HINKLEY POINT C PERMIT VARIATION

EPR/HP3228XT/V004

Technical Brief: TB006

Low Velocity Side Entry Intake Design; effect of intake intercept area.

Operations Catchment Services, Environment Agency.

2020 (DRAFT-04)

EXECUTIVE SUMMARY

This Technical Brief reviews aspects of the fish impingement estimates in section 5 of TR456 Ed2 (2019), which scales the observed impingement from Hinkley Point B (HPB) to predict the likely impingement at Hinkley Point C (HPC).

This note:

- focuses on the intake intercept area ratio applied within TR456 Ed2 due to the design of the Low Velocity Side Entry (LVSE) intake design, and
- describes an alternative approach that allows for aspects not included in TR456 Ed2.

INTRODUCTION

TR456 Ed2 estimates impingement for HPC by scaling observed values from HPB. The approach uses several assumptions, which are not clearly described, and introduces uncertainty. This note discusses the intake area scaling, which has 3 main components:

- the effective area of the HPB intake
- the effective area of the HPC intake, which is related to
- the flow patterns around the intake (HRW, 2013).

HPC intake flow patterns

HR Wallingford (2013) describes a physical model study of the flow patterns into and around the intake structure. It focuses on hydraulic design for the intake head and, as such, it does not include any direct comments about impingement. Neither does it consider any possible misalignment between the intake and the tidal axis, or effects of tidal turbulence. Although appropriate for the stated purpose, this simplification limits this particular report’s usefulness for informing the impingement assessment.

The key finding in this report is that **the intake disturbs the ambient flow only within 2m of the intake face** – and dissipates much more quickly under strong currents. This value (2m) has been carried forward into the TR456 Ed2 impingement analysis.

Impingement assessment (report TR456 Ed2)

TR456 Ed2 estimates impingement for HPC by scaling observed values from HPB. It introduces several assumptions, which are not clearly described, and introduces uncertainty.

The underlying assumption is that any fish occupying streamlines that directly cross the intake areas will be impinged, and no others. This represents the fish as passive particles in the flow – swimming is neglected. The effective area is the interaction cross-section which the intake presents to the water flow; that is, the geometric area projected onto the tidal current direction. We have no validation for this assumption, though we accept that behavioural considerations are difficult to quantify.

HPB intake cross-sectional area

It is not easy to calculate the effective area of the HPB intake, because the intake is not fully submerged at all states of the tide. TR456 Ed2 derived a tidal-average height, and multiplied by the cross-section (projected) width. While this approach seems reasonable, we derived a different value for this width. We cannot verify the height.

TR456 Ed2 contains a text description of the HPB intake configuration, in Appendix J, and an indicative sketch at Figure 2. Our interpretation of this layout is shown in the sketch below (Figure 1):

- the intake axis runs at 350° - angle $\alpha = 10°$
- the ebb tide direction is 080° - angle $\beta = 10°$
- because of equilateral triangles (regular hexagon), each angle marked $\theta = 60°$.

The target width (cross-section across the ebb tide) is $= R \sin \gamma$, where γ is the angle between the HPB intake face and the ebb tide direction. With $\theta = 60°, \gamma = 30° + \alpha - \beta$, and with $\alpha = \beta = 10°$, $\gamma = 30°$; thus $x = R \sin 30° = 0.5\, R$.

(This contrasts with the statement in TR456 Ed2 that $x = R \sin(\ 60° - \alpha - \beta\ ) = R \sin 40° = 0.64\, R$.)

