Mean High Water and Range Ratio Transfer

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ABSTRACT

The use of the range ratio method of transferring a level for Mean High Water (MHW) from a long-running tide gauge to a remote survey site was described in the Determination of Mean High Water Mark section at the back of the Manual of the New South Wales Integrated Survey Grid published by the Department of Lands in 1976. The manual claimed that a fairly accurate value for MHW could be obtained from a single-day observation of consecutive high and low water levels during a period of spring tides. The manual did not elaborate as to what the quantum was for fairly accurate nor why only spring tide periods. This paper looks at the numbers obtained by a series of MHW transfers using the range ratio method from various long-running tide gauges to see what "fairly accurate" is and if observations are limited to only spring tide periods. It also considers whether or not range ratio outcomes would satisfy the requirements of the surveying regulations in establishing tidal cadastral boundaries and the relationships of land tenure to the level of Mean High Water.

KEYWORDS: *Mean High Water, tide gauges, range ratio, accuracy, tidal cadastral boundary.*

1 INTRODUCTION

In many situations along a tidal foreshore where the bank is relatively steep or vertical, the location of the intercept of the Mean High Water (MHW) tidal plane with the land is a relatively easy process. In some ways, knowing the level of MHW is not necessary, as any tolerance or range that such a value might have will make very little if no difference to the position of the land boundary. It is only when the surveyor needs a level of MHW, for either fixing the tidal land boundary across a relatively flat foreshore or relating structures vertically in a strata type situation, that fairly accurate measurements are required.

With the introduction of a network of tide gauges throughout the coastal estuaries of NSW, surveyors have traditionally turned to the tidal gradients that could be interpolated from the tide gauge network. However, the tide gauge network only covered the main part of a waterway, so that if a MHW level were needed on a stream where there were no gauges, there had to be another way of obtaining the desired level.

From the examination of nine tidal estuaries along the coast of NSW, the shape and gradient of the MHW tidal gradient within an estuary varies from estuary to estuary and from place to place within an estuary. The logical assumption would be that similar would occur along minor branches. It could not be assumed that the MHW at the mouth of the minor stream would be the same at the top end. The establishment of extra tide gauges along the secondary stream would be one way of determining the sought-after tidal profile, but that takes time, inviably too much time. Thus the continuing need for the use of range ratio to transfer MHW from a long-term tide gauge to the desired location.

The range ratio process of transferring MHW was detailed in the Manual of the NSW Integrated Survey Grid (ISG), published by the Department of Lands in 1976 (Lands, 1976). A section was appended at the back of the manual and headed "Determination of Mean High Water Mark". According to the manual, there needed to exist an automatic tide recorder from which long-term values of the various tidal planes could be extracted. What the surveyor needed to do was to observe on one day, during a period of spring tides, consecutive high and low water levels at the survey site. The corresponding values for the same tides from the tide gauge were also needed. By applying the supplied formula, the surveyor could expect to obtain a fairly accurate value for MHW at the survey site.

The manual, however, did not qualify any claims that it made. There was no quantum for what accurate was, neither was any reason given as to why observations could only be done during spring tide periods. The only proviso given was that the observations should not be made during abnormal weather conditions or floods.

By undertaking a series of range ratio transfer exercises between long-running automatic tide gauges, it is hoped that an additional understanding of the range ratio process can be made. The aim of the exercise is to find out what the quantum of accuracy is, if it can be improved by undertaking additional measurements, what quantity of measurements and whether or not only spring tides can be used. From the results of the exercise, this paper also examines the outcomes against the requirements of the surveying regulations to see how well they comply with what surveyors should adhere to.

2 THE RANGE RATIO FORMULA

The range ratio formula can be found in the ISG manual (Lands, 1976). Figure 1 shows an excerpt from the manual, which states the formula to compute MHW and its parameters, along with providing a visual explanation of the parameters. The only qualification needed is that the Mean Tide Level (MTL) value $M.T.L._0$ equates to Mean Sea Level (MSL).

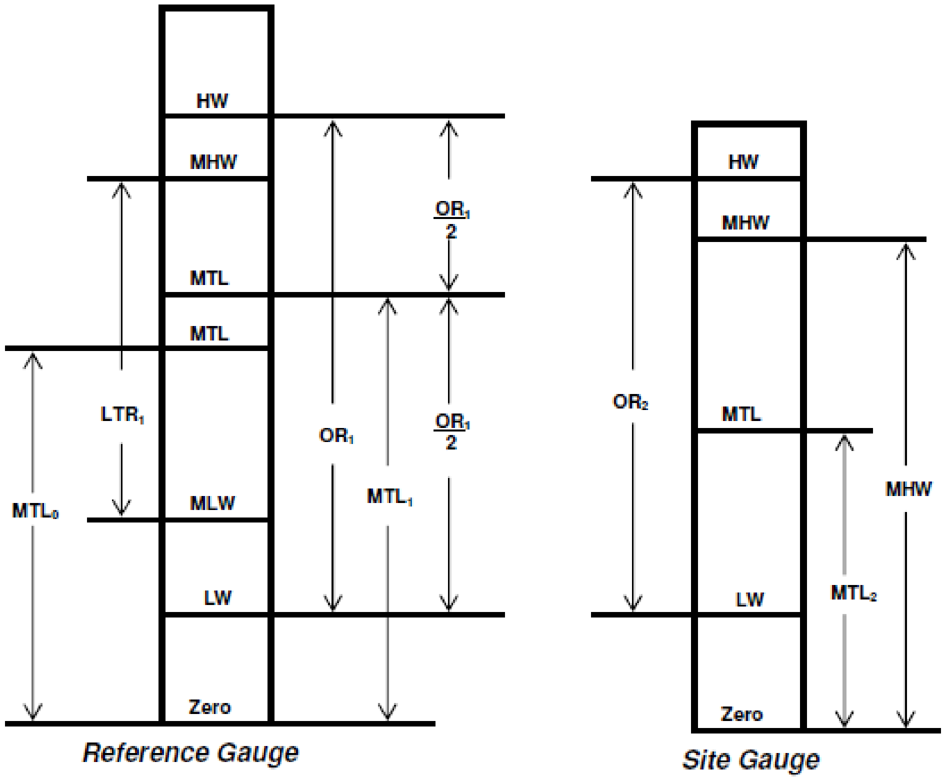

FIGURE 19 – MEAN HIGH WATER MARK BY RANGE RATIO

Approx. M.H.W. $= M.T.L._2 + K_1 + K_2$

where $K_1 = M.T.L._0 - M.T.L._1$

$$K_2 = \frac{L.T.R. \times O.R._2}{2 \times O.R._1}$$

$M.T.L._2$	=	Mean of observed high water and low water at site gauge (M.T.L. is Mean Tide Level)
$M.T.L._0$	=	Long-term value on the gauge of mean tide level at automatic gauge. (See schedule, para 22.4).
$M.T.L._1$	=	Mean of observed high water and low water at automatic gauge. (Obtainable from controlling authority).
L.T.R.	=	Difference between Mean high water and Mean low water at automatic gauge. (Mean Range-See schedule para 22.4).
$O.R._2$	=	Observed range at site gauge.
$O.R._1$	=	Observed range at automatic gauge. (Obtainable from controlling authority).

Figure 1: MHW calculation via the range ratio method (Lands, 1976).

3 THE DATA

Normally the surveyor would have their own tide data for the survey site, that is the site gauge or station 2. Such a process for this exercise was not practical, nor possible. The Clarence River was chosen as the test site and the tide gauges along the Clarence (Figure 2) used as either the reference gauge or the site gauge.

Figure 2: Clarence River tide gauges (map sourced from MHL website).

From the Manly Hydraulics Laboratory (MHL) website (https://www.mhl.nsw.gov.au/), all the necessary data can be extracted, copied, utilised and displayed under a Creative Commons Attribution 4 Licence, with appropriate attribution to, at the time of writing, the Department of Climate Change, Energy, the Environment, and Water – Biodiversity and Conservation, which is hereby duly acknowledged.

The tide gauge data correlating to the surveyed observations for a range ratio exercise can be downloaded from the Latest Values section of the tide gauges site page (Figure 3) via the Water Level menu of the website. The quantity of data covers at least four days in either 15- or 1-minute increments. Multiple downloads will need to be carried out, then combined, if the survey tide observation period is a longer duration.

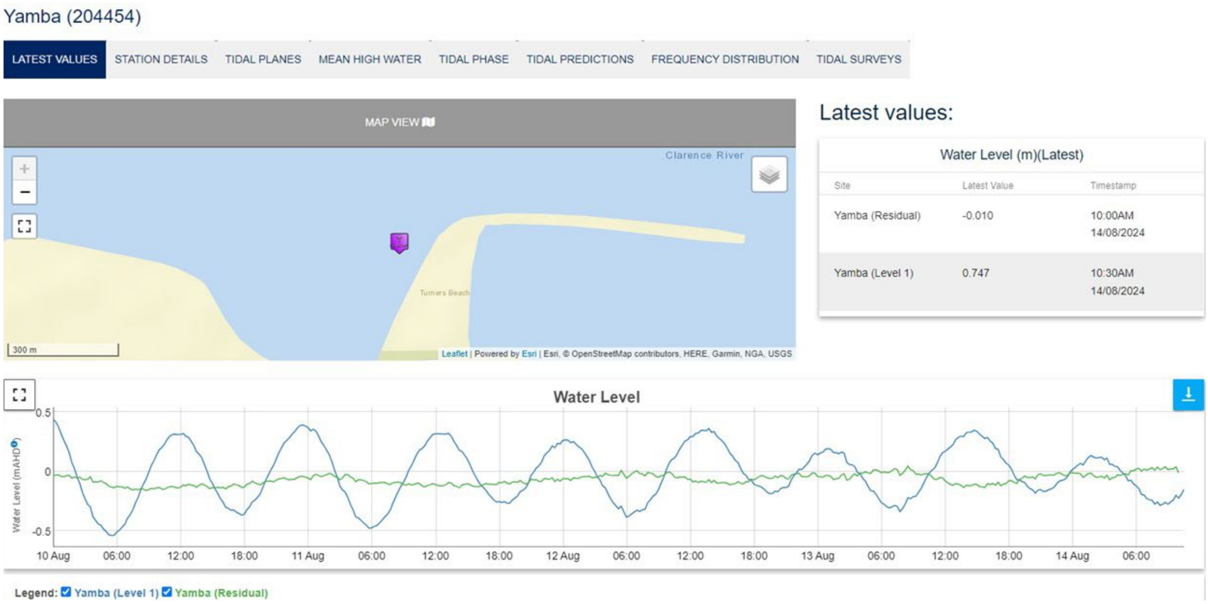

Figure 3: Latest values page, MHL website, tide gauge data download for Yamba.

The values for MHW, MSL and Mean Low Water (MLW) can be obtained from the tidal planes tables (Figure 4) for the tide gauges. Before a range ratio survey can be conducted, there are still a few details that need to be considered.

Yamba (204454)

LATEST VALUES | STATION DETAILS | TIDAL PLANES | MEAN HIGH WATER | TIDAL PHASE | TIDAL PREDICTIONS | FREQUENCY DISTRIBUTION | TIDAL SURV

Table

RECORDING STATION:	Clarence River at Yamba	ZONE:	56
DATUM:	AUSTRALIAN HEIGHT DATUM	EASTING:	535118
AWRC #:	204454	NORTHING:	6744433

