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Mean High Water and Tidal Gradients

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ABSTRACT

To find the level of Mean High Water (MHW), used to locate the intercept with the land for tidal cadastral boundary determinations, a number of methods have been used in everyday survey practice. One of those methods is the use of tidal gradients derived from long-running tide gauges throughout an estuary. The method has been used by surveyors in the past and is likely to be used in the future. However, many things change as our knowledge of processes is refined. Practices that once were commonly used, are no longer, and new procedures become the norm. This paper examines the tide gauges along 11 coastal estuaries in NSW, the data behind the derivation of MHW levels over time, and the interpolation to tidal gradients along an estuary. It analyses the data to see if the theory behind tidal gradients measures up to the standards required by the surveying regulations and our changing knowledge base.

KEYWORDS: *Mean High Water, tide gauges, tidal gradients, tidal cadastral boundary.*

1 INTRODUCTION

The Mean High Water Mark (MHWM), or more correctly, the intercept of the Mean High Water (MHW) tidal plane against the land, is not a natural boundary. It is an artificial construction handed down to surveyors from the legal system. The boundary is not a definitive line that can be found in nature (QLD Department of Environment, Science and Innovation, 2019). The habitat of species does not stop at a fixed line but transitions across a range about that line. For example, mangroves tend to grow between Mean Sea Level (MSL) and MHW, which places the MHWM about the landward edge of the bulk of mangroves (Stewart and Fairfull, 2008). Some species, however, grow across the MHWM so the demarcation line gets a little blurred.

The legal system imposed its own ‘appropriate measure’, a quarter of a lunar cycle or the mean of high tides between ordinary neap and spring tides. Unfortunately, such a method of measure is highly inaccurate as it changes considerably over even a short period in time, so surveyors have had to resort to other processes to find the appropriate level in a more reliable way, even though the legal definition of the tidal cadastral land boundary would dictate to the contrary (Songberg, 2020).

Where the bank of the estuary is very steep or vertical and encompasses the full range of high tides, the riparian boundary will mimic a natural interface. In other areas where the foreshore is relatively flat or gently sloping, the only way to find the tidal cadastral boundary is to find the level at which MHW sits and project that level laterally to locate the tidal/land boundary. To undertake a MHWM definition, Surveyor-General’s Direction No. 6 (DCS Spatial Services, 2016), which is under review at the time of writing, directs a surveyor to part 6 section 22 (the back) of the Manual of the NSW Integrated Survey Grid (ISG), published by the Department of Lands in 1976 where several methods are discussed (Lands, 1976).

In the levelling from benchmarks paragraph, the manual indicates that “in locations on the sea coast and in close proximity of the gauges”, “the position of mean high water can be fixed by normal differential levelling procedures from bench marks related to A.H.D.” (Australian Height Datum). The manual does give fair warning that “this method cannot be used with accuracy in positions within estuaries and streams unless reliable information on tidal gradients is available.” There is certainly an inference that if there were sufficient tide gauges within the estuary and a tidal gradient could be established along the estuary, then the method could be useable. When the manual was published, there were only a few tide gauges referenced (those in major ports along the coast). Since then, a whole network of gauges has been established under the management of the Manly Hydraulics Laboratory (MHL). Surveyor-General’s Direction No. 6 even directs surveyors to MHL to obtain tidal plane statistical data to assist in the definition.

The use of tidal gradients to find MHW seems to be a simple process, using a tide gauge network related to the AHD network of marks. Know the AHD level of MHW at the end points, know the AHD of survey marks in between, relate AHD levels to the foreshore, and locate the intercept of the calculated MHW level against the foreshore at the survey site. Then mark out the boundary for that tidal plane intercept, job done. But has any consideration been given to the integrity of the data being used? Is it accurate? Will it be of a standard that would meet with the requirements of the surveying regulations to which surveyors must adhere? In this paper, the tidal gradients of nine tidal estuaries along the NSW coast are examined together with the data that provides surveyors with AHD values of MHW from over 60 tide gauges to see if these questions can be confidently answered.

2 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.

2.1 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).

2.2 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.

2.3 MHW – MHL Tidal Planes

Since then, time along with 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 recently 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 (https://www.mhl.nsw.gov.au/). These publications provided easy access to the 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. In the last few years, the more recent report has become available with newer tidal data (which is also available on the MHL website), although the data from some sites is missing. 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 cadastral determinations although it has been in the past.

2.4 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 1) has also been published on the MHL website under the heading of Mean High Water on the tide gauge site page.

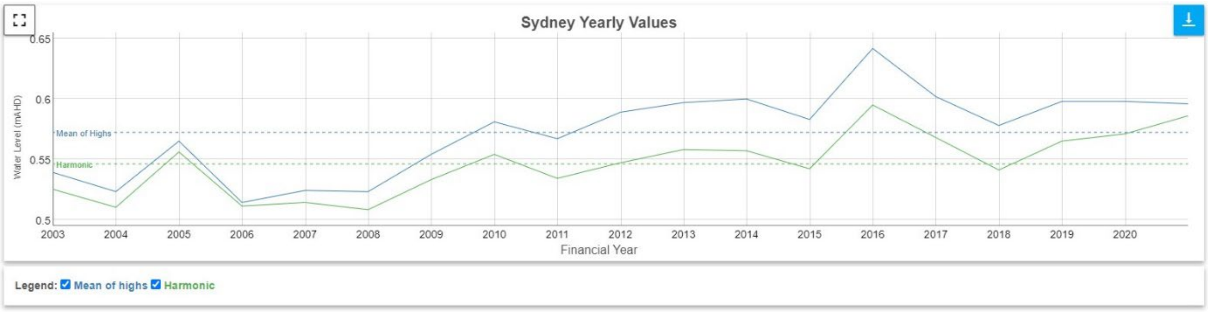

Figure 1: Mean of high tides (MHWT) compared to the harmonic mean (MHWH) (MHL website).

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 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.

2.5 MHW – Time of Survey

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 2).

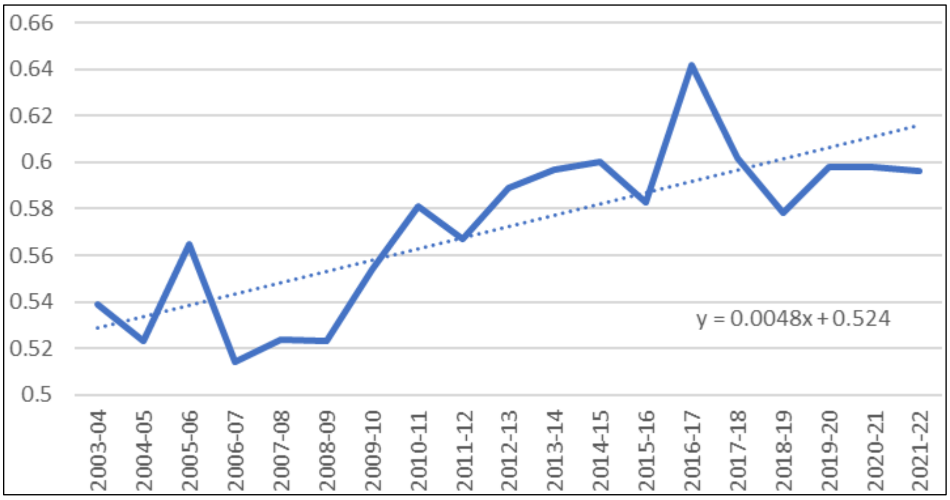

Figure 2: Sydney (Middle Head) mean high tides trend (MHL data).

