CONTRACTOR DOCUMENT FRONT SHEET
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DOCUMENT DETAILS

PROJECT				CONTRACT CODE							ASSET ZONE			SYSTEM BUILDING				DOCUMENT TYPE				SEQUENTIAL NUMBER					
H	P	C	-	D	E	V	0	2	4	-	X	X	-	0	0	0	-	R	E	T	-	1	0	0	1	5	9

DOCUMENT TITLE	Cefas BEEMS Technical Report TR515 Hinkley Point C Water quality effects of the fish recovery and return system	**EMPLOYER REVISION**	01

DOCUMENT STATUS	D4	**DOCUMENT PURPOSE**	D4 - FFC - FIT FOR CONSTRUCTION, MANUFACTURING, PROCUREMENT	**TOTAL PAGES** (Including this page)	48

CONTRACTOR DETAILS

CONTRACTOR NAME	Cefas

CONTRACTOR DOCUMENT NUMBER	TR515	**CONTRACTOR REVISION**	02

ECS CODES

REVISION HISTORY

EMPLOYER REVISION	REVISION DATE	PREPARED BY	POSITION/TITLE	CHECKED BY	POSITION/TITLE	APPROVED BY	POSITION/TITLE
01	21/04/2020	Dave Sheahan	Principal Ecotoxicologist	Brian Robinson	Director	Brian Robinson	Director

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REVISION STATUS/SUMMARY OF CHANGES

Revision	Purpose	Amendment	By	Date
1	Initial publication		LF/DS	16/01/2020
2	Update	Response to client and Environment Agency comments	DS	20/04/2020

Cefas

Hinkley Point C: Water quality effects of the fish recovery and return system

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Hinkley Point C: Water quality effects of the fish recovery and return system

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Version and Quality Control

	Version	Author	Date
Draft	0.01	Liam Fernand Dave Sheahan	25/11/2019
Internal QC	0.02	Brian Robinson	02/12/2019
Revision	0.03	Dave Sheahan	08/01/2020
Executive QC	0.04	Brian Robinson	10/01/2020
Revision	0.05	Dave Sheahan	13/01/2020
Revision	0.06	Dave Sheahan	15/01/2020
Executive QC & Final draft	0.07	Brian Robinson	16/01/2020
Submission to EDFE as Rev 1	1.00		16/01/2020
Revision	1.01	Dave Sheahan	21/01/2020
Executive QC	1.02	Brian Robinson	23/01/2020
Revision	1.03	Dave Sheahan	27/01/2020
Revision	1.04	Dave Sheahan	16/04/2020
Executive QC & Final draft	1.05	Brian Robinson	20/04/2020
Submission to EDFE as Rev 2	2.00		21/04/2020

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Executive summary

Introduction

As a result of the direct cooling of the Hinkley Point C (HPC) power station with seawater, fish will be impinged through the cooling water (CW) infrastructure. To avoid fish, invertebrates and other debris passing into the station condensers, cooling water from the intakes passes through rotating drum or vertical band screens. Fish and invertebrates are washed from the screens and are returned to sea via the Fish Recovery and Return (FRR) outfall. Delicate pelagic species such as sprat are expected to have 100% mortality within the FRR system but demersal species such as whiting and mullet and benthic species (such as eels, rockling and flatfish) and crustacea are more robust and have expected mortalities of approximately 50% and 20% respectively (BEEMS Technical Report TR456).

BEEMS Technical Report TR493 has considered the effects of fish and crustacea loading on the survivability of fish within the HPC FRR system and BEEMS Technical Report TR479 has modelled the locations where dead fish discharged from the FRR system are likely to wash up on local beaches and how long they will remain before being consumed by gulls. This report (BEEMS Technical Report TR515) considers the potential effects on local water quality from decomposing dead fish discharged from the HPC FRR system. (Hinkley Point B (HPB) does not have an FRR system and so no impinged fish are discharged back to sea).

The biomass of moribund organisms discharged from the HPC FRR system is calculated from the results of the HPC impingement assessment presented in BEEMS Technical Report TR456.That assessment is based upon the estimated performance of the two impingement mitigation systems that are planned for HPC:

a. Low Velocity Side Entry (LVSE) intakes
b. The FRR System

In this report the estimated reductions in impingement mortality from these two systems are as detailed in BEEMS Technical Report TR456. Results of a recalculation of the LVSE impingement reduction factor following stakeholder consultation are discussed but the change is not material. The report assumes that an AFD is not fitted to HPC.

The purpose of this assessment was to determine whether there would be any deterioration in the water body status under the Water Framework Directive (WFD) from the FRR discharges. The assessment considered effects on the WFD water bodies and associated Marine Strategy Framework Directive (MSFD) sea area within the local area of the HPC FRR outfall:

a. Bridgwater Bay (coastal water body, C21): the HPC cooling water will be abstracted from this water body and the HPC cooling water and FRR discharges will be discharged into this water body. The HPB intake is also in this water body.

b. Parrett Estuary (transitional water body, T18): The HPB cooling water discharge is into this water body.

c. MSFD sea area: Celtic Sea

This assessment considered the potential effects of the HPC FRR discharge on nutrient concentrations, biochemical oxygen demand, un-ionised ammonia, phytoplankton production and organic enrichment of the seabed sediments due to smothering and resulting potential habitat loss.

The assessment methodology considered whether there was any deterioration in status in either of the Bridgwater Bay or Parrett Estuary water bodies; if none was identified then no deterioration could be concluded for adjoining water bodies both upstream and downstream of the discharges. If a potential deterioration was identified, the resulting effect on other WFD water bodies outside of those initially selected would be undertaken within the WFD ‘Further Assessment’ stage.

Assessment Results

Water Quality

Dissolved inorganic nitrogen and Dissolved inorganic phosphorus

The FRR discharge is predicted to release dissolved inorganic nitrogen (DIN) into the Estuary. Under the WFD standards, the Bridgwater Bay water body has ‘Good’ status for DIN. Discharges from an operational HPC with an FRR fitted (Appendix C, Table 13) would result in a very small elevation in DIN in the receiving water body representing <0.04% of the mass present in daily tidal exchange for Bridgwater Bay (with ca. 13% of this from the FRR) for daily operational inputs in combination with those from the FRR. For dissolved inorganic phosphorus (DIP) combined inputs from operation and the FRR would result in a very small elevation in DIP in the receiving water body representing <0.1% of the mass present in the daily tidal exchange for Bridgwater Bay (with around 50% of this from the FRR). This level of input for both DIN and DIP is negligible and would not change the current nutrient status of the water body or have a significant effect for wider sea areas.

Biochemical oxygen demand (BOD)

The decaying biomass of moribund fish from the FRR would have negligible impact on the oxygen levels for either water body with the predicted demand being equivalent to an area of 0.81 km^2 that would be subject to an oxygen reduction of 1mg/l relative to background.

Un-ionised ammonia

Considering the maximum mass of un-ionised ammonia derived from FRR biomass under conditions of thermal influence this would represent a very small fraction (0.0002%) of the mass that would be present in the daily exchange based on the mean annual background concentration.

Organic enrichment of benthic habitat due to smothering

For organic carbon deposition a benchmark value is defined as 100g organic carbon/m^2/year. An equivalent daily value would be 0.3g organic carbon/m^2/day. During the winter the highest numbers of fish are discharged from the FRR and adopting the peak value of associated carbon for the equivalent moribund biomass of fish this would contribute to an organic carbon loading at the benchmark standard level over an area of 0.15 km^2 (15.44 ha) in the worst case month of December. Based on annual average biomass inputs the area at benchmark value would be equivalent to 0.06 km^2 (6.17 ha).

Potential effects of elevated nutrients on phytoplankton status

Due to the high turbidity environment, productivity in the Severn Estuary is light-limited (Underwood, 2010) and the effects of a minor DIN loading on phytoplankton in the Severn Estuary are considered insignificant. To confirm this conclusion, an attempt was made to model the effects of additional nutrients on phytoplankton production using a Combined Phytoplankton and Macroalgae (CPM)model (Appendix C). Without using unrealistically low values of suspended sediment concentration (SSC), no phytoplankton production was predicted to occur. With these very low SSCs phytoplankton production was predicted but the addition of nutrients from HPC, including from the FRR system, had no effect on production as would be expected due to the light limitation. The FRR discharge would therefore cause no deterioration in the water body status under the WFD for phytoplankton.

Test for inclusion of habitats in the WFD assessment

The tests for inclusion of habitats in a WFD assessment are if the footprint of FRR discharge is any of the following:

i. 0.5km^2 or larger
ii. 1% or more of the water body’s area
iii. within 500m of any higher sensitivity habitat
iv. 1% or more of any lower sensitivity habitat

Tests i. and ii. are not met.

Potential effects on higher and lower sensitivity WFD habitats

The discharge of the FRR is within 500 m of higher sensitivity habitat polychaete reef and the organic carbon deposition has a very small potential overlap of 0.01% of the *Sabellaria* sublittoral reef habitat area for Bridgwater Bay. However, there is no overlap of the predicted area affected for dissolved oxygen reduction, or elevated un-ionised ammonia with this habitat. The area potentially affected by the discharge footprints is based on a most conservative assessment and considers the peak biomass discharge and assumes no predation of dead fish. *Sabellaria* reef habitat is also not considered a sensitive receptor for the additional organic carbon input as they are typically associated with dispersive conditions that would reduce settlement of organic material and evidence suggests (Walker and Rees, 1980) an ability of *Sabellaria* to adapt to organically enriched conditions.

The FRR discharge would overlap with lower sensitivity intertidal and subtidal soft sediments. The potential impact footprint for elevated un-ionised ammonia is negligible. For reduced dissolved oxygen oxygen the influence of the plume may extend over 0.81 ha of low sensitivity habitat but this would represent less than 1% of each habitat concerned.

The organic carbon deposition has a larger footprint of potential area affected and this could overlap with an area of 6.31% moderate energy littoral rock, 5.24% intertidal soft sediments.

Overall, discharges from the FRR are likely to have neutral to localised minor effects on core species of intertidal soft sediment habitats in Bridgwater Bay. No significant changes to the community structure or function of these habitats are expected.

Localised changes to community structure and function within the small proportion (6%) of littoral rock that is intersected by the FRR footprint may occur but these changes are not expected to be significant.

Summary

The decay of fish that do not survive passage through the FRR and that are part of the FRR discharge has been assessed. The assessment is conservative accounting for the highest potential biomass discharge from the FRR and takes account of physicochemical extremes and influence of thermal elevation upon potential water quality effects that could be contributed by the moribund fish biomass discharged from the FRR. The zone of potential impact at the point of discharge of the FRR is predicted to affect a relatively small area.

The FRR discharge is within 500 m of polychaete reef, a WFD higher sensitivity habitat and there is a small 0.01% potential overlap with this habitat. There is no predicted overlap of this *Sabellaria* habitat with the predicted effect area for dissolved oxygen reduction and elevated un-ionised ammonia. However, the sensitivity of *Sabellaria* to the influence of elevated organic carbon loading is considered to be low. The FRR discharge is, therefore, not expected to have a significant effect on WFD higher sensitivity habitats.

The FRR discharge will overlap with low sensitivity intertidal and subtidal soft sediments. The overlap of the un-ionised ammonia discharge would be negligible. For reduced dissolved oxygen the influence of the plume may extend over 0.81 ha of low sensitivity habitat but this would represent less than 1% of each habitat concerned.

The effect of elevated organic carbon loading discharge on lower sensitivity habitats from the FRR is likely to be neutral to localised minor effects on core species of intertidal soft sediment and moderate energy littoral rock habitats in Bridgwater Bay. No significant changes to the community structure or function of these habitats are expected.

This assessment is conservative and the predicted changes in water quality, to inorganic enrichment of benthic habitat and to phytoplankton production in Bridgwater Bay or Parrett Estuary water bodies due to the FRR discharges are predicted to be negligible and to cause no deterioration to the status of either of the water bodies. No deterioration can therefore be concluded for adjoining water bodies both upstream and downstream of the discharge. The small areas of elevated BOD and ammonia and relevant loadings would not change the current MSFD status of “good” for the Atlantic Celtic Sea sub-region.