YEAR	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	Annual Average	Std Deviation (+/-)
TIDAL PLANES	AMPLITUDE (metres)																				
HHWSS	1.022	0.974	0.964	0.998	1.039	0.995	1.011	1.015	1.034	1.050	1.027	1.023	1.007	1.001	0.977	1.006	1.001	0.971	0.984	1.005	0.024
MHWS	0.699	0.640	0.625	0.639	0.668	0.601	0.613	0.607	0.618	0.647	0.632	0.653	0.660	0.686	0.674	0.709	0.705	0.667	0.675	0.654	0.033
MHW	0.567	0.507	0.491	0.502	0.525	0.466	0.482	0.477	0.486	0.520	0.502	0.524	0.527	0.553	0.544	0.579	0.574	0.537	0.546	0.522	0.034
MHWN	0.435	0.373	0.356	0.364	0.382	0.330	0.351	0.348	0.354	0.393	0.373	0.395	0.395	0.421	0.414	0.449	0.443	0.406	0.417	0.389	0.035
MSL	0.083	0.015	0.008	0.023	0.042	0.006	0.038	0.038	0.040	0.081	0.061	0.073	0.056	0.079	0.063	0.100	0.093	0.048	0.061	0.053	0.028
MLWN	-0.269	-0.343	-0.341	-0.319	-0.297	-0.317	-0.275	-0.272	-0.274	-0.230	-0.251	-0.249	-0.282	-0.263	-0.287	-0.250	-0.258	-0.309	-0.295	-0.283	0.032
MLW	-0.401	-0.477	-0.475	-0.456	-0.441	-0.453	-0.407	-0.401	-0.406	-0.357	-0.380	-0.378	-0.414	-0.395	-0.417	-0.380	-0.389	-0.440	-0.424	-0.415	0.034
MLWS	-0.533	-0.610	-0.610	-0.593	-0.584	-0.588	-0.538	-0.530	-0.538	-0.485	-0.510	-0.507	-0.547	-0.528	-0.547	-0.509	-0.519	-0.571	-0.553	-0.547	0.036
ISLW	-0.763	-0.848	-0.852	-0.850	-0.848	-0.869	-0.822	-0.822	-0.835	-0.772	-0.792	-0.770	-0.795	-0.753	-0.763	-0.722	-0.731	-0.787	-0.773	-0.798	0.044
TIDAL PLANE RANGES	AMPLITUDE (metres)																				
MNR	0.704	0.716	0.696	0.683	0.680	0.648	0.626	0.620	0.628	0.623	0.624	0.644	0.677	0.684	0.701	0.700	0.701	0.715	0.712	0.673	0.035
MR	0.967	0.983	0.966	0.958	0.966	0.918	0.888	0.878	0.892	0.877	0.883	0.902	0.942	0.949	0.961	0.959	0.963	0.976	0.970	0.937	0.038
MSR	1.231	1.250	1.235	1.232	1.252	1.189	1.151	1.137	1.157	1.132	1.141	1.160	1.207	1.214	1.221	1.218	1.225	1.238	1.229	1.201	0.041
R	1.785	1.822	1.816	1.849	1.887	1.864	1.833	1.837	1.869	1.822	1.818	1.793	1.802	1.753	1.740	1.728	1.731	1.758	1.757	1.803	0.048
TIDAL CONSTITUENTS	AMPLITUDE (metres)																				
M2	0.484	0.492	0.483	0.479	0.483	0.459	0.444	0.439	0.446	0.439	0.441	0.451	0.471	0.474	0.481	0.479	0.481	0.488	0.485	0.468	0.019
S2	0.132	0.134	0.135	0.137	0.143	0.135	0.131	0.129	0.132	0.127	0.129	0.129	0.133	0.132	0.130	0.130	0.131	0.131	0.129	0.132	0.004
K1	0.147	0.150	0.152	0.160	0.165	0.172	0.173	0.175	0.176	0.173	0.170	0.163	0.158	0.144	0.139	0.137	0.135	0.138	0.139	0.156	0.015
O1	0.084	0.088	0.090	0.097	0.099	0.109	0.111	0.116	0.120	0.114	0.112	0.101	0.090	0.081	0.078	0.076	0.076	0.078	0.081	0.095	0.015
MSF	0.023	0.011	0.030	0.008	0.023	0.033	0.002	0.021	0.003	0.006	0.011	0.006	0.002	0.023	0.012	0.011	0.013	0.008	0.002	0.013	0.010
z0	0.083	0.015	0.008	0.023	0.042	0.006	0.038	0.038	0.040	0.081	0.061	0.073	0.056	0.079	0.063	0.100	0.093	0.048	0.061	0.053	0.028
TIDAL CONSTITUENTS	PHASE (degrees)																				
M2	0.484	0.492	0.483	0.479	0.483	0.459	0.444	0.439	0.446	0.439	0.441	0.451	0.471	0.474	0.481	0.479	0.481	0.488	0.485	0.468	0.019
S2	0.132	0.134	0.135	0.137	0.143	0.135	0.131	0.129	0.132	0.127	0.129	0.129	0.133	0.132	0.130	0.130	0.131	0.131	0.129	0.132	0.004
K1	0.147	0.150	0.152	0.160	0.165	0.172	0.173	0.175	0.176	0.173	0.170	0.163	0.158	0.144	0.139	0.137	0.135	0.138	0.139	0.156	0.015
O1	0.084	0.088	0.090	0.097	0.099	0.109	0.111	0.116	0.120	0.114	0.112	0.101	0.090	0.081	0.078	0.076	0.076	0.078	0.081	0.095	0.015
MSF	0.023	0.011	0.030	0.008	0.023	0.033	0.002	0.021	0.003	0.006	0.011	0.006	0.002	0.023	0.012	0.011	0.013	0.008	0.002	0.013	0.010
z0	0.083	0.015	0.008	0.023	0.042	0.006	0.038	0.038	0.040	0.081	0.061	0.073	0.056	0.079	0.063	0.100	0.093	0.048	0.061	0.053	0.028
TIDAL CONSTITUENTS	PHASE (degrees)																				
M2	349.057	349.426	349.561	349.902	349.435	349.072	348.670	347.412	346.343	346.226	345.130	345.723	345.365	344.982	345.865	346.556	346.824	348.077	348.577	347.484	1.698
S2	257.981	256.658	256.189	255.987	254.354	259.313	256.949	259.397	257.180	258.107	257.849	257.614	258.214	256.639	257.703	257.687	256.861	257.326	257.565	257.346	1.154
K1	144.330	146.459	146.630	145.615	144.883	142.667	142.008	141.596	135.718	132.231	129.061	126.972	126.107	128.229	129.055	134.476	137.619	140.173	143.124	137.734	7.232
O1	201.001	199.405	198.040	199.146	199.232	201.987	203.411	206.701	210.242	215.731	221.470	225.365	224.913	221.927	218.660	213.373	208.166	205.410	202.324	209.290	9.469
MSF	303.658	36.020	30.357	348.791	45.871	109.841	282.168	86.919	157.566	173.220	290.212	36.398	273.238	20.904	5.642	359.752	40.431	298.339	218.971	164.121	126.747
RESIDUAL ERROR	ROOT MEAN SQUARE (metres)																				
	0.067	0.096	0.071	0.083	0.068	0.101	0.069	0.098	0.085	0.090	0.069	0.095	0.080	0.090	0.075	0.075	0.078	0.089	0.074		
DATA ANALYSED	YEARLY PERCENTAGE (%)																				
	64.2	92.9	59.7	98.7	57.8	65.7	96.6	92.6	97.2	82.1	92.2	86.0	97.1	89.9	96.0	91.0	94.2	98.0	93.3		

HAT/LAT	Value (m)	Date and time from prediction	Uncertainty at 95% CI (m)	Average number of days per year that HAT was exceeded (2001-2020)
Highest Astronomical Tide (HAT)	1.11	03/07/2004 21:15	±0.18	3.6
Lowest Astronomical Tide (LAT)	-0.83	29/09/2015 02:45		
COMMENTS				

The information supplied has been collected for use by the Department of Planning and Environment and the tidal plane heights only approximately relate to Australian Height Datum (AHD) or other specified datum.
Other users should independently verify the suitability of this data for their particular use.

Figure 4: Typical tidal planes table of a tide gauge from the MHL website.

4 MEAN HIGH WATER IS NOT EQUAL TO MEAN HIGH WATER

Some surveyors do not consider such a thing as there could be different MHW identities. It all depends upon your perspective and the definition under which your exercise is being conducted. Differing definitions will provide different values because of the way MHW is computed. For cadastral boundary definitions, surveyors will need to adhere to the definition provided under the surveying regulations, but that can create its own dilemma.

4.1 MHW – Surveyor Legal Cadastral Requirement

The MHW handed to surveyors from the legal system is based on the taking of observations of only high tides to establish the mean. That mean was to be calculated from high tides between spring and neap tide cycles over a period of a quarter of a lunar cycle, a period of approximately 7 days. Or that was what it was when the ruling was handed down from *Attorney General v. Chambers* in 1854. Since then, surveyors have had further limiting conditions imposed by the legal system from *Tracey Elliot v. Morley (Earl)* in 1907. Now the cadastral MHW that surveyors must use for boundary definitions (MHWC) is one only obtained from the mean of high tides between the ordinary high-water spring and ordinary high-water neap tides. What that is interpreted as and which high tides should be excluded has only left surveyors in a quandary and turning elsewhere (Songberg, 2020).

4.2 MHW – ISG Manual

The ISG manual was meant to be a definitive guide to establishing MHW but legally it was more of a hinderance than a help. The writers introduced their own idea of what surveyors should be seeking by changing the MHW requirements to the mean of all high tides including neap and spring taken over a long period of time (Lands, 1976; Songberg, 2015). The extent of the time period was not identified with respect to the definition in the manual. Using this definition would make it easier for surveyors but, from a legal perspective, the practice would not meet with the legal rulings.

4.3 MHW – MHL Tidal Planes

Since then, time, changing knowledge and resources have helped surveyors with a quick and easy realisation of MHW. Firstly, in the publication of the NSW tidal planes analysis 1990-2010, report MHL2053 (MHL, 2012), and more lately with an updated tidal planes analysis for 2001-2020, report MHL2786 (MHL, 2023). The MHL2786 tidal planes tables are also published on the MHL website (see Figure 3). These publications provided easy access to the Australian Height Datum (AHD) level for not only MHW, but many other tidal components. The levels for MHW, initially from the MHL2053 report, have been used by surveyors many times in establishing MHW at a survey site. Unfortunately, the MHW in the MHL reports does not equate to the MHW required by surveyors from the legal rulings. The MHW in the tidal planes tables has not been derived from a mean of high tides. It has been calculated from a harmonic analysis, mathematical modelling, of all tidal data. No mean of high tides has been undertaken thus, from a legal definition perspective, the harmonic derived MHW (MHWH) cannot be used by surveyors for boundary determinations although it has been in the past.

4.4 MHW – MHL Mean of High Tides

MHL has recently recognised this situation and now published the MHW levels for tide gauges based on the mean of high tides, together with another MHWH dataset in report MHL2902 (MHL, 2024). The MHW from the mean of high tides (MHWT) for the period 2003 to 2022 (Figure 5) has also been published on the MHL website under the heading of Mean High Water on the tide gauge site page.

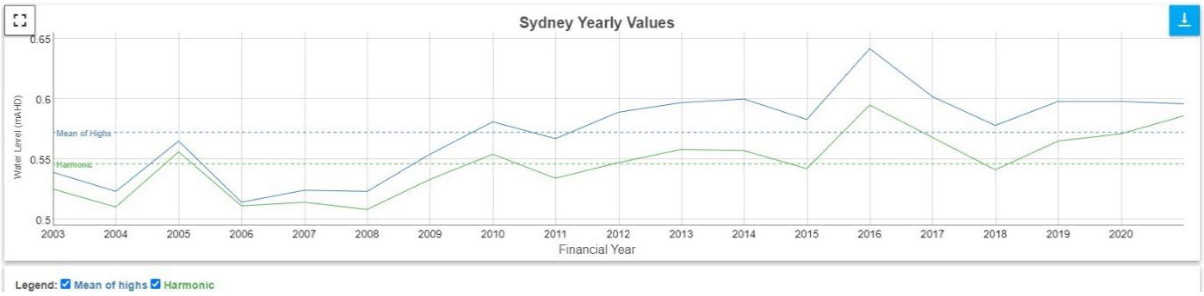

Figure 5: Mean of high tides (MHWT) compared to the harmonic mean (MHWH) (MHL website).

The interactive chart shows not only the mean of high tides compared to the harmonic mean over the report period, but the individual yearly values can also be extracted. The associated report also reveals that for the most part the MHWH understates the MHWT by anything up to 0.075 m (MHL, 2024). So, surveyors using the MHW from the tidal planes tables will generally obtain too low a value and thus establish the riparian boundary too far out into the water.

MHL's MHWT uses all available high tides to calculate the mean initially for each 12-month period then averaged over the 19-financial-year cycle. There is no indication in the report that there is any exclusion of high tides based on the need to only mean the high tides between ordinary spring and ordinary neap tides. Thus, this value of MHW will closely equate to the definition of the ISG manual. The values obtained will be close to the cadastral MHW that surveyors require but not exactly the same, thus MHWT ≠ MHWC. What the difference will be, if any, is still in the realm of the great unknown.

Another aspect of the MHL2902 report is that MHL includes all tide gauges that have a minimum number of tidal observations obtained to produce the necessary profiles. Unfortunately, this can sometimes be misleading and give surveyors the wrong direction as many tide gauges are located in Intermittently Closed and Open Lakes and Lagoons (ICOLLs). Even though MHL provides the MHWT values for the sometimes-tidal periods, the water boundaries in ICOLLs are not the MHW mark (MHWM) but instead the bank. Despite the report seemingly being directed particularly to surveyors, in the foreword it says that the data can be used for multiple purposes including as an input for determining tidal water boundaries. The report was therefore not directed solely to surveyors who, when using the data, must be careful to identify an ICOLL as an entity and not rely on MHL's tide gauge data as a means of identifying the riparian boundary type.

4.5 MHW Over Time

Sceptics, conspiracy theorists and anti-climate change adherents aside, sea level is rising, and it is measurable over surprisingly short periods of time. If a surveyor were doing a MHW derivation for a survey today, then the MHW of 10 years ago is ancient history and invalid to the survey. Thanks to the diligent work of MHL, surveyors have easy access to various 19-year datasets for most tide gauges in the MHL network. Running a linear trend line through the yearly values of MHWT will generally produce a line of increasing slope over time (Figure 6).

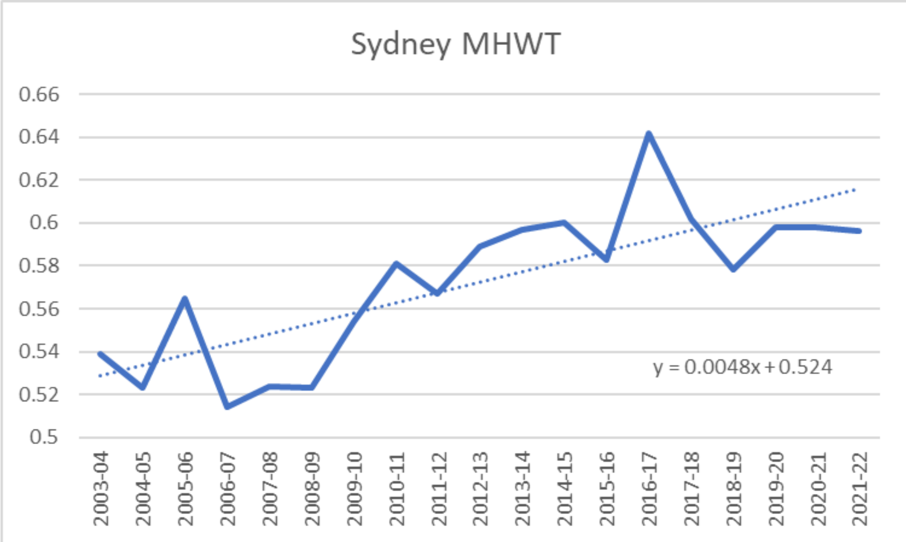

Figure 6: Sydney (Middle Head) mean high tides trend (MHL data).

