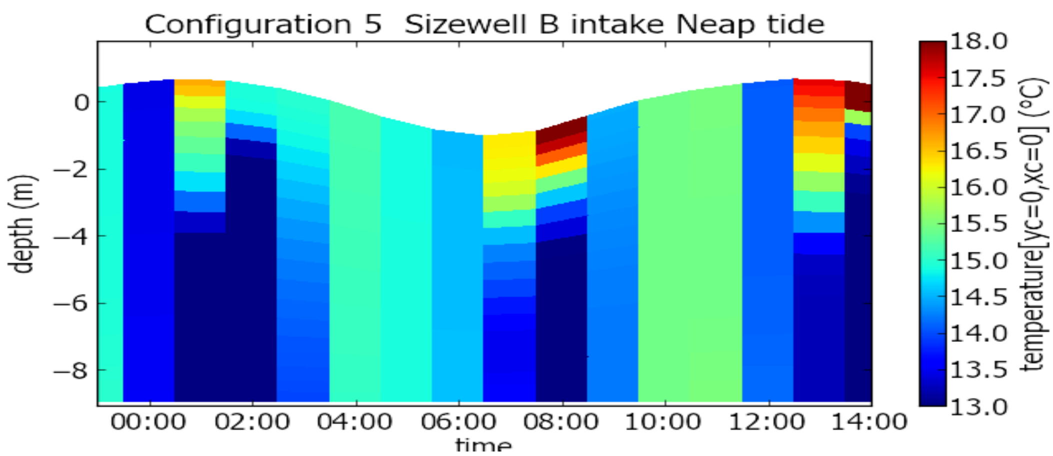

Figure 58 Temperature at the Sizewell B intake, GETM model simulation at 25m resolution. GETM model output shows absolute temperatures but using a similar scale range to the Delft model i.e. 5 °C. Extracted from the annual run at 1hr intervals 00:00 – 14:00 13th May. Mean excess temperature was 2.07 °C

Note: The apparent agreement between the 2 model estimates of mean excess temperatures needs to be considered in the context of the high variability in the daily excess temperatures shown in Figure 56.

The two models have different approaches and thus direct comparison of outputs is difficult. However the two models do show similar features, in that maximum temperatures in the vicinity of the intake are predicted just after low water, rather than at high water slack, as is presently observed and modelled for Sizewell B. The models suggest that peak temperatures at the intake depth occur during maximum current flow, about 2hours after slack water. e.g. at times 04:00 and 16:00 in Figure 59. Depending on how the intakes extract water at slack tide, then there will also be sharp peaks associated with the high water and low water slack tide periods.

