Spatial Variability of Environmental Field Data between Two Adjacent Tidal-Inlet Entrances

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Abstract
This study is part of a broader research project to build longer, more durable and stable tidal-inlet entrance channels in Currumbin and Tallebudgera Creeks. The sediment exchange and associated maintenance dredging of the inlets are also inherently linked to the development of a strategy to address the present vulnerability of the development-backed, open coast beach situated between the two inlets. These creeks are two of several small tidal inlets in south-eastern Queensland, Australia. There is a long morphological history of changes to the surrounding beaches, which are interconnected to the spatial changes of the mouth and entrance channel of these creeks. This has caused the local authority to perform regular stabilization work and maintenance dredging at great expense. Consequently, an effective long-term management plan is necessary so as to offer improved economic and environmental outcomes. To provide data for establishment of such a plan, a field measurement campaign was carried out in April-May 2011 by measuring a six-week nearshore wave regime, six weeks of tidal level measurements and two spring and two neap current recordings inside the creeks. The investigations showed the differences between these two adjacent inlets, in terms of dominant tide type, tidal prism volume and nearshore processes. Therefore, two different managerial action plans should be considered in contrast to what exist at the moment. The findings of this research will contribute to the design of alternative entrance geometry or maintenance strategies for Currumbin and Tallebudgera Creeks.

Keywords: Tidal inlets, Tidal level variation, Tidal discharge and velocity, Tidal constituent analysis.

1. Introduction

Tidal inlets are valuable features of coastal environments. Specifically, small inlets play important roles in the provision of fresh nutrients for their inland water body, as there are periodic exchanges of water through inlets. Besides that, the back barrier areas may also be used for the construction of small fisheries or leisure harbours which, in turn, necessitates providing safe navigation facilities.

Normally, the natural deposition of sediment within, and in front of, inlet entrances (i.e. shoals), may block the entrance channel cross-section fully or partially and so prevent the desirable exchange of water as well as sufficient channel depths for safe navigation [2]; [3]; [6]. Therefore, keeping the entrance open with maintenance activities becomes necessary. A typical activity is a periodic deepening of the entrance channel by dredging operations, although the dredge areas and operation times are necessarily limited. Furthermore, a dredging operation is not always deemed to be financially viable and also may have some resulting side-effects, such as downdrift beach erosion. Therefore it is not possible to solely rely on dredging operations. Another limitation is the interaction and interconnection of adjacent morphological features which influence each other's temporal and spatial evolutions.

In this study, comprehensive field measurements of two adjacent small tidal inlets, i.e. Currumbin and Tallebudgera Creeks, are presented to investigate the spatial variability of environmental parameters. This study can contribute to a better managerial action plan for these two inlets which, by itself, is a part of a larger project dealing with long term morphological studies of the area.

2. Study Area

The study area is within the City of Gold Coast in south-eastern Queensland, Australia, which contains several tidal inlets. The area is also one of the most important Australian tourist destinations. There have been a number of studies over the past 40 years to develop an action plans which have been influenced, to varying degrees, by financial or technical limitations [4]; [1]. The entrance of Currumbin Creek (highlighted in Figure 1) is trained by two jetties of which the southern one connects the land to a natural headland (known locally as Currumbin Rock). The entrance of Tallebudgera Creek (likewise highlighted in Figure 1) also has a south-side training wall and the north-side is bounded by a natural elevated headland rock (Burleigh Head).

3. Methodology for Data Collection

An extensive field measurement campaign was conducted for the Gold Coast City Council by the DHI Group and the Griffith Centre for Coastal Management (GCCM) in April and May, 2011. The field campaign included measurements of several parameters of which the following are used herein:

- nearshore wave and current regime at three different locations; and
- creek current discharge and water level variations.

