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Dear Tui,

MHL2892 – Tweed Sand Bypass Tidal Analysis 2021/22

MHL is pleased to provide this report for a tidal analysis of the Tweed River entrance for the period March 2021 – April 2022. The study consists of a tidal harmonics analysis for three locations on the Eastern Australia coastline: two in northern NSW and one on the Sunshine Coast in QLD (**Figure 1**). By observing long term trends in tidal response characteristics against two control sites, it can be determined if the entrance dynamics of an estuary are changing over time.

1 Tweed Entrance Behaviour

A tidal harmonic analysis was performed on three tidal measurement datasets: Letitia 2A at the Tweed River entrance, Coffs Harbour Jetty, and Mooloolaba on the Sunshine Coast. This harmonic analysis can be used to, among other things, remove meteorological and flood events from a measured tidal signal, extracting from the noisy measurements only those components which can be described by periodic astronomical forcings. From these components, descriptive characteristics of the tidal signal at the given location can be generated and it is these characteristics which are analysed and compared to gain insight into whether the morphology of an estuary is changing over time.

2 Data

Water level data for Letitia 2A, Coffs Harbour Jetty, Barneys Point, and Tweed Entrance have been collected by automatic water level recorders in northern NSW (see **Table 1**). These stations are part of a larger network of water level stations in New South Wales which MHL manages on behalf of the NSW Department of Planning and Environment - Environment, Energy and Science division (DPE - EES). The Mooloolaba dataset has been collected from Queensland Government Hydraulics Laboratory, Department of Environment and Science. However, MHL provided previous report for a tidal analysis of the Tweed River entrance for the period March 2020 – February 2021 for all stations.

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

Station	Data Interval	Location	Period of Data Analysed	Length of Analysis
Letitia 2A	15 minutes	Northern NSW	May 2020 – April 2022	1 year 11 months
Coffs Harbour Jetty	15 minutes	Northern NSW	Mar 2021 – April 2022	1 year 2months
Mooloolaba	1 minute	Sunshine Coast	Mar 2021 – April 2022	1 year 2months
Barneys Point	15 minutes	Northern NSW	Mar 2021 – April 2022	1 year 2months
Tweed Entrance South	15 minutes	Northern NSW	Mar 2021 – April 2022	1 year 2months

Classification: Release by consent

3 Tidal Analysis Methodology

3.1 Tidal Planes Analysis

Tides are primarily the result of gravitational forces exerted by the moon and the sun in combination with the rotation of the earth. The resultant forces cause the movement of water on the earth's surface in the direction of the force (tides). Analyses of coastal water level records shows 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 astronomical components. Tidal planes in this study were calculated using four major harmonic constituents: M_2, S_2, O_1 and K_1, together with Mean Sea Level, Z_0. Details of 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**. Each tidal constituent is defined by its periods and angular speed, while the phase and amplitude vary for different locations.

Table 2 - Major constituents used in Tidal Plane calculations

Constituent	Origin	Period (hours)	Angular speed (minutes/degrees)
M_2 (semi-diurnal)	Principal lunar	12.42	2.07
S_2 (semi-diurnal)	Principal solar	12.00	2.00
K_1 (diurnal)	Principal lunar/ Principal solar	23.93	3.99
O_1 (diurnal)	Principal lunar	25.82	4.30

Table 3 - Calculation of Tidal Planes from 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 Ranges

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 Tide Predictions and Anomalies

The predicted tide refers to 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 (The Unified Tidal Analysis and Prediction model) software (Codiga, 2011). An important result from the tidal analysis is the tidal anomaly (or residual), determined by the measured signal minus the predicted signal. 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 be some residual tide signal in the anomaly.

Tidal anomalies were calculated using the formula:

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

To determine whether a predicted tide provides a good representation of the observed water level recordthe relative magnitude of the tidal residual can be used. This residual error is expressed in terms of the root mean square (RMS) of the difference between the observed and predicted tides (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

4 Analysis Results

4.1 Tidal Comparison

Figure 2 shows the Mean Water Level behaviour for each of the 3 locations over the preceding 14 months. Mean levels behave consistently between all three sites with Mooloolaba and Letitia behaving nearly identically over the period.

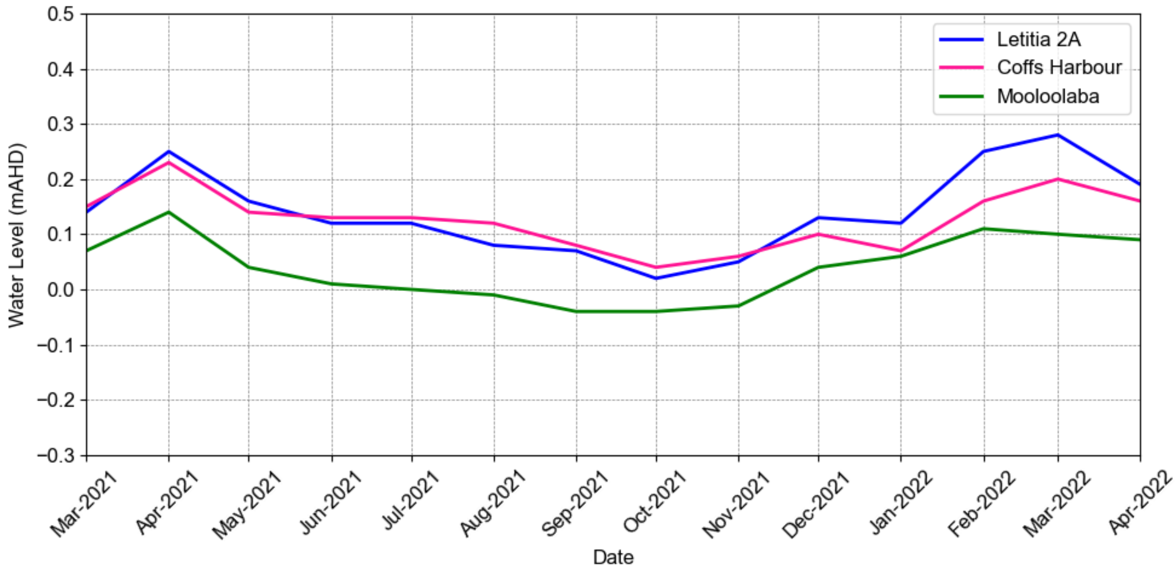

Figure 2 - Mean Water Level Comparison

Figure 3 compares the spring tidal range of the three sites. The spring tidal range is steady across the 14-month period and consistent with the previous year's analysis. **Figure 4** compares the ratio of spring tidal ranges between Letitia 2A, Coffs Harbour and Mooloolaba. This comparison will show any significant changes in the tidal range within the Tweed estuary compared to that in the open ocean. The ratio of spring tide range between sites also remains consistent with last year's analysis.

