



CAWTHRON

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Dear Stephen,

RE: Review of Bay of Plenty modelling study conducted by ASR Ltd.

This letter is in response to your request that Cawthron review the ASR Ltd (ASR) hydrodynamic and primary production modelling study of the Bay of Plenty which was commissioned by Environment Bay of Plenty (EBoP). It is our understanding that the goal of this work is 'to provide focused information over-viewing the Bay of Plenty for planning AMAs (Aquaculture Management Areas)', as stated in the report for the primary production model.

The scope of this review has been restricted to the technical details of the modelling, and only very limited time has been made available for the review, so many of the technical aspects will not be covered to a detailed level. It must also be highlighted that a major shortfall in many modelling studies is that the study fails to achieve the desired objectives of the agency commissioning the study. Hence, although 'fitness for purpose' has been excluded from this review, I highlight that it is important that this aspect of the review process be considered by EBoP.

This review is separated into a section detailing comments on each model and then a final summary section, as follows.

Hydrodynamic model

The hydrodynamic model numerical scheme is based around the 3DD modelling suite. This modelling suite has been developed over a number of years and has been applied in numerous coastal regions where it has been validated against *in situ* data. Shortfalls in the numerical scheme are likely to be the result of a lack of global knowledge and ability to adequately parameterise some processes (i.e turbulence), rather than any inherent shortfalls of this particular model.

The model as applied here used grid resolutions of either 1 km by 1 km, or 3 km by 3 km. The grid was generated using bathymetry and coastline data supplied by EBoP. This resolution is adequate for resolving the gross dynamical processes occurring within the Bay of Plenty. However it should be noted that this resolution is not adequate for resolving details of the flows in the vicinity of the proposed farms; although this level of resolution does not appear to be within the scope of this work.

A range of boundary conditions were used. For the tidal open ocean conditions, a global tidal circulation model was used to generate local conditions. Surface wind conditions were determined from several sources, including local wind data. Some scaling of the dataset were required to achieve the best fits and this is common practice. Daily averaged river flows were also used as boundary conditions.

The open ocean conditions for the three dimensional flows were determined from a combination of global datasets, and *in situ* data collected during the field programs. It is good to see that a comprehensive attempt was made to use available data (although altimetry data could also have been used). These data should be adequate to generate for example seasonal conditions, however I do wonder if these data were able to capture events such as deep water intrusions that are not seasonal, and which lie outside the weather-bands. The significance of these events whereby parcels of oceanic water are transported into shelf waters can have profound effects on primary production processes.

From the reports, it appears that the model was primarily validated against the *in situ* dataset consisting of approximately two months of current meter, temperature and salinity data from several locations on the nearshore zone. Remotely sensed sea surface temperature data were also used for validation purposes. Some tuning of the model was required in order to optimise the fit to the data and this is common practice in hydrodynamic modelling studies. Furthermore, some of the differences are to be expected, for example the initial inability of the model to adequately describe dispersion of the river plumes.

There are two issues that I would raise with regards to the validation processes. Firstly, it is clear that local tidal currents and broad seasonal temperature and salinity signals are captured in the model dynamics. What is less clear is whether the model can reproduce sporadic intrusions of deep water from off the shelf as they are not necessarily captured in the open ocean temperature/salinity conditions. As highlighted above, these events can play a critical role in preconditioning shelf waters and hence primary production processes. For example in some coastal regions, the primary source of variability in primary production is associated with these sorts of events.

The second issue is whether the fluxes through each grid cell face are accurate enough to properly underpin to the required fluxes in the primary production model. A common

problem with coupled or particularly de-coupled hydrodynamic/primary production ocean models is that whilst the hydrodynamic processes can faithfully simulate the broad physical processes, high frequency variability in, for example, vertical velocities predicted by the physical components of the models can substantially constrain the accuracy of the biological model. Given the information presented in the reports, only the authors know if this is indeed an issue in this case.

Primary production model

Using the information available in the report, it appears that the primary production model is run in a decoupled arrangement whereby the hydrodynamic model is run first, and then key outputs are used to force the primary production model. The primary production model is run on a similar 3 km by 3 km orthogonal horizontal grid, which is of high enough resolution to capture the underlying lower trophic level dynamics, but too low resolution to adequately describe processes occurring around and within the proposed farms. However this shortfall applies to almost all of these types of modelling studies as the scales are so vastly different.