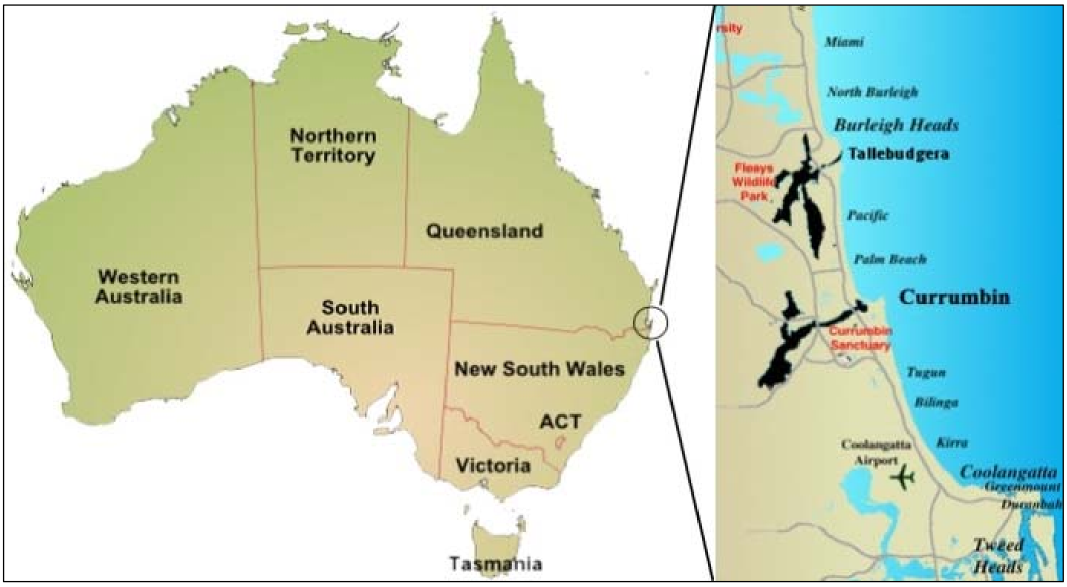

Figure 1 Map of the Study Area

An aerial view of the measurement stations is presented in Figure 2. Wave data was collected by RDI-ADCPs from April 12th, 2011 until May 30th, 2011, in two stages with a one-week gap for data acquisition and device re-deployment. In the following sections, the two stages of the data collection period are referred to as the first and second halves. These nearshore wave stations were located (from south to north) in Tugun, Palm Beach and Burleigh areas. Similarly, tidal discharges were measured on May 4th and 10th, 2011 for Tallebudgera Creek and May 6th and 12th, 2011 for Currumbin Creek. These data were collected over two neaps and two springs by a boat-mounted RDI-ADCP transecting across an arbitrary cross-section of each creek at half-hour intervals. Apart from that, water levels were also continuously recorded using a Valeport Water Level Recorder for each creek from April 14th, 2011 and retrieved on May 30th, 2011, with a few days' gap in-between for maintenance activities.

4. Results and Discussion

Investigations of the individual outcomes for each

Figure 2 Aerial view of the data collection stations

of these creeks have already been published by the authors [8]; [9]. However, this paper compares those results, in order to find possible spatial variability and explanations for these.

4.1 Nearshore Waves and Currents

4.1.1 Wave and Current Measurements

The wave and current data were recorded in three different stations, spaced about 3.5 km from each other, by ADCPs at a depth of about 7.5 m. A summary of data is presented in Table 1 and Table 2. A corresponding series of wave and current roses are also presented in Figure 3 and Figure 4. A problem with the compass calibration of the instrument resulted in the removal of some potentially un-reliable direction data for the Palm Beach station during the second half of measurements.

Table 1 Wave characteristics of nearshore stations

Station	**Hs (m)**		**Hmax (m)**	**T peak (s)**	**Direction (deg)**
	Max	**Mean**			
First half of measuring campaign					
Tugun	2.02	1.03	2.56	4.50-14.90	40-110
Palm Beach	1.98	1.10	2.51	4.50-14.90	40-130
Burleigh	2.18	1.12	2.77	5.40-14.90	40-100
Second half of measuring campaign					
Tugun	1.81	0.89	2.30	6.02-19.50	30-120
Palm Beach	1.99	0.88	2.53	6.20-19.50	Missed Data
Burleigh	1.94	0.96	2.47	5.90-16.90	45-95

