31 October 2017 frc ref: 171006Ri

Re: Toondah Harbour: Preliminary Turbidity Analyses

This report by letter provides a summary of the turbidity data collected at Toondah Harbour between 9 September 2015 and 22 September 2017.

Summary of the Turbidity Logging Program

Potential impacts of excavation and dredging works on aquatic ecosystems include changes to water quality, and in particular increased suspended sediment in the water column. Increased loads of suspended sediments reduce the amount of light available to key sensitive receptors, such as seagrass and coral, negatively impacting photosynthesis. The distribution of seagrasses in western Moreton Bay is influenced by light availability, with the bottom of the seagrass depth range generally indicating the minimum light requirements.

The objective of the turbidity logging at Toondah Harbour was to provide a long term baseline of turbidity conditions, which can then be used to derive trigger levels for the proposed works. The turbidity data can also be used in the water quality modelling (when correlated with TSS data also collected in late 2015).

Turbidity was logged at three sites (Map 1):

- Logger 1 was located offshore of the PDA boundary (528776.42 m E; 6955817.37 m S): this site was selected to establish a baseline for turbidity in an area that may be impacted by reclamation of the PDA area, and is at the bottom edge of the seagrass.
- Loggers 2 and 3 were located near the Fison Channel (529220.27 m E; 6953925.39 m S; 530487.58 m E; 6954314.20 m S): these sites were selected to provide baseline data for the area that may be impacted by

dredging the channel. Both sites were at the bottom edge of seagrass, and there was also some sparse coral at Site 3.

Loggers were placed in a mounting structure that was secured in the sediment with star pickets (Figure 1). Equipment was clearly labelled with 'frc environmental Pty Ltd' and 'Permit number QS2014/CVL125' and was marked with a floating buoy. Loggers measured turbidity (NTU) generally every 15 minutes. Loggers were serviced approximately every 2 weeks, which involved downloading data, cleaning any biofouling, replacing batteries and calibrating the loggers.

Data logged between 9 September 2015 and 22 September 2017 was cleaned and analysed by Truii (refer to Appendix A). After cleaning there were between 51,542 and 57,275 individual turbidity readings for each of the three loggers.

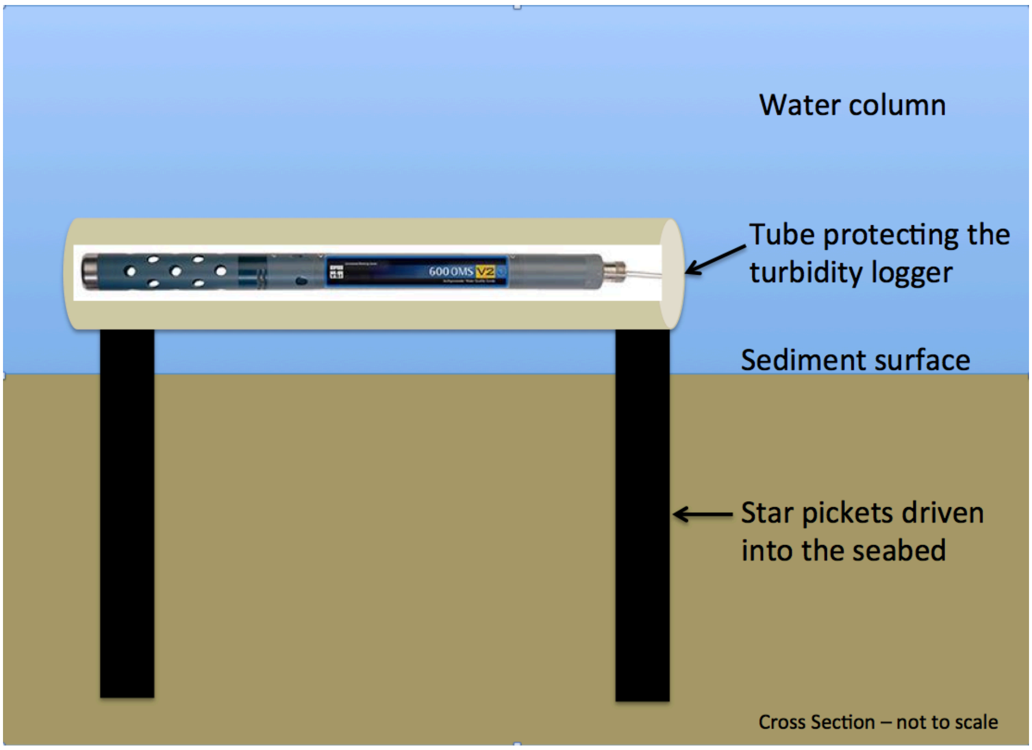


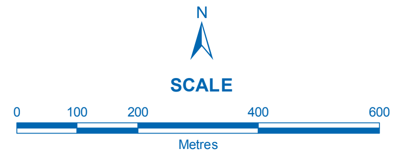
Figure.1 Cross section of turbidity logger placed in Toondah Habour.