There is a potential for some fish to beach on a wide area of the intertidal mud flats and surrounding beaches and become a nuisance. However, modelling reported in BEEMS Technical Report TR479 demonstrated that during the peak impingement period of November to January only 0.12% of the discharged dead sprat (the most abundant species in that period that would not survive impingement) would beach over a 12.1 km stretch of coast from the west of Lilstock to the east of Stolford and that these would rapidly be consumed by seabirds within 1-2 hours of daybreak. TR479 further showed that of the 12% of the dead fish that did not sink immediately in the vicinity of the FRR outfall, a total of 2.4% would be consumed by seabirds, with approximately 8.5% sinking over a wide area over a period of 24 hours. The chemical and biological effects of this latter group would be very diffuse and much less in terms of added un-ionised ammonia and nutrient concentrations, effects on dissolved oxygen levels and in terms of organic enrichment of the seabed than those due to the larger group that sank immediately after discharge.

In order to be precautionary, the assessments in this report assume that 100% of dead fish discharged from the FRR outfall will sink immediately and no reduction is made for the 12% that will be advected over a larger area. The effects due to decay of this larger discharge have been assessed in this report as negligible and as having no effect on the status of the Bridgwater Bay or Parrett Estuary water bodies or the Celtic Sea MSFD area. There is, therefore, no need to consider the water quality and biological effects of the more diffuse spread of dead fish as these will also be negligible.

Changes to V2 of TR515

Updates have been made to this version of TR515 to address points raised in the Environment Agency’s Schedule 5 notice 2:

- Literature references have been updated and source data have been fully referenced
- Corrections have been made to an incorrectly referenced extraction volume for the FRR.
- Fuller and clearer explanation and referencing has been provided for the calculation of un-ionised ammonia, dissolved oxygen reduction and organic carbon loading in supporting appendices.
- Area calculations for un-ionised ammonia have been corrected and updated and values incorporated into the assessment.
- Fish species survival values have been updated in the impingement calculations to correctly match those shown in BEEMS Technical Report TR456 and adjustments have been made to resulting calculations for nutrient loading, oxygen demand, un-ionised ammonia and organic carbon loading.
- The changes are small and so have not affected the overall water quality assessment.
- The previous v1 report focussed on water quality effects only. This report has been extended to more fully inform a WFD assessment. In particular, a full assessment of the overlap and potential influence of the FRR discharge on WFD higher and lower sensitivity habitats in the vicinity of Hinkley Point C has been made.

1 Background

As a result of the direct cooling of the Hinkley Point C (HPC) power station with seawater, fish will be impinged through the cooling water (CW) infrastructure. To avoid fish, invertebrates and other debris passing into the station condensers, cooling water from the intakes passes through rotating drum or band screens. Fish and invertebrates are washed from the screens and are returned to sea via the dedicated subtidal Fish Recovery and Return (FRR) outfall.

Delicate pelagic species such as sprat are expected to have 100% mortality within the FRR system but demersal species such as whiting and mullet and benthic species (such as eels, rockling and flatfish) and crustacea are more robust and have expected mortalities of approximately 50% and 20% respectively (TR456). The environmental impact assessment for the HPC power station requires consideration of the effects of cooling water abstraction and discharge on the coastal ecosystem. Under the Water Framework Directive (WFD), it is necessary to assess the effects of HPC upon chemical and biological indicators of water quality with one of the biological indicators being the phytoplankton index.

HPC will abstract cooling water from the marine environment at a rate of approximately 132 $m^3\ s^{-1}$ (compared to approximately 33.7 $m^3\ s^{-1}$ for the existing Hinkley B (HPB) station. The cooling water will be heated by approximately 11.6°C but not treated with a chlorine-based biocide to prevent biofouling (unless environmental conditions in the estuary change significantly in the future). The cooling water will be returned to the marine environment at approximately the same location from which it was extracted.

In this assessment the effects of the degradation of moribund fish that do not survive passage via the HPC FRR system on the chemical and biological indicators of water qualities in local WFD water bodies are assessed.

1.1 Water Framework Water Bodies

The purpose of this assessment was to determine whether there would be any deterioration in the water body status under the WFD from the FRR discharges. The assessment began with the selection of the following WFD water bodies within the local area of the HPC FRR outfall:

a. Bridgwater Bay (coastal water body, C21): the HPC cooling water will be abstracted from this water body and the HPC cooling water and FRR discharges will be into this water body. The HPB intake is in this water body.

b. Parrett Estuary (transitional water body, T18): The HPB cooling water discharge is into this water body.

The assessment methodology considered whether there was any deterioration in status in either of these two water bodies; if none was identified then no deterioration could be concluded for adjoining water bodies both upstream and downstream of the discharges. If a potential deterioration was identified, the resulting effect on other WFD water bodies outside of those initially selected would be undertaken within the WFD ‘Further Assessment’ stage. The WFD water bodies for the Bristol Channel and Severn Estuary are shown in Figure 1.

Data for the two water bodies above have been obtained from the second River Basin Management Plan (RBMP) status objectives published by the Environment Agency, as presented in the online Catchment Data Explorer and the ‘Cycle 2 Extended Water Body Summary Report’ produced for each water body[1] and presented in Table 1.

[1] Data Catchment Explorer. Environment Agency. Downloaded on 14th January 2019. Found at http://environment.data.gov.uk/catchment-planning/

Table 1 Summary of WFD water body information

WFD water body name	**Bridgwater Bay**	**Parrett**
Water body ID	GB670807410000	GB540805210900
River basin district name	South West	South West
Water body type (estuarine or coastal)	Coastal	Transitional
Water body total area (km2)	91.813	70.835
Overall water body status (2016)	Moderate	Moderate
Ecological status	Moderate	Moderate
Fish classification status	Not assessed as coastal water body	Not assessed
Chemical status	Good	Good
Target water body status and deadline	Good by 2027	Good by 2027
Hydromorphology status of water body	High	Supports Good
Heavily modified water body and for what use	No	Yes – Flood Protection
Higher sensitivity habitats present	None	Polychaete reef and Saltmarsh
Lower sensitivity habitats present	Cobbles, Gravel and shingle, Intertidal soft sediment, Rocky shore, Subtidal rocky reef, Subtidal soft sediments	Cobbles, Gravel and shingle, Intertidal soft sediment, Rocky shore, Subtidal soft sediments
Phytoplankton status	Moderate	–
History of harmful algae	Not monitored	Not monitored
WFD protected areas within 2 km	Yes (European designated sites only)	Yes (European designated sites only)

1.2 The Hinkley Point power stations in context

Hinkley Point originally had two stations (‘A’ and ‘B’), but the A station was closed in 2000. Both stations shared a common cooling water intake, which was a circular caisson structure, 39 m in diameter. The intake is located 640 m offshore and is connected by tunnels to the onshore pump houses and screening plant. (Figure 2). The HPC intakes will extend approximately 3.4 km and 3.5 km respectively from the foreshore high water mark, at a depth of approximately 20 m below the seabed. The abstracted water will be discharged back into Bridgwater Bay via a single subtidal outfall structure, which is approximately 1.8 km offshore (Figure 2). As a result of the direct cooling of HPC with seawater, fish will be impinged through the cooling water infrastructure. To avoid fish, invertebrates and other debris passing into the station condensers, cooling water from the intakes passes through rotating drum and band screens. Fish and invertebrates are washed from the screens and are returned to sea via the Fish Recovery and Return (FRR) outfall. The FRR outfall will extend out 400 m from HPC into the subtidal waters of Bridgwater Bay, discharging at a depth of ca. 7 m.

The area enclosed by the Bridgwater Bay/Parrett water bodies is not a closed system and there is greater daily exchange of water between that area and the Bristol channel than there is daily extraction of water due to the power station. The volume of the Bridgwater Bay water body at Mean Sea Level (MSL) is 9.77 x 10^8 m^3 (WFD area * mean depth of 10.6m). The Parrett water body has a smaller volume (2.24 x 10^8 m^3) and mean depth (3.6 m). A typical value for the exchange rate coefficient in partially mixed estuaries is 5% volume exchange on each tide (Dyer, 1979), thus 0.1 per day is the value used here for various assessments.

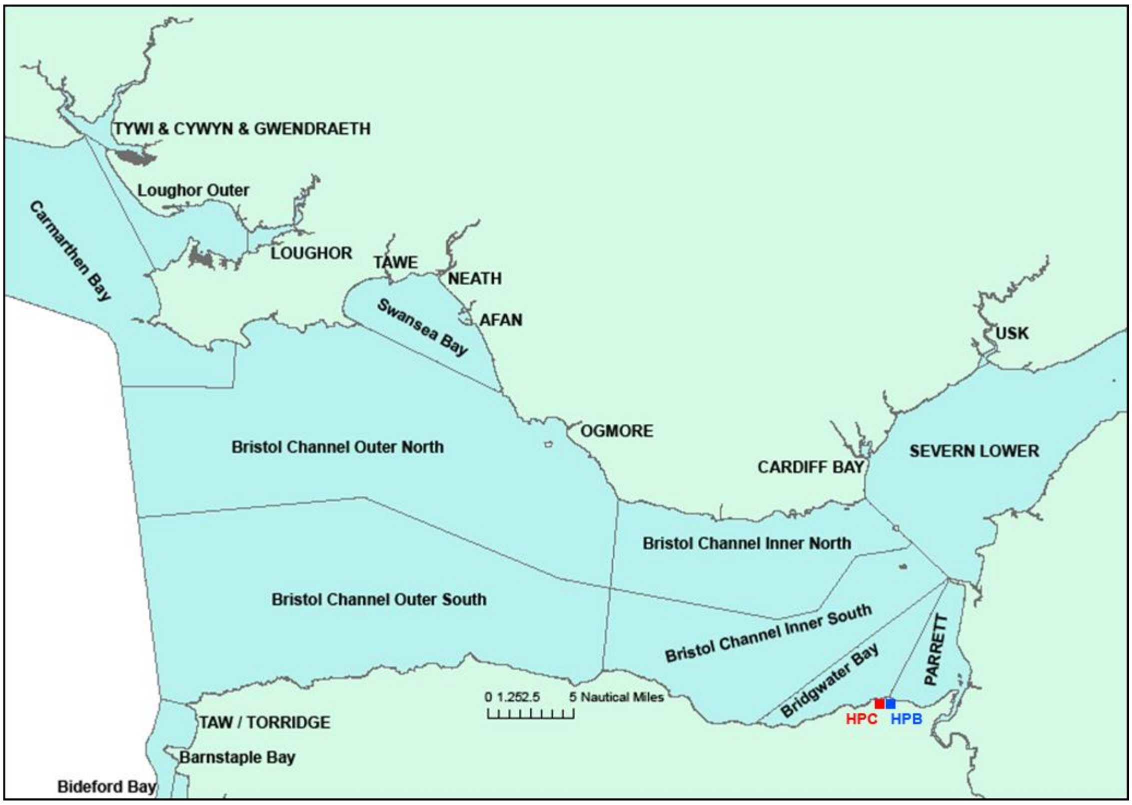

Figure 1 Map of Water Framework Directive water bodies for the Bristol Channel and Severn Estuary, including the Parrett and Bridgwater Bay water bodies and location of Hinkley B and proposed C are also indicated.