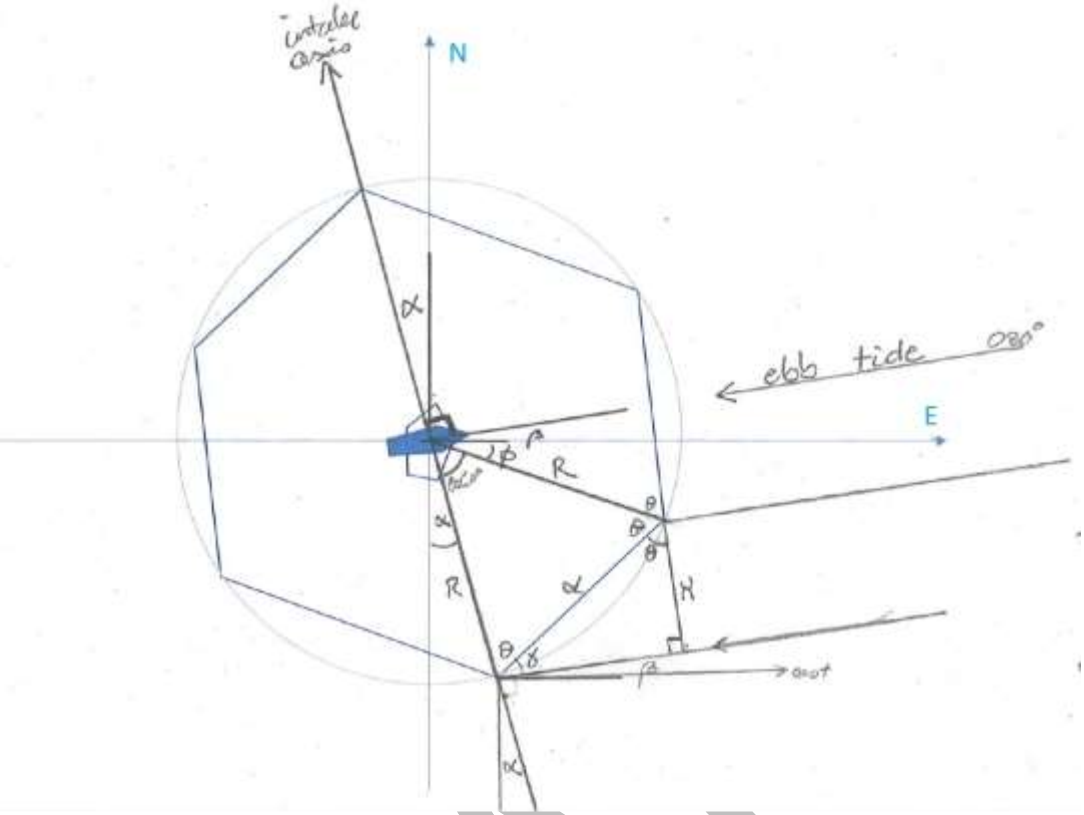

Figure 1. Interpretation of HPB intake configuration.

HPC intake cross-sectional area

TR456 Ed2 calculates the HPC area as the 2m width (the horizontal distance from the intake head to the undisturbed flow from the HR Wallingford report) multiplied by the intake height and multiplied again by 2 for the potential entry from either side of the intake head. This estimate assumes the flow is perfectly aligned with the intake axis, therefore perfectly rectilinear, and free from turbulence. These assumptions do not hold true in a real tidal environment, where flow directions will vary in time and turbulence will be present.

It is not clear that this approximation makes appropriate allowance for the length of the intake. Although the HR Wallingford 2013 physical model shows streamlines entering the intake all along its length, even with perfect alignment, the representation in TR456 Ed2 assumes that no fish will approach the intake along its length, unless they pass through the 2m plane at the upstream end. This may be appropriate for fish that simply drift with the tide, but not for free swimming fish. This approach does not allow for other factors of difference between the HPC and HPB intake designs, such as the fully-symmetric drawing behaviour at low current speeds.

A more detailed calculation would allow for varying alignment between structure and tidal flow, slack water, turbulence, and the intake length. We propose a slightly more sophisticated estimate that allows for varying alignment and slack water conditions.

We expect the scale factor to be greater than 1, because it accounts for a dynamic interaction between the tidal current and the intake faces. This effect is distinct from the increased intake volume, which is accounted for separately.

Because the physical area of the HPC intakes is so much larger than HPB, the scale factor will be more than 1 under a flowing tide, except for flows that are very closely aligned to the intake axis. Even a small misalignment gives a relatively large effective area, and the model data shows that the perfectly aligned condition is rare. (In any case, we would not expect it to be achieved simultaneously for 4 large intake structures, distributed in space, as there will be instantaneous variations in the current patterns.)

We estimated the effective area of the HPC intake, using seabed tidal current data provided by the applicant from the GETM model. The model provided 30 days – two full spring-neap tidal cycles – from which we calculated a current rose (Figure 2). This grouped the velocity data into bins of speed and direction, to simplify the subsequent calculations. Using the current rose, we established the approach velocity (speed and direction) at different times, and an intersection projected area. Slack water conditions were treated differently, as a special case (see below). We averaged the intake volume over the full model period and derived an average intersection area.

