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Mean High Water Mark: Is the Mean the Answer?

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ABSTRACT

Raising issues in respect to the determination, appropriateness and even validity of Mean High Water (MHW) and surveyor's methodologies in determining the Mean High Water Mark (MHWM) boundary has been a part of APAS since its inception; first with "Mean High Water Mark Revisited" in 1995 and then "Accurate Mean High Water determination – Fact or Fiction" in 2005. This current paper could be considered as chapter 3 in the trilogy. In 1995, the awareness of how MHW came about in relation to property boundaries was raised and whether both surveying practice and the definition in use complied with the intent prescribed by the legal profession in describing the land/sea boundary. Then in 2005, the accuracy of survey practice methods for determining MHW was brought into question. Now in 2015, the validity of determining the mean itself in MHW is to be examined. Tidal observation data is utilised to bring forward the 1995 issues testing the mean determined by the data used by surveyors against the legislated definition and early legal profession expectations to see if they all are in agreement or if there are disparities. The paper then looks toward the future by throwing sea level rise into the mix. Are we (surveyors) doing it right and will current practice be appropriate in the future? Or does something need to change? The findings presented indicate that there are disparities between practice, legislation and expectations. Introducing sea level rise creates further issues. For surveyors to answer the needs of the future in respect to determining tidal boundaries, it would seem that the how and the definition of MHWM may need to change.

KEYWORDS: *Mean High Water Mark, definition uncertainty, sea level rise, survey practice.*

1 INTRODUCTION

The riparian title boundary Mean High Water Mark (MHWM) should be familiar to most surveyors who work on the coast of NSW. So should the definition of Mean High Water (MHW) be familiar. But does any surveyor really understand what they are undertaking when defining the mean high water mark? Do they fully comprehend the implications of the definition and whether their work practice conforms to the definition?

But is it just the surveyor? What about the learned judges who have handed us down the definition of mean high water? Did they fully understand what they were doing when they tried to put into words a definition of the particular position along the coast that they were trying to define? Does the definition prescribe the boundary they considered to be the limit of the land? Now throw in sea level change, rising sea levels if you are a believer, and consider whether current practice reflects such an event. Does the definition provided by the legal profession also reflect such an event? Does current land title in NSW consider and/or reflect sea level change?

At the 1st APAS conference, Blume (1995) asked similar questions about the definition of MHW and cast similar doubts as to the validity of current practice to conform to the definition. A decade later, at the 11th APAS conference, Songberg (2005) closely examined current practice. What that investigation uncovered was that the various recognised methods did not provide repeated accuracy in defining MHW. A variability of at least ±0.1 m in level was likely between determinations.

Another decade has passed, and now at the 20th APAS conference in 2015 surveyors are still conducting MHWM definitions the same way. But now the issue of sea level rise is starting to be considered in other areas, particularly in how it is likely to impact on title. Perhaps it is time to again look more closely at the definition of MHW and to see if some of the questions, initially raised 20 years ago, can be answered and to see if survey practice needs to be refined to include sea level rise.

2 MEAN HIGH WATER DEFINITIONS

The current definition of mean high water (mark) that surveyors should be acquainted with is stated in the Surveying and Spatial Information Regulation 2012 (NSW Legislation, 2014): "*the line of mean high tide between the ordinary high-water spring and ordinary high-water neap tides*". This definition has its roots in *Attorney General v. Chambers* (1854). The case, from the south coast of Wales, involved the Attorney General taking action to retain the seashore for the Crown (then Queen Victoria) and prevent the land being used for coal mining. The judges came to the conclusion that the limit of the land was "*the medium high tide between the springs and neaps*". Although ordinary (as in ordinarily occurring tides) was a consideration in this deliberation, it was not part of the definition handed down. The term ordinary was introduced later (Blume, 1995) in the case of *Tracey Elliot v. Morley (Earl)* (1907), which referenced the mean as the average of the medium or ordinary tides (Corkill, 2013).

Another definition in current use is found in the Manual of the New South Wales Integrated Survey Grid (ISG) (NSW Department of Lands, 1976): "*the mean of all high tides (including both spring and neap tides) taken over a long period*". This definition is distinctly different from the surveying regulation definition as it specifically includes all tides and potentially could provide a different result depending how literal the interpretation is taken into survey practice.

These two definitions are not the only ones as many other variants exist and/or have existed over time, including within the surveying regulations (Blume, 1995). Does either, or any, answer to the intent of the boundary between the Crown and private lands handed down in the judgment of *Attorney General v. Chambers*? Does any exemplify current survey practice? Is it what society expects? Whichever definition is considered the most relevant, the surveyor must first come to grips with the spring and neap tides and how observation practice must relate. So, what are spring and neap tides?

3 MEAN HIGH WATER DEFINITION INTERPRETATION

In order to satisfy a criteria imposed by definitions, the surveyor must first come to terms with the meaning of the words. The definition of mean high water is no different and the result

could vary depending on the interpretation perceived. It is clear that the two definitions of MHW given at the start are very different and could potentially give different results. Even within a single definition, interpretations could vary producing varied results. At first what seems quite clear may not necessarily be so.

3.1 Spring and Neap Tides

Spring tides have nothing to do with the season spring, as they occur all year round. Simplistically, spring tides occur around the new and full moons when the earth, moon and sun align and neap tides occur when the moon is perpendicular to the earth-sun alignment (Figure 1). There are many other factors, including oscillations in the earth-sun-moon alignment, which create variations in the tides and the cycles between the tides, a discussion of which is beyond the scope of this paper. The simplistic view, however, will suffice.

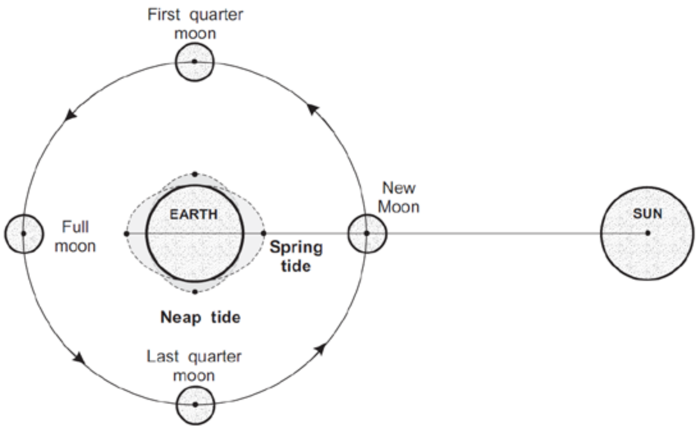

Figure 1: Spring and neap tides by moon phase (Couriel et al., 2012).

Both Figures 1 and 2 suggest that a spring or neap tide is a singular event with the spring tide being larger than the neap tide. Both diagrams suggest that the spring and neap tides occur at the time of the particular moon phase. An important point to note is the moon cycle, which is 29.53 days long, making each quarter 7.38 days (on average as in reality the duration varies slightly). The duration between spring and neap tides, in accordance with the moon, should thus be just over 7 days. Does the mean of high tides from one moon phase to the next provide a meaningful value for mean high water?

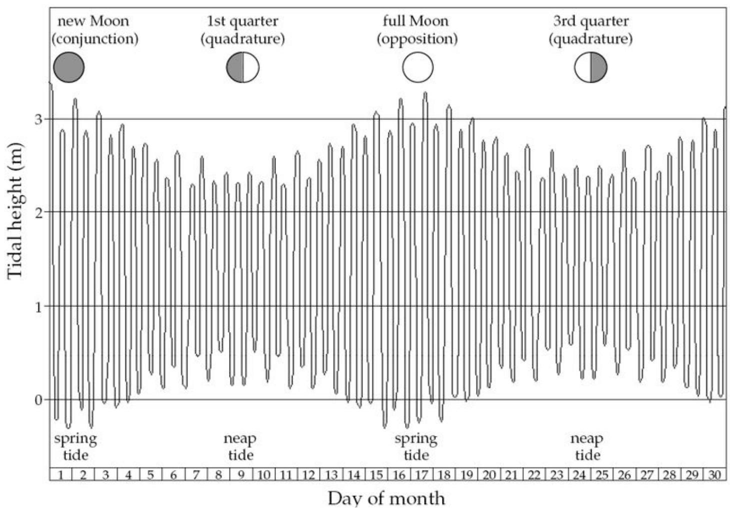

Figure 2: Spring and neap tides range (Earth Science NHS, 2015).

Dividing 12 months of tidal data into segments according to the moon phase and taking the mean of high tides from one moon phase to the next results in MHW values according to Figure 3. The result is highly varied with a 0.3 m range from the highest result to the lowest. This would mean that MHW could vary by at least 0.3 m from one week to the next and the lateral MHWM boundary could vary tens of metres over flat terrain. Such a result is not likely to have been envisaged by the proponents of MHW as a measure for a land boundary. Certainly the society of today would not consider such a variable entity as being desirable, they would not know from one week to the next where their boundary was located.

