THE UNIVERSITY OF
NEW SOUTH WALES

Water Research
Laboratory

School of Civil and
Environmental Engineering

23 June 2010

Our Ref 10065 BMM:WLP LR100618

Department of Planning
GPO Box 39
SYDNEY NSW 2001

Attention: Ms Anna Scott

Dear Anna,

**INDEPENDENT REVIEW
TILLEGRA DAM: HYDROLOGICAL AND WATER QUALITY
IMPACTS ON HUNTER ESTUARY**

In accordance with the consultancy agreement dated 17 May 2010 between the Department of Planning and the University of New South Wales and our proposal dated 13 May 2010, Dr Bill Peirson has completed a review of the estuary modelling undertaken for this project in accordance with your scope of works:

The Department requires an independent review of the hydrology and water quality impacts (including salinity) of the proposed Tillegra Dam on the Hunter Estuary (including the RAMSAR Site). The Department requires that the consultant conduct a review and comment on the following in relation to the modelling conducted:

A. *The validity and appropriateness of the model used.*
B. *The validity, accuracy and precision of the data and assumptions on which the modelling has been based.*
C. *The validity, accuracy and precision of the interpretations that have been drawn (by the proponent in their assessment documentation) on the basis of modelling results.*
D. *Is the calibration and verification of the model following due process?*
E. *Should the modelling be found to be deficient in any way, the consultant is to provide suggestions of any amendments that would be required to improve the rigour of the modelling, its output or the interpretations drawn from it.*

Additionally, the Department requires the consultant to specifically comment on:
1. *Is the estuary model accurately conceptualising estuary processes, function and behaviour (that is, is the model capable of modelling the hydrodynamics of the estuary)?*
2. *Are the predicted modelled impacts on the hydrologic and water quality (including salinity) characteristics of the Hunter Estuary due to the construction and operation of Tillegra Dam representative, accurate and precise?*
3. *Has the contribution of tidal flows in the modelling been over-estimated?*
4. *Has the estuary modelling undertaken for the Proponent assessed the worst case scenario for the hydrologic and water quality (including salinity) impacts on the Hunter Estuary (including the RAMSAR sites)?*

We note that this review explicitly excludes consideration of the hydrological modelling that is a key information input used by the estuary modelling. We will only comment on hydrological modelling as it relates to the accuracy of the estuary modelling.

This review is undertaken with reference to the following list of documents provided as background to this review and summarised in Table 1. The list has been assembled in chronological order to clarify the development of the estuary modelling.

Table 1
Documents provided by NSW Planning for this present Review

	Description	Date
12	Proposal from BMT WBM to NOW titled "RE: Modelling Services for the Assessment of Salinity Responses to River Flow Modification within the Hunter River Estuary". NOW subsequently commissioned BMT WBM to proceed with the development of Option 2, which is the FVM Model developed by BMT WBM for NOW, to underpin the water sharing plan process;	23 December 2008
2	BMT WBM (2009) 'Ramsar Wetland Modelling Investigations for the Tillegra Dam Project';	15 June 2009
3	Hunter Water Corporation (2009) 'Tillegra Dam Planning and Environmental Assessment ' (display date)	10 September 2009
5	NSW Office of Water (NOW)	18 November 2009
6	Letter from BMT WBM to HWC, titled "RE: Hunter River RAMSAR Modelling – Response to Substantive Matters raised by NSW Office of Water";	11 December 2009
7	Letter from BMT WBM to HWC, titled "Hunter River Ramsar Modelling – Accuracy of ELCOM Modelling";	29 December 2009
10	Proposal from BMT WBM to HWC, titled "Hunter River Ramsar Modelling – Finite Volume Modelling for Flow Assessment";	4 January 2010
13	Letter from BMT WBM to NSW Office of Water entitled "RE: Hunter River Salinity Calibration";	7 January 2010
11	Email from BMT WBM to HWC, with subject "Stage 1: Modelling Outcomes";	25 January 2010
1	BMT WBM (2010) 'Hunter River Ramsar Modelling (Stages 1 and 2) – Comparative Analysis of Salinity Regime within Hunter River Tidal Pool and Kooragang Wetlands';	29 January 2010
4	Hunter Water Corporation (2010) 'Environmental Assessment Submissions Report ';	24 February 2010
14	Letter from BMT WBM to NSW Office of Water, entitled "RE: Hunter River Salinity Modelling – Progress of Salinity Calibration"	24 February 2010
15	Document titled "Copy of email received 12/04/2010" – from BMT WBM to NSW Office of Water;	12 April 2010
16	Memorandum from BMT WBM to NSW Office of Water with subject "Hunter River Salinity Modelling Sensitivity Tests";	22 April 2010

