Manly Hydraulics Laboratory

Tweed Sand Bypassing Tidal Analysis

2023-24

Report MHL3072

12 September 2024

Prepared for:

Transport for NSW – Maritime

Department of Climate Change, Energy, the Environment and Water

OFFICIAL

Cover Photograph: Point Danger looking towards the Gold Coast, courtesy of Tweed Sand Bypassing

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Document Control

Issue/ Revision	Author	Reviewer	Approved for Issue	
			Name	Date
Draft	K Hasler	G Lewis	B McPherson	05/09/2024
Final	K Hasler	M Glatz	B McPherson	12/09/2024

Report Classification

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Report No. MHL3072

First published as draft in September 2024

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Executive Summary

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

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

The results of this year's analysis indicate that the Tweed River entrance is unlikely to have experienced any significant morphological changes over the study period. No significant changes to the astronomical tidal response were observed, with all parameters remaining largely consistent to those of previous years and compared to the reference oceanic sites.

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1 Introduction

The NSW government's professional specialist advisor, Manly Hydraulics Laboratory (MHL) was commissioned by Transport for NSW to perform tidal analyses as part of the ongoing environmental monitoring of the Tweed River Estuary Sand Bypassing Project (TRESBP).

The report was prepared by Kyle Hasler.

1.1 Background

Tweed Sand Bypassing (TSB) was founded following extensive negotiations between the New South Wales (NSW) and Queensland (Qld) state governments to overcome erosion along the southern Gold Coast beaches and manage the Tweed River entrance. Agreements between the 2 States were reached by signing of a Heads of Agreement in 1994, to carry out a joint project to achieve the two legislative objectives:

1. Establishing and maintaining a safe, navigable entrance to the Tweed River
2. Provide a continuing supply of sand to the southern Gold Coast beaches consistent with natural drift rates, thus restoring and maintaining the amenity of these beaches.

The system comprises a sand collection jetty constructed across Letitia Beach, just south of the Tweed River entrance (see **Figure 1.1**) and supplementary dredging as required to maintain a clear navigation channel at the entrance.

Figure 1.1 Diagram of the TSB pipeline network and jetty pumping system

1.2 Tidal harmonic analysis

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 reveal 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 are derived using harmonic analysis, which is the process of decomposing the tide signal into its causal components. Tidal harmonic analysis is the process of determining the strength of different tidal signals whose constituents, acting at different frequencies, combine to create an observed tidal record at a specific location. Comparing these signals over time and to other independent control sites gives insight into varying entrance behaviour, including the effectiveness of entrance management operations and the natural response of the entrance. Tidal harmonic analysis of recorded estuarine water levels provides a means of better understanding, monitoring and managing changing estuary entrance behaviour.

2 Data

Water level data were collected from a total of 4 sites: Letitia 2A, Coffs Harbour, and Tweed Sand Bypassing Jetty in northern NSW and Mooloolaba on the Sunshine Coast of Queensland (see **Table 2.1** and **Figure 2.1**).

Table 2.1 Analysis gauge summary

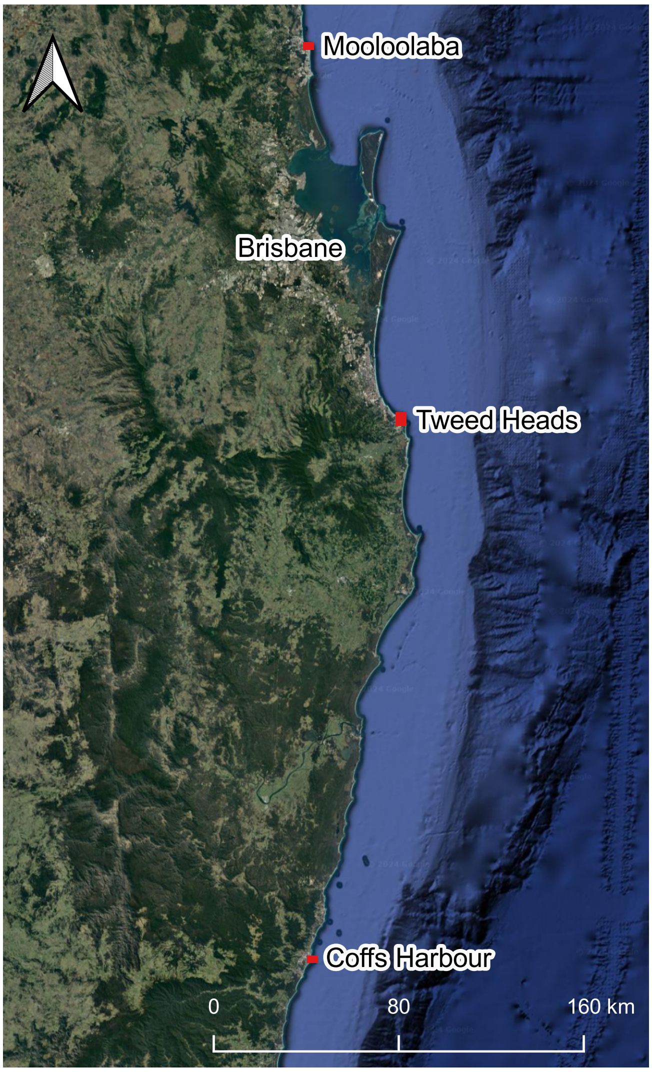
<table>
<tr><th>Station</th><th>Name</th><th>Custodian</th><th>Commenced</th><th>Status</th></tr>
<tr><td>201429</td><td>Letitia 2A</td><td rowspan="2">MHL</td><td>25 November 1987</td><td rowspan="4">Operational</td></tr>
<tr><td>205470</td><td>Coffs Harbour</td><td>06 August 1951</td></tr>
<tr><td></td><td>Tweed Sand Bypass Jetty</td><td rowspan="2">DESI</td><td>01 July 2018</td></tr>
<tr><td></td><td>Mooloolaba</td><td>28 September 1978</td></tr>
</table>

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 Climate Change, Energy, the Environment, and Water (DCCEEW).

The Tweed Sand Bypassing Jetty and Mooloolaba data were collected by automatic water level recorders operated by the Queensland Government Hydraulics Laboratory, part of the Queensland Department of Environment, Science and Innovation (DESI).

MHL has completed a yearly analysis on the tidal data of the Tweed River entrance and surrounds since 2017–18.

Relevant precipitation and barometric pressure observations and long-term rainfall averages were also sourced from the Bureau of Meteorology (BoM) Climate Data Online and MHL websites to rationalise any observed tidal anomalies.