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 engineering purposes.

3 ESTUARY TIDAL GRADIENTS

All tidal data making up the estuary tidal gradients is available from Manly Hydraulics Laboratory and its website. All data can be utilised 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.

Tidal gradients along an estuary, or (as MHL describes them) the longitudinal tidal planes, have been plotted in MHL2786 for each tidal component (Figure 3). It provides easy to see offsets for each component and the gradients in between each gauge station that link along the estuary.

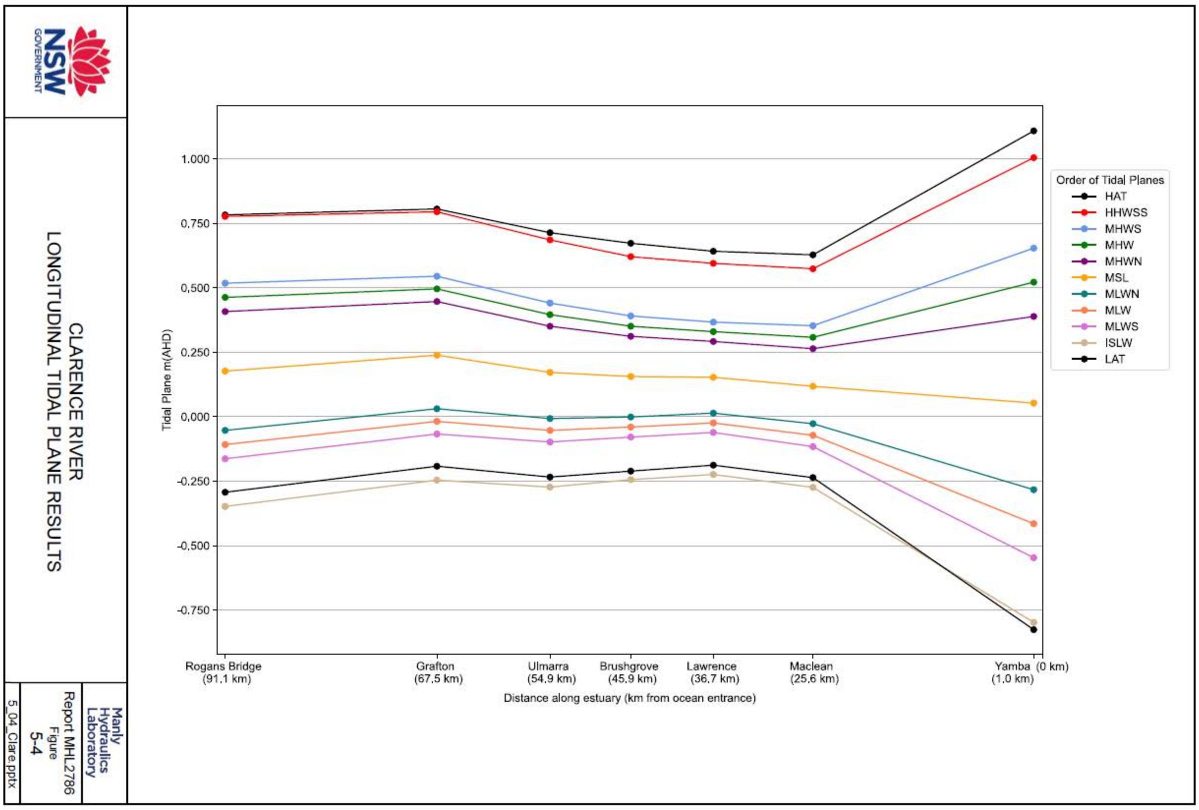

Figure 3: Typical estuary longitudinal tidal gradient chart (from MHL2786 report).

A similar chart is also found in the MHL2902 report but as there are only two components dealt with in this report, only the two related gradients are plotted, i.e. MHWH and MHWT (Figure 4). Generally, MHWT is higher than MHWH according to the tabulated values and charts but not always.

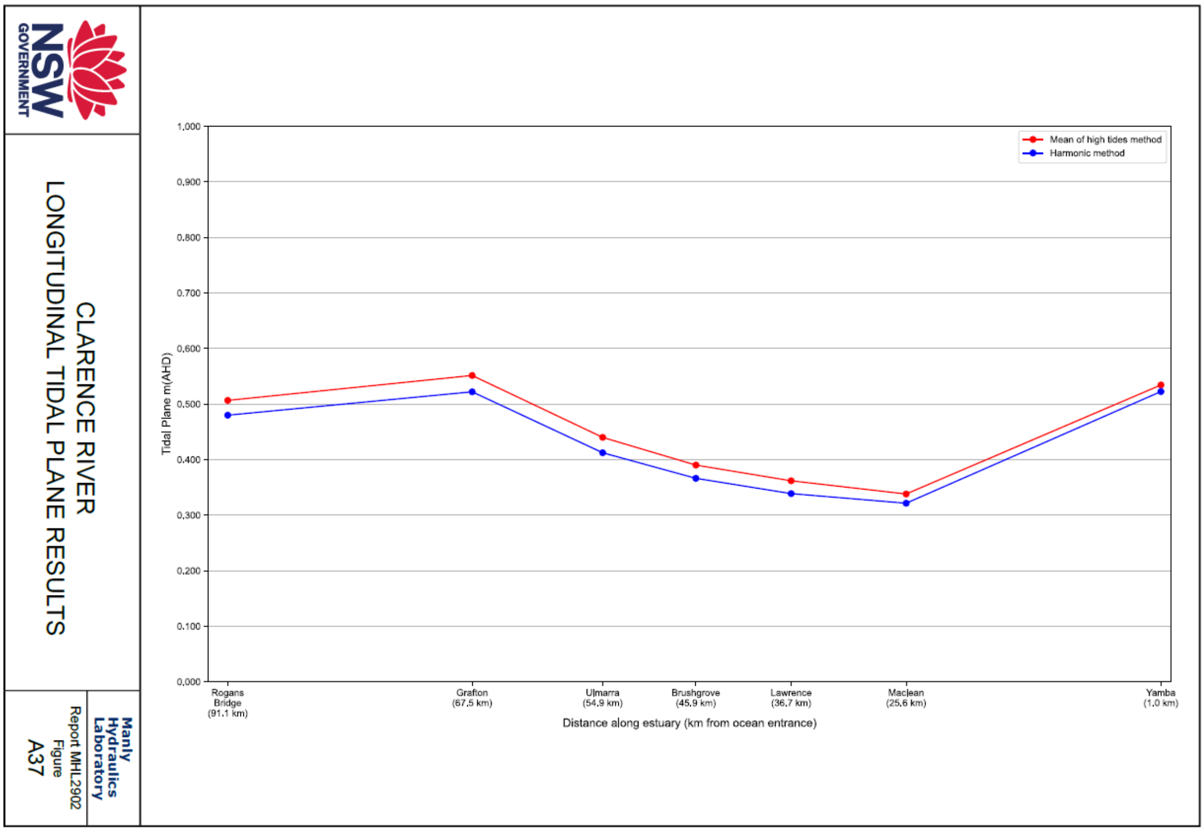

Figure 4: Typical estuary longitudinal tidal gradient chart (from MHL2902 report).

