A Small yet Complex Estuary Alongside the Proposed AQUIS Casino Development

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Abstract
The proposed AQUIS Great Barrier Reef Resort will be the largest of its kind in Australia with substantial economic benefits anticipated for the Cairns community. The proposed resort is to be situated in close proximity to Richters Creek, a small yet complex estuary intersecting the Barron River 9.5 kilometres from it's entrance and flowing into Trinity Bay. This paper details the research undertaken into Richters Creek as part of the Environmental Impact Statement (EIS) pertaining to the AQUIS development. Emphasis is placed on understanding the phasing of the tide and the complex mixing within an estuary with tidal forcing at both its downstream and upstream boundaries. This paper will also be of interest to those involved in the efforts which proponents and their consultants must go through to satisfy the regulatory authorities for such developments.

Commonly estuaries are either reflective, dissipative or a combination of the two. Seldom are the water levels forced at both the downstream and upstream boundaries. Such forcing leads to interesting phasing of the tidal velocities within the estuary. Again commonly in estuaries the downstream boundary is the source of salt, which enters the estuary on the flooding tide. In such systems there is no potential for a net transport of salt through the estuary. Due to the double ended nature of Richters Creek there is the potential for either net upstream or downstream salt transport. This paper explores the interesting tidal phasing and mixing phenomenon within Richters Creek in the context of the physical processes and their implication for the proposed AQUIS development.

The research was undertaken by examining the extensive hydrodynamic data collected by BMT WBM, and through developing and validating the three-dimensional numerical model. A simplified process based solution was developed, not as part of the original EIS but to assist in identifying key processes. The research finds that by virtue of its unique interactions with a larger tidal estuary at its upstream boundary Richters Creek behaves unlike other more typical estuaries. The research also demonstrates how this unique behaviour influences how the proposed AQUIS development could interact with the surrounding environment.

Keywords: Estuarine Mixing, Numerical Modelling, Richters Creek, AQUIS Casino

1. Introduction

The proposed AQUIS Great Barrier Reef Resort is claimed to become the largest and most exciting tourist destination in the Asia-Pacific region. The proposed development is classified as an "integrated resort", which among its many attractions includes a casino. Such developments in the Asia Pacific region are a response to a flourishing Chinese middle-class and the delight they take in gaming. The Environmental Impact Statement (EIS) [1] was submitted in June 2014 with 91% of community submissions in favour of the development as of May 2015. The development is scheduled to open in 2018 [5].

The proposed development consists of a 340.6 ha site, primarily situated over existing sugar cane fields within the Barron River delta / flood plain (Figure 1). The site is approximately 13 km north of the Cairns CBD and 6 km north of the Cairns international airport. The site sits adjacent to Richters Creek, an estuary 6.2 km in length which intersects the Barron River approximately 9.5 km upstream from the Barron's entrance. The tidal limit is marked by rocky rapids a further 4.5 km upstream on the Barron River.

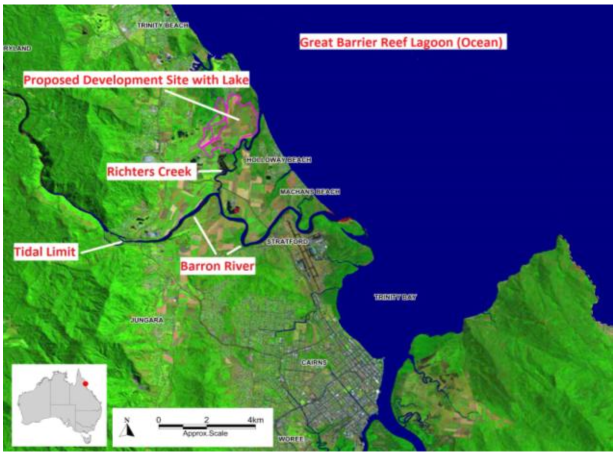

Figure 1 Location map. The development will consist of a 33 ha lake with ocean water cycled through with a 14 day residence time. Initially it was planned to discharge the lake water into Richters Creek near its entrance, presently the plan is to discharge directly into the ocean.