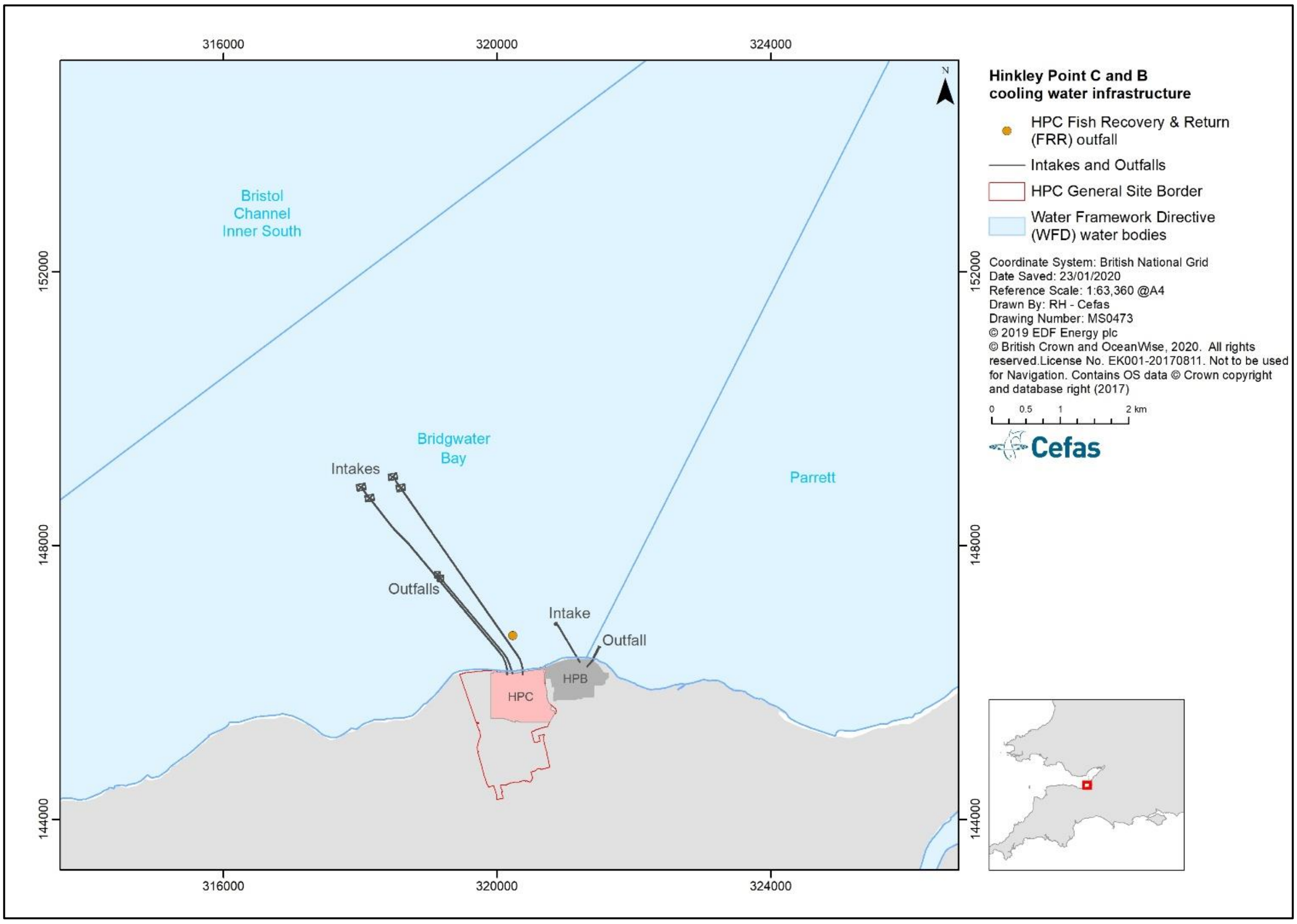

Figure 2 Location of the proposed HPC cooling water system. Also shown HPB cooling water system.

1.3 Background to assessments

During the operation of HPC, discharges of cooling water conditioning chemicals and treated sewage will increase dissolved inorganic nitrogen (DIN) and phosphorus (DIP) inputs to the marine environment (Appendix A). The HPC Fish Recovery and Return (FRR) is planned to provide a safe return of the more robust organisms from the drum and band screens directly into the marine environment. However, some of these organisms will not survive passage through the FRR system and after discharge, their subsequent decay will also introduce additional DIN and DIP into the local environment around the FRR outfall.

There are no plans to chlorinate the HPC cooling water system. In the future, if environmental conditions changed markedly in the Severn, there may be a need to protect the condensers and the essential cooling water system but if chlorination was employed the intake heads and tunnels would not be chlorinated. Chlorination would first occur after the drum and band screens but routing of the water sources that supply the FRR would mean that it would not be chlorinated.

The HPC FRR will discharge into the Bridgwater Bay water body. However, the close spatial association of the Parrett and Bridgwater Bay water bodies with Hinkley Point C means that the FRR discharges could in principle influence both water bodies. Estimates of moribund biomass discharged from the FRR have been calculated and values for nutrient input and influence on other parameters have been derived (Appendix B and C) and are discussed in the following sections.

1.3.1 Assessment thresholds

The predicted amount of change for a given impact is assessed in relation to regulatory thresholds or standardised pressure benchmarks, for example, Environmental Quality Standards (EQS). In the absence of established standards, applied thresholds based on a ‘weight of evidence approach’ and pressure benchmarks proposed in Marine Evidence-based Sensitivity Assessments (MarESA) (Tyler-Walters *et al* 2018) are used to inform impact magnitude. Pressure benchmarks provide a basis for assessing the sensitivity of a given receptor to the site-specific impacts relative to recognised standards. Exceedance of benchmark thresholds would trigger further ecological investigation and does not necessarily infer sensitivity of all receptor groups.

1.3.2 Calculation of FRR discharges

The biomass of moribund organisms discharged from the HPC FRR system is calculated from the results of the HPC impingement assessment presented in BEEMS Technical Report TR456.That assessment is based upon the estimated performance of the two impingement mitigation systems that are planned for HPC:

a. Low Velocity Side Entry (LVSE) intakes
b. The FRR System

In this report the estimated reductions in impingement mortality from these two systems are as detailed in TR456. The report assumes that an AFD is not fitted to HPC.

The predicted reduction in impingement due to the LVSE intakes was calculated for BEEMS TR456 by comparing the impingement risk zones at HPC and HPB. This was an approximate calculation and only compared performance at mid-tide assuming a fixed alignment of the head with the tide. Recognising the limitations with this approach, conservative assumptions were used in the calculation. During consultation TR456, the Environment Agency challenged the derivation of this impingement reduction factor suggesting that a full tidal cycle assessment including the effects of tidal asymmetry should be undertaken. The suggested approach recognises that the alignment of the HPC intake heads with the tide is not always perfect and that at slack water the head extracts from a much wider range of directions. The Environment Agency helpfully provided a worked example of their approach and the impingement reduction factor was recalculated based upon that methodology. However, tidal asymmetry is not extensive at the depth of the HPC intake locations and the revised calculation is within approx. 5% of the original calculation (after correcting for an error in the original calculation of the projected area of the HPB intake). This difference is not considered material and so has not been included in the assessment conducted for this report (TR515).

2 Fish Recovery and Return System - assessment of potential effects on physicochemical parameters

The FRR system is designed to minimise impacts on impinged fish and invertebrate populations. However, some species such as clupeids are highly sensitive to mechanical damage caused by impingement on the screens and incur high mortality rates. The return of dead and moribund biota retains biomass within the local food web but represents a source of organic carbon with the potential to enhance secondary production of carnivorous zooplankton and through the detrital pathways. In addition to organic loading, the potential for increases in nutrients, un-ionised ammonia concentration and reductions in dissolved oxygen are considered.

The total biomass of moribund biota that may potentially be discharged from the FRR is estimated based on the level of abstraction (pump rates) for the planned HPC intakes and the information on seasonal distribution of species and length weight distribution of the species impinged for the existing Hinkley Point B (BEEMS TR456 and Appendix B). The Hinkley Point B data indicate that the highest biomass discharged occurs in December, when a mean of 135.6 kg per day is predicted to be discharged from the FRRs and this value is used to provide a conservative value for all assessments (the average daily value is lower at 35 kg per day).The use of peak daily discharges is not appropriate for calculations of chemical effects of the FRR discharges because the discharged biomass will not decompose instantaneously and, depending upon the size of the organism, could take days to a few weeks to decompose (if not subject to predation). The use of the mean daily discharge for December reflects this integrative chemical process.

Observations reported in BEEMS TR479 indicate that 88% of moribund fish discharged from the FRR would sink immediately and be deposited in an area around the FRR discharge. The remaining 12% would be passively transported from the FRR outfall by the strong tidal currents at Hinkley Point. This group of dead fish would either:

- sink to the seabed before reaching land and either decompose or more likely be consumed by benthic organisms, or
- be consumed by foraging piscivorous birds (either whilst the fish are floating but also once any fish beach.

There is a potential for some fish to beach on a wide area of the intertidal mud flats and surrounding beaches and become a nuisance. However, modelling reported in TR479 demonstrated that during the peak impingement period of November to January only 0.12% of the discharged dead sprat (the most abundant species in that period that would not survive impingement) would beach over a 12.1 km stretch of coast from the west of Lilstock to the east of Stolford and that these would rapidly be consumed by seabirds within 1-2 hours of daybreak. TR479 further showed that of the 12% of the dead fish that did not sink immediately in the vicinity of the FRR outfall, a total of 2.4% would be consumed by seabirds, with approximately 8.5% sinking over a wide area over a period of 24 hours. The chemical and biological effects of this latter group would be very diffuse and much less (e.g. in terms of chemical concentrations, effects on dissolved oxygen levels and in terms of organic enrichment of the seabed) than those due to the larger group that sank immediately after discharge. If the larger group caused no effect on water body status, then it was considered that the effects of the more diffuse group would be less and not merit further consideration.

IOn a precautionary basis, the assessments in this report assume all 135.6 kg per day of dead fish discharged from the FRR outfall will sink immediately and no reduction is made for the 12% that will be advected over a larger range.

For the following assessments the water quality monitoring data for Hinkley Point (Amec, 2009) provides the background parameters against which the inputs estimated from HPC are considered. The HPB inputs are, therefore, included in this measured baseline.

2.1 Calculated effects of decaying moribund biomass from the FRR on DIN/DIP

The FRR discharge is predicted to release dissolved inorganic nitrogen (DIN) into the estuary. Under the WFD standards, the Bridgwater Bay water body has 'Good' status for DIN. Discharges from an operational HPC with an FRR fitted (Appendix C, Table 13) would result in a very small elevation in DIN in the receiving water body representing <0.04% of the mass making up the daily volume exchange for Bridgwater Bay (with around 13% of this from the FRR). The daily phosphate input from the FRR and operational discharge would represent ca. 0.1% of the mass of phosphate making up the daily exchange for Bridgewater Bay (with ca. 50% of this from the FRR). This level of input for both DIN and DIP from combined operational and FRR inputs would not change the current nutrient status of either of the two water bodies.

2.2 Calculated effects of decaying moribund biomass from the FRR on dissolved oxygen levels

The decaying fish biomass has the potential to contribute to the biological oxygen demand (BOD). An estimate of 3.5 g of oxygen is required for complete oxidation of one gram of dry mass is derived based on a study of particulate organic matter from fish cages (Stigbrandt*,* 2001) (see Appendix B2). This source-term for oxygen demand is used to derive an estimate of the BOD contribution from the maximum daily biomass (based on the month of December a daily average biomass value of 135.6 kg is derived). The estimate is 111 kg BOD/day (after allowing for a wet weight/dry weight adjustment see Appendix B1).

Any area that exceeds 1.5 mg l^{-1} deviation in BOD from background is expected to generate less than 0.5 mg l^{-1} impact/reduction on dissolved oxygen (OSPAR, 1997). Therefore, dividing the BOD loading by 1.5 and multiplying by 0.5 produces an estimate of the total oxygen reduction potential due to the BOD input which is 37 kg/day.

Based on a background concentration of 5 mg l^{-1} dissolved oxygen (derived from lower oxygenation values under thermal influence, BEEMS Technical Report TR186) the calculated oxygen demand requirement (37 kg) is equivalent to the mass of oxygen available in 7392 m^3, which in turn equates to 0.01% of the daily exchange for Bridgwater Bay. Reaeration at the sea surface would also replenish oxygen levels. Typical values of oxygen flux are 100mmol $m^{-2}d^{-1}$ (Hull, 2016) or 3.2 gm^{-2} d_{-1} therefore daily reaeration across 0.01 km^2 (1.78 ha) would be expected to compensate for the estimated daily oxygen consumption by decaying fish biomass. Both reaeration and tidal exchange in combination would replenish dissolved oxygen.

Under the influence of thermal inputs from HPC and HPB, oxygen concentrations could be reduced to around 5mg/l around the FRR (BEEMS Technical Report TR186). Assuming a depth of 7m at the FRR discharge the predicted oxygen demand (resulting from biomass decay) overlaid on this background would be equivalent to the mass of oxygen available in an area of 0.002 km^2 (0.16 ha). Based on plume modelling reported in BEEMS TR186, the total length of the plume would be approximately 12 times the width i.e. the equivalent theoretical ellipse for a plume area of 0.16 ha would have a total length of approximately 158 m (79 m East and West from the discharge point) and a total width of 13 m (with a spread of 6.6 m North and South of the discharge point). A wider potential area might be subject to a modest oxygen reduction for example the oxygen demand would be equivalent to a 1mg/l reduction from 5 to 4 mg/l over an area of 0.81 ha. The equivalent theoretical ellipse for a plume area of 0.81 ha would have a total length of approximately 353 m (176 m East and West from the discharge point) and a total width of 29 m (with a spread of 15 m North and South of the discharge point).

