SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

DOCUMENT TITLE	Predicted performance of the SZC LVSE intake heads compared with the SZB intakes

ISSUE REASON	P6 - For Construction

CONTRACTOR DETAILS

CONTRACTOR NAME	CEFAS

CONTRACTOR DOCUMENT NUMBER	BEEMS Scientific Position Paper SPP099	**CONTRACTOR REVISION**	05

ECS CODES

REVISION HISTORY

REVISION	REVISION DATE	PREPARED BY	POSITION/TITLE	CHECKED BY	POSITION/TITLE	APPROVED BY	POSITION/TITLE
01	05/05/2020	BR	Director	DH	Hydrodynamic modelling lead	DH	Hydrodynamic modelling lead
02	05/05/2020	BR	Director	DH	Hydrodynamic modelling lead	DH	Hydrodynamic modelling lead
03	03/07/2020	BR	Director	DH	Hydrodynamic modelling lead	DH	Hydrodynamic modelling lead
04	21/10/2020	BR	Director	DH	Hydrodynamic modelling lead	DH	Hydrodynamic modelling lead
05	13/04/2021	BR	Director	DH	Hydrodynamic modelling lead	DH	Hydrodynamic modelling lead

SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

REVISION STATUS/SUMMARY OF CHANGES

Revision	Purpose	Amendment	By	Date
1	First release		BR	05/05/2020
2	Response to client comments	Minor edits	BR	05/05/2020
3	Response to EA comments on v2	Replaced modelled hydrodynamics with measured values at SZC intake locations. Extended sensitivity analyses incorporated.	BR/DH	03/07/2020
4	Minor revision	Minor correction to filenames in Appendix A. No other changes.	BR	21/10/2020
5	Revision	Response to Environment Agency comments	BR	13/04/2021

Predicted performance of the SZC LVSE intake heads compared with the SZB intakes

SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

Blank

Predicted performance of the SZC LVSE intake heads compared with the SZB intakes

Brian Robinson

David Haverson

SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

Blank

Version and Quality Control

	Version	Author	Date
Draft	0.01	BR	10/12/2019
Revision	0.02	BR	04/05/2020
Executive QC & Final Draft	0.03	DH	05/05/2020
Submission to EDFE	1.00		05/05/2020
Revision in response to client comments	1.01	BR	05/05/2020
Executive QC & Final Draft	1.02	DH	05/05/2020
Release to EDFE as V2	2.00		05/05/2020
Revision in response to consultee comments	2.01	BR	01/07/2020
Executive QC & Final Draft	2.02	DH	03/07/2020
Release to EDFE as V3	3.00		03/07/2020
Minor correction to Appendix A	3.01	BR	21/10/2020
Submission to EDFE as V4	4.00		21/10/2010
Revision	4.01	BR	09/04/2021
Executive QA & Final draft	4.02	DH	13/04/2021
Submission to EDFE as V5	5.00		13/04/2021

SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

Blank

SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

Table of contents

Executive summary **12**

Conclusions 13

1 Background **15**

2 Description of the SZB and proposed SZC intake heads. **17**

2.1 SZB Intakes 17

2.2 SZC intakes 17

2.3 Hydrodynamic considerations 19

2.3.1 Intake head performance 19

2.3.2 What is the definition of slack water 20

3 SZC LVSE Intakes – predicted intake velocities **21**

4 Methodology used to predict the intake head intercept cross-sectional areas. **23**

4.1 Sizewell C LVSE intakes 23

4.2 SZB intakes 24

4.3 Alternative approaches to modelling the SZB intercept area 33

5 Results **34**

5.1 Revised SZB intercept area 35

5.2 Calculated SZC:SZB intercept area ratio based upon revised SZB estimated areas (assuming swimming fish) 35

5.3 Sensitivity analyses 36

6 Conclusions **37**

6.1 LVSE intake velocities 37

6.2 Ratio of SZC to SZB intake intercept areas 38

6.3 Alignment of the LVSE intakes at Sizewell. 38

References **39**

Appendix A **40**

List of Tables and Figures

Tables

Table 1: Coordinates of the SZB and proposed SZC cooling water intake and outfall heads. ... 18

Table 2: Calculated intercept area of the 4 SZC LVSE intakes (assuming that the intakes were all at locations I3b or I4b). ... 34

Table 3: Calculated intercept area of the SZB intakes over a 30 day tidal cycle. ... 35

Table 4: Calculated intercept area of the SZB intakes over a 30 day tidal cycle assuming fish swim at 0.2 m s^{-1} after with the tidal flow after slack water. ... 35

Table 5: Calculated SZC/SZB intercept area ratio (SZB area based upon swimming fish). ... 36

Table 6: Calculated intercept areas (m^2) assuming that all of the SZ LVSE intakes were either at the northern or southern intake locations with a realistic slack velocity threshold of 0.2 m s^{-1}. The cells in green provide the mean (0°), and 5th percentile and 95th percentile head misalignment values. ... 36

Table 7: Calculated sensitivity of the SZC/SZB intercept area ratio for a slack threshold =0.2 m s^{-1} ... 36

Table 8: Calculated intercept areas (m^2) assuming that all of the SZ LVSE intakes were either at the northern or southern intake locations with an unrealistic slack velocity threshold of 0.3 m s^{-1} ... 37

Table 9: Calculated sensitivity of the SZC/SZB intercept area ratio assuming a slack threshold of 0.3 m s^{-1} ... 37

Figures

Figure 1: Location of the SZB and proposed SZC cooling water intake and outfall heads. ... 19

Figure 2: Modelled range to 0.3 m/s inward velocity at different tidal current speeds. ... 21

Figure 3: Variation in inward velocity with distance from the LVSE intake surfaces with tidal current speed. ... 22

Figure 4: Modelled SZC current direction histogram at 2.5m above the seabed at the location of LVSE intake ... 24

Figure 5: SZB intake – Telemac total model domain. ... 26

Figure 6: Zoomed portion of model mesh showing the SZB intake. The dashed black line represents the extent of the intake caps, but are not included in the model domain. 26

Figure 7: Model domain and extent of particles released 50 m from SZB intake. Tidal flows enter model from left hand side and exit right hand side, with SZB intake centred at middle of domain, abstracting at a flow of 25.75 m^3 s^{-1}. ... 27

Figure 8: Flow pattern around each SZB intake at a tidal current of 0.1 m s^{-1}. Horizontal and vertical scales are metres. ... 28

Figure 9: Flow pattern around each SZB intake at near peak tidal flow (0.76 m s^{-1}). Tidal direction is at 90° to face 1. Horizontal and vertical scales are metres. ... 29

Figure 10: Particle tracks around SZB intake head, extracting at 25.75 m^3 s^{-1}, with 1.0 m s^{-1} input flow conditions. Pink lines represent the particles abstracted by the intake. ... 30

Figure 11: Particle tracks around SZB intake head, extracting at 25.75 m^3 s^{-1}, with 0.5 m s^{-1} input flow conditions. Pink lines represent the particles abstracted by the intake. 30

Figure 12: Particle tracks around SZB intake head, extracting at 25.75 m^3 s^{-1}, with 0.2 m s^{-1} input flow conditions. Pink lines represent the particles abstracted by the intake. 31

Figure 13: Options for the calculation of the intercept area of the SZB intake heads; a step change is physically unrealistic. 32

Figure 14: Tidal velocity histogram at the SZB intakes. 33

Executive summary

The proposed Sizewell C (SZC) cooling water system would be fitted with four low velocity side entry (LVSE) intake heads mounted on the seabed approximately 3 km offshore. The proposed intake heads would be capped structures with the intake surfaces orthogonal to the direction of the tidal flows. These state-of-the-art intakes are specifically designed to reduce the cross-sectional area available to intercept any fish being transported in the tidal flows. The reduction in cross-sectional area combined with their low intake velocity is predicted to substantially reduce the number of fish abstracted per cumec (cubic metre per second) of seawater compared with Sizewell B (SZB) which is fitted with two capped omnidirectional intake heads with intake velocities that exceed the ability of most fish to avoid being abstracted.

The results of initial modelling of the SZC LVSE intakes was described in BEEMS Technical Report TR406 v6. These results indicated that the predicted ratio of the SZC to SZB intake intercept areas was 0.383 which implied that SZC would abstract 38.3% of the fish and crustacea per cumec that SZB currently abstracts. The methodology used to calculate the intercept areas of the LVSE intakes in TR406 was based upon that proposed by the Environment Agency (Environment Agency 2019) but was not fully compliant as the method was still being evaluated by Cefas at the time.

This modelling work was then further refined and the methodology used in BEEMS Scientific Position Paper SPP099 v2 was fully compliant with Environment Agency (2019). The existing SZB intakes are omnidirectional and therefore the directional analysis had to be removed from of the Environment Agency methodology, but the resulting algorithm was still compliant with the remaining principles of the method; in particular it incorporated the same treatment of slack water effects. The SZB intercept area was calculated by particle tracking with a 2D model of the SZB intakes assuming drifting particles.

Consultee comments on SPP099 v2 requested that the methodology should be extended to capture the full range of tidal directions likely to occur in the real world. The Environment Agency methodology uses hydrodynamic data (current speeds and directions) from a validated 3D hydrodynamic model of Sizewell Bay. This model is forced by European Centre for Medium-Range Weather Forecasts meteorological data but the temporal and spatial resolution of those data means that the model is not able to fully reproduce the high frequency variability caused by local meteorology. This lack of high frequency components would reduce the spread of the estimated tidal directions compared to the real world. To evaluate this effect, the GETM model outputs used to derive the intake intercept areas were replaced by Acoustic Doppler Current Profiler (ADCP) measurement data from the locations of the proposed SZC northern and southern intakes measured at a height of approximately 2 m above the sea bed i.e. slightly below the centre of the proposed SZC intake faces at 2.5 m above the seabed. The tidal velocity is slightly lower and the tidal directional spread is slightly wider at 2 m than 2.5 m and the use of these ADCP data therefore produced over estimated intercept areas. No other changes were made to the methodology.

As expected the spread in measured tidal direction was larger with ADCP measurements than from the model. Part of this will have been due to measurement noise, but the majority is considered to be due to the instruments ability to capture high frequency events. The revised ratio of the SZC to SZB intake intercept areas in SPP099 v3 was 0.357. SPP099 v4 only contained minor correction to references.

In consultations on SPP099 v4 the Environment Agency commented that the SZC LVSE intercept area calculations use a different methodology than those for the SZB intake and in so doing has created uncertainty. The Environment Agency's main concern with the SPP099 v4 approach appeared to be the use of a drifting particle tracking model to calculate the SZB intercept area between the values at slack water and full tidal velocity.

This revision 5 report addresses the Environment Agency's concerns by considering the range of available options for modelling of the two intake designs. The only practical option was found to be to refine the existing particle tracking model to take account of the fact that fish swim with the tidal flow rather than act as drifting particles. Using estimates of fish swimming speeds in tidal flow from measurements made at sea, the revised ratio of the SZC to SZB intake intercept areas in this report is 0.396.