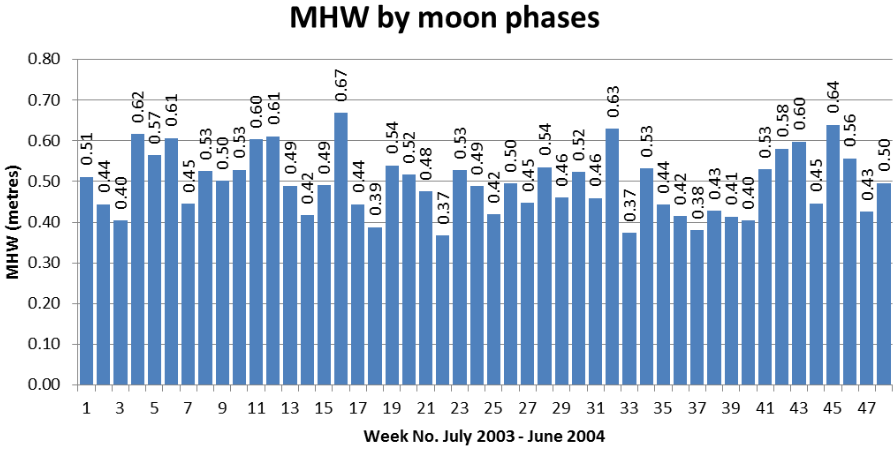

Figure 3: MHW at Port Macquarie in July 2003 – June 2004 by quarter moon cycle.

If the timing of the moon does not produce a desirable outcome for determining when the spring and neap tides occur then what other options are there for determining such necessary events as required by the surveying regulation definition? Other information suggests that spring and neap tides are not singular events but instead multiple events ranging over a period of tide behaviour. Some texts (e.g. Marine Science Australia, 2014; Port of London Authority, 2015) indicate spring high tides are typified by being higher than average and neap high tides are lower than average (Figure 4).

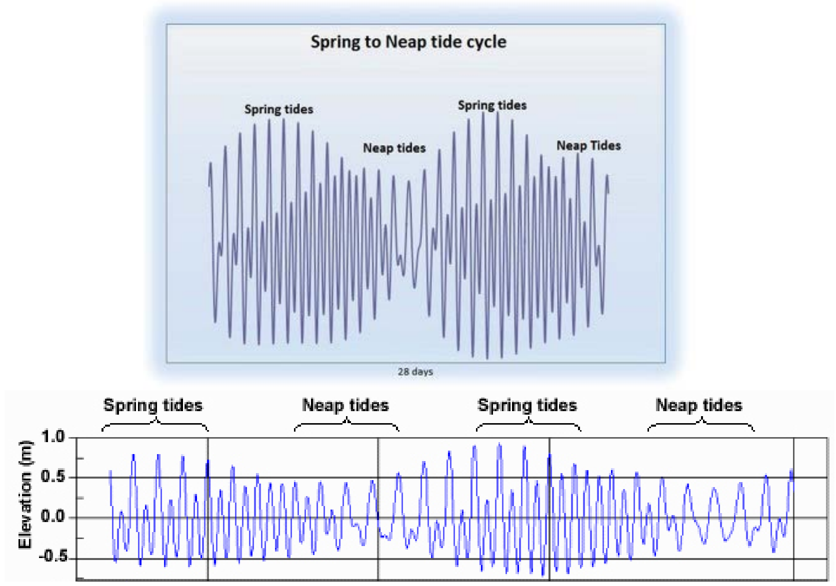

Figure 4: Spring and neap tide duration (Marine Science Australia, 2014; University Corporation for Atmospheric Research, 2007).

Examination of Figures 3 and 4 shows that even within a spring tide cycle the range between successive tides can be smaller than average so that classifying a spring or neap tide by an individual tide event can be problematic. It would appear that to determine spring or neap tides, one must stand back a little and examine the overall picture.

The exact timing of the spring and neap tides in relation to the moon phase in such a multiple event is also not exactly determinable. It can only be determined that the spring tides occur around the time of the full and new moons and the neap tides occur around the time of the 1st and 3rd moon quarters (Figure 5). Although only full and new moons are shown (for clarity), Figure 5 also suggests that the timing of the peak spring tides in relation to the moon phase can be before, during or after the moon event.

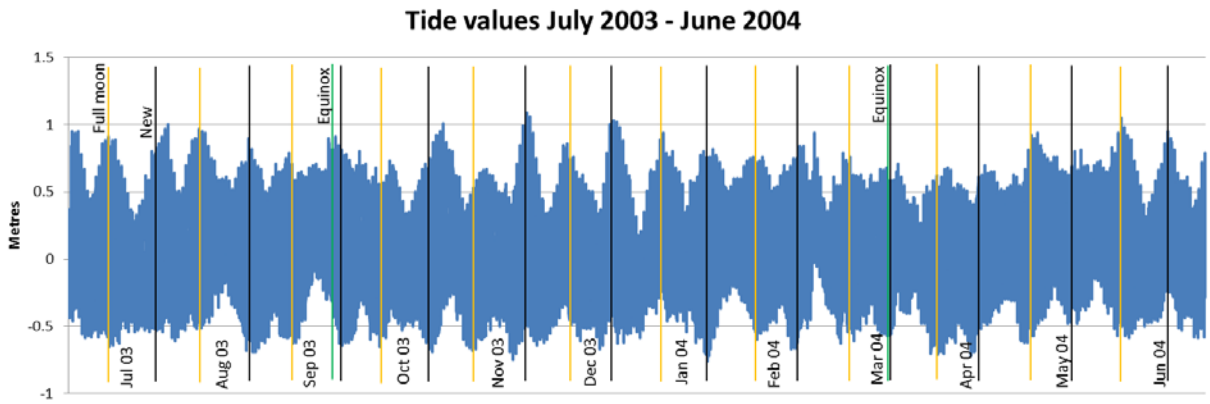

Figure 5: Tide values to moon phase at Port Macquarie in July 2003 – June 2004.

However, Figure 6 specifically indicates that the spring and neap tides occur shortly after the moon phase and only in a short interval. Figure 6 also supports the multiple-event scenario for spring and neap tides but like previous diagrams does not give a figure. The only indication is from the text which also indicates that spring tides are when the highest and lowest tides of the month occur and the neap being when the lowest high tide and highest low tides occur (VisitMyHarbour.com, 2015). This is in contrast to Figure 1, which indicates that they occur at the time of the moon phase.

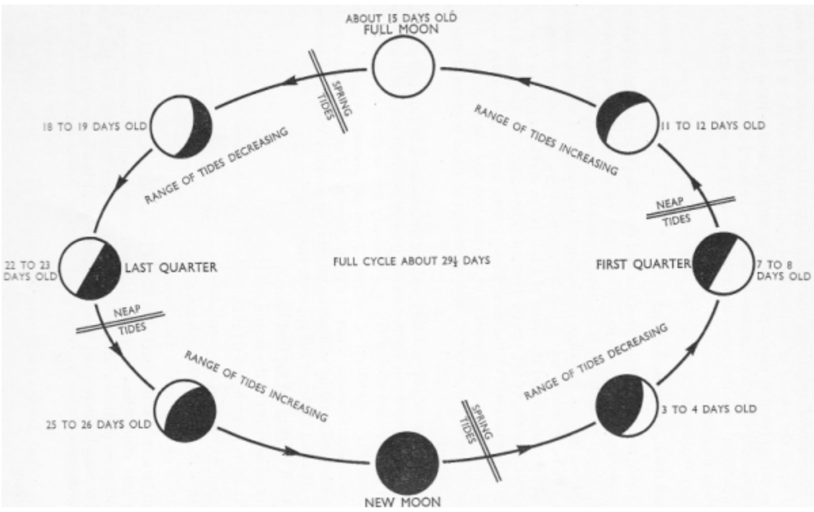

Figure 6: Spring and neap tide timing to moon phase (VisitMyHarbour.com, 2015).

Casting the information net even wider, dictionaries provide even more insight into what are spring and neap tides.
Spring tides:

- dictionary.com – either of the two tides occurring just after the full and new moons where the difference between the high and low is the greatest.
- thefreedictionary.com – a tide in which the difference between the high and low is the greatest occurring just after the full and new moons.
- oxforddictionary.com – a tide just after a new or full moon where there is the greatest difference between the high and low water.
- macmilliandictionary.com – a tide when there is a big difference between the highest and lowest levels of the sea.

Neap tides:

- dictionary.com – tides having less than half the range of spring tides occurring around the first and last quarters of the lunar cycle.
- thefreedictionary.com – tides midway between spring tides that attain the least height.
- oxforddictionary.com – a tide just after the first and third quarters of the moon where there is the least difference between the high and low water.
- macmilliandictionary.com – a tide that has the least amount of change between the highest and lowest levels of the sea.