This assessment makes worst case assumptions of instantaneous breakdown of all available biomass and no losses through predation. Reduction of oxygen concentration will only occur if the rate of oxygen use due to BOD is greater than daily exchange of Bridgwater Bay and the oxygen transfer across the water surface. The waters off Hinkley Point are well mixed vertically facilitating reaeration at the surface, the Severn Estuary generally has oxygen levels slightly below full saturation, implying that there is a continuous background consumption of oxygen, which most likely comes from the large quantities of mud that are resuspended on each tide. However, the additional BOD loading from the FRR discharge is very small compared to the natural background level. This level of change would not influence the current dissolved oxygen status of either of the two water bodies.

This is a worst-case assessment as it assumes no predation and no remobilisation of partially decayed fish. In practice both effects will take place reducing the predicted area of influence on dissolved oxygen levels.

2.3 Calculated effect of decaying moribund biomass from the FRR on un-ionised ammonia

Decaying biomass will result in local increases in un-ionised ammonia. Studies on cod tissue show ammonia contribution of 125 mg kg^{-1} NH_4-N (Timm and Jorgensen, 2002) (see Appendix B2). This value is used as a proxy in the un-ionised ammonia calculator (Clegg and Whitfield, 1995), along with relevant site background conditions for pH, temperature and salinity, to indicate the potential un-ionised ammonia contribution from decaying biomass at Hinkley point. Based on the daily average biomass of fish discharged during December (and relevant pH, salinity and temperature) the estimated NH_3 loading could be at or above the EQS (NH_3-N, 21 µg/l) in a volume of 18,973 litres of seawater (including natural background and maximum predicted NH_3-N background from HPC operation with thermal elevation). This is a conservative assessment accounting for the highest potential biomass discharge from the FRR. If temperature elevation of 2°C that might occur around the FRR due to the influence of cooling water discharge is also considered, the volume of seawater affected by elevated un-ionised ammonia would marginally increase to 22,098 litres.

Considering the maximum mass of un-ionised ammonia derived from FRR biomass under conditions of thermal influence this would represent a very small fraction (0.0002%) of the mass that would be present in the daily exchange based on the mean annual background concentration (Amec, 2009). This daily input would not change the current un-ionised ammonia status of either of the two water bodies and would be considerably less at other times of the year.

This is a worst-case assessment as it assumes no predation and no remobilisation of partially decayed fish. In practice both effects will take place further reducing the predicted area above the EQS.

2.4 Calculated effect of decaying moribund biomass from the FRR on organic carbon deposition

The peak biomass of moribund fish discharged from the FRR (135.6 kg/day, for December) would contribute an estimated input of ca. 42.3 kg organic carbon (see Appendix B2). Settlement of moribund biomass could result in smothering of the seabed and organic enrichment contributing to deoxygenation in the sediments and disturbance on sediment geochemistry. These changes can subsequently lead to decreasing numbers of sediment dwelling species, individuals and biomass.

There are no regulatory standards for assessing organic smothering of benthic organisms. In the absence of established standards, applied thresholds based on a 'weight of evidence approach' and pressure benchmarks proposed in Marine Evidence-based Sensitivity Assessments (MarESA) (Tyler-Walters *et al* 2018) have been used in the assessment of potential effects. Pressure benchmarks provide a basis for assessing the sensitivity of a given receptor to the site-specific impacts relative to recognised standards. For organic carbon deposition the appropriate benchmark is defined as 100g organic carbon/m^2/year. Exceedance of this benchmark threshold would trigger further ecological investigation and does not necessarily infer sensitivity of all receptor groups.

An equivalent daily benchmark would be 0.3 g organic carbon/m^2/day. During the winter the highest numbers of fish are discharged from the FRR and adopting the peak value of associated carbon this would contribute to an organic carbon loading at the benchmark standard level over an area of 0.15 km^2 (15.44 ha). Based on annual average biomass inputs the area at the benchmark value would be equivalent to 0.06 km^2 (6.17 ha).

This carbon loading would not change the status of either of the two water bodies.

Using the plume shape factors described in Section 2.2, the total length of the worst case organic enrichment footprint above the pressure benchmark would be approximately 12 times the width i.e. the equivalent tidal ellipse would have a total length of approximately 1536 m (radius 768) and a total width of 128 m (radius 64). For the annual average loading of biomass organic carbon the equivalent tidal ellipse would be approximately 971 m (radius 485.6) and a total width of 81 m (radius 40.5).

This is a worst-case assessment as it assumes no predation and no remobilisation of partially decayed fish. In practice both effects will take place reducing the predicted area above the benchmark level.

3 Fish Recovery and Return System assessment of potential effects on phytoplankton production

Background studies on Hinkley Point indicate that chlorophyll a in the water column is generally <10µg/l (Underwood, 2010) indicating a low phytoplankton population. The contribution of re-suspended microphytobenthos to these water column levels is not known and could be up to 20-40%. Given the available nutrients at the lower, middle and upper estuary sites, turbidity (light limitation and an unstratified water column) and flushing probably are the major reasons for low phytoplankton populations in the estuary.

Under these conditions any additional nutrient inputs are considered unlikely to influence microalgal production. To check this hypothesis predicted operational nutrient inputs have been given a preliminary assessment using a Combined Phytoplankton and Macroalgae (CPM) model with the details described in Appendix C. Use of the CPM confirmed that the additional nutrients due to the FRR discharge would not contribute to elevated phytoplankton production due to light limitation.

It is concluded that the HPC FRR discharges will have no effect on phytoplankton production in Bridgwater Bay.

4 Fish Recovery and Return System assessment of potential overlap of FRR discharge on habitats

A map of the Hinkley Point / Bridgwater Bay EUNIS habitat classes is presented in BEEMS TR184. Figure 3 shows the habitats in the vicinity of the HPC FRR discharge outfall. Based on the likely plume shape (section 2.2) an ellipse representing the area over which the discharged organic matter loading would be equivalent to the benchmark value (section 2.4) is also shown on Figure 3.

The tests for inclusion of habitats in a WFD assessment are if the footprint of FRR discharge is any of the following:

v. 0.5km² or larger
vi. 1% or more of the water body's area
vii. within 500m of any higher sensitivity habitat
viii. 1% or more of any lower sensitivity habitat

4.1 Applying the habitats tests:

i. The largest effect area is 0.15 km² (due to organic enrichment of seabed sediments due to smothering) i.e. <0.5km²
ii. 1% of the water body areas are 0.92 km² (Bridgwater Bay) and 0.71 km² (Parrett). The largest effect footprint is 0.15 km² i.e. <1%

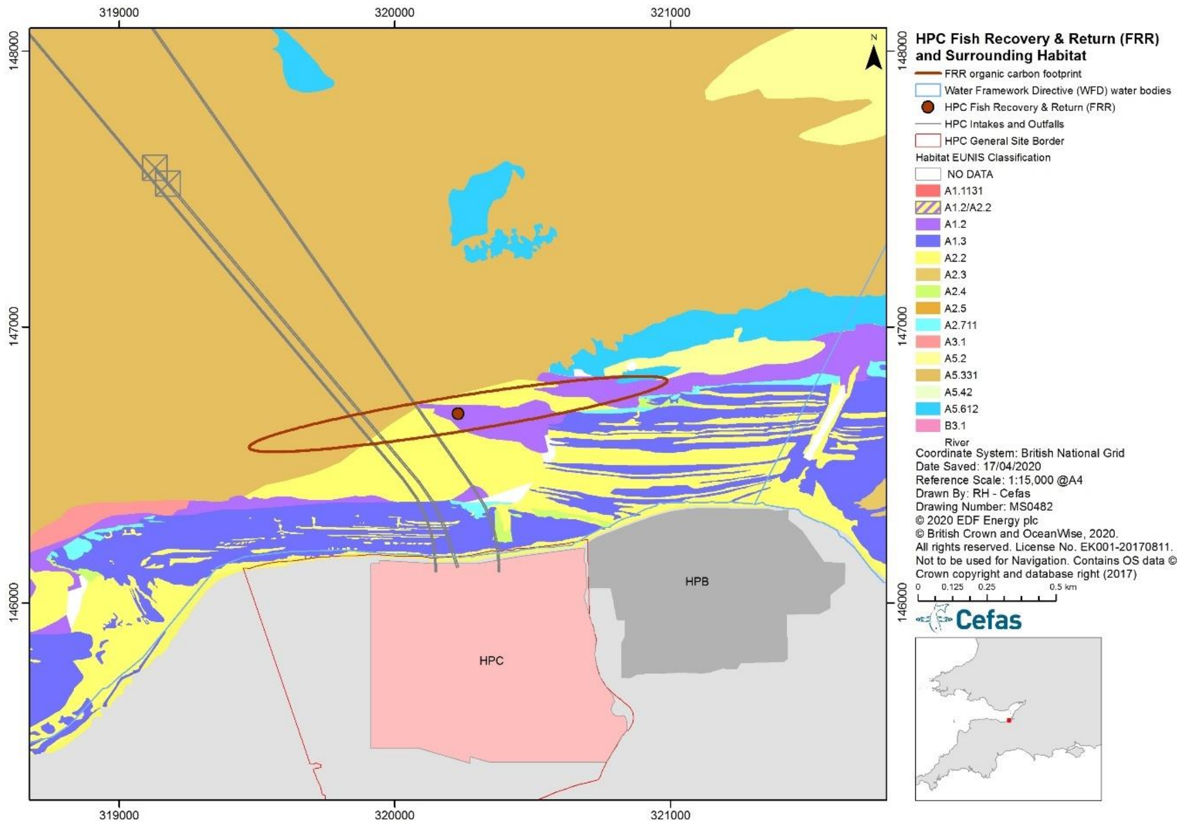

Figure 3. Location of the FRR discharge shown by the red dot, the red ellipse shows the worst case organic enrichment footprint of the FRR discharge. The colour shaded areas correspond to different EUNIS habitats with EUNIS codes shown in the legend and in more detail in Table 2 and Table 3.

Table 2 EUNIS habitat total area information for the Severn Estuary of relevance to FRR discharge (higher sensitivity habitat shaded in grey)

EUNIS Level	EUNIS code	EUNIS habitat description	Area Ha
6	A1.1131	[*Semibalanus balanoides*], [*Patella vulgata*] and [*Littorina*] spp. on exposed to moderately exposed or vertical sheltered eulittoral rock	4.5
3	A1.2/A2.2	Moderate energy littoral rock /Littoral sand and muddy sand	13.4
3	A1.2	Moderate energy littoral rock	126.8
3	A1.3	Low energy littoral rock	35.5
3	A2.2	Littoral sand and muddy sand	255
5	A2.312	[*Hediste diversicolor*] and [*Macoma balthica*] in littoral sandy mud	3532.5
3	A2.4	Littoral mixed sediments	54.8
3	A2.5	Coastal saltmarshes and saline reedbeds	186.5
5	A2.711	Honeycomb worm reefs on sand-abraded eulittoral rock	11.6
3	A3.1	Atlantic and Mediterranean high energy infralittoral rock	143.2
4	A5.2	Sublittoral sand	191.1
5	A5.331	[*Nephtys hombergii*] and [*Macoma balthica*] in infralittoral sandy mud	7512.7
4	A5.42	Sublittoral mixed sediment in variable salinity (estuaries)	604.8
5	A5.612	[*Sabellaria alveolata*] on variable salinity sublittoral mixed sediment	3503.7
3	B3.1	Atlantic and Mediterranean high energy infralittoral rock	143.2

iii. Distance from higher sensitivity habitats

The largest footprint from the FRR discharge is 0.15 km^2 above the pressure benchmark for organic enrichment of seabed sediments due to smothering (Appendix B.2). There is potentially a small area of overlap of the FRR discharge organic matter footprint with polychaete reef habitat (Table 3). The relevant EUNIS classifications are shown in Figure 3 as A2.711 (honeycomb worm reefs on sand abraded eulittoral rock) and A5.612T (*Sabellaria alveolata* on sublittoral mixed sediment).

There is no overlap of this *Sabellaria* reef habitat with the predicted area affected by the FRR for dissolved oxygen reduction (maximum effect range 100 m) or elevated un-ionised ammonia. The predicted maximum effect range for increased organic carbon is 768 m (East and West) as shown in Figure 3 the potential footprint very partially intersects with the reef areas. However, this calculation uses the worst cast month for dead fish discharges (December); using the annual average discharge the maximum effect range is reduced to 85 m (East and West) substantially reducing the possibility of intersection with the *Sabellaria* reef habitat. These assessments are also based upon two implausible assumptions:

1. no predation of dead fish either by other fish or benthic organisms; and
2. no remobilisation of partially decayed fish.

