UNIVERSITY OF SOUTHERN QUEENSLAND
FACULTY OF HEALTH, ENGINEERING AND SCIENCES

Tidal predictions in ungauged estuaries for boat-ramp access windows

A dissertation submitted by

Patrick W McFadden

In fulfilment of the requirements of

ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Spatial Science (Honours) (Surveying)

October, 2016

Abstract

Many boat ramps in Central Queensland are only accessible in the upper half of the tidal cycle. Currently predicting when the ramp is accessible is a mixture of local knowledge and some educated guesses. Central Queensland, like most areas in Queensland has experienced a huge growth in recreational boating. This has increased pressure on the boat ramp access and created demand for greater use of marginal ramps. The ability to optimize the use of availably time at these ramps may reduce the pressure on more established ramps.

The aim of this study is to predict access times at tide dependant boat-ramps using a novel and innovative method at three locations in central Queensland. Two models were tested.

At each site sea level was recorded at regular time intervals. This was done once during one of the larger tides of the month, and again during one of the smaller tides. From each set of data, the time that the boat-ramp was accessible (access window) and the actual time of the high tide was derived. A comparison was made between the observed windows and the simultaneously obtained times and amplitudes of the same tide at a nearby standard port, Mackay Outer Harbour (MoH). Model 1 used the relationship between the measured access windows at each site, and the predicted amplitudes at MoH. Model 2, in an attempt to negate some of the meteorological impacts, used the actual recorded amplitudes at MoH rather than the predicted as in Model 1. Each model than used the MoH predicted time and amplitude of a tide to predict access times at each site for that same tide.

This study showed that from a two tide observation at each location and using nearby standard port tide table, the access times was predicted at two of the three test sites. Model 1 and 2 produced similar predictions. It also showed that access times and lag vary accordingly to the amplitude of the tide. It also suggests that atmospheric factors can influence the arrival and departure times of tides.

Currently, to do an accurate prediction of tide levels, a full harmonic analysis of a particular location is required. This is usually a continuous observation of the tidal cycle for 29 days. Trends of diminishing Government resources means the communities can't rely on government agencies to provide this information for all sites. Using this method many more tide restricted boat ramps can have an adequate predictor of access times for a fraction of the cost of a full harmonic analysis.

Keywords: Tides, tidal prediction, access windows, boat-ramps

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111 & ENG4112 Research Project

Limitations of use

University of Southern Queensland

AUSTRALIA

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in and other course or institution, except where specifically stated.

Patrick McFadden

0061066631

Acknowledgement

I am heartily thankful to my supervisor, Dr Zhenyu Zhang, whose encouragement and support, particularly in the initial stages enabled me to produce this dissertation.

I would also like to thank my sister, Dr Sally McFadden, for her limitless patience with guiding me with the structure and content of this report. I would have been lost without her. My other sister, Sue Hassall was also invaluable for proofing the spelling and grammar.

Lastly, I would like to thank my brother Paul, for his never-ending emotional support and encouragement. He suggested that after every low point, a high point follows, just like a tide.

Patrick McFadden

> '*Never give in--never, never, never, never, in nothing great or small, large or petty, never give in except to convictions of honour and good sense. Never yield to force; never yield to the apparently overwhelming might of the enemy.'*
>
> Sir Winston Churchill, Speech, 1941, Harrow School

Glossary of terms

Earliest Launch Time (ELT)	The earliest time for that a boat can be launched
Latest retrieval time (LRT)	The latest time that a boat can be retrieved
Navigable level (NL)	An arbitrary datum that is judged to be the lowest accessible level for each boat-ramp
Height of high tide measured (Ma)	The measured maximum amplitude of a particular high tide.
Height of high tide predicted (M'a)	The predicted amplitude of a high tide
Time of high tide measured (Ht)	The actual time high tide occurs
Time of high tide predicted (H't)	The predicted time of high tide
Mackay Outer Harbour (MoH)	Standard Port
Predicted launch time (PLT)	The predicted earliest launch time on a particular tide
Predicted retrieval time (PLT)	The predicted latest retrieval time on a particular tide
Vertical speed	The rate of change of a tide vertically over time.
Maritime Safety Queensland (MSQ)	Government agency
Access window before high tide measured (Wb)	The time between the ELT and the Ht
Access window after high tide measured (Wa)	The time Between the Ht and the LRT
Access window before high tide predicted (W'b)	The predicted time between ELT and Ht
Access window after high tide measured (W'a)	The predicted time between Ht and LRT
Lag	The time difference between tides at different locations
Access Window	The total time that the ramp can be accessed on any particular tide.

Table of Contents

List of Photographs

List of Figures

List of Tables

List of Appendices

Chapter 1: Introduction

1.1. Introduction

The idea for this project came from a trip to Stanage Bay in central Queensland. The boat-ramp is a tide dependant ramp meaning that it is only accessible during the upper part of the tide. Currently predicting when the ramp is accessible is a mixture of local knowledge and some educated guesses. In this case, local information said it was accessible two hours either side of high tide and to add 30 minutes to Mackay Outer Harbour tides. An early start resulted in a successful launch, but others in our group slept in and were able to launch much later in the morning. It was obvious that the local knowledge was not quite right and access times depended on more than one variable. In fact during a neap tide the ramp was accessible for a much longer period of time.

Should have gone to Pat's tide predictor

Photo 1-A Stranded boat on a sandbank

Queensland has experience a huge growth in recreational boating. This has increased pressure on the boat ramp access and created demand for greater use of marginal ramps (Boon et al. 2011). The ability to optimize the use of availably time at these marginal ramps may reduce the pressure on more established ramps.

Having the knowledge of what times a particular boat-ramp is accessible can be valuable. Stakeholders who could benefit from more precise predictions include professional fishers, recreational fishers, tourism operators and Government agencies like police, search and rescue.

Knowing that on a particular date in the future you will be able to launch your boat at 8:00 am and will need to retrieve it before 4:00 pm is of great benefit. Turning up at a ramp and having to wait for the tide is inconvenient but returning from a day on the water to find the boat-ramp high and dry can lead to a long wait for the next tide. Tourist operators could plan excursions with a secure knowledge of when to return to the ramp. Safety and sustainability goals can be improved for government and private agencies.

Currently, to do an accurate prediction of tide levels, a full harmonic analysis of a particular location is required. To obtain most of the tidal constituents and hence maximum accuracy, the tides needs to be observed for a full cycle of 18.6 years (National Ocean and Atmospheric Administration 2015a). This is the case at standard ports in Queensland (Maritime Safety Queensland 2014). A shorter observation period of one lunar month, 29 days, is common practice to obtain the most significant constituents.

At standard ports in Queensland this analysis has been done and tide predictions are readily available in tide charts. From tide charts, times and height of high and low are easily extracted. Also times that the tide passes an elevation can be derived from tidal curve tables (Maritime Safety Queensland 2016a).

At other ports called secondary ports, information can be obtained that makes it possible to predict the amplitude and time difference of high and low water. A table of time differences between high and low water as well as a ratio and constant, are applied to the amplitude which converts the standard tide information to equivalent secondary port data (Maritime Safety Queensland 2015a). The locations in this study are neither primary nor secondary ports.

Many of Queensland’s boat-ramps are located in tide dependant estuarine locations which makes predicting access times for a boat difficult. The shape of the tidal curve gets distorted as it enters shallow water (Zetler & Cummings 1967). This asymmetric shape means that the access window may not be equally distributed around the time of high tide.

1.2. Objectives and research questions

The aim of this study is to predict times at which a boat can be launched and retrieved at three specific locations using a new and innovative method. This time period referred to is the *access window*. This access window is the usable time that a tide dependant boat-ramp can be used on any given day.

In this study it is not the absolute height and time of the high or low tide that is required, but moreover the time between when the sea level passes a set elevation at a known location. This elevation or lowest navigable level (NL) is usually the bottom of the boat ramp, and can be different for each location.

1.3. Structure of the dissertation

A basic summary of tides including definitions and types of tides follows in this chapter. Chapter 2 investigates the literature about tides and tidal predictions. This research is limited predicting the times that a tide passes a specific elevation at each location. This being the case some complexities can be removed to find an adequate solution. Tidal movements are also influenced by meteorological factors (Dronkers 1975). This will be covered more in chapter 2 and again in chapter 3. A method is discussed and tested to try to reduce the influence of some of the meteorological factors. This leads to a proposed model to predict access times at specific locations.

In chapter 3 an empirical method is developed and relies on the inherent repeatability of the tidal phenomenon and used a linear relationship between the observed windows, and the amplitudes at the nearby standard port. At each site, tide levels and times were logged at regular intervals as the tide approached, covered, peaked and retreated passed the lowest navigable level. This was done once during a larger tide, and again during a smaller size tide. At each site the earliest launch time (ELT), the latest retrieval time (LRT) and the time of high tide (Ht) was measured.

A comparison was made between the observed access times (windows) and the simultaneously obtained times and amplitudes of the tide at a nearby standard port. Using predicted times at the standard port, and the comparisons with the two sets of test data, a prediction was made for access times at each site.

A datum mark was placed at the navigable level and the time the water arrived and departed recorded. This was compared with the predicted times. In chapter 4 the results from two models of predicted launch and retrieval times where reviewed. The differences and possible reasons are discussed in Chapter 5. The dissertation finalises in chapter 6 with a conclusion that looks at the results of the project and possible further work.

1.4. Definition of tides

The movement of tides are due to fundamentally two forces. The first being gravitational forces of the Sun, Moon and Earth. The second is the centrifugal force of the Earth's rotation around centroid of the Earth's and Moon's gravitational field. Tides also occur in a much smaller degree are in large lakes, the atmosphere and the Earth crusts (Earth tides) (National Ocean and Atmospheric Administration 2015b).

Tides start in the oceans of the world and move towards the coastline where they can be observed as the regular rise and fall of the sea level. The high tide is when the highest part of the wave passes a particular location and the low tide when the trough passes. The difference between these is called the tidal range (National Ocean and Atmospheric Administration 2015b).

The rise and fall of the sea level causes a horizontal movement of water, called the tidal current. An incoming tide in a bay or estuary is called a flood tide and the outgoing an ebb tide.

Tides are a form of large wave that move around the globe. The high tides are when the crest passes a point and similarly a low tide is when the trough passes a point. These waves interact with each other to create great variety around the Earth. Usually to be able to predict a natural event like tides we must have a fundamental understanding to the factors that influence it. While the basic laws of fluid dynamic and geophysics are well understood there is a huge amount of unknowns caused by terrestrial factors (Hicks 2006).

1.5. Types of tides

Tides can be divided into 3 types, semidiurnal, diurnal and mixed tides. This is based on the number of high and low tides and their relative amplitude each tidal day (25 hours). Semidiurnal have two highs and two lows each day. Diurnal tides have only one low and one high per day. This comes from the position of the Moon relative to the equator. When the Moon is over the equator the Earth has two equal tidal bulges per day. Semi-diurnal tides have a wave length of 12 hours 25 min. Most areas not on the equator have two unequal bulges per day. This is called a mixed tide. In the area far from the equator, the Earth only get one high and one low per day. These diurnal tides have a period of 24 hrs and 50 min (National Ocean and Atmospheric Administration 2015b). There are exceptions to the rule in places like the Gulf of Carpentaria, Queensland where tides are diurnal (Maritime Safety Queensland 2014).

Tides are made up of both semi-diurnal and diurnal components. The division between the two types is arbitrary. In the special Publication No 9 - Australian Tides Manual (SP9) they use the ratio of (K1+O1)/ (M2+S2) is less than 0.5 the tide is semi-diurnal (two highs and two lows in one day) (Permanent committee on tides and mean sea level (PCTMSL) 2014).