As it can be seen, even the various dictionaries are not in complete harmony as to what is a spring and neap tide. Just how close to reality the definitions are is yet to be seen. From the dictionaries the most common thread is that spring tides have the greatest range between consecutive high and low tides whereas the neap tides have the least range. Utilising the data that constituted Figure 5, the high and low tides can be identified, the differences calculated and the relation to the moon phases determined. The results of such a comparison can be found in Figure 7, which shows two months of the 12-month period of data.

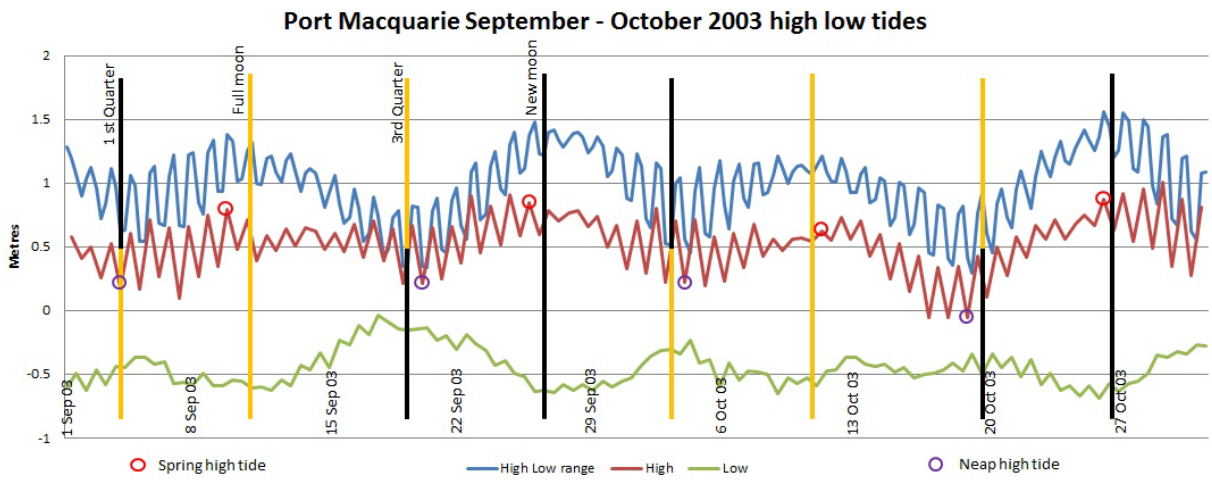

Figure 7: High low tide and range compared to moon phases at Port Macquarie in September-October 2003.

It does not take long to see that none of the dictionary definitions completely satisfies what is found in reality. Assuming a single definition that the spring tide has the greatest range between high and low and the neap the least range and correlating the appropriate range with the high tide, it can be seen that the high tide event that corresponds to a maximum spring range does not always occur after the moon phase. Sometimes the high tide occurs before the moon. The situation is similar with the neap tide event. Also the high tide associated with the greatest high low range is not necessarily the highest tide in the period. The neap tide also

exhibits a similar trait. The neap tide event does not necessarily occur with lowest high tide.

There is an immense amount of literature that gives explanations as to what and when are spring and neap tides. The above is just a sample and it shows that there is no one distinct answer. It would seem that spring and neap tides are nebulous titles given to tides that are, for spring, high tides that are larger than most coupled with low tides lower than most and have a larger than average tidal range occurring around the full and new moons, and for neap, high tides smaller than most coupled with low tides higher than most and have a lower than average tidal range occurring around the 1st and 3rd quarter moons. Because the definition of the mean in MHW is synonymous with spring and neap tides, a surveyor is faced with difficulties in identifying, in any positive manner, particular spring and/or neap tides as part of the mean determination process.

3.2 Ordinary Tides

The Surveying and Spatial Information Regulation adds another dimension to determining mean high water. It specifically requires only ordinary spring and ordinary neap tides to be taken into consideration in determining MHW. But what are ordinary tides? Lord Chancellor in *Attorney General v. Chambers* (1854) possibly provides the best insight into ordinary tides: "*The right* (the Crowns right to ownership) *is confined to what is covered by ordinary tides, whatever the right interpretation of that word. What is the meaning of the word ordinary? It is evidently a word of doubtful import*."

The judges in their deliberation did raise the issue of whether some tides were considered ordinary or not: "*There are the spring tides at the equinox, the highest of all. These clearly are excluded … for though in one sense they are ordinary, i.e. according to the usual order of nature … they do not ordinarily happen, but only at two times of the year*."

From the deliberations it may be possible to consider that the spring tides, especially the higher the king tides, are not ordinary in that the position on the foreshore covered by a spring tide is not ordinarily reached but only does so during short intervals. But what then are ordinary neap tides. Various literatures always seem to gravitate back to *Attorney General v. Chambers* and the heavy reliance on the 17th century treatise "De Jure Maris" by Lord Chief Justice Hale. The neap tides were considered by Justice Hale as being ordinary tides. This would presume than that all neap tides were ordinary tides. The judges in *Attorney General v. Chambers* however reasoned that for the same reason the highest spring tides would be excluded so too should the lowest high tides for they happen as often as each other. It would appear that the calculation of MHW does not include the higher monthly spring high tides or the lower monthly neap high tides (Corkill, 2013). The problem though is how to identify the particular spring and neap tides that could be considered to be not ordinary.

The allocation of the highest spring tides to the equinoxes in March and September may be true somewhere but not in the observations shown in Figures 5 and 8. Here, there are eight high (spring) tides of 1 m or greater mostly in November and December which is as expected in Australia and not around the time of the equinoxes. But two of the higher high tide events occurred in August and June. Most occur about the time of the new moon; however the higher tide on 3 June occurs around the full moon. A choice of 1 m as an indicator of a higher or non-ordinary high tide is completely random and does not create a justification criterion for exclusion. There are a few other high tide events falling just short of 1 m in July, August, January and May around the time of the full moons that could equally be considered as non-

ordinary events. The other issue is that MHW is an ambulatory entity. It moves up and down over time. Limiting the measurement of the high tide event places an artificial restraint and barrier to the natural movement of the tide. Such a restraint may even contravene the doctrine of accretion and erosion.

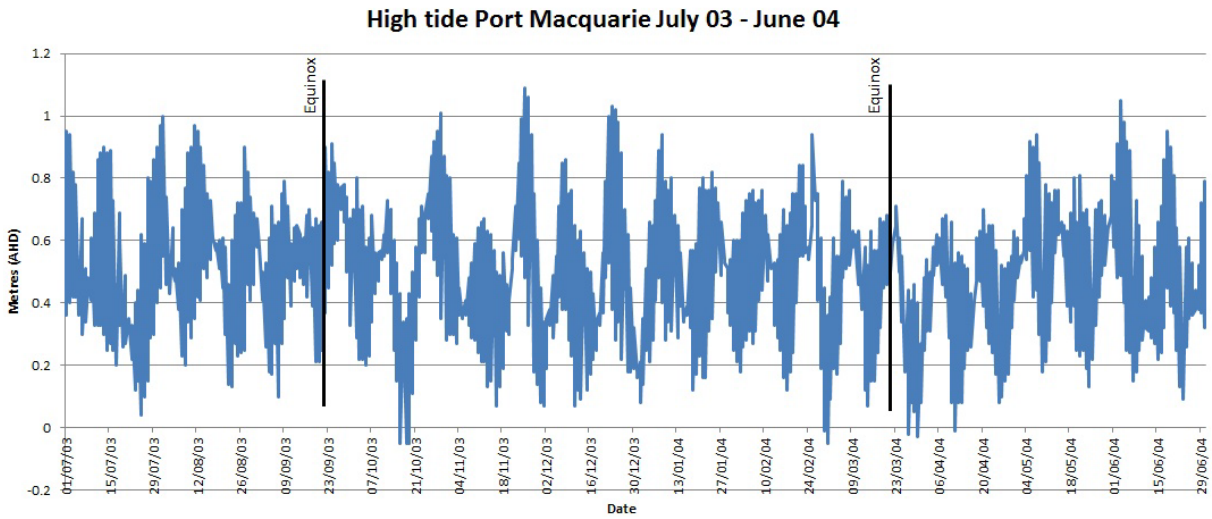

Figure 8: High tide values at Port Macquarie in July 2003 – June 2004.

It may not necessarily be the higher tides that could be considered as not being ordinary. If Figure 4, 7 or 8 is examined, it can be seen that during the spring tide cycle, there are two distinct high tides, one higher than the other. Is it possible that these lower high tides are the non-ordinary spring tides? There is probably no answer to this question. It is the same with the neap tides. There is a lower and a higher. Is it the higher that is the non-ordinary?

Attorney General v. Chambers only cited two equinox high tide events that would constitute the selection of non-ordinary tides, but as can be clearly seen that criteria does not necessarily hold valid. It was Justice Hale who suggested that the spring tides of the month, at the full and new moons, were not ordinary tides. It may well be that he was not trying to categorise the tides themselves but whether the high tide event would ordinarily or regularly cover the ground.