The tidal gradients are not just a series of points along an estuary related by level. There are many components that go into making up such a gradient. Each one has its own characteristics and to change one will change the profile of the gradient. Change the uncertainty level of any component and the uncertainty of the gradient also changes.

Surveyors working through the surveying regulations are required to undertake their work to a required level of certainty, or accuracy. Surveying outcomes generally rely on a system of checks to ensure that the answer is within the prescribed tolerances. Surveyors, at times though, must rely on the input data that is available in formulating an answer. Even then, there should be some form of assessing the reliability of that data. Basic surveying does not adopt a level of a single survey mark but checks against another at the very least.

The tidal gradient is one of the data inputs that the surveyor generally relies upon, and accepts, when undertaking a tidal boundary investigation. Even though the MHW levels associated with the tidal gradients are commonly used, how can a surveyor be sure of the accuracies, and uncertainties, of the components that make up the tidal gradients. What if the accuracy of the tidal gradient components did not meet with the standards required, and how would a surveyor know? Each of the MHL reports makes a very pointed disclaimer regarding possible errors in the documents or that the data is fit for any particular purpose. It is up to the user ensure that the information is suitable for use in a particular application.

Undoubtedly the data within the reports is suitably accurate and of sufficient reliability for the purpose in which it was originally produced. Rather than accept the data for what it portrays, for surveyors an examination is needed of the components to gauge their accuracies and asses the level of uncertainties for surveying purposes, particularly cadastral surveying.

4 TIDAL GRADIENT COMPONENT UNCERTAINTIES

To simplify the process, the tidal gradient components can be grouped together into just a few main broader components:

- The tidal values such as MHW, MSL and so forth.
- The tide gauge benchmark to which the tidal values are related and thus compared.
- The Australian Height Datum, which in this case links all the tide gauges together.
- Tide gauge location.

4.1 Tidal Values

Between the three identified MHL reports, there are now MHW datasets for a period of over 30 years. It would be desirable to combine all these datasets to get a reasonably clear picture of what the tidal values have been doing over that period and get a clearer picture of where things are likely to go in the immediate future. Unfortunately, there were some limitations uncovered that made such an undertaking difficult.

Each of the reports covers a period of 19 financial years, but they overlap each other. There is a 9-year overlap between MHL2053 and MHL2786, 7-year overlap between MHL2053 and MHL2902, and 17-year overlap between MHL2786 and MHL2902. The overlapping data only pertains to MHWH as it is tabled in each report. As MHWT is only tabled in MHL2902, there is no overlapping data, and it stands alone.

With a comparison possible between the MHWH datasets, an assessment of the tidal values can be made. It would not be too difficult to expect that for the same tides on the same date and with the same computation, the same MHW value would be realised no matter when that computation was made. However, such an assumption does not hold, as differences between datasets of up to 0.15 m were discovered between reports. The MHL2053 and MHL2786 reports indicate the same computational structure was used and differ only in the overall time period of reporting. The overlapping data shows a tendency for the MHL2053 data to be slightly higher than the MHL2786 values (Figure 5).

The comparison between MHL2053 and MHL2902 generally disclosed a more scattered result, but because of a computational difference used by MHL2902 the data comparison is a little unclear in the short overlap period. With the longer overlap period with MHL2786, a consistent wave-like difference pattern emerges (Figure 6).

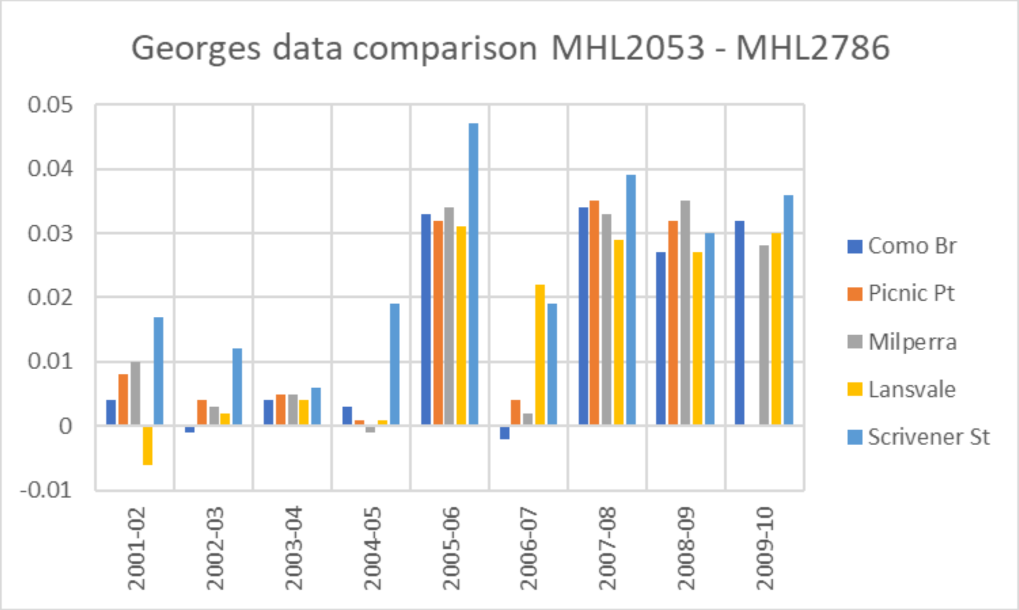

Figure 5: Data comparison for Georges River (MHL2053 to MHL2786).

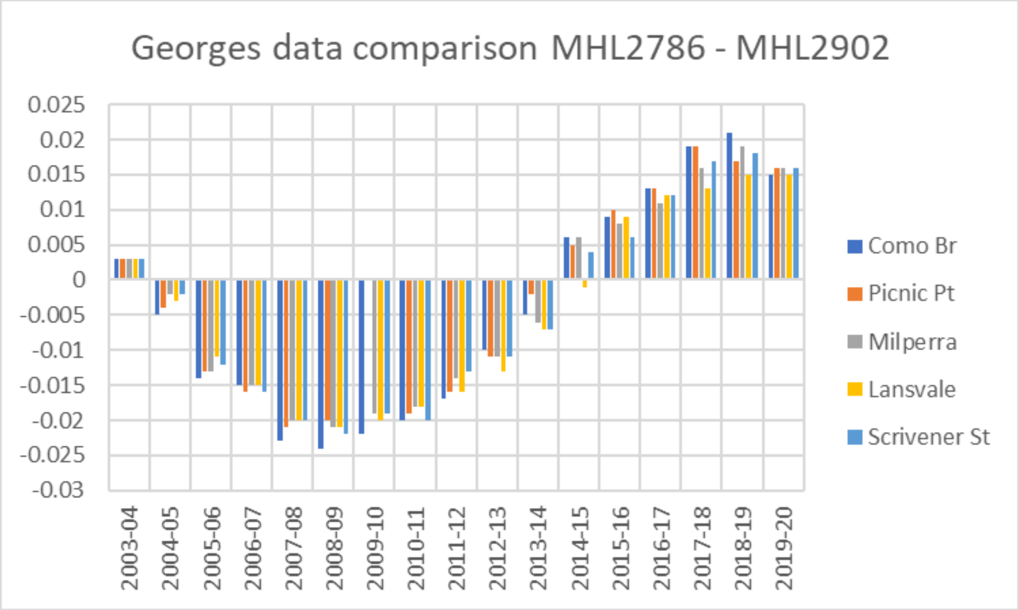

Figure 6: Data comparison for Georges River (MHL2786 to MHL2902).