Comparing the aerial map (Figure 2) of the beach with the wave roses (Figure 3), it can be inferred that these different stations recorded approximately the same nearshore wave climate

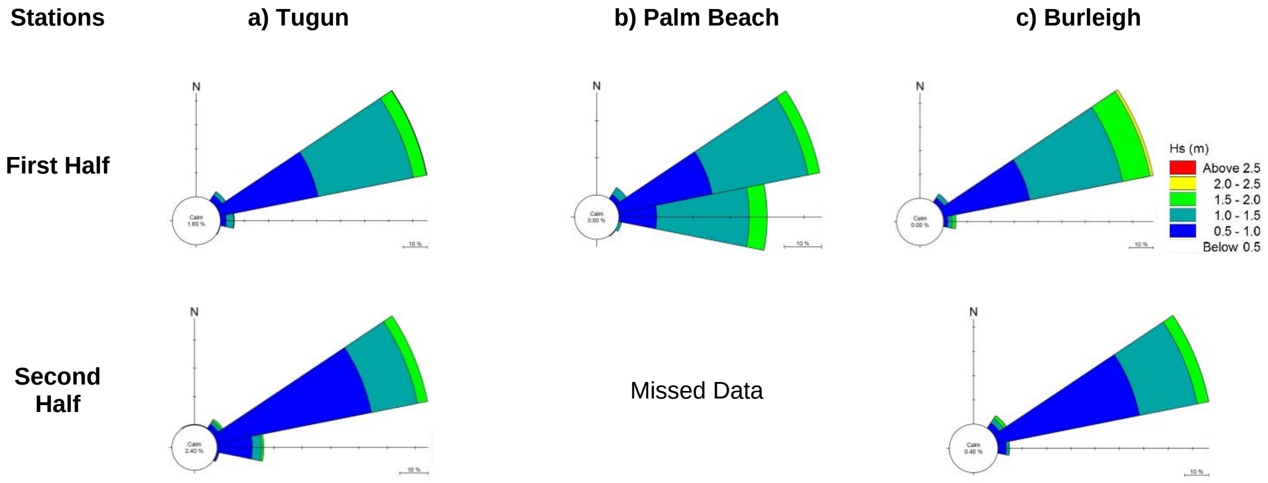

Figure 3 Wave roses for a) Tugun, b) Palm Beach and c) Burleigh stations

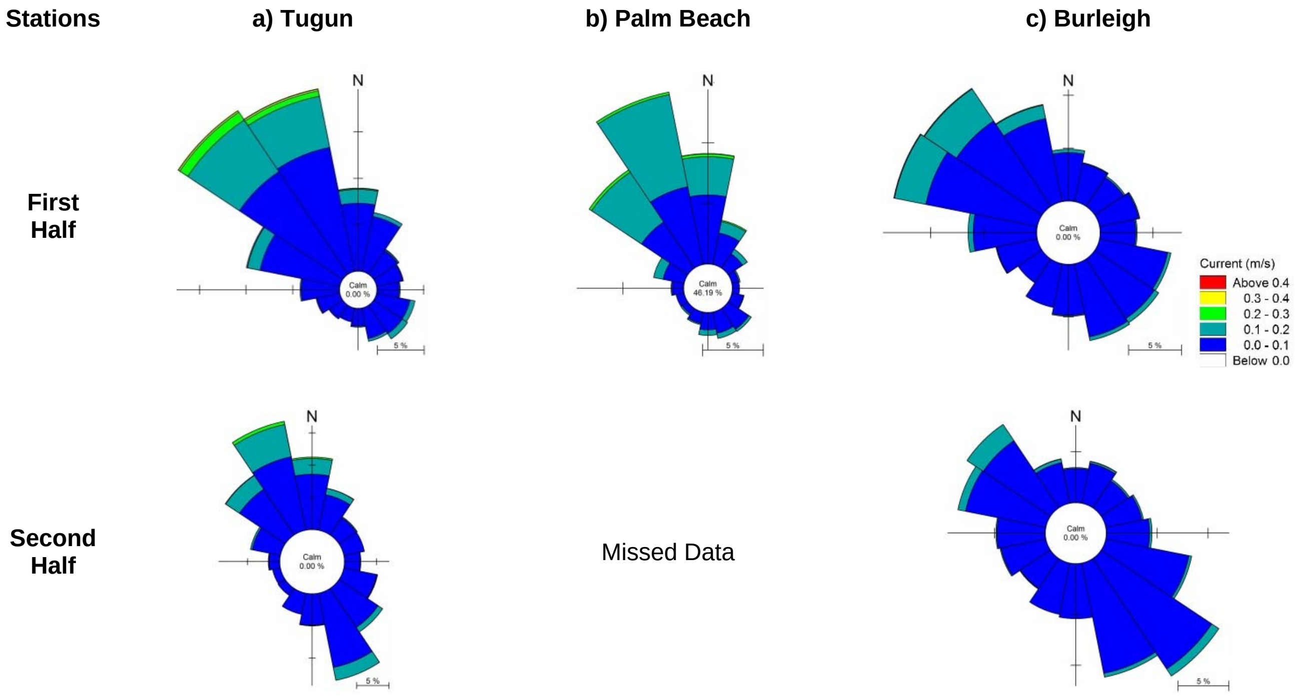

Figure 4 Current roses for a) Tugun, b) Palm Beach and c) Burleigh stations

Table 2 Current characteristics of nearshore stations

Stations	Maximum Current Speed (m/s)	Dominant Direction (deg)
First half of measuring campaign		
Tugun	0.49	315
Palm Beach	0.32	337.5
Burleigh	0.23	315
Second half of measuring campaign		
Tugun	0.26	337.5
Palm Beach	Missed Data	
Burleigh	0.26	315

(mostly from the NE), in spite of the small difference in the curvature of the beach. This phenomenon has also been noticed by other researchers [10]. This is also the case for the peak wave periods. Table 1 shows the range of peak period values at each site which are comparable. However, as expected, there are common differences between the significant and/or maximum wave heights measured at different stations. Figure 4 shows the corresponding current roses obtained from the recorded depth-averaged current data for each station. The maximum current speed and the dominant direction (derived visually from current roses) are presented separately in Table 2.

On average, the dominant current directions during the measurement periods are shore-parallel, although the incoming wave crests were also shore-parallel. The nearshore currents are constrained by the predominantly shore-parallel bathymetry and modulated by the tide. [8]; [9] Therefore, in terms of the influence of waves and currents on these two inlets, they both experienced the same nearshore regime during the measurement period.

4.1.2 Tidal Water Level Variation