Spreadsheets have been provided separately that details the calculations (Appendix A).

The results of modelling the SZC LVSE intakes in the ANSYS computational fluid dynamics (CFD) software are also presented.

Conclusions

1. LVSE intake velocities

CFD modelling of the proposed LVSE intakes at Sizewell shows that:

i) The hydrodynamic influence of the LVSE intakes is only felt over a short distance from the structure with intake velocities falling to 0.1 m s^{-1} within approximately 1.5 to 2.5 m from the intake surfaces and to 0.05 m s^{-1} at a range of approximately 3 m from the intake surfaces over the full tidal cycle;

ii) The range from the intake surface for the inward velocity to fall to the Environment Agency's required figure of 0.3 m s^{-1} is 0.0 to 0.68 m dependent upon the tidal current speed (faster tidal velocities have the effect of increasing the intake velocity). Over the tidal cycle the median distance from the intake where the inward velocity criterion of 0.3 m s^{-1} is met is 0.38 m (based upon the distribution of tidal currents at the SZC intakes).

2. Ratio of SZC to SZB intake intercept areas

Using the methodology proposed by Environment Agency (2019) the intercept area of the SZC LVSE intakes have been calculated but with ADCP data rather than model data.

This geometric methodology used to calculate the intercept area of the LVSE heads cannot be used with the omnidirectional SZB heads and so instead a particle tracking model was developed for SPP099 v3 that assumed drifting particles. On reflection and after consultation with the Environment Agency, this approach is considered to generate too large an intercept area for SZB as swimming fish would experience a lower intercept area than drifting organisms. Using estimates of fish swimming speeds in tidal flow from measurements made at sea, the SZB intercept area model has been recalculated in this report based upon the assumption that fish will swim up to 0.2 m s^{-1} in the tidal flow.

The ratio of the intercept cross-sectional areas of the proposed four SZC LVSE intakes compared with the two omnidirectional SZB intakes is 0.396 as a best estimate with values of 0.412 and 0.403 at the 5th percentile and 95th percentile head misalignment values respectively at a slack tide threshold of 0.2 m s^{-1}. This means that SZC fitted with LVSE intakes is expected to abstract 39.6% of the fish and crustacea per cumec that SZB does (assuming all other factors are constant). This ratio is appropriate to impingement assessments rather than entrainment assessments; the notable exception being for glass eels that are entrained because of their long, thin morphology.

This ratio is slightly larger than that estimated in BEEMS Technical Report TR406 v7 (at 0.357) but confidence in the result is greater because it:

a) has now been calculated fully in line with the methodology in Environment Agency (2019);

b) it has been subject to an extended sensitivity analysis that incorporates measured as opposed to only model data;

c) benefits from much more realistic modelling of the SZB intake heads; in particular how their intercept area varies during the tidal cycle and with swimming fish

Whilst the adjustment to the ratio will influence impingement predictions, such a small change has no bearing on the overall effect conclusions.

3. Alignment of the LVSE intakes at Sizewell.

The SZC LVSE inatkes will be aligned in the field by the use of ADCP survey data. Such surveys can determine the tidal axis to a directional accuracy in the range ±1 to ± 2 degrees dependent upon whether the instrument is individually calibrated or the manufacturer's worst case calibration is used. This measurement accuracy, together with a realistic estimate of the accuracy that the heads can be placed on the seabed (± 1 degree) has been built into the sensitivity analyses presented in this report.

SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

1 Background

EDF Energy plans to build a new coastal nuclear power station (Sizewell C, SZC), adjacent to the operational Sizewell B (SZB) and decommissioned Sizewell A (SZA) sites in Suffolk. The station would be of a once-through design, abstracting large volumes of seawater for cooling the condenser steam. As part of the application for the building and operation of the new station, EDF Energy is required to evaluate the effects that the abstraction of seawater may have on the marine environment. The Centre for Environment, Fisheries and Aquaculture science (Cefas) supported by a network of subcontractors has been contracted by EDF Energy to undertake the necessary marine studies to provide the evidence base for the SZC DCO application via a comprehensive set of studies known collectively as the BEEMS programme for SZC.

SZC would need to abstract approximately 132 cumecs ($m^3 s^{-1}$) compared with a nominal 51.5 cumecs for the existing SZB. SZB was commissioned in 1995 and is currently the most modern operational nuclear power station in the UK. As a first in the UK, SZB was specifically designed to reduce the losses of impinged fish and crustacea and incorporated:

a. omnidirectional intakes mounted in deeper water than at SZA in order to reduce abstraction of juvenile flatfish that use shallow water near to the Sizewell coast as a nursery area;
b. capped intake heads which reduce vertical velocities that fish are ill equipped to avoid. Previous studies in the USA had demonstrated that capped intakes could reduce pelagic fish abstraction by up to 85%;
c. intake surfaces mounted off the seabed to minimise abstraction of benthic fish and organisms; and
d. an early, rudimentary example of a Fish Recovery and Return (FRR) system designed to return as many abstracted fish as possible safely back to sea. The SZB system was focussed on reducing the mortality of juvenile sole, an important commercial species in the southern North Sea.

Trials showed that these measures successfully reduced losses of fish and crustacea per cumec abstracted compared with SZA (Turnpenny and Taylor (2000)). The SZB intake designs were state-of-the-art in 1995 and whilst representing a substantial improvement over those of SZA, their design can be further improved to reduce fish abstraction. In particular, the omnidirectional design of the SZB intakes means that whilst at slack water the intake velocity is approximately 0.23 m s^{-1}, at peak tidal velocity the intake velocity rises to over 1 m s^{-1} which is beyond the ability of nearly all fish to avoid. Environment Agency guidance (Environment Agency 2005; 2010) states that "for most power plant intake purposes a design fish-escape velocity (i.e. intake velocity) of 0.3 m s^{-1} will be suitable and meet best requirements".

The SZC LVSE intake heads have been designed to substantially reduce the abstraction of fish and crustacea per cumec compared with SZB and similar LVSE intakes are currently being manufactured for installation at Hinkley Point C (HPC) which is under construction. The HPC and SZC LVSE designs are the first examples of this technology to be constructed worldwide as far as EDF Energy is aware. These very large and highly engineered intake structures are designed to minimise impingement by:

a. limiting the exposure of the intake surfaces to the tidal stream and in so-doing reduce the risk of impingement for fish swimming with the tidal stream. i.e. they reduce the cross-sectional area of the intake presented to the prevailing tidal directions by mounting the head orthogonally to the tidal flow;
b. reducing intake velocities into the head to a target velocity of 0.3 m s^{-1} over as much of the length of the intake surface as practical during all tidal states in order to maximise the possibility of most fish avoiding abstraction; and
c. in common with the SZB design, reducing vertical velocities which fish are ill equipped to resist by means of velocity caps on the intakes.

In addition, SZC would feature other key measures to reduce the risk to fish and crustacea:

- the intakes will be situated in much deeper water than SZB that would mean that fish swimming near to the surface would be largely invulnerable to abstraction. For energetic reasons many fish use tidal stream transport to migrate in surface waters and these fish would be at much lower risk of abstraction than at SZB;
- an advanced FRR, designed from the outset to reduce fish mortality for a wider range of species than SZB, particularly for conservation species such as eel and lamprey; and
- an anti-biofouling chlorination policy whereby chlorination will only occur downstream of the filtration systems and hence not within the FRR system. This would reduce mortality for demersal species such as bass, whiting and cod compared with SZB where the intakes and intake tunnels are chlorinated all year round.

All of these measures are expected to reduce losses of fish and crustacea but this paper focusses on the predicted performance of the LVSE intakes compared to the omnidirectional intake heads at SZB in reducing the abstraction of biota per cumec abstracted.

LVSE intakes have the key advantages over other potential mitigation measures that they are expected to minimise the abstraction of biota in the first place, they are predicted to work for all fish species and they are entirely passive and therefore not prone to failure due to electrical or mechanical breakdowns.

In a schedule 5 question relating to SPP099 v4 the Environment Agency has commented that the SZC LVSE intercept area calculations use a different methodology than those for the SZB intake and in so doing has created uncertainty. This revision 5 report addresses that comment.

2 Description of the SZB and proposed SZC intake heads.

2.1 SZB Intakes

The intake structure consists of two intake heads located on a line at approximately 90 degrees to the tidal flow. Each head is octagonal, approximately 11.5 m across and is omnidirectional. The structure sits ~1.5 m above the seabed and the intake aperture is 3 m high. The tidal flows at Sizewell are highly rectilinear and peak at 1 m s^{-1} on spring tides. During peak tides, a tidal streamline of approximately the width of the intake enters the intake, whereas at slack water the water is drawn from all round around the intake.

Each of the 8 intake faces on each head has a face width of 4.76 m and a height of 3 m i.e. the area of each face is 14.29 m^2. The total intake surface area per head is therefore 114.32 m^2 and for the two heads the intake surface area is 228.65 m^2.

2.2 SZC intakes

The proposed SZC intakes will be low velocity side entry (LVSE) structures. A total of four LVSE heads will be installed with two heads fitted on each of the two intake tunnels (Table 1). The intake heads will be located approximately 3 km offshore, on the eastern side of the Sizewell-Dunwich Bank in approximately 15 m (ODN) depth (Figure 1). The detailed design of the intake heads is not yet complete but the performance of the design with the worst hydrodynamic performance has been used for this assessment in order to envelope worst case modelled performance. This design has intake surfaces of the same size as those being constructed for Hinkley Point C (HPC) with the bottom of the intake surfaces being at approximately 1.5 m off the seabed (as at HPC) in order to reduce the abstraction of benthic organisms.

The following LVSE head dimensions have been modelled:

- Each intake surface is 35.5 m long and 2m high with the middle of the intake face 2.5 m off the sea bed.
- Area per intake face = 71 m^2, 2 faces/head=142 m^2 per head. With 4 heads the total surface area = 568 m^2.
- When the tide is flowing only 4 intake faces are exposed to the tide i.e. intake exposed surface area = 284 m^2.

SPP099 PREDICTED PERFORMANCE OF SZC LVSE INTAKES

NOT PROTECTIVELY MARKED

Table 1: Coordinates of the SZB and proposed SZC cooling water intake and outfall heads.

