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# Modelling the effect of Sizewell C entrainment on the phytoplankton of Sizewell Bay.

# Modelling the effect of Sizewell C entrainment on the phytoplankton of Sizewell Bay

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## Figures

***Please note that the red line boundary used in the figures within this document was amended after this document was finalised, and therefore does not reflect the boundaries in respect of which development consent has been sought in this application. However, the amendment to the red line boundary does not have any***

***impact on the findings set out in this document and all other information remains correct.***

# Executive summary

The effect of Sizewell B (SZB) and the proposed Sizewell C (SZC) on phytoplankton that pass through the power station has been simulated using a phytoplankton box model. The model has been tuned through adjustment of the light attenuation and exchange coefficient to replicate field observations at Sizewell and the observed cycle of plankton production has successfully been simulated with emphasis on the spring bloom and summertime production. The power stations have been incorporated into the model by considering them as an increase in phytoplankton mortality.

This version of the report updates the simulation to include additional nutrient inputs from the construction and operation of SZC including sources of nitrogen and phosphorus arising from the decay of dead fish discharged from the fish recovery and return system (FRR). The effects of thermal uplifts arising from cooling water discharges during the operational phase have also been considered within the model.

The conclusions of the study are:

1. Total phytoplankton production in the modelled abstraction area is predicted to be reduced by approximately 5% due to phytoplankton entrainment mortality from SZB and SZC.
2. The simulation without the power stations shows annual production of 7491 tonnes of carbon in the abstraction zone. Environment Agency data collected from the area from 1992 to 2013 indicates that the standard deviation of monthly mean chlorophyll *a* concentrations is 42% of the mean, and annual chlorophyll *a* values varies by 45% of the mean (Table 1). Contextualised against high rates of natural variability, the predicted losses of gross annual phytoplankton productivity are minor.
3. SZC will discharge small volumes of nutrients in the form of phosphate and nitrates, which will tend to increase local phytoplankton productivity. For much of the year light availability limits phytoplankton growth and the addition of relatively small quantities of nutrients has no effect. In the summer, nitrate is a limiting nutrient (when light is not limiting) and is consumed rapidly. However, the nutrient exchange with the wider marine environment is much greater than the maximum proposed discharges, during either operation or construction, such that the predicted increase in phytoplankton growth due to the SZC discharges would be negligible (<0.3%). No discernible effects are anticipated on the prevalence of opportunistic macroalgae in the Blyth or the more distant Alde Orr Estuary as a result of the small-scale nutrient additions.
4. Local seawater temperature increases caused by the power station thermal plumes will not increase phytoplankton growth, however the uplifts will result in slightly increased zooplankton activity and grazing leading to a predicted small decrease in chlorophyll concentration and total phytoplankton production (1%).
5. Combining the effects of entrainment mortality, increased nutrient discharges and the effects of the thermal plumes, the predicted local reduction in total phytoplankton production by SZB+SZC is about 6% over the reference (no stations) condition.
6. There is greater daily exchange of water between Sizewell Bay and the greater Southern North Sea than there is daily extraction of water due to the power stations. Due to this exchange, the apparent concentration of phytoplankton will not be reduced in Sizewell Bay when considered against the high natural variability. In particular, the predicted effect of either the present SZB or the proposed SZC would not be observable in any monitoring programme.
7. Other marine organisms that predate on phytoplankton in the area would not be adversely affected because they will already be adapted to the very large natural variability in phytoplankton production.

# 1 Background and observational data relating to phytoplankton.

The environmental impact assessment for the proposed Sizewell C (SZC) power station requires consideration of the effects of cooling water abstraction and discharge on the coastal ecosystem. As a key component of that system, it is important to understand how the entrainment in the cooling water system would affect the phytoplankton community of Sizewell Bay. Experimental studies provide evidence on the responses of individual phytoplankton species or groups to the pressures associated with cooling water abstraction (BEEMS Technical Report TR363). However, estimating the effect on phytoplankton distribution and primary production is difficult and a wider approach is required to understand these effects in the context of the community. Here, we use a simple box model to estimate the effects of the SZC cooling water extraction on total phytoplankton biomass.

SZC will abstract cooling water from the marine environment at a rate of approximately 132 $m^3 s^{-1}$ (compared to approximately 51.5 $m^3 s^{-1}$ for the existing Sizewell B (SZB) station. The cooling water will be heated by approximately 11.6°C and treated with a chlorine-based biocide to prevent biofouling. The combined effect of which is estimated to be up to 90 % mortality of phytoplankton (BEEMS Technical Report TR363) for those cells that have passed through the station. The cooling water will be returned to the marine environment at approximately the same location from which it was extracted. The phytoplankton biomass, although degraded, will be unchanged.

## 1.1 Conceptual understanding of the system.

The proposed SZC intakes, at 3 km offshore, will be in an open coast situation where there is exchange with Sizewell Bay and with the open sea, whereas those of SZB are closer inshore (800 m from coast) (Figure 1), meaning that the SZB intakes extract water from Sizewell Bay, whereas the SZC intakes will extract water along the tidal excursion offshore (Figure 2). Sizewell Bay is a useful comparison unit, but it is not a closed system - there is greater daily exchange of water between Sizewell Bay and the greater Southern North Sea than there is daily extraction of water due to the power station. Due to this exchange, the apparent concentration of phytoplankton will not be reduced in Sizewell Bay by the power stations, because no effect of either the present SZB nor the proposed SZC station would be observable due to the continual refreshment and the high levels of natural variability in phytoplankton density.

Modelling can be used to estimate the effect of the power station from a simulation of the system with and without the power station, but this approach requires an estimate of the appropriate volumes for the power station effects. The intakes of Sizewell B and C will extract water along the tidal excursion. At the SZB intake, it is Sizewell Bay that can be considered as the appropriate volume that will reasonably be the water body from which the water is extracted. For Sizewell C, at 3 km offshore there is no topographical constraint, and the water will be extracted from along the tidal excursion either side of the intakes. A current meter (S2) deployed in the vicinity of the Sizewell C intakes (BEEMS Technical Report TR047) indicated that the North – South excursion is approximately 16 km, and 2km East – West during spring tides (Appendix A). Water is extracted from this distance either side of the intake, hence the appropriate comparison volume is twice this at approximately 32 km by 2 km. These volumes are approximate but serve as a guideline to help understand the significance of the potential phytoplankton reduction in the Sizewell Bay area and surroundings due to the power station.