The proposed development consists of a lake designed to ensure the site conveys flood flows as efficiently as predevelopment. The lake's bed and water surface will be maintained around -2.5 m and 1.5 m AHD respectively providing a volume of approximately 1.3 million m^3. The lake water will be isolated from groundwater. To maintain the quality of the lake water, ocean water sourced 2.2 km offshore in the Great Barrier Reef (GBR) lagoon will be cycled through the lake with an expected residence time of 14 days. The ocean water will be pumped into the lake continuously and discharged directly offshore. Initially it was planned to discharge during ebb tides into Richters Creek near its entrance. For this reason much of the EIS was concerned with this scenario and the necessity to understand the Richters Creek / Barron River system.

BMT WBM was subcontracted by Flanagan Consulting Group, the principle consultant, for the flood modelling, water quality modelling, coastal processes assessment and data collection tasks pertaining to the EIS. For the water quality modelling a numerical model was developed which incorporated the Richters Creek / Barron River system up until the tidal limit and extending out into the Ocean. The 1 in 20 year flood plain within the Barron delta and the proposed lake design was included in the model mesh to facilitate the simulation of scenarios pertaining to major flooding and subsequent flushing of the lake. Simulations were performed where the lake was filled with fresh flood waters and progressively returned to saline conditions by discharging into Richters Creek. The potential impacts on the natural environment during normal operations were also rigorously assessed using the numerical model.

Prior to the design simulations the numerical model was rigorously calibrated and validated to the data collected for the EIS. To correctly represent the physical processes within the Richters Creek / Barron River system a high resolution 3D model proved essential with both salinity and temperature driven density coupling implemented. Sediment transport and morphology were not included in the simulations. During the model development phase the complexity of both the 3D structure of the creek flows and the Richters Creek / Barron River interactions became apparent.

The data and numerical model together with a simplified model developed independently from the EIS are used in this paper to explore the intricacies of the tide within the Richters Creek / Barron River system and how these processes interplay with the transport of salt. Commentary on the implications for the operation of the proposed development is provided.

2. Methodology

2.1 Numerical Modelling System

The finite volume flexible mesh numerical software package TUFLOW-FV [6] was implemented to simulate the natural system and explore any potential impacts caused by the AQUIS casino development. The model developed encompassed Richters Creek, the Barron River up to its tidal limit, the surrounding flood plain and extended at least 5.5 km offshore (Figure 2).

Computational cells within Richters Creek and in the near vicinity of the proposed development were typically 15m in width with coarser resolution utilised elsewhere. The vertical resolution was typically 0.5m within the estuary. Such resolution permitted the relevant physical processes to be aptly represented without prohibitive simulation times.

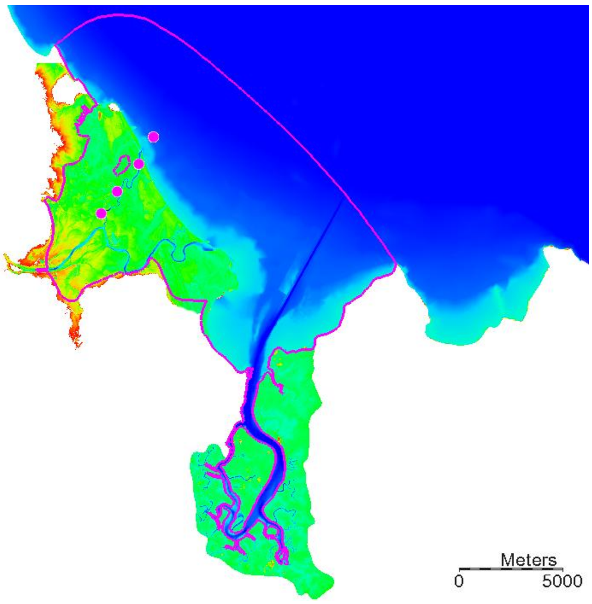

Figure 2 Extents of TUFLOW-FV mesh (pink) together with locations of the 4 measurement sites in Richters Creek. Measurements consisted of water levels, salinity & temperature and were used to validate the model.

The modelling system consisted of numerous inputs. The water levels at the open boundary were forced with tidal predictions combined with an estimated tidal anomaly sourced from HYCOM [2]. Temporally varying temperature and salinity inputs were also sourced from HYCOM and applied along the open boundary. Atmospheric forcing constituted wind, air temperature, relative humidity and both short and long wave radiation. All atmospheric inputs were sourced from the NCEP reanalysis model [3]. Fresh water inflows derived from the Myola gauge were applied at the tidal limit of the Barron River.