	Latitude WGS84 (degrees N)	Longitude WGS84 (degrees E)	Easting BNG (m)	Northing BNG (m)	Depth ODN (m)
Sizewell B					
IB	52.21472	1.63332	648297	263612	9.0
OB	52.21525	1.62658	647834	263647	5.1
Sizewell C					
I3a	52.21948	1. 66931	650726	264262	12.9
I3b	52.21945	1. 67077	650826	264264	13.6
I4a	52.21148	1. 66572	650526	263360	11.5
I4b	52.21126	1. 66714	650624	263341	13.5
O9a	52.21807	1.67435	651080	264125	16.9
O9b	52.21803	1.67544	651155	264125	16.8
WGS84: World Geodetic system 1984, BNG: British National Grid, ODN: Ordnance Datum Newlyn					

Notes:

1. IB is at the centre of the two SZB intakes, I3b and I4b are the SZC intake locations modelled in this report. OB is the SZB outfall and O9a and O9b are the two proposed SZC outfall locations.
2. I3b and I4b are shown in Figure 1 as OS22 and OS12

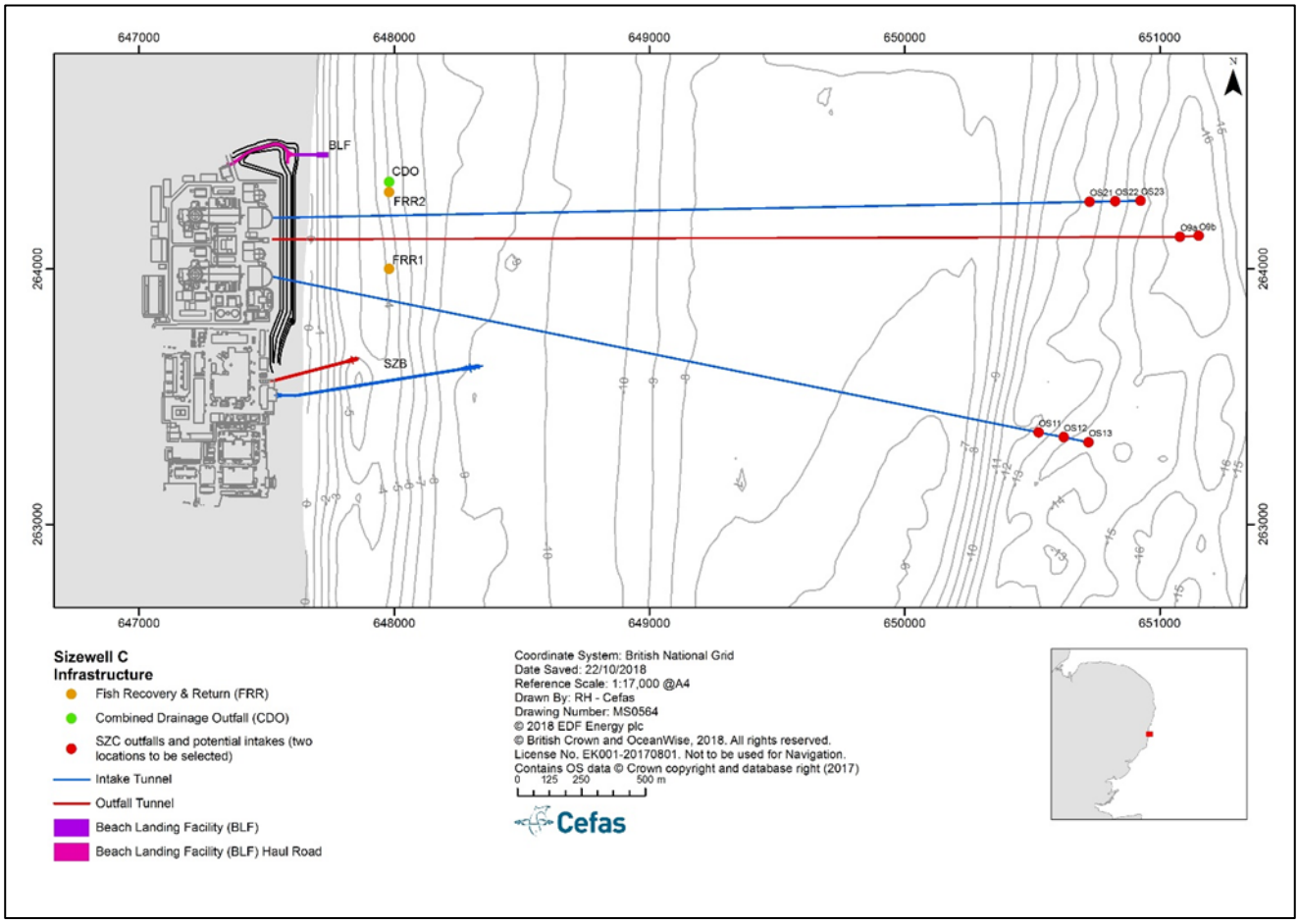

Figure 1: Location of the SZB and proposed SZC cooling water intake and outfall heads.

2.3 Hydrodynamic considerations

2.3.1 Intake head performance

At slack water, both the SZB and SZC intakes will abstract from all intake faces equally. Fish will not be transported to the heads by the tidal current and therefore only fish local to the heads or which swim into the abstraction zone (a zone parallel and close to the intake surfaces) will be abstracted. At slack water the intake velocities of both the SZC and SZB intakes is designed to be approximately 0.23 m s^{-1}.

In theory, with the SZC intakes orthogonal to the tidal flow, the current will flow past the SZC intake surfaces and only fish that are in an abstraction risk zone will be likely to be abstracted. In practice, the size of this abstraction zone (i.e. the distance from the intake surface) will depend on the effects of turbulence when the tidal current interacts with the intake head. To this end, the SZC intakes are designed to linearise flow velocities along the head and to reduce the formation of initial eddies by the use of shaped wedges at each end of the intake. The intake velocity of the SZC intakes will not increase with the tidal flow if the intakes are perfectly aligned to the tidal flow. In practice there is a spread around the modal directions of the tidal flow and there is also some tidal asymmetry, i.e. the tidal flow directions are not exactly 180 degrees apart, and so one side of

the SZC intakes will be exposed to the tide for part of each tidal cycle. This will increase the abstraction cross-sectional area of the intakes and serve to increase intake velocities.

For HPC studies, an initial rule of thumb assumption was made that the abstraction risk zone extended approximately 2 m from the head based upon physical modelling studies on the HPC LVSE heads (HRW, 2013). This would give an abstraction cross-sectional area of 2 m × 2 m height per intake face, 8 m^2 per head or a total of 32 m^2 for the four intakes designed for HPC. It has been suggested that this assumption is overly simplistic and, in particular, ignores effects at slack water when the intakes would have a larger cross-sectional area, and an alternative methodology to calculate the cross-sectional area of the LVSE intakes has been produced (Environment Agency, 2019). This methodology takes account of slack water effects and tidal spread and asymmetry on the LVSE head performance. We have adopted the Environment Agency (2019) methodology in this paper.

The SZB intakes are omnidirectional and at slack water the intake cross sectional area is 228.65 m^2. As the tidal velocity increases, water abstraction will increasingly take place on those intake surfaces facing into the tidal flow and the intake velocity on the surface facing most directly into the flow will increase to the approximate tidal current speed. In theory, at peak tidal flow the intake cross-sectional area of the SZB intakes would be expected to reduce towards the physical dimensions of the head facing into the tidal flow i.e. 11.5 m wide × 3 m depth per head = 34.5 m^2 per head or a total of 69 m^2 for both heads. In practice the intercept area will only approach the dimensions of the intake surface at the highest tidal velocities and under most tidal velocities the area will be greater than 69m^2.

2.3.2 What is the definition of slack water

As velocity increases from 0 m s^{-1}, the behaviour of the intakes will change from omni directional to preferentially abstracting from intake surfaces facing into the tidal current. In marine hydrodynamics, slack water is often characterised as velocities less than or equal to 0.1 m s^{-1}. Environment Agency (2019) considered the effects on the LVSE performance using a slack water definition of 0.1 to 0.3 m s^{-1}. This point is examined in more detail in section 4.1.

3 SZC LVSE Intakes – predicted intake velocities

The proposed SZC LVSE intakes were modelled using ANSYS computational fluid dynamics (CFD) software to determine the distribution of intake velocities across the intake surfaces in tidal currents ranging from 0 m s^{-1} to 1.0 m s^{-1} (which are representative of those experienced at the proposed locations of the SZC intake heads).

Figure 2 shows that the distance from the intake surface where the inward velocity (the velocity into the intake surfaces) falls to 0.3 m s^{-1} is 0.0 m to 0.68 m. Over the tidal cycle the median range to 0.3 m s^{-1} is 0.38 m based upon the modelled distribution of tidal currents at the SZC intakes.

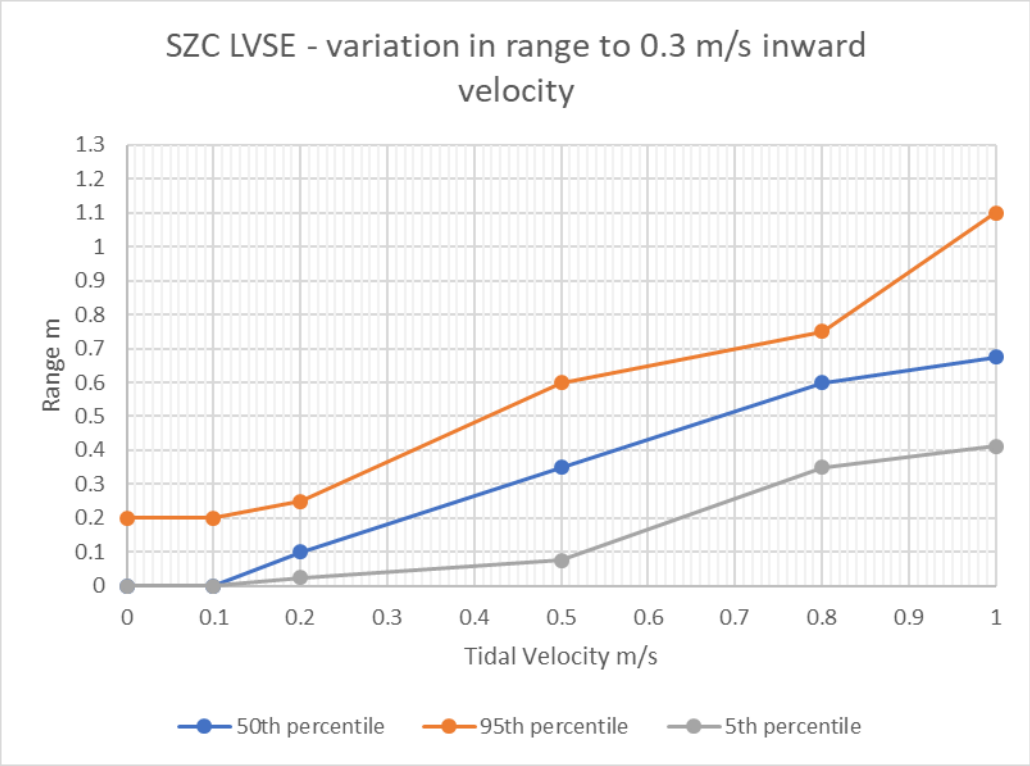

Figure 2: Modelled range to 0.3 m/s inward velocity at different tidal current speeds.

The influence of the LVSE intakes is only felt over a short distance with inward velocities falling to 0.1 m s^{-1} over a range of approximately 1.5 m to 2.5 m from the intake surfaces and further to 0.05 m s^{-1} at a distance of approximately 3 m from the intake surfaces over the full tidal cycle (Figure 3).