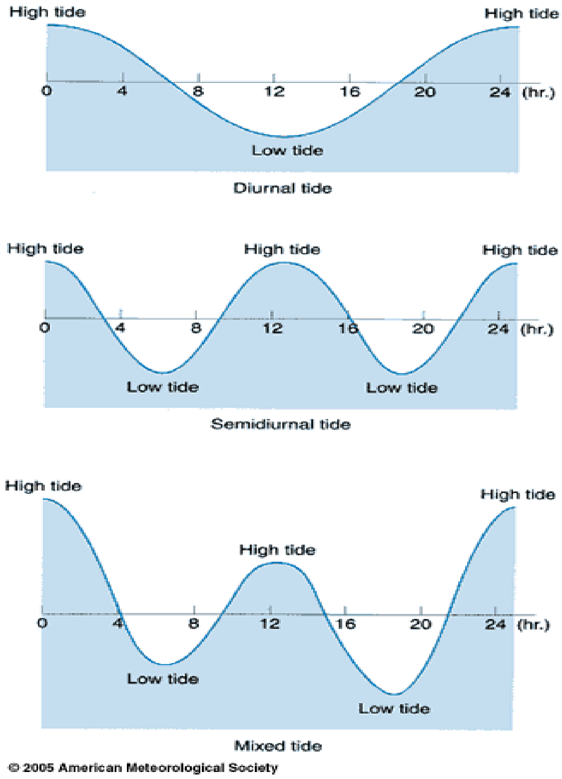


Figure 1-1 Types of tides

(Ocean motion and surface currents 2015)

Chapter 2: Literature Review

2.1. Factors that influence tides

2.1.1. Astronomical motions

The world oceans are held in place by the gravitation force of the Earth. This is an equipotential surface. In addition the gravitational forces of the Sun and the Moon influence the surface. This *tractive* force is the cause of tidal motion (National Ocean and Atmospheric Administration (NOAA) 2013). The Earth's waters are "bulged" by these external forces and resulting horizontal flow towards areas of maximum gravitational attraction produces a high tide. On the opposite side to this bulge is a corresponding "lag". The low tide is the result of the evacuation of this flow and is located half way between these two peaks. The daily rotation of the Earth, (diurnal) causes movement of these two tidal humps and two tidal depressions. This is what is known as high and low tide (National Ocean and Atmospheric Administration (NOAA) 2013).

The forces that influence the tide at the tides at the Earth's surface are a combination of the gravitational forces of the Moon and Sun and the centrifugal forces of the Earth-Moon system (and Earth-Sun) rotating around each barycentre. These rotations, while the systems remain in complete balance, the forces are not equal on all points of the Earth's surface and tides are the result (National Ocean and Atmospheric Administration (NOAA) 2013).

2.1.2. The effect of centrifugal force

The Earth and the Moon are locked in a rotating relationship around the centre-of-mass of the Earth-Moon system (G). This centre G, this lies on a line between the two centres of gravity of each and some 1719 km below the surface of the Earth. The centrifugal force component from this rotation is what is needed for the production of tides. The same system applies to the relationship between the Sun and the Earth (National Ocean and Atmospheric Administration (NOAA) 2013).

The direction of the centrifugal force is always away from the location of the centre-of-mass G. It is important to note the difference between the centrifugal force caused by this "dance" between the Earth and the Moon, is completely separate to the centrifugal force caused by the Earth own rotation around its axis. This rotation has no influence on tides because for centrifugal force is equal at all points around the centre of mass of the Earth because the distance from the centre of mass is the same (equipotential surface) (National Ocean and Atmospheric Administration (NOAA) 2013).

2.1.3. The effect of gravitational force

Newton's *Universal Law of Gravity* states that gravitational force varies inversely as the second power of the distance from the attracting body. This means that if the distance between different gravitation bodies varies, so does the magnitude of the force that it exerts. In tide theory the movement of Sun and Moon cause variations to the gravitation forces on the Earth surface and this variation moves around the globe (McCully 2006).

2.1.4. The net or differential tide-raising forces: direct and opposite tides

It has to be understood that the centrifugal force described above is equal to the gravitational force at the centre of mass of the Earth. This is because the system is in equilibrium. This means that at the centre of the Earth the net tide forces add to zero (National Ocean and Atmospheric Administration (NOAA) 2013).

At a point on the Earth's surface closest to the Moon, the gravitational force now out-weights the centrifugal force. This is because the centrifugal force remains the same but the distance between the Earth and Moon is now shorter, so the gravitational force is larger. The resultant disturbance of the sea level at this point is known as the direct tide.

Another point on the Earth's surface furthest from the Moon will again have the same centrifugal force but because the distance is greater the gravitational force is now less. This means the resultant net tide producing force is directed away from the Moon. This point, coincidentally with the direct tide, is called the opposite tide (National Ocean and Atmospheric Administration (NOAA) 2013).

2.1.5. The tractive force

It has to be noted at this point that the gravitational force of the Moon is far less that Earth's own gravitational force. The Moons force is only about one nine millionth as strong as the Earths. The gravitational force can be divided into two components, one is vertical the other tangential to the surface. This tangential or horizontal force acts to move particles of water around the surface of the Earth towards the sub-lunar and antipodal points (points closest and furthest from the Moon). This drawing of water is known as the tractive component and is what produces the tides. The movement of water tends to gather and remain stable at that location, called the tidal "bulge".

Any water accumulated in these locations by tractive flow from other points on the Earth's surface tends to remain in a stable configuration, or tidal "bulge". At points in a band at 90 degrees to these water is drained away leaving a tidal depression (National Ocean and Atmospheric Administration (NOAA) 2013).

2.1.6. The tidal force envelope

In a simplified model if the Earth was covered in uniform depth ocean, with no continents the tidal envelop of the Moon would result in a high tide followed 6 hours later by a low, then a second high after 12 hours and so on. This would be caused by the rotation of the Moon and the precession of the two tidal bulges and depressions. This is far from the actual case. First we have to identical setup from the Earth-Sun relationship. Although the distance between the two objects is much larger so is the mass of the Sun. This equals a net effect in the order of 2.5 times less than the Moon's. Now let's add the influences of land masses, ocean currents, and other retarding factors as well as the astronomical variables in the orbits of the Moon, Sun and Earth. All these factors are superimposed onto the Earth's tidal envelope.

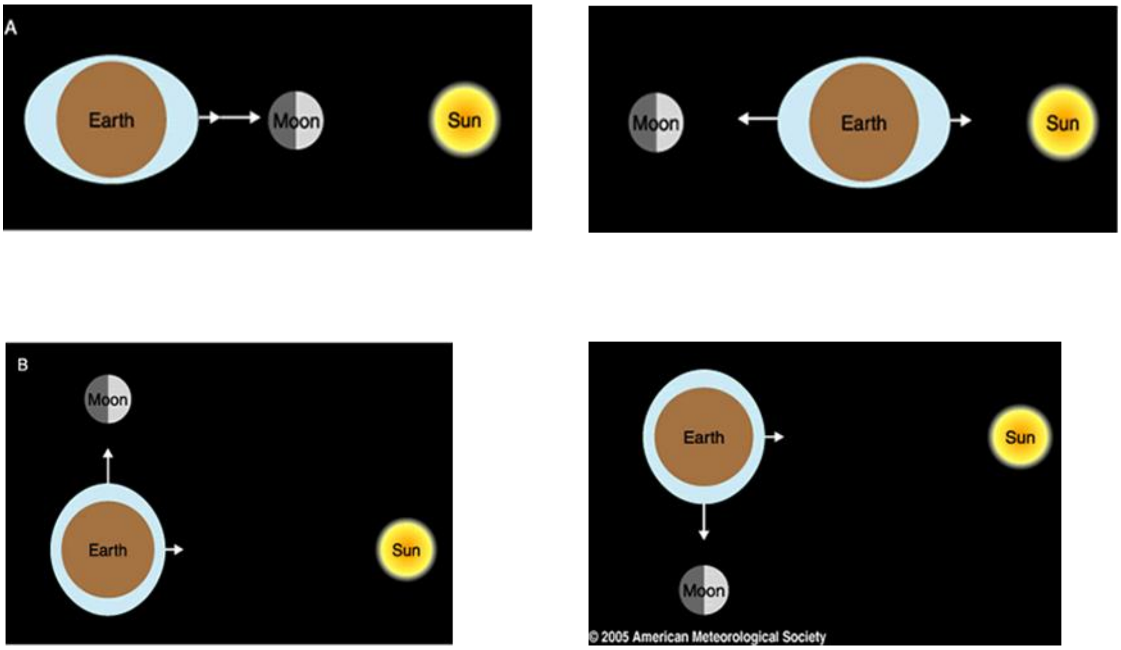


Figure 2-1 Sun and Moon orientations

2.2. Variations in the range of the tides: tidal inequalities

2.2.1. Lunar phase effect

The effects of the Moon and the Sun will vary as the relationship between them change. When the Sun and Moon are aligned, called the new Moon both act together to produce larger than average tides and lower than average low tides. These larger tidal ranges are called spring tides.

This also exists when the Sun and Moon are aligned but on opposite side to each other, as in the full Moon.

At the 1st and 3rd quarters of the Moon, the Sun and Moon are at 90 degrees to each other. These are the neap tides, where the tidal range is at minimum (Hicks 2006).

2.2.2. Parallax effects (Moon and Sun)

The distance between the Earth and the Moon will change during its monthly orbit. When the Moon is closest (perigee) to the Earth the gravitational forces are greater (Newton's Law of Gravitation) and hence producing higher than average tides. Two weeks later, when the Moon is furthest from the Earth (at apogee) the tides are less. This is also apparent in the Earth –Sun orbit with the Earth being closest at perihelion on 2nd January and furthest during aphelion on 2nd July each year (National Ocean and Atmospheric Administration (NOAA) 2013).

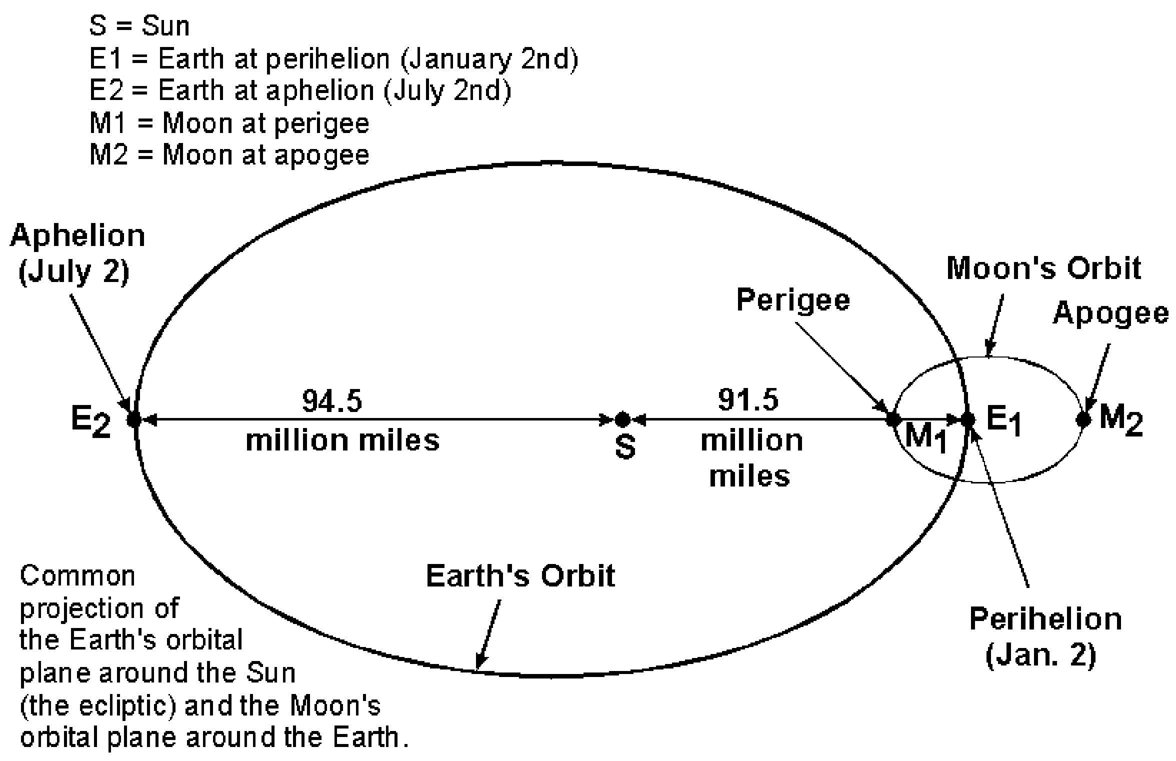


Figure 2-2 Earth and Moon orbits

2.2.3. Lunar declination effects: the diurnal inequality

Due to the fact that the Moon's orbit is inclined to the plane of the Earth's own orbit, the Moon passes twice each month over the equator. This is not dissimilar to the Sun's movement about the equator, causing the seasons. When the Moon passes over the equator the two high and low tides are at same at the same height and duration at a specific location. This is a semidiurnal tide. As the Moon moves away from the equator a difference between the two tides emerges. The phenomenon is known as the diurnal inequality.