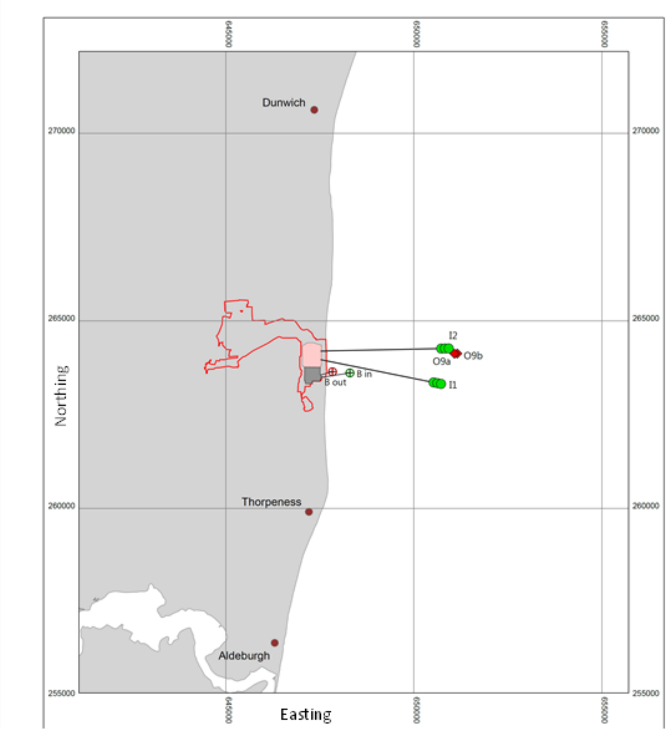

Figure 1: Overview of the SZC and SZB intakes and outfalls (top).

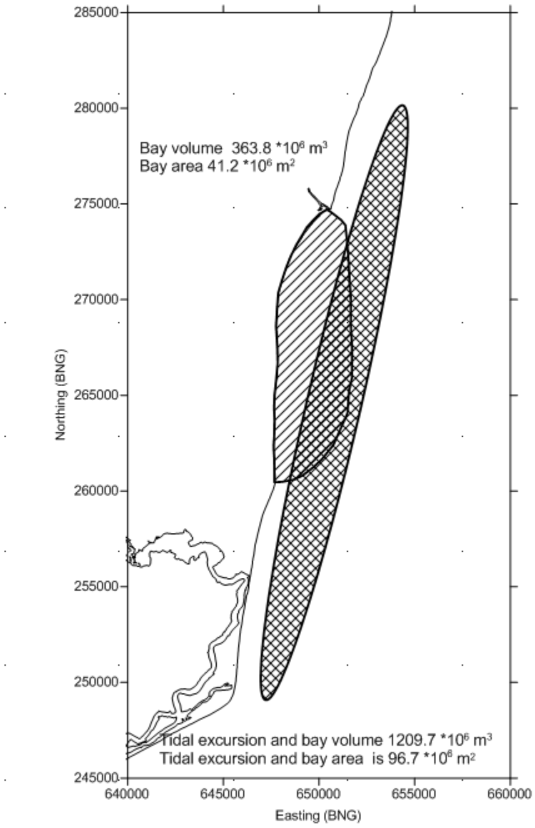

Figure 2: Areas from which the Sizewell B and Sizewell C intakes extract cooling water (used to calculate volumes for use in the simple box model). Single hash marks encapsulate the Sizewell Bay region and the double hash marks the volume used in association with the Sizewell C intakes.

## 1.2 Observations of phytoplankton (chlorophyll-a concentration).

In estimating the effect of either the SZB or SZC power station on phytoplankton, the total population has to be considered and the speed at which it reproduces. For this, measurements of chl-a concentration can be used as a direct proxy for cell concentration and hence biomass. BEEMS has characterised the phytoplankton community of Sizewell Bay, using a series of surveys to determine taxon composition, cell numbers and chl-a concentrations (BEEMS Technical Reports TR326, TR379). The Environment Agency (EA) have also gathered chl-a data from the Sizewell Bay area and the Cefas West Gabbard Smartbuoy is located off Felixstowe in a similar water body (BEEMS Technical Report TR346 reproduced in Figure 3). As shown in Figure 3, there is a strong seasonal signal in phytoplankton concentration in the area; the peak of the spring bloom occurs in early May, with a period of rapid growth beforehand and rapid mortality thereafter.

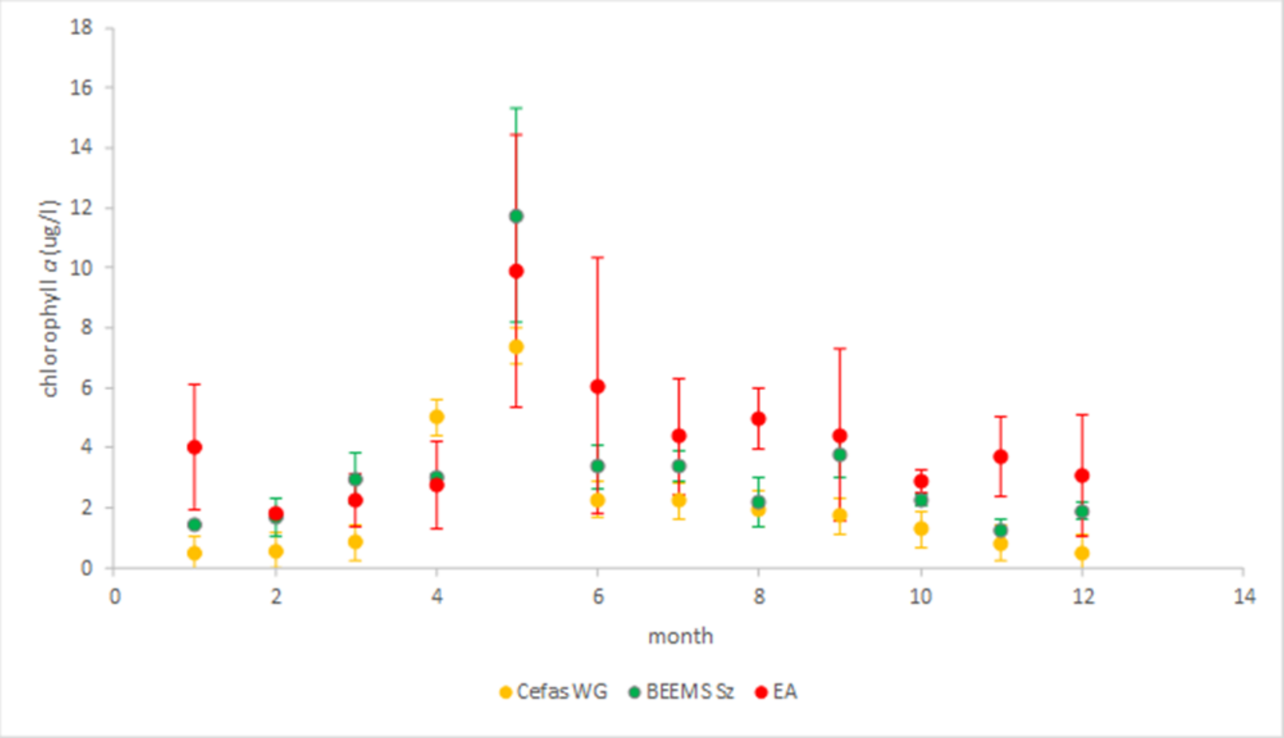

Figure 3: Combined monthly observational data from Sizewell collected by BEEMS, the Environment Agency (EA) and from the nearby West Gabbard (WG) smartbuoy location (Adapted from BEEMS Technical Report TR346). Monthly mean (± SD) of chlorophyll *a* at the West Gabbard mooring site between 2008 and 2014 (yellow), BEEMS Sizewell surveys 2012 and 2014 (green) and EA monitoring sites between 1992 and 2013 (red). X-axis represents the month of the year from January to December (1 to 12).