In practice there is likely to be substantial predation and the worst-case discharge month of December is in the period of maximum storm intensity and maximum wave energy which will produce high rates of remobilisation and subsequent tidal dispersal of decaying matter. *Sabellaria* reefs are not considered a potentially sensitive receptor of this pressure as the development of reefs is generally in areas of high water movement where material would tend to disperse rather than settle out (Pearce et al., 2014). Also that reefs are resistant to high levels of organic enrichment is suggested by the presence of *S.spinulosa* adjacent to a sewage sludge dumping area (Walker and Rees, 1980). The influence of the discharge footprint for organic matter is likely to be very limited. *Sabellaria* preference for areas of high water movement and the ability of the species associated with *Sabellaria* reef habitat to consume extra organic matter suggest that they are not sensitive to this pressure (Gibb *et a*l., 2014). The limited pressure footprint and the potential insensitivity of *Sabellaria* spp. indicate no significant effect on the *Sabellaria* reef habitat.

The FRR discharge is, therefore, not expected to have a significant effect on WFD higher sensitivity habitats.

iv. Lower sensitivity habitats

There is negligible overlap of lower sensitivity habitat for a potential un-ionised ammonia plume and a plume of seawater with a reduction of ca. 1mg/l dissolved oxygen from background (0.81 ha, 100 m plume extent) would intersect with <1% of moderate energy littoral rock and intertidal soft sediment.

Organic matter deposition from the FRR discharge will overlap with the following lower sensitivity habitats: Subtidal soft sediment and intertidal soft sediment. The area of overlap of the FRR discharge with the EUNIS habitat area available within Bridgwater Bay is shown in Table 3.

The largest area potentially affected is 0.15 km^2 for organic enrichment of seabed sediments (Appendix B.2). This area of organic matter deposition is very small relative to the area of subtidal soft sediment habitat (<0.2%) but is ca. 5% for the intertidal soft sediment habitat and 6% for the moderate energy littoral rock habitat (Table 3). As the area of subtidal soft sediment habitat is less than the 1% threshold that requires WFD assessment, the effects on this habitat are not considered further. The potential for biota of intertidal habitats to be affected by organic matter deposition (food supply, smothering and deoxygenation of sediments) from FRR discharge is assessed below.

Table 3 Areas of intersection of FRR footprint in terms of organic matter deposition and lower sensitivity EUNIS habitat

Habitat & classification codes (from Magic)	Area in Bridgwater Bay ha	FRR discharge footprint area of intersection ha	Percentage
Moderate energy littoral rock. A1.2	85.63	5.40	6.31
Low energy littoral rock A1.326	75.12	0.01	0.01
Intertidal soft sediments like sand and mud. A2.2	95.81	5.10	5.24
Subtidal soft sediment A5.22	64.14	0.02	0.03
[*Nephtys hombergii*] and [*Macoma balthica*] in infralittoral sandy mud A5.331	5061	4.66	0.09
[*Sabellaria alveolata*] on variable salinity sublittoral mixed sediment A5.612	2091	0.25	0.01

The core species that characterise intertidal soft sediment habitats in Bridgwater Bay are mainly detritivores (BEEMS TR259) that are tolerant of smothering and deoxygenation of sediment (Table 4). Such species, which include the gastropod *Peringia ulvae*, bivalve *Limecola balthica* and polychaete *Hediste diversicolor*, are unlikely to be negatively affected by organic matter deposition associated with FRR discharge but may experience localised increases in abundance and/or body mass due to an increase in food supply. Active predators, such as the polychaete *Nephtys* spp. and gastropod *Retusa obtusa*, are also among the core species. As with the detritivores, these species are tolerant of smothering and deoxygenation and are, therefore, unlikely to be negatively affected by organic matter deposition. Their numbers may increase if organic input leads to increased prey availability, which may be particularly likely for *R. obtusa* given its preference for *P. ulvae*. One core species, the amphipod *Bathyporeia sarsi*, is relatively sensitive to deoxygenation and may be negatively affected by organic matter deposition. This species is a sand licker (scrapes algae of sand grains) and tends to prefer areas of low sediment organic matter content. Localised reductions in the population density of this species are therefore possible within the footprint of organic matter deposition. Overall, discharges from the FRR are likely to have neutral to localised minor effects on core species of intertidal soft sediment habitats in Bridgwater Bay (Table 4). No significant changes to the community structure or function of these habitats are expected.

The core species in moderate energy littoral rock are all macroalgae (BEEMS *Technical Report* TR416) (Table 4). The ephemeral *Ulva* spp. and turf forming *Corallina officinalis* are often common in areas exposed to organic enrichment. The former is tolerant to extreme hypoxia but may temporarily experience reduced growth due to localised smothering, though its fast life-history implies rapid recovery times. The latter is tolerant to smothering. Organic matter deposition associated with FRR discharges are not expected to affect these two species. The perennial *Fucus serratus*, *F. vesiculosus* and *Pelvetia canaliculata* may be negatively affected by organic matter deposition. Most of the available evidence pertains to *F. vesiculosus* and suggests that early life stages are sensitive to both smothering and hypoxia. Reductions in the coverage of these species and the canopies they form may therefore occur in areas where organic matter originating from FRR discharges accumulates. This could lead to localised changes to community structure and function within the small proportion (6%) of littoral rock that is intersected by the FRR footprint. These changes are not expected to be significant.

Table 4 Lower sensitivity EUNIS habitats intersected by the FRR footprint for >1% of their total area, the core species that characterise these habitats, their predicted response to organic carbon deposition and the evidence on which predictions are based.

Habitat & classification codes	Core species	Predicted response	Evidence	References
Intertidal soft sediments (e.g. A2.2, A2.3, A2.4)	*Peringia ulvae*	Neutral to minor increase	Detritivore and grazer. Often dominates areas exposed to organic enrichment. The elevated food supply can lead to increased abundance. The species can resurface following smothering. It is tolerant of reduced sediment oxygen content and, if necessary, can relocate (by crawling or floating) to escape environmental stress.	Anger (1977), Gray *et al*., (1979), Armonie and Hartke (1995) Chandrasekara and Frid (1998), Bolam *et al*., (2004), Grilo *et al*., (2012), Schuckel *et al*., (2012)
	Limecola balthica	Neutral to minor increase	Detritivore. Often found in areas exposed to organic enrichment. The elevated food supply can lead to increased abundance and body mass. The species can burrow vertically in response to smothering. It is tolerant of reduced sediment oxygen content and, if necessary, can adjust its vertical position or relocate (by floating) to escape environmental stress.	Brafield (1963), Leppakoski (1975), Pearson and Rosenberg (1978), Madsen and Jensen (1987), Diaz and Rosenberg (1995), Long *et al*., (2008), Schuckel *et al*., (2012)
	Hediste diversicolor	Neutral to minor increase	Detritivore and omnivore. Often found in areas exposed to organic enrichment. The elevated food supply can lead to an increase in abundance. The species is an active burrower (to depths >20cm) and is therefore insensitive to smothering. It is tolerant of reduced sediment oxygen content and, if necessary, can relocate (by crawling or swimming) to escape environmental stress.	Leppakoski (1975), Anger (1977), Gray *et al*. (1979), Diaz and Rosenberg (1995), Scaps (2002), Schuckel *et* al., (2012), Aberson *et al*., (2016)

	Nephtys hombergii and *Nephtys* spp.	Neutral	Predator and scavenger. Often found in areas exposed to organic enrichment. Does not appear to respond to small variations in sediment organic matter content, but abundance may be reduced if organic pollution is severe. The taxon is an active burrower (to depths >10cm) and is therefore insensitive to smothering. It is tolerant of reduced sediment oxygen content and, if necessary, can relocate (by crawling or swimming) to escape environmental stress.	Clark *et al*., (1962), Oyenekan (1986), Diaz and Rosenberg (1995), Tomassetti and Porello (2005)
	Bathyporeia sarsi	Neutral to minor decrease	Sand licker. Typically found in areas of low organic matter content and may therefore respond negatively to organic enrichment. The species is an active burrower (to depths of up to 10cm) and is therefore likely to be insensitive to smothering. Members of this genus can survive short periods of hypoxia but are relatively sensitive to this stressor compared to many other infaunal invertebrates.	Nicolaisen and Kanneworff (1969), Anger (1977), Khayrallah (1977), Mettam (1989), Schückel *et al*., (2012)
	Retusa obtusa	Neutral to minor increase	Predator. Often abundant in areas of high organic matter content. An increase in the density of its prey species (e.g. *Peringia ulvae*) could lead to increased abundance. The species is an active burrower and is therefore likely to be able to regain its position in the sediment following smothering. Its motility and preference for areas with high organic loading suggest that it is unlikely to be sensitive to reduced sediment oxygen content.	Smith (1967), Guerra-Garcia & Garcia-Gómez (2004), Schuckel *et al*., (2012)
Moderate energy littoral rock (A1.2)	*Ulva* spp.	Neutral	Ephemeral macroalga. Often dominant in areas exposed to organic enrichment. Any plants present where organic matter accumulates could experience reduced growth due to smothering, but such effects would be highly localised, and recovery would be fast due to the taxon's fast life-history. Tolerant of severe hypoxia.	Guist & Humm (1976), Bat *et al*., (2001), Corradi *et al*., (2006), Arévalo *et al*., (2007)

	Pelvetia canaliculata	Neutral to minor decrease	Perennial macroalga. Relatively low cover has been recorded in close proximity to a source of organic enrichment. The species occupies the upper shore, where oxygen is not limited due to long emersion times. Its sensitivity to smothering is unknown, but other fucoids tend to be negatively affected by this stressor. Localised reductions in population density are possible anywhere that organic matter accumulates.	Gunnarsson and Pórisson (1976)
	Fucus serratus and F. vesiculosus	Neutral to minor decrease	Perennial macroalgae. Often the dominant canopy-forming macroalgae but can become less common where significant organic enrichment occurs. Smothering by organic matter can reduce recruitment success in *F. vesiculosus* and possibly congeners. *F. vesiculosus* germlings are also sensitive to hypoxia. Localised reductions in population density are possible anywhere that organic matter accumulates.	Soltan *et al*., (2001), Eriksson and Johansson (2003), Berger *et al*., (2004), Al-Janabi *et al*., (2016)
	Corallina officinalis	Neutral	Turf-forming coralline alga. Often common in areas exposed to organic enrichment but sometimes rare in the immediate vicinity of the source. Tolerant of smothering by sediment. Tolerance to de-oxygenation is unknown, but reduced growth upon exposure to organic effluent has been recorded. Its distribution in relation to organic matter sources suggests effects of organic matter deposition would be negligible.	Gunnarsson and Pórisson (1976), Kinding and Littler (1980), Seapy and Littler (1982), Soltan *et al*., (2001), Cabral-Oliveira *et al*., (2014)

5 Discussion

The results of the assessment of the influence of the HPC FRR inputs in combination with cooling water discharges from HPB and HPC are as follows:

Water quality effects

1. Discharges from an HPC with an FRR fitted (Appendix C, Table 13) would result in a very small elevation in DIN in the receiving water body representing <0.04% of the mass present in the daily tidal exchange for Bridgwater Bay (with ca. 13% of this from the FRR). For dissolved inorganic phosphorus (DIP) combined inputs from operation and the FRR would result in a very small elevation in DIP in the receiving water body representing <0.1% of the mass present in the daily tidal exchange for Bridgwater Bay (with just under 50% of this from the FRR). This level of input for both DIN and DIP is negligible and would not change the current nutrient status of the either water body or have significant influence of the MSFD area Celtic sea.

2. The decaying biomass of moribund fish from the FRR would have negligible impact on the oxygen levels for either water body with the predicted demand being equivalent to an area of 0.81 km^2 that would be subject to an oxygen reduction of 1mg/l relative to background. Taking account of thermal elevation of the water body from HPB and HPC inputs the area affected by a 1 mg/l reduction in oxygen would be at the moderate/good boundary for dissolved oxygen.

3. Based on the daily average biomass of fish discharged during December (and relevant pH, salinity and temperature) the estimated NH_3 loading is equivalent to a relatively small volume of water at the EQS concentration (NH_3-N, 21 µg/l) of ca. 18,973 litres around the FRR. As the ammonia is produced from decaying organic matter it is likely to be rapidly mixed and dispersed by tidal currents so that negligible areas are affected by un-ionised ammonia levels at or above the EQS. Hypothetically if mixed evenly through the full depth of the water column (7m) the volume of seawater at the EQS would affect a very small area of ca. 1.65 m^2. Accounting for a temperature elevation of 2°C that might occur around the FRR due to the influence of cooling water discharge, the volume affected by elevated un-ionised ammonia would marginally increase to 22,098 litres. Hypothetically if mixed evenly through the full depth of the water column (7m) the volume of seawater at the EQS would affect a very small area of ca. 2.05 m^2. Considering the maximum mass of un-ionised ammonia derived from FRR biomass under conditions of thermal influence this would represent a very small fraction (0.0002%) of the mass that would be present in the daily exchange based on the mean annual background concentration.

