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7 November 2014

NSW Department of Planning and Environment
GPO Box 39
Sydney NSW 2001

Attention: Robert Byrne

Dear Robert

RE: ESTUARINE MANAGEMENT STUDY: PROPOSED MIXED USE SUBDIVISION - WEST CULBURRA, NSW. PEER REVIEW.

Thank you for the invitation to review the above report. I have completed my review and the outcomes are presented below. As you will see, the review is not favourable, and as such I would like to discuss it with you once you have read it and considered its recommendations. I would also ask that you circulate the letter internally only until we have chatted.

I look forward to discussing this matter with you.

Yours Faithfully
BMT WBM

Dr Michael Barry
B.E. (Hons), B.Sc., PhD, FIEAust, CPEng, RPEQ, NPER
Manager, Catchments and Receiving Environments

1 Brief

BMT WBM has been invited by the NSW Department of Planning and Environment to review a receiving water quality model report prepared in relation to the proposed mixed use subdivision at West Culburra. Specifically, BMT WBM has been invited to review the report with respect to the acceptability or otherwise of the modelling undertaken, and to assess it against industry standards. This letter presents that review.

2 Review

The report reviewed by BMT WBM is entitled *Estuarine Management Study: Proposed Mixed Use Subdivision – West Culburra, NSW (P1203365JR02V03 August 2014)*.

2.1 Model Suite

The consultants have developed hydrodynamic and advection-dispersion (AD) receiving models of the Crookhaven River. The adopted modelling software platforms belong to a well established modelling suite, especially for broader floodplain style analyses. This software suite was developed by BMT WBM, and this reviewer is the author of the AD module deployed in the reviewed report. As such, the focus of this review has not been the modelling suite itself, but rather its application to the Crookhaven River in investigating the likely impact of the proposed mixed use development on receiving waters.

2.2 Modelling Process

The industry accepted modelling process in these types of studies is generally as follows:

(1) Develop hydrodynamic model. For example, this includes collating/developing bathymetric, inflow volume, tidal boundary etc. data sets and importing them into forms acceptable to the hydrodynamic model

(2) Calibrate hydrodynamic model. This is a crucial step in the modelling process as it presents evidence that the underlying hydrodynamic model is accurately reproducing the transport of water throughout the model domain. Such calibration is usually to water levels and transect flows

(3) Develop AD model. For example, this includes collating/developing inflow quality, tidal boundary quality etc. data sets and importing them into forms acceptable to the AD model

(4) Calibrate AD model. This involves comparison of model solute predictions (such as salinity) to measurements

(5) Select a range of periods over which to simulate scenarios, ensuring that these periods capture worst case conditions for assessment purposes

(6) Execute scenarios

(7) Report results

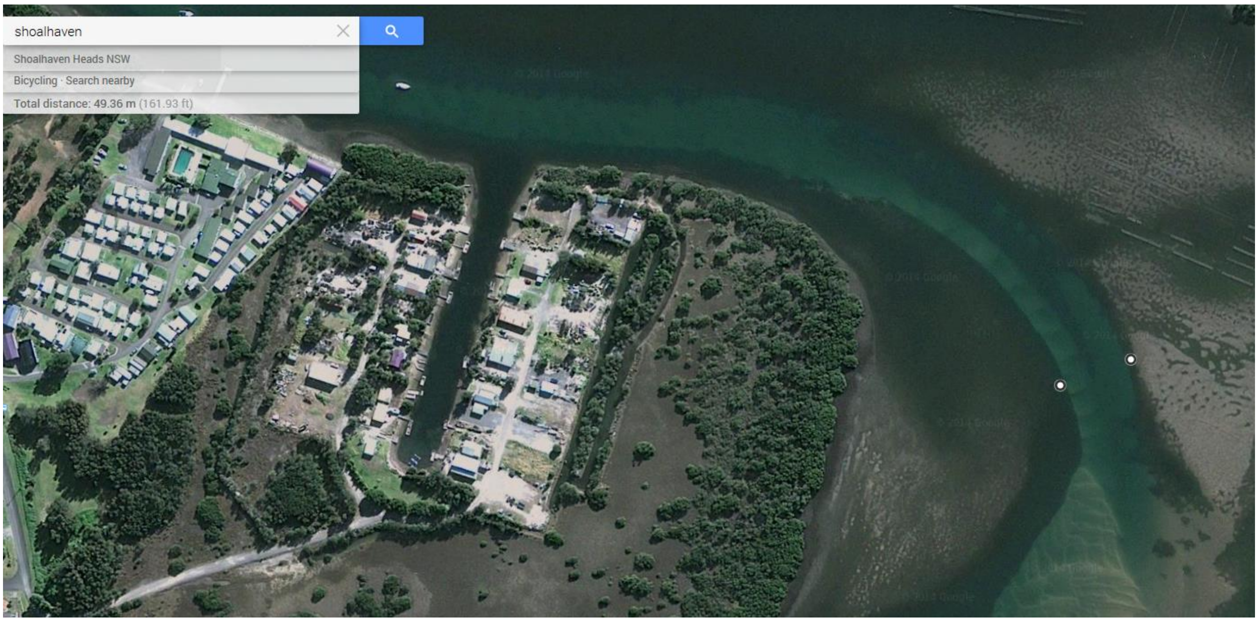
Each section below presents a review of items (1) to (6) above.