Noticeable from Figure 3 is the large interannual variation in monthly chlorophyll measurements. The EA dataset has the longest observation span and it is, therefore, the most appropriate data to use for consideration of interannual variability as shown in Table 1. The standard deviation as a percentage of the mean represents a typical interannual variance of monthly values between years and is 42% by month or 45% by total mass of chlorophyll.

Table 1 Monthly mean chlorophyll-a and inter-annual variance from the EA 1992 - 2013 data.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 4.0 | 1.8 | 2.3 | 2.8 | 9.9 | 6.1 | 4.4 | 5.0 | 4.4 | 2.9 | 3.7 | 3.1 |
| Stdev | 2.1 | 0.1 | 0.9 | 1.5 | 4.6 | 4.3 | 1.9 | 1.0 | 2.9 | 0.4 | 1.3 | 2.0 |
| Stdev as % of mean value | 52% | 6% | 39% | 53% | 46% | 70% | 44% | 20% | 65% | 13% | 35% | 66% |

# 2 Model setup and validation

## 2.1 Model description

We used the Combined Phytoplankton and Macroalgae (CPM) model to predict the effect of Sizewell C on phytoplankton community biomass. This 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 (EA): 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.

## 2.2 Basic concepts ('how the model works')

A detailed presentation of the physical, biological and mathematical structure of the model is given by Aldridge and Tett, 2011. A schematic summary of the main features of the model is shown in Figure 4. 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. It does not simulate seagrasses or saltmarsh, but this is of no import for the current application because there are no seagrass or saltmarsh habitats in the area from which SZC will extract seawater. In the case of Sizewell Bay, the intertidal and subtidal seabed is predominantly devoid of macroalgae, so these are not important for our purposes and are not considered.

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.

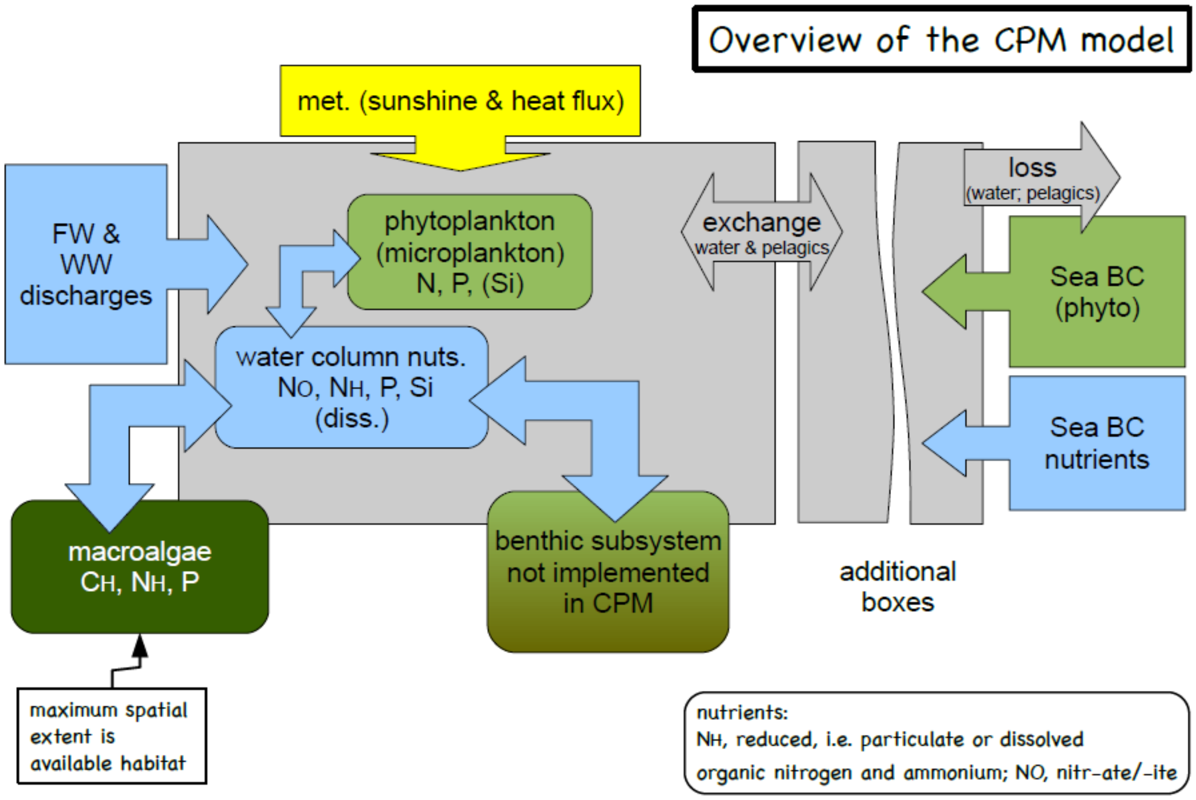

Figure 4: Schematic of CPM model components and processes (Aldridge et al., 2011)

Where FW is fresh water, WW wastewater, N nitrogen, P phosphorous, Si silicate, BC boundary conditions, No nitrate and nitrite, $N_H$ organic ammonium and Nitrogen, $C_H$ Carbon,

## 2.3 Model sensitivity to light extinction coefficient and exchange rate

Table 2: Typical initial parameters for model sensitivity tests

| **Spring tidal range (m)** | **Winter N Concentration in adjacent seawater ($S_0$), (µM $l^{-1}$)** | **Summer N Concentration in adjacent seawater ($S_0$), (µM $l^{-1}$)** | **Winter P Concentration in adjacent seawater ($S_0$), (µM $l^{-1}$)** | **Summer P Concentration in adjacent seawater ($S_0$), (µM $l^{-1}$)** | **Exchange rate (E), ($d^{-1}$)** | **Loss of microplankton (L), ($d^{-1}$)** | **Mean Kd ($m^{-1}$)** |
|---|---|---|---|---|---|---|---|
| 2.20 | 30.00 | 10.00 | 1.29 | 0.65 | 0.10 | 0.137 | 0.60 |

Note: Winter = Oct-Mar, Summer = Apr-Sep

The model has a number of key parameters which need to be considered during the setup. The most important are the light attenuation coefficient (Kd) and the exchange rate with the larger environment E. If observations are available, it is recommended to tune these values to fit the model to the observations.

There is a strong seasonal signal to the suspended sediment concentration (SSC) in Sizewell Bay with very high winter values to much lower summer values. (BEEMS Technical Report TR346). All observations both in situ and inferred from satellite show a consistency in this seasonal cycle and that inshore of the Sizewell bank has higher SSC than offshore in the surface waters where phytoplankton production takes place. The model is not sophisticated enough to use a time varying SSC and hence light attenuation coefficient; the value chosen therefore corresponds to the major period of interest i.e. the spring bloom and summer. In the Sizewell Bay region where SSC is high the light attenuation coefficient is correspondingly high with typical values in the range 0.4 to 0.6 $m^{-1}$ which corresponds to SSC of 6 -15mg $l^{-1}$ (Devlin 2008)

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. In the open sea greater variability could be expected, however, it is during calm periods, when only tidal processes operate that blooms are most likely, and this value is therefore used as a starting test value. Both the exchange rate and the light attenuation coefficient are directly determined by the meteorological conditions prevalent at the time. This relatively simple model is not able to incorporate these time varying elements and it is, therefore, relevant to run several scenarios in order to select the model that best fits the observations.