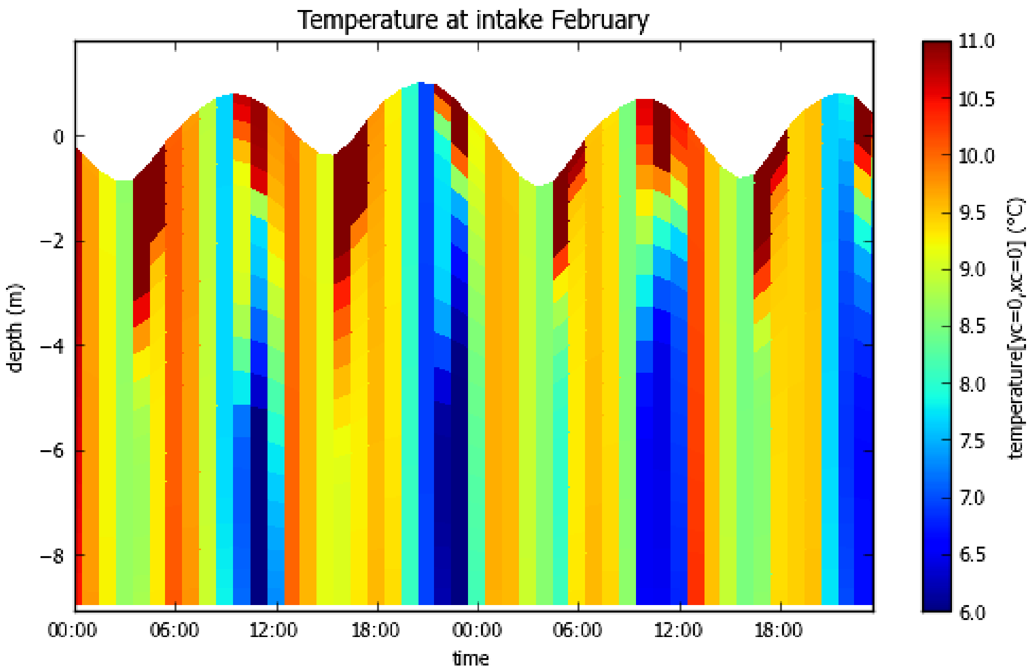

Table 20 shows that the inter-monthly variance in the predicted excess temperature at the SZ B intakes from the GETM model is large. In June and July the predicted mean increase is approximately +2 °C which is similar to the Delft 3D predictions (with low wind speeds of 5ms^{-1}) whereas in February it is up to +4.5 °C.

Table 20 GETM monthly temperature variation for both the zero reference run, SZB (present) and SZC Configuration 5 at the SZB intakes.

Figure 59 Modelled absolute temperature at SZ B intakes in February. Note strong mixing down leading to high intake temperatures.

	I: Monthly Mean °C					II: Maximum Daily mean temp °C			III: Maximum value (hourly record) °C				
				Difference								Average Daily Max excess.	
	Ref Zero	SZB	C5	C5 - SZB	C5-Ref	Ref	SZB	C5	Ref	SZB	C5	C5 -SZB	C5-Ref
Jan	4.1	5.1	7.6	2.5	3.5	5.7	5.7	8.4	5.8	7.1	11.0	3.9	5.7

Feb	3.4	5.2	7.9	2.7	4.5	5.0	6.4	9.0	5.2	7.7	11.1	3.8	6.5
Mar	5.8	7.2	9.5	2.3	3.7	6.5	8.5	10.5	7.0	9.6	12.9	3.6	5.6
Apr	9.2	10.4	12.3	1.9	3.0	10.8	11.6	13.8	11.6	13.5	15.9	3.0	4.6
May	12.9	13.6	15.6	2.1	2.8	15.7	16.9	17.7	16.5	18.4	19.4	3.2	4.2
Jun	17.2	18.0	19.3	1.3	2.1	19.6	20.4	21.4	20.6	21.6	23.0	2.3	3.4
Jul	19.6	20.1	21.8	1.7	2.2	20.5	21.1	22.5	21.3	22.3	24.3	2.8	3.6
Aug	20.0	20.8	22.6	1.8	2.7	20.6	21.5	23.7	21.0	22.6	24.9	2.7	4.1
Sep	17.6	18.7	20.6	1.9	3.0	19.0	19.9	22.1	19.2	20.6	23.7	2.8	4.5
Oct	14.6	16.0	18.1	2.1	3.5	16.9	18.3	20.2	17.0	19.2	21.9	3.1	5.3
Nov	11.3	12.0	14.7	2.6	3.4	13.3	14.7	17.0	13.7	15.6	18.9	4.2	5.6
Dec	7.3	8.4	10.9	2.5	3.6	9.1	9.9	12.6	9.8	10.9	15.1	3.6	5.9

The average daily maximum excess temperatures have been calculated by extracting the maximum excess temperatures in each day from the GETM simulations for 2009 (The excess temperatures being the difference between the model run with power station(s) and the zero reference with no power station). The daily maximums in each month were then averaged to calculate the average daily maximum for each month i.e. for each day in a particular month they represent the size of the largest recirculation spike as a 50%ile. (Note: These temperatures are very similar to the 95%iles calculated from the hourly record of excess temperatures)

Table 21 Estimates of Sizewell B Intake temperatures from the two models (Delft3D and GETM) compared to a zero reference (no power station).

	Mean excess temperatures ºC			Maximum excess temperatures ºC
Model	Mean at bed	Mean at Intake depth (mid water)	Depth Average	At the intake depth
Delft3D over one spring neap cycle. (background water temperature of 11.6ºC and wind speeds of $5 ms^{-1}$ from one chosen direction were constant during each model run).	1.1	1.2	1.3[1]	**3.8** (maximum from one tide during Neaps)
GETM – values derived from August model outputs only (Derived in Appendix B)	2.6	2.75	3.1	**4.0** (95%ile)
GETM – From an entire 12 month annual cycle (Model had 6 hourly input meteorology.) (Derived in Appendix B)	3.1	3.2	3.5	5.4 (95%ile)

[1]These values are derived from averaging the outputs from the 4 meteorological conditions described in BEEMS Technical ReportTR133.