2.2 Calibration and Validation

Four instruments capable of recording depth, salinity and temperature were deployed near the bed in Richters Creek to assist in the development of the numerical model (Figure 2).

The water levels measured from the offshore instrument and that located just within the creek's entrance were used to compliment the limited up-to-date bathymetric data over the inlet and to help generate a synthetic ebb tide delta which provided the requisite amount of flow resistance to match the observed water level immediately inside the entrance. The measured water levels from the other gauges revealed that the tidal amplitude was essentially consistent throughout Richters Creek.

During the initial deployment (15 December 2013 – 24 February 2014) there were two significant freshwater flows down the Barron River. Both these events, with peak flows of approximately 250 and 500 m^3/s respectively provided valuable information into how the water levels, salinity and temperature responded and then recovered, both spatially and temporally. Appendix M of the EIS [1] presents the data and the model results together demonstrating that the 3D model was highly capable of simulating the water levels, salinity and temperature within the system. A subset of the full calibration results is presented in Figure 8.

The flows through Richters Creek during both a spring and a neap tide were recorded using a boat-mounted downward facing ADCP. Appendix M of the EIS [1] demonstrates the model was highly capable of simulating the flows through Richters Creek. The flow calibration during the spring tide is presented in Figure 5.

3. Results & Discussion

3.1 Shape and Phase of Tide

3.1.1 Ocean Tide

The ocean tide offshore from the proposed development is comprised of distinct semi-diurnal and diurnal signals. There is a distinct spring-neap tide cycling with the high-high to low-low range approaching 3.5 m during the spring tides and subsequently reducing to 0.6 m during the neaps. The low-high to high-low range can almost disappear during some neap tides. The shape of the tide is mostly symmetrical.

3.1.2 Effects of Entrance Morphology on Tide

The distribution of tidal and freshwater flows between Richters Creek and the Barron River is dependent on the current morphological states of the respective entrances. In general the effect of a constricted entrance is most apparent towards low tide as the ratio of frictional forces to those induced by the water level gradient increases, with the effect of slowing the outgoing water and preventing the water levels in the channel from reducing to those in the ocean. The efficiency of both the Richters Creek and Barron River entrances at passing the ebb tide will depend on recent freshwater outflows and offshore wave conditions, with freshwater outflows acting to open the respective entrances and waves acting to close them.

The temporal evolution of the creek and river entrances would be similar as they pass highly correlated freshwater flows and are exposed to similar waves. It is however possible that either entrance may restrict the outgoing tide to a greater extent than the other and maintain higher water levels around low tide within their respective channel. Since the morphological states of the respective entrances respond markedly to significant weather events it can be assumed that the shape of the tide inside both the creek and river would also respond on the same timescales.

Measurements from August 2014 show low tide water levels during a spring tide in Richters Creek below those in the Barron River. Under these conditions it is reasonable to assume that towards low tide, water within the Barron River would flow back towards the bifurcation and proceed seaward through Richters Creek. Simultaneous water level measurements for both the creek and river did not exist in early to mid-2014 when the numerical model was developed and modelling for the EIS performed. At that stage it was assumed that the low tide levels in the river could be lower than those in the creek due to the river's larger share of freshwater outflows following rain events in the Barron Catchment. This assumption was conservative with regard to the EIS as it slightly limited the creeks capacity at flushing saline lake water, initially discharged into the creek, out through its entrance.

3.1.3 Tidal Water levels and Currents in Richters Creek & the Barron River

Once inside the respective entrances, dissipation of the tidal energy due to friction is minimal and the tidal wave reflects off the rocky rapids which mark the tidal limit. Due to this reflection the tidal wave behaves similar to a standing wave in a frictionless channel (Figure 3). The current signal is principally a function of the flow through the entrance, the distance upstream from the entrance and the cross sectional area of the channel where the currents are observed. The modelled river entrance was more efficient at passing the ebb flows than the creek's, resulting in lower water levels within the river around low tide. Subsequently creek water begins to flow out to sea via the Barron River towards low tide (Figure 3).