2.3 Develop Hydrodynamic Model

Some components of this task appear to have been undertaken appropriately. For example, the setting of the domain size, tidal boundaries and Mannings roughnesses all seem to be reasonable. The tidal boundary is perhaps a little too close to the site of interest (and hence the *a priori* water quality settings will influence the model predictions in the area of interest), but this is of comparatively less concern than issues described elsewhere in this review.

There are several issues with the hydrodynamic model setup that are of concern. Most importantly, it is the opinion of BMT WBM that the selected cell size of 50m is too large. It is understood that the report notes that any higher resolution grid size (i.e. smaller grids cells) presents computational issues. This is a common occurrence, where model resolution and computational speed need to be balanced, and often compromises are made such that model resolution (and hence predictive skill) is detrimentally affected.

In the case of this study however, the choice of a 50m cell size should not have been considered in any case, regardless of computational overhead issues. This is because the key bathymetric features of the river that control the exchange of tidal waters are of a similar scale to the cell size, and thus resolving them appropriately is difficult (or impossible) in such a coarsely defined model. For example, there is a hydraulic constriction near Billy's Island that includes a deep channel with fringing shallows (including oyster leases). The width of this channel is 50 metres, as shown below (the distance between the pair of white dots spanning the channel is shown in the left panel).



It is unacceptable to have a model attempt to resolve such a critical flow channel with only one cell. It would normally be expected that such a key channel would be resolved by at least 3 cells, and more likely 4 to 6 cells. Without this resolution, it is unlikely that a model such as that reported here would be able to resolve and capture the required hydrodynamic exchange processes through this (and other) section that are critical to a study that is investigating pollutant advection and dispersion. Issues that might arise from this inappropriate assignment of cell size include:

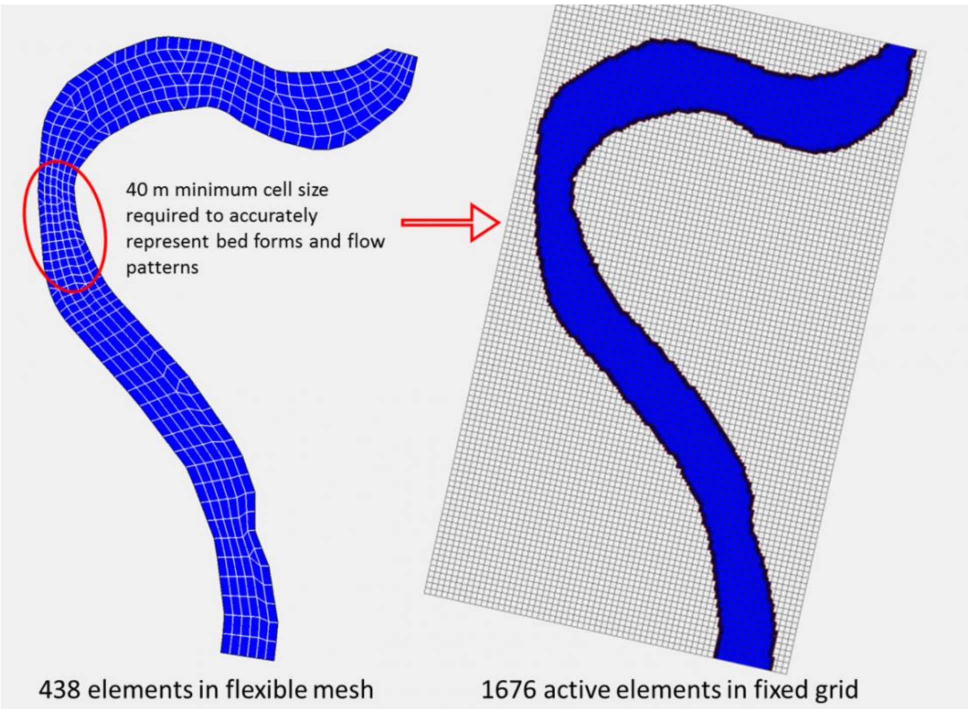
- Potentially large overestimates of bed friction due to numerical drag
- Artificial retardation and constraint of tidal flows
- Appearance of 'steps' in the model bathymetry that are not realistic, but are a result of the model's inability to resolve natural flow paths. These steps block flow.

