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Dear Matthew and Sarah,

MHL2952 – Tweed Sand Bypass Tidal Analysis 2022-23

The Tweed River is situated in the Northern Rivers region of NSW. The Tweed River Entrance Sand Bypassing project commenced in the mid-1990s, with the objective to maintain a safe, navigable entrance to the Tweed River, and to restore and maintain alongshore sediment transport to the beaches of the southern Gold Coast of Queensland.

Tidal harmonic analysis of recorded estuarine water levels provides a means of better understanding, monitoring and managing estuary entrance behaviour with time. Tidal harmonic analysis involves determining the strength of tidal signal constituents from a water level time series. Comparing these signals over time and to other independent control sites gives insight into the entrance behaviour, including the effectiveness of entrance management operations and the natural response of the entrance over time.

MHL is pleased to provide this report for a tidal analysis of the Tweed River entrance and surrounding control sites for the period between and inclusive of April 2022 and March 2023, building on the previous analyses over the last six years.

1 Executive Summary

The Tweed River entrance is unlikely to have experienced any significant morphological changes over the study period resulting in changes to the astronomical tidal respone, with the observed parameters largely consistent with that of previous years and consistent characteristics observed when comparing sites.

2 Data

Water level data were collated from a total of three sites, namely Letitia 2A and Coffs Harbour Jetty in northern NSW and Mooloolaba on the Sunshine Coast of Queensland (see **Figure 1** and **Table 1**).

Table 1 – Summary of data, locations, periods, and intervals analysed

Station	Interval	Region	Period	Length
Letitia 2A	15 min	Northern Rivers	April 2022 – March 2023 (inclusive)	12 months
Coffs Harbour Jetty				
Mooloolaba	1 min	Sunshine Coast		

The water level data for the northern NSW sites were collected by automatic water level recorders operated as part of a larger network of water level stations which MHL manages on behalf of the NSW Department of Planning and Environment (DPE)

The Mooloolaba data were collected by automatic water level recorders operated by the Queensland Government Hydraulics Laboratory, part of the Department of Environment and Science.

MHL has previously completed similar analyses on the tidal data of the Tweed River entrance and surrounds, the results of which were also compiled for the purposes of comparison.

Relevant obersvations and long-term climate statistics were also sourced from the Beaurau of Meterology (BoM) Climate Data Online website.

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Figure 1 - Map of study area and data gauges

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Figure 1

Figures_MHL2952

3 Methodology

3.1 Tidal Planes and Comparisons

Tides are the result of gravitational forces exerted by the moon and the sun in combination with the rotation of the earth, known as astronomical forcing. These forces cause the movement of water across the earth's surface, manifesting in periodic rises and falls in water level over time. Analyses of coastal water level records reveals clear patterns over regular periods. The principal cycles of a tidal record are related to the relative positions of the sun, moon, and earth.

Tidal planes describe the usual variability of water levels due to astronomical forcing. Tidal planes are derived using harmonic analysis, which is the process of decomposing the tide signal into its causal components. Tidal planes in this study were calculated using four major harmonic constituents: M_2, S_2, O_1 and K_1, together with the Mean Sea Level, Z_0. Details of these major harmonic constituents are presented in **Table 2**. Combinations of the amplitudes of the dominant harmonic constituents were used to calculate the tidal planes and ranges at each station. Formulas for the calculation of these are provided in **Table 3** and **Table 4**, respectively. Each tidal constituent is defined by its periods and angular speed, while the phase and amplitude vary for different locations.

Table 2 - Major Harmonic Constituents

Constituent	Origin	Period (hour)	Angular speed (minute/degree)
M_2	Principal lunar semi-diurnal	12.42	2.07
S_2	Principal solar semi-diurnal	12.00	2.00
K_1	Lunar diurnal	23.93	3.99
O_1	Lunar diurnal	25.82	4.30

Table 3 - Calculation of Tidal Planes from Major Harmonic Constituents

Tidal plane		Equation
Highest High Water Springs	HHWS	$(Z_0 + M_2 + S_2 + K_1 + O_1) - M_{sf}$
Mean High Water Springs	MHWS	$Z_0 + (M_2 + S_2)$
Mean High Water Neaps	MHWN	$Z_0 + (M_2 - S_2)$
Mean Water Level	MWL	Z_0
Mean Low Water Neaps	MLWN	$Z_0 - M_2 - S_2$
Mean Low Water Springs	MLWS	$Z_0 - M_2 + S_2$
Lowest Low Water Springs	LLWS	$Z_0 - M_2 - S_2 - K_1 - O_1$

Table 4 - Calculation of Tidal Plane Ranges from Harmonic Consituents

Tidal plane range		Equation
Mean Spring Tidal Range	MSTR	$2(M_2 + S_2)$
Mean Neap Tidal Range	MNTR	$2(M_2 - S_2)$
Spring Tidal Range	STR	MHWS - MLWS

3.2 Tidal Anomalies

A predicted tidal signal for each location of interest was generated using a synthetic tide signal reconstructed from the constituent components as described above. The constituents used to calculate the tidal predictions are generated using the UTide (Unified Tidal Analysis and Prediction Model) software (Codiga, 2011).

An important result from the tidal analysis is the tidal anomaly (or residual) which was determined by calculating the difference between the predicted and measured water levels over time. Theoretically, the anomaly is the sum of all non-astronomical influences, but in application the tidal analysis is imperfect and affected by noise, so there will always be some residual tide signal in the anomaly.