A linear trend line was used in this exercise because it was easy, serves the purpose and shows what is occurring. A more comprehensive analysis over a larger data range may be needed to provide the most appropriate analysis and trend. A surveyor doing a survey today, in 2025, because of rising sea levels, would have to extrapolate the historical levels of MHW to the present. In this example, the mean of the 19-year MHWT dataset is 0.572 m, which is the value that would commonly be used for property boundary definitions. The timing of this value is now over 10 years old and, from a rising sea level perspective, out of date. The extrapolated MHW level for 2025 is 0.639 m. The 0.067 m height difference would make a significant impact on the position of the MHWM on a relatively flat foreshore. If a surveyor were to use the harmonic 19-year mean from the tidal planes tables off the MHL website or from the MHL2786 report, then they would be using a value of 0.540 m.

It is clear then that a surveyor seeking accuracy in a MHW level must be very aware of which MHW should be used and for which purpose. MHWT (at the time of survey) for cadastral purposes, as it is the closest value with statistically available data to MHWC, and perhaps MHWH (latest 19-year) mean for broader purposes.

4.6 MHW Range Ratio

For a range ratio exercise the MHW – MSL – MLW combination datasets, required in the formula, are only available within MHL’s harmonic tidal planes tables. Even though MHL has now provided surveyors with the MHWT for cadastral boundary purposes, the mean of low water tides has not been conducted. There is no guarantee that the harmonic MSL would be the same as that produced from the means of high and low tides. So, to conduct a range ratio exercise, the surveyor must work from the harmonic data, then offset the results to MHWT and extrapolate this to the time of survey. That offset is not a parallel offset from the harmonic values over time (see Figure 5), nor is it the same for each tide gauge. It must be repeated that despite being the best data for cadastral purposes that there is, MHWT is not equal to MHWC although it is likely to be close.

5 ACCURACY

The ISG manual promised a reasonably accurate result from range ratio. But what quantum of accuracy would a surveyor have to meet if working within the surveying regulations? For measuring of a length of a line, it must be done to an accuracy of 10 mm + 50 ppm. The relative tolerance between two points, such as either end of a boundary line, is $\sqrt{2}(0.1+d/20{,}000)^2$ where d is the distance of the line.

To position the MHW boundary to a tolerance of a boundary line by establishing the level of the MHW tidal plane within the specifications of the surveying regulations, Table 1 will give you an indication of how accurate you would need to find the MHW level for the different foreshore grades.

Table 1: Vertical accuracy of MHW level for boundary length on foreshore grade (all values in metres).

Length	1in1	1in2	1in5	1in10	1in20	1in50	1in100
20	0.008	0.004	0.002	0.001	0.000	0.000	0.000
50	0.009	0.004	0.002	0.001	0.000	0.000	0.000
100	0.011	0.005	0.002	0.001	0.001	0.000	0.000
200	0.014	0.007	0.003	0.001	0.001	0.000	0.000
500	0.025	0.012	0.005	0.002	0.001	0.000	0.000
1,000	0.042	0.021	0.008	0.004	0.002	0.001	0.000

From this table, it is clear that to find a level of MHW within an accuracy that would position the MHW boundary along a sloping foreshore in such a way that it would fall within the tolerance of the stated distance of a boundary line, is within the impossible realm. Clearly, the surveying regulations are not meant to be interpreted in this way. It is when the surveyor has decided where the MHWM is positioned that the measured tolerance of the boundary comes into play.

The surveying regulations give the surveyor a bit of leeway from another perspective. To establish a benchmark for the extension of AHD, it must be done within a vertical positional uncertainty of 0.01 m or less. If the establishment of a level for MHW on a survey site is considered a benchmark, not only for the MHWM survey but also for any vertical referencing, then the MHW level would need to be within that 0.1 m to comply with the regulations. For a 0.1 m vertical uncertainty the range over which the MHW intercept could be found on a sloping foreshore would be for 1in1, 0.1 m; 1in2, 0.2 m; 1in5, 0.5 m; 1in10, 1 m; 1in20, 2 m; 1in50, 5 m; 1in100, 10 m. Achieving a range ratio result for the remote site of 0.1 m vertically would be acceptable for most cases. But on a fairly flat foreshore across mangrove swamps and salt marshes where the foreshore slope could be around 1in50 or 1in100, a surveyor would be expected to a achieve a better result than within 5 or 10 metres.

Choosing the wrong MHW must also flow into the accuracy consideration. Choosing the MHW that has been historically used by surveyors, the mean from the tidal planes tables, MHWH, would result in a significant error factor. For a survey using the Sydney gauge, the 0.093 m difference from the 19-year mean MHWH to the 2025 MHWT would have an appreciable impact.

6 RANGE RATIO EXERCISES

On the Clarence River, the tide gauges Palmers Island Bridge and Ulmarra were adopted as the unknown survey site stations. Range ratio exercises were then carried out to transfer the MHW from the gauges on either side (see Figure 2). The 'observations' were conducted using a different number of tidal events to see if the 1-day consecutive high-low readings were adequate for an accurate result or if a greater number of observations were needed. Exercises were carried out during full moon, new moon, spring tide events, half-moon and neap tide events to ascertain what differences would result.

The observations included:

- A single consecutive high and low water for both a predicted highest and the observed highest spring tides.
- A single high and low during neap tides at half-moon.
- A full day during spring tide, 2 high water and 2 low water tides or the mean of 4 results.
- A full day during neap tides.
- Three days of continuous readings during spring tides, the mean of 12 high-low combinations.
- Three days during neap tides.
- Two long period observations of 35 and 50 days from different time periods.

To see if distance has any effect, Yamba was used as a reference gauge and range ratio height differences determined for each leg up the estuary and a height difference traverse conducted from Yamba to Rogans Bridge (90 km) and return. This was then compared to the direct range ratio transfer from Yamba. This exercise was conducted for multiple 3-day observation periods and for both the 35- and 50-day observation sets.

7 NUMBERS

The numbers obtained from the tide gauges are raw data. They have not been modified by any means and so are subject to all the variabilities as would a surveyor experience if setting up their own tide gauge. For this exercise, the numbers have not been filtered so to evaluate the effects of varying conditions have on the results and the subsequent effect on accuracy. The observations for the various scenarios resulted in a lot of numbers, summarised in tables available in Appendix A. For the range ratio determination of Palmers Island Bridge gauge from Yamba (16 km downstream) and from Maclean (8 km upstream), a summary of the numbers can be found in Table 2.

At first glance, it seems that distance could have an effect. The results from Yamba, twice the distance away than Maclean, have a wider spread and are less accurate. However, the 50-day results indicate with close agreement that distance might not have an effect. The 35-day results differ considerably, but the overall mean tends to confirm the 50-day results. Neap tide observations tend to have a larger spread than spring tide observations, and the resulting MHWH was usually lower than the spring tide values. The overall result is that range ratio transfer of MHW has resulted in a lower value for Palmers Island Bridge gauge than expected. The AHD value of MHWH for Palmers is 0.374 m, whereas these exercises would give it a value of 0.34 m.

Table 2: Palmers Island Bridge MHWH from range ratio using different observation lengths.

To				Palmers			
From		(16km)	Yamba		Maclean	(8km)	
		Spread	Mean		Mean	Spread	mean diff
Obs type							
Single predicted spring		0.175	0.335		0.357	0.062	-0.021
Single highest spring		0.175	0.333		0.358	0.062	-0.026
Single neap		0.196	0.282		0.280	0.115	0.001
1 day spring		0.085	0.388		0.363	0.041	0.025
1 day neap		0.08	0.324		0.363	0.065	0.027
3 day spring		0.082	0.378		0.358	0.035	0.021
3 day neap		0.075	0.327		0.328	0.05	-0.001
35 day average			0.389		0.336		0.053
50 day average			0.338		0.341		-0.003
Combined mean			0.344		0.335		0.009
AHD MHWH				0.374			

The results for Ulmarra, some 38 km upstream, portray a different set of numbers entirely (Table 3).

Table 3: Ulmarra MHWH from range ratio using different observation lengths.

To				Ulmarra			
From		(9km)	Brushgrove		Grafton	(12km)	
		Spread	Mean		Mean	Spread	mean diff
Obs type							
Single predicted spring		0.016	0.365		0.292	0.038	0.073
Single highest spring		0.017	0.365		0.292	0.036	0.072
Single neap		0.042	0.382		0.277	0.061	0.105
1 day spring		0.017	0.371		0.287	0.038	0.084
1 day neap		0.024	0.373		0.276	0.076	0.097
3 day spring		0.014	0.370		0.287	0.038	0.083
3 day neap		0.019	0.375		0.290	0.027	0.085
35 day average			0.375		0.279		0.096
50 day average			0.374		0.295		0.079
Combined mean			0.372		0.286		0.086
AHD MHWH				0.396			

Again, the transfer using the larger distance appears to have a wider spread in the results. But the concept of neap tide results being lower than spring tide results does not appear to hold true. In this exercise, some neap tide results are actually higher than the spring tide results. There is also a repeat of the results being lower than expected. This time, however, the results from the two reference gauges differ considerably.

The exercise testing distance gives a very surprising result and an entirely different view on distance effects (Table 4). In each case there is very little difference in the values obtained for each tide gauge whether it be from a differential height traverse up the estuary or by direct range ratio transfer. The only real difference is between the two datasets, taken at different times. The results for the 3-day mean (Appendix A3) show a similar trend. The mean results are of a similar calibre as those for the long-period observations but the spread of results from the 3-day datasets is a little wider than for the two long-period datasets. This indicates that the longer datasets have a higher consistency. If these results are correct, then distance is not a factor in the transfer of MHW using range ratio. What differences there are must be a result of other factors.

Table 4: Range ratio differential height estuary traverse to direct distance comparison.

Estuary long period obs traverse - direct comparison							
	Yamba	Palmers	Maclean	Lawrence	Brushgrove	Ulmarra	Grafton	Rogans Br
AHD MHWH	0.522	0.374	0.307	0.33	0.351	0.396	0.496	0.463
35 day trav	0.522	0.389	0.363	0.41	0.452	0.476	0.694	0.574
35 day direct	0.522	0.389	0.355	0.402	0.448	0.475	0.697	0.58
trav-direct diff		0	0.008	0.008	0.004	0.001	-0.003	-0.006
50 day trav	0.522	0.338	0.306	0.355	0.39	0.413	0.615	0.486
50 day direct	0.522	0.338	0.302	0.351	0.389	0.415	0.62	0.497
trav-direct diff		0	0.004	0.004	0.001	-0.002	-0.005	-0.011
35day-50day trav		0.051	0.057	0.055	0.062	0.063	0.079	0.088
35day-50day direct		0.051	0.053	0.051	0.059	0.06	0.077	0.083

8 CONSIDERATIONS

Under ideal conditions, without any outside influences, the process of transferring MHW to a remote station via range ratio undoubtedly works very well. Unfortunately, surveyors do not work in ideal conditions, and the data obtained on site or without filtering from automatic tide gauges will be subject to all those outside influences. Abnormal water flows within the estuary, wind speed and direction pushing the water surface about, high or low atmospheric conditions lowering or increasing the overall height of the water surface, sea conditions influencing the tide gauges near the ocean or just the idiosyncrasies of the tidal regime are but a few of the factors that could affect the outcome. As the data used to generate the numbers is subject to any or all of those influences, a degree of variation in results would be expected. The effect will certainly have some impact on accuracy.

8.1 Accuracy and Neap Tides

The ISG manual promised reasonably accurate results from single high-low combination observations on one day. The results indicate that accuracy increases with the number of observations taken when near the estuary entrance (see Table 2) but this makes very little difference further up the estuary (see Table 3). Whether or not neap tide observations are accurate or if they can be used, follows a similar profile. Low accuracy near the mouth of the estuary and improving in accuracy higher up the estuary.

The spread of results (0.261 m) for all observations over 50 days for Palmers from Yamba (Figure 7a) is clearly much greater than for Ulmarra from Brushgrove (0.054 m) (Figure 7c) or for Ulmarra from Grafton (0.049 m) (Figure 7d). Even the spread of results for Palmers from Maclean (Figure 7b) is marginally better at 0.205 m.

