An Experiment in Determining the High-water Mark

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Abstract

As a boundary of the seashore, the high-water mark (HWM) is relevant to the public, the State, and other rights holders in the coastal zone. Unlike most fixed property boundaries that are surveyed and beaconed, the HWM is subject to dynamic natural coastal processes and moves over time. Its location is difficult to determine, and the precision of this determination is unknown. This paper reports on an experiment to measure the precision (variability/repeatability) of the location of the HWM at a variety of sites near Cape Town, by volunteer participants. Four sites were chosen along stable (non-mobile) shores along the open, high energy oceanic shores south of Cape Town on the Cape Peninsula. One of these sites exhibits large variation in coastal terrain and type – at this site three sets of measurements were undertaken, bringing the total number of experimental sites to six. Surveying was undertaken in the South African national control survey system using network real-time kinematic global navigation satellite systems (GNSS).

This experiment shows that the professional land surveyors located the HWM to ±1,6m, coastal engineers to ±4,1m, and the group of 'others' to ±4,2m. The professional land surveyors determined the height of the HWM to ±0,4m over all sites, compared to ±0,7m for all participants. The HWM is likely to be about 4 - 5m above the lowest astronomic tide. However, the line is not a contour – it is affected by weather and local variations in the coastline such as slope and seashore composition. The averaged heights of the HWM at each of the sites for all participants showed a range of 1,3m. Since the boundaries of the seashore cannot be determined with precision, property, cadastral and environmental law needs to continue to respect the nature of this environment and the limitations of locating the HWM.

Keywords: *high-water mark, seashore, coastal land, surveying*

1. Introduction

Any citizen who enjoys coastal areas has an interest in, and the right to access, the seashore. The State acts as a trustee of this important area — it has a duty of care and must act in the best interests of the public. The State is the custodian of the high-water mark (HWM) and low-water mark (LWM) which define the landward and seaward limits of the seashore. Public users of the seashore need to know the limits of this area, as do other coastal land rights holders and the State. The HWM is now also used to determine the inland boundaries of coastal zones by lines determined a certain distance inland of the HWM (coastal set-back lines). The HWM is a challenging boundary to determine. It is curvilinear but also ambulatory, so its location is constantly changing along with littoral processes. In South Africa, it is not a line of constant height, while it is influenced by many physical factors such as tidal forces and meteorological changes. However, the location of the HWM is becoming increasingly important as land in coastal areas is developed and increases in value, in managing the coastal environment and development, and in maintaining the rights of the public to the seashore.

The origins of the HWM as a legal boundary and the issues involved in interpreting these are reflected by Mackie (2015). The HWM intersects the domains of the land and the sea and is thus a critical boundary in terms of coastal processes and uses. The economic activities of these domains are, in general, fundamentally different and it is common practice to elect the intersections of these domains as legal property boundaries. The earliest reference, as a common source for the practice, is contained in the Institutes of Justinian (533 AD) (Thomas 1975). The relevant section is *Book II, Title 1, Clause 3 – Of the Different Kinds of Things*. The primary intent of this section is a catalogue of the various classes of ownership of things — the important issue is ownership, not the precise physical nature of the object or, in this case, the location of a boundary. However, the key sentence in the Institutes reads:

"Est autem litus maris, quatenus hibernus fluctus maximus excurrit."

Which is most reasonably translated as (Mackie 2000: 45):

"The seashore, however, is as far as the greatest run-up of the winter waves."

This does carry with it the intent of the intersection of the two domains but with the words *"run-up of the winter waves"* recognises a fundamentally dynamic character to the HWM as a boundary.

It would appear that the concept and characterisation of the HWM has been developed through time, starting with Justinian, by a process of intellectual, legal argument without recourse to reality. In the beginning, the issue was of little more concern than that of cows grazing along the seashore and fishermen drawing up their skiffs on the beach. Justinian covers this aspect by extension of the concept of the freedom of the sea to freedom of the seashore.

The HWM definition and method of location varies considerably depending on a nation's legal system and laws. The South African legal system is a combination of Roman-Dutch law, English law, and African customary law. Roman-Dutch law guides understanding of the HWM and seashore, while the English law of evidence guides the location of the line on the ground. In the context of this paper, *location* is where the HWM is identified on the ground by observing and interpreting evidence on site, while *position* means the surveyed coordinates of the located HWM using standard cadastral surveying technology and methods. According to legal requirements, the HWM as a property boundary of the seashore and landward parcels, is located and then positioned by professional land surveyors in accordance with the Land Survey Act 8 of 1997, the National Environmental Management Integrated Coastal Management Act 24 of 2008 (ICMA), as well as some key case law going back well over a century. Recently, environmentalists and coastal engineers have also attempted to locate the HWM for various purposes.

The case of Anderson and Murison v The Colonial Government (1890 – 1891) 2 SC 293 highlights the right of the public to the seashore and determined that this area lies between the HWM and LWM. The case of Milnerton Estates, Limited, v The Colonial Government (1899) 16 SC 177 determined that where a landward parcel extends to the seashore that this is to be read as the HWM. This is confirmed in Horne & Another v Struben & Another 1902 19 SC 317 PC. Colonial Government v Town Council of Cape Town (1902) 19 SC 87 highlights that accession (seaward movement of the HWM) does not take place because of human actions since these do not accord with the doctrine of alluvium. This is confirmed in Cader Hoosen v Durban Corporation (1916) 37 NPD 115. The case of Pharo v Stephan 1917 AD 1 is a landmark case with respect to the definition of the HWM – it is this case that led to the definition of the HWM in the Sea-Shore Act 21 of 1935 Section 1 (now repealed):

High water mark *means the highest line reached by the water of the sea during ordinary storms occurring during the most stormy period of the year, excluding exceptional or abnormal floods.*

For more than seventy years these definitions were used in South African law and practice. The ICMA replaced the Sea-Shore Act 21 of 1935 along with new definitions. The definition of the HWM was critiqued by Whittal (2011) and thereafter amended (Act 36 of 2014). Currently, the HWM is defined in the ICMA (1(1)):

"high-water mark" means the highest line reached by coastal waters, but excluding any line reached as a result of:

a) exceptional or abnormal weather or sea conditions; or

b) an estuary being closed to the sea;

Without considering the complexities of estuaries, the definition implies that the HWM is delineated by the maximum landward excursion of the sea during weather and sea conditions that are not considered "exceptional or abnormal" but that include storms and the regular 18,6-year cycle of the tide-raising forces of the moon and the sun. The HWM location may vary considerably due to the slope of the coastal terrain and its composition (e.g., rocks, sand, vegetation). Figure 1 illustrates the coastal waters reaching a location close to the HWM.