Tidal anomalies were calculated using the formula:

$$\text{Residual Water Level (RWL)} = \text{Meaured Water Level (MWL)} - \textit{Predicted Water Level (PWL)}$$

The relative magnitude of the tidal residual can be used to determine whether a predicted tide provides a good representation of the observed water level record. This residual error is expressed in terms of the root mean square (RMS) of the tidal residual and is calculated as follows:

$$X_{RMS} = \sqrt{\frac{\sum X_i^2}{n}}$$

Where:

X_i = Residual Water Level (RWL) at time i

n = number of tidal records

3.3 Meteorological Effects

The occurrence of precipitation and fluctuations in atmospheric pressure can cause short-term deviations in the recorded water levels investigated in this study. This is particularly relevant at the Mooloolaba and Letitia 2A sites due to the influences of the Mooloola and Tweed Rivers, respectively. To identify and explain any significant oberserved anomalies, the BoM website was interrogated to source daily recorded rainfall and monthly long term average rainfall for comparison, as well as atmospheric pressure data at any times of significant anomaly.

4 Results and Discussion

4.1 Tidal Planes

Table 5 to **Table 16** present a series of monthly tidal plane results at each of the three sites.

The root-mean-squares (RMSs) of the monthly residuals over the study period at Letitia 2A range from a high of 0.10m to a low of 0.07m. Identical median residuals of 0.08m for Coffs Harbour, Mooloolaba, and Letitia 2A were recorded. This demonstrates general consistency between all sites, and the result for Letitia 2A and accords with the previous analyses.

Table 5– Tidal planes and ranges for April 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.096	0.978	1.097
MHWS	0.859	0.749	0.839
MHWN	0.489	0.457	0.421
MWL	0.157	0.194	0.098
MLWN	-0.545	-0.361	-0.643
MLWS	-0.175	-0.069	-0.225
LLWS	-0.782	-0.590	-0.901
MSTR	1.404	1.110	1.482
MNTR	0.664	0.526	0.646
Residual	0.097	0.103	0.074

Table 6 - Tidal planes and ranges for May 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.107	1.000	1.119
MHWS	0.831	0.741	0.814
MHWN	0.555	0.525	0.504
MWL	0.172	0.212	0.140
MLWN	-0.487	-0.317	-0.534
MLWS	-0.211	-0.101	-0.224
LLWS	-0.763	-0.576	-0.839
MSTR	1.318	1.058	1.348
MNTR	0.766	0.626	0.728
Residual	0.091	0.070	0.115

Table 7 - Tidal planes and ranges for June 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.117	0.956	1.052
MHWS	0.811	0.666	0.710
MHWN	0.625	0.516	0.494
MWL	0.199	0.158	0.069
MLWN	-0.413	-0.350	-0.572
MLWS	-0.227	-0.200	-0.356
LLWS	-0.719	-0.640	-0.914
MSTR	1.224	1.016	1.282
MNTR	0.852	0.716	0.850
Residual	0.083	0.064	0.065

Table 8 - Tidal planes and ranges for July 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.083	0.962	1.056
MHWS	0.775	0.674	0.722
MHWN	0.557	0.502	0.476
MWL	0.145	0.159	0.055
MLWN	-0.485	-0.356	-0.612
MLWS	-0.267	-0.184	-0.366
LLWS	-0.793	-0.644	-0.946
MSTR	1.260	1.030	1.334
MNTR	0.824	0.686	0.842
Residual	0.082	0.077	0.078

Table 9 - Tidal planes and ranges for August 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.057	0.886	1.011
MHWS	0.770	0.625	0.704
MHWN	0.452	0.369	0.340
MWL	0.082	0.072	-0.014
MLWN	-0.606	-0.481	-0.732
MLWS	-0.288	-0.225	-0.368
LLWS	-0.893	-0.742	-1.039
MSTR	1.376	1.106	1.436
MNTR	0.740	0.594	0.708
Residual	0.085	0.078	0.051

Table 10 - Tidal planes and ranges for September 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.083	0.900	0.992
MHWS	0.839	0.678	0.735
MHWN	0.449	0.356	0.293
MWL	0.112	0.098	-0.021
MLWN	-0.615	-0.482	-0.777
MLWS	-0.225	-0.160	-0.335
LLWS	-0.859	-0.704	-1.034
MSTR	1.454	1.160	1.512
MNTR	0.674	0.516	0.628
Residual	0.080	0.073	0.075

Table 11 - Tidal planes and ranges for October 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.030	0.908	1.005
MHWS	0.785	0.684	0.745
MHWN	0.415	0.396	0.329
MWL	0.070	0.126	0.009
MLWN	-0.645	-0.432	-0.727
MLWS	-0.275	-0.144	-0.311
LLWS	-0.890	-0.656	-0.987
MSTR	1.430	1.116	1.472
MNTR	0.690	0.540	0.640
Residual	0.061	0.083	0.102

Table 12 - Tidal planes and ranges for November 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.067	0.918	0.999
MHWS	0.777	0.647	0.684
MHWN	0.493	0.423	0.362
MWL	0.106	0.111	-0.011
MLWN	-0.565	-0.425	-0.706
MLWS	-0.281	-0.201	-0.384
LLWS	-0.855	-0.696	-1.021
MSTR	1.342	1.072	1.390
MNTR	0.774	0.624	0.746
Residual	0.060	0.083	0.060