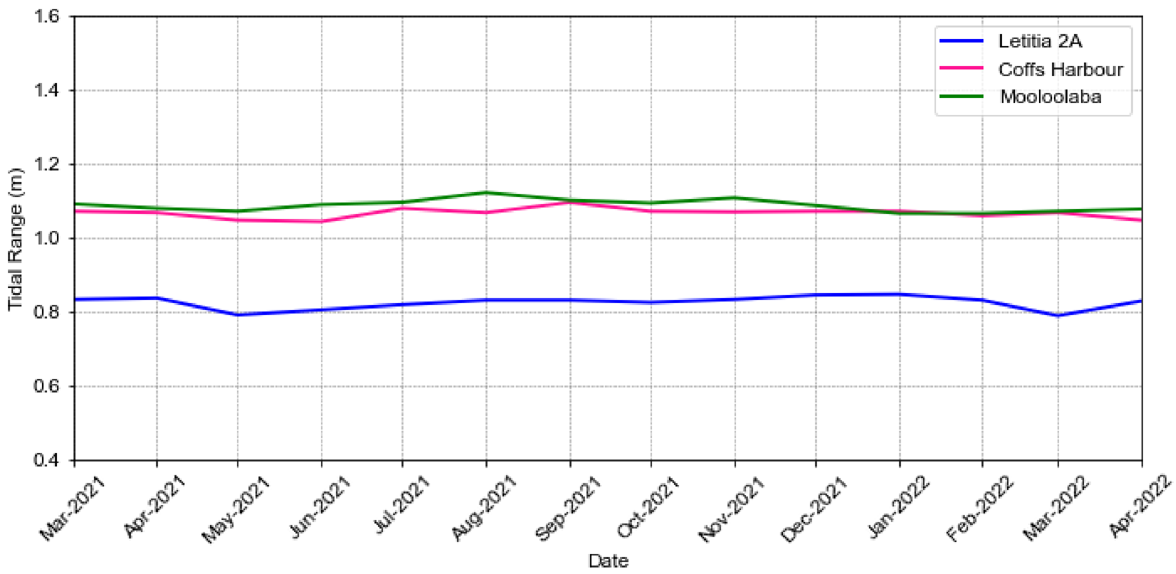

Figure 3 – Spring Tidal Range Comparison

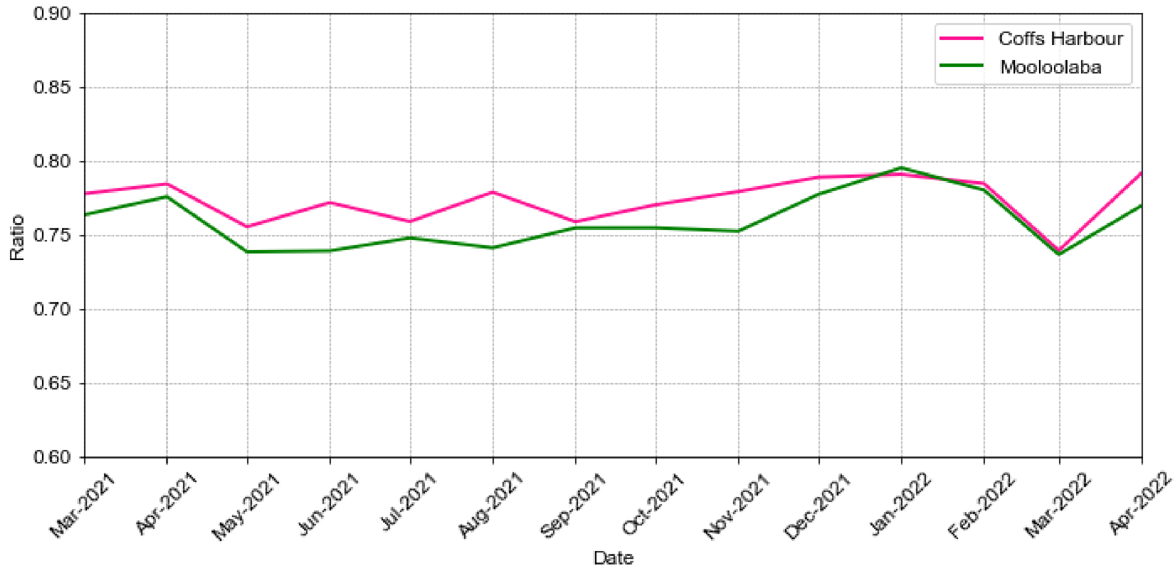

Figure 4 - Spring Tidal Range Ratio Comparison (Letitia 2A to Other Sites)

Figure 5 compares the Mean High Water Springs (MHWS) and Mean Low Water Springs (MLWS) respectively among the three sites. These tidal planes remain consistent with the previous years and are steady over this 14-month analysis period.

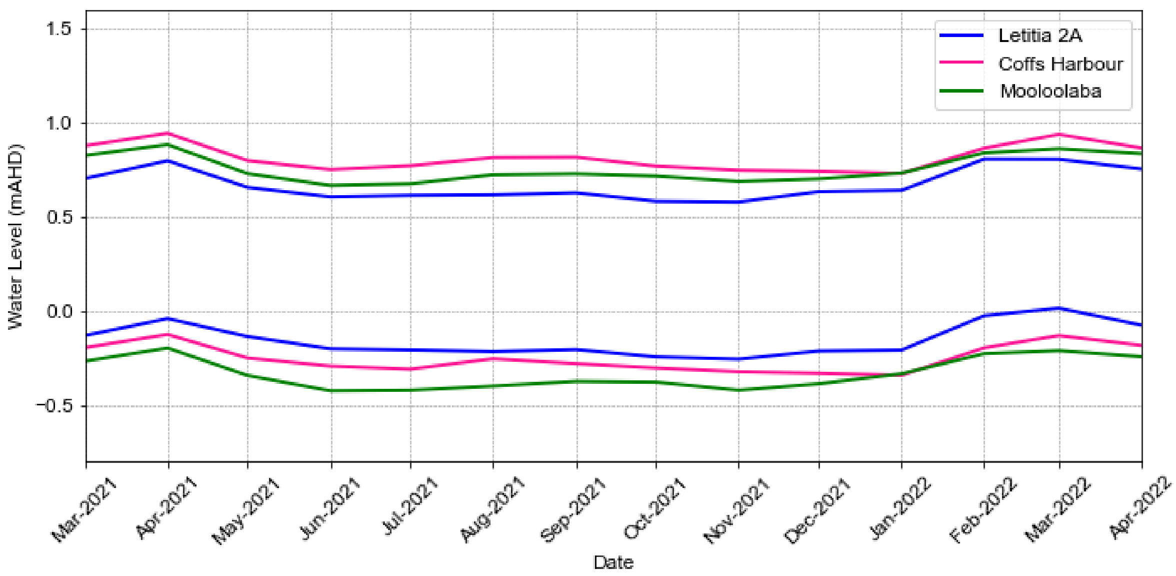

Figure 5 - Spring Tidal Planes Comparison (MHWS and MLWS)