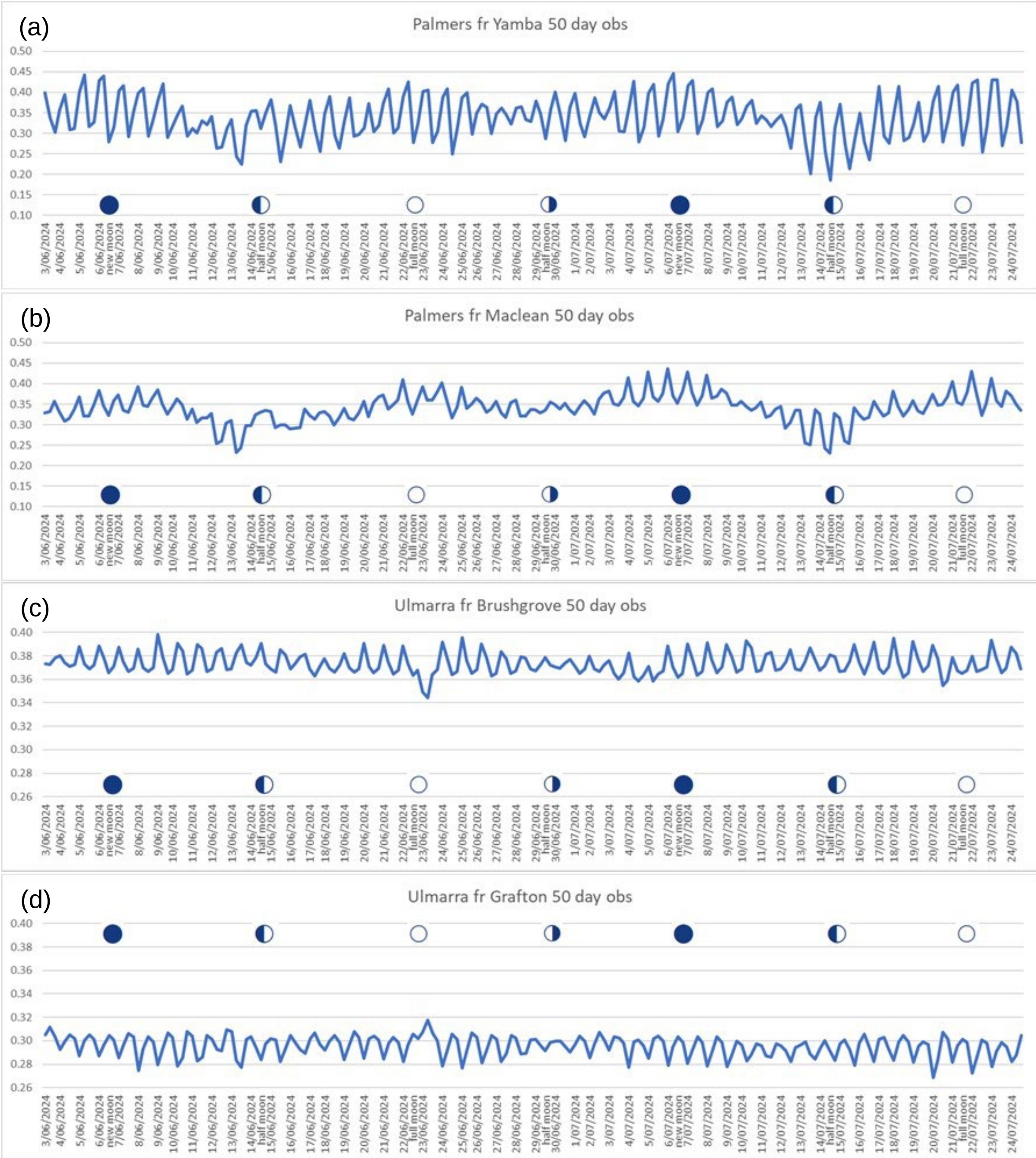

Figure 7: All range ratio results over 50 days: (a) Palmers from Yamba, (b) Palmers from Maclean, (c) Ulmarra from Brushgrove, and (d) Ulmarra from Grafton.

The neap tide results tend to give a lower value than those for spring tides, especially near the estuary entrance, but not always. The second neap tide results in Figure 7a are similar to the spring tide values. In Figure 7c, it is actually a full moon spring tide that gives the lowest value, and outside the trend with the rest. The numbers, in Table 3 and Figure 7, even suggest that range ratio using neap tides could give a satisfactorily accurate result comparable to spring tides, provided the observations were carried out away from the estuary entrance. When looking at the spread of results for Ulmarra (Figures 7c & 7d), it suggests that a range ratio exercise could be conducted at any time, in the mid to upper estuary, irrespective of the moon cycle.

8.2 Distance

The numbers from Table 4 show that distance has very little, if any, effect on range ratio observations, particularly if a long observation period is used. What cannot be numerically explained is why the results from the 35-day observation set are consistently higher than those from the 50-day observations. It could be speculated that a 2 m rise in the river at Rogans Bridge two weeks before the commencement of the 35-day observations had not completely dissipated from the estuary but had spread out and was still being partially contained, raising the water level slightly.

Charting the numbers from Table 4, the comparison between the estuary differential traverse, tide gauge to tide gauge along the estuary, compared to the direct range ratio from Yamba is easier to see (Figure 8). The 35-day dataset is consistently higher than the 50-day dataset. The 50-day dataset is more comparable with the AHD values of MHWH than the 35-day data, which gives further speculation that there is some effect that is skewing the data.

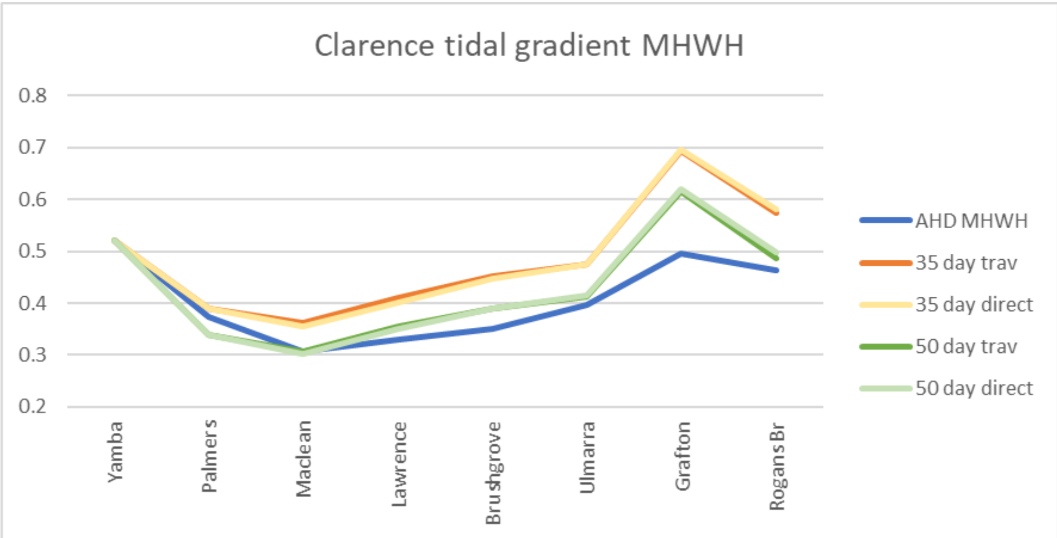

Figure 8: Estuary range ratio height difference traverse and direct from Yamba compared to MHWH gradient.

While the MHWH values realised from the 50-day range ratio estuary traverse more closely align to the AHD values than the 35-day realised data, there is still considerable disagreement with the height of Grafton. This leads to speculation that there could be some incorrect data within the Grafton dataset that could explain why the range ratio determination of Ulmarra was significantly different to that determined from Brushgrove. The chart also identifies the lower value at Palmers indicated by range ratio. There is also a possibility that the Brushgrove AHD height may be lower than what range ratio indicates.

8.3 Tidal Component Uncertainty

In a parallel study of tidal gradients (Songberg, 2025), it was found that there could be reason to suspect an unusual level of uncertainty of either the tide gauge benchmarks or the MHW tidal component. MHL indicates that the vertical uncertainty for the tide gauge benchmarks ranges from ±0.003 m to ±0.22 m (MHL, 2024). The harmonic tidal components have an uncertainty level between ±0.15 m and ±0.33 m but are station dependent. It is possible that although the results are within the MHL uncertainty range, some of the range ratio results could be influenced by levels of uncertainty that will affect the outcome especially from an accurate surveying perspective. There is also the uncertainty of AHD over large distances and even anomalies within itself that could influence the range ratio outcomes. Acknowledging the distances over which the range ratio method may be used, it is something that needs to be taken into consideration.

Using the theory that distance has little or no effect in range ratio considerations, the MHWH levels for Palmers, Ulmarra and Grafton can be computed from range ratio transfers from every other tide gauge along the estuary (Table 5).

Table 5: Range ratio results for Palmers, Ulmarra and Grafton from all other gauges.

		Palmers	Ulmarra	Grafton
from				
Yamba		0.338	0.415	0.62
Palmers			0.429	0.66
Maclean		0.341	0.417	0.62
Lawrence		0.312	0.388	0.589
Brushgrove		0.299	0.374	0.575
Ulmarra		0.322		0.598
Grafton		0.221	0.295	
Rogans Br		0.321	0.396	0.595
Mean		0.308	0.388	0.608
AHD MHWH		0.374	0.396	0.496
Mean excl Grafton		0.322	0.403	

The mean range ratio results from all tide gauges indicate that the value for Palmers should be 0.308 m, for Ulmarra 0.388 m and for Grafton 0.608 m. But when the results are charted (Figure 9), it becomes quite evident that the results for Grafton are too low. Excluding the result from Grafton, Palmers becomes 0.322 m and Ulmarra 0.403 m.

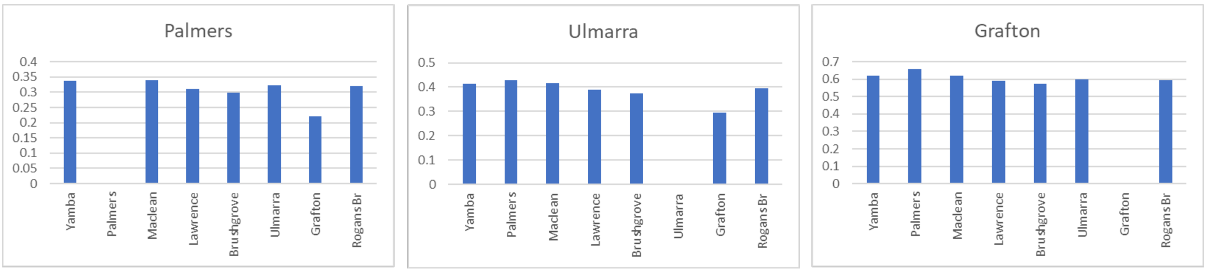

Figure 9: Range ratio MHWH results for Palmers, Ulmarra and Grafton from all other gauges.

Results for Palmers indicate that MHWH could be 0.03-0.05 m lower:

AHD 19-year mean MHWH:	0.374
Range ratio from Yamba:	0.344 (Table 2)
Range ratio from Maclean:	0.335 (Table 2)
Range ratio all gauges:	0.322

Results for Ulmarra indicate that Grafton is incorrect and should have a value of about 0.61 m, creating an increase in the initial result from 0.286 m to 0.4 m.

AHD 19-year mean MHWH:	0.396
Range ratio from Brushgrove:	0.375 (Table 3)
Range ratio from Grafton:	0.286 (Table 3)

Range ratio all gauges:	0.403
Adjusted range ratio from Grafton:	0.4

Factoring in an adjustment to both Palmers and Grafton AHD values of MHWH from a possible tidal component error provides a closer agreement between the overall range ratio estuary traverse to MHWH (Figure 10).

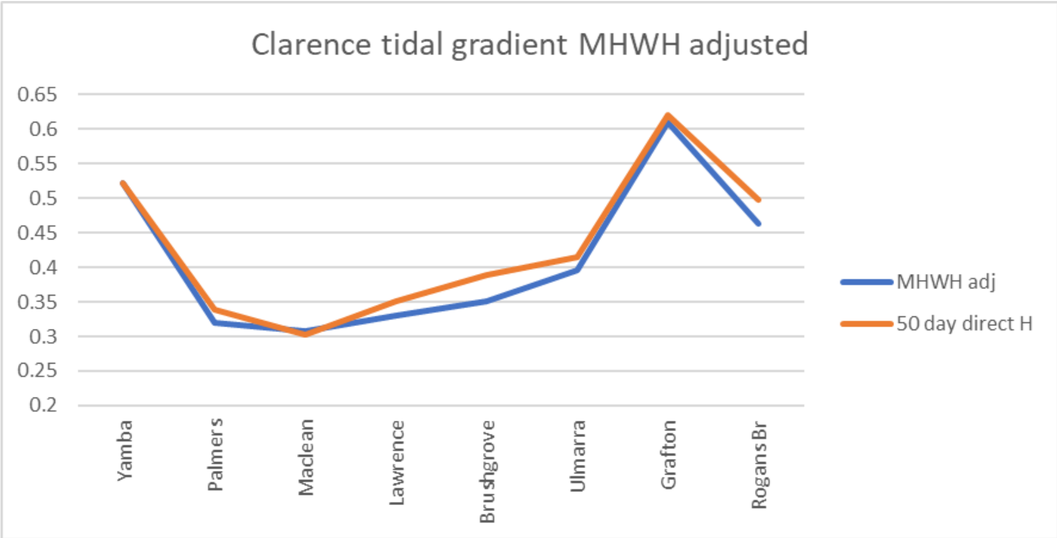

Figure 10: Clarence River tidal gradient MHWH adjusted for tide gauge inconsistencies compared to range ratio gradient.

However, it is not clear which component the source of the uncertainty is, either the tidal data or the tide gauge benchmark. Comparison of datasets indicate that the MHL2786 value of MHWH for Palmers is too high against MHL2902 data but does not appear to be so when compared against MHL2053 data (Songberg, 2025). It is more difficult to see if the MHWH for Grafton discloses any anomaly. Range ratio results from Grafton to every other gauge are consistently too low compared to the assigned AHD value. Similarly, the results from Palmers are consistently too high. Another possibility is that there is an anomaly in the AHD network itself.