17	Memorandum from NSW Office of Water to BMT WBM, with subject "Progression with the Hunter Estuary Inflow Assessment Modelling Project";	30 April 2010
8	Email from HWC to Department of Planning, with subject "FW: ELCOM Model runs clarification" (this email contains an email from BMT WBM to Aurecon and HWC dated 11 January 2010);	14 May 2010
9	BMT WBM (undated) Figure titled "Longsection profile along Hunter River North Arm";	undated
18	Working internal document from NSW Office of Water (undated) titled "Water Sharing Plan Performance Monitoring: Hunter Estuary inflow salt wedge modelling project. Project Summary (Working document 2009)".	undated

Dr Peirson's review follows this letter.

If you have any questions with regard to the review, please do not hesitate to contact Dr Peirson or myself.

Yours sincerely,

Brett Miller
Manager.

INDEPENDENT REVIEW
TILLEGRA DAM: HYDROLOGICAL AND WATER QUALITY IMPACTS ON HUNTER ESTUARY

by W L Peirson, 15 June 2010

Introductory Remarks

The consultant's brief specified that a series of issues be considered in relation to modelling studies of the Hunter Estuary. For clarity, these issues have been numbered and are referred to as *issues A* to *E* and *1* to *4* and are shown in bold type in the review presented below. Numbers in square brackets refer to the documents supplied for the purposes of this review and listed in Table 1 of the accompanying letter.

Determining the impacts on the Hunter Estuary and its fringing wetlands requires an estuarine environmental flow assessment. Such issues may be discussed in other study documents not available to this reviewer. However, based on the documents provided, these present studies seem to have been undertaken with little reference to previously published approaches to estuarine environmental flow assessment (e.g. Peirson *et al*., 2002; Sheltinga *et al*., 2006). Some sort of synoptic view of the environmental effects of reduced freshwater flows is essential to guide studies and ensure that all important considerations are addressed (e.g. Table 2 in Peirson *et al.*, 2002).

Australia has a hydrological character which is unusual internationally and environmental flow assessments must recognise this. This is a particular issue in eastern Australia where rainfall shows very weak seasonality. Victoria shows stronger seasonality than NSW and this has guided some of their approaches to determining estuarine environmental flows including the use of spells analysis (e.g. Doeg and Pope, 2006). The practical implication of this weak seasonality in NSW is that estuarine behaviour and saline structure are strongly dependent on the antecedent flow conditions (Peirson *et al*., 2001). In particular, salt intrusion and stratification are very dependent on the antecedent flow conditions which has significant consequences for estuarine ecosystems (Peirson *et al.*, 1998; Peirson *et al.*, 2002).

A. The validity and appropriateness of the model used?

This present review is complicated in that three separate model codes (ELCOM, Hodges and Dallimore, 2006; TUFLOW BMT-WBM, 2008; and, TUFLOW-AD, BMT-WBM, 2010) seem to have been used for the investigation. The review is further complicated in that two distinct TUFLOW model meshes seem to have been used. A mesh consists of the numerical *domain* (area of estuary bathymetry and adjacent topography) and how it is discretised (Peirson, 2009).