Any high tide event that was greater than the lowest high tide would cover the ground so the lower high tides, the neap tides, could be considered to usually, or ordinarily, cover the ground. Justice Hale also considered that ordinary tides were neap tides. This would make all neap tides ordinary tides. If this is the situation, then the Surveying and Spatial Information Regulation use of the term ordinary when associated with neap tides is redundant or inappropriate.

If on the other hand there are non-ordinary neap tides, then can they be identified? Which of the neap high tides in Figure 8 could be considered as not ordinary and could be excluded? The judges in *Attorney General v. Chambers* did consider such a proposition: "*the same that excludes the highest tides of the month excludes the lowest high tides for they happen as often as each other*." There are at least some that think the higher and lower tides need to be first excluded (Corkill, 2013).

A random level could be chosen, as was done for the spring tides, and the neap tides falling short could be excluded as being non-ordinary. The lowest high tide is -0.05 m and so a value

of zero might seem appropriate as the criteria. There are 8 tides lower than zero occurring during October and spread throughout February, March and April with considerably more tides close to zero spread throughout the year. Clearly the same arguments against making any exclusion based on such a level criteria for spring tides equally applies to neap tides. There is simply no justification for doing such.

Making any exclusion from high tide observations using the level in which the tide reached as a measure of ordinary would introduce a bias into the observation and as stated introduce an artificial barrier to the natural movement of the tide. It could also unintentionally lower or increase the height of the determined mean and take the surveyor away from the natural mean. Any tide event that is a natural result of the influences of the sun and moon could be considered as an ordinary tide and would have to be included in the observation set. Quite possibly only tides heavily influenced by extreme weather events such as during a flood could be considered as not being ordinary. Creating an artificial upper and lower barrier of the tidal range cannot be justified.

Although the *Attorney General v. Chambers* judges were trying to come to grips with an explanation of ordinary tides, it is not clear as to whether or not they intended to exclude the higher spring tides or indeed any tides. An interpretation of their deliberations is that they were more concerned with the reach of the tide that would ordinarily occur; that point on the foreshore which the tides would more often reach as not. They were debating what would be the limit of the Crown ownership of the foreshore or that part which would ordinarily be covered by the sea given the periodic influx of the high tides: "*It is true of the limit of the shore reached by these tides that it is for more frequently reached and covered by the tide than left uncovered by it.*" "*The Crown's right is limited to land which is for the most part not dry and maniorable.*" Although the judges seemingly became tangled in the issues between what the tide ordinarily covered and what was an ordinary tide, the two concepts may not necessarily be equated. One interpretation is that the extent of land, the limit of ownership, was the more important factor and not whether or not the tide that made that line was an ordinary tide. In the end the judges did not use the word ordinary, undoubtedly because it was "*a word of doubtful import*", and instead opted for a simpler line of demarcation; "*the medium high tide between the springs and neaps*". The use of the word ordinary in the Surveying Regulation definition may well be misdirection by those who tried to come to grips with this concept of ordinary tides when there was no need to.

In their deliberations the judges of did not simply leave the problem with just their final ruling but also tried to provide some insight as to what they considered would be a means of measuring this tidal event that would ordinary cover the ground. It is from these deliberations and the wording of the Surveying Regulation that the surveyor can consider what methods could be employed to fully satisfy the definition of mean high water.

3.3 Between or Including Spring and Neap Tides?

A key word in the Surveying and Spatial Information Regulation definition is "between". The use of "between" makes this definition distinctly different from the ISG manual definition. One interpretation of between is that it does not include the end points but includes everything else in between. For surveyors to comply with this interpretation, they must first exclude the spring and neap high tides (setting aside the ordinary part for the moment), then take the mean of all the high tides that are left.

The identification of the spring and neap tides is, as has been shown, problematic and may not be able to be achieved in any positive manner. It may only be possible to identify a high tide as being either characteristic of being a spring tide or characteristic of being a neap tide. Without a precise definition to identify a spring and neap tide, it is not possible to identify the high tides that need to be excluded in order to take the mean of those high tides left in between. It is quite probable that it might be impossible to satisfy the Surveying and Spatial Information Regulation definition of MHW if the surveyor must exclude the end points and only take the mean of those observations in between. Given a set of data such as that in Figure 8, which are the spring high tides and which are the neaps? Which tides need to be excluded and which tides should be included to get the mean?

One possible interpretation of spring and neap can provide an answer, of sort. Presume first that the spring tide is a singular event determined by the greatest range between consecutive high and low tides (see dictionary definitions) and that the neap tide is the converse, having the least tidal range. Then using tidal data from a tide gauge, in this instance Port Macquarie from 1 July 2003 to 30 June 2004, both the high and low tides can be identified and the difference, or range, between computed. The result, shown in Figure 7 for September-October 2003, is then readily interpreted to find the greatest and least ranges for each cycle and which high tide can be considered the spring and which the neap. The mean can then be taken of all the high tides between but not including the identified tides for the entire 12-month dataset.

The resulting MHW values for “between” spring and neap tides (Figure 9) show a remarkable similarity to the moon phase determination (Figure 3) with just as much variation, 0.32 m in this instance. There are other differences not immediately discernible. The maximum time between the moon phases was 8.6 days and the minimum 7.4 days. This means the moon phase determinations have between 17 and 12 high tides contributing to a mean. This compares to the between neap and spring tide range of 10.4 to 3.6 days or as much as 20 high tides or as low as 7 high tides (see also Table 1). With such differences it would be expected that there are significant differences between the two determinations. As the moon phase determination was not acceptable because of considerable variability, so too are these results. However, the results do satisfy to some extent the requirements of the Surveying and Spatial Information Regulation definition for MHW. There is still however an additional factor that must also be considered.

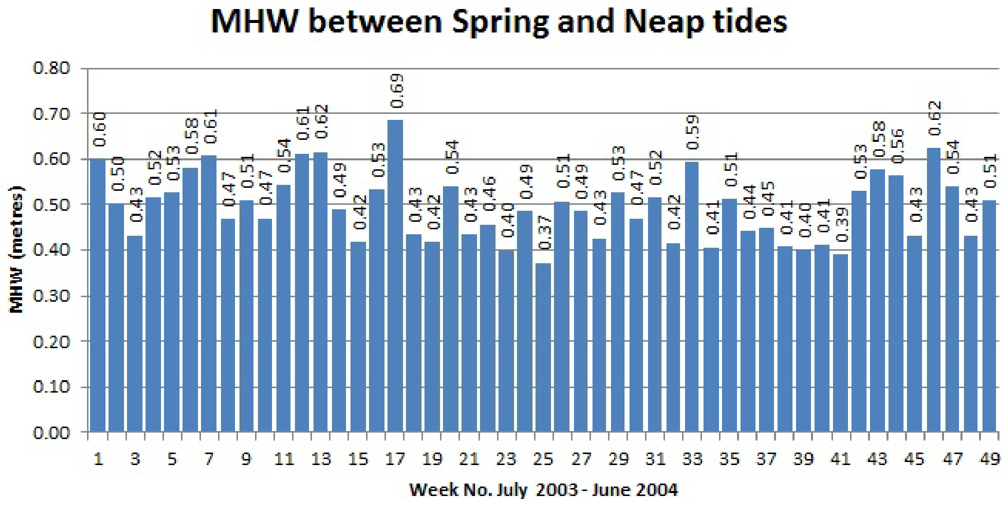

Figure 9: MHW between but excluding spring and neap tides at Port Macquarie in July 2003 – June 2004.

Now add in the uncertainty of ordinary. The above exercise excluded all the spring and neap tides but the definition requires only the non-ordinary tides. By virtue of the label it would mean that some spring and neap tides should be included. It is however not possible to identify which tides are the ordinary and which are the non-ordinary. Where does this leave the surveyor? Possibly close but not necessarily close enough to be fully compliant.

Another interpretation of between is that the mean tide, between the spring and neap, is a result of both. That is, it is the average of both the spring and the neap which exists as a mean in between. This interpretation however changes the practice to align more with the definition in the ISG manual and potentially taking the surveyor away from the legislation. Going back to the data that generated Figure 9, the spring and neap tides can be put back into the computation mix and a revised determination for MHW made.

The inclusion of spring and neap tides (Figure 10) looks almost identical to the excluded tides result of Figure 9. For the most part it is, as the variation of 0.28 m is similar, but careful examination reveals that the differences between the two results can be as much as ±0.04 m. This is a consequence of the inclusion of the end point high tides, the springs and neaps, which creates a different balance in the mean. The supposition examined earlier that exclusion of some tides could produce a bias in the result would appear to be well founded. It also stands to reason that the two methods are not interchangeable as they produce differing results and potentially different MHWM boundaries for the same period of observation.