The range ratio results indicate that either the tide gauge benchmark, the MHWH value or AHD need a slight adjustment. But this is all within the harmonic environment, which is not what is required for cadastral purposes. Assuming that the error is within the realisation of the tide gauge benchmarks, the adjustments applied to MHWH can then be applied to MHWT and compared to the estuary wide range ratio result (Figure 11). Because the estuary range ratio is anchored on the values of Yamba, the difference between Yamba MHWH and Yamba MHWT is applied to the range ratio traverse and MHWT is adjusted at Palmers and Grafton.

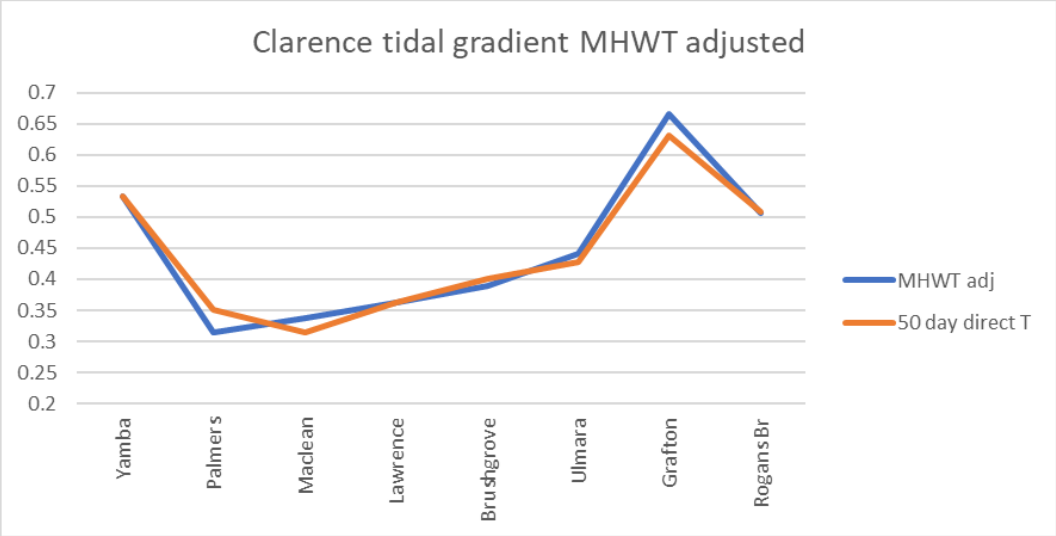

Figure 11: Clarence River adjusted MHWT tidal gradient compared to range ratio gradient.

The chart indicates a reasonably favourable outcome though Palmers now looks like it could be too low and perhaps should not have been adjusted. The other possibility is that the error was not in the benchmark but rather in the tidal data. Transposing the information in a similar manner to the time of survey (ToS) causes further doubt (Figure 12). It now looks like the Grafton error may also not have been in the benchmark.

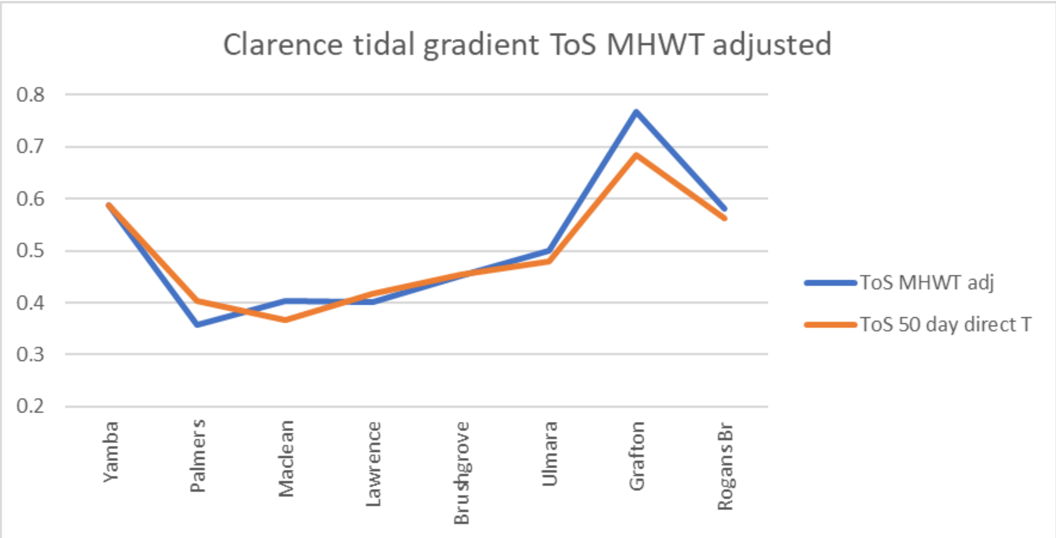

Figure 12: Clarence River benchmark adjusted MHWT tidal gradient compared to range ratio direct gradient.

Changing estuary dynamics over time must be given appropriate consideration. Matching the range ratio results to the MHWH values, which are old and out of date, does not appear to produce accurate results. It is quite possible that a range ratio survey will only produce results that are consistent with the estuary tidal dynamics present at the time of survey. The estuary dynamics do not change evenly throughout the estuary but are more site specific, so the step from the MHWT mean to the ToS will be variable. As data for the time of survey was not available, the ToS profile can be estimated from the trend across the existing data (Appendix B). Without making any data error considerations or adjustments, the 50-day estuary range ratio traverse aligns remarkably well with the ToS tidal gradient estimated from MHWT data (Figure 13).

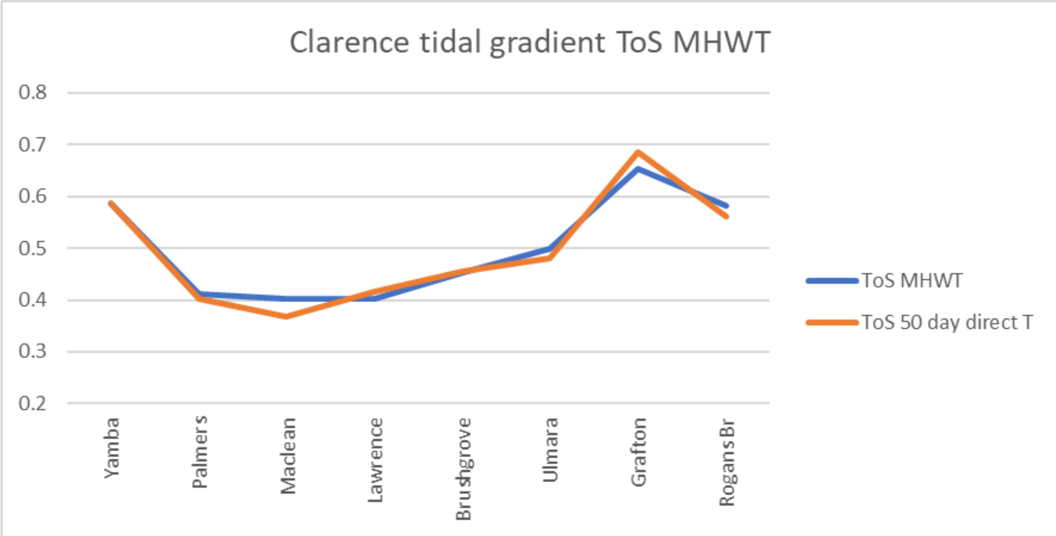

Figure 13: Clarence River tidal gradient ToS MHWT compared to estuary range ratio traverse.

The only consideration that needs to be made is that the range ratio traverse uses Yamba tide gauge as the benchmark. This would assume that Yamba has a zero-uncertainty value, which is highly unlikely. Offset computations between the two profiles determined that there is only a 0.005 m imbalance, so that adopting a floating benchmark and shifting the traverse vertically by that amount would produce a balanced outcome that would achieve the greatest accuracy (Table 6).

Table 6: Offset balanced 50-day estuary range ratio traverse to time of survey (ToS) MHWT.

	Yamba	Palmers	Maclean	Lawrence	Brushgrove	Ulmarra	Grafton	Rogans Br	
ToS MHWT	0.587	0.412	0.403	0.402	0.452	0.499	0.653	0.582	
50 day trav	0.592	0.408	0.372	0.421	0.459	0.485	0.690	0.567	
offset	0.005	-0.003	-0.031	0.019	0.007	-0.014	0.037	-0.015	0.000
									mean

This indicates that the tide gauges with the greatest uncertainty are Maclean and Grafton. Using the ToS MHWT as the base values in the initial range ratio exercises will change the outcomes of the survey.

From Table 2, the combined range ratio results for Palmers translated to ToS outcomes are:

From Yamba: 0.409
From Maclean: 0.431
Mean: 0.42
ToS MHWT: 0.412 (Table 6)
Estuary traverse: 0.408 (Table 6)
Mean all gauges: 0.401

From Table 3, the Ulmarra results translated to ToS outcomes are:

From Brushgrove: 0.473
From Grafton: 0.443
Mean: 0.458
ToS MHWT: 0.499 (Table 6)
Estuary traverse: 0.485 (Table 6)
Mean all gauges: 0.502

Shifting from the harmonic baseline to the MHWT time of survey baseline causes the results from Yamba and Maclean to disagree slightly. Despite this, the mean is now much closer to the given value for Palmers, differing by only 0.008 m from ToS MHWT compared to the previous 0.035 m using MHWH. The results for Ulmarra show that the difference between the two range ratio surveys has been reduced to 0.03 m using ToS MHWT from the original 0.115 m using MHWH. The mean result is more certain than previously but is around 0.04 m low. As a check on the results, range ratio computations to Palmers and Ulmarra utilising the 50-day dataset were conducted from all tide gauges and the mean taken. The result does not significantly differ for Palmers than what was achieved via the mean from the two tide gauges either side. However, the mean for Ulmarra is higher and more in line with the ToS MHWT value. The result is not surprising, considering that the ToS MHWT for both Brushgrove and Grafton are lower than the estuary traverse and Ulmarra is higher (see Table 6). This would create a bias for the original range ratio results to be lower than expected. The mean results from all tide gauges even out any bias.

It appears that given enough data behind the range ratio transfer of MHW, the results can be quite accurate. The more tidal observations are made and accepting the mean as the 'correct' result, the more this reduces the uncertainty levels associated with the base data. The same applies for transferring MHW from the long-term tide gauge. The greater the number of transfers from a greater number of tide gauges, the higher the certainty that the answer is appropriate. Given enough data, it might even be possible to detect which tide gauges have the highest degree of uncertainty. If the uncertainty is high enough, it could lead to the possibility that a particular gauge and the associated MHW information should be excluded from a MHWM determination. It may not be possible to determine which tidal component creates the uncertainty, but it could lead to a direction in which further investigations could be warranted.

9 CONCLUDING REMARKS

The big question is: Can a surveyor obtain a reasonably accurate benchmark for mean high water at a remote site using range ratio in the manner described by the ISG manual? The answer: You could be lucky enough to get the answer you need, but you will never know. Such an approach cannot be validated, so for the most part the answer must be no!

This study also found that range ratio transfer from a long-term tide gauge tends to be more accurate in the reaches of an estuary that are away from the influences of the coast. It also found that within those limits the timing of the range ratio exercise was not dependent on being performed at spring tides but could be performed at any time, including neap tides. However, near the coast neap tide observations tend to produce results that are too low so are not generally usable. Near the coast all results for single high-low combinations varied too widely, including at spring tide occurrences, to be considered accurate.

Even though the range ratio method, given the right circumstances, could give an accurate answer, using it in a manner prescribed by the ISG manual goes against all principles of responsible surveying. To follow the guiding principle from the surveying regulations, a surveyor would need to conduct measurements from at least two different tide gauges before a conclusion on accuracy could be made. Even then, if a similar bias, high or low, was in both uncertainties of the tide gauge, then that bias will be translated to the range ratio outcome.

Another aspect that was realised was that more is better. But even this could have limitations if comparative exercises were conducted at different times. A single-day observation of consecutive high and low tides is never going to work for a surveyor seeking accuracy. Range ratio instead needs to be carried out over several days, if not weeks, and the mean taken before a reasonably accurate result could be obtained. This would especially be the case if the exercise was carried out near the coastal fringe. The same conclusion was made for the number of tide gauges required to provide an accurate answer: more is better. Distance did not seem to have any noticeable effect on accuracy of the MHW transfer. The limitation of reliance on AHD in situations only less than 10 km apart does not seem to apply to range ratio. So, the selection of which gauges in the estuary should be used does not matter as to how close they are to the survey site. A surveyor could use all gauges in the estuary if desired.

Overall, this study found that to obtain a reasonably accurate benchmark for a MHWM exercise, range ratio transfers of MHW should be carried out over four or five days at least, and from at least three different tide gauges, if not more. If near or on the immediate coastline, it would still be essential to carry out the exercise on or about the spring tides. Higher up the estuary it does not appear to matter. The mean results obtained from each tide gauge must then be analysed for possible tidal component uncertainties before the final answer is obtained.

Also, because of data limitations, range ratio exercises need to be conducted within the harmonic tidal environment, MHWH, and then the results translated to the mean of high tides environment, MHWT. Because the dynamics of the estuary are constantly changing, especially when rising sea levels are taken into consideration, the MHWT at the time of survey must also be used. Range ratio results will be reflective of the estuary conditions at the time of survey, so instead of comparing the results to the mean of a 19-year cycle, compiled some years before and now out of date, the trend through the data to the time of survey must be utilised to smooth out the year-to-year variations inherent in any tidal data.