There should be some description of the ELCOM domain and discretisation in Section 4 of [2] but none could be found. Some indication of model domain and discretisation was found on page 165 of [3]. Presumably, (i) the ELCOM simulations were undertaken with the salinity and density fully coupled to the flow behaviour but this is not described,.(ii) the ELCOM simulations are capable of simulating the observations cited as Sanderson *et al*. (2002) in Figure 2 of [13] but no comments on this could be found within the documents provided. Improvements in the modelling documentation are recommended.

It appears from the comments in Section 3.2 of [2] and Section 3.1.2 of [1] that different meshes were used for the TUFLOW flood and salinity investigations but the relationship between the two meshes remains unclear. This should be clarified.

In [2], reference is made exclusively to TUFLOW-FV which is presumed to be the hydrodynamic flow-velocity component. BMT-WBM (2010) describe TUFLOW-AD as a separate model. The relationships and coupling between the hydrodynamics and advection-dispersion of constituent components are not explicit in [1]. This is of concern in view of the draft status of the TUFLOW-AD documentation. These relationships and model couplings should be clearly specified for the purposes of the present study.

The preceding remarks have been made to provide some background prior to addressing issue A.

As response to issue A, the following three points are made:

i. The data of Sanderson *et al*. (2002) show that the estuary has periods of partial salinity stratification (Peirson *et al*., 2002, p. 31). The partial stratification will have greatest influence on salinity levels in the lower estuary and an important region of interest is in the lower estuary (the Ramsar sites). Unless investigators can show that stratification effects are irrelevant or insignificant, the model selected and used should have this capability. The TUFLOW-type models do not have this capability and ELCOM has this capability but with some apparent constraints (Section 3.3 in [12]). There is no explanation as to why these models were selected when alternative models with greater capability, flexibility and track record were not used on this study. (Please refer to the international estuarine and coastal modelling series sponsored by the Waterway, Port, Coastal and Ocean Division of American Society of Civil Engineers has many examples and applications dating from the early 1990s.) The apparent inability of ELCOM to simulate long periods of antecedent flow conditions is a significant weakness of this model in its application to Australian estuaries.

   Present evidence is that partial stratification is important in the lower estuary (lower panels of page 13 of [1] and the associated discussion on page 8 of [1]). The TUFLOW model has not been able to adequately represent the observed salinity structure in a key area of interest due to the effects of partial stratification. Such representation is a fundamental requirement of the investigation (Peirson *et al.*, 2002, Table 2).

ii. Saline intrusion into the upper estuary is likely to have a vertically homogeneous structure (Peirson *et al*., 2002, p. 32) and unstratified models have been used successfully to investigate estuarine environmental flows in such reaches (e.g. Peirson *et al*., 1999; Miller *et al*., 2006). If intrusion into the upper Hunter Estuary arms is of interest to this study, TUFLOW-type models may well be suitable. However, none of the salinity calibration data presented in these reports is suitable to validate the models in these reaches as it has been obtained only in the lower estuary reaches (Figure D-1 in [2] and page 13 in [1]).

iii. Estuarine environmental flow assessments should at least consider the issues summarised in Peirson *et al*. (2002), Table 2. In [2], consideration is given to floods (e.g. [2], Section 3 and [2], Figure 4-3) of different magnitudes. The TUFLOW model may well be suitable for such simulations but key information appears to be missing from the documentation (e.g. the model domain; discretisation; the extent of overbank flow; marshing processes) and the relationship between the model configuration and the key ecosystems of interest (for example, saltmarsh). Particular items of interest to ecological studies are the approximate bankful flows of the system, their frequency of exceedance, flood duration and how these may change under the developed condition. This information was not apparent in the documentation provided.

B. The validity, accuracy and precision of the data and assumptions on which the modelling has been based.

An important gap in the analysis appears to be that tides and floods have been treated as distinct processes. In reality, they are coupled estuarine processes. In the case of the Hunter system, inundation of wetland systems by frequent floods could be an important ecological process ([1], p. 15*ff*). There appears to be no consideration of how the proposed changes to water extractions may modify the more frequent inundations of fringing wetlands. Smaller floods which inundate wetland systems should be able to be represented by the present TUFLOW tidal model. By comparing the statistical distributions of extreme water levels obtained from simulations of substantial duration, the impacts of water extractions on more frequent floods should be able to be assessed.