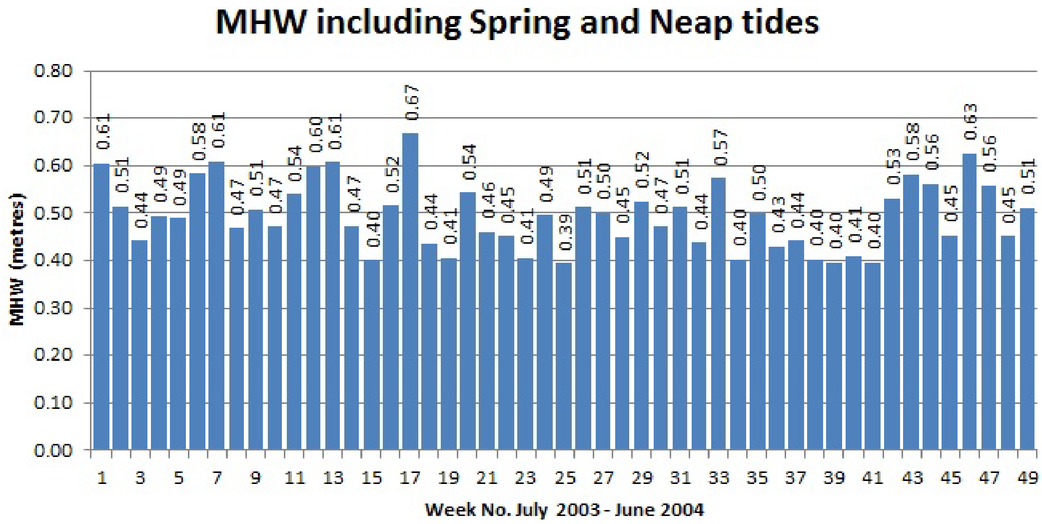

Figure 10: MHW including spring and neap tides at Port Macquarie in July 2003 – June 2004.

While the Surveying and Spatial Information Regulation requires the surveyor to subjectively exclude the non-ordinary tides, the ISG manual does not and instead requires the surveyor to consider all tides. The results of Figure 9 potentially satisfy the Surveying and Spatial Information Regulation and those of Figure 10 the ISG manual but there is a difference between the two in the results. If the non-ordinary tides cannot be identified, where does that leave the surveyor? The only possible answer is the ISG manual definition. This presumption would mean that it may be impossible to comply with the Surveying and Spatial Information Regulation definition as it requires exclusions which are not identifiable.

With the uncertainty and ambiguity of identifying particular tides for compliance with the Surveying and Spatial Information Regulation definition, how does the surveyor evolve a set of practice to determine the mean in mean high water?

4 MEAN HIGH WATER DEFINITION IN PRACTICE

The Surveying and Spatial Information Regulation definition provides inadequate guidance as to what practices would achieve a result that would comply with its requirements. It is up to the surveyor to make the most of what guidance there is. Some guidance can be gained from the deliberation of the judges in *Attorney General v. Chambers* who were seemingly attempting to describe a point on the foreshore where the high tides more often or not reached: "*What are then the lands which for the most part of the year are reached and covered by the tides? … the limit of the shore reached by these tides that is more frequently reached and covered by the tide than left uncovered by it. For about three days it is exceeded, and for about three days it is left short, and on one day it is reached. This point of the shore is about four days in every week*." Thus one practice method that the judges appear to have opened up to a surveyor is to observe every high tide for a week and find the height of the tide that would only cover the land four out of seven days. The three highest tide values for the week need to be excluded with the fourth highest being the desired criteria of MHW for that week.

In 2005 it was shown that the results from determining MHW by the height reached four days in seven varies considerably (Songberg, 2005). Making the comparison once again, but this time for the Port Macquarie data already utilised, the results from this method produce even wider results than those already discussed (Figure 11). Here the range between highest and lowest is 0.56 m and the largest of the methods considered, but more surprising is the higher trend in all the values. This method produces a mean for the whole year of 0.66 m whereas the other methods provide a yearly mean of 0.49 m. The criterion of four days in seven does not agree very well at all with other methods and consequently the judges may not have been as learned as they thought. This method can likely be discounted entirely.

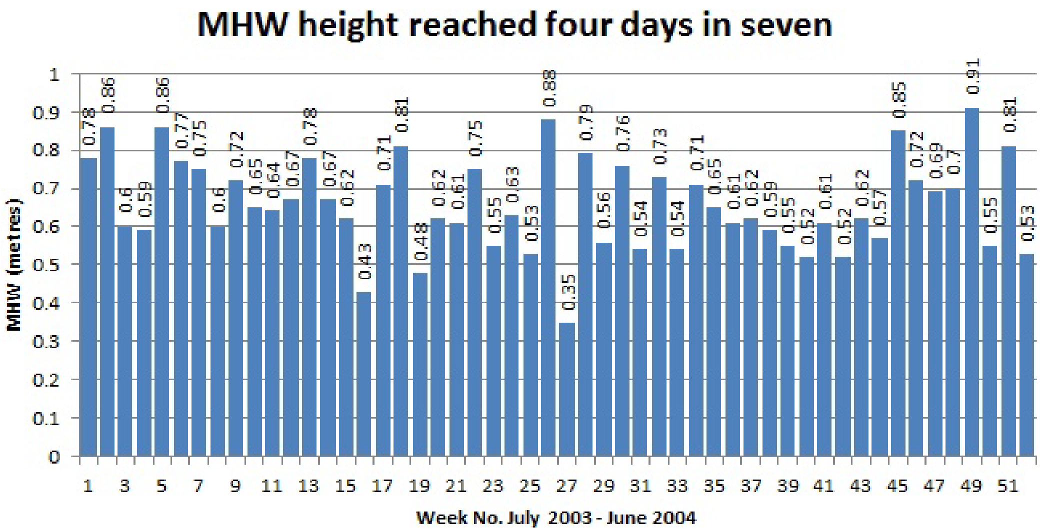

Figure 11: MHW as height reached 4 days in 7 days at Port Macquarie in July 2003 – June 2004.

The other approaches that were also considered by the judges in as to the limit of the sea or land were: "*The medium tides therefore of each quarter of the tidal period afford a criterion which we think may be best adopted … the average of these medium tides in each quarter of a lunar revolution during the year gives the limit … the limit indicating such land is the line of the medium high tide between the springs and neaps*." These deliberations can also be considered as plausible practice methods for determining mean high water and still be compliant with the judges' intent.

The results however are not necessarily the same. The measure utilising the moon phases and that of the line between spring and neap tides has already been shown. Although the results appear remarkably the same, they are not. Comparing the differing methods that were seemingly sanctioned by the judges of *Attorney General v. Chambers* as providing a measure of mean high water, it is soon found that the methods do not give the same result (Table 1). (It must again be stressed that the spring neap tide identification is only on the presumption that they are singular events and determined by the greatest range between consecutive tides is the spring and least range the neap. This presumption may not hold true.) The first three methods in Table 1 are those considered by the judges as providing a measure of the ordinary tidal event that usually covers the land. The fourth also compares the ISG possibility of a measure.

Table 1: MHW methods compared, data results from Port Macquarie in July 2003 – June 2004.

	Sample Interval				**Sample Quantity**		**Value**		
Method	**Max (days)**	**Min (days)**	**Ave (days)**	**Number intervals**	**Max (days)**	**Min (days)**	**Max (metres)**	**Min (metres)**	**Ave 1yr (metres)**
Moon phases (Fig. 3)	8.6	6.2	7.4	48	17	12	0.67	0.37	0.496
Betw. spring & neap (Fig. 9)	10.4	3.6	7.3	49	20	7	0.69	0.37	0.494
4 days in 7 (Fig. 11)			7.0	52	14	13	0.91	0.35	0.657
Incl. spring & neap (Fig. 10)	10.4	3.6	7.3	49	22	9	0.69	0.39	0.494

It is clear that there is no consistency with the resulting MHW from practice methods considered. The inconsistency is a consequence of the observation period being limited to the interval of the spring and neap tide cycle or an approximation to it (about 7 days). With results that vary over a 0.56 m range, depending on the method and time interval, the horizontal translation to the shoreline could result in differences in the tens of metres across a fairly flat foreshore. It is very doubtful that the judges in *Attorney General v. Chambers* envisaged such an ill-defined position to mark the boundary between the Crown and freehold foreshore. Community and property owner expectations of today would also not tolerate such a loose definition of the land. It is thus likely that none of these methods form an acceptable practice in determining mean high water.

The results shown have not included the identification of non-ordinary spring and neap tides so that none of the results will be fully compliant with the Surveying and Spatial Information Regulation. The closest that could be achieved is the “between” spring and neap dataset. This dataset excluded all spring and neap tides. Unfortunately the non-ordinary cannot be determined, so there is no way in which the surveyor can determine which is included and which is excluded in order to comply with the Regulation. This situation could possibly invalidate the Surveying and Spatial Information Regulation definition.