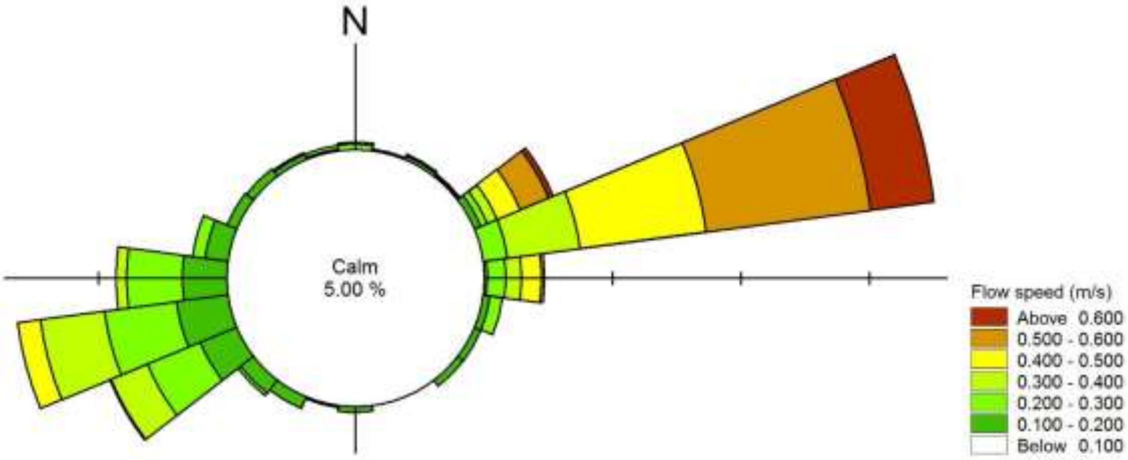

Figure 2. Seabed current rose at HPC intake location.

At slack water, water is drawn evenly from all faces at a low velocity (nominally 0.3 m/s). This is fully represented by the increased volume flow (and included in the linear scaling factor); for this reason we consider the area scale factor in this condition to be 1. Some fish would be able to swim away from the intake at these speeds, but with no warning system to cue ‘escape’ behaviour, this advantage may not be realised. Therefore 1 is the lowest reasonable value. The threshold speed for considering the tide to be ‘slack’ will be subjected to uncertainty analysis, as the calculation is sensitive to this parameter.

We have not made any attempt to include turbulence effects explicitly because such analysis would require a dedicated hydrodynamic model, which we cannot provide within the scope of this review. However, we anticipate that the varying approach direction will have a more important effect on the impingement estimate.

RESULTS

Using the approach described above, we calculated the effective areas and scale factor ranges shown in Table 1.

Here, the scale factor is the ratio of HPC/HPB area, using the Environment Agency (EA) value for HPB area as described above. The range of HPC areas was obtained by adjusting the velocity threshold for the ‘slack’ water condition.

Table 1. Effective areas of HPB & HPC intakes and corresponding scaling factor.

	TR456 Ed2	**Environment Agency**		
		lower	**middle**	**upper**
HPB	49.5 m^2	-	38.7 m^2	-
HPC	32 m^2	48 m^2	54 m^2	62 m^2
scale factor (ref EA)	0.827	1.240	1.394	1.591

This scale factor has been used in our impingement and biomass calculations (see EA, 2019) using the ‘middle’ estimate, 1.394. It is also included in the uncertainty analysis, to quantify the sensitivity to this parameter.

Consideration of fish behaviour for the approach

The approach adopted within this paper is a purely geometric comparison of the effective intake draw zone areas presented to fish moving with the tidal flow, between HPB and HPC. At slack water, the ratio used is 1 because the increased intake draw zone area presented to fish at HPC compared to HPB is fully accounted for by the increase in volume between HPB and HPC calculated in the previous step of the assessment. During the ebb and flood tide, the draw zone areas presented to fish moving with the tide are generally larger at HPC than at HPB. This means that, as well as more water being abstracted between HPB and HPC, as accounted for in the previous step of the assessment, the number of fish being presented to the intakes and draw zone, as they move with the tidal flow, will increase.