Table 13 - Tidal planes and ranges for December 2022

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.073	0.981	1.055
MHWS	0.749	0.684	0.713
MHWN	0.545	0.524	0.485
MWL	0.121	0.188	0.065
MLWN	-0.507	-0.308	-0.583
MLWS	-0.303	-0.148	-0.355
LLWS	-0.831	-0.605	-0.925
MSTR	1.256	0.992	1.296
MNTR	0.848	0.672	0.840
Residual	0.049	0.091	0.109

Table 14 - Tidal planes and ranges for January 2023

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.006	0.887	0.988
MHWS	0.695	0.599	0.655
MHWN	0.437	0.405	0.373
MWL	0.040	0.089	-0.007
MLWN	-0.615	-0.421	-0.669
MLWS	-0.357	-0.227	-0.387
LLWS	-0.926	-0.709	-1.002
MSTR	1.310	1.020	1.324
MNTR	0.794	0.632	0.760
Residual	0.066	0.089	0.075

Table 15 - Tidal planes and ranges for February 2023

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.078	0.964	1.031
MHWS	0.805	0.712	0.742
MHWN	0.439	0.434	0.340
MWL	0.108	0.169	0.019
MLWN	-0.589	-0.374	-0.704
MLWS	-0.223	-0.096	-0.302
LLWS	-0.862	-0.626	-0.993
MSTR	1.394	1.086	1.446
MNTR	0.662	0.530	0.642
Residual	0.087	0.101	0.075

Table 16 - Tidal planes and ranges for March 2023

	Coffs Harbour	Letitia 2A	Mooloolaba
HHWS	1.056	0.923	1.020
MHWS	0.829	0.706	0.771
MHWN	0.425	0.376	0.323
MWL	0.119	0.136	0.027
MLWN	-0.591	-0.434	-0.717
MLWS	-0.187	-0.104	-0.269
LLWS	-0.818	-0.651	-0.966
MSTR	1.420	1.140	1.488
MNTR	0.612	0.480	0.592
Residual	0.071	0.065	0.062

4.2 Tidal Plane Comparisons

Figure 2 shows the mean water level for each of the three sites over the study period. Mean water levels levels behave consistently between all three sites and accord with previous years.

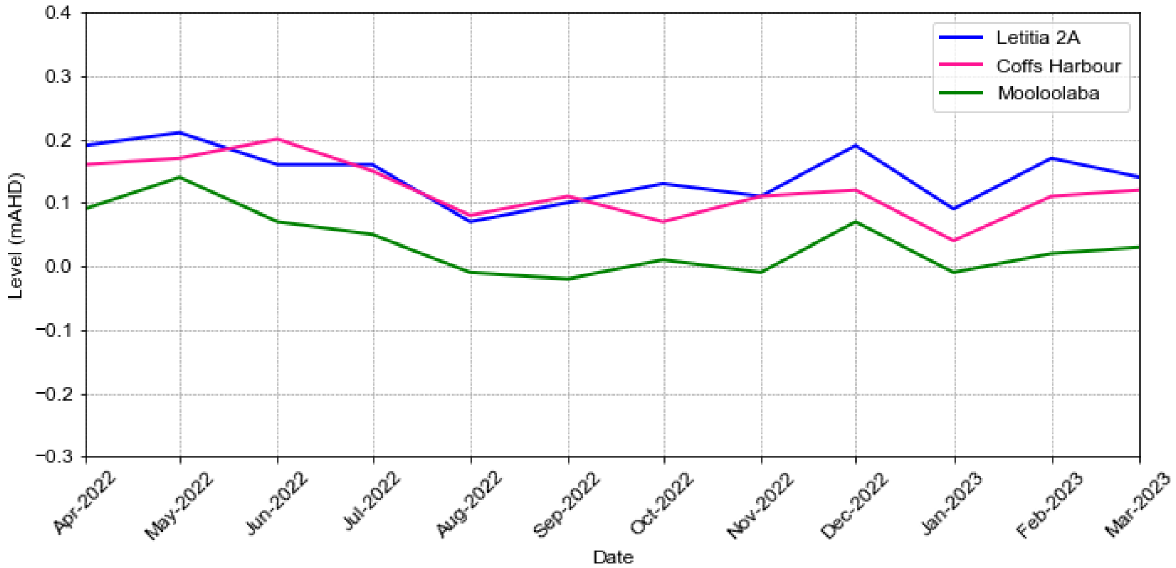

Figure 2 - Mean Water Level Comparison

Figure 3 compares the spring tidal range for each of the three sites over the study period. The spring tidal ranges are steady across each site over the study period and accord with with previous years.