The HWM of commonwealth countries (the USA, Australia, New Zealand etc.) differs from that in South Africa in that their HWM is defined as the intersection of a tidal datum (a surface of constant height) and the terrain (Liu *et al*, 2014). Tidal datums are calculated through long-term tidal records. HWMs derived from tidal datums are less sensitive to recent changes in the HWM than those that are of variable height and rely on ground-based evidence only, such as in South Africa (Liu *et al*, 2014). A detailed document on determination of the HWM is produced for New Zealand (Baker and Watkins, 1991). For early grants in New Zealand, the HWM at ordinary tides was used in coastal property boundary definition. In relocating these boundaries, evidence of the HWM location over an ordinary tide cycle is used. Liu *et al* (2014) highlight the challenges of interpreting the evidence and locating the HWM on site. In other HWM determinations in New Zealand, the intersection of the mean high-water (MHW) datum with the terrain is used to determine the mean high-water mark (MHWM) (a process explained in Baker and Watkins, 1991). Practically, the MHW datum height is surveyed relative to local heighted points (benchmarks) on site – the surveyor then sets out the HWM as a line of constant elevation along the shore. However, the MHW datum precision degrades with distance from the tide gauge (0,2m over a few kilometres in New Zealand). Determinations of the MHW datum have the following vertical precisions: ±(0,02 – 0,04)m with 19 years of nearby tidal data, ±0,1m with 1 year of tidal data, and ±0,25m with 1 month of tidal data (Baker and Watkins, 1991). The uncertainty of HWM lines derived from datums (e.g. MHW), and of HWM lines established from evidence on site, increases when the coastal terrain has a shallow slope (Liu *et al*, 2014). Since legal systems, definitions, and laws of evidence differ, international research and experience is only instructive in so far as it aligns with national law. There is minimal guidance on locating the HWM in South Africa and in countries with a similar Roman-Dutch legal system, while research on the precision with which the HWM can be located, is lacking.

Figure 1: Clear weather storm swash reaching to terrestrial vegetation

Fisher and Whittal (2020) interpret the current legal definition of the HWM, the processes involved in its location, and surveying the HWM as a legal property boundary. In particular, the list by Fisher and Whittal (2020) of site evidence to be considered when locating the HWM (as per Williams-Wynn, 2013) is relevant to this experiment. In summary, debris and waste, vegetation types (such as halophobic plants), drift sands, discolouration on coastal rocks, photographic and video evidence, and evidence of residents, may all be used in the determination of the location of the HWM (Fisher and Whittal, 2020). A meeting of the South African Surveyors-General (2012) resolved how to arrive at a legitimate HWM (but not necessarily supported in law) for the purposes of managing the coastal zone. The aspects decided in this meeting are reflected in Fisher and Whittal (2020).

After having established the HWM *location*, it is a simple matter to survey the *position* of the location to a high degree of precision through established cadastral surveying processes. A simple way to assess the precision (variability/repeatability) of *location* of the HWM is to conduct an experiment at a variety of sites near Cape Town, by volunteer participants. This was undertaken in March 2018 and is reported in this paper.

2. Method

An experimental method was used. As with all experiments involving human subjects in real world settings (rather than in a controlled laboratory), some aspects of bias may be evident – in this case due to the professional backgrounds of the participants. However, these mimic the real differences in practice between people tasked with locating the HWM, and so are valid and important to the conclusions. The workflow of the experimental method is illustrated in Figure 2.

2.1. Planning

2.1.1. Site selection

The precision of locating the HWM should be tested for challenging sites. These are identified as sites with open, high energy, oceanic shores with very little protection from headlands and which have a semidiurnal meso-tidal regime such as are found on the western shores of the Cape Peninsula. The Cape Peninsula is bounded on the west by the Atlantic Ocean with a regular tidal range of about 1,7m. The coastal waters are infamous for their rough stormy seas - hence the Cape Peninsula goes by the name 'The Cape of Storms'. Figure 3 illustrates a particularly challenging site to locate the HWM. Six sites were selected, all on the western side of the Cape Peninsula, south of the central business district of Cape Town (Figure 3 & Figure 4). For all sites, the applicable tide gauge for establishing Lowest Astronomical Tide (LAT, which is the chart datum) is the Cape Town tide gauge located in Table Bay harbour.

Three of the sites, Granger Bay (G), Llandudno Sewage Works A (LA) and Llandudno Sewage Works B (LB) are stable rock shores. Site Llandudno Sewage Works C (LC) is a bimodal beach. The substratum exposed during the winter seas is rounded sea boulders of two tons to 20 tons and quite stable. The summer beach is a sand cover but insufficient at the presumed level of the HWM at the site to make a significant difference to the profile presented by the substratum. Sites Hout Bay (H) and Witsand (W) are sandy beaches capable of summer-winter profile changes but substantially stable during the portion of the season when the experiment was performed. Of the six sites, four are natural sites while the other two sites have dune stabilisation (Site H) and reclamation (Site W). Each site had cell phone connectivity required for the method of surveying used (section 2.1.3).