10 CAVEAT

Even though this study provided some positive direction as to how a reliably accurate value could be obtained for MHW at a remote site using range ratio transfer, it is only one study, on one estuary, and of limited duration. It would be preferable that similar studies be carried out on different estuaries using a greater number of time frames and the results compared before the concluding practices could be considered as the way forward. But that takes a lot of time and a lot of data and a lot of analysis.

This study was also limited in that it was confined to an estuary. Surveyors also need to be able to establish MHW along the coast. To offer some insight as to the possible use of range ratio to transfer of MHW on the coast, a brief presentation of a range ratio exercise along the NSW coast, using the outcomes from the estuary experience, is offered in Appendix C.

It should also be understood that the sought-after level of accuracy or vertical uncertainty for surveying purposes used in this instance is 0.1 m or better (NSW Legislation, 2025). This level of accuracy is much higher than the accuracy levels assigned to most of the data available for conducting a range ratio exercise. Consequently, techniques need to be considered, and put into play, to minimise the level of uncertainty of the data inputs, identify any input anomalies and to verify the outcomes.

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APPENDIX A: RANGE RATIO COMPUTATION RESULTS, CLARENCE RIVER

A1 Palmers Island Bridge

Table A1: Palmers from Yamba and Maclean – single high/low combination, predicted spring tide.

Single high low combination predicted high spring tide							
	To			Palmers			
	From	(16km)	Yamba		Maclean	(8km)	
Moon	Date	L/H	H/L		L/H	H/L	
New	11/02/2024	0.322	0.355		0.345	0.35	
New	10/03/2024	0.348	0.389		0.381	0.384	
Full	24/03/2024	0.325	0.341		0.351	0.356	
Full	25/04/2024	0.386	0.395		0.327	0.343	
New	8/05/2024	0.392	0.418		0.371	0.382	
New	6/06/2024	0.279	0.315		0.322	0.358	
Full	23/06/2024	0.306	0.243		0.361	0.38	
New	5/07/2024	0.294	0.355		0.356	0.375	
Full	22/07/2024	0.254	0.318		0.323	0.352	
							Mean diff
	Spread		0.175		0.062		
	Mean		0.335		0.357		0.022
	AHD HMWH			0.374			

Table A2: Palmers from Yamba and Maclean – single high/low combination, highest spring tide.

Single high low combination highest spring tide							
	To			Palmers			
	From	(16km)	Yamba		Maclean	(8km)	
Moon	Date	L/H	H/L		L/H	H/L	
New	9/02/2024	0.297	0.341		0.362	0.36	
New	10/03/2024	0.348	0.389		0.381	0.384	
Full	24/03/2024	0.325	0.341		0.351	0.356	
Full	25/04/2024	0.386	0.395		0.327	0.343	
New	7/05/2024	0.406	0.418		0.356	0.371	
New	6/06/2024	0.279	0.315		0.322	0.358	
Full	23/06/2024	0.306	0.243		0.361	0.38	
New	4/07/2024	0.279	0.315		0.346	0.365	
Full	21/07/2024	0.271	0.334		0.35	0.379	
							Mean diff
	Spread		0.175		0.062		
	Mean		0.333		0.358		0.025
	AHD HMWH			0.374			

Table A3: Palmers from Yamba and Maclean – single high/low combination, neap tide.

Single high low combination neap tide							
	To			Palmers			
	From	(16km)	Yamba		Maclean	(8km)	
Moon	Date	L/H	H/L		L/H	H/L	
Half	17/03/2024	0.248	0.29		0.341	0.294	
Half	2/04/2024	0.218	0.23		0.249	0.244	
Half	16/04/2024	0.311	0.244		0.276	0.231	
Half	1/05/2024	0.381	0.24		0.253	0.226	
Half	15/05/2024	0.321	0.295		0.296	0.281	
Half	14/06/2024	0.355	0.311		0.325	0.331	
Half	29/06/2024	0.348	0.287		0.328	0.336	
	14/06/2024	0.245	0.185		0.243	0.231	
							Mean diff
	Spread		0.196		0.115		
	Mean		0.282		0.280		0.002
	AHD HMWH			0.374			

Table A4: Palmers from Yamba and Maclean – 1-day mean, spring tide.

1 day mean spring tide					
	To		Palmers		
	From	Yamba		Maclean	
Moon	Date				
New	10/02/2024	0.384		0.343	
New	10/03/2024	0.393		0.363	
Full	25/03/2024	0.376		0.355	
Full	24/04/2024	0.432		0.351	
New	8/05/2024	0.435		0.367	
Full	12/05/2024	0.409		0.364	
New	6/06/2024	0.369		0.35	
Full	22/06/2024	0.352		0.362	
New	6/07/2024	0.376		0.384	
Full	21/07/2024	0.356		0.369	
					Mean diff
	Spread	0.083		0.041	
	Mean	0.388		0.363	0.025
	AHD HMWH		0.374		

Table A5: Palmers from Yamba and Maclean – 1-day mean, neap tide.

1 day mean neap tide					
	To		Palmers		
	From	Yamba		Maclean	
Moon	Date				
Half	17/02/2024	0.351		0.317	
Half	1/05/2024	0.308		0.273	
Half	2/04/2024	0.28		0.274	
Half	16/04/2024	0.323		0.269	
Half	15/05/2024	0.36		0.307	
Half	14/06/2024	0.335		0.313	
Half	29/06/2024	0.344		0.334	
Half	14/07/2024	0.289		0.284	
					Mean diff
	Spread	0.08		0.065	
	Mean	0.324		0.296	0.028
	AHD HMWH		0.374		

Table A6: Palmers from Yamba and Maclean – 3-day mean, spring tide.

3 day mean spring tide					
	To		Palmers		
	From	Yamba		Maclean	
Moon	Date				
Full	25/03/2024	0.366		0.351	
Full	24/04/2024	0.426		0.347	
New	8/05/2024	0.43		0.366	
New	6/06/2024	0.363		0.346	
Full	22/06/2024	0.348		0.346	
New	6/07/2024	0.365		0.381	
Full	21/07/2024	0.35		0.366	
					Mean diff
	Spread	0.082		0.035	
	Mean	0.378		0.358	0.02
	AHD HMWH		0.374		

Table A7: Palmers from Yamba and Maclean – 3-day mean, neap tide.

3 day mean neap tide					
	To		Palmers		
	From	Yamba		Maclean	
Moon	Date				
Half	17/02/2024	0.323		0.323	
Half	1/05/2024	0.323		0.397	
Half	15/05/2024	0.368		0.312	
Half	14/06/2024	0.311		0.3	
Half	29/06/2024	0.344		0.34	
Half	14/07/2024	0.293		0.293	
					Mean diff
	Spread	0.075		0.104	
	Mean	0.327		0.328	0.001
	AHD HMWH		0.374		

A2 Ulmarra

Table A8: Ulmarra from Brushgrove and Grafton – single high/low combination, predicted spring tide.

Single high low combination predicted high spring tide							
	To			Ulmarra			
	From	(9km)	Brusghrove		Grafton	(12km)	
Moon	Date	L/H	H/L		L/H	H/L	
Full	24/03/2024	0.362	0.363		0.286	0.283	
Full	25/04/2024	0.355	0.357		0.27	0.268	
New	8/05/2024	0.368	0.37		0.282	0.284	
New	6/06/2024	0.366	0.371		0.306	0.304	
Full	23/06/2024	0.364	0.368		0.306	0.3	
New	5/07/2024	0.364	0.367		0.304	0.3	
Full	22/07/2024	0.368	0.371		0.301	0.298	
							Mean diff
	Spread		0.016		0.038		
	Mean		0.365		0.292		0.073
	AHD MHWH			0.396			

Table A9: Ulmarra from Brushgrove and Grafton – single high/low combination, highest spring tide.

Single high low combination highest spring tide							
	To			Ulmarra			
	From	(9km)	Brusghrove		Grafton	(12km)	
Moon	Date	L/H	H/L		L/H	H/L	
Full	24/03/2024	0.362	0.363		0.286	0.283	
Full	25/04/2024	0.355	0.357		0.27	0.286	
New	7/05/2024	0.371	0.372		0.28	0.277	
New	6/06/2024	0.366	0.371		0.305	0.301	
Full	23/06/2024	0.364	0.368		0.306	0.3	
New	4/07/2024	0.358	0.363		0.301	0.296	
Full	21/07/2024	0.365	0.368		0.301	0.298	
							Mean diff
	Spread		0.017		0.036		
	Mean		0.365		0.292		0.072
	AHD MHWH			0.396			

Table A10: Ulmarra from Brushgrove and Grafton – single high/low combination, neap tide.

Single high low combination neap tide							
	To			Ulmarra			
	From	(9km)	Brusghrove		Grafton	(12km)	
Moon	Date	L/H	H/L		L/H	H/L	
Half	2/04/2024	0.395	0.383		0.265	0.266	
Half	16/04/2024	0.364	0.374		0.249	0.239	
Half	1/05/2024	0.369	0.378		0.272	0.269	
Half	15/05/2024	0.4	0.406		0.279	0.276	
Half	14/06/2024	0.379	0.391		0.294	0.284	
Half	29/06/2024	0.373	0.378		0.296	0.291	
Half	14/06/2024	0.371	0.381		0.3	0.291	
							Mean diff
	Spread		0.042		0.061		
	Mean		0.382		0.277		0.105
	AHD MHWH			0.396			

Table A11: Ulmarra from Brushgrove and Grafton – 1-day mean, spring tide.

1 day mean spring tide					
	To		Ulmarra		
	From	Brushgrove		Grafton	
Moon	Date				
Full	25/03/2024	0.36		0.278	
Full	24/04/2024	0.371		0.26	
New	8/05/2024	0.374		0.278	
Full	12/05/2024	0.377		0.298	
New	6/06/2024	0.376		0.297	
Full	22/06/2024	0.373		0.296	
New	6/07/2024	0.372		0.294	
Full	21/07/2024	0.367		0.295	
					Mean diff
	Spread	0.017		0.038	
	Mean	0.371		0.287	0.084
	AHD HMWH		0.396		

Table A12: Ulmarra from Brushgrove and Grafton – 1-day mean, neap tide.

1 day mean neap tide					
	To		Ulmarra		
	From	Brushgrove		Grafton	
Moon	Date				
Half	1/05/2024	0.363		0.221	
Half	2/04/2024	0.374		0.277	
Half	16/04/2024	0.364		0.26	
Half	15/05/2024	0.387		0.292	
Half	14/06/2024	0.379		0.296	
Half	29/06/2024	0.372		0.297	
Half	14/07/2024	0.374		0.292	
					Mean diff
	Spread	0.024		0.076	
	Mean	0.373		0.276	0.097
	AHD HMWH		0.396		

Table A13: Ulmarra from Brushgrove and Grafton – 3-day mean, spring tide.

3 day mean spring tide					
	To		Ulmarra		
	From	Brushgrove		Grafton	
Moon	Date				
Full	25/03/2024	0.361		0.28	
Full	24/04/2024	0.368		0.262	
New	8/05/2024	0.375		0.28	
New	6/06/2024	0.375		0.298	
Full	22/06/2024	0.368		0.3	
New	6/07/2024	0.37		0.295	
Full	21/07/2024	0.37		0.292	
					Mean diff
	Spread	0.014		0.038	
	Mean	0.370		0.287	0.083
	AHD HMWH		0.396		

Table A14: Ulmarra from Brushgrove and Grafton – 3-day mean, neap tide.

3 day mean neap tide					
	To		Ulmarra		
	From	Brushgrove		Grafton	
Moon	Date				
Half	1/05/2024	0.366		0.27	
Half	15/05/2024	0.385		0.295	
Half	14/06/2024	0.377		0.295	
Half	29/06/2024	0.372		0.297	
Half	14/07/2024	0.375		0.292	
					Mean diff
	Spread	0.019		0.027	
	Mean	0.375		0.290	0.085
	AHD HMWH		0.396		

A3 Estuary Traverse

Table A15: Estuary traverse from Yamba – 3-day mean, spring tide.

Estuary Traverse 3 day means spring tide									
moon	Date	Yamba	Palmers	Maclean	Lawrence	Brushgrove	Ulmarra	Grafton	Rogans Br
Full	25/03/2024	0.522	0.366	0.323	0.37	0.405	0.415	0.631	0.512
Full	24/04/2024	0.522	0.426	0.392	0.441	0.489	0.506	0.74	0.614
New	8/05/2024	0.522	0.43	0.376	0.412	0.443	0.467	0.683	0.567
New	6/06/2024	0.522	0.363	0.329	0.371	0.402	0.426	0.624	0.51
Full	22/06/2024	0.522	0.348	0.294	0.342	0.371	0.388	0.584	0.455
New	6/07/2024	0.522	0.365	0.3	0.347	0.373	0.391	0.593	0.466
Full	21/07/2024	0.522	0.35	0.297	0.344	0.378	0.397	0.602	0.462
	AHD MHWH	0.522	0.374	0.307	0.33	0.351	0.396	0.496	0.463
	Spread		0.082	0.098	0.099	0.118	0.118	0.156	0.159
	Mean		0.378	0.330	0.375	0.409	0.427	0.637	0.512

Table A16: Estuary traverse from Yamba – 3-day mean, neap tide.