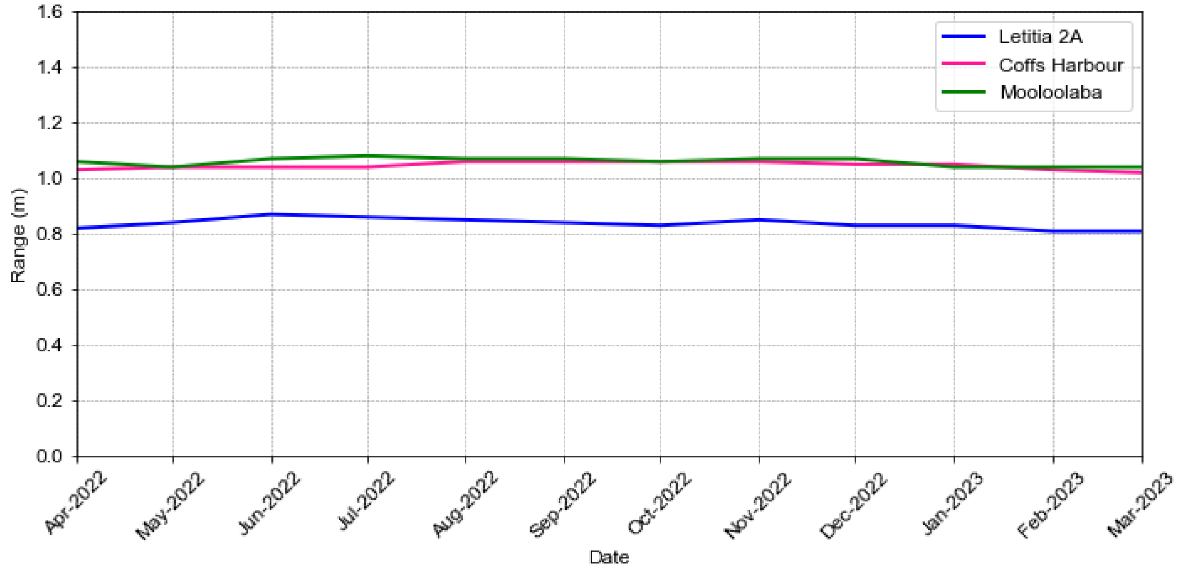

Figure 3 – Spring Tidal Range Comparison

Figure 4 compares the ratio of spring tidal ranges between Letitia 2A and Coffs Harbour and Mooloolaba over the study period. The ratio of spring tide range between sites shows no significant variations and accords with previous years.

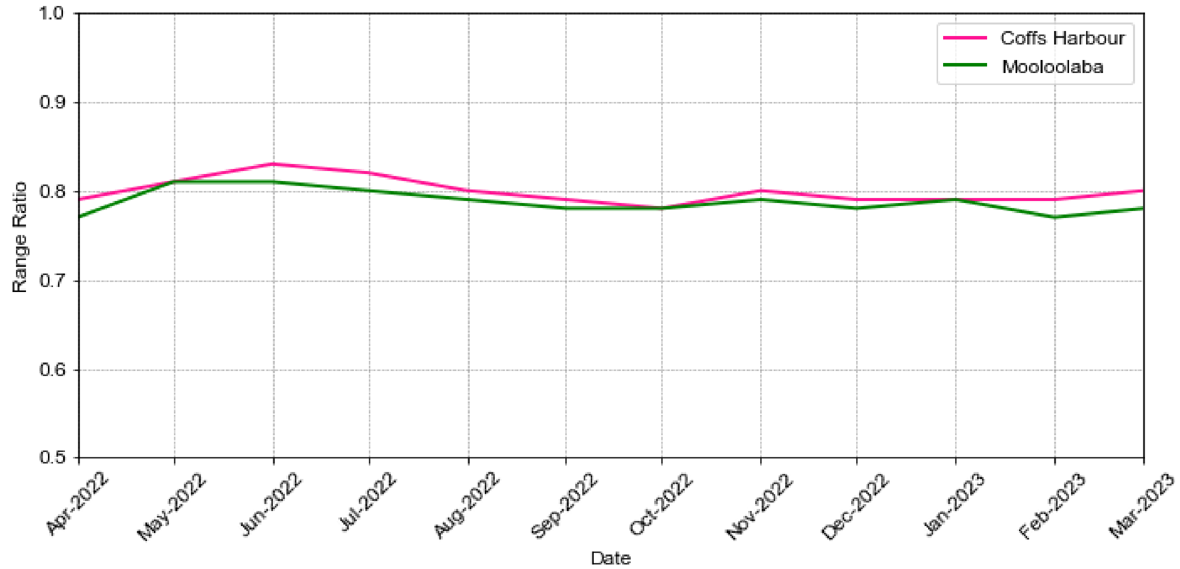

Figure 4 - Spring Tidal Range Ratio Comparison (Letitia 2A to Other Sites)

Figure 5 compares the Mean High Water Springs (MHWS) and Mean Low Water Springs (MLWS) for each of the three sites over the study period. These tidal planes behave consistently between all three sites and accord with previous years.