Compounding the above, is the fact the Crookhaven River is highly sinuous in the region being modelling. It is well established that application of fixed grid models (such as the adopted software for this application) to sinuous river channels such as the Crookhaven is problematic because the cells in a fixed grid model cannot, by the very nature of their spatial arrangement, always align smoothly with the natural bathymetry. For example, if the grid was aligned, say, such that it was parallel to the channel above, subsequent cells could not be also parallel to other parts of the channel after the channel has changed direction.

This mismatch in alignment again leads to generation of numerical artefacts such as enhanced drag and horizontal momentum loss, both of which contribute to retardation of tidal flows and compromise of associated flushing and exchange processes. Electing to use a 50m cell size in the current model (that is similar to the width of key bathymetric features) means that there is a high likelihood that these numerical issues detrimentally influence the hydrodynamics of this model.

It is not possible to provide more detailed review of the impact of the above artefacts in the Crookhaven River model as the model bathymetry was not presented in the report. Omitting model bathymetry maps from model reports is unusual, and BMT WBM assumes that this was an oversight, or that a separate report has been prepared but not included in this review. Viewing this bathymetry would assist in assessing the impact of the issues discussed above on the reported modelling.

Notwithstanding this however, it is BMT WBM's view that a 50m cell size is too coarse for this application and either (a) a much finer grid size should have been adopted, or even better, (b) a model appropriate to the hydrodynamic setting should have been used. Such a model would use a flexible computational mesh rather than the fixed grid mesh model adopted here. The image below presents a comparison of how differently the flexible (left) and fixed (right) grid model meshes behave in sinuous settings. The flexible mesh easily and smoothly resolves the sinuous channel and uses fewer computational elements than a similarly sized fixed grid model. The flexible mesh model also has no jagged edges on the river banks, whilst the fixed grid model does have rough edges that have the potential to create numerical drag issues in a tidal environment, as discussed above.



2.4 Calibrate Hydrodynamic Model

No calibration of the hydrodynamic model was presented. It is hoped that this has been presented elsewhere rather than not undertaken by the consultant. If it is has been presented elsewhere then BMT WBM would like to review that/those reports, although recent telephone conversations with NSW Government have indicated that it is unlikely that another such report has been prepared. If this is the case, and hydrodynamic calibration has been overlooked, then this is a fatal flaw for this study and the model predictions should not be relied on.

2.5 Develop AD Model

Most components of this task appear to have been undertaken in a fashion generally consistent with industry standards. Dispersion coefficients are within accepted ranges, albeit towards the high end of typical values.

