Swansea Tidal Lagoon

Technical Note: ELAM[1] Fish Turbine Encounter Modelling – sensitivity testing

Prepared for: Swansea Bay Tidal Lagoon plc.

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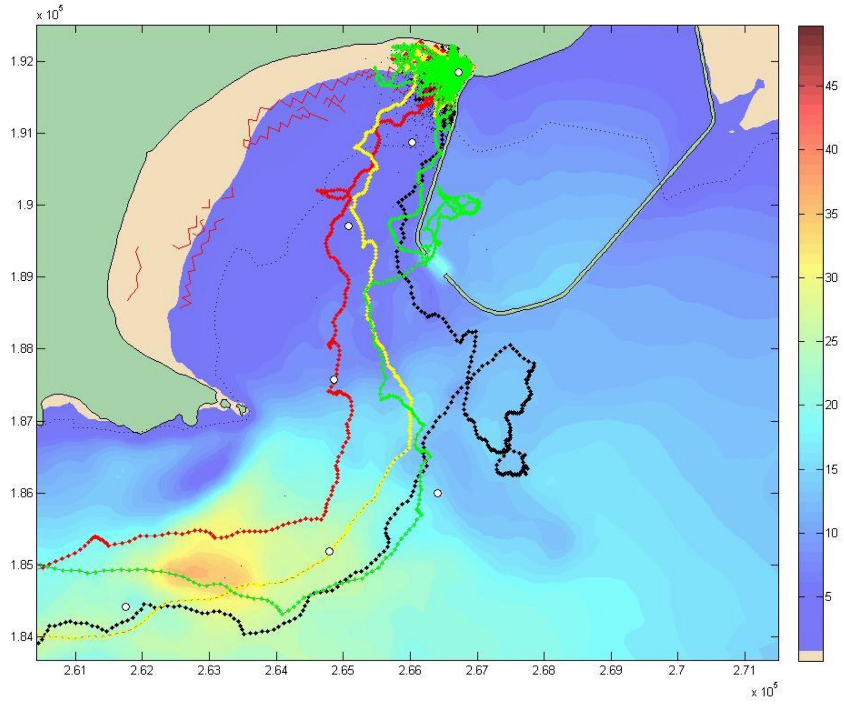

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[1] Eularian Lagrangian Agent Method

Swansea Tidal Lagoon: Fish Turbine Encounter Modelling

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Swansea Tidal Lagoon: Technical Note: ELAM Fish Turbine Encounter Modelling - Sensitivity testing

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1.0 Introduction – sensitivity Testing

1.0.0.1 This document is written in response to a request for clarification made regarding Tidal Lagoon Swansea Bay Environmental Statement Volume 3, Appendix 9.3, entitled: ELAM Fish Turbine Encounter Modelling. Throughout the remainder of this document this original document is referred to as 'ES Appendix 9.3'. This introduction summarises the main points and subsequent sections provide further detail including the sensitivity of all parameters in tabular form.

1.0.0.2 Further clarification and listing of all variable parameters was provided in the additional document: *'Extension to Appendix 9.3, Fish Turbine Encounter Modelling - Further clarification of parameters and behaviours* (THA document number: 580R0801) which was provided through the Marine Licence process on 29 May 2015. Further model sensitivity in relation to large scale changes in initialisation was also undertaken for salmonids. (THA July 2014). This new document now provides detailed sensitivity testing to all the variable parameters outlined in the former documents. These former documents provided a comprehensive discussion of the philosophy behind the models and the choices of variable parameters. The parameters are only briefly summarised here to avoid duplication, but the interested reader is advised to refer to the document above for a full explanation.

1.1 Summary of models assessed in this sensitivity test

1.1.0.1 The models used in this part of the assessment are individual based models (IBM) and one of the major benefits of IBMs is that realistic meaningful parameters can be used (Willis 2012). We have focused on very specific segments of journeys that the fish make during their lifetime when we think they are at most risk of interaction with the planned tidal lagoon. Thus the parameters required are few namely speed, variation in speed, directedness, and navigational frequency and these are looked at further in the following sections. The parameters relate to real things that are measurable such as speed and navigational accuracy. These parameters can be derived from published studies. For instance there are many studies of instantaneous swim speed for fish, and those studies which provide a 'ground speed' for longer sections of travel can be used to infer navigational accuracy. The way these studies have been used to calibrate the models is explained in ES Appendix 9.3. These parameters govern the distributions of the specific capabilities of each model fish.