Toondah Harbour
Installation and Maintenance of Loggers

Map 1:
Toondah Harbour loggers

LEGEND

Logger



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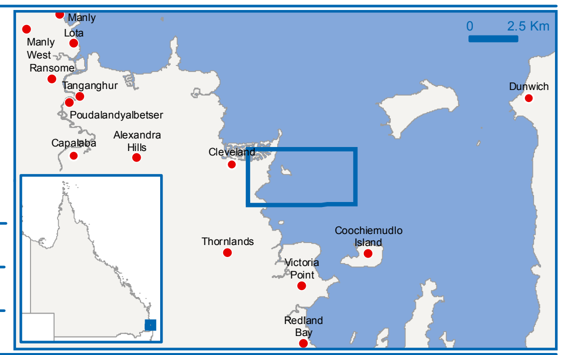

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SOURCES

Document Path: Y:\Projects\2015\150803_AEC_Toondah_turbidity\Mapping\Workspaces\150803_Logger_Locations_Sep16.mxd

Summary of Data

The mean turbidity over the 24 months of sampling was lower at site 3 (12.6 NTU) than at sites 1 (20.6 NTU) and 2 (30.5 NTU). Overall, turbidity was generally highest during the wetter seasons of late spring and summer at all sites (Appendix A). During the wet season, sediment laden runoff and resuspension of sediments by strong winds can lead to a reduction in water clarity.

Water Quality Objectives

Water quality in Queensland is protected under the *Environmental Protection (Water) Policy 2009 (EPP (Water))* using Water Quality Objectives (WQOs). The *Moreton Bay Environmental Values and Water Quality Objectives (June 2010)* specifies a WQO for the project area (Area C2 on Plan WQ1441) for turbidity of 5 NTU. The median turbidity at all three sites over the 24 months (7.8 NTU to 11.1 NTU) exceeded the WQO. Turbidity at all three sites generally complied with the WQO in winter and exceeded the WQO during late spring and summer. Consequently, it is advisable to set local water quality objectives or trigger levels for this area, before development work starts. The *Queensland Water Quality Guidelines 2009* recommends that trigger levels should be based on data collected preferably over 24 months in order to capture two complete annual cycles. Data has been collected over 24 months at Toondah Harbour and thus can be used to calculate local trigger levels for the development. However, given data is currently still being logged at the three sites, it is advisable to calculate trigger levels on completion of the program when the loggers are removed to incorporate all available data.

Analysis of Data Regarding Ferry Movements

There is a visible increase in turbidity in Fison Channel associated with ferry movements. This has been observed by staff when downloading data from the loggers. Site 2 is located very close to Fison Channel. However there was no obvious relationship detected between ferry passing and turbidity levels at site 2.

Given turbidity levels can be visually seen as a result of the passing ferry, we recommend this is investigated further. This could be done by moving the position of the loggers to specifically target areas likely to be impacted by ferry movements and by recording passing ferries. This will assist in determining the likely impacts of the proposed works (i.e. deepening the channel is likely to reduce turbidity associated with ferry movements).

Consequently identifying the contribution of ferry movement to current turbidity levels will be a key consideration in assessing impacts from the proposed development.

Analysis of Data Regarding Tides, Rainfall and Wind

Typically turbidity in Moreton Bay is highest in the late spring and summer when strong south-east and north-east winds resuspend the sediment and rainfall is more prominent. However, there was no significant relationship between tide, rainfall or wind and turbidity when assessed throughout the 24 month period (Appendix A).

Conclusion

Turbidity is a measurement of water clarity and provides important information on the potential impact of dredge and reclamation works on the marine environment. Higher turbidity indicates reduced light reaching key benthic habitats, such as seagrass and coral.

Turbidity has been logged (approximately every 15 minutes) at three sites near seagrass and / or coral habitat near the proposed development at Toondah Habour over 24 months. The median turbidity over 24 month at all three sites exceeded the WQO, with median values generally compiling with the WQO in winter months and exceeding the WQO in late spring and summer months. During the wet season, sediment laden runoff and resuspension of sediments by strong winds are likely to lead to a reduction in water clarity. Consequently, it is advisable to set local trigger levels for this area before development work starts. Data has been collected over 24 months at Toondah Harbour and thus can be used to calculate local trigger levels in accordance with the *Queensland Water Quality Guidelines 2009* prior to the development.

Given turbidity levels can be visually seen as a result of the passing ferry, we recommend this is investigated to assist in determining the likely impacts of the proposed works, including whether deepening the channel is likely to reduce turbidity associated with ferry movements. This could be done by moving the position of the loggers to specifically target areas likely to be impacted by ferry movements and recording passing ferries.