Figure 6 presents the Mean Low Water Springs (MLWS) at Letitia 2A for the period May 2020 to April 2022. The results reveal that the Mean Low Water Springs (MLWS) of Letitia 2A is above -0.6 mAHD over this period of analysis.

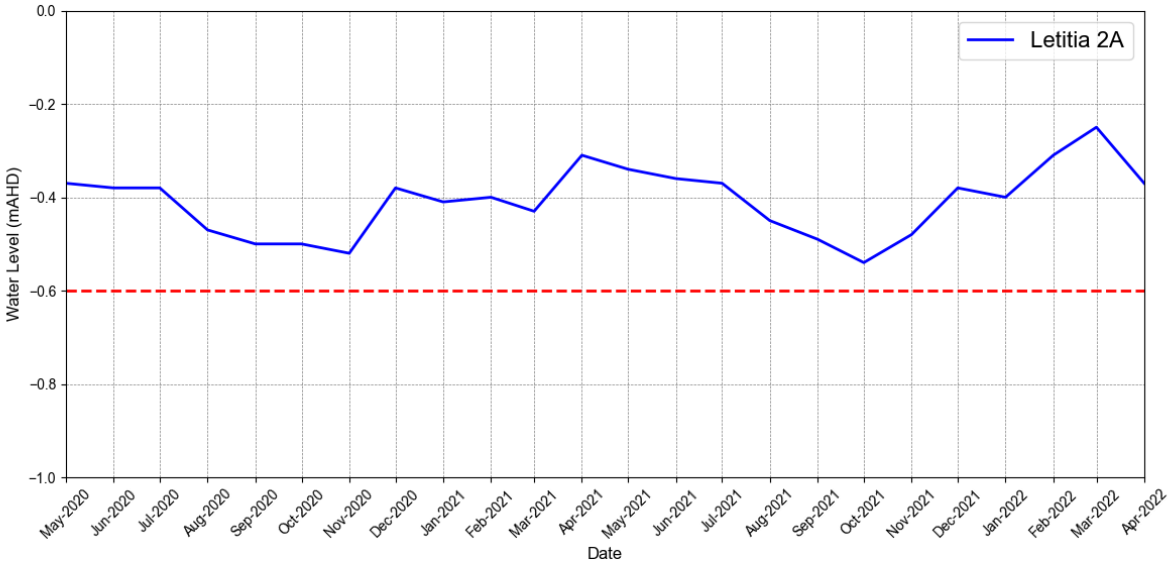

Figure 6 – Letitia 2A Mean Low Water Springs (MLWS)

4.2 Meteorological Effects

Monthly rainfall at Murwillumbah, on the Tweed River, is presented in **Table 5**. Contrasting to last year, this 14-month period was characterised by more rain, with four months exceeding long term values. Around 121% of the long-term rainfall was recorded over this period, with over 30% of that occurring in January and February 2022 which culminated in a large flood on the Tweed River.

Table 5 - Murwillumbah recorded rainfall for the period March-2021 to April 2022 (all values in mm)

	Long Term Average	Monthly Totals	Highest Daily Recording	% Monthly Avg
Mar-21	216.3	361.4	84	167.08%
Apr-21	149.3	154.7	55	103.62%
May-21	127	128.1	51.5	100.87%
Jun-21	105	34.8	18	33.14%
Jul-21	62.8	103.5	48	164.81%
Aug-21	51.8	16	3.5	30.89%
Sep-21	39.7	40.5	30	102.02%
Oct-21	109.6	205.4	34	187.41%
Nov-21	120.3	214.9	76	178.64%
Dec-21	177.6	261.6	93	147.30%
Jan-22	206.6	303.3	45	146.81%
Feb-22	237.2	481.4	169	202.95%

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Mar-22	216.3	162.8	36.1	75.27%
Apr-22	149.3	83.5	16	55.93%
Mean:			54	121.19%
Sum:	1968.8	2551.9		

4.3 Tidal Planes

Table 6 to **Table 19** present a series of monthly tidal plane results for the seven selected sites. The monthly residuals over this period range from a high of 0.19m at Letitia 2A, to a low of 0.04m at Letitia 2A, with a median of 0.08m for Coffs Harbour, 0.07m for Mooloolaba, and 0.08m for Letitia 2A. The impact of a large meteorological event in March/April 2022 is evident at all sites with elevated mean water levels over this period compared to last year. Therefore, most large tidal anomalies recorded at Letitia 2A were due to floods or regional meteorologic events and unrelated to changes in entrance dynamics.

Key:

- **HHWS** - Highest High Water Springs
- **MHWS** - Mean High Water Springs
- **MHWN** - Mean High Water Neaps
- **MWL** - Mean Water Level
- **MLWN** - Mean Low Water Neap
- **MLWS** - Mean Low Water Springs
- **LLWS** - Lowest Low Water Springs
- **MSTR -** Mean Spring Tidal Range
- **MNTR** - Mean Neap Tidal Range
- **Residual** - Root Mean Square Residual

Table 6– Tidal planes and ranges for March 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.090	0.890	1.046	0.914	0.882	0.879	0.947
MHWS	0.878	0.704	0.826	0.728	0.713	0.717	0.762
MHWN	0.496	0.402	0.400	0.407	0.458	0.479	0.414
MWL	0.151	0.136	0.067	0.130	0.232	0.267	0.121
MLWN	-0.576	-0.432	-0.692	-0.469	-0.250	-0.183	-0.520
MLWS	-0.194	-0.130	-0.266	-0.148	0.005	0.055	-0.172
LLWS	-0.788	-0.618	-0.912	-0.655	-0.419	-0.345	-0.705
MSTR	1.454	1.136	1.518	1.197	0.964	0.900	1.282
MNTR	0.690	0.532	0.666	0.555	0.453	0.424	0.586
Residual	0.097	0.113	0.075	NA	NA	NA	NA