When a point on the Earth's surface lies beneath the tidal envelope and 12 hours later lies beneath a significantly smaller envelope, this results in a successive high and low tides of unequal height. This tide is called a mixed tide. Lastly, a diurnal tide is when the point is beneath the tidal envelope and 12 hours later lies above the envelope, then tidal forces produce only one high tide and one low tide a day

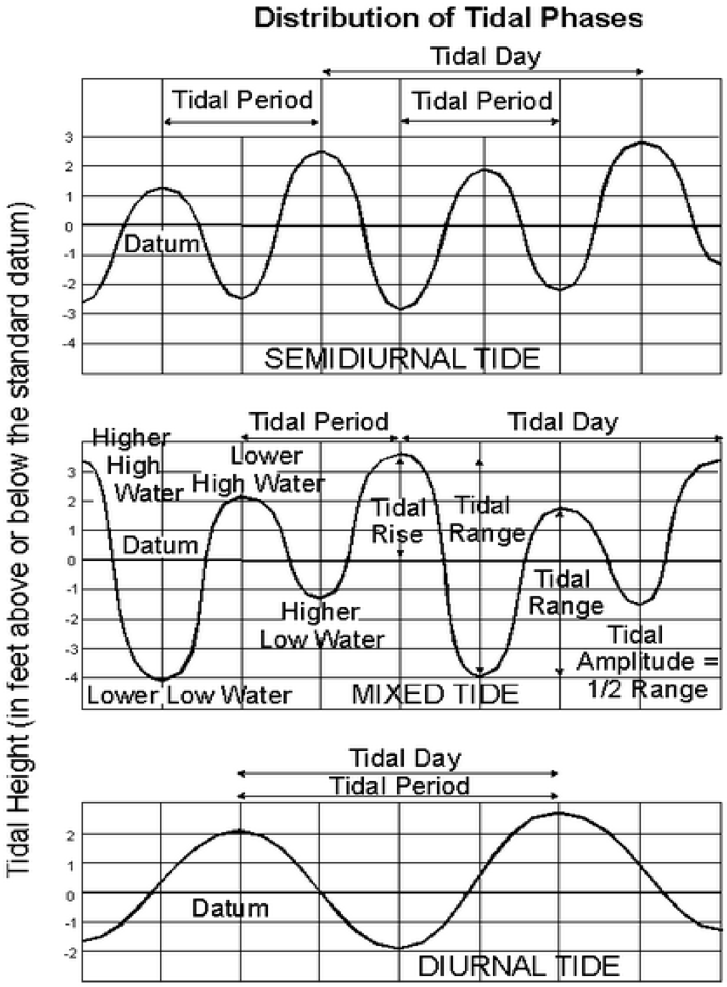


Figure 2-3 Distribution of tidal phases

2.3. Factors influencing the local heights and times of arrival of the tides

From the previous section it was shown successive tides can have difference ranges. From observations of tides at specific locations also shows a variation in the arrival time. These variations are the result of many factors, some of which are the harmonic motions and oscillations of the Earth and Moon. There are two principle astronomical effects that cause variation in arrival time of tides.

The Earth rotates around it axis every solar day or 24 hours. The Moon also rotates around the Earth at a slower rate, 12.2 degrees per day and in the same direction. So for the tidal force applied to the tidal envelope to “line up” again over up a particular location takes longer than 1 day. In fact it is about 360 degrees plus the 12.2 degrees. This phenomenon is the lunar retardation. If this single astronomical influence is considered equates to about 24 hours 50 mins between successive sub-lunar tides (the point when the tide-raising influence is highest). This is why the tidal day is 24 hours and 50 minutes.

The idea that the maximum forces, hence the arrival of the tide as the Moon passes over that meridian is not always the case. *Priming of the tide* is the result of the alignment of the Sun and the Moon. Between the new Moon and the first quarter of the cycle and again between the full Moon and the third quarter the tidal forces can accelerate the arrival of the tide, before the Moon passes over that meridian. The reverse is the case during second and fourth quarters of the Moon’s path, known as *lagging of the tide.*

In addition to these two astronomical phenomenon, tides have many other forces to deal with. These include bathymetric complications (sea floor restrictions, friction, shape), hydraulic and hydrodynamic factors. Overlaying these are meteorological conditions, significant in their own right (McCully 2006).

Partial List of the Astronomic Cycles Related to the Tides

Phenomenon	Period	Cause
Semidiurnal tide	12.43 hours	Rotation of the earth relative to the moon
Diurnal tide	23.93 hours	Influence of lunar and solar declination
Lunar fortnightly effect	13.66 days	Varying lunar declination
Spring tide interval	14.75 days	Phase relation between the sun and moon
Anomalistic month effect	27.55 days	Moon's elliptical orbit of the earth
Solar semiannual effect	182.6 days	Varying solar declination
Anomalistic year effect	365.26 days	Earth's elliptical orbit
Regression of the moon's nodes	18.6 years	Period of the maximal amount of lunar declination

Figure 2-4 Astronomical cycles

2.4. Atmospheric and meteorological influences on tides

The weather can have a significant influence on sea levels. Factors like barometric pressure, wind speed, duration and direction can cause distortions from predicted tides. During a period of high pressure, the sea is depressed and lower than predicted, and conversely during periods of low pressure the sea level is elevated. Tidal predictions are made with an average value of barometric pressure. This means that variations to the actual barometric pressure will cause differences in the observed sea level. A change of about 10 hectopascals (hPa) from the value used in the prediction can change sea level by 0.1m. This is called the inverted barometric effect. These effects rarely exceed 0.3m but because changes in barometric pressure are related to wind speed and direction the result can be compounded (Bureau of Meteorology 2016). Severe changes in barometric weather can cause changes in sea level of 30 cm (McCully 2006)
.

Wind can influence sea levels when it pushes oceans into landmasses. In deep oceans wind has negligible influence, but in the shallower seas restricted by landmasses, the wind can cause a gradient on the ocean (McCully 2006). Wind blowing onshore will cause the sea level to pile up, raising the level of the ocean to above the predicted level. This is labelled the wind setup. The same is true for the opposite direction with sea level less than predicted. Longitudinal wind, along the coast, can increase the tidal range. These influences are variable and very reliant on local topography (Bureau of Meteorology 2016).Together these terrestrial influences of wind, runoff into rivers and barometric pressure can cause differences between predicted to observed tidal level (Hicks 2006) .

Some other terrestrial factors are.

1. The depth variations of the oceans
2. Shallow sections the deform the tidal wave
3. Land masses
4. Friction factors of the sea floor
5. Water viscosity
6. Turbulence

(Hicks 2006)

2.5. Tidal distortion in estuaries

As tide move into an estuary a complex set of interactions occurs. When the progressive wave enters an estuary and hits a barrier, the harmonics of each wave can reflect off each other to form a standing wave. Bottom friction complicates this, as the tide is attenuated. This damping effect on the inward and outward reflection results in a complex wave that has some progressive component. The change of the tidal form as its hits shallow water makes tide prediction more difficult (Zetler & Cummings 1967). Depending on the shape of the estuary and the location of the standing wave nodes, the tide can be greatly increased or dampened (Hicks 2006). An example is in the Minas Basin where the tide is amplified in the gulf of Maine and again as it passes into the Bay of Fundy resulting in the one of the highest tides in the world (15.4 m range).

Another example of wave attenuation is a wave rebounding from the head of the estuary. This additional tidal surge can cause net wave increase or decrease (Quinn et al. 2012). The bathymetry of the sea floor also has a huge influence. Studies have shown that the friction factor is significant controller of wave properties. This causes lags in the periods of waves (Tang & Grimshaw 2003).

Tidal asymmetry can be defined as variations in the period and amplitude of the incoming (flood) tide and the outgoing (ebb) tide. In a flood dominated system, the incoming wave has a shorter period and higher current magnitudes. This is typical in a restricted or ‘choked’ estuary (MacMahan et al. 2014). In an ebb dominated system the outgoing tide has the higher velocity and shorter period.

In the UK, the National Tidal and Sea Level Facility attempted to overcome the inherent problems with predicting high water events with an empirical approach to improving tidal predictions using recent real-time tide gauge data. The Empirical Correction Method was shown to reduce prediction errors by up to 10 cm (Hibbert et al. 2015).

A 2d hydrodynamic study of the Solant-Southampton estuarine system used the MIKE-21 software and data from tide gauges was able to predict tidal surges up to an accuracy of 0.09m (Quinn et al. 2012).

2.6. Benefits of tidal prediction

Knowledge of tidal movement and more importantly being able to predict it has always been vital for coastal peoples around the world. Navigation into ports, particularly with sailing ships, had to take into account not only depths but strength and direction of currents. This is still important today with ships becoming larger all the time and little margin for error. The determination of a Lowest Astronomic Tide (LAT) is used on hydrological charts. Real time sea level measurements are used in many major ports to provide safety and efficiency (National Ocean and Atmospheric Administration 2015b).

Professional fishermen rely on knowledge of tides for improving their catch. Even recreational users, surfers, fishers and beach walkers all need information about tides.

Engineering works associated with the coast zone, like construction of bridges, wharfs, walk-ways and boat-ramps all require tidal knowledge.

Establishment of legal boundaries often have definitions relating to tides. Highest Astronomical Tide (HAT) is commonly used.

Scientists are also concerned with tides, sea level changes, currents and a mirage of other related phenomenon. The Mean Sea level (MSL) is used in geodesy and datum establishment.

2.7. Tidal measurement

2.7.1. History

Historically a tide was measured with the tide pole or stick. This was replaced by more automated mechanical systems involving a float in a tube connected to a pen and ink strip. This produced a continuous line on a roll of paper. A *stilling* well calms the water level, usually a 30 cm pipe with the float suspended inside. This float was connected to the recording device (National Ocean and Atmospheric Administration 2015b).

Time line of tide measuring techniques

1831 – Henry R Palmer. A float in a well is connected to a recording device using wheels and shafts. The pencil creates a line as a function of tide and time.

1834 – In Le Havre, France a self-recording tide gauge built.

1846 – United States and India.

1858 – Australia.

1870 – 15 tide gauges on the shores of Europe.

1883 – The first determination of mean sea level around Europe 67 tide gauges.

(Matthäus 1972)

This is a mechanical "punch" recorder that was brought into service when computers first became available for analysing tidal patterns (National Ocean and Atmospheric Administration 2015b). Later in the 1960s it was replaced by a punched paper tape that could be feed into early computers (National Ocean and Atmospheric Administration 2015b).

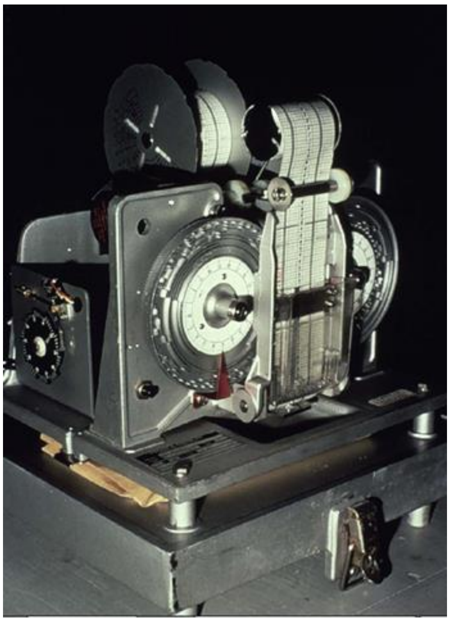


Photo 2-A Early tide recording device

2.7.2. Current methods

The latest measuring method uses advanced electronic and an acoustic signal that is transmitted though the water column. The time it takes to return is recorded and water depth calculated. This is now an automated process and the data is stored and transmitted. Other data like wind speed, current, air and water temperature and atmospheric pressure can be recorded. In the

United States this data can be accessed remotely through the Geostationary Operational Environment Satellites (GOES) (National Ocean and Atmospheric Administration 2015b). The main types of water level sensors in use in standard ports in Australia are the microwave (radar), acoustic and pressure sensors. Also used, but less common are laser ranging and ADCP current meters. Radar units have not direct contact with the water so are easy to maintain. They send a microwave signal down to water surface and measure's its return. Acoustic sensors send a pulse down an environmental tube. Pressure sensors are lowered to sea floor and measure depth of water above. They have to be calibrated to a datum and to air pressure (Permanent committee on tides and mean sea level (PCTMSL) 2014).