Some of the numerical functional relationships used are different to what myself and some others use, and given the time constraints of this review, it is not possible to investigate how these differences may influence the results. However, it is worthwhile highlighting a few pertinent aspects. The level of detail of the processes used in this study is lower than the level currently utilised by those working at the forefront of this field. For example, no biomechanical aspects in the form of plankton size structure or multiple species are included. Also there are no internal reserves of nutrients, energy etc. described for the phytoplankton, and zooplankton encounter rate processes have not been included. However, these differences are not necessarily shortfalls in the models used here, as it can be undesirable to simply add more and more levels of complexity into these models unless the underlying processes are adequately parameterised and the required validation data are available.

A particular area of concern for all models attempting to simulate the effects of establishing mussel farms on phytoplankton communities is that our knowledge of *in situ* mussel feeding rates, and in particular the rates of regeneration and excretion of inorganic nutrients by cultured mussels is poor. Furthermore, primary production models have been shown to be extremely sensitive to some of these rates and are therefore a considerable source of uncertainty.

The boundary conditions for the primary production models were derived from outputs of the hydrodynamic models, and limited data where available. I am concerned over the lack of data available for the biological components. As far as I can determine from the

reports, the only data available are limited measurements of chlorophyll *a*. Chlorophyll *a* can be a poor proxy for phytoplankton abundances and the lack of supporting data such as dominant species, size fractionated chlorophyll *a*, and phytoplankton and zooplankton abundance data is a major shortfall. Once again, the model is not to blame here, rather a lack of availability of the required data. Therefore, given the lack of available data it is difficult to assess the accuracy of the internal diagnostics of the model.

The only data available to validate the model consisted of time series of chlorophyll *a* data at several sites. In general, the model often either underestimated or overestimated the concentrations by nearly 100 % at times. This level of agreement is to be expected given the circumstances, and does not indicate extreme problems with the model numerics; rather a lack of opportunity to really calibrate the model against *in situ* data. What this does indicate however, is that estimates of phytoplankton changes resulting from the farm must be given very wide error bars.

Despite the aspects described above, the magnitude of depletions predicted does roughly agree with observations and predictions from other sites around New Zealand. However, the lack of high spatial resolution around the farms themselves means that the size of depletion haloes are not well described, and given data from other sites, are likely to be an overestimate.

Summary

The modelling work consisted of running a well-established hydrodynamic model, and using outputs from these runs to run a new primary production model. The hydrodynamic model is well proven, and the boundary conditions and bathymetry data adequate for the model to be able to simulate tidal flows and local wind driven flows. My major concern is whether the open ocean hydrographic boundary condition data available are adequate enough to be able to capture many of the events occurring at the offshore boundary that may potentially play a major role in the primary production processes.

The primary production model has considerably less pedigree by comparison to the 3DD hydrodynamic suite. The model is more simplistic than other models in terms of the level of detail at which key phytoplankton processes are simulated. However, unless back-to-back comparisons are performed, it is difficult to assess the performance of this model. In theory the model should be able to predict gross patterns in phytoplankton processes, and the validation against the very limited data available suggests that broad seasonal processes have been reproduced. The validation against chlorophyll *a* data shows that the model is at times around 100 % inaccurate, although this is not too surprising with these models. However, we are generally looking for changes in chlorophyll *a* concentrations of



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often around 1-4 % as a result of the establishment of the farms; hence we must bear in mind the uncertainty in the accuracy of the model when considering these changes.

Of some concern is the lack of biological and nutrient data for driving and validating the primary production model. This lack of data means that it is not possible to check the internal dynamics of the model. This does not mean to say that the model is simulating processes incorrectly, rather that we cannot check the accuracy other than through coarse chlorophyll *a* concentrations.

The magnitude of the effects of the proposed farms is in the ballpark that we would expect from data from collected from other regions within New Zealand. However, the spatial size of phytoplankton depletion shadows is considerably larger than we would expect and this may be an artifact of the coarse resolution of the model around the farm sites.

Finally, there are several strong over-arching comments in the reports themselves that are not well justified. For example, at the end of Section 3.1.1 in the primary production report it states that 'the Pukehina farm appears to be better situated than the Opotiki farm'. This is a sweeping statement that should be considered with caution, as what is considered 'better' depends on a large number of factors and circumstances, one of which may be predicted phytoplankton depletion haloes. However these predicted haloes should not form the sole basis for such a decision, as suggested here.

Please contact me if you have any queries regarding this review.

Yours sincerely,

Dr Mark Gibbs