These differences in the data and the different computational technique applied in the MHL2902 data make combining all three reports into a 30-year data bank uncertain. That there is a difference in the reported MHWH value for a particular year between datasets is an issue in itself as to the reliability or uncertainty of the reported data values. The data comparison also highlights data that stands out from the rest of the trend as a possible outlier being potentially erroneous (Figures 7 & 8). Across the nine estuaries examined, quite a few data outliers were discovered.

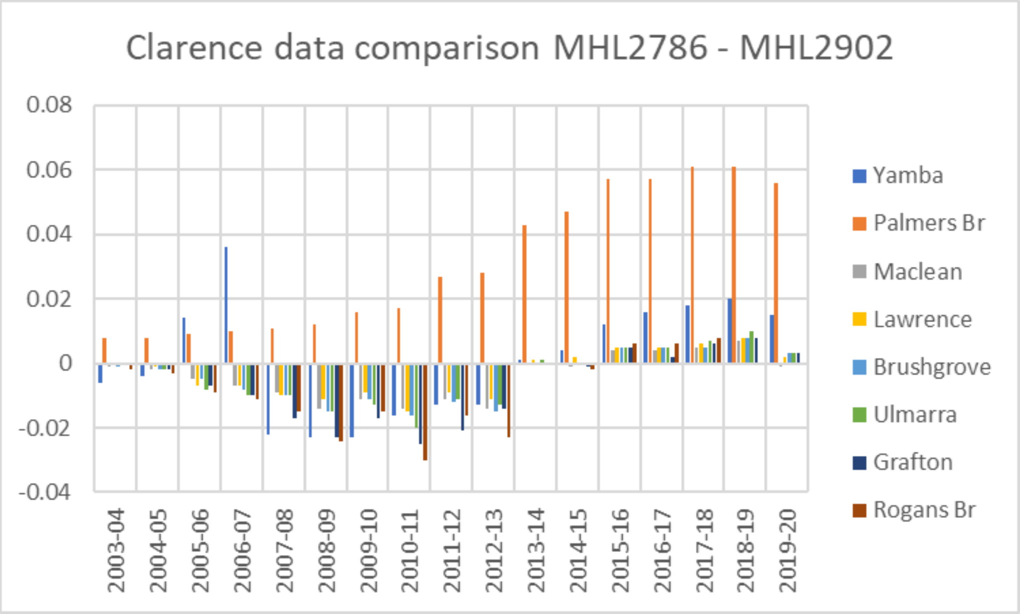

Figure 7: Data comparison for Clarence River (MHL2786 to MHL2902).

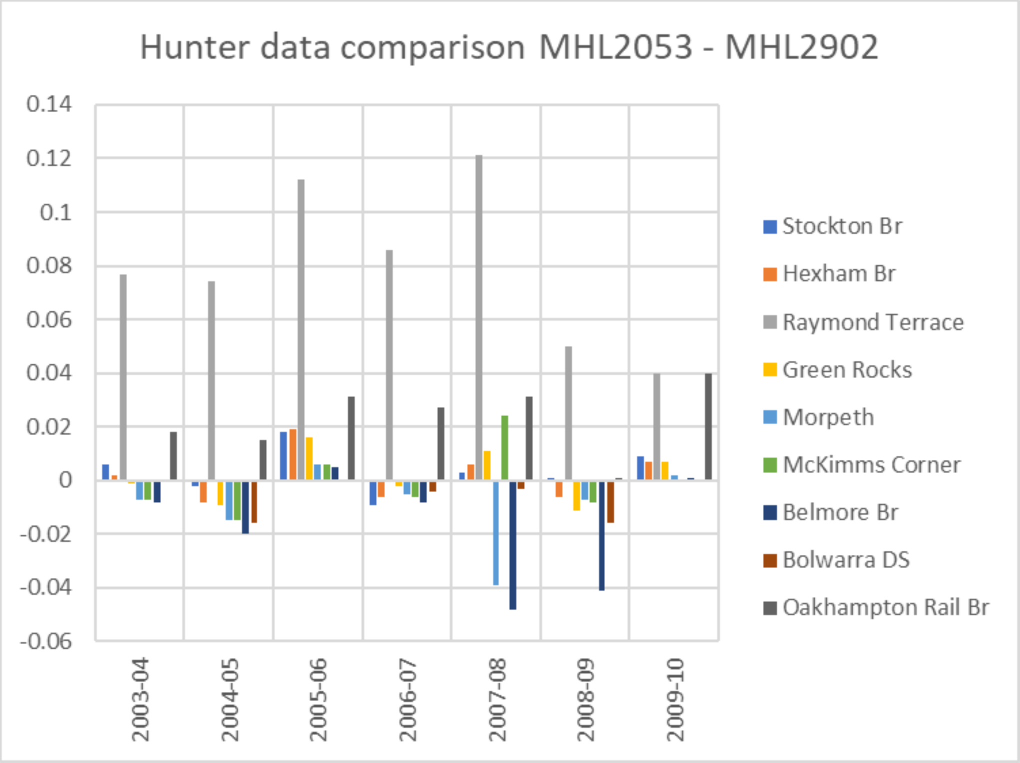

Figure 8: Data comparison for Hunter River (MHL2053 to MHL2902).

On the Clarence River, the Palmers Island Bridge data stands out as being substantially different to the rest of the data trend. The MHL2786 values appear to be higher in comparison to the overall data pattern. The associated range ratio exercise on the Clarence River (Songberg, 2025), utilising the MHL2786 data, found that the MHL2786 AHD mean for MHWH for Palmers Island Bridge was higher than what the range ratio computed value indicated. Yamba for 2005-06 and 2006-07 also produced outliers that stand out.

On the Hunter River, the MHWH values in MHL2053 for Raymond Terrace appear to be at odds with the other data. That imbalance is also in evident in the other comparisons, and so casts doubt on the accuracy of the Raymond Terrace data.

The tidal data for some tide gauges is not on AHD. Some are reported on the local hydrographic datum. Translating this data from the hydrographic datum to AHD can only be achieved by use of the conversion factor provided by MHL. These factors are listed in the various tidal planes reports and on the site reports of the MHL website. Each tide gauge has its own unique offset from the hydrographic datum to AHD. Surveyors must accept these values as being correct. There is no information provided that can be used to validate the information. If one, or more, of these conversion factors is not correct, then it would create an anomaly in the tidal gradient similar to what an anomaly in the AHD network would create. A hill or a hole could be created where in reality none exists.

The tidal data uncertainty disclosed by the data comparisons is of concern when trying to establish a reliable MHW value for both cadastral and engineering purposes. The uncertainty level of the tidal components from the harmonic analysis shows that for MHWH the uncertainty of the data is between ±0.15 m and ±0.33 m and is site specific (MHL, 2024). The MHWT values are simply the mean of the high tides that have gone through a filtering process, removing anomalous readings such as during floods. It is unclear as to what the uncertainty is of MHWT values. All these data differences are well within the specified tolerances so that the data is not considered as being incorrect, although it is not understood why there should be any difference. What must be decided by the surveyor is how correct the data is for the surveying purpose to which it is being used.