Nutrient data were used to drive the model and initial conditions were the 99th percentile winter values at 30 µmol $l^{-1}$ for nitrate and 1.29 µmol $l^{-1}$ for phosphate (BEEMS Technical Report TR314). Summertime values have been derived by combining the summer (June, July), values for site SZ3 and SZC (Tables 61 and 64 of TR314).

Evident from Figure 5 is that a model setup of $k_d$ of 0.55 and with an exchange co-efficient of 0.1 is likely to best represent the situation at Sizewell, both in peak and in duration of the spring bloom. The value of 0.55 is consistent with the light attenuation coefficient expected from a turbid coastal water body (Devlin et al., 2008) with an SPM of 10 $mgl^{-1}$ which is within the range of values measured during April to August at Sizewell as shown in Figure 3 BEEMS Technical Report TR346.

The late autumn bloom (day 250) is not represented in this model. As the observational data include the present effect of Sizewell B its mortality has been incorporated into this simulation.

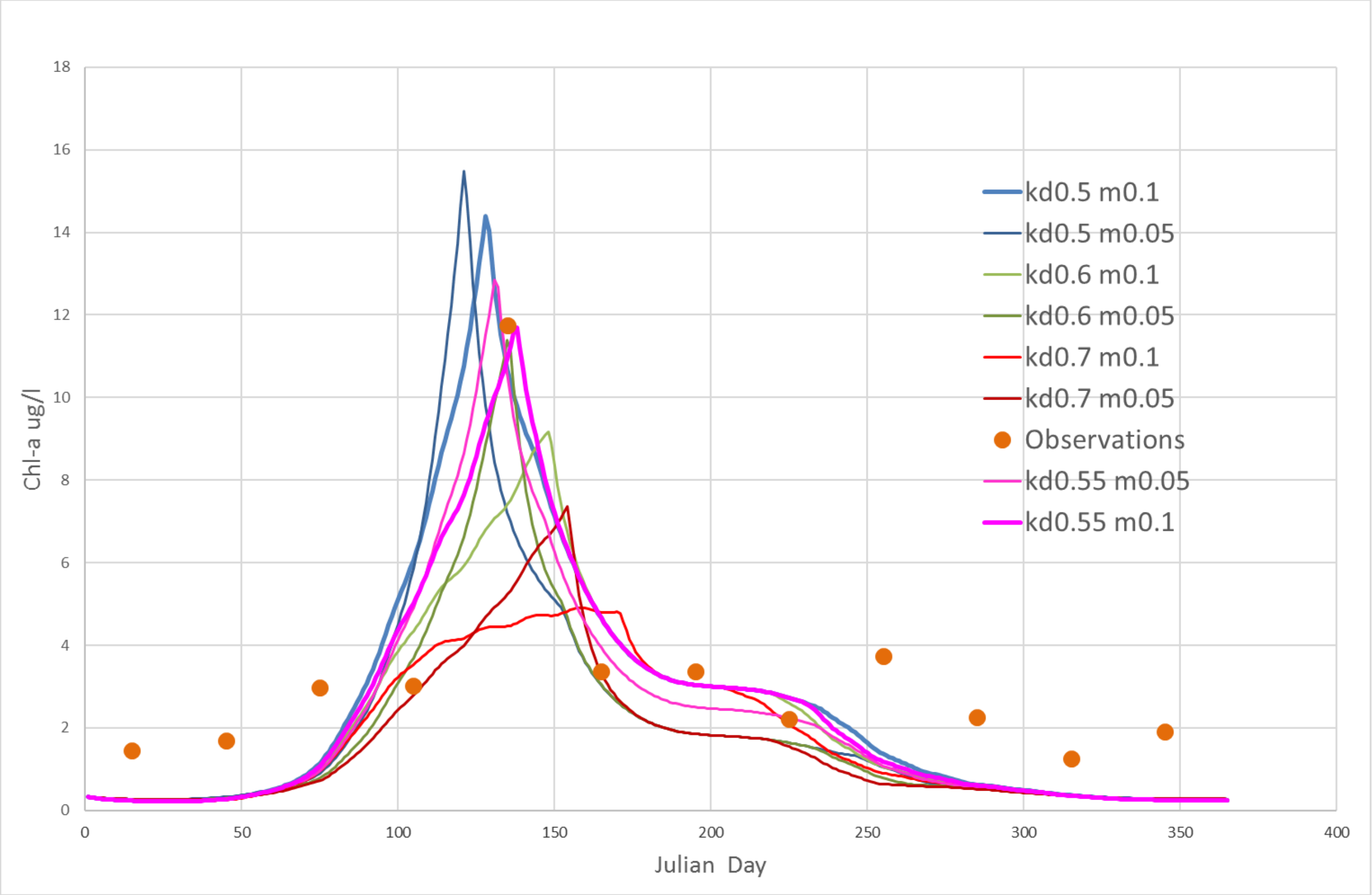

Figure 5: Model sensitivity to different light attenuation coefficients ($k_d$) 0.5, 0.55, 0.6, 0.7 and for two exchange coefficients (0.05 and 0.1), compared with the observations from BEEMS TR346 surveys (orange dots). The magenta heavy line is the chosen best fit model parameterisation ($k_d$ 0.55, m 0.1).

# 3 Model runs incorporating the effect of Sizewell B and Sizewell B + C

## 3.1 How to incorporate the effect of the power station

As the power stations extract water and return it to a similar location, thereby conserving the total mass of water and nutrients, then it is only the effect on mortality of phytoplankton that needs to be considered in the modelling. The effect of a power station can be simulated by increasing the daily natural mortality by the fraction of the box model volume that the power station filters each day.

The natural mortality for phytoplankton used in the model is 0.125 per day (Aldridge 2008). Sizewell B filters 51.5 x 24 x 3600 $m^3$ of water per day. Experiments simulating entrainment conditions have shown up to 90% mortality for some phytoplankton species and up to 73% reductions in chlorophyll *a* (BEEMS Technical Report TR363). Therefore 90% entrainment mortality has been assumed in the modelling. This is considered to be conservative as the smaller (more abundant) size fraction of the phytoplankton community has greater sensitivity hence the larger reduction in cell numbers relative to chlorophyll (BEEMS Technical Report TR363).

The Sizewell B intakes are inshore of the Sizewell-Dunwich Bank and therefore the appropriate region to consider is Sizewell Bay (Single hash area Figure 2). Using this volume, the local daily mortality rate increases to 0.136. For Sizewell C the intakes are 3 km offshore and the tidal excursion at this distance is much greater than inshore; the excursion is 16km thus plankton 16km north of the station could be captured during the flood tide and a corresponding distance south during the ebb. The combined volume of the Sizewell Bay and the tidal excursion (single hash and double hash in Figure 2) is 1209.7 x $10^6$ $m^3$, with a combined extraction of 175 $m^3$ $s^{-1}$ for SZB + SZC. This increases the local daily mortality from 0.125 to 0.1365, similar to the SZB case but acting over a larger volume. The area outside of the Sizewell Bank has a greater water depth (12.5m compared to 8.8m inshore of the Bank) and therefore generally lower suspended sediment in surface waters leading to a lower light attenuation coefficient of 0.4 derived proportionality from the inshore value. As shown in TR346 there is strong seasonal cycle to the suspended sediment, these values are consistent with the spring/early summer.

