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Sediment resuspension within a microtidal estuary/embayment and the implication to channel management

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ABSTRACT

Sediment transport patterns within coastal environments continue to be of strong concern to the coastal engineer, scientist and manager. A study was conducted on Saltwater Creek, Gold Coast, Australia, which is a small microtidal estuary/embayment system that has no continual inflow of freshwater with inflows only resulting from direct catchment rainfall. Use was made of an Acoustic Doppler Current Profiler (ADCP) and a profiling transmissometer to determine the likelihood of tidal flow induced resuspension. Results showed that the apparently simple system was actually highly complex in nature. It was susceptible to significant sediment loadings as the result of catchment runoff and biological activity. Resuspension activity within the main channel was qualified and found to play only a minor role in the observed suspended sediment loadings. The results obtained have permitted the development of a conceptual model, from which some future management strategies can be proposed. Importantly, the techniques used in this study can be applied elsewhere to investigate sediment transport (including resuspension) properties when equipment resources are limited.

ADDITIONALINDEX WORDS: *Words: Saltwater Creek, LISST100*

INTRODUCTION

The characteristics of estuarine flow and sediment transport patterns are important as they play a critical role in the functionality and health of these systems. When bottom sediment is resuspended, trace metals, nutrients and organic contaminants can be released into the water column, which in turn can limit the amount of light entering the water and reduce the water quality (MORRIS and HOWARTH, 1998). Sediment settling can inhibit channel continuity by deposition in navigational areas. If any of these issues create a significant problem, management strategies must be developed in order to rectify the situation and/or preserve the environment in a suitable state.

Suspended sediment enters estuarine systems through a variety of sources, including catchment area surface runoff, bank erosion and advection due to tidal and river currents. Once sediment has entered the system, it will either continue to be advected or be deposited on the bed. The deposited sediment will remain trapped until it is disturbed by aquatic fauna activity, high tidal and/or river induced shear flows, or human derived activities such as dredging or boat wash (eg SCHOELLHAMER, 1996; OSBORNE and BOAK, 1999).

It is evident from a number of studies (eg DYER, 1986; LINDSAY *et al*., 1996; LYONS, 1997; MORRIS and HOWARTH, 1998), that the principal physical cause of sediment resuspension in most estuaries is tidal currents. The higher the current velocity, the greater the potential for resuspension, due to the increased shear stresses placed on the bed. Generally the flood cycle of the tide has a greater velocity but shorter duration than that of the ebb tide and hence produces more resuspension. This results in a net landward transport of sediment into an estuary (see also WEEKS *et al*., 1993; ANDERSEN and PEJRUP, 2000). This has the effect of increasing the deposited and suspended sediment levels within the upper reaches of an estuary until it is flushed out by storm events.

The primary aim of this study was to develop a conceptual understanding of the general properties of a small microtidal creek by assessing the flow and suspended sediment patterns. A second aim was to assess the suitability of a LISST-100 sediment sampler (TRAYKOVSKI *et al*., 1999), teamed with an Acoustic Doppler Current Profiler (ADCP) in determining whether the presence of suspended sediment in the channel was due to resuspension activity or simply advection. This study showed that the method could help determine the characteristics of sediment transport mechanisms (ie advection vs resuspension) when limited resources are available.

METHODS

Site Description

Saltwater Creek is a small microtidal estuary in the Gold Coast region of Australia (see in Figure 1). The creek has a catchment area of 30 km2, with varied landscapes including near virgin bush and housing subdivisions. This region is one of the fastest growing areas in Australia, with a strong demand for new waterside housing accommodation, which is causing significant development and placing pressure on the surrounding environment. The total length of the creek is 17 km, with the lower 10 km being a marine environment. The depth and width of the creek generally decreases in the upstream direction, ranging from 3 m depth and 40 m width near the mouth to a shallow 10 m wide exposed rock wall that spans the entire creek 10 km upstream. An exception to this pattern is a 5 m deep hole that exists near the branch that joins the creek to the neighbouring Coomera River (as shown in Figure 1 at 5.9 km upstream from the mouth). This branch has a mean depth of 1 m and a width of 15 m. The tides in this region are mixed semi-diurnal with the tidal range within the creek generally less than a metre.