2.8. Datum

Tidal measurements are connected to bench marks located on an adjacent stable location. A tidal datum is defined, and used for hydrographical maps. In Australia it is the lowest astronomical tide (LAT) (Maritime Safety Queensland 2014).

The tidal epoch is the time over which continuous observations are made to establish a tidal datum or plane. In Australia we have adopted the 20-year tidal datum epoch 1992 to 2011 (inclusive) (Maritime Safety Queensland 2012). It is intended to keep these values fixed until the tidal datum epoch review in 2018. In Australia the tide height is in decimal meters above the port datum (LAT). If the tide is lower it has a negative sign.

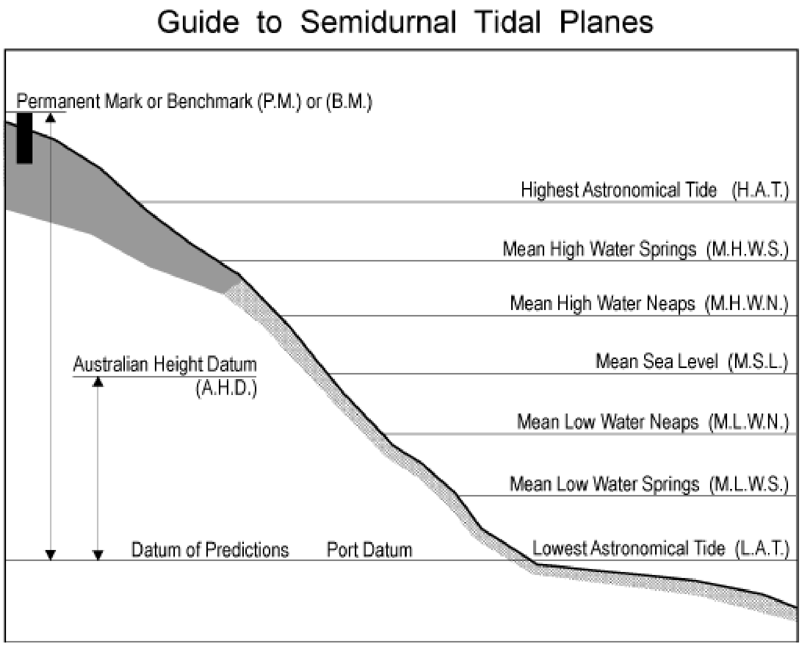


Figure 2-5 Tidal planes

(Maritime Safety Queensland 2014)

Observations are made to establish a datum point over a period of time. This is normally longer than 18.6 years so as to include full lunar cycle. The original Australia Height Datum, AHD was created in 1971 by connecting bench marks based on mean sea observations from only a two year period. (This is one of the reasons that AHD is not a true equipotential surface and has errors in it.)

2.9. Predicting tides

2.9.1. Tidal harmonic method

Newton is considered the founder of tidal theory. Laplace (1799) worked on tide theory in France and Whenwell (1833) in England. These methods were improved by English mathematician, Sir George Darwin. In particular was the focus on the study of the forces that caused tides. Early tide prediction used the lunitidal interval method. This measured the time interval of the transit of the Moon over the local meridian to the first high tide. By the 1870's the harmonic method was introduced. In the United States the Maxima and Minima Tide Predictor of William Ferrel summed 19 constituents in 1885. Rollin A. Harris and E. G. Fischer summed 37 constituents and was used from 1912 through 1965 (National Ocean and Atmospheric Administration 2015a). This involved a tedious calculation involving cosine curve additions. A series of mechanical machines were developed to add this calculation. In 1921 'The harmonic development of the tide-generating potential' by AT Doodson (1921) is seen as a benchmark work at harmonic analysis. Doodson expanded on George Darwin's work using a purely harmonic method and added constituents ignored by Darwin (Doodson 1921; Matthäus 1972; Foreman 1977; Hicks 2006; National Ocean and Atmospheric Administration 2015b).

The many great works of J.J. Dronkers of the hydraulic department, Netherlands, are considered fundamental to tide prediction calculations. Dronkers developed mathematical methods of computing the constituents of the harmonic method. This was during the development of the computer so previously cumbersome hand calculations of matrices were often required. With the aid of computers these calculations greatly simplified and more complex solutions developed (Dronkers 1975).

In the deep oceans, tides may be predicted with 60 tidal constituents for 12 months predictions, (Doodson 1921). In shallow seas, tide are distorted by friction factors so additional higher frequency constituents are needed. Extended Harmonic Method (EHM) uses 114 constituents to achieve 1 year of predictions (Hibbert et al. 2015).

The harmonic method is used to this day for tide prediction. With the benefit of ever more powerful computers, more constituents can be extracted from the observed data.

When the tide height is plotted against time, a simple looking cosine curve is apparent. This curve is actually the result of many small curves and takes into account all effects including, currents, hydrological effects and meteorological factors.

Due to the many unknown variables that influence tides, the knowledge of the position and movement of the Sun and Moon is not sufficient to predict tides. This is why the empirical approach of taking many continuous measurements at a particular location is used.

Standard analysis involves the derivation of 37 constituents. The period of the regression of the Moons nose is about 18.6 years and results in very slowly variations in the tidal cycle. This means that a full harmonic analysis needs about 19 years of data to extract all of the individual curves that make up the tide. Generally while 19 years is desirable, lesser time periods of 1 year can extract most of the significant constituents and even I month in semidiurnal dominated tides. (Hicks 2006; Maritime Safety Queensland 2012; National Ocean and Atmospheric Administration (NOAA) 2013).

To predict the tide at a particular location it is a simple process of measuring the tide for a period of time, extracting the tidal harmonics and adding the extracted cosine curves to get the predicted curve.

While all these processors may not be fully understood, the tide phenomenon is reflected in that the Earth is a *consistent responder* to these tide generating forces (National Ocean and Atmospheric Administration 2015a). What this means is, if we ignore the meteorological factors, the tide will repeat its behaviour at a specific location and a period of time.

2.9.2. Empirical Correction method

The Harmonic method High water (HW) or empirical Correction method used some recent HW observations to self-correct predicted HW levels. Deals with HW only and interested in flood forecasting. Does not apply to whole tidal curve just HW. Ignores the lag or time difference in HW arrival.

2.9.3. Species Concordance technique

The Species Concordance technique uses long records at a reference location that does not have any distortion to predict short term surges. An extension of the Response Method and used to reduce distortions from shallow water and flood flows.

2.9.4. Artificial Neural Network (ANN)

In more current times the process of harmonic analysis refined by using an Artificial Neural Network (ANN) model for forecasting the tidal-levels using the limited measured data (Lee & Jeng 2002; Makarynskyy et al. 2004; Karimi et al. 2013; Meena & Agrawal 2015). ANN models use a series of data sets to first train a network and then validate it. The model uses a training data set and tries to adjust itself by iteration to minimize the error by comparing itself the authentication data set. ANN allows whole of tidal curve prediction (Hibbert et al. 2015).

2.10. The gap in the literature

This literature review presents information that shows how gravity and centrifugal force are the basic drivers of tides. Tides are then made more complex by the motions and interactions of these celestial bodies. As tides approach land, they are again modified. In addition to this meteorological influences impact on sea level and are hard to predict. It was shown that tides can be measured, and if over a long enough time, the underlying constituent curves extracted and predictions made. These predictions are used mostly to find the highest or lowest point of the tide and the time to do this prediction means continual observation at each site for a period of time.

What this review does not show is how much data is required to just work out the interaction between a known elevation (boat-ramp) and the tide at a specific site. We don’t need all the information about the tide, just its “footprint duration” over a known location.

2.11. Hypothesis

From the literature it can be stated that

- At any particular site the tidal pattern will be repeatable.
- The time between a high tide at a standard port and the time of the same high tide at a nearby tertiary port may be different. This will be called the Lag.

- The time between the arrival of a tide and high tide may not always equal to the time from high tide to the departure of the tide. This is due to asymmetrical nature of the tidal curve in constricted estuaries.
- Atmospherics influence tide height and hence tide arrival times and are hard to predict.

In this paper the following hypothesis will be investigated

- *That different tidal amplitudes impact on access time duration (windows).*
- *Adequate access time predictions at specific locations can be made using the relationship between the simultaneous measured amplitudes at a nearby standard port and the sites corresponding access times.*

2.12. A model for predicting access times

2.12.1. Model 1

The basic assumption for this model is that tides are the result of a combination of forces that result in variations in sea level (ref). This includes the gravitational, centrifugal forces and local bathymetric conditions. These forces, while ever changing, are repeatable. This means for each site, with the local bathymetric conditions being constant, a tide should react the same way as any other tide under the same forces. Draped over these forces are meteorological influences. It has been shown that prolonged wind, barometric pressure, salinity and flood waters can influence sea level (Bureau of Meteorology 2016).

The earliest time that a boat can be launched at a particular boat ramp (ELT) and the latest retrieval time (LRT) can also be recorded for a particular site and tide. The total access time for that ramp is LRT – ELT.

As tides move into shallow water the tidal form can be distorted (Friedrichs & Aubrey 1988). This means the shape of the tide is no longer symmetrical, like it would be in the open ocean. The level of the distortion or asymmetry depends on the local bathymetry and the amplitude of the tide. For this reason the access window has been divided into two parts. At each location, Wb is the access time from ELT to the time of high tide (Ht) and Wa is the time between Ht through to LRT. The total access window for each site is Wb + Wa.

To predict access times we need more than the access window, the prediction needs to be in real time that is 8.00 am to 3.00 pm for example. The time difference between a high tide in Mackay and the time of the same tide at a nearby site (lag) varies with location.

The predicted launch time (PLT) at a specific location is equal to the time of the standard ports high tide plus/minus the lag, minus access window before high tide.

$$PLT = M'_{t_3} + Lag - W'b$$

It also follows that the predicted retrieval time (PRT) is equal to the time of the standard ports high tide plus/minus the lag, plus access window after high tide.

$$PRT = M'_{t_3} + Lag + W'a$$

This means that by measuring a repeatable phenomenon at a specific location, once during a large tide and again during a small tide, and using simultaneous observations at a nearby standard port, a prediction can be made at each of the measured sites using the its relationship to the standard ports tidal amplitude.

The last point means that if for example, a 5m amplitude tide at Standard port equates to an 8 hour window, and a 4m tide at the same Standard port equates to a 7 hour window, then a 4.5 m tide will be mid-way between the two, equating to 7.5 hours long. This proportional relationship will be applied to the time periods of Wb and Wa, and the lag.

At each test site we can measure the ELT, LRT and time of actual high tide (Ht) twice. Once during a large Mackay tide, and again during a smaller Mackay tide. The predicted tide will hopefully lie somewhere in between. This means we get the measured data for session 1 and 2 and make a prediction for session 3.

The ratio R is a linear factor based where the amplitude of the predicted tide for session 3 in relation to the session 1 and 2 amplitudes. If the predicted high tide was 4.5 m and the range of tides observed at the site was between 4 m and 5 m than the ratio is

$R = (4.5-4) / (5-4) = 0.5/1 = 0.5$

In conclusion, if the access windows are measured at a site for two sessions, we can calculate a future window based on its corresponding amplitudes at a nearby standard port.