1.2 Large scale changes and worst cases

1.2.0.1 There are other changes to the entire group of models, these are spatial or temporal parameters which relate to the entire ensemble of models. Such things as spring tide or neap tide, or overall approach from the west or east, or fish directed at the Neath or Tawe. These initialisation parameters relate to large scale changes which are not necessarily on a smooth continuum, or over which it is otherwise unfeasible to spread all the individual models. For instance the spring to neap tidal cycle is 13 days long and the computational time to run scenarios for this length is a prohibitive factor. In these cases the entire ensembles of 10,000 models for a species is run with different initialisations and the worst case chosen. The reason why the worst case is used rather than an average of all cases, is that the average may be biased by choice of scenario, and since these represent uncertainty the most conservative approach is to report the worst case. The detail of this type of sensitivity test is included in ES Appendix 9.3 .

1.3 Uncertainty and prediction

1.3.0.1 A further benefit of IBM's is that many runs of the same model can be assessed with slight variations incorporated for each model fish. Thus natural variability in a population can be incorporated directly in the model. Furthermore, any additional uncertainty about unknown parameters can be introduced by sampling across the entire plausible distribution. These computational methods are well established for providing a probabilistic prediction to complex situations where all the input parameters are not known precisely. They are called Monte Carlo methods and were first developed at Palo Alto during the 1940's as part of the Manhattan Project. By default we run 10,000 different models simultaneously – each one represents a random selection from the plausible range of parameter uncertainty, including natural variation in the population, and thus the probabilistic prediction that is developed is dependent on an assessment of all the plausible range of uncertainty. Thus each group model is, of itself, a massive saturation sensitivity test. But it is also informative and useful to record the overall change in prediction of using whole different groups of parameters. Thus this document shows the effect of changes to the entire probabilistic group of models by alteration of such parameters as mean swim speed. It is to be noted that this may take the models outside of their calibrated range, and thus is not intended as a kind of new wider uncertainty envelope, but is merely an illustration of the impact of changes to variables *en-masse*.

1.4 Methods

1.4.0.1 A traditional sensitivity test operates by holding all variables constant except for one. The one is then varied through a range above and below the default value and the impact on the final result is recorded. For these models the final result was mortality of a model fish which includes coupling the IBM model with the STRIKER™ model which determines mortality of a model fish encountering the turbines at various times during their operation. The coupled models also predict uncertainty in mortality. The final result is a probability of mortality for a single fish undertaking the journey defined in the model. The ensemble runs of 10,000 were split into 5 groups of randomly selected groups of 2000. For each group of 2000 a parameter was varied up and down. The (mean) swim speed parameter was varied by one standard deviation in the variation of swim speed. Thus the entire normally distributed range of swim speeds was increased by one standard deviation and decreased by one standard deviation in two separate groups of 2000. This single test therefore tested the sensitivity of the combined swim speed parameter (mean, variance and range).

1.4.0.2 The second test was of the determination parameter, aka steadfastness (Pascual and Quinn 1991) (this is the variation in the correlated random walk of every fish – this controls the wrigglyness of the track, all parameters are explained in ES Appendix 9.3 and in detail in *'Extension to Appendix 9.3, Fish Turbine Encounter Modelling - Further clarification of parameters and behaviours* (THA document number: 580R0801)). Directedness was varied by +10% and -10%. Determination is itself a measure of uncertainty so this test served to make the model fish more accurately directed in their chosen direction.

1.4.0.3 The final pair of sensitivity tests was on the navigational frequency parameter. This governs how often (on average) a fish is able to get good navigational information and thus realign itself to the olfactory trail or other target it has. It is also a measure of uncertainty but at a different range of scales to the determination parameter above. This parameter was changed by one step up and one down for two groups of 2000.

1.4.0.4 The water model used was 'waterModel/16t8s_low_res_Area_HD_SpNp.dfsu' (known as the 10-8 low resolution model), and the STRIKER™ mortality probabilities were for the Andritz 3-blade Variable turbine options. The species tested were similar to those outlined in Technical Note: 'Selection of turbine technology to minimise impacts on fish' which was submitted through the Marine License process.