WEBSTER and LEMCKERT (2001) found that the creek is a system that experiences a wide range of hydrodynamic and sediment loadings depending upon the inflow conditions. Saltwater Creek system is void of any significant freshwater input outside of rain events. Consequently, the estuary behaves similar to an embayment, where ocean water simply flows in and out due to the movements of the tide. The sediment load in the upper sections of the creek was found to be extremely high following a major rain event. This sediment entered the watercourse as a result of erosion and runoff in the upper catchment region and was comprised mainly of small particle sizes (< 5 µm), typical of the soil types found in the upstream section. The heavy load of sediment was gradually removed from the system by settling and tidal induced advection. The section of the creek that is located downstream of the connection with the Coomera River was found to clear up quickly, while the upstream section maintained high turbidity levels (see Figure 2). It is likely that this high level was due to an elevated presence of bioturbation.

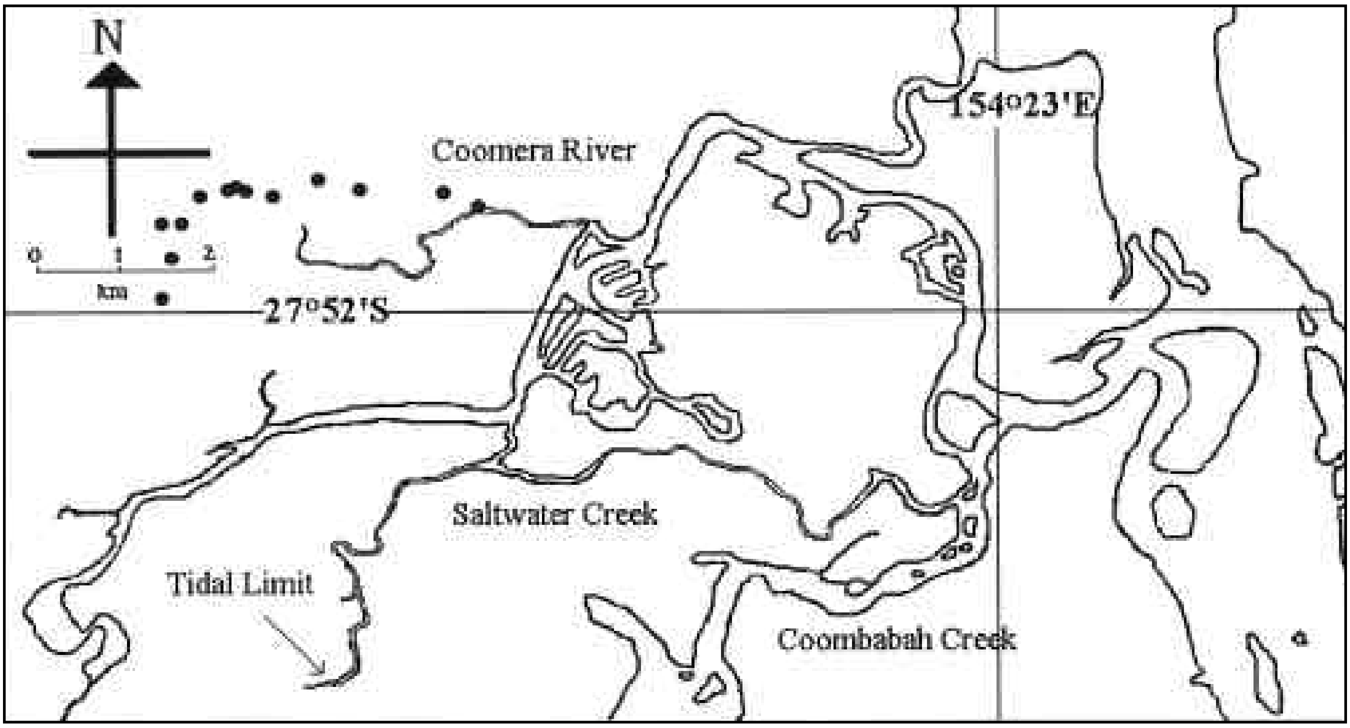

Figure 1. Map of Saltwater Creek, with the dark spots showing the various sampling sites used in this study.