Table 3: Values that vary between the simulation runs

| Waterbody Name | Loss of microplankton (L), ($d^{-1}$). | Area average of MHWS and MLWS ($km^2$). | Average water depth (m). | Mean $k_d$ ($m^{-1}$). |
|---|---|---|---|---|
| Bay (Sizewell Bay no power station) | 0.125 | 41.20 | 8.80 | 0.55 |
| SZ B (Sizewell Bay, with power station) | 0.136 | 41.20 | 8.80 | 0.55 |
| Reference (Sizewell Bay and area beyond no power station) | 0.125 | 96.70 | 12.50 | 0.40 |
| SZB + SZC (Sizewell Bay and area beyond plus power station). | 0.1365 | 96.70 | 12.50 | 0.40 |

## 3.2 Model Results - production

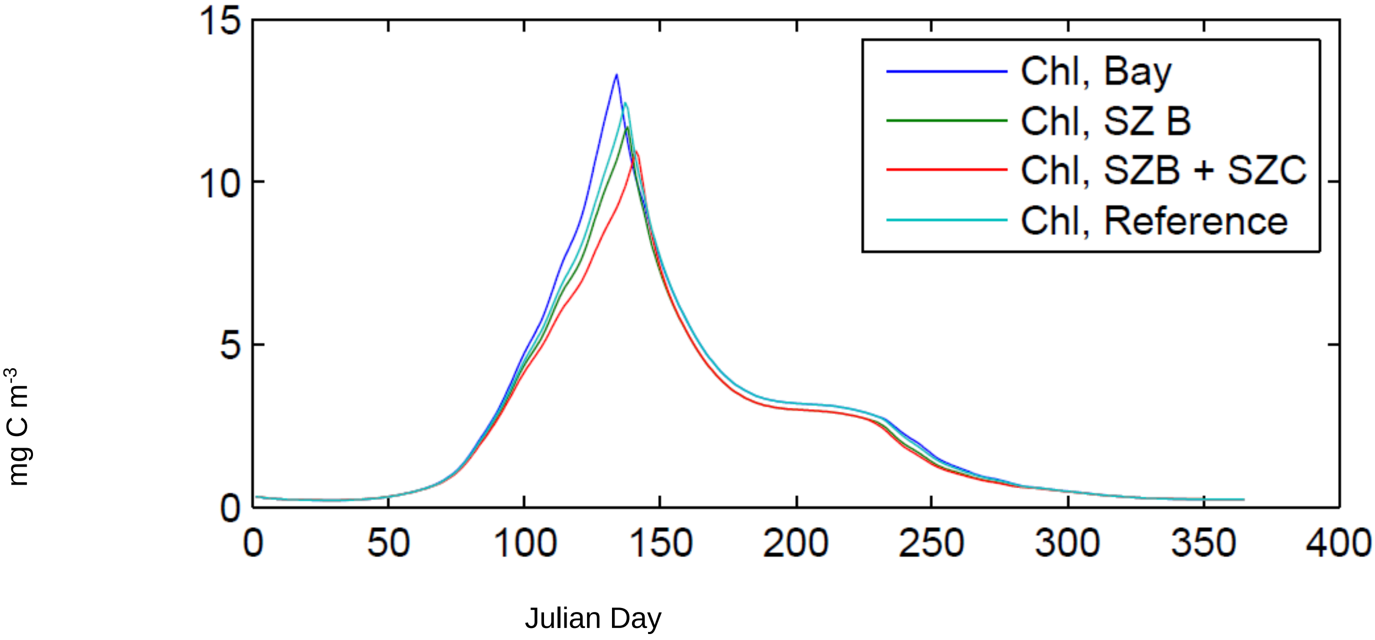

Figure 6:Phytoplankton production (mg C $m^{-3}$), for Sizewell Bay with no power station (blue), Sizewell Bay including SZB (green), Sizewell Bay + tidal excursion no power station (cyan), Sizewell Bay + tidal excursion SZB + SZC (red).

Evident from Figure 6 is that in both power station scenarios the peak of the bloom is delayed, with a slight reduction in the peak production. These results are to be expected as the effect of increasing mortality is to reduce the instantaneous growth rate without reducing the available nutrients.

Table 4: Total Gross Production (g C $m^{-2}$ $y^{-1}$) for the four scenarios.

| **Scenario** | **Phyto Annual Gross Production, (g C $m^{-2}$ $y^{-1}$)** | **Phyto Average Summer (Apr-Sep) Daily Gross Production, (g C $m^{-2}$ $d^{-1}$)** | **Total mass In tonnes** | **Loss due to power station in tonnes of C (% change) compared with no power station** |
|---|---|---|---|---|
| Bay (no power station) | 56.86 | 0.30 | 2342 | |
| SZ B operational | 54.10 | 0.28 | 2228 | 113 (4.85%) |
| Bay + Tidal excursion (no power station) (GSB) | 77.47 | 0.41 | 7491 | |
| SZB + SZC | 73.34 | 0.39 | 7092 | 398 (5.3%) |
| SZC | | | | 285 (3.8%) |

Evident from Table 4 is that the local total gross production is reduced by approximately 5% in the power station scenarios, as compared to the baseline no power station case. The additional contribution of Sizewell C is a loss of 285 tonnes C compared to 113 tonnes C for SZB only.

This reduction in biomass should be considered in the context of natural variability. In Section 2 observations were presented of observed chlorophyll-a concentration. There is not an exact correlation between total annual production and measurements of chlorophyll concentration because of the variability of production rates and loss due to predation but crudely the extent of variability in annual primary production is mirrored by the variability in chlorophyll measurements. As shown earlier the standard deviation of annual production is approximately 45% of the mean value. In comparison the effect of the power station is a reduction by 5%. A poor year of primary production could be defined as one where the primary production is less than one standard deviation from the mean, with a good year being when primary production exceeds one standard deviation above the average. If primary production is normally distributed, then by definition poor years occur 16% of the time. In the power station (SZB + SZC) situation where the mean is reduced by 5% but the standard deviation (which is due to natural variation) remains the same, then using the same value for biomass as the baseline case, then a poor year would occur 19% of the time. i.e. a 3% increase in poor years and 3% fewer good years. Such small reductions would not be observable by any form of monitoring campaign as over the long time period required to detect such a reduction other changes are likely to occur.

## 3.3 Limiting factors that control phytoplankton growth.

Figure 7 shows the limiting factors during the annual cycle. Up to day 140 light is the limiting growth factor, for a brief period of two days phosphate is limiting, up to day 220 nitrate is the limiting nutrient with light limiting after that. As nitrate is limiting during summer then if additional sources of nitrate occur the effect of these must be considered.