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Table 7 - Tidal planes and ranges for April 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.156	1.004	1.129	1.022	0.992	0.988	1.047
MHWS	0.944	0.798	0.884	0.818	0.797	0.796	0.845
MHWN	0.592	0.530	0.480	0.527	0.572	0.588	0.523
MWL	0.234	0.245	0.142	0.231	0.315	0.341	0.212
MLWN	-0.476	-0.308	-0.600	-0.355	-0.166	-0.114	-0.421
MLWS	-0.124	-0.040	-0.196	-0.065	0.058	0.094	-0.099
LLWS	-0.688	-0.514	-0.845	-0.560	-0.362	-0.306	-0.623
MSTR	1.420	1.106	1.484	1.173	0.963	0.910	1.266
MNTR	0.716	0.570	0.676	0.592	0.515	0.494	0.622
Residual	0.091	0.108	0.119	NA	NA	NA	NA

Table 8 - Tidal planes and ranges for May 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.054	0.900	1.016	0.916	0.875	0.866	0.937
MHWS	0.799	0.657	0.730	0.671	0.640	0.634	0.691
MHWN	0.527	0.457	0.420	0.454	0.474	0.480	0.449
MWL	0.139	0.161	0.039	0.139	0.201	0.216	0.109
MLWN	-0.521	-0.335	-0.652	-0.393	-0.238	-0.202	-0.473
MLWS	-0.249	-0.135	-0.342	-0.175	-0.071	-0.048	-0.231
LLWS	-0.776	-0.578	-0.938	-0.637	-0.473	-0.434	-0.719
MSTR	1.320	0.992	1.382	1.064	0.878	0.836	1.164
MNTR	0.776	0.592	0.762	0.629	0.545	0.528	0.680
Residual	0.083	0.065	0.048	NA	NA	NA	NA

Table 9 - Tidal planes and ranges for June 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.047	0.875	0.984	0.891	0.839	0.825	0.912
MHWS	0.752	0.606	0.667	0.621	0.578	0.568	0.641
MHWN	0.552	0.448	0.439	0.449	0.454	0.456	0.451
MWL	0.130	0.124	0.008	0.105	0.161	0.174	0.078
MLWN	-0.492	-0.358	-0.651	-0.411	-0.257	-0.220	-0.485
MLWS	-0.292	-0.200	-0.423	-0.240	-0.133	-0.108	-0.295
LLWS	-0.787	-0.627	-0.968	-0.681	-0.518	-0.477	-0.756
MSTR	1.244	0.964	1.318	1.032	0.836	0.788	1.126
MNTR	0.844	0.648	0.862	0.689	0.587	0.564	0.746
Residual	0.082	0.080	0.079	NA	NA	NA	NA

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Table 10 - Tidal planes and ranges for July 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.064	0.884	0.999	0.905	0.848	0.835	0.935
MHWS	0.772	0.614	0.676	0.635	0.588	0.579	0.664
MHWN	0.558	0.450	0.430	0.454	0.457	0.459	0.460
MWL	0.125	0.122	0.005	0.106	0.160	0.174	0.085
MLWN	-0.522	-0.370	-0.666	-0.422	-0.269	-0.231	-0.494
MLWS	-0.308	-0.206	-0.420	-0.241	-0.137	-0.111	-0.290
LLWS	-0.814	-0.640	-0.989	-0.693	-0.528	-0.487	-0.765
MSTR	1.294	0.984	1.342	1.057	0.857	0.810	1.158
MNTR	0.866	0.656	0.850	0.695	0.593	0.570	0.750
Residual	0.085	0.066	0.045	NA	NA	NA	NA

Table 11 - Tidal planes and ranges for August 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.078	0.866	1.011	0.895	0.827	0.813	0.934
MHWS	0.815	0.617	0.724	0.646	0.588	0.577	0.686
MHWN	0.501	0.383	0.374	0.388	0.401	0.407	0.396
MWL	0.124	0.084	-0.012	0.072	0.131	0.149	0.056
MLWN	-0.567	-0.449	-0.748	-0.502	-0.325	-0.279	-0.574
MLWS	-0.253	-0.215	-0.398	-0.244	-0.138	-0.109	-0.284
LLWS	-0.830	-0.698	-1.035	-0.750	-0.564	-0.515	-0.822
MSTR	1.382	1.066	1.472	1.147	0.913	0.856	1.260
MNTR	0.754	0.598	0.772	0.632	0.538	0.516	0.680
Residual	0.080	0.074	0.060	NA	NA	NA	NA

Table 12 - Tidal planes and ranges for September 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.045	0.835	0.968	0.864	0.792	0.776	0.905
MHWS	0.817	0.628	0.729	0.657	0.593	0.580	0.698
MHWN	0.431	0.338	0.301	0.340	0.360	0.368	0.342
MWL	0.076	0.067	-0.036	0.055	0.119	0.138	0.038
MLWN	-0.665	-0.494	-0.801	-0.548	-0.355	-0.304	-0.622
MLWS	-0.279	-0.204	-0.373	-0.230	-0.122	-0.092	-0.266
LLWS	-0.893	-0.701	-1.040	-0.755	-0.554	-0.500	-0.829
MSTR	1.482	1.122	1.530	1.205	0.948	0.884	1.320
MNTR	0.710	0.542	0.674	0.570	0.482	0.460	0.608
Residual	0.061	0.058	0.057	NA	NA	NA	NA

Table 13 - Tidal planes and ranges for October 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.005	0.799	0.969	0.831	0.756	0.740	0.875
MHWS	0.770	0.583	0.717	0.615	0.549	0.537	0.659
MHWN	0.388	0.285	0.293	0.291	0.314	0.325	0.299
MWL	0.043	0.021	-0.042	0.013	0.079	0.101	0.003
MLWN	-0.684	-0.541	-0.801	-0.588	-0.391	-0.335	-0.653
MLWS	-0.302	-0.243	-0.377	-0.264	-0.155	-0.123	-0.293
LLWS	-0.919	-0.757	-1.053	-0.804	-0.597	-0.538	-0.869
MSTR	1.454	1.124	1.518	1.203	0.940	0.872	1.312
MNTR	0.690	0.528	0.670	0.555	0.470	0.448	0.592
Residual	0.060	0.043	0.060	NA	NA	NA	NA