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Tidal gauge locations

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Figure 2.1

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3 Methodology

3.1 Tidal planes and comparisons

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 3.1**. 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 3.2** and **Table 3.3**, respectively. Each tidal constituent is defined by its periods and angular speed, while the phase and amplitude vary for distinct locations.

Table 3.1 Major harmonic constituents

Constituent	Origin	Period (hours)	Angular speed (min/deg)
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 3.2 Calculation of tidal planes from major harmonic constituents

Tidal plane		Equation
Highest High Water Springs Solstices	HHWSS	$Z_0 + M_2 + S_2 + 1.4(K_1 + O_1)$
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	$Z_0 - M_2 - S_2$
Indian Springs Low Water	ISLW	$Z_0 - M_2 - S_2 - K_1 - O_1$

Table 3.3 Calculation of tidal ranges from tidal planes

Tidal plane		Equation
Mean Spring Tidal Range	MSR	MHWS – MLWS, i.e., $(Z_0 + M_2 + S_2) - (Z_0 - M_2 - S_2)$, or $2(M_2 + S_2)$
Mean Neap Tidal Range	MNR	MHWN – MLWN, i.e., $(Z_0 + M_2 - S_2) - (Z_0 - M_2 + S_2)$, or $2(M_2 - S_2)$

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:

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

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 act to exacerbate observed tidal anomalies. To identify and explain any significant anomalies observed at the Letitia 2A and baseline oceanic sites, daily recorded rainfall and barometric pressure observations were collated, presented and interrogated at any times of significant tidal anomaly.

4 Results

4.1 Tidal metrics

Table 4.1 to **Table 4.12** present a series of monthly tidal plane, tidal range, and tidal anomaly RMS results at each site.

The tidal planes, tidal ranges, and tidal anomaly RMSs at Letitia 2A were generally comparable to the baseline oceanic sites and in alignment with previous analyses. Further comparison and discussion of these results are presented in **Section 4.2**.

It is noted that tidal planes are displayed in metres above Australian Height Datum (mAHD), while the tidal ranges and tidal anomaly RMSs are displayed in metres (m).

Table 4.1 Tidal planes and ranges for May 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.109	1.223	1.192	1.199
MHWS	0.743	0.847	0.753	0.789
MHWN	0.540	0.579	0.446	0.505
MSL	0.228	0.190	0.080	0.121
MLWN	−0.084	−0.199	−0.286	−0.263
MLWS	−0.287	−0.466	−0.593	−0.547
ISLW	−0.549	−0.735	−0.907	−0.840
MSTR	1.030	1.313	1.345	1.336
MNTR	0.623	0.778	0.732	0.768
Residual	0.065	0.088	0.058	0.099

Table 4.2 Tidal planes and ranges for June 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.079	1.197	1.148	1.168
MHWS	0.663	0.770	0.667	0.703
MHWN	0.529	0.594	0.472	0.512
MSL	0.180	0.163	0.033	0.086
MLWN	−0.169	−0.269	−0.405	−0.341
MLWS	−0.302	−0.445	−0.601	−0.532
ISLW	−0.600	−0.750	−0.944	−0.863
MSTR	0.965	1.216	1.268	1.235
MNTR	0.698	0.863	0.877	0.853
Residual	0.054	0.070	0.049	0.080

Table 4.3 Tidal planes and ranges for July 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.023	1.137	1.104	1.109
MHWS	0.622	0.709	0.648	0.665
MHWN	0.459	0.494	0.406	0.431
MSL	0.124	0.082	0.002	0.026
MLWN	−0.212	−0.330	−0.401	−0.379
MLWS	−0.375	−0.545	−0.643	−0.613
ISLW	−0.661	−0.851	−0.969	−0.930
MSTR	0.997	1.254	1.292	1.279
MNTR	0.671	0.824	0.808	0.809
Residual	0.060	0.073	0.076	0.069

Table 4.4 Tidal planes and ranges for August 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.046	1.177	1.132	1.127
MHWS	0.679	0.792	0.709	0.726
MHWN	0.418	0.462	0.340	0.375
MSL	0.131	0.107	−0.004	0.024
MLWN	−0.156	−0.248	−0.347	−0.327
MLWS	−0.417	−0.578	−0.716	−0.678
ISLW	−0.679	−0.853	−1.018	−0.964
MSTR	1.095	1.370	1.424	1.404
MNTR	0.574	0.710	0.687	0.701
Residual	0.079	0.096	0.050	0.079

Table 4.5 Tidal planes and ranges for September 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	0.901	1.035	0.974	0.963
MHWS	0.590	0.704	0.630	0.626
MHWN	0.270	0.309	0.191	0.201
MSL	0.004	−0.026	−0.122	−0.122
MLWN	−0.262	−0.360	−0.434	−0.446
MLWS	−0.583	−0.755	−0.873	−0.871
ISLW	−0.805	−0.992	−1.119	−1.111
MSTR	1.173	1.459	1.503	1.497
MNTR	0.532	0.669	0.625	0.646
Residual	0.080	0.074	0.096	0.107

Table 4.6 Tidal planes and ranges for October 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	0.962	1.101	1.094	1.028
MHWS	0.650	0.756	0.723	0.684
MHWN	0.362	0.386	0.299	0.283
MSL	0.101	0.040	−0.020	−0.041
MLWN	−0.160	−0.306	−0.340	−0.365
MLWS	−0.449	−0.677	−0.764	−0.766
ISLW	−0.671	−0.923	−1.029	−1.011
MSTR	1.099	1.433	1.488	1.450
MNTR	0.522	0.692	0.640	0.648
Residual	0.091	0.097	0.073	0.089

Table 4.7 Tidal planes and ranges for November 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	0.938	1.047	1.022	0.999
MHWS	0.572	0.653	0.597	0.593
MHWN	0.350	0.376	0.288	0.291
MSL	0.042	−0.016	−0.098	−0.091
MLWN	−0.266	−0.409	−0.485	−0.474
MLWS	−0.489	−0.685	−0.793	−0.775
ISLW	−0.750	−0.967	−1.097	−1.065
MSTR	1.061	1.338	1.390	1.368
MNTR	0.616	0.785	0.773	0.765
Residual	0.065	0.080	0.087	0.056

Table 4.8 Tidal planes and ranges for December 2023

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	0.981	1.130	1.116	1.056
MHWS	0.583	0.687	0.645	0.607
MHWN	0.439	0.488	0.426	0.395
MSL	0.097	0.051	−0.005	−0.032
MLWN	−0.245	−0.386	−0.436	−0.459
MLWS	−0.390	−0.585	−0.655	−0.671
ISLW	−0.674	−0.901	−0.991	−0.992
MSTR	0.973	1.272	1.299	1.278
MNTR	0.684	0.874	0.862	0.853
Residual	0.063	0.059	0.053	0.078