Table 2-I Model 1 formulae

Where:	$W'b = (Ht_1-ELT_1)-(Ht_2-ELT_2)*R+(Ht_2-ELT_2)$

	$W'a = (Ht_1-LRT_1)-(Ht_2-LRT_2)*R+(Ht_2-LRT_2)$
With	$Lag = ((Ht_1-M't_1)-(Ht_2-M't_2))*R+(Ht_2-M't_2)$
	Ratio $R = (M'a_3-M'a_2)/(M'a_1-M'a_2)$

Table 2-II Measured variables

Measured Variables	Description
ELT_e	The actual measured earliest launch time at each site for session $_e$
LRT_e	The actual measured Latest Retrieval Time at each site for session $_e$
Ht_e	The actual measured time of high tide at each site for session $_e$
Ma_e	The actual amplitude of high tide at Mackay Outer Harbour for session $_e$
Mt_e	The actual time of high tide at Mackay Outer Harbour for session $_e$

Table 2-III Predicted variables

Predicted Variables	
$M't_e$	The predicted time of high tide at Mackay Outer Harbour for session $_e$
$M'a_e$	The predicted amplitude of high tide at Mackay Outer Harbour for session $_e$

Table 2-IV Derived variables

Derived Variables	
PLT	is the Predicted Launch Time at a specific tertiary port for a given day
PRT	is the Predicted Retrieval Time at a specific tertiary port for a given day
W´a	Is the predicted access time after high tide at the tertiary port
W´b	Is the predicted access time before high tide at the tertiary port
Lag	is the measured time difference between high tides at the Standard port and the tertiary port

Ratio R	The ration between the test day predicted MOH amplitude, and the range of amplitudes measured at each site.

The subscript $_e$ refers to the session that the data come from. Session 1 and 2 are the two data gathering sessions, session 3 is the test session.

2.12.2. Model 2

Model 1 above used the predicted amplitudes of the nearby standard port's amplitude to determine the ratio factor R. It has been shown in Section 2.6 above that meteorological factors can influence sea level. Some factors like prolonged wind and barometric pressure can be seen as regional rather than local. If the test sites for this paper are located in the same area than it is assumed that the same region's forces impact simultaneously at the standard port and at each site.

As mentioned in the section 2.6 above, meteorological influence impact of sea level. Model 2 attempts to negate some of these influences in the two data sets from each site. Model 1 used a relationship between the windows at each site and the predicted amplitudes at Mackay for the same tide. Those predicted amplitudes were surmised to be the underlying force behind the resultant window at each site. If the actual measured amplitudes at the standard port were used instead of the predicted, then this may negate some of the regional meteorological factors. The meteorological forces that deflected the sea level at the standard port could be assumed to be of the same magnitude as at the nearby test location. For example a predicted tide at Mackay could be 5 m but the actual measure same tide was 5.1 m meaning that the access window should be related to the larger tide. This data is available from The Queensland Government at

https://data.qld.gov.au/dataset/coastal-data-system-near-real-time-storm-tide-data/resource/7afe7233-fae0-4024-bc98-3a72f05675bd

Example of real time data at Mackay on the 24th March 2016

Table 2-V Mackay real time sea levels

Date / Time	Actual	Predicted	Residual
2016-03-24T10:40	5.098	5.202	-0.104
2016-03-24T10:50	5.149	5.264	-0.115
2016-03-24T11:00	5.195	5.308	-0.113
2016-03-24T11:10	5.232	5.334	-0.102

2016-03-24T11:20	5.236	5.34	-0.104
2016-03-24T11:30	5.23	5.326	-0.096
2016-03-24T11:40	5.201	5.292	-0.091

The difference is called the residual. These residuals are regularly up to 100 mm during normal weather conditions.

Model 2 is the same except for the ratio factor, which uses the actual amplitudes of the high tides.

Table 2-VI Model 2 formulae

	Model 2
	PLT = M'_{t3}+Lag-W´b
And	PRT = M'_{t3}+Lag-W´a
Where:	W´b = (Ht_1-ELT_1)-(Ht_2-ELT_2)*R+(Ht_2-ELT_2)
	W´a = (Ht_1-LRT_1)-(Ht_2-LRT_2)*R+(Ht_2-LRT_2)
With	Lag = ((Ht_1-M'_{t1})-(Ht_2-M'_{t2}))*R+(Ht_2-M'_{t2})
	Ratio R = (M'_{a3}-Ma_2)/(Ma_1-Ma_2)

Chapter 3: Methodology

3.1. Design

Table 3-I Design elements

Group	Site	Data Set Source		time of measurement			Variables	N
		P	A	Hrs	Sample rate (min)			
1	Mackay OH	y		66h 20 m 72 h	10 10	23/03/16 24/07/16	M′t, M′a	1
2	Mackay OH		y	66h 20 m 72h 72 h	10 10 10	23/03/16 23/05/16 24/07/16	Mt, Ma	3
3	Site 1 Camila		y	9h 33m 8h 00m	5 5, 2.5	23/03/16 24/05/16	ELT, Ht, LRT	2
4	Site 2 Bucasia		y	7h 40m 4h 00m	5 5, 2.5, 1	25/03/16 23/05/16	ELT, Ht, LRT	2
5	Site 3 Murray		y	10 h 9h 30m	5 5,2.5,1	24/03/16 25/05/16	ELT, Ht, LRT	2

As mentioned in the previous chapter, one of the hypotheses is to

- Adequate predictions of access times at specific locations can be made using the relationship between the simultaneous measured amplitudes at a nearby standard port, and the sites corresponding amplitudes and access times.

Group 1 refers to the predicted tide levels at a standard port, Mackay Outer Harbour (MoH). This data represents a predicted level at 10 minute intervals. Group 2 is the corresponding actual tide levels at MOH. The difference between the actual and predicted is the residual, which reflect how atmospheric influences can impact on local sea levels. The 10 minute predicted tide data for May was not available although the predicted time and level for all tide changes are available through tide charts.

These were obtained online from the Queensland Government at

http://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/mackay/

The measured variables in group 3, 4 and 5 were

- Earliest Launch Time (ELT)
- Latest Retrieval Time (LRT)
- The actual time of high tide (Ht)

These variables were extracted from the tidal shape curve, a plot of sea level over time.

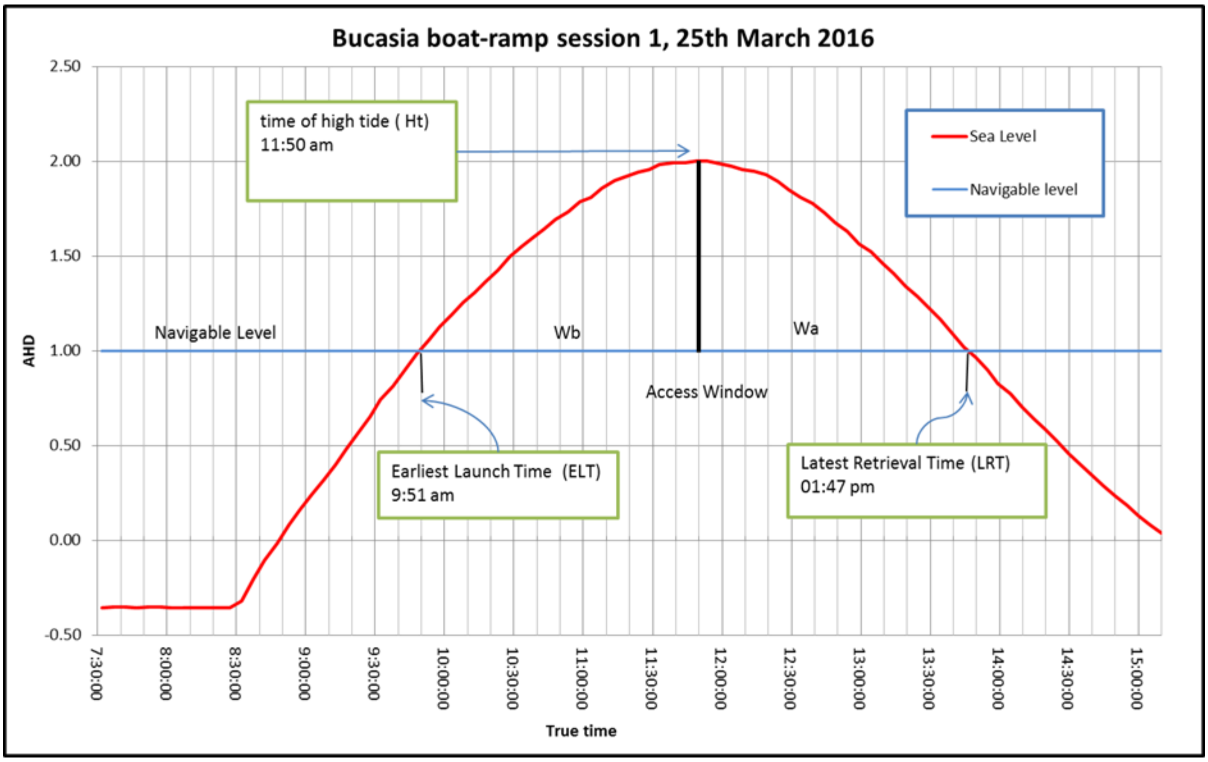


Figure 3-1 Bucasia sea levels 25th March

At each site the sea level was observed and heights recorded at regular intervals. This was done from before the tide reached the ramps navigable level, continuously through the ebb (high tide), until the tide dropped below the navigable level, a period of many hours. This varied between sites as the elevation of each ramp was in a different part of the tidal curve. This process was repeated twice. The first, during one of the larger amplitude tides of the month and the second during one of the smaller tides. Note that these tides are not the biggest nor the smallest that could expect but most other tides would lie between these two amplitudes.

In subscript ELT_1 or ELT_2 refers to the session number. In the design of these data gathering days, it was not possible to get the perfect tidal amplitude. The reason for this are

- The number of sites was 3, so it had to be done over a 3 day period.

- The time of high tide had to be around midday so that the full tidal curve could be observed in daylight. The equipment could still measure at night, but the operator did not.

These two sets of data, and the simultaneously recorded MoH data are the basis for the access window predictor.

From the observed data a curve of height over time was constructed. This plot shows the tidal shape at each location. In total, six graphs were produced, two from each location. The actual time of the ebb (Ht) is the time of the highest point on the curve. The earliest launch time (ELT) and the latest retrieval time (LRT) can be interpolated from the curve at the navigable elevation of each ramp.

From each session, the *lag*, that is the time difference between MoH and the sites high tide (Ht), and the actual time the sea level crossed the navigable level, the ELT and LRT, was recorded. The length of time between the ELT and Ht is the access window before high tide (Wb) and the time between the Ht and LRT is the access window after high tide (Wa).

The assumptions made are that there is a relationship between the access times Wa and Wb with the changes in the amplitude of the MoH tides. Two 'snapshots' were recorded and the data used to linearly interpolate for other MoH tide amplitudes.

These variables are then used to calculate the Predicted Launch Time (PLT) and the Latest Retrieval Time (LRT) at each location using the time and height of the predicted tide at MOH.

3.2. Reducing the impact of meteorological conditions

As described in the previous chapter, meteorological and atmospheric conditions play a significant role in sea level prediction. Prolonged onshore winds can temporarily raise the sea level and a high barometric pressure can lower local levels. This can have major influence during severe weather. Periods of extreme weather were avoided during the data collection. However, even during normal weather conditions anomalies exist.

Initially the design was to compare the predicted amplitude of the test day with the predicted amplitudes from the two data gathering session. This was used to obtain a ratio factor to apply to the access windows. It can be said that the meteorological forces that have deflected the tides at MoH will have a similar impact at a nearby port on that given day. So if a strong onshore wind had caused the sea level to rise a 100 mm at Mackay (not uncommon) then the same 100 mm would apply to each site on that same day.

Having the actual and predicted tide levels at Mackay allows for two solutions of access windows, one using only predicted amplitudes and the other using actual measured tides levels for the sessions 1 and 2.

3.3. Site selection

3.3.1. Camila site characteristics

Camila boat ramp is located on Camila creek, about 6 km from the Bruce Highway near the small township of Camila.

- Ramp is close to open ocean but has exposed flats at low tide
- Located 93 km south of MoH
- Accessible during mid to low tide

The ramp has always been a popular recreational boating launching point for access to the remoter island in the Broad Sound. This area is notorious for shallow water and large tides. The ramp has always been considered a half tide ramp although the ramp has been recently extended to allow smaller boats to launch and access the permanent tidal pools that remain at low tide. According to locals this extension has cause the flow to increase around the ramp making launching dangerous during the flood tide.