4. For organic carbon deposition a benchmark is defined as 100g organic carbon/m^2/year. An equivalent daily value would be 0.3g organic carbon/m^2/day. During the winter the highest numbers of fish are discharged from the FRR and adopting the peak value of associated carbon this would contribute to an organic carbon loading at the benchmark standard level over an area of 0.15 km^2 (15.44 ha). Based on annual average biomass inputs the area at benchmark value would be equivalent to 0.06 km^2 (6.17ha).

These assessments are considered conservative as they assume instantaneous breakdown of biomass discharged from the FRR, no predation from benthic organisms and no redistribution of decaying material by tidal or wave action. In practice all these effects will occur and the predicted areas of effect on water quality status will be further reduced.

Ecological effects

1. Phytoplankton production levels within the two water bodies would not increase due to the added nutrients from the FRR.

2. The discharge of the FRR is within 500 m of higher sensitivity habitat polychaete reef and the organic carbon deposition has a very small potential overlap of 0.01% of the *Sabellaria* sublittoral reef habitat area for Bridgwater Bay. However, there is no overlap of the predicted area affected for

dissolved oxygen reduction or elevated un-ionised ammonia for this habitat. The area potentially affected by the discharge footprints is based on a most conservative assessment and considers the peak biomass discharge and assumes no predation of dead fish.

3. *Sabellaria* reef habitat is not considered a sensitive receptor for the additional organic carbon input as they are typically associated with dispersive conditions that would reduce settlement of material and evidence suggests ability to adapt to organically enriched conditions.

4. The FRR discharge would overlap with lower sensitivity intertidal and subtidal soft sediments. The potential impact footprint for elevated un-ionised ammonia is negligible. For reduced dissolved oxygen the influence of the plume may extend over 0.81 ha of low sensitivity habitat but this would represent less than 1% of each habitat concerned.

5. The organic carbon deposition has a larger footprint of potential area affected and this could overlap with an area of 6.31% moderate energy littoral rock, 5.24% intertidal soft sediments.

6. An assessment of the core species for each of the habitats with greater than 1% area affected indicates that many of the species are tolerant of smothering and deoxygenation. For moderate energy littoral rock areas macroalgal species may temporarily experience reduced growth with smothering but short life histories offer an advantage for rapid recolonisation and so effects are not expected to be significant.

7. Overall, discharges from the FRR are likely to have neutral to localised minor effects on core species of intertidal soft sediment and moderate energy littoral rock habitats in Bridgwater Bay. No significant changes to the community structure or function of these habitats are expected.

8. Localised changes to community structure and function within the small proportion (6%) of littoral rock that is intersected by the FRR footprint may occur. But these changes are not expected to be significant.

5.1 Conclusion

The predicted changes in water quality, to inorganic enrichment of benthic habitat and to phytoplankton production in Bridgwater Bay or Parrett Estuary water bodies due the FRR discharges are negligible and would cause no deterioration to the status of either of the water bodies. There is no overlap of predicted areas of potential effect for dissolved oxygen and un-ionised ammonia and only a very small overlap of the organic carbon footprint with sensitive *Sabellaria* reef habitat. However, the sensitivity of *Sabellaria* to the influence of elevated organic carbon loading is considered to be low. Insignificant areas of low sensitivity habitat would be affected by reduced dissolved oxygen or elevated un-ionised ammonia although small areas ca. 5% of two habitats are also affected by elevated organic carbon loading. However, the core species either are tolerant of smothering and or have short life histories and are able to rapidly recolonise new areas of habitat and as the assessments are conservative (not accounting for predation or initial dispersal of discharged biomass or the turbulent mixing within the water column the effects are minor and localised. No deterioration is therefore concluded for adjoining water bodies both upstream and downstream of the discharge.

In terms of the most recent Marine Strategy Framework Directive (MSFD) eutrophication assessment, the elevated BOD and ammonia have very localised influence and would not change the current MSFD status of “good” for the Atlantic Celtic Sea sub-region. The most recent eutrophication assessment published in 2019 (https://moat.cefas.co.uk/pressures-from-human-activities/eutrophication/) by Defra, showed that only a small number of eutrophication problems remain in coastal and estuarine waters, representing 0.03% of the total UK Exclusive Economic Zone, and 0.41% of estuarine and coastal waters. The closest “problem area” to HPC according to this assessment is the Loughbor estuary West Wales, and as the additional output of BOD and ammonia would be very localised, it would not contribute to the elevated concentrations observed there. Currently, there are no major outstanding issues for eutrophication in the UK as a whole and the inputs indicated for this assessment would make a negligible contribution to the overall loading for the Severn.

6 References

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Appendix A Nutrient chemicals potentially present in discharges during Hinkley Point C operation

A.1 Dissolved inorganic nitrogen and phosphorus inputs during operation

Source nutrient data for the operational discharge from the Hinkley Point C development is based on information provided in EDF, 2014 and is summarised in Table 5 and Table 6.

Table 5 – Nitrogen sources during operation of Hinkley point C based on (EDF, 2014)

Chemical	Maximum annual loading (kg y^{-1})	Maximum 24-hour loading (kg d^{-1})	Sanitary Waste Annual (kg y^{-1})	Sanitary Waste 24-hour loading (kg d^{-1})	Total Waste Annual (kg y^{-1})	Total Waste 24-hour loading (kg d^{-1})
Nitrogen (as N) (excluding hydrazine, morpholine and ethanolamine)	10130	328	1595[1]	4.4[1]	11725	332

1 These values were derived from waste stream G of HPC environmental permit. 1750 max staff during outage but have been updated for 1900 staff and have referenced and back calculated from figure of 23 mg/l discharge.

Table 6 – Phosphorus sources during operation of Hinkley point C based on (EDF, 2014)

Chemical	Maximum annual loading (kg y^{-1})	Maximum 24-hour loading (kg d^{-1})
Phosphate PO_4	790[1]	352.5[1]

1 Phosphorus values were calculated from these totals to give 257 and 115 kg P per year and per day respectively

Appendix B Calculation of moribund biomass from the FRR and potential contribution to nutrients,

B.1 Calculation of moribund biomass of fish discharged from the Fish Recovery and Return system

This section provides the supporting data and calculation used to derive the values for the FRR assessment. The values are the outputs of the modelling approach used to estimate impingement at HPB and are the same values that form the basis of the final impingement estimates (BEEMS Technical Report TR456). In TR456, only the final annual estimates for HPB are given.

For this work, calculations were carried out on the 8 most impinged species which account for over 96 % of the total number of fish impinged at HPB (Table 7). The base data for the calculations are the daily numbers of fish (and numbers at length) that were calculated for each of the HPB CIMP sampling visits in 2009 -2010 and which were used in the HPC impingement predictions (Table 8 HPC mean daily estimated number of fish impinged - **no head adjustment** (24 hours, full pumping capacity)

Species	Mean JAN	Mean FEB	Mean MAR	Mean APR	Mean MAY	Mean JUN	Mean JUL	Mean AUG	Mean SEP	Mean OCT	Mean NOV	Mean DEC
Sprat	33068	287	84	50	134	47	131	154	154	121	41635	51639
Whiting	5682	8461	3869	3363	2035	10890	3225	5640	5518	3137	9761	13108
Sole, Dover	8	74	78	465	2016	1255	4802	6474	1586	477	324	56
Cod	885	65	15	0	432	6070	911	1034	837	555	1031	724
Mullet, Thin-lipped grey	3119	248	122	10	3	0	14	58	198	60	220	2953
Flounder	64	190	157	1144	1286	1902	1067	553	443	110	34	24
Herring												
Goby	781	2222	280	35	0	104	90	64	100	133	238	202
Bass	17	148	77	158	51	23	2	836	304	313	502	174

Table 9). A description of the CIMP sampling carried out can be found in BEEMS Technical Report TR456.

For this analysis, mean daily numbers of fish impinged were calculated for each month, using the samples from that month. A monthly estimate of numbers impinged was calculated from the mean daily value and the number of days in that month. The annual total was obtained by summing the 12 monthly totals. This method differs from the final method used in the Hinkley Point impingement predictions (BEEMS TR456), in which the samples from each quarter were summed and a mean daily estimate was obtained for the quarter. Quarterly impingement numbers were calculated by raising by the ratio of the number of days in the quarter versus the number of samples. This means that the annual totals calculated using the two methods will be slightly different. For both methods, the mean estimated daily values for HPB (Table 7) were raised to predicted daily values for HPC (Table 8) on the ratio of the pumping capacities of the two stations (i.e. the HPB daily mean values were multiplied by 131.86/33.7 cumecs).

Next, survival through the HPC FRR was considered, as the more robust species will not all die during their passage through the cooling water systems. The mean daily HPC values are adjusted to account for the reduction in impingement from the planned LVSE intake heads, Table 9. (Impingement reduced by a factor of 0.646). Due to the capped head design, the impingement of pelagic species will be reduced by an additional factor of 0.38.

Adjustments are then made for survival rate for different species with the FRR fitted (Table 10).

The resulting numbers lost to impingement were then converted to weight using the mean length of each species in the impingement samples and published length-weight relationships (Table 11). The size distributions used are shown are the same as those used to calculate Equivalent Adult Value metrics for Hinkley Point species and are given in the Appendix of BEEMS Technical Report TR426. The length-weight relationships used were taken from Silva *et al* (2013).

The predicted reduction in impingement due to the LVSE intakes is as described in BEEMS Technical Report TR456 and was calculated by comparing the impingement risk zones at HPC and HPB. This was an approximate calculation and only compared performance at mid tide assuming a fixed alignment of the head with the tide. Recognising that the limitations with this approach, conservative assumptions were used in the calculation. In stakeholder meetings with the Environment Agency after the production of TR456 the derivation of this impingement reduction factor has been discussed. The EA have criticised the methodology and suggested that a full tidal cycle assessment including the effects of tidal asymmetry should be undertaken. This approach recognises that the alignment of the head with the tide is not always perfect and that at slack water the head extracts from a much wider range of directions. The EA helpfully provided a worked example.

It is agreed that the proposed EA approach is more thorough and so the impingement reduction factor has been recalculated based upon the EA methodology. Tidal asymmetry is not extensive at the HPC intake locations and it was found that the revised calculation of the LVSE improvement factor is within approx. 5% of the original calculation (after correcting for an error in the original calculation of the projected error of the HPB intake). This difference is not material and so has not been included in the assessment conducted for this report (TR515)

Table 7 HPB mean daily estimated number of fish impinged

Species	MeanJAN	MeanFEB	MeanMAR	MeanAPR	MeanMAY	MeanJUN	MeanJUL	MeanAUG	MeanSEP	MeanOCT	MeanNOV	MeanDEC
Sprat	8451	73	22	13	34	12	34	39	39	31	10641	13197
Whiting	1452	2163	989	860	520	2783	824	1441	1410	802	2495	3350
Sole, Dover	2	19	20	119	515	321	1227	1655	405	122	83	14
Cod	226	17	4	0	110	1551	233	264	214	142	264	185
Mullet, Thin-lipped grey	797	64	31	2	1	0	3	15	51	15	56	755
Flounder	16	48	40	292	329	486	273	141	113	28	9	6
Herring	200	568	71	9	0	27	23	16	26	34	61	52
Goby	4	38	20	40	13	6	1	214	78	80	128	44
Bass	24	43	24	35	8	35	18	11	23	30	17	19

Table 8 HPC mean daily estimated number of fish impinged - **no head adjustment** (24 hours, full pumping capacity)

Species	MeanJAN	MeanFEB	MeanMAR	MeanAPR	MeanMAY	MeanJUN	MeanJUL	MeanAUG	MeanSEP	MeanOCT	MeanNOV	MeanDEC
Sprat	33068	287	84	50	134	47	131	154	154	121	41635	51639
Whiting	5682	8461	3869	3363	2035	10890	3225	5640	5518	3137	9761	13108
Sole, Dover	8	74	78	465	2016	1255	4802	6474	1586	477	324	56
Cod	885	65	15	0	432	6070	911	1034	837	555	1031	724
Mullet, Thin-lipped grey	3119	248	122	10	3	0	14	58	198	60	220	2953
Flounder	64	190	157	1144	1286	1902	1067	553	443	110	34	24
Herring												
Goby	781	2222	280	35	0	104	90	64	100	133	238	202
Bass	17	148	77	158	51	23	2	836	304	313	502	174