Table 4.9 Tidal planes and ranges for January 2024

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.074	1.133	1.186	1.153
MHWS	0.677	0.704	0.726	0.703
MHWN	0.479	0.450	0.444	0.431
MSL	0.175	0.044	0.046	0.031
MLWN	−0.129	−0.362	−0.351	−0.369
MLWS	−0.328	−0.616	−0.633	−0.641
ISLW	−0.611	−0.922	−0.961	−0.961
MSTR	1.004	1.319	1.359	1.344
MNTR	0.608	0.812	0.795	0.800
Residual	0.103	0.061	0.076	0.101

Table 4.10 Tidal planes and ranges for February 2024

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.049	1.162	1.180	1.127
MHWS	0.696	0.787	0.776	0.736
MHWN	0.422	0.426	0.378	0.349
MSL	0.157	0.085	0.049	0.009
MLWN	−0.109	−0.255	−0.280	−0.331
MLWS	−0.382	−0.617	−0.678	−0.719
ISLW	−0.634	−0.884	−0.966	−0.997
MSTR	1.078	1.404	1.453	1.455
MNTR	0.531	0.681	0.658	0.681
Residual	0.067	0.088	0.051	0.078

Table 4.11 Tidal planes and ranges for March 2024

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.068	1.104	1.181	1.138
MHWS	0.758	0.775	0.829	0.793
MHWN	0.454	0.376	0.388	0.364
MSL	0.212	0.058	0.090	0.054
MLWN	−0.030	−0.261	−0.208	−0.257
MLWS	−0.335	−0.660	−0.649	−0.686
ISLW	−0.556	−0.895	−0.900	−0.932
MSTR	1.093	1.436	1.477	1.479
MNTR	0.484	0.637	0.596	0.621
Residual	0.074	0.092	0.061	0.074

Table 4.12 Tidal planes and ranges for April 2024

Tidal metric (mAHD, m)	Letitia 2A	Coffs Harbour	Mooloolaba	Tweed Sand Bypass Jetty
HHWSS	1.142	1.291	1.239	1.226
MHWS	0.816	0.946	0.866	0.859
MHWN	0.553	0.593	0.474	0.477
MSL	0.286	0.251	0.150	0.139
MLWN	0.018	−0.091	−0.175	−0.199
MLWS	−0.245	−0.443	−0.566	−0.582
ISLW	−0.477	−0.690	−0.833	−0.844
MSTR	1.061	1.39	1.432	1.441
MNTR	0.535	0.684	0.649	0.676
Residual	0.074	0.107	0.061	0.074

4.2 Comparisons

Figure 4.1 compares the mean water level observed at Letitia 2A and the oceanic baseline sites over the study period. Mean water levels behaved generally consistently between all sites over the year, with mean water levels at Letitia 2A being consistently higher than all oceanic baseline sites.

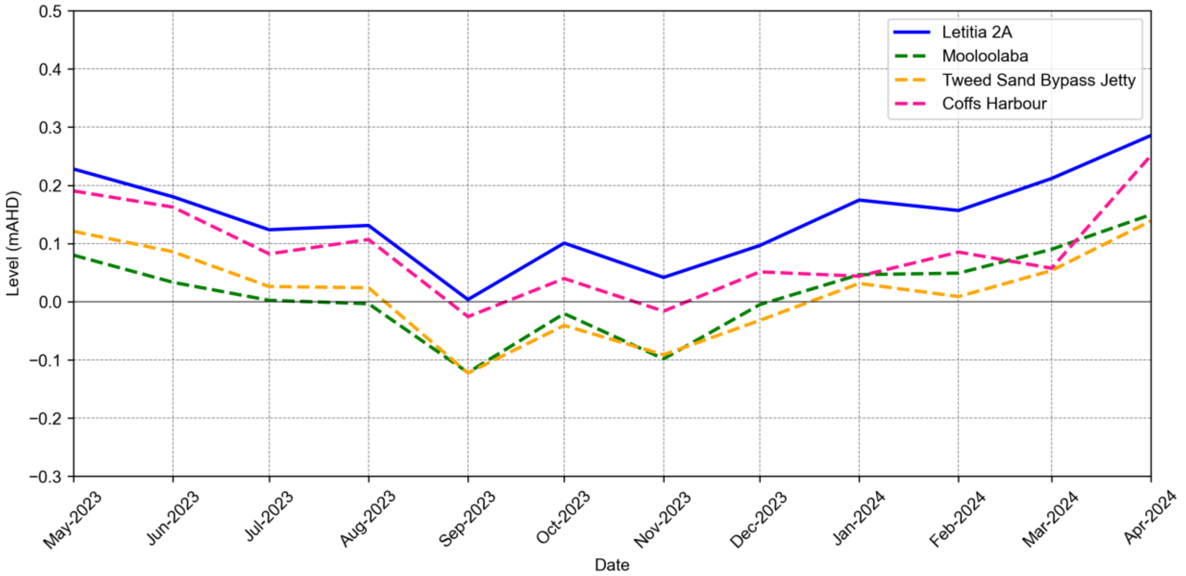

Figure 4.1 Mean Water Level Comparison

Figure 4.2 compares the spring tidal ranges observed at Letitia 2A and the oceanic baseline sites over the study period. The spring tidal ranges vary uniformly over the solar year across each site, in accordance with previous years.