From the recorded pressure variations in nearshore stations, it is also possible to obtain water level variation data. Analyses of this dataset showed that these three nearshore stations recorded almost the same tidal water level variations with a negligible time lag between significant tidal parameters (Table 3). In other words, the highest and lowest water levels during the measurement period and the tidal ranges were similar between these stations. This conclusion is also consistent with having the same wave and current regimes in all three nearshore stations.

Table 3 Tidal Water Level Variations of nearshore stations

Stations	**Tidal Water Level (m)**	
	Maximum	**Minimum**
First half of measuring campaign		
Tugun	1.06	-0.92
Palm Beach	1.04	-0.90
Burleigh	1.07	-0.95
Second half of measuring campaign		
Tugun	1.14	-0.80
Palm Beach	1.15	-0.80
Burleigh	1.16	-0.79

4.2 Tidal Level Variations inside the creeks

The tidal variations of water levels inside the creeks were measured at stations located close to the entrances of the creeks (downstream stations) [8]; [9]. The graphs in Figure 5 show daily water level variation extremes. As can be seen, both creeks show a semi-diurnal tidal variation pattern. The daily high water levels of Currumbin Creek are higher than those for Tallebudgera Creek. Conversely, the daily low water levels of Tallebudgera Creek are higher than what is the case for Currumbin Creek. Therefore, it means that the tidal range of the downstream station at Tallebudgera Creek is smaller than that for Currumbin Creek, although they receive the same tidal forces from the ocean. Moreover, checking the aerial maps of these creeks (at about the time of measurements) reveals that their inlet channels have almost the same width at gorge (about 55m), yet their average cross-sectional areas are different. Thus, this difference further illustrates the influence that the inlet geometry has on altering the oceanic tidal variations.