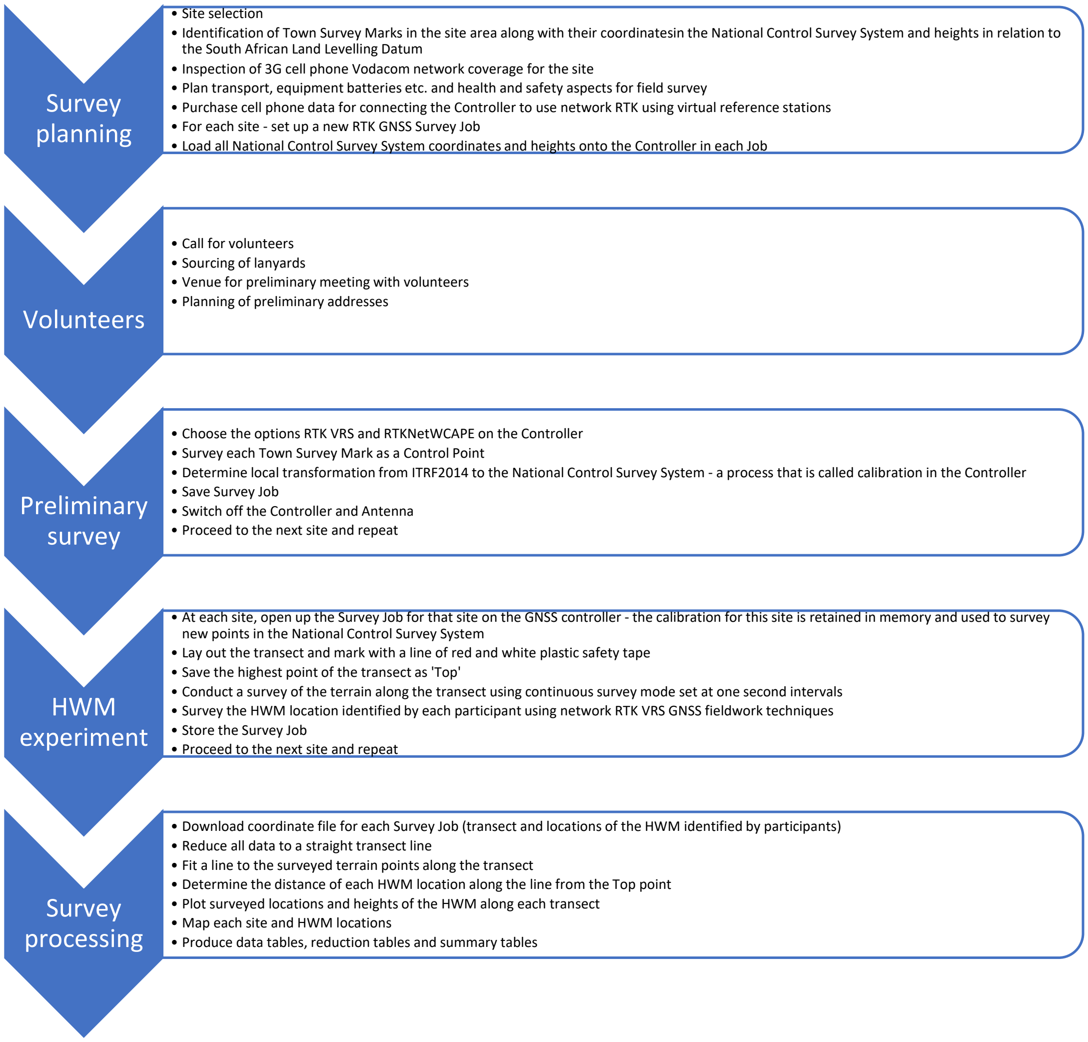

Figure 2: Workflow Diagram

Table 1: Sites selected

Abbreviated site name	Site name	Site type
G	Granger Bay	Beach outside the car park of the Hotel School
LA	Llandudno Sewage Works	Rock shore (Logies Bay)
LB		Rock shore (Logies Bay)
LC		Steep sandy shore (east end main beach)
H	Hout Bay	Restored sandy dune shore, west end of Hout Bay
W	Soetwater/Witsand	Sand beach reclamation over landfill

Figure 3: Soetwater/Witsand - Site W
The site is a managed reclamation – landfill with dune stabilization. It illustrates challenging conditions for HWM location.

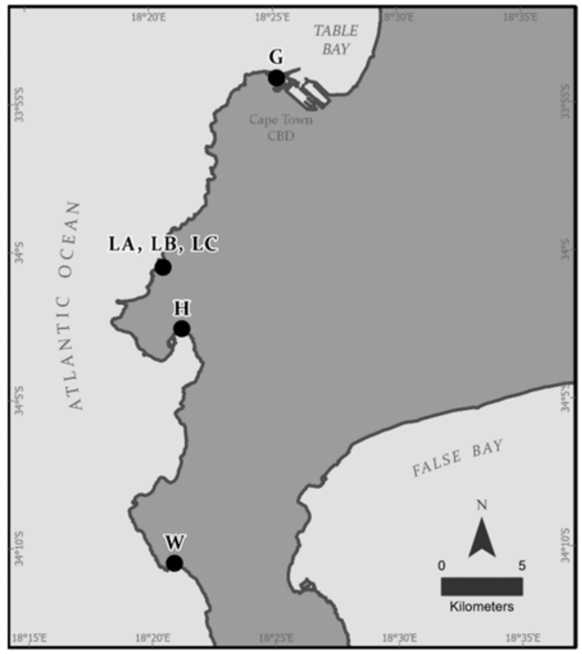

Figure 4: Locality map of the sites on the Cape Peninsula, Cape Town

2.1.2. Volunteer planning

A call for volunteers was put out through the Western Cape Branch of the South African Institution of Civil Engineers including its Marine Division, the local branch of the South African Geomatics Institute, and the Coastal Management Section of the City of Cape Town. A total of 14 persons volunteered of which 13 were present at all sites. The participants consisted of professional land surveyors (3), coastal engineers (4) and 'others' (7). The 'others' included a civil engineer, a mechanical engineer, a coastal environmental scientist as well as four friends and family members.

2.1.3. Survey design and planning

Surveying of the locations was undertaken using Global Navigation Satellite Systems (GNSS). The chosen network Real-time Kinematic surveying (RTK GNSS) virtual reference station (VRS) design uses base station data from continuously operating reference stations maintained by the State (called TrigNet). This network models corrections (e.g. for atmospheric refraction and orbit errors) using Trimble software. The data from the TrigNet system is accessed automatically through the GNSS Controller using cell phone communication. Cell phone reception is thus required at all sites. Without cell phone connectivity, a different survey method, such as 'Own base' RTK GNSS, could be used. The surveying equipment (Trimble R2 GNSS) was checked using control points at University of Cape Town (UCT). The method of surveying is reported as accurate to 0,01m horizontal by Du Toit (2007), and 0,008m horizontal and 0,02m vertical by Marais (2008). Häkli (2004) reports accuracies at the centimetre level in Finland. The method is suitably accurate to survey the HWM locations identified by the participants, given the expected (and shown) locational uncertainty.

National Town Survey Marks (TSMs) within the vicinity of each site were identified. The City of Cape Town Open Data Portal provides TSM coordinates in the National Control Survey System (NCSS), heights in relation to the South African Land Levelling Datum (LLD) (Table 2), as well as maps of their locations (locations are illustrated in Figure 5 - Figure 8).

Table 2: Town Survey Marks in the NCSS and residuals from the calibration

Site: Granger Bay (G)					
TSM	**y coordinate (m)**	**x coordinate (m)**	**H height (LLD) (m)**	**Horizontal residuals (m)**	**Vertical residuals (m)**
8 I4	54429,44	3752724,77	5,819	0,004	-0,003
9 I4	54492,71	3752672,06	6,293	0,004	0,007
10 I4	54741,40	3752694,82	5,448	0,009	-0,007
11 I4	54736,41	3752763,81	5,991	0,008	0,003
Site: Llundudno Sewerage Works (sites LA, LB and LC)					
TSM	**y coordinate (m)**	**x coordinate (m)**	**H height (LLD) (m)**	**Horizontal residuals (m)**	**Vertical residuals (m)**
3BS66	60120,72	3765023,06	151,17	0,003	-0,027
4BS66	60202,06	3764817,12	136,89	0,007	0,013
5BS66	60250,20	3764679,93	129,42	0,004	0,014
Site: Hout Bay (H)					
TSM	**y coordinate (m)**	**x coordinate (m)**	**H height (LLD) (m)**	**Horizontal residuals (m)**	**Vertical residuals (m)**
19 AB2	60,202.55	3,769,069.54	3,088	0,013	0,004
21 AB2	60,235.31	3,768,685.53	16,686	0,017	-0,020
32 AB2	60036,36	3768766,78		0,013	---
45 AB3	59985,92	3768850,56	3,928	0,008	0,004
Site: Witsand (W)					
TSM	**y coordinate (m)**	**x coordinate (m)**	**H height (LLD) (m)**	**Horizontal residuals (m)**	**Vertical residuals (m)**
11AB17	60472,71	3783024,90	13,662	0,004	0,017
13AB17	60613,65	3783086,19	10,577	0,007	-0,013
14AB17	60842.94	3783103.05	6,870	0,009	0,000
15AB17	61029.77	3783015.05	5,183	0,005	-0,004