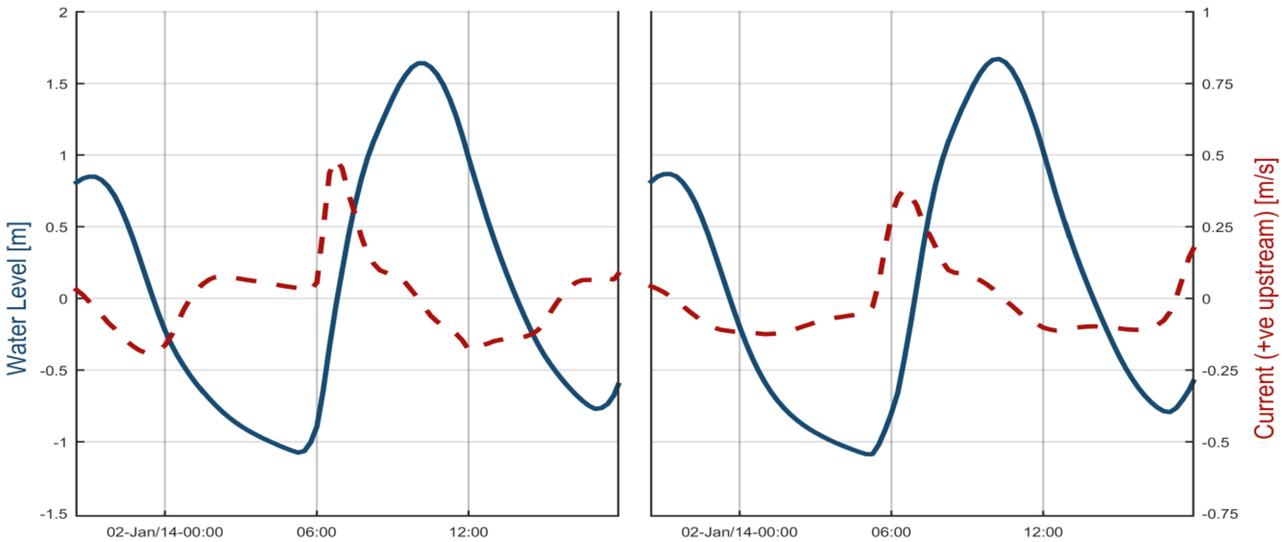

Figure 3 Simulated water levels (blue) and currents (red) for both Richters Creek (left) and the Barron River (right) both 1.5 km downstream of the bifurcation. Note that slack water occurs at high and low tide revealing how the tide behaves similar to a standing wave. Also note the upstream (+ve) currents in Richters Creek during the ebbing tide. This is due to the slightly lower water levels in the river towards low tide drawing creek water back through the bifurcation, a phenomenon related to the “openess” of the respective entrances.

3.1.4 Tidal Flows in Richters Creek

Because the length of Richters Creek is far shorter than the tidal wave and the water levels inside the creek are highly dependent on the capacity of its entrance to pass ebb flows, the water levels and flows in the creek can be mostly represented by a simple process based model. The model (Tides in Coastal Lagoons) as detailed in [4] is based on the energy equation and accounts for the water level outside and inside the entrance and the acceleration of water and the local friction losses within the entrance. This simple model was applied independently of the EIS process and used to assist in identifying key processes.

As detailed in Section 3.1.2 friction effects are more significant towards low tide due to the shallow depths across the entrance leading to significant discrepancies between the ocean tide and that inside the entrance (Figure 4).

For a symmetrical tidal wave like that in the ocean, the temporal water level gradient is steepest around mid-tide where the curve changes from concave to convex and vice versa. These temporal water level gradients translate to a spatial gradient when forcing water through an entrance from one system to another, in this case between the ocean and Richters Creek. Thus the peak flows through the entrance and thus in the creek would occur around ocean mid-tide when the effects of mangrove habitat is neglected (Figure 4).

The second peak in the flows during the flooding tide is a response to the sudden increase in surface area of the short creek when the water levels reach a certain level (Figure 4). This sudden increase in surface area typifies the breaching of creek banks and inundation of mangrove flats, like those along Richters Creek.

Due to the relatively large surface area of the creek at high tide the ebb flows through the entrance during this period are greater than those during mid-tide (continuity). This is despite the lesser temporal gradient in the ocean tide levels and hence lesser spatial gradient across the entrance driving the flows. In general for short estuaries with constricted entrances the effect of mangrove habitat is to bring the peaks in the flood and ebb flows towards high tide, incurring a fast switch between flood and ebb flows (Figure 4).