4.3 Tidal Discharge from the Creek

Tidal discharge measurements inside the creeks have been conducted by means of a boat-mounted ADCP (which was chosen based on the project's needs and budget). The recordings were performed on two different days over spring and neap tides for about 15 hours each day for each creek. Considering the temporal changes of flow fluxes during the survey period, the graphs of Figure 6 and Figure 7 are based on the occurrence at time of day and the actual dates are ignored to aid comparison. In these graphs, positive discharges and flow velocities denote an ebb tide current from the creek towards the ocean; and negative discharges represent flood tide currents. From Figure 6, it is concluded that although the maximum discharges of the creeks are roughly the same during ebb and flood currents, the maximum discharge of Currumbin Creek during the flood tide on Day 1 was almost twice as large as other similar values. Considering the records of tidal water variations inside Currumbin Creek at the time of the discharge measurements [8], this anomaly does not explain the difference at that specific date. Therefore, there is no clear conclusion in this regard; but it indicates the need to collect more simultaneous data for such investigations.

Further analysis of this dataset allowed for determination of current speed and tidal flow durations [5]. In the same way, the graphs in Figure 7 present the flow velocity measured inside the creeks for a period of about 15 hours. Disregarding the actual date again, comparison of the velocities (Table 4) demonstrates that Tallebudgera Creek has lower flow velocity than Currumbin Creek. This can be an indication that the tidal flushing of Currumbin Creek has more energy to improve water quality and maintain adequate water depths within its inlet channel. This is also apparent from the volume of deposited sand in the Tallebudgera inlet channel.

Table 4 Flow velocity characteristics at arbitrary cross-sections of the creeks (cm/s)

	Currumbin Cr.			**Tallebudgera Cr.**		
	Max.	Ave.	Min.	Max.	Ave.	Min.
Day 1	17	-6	-36	12	-4	-22
Day 2	28	1	-28	6	-1	-13

By integrating the individual flow and discharge of each transect over the measurement period, the volume of each tidal prism and tidal cycle durations were also obtained (Table 5) [8], [9]. It is seen that the average volume of the tidal prism for Tallebudgera Creek is almost 15% larger than Currumbin Creek which is not in accordance with the relative values of their tidal ranges.

Moreover, Currumbin Creek appears more flood-dominated while Tallebudgera Creek seems to have the same dominance of ebb and flood tides. However, the average tidal cycle durations were almost the same during the measurement period.

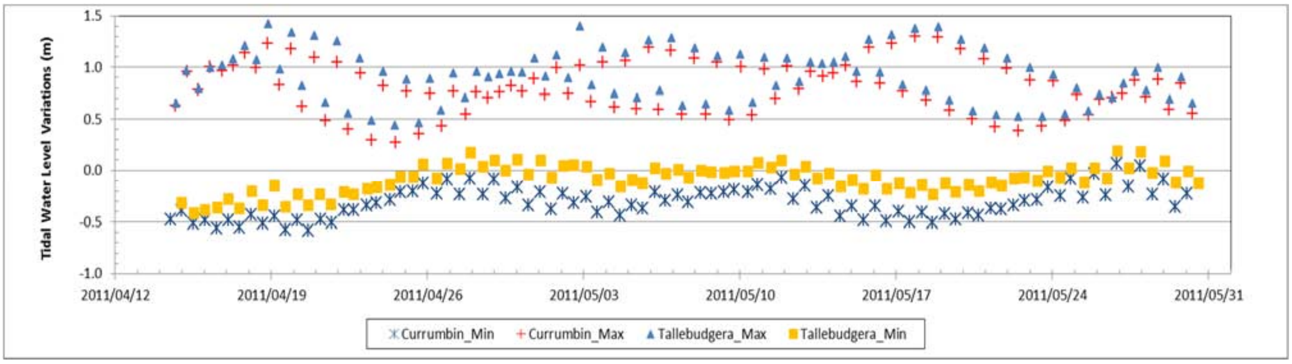

Figure 5 Extremes of tidal water level variations at creek downstream stations (Ref. to MSL)