2.6 Calibrate AD Model

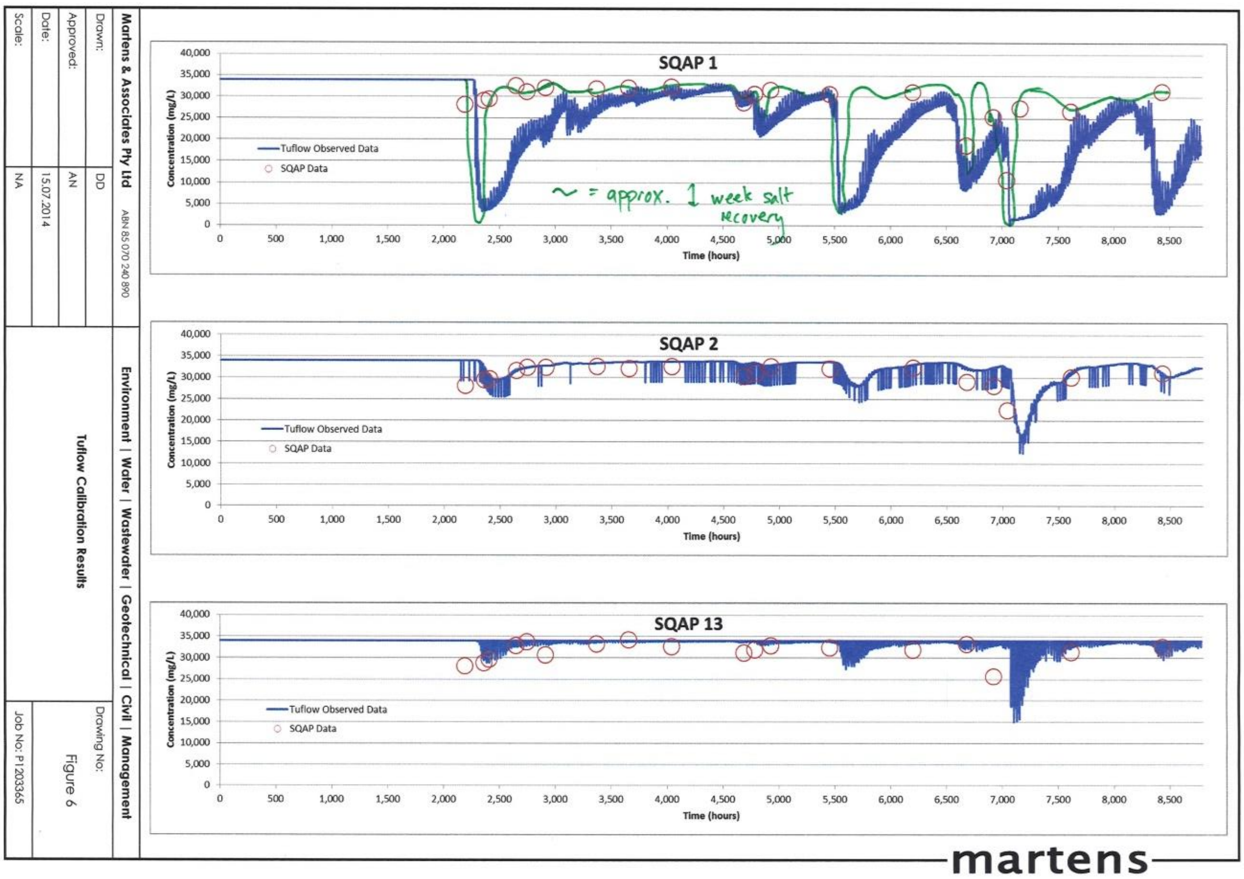
It is appropriate to use salinity recovery data to calibrate AD models. The uncertainty in the timing and quality of salinity measurements described in the report for this study, and the consequent uncertainty in AD calibration, is noted.

The assessment of the calibration performance presented in section 3.3.3 of the report is also noted, where, for example, the model performance at site SQAP 1 was described as ‘seems to be slightly underestimated overall … the calibration in this area is acceptable’ (page 19 section 3.3.3 bullet 3). BMT WBM disagrees with this assessment. In particular, it is our view that the model is not capturing advective processes responsible for salt (and therefore pollutant) transport within the system. Our reasons for taking this view are described below.