Study Techniques

A Sequoia Scientific LISST-100 instrument (eg see TRAYKOVSKI *et al*., 1999; GARTNER *et al*., 2000) was used to record the transmission properties of the water over a 5 cm path length. A Seabird SBE-37SI conductivity, temperature and depth (CTD) serial interface sensor was connected to the LISST-100 instrument by a data cable, thereby allowing data obtained by the CTD to be recorded by the LISST-100 instrument, ensuring measurements from both apparatus to correspond in time. The CTD instrument was securely attached to the frame of the LISST-100, thereby allowing the positioning of both instruments to be identical. The CTD sensor measured the conductivity of the water in a range of 0 to 7 Sm^{-1}, with an accuracy of 0.0003 Sm^{-1} and a resolution of 0.00001 Sm^{-1}. Temperature was measured with an accuracy of 0.002 °C and a resolution of 0.0001 °C, while depths were recorded with a resolution of 5 mm. Salinity estimates, obtained from the CTD data, are calculated using the equations of state for standard seawater. An example of the data derived from the instrument is presented in Figure 2.

The velocity properties of the water at various locations within the creek were recorded using an RDI 1200 kHz ADCP. As a consequence of the shallow nature of the estuary the ADCP apparatus was mounted in a frame and deployed on the bottom, facing upward.

The LISST-100 and ADCP combination allowed the development, validation and refinement of a measuring technique that was able to identify the methods of transport of suspended sediment within the creek. This was achieved by distinguishing between sediment resuspension and tidal current induced advection.

While the upward looking ADCP was recording the velocity of the water, longitudinal transects were performed using the LISST-100. The transect sites were positioned several kilometres downstream and upstream of the location of the ADCP, to enable an adequate picture of the vertical and longitudinal conditions to be developed. Transects were repeated constantly over the period of ADCPdeployment in order to develop a picture of how the conditions of the creek changed during a set period. The transmission data was then matched to the velocity data in order to assess whether periods of high velocity were associated with a decreased amount of light transmission near the bed of the estuary, which would indicate a resuspension event. It was also possible to track the movement of an individual body of sediment that was being advected by the tide. This procedure therefore permitted the discrimination between resuspension or advection occurrences. This proved an efficient sampling procedure, as instrumentation was limited.

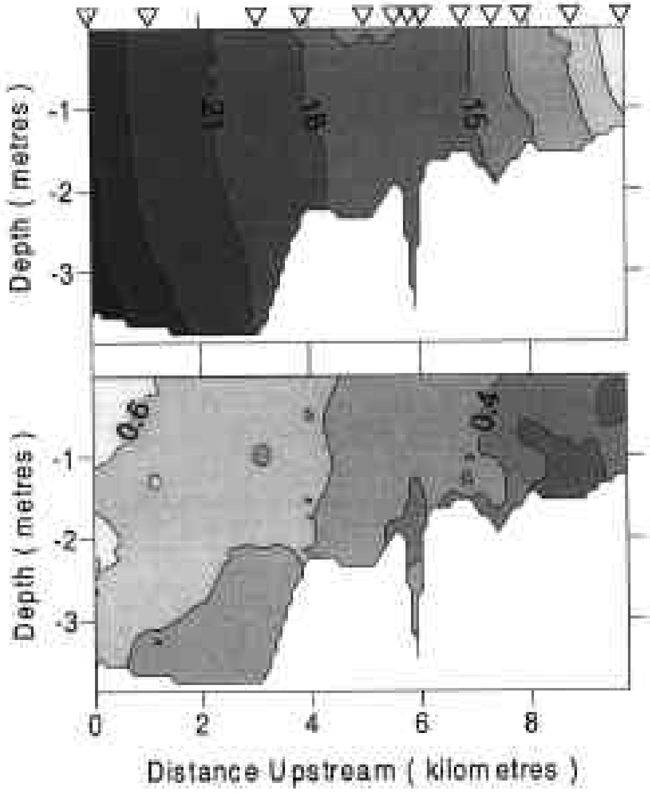

Figure 2. Saltwater Creek a) salinity structure with contours of 3 ppt and b) light transmission with contours of 0.1 uncalibrated transmission units five days after a significant rain event within the catchment, reproduced from WEBSTER and LEMCKERT, (2001). Data is from 27/03/2001.