Location of Camila boat ramp - curtesy of google maps

Photo 3-A Camila location

Camila flood tide

Photo 3-B Camila Flood tide

Camila datum point

Photo 3-C Camila boat-ramp

3.3.2. Bucasia site characteristics

Bucasia ramp is located on the northern side of Eimeo Creek in Mackay. This is definitely only a half tide ramp with the water only reaching the ramp a few hours either side of high tide. It is close to the open ocean with extensive tidal flats exposed at low tide.

- Only accessible during upper part of tide
- Very close to open ocean
- Not far from Mackay Outer Harbour (MoH)

Photo 3-D Bucasia location

Bucasia boat-ramp at low tide

Photo 3-F Bucasia boat-ramp

Bucasia datum point with the tide approaching

Photo 3-E Bucasia boat-ramp

3.3.3. Murray Creek site characteristics

This ramp is located at the end of a dirt track on Constant Creek north of Mackay. This is very popular recreational and up until recently professional fishing area. It has received a surge of popularity since the State Government introduced several ‘net ban’ areas in Queensland. The increase in activity has resulted in a refurbishment of the car park recently. Maritime Safety Queensland (MSQ) has it listed as a tide dependant ramp, although similar to Camila, small boats can launch at most tides since a ramp extension. It is located on a complex estuary system some way upstream from the mouth. It has some rock-bars that restrict tidal flow (and outboard motors).

- Located in the upper regions of complex estuarine system
- Accessible in the lower half of the tide.
- located 47 km north of MOH
- rock bars cause restricted flow

Photo 3-G Murray Creek location

Murray Creek boat-ramp

Photo 3-H Murray Creek boat-ramp

Murray Creek datum point

Photo 3-I Murray Creek boat-ramp

3.4. Datum

3.4.1. Types of Datum

Since 1994 the datum on tide charts in Australia in the lowest astronomical tide (LAT). This datum represents the lowest level that can be predicted to occur under normal conditions. The port datum is the LAT at that site. Levels on tide charts are added to the port datum. When using a marine chart, the depth is added to the interpolated tide level for that time to give you water depth (Maritime Safety Queensland 2012).

Mean sea level (MSL) is the average sea level measured over a long time period. This time is called the tidal epoch and in Queensland is 18.6 years (Maritime Safety Queensland 2016b).

Australian Height datum (AHD) is the vertical datum adopted by the National Mapping Council of Australia for all mapping. Note that AHD, while initially it was conceived to be the same as MSL, is not the same nor are they parallel.

Mean Sea level used for the tidal predictions – 2016

An allowance of 2.2 mm per year for sea level change has been made in the mean sea level (MSL) estimate. The allowance is calculated from the central date of the observation period to the central date of the prediction year. The heights are referred to Lowest Astronomical Tide datum.

Place	Observation Period	MSL	Place	Observation Period	MSL
Gold Coast Seaway	Jan 1993 to Feb 1999	0.797	Cape Ferguson	Jan 1991 to Dec 2013	1.730
Brisbane Bar	Jan 1985 to Dec 2013	1.306	Townsville	Jan 1985 to Dec 2013	1.982
Mooloolaba	Jan 1987 to Dec 2013	0.989	Lucinda (Offshore)	Jun 1985 to Dec 2013	1.926
Noosa Head	Dec 1970 to Dec 1971	1.135	Clump Point	Dec 1985 to Dec 2013	1.787
Waddy Point (Fraser Island)	Oct 1976 to Feb 1978	1.165	Mourilyan Harbour	Jan 1985 to Dec 2013	1.777
Urangan	Sep 1986 to Dec 2013	2.118	Cairns	Jan 1985 to Dec 2013	1.732
Bundaberg (Burnett Heads)	Jan 1985 to Dec 2013	1.754	Port Douglas	Jan 1987 to Dec 2013	1.634
Gladstone	Jan 1985 to Dec 2013	2.374	Leggatt Island	Sep 1995 to Apr 1996	1.700
Port Alma	Jan 1986 to Dec 2013	2.937	Twin Island	Jul 1974 to Dec 1975	1.785
Rosslyn Bay	Jan 1993 to Dec 2013	2.460	Thursday Island	Jan 1985 to Dec 2013	1.905
Hay Point	Jan 1985 to Dec 2013	3.408	Goods Island	Jan 1990 to Dec 2013	2.174
Mackay Outer Harbour	Jan 1988 to Dec 2013	3.052	Booby Island	Jan 1990 to Dec 2013	2.457
Bugatti Reef	Oct 1996 to Mar 1997	1.581	Weipa (Humbug Point)	Jan 1985 to Dec 2013	1.878
Shute Harbour	Jan 1987 to Dec 2013	1.954	Karumba	Dec 1985 to Dec 2011	2.154
Bowen	Jan 1986 to Dec 2013	1.795	Mornington Island	Jun 2007 to Dec 2013	2.074
Abbot Point	May 1985 to Dec 1995	1.725			

Figure 3-2 Tidal datums 2016

(Maritime Safety Queensland 2016b)

From the table above we can see that the MSL was determined at MoH from 1988 to 2013 and measured at 3.052 m above LAT.

Semidiurnal Tidal Planes - 2016

Height above lowest astronomical tide

Place	Latitude	Longitude	Time Difference		MHWS	MHWN	MLWN	MLWS	AHD	MSL	Ratio	Cons	HAT
	South	East	HW	LW									
Tidal Datum Epoch 1992 - 2011			1	2	3	4	5	6	7	8	9	10	11
			H M	H M	m	m	m	m	m	m			m
Mackay Outer Harbour	**21 06**	**149 14**	**Standard Port**		**5.29**	**4.07**	**1.96**	**0.74**	**2.941**	**3.02**	**1.00**	**0.00**	**6.58**
Thirsty Sound	22 08	150 02	-0 26	-0 37	6.08	4.68	2.25	0.85		3.45	1.15	0.00	7.57
Keswick Island	20 55	149 26	-0 03	+0 04	4.71	3.62	1.74	0.66		2.69	0.89	0.00	5.86
Halliday Bay	20 54	148 59	+0 09	+0 23	5.03	3.73	1.69	0.56	2.63	2.65	0.92	0.00	6.14
Finlayson Point	20 53	148 56	+0 20	+0 20	5.40	4.15	2.00	0.75		3.07	1.02	0.00	6.71
Carlisle Island	20 47	149 17	+0 02	-0 02	4.44	3.42	1.65	0.62		2.53	0.84	0.00	5.53
Laguna Quays Marina	20 36	148 40	+0 30	+0 25	4.74	3.74	1.87	0.88	2.81	2.74	0.91	+0.02	6.30

Figure 3-3 Semisiurnal tidal planes

(Maritime Safety Queensland 2016b)

From the tidal plane table we can see that the difference between AHD and LAT (or port datum) at MoH is 2.941 m. We can also see that this not a constant and varies with the location.

In summary, LAT is used on tide charts, AHD is used for vertical mapping, and they are neither co-planner nor parallel. The difference between the two is 2.941 at Mackay.

For this study AHD will be assumed to be 2.941 m above LAT for all three of the test sites. This will work because the measurements at each site will be only relative to that site. The elevation of the sea level and the determination of the navigable level will be relative to each other. The only comparisons with MoH are time based, so the relationship between the datum at each site is immaterial. The three measured variables at each site are ELT, Ht and LRT and are time based.

3.4.2. Datum at each site

At each of the selected sites a datum was selected to measure the tide. Permanent Survey Mark (PSM) connected to Australian Height Datum (AHD) where used.

A search was carried out on line from the Queensland globe website for PSMs. These were printed out and a site visit used to find which were accessible.

At Bucasia, two nearby PSMs (141684, 43073) were adopted. The level was transferred using trigometric heighting method. A mark was placed at a convenient location close to the ramp.

BUC2	4.822 m AHD

At Murray Creek, PSMs (190786, 190785), installed by Maritime Safety Queensland (MSQ) were located near the ramp. At convenient mark was established.

MUR2	3.108 m AHD

At Camila the PSM 183083 installed by MSQ had been disturbed (the top of the mini mark had been sheared off) so a check was carried from a PSM 23065 in Camila using RTK GPS techniques. This datum was then transferred onto a convenient location close to the ramp by theodolite.

CAM 1A	5.025 m AHD

3.4.3. Navigable datum

The term navigable datum refers a nominal level at each boat-ramp that enables free launching and navigation to the sea. This level is not the same for each site. At each site a profile of the boat-ramp was recorded and a determination of the lowest navigable level made. Normally this level can said to be the bottom of the ramp. This was the case at Bucasia. Both the ramps at Murray's creek and Camila have had ramps extended so that access was at all but for the lowest of tides. Due to nature of those locations, this very bottom of the ramp, while accessible, wasn't much use as navigation in the system and access to the open ocean was restricted at these levels. For the purpose of this study an arbitrary level was allocated for each site based on personal observations.

- For Bucasia it was the actual bottom of the concrete boat-ramp at AHD 1.0m.
- For Camila it was AHD 0.3m
- And for Murray Creek it was AHD - 0.4m

The fact that at both Camila and Murray Creek the navigable datum is not the bottom of the ramp does not impact on testing the method. What is important is that each of the sites is at a different point in the tidal cycle.

For the purpose of this study, an arbitrary navigable elevation was adopted for these two ramps.

3.5. Equipment

3.5.1. List

Table 3-II equipment list

ITEM	Provided by	
Trimble R8 RTK GPS and base.	Patrick McFadden	
Trimble S6 total station.	Patrick McFadden	
Survey Legs (2 sets)	Patrick McFadden	
Traverse Prisms	Patrick McFadden	
Trimble TSC3 controller	Patrick McFadden	
Trimble Business Centre software.	Patrick McFadden	
mini 360 degree prism	Patrick McFadden	
Float and tether	Patrick McFadden	
Hat/ Sunscreen / insect repellent.	Patrick McFadden	
Laptop	Patrick McFadden	
Microsoft Excel.	Patrick McFadden	

Site access will be my vehicle.

3.6. Innovative methods

The established method of measuring tide levels at non-standard ports is to use a pressure device that is lowered to the sea floor and left to record the water level overhead. Normally this is left for 29 days so that a local datum (LAT) can be established for hydrological studies. Inquiries were made with a colleague about obtaining a loan of one from MSQ. They are expensive, and when left un-attended they tend to go missing or at least get pulled up from their tethered position as the float resembles a crab pot marker. This movement destroys the integrity of the data. This option was not available for this study.

For data gathering stage of this study an innovative method was developed with the equipment available. A small 360 degree prism was attached to a basic float, being a piece of polystyrene foam. This was tethered to a cord with a weight about a meter along the line to anchor the float. The cord continued on to another weight that secured it to the bank.

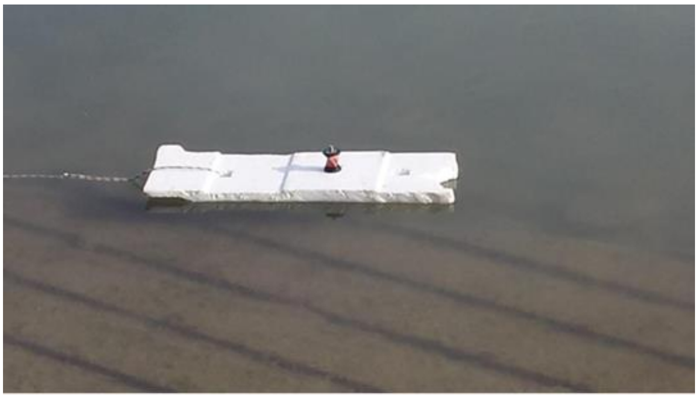
Using a S6 Trimble total station and a TSC3 controller set up so the S6 tracked a small 360 degree prism which was attached to a float. The height of the prism above the water level was recorded as 0.035 m.

The total station was set up over the local datum point, aimed at the prism and using the track mode started recording elevations. The on-board program 'continuous topo' was used and the prompt for observations was set to a time interval. The initial visits used a time interval of 5 minutes, but subsequent visits this was reduced to 2.5 minutes and some 1 minute observations.

A survey equipment supplier in Brisbane, Sitech provided a custom template that output Point number, Easting, Northing, RL and date and time stamp.