Due to the weak seasonality of rainfall in Eastern Australia, major storages may await a significant period of time to reach a useful storage level. During the filling period, reservoir operations may differ and whether or how they might differ should be clearly stated. From the documents provided, there appears to be no discussion of how the reservoir will be managed whilst it awaits filling nor what might be the consequences for environmental flows during this period.

There are four data forms that are of importance to these investigations:

i. bathymetric/topographic
ii. boundary conditions: inflows and tailwater levels
iii. calibration data: water level, velocity (discharge), salinity
iv. verification data: water level, velocity (discharge), salinity.

It has been assumed that water quality modelling (apart from salinity) is excluded from this assessment as no numerical modelling of water quality appears to have been undertaken. Bulk nutrient budgets are presented in Section 6 of [2] but it is outside the scope of this investigation to review these values. Water quality in estuaries can be influenced by reduced freshwater flows due to reduced vertical mixing (Peirson *et al.*, 2002, Table 2, Low-1, increased hostile water-quality conditions at depth) but such effects do not appear to have been addressed.

Specific concerns relating to bathymetric, calibration and verification data were raised in the discussion of Issue A (lines 60 to 86) and will not be reiterated.

Although the different data types are addressed in the reports, there is no clear summary statement of available data that are relevant to this investigation. Other significant measurements of flooding and salinity may have been undertaken on the Hunter since the work of Moore (1959).

No review of the hydrological inputs to the models is undertaken here as this is understood to be undertaken by another reviewer. The locations of freshwater flow inputs to the TUFLOW estuary model appear to be significantly different ([1] Figure 3-1) from those of the TUFLOW flood model ([2] Section 3). The relationship between these two models should be more clearly stated.

The only comments offered in this review relating to flow inputs are those concerning hydraulic issues. Specifically, they are:

i. Why is there a significant jump in the flood frequency distribution in Figure 3-1 of [2]? This seems to have been carried over into Figure 3-2.
ii. The magnitude of flow of large ARI floods would be expected to be such that dam storages are filled on the rising limb of the flood and then, once filled, have no effect on the subsequent flood discharge. This does not appear to be the case in Figures 3-4 to 3-7 and deserves explanation to reassure the reader that the study findings are robust.

The potential hydrodynamic coupling of the north and south arms of the Hunter could be complex and a potentially important aspect of estuary behaviour. Justification of how this was accomplished and verified was not apparent in the documentation provided and should be made.

The reasons for the selected tail water conditions used for the flood study in [2] are not documented. The magnitude of the February 1990 event and the performance of the model for this flood are not described. By examining the tabulated flood series, it is apparent that the February 1990 event had a large recurrence interval. Model verification for a minor flood would be useful. Such results are important for determining model accuracy for flood events of differing recurrence intervals.

In summary, the data used seems to be entirely appropriate but there seems to be gaps in the data assembly and reporting for this investigation. It is impossible to assess adequately the assumptions made during the modelling until these issues are resolved.

C. The validity, accuracy and precision of the interpretations that have been drawn (by the proponent in their assessment documentation) on the basis of modelling results;

Model validity, accuracy, precision and any subsequent interpretations are fundamentally determined by the model calibration and verification processes adopted. This is issue D but will be addressed here.

Please note that recorded field data is extremely valuable yet expensive to collect. Consequently, many studies often may not have sufficient data available for independent model verification (for example, see line 157).

Concerns relating to the calibration of the flood model were raised under issue B (lines 154 to 158).

Points of concern in the calibration and verification of the models for salinity were discussed under issue A (lines 60 to 86).

In [2], calibration of the ELCOM model is made for water levels and discharges. Calibration is evaluated by a skill parameter shown on page D-1. There is no justification of the scale adopted for goodness of fit and the raw data is not presented in comparison with the recorded data.