RESULTS AND DISCUSSION

General Sediment Dynamics

The possibility of sediment resuspension within the main channel of the creek was studied in order to assess whether resuspension was contributing to the overall sediment loadings within the creek. A series of transects along the creek were made between 0.4 and 3.1 km upstream on the 28th June, 2001, where sampling was conducted at regular time and space intervals to determine the characteristics of the water column in this area. The ADCPwas also deployed 2.5 km upstream at this time to relate the velocity of the water. Data from this experiment are presented in Figures 3 and 4.

Figure 3 presents the data derived from the ADCP. The data reveals that there was a significant tidal lag within the system. The period of lowest water occurred at approximately 10 am, while slack water was at 11 am. It

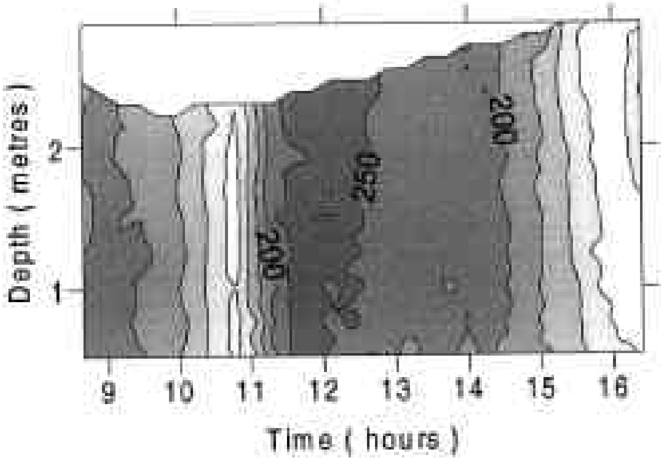

Figure 3. Saltwater Creek along channel tidal velocity at 2.5 km upstream with a contour interval of 50 mms^{-1} during an inflowing tide on 28/06/2001.