Figure 5: Location of Town Survey Marks in relation to the transect in Granger Bay

Figure 6: Location of Town Survey Marks in relation to the transect in Llundudno

Figure 7: Location of Town Survey Marks in relation to the transect in Hout Bay

Figure 8: Location of Town Survey Marks in relation to the transect at Witsand

2.2. Preliminary Survey Work

The first author was assisted by a final-year UCT BSc Geomatics student in all aspects of the survey work. Preliminary surveying, one week before the experiment, was undertaken to determine the local transformations from the GNSS system (ITRF2014 3D coordinates) into the NCSS (two-dimensional coordinates and heights). Transformations (termed 'calibration') were determined for each site since the TSM co-ordinates may be inconsistent. For each site, a unique Survey Job is opened and the TSMs are surveyed as Control Points with tolerances set at 0,01m in horizontal and 0,02m in vertical. The transformation ('calibration') is undertaken in the Controller. The residuals from the calibration at each site are given in Table 2. The Survey Job is then stored and the GNSS receiver is shut down. The transformation parameters for each site stored in the Survey Job may then be used on the day of the experiment.

2.3. HWM Experiment

2.3.1. Preliminary meeting

A welcome address and instruction on the determination of the legal HWM, through assessing evidence along the coast, was undertaken at the Hotel School at Granger Bay. The second author presented the issues from an engineering perspective, while the first author gave the cadastral perspective used to determine the legal HWM. Participants completed an attendance form and were handed a lanyard and label showing their unique, random, participant number. Outside the venue was the first site, Granger Bay. Thereafter, participants travelled from site to site using private transport.

2.3.2. Data acquisition

At each site a transect was laid out with red and white safety tape along a line roughly perpendicular to the shoreline. The relevant GNSS Survey Job with its site calibration was used to survey new points with a tolerance setting of 0,015m. A point 'Top' was surveyed as the landward terminal of the transect. In the order of their lanyard number, each participant assessed their location of the HWM along the transect and placed a ranging rod at that location. The position was then surveyed. Network RTK GNSS VRS produces coordinates and heights without post-processing.

2.4. Survey Processing

2.4.1. Locations of the HWM identified by participants along the transects

After downloading the data, the surveyed coordinates were reduced to a perfect straight transect line after which the point 'Top' and the HWM locations were plotted. From this reduced data, the sample mean, standard deviation and range were calculated for the distances along each of the transects. For each site the results of the professional land surveyor participants and the coastal engineer participants are also disaggregated.

2.4.2. Datums, levels, water marks and the reduction of heights

To proceed with the analysis of the heights of the points surveyed, it is important to understand the HWM in relation to other vertical datums in the coastal zone and offshore. Figure 9 illustrates these relationships and may be read in conjunction with some brief explanations below.

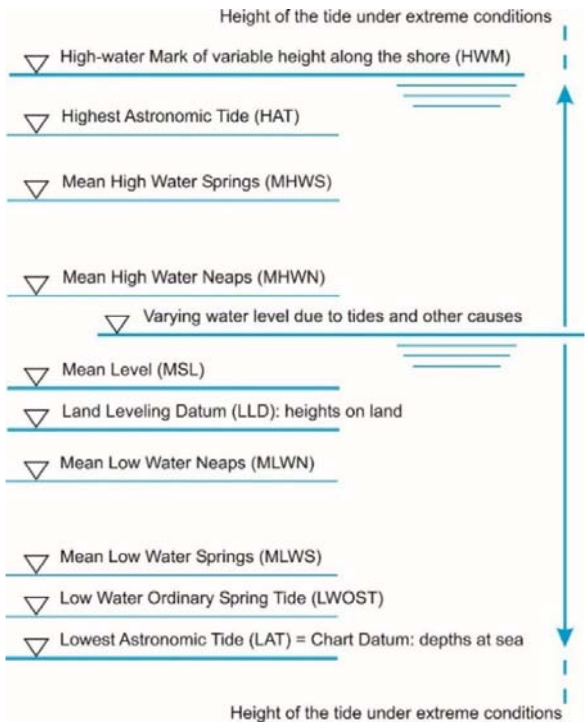

Figure 9: Tidal parameters on the South African Coast

Tide gauges at some South African ports measure the time-varying height of coastal waters. Tides on the Southern African coasts are regular, semidiurnal (two highs and two lows per day), with a range that seldom exceeds 2,2 m. These tide gauge data are modelled (using data over more than 18,61 years to reflect the full range of astronomical factors) to produce mean sea level (MSL) and LAT at each tide gauge. LAT can be used to produce a tidal datum surface (termed a hydroid) from which depths at sea are recorded. For definitions of Highest Astronomical Tide (HAT), LAT, Mean High/Low Water at Springs/Neaps (MHWS, MHWN, MLWS, MLWN), and Mean Level (ML), please refer to the online dictionary of the International Hydrographic Organisation (IHO, 2019).

Mean Sea Level (MSL) is determined from the average of tide gauge readings over a defined period – this and the date should be stated with all MSL determinations. The Land Levelling Datum (LLD) is the national heighting datum used in South Africa. It is offset from the MSL by varying amounts at each tide gauge. These offsets range from 0,143m below the MSL in Table Bay, Cape Town, to 0,341m below MSL in Durban (Merry, 1972). The surveyed heights in this experiment were reduced to the LAT using the offset of +0,825m of the LLD from the LAT at Cape Town (Mather *et al*, 2009, 149). The LAT, HAT, and ML used here are for the Cape Town tide gauge (SANHO).

3. Results

3.1. Reduced Survey Data – Horizontal Distances from 'Top" and Heights Above LAT

The following tables (Table 3 – Table 7) reflect the horizontal locations of the HWM in terms of distances from the point 'Top' along each transect, the heights of each point above LAT, and various sample statistics for all participants, for the land surveyors, and for the coastal engineers.