The approach does not account for the behaviour of fish within the tidal flow or at slack water.

At slack water, the tidal flow will not be moving fish towards the intake, and therefore to enter the intake draw zone fish will need to actively swim into it. It is uncertain whether more fish will actively swim into the intake draw zone at HPB or at HPC. More fish could swim in at HPC because slower intake velocities will reduce avoidance of high velocities, or fewer fish could swim in because avoidance behaviours are likely to be more successful if attempted.

During the ebb or flood tide, the tidal flow will move more fish into the intake draw zone at HPC than at HPB simply because the HPC intake area is much bigger. (Even though the draw zone is confined close to the intake face, thanks to the low velocities.) Again, it is uncertain at present whether the behaviours of fish at HPC, compared with HPB, will mitigate against this increase or worsen it.

Therefore, no allowance has been made for potential attraction or avoidance of the draw zone, at any stage of the tide, because of the limited evidence to quantify the effects.

LVSE Intake Head as Fish Impingement Mitigation

Environment Agency guidance (2005 and 2010) indicates that a combination of mitigation measures need to work together to provide fish protection at large direct-cooled power stations in estuarine and coastal waters. The LVSE intake heads working in combination with a behavioural cue, such as from an AFD, are needed to deflect the more fragile, hearing-specialist fish species who would not be likely to survive the journey through the fish recovery and return system. Appendix 1 presents a partial summary of previous comment and evidence, discussing the requirement for sensory cues to stimulate avoidance behaviour. For example, TR117, Turnpenny (2010): “the outcome would also depend on whether or not fish were able to detect and respond to the structure. At the high turbidities usually present at Hinkley Point, in the absence of visual cues, this would depend upon the creation of other suitable sensory cues … by other artificial stimuli such as from acoustic fish deterrents."

CONCLUSIONS

We have used a calculation based on the applicant's general method, but with some refinements to produce our estimate of the LVSE intake intercept area factor. The main component of this calculation is the cross-sectional area that the intake faces present to the tidal current. Because the intake faces are large (specifically to reduce the intake velocities) this area is also larger than with other intake designs. The calculation does not include any factors relating to fish behaviour, because we do not know to what extent fish may avoid the intake. We therefore conclude that impingement (partly driven by the ambient current flows) may be larger than for other intake designs (factor >1).

This conclusion may surprise a reader, given the EA's guidance in favour of LVSE designs. The reason for this is simple: an LVSE configuration gives fish a chance to swim away from the intake *if they wish to do so*. In the present case, there is no reason to assume that they will wish to avoid the intake, without a behavioural cue of some sort. This subject has been discussed at length in earlier stages of the HPC design, as summarised in Appendix 1. In the original design for HPC, the cue was provided by the acoustic fish deterrent; with its removal, it may be that the fish are ambivalent towards the intake, or unaware of its presence (in the dark and turbulent waters of the Severn Estuary) until they are well within the intake system, where escape will be impossible.

Table 1. Conclusion results

	Used in Applicant's assessment	**Used in Environment Agency's assessment**	
		Predicted	Uncertainty Range
Intake intercept area factor	0.646	1.394	1.24 – 1.591

REFERENCES

BEEMS (2019a) Revised Predictions of Impingement Effects at Hinkley Point C – 2018. Technical Report TR456 Edition 2 Revision 10. Cefas.

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Turnpenny, A. (2010). Assessment of Effects of CW Intake Velocity on Fish Entrapment Risk at Hinkley Point Edition 2. BEEMS Technical Report TR117 Edition 2.

Appendix 1. LVSE Intake Head as Fish Impingement Mitigation

Environment Agency guidance (2005 and 2010) indicates that large direct-cooled power stations in estuarine and coastal waters need a combination of mitigation measures that work together to provide fish protection. This guidance is based on and supported by a number of BEEMS (TR117, TR148 and TR197) and other technical reports (NNB (2016) and references below). The LVSE intake heads need to work in combination with a behavioural cue (such as from an AFD) are needed to deflect the more fragile, hearing-specialist fish species are not likely to survive the journey through the fish recovery and return system.

This section presents a summary of previous comments and evidence, discussing the requirement for sensory cues to stimulate avoidance behaviour. Please note the italics have been added to emphasise of some important points.