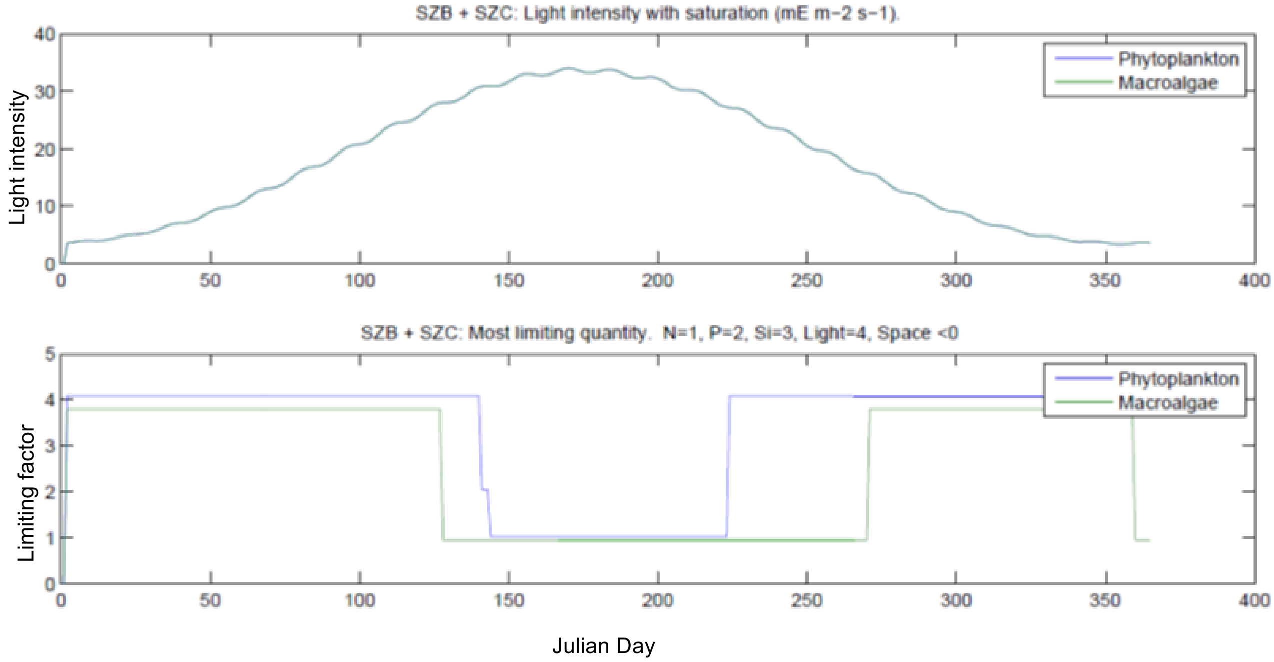

Figure 7: Limiting factors controlling phytoplankton growth, top figure is light, bottom figure is the limiting parameter. Day 0 is 31st Dec.

## 3.4 Consideration of the effect of the nitrate and phosphate discharges during the construction and operation of Sizewell C on phytoplankton growth.

During construction and operation, the power station discharges relatively small quantities of nitrate and phosphate; primarily from the use of conditioning chemicals in the various circuits but also from treated sewage. During construction the exact mass of the discharges has considerable variation, depending on which activity is occurring and varies considerably with the workforce on site. The details of this variation are described in BEEMS Technical Report TR193, where worst cases have been used and reproduced in Table 5 below.

During operation, the maximum number of people on site occurs when there are refuelling outages, during this time nitrate and phosphate loads are increased above background concentrations and these contributions are represented by the peak 24 hour loading during operation. The refuelling outages typically last four to six weeks but can occur at any time of year. During the winter period light is limiting and there is no effect resulting from the additional supply of nutrients. It is only in summer that the discharge needs to be considered.

Typically, in offshore waters of the UK nutrient concentrations are reduced to very low levels due to phytoplankton uptake, but in the near shore coastal waters (3-5 km from the coast) off Sizewell due to the turbid nature of the coastal environment and continual freshwater input from the south of the area (River Orwell and River Deben) there are background summertime inputs of nutrients. Observations (BEEMS Technical Report TR314) show these to be around 10 µMol $l^{-3}$ for nitrate and 0.65 µMol $l^{-3}$ for phosphate. As the daily exchange of water is around 10%, the total additional mass of nitrate per day in summer is the volume x 10% x concentration, this gives a daily exchange of 16.9 tons of nitrate and 2.4 tons of phosphate.

Table 5 Summary of phosphate and nitrogen discharge during operational phase and the daily exchange with the wider environment.

| **Substance** | Daily loading during operation kg (annual loading kg) plus including FRR discharge | Peak 24 hr load during operation kg $d^{-1}$ | Peak loading in construction (2 EPR units + sewage) per day kg. | Daily exchange with wider environment, kg | % of daily loading in operation | % max possible daily loading in operation | Fraction of maximum possible daily loading in construction |
|---|---|---|---|---|---|---|---|
| Nitrogen (as N)<br>Including FRR | 32 (11725)<br>69.3 (25291) | 332[1] | 17.3[2] | 16900 (as N) | 0.2%<br>0.4% | 1.9% | 0.1% |
| Phosphates as P<br>Including FRR | 0.71 (257)<br>6.04 (2205) | 115[1] | 28.2[2] | 2440 | 0.03%<br>0.25% | 5% | 1.1% |

[1] Extracted from BEEMS TR193 (operational loadings as N and $PO_4$ loading converted to P). [2] The Phosphate as P load values are derived from groundwater, sewage and EPR commissioning inputs as described in BEEMS TR193 section on 'Assessment of construction discharge'.

During construction (Table 5) all daily inputs are less than 1% of the normal daily exchange of nutrients at the boundary and therefore would be indistinguishable from the modelled situation without the SZC discharges. During the operational phase, peak daily loading for nitrogen does reach 1.9% of the daily exchange but it is expected that this peak value is for short periods only. The more realistic average daily value of N (including FRR discharges) is low at 0.4% of the daily exchange (69.3/16900). For phosphates the maximum daily value can be 5% of the daily exchange, however phosphate is not a limiting nutrient and therefore the addition of more phosphate does not produce more growth. In addition, over a whole year the phosphate contribution (including FRR) is very small at less than 0.3%.

To provide greater reassurance of this assessment, model runs were conducted to assess the influence on phytoplankton growth of representative inputs of nutrients (i.e., total annual loadings) from the power station during operation and during construction including commissioning inputs.

For the operation run entrainment mortality was accounted for. The Fish Return and Recover system (FRR) aims to discharge fish live to the receiving waters. However, clupeids such as sprat and herring are highly sensitive to mechanical damage during passage through the cooling water system and incur high mortality rates (assumed to be 100%). 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 strong seasonal bias to impingement numbers, and the return of dead biomass. The largest quantity of dead biomass is returned in January, February and March, however during this period light is the limiting factor for phytoplankton growth. Dead biomass returned during the summer months, coinciding with periods of nutrient limitation, is much lower than in winter. However, as a highly precautionary measure the total biomass discharged per annum was modelled as a daily average equating to approximately 1065.5 kg of fish (wet weight). These values are based on rates of impingement at Sizewell B and extrapolated to account for abstraction volumes. They do not account for the impingement reductions expected from the SZC low velocity side entry intake designs and should be considered as precautionary (BEEMS TR193 Edition 4). A further highly conservative assumption was applied whereby all of this mass of fish was assumed to be available as nitrogen and phosphorus sources (i.e. no predation was assumed) leading to an additional 37.3 kg per day of nitrogen (based on Walker *et. al.,* 2011) and 5.3 kg of phosphorus (based on Gende *et. al.,* 2004) per day, in addition to inputs from the discharge due to sewage and conditioning chemicals.