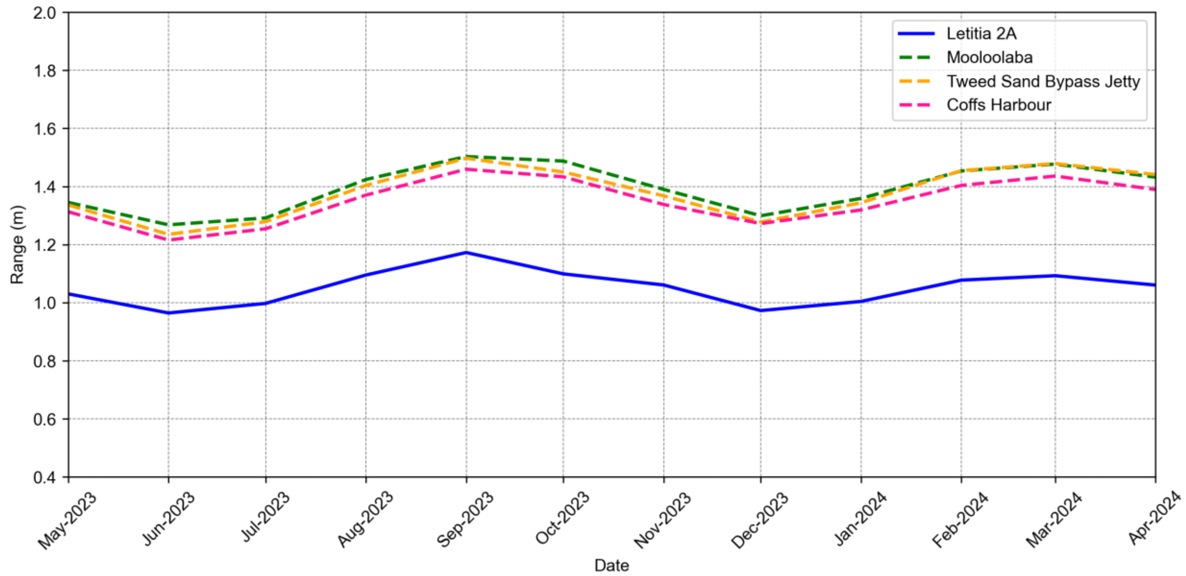

Figure 4.2 Spring tidal range comparison

Figure 4.3 compares the ratio of spring tidal ranges between Letitia 2A and the oceanic baseline sites over the study period. The ratio of the spring tidal ranges between sites is uniform throughout the solar year and across oceanic sites, in accordance with previous years.

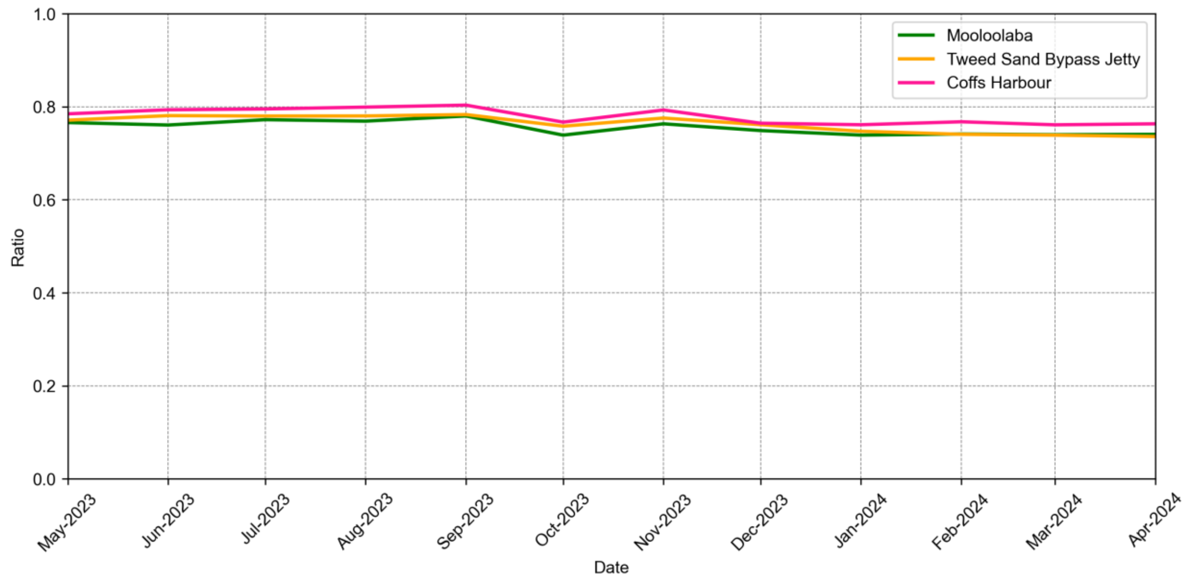

Figure 4.3 Spring tidal range ratio comparison (Letitia 2A to other sites)

Figure 4.4 compares the Mean High Water Springs (MHWS) and Mean Low Water Springs (MLWS) observed at Letitia 2A and the oceanic baseline sites over the study period. These tidal planes behave consistently between all 3 sites, in accordance with previous years. It is noted that the reduction in spring tidal range at Letitia 2A is predominantly driven by an elevated MLWS plane, with a smaller effect stemming from a depressed MHWS plane. This means that high tides in the Tweed estuary are more similar to the oceanic sites, while low tides remain more elevated.

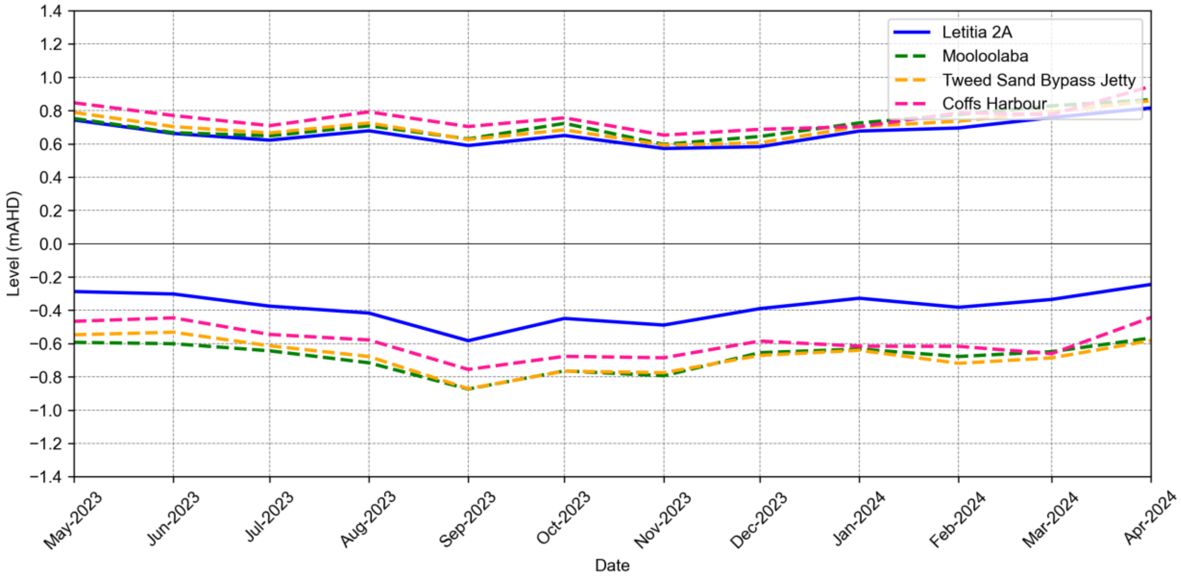

Figure 4.4 Mean High Water Springs and Mean Low Water Springs Tidal Plane Comparison

Figure 4.5 presents the Mean Low Water Springs (MLWS) at Letitia 2A, with the red dashed line representing the datum 0.6 m below AHD. It is noted that the recorded Letitia 2A MLWS plane remained above −0.6 mAHD in each month of the study period, in accordance with previous years.