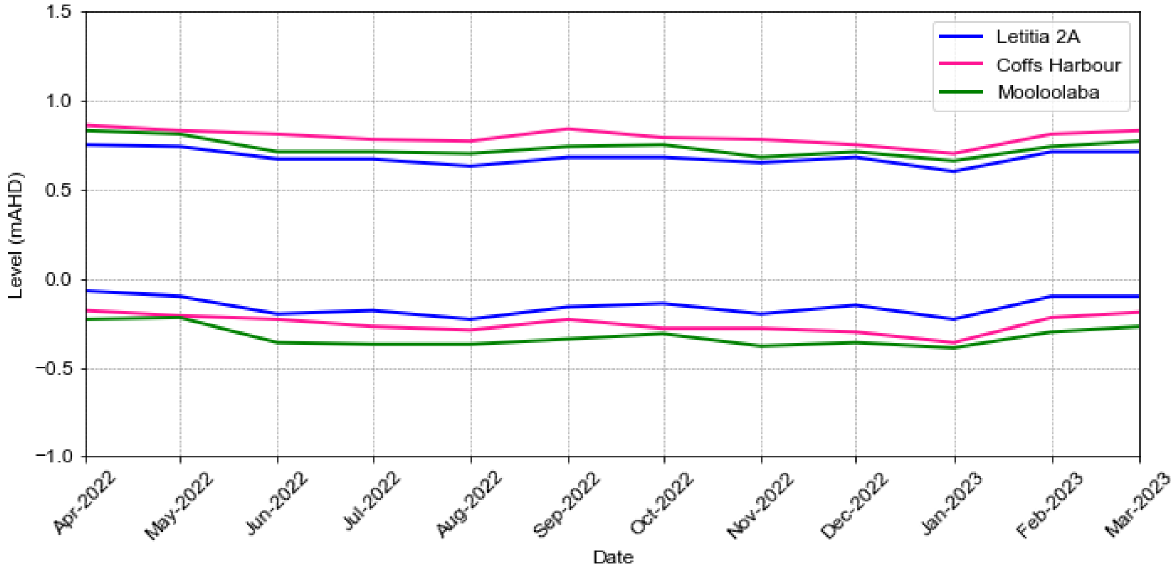

Figure 5 – Mean High Water Springs and Mean Low Water Springs Tidal Plane Comparison

Figure 6 presents the Mean Low Water Springs (MLWS) at Letitia 2A only, with the red dashed datum representing a level 0.6m below AHD. The results confirm that the recorded Letitia 2A MLWS level remains above -0.6 mAHD over the study period.

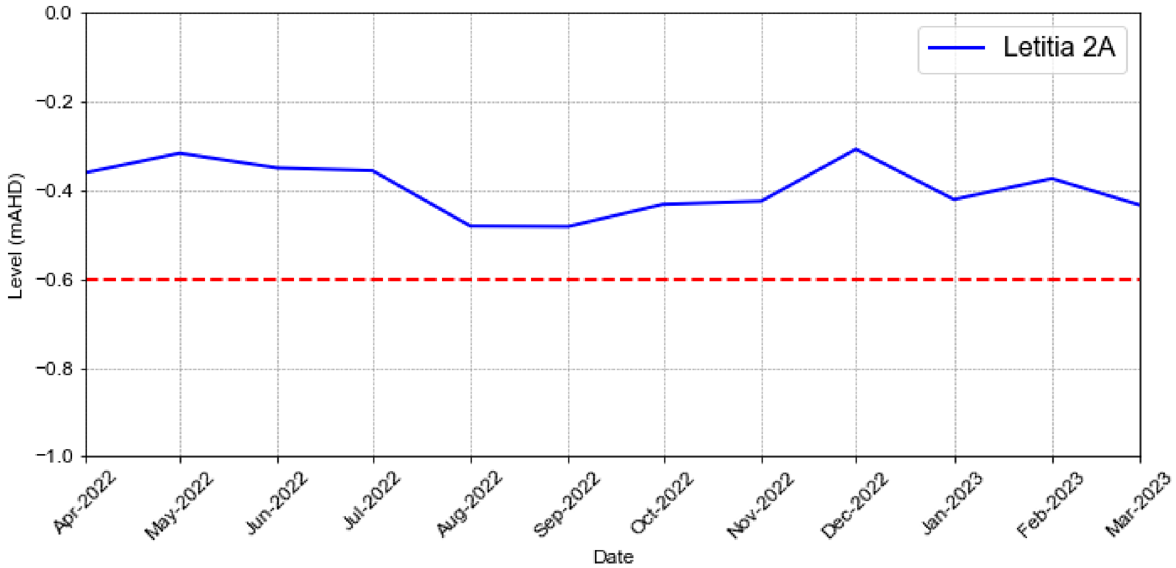

Figure 6 – Mean Low Water Springs at Letitia 2A

4.3 Tidal Anomalies

Figure 8 to **Figure 11** presents the predicted and recorded water levels at Letitia 2A, Coffs Harbour, and Mooloolaba over the study period. The blue curve is the measured water level, the red curve is the predicted tide using the constituents from the harmonic analysis, and the green curve is the anomaly between the two.