Seagrass and coral survival and growth is related to the amount of light they receive, in particular the amount of photosynthetically active radiation (PAR). The amount of PAR light they receive is dependent on a number of factors including day length, cloud cover, surface light intensity, water depth, water colour and water clarity. While turbidity gives an indication of the amount of light available to seagrass it does not give an accurate measurement. To ensure the most appropriate minimum light requirements are established for the seagrass and coral habitat adjacent to Toondah Harbour, we recommend PAR is logged in addition to turbidity.

Kelli, if you have any further queries related to this data analyses, please let me know.

Yours sincerely,

Liz West
on behalf of frc environmental

Appendix A Detailed Statistical Analyses

Cleveland Turbidity analysis

Prepared for FRC Environmental

21 October 2017

Dr Nick Marsh

Managing Director

1 Executive summary

There where statistically significant associations between all of the potential influencers of turbidity and the turbidity value, however the overall variability in turbidity explained by these parameters is low.

No correlations with predictive power between turbidity and environmental (rainfall, wind speed, tide height) or ferry passing were detected.

2 Background

FRC environmental commissioned Truii Pty Ltd to conduct analysis on three turbidity loggers located in Moreton Bay (near Cleveland). The brief was to investigate the relationship between turbidity levels and environmental factors (rainfall, wind speed and direction and tidal influence) as well as the impact that ferry's may have on turbidity levels. Specifically the turbidity for Logger 2, located near the ferry channel.

3 Input data and preparation

3.1Supplied data - Turbidity

Data from three turbidity loggers was supplied. The turbidity data spans the period 9 September 2015 – 22 September 2017.

The turbidity data was cleaned based on the following procedures

- All negative turbidity values were removed.
- Isolated turbidity spikes above 50NTU were removed, where a spike was defined as exceeding the mean of the preceeding ten samples by a factor of 3 (see Figure 1).
- Specific periods where obvious drift occurred and data removed as noted in table.

Table 1: specific periods where data was removed due to apparent logger drift (extended elevated NTU records)

Start	end	logger	rationale
04 Oct 2015	10 Oct 2015	1	Consistently >500NTU
02/03/2016	12/03/2016	1	Drift period
19/04/2016	27/04/2016	1	Consistently >500NTU
1/9/2016	13/09/2016	1	
23/09/2016	11/10/2016	1	Elevated – doesn't return to baseline
03/11/2016	11/11/2016	1	Elevated – doesn't return to baseline
21/5/2017	1/7/2017	1	Elevated – doesn't return to baseline
22/12/2015	29/12/2015	2	Very high for several days
03/07/2016	15/07/16	2	drift
28/07/16	13/08/16	2	drift
2/3/17	10/4/17	3	Drift
29/6/17	21/7/17	3	drift

Even after the above data cleaning steps there are many very high spikes > 200NTU (especially for logger 2) which may need further investigation.

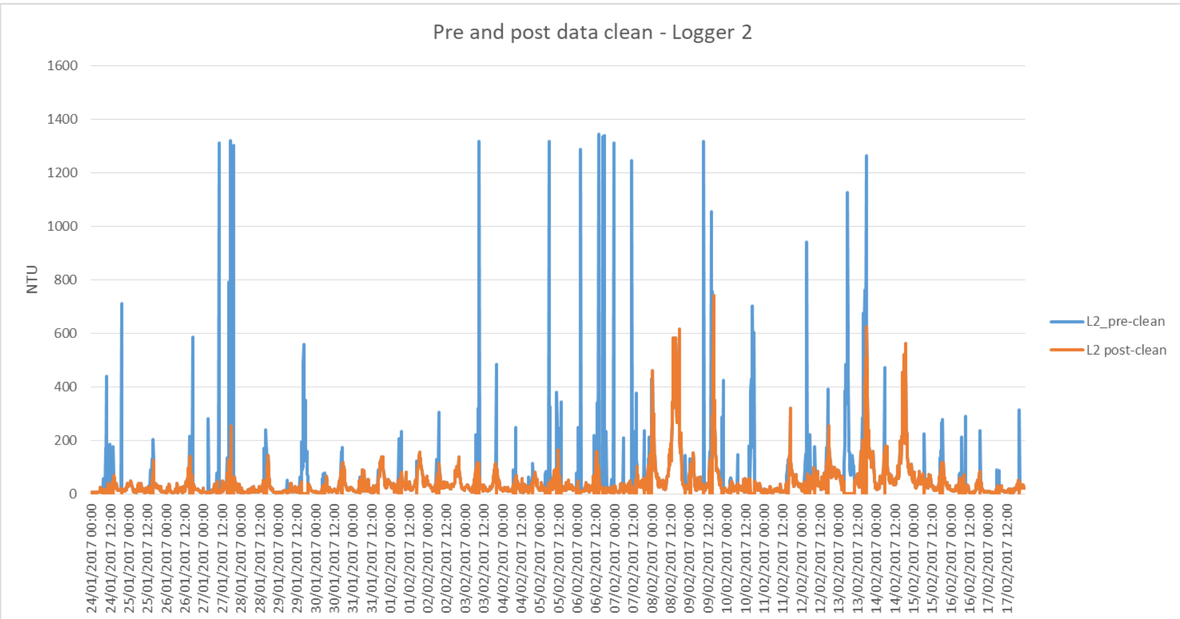

Figure 1: Example of unexplained peak NTU value removal for logger 2.