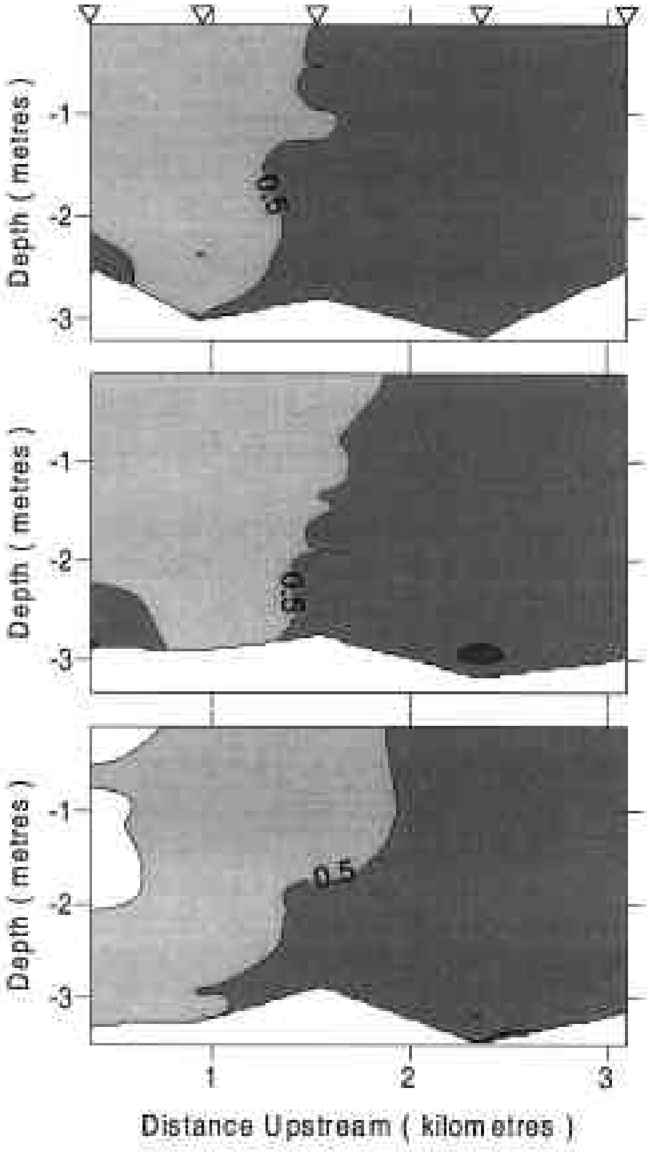

Figure 4. Transects of Saltwater Creek showing light transmission with a contour interval of 0.1 unscaled transmission units on an incoming tide, at a) 11:00, b) 11:40, c) 12:20, on 28/06/2001. The inverted triangles show the profile sites. The bottom contour changes slightly because of the influence of the tides and the fact that the sample sites were not exactly replicated on each transect.

was found that the tide reached a maximum velocity of approximately 250 mms^{-1} at around 12:00, before dropping.

Figure 4 presents the longitudinal light transmission data taken at 40 minute intervals. The advection of material upstream through the creek is shown with the 0.5 transmission value contour line moving slowly upstream with the rising tide. The 0.6 transmission value contour line indicated by the lighter patch can also be seen entering the study area from the cleaner ocean side (see Figure 4c).

Associated with the period of maximum velocity were reduced levels of light transmission near the bed (see Figure 4b). The apparent resuspension activity is reduced to a negligible level 40 min later (see Figure 4c) when the tidal velocity had reduced. The elevated turbidity level near the bed was therefore caused by elevated tidal shear, as there were no other relevant factors present. Since the data were collected on a day of typical tidal range the low levels of resuspension indicate that this process is not a major contributor to suspended sediment levels within the creek.

The data presented in Figure 3 and 4 clearly show how a simple data collection strategy can be used to differentiate between advection and resuspension events. These results and those of Webster and Lemckert (2001) therefore suggest that inflows, bioturbation, and possibly bank erosion will be the dominant generation mechanisms for suspended sediment loadings.

General Hydrodynamics

To help understand the overall dynamics of the creek one field experiment was conducted on 26/09/2001 with the ADCPdeployed for half a tidal cycle in the deep hole at the confluence of Saltwater Creek and the connection branch to the Coomera River. This deployment permitted the through connection flow (north-south velocities) to be measured. The data is presented in Figure 5. There was only a small east component of velocity at most times, with the exception of two points that were above 50 mms^{-1}. This was due to the fact that the channel is orientated on a north - south direction, so a small east velocity component could be expected. The velocity recordings of the north-south plot (Figure 5a) are similar to those of the east plot at most times, having almost negligible values. This indicates that the channel generally had little through flow and therefore would have had little effect on water within the creek. However, it can be seen that there was a sharp rise in the velocity prior to the high tide, with a maximum value of 230 mms-1 recorded close to the bed. This was a short lived event that would have been driven by a mismatch in tidal lags between the Coomera River and Saltwater Creek on either side of the connecting channel. The bed in this location is comprised of rocky material as the smaller grains have been deposited elsewhere. The sinking resulted because the Coomera River water was saltier than that of the creek (and denser). This is shown in Figure 6 via the elevated salinity levels within the hole.