4.2 Tide Gauge Benchmark

The height values of State Survey Marks (SSMs) and Permanent Marks (PMs) held on public record within the Survey Control Information Management System (SCIMS) provide surveyors with a connection to the AHD network. If a surveyor wishes to add additional benchmarks to the network, there are protocols and accuracies that need to be complied with before such a mark can be accepted. In general terms, the new mark must be connected through a closed loop to two existing SCIMS marks that have accurate levels, are within 250 metres, and one should be within 30 metres. The result also must have at least class B or LD, or a vertical (AHD) uncertainty of at least 0.1 m or better (NSW Legislation, 2025).

The tidal gradients along the coast and inland along the tidal estuaries are not directly linked to AHD like the SCIMS marks. The link that ties the tidal planes and gradients together is the network of tide gauges and their local benchmarks. A few tide gauges, through Global Navigation Satellite System (GNSS) connections and the state’s Continuously Operating Reference Station (CORS) network (CORSnet-NSW), have continued close monitoring for both sea and land level changes (Janssen et al., 2013). Most tide gauges that surveyors turn to when establishing MHW do not receive such close attention. These tide gauges, established within the MHL network, have a much less stringent level of monitoring. On the tidal planes tables within the MHL2053 and MHL2786 reports, MHL stipulate that “the tidal plane heights only approximately relate to Australian Height Datum (AHD) or other specified datum”. The MHL2902 report gives an assessment of the uncertainty level of the tide gauge benchmarks as being from ±0.003 m to ±0.22 m. These numbers suggest that some tide gauge levels might be more accurate than others and that some may be suitable for accurate survey purposes, while others might not. A surveyor will not know which.

A measure of suitability for surveying might be possible from examining the tide gauge benchmark derivation against the requirements of the surveying regulations. Table 1 provides the list of tide gauges examined in establishing the tidal gradient for each of the 11 estuaries examined.

Table 1: List of tide gauges in each estuary used to obtain the tidal gradient.

Estuary	Tide gauge								
Tweed	Tweed Heads	Letitia 2A	Letitia 2B	Barneys Point	Tumbulgum	Nth Murwillumbah	Murwillumbah Bridge		
Richmond	Ballina Breakwall	Missingham Br	Byrnes Pt	Wardell	Woodburn	Bungawalbin	Coraki	East Gundurimba	Woodlawn College
Evans	Fish Coop	Iron Gates	Tucombil	Rocky Ck					
Clarence	Yamba	Palmers Br	Maclean	Lawrence	Brushgrove	Ulmara	Grafton	Rogans Br	
Macleay	SW Rocks	Smithtown	Kempsey	Aldaville DS	Euroka US				
Hastings	Port Macquarie	Settlement Pt	Dennis Br DS	Wauchope					
Manning	Crowdy	Harrington	Croki	Dumaresq Is	Taree	Wingham			
Hunter	Stockton Br	Hexham Br	Raymond Terrace	Green Rocks	Morpeth	McKimms Corner	Belmore Br	Bolwarra DS	Oakhampton Rail Br
Hawkesbury	Patonga	Spencer	Gunderman	Webbs Ck	Colo	Sackville	Ebenezer	Windsor	Freemans Reach
Geoges	Como Br	Picnic Pt	Milperra	Lansvale	Scrivener St				
Shoalhaven	Crookhaven heads	Greenwell Pt	Shoalhaven Heads	Terara	Nowra Br	Gradys			

The surveying regulations require the survey for a new benchmark to be connected to at least two existing established SCIMS marks. The site reports for the tide gauges found on the MHL website, however, only list one SCIMS mark as the reference mark. More may have been used in establishing the benchmark value of the tide gauge, but that information is not disclosed. Table 2 lists the SCIMS marks for each tide gauge examined.

Table 2: SCIMS marks cited as being the reference marks for the tide gauges of Table 1.

Estuary	Survey mark reported as used to obtain AHD at tide gauge								
Tweed	PM182920	SS186201		PM41441	PM40629	SS186213	SS186200		
Richmond	PM170699	SS69161	SS92289	SS6279	PM34926	PM44353	PM40477	SS59096	SS55424
Evans	PM34734	PM38979	PM34919	SS123205					
Clarence	SS38357	SS12966	PM71124	PM43119	PM43161	PM34913	PM48311	PM43054	
Macleay	PM74277	SS81070	PM33668	PM104338					
Hastings	SS10544	PM45131	SS33236	PM34956					
Manning	SS59002	SS90917	PM78056	PM13847	PM13704	PM78091			
Hunter	PM49777	SS57713	PM76363	PM75295	PM18506	PM151591		PM30934	RSA6253
Hawkesbury	SS94488	PM109300	SS130597	PM32886		PWD935	PM12722	PM1455	PM45523
Geoges	PM32892	PM32545	SS175487	PM50715	SS78000				
Shoalhaven	SS119226	SS54436	PM27434	PM73864	PM55662	SS144042			

It should be noted that two tide gauges are not reference to SCIMS marks. Oakhampton Rail Bridge on the Hunter River is referenced to a railways benchmark and Sackville on the Hawkesbury River is referenced to a Public Works Department (PWD) mark. SS130597 listed against the Gunderman tide gauge on the Hawkesbury River was not listed in SCIMS.

The surveying regulations are unclear as to whether the maximum distance for a level transfer to a new benchmark is the traverse distance or the direct overland distance. The tide gauge site reports do not disclose how far the gauge is away from the reference mark, but the reports do provide horizontal coordinates for the tide gauges. Thus, the direct distance between the tide gauge and the reference mark can be computed from coordinates (Table 3). The traverse distance can be substantially greater.

Table 3: Direct distance (in metres) between tide gauge and SCIMS reference mark.

Estuary	Distance (m) between survey mark and tide gauge								
Tweed	110	60		90	20	40	70		
Richmond	10	200	60	90	190	1510	70	40	1890
Evans	100	565800	70	10					
Clarence	420	600	320	140	260	180	220	380	
Macleay	210	320	90	740					
Hastings	5	260	310	160					
Manning	160	540	890	100	150	220			
Hunter	860	290	90	40	90	220		390	
Hawkesbury	30	200		290			228530	470	470
Geoges	64350	330	120	60	130				
Shoalhaven	70	30	80	240	140	340			

Of note are the three gauges that have reference marks seemingly a very large distance away. Iron Gates gauge on the Evans River is reported as referencing PM38979. This mark, however, is in western Sydney 565.8 km away (720 km by road). No other mark could be found in the immediate vicinity of the tide gauge that has a number closely resembling the PM number. Clearly this, and the other similar marks, must be a reporting error.

Not including the wrongly listed marks, Table 3 shows that over 30% of marks are at a distance greater than 250 m. Only 9% of marks are within 30 m of the gauge. Clearly, when considered as a benchmark establishing a tidal plane, a large percentage of tide gauges would not conform to the surveying regulation standards when establishing a connection to the AHD network. The distance from which levels are transferred from SCIMS marks are for the most part considerably greater than the surveying regulations dictate. MHL assumes a level run of up to 2 km is acceptable to transfer a level (MHL, 2023).