Float and prism setup

Photo 3-J New tide measuring device



Pat's tide measuring device

Photo 3-K Detail of prism setup

3.7. Methods

3.7.1. Timeline

Table 3-III Project time-line

Date	Field work activity
19/03/16	Compile a survey control list at each site using Queensland Globe. Construct version 1 of Pats tide measuring float assembly.
21/03/16	Preliminary visit to site 1 Camila. Find control, establish a Bench mark, survey the ramp profile
22/03/16	Preliminary visit to site 2 Bucasia. Find control, complete survey traverse to the ramp and establish a bench mark. Survey ramp. Preliminary visit to site 3 Murray Creek. Control nearby, established a BM and surveyed ramp.
23/03/16	Session 1 tide data collection. Camila from 8:23 am to 6:00pm 9 h 37 min
24/03/16	Session 1 tide data collection. Murray Creek 8:02 am to 5:53 pm 9 h 51 min
25/03/16	Session 1 tide data collection. Bucasia 7:32 am to 3:10 pm 7 h 38 min
23/05/16	Session 2 tide data collection. Bucasia 9:33 am To 1:28 pm 3 h 55 min
24/05/16	Session 2 tide data collection. Camila 8:10 am to 4:10 pm 8 h
25/05/16	Session 2 tide data collection. Murray Creek 7:40 am to 5:06 pm 9 h 26 min

23/07/16	Session 3 test day, Bucasia
24/07/16	Session 3 test day, Camila
25/07/16	Session 3 test day, Murray Creek

3.7.2. Data processing

The collected data from each site was downloaded from the TC3 controller using the custom export format that attached a time stamp. The data was then processed in Microsoft Excel to a format of height and time. The time had to be extracted from the downloaded format into hours, minutes and seconds. This was then re-compiled into decimal time format and then into excel time format.

Table 3-IV Example of data download

point	east	north	AHD	date	hours	mins	secs	dec time	
2000	754385.11	7575095.25	-0.50	2016.0524	8	10	21	8.1725	8:10:21
2001	754385.11	7575095.25	-0.51	2016.0524	8	12	51	8.2142	8:12:51
2002	754385.11	7575095.25	-0.51	2016.0524	8	15	22	8.2561	8:15:22
2003	754385.11	7575095.25	-0.51	2016.0524	8	17	53	8.2981	8:17:53
2004	754386.23	7575098.16	-0.51	2016.0524	8	21	35	8.3597	8:21:35
2005	754386.37	7575097.99	-0.51	2016.0524	8	26	36	8.4433	8:26:36

3.8. Preliminary analysis

3.8.1. Creating plots

The data for each site and session can be simplified down to time, elevation and navigable datum. The navigable datum is a constant for each site but varies from site to site. A smooth line X Y scatter plot was produced. One line represents the tidal curve, the other a horizontal line representing the navigable datum. The tidal curve in the open ocean looks like a cosine oscillation. In an estuarine environment the shape is somewhat distorted.

The distance on the graph from the intercept of the tidal curve and the navigable datum is the actual time the sea level was above the navigable level – this is the *access window* for that site on that day.

Also from the curve the highest point is the time of high tide. From this point the actual time of high tide at that site can be interpolated (Ht).

The access window has to be divided into two components, as tides in estuarine areas can be asymmetrical, that is the time from high tide to when the water first crossed the navigable datum to when it retreats is not always equal. The terms earliest launch time (ELT) and latest retrieval time (LRT) refer to these two points.

From each graph the variables ELT, Ht and LRT is extracted.

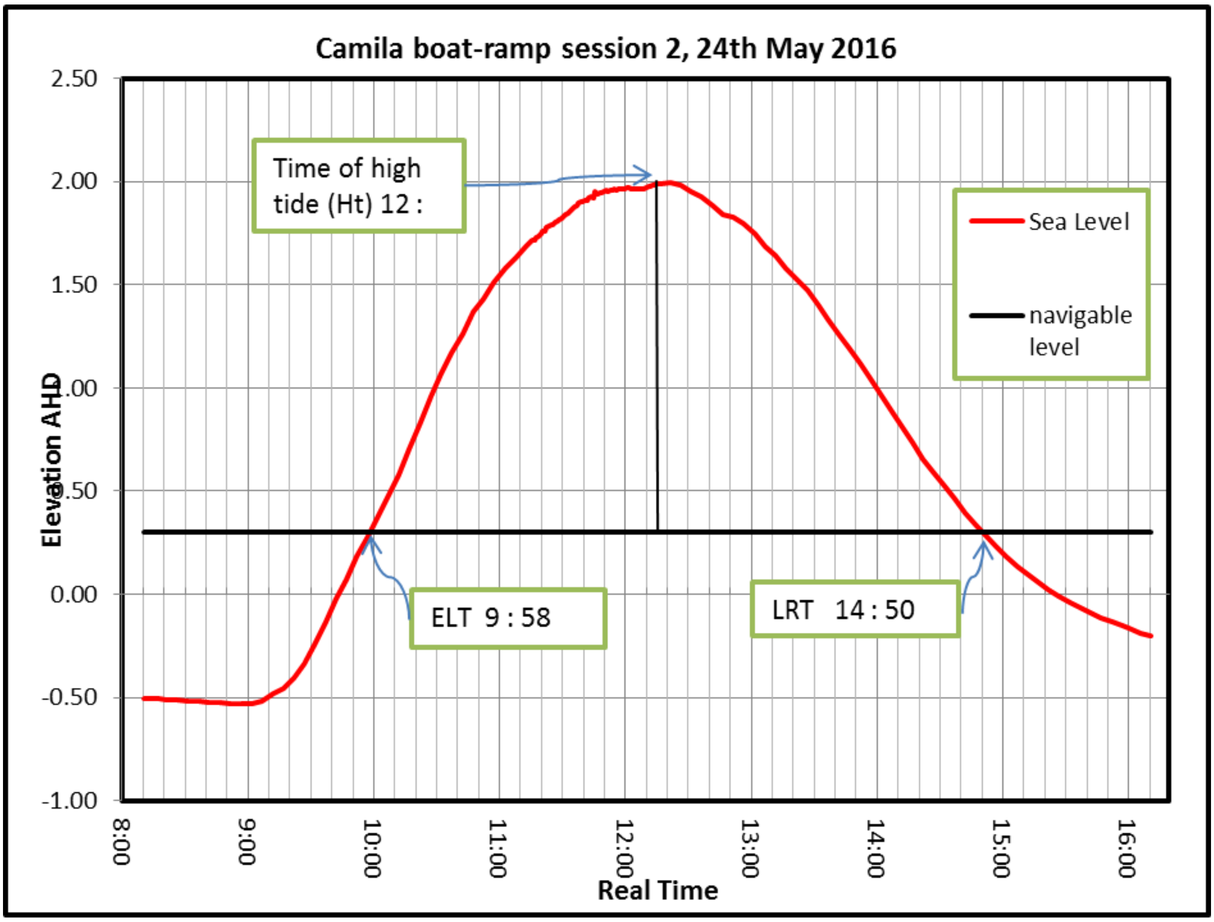


Figure 3-4 Camila sea level 24th May

3.9. Making a prediction

From two sets of data from each site, session 1 and session 2, we have the variables ELT Ht and LRT.

To make a prediction of a specific day, the time and height of high tide at Mackay is obtained from the 2016 Queensland Tide Tables Standard Port Tide Times (M'_{t3} M'_{a3}) and entered into the equation.

Table 3-V Model 1

	$PLT = M'_{t3}+Lag-W'b$
And	$PRT = M'_{t3}+Lag-W'a$
Where:	$W'b = (Ht_1-ELT_1)-(Ht_2-ELT_2)*R+(Ht_2-ELT_2)$
	$W'a = (Ht_1-LRT_1)-(Ht_2-LRT_2)*R+(Ht_2-LRT_2)$
With	$Lag = ((Ht_1-M't_1)-(Ht_2-M't_2))*R+(Ht_2-M't_2)$
	Ratio $R = (M'a_3-M'a_2)/(M'a_1-M'a_2)$

In section 3.2 it was suggested that the impacts of meteorological conditions may be reduced if instead of using the MoH predicted amplitudes in the session 1 and 2 calculations, that the actual measured amplitudes at MoH be used. This will alter the ratio factor R and hence the resulting predictions. Also the lag measured for each session can be adjusted to include the actual time of high tide at MoH instead of the predicted (from tide chart).

So in Model 2

Table 3-VI Model 2 ratio

Ratio $R = (M'a_3-Ma_2)/ (Ma_1-Ma_2)$

In essence this means that we have two solutions for the PLT and PRT.

3.10. Testing the prediction

3.10.1. Navigable level pins at each site

The test day for each site was selected based on the occurrence of high tide being around midday and the amplitude of the tide being hopefully somewhere in between the two data gathering session. The design of the two data gathering days was that one was during a larger tide and the other during a smaller tide. The formula is based on a linear interpolation between the amplitudes of the nearby MoH tides. If the test day is outside of the session 1 and 2 range then it becomes an extrapolation. If the test day is at the same amplitude as one of the days then it does not really test the relationship except to reinforce that tides are repeatable.

At each site a visible bench mark was installed at the nominal navigable level. On the test day the site was visited and the time when the sea reached the benchmark was recorded via a photo with a time stamp. The same applied to when the water retreated and exposed the benchmark.

Datum pin set at nominated navigable level

Photo 3-L Navigable level pin

Chapter 4: Results

4.1. Camila Results

4.1.1. Session 1

Camila creek boat-ramp was visited on 24th March. The tide was observed at 5 minute intervals from 8:20 in the morning through to 6:00 pm. The observations were downloaded and plotted. The navigable datum was arbitrarily determined to be 0.3m AHD. The earliest launch time (ELT), time of high tide (Ht) and latest retrieval time (LRT) extracted from the curve.

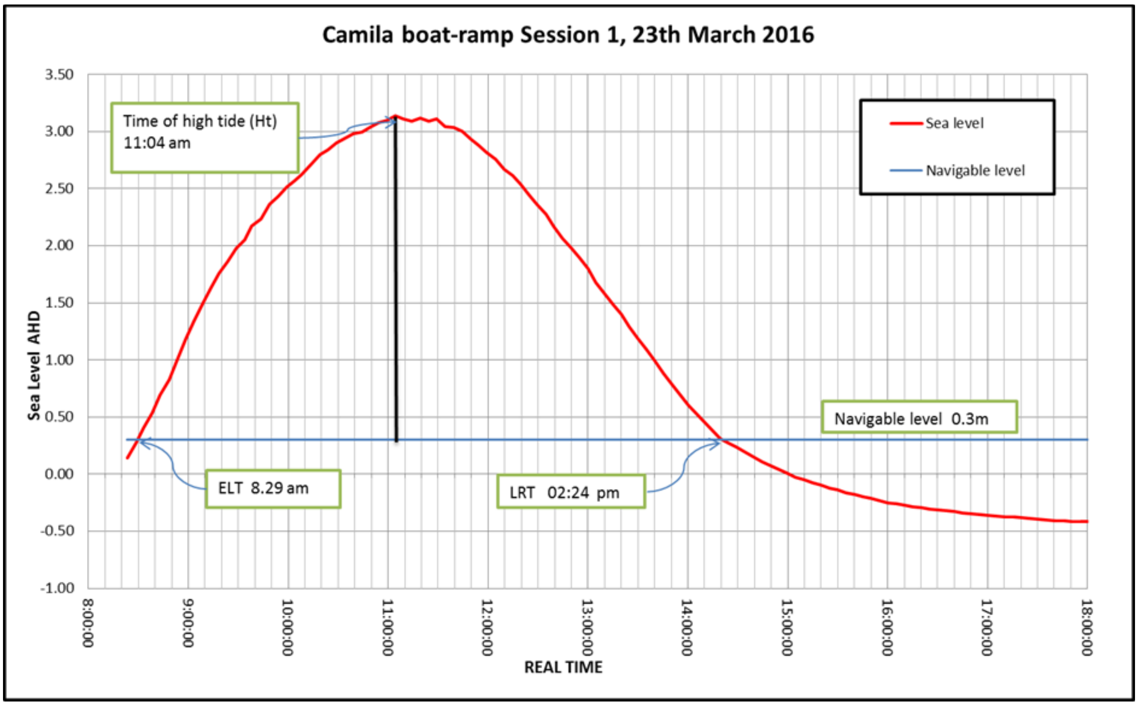


Figure 4-1 Camila sea level 23rd March

The time of ELT and LRT was the intercept between the tidal curve and the navigable level. The actual time of high tide was the top of the curve. In this case, there is some oscillation at the top of the curve. This could be possible resonance in the estuarine system. The vertical line shows the point decided as the time of high tide (Ht).