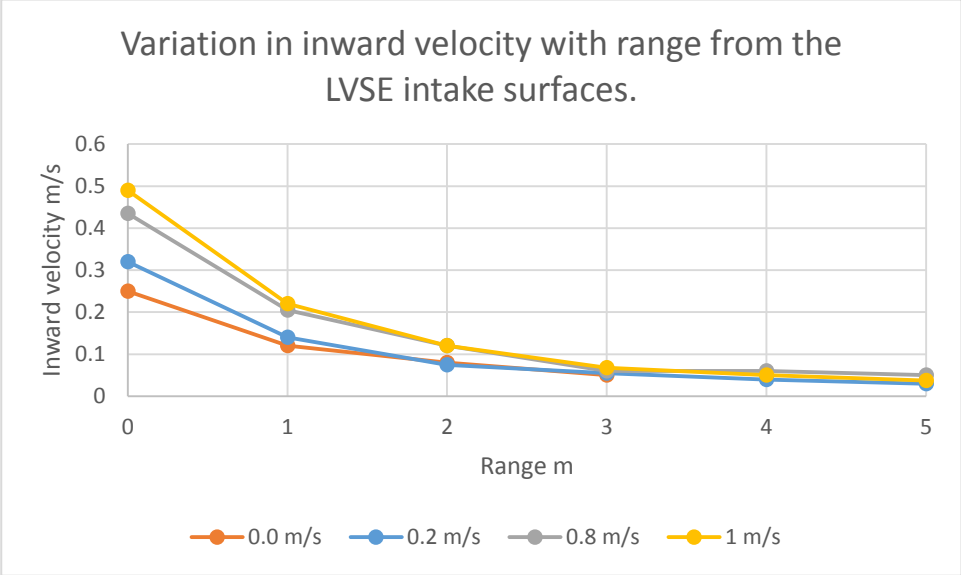

Figure 3: Variation in inward velocity with distance from the LVSE intake surfaces with tidal current speed.

4 Methodology used to predict the intake head intercept cross-sectional areas.

4.1 Sizewell C LVSE intakes

As described in section 2.3.1, we have used the methodology described in Environment Agency (2019) to calculate the intercept cross-sectional area of the four SZC LVSE intakes. The data source for the required tidal current speed and directions in this method was the validated GETM 3D model of Sizewell Bay. In subsequent comments the Environment Agency requested that that the methodology should be extended to capture the full range of tidal directions likely to occur in the real world. As a consequence, we have changed the data source from model output to field measurements as described below.

Environment Agency (2019) describes the results of 3 variants to the preferred approach with different slack water thresholds of 0.1, 0.2 and 0.3 m s^{-1}. We have adopted the same methodology as Environment Agency (2019) and with the parameterisation described below:

i. The tidal current data are from BEEMS 2018 ADCP monitoring data at the location of the proposed SZC northern and southern intakes at a height of approximately 2m off the seabed (2.04m and 2.09m respectively). These data replaced results used in v2 of this report from the validated Sizewell GETM 3D hydrodynamic model (BEEMS Technical Report TR302) at the proposed location of two of the LVSE intakes at a height 2.5 m above the sea bed (i.e. at the midpoint of the LVSE intake surfaces). There are three possible intake locations on each of the two SZC intake tunnels for two LVSE intake heads and so we have selected the mid positions (I3b and I4b on each tunnel alignment). The ADCP measurements were made with two landers placed within 50m of the I3b and I4b locations. The separation of the intakes on each tunnel alignment is sufficiently small that the local hydrodynamics do not vary significantly but we considered the two tunnel runs were sufficiently different due variations in water depth and underwater topology to merit modelling heads on each tunnel.

ii. The ADCP data were for 30 days (720h) in November to December or two full spring-neap tidal cycles at a 10-minute interval.

iii. The ADCP output was transformed into a 2-dimensional histogram with rows of direction and columns of current speed with the directions and velocities grouped into bins. From the modelling data it had previously been determined that tidal direction is very tightly distributed around the modal direction at Sizewell (Figure 4) and it is, therefore, very important to use a sufficiently small directional bin size to avoid biasing the analysis results. It was found that a 1 degree bin size was satisfactory. For current speed the same bin size was used as in Environment Agency (2019) (0.1m/s).

iv. Head alignment. EDF's construction engineers have confirmed that they can readily place the heads at any desired alignment to an accuracy of at least 1 degree. Due to the slight tidal asymmetry at each location, we adjusted the head alignment at each location to achieve minimum intercept cross-sectional areas at each location.

v. The intercept projected area of the LVSE intakes was calculated as described in Environment Agency (2019).

vi. Slack water conditions were treated differently. At slack water, the area scale factor of the LVSE intakes compared with the SZB intakes was set at 1 i.e. differences in abstraction were determined by the differences in flow rates. The flow velocity at slack was set to 0.3 m s^{-1} (i.e. greater than the design

specification of 0.23 m s^{-1}. That parameter choice only produced a small overestimate in calculated intercept area.). Both parameters are as described in Environment Agency (2019).

vii. The threshold speed for considering the tide to be slack was subjected to uncertainty analysis as the calculation is sensitive to this parameter. Based upon inspection of model and measured ADCP data at SZC and modelling data at SZB, slack water can conservatively be represented by speeds less than or equal to 0.2 m s^{-1}.

viii. The calculation of the intercept area for the omnidirectional SZB intakes is described in section 4.2.

ix. Spreadsheets showing the calculations are provided as described in Table A1.

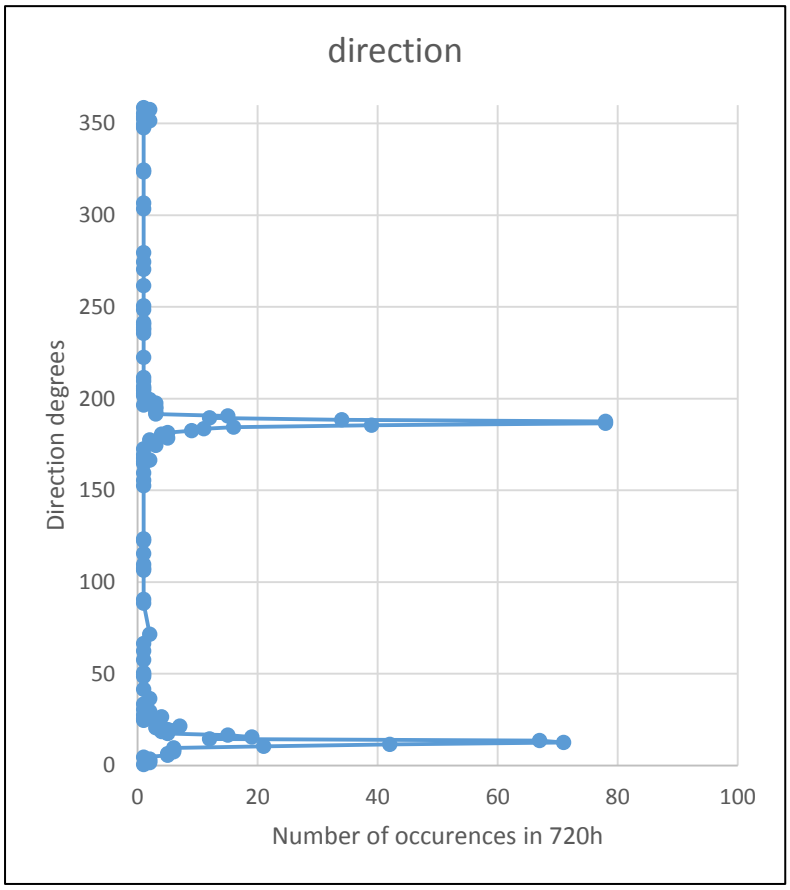

Figure 4: Modelled SZC current direction histogram at 2.5m above the seabed at the location of LVSE intake.

4.2 SZB intakes

As described in section 2.1, the combined area of the two SZB intake surfaces is 228.65 m^2 and in accordance with Environment Agency (2019) this is used as the SZB intercept area at slack water. At peak tidal flow, the

intercept area is expected to approach the physical cross section of the structures of 69 m^2 (11.5 m width × 3 m height × 2 heads). Simplistically, the intercept area could be regarded as 228.65 m^2 at slack water (for example, at tidal velocities up to 0.1 m s^{-1} and then falling as a step function to 69 m^2 for higher tidal velocities; but this is clearly an unrealistic over simplification for the SZB omnidirectional head).

To gain a greater understanding of the SZB intake head performance, a hydrodynamic model of one of the two heads was constructed based upon scaled drawings provided by EDF Energy. A 2D hydrodynamic model of the SZB intake head was made using Telemac2D. The Telemac system was designed to provide realistic simulations of hydrodynamic flows around and through structures for engineering purposes and the system produces results that compare well with physical models. For the purposes of this study a model consisting of a simple channel domain 300 m long and 100 m wide, with the SZB intake centred in the middle of the domain was created, as shown in Figure 5. Figure 6 shows a zoomed portion of the model domain, focussing on the SZB intake, based on designs provided by EDF. The resolution of the model domain varies between 2.5 m along the boundary down to 5 cm at its finest around the intake structure. As the model is 2D, the depth of the domain is 3 m representing the vertical slice of the water column that runs through the open aperture of the intake head. This is a reasonable assumption given the velocity caps on the intake head reducing the vertical drawdown of currents above and below the intake head. Given the scale of the node density, a k-ϵ turbulence model has been used in the model.

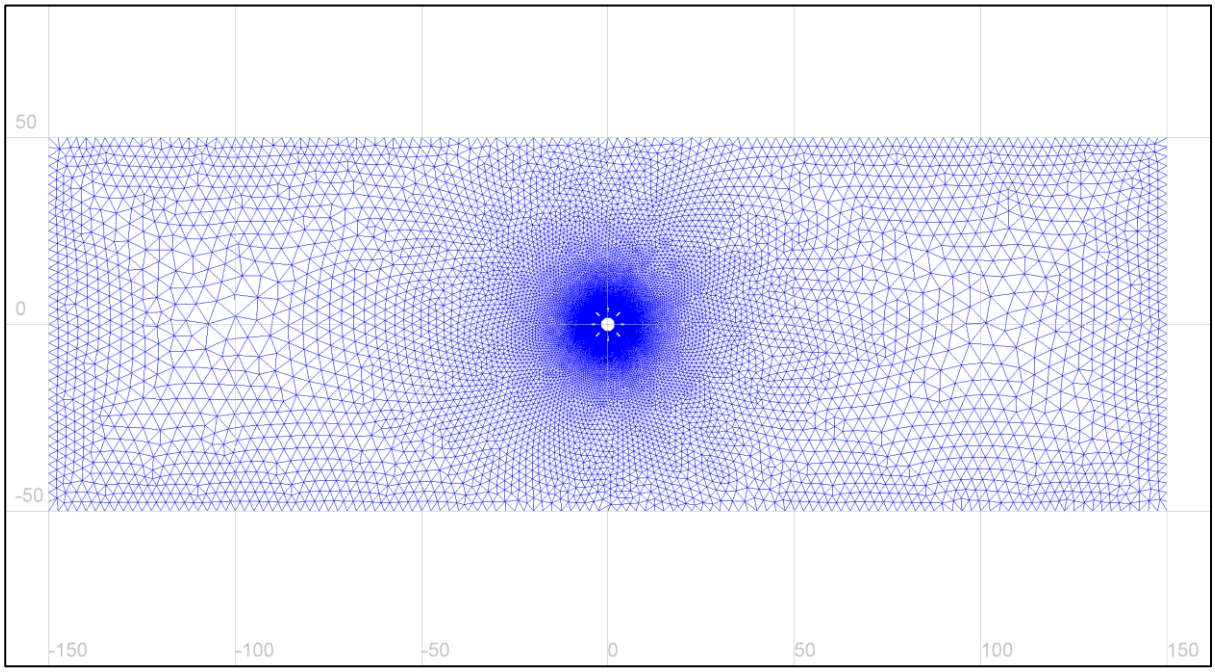

Figure 5: SZB intake – Telemac total model domain.