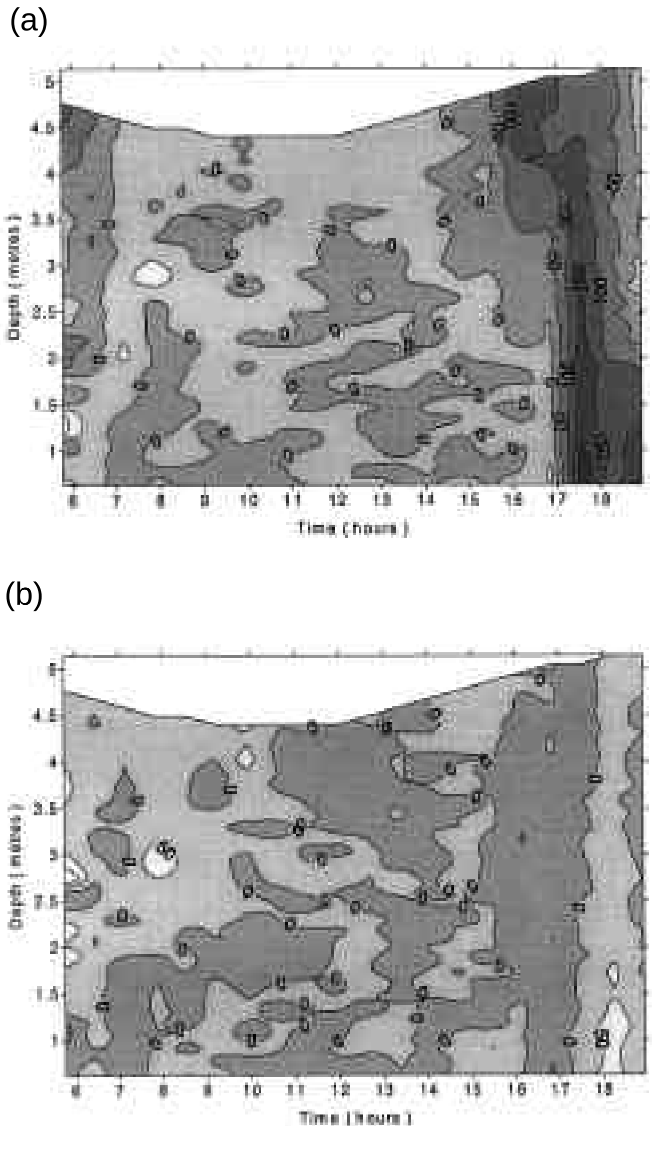

Figure 5. Contour plots of (a) northward water velocity (-ve means south flowing into the creek) and (b) eastward water velocity (-ve means flowing upstream) at the confluence of Saltwater Creek and the Coomera River branch on the 26/09/2001. Contour intervals are 50mms^{-1}.

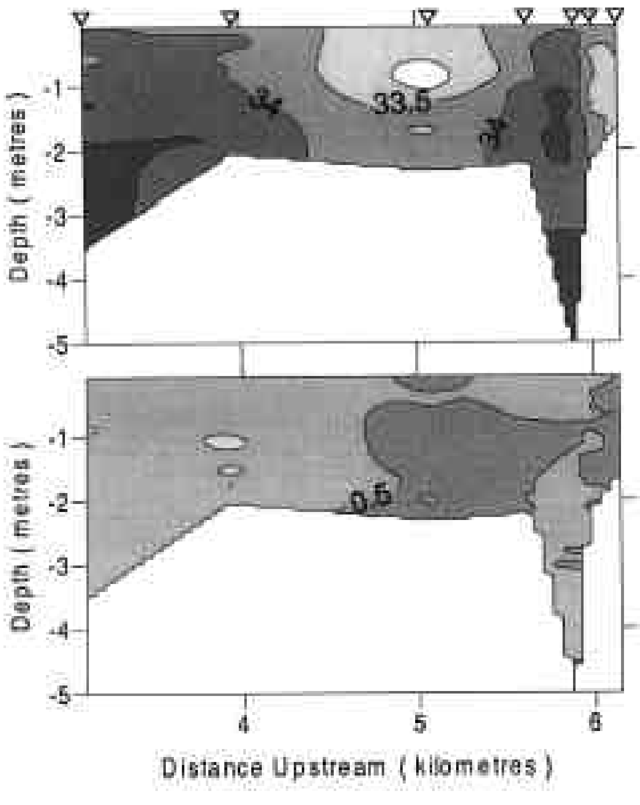

Figure 6. Saltwater Creek at high tide showing a) salinity structure with a contour interval of 0.5 ppt and b) light transmission with a contour interval of 0.05 uncalibrated transmission units. Data were collected on 26/09/2001 at 1730 hrs which corresponded to the high tide and maximum velocity levels presented in Figure 5.