In general, it is relatively easy to match extreme water levels within an estuarine system. More challenging tests of tidal performance are tidal lags, tidal exchange volumes (Nittim and Peirson, 1987) and salinity structure. In [1] Figure 3-3, there are significant differences between measured and modelled water levels which are not discussed in the report. It is impossible to compare adequately the tidal lags in [1] Figure 3-3. There is no comparison of measured and modelled tidal volumes that clearly shows the absolute differences in magnitude.

It seems surprising that salinity assessment in [1] is only presented for locations in the upper Hunter and Paterson Rivers. Assessment at a greater range of sites within the estuary would reassure the reader that changes in the remainder of the estuarine system are insignificant.

No formal model verification appears to have been undertaken during this investigation except for ELCOM water levels (which is not a strong test of model skill). It is possible that insufficient data exists for formal verification. However, this needs to be clearly stated with reference to a statement of relevant available data as highlighted under issue B (lines 132 to 134).

As far as interpretation of the model results are concerned, the authors have elected to apply spells analysis to salinity. In this reviewer's experience, application to salinity is unconventional but may have been specifically requested by ecologists using the model data. If such presentations were used and interpreted effectively by ecological colleagues, the approach is justified. However, in my experience long term average values of water levels or salinity (Table 4-3 in [1]) are not effective statistics in characterising ecological system behaviour. In general, estuarine ecosystems will undergo greatest stress during periods of prolonged drought. Consequently, characterising the extremes of flow, inundation and salinity are important to understanding ecological shifts (e.g. Figure 2 in Peirson *et al.*, 2002). Although the spells analysis does reveal some significant shifts under modelled scenarios (e.g. Figure 4-16, 2.5ppt) this may not be the best method of capturing shifts in extremes in a climate of weak seasonality and it is recommended that more conventional presentations be used. Based on my experience as a numerical modeller working with a number of estuarine ecologists, their primary concerns are how saline structure is anticipated to shift along an estuarine system. My recommendation is that such a form would clarify the results of the present investigation (that is, similar to the format used in [2], Figures E-5 to E-8 but presented in terms of frequency of exceedance of a given salinity and contrasting the scenario conditions).

Reductions in flood level are shown in pp. 96 to 98 of [2] but it not clear how these relate to the topography of the wetland. Frequency of inundation may be critical to ecosystem function ([1], p. 15*ff*). By taking a spatial average over a substantial length of estuary, Figure 34 in [3] may mask any gradients through the wetland system along the estuary which may correlate with gradients in changes to flood level (Table 10 in [3], p.95).

D. Is the calibration and verification of the model following due process?;

This issue is addressed at the beginning of issue C (lines 166 to 197).

E. Should the modelling be found to be deficient in any way, the consultant is to provide suggestions of any amendments that would be required to improve the rigour of the modelling, its output or the interpretations drawn from it.

The responses to the issues have been prepared to provide specific guidance on how the issues could be addressed.

1. Is the estuary model accurately conceptualising estuary processes, function and behaviour (that is, is the model capable of modelling the hydrodynamics of the estuary)?

This issue is addressed in detail in the review comments on issue A.

2. Are the predicted modelled impacts on the hydrologic and water quality including salinity) characteristics of the Hunter Estuary due to the construction and operation of Tillegra Dam representative, accurate and precise?

This issue has been addressed in detail in the review comments on issue B (all comments) and issue C (see lines 166 to 197).

3. Has the contribution of tidal flows in the modelling been over-estimated?

Assuming that tidal flows refers to the intrusion of salinity into the estuary, it is not possible on the present level of documentation to determine a definitive answer to this question. Please refer to previous comments on issue A (lines 60 to 86), issue B (lines 150 to 152) and issue C (lines 190 to 192).

4. Has the estuary modelling undertaken for the Proponent assessed the worst case scenario for the hydrologic and water quality (including salinity) impacts on the Hunter Estuary (including the RAMSAR sites)?