Of the SCIMS marks referenced to the tide gauges, 6% have a class worse than B or LD (Table 4). However, this does not guarantee that these marks, and consequently the tide gauge, are of an accuracy standard for a benchmark. SS90917, the reference mark to the Harrington tide gauge on the Manning River, has a class of LB assigned (Table 4). This is supposedly of acceptable accuracy. The AHD-PU assigned to that mark is 0.28 m (Table 5), which would place the accuracy level well below LB standard. Consequently, the accuracy level of the tide gauge will also be lower than expected and would not be considered as acceptable as a newly established benchmark.

Table 4: SCIMS mark class for each tide gauge reference mark.

Estuary	SCIMS mark class								
Tweed	LC	LC		LC	LB	LC	LC		
Richmond	B	LB	LC	LA	LA	LA	LA	LC	E
Evans	LA		B	LC					
Clarence	LB	LB	LB	LC	LC	LB	LC	B	
Macleay	LC	LC	LB	B					
Hastings	LB	B	LB	LB					
Manning	U	LB	B	LC	LC	B			
Hunter	B	LB	B	LC	B	LD		LB	
Hawkesbury	B	LC		LA				LA	LB
Geoges		LC	LB	LB	U				
Shoalhaven	E	LB	LB	U	LB	B			

Table 5: AHD Positional Uncertainty of tide gauge reference marks in SCIMS.

Estuary	Positional Uncertainty (PU) of AHD height								
Tweed									
Richmond	0.03	0.01	0.02	0.02	0.01	0.02	0.03		
Evans	0.01								
Clarence	0.05	0.02		0.04	0.03	0.04	0.02	0.05	
Macleay	0.08	0.06	0.11						
Hastings			0.02	0.02					
Manning		0.28							
Hunter				0.03				0.15	
Hawkesbury		0.03		0.01				0.01	0.15
Geoges		0.16		0.02					
Shoalhaven			0.25		0.06				

Of the SCIMS survey marks referenced to tide gauges, less than half have an AHD-PU. Of those that have an AHD-PU value, 16% have a value that is greater than 0.1 m. Of all the SCIMS marks identified with the tide gauges, only 8% have an AHD-PU greater than 0.1 m.

In the site reports, MHL nominates a Reduced Level (RL) that is used for the SCIMS reference mark. Ideally, the MHL RL and the SCIMS RL should be the same, but in many instances they are not (Table 6). Some differences may be attributed to SCIMS updates after the use by MHL but of greater interest are the larger numbers. For the Tweed Heads gauge on the Tweed River much of the data is on the Tweed Hydro Datum. The site report for the Tweed Heads gauge cites PM182920 as the reference mark, giving it an RL of 3.087 m as being on AHD. With the SCIMS level of the mark being 2.193 m, there is a difference of 0.894 m. The MHL-given offset from the hydro datum to AHD for the gauge is -0.893 m. The likely possibility is that the reported RL on AHD is a reporting error and was not converted from the hydro datum to AHD before placing it in the site report. Similar explanations can be made for the 0.914 m and 0.815 m differences on the Richmond River but there is no reason discernible from the reports as to why the differences exist in other instances. Overall, 30% of reference marks have been assigned an RL that is different from that shown in SCIMS.

Table 6: MHL assigned RL of tide gauge SCIMS marks compared to SCIMS RL.

Estuary	MHL ref mark level above or below SCIMS level								
Tweed	0.894	0	0	0	0	0	0		
Richmond	0.914	0	0.035	0	0.815	0	0	-0.026	0.05
Evans	0.053		0	0.021					
Clarence	0	0	0	0	-0.004	0	-0.022	0.024	
Macleay	0	0	0	0					
Hastings	0	0	-0.002	0					
Manning	0.072	0	-0.005	0	0	0			
Hunter	0	0	-0.081	0	0.011	0		0	
Hawkesbury	0	0		0				0.002	0.001
Geoges		0	0	0	0.652				
Shoalhaven	0.006	0	0	-0.124	0	0			

Examination of the data behind tide gauge benchmarks gives a worrying view that a significant proportion of the tide gauges may not be of a surveying regulation standard that would be acceptable as a benchmark for establishing a reliable tidal plane. The data, however, does not indicate which tide gauges have high or low uncertainties. Without some form of independent checking, it is not possible to identify these.

4.3 AHD

The AHD network is now over 50 years old. Even though a considerable amount of work over many years has been undertaken to maintain, enhance and fix errors or anomalies (Janssen and McElroy, 2021b) there may still be places where AHD may not be as reliable as expected. While AHD may be quite practical over shorter distances of 10 km or less (Janssen and McElroy, 2021a), the distances between tide gauges can be considerably greater than 10 km. The differential heights of MHW between tide gauges are usually relatively small (less than 0.1 m). At this level of scrutiny, AHD over the larger distances might not guarantee that the tidal gradient is going up or down. On the Richmond River, the distance between the Coraki to East Gundurimba tide gauges is 33 km. The MHWT gradient supposedly rises 0.025 m, according to the tide gauges and their link to AHD, or maybe it does not. Or maybe, thanks to estuary dynamics or AHD anomalies, there is a rise in between them and then a fall. What the tidal gradient is over such large unmeasured distances could be quite speculative.

AHD might not have too great an uncertainty level from anomalies in the eastern part of NSW as there was a considerable amount of first-order levelling conducted for the realisation of the network (Janssen and McElroy, 2021a). But since then, things have moved and the accuracy level of many marks has diminished, which could explain the 0.28 m AHD-PU value for a LB class level for the Harrington tide gauge reference mark.

Mark movement has always been an issue in maintaining the accuracy of AHD. Just as it is a problem in AHD, movement in the reference marks will be translated to the tide gauge and create a similar anomaly in the tidal gradients as it created in AHD.

4.4 Tide Gauge Location

The positioning of a tide gauge can have an impact on the tidal gradient results. On the Manning River, the Wingham tide gauge is attached to the low-level bridge across the river on the southern side of town. The gauge was installed for the floodplain management program and is useful for monitoring floods and assessment of flood damage (see site details on the MHL website). Unfortunately for tide monitoring, the bridge is upstream of a gravel bar, which at most low tides, creates a riffle over which the river flows (Figure 9). The impact of this is that the tide gauge sits in a slightly elevated pond and does not register correctly many of the low tides. This will create a bias in the tidal components, creating an unknown uncertainty. Useful though this gauge may be for floodplain management, it might not be quite so useful for surveying.

Figure 9: Wingham tide gauge location, Manning River.

Location, location – a buzz phrase sometimes attributed to real estate sales. But location can create unintended uncertainties. While the MHL2902 report has a particular emphasis to surveyors with MHWT values, it (along with the other reports) includes all tide gauges that have the minimum number of tidal observations obtained to produce the necessary profiles. Unfortunately, this can sometimes be misleading and give surveyors the wrong impression as many tide gauges are located in ICOLLs. Even though MHL provides the MHW values for the sometimes-tidal periods, the water boundaries in ICOLLs are not the MHWM but instead the bank (see section 2.4). In the MHL2902 foreword, the report says that the data can be used for multiple purposes including as an input in determining tidal water boundaries. The report was not directed solely to surveyors, although the introduction seems to indicate that assistance to surveyors in establishing boundaries against tidal waters was a primary objective. Even so, surveyors must be careful of location, location when using the data provided in the report. ICOLLs must be correctly identified as a unique entity and not assessed by MHL's tide gauge data as a means of classifying the riparian boundary type.