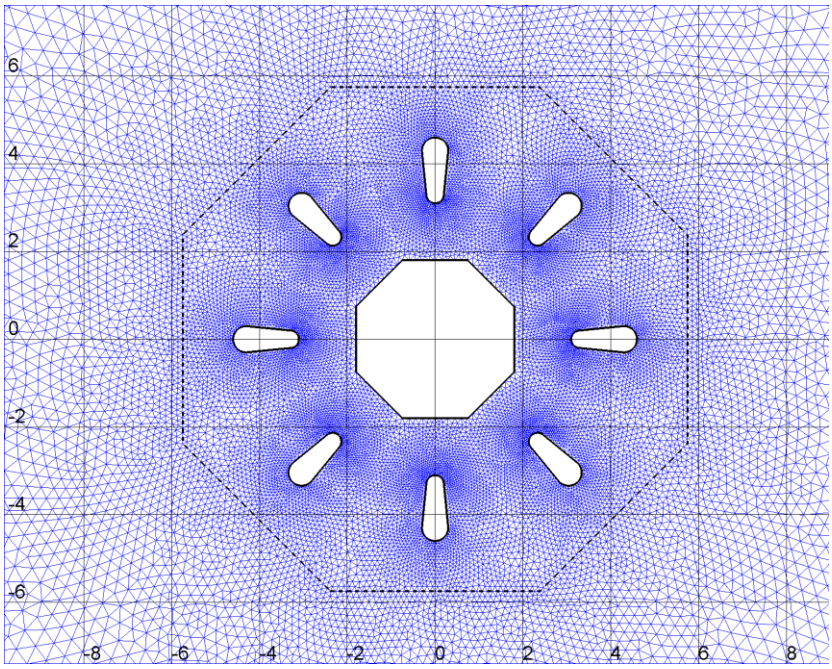

Figure 6: Zoomed portion of model mesh showing the SZB intake. The dashed black line represents the extent of the intake caps, but are not included in the model domain.

The head is omnidirectional and does not incorporate any special hydrodynamic features to shape the flow field and, therefore, the head was modelled at different tidal speeds in Telemac 2D. The flow fields were determined at tidal current speeds from 0m s^{-1} to 1m s^{-1} (at intervals of 0.1 m s^{-1}) to determine at what velocity

the head performance deviated from omnidirectional and to find out how the intercept area varied with current speed. As the model is a simple channel model of just the intake head and is running at steady state intervals, there is no way to calibrate or validate the model. This is akin to CFD modelling in that calibrated/validated models are not used and reliance is placed upon the use of industry standard algorithms (indeed validation is not normally possible except by physical models).

To further explore that issue, the head model was also subject to passive particle tracing. Passive particles were released 50 m upstream of the intake along the width of the channel, at a lateral spacing of 25 cm for the first 25 m centred on the origin, then increasing to every 50 cm for a further 15 m and then increasing to 1 m thereafter. An indicative plot of the particle release is shown in Figure 7 and is not representative of a particular flow speed.

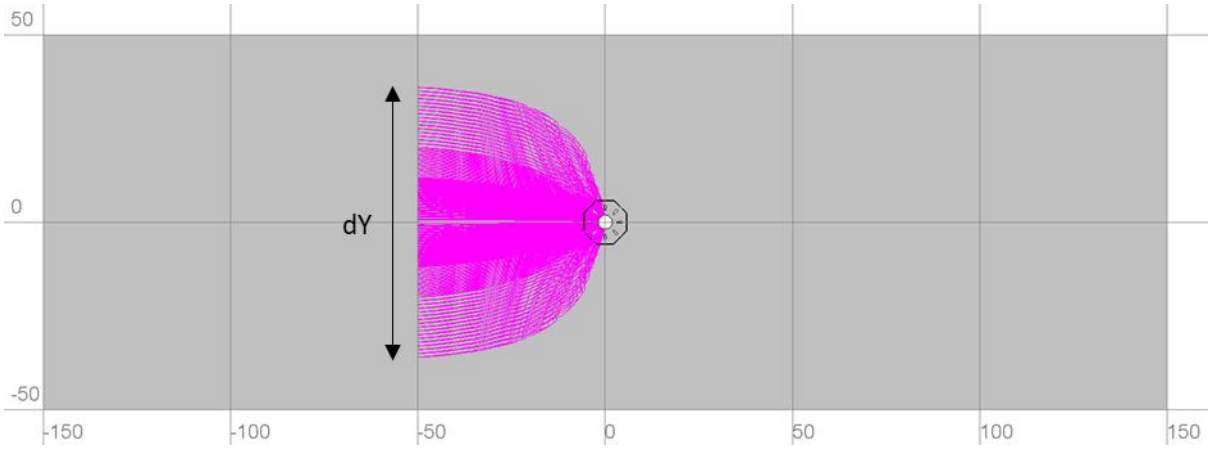

Figure 7: Model domain and extent of particles released 50 m from SZB intake. Tidal flows enter model from left hand side and exit right hand side, with SZB intake centred at middle of domain, abstracting at a flow of 25.75 $m^3 s^{-1}$.

The head was found to be fully omnidirectional at tidal currents of up to 0.1 m s^{-1}, i.e. the intake velocity at each of the 8 intake faces was virtually identical (Figure 8). Figure 8 and Figure 9 show vector plots of the current, with the arrow's direction showing the current direction. The vector length varies and is proportional to the current speed, with larger arrows representing faster flow. The magnitude of current speed is shown by the colour of the arrow. The variation in arrow density is due to the model's unstructured mesh, with a higher node density around the intake structure.

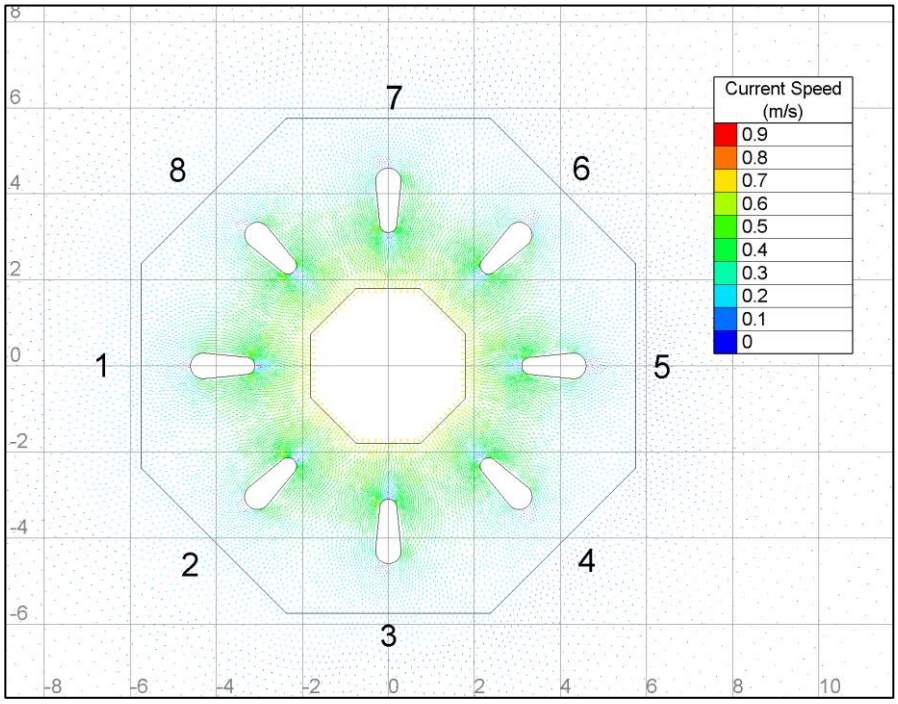

Figure 8: Flow pattern around each SZB intake at a tidal current of 0.1 m s^{-1}. Horizontal and vertical scales are metres.

As the tidal current increases after slack water, abstraction increases progressively on those entrances on the side of the head facing more directly into the incoming tidal flow. Figure 9 shows the modelled flow at a tidal current of 0.76 m s^{-1} and it can be seen that water is abstracted predominantly by faces 1, 2, 3, 7 and 8 with much reduced flow into faces 4 and 6 and negligible flow into face 5. Due to turbulence created around the head caused by the head shape, even at tidal currents of 0.76 m s^{-1} faces 3 and 7 abstract water. This was explored further by tracking passive particles released around the modelled head to predict the intercept zone of the head. At a tidal speed of 1 m s^{-1} (see Figure 10) the intercept width was only slightly greater than the physical width of the head (12 m versus the physical width of 11.5 m) which is as expected. At 0.5 m s^{-1} the modelled intercept width increased to 16.5 m (see Figure 11) and to 40 m at 0.2 m s^{-1} (see Figure 12).