The preliminary review assessment is that there are gaps in the analysis which need to be addressed before this question can be answered (see especially lines 160 to 162).

Summary and Conclusions

This review has revealed the following key concerns in relation to the reported investigations of Tillegra Dam and its hydrological and water quality impacts on Hunter Estuary:

1. The reports provided do not clearly define the ecological issues under consideration and the consequent linkages and requirements of the numerical modelling studies undertaken.
2. No comprehensive summaries of the available data for calibrating and verifying numerical models have been presented.
3. The level of development and documentation of the models used appears to have had impacts on the outcomes of the numerical modelling study.
4. The interaction between floods and tides in determining the flooding of saltmarsh and wetlands adjacent to the Hunter Estuary does not appear to have been addressed by the present modelling.
5. Rainfall patterns in the study region are weakly seasonal and limitations in the characterisation of impact under a historically variable climate have been identified.

Within the reports provided, there are significant gaps and it is not presently possible to determine whether the approach taken and the consequent conclusions made are reliable.

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Table 2 Checklist of major ecological processes by which reduced estuary inflows may cause impacts on estuarine ecosystems and the adjacent marine environment[1]. (From Peirson *et al.*, 2002)

Low-magnitude inflows (Low-):

Low-1: increased hostile water-quality conditions at depth

- reduced inflows, and concomitant reduced vertical mixing (turbulence), resulting in hostile water-quality conditions (e.g. low DO at depth) in deep sections within the upper-middle estuary where water retention times are protracted; higher salinity at depth would aggravate problems with DO; demersal eggs and large-size taxa are at most risk because they are found in deeper sections where water quality is likely to be most hostile

Low-2: extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna

- reduced inflows resulting in extended durations of elevated salinity in the upper-middle estuary; fauna with low salinity tolerance (eggs, larvae, juveniles or adults) could be adversely affected through physiological stress and/or by competition and predation from colonising large fauna normally found in the lower estuary; increased parasitism may also be involved; avoidance response to salinity may cause occupation of suboptimal habitat and/or overcrowding; Odum (1970) indicated that the low-salinity region of an estuary acts as an important nursery ground for juvenile fish and invertebrates

Low-3: extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora

- reduced inflows resulting in extended durations of elevated salinity in the upper-middle estuary; instream and/or riparian plants with low salinity tolerance will be adversely affected through physiological stress; a considerable range of subsequent impacts could result: loss of shelter and foraging areas (riparian & instream plants) for fauna, reduced water quality as plants have diminished capacity to trap nutrients and sediments (riparian & instream), reduced bank stability if riparian plants die and subsequent water-quality deterioration if collapsed bank materials release nutrients to the water

Low-4: extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota

- reduced inflows resulting in extended durations of elevated salinity in the lower estuary; marine biota thus able to colonise the lower portion of the estuary; sensitive biota either displaced through competition or predated upon, and may be additionally disadvantaged by high-salinity induced physiological stress

Low-5: extended durations when flow-induced currents cannot suspend eggs or larvae

- reduced inflows resulting in extended durations when flow-induced currents cannot suspend eggs or larvae in the upper-middle estuary; eggs or larvae settle to the bottom and mortality results

Low-6: extended durations when flow-induced currents cannot transport eggs or larvae

- reduced inflows resulting in extended durations when flow-induced currents cannot transport eggs or larvae in the upper-middle estuary to favourable habitats for later life-history stages (inhibition of advection); growth/recruitment opportunities are lost

Low-7: aggravation of pollution problems

[1] This checklist is adapted and expanded from Bishop (1999) who developed a checklist based on a literature review which strongly relied on the work of Drinkwater and Frank (1994). All processes could lead to reductions in survival and growth rates, abundance, biomass & diversity of the biota. The processes are grouped in relation to the fresh water inflow magnitudes where they are likely to have the greatest relevance. DO = dissolved oxygen.