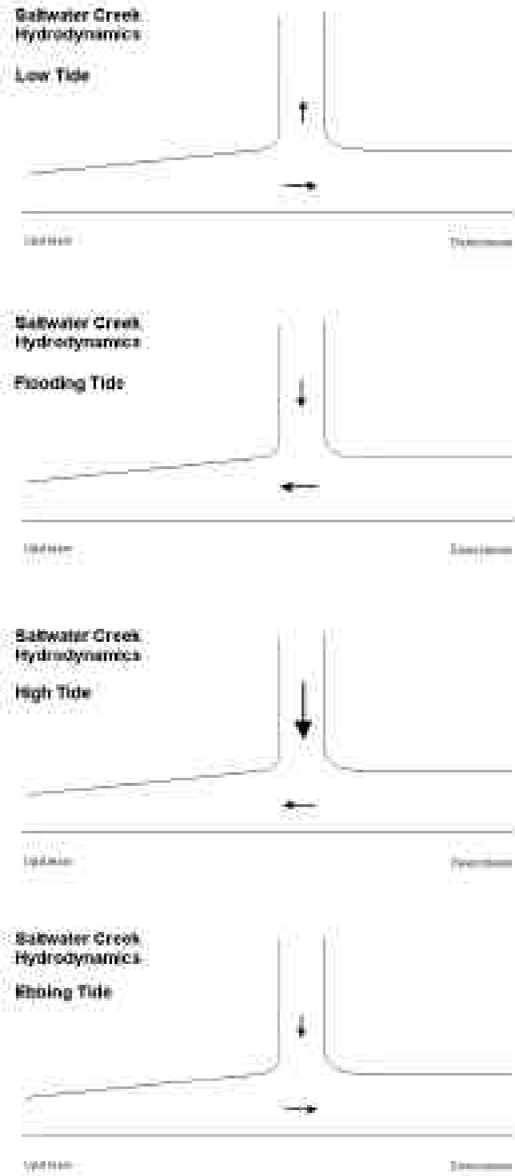

Figure 7. Conceptual hydrodynamics model of Saltwater Creek at a) Low Tide, b) Flooding Tide, c) High Tide and d) Ebbing Tide.

The velocity data allowed a conceptual model of the interaction between Saltwater Creek and the Coomera River to be developed. The conceptual model, as presented in Figure 7. Near low tide water flows out of the creek along the channel and through the connection (Figure 7a). Dirty upstream water is carried into the lower reaches of both systems. As the tide begins to flood water flows into the upper reaches of the creek from the main channel and the connection (see Figure 7b). This effectively dilutes the Saltwater Creek water with Coomera River water. Just before high tide the water contribution from the Coomera River dramatically increases (see Figure 7c). When the tide begins to ebb the water Coomera River water velocity reduces significantly. The net result is that the Coomera River acts to dilute the Saltwater Creek water and enhance downstream pumping (compared to the case if the connection not present). Given the occurrence of continual reduced light transmission levels upstream of the connection (see Figure 2 and Webster and Lemckert, 2001) and the low velocities expected in this region the turbid nature of the system is likely caused by bioturbatious activity (P. Teasdale, 2001 pers. comm.)

CONCLUSIONS

It is evident from the study that Saltwater Creek is a complex system with the interaction between the creek and the adjacent Coomera River system complicating the hydrodynamics and affecting water quality properties.

The methods used in this study show how the combination of a current meter and an in situ sediment sampler (in the form of an ADCP and LISST-100) can be used to differentiate between suspended sediment that has been resuspended or advected. Performing repeated transects in order to obtain many suspended sediment profiles over time and space allowed a picture of the suspended sediment to be developed. This was then matched to the current profile in order to determine if there was a sharp increase in sediment due to the resuspension velocity being exceeded by the tidal flow.

The outcomes of this study will aid in the development of management strategies for the Saltwater Creek catchment area and creek itself. The conceptual model indicates that it will be necessary to accurately model the complete Coomera/Saltwater systems if the flow and suspended sediment patterns are to be predicted. Only then would it be possible to predict the influence of such processes as channel deepening for navigational purposes.

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