EA (2010) – Cooling Water Options:

- Page 5: "… the findings of our study indicate that direct cooling can be BAT for estuarine and coastal sites, provided that best practice in planning, design, mitigation and compensation are followed. The potential BAT-status of direct cooling has essentially been preserved owing to improved understanding of survivability of the entrainment process, and substantial developments in impingement mitigation techniques since the BREF was written."

EA (2005 - Turnpenny & O'Keefe) - Screening for Intake and Outfalls:

- Section 3.4.7.1: "Experience of UK sites where velocity caps are present has shown that fish entrainment remains a problem and velocity caps are therefore not in themselves a solution. *Other measures, including use of side-entry, of behavioural deterrents and onshore fish return systems need to be considered.*"
- Section 5.2: "The required criterion is that the fish approaching an intake should be able to swim fast enough and for long enough to ensure their escape via the bywash or any other route provided to return them to the main river flow. Whether this is achieved by using sustained (aerobic) or burst (anaerobic) swimming will depend on conditions: *burst swimming will usually require high motivation by the fish, e.g. a startle response that might be caused by a strong stimulus (e.g. electric shock, sound pulse or strobe light flash).*"

TR117 (Turnpenny):

- "These finding should not, in the absence of other measures, be taken to imply that these proportions of fish would in practice escape, as *the outcome would also depend on whether or not fish were able to detect and respond to the structure. At the high turbidities usually present at Hinkley Point, in the absence of visual cues, this would depend upon the creation of other suitable sensory cues.*"

TR197 (Cefas):

- "To minimise fish ingress and subsequent impingement on the station cooling water drum-screens, Hinkley C will have an Acoustic Fish Deterrent (AFD) system to allow fish to detect the intake in the turbid conditions present at Hinkley, and low velocity cooling water intakes designed to allow the larger fish to avoid entrapment by swimming away. These intakes in conjunction with an acoustic fish deterrent are designed to reduce losses due to impingement for fish that can respond to the sound cue eg hearing specialists such as herring, sprat and shad (BEEMS Technical Report TR148)."

TR148 (Cefas), Section 3.1:

- "Because of the usual high water turbidity at Hinkley Point and the consequent absence of visual clues, any mitigating effect of the low-velocity intake is only likely to be realised if it is combined with some form of artificial stimulus (e.g. an acoustic fish deterrent) to induce fish to swim away from the intake structure. Equally however, an acoustic fish deterrent is unlikely to be fully effective on its own if the intake velocity exceeds the swimming capabilities of the fish. For these reasons low-velocity intake and AFD need to be considered as a combined mitigation measure."

CW 1 report (EDF):

- 4.3.4 "intake flow rates should be slow (i.e. slower than the 'burst' swimming speed of fish) so that they can swim away from the intake, *provided they are able to detect it.*"
- 11.2.39 As described in the Development Consent Order (DCO), it is planned that Hinkley point C will be fitted with an Acoustic Fish Deterrent (AFD) System to provide a behavioural cue for fish to swim away from the intake head and thus avoid being entrapped in the first place. The AFD would be more effective for those fish species with good and moderate hearing such as sprat and herring – these species are delicate and not expected to survive impingement on the filtration screens anyway. The Acoustic Fish Deterrent (AFD) system is currently in the very early stages of design and will be discussed through a separate work stream and reported in a subsequent report to inform the discharge of DCO Requirement CW1 (when paragraph (2) is addressed).

Relevant statements from Section 5.1.9 Fish deterrent from Reference 16 to NNB GenCo report to discharge CW1 (para 1) - HPC intake and outfall heads ALARP and BAT review:

- It is clear that from an environmental point of view, preventing fish from entering the intake heads is preferable to reliance upon a Fish Recovery and Return system (FRR).

- The target intake velocity of 0.3 m/s was chosen in order to minimise the possibility for fish to be sucked into the intake heads as it is a speed that most fish can escape. However, *the use of a low intake velocity is only effective if fish can detect it and consequentially swim away from it*. Therefore it is generally recommended to use some form of fish deterrent such as an AFD or a Louvre screen.
- Based on these considerations it can be concluded that Louvre screens are not suitable for fish deterrence at the HPC intake heads. In the absence of a passive method of deterring fish, *it was decided that an Acoustic Fish Deterrent would be required*.
- If the [AFD] line were to fail, the intake heads would no longer be provided with a fish deterrent, and therefore would not meet the environmental requirements.
- At this stage of the intake head design, a final option for an Acoustic Fish Deterrent has not been chosen. However, *it has been acknowledged that such a system is required in order to meet the environmental requirements*, and a number of preliminary options have been identified.