	Estuary Traverse 3 day means neap tide								
moon	Date	Yamba	Palmers	Maclean	Lawrence	Brushgrove	Ulmarra	Grafton	Rogans Br
Half	1/05/2024	0.522	0.323	0.333	0.384	0.423	0.438	0.667	0.529
Half	15/06/2024	0.522	0.368	0.361	0.422	0.476	0.51	0.713	0.609
Half	14/06/2024	0.522	0.311	0.318	0.37	0.413	0.439	0.642	0.514
Half	29/06/2024	0.522	0.344	0.308	0.362	0.402	0.423	0.623	0.483
Half	14/07/2024	0.522	0.293	0.311	0.373	0.421	0.445	0.65	0.516
	AHD MHWH	0.522	0.374	0.307	0.33	0.351	0.396	0.496	0.463
	Spread		0.075	0.053	0.06	0.074	0.087	0.09	0.126
	Mean		0.328	0.326	0.382	0.427	0.451	0.659	0.530

Table A17: Estuary traverse from Yamba – 3-day mean, spring tide.

Estuary direct from Yamba 3 day means spring tides									
moon	Date	Yamba	Palmers	Maclean	Lawrence	Brushgrove	Ulmarra	Grafton	Rogans Br
Full	25/03/2024	0.522	0.366	0.321	0.367	0.404	0.415	0.632	0.515
Full	24/04/2024	0.522	0.426	0.378	0.426	0.477	0.497	0.735	0.611
New	8/05/2024	0.522	0.43	0.372	0.408	0.439	0.461	0.675	0.556
New	6/06/2024	0.522	0.363	0.247	0.361	0.393	0.418	0.617	0.503
Full	22/06/2024	0.522	0.348	0.29	0.338	0.368	0.386	0.582	0.452
New	6/07/2024	0.522	0.365	0.295	0.342	0.368	0.386	0.585	0.457
Full	21/07/2024	0.522	0.35	0.292	0.338	0.372	0.392	0.597	0.457
	AHD MHWH	0.522	0.374	0.307	0.33	0.351	0.396	0.496	0.463
	Spread		0.082	0.131	0.088	0.109	0.111	0.153	0.159
	Mean		0.378	0.314	0.369	0.403	0.422	0.632	0.507

Table A18: Estuary traverse from Yamba – 3-day mean, neap tide.

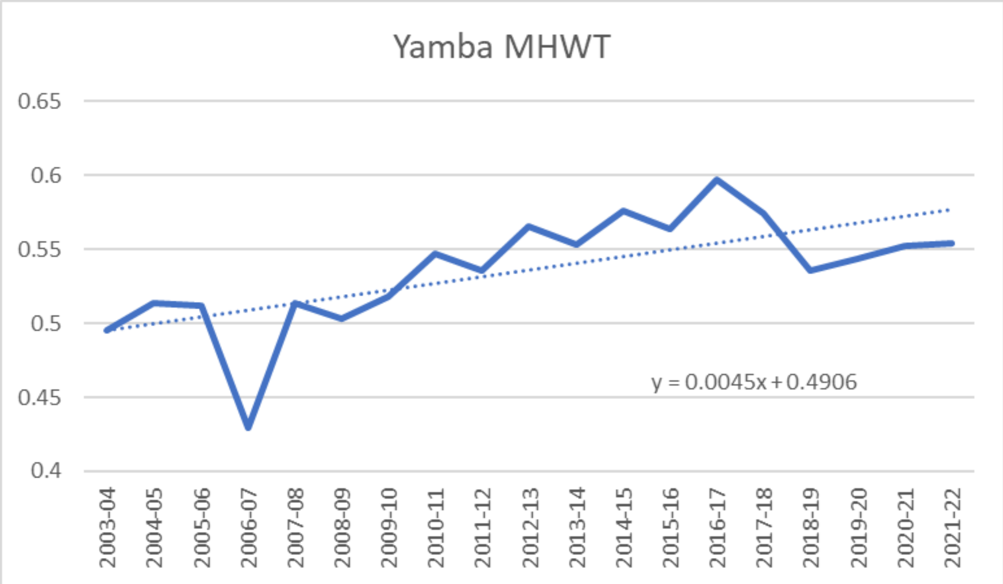
Estuary direct from Yamba 3 day means neap tides									
Moon	Date	Yamba	Palmers	Maclean	Lawrence	Brushgrov	Ulmarra	Grafton	Rogans Br
Half	1/05/2024	0.522	0.323	0.329	0.382	0.426	0.449	0.689	0.563
Half	15/05/2024	0.522	0.368	0.355	0.42	0.481	0.524	0.737	0.63
Half	14/06/2024	0.522	0.311	0.314	0.365	0.415	0.45	0.665	0.556
Half	29/06/2024	0.522	0.344	0.306	0.36	0.403	0.429	0.633	0.499
Half	14/07/2024	0.522	0.293	0.307	0.37	0.427	0.461	0.68	0.565
	AHD MHWH	0.522	0.374	0.307	0.33	0.351	0.396	0.496	0.463
	Spread		0.075	0.049	0.06	0.078	0.095	0.104	0.131
	Mean		0.328	0.322	0.379	0.430	0.463	0.681	0.563

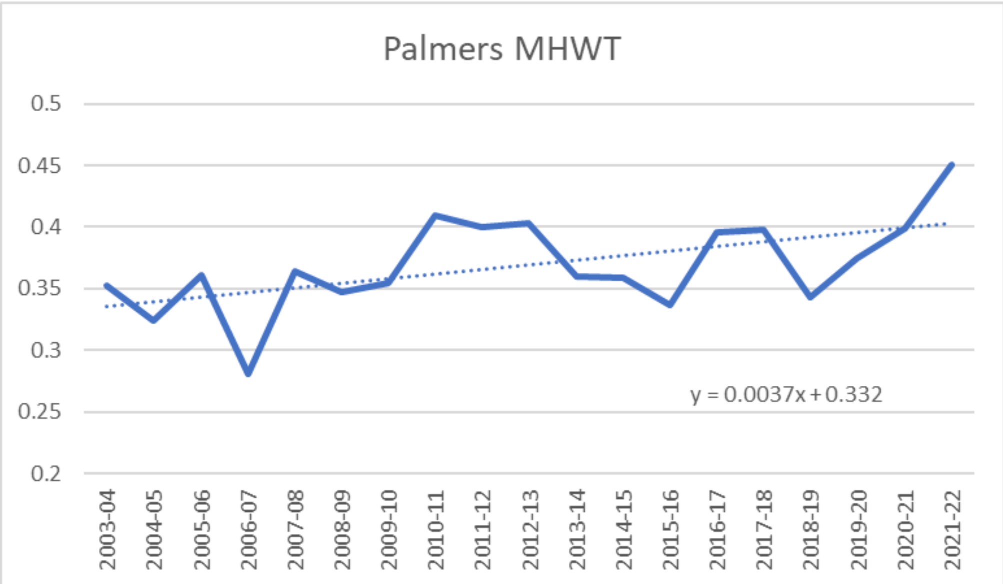
Table A19: Estuary 3-day mean traverse – direct comparison.

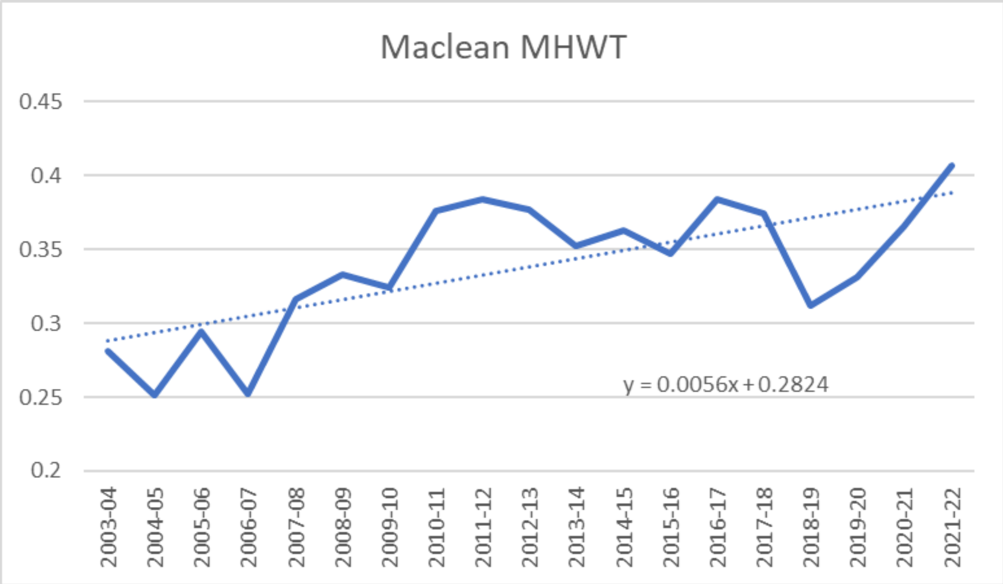
Estuary 3 day traverse - direct comparison									
		Yamba	Palmers	Maclean	Lawrence	Brushgrov	Ulmarra	Grafton	Rogans Br
	AHD MHWH	0.522	0.374	0.307	0.33	0.351	0.396	0.496	0.463
3 day trav spring		0.522	0.378	0.330	0.375	0.409	0.427	0.637	0.512
3 day direct spring		0.522	0.378	0.314	0.369	0.403	0.422	0.632	0.507
trav-direct diff			0	0.017	0.007	0.006	0.005	0.005	0.005
3 day trav neap		0.522	0.328	0.326	0.382	0.427	0.451	0.659	0.530
3 day direct neap		0.522	0.328	0.322	0.379	0.430	0.463	0.681	0.563
trav-direct diff			0	0.004	0.003	-0.003	-0.012	-0.022	-0.032
spring-neap trav diff			0.050	0.004	-0.007	-0.018	-0.024	-0.022	-0.018
spring-neap direct diff			0.050	-0.009	-0.011	-0.027	-0.040	-0.049	-0.055

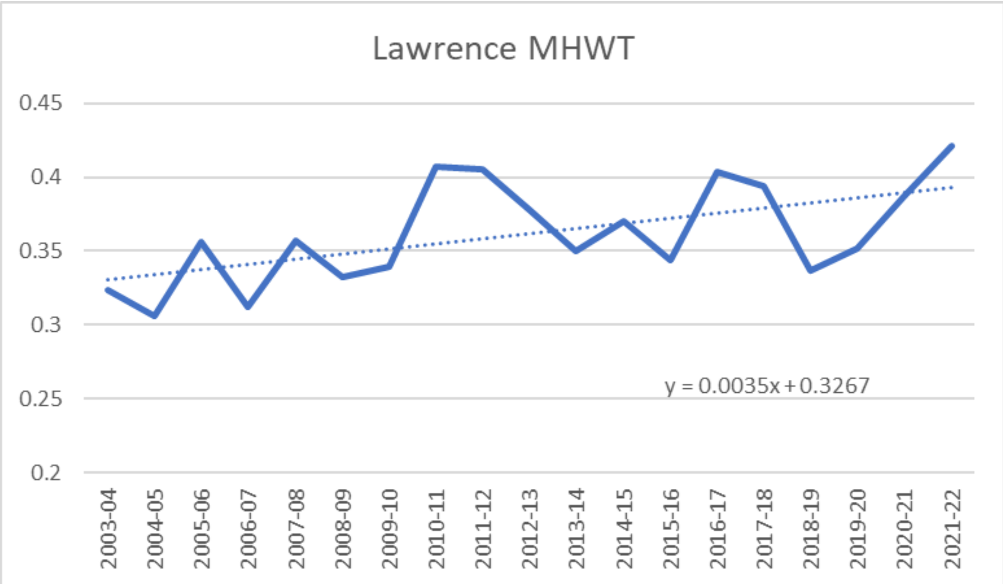
APPENDIX B

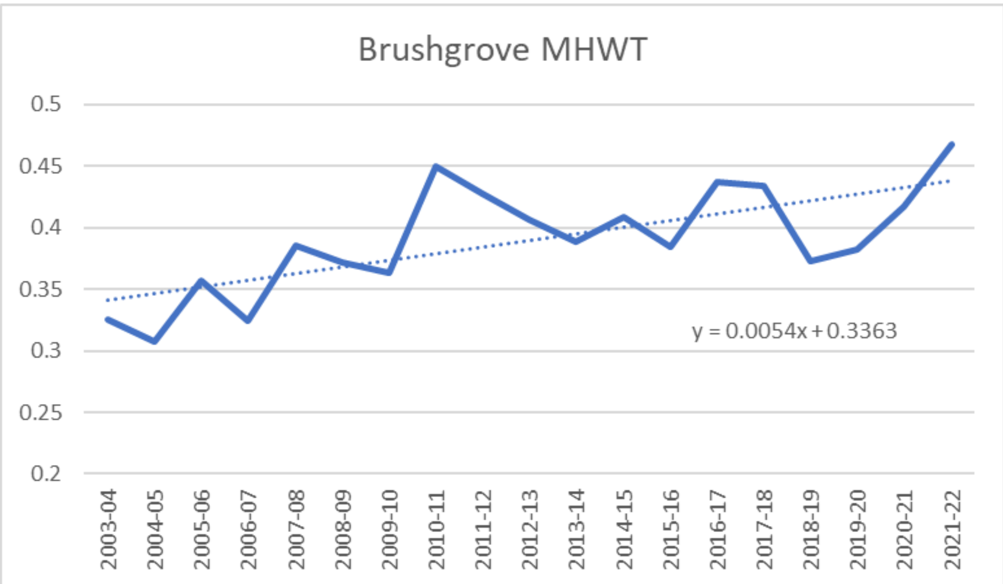
Trent assessment of MHWT data for each Clarence River tide gauge:






Maclean MHWT
0.45
0.4
0.35
0.3
0.25
0.2
y = 0.0056x + 0.2824
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22


Lawrence MHWT
0.45
0.4
0.35
0.3
0.25
0.2
y = 0.0035x + 0.3267
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22


Brushgrove MHWT
0.5
0.45
0.4
0.35
0.3
0.25
0.2
y = 0.0054x + 0.3363
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
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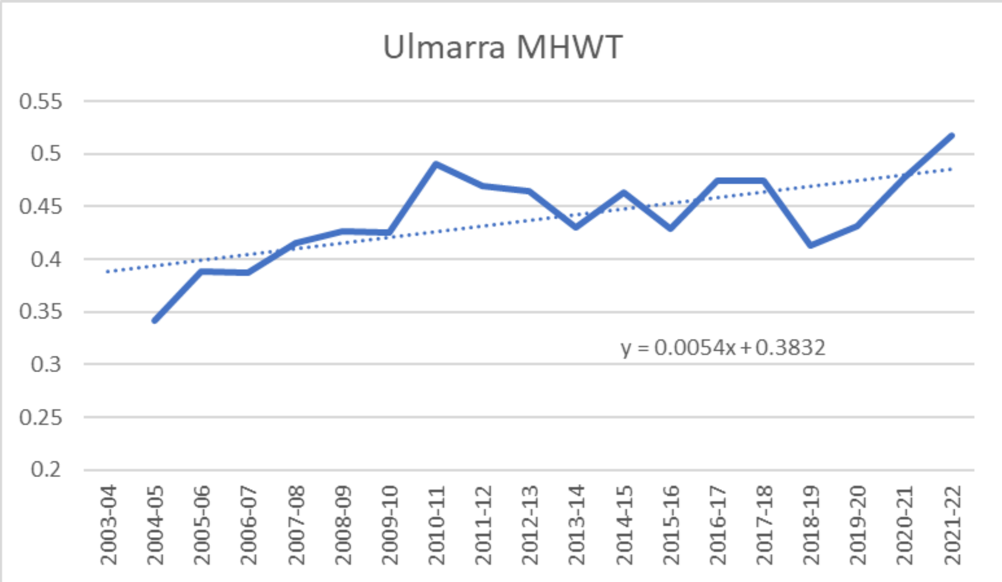
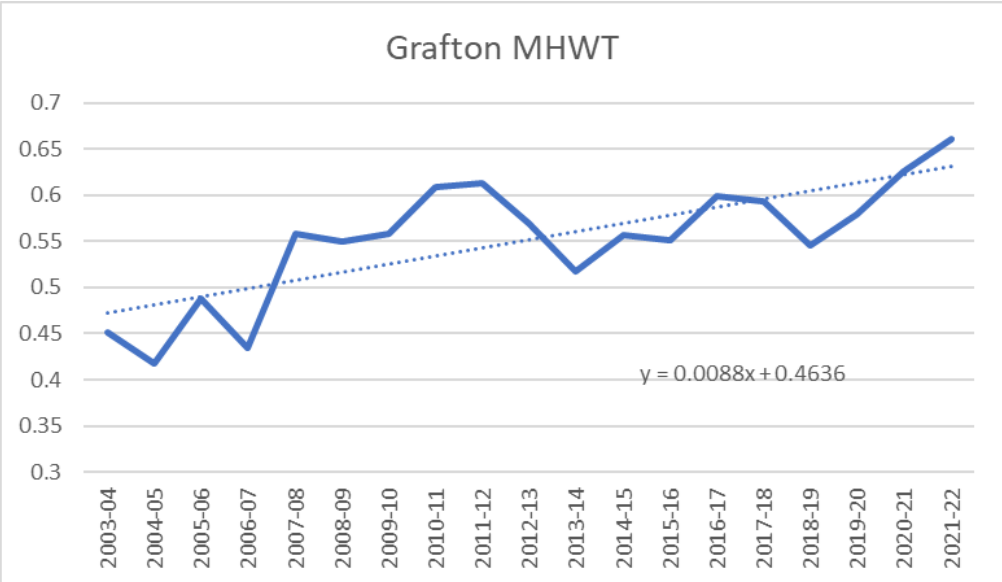
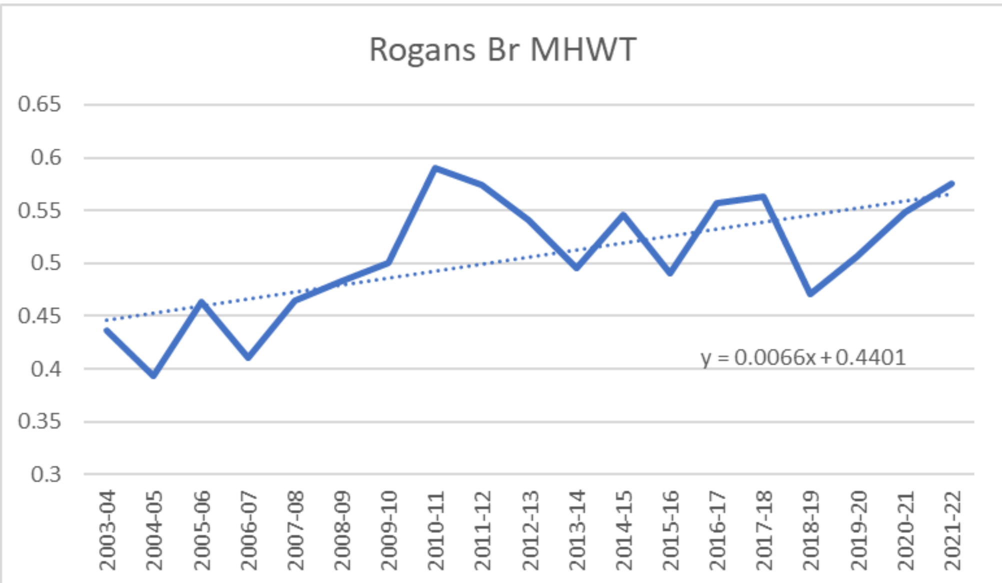
2018-19
2019-20
2020-21
2021-22

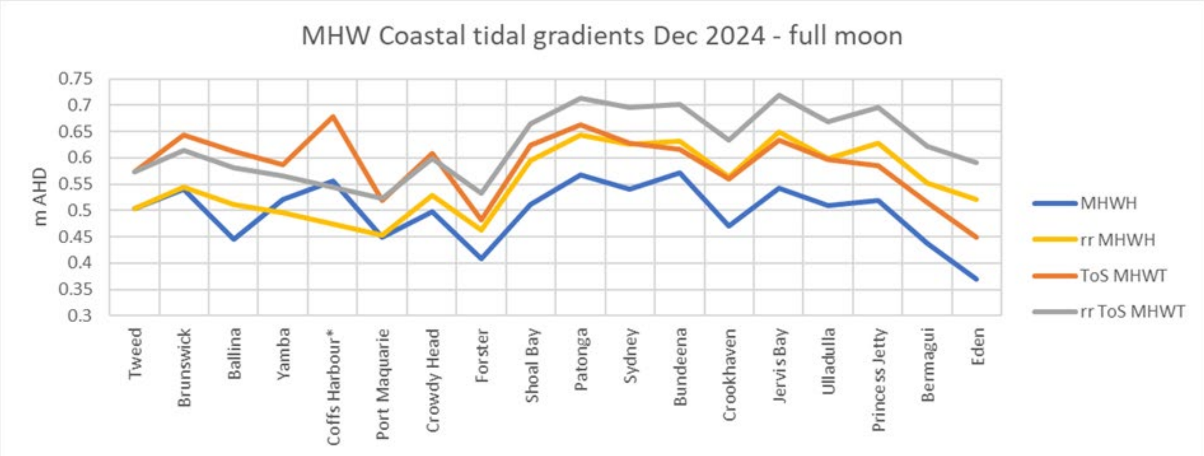

Ulmarra MHWT
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
y = 0.0054x + 0.3832
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22


Grafton MHWT
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
y = 0.0088x + 0.4636
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22


Rogans Br MHWT
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
y = 0.0066x + 0.4401
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22

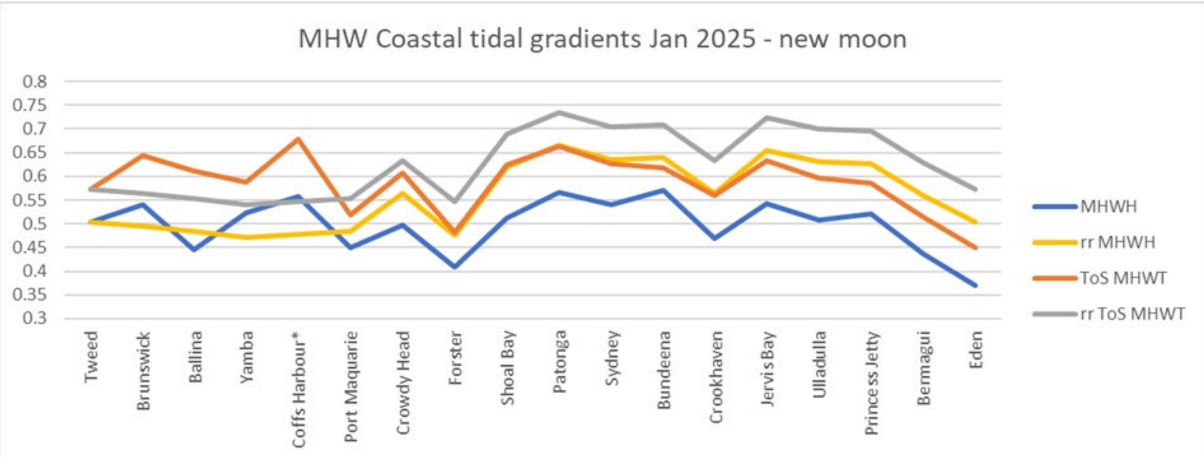
APPENDIX C: MHW TRANSFER ALONG THE COAST

Conducting a MHW transfer along the coast is another case that must be given some consideration. It has already been found that the conditions close to the coast tend to degrade the accuracy potential of range ratio. To see if range ratio is viable along the coast, two range ratio differential height traverses have been conducted from Tweed Heads along the MHL coastal tide gauge network for 1,100 km to Eden and return (Figures C1 & C2). Using the lessons learnt in the estuary exercises, the observations between tide gauges were conducted over several days and the average height difference used to conduct the traverse. The traverse result was also compared to the direct MHW transfer from Tweed Heads to Eden.



Observation duration: 8 days surrounding full moon.
Loop misclose: 0.029 m. Data spread each leg traverse: 0.051 m – 0.247 m.
Difference at Eden traverse to direct: 0.008 m. Data spread Eden direct: 0.331 m.
Coffs Harbour*: data not available.

Figure C1: Traverse 1 – MHW coastal tidal gradients Dec 2024 (full moon).



Observation duration: 4.75 days surrounding new moon.
Loop misclose: 0.034 m. Data spread each leg traverse: 0.050 m – 0.244 m.
Difference at Eden traverse to direct: 0.060 m. Data spread Eden direct: 0.192 m.
Coffs Harbour*: data not available.

Figure C2: Traverse 2 – MHW coastal tidal gradients Jan 2025 (new moon).

These figures plot the range ratio traverse (rr) results against the harmonic calculated MHW (MHWH) and the estimated time of survey mean of high tides (ToS MHWT). The MHWH has been obtained from the 19-year means of 2001/02 to 2019/20 of each tide gauge in report MHL2786. The ToS MHWT has been estimated from a linear trend of yearly MHWT values of each tide gauge for the years 2003/04 to 2021/22 in report MHL2902.

What these figures tell us is yet to be determined. There are similarities and there are differences. The greatest variance between the range ratio traverse results and the comparison components is 0.14 m (at Eden). The greatest difference between the two traverse results is 0.05 m (at Brunswick Heads). What the numbers do suggest is that range ratio determination of MHW along the coast could be viable. With a misclose of less than 0.1 m for a run of 2,200 km, using tide ratios to transfer levels would be of a standard comparable to precise levelling which, over a similar distance, would have an allowable misclose of 0.094 m. Or is such a comparison not valid? Just as GNSS levelling is pushing beyond the limits of AHD, could range ratio be used to interrogate AHD values along the coast? But what are the issues?

The following should be considered:

- Is 4 days or 8 days of observational data enough or need there be more? The numbers suggest 8 days is better than 4.
- Would the results be similar if a similar exercise were conducted in 6 months' time?
- What impact do weather patterns have on the results? The weather patterns at the time were not noted as the observation period selected was based on the spring tide occurrence about the full or new moon.
- Do ocean currents impact the results?
- Many of the tide gauges are not at the ocean front but up to 1 km inside the estuary. What impact does this have on the true coast value of MHW? Can range ratio be used to transfer MHW between estuaries?
- What of Coffs Harbour? Could the tide gradient between the gauges either side indicate that the value of MHW at Coffs Harbour could be wrong? Or are there similar situations in the longer spans between gauges along the coast? Or is there a glitch in AHD at Coffs Harbour?
- What is the validity, or accuracy, of the tide gauge benchmark levels?
- Is this the real shape of MHW along the coast? Low in the north, rising to a long peak in the middle and falling even lower in the south.
- What other questions do these results raise?
- And of course, is such a technique valid?

No conclusions have been drawn from these observations. It is left to the reader to evaluate an outcome and to see where it might lead or if it could go further.