If the methods envisaged by the definitions and the judges of *Attorney General v. Chambers* are not appropriate in seeking an acceptable practice, the surveyor is left to follow historical procedures or other published guidelines. Of the guidelines that are available for the determination of MHW, the ISG manual ones are those that stand out. However, the practices recorded in the manual are synonymous with the manual’s definition of MHW and thus are not compliant with the requirements of the Surveying and Spatial Information Regulation as no exclusions are made. The ISG manual definition distinctly requires all tides to be considered. The ISG manual definition also goes away from the *Attorney General v. Chambers* expectations in that it adds an additional criterion, i.e. “*taken over a long period*”.

An examination of the ISG manual practices has shown that they fall considerably short of the expectations published (Songberg, 2005). A range of more than 0.2 m is quite probable between determinations and methods. Although not as bad as the 0.3 m result from the spring-neap cycle methods (or 0.6 m if the 4-days-in-7 method is considered valid), the ISG manual methods still do not provide consistency. What has not been considered and which now needs to be examined is what constitutes the "*taken over a long period*" part of the ISG definition? Do results change with variations in the length of the period?

Like the Surveying and Spatial Information Regulation, the ISG manual is not really helpful in defining a long period. It does, however, indicate in paragraph 22.5 (point 2) that "*observations extending over at least 12 months are necessary to obtain accurate results*". This statement would seem to suggest that observation sets shorter than 12 months are not acceptable. This would mean that the Surveying and Spatial Information Regulation spring to neap (7 days) and the manual's own lunar cycle (29 days) practice methods are both unacceptable. But is a 12-month period acceptable and does it provide any better result?

Manly Hydraulics Laboratory publishes tidal values for their tide gauges throughout the tidal reaches of NSW. One of these values is MHW determined over successive 12-month periods. It is these results that are today's mainstay of surveying MHWM boundary practice. But are they any better than the spring-neap cycle determinations?

Figure 12 shows the results from the Port Macquarie gauge over a 20-year period. As can be seen, there is a 0.12 m spread in the 12-month mean determinations. This at first seems a significant improvement over the 0.3 m spread of the spring-neap dataset. Port Macquarie, however, is only one of over 200 gauges and results vary considerably over the network. The spread in the 12-month determinations at any one gauge site vary from a low of 0.04 m to a high of 0.33 m. Clearly, a 12-month observation length provides little better results than a 7-day observation length.

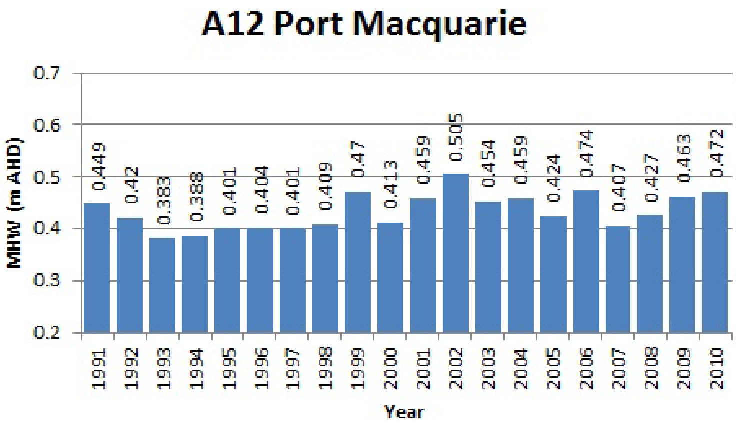

Figure 12: Yearly MHW values at Port Macquarie 1991-2010.

For Port Macquarie, extending the observation length to 2 years reduces the spread between highest and lowest means only marginally to 0.1 m. As the observation length increases, the spread does reduce to 0.07 m for a 5-year period and to 0.04 m for a 10-year period. Determinations of the mean from all sites exhibited a similar reduction in the spread between maximum and minimum datasets as the observation length increases. From Figure 13 it can be seen that the value of MHW seems to settle down after meaning an accumulation of about 6 months observing every high tide event. For a surveyor to accumulate such a dataset, they would need to observe somewhere in the order of 350 high tide events. Such a scenario is not

likely to occur unless a temporary tide gauge is installed to perform the observations. This also seems to suggest that at least a 6-month observation period is required for any meaningful answers to be achieved, not a 12-month period as indicated in the ISG manual.

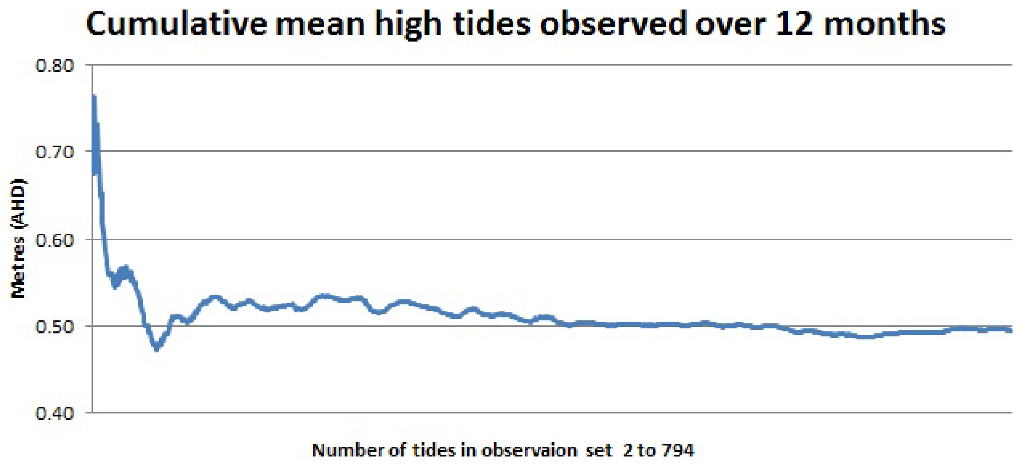

Figure 13: Cumulative mean high tides at Port Macquarie in July 2003 – June 2004.

The latest MHW values published by Manly Hydraulics Laboratory (Couriel et al., 2012) are a result of the mean of individual 12-month means over 2 to 20 intervals. Computation of cumulative means for records of 18 to 20 datasets found that a similar settling of the mean does not necessarily occur. Some sites seem to exhibit such a settling but some do not. Many site records are for considerably shorter periods. As a consequence, the MHW value over the period could still be subject to significant variability. As a result, the suitable length of "*taken over a long period*" remains uncertain. A lot will depend on the site conditions and particularly the variability of the tides.

5 SURVEYING REGULATION VS. SURVEYING PRACTICE

In today's surveying of the MHWM boundary, there is almost a total reliance on the published values of MHW from Manly Hydraulics Laboratory. Surveyors adopt the Australian Height Datum (AHD) level of MHW as published and simply level from the nearest coordinated marks out along the foreshore to establish the MHWM boundary.

In determining MHW values, Manly Hydraulics Laboratory does not undertake to mean the high tide values (Blume, 1995) nor do they selectively mean the tides between the ordinary spring and neap. Instead the MHW value is, as with all the other values, a result of a harmonic analysis of the entire dataset from the various tide gauges ranging from 12-month to 20-year periods. Only data that has been influenced by fresh water inflows has been removed (Couriel et al., 2012). The resultant MHW values are not a direct result of high tide observations but rather the result of a mathematical model. The practice used by surveyors that has evolved over time is thus unique unto itself and in theory would not meet with the regulatory requirements within the Surveying and Spatial Information Regulation for a MHWM boundary definition.

From contemplations of the definition of mean high water and possible practice methods that could relate to the definitions, what then is the mean of mean high water? For the data examined at Port Macquarie, there are the following possible determinations of the mean:

- From between the spring-neap intervals: 0.37 m to 0.69 m.
- High tide observations over a 12-month period (01/07/2003 – 30/06/2004): 0.494 m.
- Manly Hydraulics Laboratory harmonic analysis (01/07/2003 – 30/06/2004): 0.459 m.
- 20-year average of yearly harmonic analysis (01/07/1990 – 30/06/2010): 0.434 m.
- Year-to-year harmonic analysis determination: 0.383 m to 0.505 m.

None of these values fully satisfies the legislative requirements of the Surveying and Spatial Information Regulation as a value of the mean in MHW. The spring-neap means provide the closest possible answer to the Surveying and Spatial Information Regulation definition, and the 12-month mean of all high tides satisfies the ISG manual definition. The Manly Hydraulics Laboratory values for the mean unfortunately do not conform to either definition as they are not a direct result of the mean of high tide observations. What then is the true mean of mean high water? Is the mean the answer?

There is yet one more aspect to be examined: sea level rise. None of the values determined so far take into account sea level rise. Is there an effect and should it be included as part of the MHWM boundary deliberation?