- reduced inflows aggravating pollution problems in the upper-middle estuary originating from either agricultural, industrial or urban pollution sources; may include consequent biological 'pollution' (e.g. algal blooms, etc.); lowered dilution of pollutants and/or stratification-induced deoxygenation causing the releases of toxicants from estuary-bed sediments; higher salinity at depth would aggravate problems with DO; consequent lowered abundance of fish, shellfish and crustacea, and contamination of tissues; nutrients may also be released from sediments causing algal problems for example.

Low-8: reduced longitudinal connectivity with upstream river systems

- decreased inflows can sever, or halt the establishment of, connectivity between the estuary and upstream river systems; this can have severe impacts on fauna with diadromous lifecycles (e.g. mobile fauna such as fish and crustaceans)

Middle- and high-magnitude inflows (M/H-):

M/H-1: diminished frequency that the estuary bed is flushed fine sediments and organic material (physical-habitat quality reduction)

- reduced inflows greatly altering the frequency that the bed of the upper-middle estuary is flushed of fine sediments and organic material (i.e. high flows causing substrate turnover); this is significant as many fauna lay their eggs on or within hard substrates - the presence of sediment/organic matter will result in lowered reproductive success as suitable egg deposition/attachment sites will become limited

M/H-2: diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction)

- reduced fresh water inflows greatly altering the frequency that organic material deposited on the bed of deep sections in the upper-middle estuary is flushed out; this is significant as a high organic load can result in hostile water-quality conditions (for example, low DO); again demersal eggs and poorly mobile taxa are at most risk

M/H-3: reduced channel-maintenance processes

- reduced inflows greatly reducing channel-maintenance processes (mediated by flushing flows) in the upper-middle estuary with a result that major habitat contraction occurs in the longterm; deep sections of the estuary are most vulnerable as very large flows are required to remove infilling material; again demersal eggs and large-sized taxa are at most risk; could be relevant to the lower estuary in respect to the closing of the estuary mouth through the deposition of transported marine sands; a range of impacts on migrating fauna may result from the reduced estuary-marine connectivity; water quality impacts could occur if tidal exchange flushing is substantially reduced

M/H-4: reduced inputs of nutrients and organic material

- decreased inflows subsequently reducing the input of natural river-borne nutrients and organic material; reduced primary production followed by reduced zooplankton abundance along the length of the estuary and into adjacent coastal areas; fish and crustacean abundance diminishes in response to decreased food supply and sheltering areas (instream plants)

M/H-5: reduced lateral connectivity and reduced maintenance of ecological processes in waterbodies adjacent to the estuary

- decreased inflows can sever, or halt the establishment of, connectivity between the estuary and adjacent waterbodies (floodplain billabongs, wetlands, etc.) for mobile fauna; the loss of connecting flows may also result in ecological processes in the waterbodies not being activated or maintained

Across all inflow magnitudes (All-):
All-1: altered variability in salinity structure

- altered variability of inflows to the estuary, and the consequent change in patterns of variation in the salinity structure of the estuary, is likely to disrupt life cycles as suitably-timed breeding and/or migration cues for fish and crustaceans are masked; can also have relevance to plants; growth/recruitment opportunities are lost because of a lack of synchronization with the temperature regime.

All-2: dissipated salinity/chemical gradients used for animal navigation and transport

- reduced inflows which subsequently dissipate salinity & other chemical gradients out from the mouth of the estuary, and/or along the estuary; this is significant as there is evidence (Odum 1970; Grange et al. 2000) that some juvenile estuarine fish and invertebrates species use such gradients to navigate their way into and along estuaries. Salinity-gradient upstream transport mechanisms could also be inhibited.

All-3: decreases in the availability of critical physical-habitat features, particularly the component associated with higher water-velocities

- reduced inflows lower water velocities thereby altering an important physical habitat component, particularly in the upper estuary where tide-induced water currents are less prevalent. Biota favouring higher velocity areas are disadvantaged; generally native biota are disadvantaged more than alien biota.