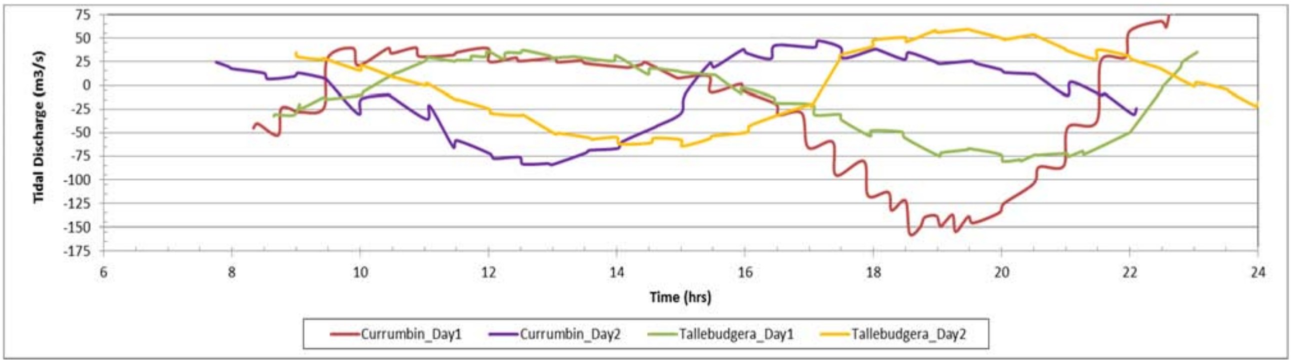

Figure 6 Creeks tidal discharges (m3/s) (positive values denote an ebb tide; and negative values represent a flood tide)

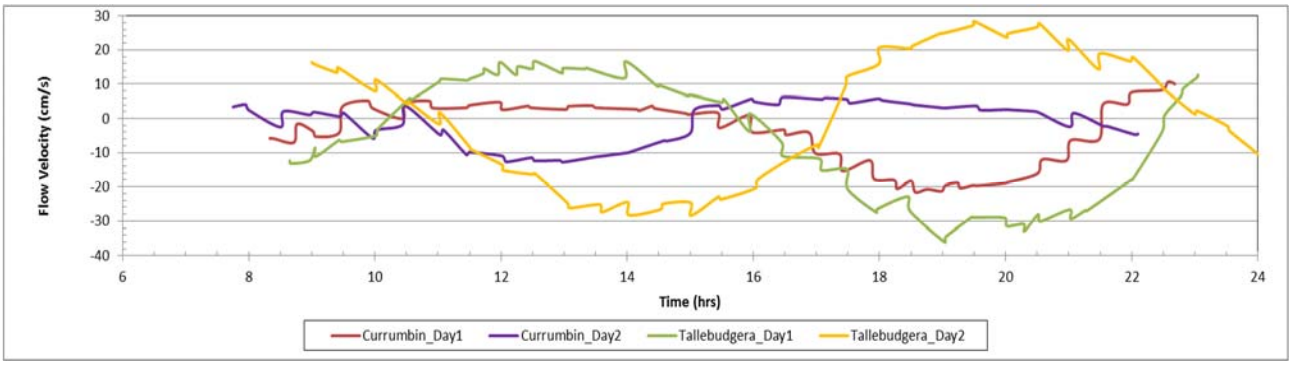

Figure 7 Creeks tidal flow velocities (cm/s) (positive values denote an ebb tide; and negative values represent a flood tide)

Table 5 Flood/Ebb duration (hrs) and Tidal Prism (m^3) derived from post-processing of Figure 6 and Figure 7 data