As noted above, model performance at site SQAP 1 is described in the report as 'slightly underestimated overall', and yet the model does not capture the salt recovery associated with the first inflow event at approximately 2500 hours. Rather, the model predicts a salt recovery time of approximately 1000 hours (acknowledging that there are some smaller inflow events over this period that will marginally retard salt recovery), which is approximately 40 days. This is a very long recovery time, especially given that (a) the monitoring data shows almost immediate salt recovery at SQAP 1 (even within the 7 day sampling error bounds noted in the report) and (b) the distance from site SQAP 1 to the open ocean is only a matter of a six or seven kilometres – salt recovery over this short distance is very unlikely to take 40 days in an area where spring tidal ranges are almost 2 metres. Recovery over 40 day seems implausible, and isn't supported by measured data.

A more plausible salt recovery time over this short distance to SQAP 1, in the opinion of BMT WBM, more like several days following inflow cessation, up to a maximum of perhaps a week (approximately 160 hours). This timeframe is consistent with all measured data, and much shorter than that predicted by the model.

Below is a hand drawn alternative for a model prediction that BMT WBM would expect to be more likely in this small estuary. Clearly this hand drawn prediction is qualitative only and is not meant to indicate anything other than a possible alternative to the predictions presented, with this alternative being consistent with a 7 day (maximum) recovery time and salinity measurements at SQAP 1.



To summarise, it appears that the model is predicting salinity recovery times in excess of what would be expected in such a small estuary, and these recovery times are inconsistent with measured data. One cause of this poor prediction of recovery time (and hence subsequent prediction of pollutant advective and dispersive transport) might be that the hydrodynamic model is not correctly transporting water back and forth during tidal cycles. Specifically, these slow recovery times could be caused by, and are consistent with, the hydrodynamic model underpredicting tidal volume exchange, and hence salt exchange and transport as discussed above.

Directly following from discussion in Section 2.3, this underprediction of tidal exchange is consistent with a hydrodynamic model that suffers from the issues described above, with the most likely issues being the presence of artificial bathymetric steps and significant numerical drag caused by inaccurate representation of riverine bathymetry and application of a 50m cell fixed grid model to a sinuous estuary. Further assessment of these issues by BMT WBM is not possible because neither a hydrodynamic calibration report or model bathymetric maps have been provided. If the former is due to no hydrodynamic calibration having been undertaken, then it is BMT WBM's view that the AD modelling undertaken and presented in the reviewed report is also fatally flawed.

As an aside, an argument might be put forward that because the AD model is significantly overpredicting salinity recovery time (i.e. the model is somewhere/somehow choked and is restricting flushing) that it is a conservative estimator of the receiving water impacts of the proposed development. It may then be suggested that it follows that this conservativeness is favourable for the current predictions of impact. BMT WBM does not agree with this stance – interpreting predictions from a model that has serious flaws is not consistent with best practice.

2.7 Select Scenario Period

Selection of appropriate periods of time over which to execute scenario assessments is central to the success of a modelling study of this nature. In particular, selection of several separate periods that have varied rainfall patterns (e.g. wet, typical and so on) is important so as to ensure than assessments take into account a range of possible meteorological (and hence pollutant export) conditions. In all cases, this range of periods must be selected to suit the problem at hand, i.e. professional judgement is required in determining appropriate scenario periods.

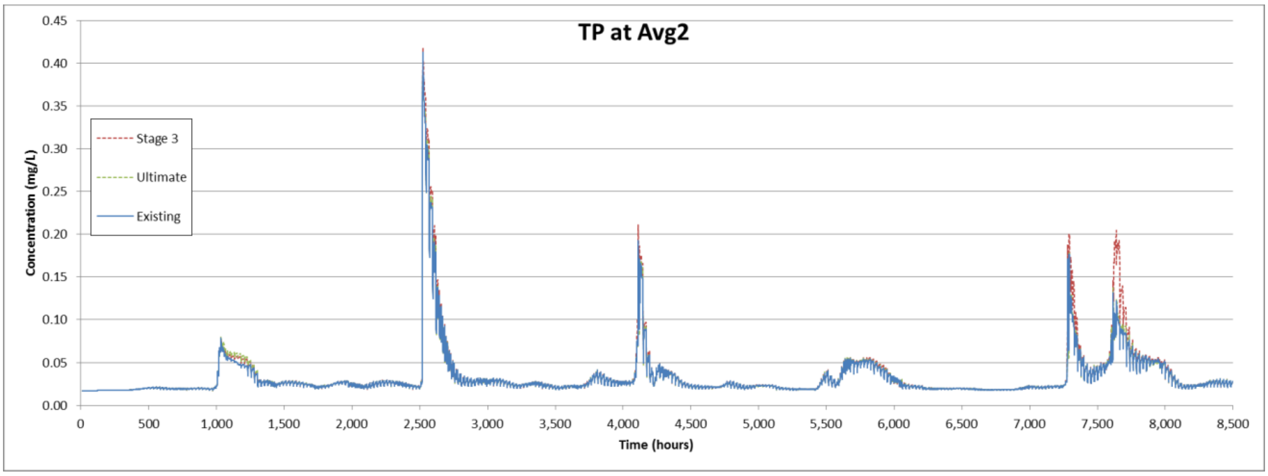
Nonetheless, in cases where proposed land use changes encompass all (or at least a significant majority) of a catchment draining to a receiving waterway of interest, selecting a wet period for scenarios that see significant inflow events delivered to that waterway would generally be appropriate. In such a case, we would expect to see significant increases in pollutant loads delivered to the waterway over the base case if a large portion of its catchment is developed (without mitigation measures). It would then be appropriate to include wet years (or periods) in the scenario analysis.