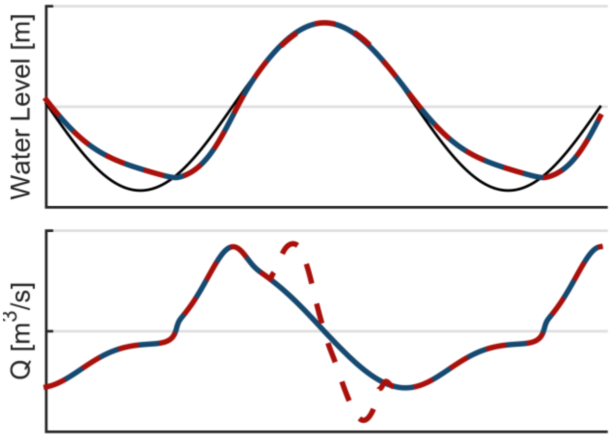

Figure 4 Top: ocean water levels (black) against water levels in the short creek (red and blue). Bottom: flows into short creek derived from simple “tidal lagoon model”. Blue line depicts scenario where creek cross section is rectangular. Red dashed line depicts scenario where the surface area of the short creek increases significantly above a certain tide level, representing mangrove habitat. Such habitat significantly affects the flows into the creek with little effect on the water levels.

The shape of the measured flows through Richters Creek and those returned by the numerical model (Figure 5) are similar to those returned by the "tidal lagoon model" (Figure 4). Thus the processes and assumptions for which the "tidal lagoon model" is based (shape of ocean tide, constricted entrance, short channel and extensive mangrove habitat) can be assumed to be the dominant processes driving the 2D flows through Richters Creek outside periods of high fresh water flows.

The upstream ebb currents / flows discussed in Section 3.1.3 resulting from the interaction between Richters Creek and the Barron River are of small magnitude when compared to the peak flows and occur principally in the upper reaches of the creek, towards the bifurcation. Nevertheless it is these small flows which can drive net circulations through a system which are important in the context of salt transport as will be discussed in a following section, Section 3.2.2.

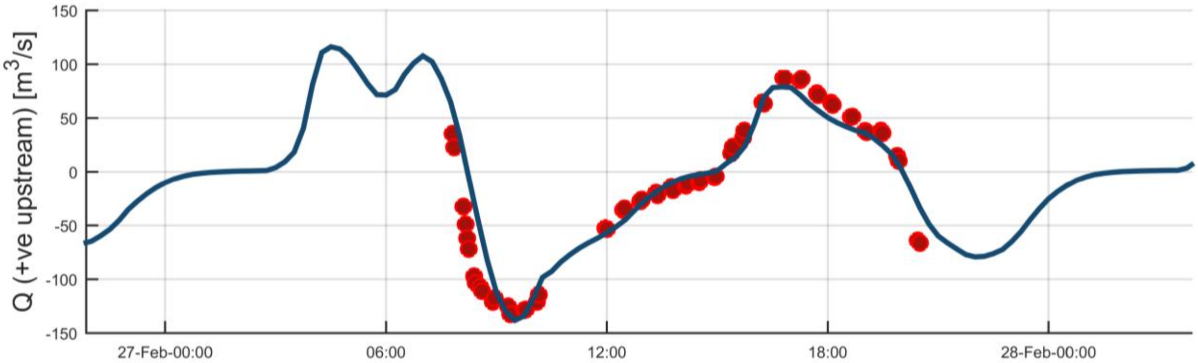

Figure 5 Simulated flows (blue line) and measured flows (red circles) through Richters Creek 750 m from entrance. Note the second peak in the flood flows at around 07:00 and the sudden reversal of the flows around high tide. Both phenomena are related to the additional surface area of the Richters Creek system provided by the magroves habitat and big high tides.

3.2 Estuarine Mixing

3.2.1 Stratified flow in Richters Creek

Richters Creek is often well stratified with denser saline water from the ocean entering the system as a salt wedge. Turbulent mixing is limited within the creek, especially during neap tides and the stratification is maintained throughout the creeks entire length. Subsequently freshwater sourced from the upstream catchment flows downstream and exits the creek relatively efficiently compared to if the creek was well mixed (Figure 6). For the same reason saline ocean water flows upstream towards the bifurcation more efficiently than if the creek was well mixed (Figure 8).