3.1.1 Turbidity data summary

After cleaning there were 50,000-57,000 individual turbidity samples for each of the three loggers (data summary in Table 3). The long term median turbidity value for the area was approximately

10NTU (Table 2). Logger 2 (near the ferry channel) had a similar median (baseline) but more and higher peaks demonstrated by the 95th percentile of 100NTU.

The coloured cells in Table 3show that there is a consistent temporal pattern across the three loggers (high months are high in all three loggers).

Table 2: long term turbidity values

	Logger1	Logger2	Logger3
Count	51542	57275	55375
Mean	20.6	30.5	12.6
StDev	31.1	81.0	19.5
median	9.7	11.1	7.8
95th%ile	74.9	100.0	40.4
5th%ile	1.2	0.9	0.8

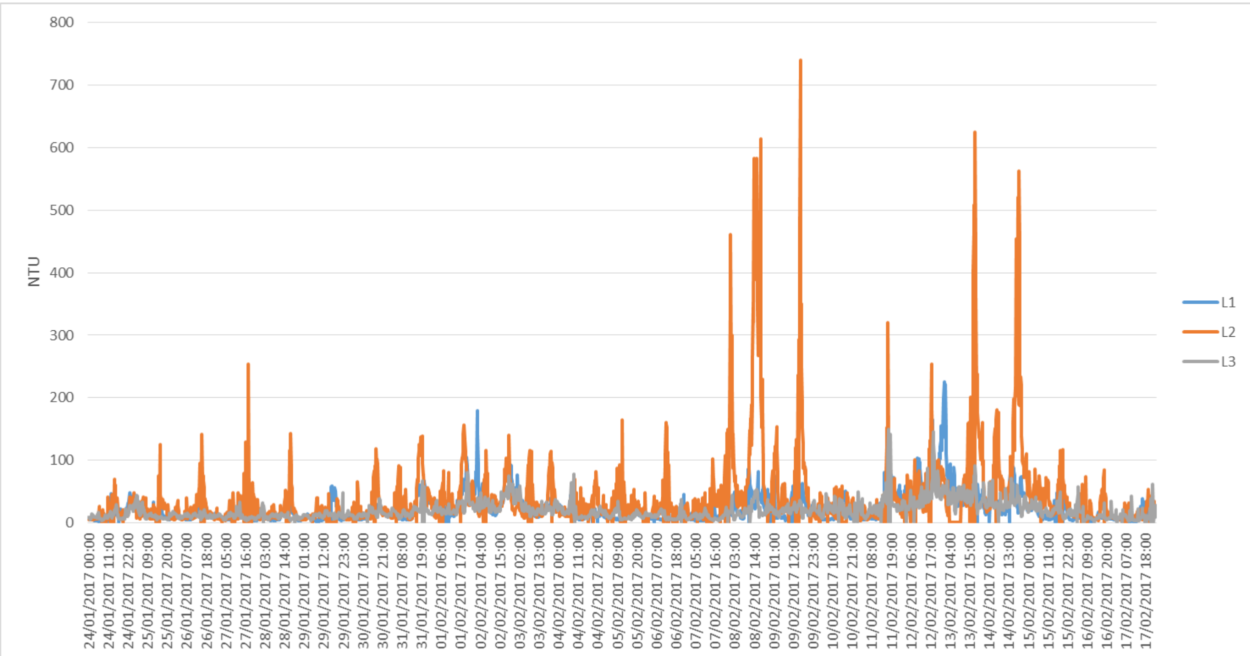

Figure 2: Example month sampling across three turbidity loggers (cleaned data).