Table 9 HPC mean daily estimated number of fish impinged – **with head adjustment** (24 hours full pumping capacity)

Species	MeanJAN	MeanFEB	MeanMAR	MeanAPR	MeanMAY	MeanJUN	MeanJUL	MeanAUG	MeanSEP	MeanOCT	MeanNOV	MeanDEC
Sprat	8117	70	21	12	33	12	32	38	38	30	10221	12676
Whiting	3670	5466	2499	2173	1314	7035	2083	3644	3565	2026	6306	8468
Sole, Dover	5	48	50	301	1302	811	3102	4182	1025	308	209	36
Cod	571	42	10	0	279	3921	589	668	541	359	666	468
Mullet, Thin-lipped grey	2015	161	79	6	2	0	9	38	128	39	142	1908
Flounder	41	122	102	739	830	1229	689	357	286	71	22	15
Herring	504	1436	181	23	0	67	58	42	65	86	154	130
Goby	11	95	50	102	33	15	1	540	196	202	324	112
Bass	61	109	61	89	21	89	45	28	57	76	42	48

Table 10 HPC mean daily estimated number of fish impinged – **with FRR fitted** (24 hours full pumping capacity)

Species	MeanJAN	MeanFEB	MeanMAR	MeanAPR	MeanMAY	MeanJUN	MeanJUL	MeanAUG	MeanSEP	MeanOCT	MeanNOV	MeanDEC
Sprat	8117	70	21	12	33	12	32	38	38	30	10221	12676
Whiting	1835	2733	1250	1086	657	3518	1042	1822	1782	1013	3153	4234
Sole, Dover	1	10	10	60	260	162	620	836	205	62	42	7
Cod	286	21	5	0	140	1961	294	334	270	179	333	234
Mullet, Thin-lipped grey	1007	80	39	3	1	0	4	19	64	19	71	954
Flounder	8	24	20	148	166	246	138	71	57	14	4	3
Herring	504	1436	181	23	0	67	58	42	65	86	154	130
Goby	2	19	10	20	7	3	0	108	39	40	65	22
Bass	43	76	43	62	15	62	32	20	40	53	30	34

Table 11 HPC mean daily estimated weight of fish impinged (kg)

Species	weight at mean length (kg)	MeanJAN	MeanFEB	MeanMAR	MeanAPR	MeanMAY	MeanJUN	MeanJUL	MeanAUG	MeanSEP	MeanOCT	MeanNOV	MeanDEC
Sprat	0.005	43.5	0.4	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	54.8	67.9
Whiting	0.013	23.8	35.4	16.2	14.1	8.5	45.5	13.5	23.6	23.1	13.1	40.8	54.8
Sole, Dover	0.013	0.0	0.1	0.1	0.8	3.4	2.1	8.1	10.9	2.7	0.8	0.5	0.1
Cod	0.012	3.5	0.3	0.1	0.0	1.7	24.0	3.6	4.1	3.3	2.2	4.1	2.9
Mullet, Thin-lipped grey	0.008	8.2	0.7	0.3	0.0	0.0	0.0	0.0	0.2	0.5	0.2	0.6	7.8
Flounder	0.041	0.3	1.0	0.8	6.1	6.8	10.1	5.7	2.9	2.4	0.6	0.2	0.1
Herring	0.006												
Goby	0.001	0.000	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.08	0.03	0.03	0.05
Bass	0.035	1.5	2.7	1.5	2.2	0.5	2.2	1.1	0.7	1.4	1.9	1.0	1.2
Day total	-	84.1	49.7	20.3	23.4	21.2	84.5	32.6	43.0	34.0	19.5	103.0	**135.6**
Month total	-	2606	1393	629	701	656	2535	1010	1332	1020	603	3091	**4204**

[1]Maximum for the year daily mean biomass value was for month of December and this is used for calculation (135.6 kg a day and 4204 kg/month);

B.2 Calculation of dead biomass discharged from the HPC FRR system potential contribution to nutrient input, influence on dissolved oxygen, un-ionised ammonia and organic enrichment

The total biomass of dead biota that potentially may be discharged from the FRR has been estimated based on the level of abstraction (pump rates) for the planned Hinkley Point C intakes and the information on seasonal distribution of species and length weight distribution of the species impinged for the existing Hinkley Point B (BEEMS TR456). The derived HPC data indicate that the highest biomass discharged occurs during December at an average value of 135.6 kg per day. Estimates of tissue concentration for nitrogen and phosphorus from several studies are shown in Table 12.

Table 12 Phosphorus and nitrogen concentration data for fish tissue derived from several studies and which is used in calculation of potential nutrient loadings released during decay of dead fish released from the FRR

Nutrient	g/kg	Percentage (wet weight)	Average daily biomass (135.6 kg) nutrient content April to September	Average Daily biomass (54.2 kg) nutrient content (January - December)	Literature Source
P content	3.74-4.7 (ww)	0.47	(135.6/100) x0.47=0.64 kg	-	Storebakken et al., 2000
P content		0.45-0.5	**0.68 kg**	0.27	Gende et. al., 2004
N content		3.2-3.5	**4.75 kg**	1.90	Walker et. al., 2011
N content		3.4	4.61 kg	1.94	Gende et. al., 2004

The April to September period represents a time when sea temperatures and light levels at depth are increasing and phytoplankton growth is also increasing. The highest mean daily loading of impinged fish is predicted for December and so this value (135.6 kg) is used in calculations. Multiplying 135.6 kg by the maximum estimates of phosphorus and nitrogen (Table 12) give maximum daily loadings of **4.75 kg N** and **0.68 kg P** per day.

Un-ionised ammonia

Un-ionised ammonia is also calculated for December as increasing temperatures and increasing growth and reproduction of species make this a more critical period. The ammonia, NH_4-N concentration derived from a study of cod tissue (Timm and Jorgensen, 2002) is used to derive an equivalent value for fish biomass:135.6 (kg) fish biomass x 125 =Total mg NH_4-N (16,950). This value was used in the un-ionised ammonia calculator along with extreme background conditions (except for temperature) for Hinkley Point (pH 8.06 (95th percentile), salinity 31.7 (5th percentile) and mean temperature 12.55°C (annual mean), to derive an equivalent un-ionised ammonia value= 349,665 μg NH_3-N
A mean background NH_4-N concentration of 124 μg/l measured in an annual survey at Hinkley Point (Amec, 2009) was converted to an equivalent NH_3-N background value of 2.57 μg/l based on average temperature, salinity and pH from the same annual survey.

Volume litres required to dilute this mass of NH_3-N to the EQS of 21 μgl^{-1} NH_3-N minus natural background: 349665/(21-2.57)=18,973 litres

The 18,973 litres of seawater with an ammonia concentration equivalent to the EQS of 21 μgl^{-1} NH_3-N is derived from decaying organic matter that is likely to be predominantly associated with the seabed. As the ammonia is produced from decaying organic matter it is likely to be rapidly mixed and dispersed by tidal currents so that negligible areas are affected by un-ionised ammonia levels at or above the EQS. Hypothetically if mixed evenly through the full depth of the water column (7m) the volume of seawater at EQS would affect a very small area of ca. 1.65 m^2.

Using the same biomass loading a similar calculation was made but including an uplift of 2°C to account for thermal elevation by HPB+HPC. These values were used for the un-ionised ammonia calculator. This adjustment results in un-ionised ammonia load of 407,484 µg NH_3-N and a dilution volume of 22,098 litres (. Hypothetically if mixed evenly through the full depth of the water column (7m) the volume of seawater at EQS would affect a very small area of ca. 2.05 m^2.

Based on the natural background concentration of 2.57 µg/l NH_3-N and a daily exchange in Bridgwater Bay of 10% (Dyer, 1979) of the total volume (9.77×10^7) an equivalent mass of 251 kg NH_3-N/day would be present in the water exchange. The maximum mass of 407,484 µg NH_3-N from the daily biomass (including thermal influence) predicted to be discharged from the FRR represents only 0.0002% of the daily mass of un-ionised ammonia present in the daily tidal exchange for Bridgwater Bay.

BOD

For BOD calculation the annual daily average for December (the highest daily value) is used = 135.6 kg per day biomass
The oxygen demand generated from this biomass is estimated based on an equivalent value of 3.5 g oxygen are required for complete oxidation of one gram of organic matter (Stigebrandt, 2001).
The estimate of BOD load per day is:
135.6 x (3.5 x dry weight/wet weight conversion 0.36, from Wang *et al*., 2013) = 171 kg BOD -Total oxygen reduction potential based on OSPAR information a BOD of 1.5 mgl^{-1} is equivalent to 0.5 mgl^{-1} oxygen reduction in the receiving water:

(i) (171/1.5) x 0.5= **57 kg/day O_2 reduction**
(ii) At a background dissolved oxygen concentration level of 5mg/l 11,390 m^3 of seawater would contain 57 kg oxygen. This volume is present in a surface area of 0.16 ha at depth 7 m
(iii) A dissolved oxygen reduction of 1mg/l in a volume of 56,952 m^3 would also be equivalent to 57 kg oxygen and would represent an area of 0.81 ha at depth 7 m
(iv) The daily volume exchange of 10% (Dyer, 1979) = 97,700,000 m^3
(v) 11,390/97,700,000=**0.01% of daily exchange**

Also, in addition to daily exchange, daily reaeration at the sea surface contributes 3.2 $gm^{-2}d^{-1}$ (Hull et al., 2016):

Based on an O_2 reduction of 57 kg reaeration over 57/0.0032= 17,797 m^{-2} (**1.78 ha**) would also meet this daily oxygen demand.

Organic enrichment

The area potentially effected by organic enrichment resulting from the decomposition of moribund fish biomass was determined relative to a benchmark of 100g organic carbon/m^2/year (Tyler-Walters *et. al*., 2018). The carbon content of fish biomass was derived from results reported by Alves *et. al*., 2019 that the carbon content of fish processing waste was 64.7% of the dry weight and the wet weight to dry weight conversion factor was 0.48.

Area calculations were as follows:

(i) Peak biomass of fish discharged from FRR was in December at 135.6 kg per day
(ii) 135.6 kg converted to dry weight and then to weight of carbon (135.6 x 0.48) x 0.65 = 42.3 kg
(iii) Daily carbon load is divided by daily benchmark carbon as referenced above and converted to a daily value 42.3/(0.1kg/365 days)=154,421 m^2 effected
(iv) Convert metres to hectares and square kilometre = **15.44 ha or 0.15 km^2**.

Appendix C Phytoplankton and Macroalgal model trial run incorporating the effect of Hinkley Point C

The nutrient loadings during construction/cold commissioning, operation and including the FRR are shown in Table 13. A typical value for the exchange rate coefficient in partially mixed estuaries is 5% volume exchange on each tide (Dyer, 1979), thus 0.1 per day is the value used in Table 13 for calculation of the daily nutrient exchange of Bridgwater bay with the wider environment.

Table 13 Summary of phosphate and nitrogen discharge during construction/cold commissioning and operational phase and the fraction relative to the daily exchange with the wider environment.

Substance	Daily loading during operation kg (and annual loading kg) including FRR	Peak 24 hr load during operation kg d^{-1}	Daily exchange with wider environment, Kg	% of exchange for average daily loading in operation and including FRR
Nitrogen (as N) Including FRR	32 (11725) +4.64 (1694)	332[1]	96,873 (as N)[2]	0.03% 0.04%
Phosphates as P Including FRR	0.71 (257) +0.66 (241)	115[1]	1,075 (as P)[2]	0.10% 0.13%

[1] Extracted from EDF, 2014 (operational loadings of different nitrogen sources as N and PO_4 loading converted to P). [2] These values are based on a 10% exchange of the volume of Bridgwater bay and are derived from background concentrations of N and P (Amec, 2009).

An attempt was made to model the effects of increased nutrients on phytoplankton production in Bridgwater Bay. This appendix describes the results of that assessment

C.1.1 Observations of chlorophyll-a concentration Bridgwater Bay.

In estimating the effect of either the HPB or HPC power station on phytoplankton, the total population must be considered and the speed with which it reproduces. For this, measurements of chl-a concentration can be used as a proxy for cell concentration and hence biomass. In the Severn Estuary, the high levels of suspended solids result in a much-reduced euphotic zone ca.3% of the water column (Joint and Pomroy, 1981). As shown in Figure 4 the mean concentrations of chlorophyll in Bridgewater bay are low and there is not a particularly strong seasonal signal in chlorophyll-a concentration in the area; there are generally higher values in the summer months when primary production would be expected to occur, but only a few µg/l above the background winter levels.