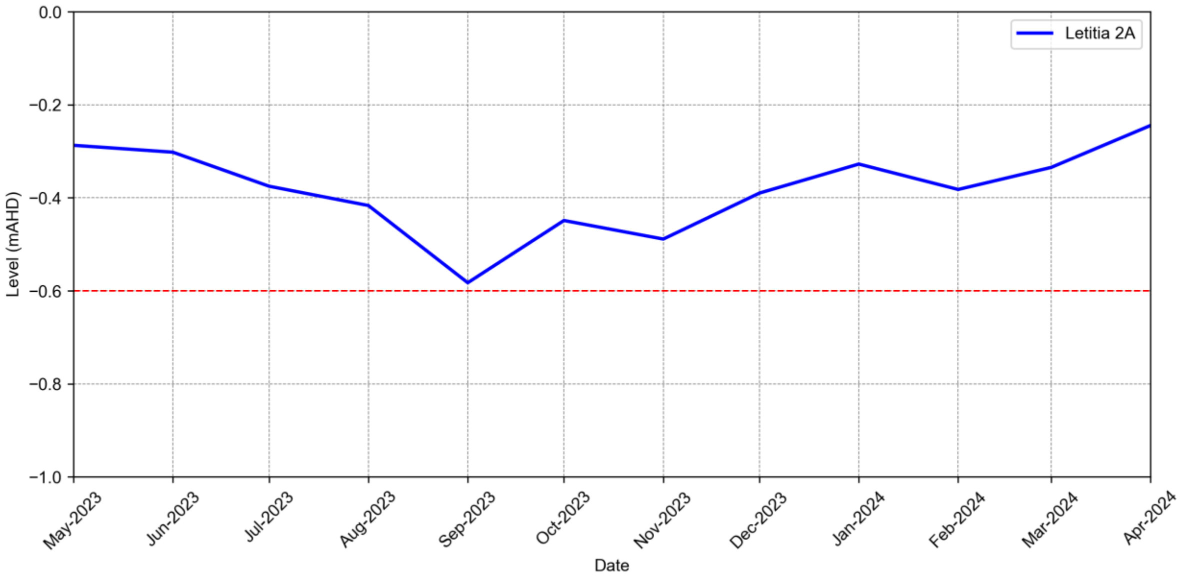

Figure 4.5 Mean Low Water Springs at Letitia 2A compared to the −0.6 mAHD datum

4.3 Tidal anomalies

Figure 4.6 to **Figure 4.9** present the predicted and recorded water levels at Letitia 2A and the oceanic baseline sites at Tweed Sand Bypassing Jetty and Coffs Harbour 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 difference between the two.

Inspection of these time series shows evidence of localised elevated tidal anomalies in the Tweed estuary, most notably in two distinct events in early- and mid-January 2024.

More widespread tidal anomaly events are observable across all sites periodically throughout the analysis period, most apparently in late-May 2023, late-December 2023 and early-April 2024. During these events and at other times, the relative anomaly behaviour is largely consistent between the estuary and baseline oceanic sites.