Table 3: Granger Bay – Site G

Point	**Distance from top of transect (m)**	**Height (m) above LAT**
All participants		
Top	0,00	7,27
G6	4,04	7,02
G4	7,58	5,70
G9	8,91	5,28
G2	9,24	5,18
G7	9,69	5,13
G10	10,41	4,99
G3	10,79	4,93
G8	11,59	4,78
G5	21,30	4,32
G13	23,96	4,10
G1	24,81	3,96
G11	26,09	3,82
G12	26,97	3,75
Mean	15,03	4,84
Std dev	±8,20	±0,90
Range	22,93	3,27
Location of HWM along transect		
	Land Surveyors	**Coastal Engineers**
Mean	9,91	19,41
Std dev	±0,80	±9,11
Range	1,55	19,39

Table 4: Llandudno Sewerage Works – Site LA

Point	**Distance from top of transect (m)**	**Height (m) above LAT**
All participants		
Top	0,00	4,28
LA4	0,02	4,22
LA2	0,04	4,23
LA9	1,01	4,50
LA8	1,21	4,54
LA3	1,49	4,24
LA13	2,14	4,07
LA10	3,06	3,32
LA11	3,09	3,31
LA6	3,58	5,98
LA5	4,71	3,00
LA1	5,88	2,75
LA7	6,05	3,05
LA12	7,80	2,95
Mean	3,08	3,86
Std dev	±2,44	±0,91
Range	7,78	3,23
Location of HWM along transect		
	Land Surveyors	**Coastal Engineers**
Mean	2,53	3,60
Std dev	±3,14	±3,23
Range	6,01	7,78

Table 5: Llandudno Sewerage Works – Site LB

Point	**Distance from top of transect (m)**	**Height (m) above LAT**
All participants		
Top	0,00	7,69
LB6	5,21	6,16
LB9	6,29	5,61
LB4	6,73	5,21
LB8	7,15	4,97
LB7	7,20	4,97
LB2	7,58	5,09
LB3	8,39	4,70
LB11	8,56	4,65
LB5	9,20	4,55
LB13	9,21	4,51
LB10	9,84	4,55
LB12	9,87	4,53
LB1	10,98	4,12
Mean	8,17	4,89
Std dev	±1,65	±0,54
Range	5,77	2,04
Location of HWM along transect		
	Land Surveyors	**Coastal Engineers**
Mean	7,72	8,66
Std dev	±0,60	±1,79
Range	1,18	4,25

Table 6: Llandudno Sewerage Works – Site LC

Point	**Distance from top of transect (m)**	**Height (m) above LAT**
All participants		
Top	0,00	5,52
LC9	0,05	5,41
LC4	0,66	5,65
LC8	0,68	5,63
LC7	0,69	5,22
LC3	1,15	5,12
LC2	1,50	5,08
LC13	1,91	5,17
LC11	1,92	5,18
LC6	1,93	6,19
LC12	3,58	4,71
LC10	3,58	4,70
LC5	4,27	4,61
LC1	5,70	4,10
Mean	2,12	5,14
Std dev	±1,67	±0,53
Range	5,65	2,09
Location of HWM along transect		
	Land Surveyors	**Coastal Engineers**
Mean	1,11	2,51
Std dev	±0,40	±2,14
Range	0,80	5,03

Table 7: Hout Bay – Harbour Side – Site H

Point	**Distance from top of transect (m)**	**Height (m) above LAT**
All participants		
Top	0,00	5,57
H6	0,10	5,46
H5	4,33	4,55
H3	5,21	4,32
H7	5,56	4,08
H8	5,57	4,06
H13	5,86	3,92
H11	5,98	3,87
H2	6,23	3,79
H1	6,37	3,73
H4	6,73	3,63
H12	7,23	3,48
H10	7,76	3,33
H9	8,08	3,28
Mean	5,77	3,96
Std dev	±1,99	±0,58
Range	7,98	2,18
Location of HWM along transect		
	Land Surveyors	**Coastal Engineers**
Mean	5,67	6,38
Std dev	±0,52	±0,64
Range	1,02	1,66

Table 8: Witsand/Soetwater – Landfill – Site W

Point	**Distance from top of transect (m)**	**Height (m) above LAT**
All participants		
Top	0,00	6,54
W6	0,23	6,41
W2	3,37	5,70
W14	4,04	5,58

W8	5,28	5,30
W5	6,10	5,05
W7	6,20	5,04
W3	7,09	4,74
W10	7,71	4,57
W13	7,81	4,53
W1	8,29	4,41
W9	10,06	4,36
Mean	6,02	5,06
Std dev	±2,72	±0,64
Range	9,83	2,05

Location of HWM along transect		
	Land Surveyors	**Coastal Engineers**
Mean	5,24	7,12
Std dev	±1,86	±2,62
Range	3,72	6,02

3.2. Summary of the Horizontal Locations of the HWM for Each Transect

Table 9 summarizes the horizontal locations of the HWM in terms of mean ranges for each transect, as well as the standard deviation of the observations for that site. The mean range and mean standard deviation are shown for each participant group for all sites. The large range and standard deviation for the horizontal location at the first site, G, is most likely due to inexperience in locating the HWM. The participants appeared to gain understanding after assessing this initial site.

Table 9 and Figure 10 show how the land surveyors' results were of a higher precision than those of other participants. This is expected since surveying the HWM is a task of professional land surveyors. Of interest is that the professional land surveyors' results for the first site, G, were precise indicating that they did not benefit as much as others from the initial on-site experience. Figure 10 and Figure 11 show how the results of the land surveyors, the coastal engineers, and the 'others' compare to the overall sample.

Table 9: Horizontal location summary for all participants as well as disaggregated by participant group

All participants

SITE:	**G**	**LA**	**LB**	**LC**	**H**	**W**	**Mean**
range (m)	22,9	7,8	5,8	5,7	8,0	9,8	10,0
std dev (m)	±8,2	±2,4	±1,7	±1,7	±2,0	±2,7	±3,9

Land Surveyors

SITE:	**G**	**LA**	**LB**	**LC**	**H**	**W**	**Mean**
range (m)	1,6	6,0	1,2	0,8	1,0	3,7	2,4
std dev (m)	±0,8	±3,1	±0,6	±0,4	±0,5	±1,9	±1,6

Coastal Engineers

SITE:	**G**	**LA**	**LB**	**LC**	**H**	**W**	**Mean**
range (m)	19,4	7,8	4,3	5,0	1,7	6,0	7,4
std dev (m)	±9,1	±3,2	±1,8	±2,1	±0,6	±2,6	±4,1

Others

SITE:	**G**	**LA**	**LB**	**LC**	**H**	**W**	**Mean**
range (m)	18,0	3,7	6,2	4,3	8,0	7,6	8,0
std dev (m)	±7,2	±1,3	±2,6	±1,8	±3,3	±3,6	±4,2