6 SEA LEVEL RISE AND MHW

There are possibly still some sceptics out and about that do not believe that the sea is rising, just as there are sceptics that say there is no climate change. CSIRO and Manly Hydraulics Laboratory both fully recognise that sea level rise has occurred and is occurring. Over the last two decades, CSIRO provides a trend value of global sea level rise in the order of 3.2 mm/yr (CSRIO, 2014). It should be noted that CSIRO does stress that sea level rise is not uniform throughout the globe.

Manly Hydraulics Laboratory on the other hand provides a value of 0.94 mm/yr taken from data out of Fort Denison 1914-2004 (Couriel et al., 2012). However, the overall trend is a result of periods of apparently static mean sea level and other periods of apparent rapid rise. The two decades (1990-2010) covering the data analysis was a period of sustained El Nino which caused a depressing of sea levels and a flat trend in sea level rise. As a consequence, no adjustment of the data was made to consider sea level rise (Couriel et al., 2012).

The Fort Denison MHW values were published in 1994 (Ireland, 1994) and later extended to 2002. The chart of these values (Figure 14) provides some insight into what is occurring in respect to sea level rise, showing a linear rising trend of 0.8 mm/yr. Figure 14 also gives further insight into just how variable mean high water actually is. It is this variability that causes such a wide range in mean values (Songberg, 2005). But how much of this variability is influenced by sea level rise?

Earlier, the length of "*taken over a long period*" was considered. It was shown that the mean tended to settle down after about 6 months of high tide observations (Figure 13). The same tendency was not observed or was inconclusive in calculating the cumulative means for the 20-year values from Manly Hydraulics Laboratory (Couriel et al., 2012).

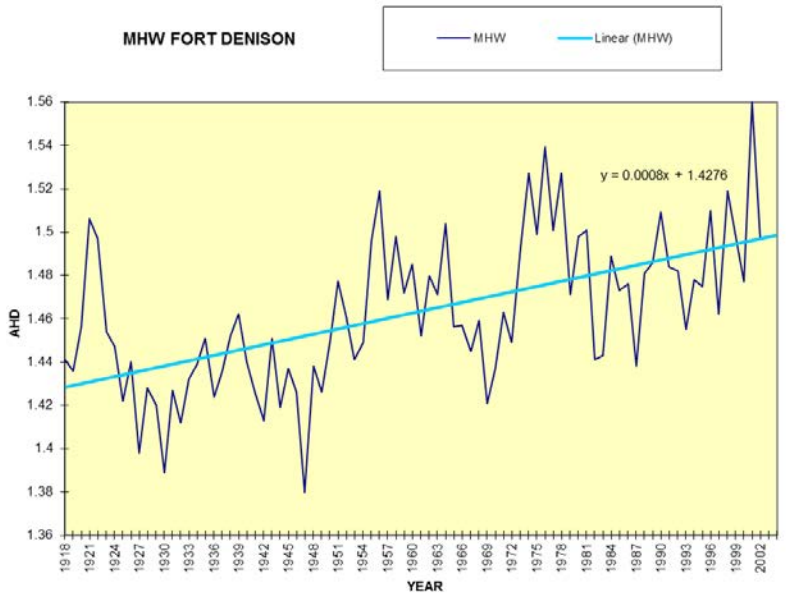

Figure 14: MHW values at Fort Denison 1918-2002.

Utilising the Fort Denison data to calculate an accumulative mean, there is also an apparent settling of the mean after about 20 years, or 20 observations, which continues for about another 15 years or observations. After this initial "*taken over a long period*" time, Figure 15 shows that the mean is then influenced by a rising sea level. The cumulative mean continues to rise as sea level rises. As a consequence of sea level changes, there does appear to be a limit to how long a period over which a mean can be taken before the sea level changes has an influence. The ISG manual definition now has a time limit.

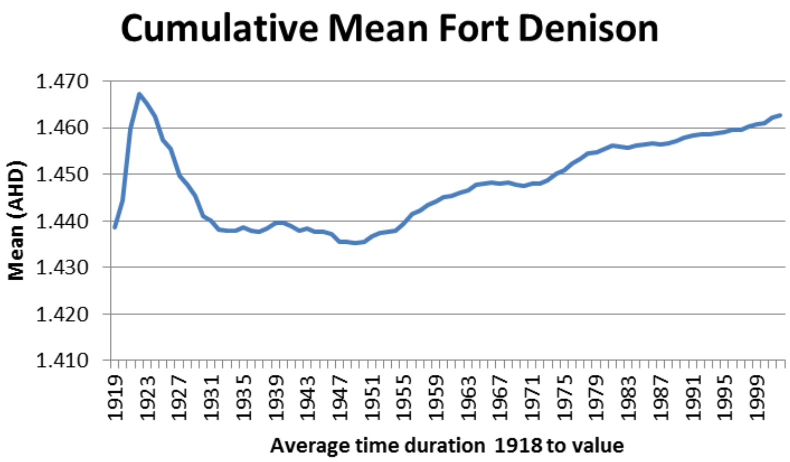

Figure 15: Cumulative mean values at Fort Denison 1918-2002.

But what of the 20-year records that are published by Manly Hydraulics Laboratory and predominantly used by surveyors? Is the 20-year mean (setting aside its non-compliance with the Surveying and Spatial Information Regulation) an acceptable period over which to take a mean value or should sea level rise be part of the consideration? Because of the various cycles affecting the moon and thus the tides, a 19-year period is considered as the most appropriate to establish the various tidal constants. The Fort Denison cumulative mean data suggest that it is only just long enough to determine the mean but is it long enough to show sea level rise?

Couriel et al. (2012) show around 200 sets of results of the harmonic analysis of the tide gauge readings. Excluding gauges that were set in non-tidal lakes such as Narrabeen Lagoon and those with only limited datasets, there are still at least 150 sets that can be interrogated to see if there is any tendency to show a trend for sea level rise. Creating charts for each dataset and plotting a linear trend through each, the results disclosed were a little mixed. The MHW values for Port Macquarie (Figure 16) show a rising linear trend of nearly 3 mm/yr. The data for Sydney, in this instance from HMS Penguin in Hunters Bay on Middle Head, shows only 1 mm/yr rising trend (consistent with the longer term Fort Denison trend).

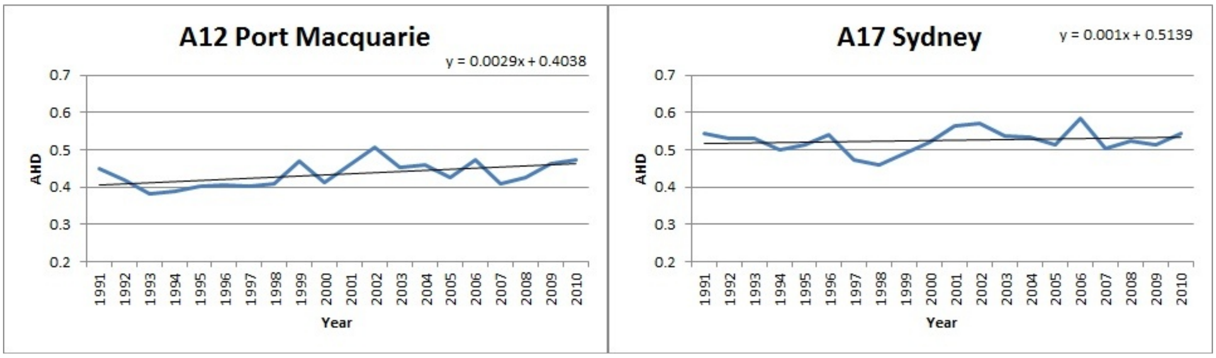

Figure 16: MHW trends over 20-year period (1991-2010) at Port Macquarie and Sydney.

However, not all tide gauge sites exhibited a rising trend. There were some that exhibited a negative or falling sea level trend. The 16 coastal gauge sites along the NSW coast provided a mixed result (Figure 17). The figures range from +4.7 mm/yr at Tweed Heads to -4.8 mm/yr at Crookhaven Heads. The overall analysis with gauges running up within the estuaries showed a similar mixed result (Figure 18).

A wide range of results was found from a -7 mm/yr to a staggering +23 mm/yr, suggesting that either the dataset is too short or there could be stability issues with the gauge. Overall, the results show a distinct tendency for the majority of datasets to show a positive linear trend indicating that sea level rise is most likely to be evident within the 20-year datasets. The average linear gradient suggests that for NSW there is a sea level rise of around 3 mm/yr. This result would mean that the sea level rise for NSW was generally within the quantum determined by CSIRO for the last two decades. It also indicates that the supposed flat trend in the sea level changes (Couriel et al., 2012) over the last two decades may not be as flat as first considered.