The discharge of nutrients during the SZC construction phase is primarily into the Sizewell Bay area inside of the Bank, as it is mostly via the combined discharge outfall (CDO). However, it is possible that there will be discharge of some nutrients via the main cooling water outfalls during functional testing. As the suspended sediment is less in offshore surface waters, i.e. where there is a better light regime, a worst-case scenario has been assumed that all these nutrients are discharged offshore. As it is likely there will be periods of SZB outage during the construction of SZC the increased mortality due to SZB has been ignored, so that these results will slightly over predict the role of the increased nutrients (i.e. a conservative assumption).

Model parameters were otherwise the same as those described in Section 3 of this report. The change in phytoplankton growth (carbon) when additional nutrient inputs are considered for the construction and operational phase of SZC (SZB influence also accounted for) are shown in Table 6. Operational inputs have a slightly higher influence on phytoplankton production but for both construction and operation there is less than a negligible 0.3% increase in annual gross production of carbon.

Table 6 Summary of change in annual production taking account of entrainment mortality where relevant and with and without inclusion of phosphate and nitrogen discharge inputs during construction and operation of SZC and inclusion of potential inputs from the FRR

| **Scenario** | **Phytoplankton Annual Gross Production (g C $m^{-2}$ $y^{-1}$)**<br>**With SZC discharges** | **Phytoplankton Annual Gross Production (g C $m^{-2}$ $y^{-1}$)**<br>**Without SZC discharges** | **Percentage difference** |
|---|---|---|---|
| SZB + SZC (no entrainment mortality) Construction SZC | 77.57 | 77.47 (Baseline - no power station) | 0.13% |
| SZB + Operational inputs from SZC | 73.42 | 73.34 (including mortality only) | 0.11% |
| SZB +Operational inputs from SZC including FRR | 73.55 | 73.34 (including mortality only) | 0.29% |

The potential for nutrient additions to enhance opportunistic macroalgae in the Blyth or the more distant Alde Orr Estuary has been raised. Direct links between nutrient loading and macroalgal growth have been established but evidence supporting direct causal linkages between effluent discharges and the macroalgae community structure is limited (Wells et al., 2010). Prolific macroalgal growth during periods of high nutrients is dependent on other factors such as the position on the littoral zone, tidal action, light availability and seasonal temperature (Wells et al., 2010). During the construction and operational phases of the proposed development, additional nutrients would be added to the system. However, nutrient additions represent a very small fraction of the daily exchange with wider sea areas (Table 5) and modelling has demonstrated no negligible enhancement of phytoplankton growth above present background. The point source is located a considerable distance from the estuaries, over 10km from the mouth of the Blyth and 23km from the mouth of the Alde-Orr estuary at Shingle Street. Furthermore, the inshore estuaries and tidal areas of Eastern England, monitored for opportunistic macroalgal as part of the WFD, do not appear to exhibit excessive growth (Painting et al., 2017). As such, no discernible effects on opportunistic algae as a result of nutrient discharges from the proposed development are anticipated.

## 3.5 Consideration of the effect of thermal uplift in Sizewell Bay in combination to nitrate and phosphate discharges during the operation of Sizewell C on phytoplankton growth.

During operation, the power station discharges relatively small quantities of nitrate and phosphate and raises the temperature of the cooling water that is discharged. The thermal uplift contributed by the power station has the potential to influence phytoplankton growth and mortality in combination with the influence of the nutrient inputs. Table 7 shows the area of excess temperature associated with certain uplifts. The area of the Greater Sizewell Bay (GSB) used in the modelling is 9670 hectares. i.e. very similar to the values associated with the 0.5 °C mean uplift for either the bottom or surface values.

Table 7 Areas of mean excess temperature from SZB + SZC (Conf 12)

| CONF12 Mean Excess | Temperature uplift (°C) | Area (ha) |
|---|---|---|
| Bottom | > 0.5 | 9529 |
| | > 0.75 | 7019 |
| | > 1 | 4256 |
| Surface | > 0.5 | 10111 |
| | > 0.75 | 7645 |
| | > 1 | 4906 |

The value of 0.5 °C has therefore been used as representative of the whole GSB, along with a 1°C value for comparative purposes.

Four scenarios were compared:

1. a reference with no power station;
2. power station operating (accounting for increased mortality and nutrient inputs) but no thermal input;
3. power station operating (accounting for increased mortality and nutrient inputs) and including a 0.5 °C temperature increase, and;
4. power station operating (accounting for increased mortality and nutrient inputs) and including a 1 °C temperature increase

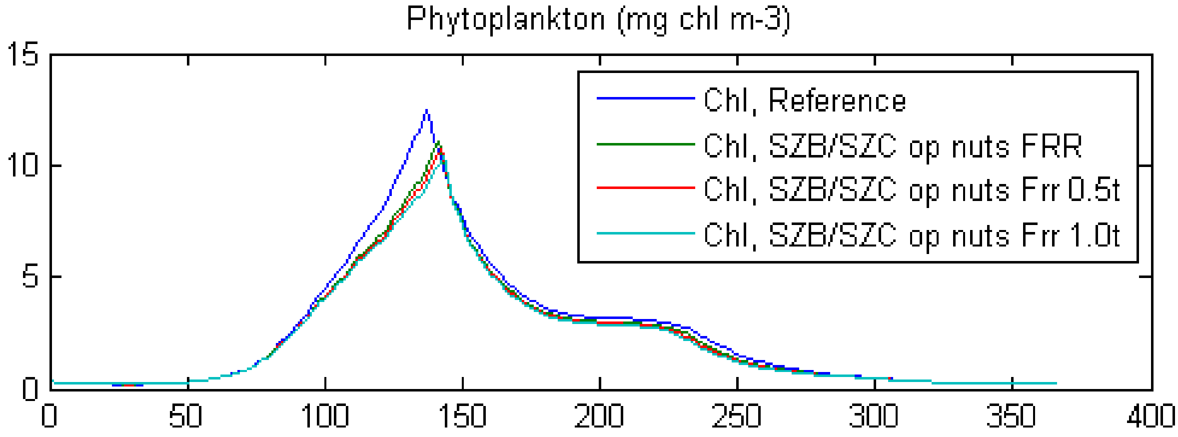

Figure 8 Phytoplankton model values (4 simulations including temperature rise, of 0.5 °C and 1.0 °C)

The CPM is parameterised such that the light climate and nutrients are the primary factors controlling productivity. At Sizewell the Spring bloom occurs in early May, during which time the system is controlled by light (Figure 7). During this period phytoplankton growth rate is determined by light not by temperature and temperature uplifts do not result in enhancements in productivity. In a light limited environment, increases in temperature have been shown not to enhance photosynthesis (Underwood and Kromkamp, 1999).