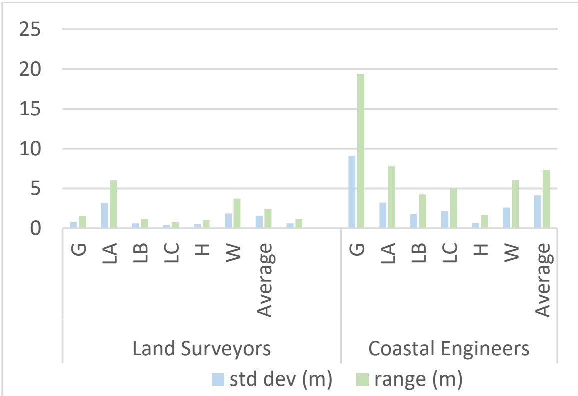

Figure 10: The ranges of HWM locations and standard deviations for land surveyors and coastal engineers

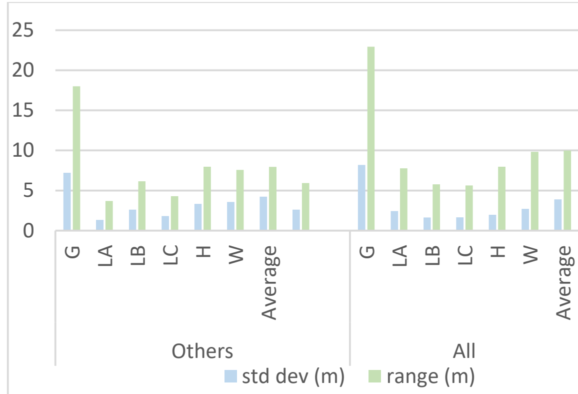

Figure 11: The ranges of HWM locations and standard deviations for the 'others' and for all participants

3.3. Summary of the Heights of the HWM for Each Transect

Remembering that the HWM is not a line of constant height due to slope of the coastal terrain and the composition of the shore (rock, sand etc.), it would be useful to have an idea as to the height of this line relative to the LLD, LAT, and HAT. The heights surveyed with GNSS are relative to the LLD based on the calibration using TSMs. The LLD is 0,825m above LAT at the Cape Town tide gauge which is used as the reference tide gauge in this study. Table 10 reflects the mean heights and standard deviations for all participants for each transect relative to the LAT and the LLD. These data are also reported for the land surveyors, since these professionals survey the HWM.

Table 10: Vertical location summary for all participants and for land surveyors

All participants

SITE:	**G**	**LA**	**LB**	**LC**	**H**	**W**	**Range**	**Mean**
height above LAT (m)	4,8	3,9	4,9	5,1	4,0	5,1	1,3	4,6
height above LLD (m)	4,0	3,0	4,1	4,3	3,1	4,2		3,8
standard deviation (m)	0,9	0,9	0,5	0,5	0,6	0,6		0,7

Land Surveyors

SITE:	**G**	**LA**	**LB**	**LC**	**H**	**W**	**Range**	**Mean**
height above LAT (m)	5,1	3,8	4,9	5,1	4,0	5,3	1,4	4,7
height above LLD (m)	4,3	3,0	4,1	4,3	3,2	4,4		3,9
standard deviation (m)	0,1	0,7	0,2	0,1	0,3	0,5		0,4

3.4. Maps and Cross-sections

This section reflects the locations identified for the HWM by participants in the form of site maps (produced in ArcGIS) and transect cross-sections. The transect cross-sections show the distances of each HWM location from 'Top'; the heights are shown relative to LAT. The seaward terminals of the transects are not plotted in the cross-sections. The HWM locations identified by the land surveyors, coastal engineers and 'others' (a civil engineer, a mechanical engineer, a coastal environmental scientist and four friends and family members) are distinguished by colour code.

3.4.1. Granger Bay

Figure 12: Granger Bay transect site map

Figure 12 and Figure 13 reflect the results at the first experimental site (G). In the transect cross-section the land surveyors' locations are clustered towards the landward side of the transect while those of the coastal engineers and the others show a wide range stopping just seaward of the coastal vegetation.

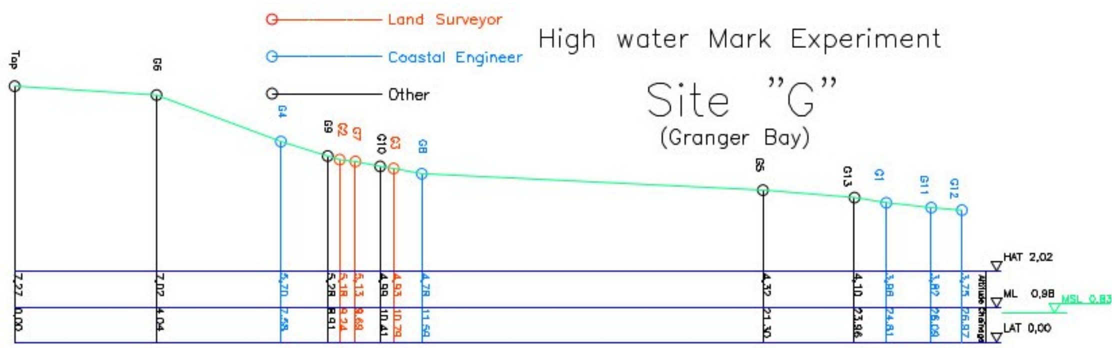

Figure 13: Transect of participants' HWM estimations (Table 3) for Granger Bay.

3.4.2. Llandudno

The second experimental site (LA) near the sewerage works at Llandudno is a rocky steep shoreline (Figure 14). There was little evidence of the HWM except for the transition from the rocks to the vegetated slope. The plot shows a large range of locations without any subset of participants in agreement as to the location of the HWM along this transect (Figure 15).

Figure 14: Llandudno transect site map

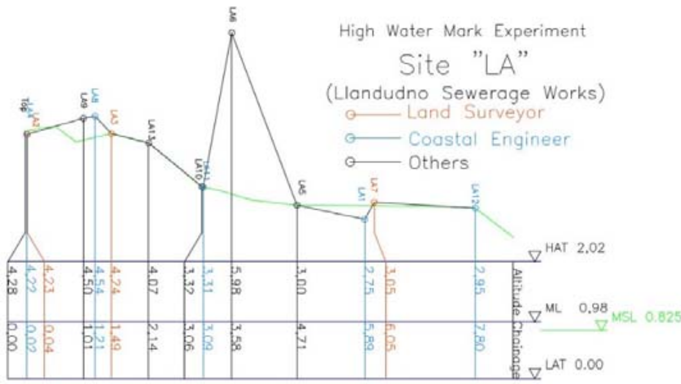

Figure 15: Transect of participants' HWM estimations (

Table 4) for Site LA

The third experimental site (LB), also near the sewerage works at Llandudno, is also a rocky steep shoreline close to site LA (Figure 14). The plot shows clustering of the land surveyors' locations around the middle of the transect while those of the coastal engineers are spread out either side of these (Figure 16). The locations of the 'others' show the widest range.