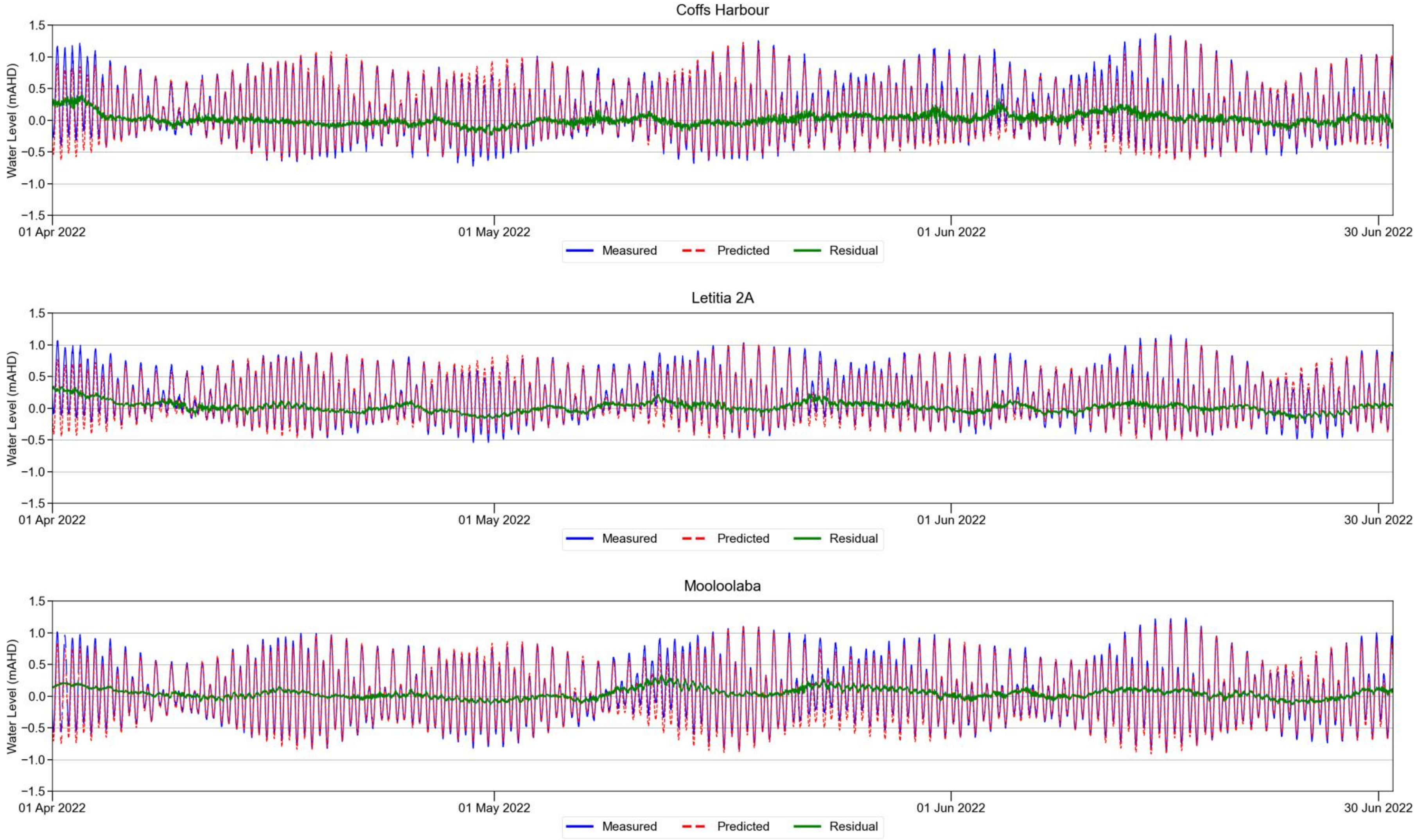

Figure 8 - April 2022 to June 2022 Water Level and Anomaly Comparison

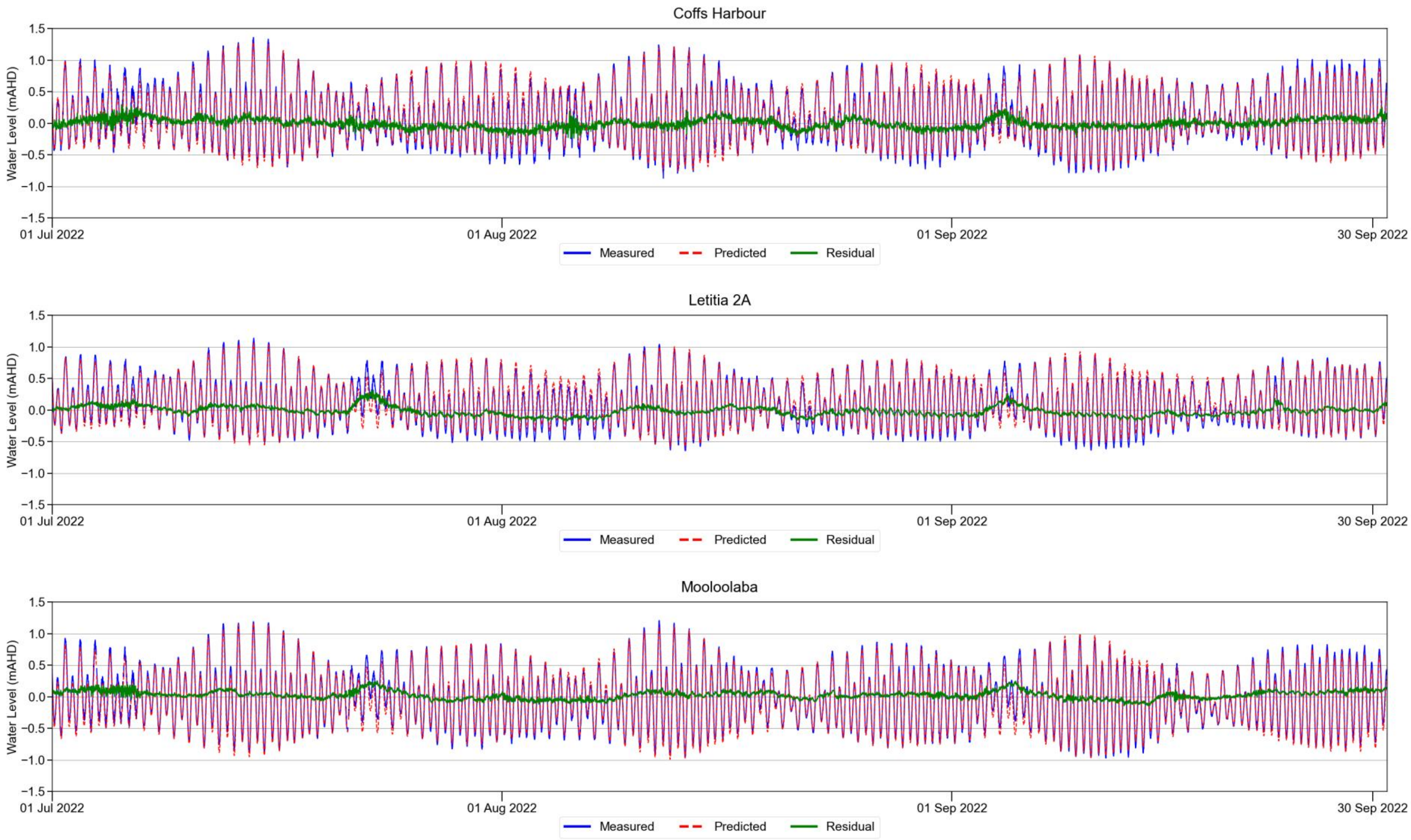

Figure 9 - July 2022 to September 2022 Water Level and Anomaly Comparison

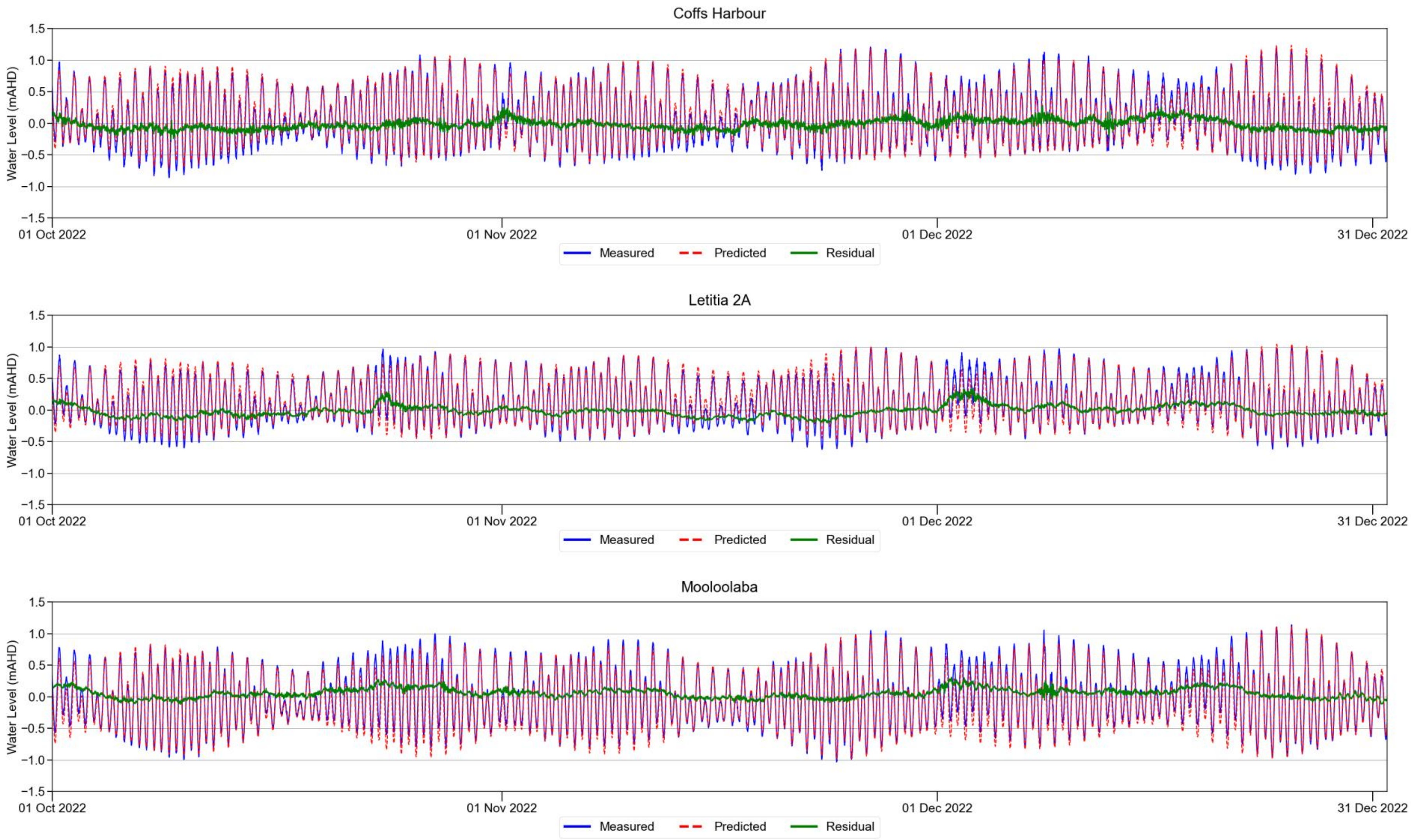

Figure 10 - October 2022 to December 2022 Water Level and Anomaly Comparison

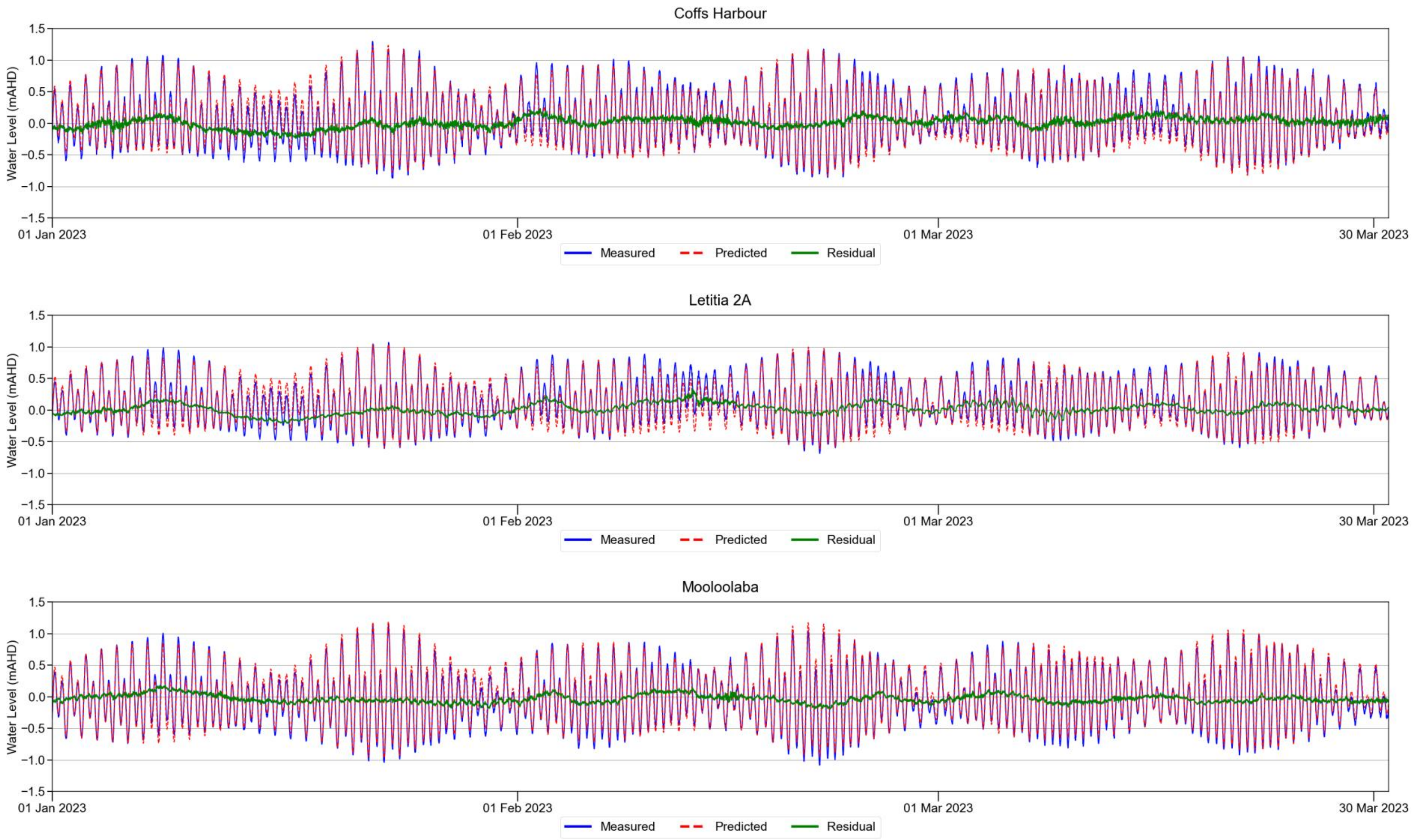

Figure 11 - January 2023 to March 2023 Water Level and Anomaly Comparison

4.4 Meteorological Effects

Monthly rainfall at North Murwillumbah on the Tweed River, is presented in **Table 17**. This period was characterised by variability, with particularly dry and wet months relative to the long-term averages. Over this 12-month study period, this had the net effect of 98% of the long-term average falling. Rainfall events generally falling across the Tweed catchment accounted for most of the short-term anomalies observed at Latitia 2A.

Table 17 Recorded and average rainfall at North Murwillumbah (Tweed River) for the period inclusive of April 2022 to March 2023