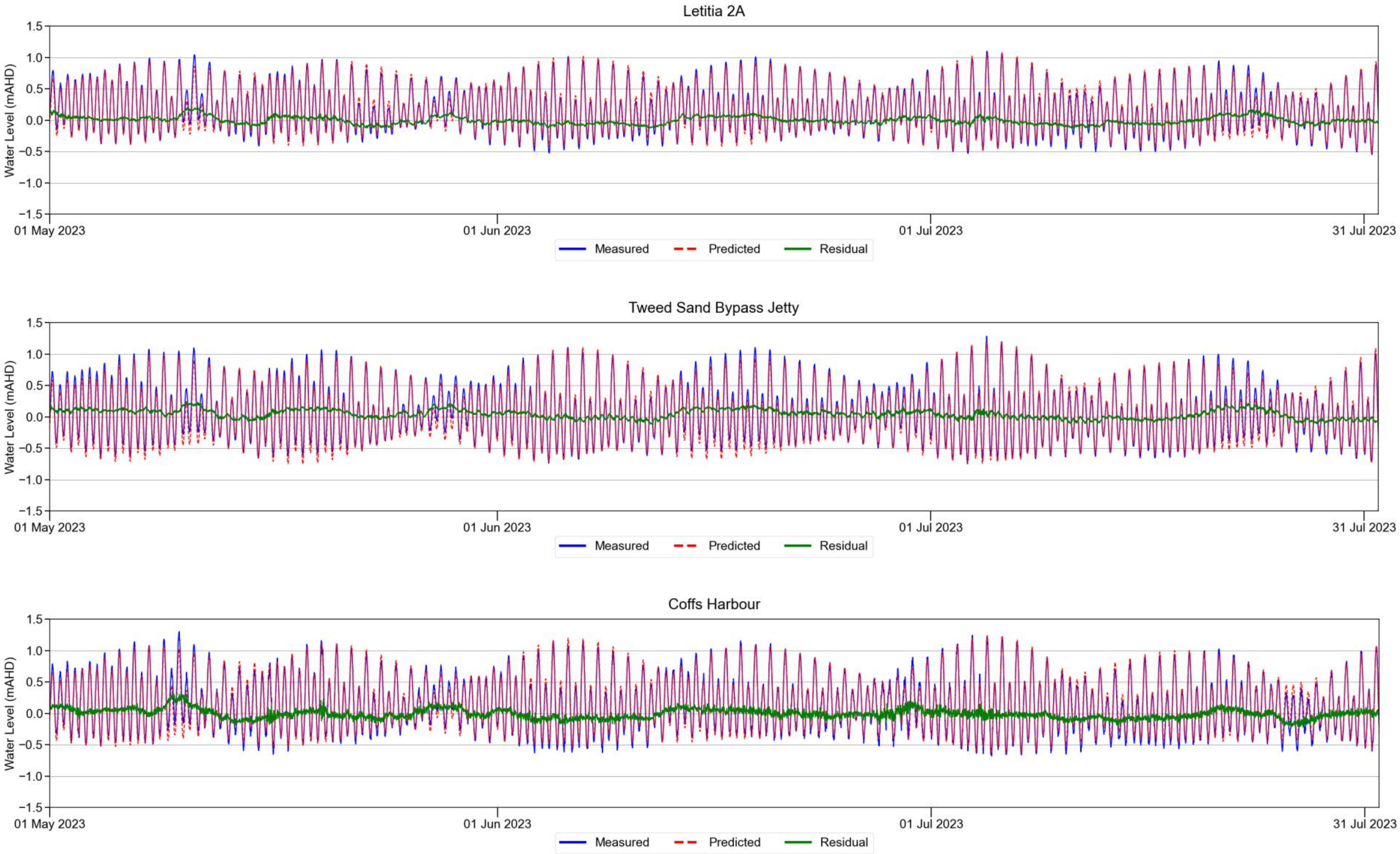

Figure 4.6 May 2023 to July 2023 water level and tidal anomaly comparison

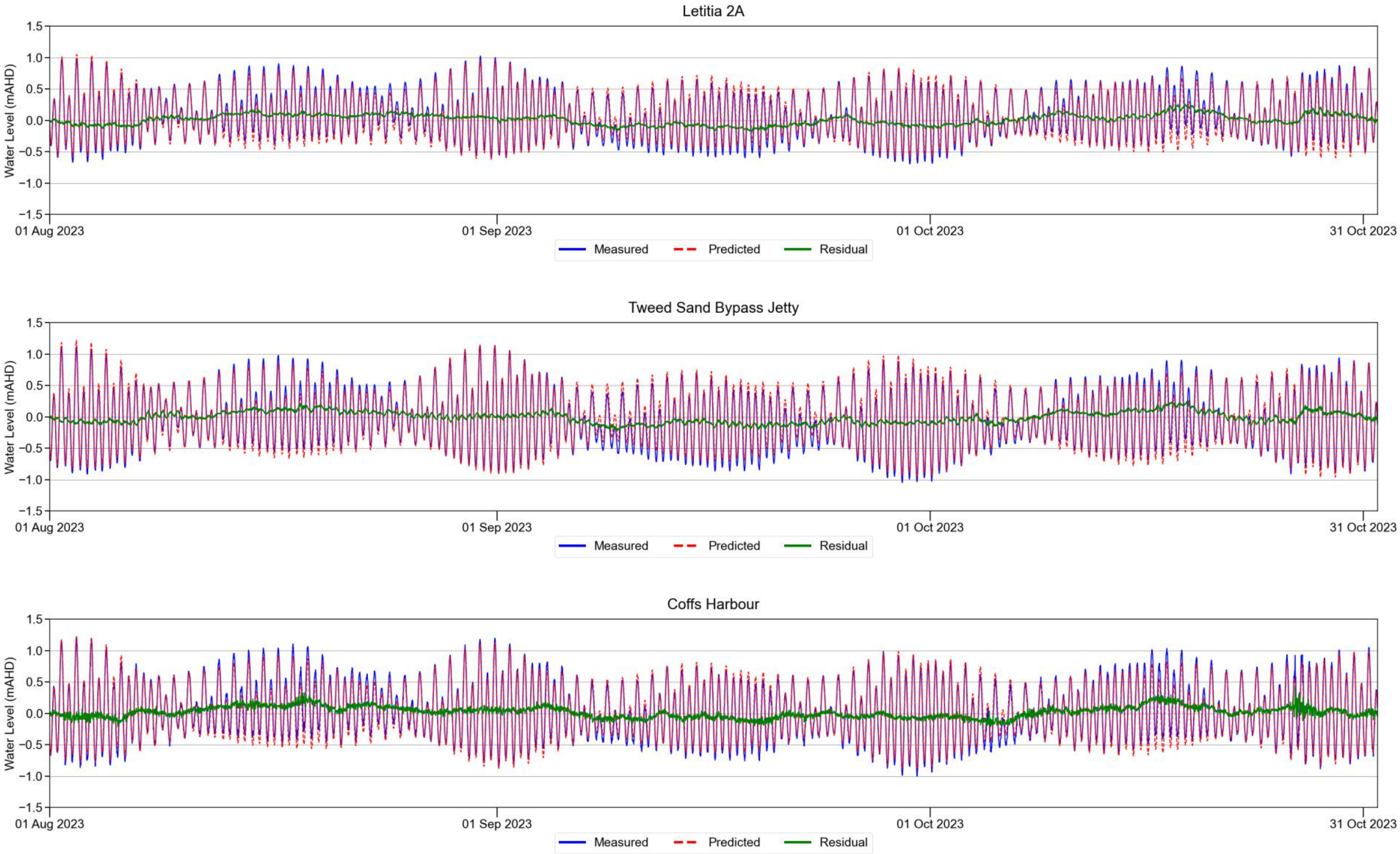

Figure 4.7 August 2023 to October 2023 water level and tidal anomaly comparison

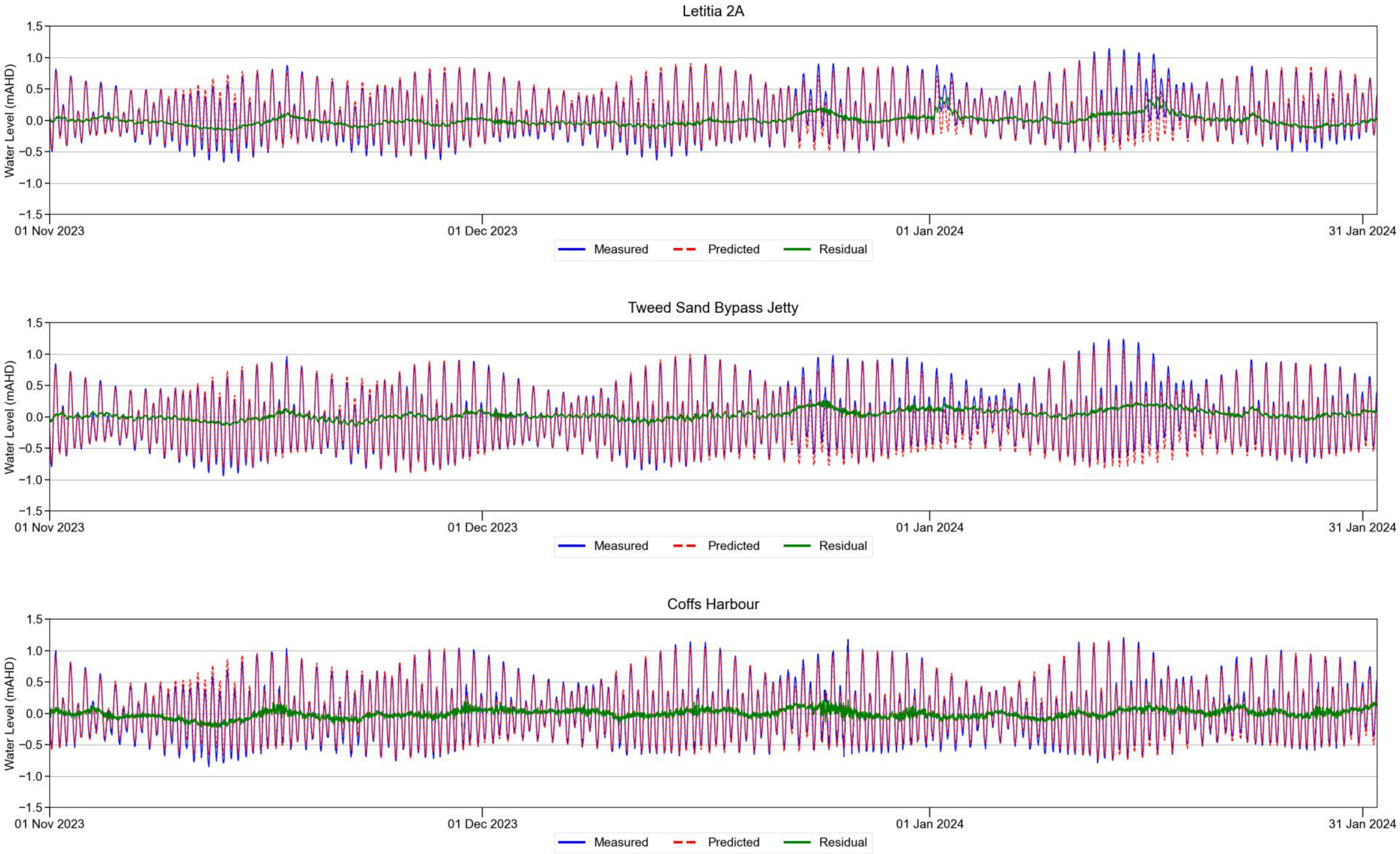

Figure 4.8 November 2023 to January 2024 water level and tidal anomaly comparison

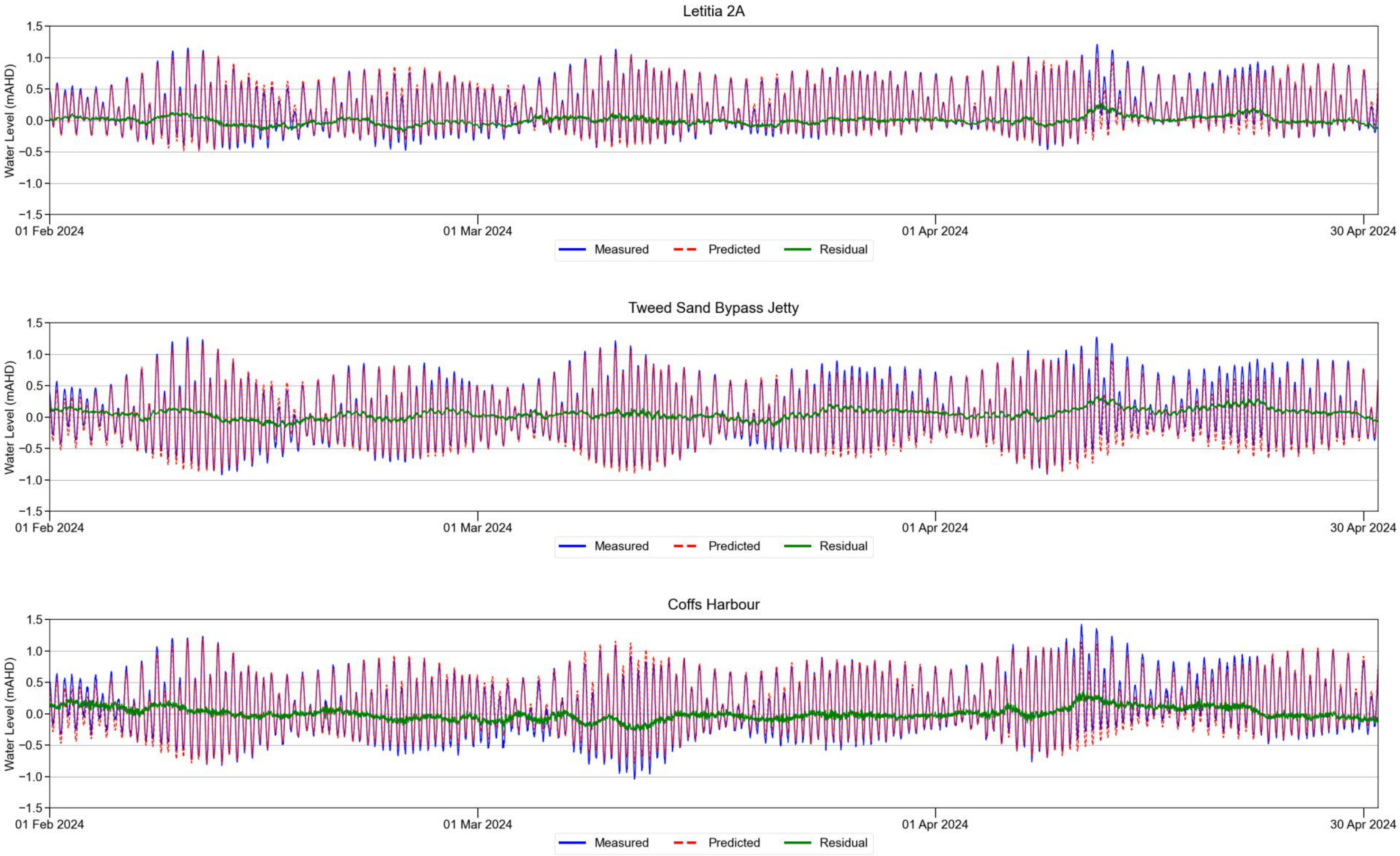

Figure 4.9 February 2024 to April 2024 water level and tidal anomaly comparison

4.4 Meteorological effects

Monthly rainfall at North Murwillumbah on the Tweed River is presented in **Figure 4.10** and **Table 4.13**. As can be seen, this period was characterised largely by average to below-average rainfall conditions. However, the month of January 2024 saw several significant rainfall events, driving the monthly total to more than double the long-term average. Therefore, it can be said that tidal anomalies in the Tweed estuary should be generally unaffected by the effects of catchment runoff over the analysis period. However, short-term tidal anomalies should be expected and are observable during rainfall events, particularly the large event seen in January 2024.