On the MHL website, there is a list of tide gauges that are assigned as gauges having ocean tidal data. Unfortunately, some of them are 0.5 km to 1 km upstream of the river mouth between retaining walls. The tidal races through those retaining walls can be quite strong, potentially creating a significant gradient between the tide gauge and the ocean. This creates some doubt as to whether these gauges would provide a true representation of the ocean tidal levels.

5 SURVEYING WITH TIDAL GRADIENTS

The uncertainties within the tidal components that produce the tidal gradients give some indication as to the uncertainty levels of the gradients themselves. A surveyor undertaking surveys utilising the tidal gradients must be aware of the level of uncertainty that could be associated and make the appropriate decision as to the suitability for the task at hand.

The other component adding a further degree of uncertainty is the estuary dynamics. The estuaries are in a constant state of flux with a large list of influences causing change. The consequence is that the tidal gradients are also constantly changing, which is evident in the data from year to year (Figure 10).

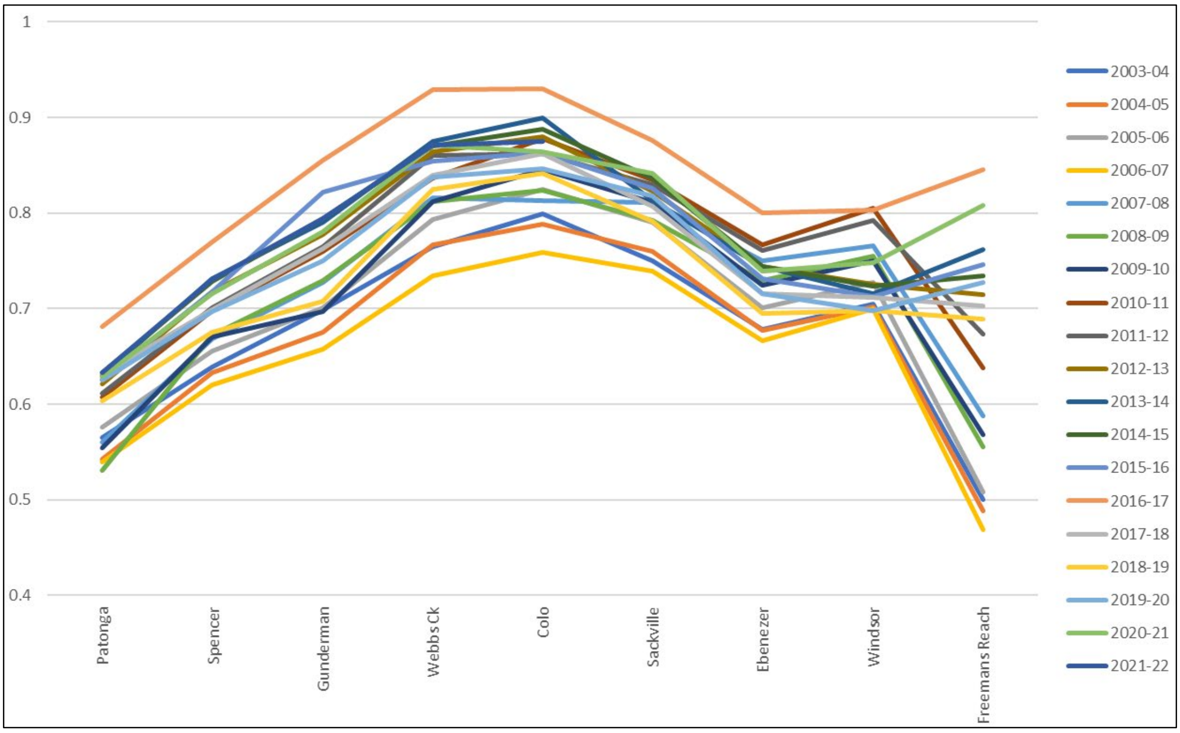

Figure 10: Hawkesbury River MHWT tidal gradient changes over time.

The changing tidal gradients are clearly visible on the Hawkesbury River where flooding in 2011 and 2012 changed the bathymetry of the river around Freemans Reach (MHL, 2024). Also note the top line in Figure 10 (2016-17 tidal gradient), which stands out from the rest. The most common practice in establishing the tidal gradient is to take the mean gradient across the 19 years. Usually with a data spread of 0.2 m, the mean often has an acceptable degree of uncertainty. In this instance, the 19-year mean would no longer be acceptable as the data spread at Freemans Reach has widened out to nearly 0.4 m. A surveyor would have to consider only using the data later than 2011-12 for any survey. The 19-year mean is out of date and likely too low a value, especially at Freemans Reach, and if the trend of rising sea levels is also factored in, very much out of date for a lot of purposes.

Thus, the surveyor’s only option to manage the uncertainty levels is to adopt a trend line through the yearly values. For the Sydney tide gauge (see Figure 2), the trend value of 0.615 m for year 2021-22 is more likely to be representative of the prevailing estuary conditions and more likely to provide an accurate assessment of MHW than the overall mean of 0.572 m or the 0.540 m at the other end of the data timeline.

Management of the uncertainties to provide a more accurate or more certain outcome is one tool a surveyor needs to employ to be able to utilise tidal gradients. The other technique that also needs to be considered is a verification process that can check the validity of the answer. This is basic surveying practice, which is possibly too often ignored to the detriment of the final product.

Of concern are the tide gauge benchmark values. As seen, the relation to AHD could have a relatively high level of uncertainty. Even AHD has a degree of uncertainty along the tidal gradient. Consideration needs to be given to undertaking supplementary survey practices that could complement the determination of MHW along the tidal gradient by verifying the given values. If the verification process ended up showing that there was an error, then that error could be corrected, thus decreasing the uncertainty and potentially increasing the accuracy of the information.

One supplementary survey practice that might be effective in verifying the tide gauge benchmark data is the range ratio. A parallel range ratio study on the Clarence River (Songberg, 2025) found that distance had little or no effect on the outcome. If this is the case, then it could be an advantage to a surveyor to conduct a 1-2 week long range ratio survey through the tide gauges along the estuary to verify the MHWT values produced from each tide gauge (Figure 11).

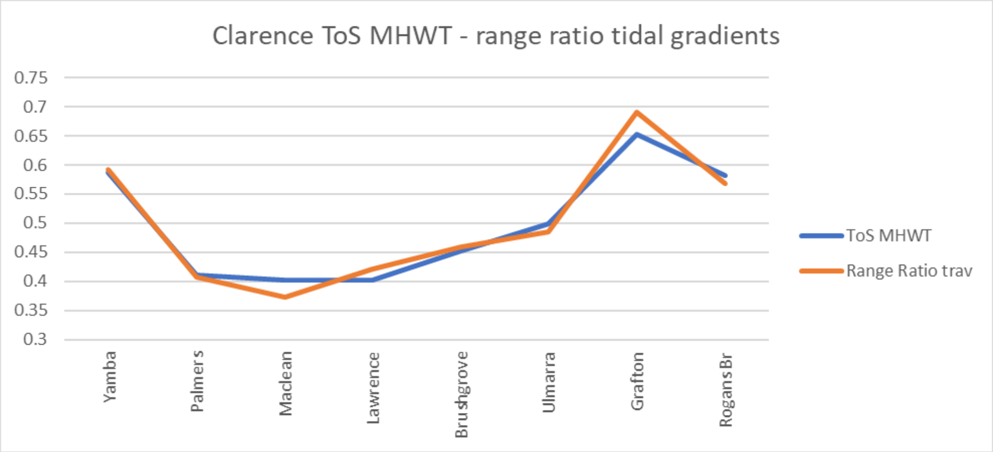

Figure 11: Clarence River tidal gradients – MHWT at the time of survey (ToS) vs. range ratio.