Year	Month	Average (mm)	Recorded (mm)		Recorded % of Average
			Total	Highest Daily	
2022	April	105	108	17	103%
	May	94	340	47	363%
	Jun	117	5	2	4%
	Jul	54	161	47	297%
	Aug	47	18	4	38%
	Sep	42	198	91	475%
	Oct	119	157	64	132%
	Nov	102	14	5	14%
	Dec	173	80	18	46%
2023	Jan	195	79	16	40%
	Feb	254	258	72	102%
	Mar	231	84	23	36%
	Annual	1532	1502		98%

Twice-daily mean sea level pressure observations were also sourced for the study period to account for any anomalies not adequately explained by the precipitation observations. This data was sourced from the nearby BoM station at Coolangatta in Queensland. It was found that each of the remaining significant anomalies were explained by concurrent events of below-average atmospheric pressure. This is confirmed by the correspondence of the anomalies at Letitia 2A with that at the other oceanic sites.

In summary, most significant tidal anomalies recorded at Letitia 2A due to elevated water levels which were caused by precipitation in the Tweed catchment or synoptic meteorological events.

5 Conclusion

Based on the analyses and comparisons presented above, the Tweed River entrance is unlikely to have experienced any significant morphological changes over the study period resulting in changes to the astronomical tidal respone.

I trust that this report is satisfactory to meet the requirements of Transport for New South Wales. Please contact me on (02) 9949 0244 or at bronson.mcpherson@mhl.nsw.gov.au, or Kyle Hasler on (02) 9949 0206 or at kyle.hasler@mhl.nsw.gov.au should you wish to discuss any aspects further.

Yours sincerely

Bronson McPherson
Director of Engineering, MHL
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6 References

BoM, 2023. *Climate Data Online.* [Online]
Available at:
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=2022&p_c=-677139015&p_stn_num=058186
[Accessed 17 April 2023].

Codiga, D. L., 2011. *Unified Tidal Analysis and Prediction Using the UTideMatlab Functions. URI/GSO Technical Report 2011-01, University of Rhode Island.,* s.l.: s.n.

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