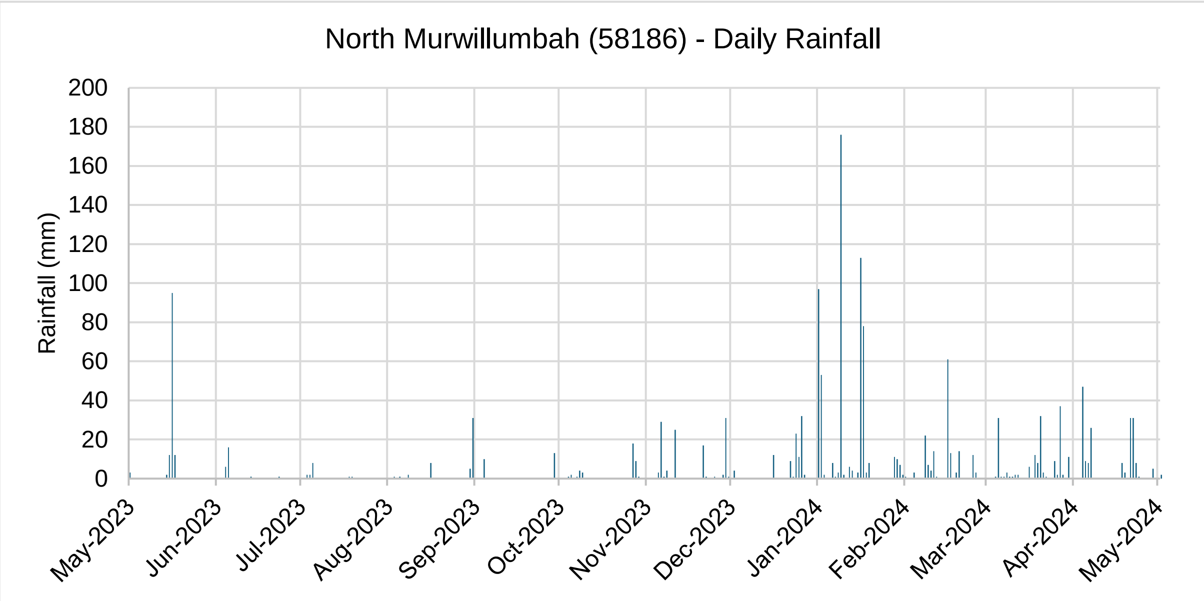

Figure 4.10 Recorded daily rainfall at North Murwillumbah (Tweed River) from May 2023 to April 2024

Table 4.13 Recorded and average monthly rainfall at North Murwillumbah (Tweed River) from May 2023 to April 2024

Year	Month	Recorded (mm)		Long-term Average (mm)
		Highest daily (date)	Total	
2023	May	95 (16)	124	96
	June	16 (04)	24	109
	July	8 (05)	14	53
	August	31 (31)	48	47
	September	13 (29)	23	41
	October	18 (27)	39	115

	November	31 (29)	115	103
	December	32 (26)	94	170
2024	January	176 (09)	587	212
	February	61 (16)	158	250
	March	37 (27)	166	228
	April	47 (04)	177	106
Annual			1,569	1,530

Barometric pressure observations were also sourced from the nearby MHL station at Kingscliff to account for any anomalies not adequately explained by catchment runoff. These data are presented in **Figure 4.11**, revealing that many of the remaining significant anomalies, including the previously identified significant events in late-May 2023, late-December 2023 and early-April 2024, were explained by concurrent anomalies in barometric pressure. Generally, and as should be expected, an inverse relationship between barometric pressure and water level anomaly is observable.

The attribution of barometric forcing as a cause for these anomaly events is supported by the correlation between the anomalies at Letitia 2A with those at the baseline oceanic sites, which are subject to these same synoptic-scale conditions.

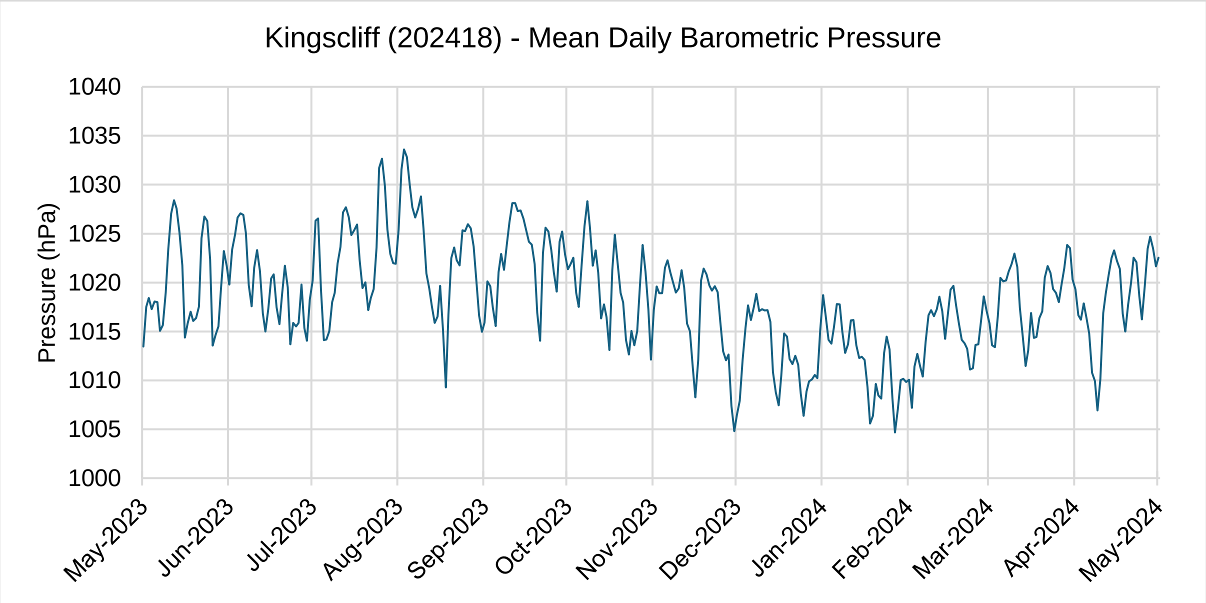

Figure 4.11 Mean daily barometric pressure observed at Kingscliff (202418)

In summary, the significant tidal anomalies recorded at Letitia 2A were found to be due to runoff-driven elevated water levels in the Tweed catchment and/or synoptic-scale barometric 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. No significant changes to the astronomical tidal response were observed, with all parameters remaining largely consistent to those of previous years and compared to the reference oceanic sites.

Please contact Bronson McPherson (bronson.mcpherson@mhl.nsw.gov.au), or Kyle Hasler (kyle.hasler@mhl.nsw.gov.au) should you wish to discuss any aspects of this report.

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