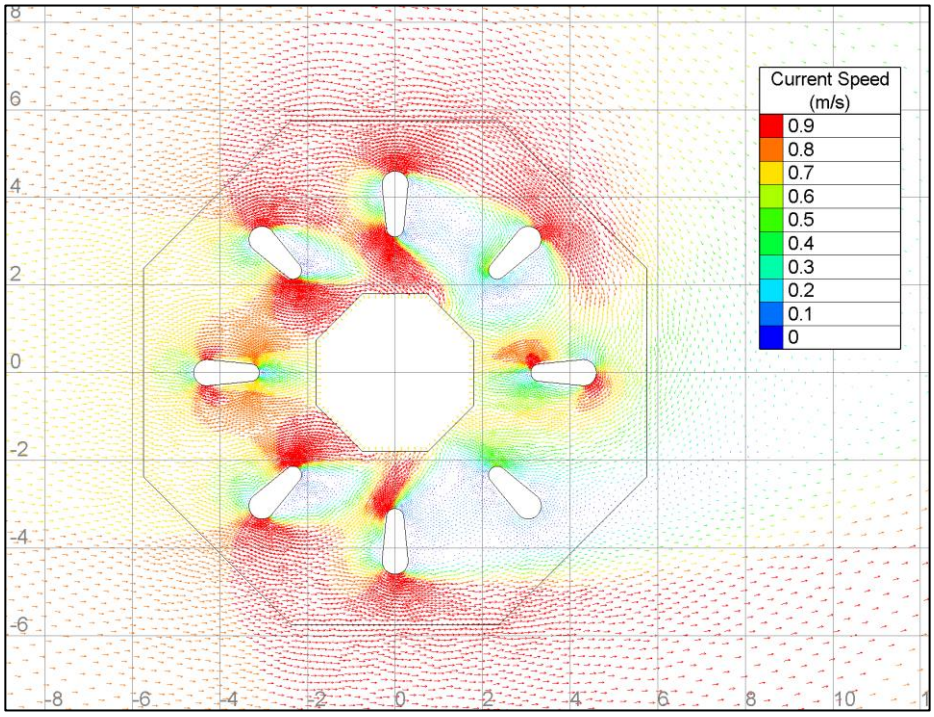

Figure 9: Flow pattern around each SZB intake at near peak tidal flow (0.76 m s^{-1}). Tidal direction is at 90° to face 1. Horizontal and vertical scales are metres.

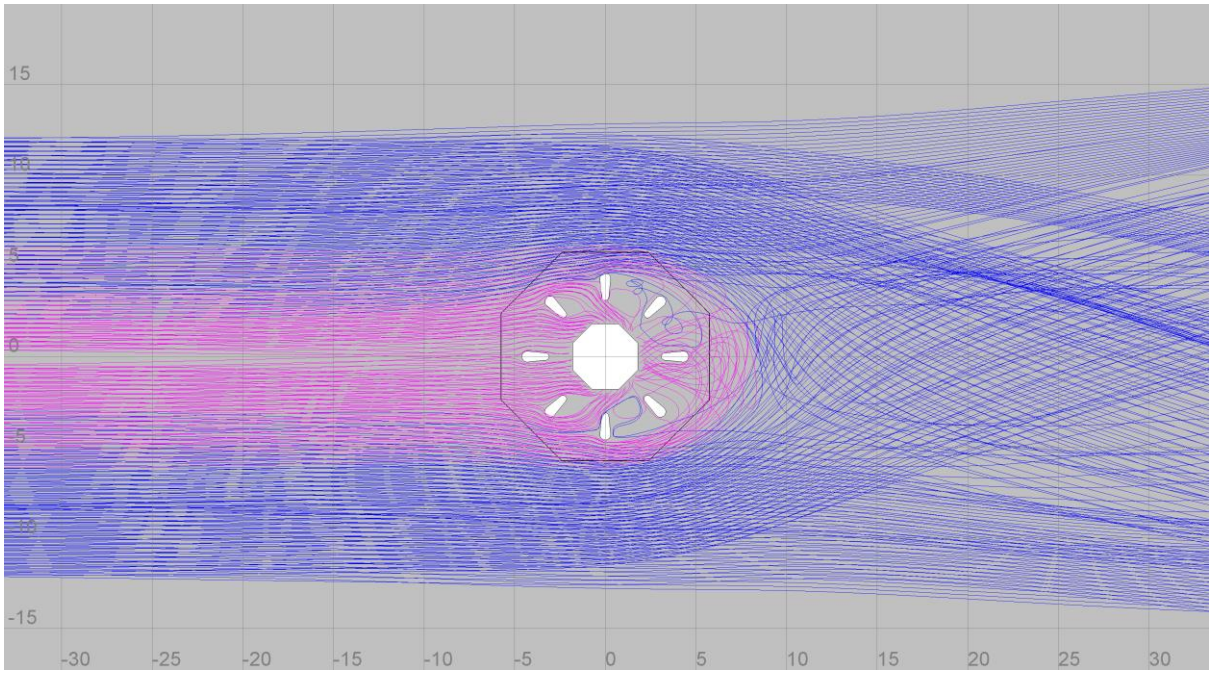

Figure 10: Particle tracks around SZB intake head, extracting at 25.75 $m^3 s^{-1}$, with 1.0 m s^{-1} input flow conditions. Pink lines represent the particles abstracted by the intake.

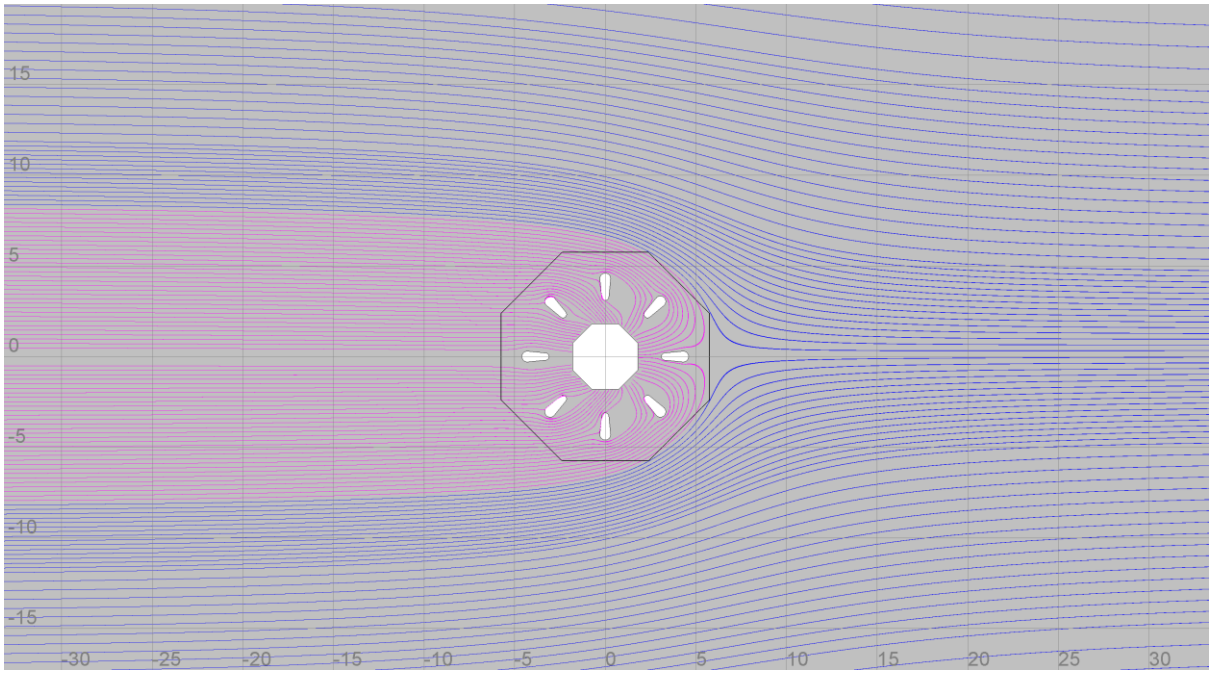

Figure 11: Particle tracks around SZB intake head, extracting at 25.75 $m^3 s^{-1}$, with 0.5 m s^{-1} input flow conditions. Pink lines represent the particles abstracted by the intake.

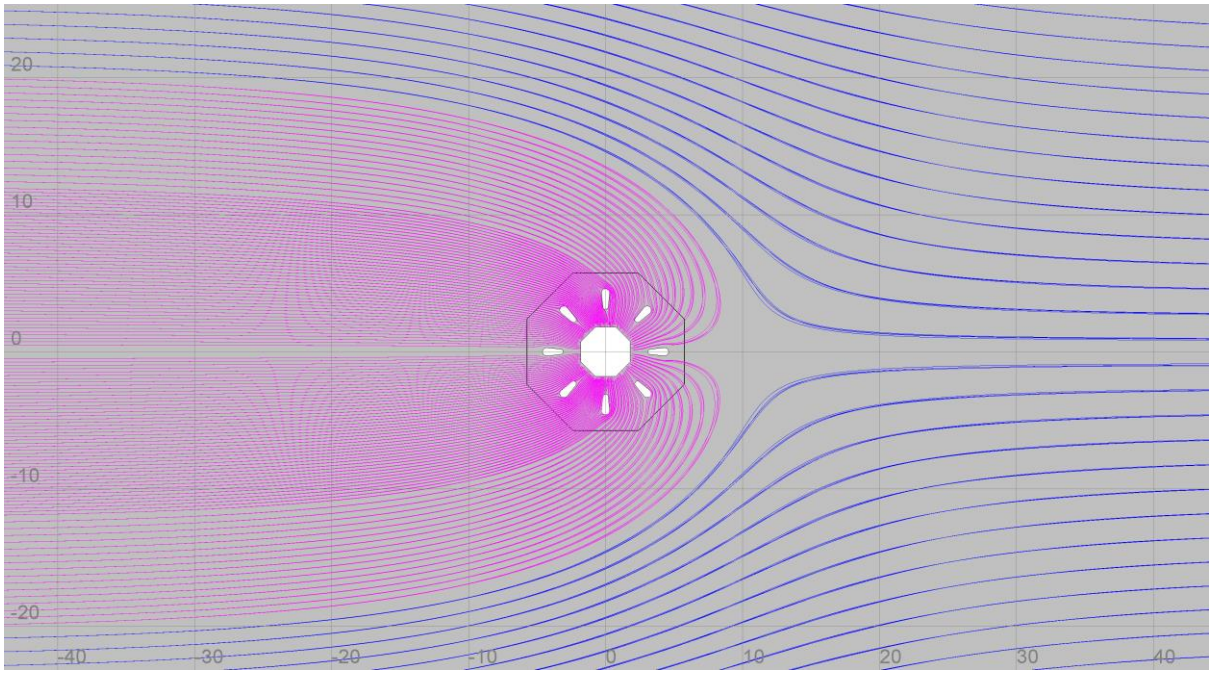

Figure 12: Particle tracks around SZB intake head, extracting at 25.75 $m^3 s^{-1}$, with 0.2 m s^{-1} input flow conditions. Pink lines represent the particles abstracted by the intake.

Due to the use of a 2D model, these are approximations to reality in that they do not take into account changes in abstraction from outside of the height of the intake surface, however, due to the use of the velocity cap, the predicted intercept zones are expected to be reasonable at mid to high current speeds but overestimated at tidal speeds near to slack water. The SZB intercept area for this report was, therefore, calculated from particle tracking (abstract width × height of the intake surface) for tidal velocities greater than 0.3 m s^{-1} but set at the physical area of the intake surface for tidal velocities less than or equal to 0.3 m s^{-1} (Figure 13). The abstraction width of the particle tracking is the width Δy shown in Figure 7.

It should be noted in Figure 13 that the area of interception, as calculated by particle tracking, decreases with increasing tidal flow but with a small increase above 0.7 m s^{-1} before decreasing again. This is caused by eddy shedding off the internal support structures with flows above 0.7 m s^{-1}, initially increasing the width of influence over particles travelling past the structure. Thereafter, with increasing strength of the tidal currents, the impact of the eddy shedding is reduced.