Table 3: Cleaned turbidity data summary

Yr	mnth	Logger 1						Logger 2						Logger 3					
		n	Mean	StDev	median	95th%ile	5th%ile	n	Mean	StDev	median	95th%ile	5th%ile	n	Mean	StDev	median	95th%ile	5th%ile
Monthly summary																			
15	9	155	18.6	16.8	14.0	51.3	0.0	651	30.5	19.2	5.6	51.05	0.3	826	5.6	5.0	4.1	12.6	1.8
15	10	2071	21.2	31.0	11.1	69.1	3.5	2503	23.8	29.3	13.5	76.0	1.9	2448	11.2	17.9	6.4	36.2	0.9
15	11	2832	39.1	45.6	22.2	129.4	4.0	2694	39.0	50.4	22.0	137.9	5.5	2838	19.6	16.8	13.8	52.6	4.9
15	12	2857	25.6	34.5	14.8	79.8	4.7	2187	39.0	51.2	23.4	121.4	7.2	2918	16.9	13.4	12	46.2	6.1
16	1	2937	19.5	25.7	10.1	75.6	2.8	2734	20.5	26.8	10.8	69.4	1.7	2826	19.8	24.8	11.9	63.2	4.0
16	2	1555	27.3	23.2	18.1	76.4	5.5	2521	31.4	36.6	18.3	104.9	5	2715	16.1	12.8	12.5	44.9	5.6
16	3	1926	10.4	10.0	6.4	28.6	3.1	2610	11.7	14.6	6.9	37.3	1.4	2495	7.5	5.7	6.1	15.9	2.8
16	4	2067	12.3	10.9	8.6	32.5	3.8	2432	13.1	16.2	7.4	48.7	0.5	1830	4.8	5.0	3.3	14.1	0.9
16	5	1995	7.9	16.2	4.0	20.7	0.6	2882	7.0	11.2	2.9	30.5	0.4	2067	4.2	4.2	2.9	11.5	1.0
16	6	2796	10.2	24.8	3.4	40.0	0.8	2695	16.1	19.7	7.2	54.5	2.3	2850	3.7	6.2	1.6	15.8	0.2
16	7	2826	5.1	13.9	2.1	19.4	0.1	1345	12.0	16.2	4.8	45.2	0.6	2946	1.4	2.1	0.9	4.1	0.2
16	8	2916	5.5	6.1	3.4	18.4	0.6	1652	9.1	12.5	3.9	37.9	1.1	2949	6.8	14.7	2.5	48.2	0.5
16	9	927	31.1	30.9	21.9	96.2	3.2	2699	19.3	23.9	10.8	67.1	3.29	2595	21.0	60.2	5.9	78.4	2.0
16	10	1829	25.4	22.9	19.4	63.9	3.4	2797	18.5	24.6	11.1	58.0	2.4	2884	11.0	11.8	7.8	31.1	2.8
16	11	1889	29.1	39.8	13.0	109.2	2.1	2687	18.1	20.2	11.6	54.4	2.5	2111	14.2	12.5	10.1	41.8	3.6
16	12	2627	44.4	45.9	29.6	133.1	3.3	2474	56.6	70.8	37.7	164.1	1.665	2128	24.0	21.1	19.85	55.7	4.8
17	1	2613	29.7	31.0	19.5	90.7	3.9	2500	53.1	63.6	30.9	190.1	5.9	2602	19.9	14.9	15	48.0	5.9
17	2	2658	28.8	25.9	21.3	79.9	4.0	2332	190.5	300.1	42.4	924.2	8.7	2627	19.6	14.7	15.8	47.6	5.0
17	3	546	16.9	17.8	10.3	51.8	4.1	2643	51.0	106.9	15.8	212.9	2.6	86	15.6	5.5	14.9	25.7	8.3
17	4	2773	20.7	20.6	13.0	56.0	3.9	1759	46.5	64.0	20.4	180.9	1	1766	16.2	10.0	13.6	36.3	6.1
17	5	860	17.5	17.8	11.0	53.6	1.0	2710	12.3	17.1	6.1	48.7	1	2316	10.7	8.0	8.8	26.1	2.3
17	6	60	13.2	11.5	7.4	31.7	1.4	2768	8.6	12.6	3.5	35.3	0.3	2100	10.6	10.1	7.4	31.8	1.4
17	7	2947	7.0	10.9	3.6	27.3	0.7	1801	8.5	13.4	3.2	34.4	0.1	1039	6.9	9.1	4.1	24.4	1.5
17	8	2958	16.5	33.4	7.1	54.7	1.3	2434	9.5	13.5	3.9	38.0	0.2	1911	11.7	13.4	6.8	40.9	1.4

Yr	mnth	Logger 1						Logger 2						Logger 3					
		n	Mean	StDev	median	95th%ile	5th%ile	n	Mean	StDev	median	95th%ile	5th%ile	n	Mean	StDev	median	95th%ile	5th%ile
17	9	1930	29.4	56.5	11.4	121.2	2.4	767	18.1	25.8	9.4	55.6	0.6	1509	7.8	13.9	3	33.4	0.7
Annual Summary																			
15		7915	29.2	38.6	16.1	98.3	3.9	8035	32.2	44.1	18.4	105.7	2.7	9030	15.1	16.0	10.4	46.6	2.2
16		26290	17.7	27.9	7.6	70.3	0.9	29528	19.8	31.9	9.3	70.8	1.1	30396	11.1	22.8	5.6	38.3	0.6
17		17345	20.9	31.2	10.5	69.5	1.6	19714	45.8	127.8	11	182.0	0.6	15956	13.9	13.1	10.2	40.4	1.6

3.2Sourced and derived data

3.2.1 Wind Speed and direction

The wind speed and direction data for the Birsbane airport was sourced from the Bureau of Meterology. The last 14 months of daily summaries only is available (August 2016 – September 2017).