2.0 Results

2.0.0.1 The complete parameters and modes of behaviour that distinguish one type of model fish from another (ie parameters which are not spatially explicit) are listed in the Table 1. This is a tabular representation of the information that is provided in sections 5.1 to 5.15 and table 6 of ES Appendix 9.3. Thus for instance: ‘standard round fish function’ in 5.14.0.1 relates to similar parameters to a salmon for all parameters other than speed; and calibration source in 5.8.0.2 ‘see above example calibration for details of salmon’ means similar parameters to salmon adult (or smolt) unless otherwise stated, especially determination and navigational frequency (again excepting speed which was specifically stated for all model fish in table 6 of ES Appendix 9.3).

2.0.0.2 References to scientific peer reviewed papers and method explanation are also in ES Appendix 9.3, 5.1 to 5.15 which are unavailable in the following table 1. The deepest area in the domain was about 40 m so a deep threshold of 45 means that depth was not relevant.

2.0.0.3 The combined mortality figures showing the sensitivity of the mortality results to parameter variation are presented in Table 2. These mortality figures and focal species are based on Table 5a Updated results: 'Technical Note: 'Selection of turbine technology to minimise impacts on fish' .

Table 1. Complete parameters and behaviours which differentiate species.

Species	Scenario identifier	Mean swim speed (m/s)	SD swim speed (m/s)	Determination ×π/step	Navigation frequency (step)	STST*	Deep limit (m)	Shallow limit (m)	Subs.**	light+	Mode
Salmon adult	TEM-A01	0.9	0.12	0.2	5	no	45	1	no	no	Trail
Salmon smolt	TEM-J01	0.18	0.02	0.3	4	no	45	1	no	no	Trail
Sea trout adult	TEM-A02	0.52	0.02	0.2	5	no	45	1	no	no	Trail
Sea trout smolt	TEM-J02	0.28	0.02	0.3	4	no	45	1	no	no	Trail
Shad	TEM-A03	0.52	0.07	0.2	5	no	45	1	no	no	Trail
Herring adult	TEM-A04	0.45	0.02	0.3	4	no	45	1	column†	yes	Spawn
Eel adult	TEM-A05	0.75	0.2	0.3	4	no	45	0	no	no	Trail
Eel elver	TEM-J05	0.07	0.01	0.2	5	yes	45	0	no	yes	Trail
River Lamprey adult	TEM-A06	0.35	0.03	0.2	5	yes	45	0	no	yes	Trail
River Lamprey transformer	TEM-J06	0.16	0.02	0.3	4	no	45	0	no	no	Trail
Sea Lamprey Adult	TEM-A07	0.6	0.05	0.2	5	yes	45	0	no	yes	Trail
Sea Lamprey transformer	TEM-J07	0.22	0.02	0.3	4	no	45	0	no	no	Trail
Bass adult	TEM-A08	0.3	0.05	0.2	8	no	8	0.1	no	no	Area
Bass juvenile	TEM-J08	0.1	0.05	0.2	8	no	8	0.1	no	no	Area
Plaice juvenile	TEM-J09	0.08	0.01	0.2	1	yes	5	0.1	sand	no	Area
Neath adult salmon	TEM-A10	0.9	0.12	0.2	5	no	45	1	no	no	Trail
Sandeel	TEM-A11	0.4	0.1	0.2	8	no	8	0.1	0.3	yes	Area

Table 1 Notes:
* STST indicates Selective Tidal Stream Transport in which fish are able to stop when tides are disadvantageous to their intended migration and vice versa.
** Subs. indicates behaviour related to substrate types (attractive to certain types or sand gravel etc.), a number indicates where the fish is modelled as permanently close to the bed and thus less exposed to water currents, uniformly by this modifier.
† 'column' means randomly distributed in the water column where water current exposure is modified by standard velocity at depth profile for shallow channels.
+ Light indicates behaviour with respect to state of daylight.