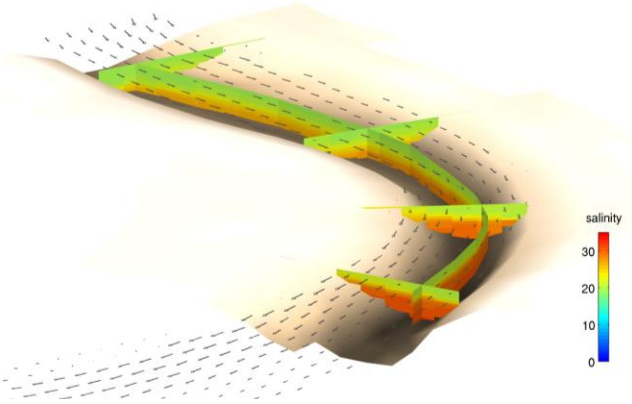

Figure 6 Saline ocean water underneath fresher less dense water in a section of Richters Creek. Due to limited mixing Richters Creek remains well stratified and freshwater flows downstream and saline water upstream more efficiently than if the creek was well mixed.

Fresh water flow events (Figure 7) are capable of completely flushing the upper reaches of the Richters Creek / Barron River system. Once the fresh water flows subside the near-bed salinity quickly recovers (Figure 8).

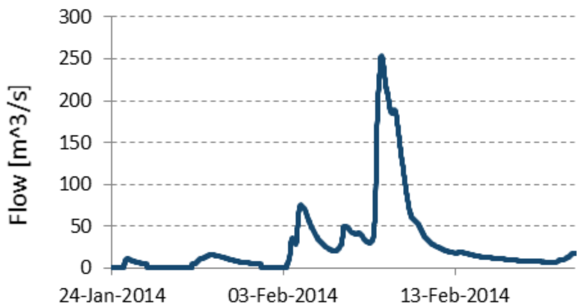

Figure 7 Freshwater inflows into the Barron River at the tidal limit.

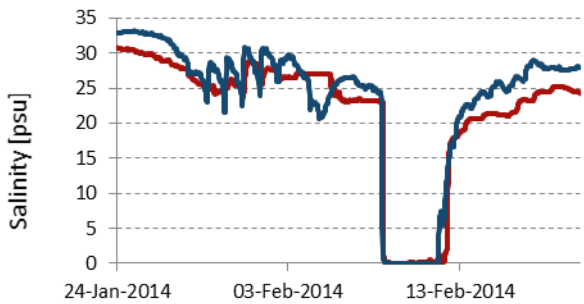

Figure 8 Simulated (blue) and measured (red) near-bed salinity response in Richters Creek 1 km from the bifurcation to the freshwater inflows depicted in Figure 7. Note the quick recovery of the near-bed salinity. This demonstrats how effeciently ocean water can migrate up the creek underneath fresher surface water.

3.2.2 Net Salt Transport through System

Despite the net downstream flows in both Richters Creek and the Barron River due to fresh water inflows at the tidal limit there is a net flux of salt from the creek through the bifurcation and into the River (Figure 9 & Figure 10). The upstream currents experienced during the ebb tide in Richters Creek are principally responsible for this net flux. The upstream currents are related to the relative efficiency of the creek and river's entrances at passing their respective ebb flows and hence so too is the direction of the net flux. Since the morphological state of the two entrances will respond to significant weather events it is likely that the direction of net salt flux could also change at such time scales.