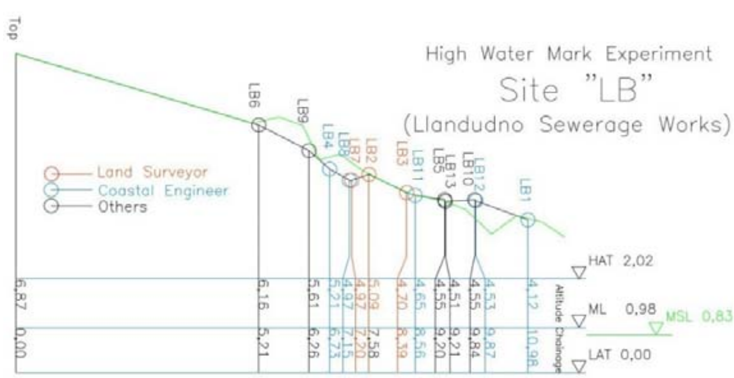

Figure 16: Transect of participants' HWM estimations (Table 5) for Site LB

The fourth experimental site (LC) is on the sandy shore of Llundudno beach (Figure 1 and Figure 14). The plot shows clustering of the land surveyors' locations at the landward side of the transect while those of the coastal engineers, and the 'others' show a wide range (Figure 17).

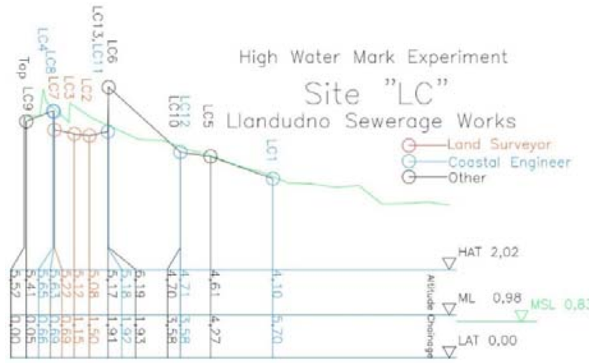

Figure 17: Transect of participants' HWM estimations (Table 6) for Site LC

3.4.3. Hout Bay

The fifth experimental site (H) is on the restored sandy dune shore of the west end of Hout Bay beach (Figure 18). The plot shows clustering of the land surveyors' locations in the middle of the transect while those of the coastal engineers show a wider range extending seaward (Figure 19). The locations identified by the 'others' show a wide range seaward and landward.

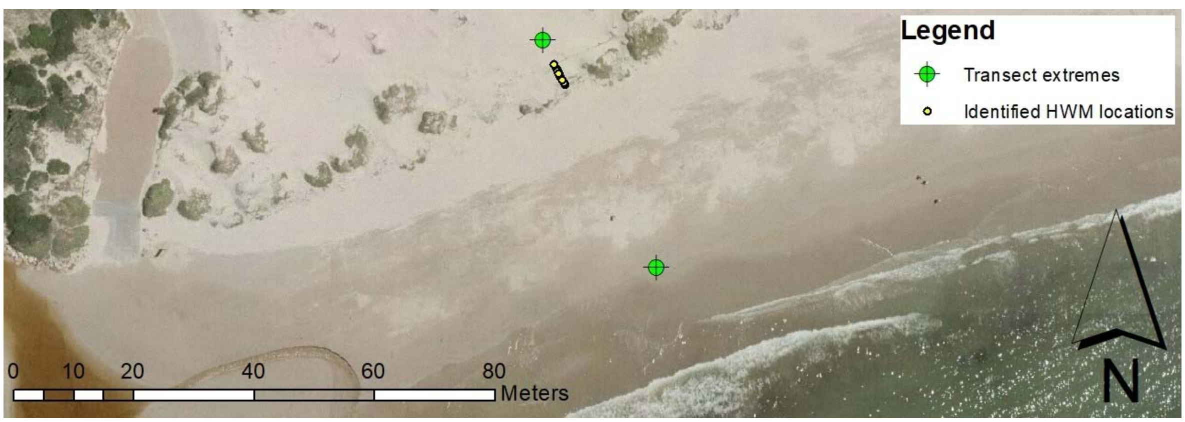

Figure 18: Hout Bay transect site map

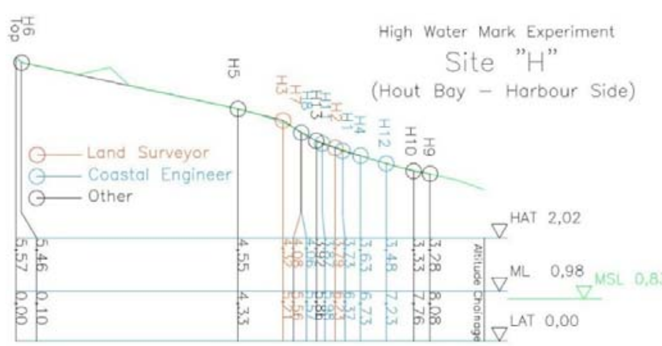

Figure 19: Transect of participants' HWM estimations (Table 7) for Site H

3.4.4. Witsand

The sixth and final experimental site (W) is on the sandy beach reclamation over landfill at Witsand beach (Figure 20). There was little evidence of the HWM in this location which was even more challenging given that there was evidence of dune stabilization. The plot shows little agreement between the land surveyors or between the coastal engineers as to the location of the HWM (Figure 21). Again, the 'others' show a wide range of HWM locations extending to near 'Top' and down to the line of wet sand.