In terms of the current study however, the proposed development covers 109 ha, but the upstream catchment draining to this arm of the Crookhaven River is approximately 10,000 ha (100km^2). This is a very rough estimate that needs to be confirmed, however it is correct in order. With this approximately 1% proportion of the catchment having a proposed change in landuse, it would reasonably be expected that in very wet periods, runoff and pollutant load delivered to the Crookhaven River from the 109 ha site would be overwhelmed by the flows and loads originating from upstream and outside of the proposed development footprint. Indeed, the report mentions this fact in several places:

- Page 22, section 3.5.2 bullet 1b ‘This is because the River [*sic*] itself directly receives the largest volume of upstream flow and pollutant mass.’
- Page 22, section 3.5.2 bullet 1c ‘During infrequent storm events there is a significant freshening effect in the entire system.’
- Page 22, section 3.5.2 bullet 1d ‘During infrequent storm events, the concentrations of each pollutant change considerably when compared with mean and median values’. The report then notes some percentage changes of up to 3000%, including 850% for TP. Whilst these numbers are not particularly meaningful, they do show that the upstream catchment delivers a very large pollutant load to the estuary
- Page 22, section 3.5.2 bullet 1e ‘Both the Crookhaven River and Curley’s Bay receive a large amount of pollutants over the course of a year.’

The modelling report reviewed here has chosen a very wet year for scenario analysis (1969) and notes this period was chosen as it had ‘the highest annual rainfall of the period assessed – more rain fell in 1969 than the previous two years combined’ (page 15, section 3.2.3. bullet 3bii). This is a poor choice of scenario period for this study because any impacts of the proposed development on the Crookhaven River during very wet periods such as 1969 would reasonably be expected to be undetectable in the receiving water. This in turn is because the riverine pollutant concentrations will be dominated by delivery of existing (off site) upstream pollutant loads.

The report presents base case results that demonstrate this ‘swamping’ of the river by upstream flows. One timeseries (TP) of model outputs is presented below from the report. The spikes at hours 1000, 2500, 4100, 5500 and 7300 show very large base case (blue line) spikes in TP. This means that the upstream catchment is dominating the pollutants delivered to the river. It is only the last event at 7600 hours where some differences are noticeable between base case and scenarios.



Given this, one could not reasonably expect to see any significant modelled impacts from the developed 109 ha site, and the above figure supports this view. Perhaps it is not surprising then, that the report predicts minor impacts of the development (page 23 section 3.5.2 bullet 2ai ‘The vast majority of results show that changes to salinity, TN, TP and TSS at all points are negligible’).

One suggestion for a more representative scenario is where upstream inflows are minor, but local rainfall generates runoff from the proposed development and its surrounds. This may well be a ‘dry’ year/period from a whole of catchment perspective, but one that still includes several rainfall events over the site of interest, such as local storm cell type events or similar. Without this style of scenario arrangement, nothing meaningful can be expected from the scenario assessments presented in the report. Given this, and noting that (a) the hydrodynamic modelling is flawed and (b) the AD model is poorly calibrated and does not capture salt recovery behaviour, no further effort has been made in this review to consider the scenario assessments beyond the above.