	Currumbin Creek			**Tallebudgera Creek**		
	Tide Duration	**Tidal Prism**	**Prism Type**	**Tide Duration**	**Tidal Prism**	**Prism Type**
Day 1	05:00	420,600	Ebb Prism	05:50	501,850	Ebb Prism
	06:35	1,177,200	Flood Prism	06:05	1,845,000	Flood Prism
Day 2	06:30	962,450	Flood Prism	05:35	1,012,750	Flood Prism
	06:05	780,550	Ebb Prism	05:40	562,500	Ebb Prism
Average		835,200			980,525	

Table 6 Tidal constituent analysis (Amplitudes are in meter and Phases are in degree)

Major Constituents / Locations	Z0	M2		S2		K1		O1		Ratio
		Amp.	Phase	Amp.	Phase	Amp.	Phase	Amp.	Phase	
Currumbin_Downstream	0.25	0.52	238	0.12	250	0.19	132	0.11	106	0.47
Tallebudgera_Downstream	0.40	0.44	323	0.10	260	0.18	138	0.11	183	0.53
Palm Beach_1st half	7.32	0.52	229	0.14	231	0.18	128	0.11	104	0.43
Palm Beach_2nd half	7.77	0.56	230	0.12	245	0.21	126	0.11	104	0.48
Burleigh_1st half	7.83	0.54	229	0.15	231	0.18	128	0.11	104	0.42
Burleigh_2nd half	8.03	0.56	230	0.12	245	0.22	126	0.11	104	0.48

4.4 Tidal Analysis

Water level variations obtained from the nearshore stations and also the creek stations are accepted to be mainly tidally driven [8]; [9]. Therefore, by performing harmonic analysis, it is possible to retrieve tidal constituents from them (Table 6). Hereinafter, Z_0 is the average water level in the tidal constituent analysis and M_2, S_2, K_1 and O_1 are four major tidal constituents, which are derived from the harmonic analysis of the datasets. In addition, in Table 6, the last column shows the well-known ratio of $(K_1+O_1)/(M_2+S_2)$, which indicates the type of tidal variations [7]. Here, all ratio values are between 0.25 and 1.5, indicating a mixed, but mostly semi-diurnal, tide type. These are also in accordance with the results obtained from the tidal level analysis inside the creeks. Almost all of the parameters are similar for the different stations, except for the downstream station of Tallebudgera Creek. This similarity indicates a good conformity to tidal currents inside Currumbin Creek, but for Tallebudgera Creek, it can be another indication of dissimilar behaviour in some of the abovementioned sections. In addition, it is seen from the last four rows (Table 6) that the nearshore stations have similar values for each half period, proving the relative importance and power of tidal currents in the vicinity of these inlets.

5. Conclusion

In this paper, field measurements were analysed to investigate the dynamics of the Currumbin and Tallebudgera Creek tidal entrances. The findings to be used for other parts of the project, such as sediment transport modelling of the entire beach and creek system, are:

- Nearshore measurements revealed that both inlets experienced the same nearshore wave regimes during the measurement period.
- Tidal analyses showed a mixed, but mostly semi-diurnal tide type exists in this area which also remains dominant inside the inlet back barriers.
- The extreme tidal water levels of the nearshore stations and also their recorded tidal ranges were almost identical during the measurement periods. However, the tidal range of the downstream station at Tallebudgera Creek was smaller than that for Currumbin Creek, which can be an indication of the influence of inlet geometry.
- The maximum measured discharges of the creeks (either ebb or flood) were roughly the same during the measurement period. However, Tallebudgera Creek has lower flow velocity than Currumbin Creek, indicating a higher tidal flushing energy for Currumbin Creek and better cleaning of its inlet channel.
- The average volume of the tidal prism for Tallebudgera Creek was almost 15% larger than Currumbin Creek, in spite of the fact that Tallebudgera Creek had a smaller tidal range. Accordingly, Currumbin Creek looks more flood-dominated while Tallebudgera Creek seems to have the same dominance of ebb and flood tides.

6. Acknowledgement

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7. References

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