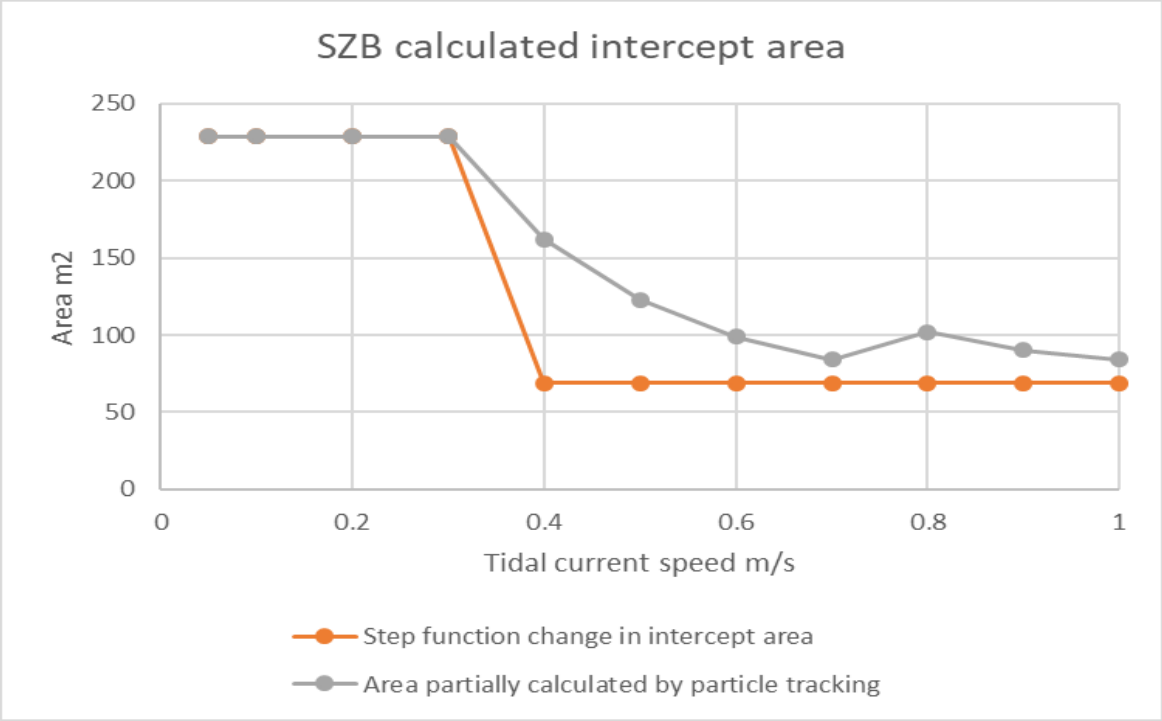

Figure 13: Options for the calculation of the intercept area of the SZB intake heads; a step change is physically unrealistic.

Figure 14 shows the modelled histogram of tidal current speed at the Sizewell B intakes from the validated Sizewell GETM model at 2.5 m above the sea bed.

The Sizewell C intake area calculations use ADCP data whereas the SZB intake area has been calculated with GETM model data. This then provokes the question whether the continued use of model data leads to an underestimate in the SZB calculated intercept area. Comparison of the SZC model and ADCP data at the same location does indeed show that the velocity histograms are different with the ADCP data showing a higher percentage of velocities in the range 0.1 to 0.5 m/s. However, if the same pattern is assumed at SZB, sensitivity tests show that this change only results in a 1% underestimate in the SZB intercept area because there is no directional component in the SZB analysis (due to the omnidirectional heads at SZB). This small error has been ignored, thereby slightly overestimating the calculated ratio of the SZC/SZB intercept area which is conservative.

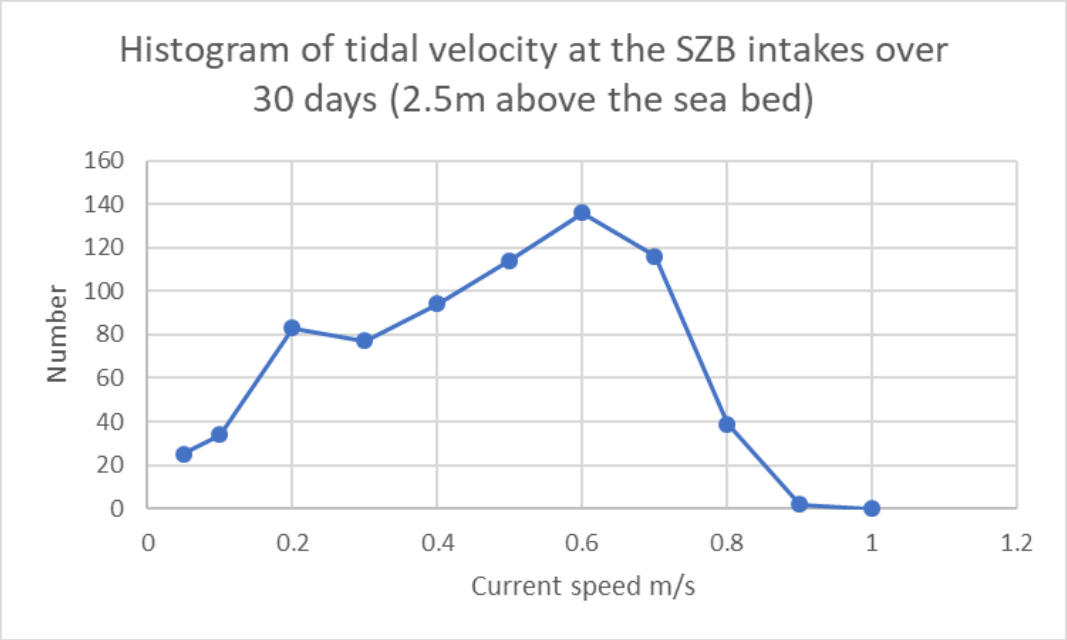

Figure 14: Tidal velocity histogram at the SZB intakes.

4.3 Alternative approaches to modelling the SZB intercept area

In their response to SPP099 v4, the Environment Agency have commented that the methodology used for calculating the intercept areas of the SZC LVSE intakes is different from that used for the SZB intakes and that this creates uncertainty.

In part the difference is a function of the different head geometries and the geometric approach devised for the calculation of the LVSE head intercept area simply does not apply for the omnidirectional SZB heads. In practice the SZB calculation is founded upon geometry, in that the two end points i.e. the areas at slack water and peak tidal velocity are based upon geometric calculations. The issue is how to calculate the intercept area in the region between slack water and peak tidal velocity. In SPP099 v4 we undertook particle tracking on a 2D model of the SZB head to determine how far away from the intake surface had to be to avoid abstraction.

A purely geometric approach cannot realistically be adopted for the SZB heads due to their omnidirectional character. As an alternative the possibility of constructing a particle tracking model of the LVSE heads has been considered. The existing Telemac 2D model would not be suitable as the LVSE head has a complex 3D shape specifically designed to streamline the local hydrodynamics that would not be reproduceable in 2D. For example, the nose pieces are critical to the performance of the LVSE head but in a 2D model they would have no effect and the head would apparently have a solid boundary perpendicular to the tidal flow which would create large eddies that do not exist in practice. A 3D model of the head would get around this problem but TELEMAC 3D cannot create a vertical mesh of sufficient complexity to cope with the complex vertical shape of the LVSE heads. The LVSE design in the vertical plane is critical to its performance and so must be reproduced in any modelling based approach.

An ANSYS Computational Fluid Dynamics (CFD) model already exists of the LVSE head and this would seem a much more promising solution. Discussions with the model developer have, however, ruled this option out as the software cannot undertake the required particle tracking study. In principle, a CFD approach is the way to proceed but our investigations show that this would require starting again with a brand-new model using

state of the art software in a novel manner. We have explored the practicality of this with an expert CFD modeller and have determined that the resources and timescale for such a major project are both disproportionate and infeasible given the Sizewell C DCO timetable. There is no commercial (or research) off-the-shelf solution to this problem and any practical proposal would require new model capabilities to be coded and integrated into public domain software before any results could be obtained with no guarantee of success. It has therefore been decided that a modelling approach is not feasible at this time.

Returning to basics, the existing SZB modelling is only trying to calculate the head performance between slack water and peak tidal velocity. On reflection the use of passive particle tracking, whilst appropriate for drifting organisms is unlikely to be correct for fish that will be swim with the tidal flow. It would be possible to build swimming speed into the particle tracking model but there is a simpler solution. From the existing modelling the variation of the SZB intercept area with tidal velocity is known; as the tidal velocity increases the intercept area reduces. The SZB intercept area for a fish swimming at say 0.1 m s^{-1} is equivalent to the intercept area at any tidal velocity + 0.1 m s^{-1}. The scientific literature contains many examples of flume experiments whose aim was to determine the maximum swimming speed of specific fish species under different environmental conditions. These studies are not helpful as fish swimming with the tide will normally do so in manner that consumes the least energy whilst maintaining attitude control. Experiments on fish in their natural habitat are difficult to do perform and usually involve tracking of tagged fish using sonar systems. For example, a series of experiments performed by Cefas scientists using high resolution scanning sonar and acoustic tags indicate that the experimental animals swam at typically 0.6 body lengths s^{-1} for plaice using selective tidal stream transport (Buckley & Arnold, 2001) and 0.3-0.9 body lengths s^{-1} for cod (Arnold *et al.,* 1994). An estimated fish swimming speed of 0.6 body lengths s^{-1} therefore seems to be a good starting point.

The mean length of the four most abundant species impinged at Sizewell B from impingement records are sprat 10.7 cm, herring 22 cm, whiting 18.1 cm, bass 20.9 cm with calculated swimming speeds of 0.064, 0.13, 0.11 and 0.125 m s^{-1} respectively at 0.6 body lengths s^{-1}. In order to avoid having a different threshold for each species in the LVSE intercept area calculation, a precautionary swimming speed of 0.2 m s^{-1} has been adopted.

5 Results

The following results are from the provided supplementary spreadsheets (Appendix A).

The calculated intercept areas of the SZC intakes are shown in Table 2.

Table 2: Calculated intercept area of the 4 SZC LVSE intakes (assuming that the intakes were all at locations I3b or I4b).

Assumed slack water threshold m s^{-1}	Intake I3b (northern) intercept area m^2	Intake I4b (southern) intercept area m^2
0.1	33.19	33.61
0.2	41.61	43.04
0.3	50.23	53.3

Table 3 shows the calculated intercept area of the SZB intakes calculated using passive particle tracking.

Table 3: Calculated intercept area of the SZB intakes over a 30 day tidal cycle.