Table 14 - Tidal planes and ranges for November 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.027	0.832	0.983	0.863	0.798	0.785	0.905
MHWS	0.748	0.579	0.688	0.609	0.559	0.551	0.650
MHWN	0.442	0.351	0.352	0.359	0.379	0.389	0.370
MWL	0.060	0.048	-0.034	0.040	0.110	0.133	0.030
MLWN	-0.628	-0.483	-0.756	-0.528	-0.338	-0.285	-0.590
MLWS	-0.322	-0.255	-0.420	-0.278	-0.159	-0.123	-0.310
LLWS	-0.907	-0.736	-1.051	-0.782	-0.578	-0.519	-0.845
MSTR	1.376	1.062	1.444	1.137	0.897	0.836	1.240
MNTR	0.764	0.606	0.772	0.637	0.537	0.512	0.680
Residual	0.049	0.041	0.055	NA	NA	NA	NA

Table 15 - Tidal planes and ranges for December 2021

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.052	0.912	1.028	0.923	0.859	0.840	0.937
MHWS	0.742	0.634	0.702	0.645	0.595	0.581	0.659
MHWN	0.534	0.468	0.474	0.466	0.473	0.475	0.463
MWL	0.102	0.128	0.044	0.110	0.170	0.185	0.086
MLWN	-0.538	-0.378	-0.614	-0.424	-0.256	-0.211	-0.487
MLWS	-0.330	-0.212	-0.386	-0.245	-0.134	-0.105	-0.291
LLWS	-0.848	-0.656	-0.940	-0.702	-0.520	-0.470	-0.765
MSTR	1.280	1.012	1.316	1.068	0.851	0.792	1.146
MNTR	0.864	0.680	0.860	0.711	0.607	0.580	0.754
Residual	0.066	0.066	0.088	NA	NA	NA	NA

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Table 16 - Tidal planes and ranges for January 2022

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.032	0.916	1.052	0.916	0.864	0.845	0.917
MHWS	0.731	0.641	0.733	0.643	0.608	0.596	0.646
MHWN	0.481	0.453	0.461	0.440	0.460	0.462	0.422
MWL	0.070	0.123	0.064	0.105	0.175	0.194	0.079
MLWN	-0.591	-0.395	-0.605	-0.434	-0.258	-0.208	-0.488
MLWS	-0.341	-0.207	-0.333	-0.231	-0.110	-0.074	-0.264
LLWS	-0.892	-0.670	-0.924	-0.707	-0.515	-0.457	-0.759
MSTR	1.322	1.036	1.338	1.077	0.867	0.804	1.134
MNTR	0.822	0.660	0.794	0.671	0.569	0.536	0.686
Residual	0.087	0.111	0.103	NA	NA	NA	NA

Table 17 - Tidal planes and ranges for February 2022

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.127	1.024	1.114	1.032	1.006	0.999	1.042
MHWS	0.865	0.807	0.840	0.810	0.821	0.826	0.815
MHWN	0.509	0.521	0.444	0.510	0.579	0.600	0.495
MWL	0.157	0.248	0.109	0.224	0.352	0.391	0.190
MLWN	-0.551	-0.311	-0.622	-0.363	-0.116	-0.044	-0.435
MLWS	-0.195	-0.025	-0.226	-0.063	0.126	0.182	-0.115
LLWS	-0.813	-0.528	-0.896	-0.584	-0.301	-0.217	-0.662
MSTR	1.416	1.118	1.462	1.173	0.937	0.870	1.250
MNTR	0.704	0.546	0.670	0.573	0.453	0.418	0.610
Residual	0.071	0.176	0.126	NA	NA	NA	NA

Table 18 - Tidal planes and ranges for March 2022

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.159	1.024	1.100	1.048	1.047	1.055	1.081
MHWS	0.938	0.806	0.862	0.830	0.831	0.840	0.863
MHWN	0.534	0.536	0.416	0.523	0.628	0.662	0.505
MWL	0.202	0.276	0.103	0.250	0.391	0.433	0.214
MLWN	-0.534	-0.254	-0.656	-0.330	-0.050	0.026	-0.435
MLWS	-0.130	0.016	-0.210	-0.023	0.153	0.204	-0.077
LLWS	-0.755	-0.472	-0.894	-0.548	-0.265	-0.189	-0.653
MSTR	1.472	1.060	1.518	1.160	0.880	0.814	1.298
MNTR	0.664	0.520	0.626	0.546	0.475	0.458	0.582
Residual	0.066	0.188	0.085	NA	NA	NA	NA

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Table 19 - Tidal planes and ranges for April 2022

	Coffs Harbour	Letitia 2A	Mooloolaba	Kerosene Inlet	Tony's Island	Barneys Point	Tweed Entrance South
HHWS	1.095	0.976	1.086	0.993	0.953	0.944	1.017
MHWS	0.866	0.755	0.836	0.772	0.734	0.726	0.795
MHWN	0.496	0.463	0.418	0.459	0.483	0.490	0.453
MWL	0.157	0.194	0.088	0.181	0.230	0.243	0.163
MLWN	-0.552	-0.367	-0.660	-0.410	-0.274	-0.240	-0.469
MLWS	-0.182	-0.075	-0.242	-0.097	-0.023	-0.004	-0.127
LLWS	-0.781	-0.588	-0.910	-0.631	-0.493	-0.458	-0.691
MSTR	1.418	1.122	1.496	1.182	1.008	0.966	1.264
MNTR	0.678	0.538	0.660	0.556	0.506	0.494	0.580
Residual	0.092	0.091	0.074	NA	NA	NA	NA

5 Tidal Anomalies

Figure 7 to **Figure 11** present the predicted and recorded levels at Letitia 2A, Coffs Harbour, and Mooloolaba. 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 (anomaly). The most significant event was a large flood in February/March 2022 which elevated levels on the Tweed River, causing a significant positive anomaly at Letitia 2A for a period of weeks. Other notable events include prolonged elevated water levels in April 2021 and January 2022 driven by low-pressure systems along the coast; as well as a shorter but more pronounced event in June 2022. In addition, the impact of the eruption of the Hunga Tonga-Hunga Ha'apai Volcano in January 2022 is evident at all sites with long-period waves impacting the coast for several weeks.