The greatest difference between the time-of-survey MHWT and the range ratio gradients was 0.037 m. It indicates that the uncertainty of the tide gauge levels is fairly low and certainly within the 0.1 m tolerance accepted as a benchmark by the surveying regulations. A surveyor could be reasonably confident in using the tide gauge data depicted in establishing MHW.

MHL provides real-time tide gauge readings on its website for all tide gauges in the network. The range ratio survey is thus a desktop survey rather than a field exercise. Range ratio results, however, reflect the tidal dynamics at the time of survey, so MHW values of the tide gauges have to be translated to the time of survey, which could require extrapolating the latest data forward along the trendline if no current data is available.

Within the longer reaches between tide gauges, a surveyor could also consider installing a temporary gauge for a week or two and combine it with range ratio exercises from either side. This should have a good chance at confirming (or not) the tidal gradient in between the tide gauges. For example, Figures 3 & 4 depict the tidal gradient between Yamba and Maclean on the Clarence River to be an even gradient in between. There is another tide gauge in between on the Palmers Island Bridge. This gauge is about 150 m inside a side creek off the main river, so there is potential for a small tidal gradient along the creek to the main river. Incorporating this gauge into the tidal gradient would result in the gradient being 0.07-0.10 m lower at that point (see Figure 11). A similar situation could occur anywhere along any gradient.

Should the range ratio exercise find the benchmark value of a tide gauge to be too inconsistent with the assigned value, then this would need to be further investigated. Determining if the inconsistency is within the benchmark value itself would be the first step. Verifying the level of the nominated survey reference mark would be one task, but sometimes that might not be possible or have little bearing on the level of the tide gauge as the mark could be a considerable distance away and the error may lie in the survey between the two. It is the local reference mark to the tide gauge, which could be just a triangle cut in concrete, that needs to be verified. The information as to what that mark is, and its level, can be found in the tide gauge site reports on the MHL website.

A tide gauge verification exercise should even be considered if a surveyor is just using a levelling exercise from the tide gauge, or from another AHD mark nearby, a recognised practice from the ISG manual. The gauge you are using could be the one with the large error and not be correctly related to AHD. Finding out if the inconsistency is not within the tide gauge benchmark but instead within AHD would be an entirely different matter.

A survey tool available that could help in the verification processes of the tide gauge benchmarks and AHD is the use of modern GNSS techniques. Such techniques have been used in the preservation of AHD (Janssen and McElroy, 2021b), so it is logical to assume the same techniques could be used to verify the tide gauge benchmarks along the estuary. It could also assist in helping to verify AHD or upgrading the AHD values of the tide gauge and decreasing the uncertainty.

Combining a temporary tide gauge with the range ratio to establish MHWT at the temporary gauge and GNSS to verify the AHD component could provide a possibility of verifying the entire tidal gradient or even establishing it at a greater accuracy, if it were felt that adjustments were warranted. It would depend on what level of accuracy is required and as to how much effort is considered appropriate to be expended on achieving that accuracy.

6 CONTEMPLATIONS

It might seem that the picture being presented in this paper is that the tide gauge levels and associated tidal data is of high uncertainty and of low accuracy. That is not the intention. The gauges established in the network and the resulting data collected by them are as accurate and reliable for the needs for which the network was set up. Even though the data is freely available for use, MHL emphasises that it is up to the user to determine if the data is suitable for their needs. Unfortunately for surveyors, the accuracy that is sought for many surveys may be beyond the tolerance levels associated with the data. For the purposes of this undertaking, the degree of accuracy assumed to be required by a surveyor is a vertical uncertainty of 0.1 m or better.

One objective of this study is to see how well the data would compare against such a measure and to provide some insight as to where to look and how to manage the data that might not quite measure up but could still be used if handled properly. MHL has, in some ways, helped in managing the uncertainties to be more suited for surveying purposes by providing a measure of MHW that is synonymous with the surveying regulation definition (MHWT in MHL2902). However, it is still up to the surveyor to determine just how much assistance that is for the task at hand.

7 CONCLUDING REMARKS

This paper has examined the tide gauges along 11 coastal estuaries in NSW, the data behind the derivation of MHW levels over time, and the interpolation to tidal gradients along an estuary. It has analysed the data to see if the theory behind tidal gradients measures up to the standards required by the surveying regulations and our changing knowledge base.

There are some arguments to say that tidal gradients cannot be used for surveying purposes. There are other arguments to say that they can. The answer is that both arguments are correct and that there is also ground in between. What the examination of the data behind the tidal gradients has found is that as the sought-after accuracy for the survey increases, the uncertainty level of the data becomes unacceptable. The trouble is that it is difficult to determine where the uncertain data lays and how uncertain it is. The tidal gradients can be used to establish water levels through the estuary, provided the accepted tolerance of the survey is in line with the tolerance within the data. For the most part that tolerance is around ±0.2 m but has potential to be a little larger.

For higher precision results and to establish the MHW intercept on the shoreline for cadastral work, such a tolerance would not be acceptable and so the tidal gradients, in their raw state, cannot be used. Even levelling from an AHD mark not too distant from the tide gauge could be of low accuracy because the tide gauge link to AHD could be inaccurate. But there is an issue with such a view. Some of the level data is accurate and would be more than capable of meeting the requirements of cadastral work. The problem is that it is not known which data is acceptable and which is not. The low tolerances and unknown location of data issues can mostly be overcome with complementary work.

For cadastral work, the mean of high tides (MHWT) data must be used and instead of utilising 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 should be utilised to smooth out the year-to-year variations inherent in any tidal data. This is essential for ensuring rising sea levels are also factored into changing cadastral boundaries. Undertaking a similar treatment to the harmonic data should also be considered if any harmonic values were being used for a survey.

Verifying the base levels or benchmarks of the tide gauges will ensure greater reliability of the gradient, at least near the tide gauges. A range ratio exercise throughout the estuary can help identify which tide gauge levels may be inaccurate. To verify the tide gauge level, it is essential that the level of the local benchmark attached to the tide gauge within a short distance should be verified and not the SCIMS mark which could be up to 2 km away.

Once the tidal data has been managed to ensure the most probable value is used and the tide gauges are accurately related to AHD, then for at least the shorter distances between tide gauges, the tidal gradient should be of sufficient accuracy (or at least within the 0.1 m or better measure) to investigate a MHW boundary. To ensure the viability of the gradient over longer distances, the gap would ideally need to be split up into shorter spans.

Modelling of the MHW tidal gradient within an estuary in this manner does not change the need for appropriate site inspections. Locating MHWM out in the middle of a mangrove forest (because that is where the numbers say it is) does not mean that it is correct when logic and supplementary information say it should be somewhere near the landward side of the forest.

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