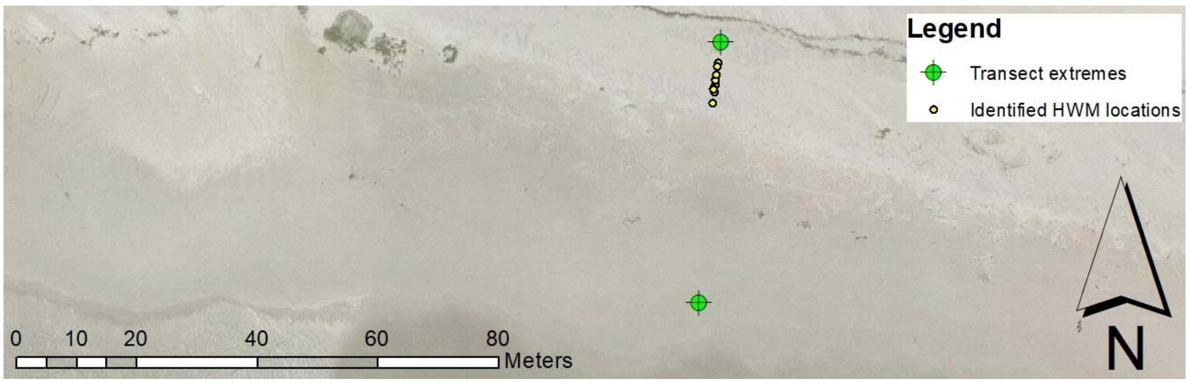

Figure 20: Witsand transect site map

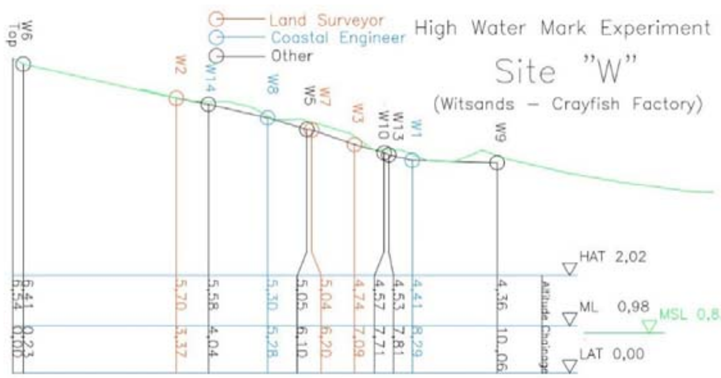

Figure 21: Transect of participants' HWM estimations (Table 8) for Site W

3.5. Interpretation of Results

3.5.1. Horizontal locations measured along the transects

Since the location of the HWM is most often required to delimit rights to land, it is most important to establish how precisely it can be located in plan along the transects. The coastal engineers had probably little, if any, prior experience in identifying the HWM on site although they probably have much better knowledge of the oceanographic processes on the seashore. Their results showed some coherence – their mean range was 7,4m ±4,1m for all the sites (Figure 10, Table 9). Omitting the data from Granger Bay yields a range 4,9m ±2,3m for the coastal engineers.

The 'other' participants in the group (including a civil engineer, a mechanical engineer, a coastal environmental scientist and four friends and family members) demonstrated a slightly larger range than the coastal engineers at 8,0m ±4,2m for all the sites (Figure 11, Table 9). Omitting the data from the first site, Granger Bay, yields a range of 6,0m ±2,6m for these participants.

The land surveyors' results are more coherent than those of the coastal engineers and the 'others', with a mean range of 2,4m ±1,6m for all the sites (Figure 10, Table 9). However, at site LA, they exhibited variation in the range of 6m. For sites G, LB, LC and H, their results were highly consistent with the mean range over those three sites of 1,1m ±0,6m. The three land surveyors were all senior professionals – it would appear that they all had some prior experience in identifying the HWM.

3.5.2. Vertical location of the HWM relative to the LLD, LAT and HAT

The GNSS surveyed heights of the HWM located by all participants at all sites has a range of 1,3m, a mean height of 4,6m above LAT, with a mean standard deviation of ±0,7m (Table 10). Since HAT is about 2,02m above LAT, the height of the HWM is 2,6m above HAT – about 3,8m above LLD – for all sites and including all participants.

Since it is professional land surveyors who undertake the location and surveying of the HWM, it is instructive to report the data for this subset of participants. The results for the HWM as determined by the land surveyors has a range of 1,4m, a mean height of 4,7m above LAT, with a mean standard deviation of ±0,4m. The HWM as located by the land surveyors is 2,7m above HAT – about 3,9m above LLD.

The HWM is thus likely to be found around four to five metres above the LAT, corresponding to about three to four metres above the LLD. However, setting out the HWM as a contour does not meet legal requirements since there will be local variations in the height of coastal water swash (run-up) because of combined action of weather and tides. It is a conservative line from an environmental viewpoint – higher than one would usually expect coastal waters to reach under average conditions.

3.6. Future Work

The inland boundary of the Coastal Protection Zone (in terms of the ICMA) is determined as a setback line from the HWM. Coastal property development rights within this zone are thus impacted by the precision of the location of the HWM with important implications for administering land rights and interests in the coastal zone. A next step may be to approach the HWM determination using oceanographic modelling with subsequent comparison. Another next step may involve comparing these results with the intent of the definition in the Institutes of Justinian and of various derivatives thereof. Interpretations of these results need to be understood against the growing number of statutory offsets from the HWM, starting with the French Colonial *cinquante pas géométrique* – a crown reserve of fifty double paces each of five large French feet or a total of about 81,2m inland of the HWM. Similar coastal reserves exist in South Africa. These usually (but not always) extend inland of the HWM by 45,7m and 61m in the former colonies of Natal and the Cape respectively.

4. Conclusions

This experiment tested the ability of a range of participants, professional and otherwise, to locate the HWM for six sites. The sites reflect a realistic sample of the morphology of the shoreline and the concomitant impediments to identifying the HWM along the South African coast. At none of the sites could the participants easily identify the natural indicators and interpret the HWM location with precision. Although the number of participants who took part in this experiment is quite small, the results provide information on the variable precision to which the HWM is determined.

It was clear from observing the deliberations of participants on site, that many had not understood the criteria presented in the brief introduction and did not apply them correctly or consistently, even though they are competent professionals. While the professional land surveyors' results did not show improvement over the experiment, the results of other participants did improve significantly after the first site. It is indicated that even professional people need instruction on interpreting the law with respect to HWM location, as well as practical experience on site.

For the horizontal location of the HWM, the professional land surveyors' estimations of the locations had a mean standard deviation in plan of ±1,6m, that of the coastal engineers was ±4,1m, and that of 'other' participants was ±4,2m. For the vertical location of the HWM, the professional land surveyors' estimations had a mean standard deviation in height of ±0,4m, while that of all participants was ±0,7m.

The experiment did not aim to define the position of the HWM for the sites in plan or height. The mean results from the entire sample would not result in a HWM line that would stand up to legal scrutiny since only a professional land surveyor may locate and survey the HWM following the prescriptions of the Land Survey Act 8 of 1997. Also, the horizontal location of the HWM will vary from site to site due to local variations in the slope of the coastal terrain and the composition of the shore (rock, sand etc.). However, the results, particularly those of the land surveyors, are a persuasive indication of a likely height of the HWM between 4 - 5m above the LAT – equivalent to about 3 - 4m above the LLD.

The dynamic HWM cannot be permanently beaconed or marked, so evidence that accords with the legal definition of the HWM regarding the reach of coastal waters is used in its onsite location. Since coastal areas are subject to dynamic natural coastal processes, there is concomitant variability and uncertainty in the location of the HWM. The precision of location of the HWM is significantly less than expected in locating of urban property boundaries. Property, cadastral and environmental law needs to continue to respect the nature of the coastal environment and the limitations in precision of locating the HWM.

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