However, whilst phytoplankton growth is mostly unchanged by thermal uplifts, increased zooplankton activity and grazing on phytoplankton occurs. The overall result is a small decrease in simulated chlorophyll concentration and total phytoplankton production.

In the coastal waters off Sizewell the SZB+SZC thermal plumes will increase average seawater temperatures across the model domain by 0.5 °C. Application of the CPM model demonstrates that such a temperature increase would have minimal effects on phytoplankton gross annual productivity. Specifically, the decrease is from 73.55 g C $m^2$ with no thermal uplift to 72.78 g C $m^2$ with the predicted 0.5 °C uplift or a negligible 1% change (Table 8).

The overall reduction in gross annual production over the GSB area is predicted to be approximately 6% lower with both stations' operation in comparison to a hypothetical situation with no existing station (Table 8).

Table 8 Summary of change in annual production incorporating the effect of thermal uplift, increased mortality and with increased nutrient discharge.

| **Scenario** | **Phyto Annual Gross Production, (g C $m^{-2}$ $y^{-1}$)** | **Percentage difference (from reference)** | **Total mass**<br>**In tonnes** | **Loss due to power station in tonnes of C (% change)** |
|---|---|---|---|---|
| 1. Reference (no power stations) | 77.47 | | 7491 | |
| 2. SZB +Operation SZC including FRR (no thermal uplift) | 73.55 | -5% | 7122 | 5% |
| 3. SZB + Operational SZC including FRR + thermal uplift (0.5 °C) | 72.78 | -6% | 7038 | 6% |

# 4 Summary

The effect of Sizewell B (SZB) and the proposed Sizewell C (SZC) on phytoplankton that pass through the power station has been simulated using a phytoplankton box model. The model has been tuned through adjustment of the light attenuation and exchange coefficient to replicate field observations at Sizewell and the observed cycle of plankton production has successfully been simulated with emphasis on the spring bloom and summertime production. The power stations have been incorporated into the model by considering them as an increase in phytoplankton mortality.

The conclusions of the study are:

1. Total phytoplankton production in the modelled abstraction area is predicted to be reduced by approximately 5% due to phytoplankton entrainment mortality from SZB and SZC.
2. The simulation without the power stations shows annual production of 7491 tonnes of carbon. Environment Agency data collected from the area from 1992 to 2013 indicates that the standard deviation of monthly mean chlorophyll *a* concentrations is 42% of the mean, and annual chlorophyll *a* values varies by 45% of the mean (Table 1). Contextualised against high rates of natural variability, the predicted losses of gross annual phytoplankton productivity are minor.

3. SZC will discharge small volumes of nutrients in the form of phosphate and nitrates, which will tend to increase local phytoplankton productivity. For much of the year light availability limits phytoplankton growth and the addition of relatively small quantities of nutrients has no effect. In the summer, nitrate is a limiting nutrient (when light is not limiting) and is consumed rapidly. However, the nutrient exchange with the wider marine environment is much greater than the maximum proposed discharges, during either operation or construction, such that the predicted increase in phytoplankton growth due to the SZC discharges would be negligible (<0.3%). No discernible effects are anticipated on the prevalence of opportunistic macroalgae in the Blyth or the more distant Alde Orr Estuary as a result of the small-scale nutrient additions.

4. Local seawater temperature increases caused by the power station thermal plumes will not increase phytoplankton growth, however the uplifts will result in slightly increased zooplankton activity and grazing leading to a predicted small decrease in chlorophyll concentration and total phytoplankton production (1%).

5. Combining the effects of entrainment mortality, increased nutrient discharges and the effects of the thermal plumes, the predicted local reduction in total phytoplankton production by SZB+SZC is about 6% over the reference (no stations) condition.

6. There is greater daily exchange of water between Sizewell Bay and the greater Southern North Sea than there is daily extraction of water due to the power stations. Due to this exchange, the apparent concentration of phytoplankton will not be reduced in Sizewell Bay when considered against the high natural variability. In particular, the predicted effect of either the present SZB or the proposed SZC would not be observable in any monitoring programme.

7. Other marine organisms that predate on phytoplankton in the area would not be adversely affected because they will already be adapted to the very large natural variability in phytoplankton production.

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# Appendix A Current meter data near SZC intakes.

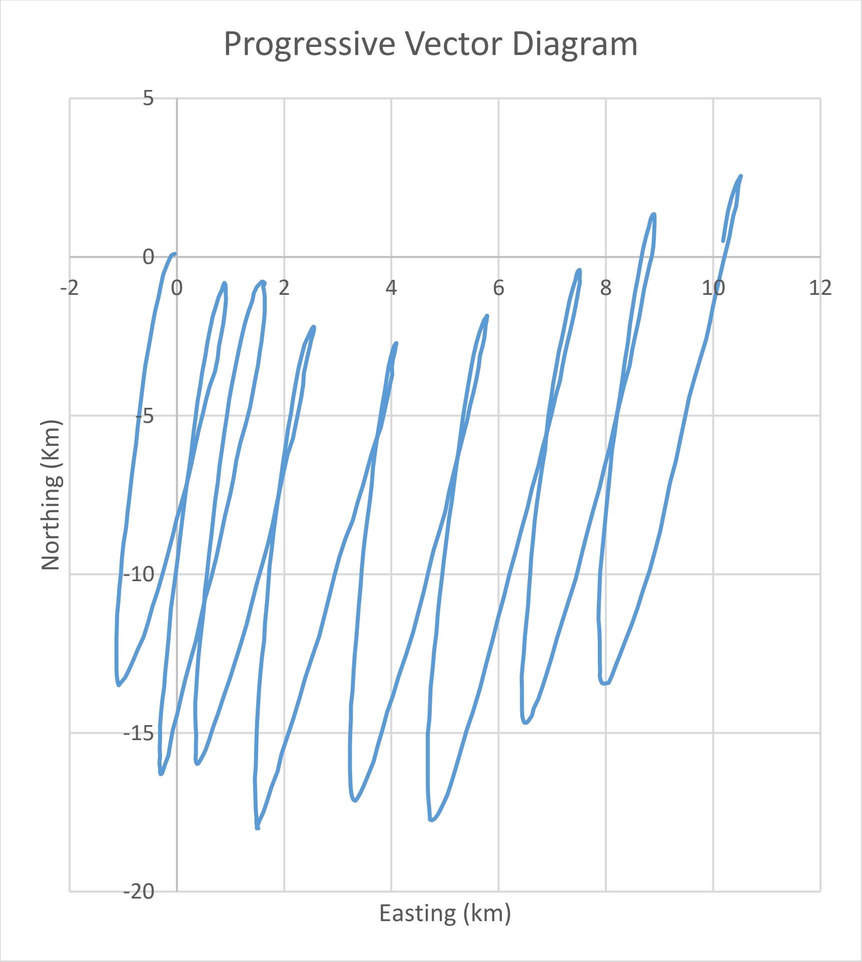

Figure 9 Progressive Vector diagram, mooring S2 (BEEMS Technical Report TR047) depth averaged current. During Springs starting on the start of the flood tide (low tide).