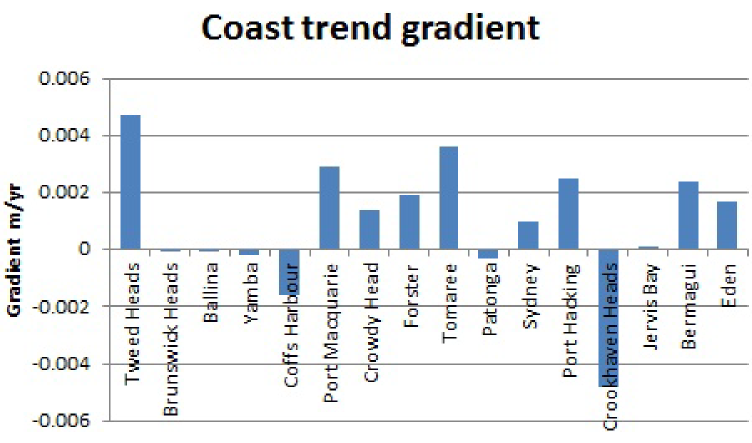

Figure 17: Linear sea level trends along the NSW coast (in metres).

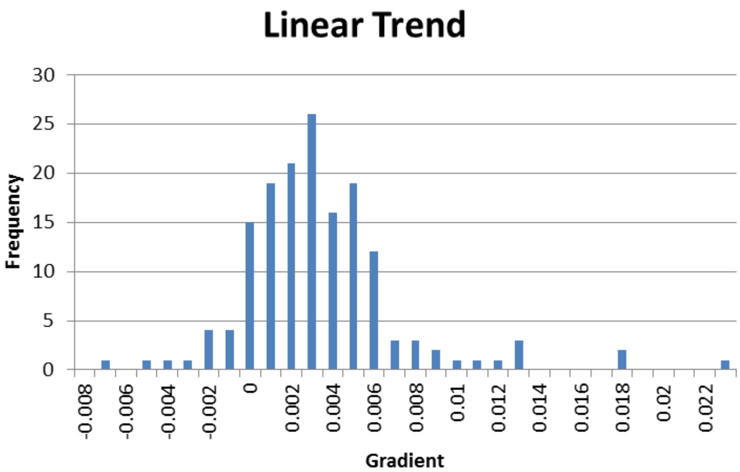

Figure 18: Linear trend histogram for all results.

As not all datasets included 20 groups, consideration was also given to find any correlation between gradients and the number of datasets. No correlation could be found. Within one standard deviation of the average trend gradient there were datasets with a count as low as 5. Outside the one standard deviation were datasets with counts of 18, 19 and 20 (Figure 19). Once again the result may not be a result of the data length but rather the stability of the gauge or even an issue with the AHD relationship. There was however a tendency for the smaller datasets to exhibit a higher grade and the larger datasets a lower grade.

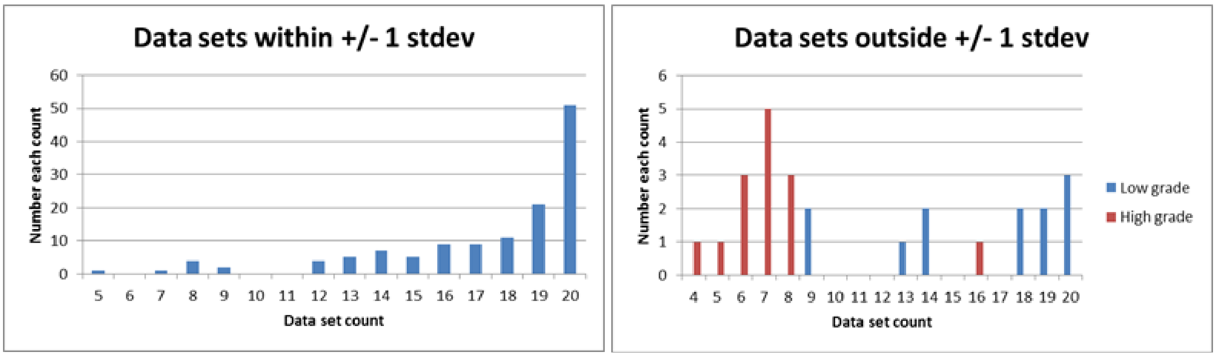

Figure 19: Count of datasets within and outside one standard deviation of the mean trend gradient.

With the distinct possibility that sea level rise is evident within the data used by surveyors, what implications does that have for the mean? The datasets used for this paper, and still commonly used by surveyors, are now 5 years out of date. If sea level rise has an effect on the data, then the mean derived from that data may not be acceptable. The mean may not be the answer. Expanding that dataset may also not be the answer, as sea level rise will continually affect the mean, as was shown in Figure 15. What can the surveyor do?

Surveyors could go against long accepted practice and adopt a 7-day tide observation period to determine a mean that is likely to be more compliant with the Surveying and Spatial Information Regulation, but the results would wildly fluctuate and would be unacceptable in today's expectations. The other option is for the surveyor to take into consideration sea level rise and account for it. The implication this has on the 1990-2010 datasets is that the value of MHW would need to be adjusted for sea level rise, not at the time of the data but for the time of the MHWM observation.

If that observation were today in 2015, what is the likely affect? Utilising only the 1990-2010 datasets and the derived linear trends, a predicted difference between the mean value and the trend value can be determined (Figure 20). The consequence is that there is likely to be around 20-60 mm difference in MHW between that published and that likely given sea level rise. If a surveyor were to use the published value then they would be too low in their estimate and have the boundary too far seaward. As time increases, the difference between the mean and the trend will become greater. Even if the survey were to have been conducted at 2010, the value of MHW used by the surveyor is likely to have been too low by about 10-40 mm.

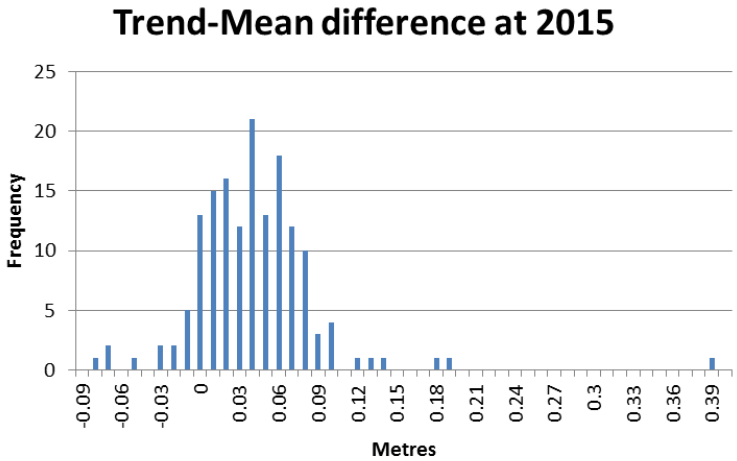

Figure 20: Difference between trend MHW and mean for 1990-2010 at 2015.

So is the mean the answer? If sea level rise is a fact and should be considered in determining MHWM boundaries, then it is likely that the mean will not be the answer. For many years the value of MHW adopted in Sydney remained static (Blume, 1995) but more recently it was felt that the value be periodically revised using a period of 5 years (Ireland, 1994). If the data examined is any indication, this 5-year increment between adjustments may not be an appropriate mechanism for dealing with sea level rise. As the published figures are always running behind the time of survey, in some cases years, more likely a trend, utilising the mean would provide a better realisation of MHW. It would also provide limited forward projection from the time of publication to the time of survey.

7 CONCLUDING REMARKS

Surveyors today would be surprised to learn that their MHWM definitions do not comply with the Surveying and Spatial Information Regulation 2012 and have not done so for a long time. Close examination of the definition of MHW in the Regulation and the data used by surveyors to firstly determine the MHW value, which is subsequently used to undertake the boundary definition, supports the belief. Surveyors would be further dismayed to learn that the definition in the Regulation cannot be complied with. The problem is in the wording of the definition. If strict adherence to the wording of the legislation is required for compliance, then the uncertainty in identifying the particular features of the definition such as spring tides, neap tides, non-ordinary tides and the need to exclude equally uncertain sets of data make compliance impossible. Data used by surveyors today in establishing the mean in MHW is not a numerical mean of high tides but rather the result of mathematical analysis over the entire tidal range and as a consequence does not comply with the specific requirements of the Regulation. References to spring or neap tides and the range in between must be removed from the definition and a new definition formulated that complements current survey practice.

Long-term data shows that sea level rise is a factor, and if the mean is taken over too lengthy a period, then sea level rise will have an influence. If not taken into account, then the resultant mean will be too low. Taking the mean over shorter periods, however, leads to wildly fluctuating results, a factor which would not be tolerated in today's need for more precise property definitions. The length of the period after which the mean becomes unstable as a result of sea level rise is somewhat uncertain. With only 20-year datasets available for examination, the results, although supportive of the concept, were not fully conclusive. Expansion of the data and more reaching analysis is required before a fully definitive result can be produced. However, from what has already been examined, the data does support the concept that the mean of mean high water is not as reliable an answer as was previously considered and that a new definition that will agree with current survey practice and take into account sea level rise is required for the determination of tidal riparian boundaries. Early data examination suggests that criteria utilising the trend in sea level rise coupled with mean high tide determinations from tide gauge harmonic analysis might be the way forward.

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