The maximum daily wind speed and direction was disaggregated to apply to all 15 minute time steps for the record. The wind direction was converted to four primary prevailing wind directions (N, E, S, W).

3.2.2 Rainfall

Daily rainfall data for the Brisbane Airport was used for the period august 2016-september 2017. The daily rainfall data for Cleveland (from SILO point drill) was used to represent rainfall from September 2015 – August 2016).

3.2.3 Ferry times

The possible passing of ferry times was based on the ferry timetables for the North Stradbroke Island vehicle ferry and the bay islands vehicle ferry (https://www.stradbrokeferries.com.au/timetables/). The arrival times for the North Stradbroke island vehicle ferry were estimated based on the Dunwich departure times +50 minutes as the advertised travel time.

In order to develop a time series represent when the ferries would pass logger 2 (which is 5 minutes travel time from the ferry terminal) each of the ferry arrival times was reduced by five minutes and each departure time was increased by five minutes. A data set was then created at the same 15minute time intervals as the turbidity logger data. Each record presents a score of potential ferry impact at the site. The scoring schema used was:

Score = 3 if ferry passed within 0-5 minutes of logger sample time

Score = 2 if ferry passed within 5-10 minutes of logger sample time

Score = 1 if ferry passed within 10-15 minutes of logger sample time

Score = 0 if ferry passed logger >15 minutes from sampling time

The ferry impact series takes account of the varying Ferry timetables for different days of the week (mon-thur, Fri, Sat, Sun). the ferry series does not take account of public holiday timetables.

3.2.4 Tidal data

The hourly measured Brisbane bar height (data sourced from https://uhslc.soest.hawaii.edu/data/?fd#uh331). The hourly water levels where linearly interpolated to give an approximate water level at the 15 minute turbidity sampling intervals.

Where low tide was specifically analysed, this has been assessed as the lower 1/3 of water levels across the analysis period.

4 Analysis

The basic approach for the analysis was to determine the impact if any of local ferry traffic on turbidity levels. The turbidity values are high variable through time. The first steps of this anslysis where therefore to identify and remove the effect of rainfall and wind induced wave action from the turbidity data. The residuals (turbidity not due to rainfall and wind) were then considered in terms of the potential contribution to the turbidity from local ferry movements (particularly at low tide).

4.1Effect of rainfall on Turbidity

The first consideration was to look at the effect of large rainfall events on the local turbidity either through major river outflows (multiple day impacts) or local stormwater impacts (single day). The overlay of rainfall timeseries and turbidity data showed no clear relationship (see Figure 3). Similarly a correlation test between rainfall and turbidity showed no significant relationship (slope of best fit not significantly different from zero (@P<0.05).