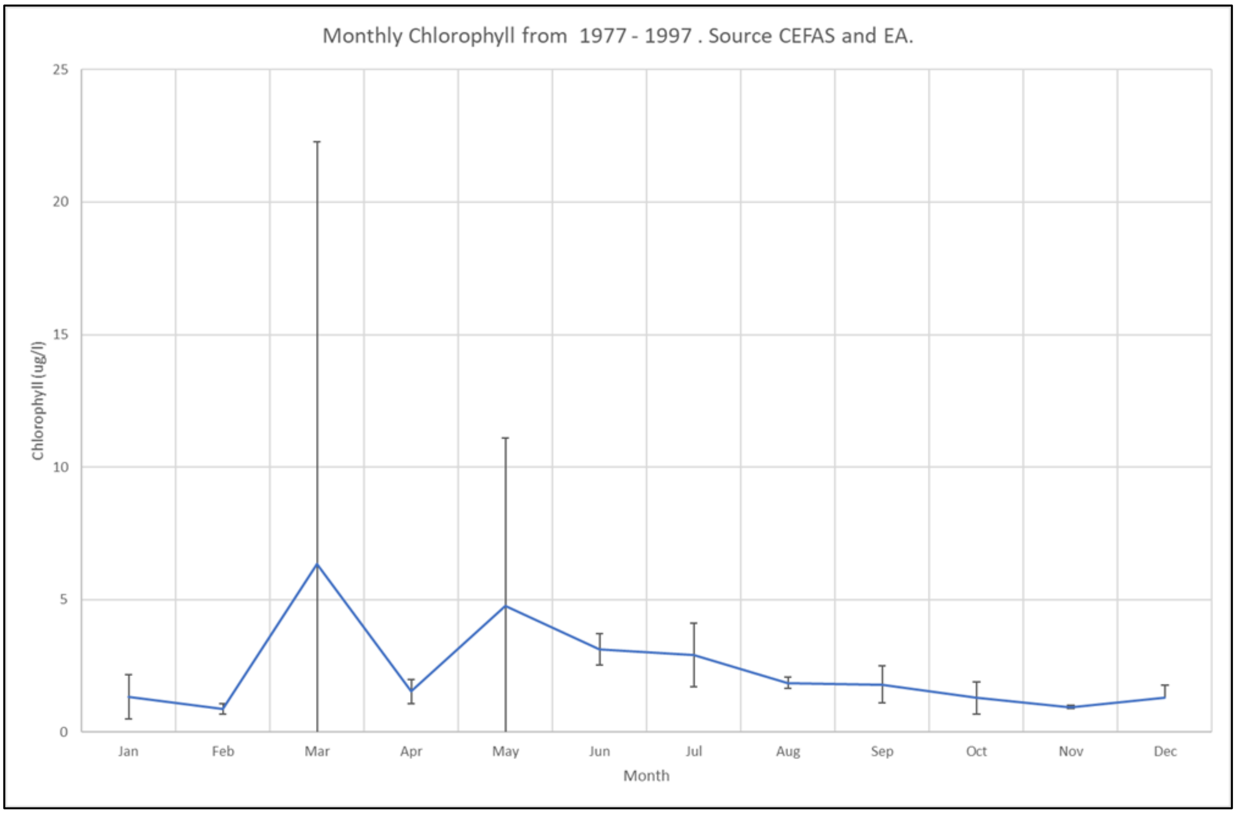

Figure 4 Observations of Chl-a in Bridgewater bay per month from Cefas database 1977 – 1997. The March data has one data point at 48 µg/l which skews the data set.

C.1.2 Phytoplankton production model description

The Combined Phytoplankton and Macroalgae (CPM) model was used to predict the effect of Hinkley C on phytoplankton community biomass. This model has been successfully deployed to model phytoplankton production in other estuaries but not in the Severn.

The model simulates the dynamics of phytoplankton biomass using data on known environmental drivers such as nutrients and light. The original CPM model combined two earlier models developed for the Environment Agency : one for phytoplankton, based on the UK Comprehensive Studies Task Team (CSTT) (CSTT, 1994, 1997; Painting *et al.*, 2003, 2007) and one for macroalgae (Cefas, 2003; Aldridge and Trimmer, 2009). The first version of the CPM model (Aldridge *et al.*, 2008) was developed as a static equilibrium model based on summer or annual average values, the subsequent version (used here) implements a dynamic model that does not rely on equilibrium assumptions and permits daily estimates of phytoplankton growth.

C.2 Basic concepts ('how the model works')

A detailed presentation of the physical, biological and mathematical structure of the model is given by Aldridge *et a*l., 2010. A schematic summary of the main features of the model is shown in Figure 5. Several kinds of primary producers are found in coastal environments. Microalgae are found in the water column, as the phytoplankton, and in or on the seabed, as the microphytobenthos. Associated larger producers include seaweeds (macroalgae) and aquatic macrophytes (seagrasses and saltmarsh). The current CPM model simulates phytoplankton and macroalgae.

At any instant the total biomass of producers is controlled by the least available, or limiting, resource. This can be a nutrient (nitrogen or phosphorous), or light. If nutrients control biomass, then the total biomass of primary producers stops increasing when the rate of nutrient input equals the rate of consumption. However, the limiting resource changes with time and the dynamic model solves the underlying equations for the rate of change of phytoplankton biomass without requiring assumptions of equilibrium. The version of the dynamic CPM model represented here is a single box with an exchange rate with outside waters.

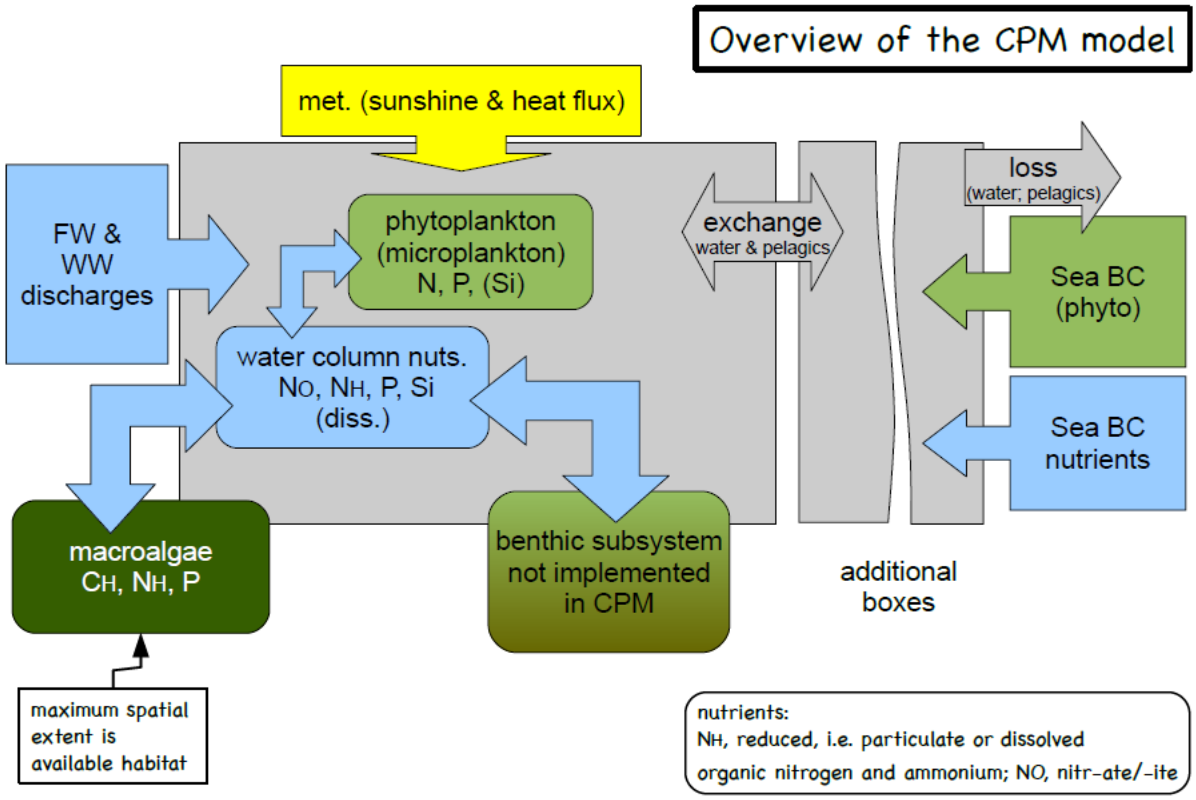

Figure 5: Schematic of CPM model components and processes (Aldridge *et al*., 2010 and Aldridge *et al*., 2012)

Where FW is fresh water, WW wastewater, N nitrogen, P phosphorous, Si silicate, BC boundary conditions, N_O nitrate and nitrite, N_H organic ammonium and Nitrogen, C_H Carbon,

C.3 Phytoplankton and model runs incorporating the effect of Hinkley C

An attempt was made to parameterise the CPM model for Bridgwater Bay (Table 14) but it was not possible for the model to simulate phytoplankton production at Kd values greater than 1. This is much lower than would be directly measured in estuary, or that predicted by the equation of Devlin 2009. Using the Devlin equation, the value of 1 is associated with SPMs of about 15 mg/l. Values in near surface waters around Bridgwater Bay could theoretically be as low as this on exceptionally calm days in summer but are more realistically in the range of 100 – 800 mg l^{-1} (Underwood, 2010). However, if such realistic values are used the model does not predict any production at all. It is entirely possible that no primary production occurs in the water column and that all measurements are due to Microphytobenthos from the sediment being resuspended. Using an unrealistic value of Kd of 1 enabled some production to occur so that the theoretical effect of the power station discharges could be seen.

Table 14 Input parameters for CPM model

Area (km2)	Average depth (m)	Light attenuation coefficient	Winter background N µmol l^{-1}	Winter background P µmol l^{-1}	Summer background N µmol l^{-1}	Summer background P µmol l^{-1}
91.84	10.6	1	75	1.9	50	1.9

C.3.1 Incorporation of nutrients.

To confirm that additional nutrient inputs make no contribution to production in a light limited system model runs included the nutrients due to the operational discharges of treated sewage and operational inputs of nitrogen and phosphorus. During operation a FRR would be operational and there is some potential that nutrient inputs may be contributed from decaying biomass:

The FRR aims to discharge fish live to the receiving waters. However, some sensitive species such as clupeids are highly sensitive to mechanical damage caused during passage through the cooling water intakes, drum screens and FRR channels and incur high mortality rates. The return of dead and moribund biota retains biomass within the system, but decay of organic material would release nutrients into the system. There is a variable seasonal bias to impingement numbers, and the return of dead biomass.

A further highly conservative assumption was applied whereby all this mass of fish was assumed to be available as nitrogen and phosphorus sources leading to an additional 4.64 kg per day of nitrogen (based on *Walker et. al., 2011*) and 0.66 kg of phosphorus (based on Gende *et. al.,* 2004) per day, in addition to other operational inputs (Appendix A1).

The nutrient loadings during operation including the FRR are shown in Table 12. A typical value for the exchange rate coefficient in partially mixed estuaries is 5% volume exchange on each tide (Dyer, 1979), thus 0.1 per day is the value used in Table 13 for calculation of the daily nutrient exchange of Bridgwater bay with the wider environment.

C.3.2 Model results - production.

Under background conditions phytoplankton gross production is 10.49g Carbon m^{-2} y^{-1}. Evident from Table 15 is that only entrainment mortality influences change in predicted phytoplankton production with a 6.5% reduction resulting from entrainment. It should be noted that the phytoplankton production in the estuary is very low and these estimates are likely to be overestimates.

Table 15 Summary of change in annual production taking account of entrainment mortality, and nutrient inputs for an operational HPC.

Scenario	Phyto Annual Gross Production, (g C m^{-2} y^{-1})	Phyto Annual Gross Production, (g C m^{-2} y^{-1}) Reference	Percentage difference from reference
HPC operation nutrients no FRR	9.81	10.49	6.5%
HPC operation + nutrient with FRR	9.81	10.49	6.5%

Light is the limiting factor throughout the entire year. In the absence of entrainment mortality due to chlorination the reduction in phytoplankton production would be smaller (contributed by thermal elevation only) but additional nutrient input from the FRR would make no difference to the predicted phytoplankton production due to light limitation.