Assumed slack water threshold m s^{-1}	SZB intakes intercept area m^2
0.1	118.4
0.2	118.4
0.3	123.5

Notes

1. The calculated area does not change with an assumed slack water threshold of 0.1 m s^{-1} as the physical area of the intake surfaces is used at that current speed.
2. The SZB areas are slightly larger than reported in SPP099 v2 because the bin velocities in the analysis of the tidal currents at SZB were set at maximum rather than the correct mid bin velocities.

Model and measurement data show that flow into the SZB head deviates significantly from omnidirectional after the tidal velocity increases past 0.1 m s^{-1}. The use of a slack threshold of 0.2 m s^{-1} is therefore precautionary. By extending the definition of slack water to 0.3 m s^{-1} the duration of 'slack' increases beyond one hour and since the calculations of SZB intercept area do not take account of this extended duration, the intercept area calculations at 0.3 m s^{-1} shown in Table 3 are underestimates, possibly large underestimates.

5.1 Revised SZB intercept area

Table 4 shows the calculated SZB intercept area assuming that fish approach the intake in the tidal stream after slack water at a velocity of 0.2 m s^{-1}. The effect of applying fish swimming speed reduces the head intercept area at Sizewell B by 10%.

Table 4: Calculated intercept area of the SZB intakes over a 30 day tidal cycle assuming fish swim at 0.2 m s^{-1} after with the tidal flow after slack water.

Assumed slack water threshold m s^{-1}	SZB intakes intercept area m^2
0.1	106.77
0.2	106.77
0.3	111.57

5.2 Calculated SZC:SZB intercept area ratio based upon revised SZB estimated areas (assuming swimming fish)

Table 5 shows the ratio of the SZC to SZB intercept area at each of the slack water thresholds. The ratio differs slightly at the SZC northern and southern intake locations (I3b and I4b respectively) and so the mean result is also shown as there will be 2 intake heads on each tunnel alignment.

Table 5: Calculated SZC/SZB intercept area ratio (SZB area based upon swimming fish).

Slack water threshold m s^{-1}	Northern	Southern	Mean ratio
0.1	0.311	0.315	0.313
0.2	0.390	0.403	0.396
0.3	0.434	0.461	0.447

5.3 Sensitivity analyses

The LVSE intakes will be aligned in the field by the use of ADCP survey data. Such surveys can determine the tidal axis to a directional accuracy in the range ±1 to ± 2 degrees dependent upon whether the instrument is individually calibrated or the manufacturer's worst case calibration is used.

EDF Energy's construction constractors have confirmed that the intake heads can be placed on the seabed to an accuracy of ± 1 degree.

For sensitivity tests it has been assumed that the ADCP will not be individually calibrated and that the instrument will produce normally distributed errors with one standard deviation of 1 degree. Head placement errors will also be normally distributed with one standard deviation of 0.5 degrees. Simulating the combined error from the two independent error sources over 10,000 trials gives 5th and 95th percentile errors of ± 1.85 degrees.

Table 6 shows the calculated intercept area for the 4 SZC intakes for up to ±3 degrees misalignment around the optimum head alignment directions. The cells in green provide the mean, upper and lower confidence limits.

Table 6: Calculated intercept areas (m^2) assuming that all of the SZ LVSE intakes were either at the northern or southern intake locations with a realistic slack velocity threshold of 0.2 m s^{-1}. The cells in green provide the mean (0°), and 5th percentile and 95th percentile head misalignment values.

SZC intake	-3°	-2°	-1.85°	0°	+1.85°	+2°	+3°
Northern	45.27	43.39	43.20	41.61	42.25	42.35	43.66
Southern	46.77	44.89	44.70	43.04	43.80	43.86	45.28

Table 7 shows the ratio of the SZC to SZB intercept areas calculated from Table 6 and Table 3. The cells in green provide the mean (0°), and 5th percentile and 95th percentile head misalignment values.

Table 7: Calculated sensitivity of the SZC/SZB intercept area ratio for a slack threshold =0.2 m s^{-1}.

SZC intake	-3°	-2°	-1.85°	0°	+1.85°	+2°	+3°
Northern	0.424	0.406	0.405	0.390	0.396	0.397	0.409
Southern	0.438	0.420	0.419	0.403	0.410	0.411	0.424
Mean ratio	**0.431**	**0.413**	**0.412**	**0.396**	**0.403**	**0.404**	**0.417**

The mean ratio of 0.396 is 10.9% larger than that calculated in SPP099 v4 (at 0.357) due to the revised SZB intercept areas in Table 4.

The calculations have also been repeated for completeness at an assumed slack water threshold of 0.3 m s^{-1}. As stated in Section 4.1, this threshold is considered unrealistically high based upon model and measurement data at Sizewell. The cells in orange provide the calculated mean (0°), and 5th percentile and 95th percentile head misalignment values s without compensation for the length of slack tide at this threshold. This will mean that the estimated SZC/SZB intercept ratio is likely to be overestimated.

Table 8: Calculated intercept areas (m^2) assuming that all of the SZ LVSE intakes were either at the northern or southern intake locations with an unrealistic slack velocity threshold of 0.3 m s^{-1}.

SZC intake	-3°	-2°	-1.85°	0°	+1.85°	+2°	+3°
Northern	53.85	52.00	51.81	50.23	50.84	50.94	52.21
Southern	57.00	55.15	54.97	53.30	53.95	54.04	55.40

Table 9: Calculated sensitivity of the SZC/SZB intercept area ratio assuming a slack threshold of 0.3 m s^{-1}.

SZC intake	-3°	-2°	-1.85°	0°	+1.85°	+2°	+3°
Northern	0.465	0.449	0.448	0.434	0.439	0.440	0.451
Southern	0.493	0.477	0.475	0.461	0.466	0.467	0.479
Mean ratio	**0.479**	**0.463**	**0.461**	**0.447**	**0.453**	**0.454**	**0.465**

6 Conclusions

6.1 LVSE intake velocities

Computational Fluid Dynamic (CFD) modelling of the proposed Sizewell C LVSE intake heads shows that:

i) The hydrodynamic influence of the LVSE intakes is only felt over a short distance with inward velocities falling to 0.1 m s^{-1} over a distance of approximately 1.5 to 2.5 m from the intake surfaces and to 0.05 m s^{-1} at a distance of approximately 3 m from the intake surfaces over virtually the full tidal cycle;

ii) The range from the intake surface for the inward velocity to fall to the Environment Agency (2005, 2010) criterion of 0.3 m s^{-1} is 0.0 to 0.68 m dependent upon the tidal current speed. Over the tidal cycle the median distance to an inward velocity of 0.3 m s^{-1} is 0.38 m based upon the distribution of tidal currents at the SZC intakes.

6.2 Ratio of SZC to SZB intake intercept areas

Using the methodology proposed by Environment Agency (2019) the intercept area of the SZC LVSE intakes have been calculated but with ADCP data rather than model data.

This geometric methodology used to calculate the intercept area of the LVSE heads cannot be used with the omnidirectional SZB heads and so instead a particle tracking model was developed for SPP099 v3 that assuming drifting particles. On reflection and after consultation with the Environment Agency, this approach is considered to generate too large an intercept area for SZB as swimming fish would experience a lower intercept area than drifting organisms. Using estimates of fish swimming speeds in tidal flow from measurements made at sea, the SZB intercept area model has been recalculated in this report based upon the assumption that fish will swim up to 0.2 m s^{-1} in the tidal flow.

The ratio of the intercept cross-sectional areas of the proposed four SZC LVSE intakes compared with the two omnidirectional SZB intakes is 0.396 as a best estimate with values of 0.412 and 0.403 at the 5th percentile and 95th percentile head misalignment values respectively at a slack tide threshold of 0.2 m s^{-1}. This means that SZC fitted with LVSE intakes is expected to abstract 39.6% of the fish and crustacea per cumec that SZB does. This ratio is appropriate to impingement assessments rather than entrainment assessments; the notable exception being for glass eels that are entrained because of their long, thin morphology.

This ratio is slightly larger than that estimated in BEEMS Technical Report TR406 v7 (at 0.357) but confidence in the result is greater because it:

a) has now been calculated fully in line with the methodology in Environment Agency (2019);

b) it has been subject to an extended sensitivity analysis that incorporates measured as opposed to only model data;

c) benefits from much more realistic modelling of the SZB intake heads; in particular how their intercept area varies during the tidal cycle and with swimming fish

Whilst the adjustment to the ratio will influence impingement predictions, such a small change has no bearing on the overall effect conclusions.

6.3 Alignment of the LVSE intakes at Sizewell.

The SZC LVSE intakes will be aligned in the field by the use of ADCP survey data. Such surveys can determine the tidal axis to a directional accuracy in the range ±1 to ± 2 degrees dependent upon whether the instrument is individually calibrated or the manufacturer's worst case calibration is used. This measurement accuracy, together with a realistic estimate of the accuracy that the heads can be placed on the seabed (± 1 degree) has been built into the sensitivity analyses presented in this report.

References

G. P. Arnold, M. Greer Walker, L. S. Emerson, B. H. Holford. 1994. Movements of cod (*Gadus morhua* L.) in relation to the tidal streams in the southern North Sea. ICES Journal of Marine Science. 51 (2), 207–232,

BEEMS Technical Report TR302 Ed. 3. Sizewell Thermal Plume Modelling: GETM Stage 3 results with the preferred SZC cooling water configuration. Cefas, Lowestoft

BEEMS Technical Report TR406 Ed 2 v7. Sizewell C – Impingement predictions based upon specific cooling water system design. Cefas, Lowestoft

Buckley A., Arnold G. 2001. Orientation and Swimming Speed of Plaice Migrating by Selective Tidal Stream Transport. In: Sibert J.R., Nielsen J.L. (eds) Electronic Tagging and Tracking in Marine Fisheries. Reviews: Methods and Technologies in Fish Biology and Fisheries, vol 1. Springer, Dordrecht.

Environment Agency. 2010. Cooling Water Options for the New Generation of Nuclear Power Stations in the UK SC070015/SR3. Environment Agency, Bristol UK.

Environment Agency. 2019. Low Velocity Side Entry Intake Design; effect of intake intercept area. Technical Brief: TB006 draft 3.

HRW. 2013. Numerical & Physical Modelling of the Hinkley Point C Intake & Outfall Structures. Task 1 – Physical Modelling of Flows at Intake Heads (TN-10). HR Wallingford Ltd. May 2013.

Turnpenny, A.W.H., Taylor, C.J.L. 2000. An assessment of the effect of the Sizewell power stations on fish populations. Hydroecol. Appl 12, 87–134.

Appendix A

Table A1: Spreadsheets showing detailed calculations provided in support of this Scientific Position Paper.

Filename	Contents
SZC intake velocities awac 11 April 2021.xlsx SZC intake velocities awac 11 A|	Intercept area calculations SZC (using ADCP data)
SZB intake velocities 11 April 2021.xlsx SZB_intake_velocities_11 April 2021.xlsx	Intercept area calculations SZB (using GETM model)
LVSE Supplemental calculations 5May2020.xlsx lvse supplemental calculations 5May20	LVSE intake velocities (CFD results)