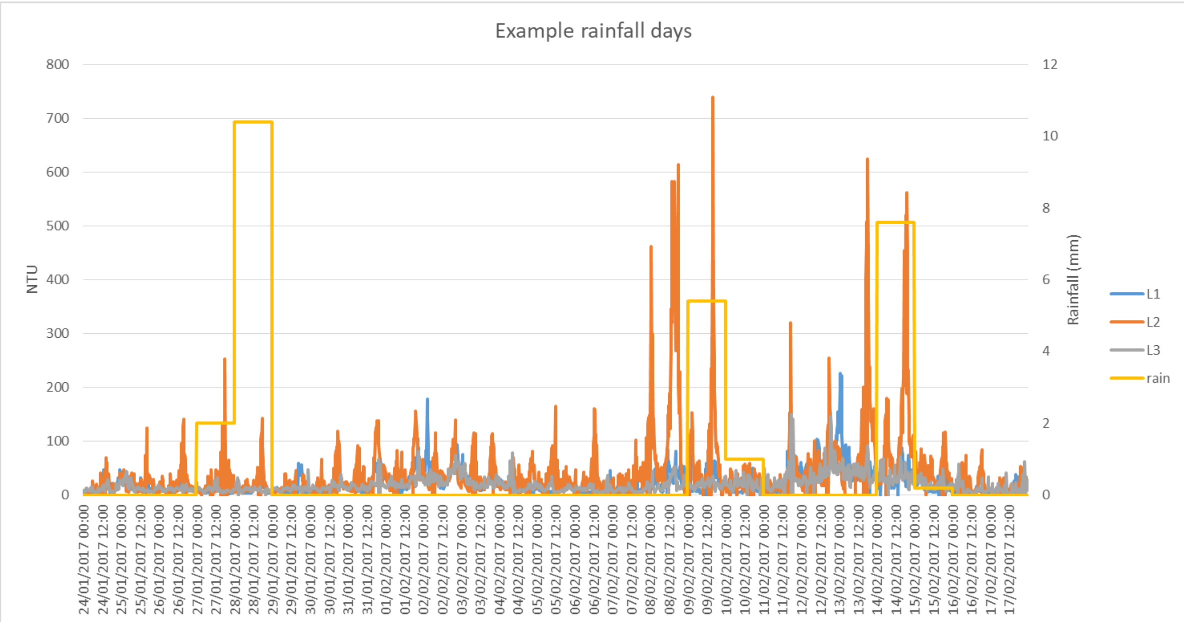

Figure 3: There is no discernible pattern between rainfall and the local turbidity values over the data collection period.

Given the low overall correlation between rainfall and turbidity, rainfall was not considered further in the analysis.

4.2Effect of wind direction

The dominant wind direction was divided into four wind quadrants (N, E, S, W) for the 13 month period of available wind data. For each of the prevailing wind direction subsets of data, the correlation between the speed of the maximum wind gust for the day and the logger2 turbidity values was tested.

Table 4 shows that the relationship between wind speed and turbidity for logger 2 was significant ($P<0.05$) for each quadrant, however the predictive power was very low (low R^2). The exception is the wind from the south which describes around 12% of the variance in turbidity. The reason for this higher correlation with southerlies is because the wind speed range for southerly was lower (max wind gust ~60km/h – compared to a 156km/h gust from the north).

To further explore the influence on wind direction and speed on turbidity, each of the four quadrant datasets was further subset to only include turbidity observations taken in the bottom third of the tide. The hypothesis here is that wind speed and direction is the primary driver of wave action in Moreton Bay. At low tide, the depth to the bay bed on average is reduced, increasing the opportunity for wave derived sediment resuspension during windy days. There was very little difference in the variance in turbidity explained by wind speed for the low tide subset data.

Given the low overall correlation between turbidity and wind the influence of wind direction and speed was not considered further.

Table 4: wind quadrant analysis summary

Wind Quadrant	Number of turbidity samples	Adjusted R2 for correlation	P value
N	12263	0.0264	1.64E-73
E	6277	0.01267	2.26E-19
S	8760	0.1245	1.8E-255
W	3071	0.030778	7.20E-23

4.3Tidal impact

One would expect a greater turbidity value at low tide, simply due to wave action interacting with the bed. Figure 4 shows a regular pattern of turbidity spike in logger 2. However this does not maintain an in-phase association with the tidal cycle. A regression analysis between water level and logger 2 turbidity gives a significant P value ($p<0.05$) however the variance in turbidity explained by water level is very low (R^2 0.011). We further partitioned the data to just look at this relationship for low tide (bottom 1/3 of the tidal cycle). The r2 was slightly improved but still very low (R^2 0.015)