2.8 Summary

The report reviewed presents modelling that is fatally flawed. Although the actual numerical packages selected for use (TULFOW and TUFLOW AD) are robust and well respected packages, they have been applied inappropriately to the Crookhaven modelling study. Specifically, the following issues were identified in this review:

- **Model selection.** TUFLOW and TUFLOW AD are industry leading fixed grid software packages, that are mostly applied to open floodplains. They are also applied (less often) in studies of this type, however, they should not be applied to sinuous rivers like the Crookhaven, unless a suitably small model cell size is used. It is well known that fixed grid models often poorly capture key bathymetric flow paths in sinuous riverine environments.
- **Model cell size**. The selected model grid was too coarse. A 50m cell size is too large to properly resolve key bathymetric features in the river, and hence capture tidal flows. If using smaller cell sizes presented computational issues, then a different modelling package should have been considered to overcome this issue. TUFLOW FV is such a suitable model.
- **Hydrodynamic Calibration**. The TUFLOW hydrodynamic model was not calibrated to either water levels or tidal flows. Unless other reports exist that present hydrodynamic calibration, then this is a fatal flaw in the study.
- **AD Calibration**. The AD calibration was poor. The calibration figures presented demonstrated the model's inability to properly capture salt recovery events. Surprisingly, the model predicted that almost 40 days were required for salt recovery to only 6 or 7 kilometres upstream from the open ocean. This is too long, is inconsistent with the monitoring data (which shows a rapid salt recovery), and points to a problem(s) in the hydrodynamic model, most likely along the lines bullet pointed above.
- **Scenario Assessment**. The period adopted for scenario assessment was 1969, which was a very wet year. During this year, several very large inflow events entered the Crookhaven River in the base case (i.e. undeveloped), and these saw delivery of significant pollutant mass to the estuary, even in the absence of the proposed development. These very large pollutant loads then 'swamped' any potential signals of the pollutant load delivered from the proposed development in the model predictions – the background concentrations were already so high in the base case that the additional signal of the proposed development was negligible. This is not surprising. A period that included localised rainfall and minor (or nil) inflows from upstream should have been considered as it is these events that will likely show a noticeable impact on the Crookhaven River as a result of the proposed development, and represent risks to the downstream receiving environment.

Given the above, this review finds that the modelling presented in the report '*Estuarine Management Study: Proposed Mixed Use Subdivision – West Culburra, NSW, August 2014*' is fatally flawed and its supporting model predictions should not be relied on.

3 Alternative Approach

In order to provide robust modelling outcomes for this study, BMT WBM recommends that the following tasks be undertaken, in approximate order of execution:

- Select a flexible mesh numerical model appropriate for this river. An example would be TUFLOW FV (http://www.tuflow.com/Tuflow%20FV.aspx)
- Build the model with bathymetry-following flexible mesh arrangements, noting and including the key bathymetric features of the Crookhaven River.
- Collection of appropriate hydrographic (and AD) data to calibrate the model's hydrodynamic performance. These data are relatively easy to collect, especially in a river so close to a town and boat ramps. Some suggestions for precisely what data are as follows:
  - Boat mounted acoustic Doppler current profiler (ADCP) transects at a location near to the river mouth (noting that the presence of mangroves may need to be accounted for).
  - Concurrent tidal measurements near the mouth, and as far upstream as practicable and tidally influenced. These instruments could also measure temperature and salinity easily (as conductivity temperature depth, CTD), and these data would add considerably to the model outcomes.
  - These data should be collected over both neap and spring tide conditions, and the CTD instruments can be left in the water between tidal phases.

  The above is a fairly standard data suite, and is not likely to incur significant expense, but is essential to the study. Without these hydrographic data sets with which to undertake calibration, the hydrodynamics (and hence AD) predictions are unsubstantiated.
- Calibrate the hydrodynamic and AD models using the above data and catchment model.
- Select appropriate periods and meteorological conditions over which to execute scenarios.
- Execute scenarios.

None of the above suggestions are particularly onerous or costly, and represent the minimum requirements for acceptable execution of a modelling study such as the one reviewed here.