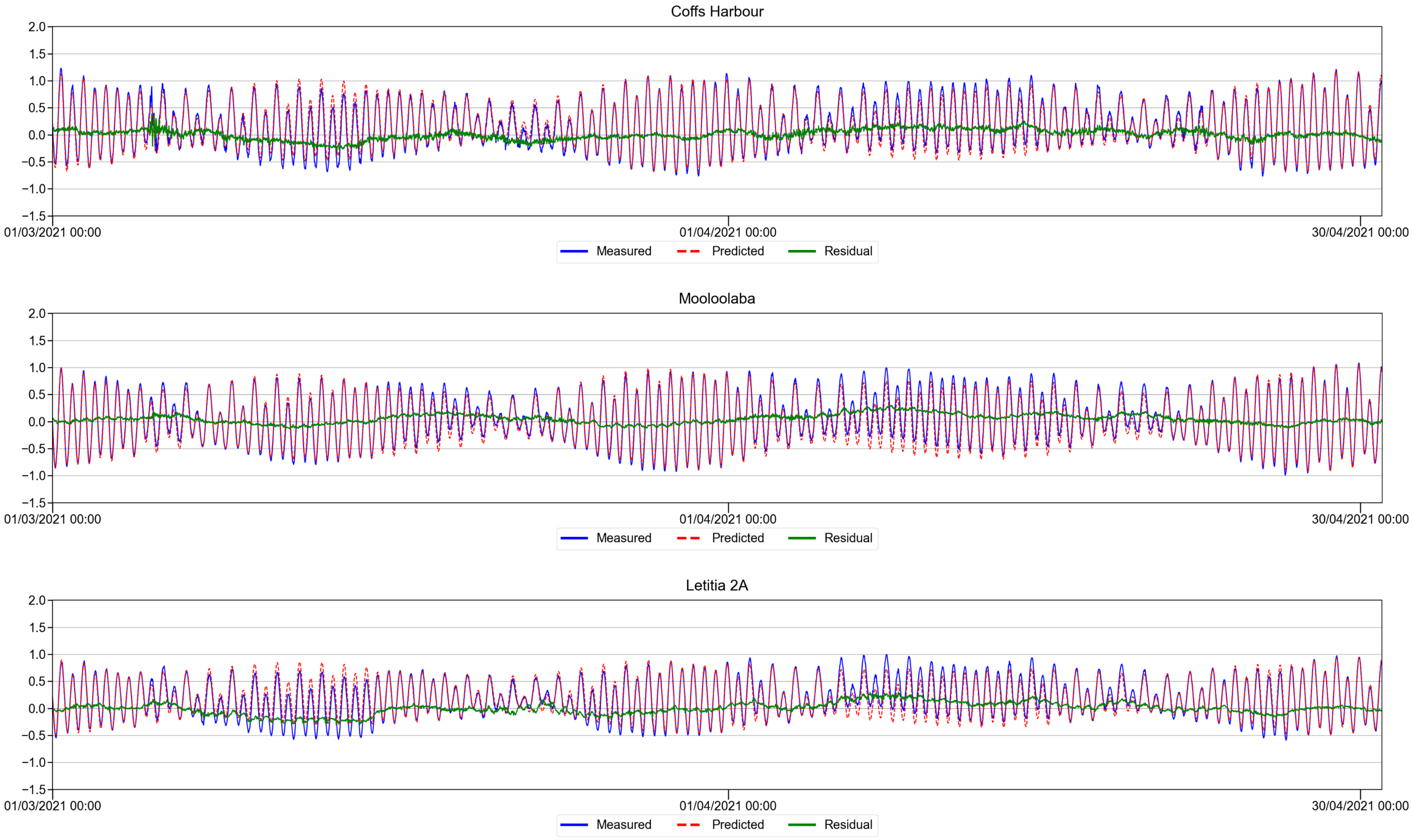

Figure 7 -March 2021 to April 2021 Water Levels

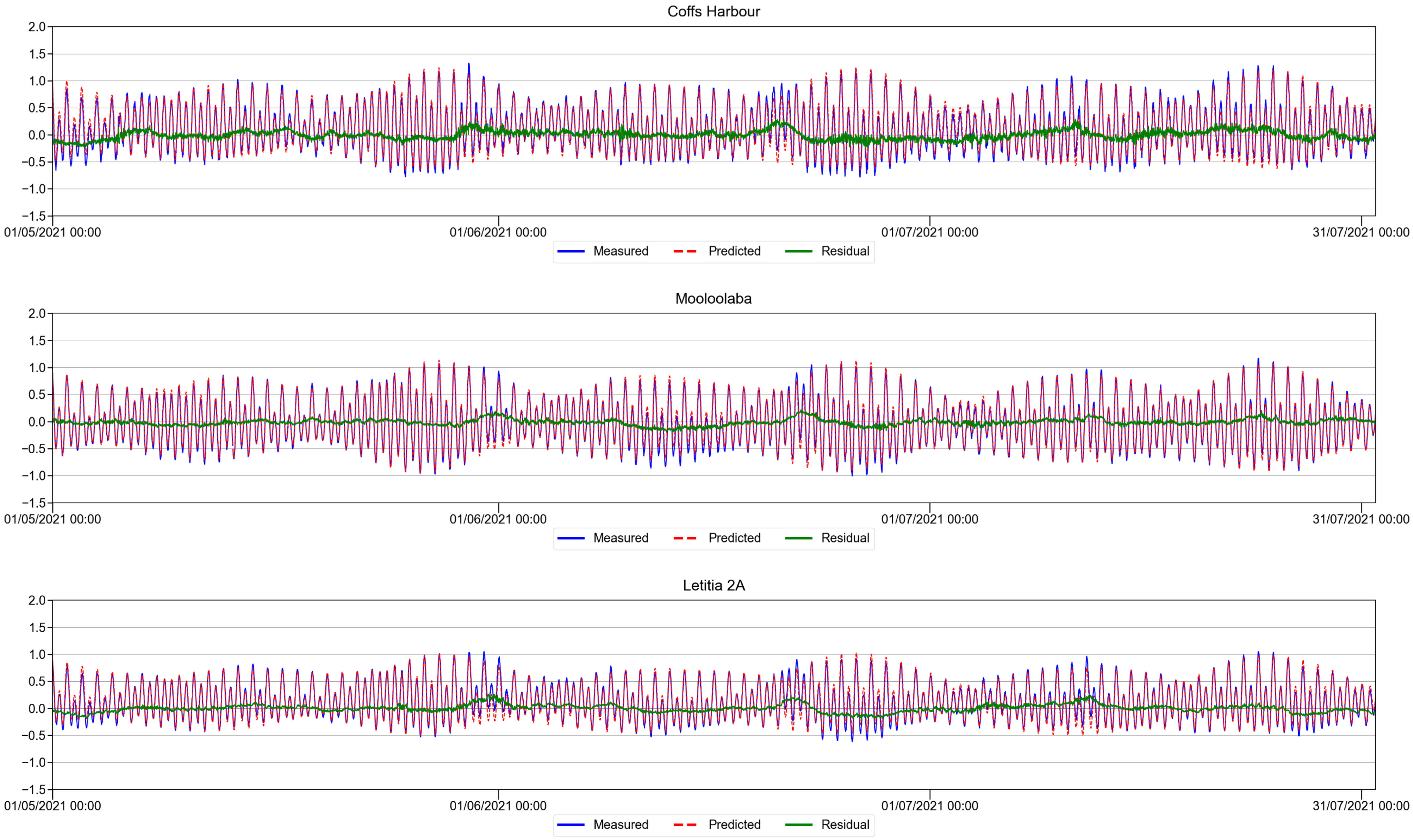

Figure 8 - May 2021 to July 2021 Water Levels

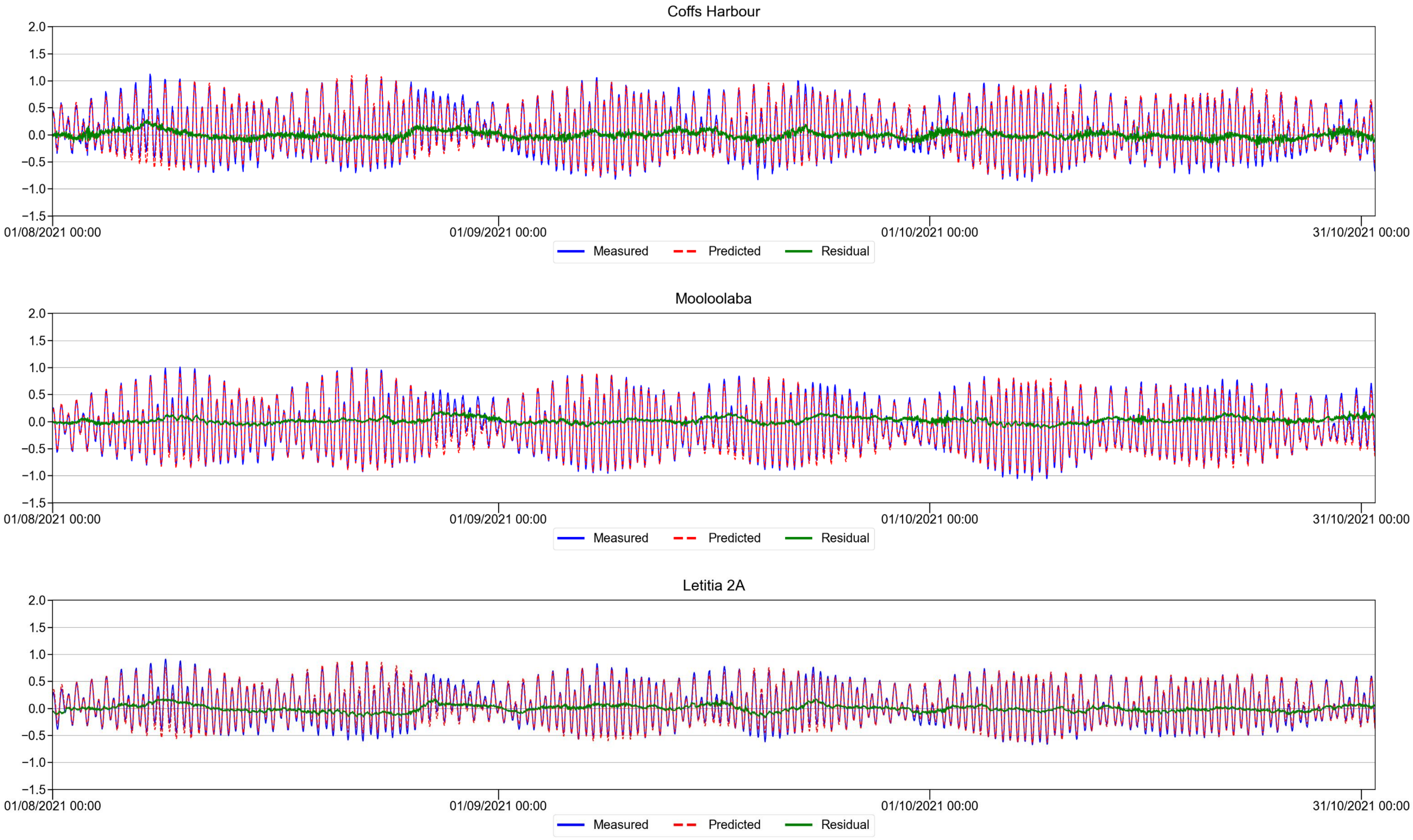

Figure 9 - August 2021 to October 2021 Water Levels

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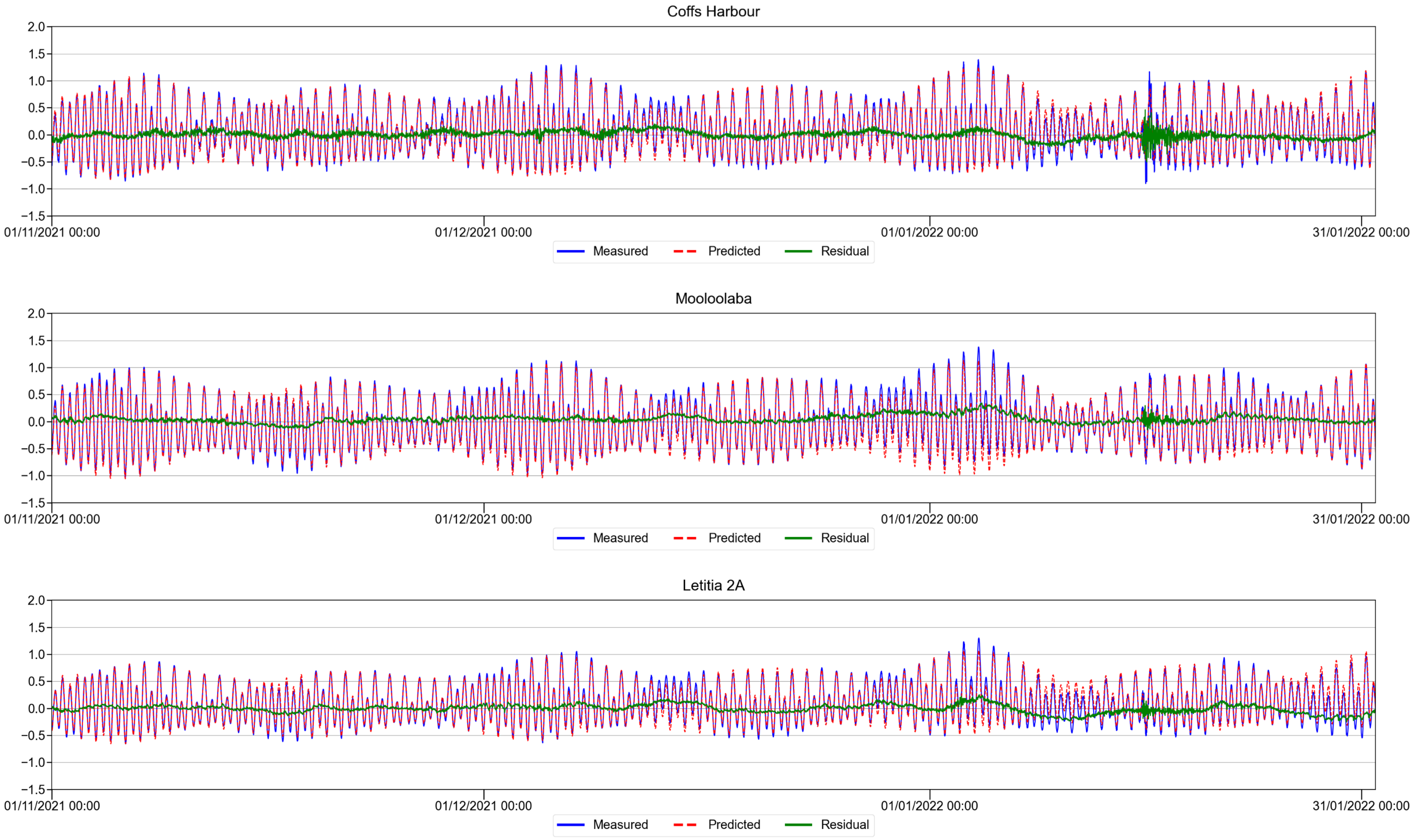