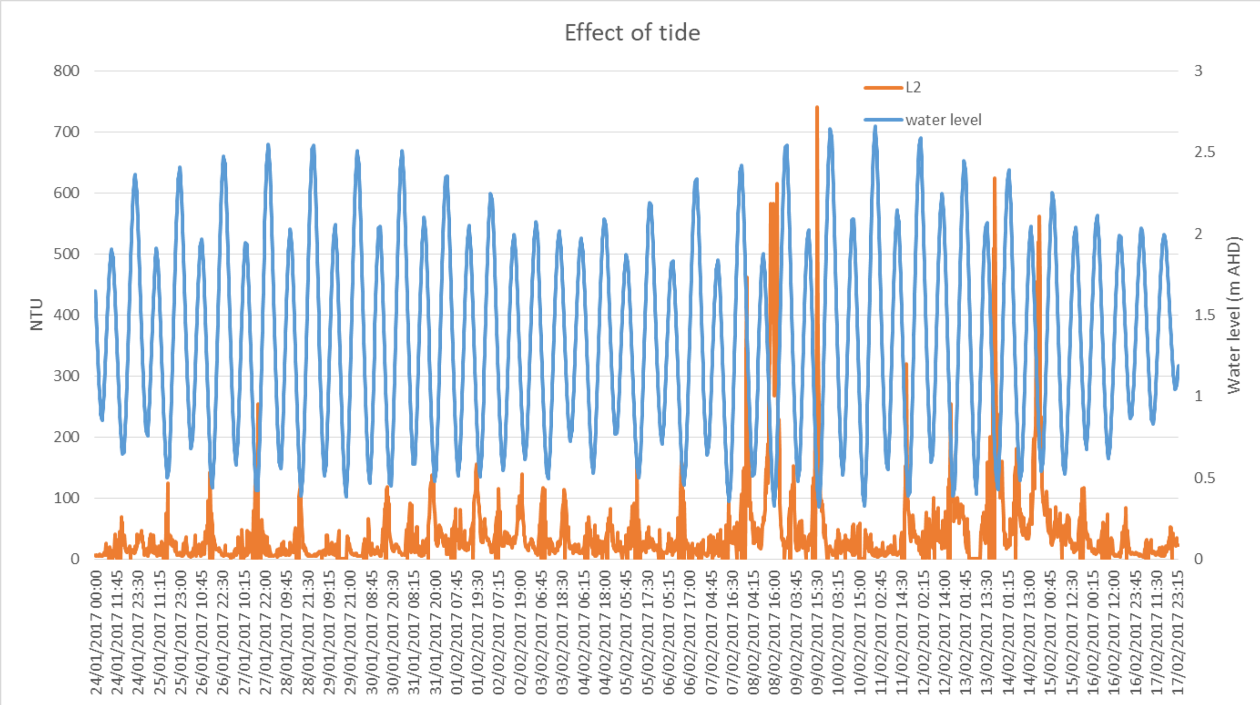

Figure 4: effect of tide on Logger 2 turbidity. Turbidity spikes roughly coincide with low tide, but there are several exceptions.

4.4Ferry impact

Logger 2 is located very close to the main ferry channel. This analysis is to consider how the turbidty values are correlated with the time since ferry passing. The purpose of the analysis is to determine if the ferries are significantly increasing the turbidity. From Figure 5 there is no obvious relationship between ferry passing and turbity levels. This is demonstrated by a correlation check (R^2 0.0015). Even if we only consider the low tide (bottom third of tidal range) then the effect of ferry passing only explains about 0.6% (R^2=0.006) of the variation in turbidity values.

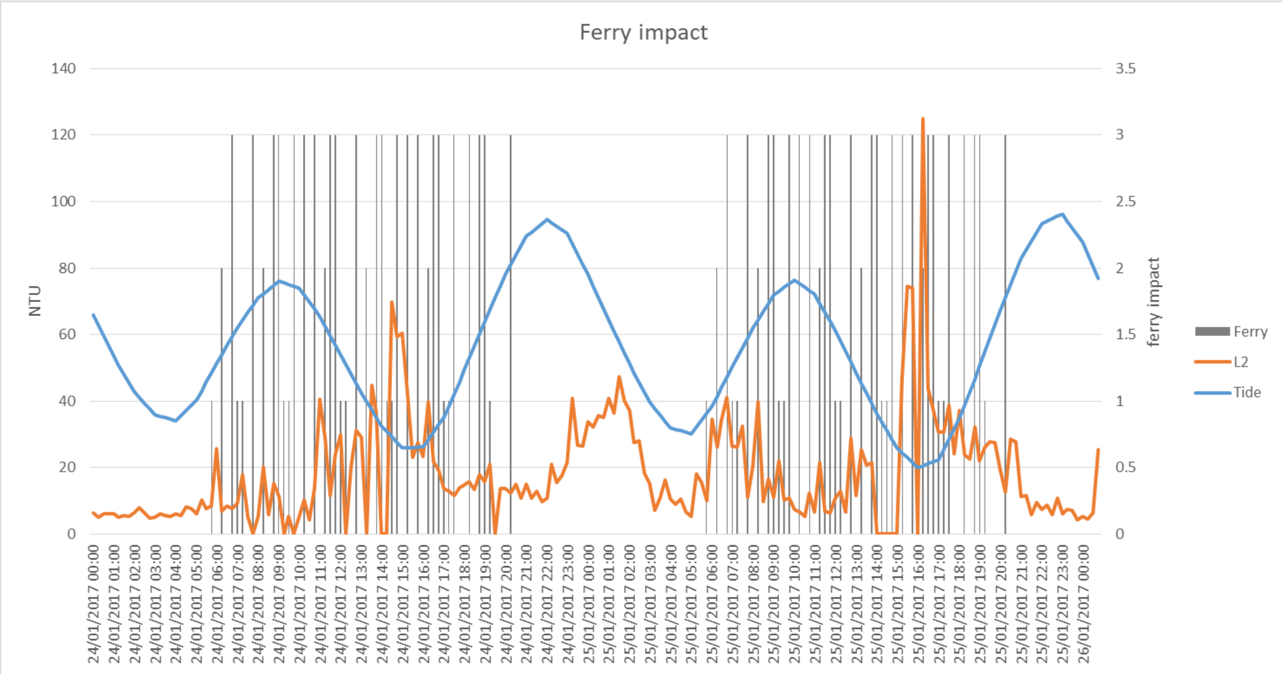

Figure 5: ferry impact (grey bars) shows no correlation with turbity. There appears to be no strong tidal influence.