Table 2. Sensitivity of mortality results to parameter variation

Species	Scenario identifier	Mean swim speed (m/s)	SD swim speed (m/s)	Det. ×π per-step	Nav. freq. (step)	Mortality (%)	SD Mort. (%)	Mortality speed +SD (%)	Mortality speed -SD (%)	Mortality Det. -10% (%)	Mortality Det. +10% (%)	Mortality Step -1 Nav. (%)	Mortality Step +1 Nav. (%)
Salmon adult	TEM-A01	0.9	0.12	0.2	5	**0.53**	0.07	0.32 †	0.75	0.41	0.65	0.40	0.78
Salmon smolt	TEM-J01	0.18	0.02	0.3	4	**0.13**	0.04	0.12	0.10	0.16	0.12	0.15	0.11
Sea trout adult	TEM-A02	0.52	0.02	0.2	5	**2.18**	0.15	1.84	2.62	1.76	2.68	1.72	2.55
Sea trout smolt	TEM-J02	0.28	0.02	0.3	4	**0.13**	0.04	0.13	0.12	0.11	0.13	0.14	0.12
Shad	TEM-A03	0.52	0.07	0.2	5	**0.61**	0.08	0.33	1.19	0.38	1.15	0.25	1.42
Herring adult	TEM-A04	0.45	0.02	0.3	4	**18.9**	0.40	15.45	23.00	16.77	17.73	19.16	20.00
Eel adult	TEM-A05	0.75	0.2	0.3	4	**0.19**	0.04	0.14	0.21	0.14	0.17	0.10	0.19
Eel elver	TEM-J05	0.07	0.01	0.2	5	**0.07**	0.03	0.08	0.08	0.06	0.07	0.07	0.07
River Lamp. adult	TEM-A06	0.35	0.03	0.2	5	1.35	0.11 +	-	-	-	-	-	-
River Lamp. trans.	TEM-J06	0.16	0.02	0.3	4	0.02	0.02	-	-	-	-	-	-
Sea Lamprey Adult	TEM-A07	0.6	0.05	0.2	5	**1.53**	0.12	0.74	1.03	0.84	1.00	0.93	0.91
Sea Lamp. trans.	TEM-J07	0.22	0.02	0.3	4	0.15	0.04	-	-	-	-	-	-
Bass adult	TEM-A08	0.3	0.05	0.2	8	0.27	0.01	-	-	-	-	-	-
Bass juvenile	TEM-J08	0.1	0.05	0.2	8	0.27	0.01	-	-	-	-	-	-
Plaice juvenile	TEM-J09	0.08	0.01	0.2	1	**0.003**	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Neath adult salmon	TEM-A10	0.9	0.12	0.2	5	0.002	0.005	-	-	-	-	-	-
Sandeel	TEM-A11	0.4	0.1	0.2	8	0.01	0.01	-	-	-	-	-	-

Table 2 notes:

† The variance of these mortality estimates was roughly similar to the default values with standard deviations around 20-25% of the central quoted value.

+ Non-focal species greyed out as per. 'Technical Note: 'Selection of turbine technology to minimise impacts on fish'

3.0 Discussion

3.0.0.1 The results demonstrate that the model is sensitive to variation in the primary parameters in a way that is logical and smooth, without apparent thresholds or extreme sensitivity.

3.0.0.2 As an example take adult sea trout in table 2, line 3 from the top. This shows that when the speed is increased from 0.52m/s by one SD (0.02m/s) to 0.54m/s, mortality is decreased to 1.84% which is below the 2% threshold level which was defined in the ES as a significant impact. Whereas when speed is decreased from 0.52m/s by one SD (0.02m/s) to 0.50m/s, and the fish are therefore more at the mercy of the currents, mortality is increased above the ES threshold level from 2.18% to 2.62%. A slower fish is more likely to encounter the turbines.

3.0.0.3 This is also evident for the directedness and navigational frequency sensitivity. In each case an increase in uncertainty (or variability – i.e. more directedness or more steps between navigations) leads to an increase in mortality, whereas in the opposite cases the opposite is the result.

3.0.0.4 The determination variable is a measure of variation, so the lower its value the more determined or directed the fish is, likewise with navigational frequency – the lower the value, the better the navigation (i.e. the lower the number of steps between good orientations). This is logical, as the model examines the case where fish are accidently drawn into the turbines while on their way elsewhere. If they are less sure of their direction, an encounter is more likely.

3.0.0.5 This bracketing (one below and one above) of the default value by the extremes of the sensitivity test, show values that are different but not notably different, is a very positive result for a sensitivity test. Examination of the Sea Trout, line 3, above demonstrates the significance of the difference using the standard deviations (see notes). It means that the variables have an understandable impact on the result, and that there are unlikely to be sudden thresholds or extreme sensitivities as the parameters are varied outside the ranges defined by calibration.

4.0 References

Pascual MA, Quinn TP. (1991). Evaluation of alternative models of the coastal migration of adult Fraser River sockeye salmon (Oncorhynchus nerka) Can. J. Fish. Aquat. Sci. 48(5): 799-810

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