Environment Agency (2012), Original Appropriate Assessment:

- "It is thought that in waters of high visibility, the sight of the intake structure along with the low velocity would significantly reduce the number of fish being impinged on the intake structure as fish would have a visual cue to avoid it. However, *since visibility is poor within the estuary, this would not be the case and therefore another type of deflection is required for the low velocity intake to be effective*."

Environment Agency (2018): Protection of biota from cooling water intakes at nuclear power stations: scoping study: Section 5 (Richard Horsfield)

- The Environment Agency (2010a) report indicated that, despite environmental challenges, direct seawater cooling can still be considered BAT as per the Integrated Pollution Prevention and Control Directive (Environment Agency 2003), 'provided that best practice in planning, design, mitigation and compensation are followed', which would include the use of behavioural fish deterrents as described in Environment Agency (2005) to minimise the risk of impingement of hearing-sensitive species that are not amenable to the FRR process. Such species notably include fragile pelagic species such as herring, sprat and shad, but many other less fragile species such as gadoids and bass can also benefit from deflection at the CWS intake point.

Environment Agency (2019): Nuclear power station cooling water: protecting biota (SC180004/R1):

- **Section 4.2.3:** "A factor that needs to be considered is that large structures on the sea bed are often attractive to fish. Intake structures have been shown to act as attractors (Helvey and Dorn 1981). The building of artificial reefs is a common practice to enhance fish communities around the world (Broughton 2012, Carr and Hixon 1997, Becker, Taylor and Lowry 2016)…. How the attraction of the structure interacts with the capture rate of fish is difficult to predict.”

- **Section 4.3.5:** Evidence review conclusions for approach/escape velocity: “Approach velocities influence the likelihood of a fish being able to escape an intake. Once a fish is in the body of water that will enter the intake, it can only avoid capture if it can swim to a safe area. The lower the intake approach velocity, the higher proportion of the fish that can escape. However, just because a fish is capable of escaping, does not mean that it will. Large fish with swimming abilities that mean they should escape capture are regularly caught on power station screens. How fish detect the objects such as intakes is still being studied. Factors examined have included the effect of light and dark on detection probability, the effect of vibrating a screen, the impact of intake velocity and the hydrodynamic signals caused by flow around structures.”

Consultation response ANON-AWF5-UY75-D to the proposed variation reiterates the position that

- “The use of an AFD in combination with a low velocity intake is intended to deflect the more fragile hearing-sensitive species that are unable to survive passage through the tunnels and forebay and water channels and handling by the CW screens. The more robust species such as eels and flatfish tend to have poor hearing but are very resistant to handling and survive well after return to the water body via the FRR.”

Swimming ability versus tidal currents in the Severn

The Severn Estuary has among the highest tidal ranges in the world with accompanying strong tidal flows and high turbidity. The CW1 P1 paper tests the escape velocities along the intake head at tidal flows up to 1.5ms^{-1}. Given the small size of the fish impinged at HPB, and at HPC, and the strong tidal flows, these small fish would not be able to maintain sustained swimming against the tidal streams. Even if they could, it would not be energetically efficient. So, the pelagic fish being impinged at HPB are most likely following the tidal streams through the estuary and being carried wherever they are taken.

Figure 3 (reproduced from CW1 P1) shows that at peak tidal flow, the escape velocity needed by fish to avoid entry to the intake head is generally above 0.4ms^{-1} along both sides of the intake head. The Environment Agency Best Practice Guide (2005) recommends that the velocity at intake screens be kept to at or below 0.3 ms^{-1} in order to allow fish to escape given a cue to do so. From EA (2005), “*swimming performance is strongly influenced by the species and the length of the fish and to a lesser extent by water temperature. The required criterion is that the fish approaching an intake should be able to swim fast enough and for long enough to ensure their escape via the bywash or any other route provided to return them to the main river flow. Whether this is achieved by using sustained (aerobic) or burst (anaerobic) swimming will depend on conditions: burst swimming will usually require high motivation by the fish, e.g. a startle response that might be caused by a strong stimulus (e.g. electric shock, sound pulse or strobe light flash).*”

According to CW1 P1, the HPC LVSE intake heads are predicted to achieve this criterion 66% of the time. Although this is not entirely compliant with the 0.3 m s^{-1} criterion recommended by the Environment Agency, the CW1 P1 document concludes that the HPC intake heads should still be considered acceptable as they achieve 0.4 m s^{-1} for 86% of the time and 0.5 m s^{-1} for 95% of the time, which are considered to be protective of fish species likely to be entrapped.