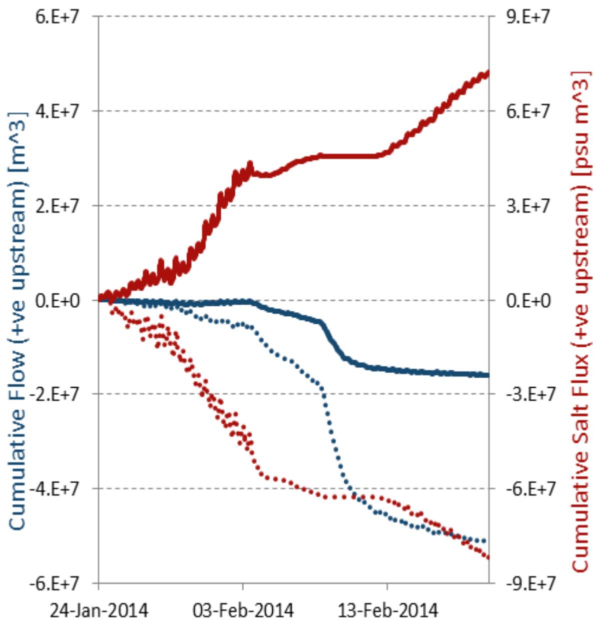

Figure 9 Simulated net flow (blue) and net salt flux (red) through Richters Creek (solid line) and the Barron River (dotted line) in the vicinity of the bifurcation. Note the net downstream flow for both watercourses generated by the freshwater inflows. Also note the upstream flux of salt through the creek and the downstream flux of salt through the river, refer Figure 10.

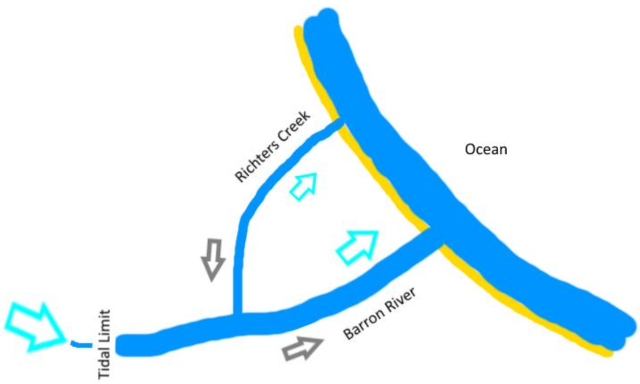

Figure 10 Schematisation of net flows (blue arrows) and net salt transport (grey arrows).

3.3 Implications for Proposed Development

Initially when the data was collected and numerical model developed for the EIS pertaining to the proposed AQUIS casino it was anticipated that the lake water would be sourced from the ocean and discharged into Richters Creek near its entrance. At this stage in the EIS it was imperative that a numerical model capable of simulating the Richters Creek / Barron River system was developed and rigorously validated as:

- The 3D structure of the creek flow is important when discharging water into the creek with the intent of minimising residence time;
- Any net transport of salt through the Richters Creek / Barron River system could increase or decrease such residence times.

As the EIS progressed so too did the design of the lake system and the discharge location was moved out into the ocean. Following this significant design change the potential impacts on Richters Creek are essentially avoided all together and the focus is shifted onto sensitive receptors in the ocean in the vicinity of the new outfall location.

4. Conclusion

The physical processes driving the Richters Creek / Barron River system originally pertinent to the AQUIS casino EIS are complicated, finely balanced and in all likelihood changing on the timescales of significant weather events. The volumes of freshwater entering the system, the degree of stratification within the channels and the relative state of the two entrances all influence the circulation of discharged lake water and any entrained pollutants through the system. Presently the discharge location has been moved into the ocean and such processes are of lesser importance.

The TUFLOW-FV 3D numerical model developed for the EIS was highly capable at representing the relevant processes and thus ideal for assessing any potential impacts the proposed development may have had on the environment. A 2D model or 3D model which did not adequately represent the mixing processes would have led to erroneous results and potentially misplaced decisions relating to the design of the proposed development.

5. References

[1] Flanagan consulting Group (2014). AQUIS Resort at the Great Barrier Reef PTY LTD, Environmental Impact Statement, report prepared for AQUIS Great Barrier Reef Resort, June 2014.

[2] HYCOM + NCODA Global 1/12^{o}, data provided by the Naval Research Laboratory, USA, from their Web site at *https://hycom.org/data/glba0pt08/expt-91pt1*

[3] NCEP_Reanalysis 2, data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at *http://www.esrl.noaa.gov/psd/*

[4] Nielsen, P. (2009). Coastal and estuarine processes. Singapore, World Scientific.

[5] Project Fact Sheet, project Overview. AQUIS Great Barrier Reef Resort, Accessed May 2015, http://aquiscasino.com/fact-sheets/

[6] TUFLOW-FV Science Manual 2013, from http://www.tuflow.com/Download/TUFLOW_FV/Manual/FV_Science_Manual_2013.pdf