Figure 10 - November 2021 to January 2022 Water Levels

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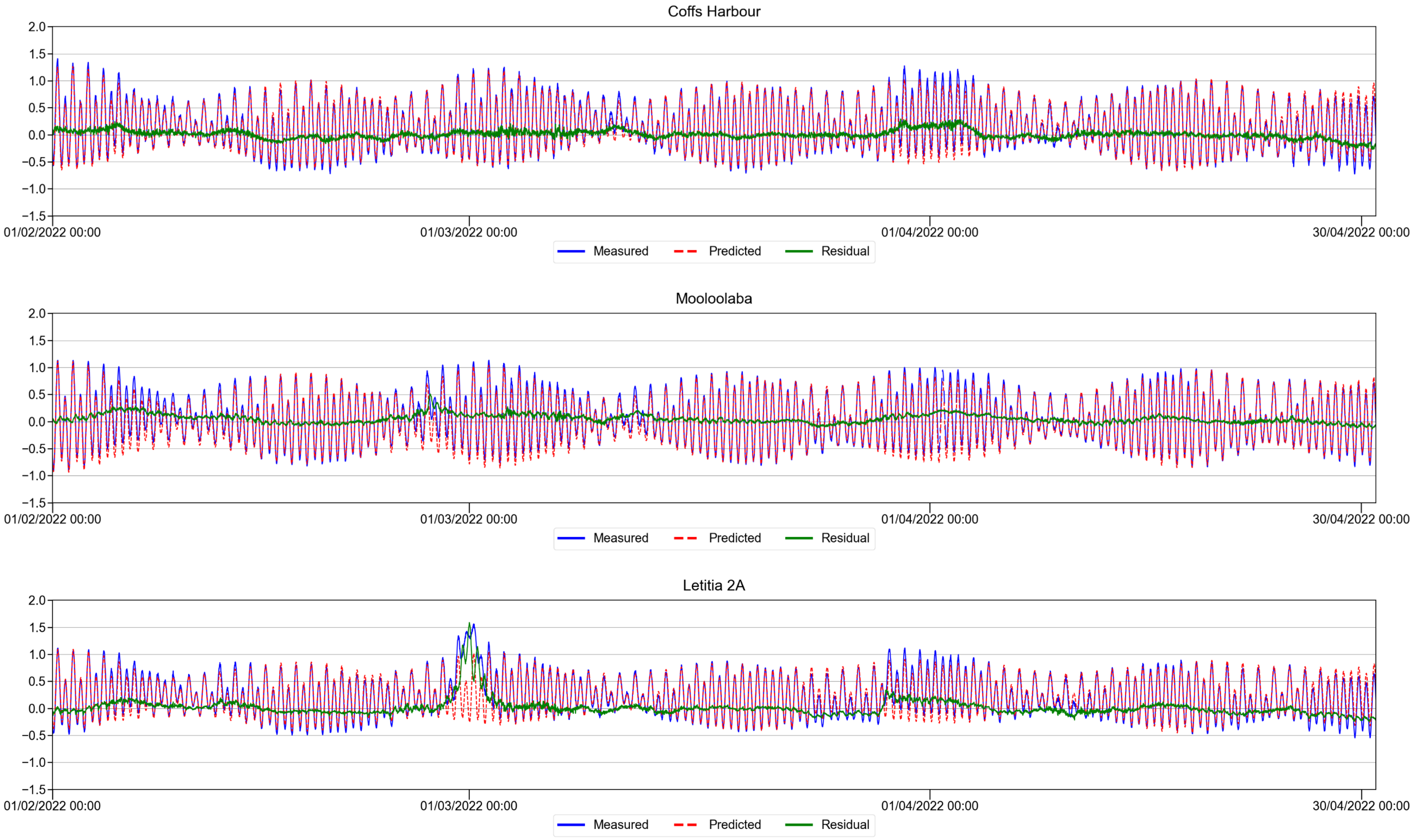

Figure 11 - February 2022 to April 2022 Water Levels

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6 Conclusions

Based on the analysis presented above it is unlikely that the Tweed entrance has experienced any significant morphological changes in the preceeding 12-months which would manifest in changes to the astronomical tidal response.

Should you require further information please contact **Bronson McPherson** on (02) 9949 0244 or by email at Bronson.Mcpherson@mhl.nsw.gov.au

Yours sincerely

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7 References

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