TR117 (2010) reiterates the point that that assuming that fish can detect and respond to the inlet structure, entrapment risk is critically dependent upon the fish species, the fish size and the water temperature. The fish population at Hinkley largely consists of juvenile, small fish with correspondingly low sustained swimming abilities. This report looked at the swimming abilities of 6 species regularly impinged at HPB (shad, cod, whiting, sole, bass, herring) versus the intake head velocity at a number of tidal states and velocities. A later Turnpenny Horsefield Associates paper adds sprat to list of fish comparing swimming speeds relative to the HPC intake velocities (Turnpenny, 2015). TR117 presents tables of potential HPB-sized fish that could escape the HPC intake head velocities at different tidal states, it also very clearly states that "*these findings should not, in the absence of other measures, be taken to imply that these proportions of fish would in practice escape, as the outcome would also depend on whether or not fish were able to detect and respond to the structure. At the high turbidities usually present at Hinkley Point, in the absence of visual cues, this would depend upon the creation of other suitable sensory cues*."

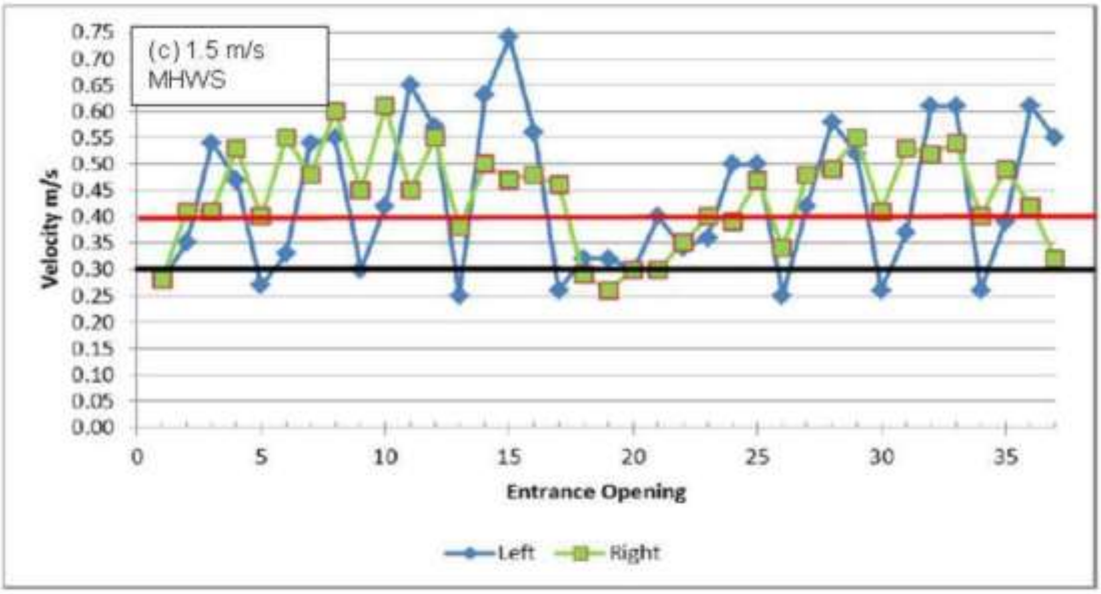

Figure A5 Escape velocities measured at points along the screen face in physical hydraulic model at 1.5 m s^{-1} tidal flow (Ref [18])

Figure 3. Figure A5 from CW1 P1 paper.

References

BEEMS Technical Report TR117: Assessment of Effects of CW Intake Velocity on Fish Entrapment Risk at Hinkley Point, Edition 2. Turnpenny Horsfield Associates, 2010.

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