4.1.2. Session 2

Camila was visited for the second time on the 24th of May. The tide was observed from 8:10 am through to 4: 10 pm at a mixture of 5, 2.5 and 1 minute intervals. The frequency of observations was increased to help capture to true change in tide moment. When using 5 minute observations, if a measurement was missed due to interference from boat traffic, the interval increased to 10 minutes. The data was again downloaded and plotted.

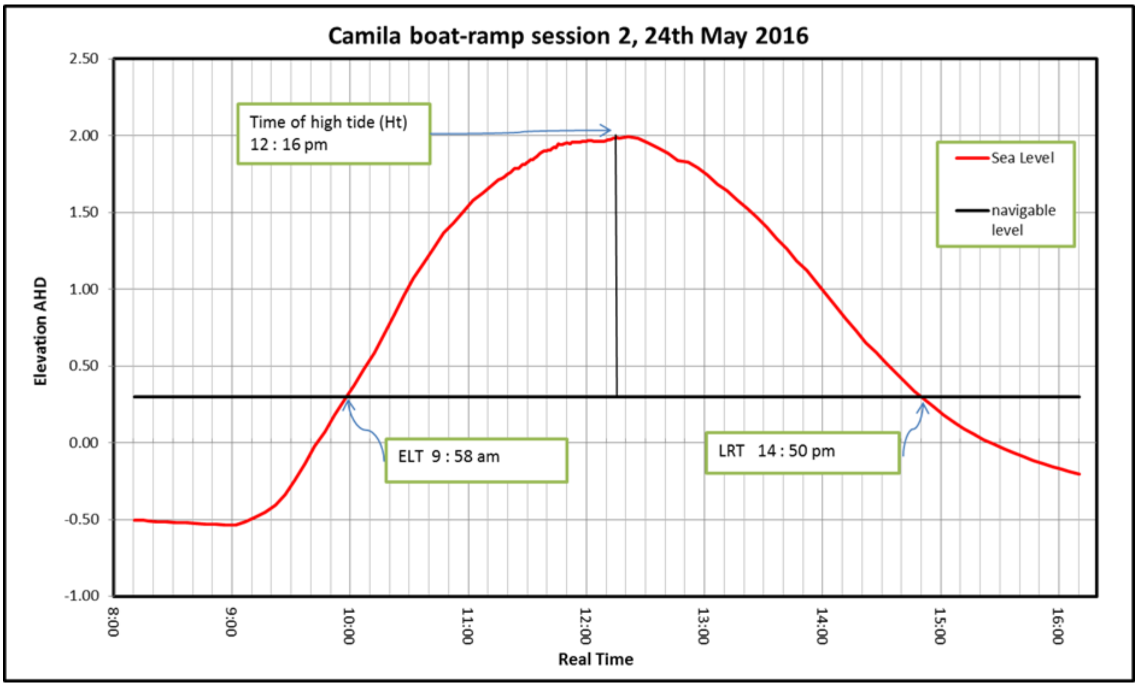


Figure 4-2 Camila sea level 24th May

4.1.3. Mackay outer Harbour

At Mackay outer harbour (MoH) the data from the automatic tide measuring device was downloaded and plotted. The height and time of the actual and predicted high tide extracted for both the 23rd March and the 24th May, corresponding to the session 1 and 2 dates.

On the 23rd March both observed and predicted sea level at 10 minute interval was available from MSQ website. The 24th May data only the measured (actuals) data was available. The predicted data comes from the 2016 Queensland Tide Tables Standard Port Tide Times.

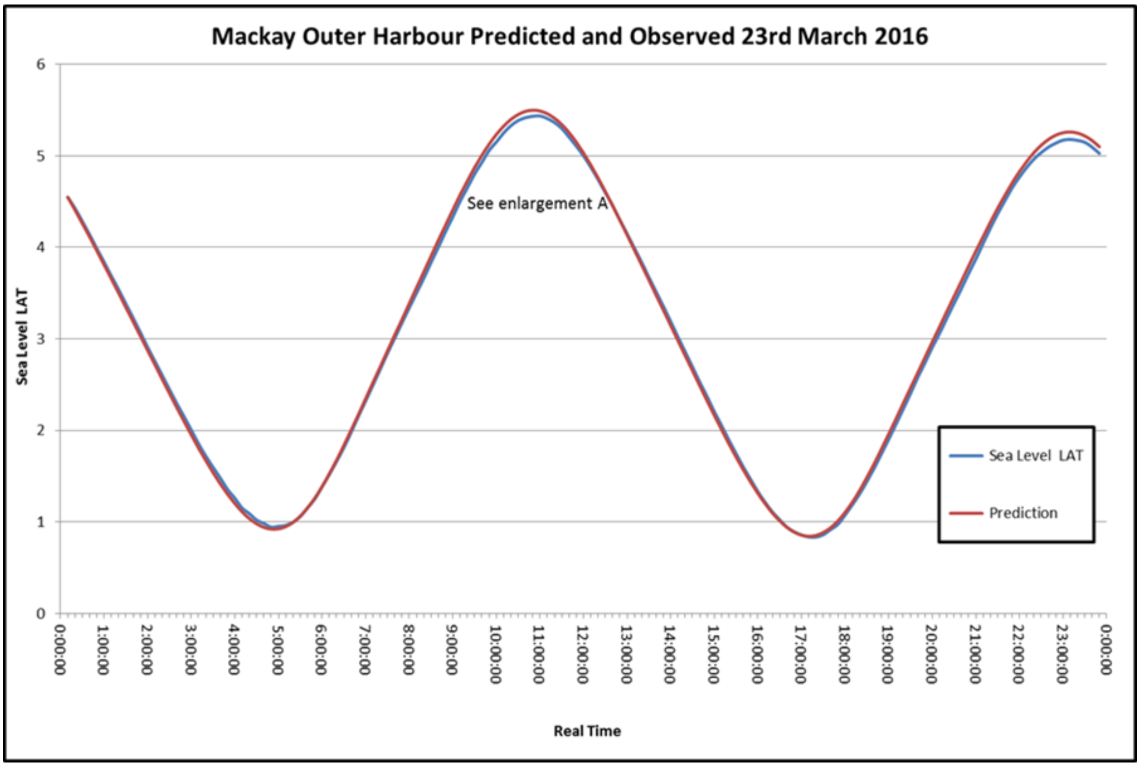


Figure 4-3 MoH sea level 23rd March

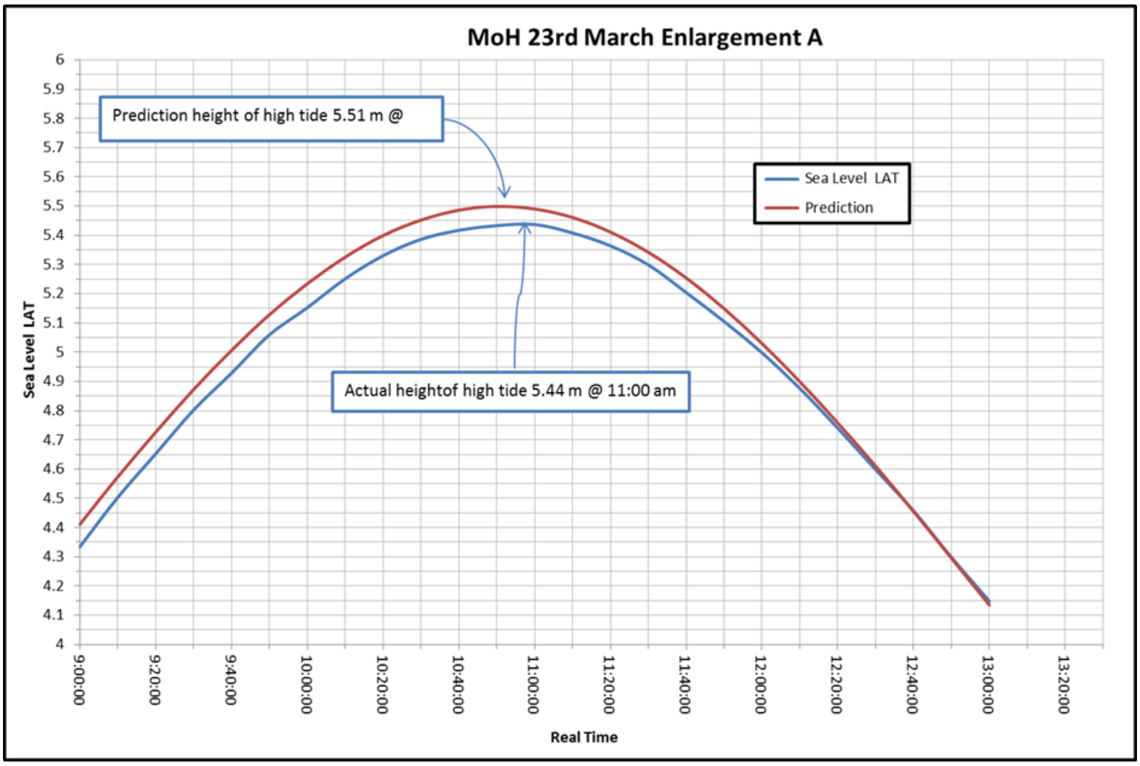


Figure 4-4 Enlargement A

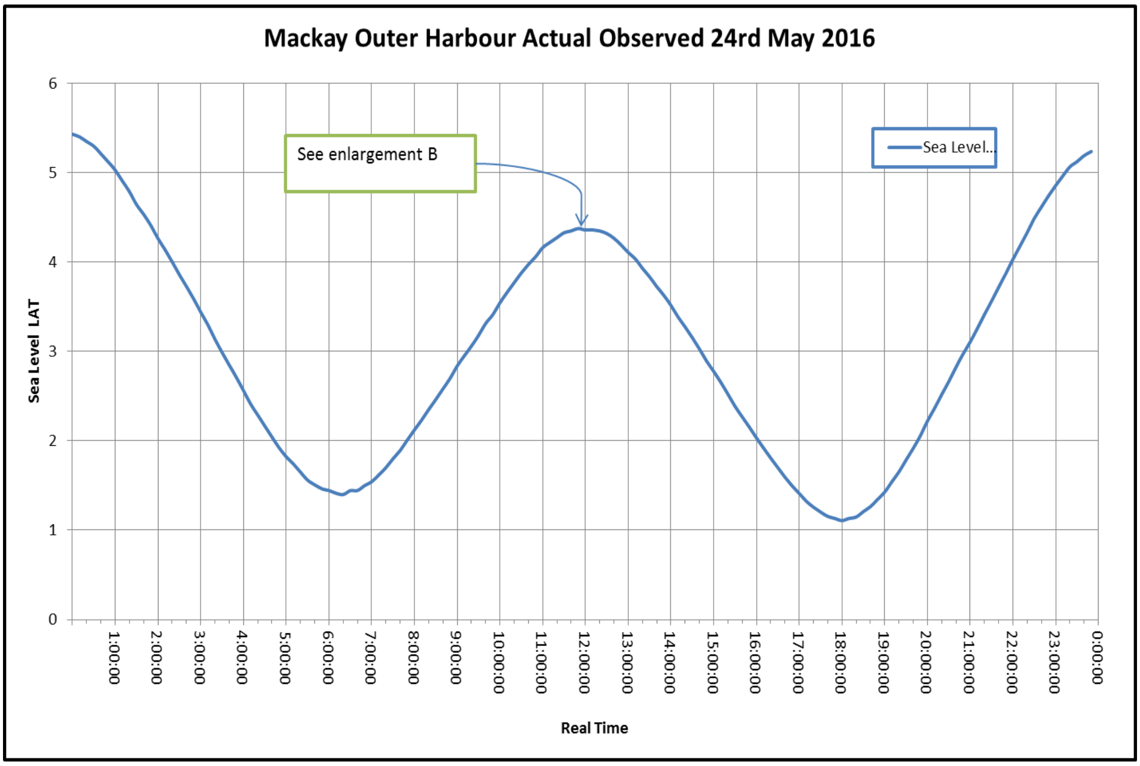


Figure 4-5 MoH sea levels 24th May

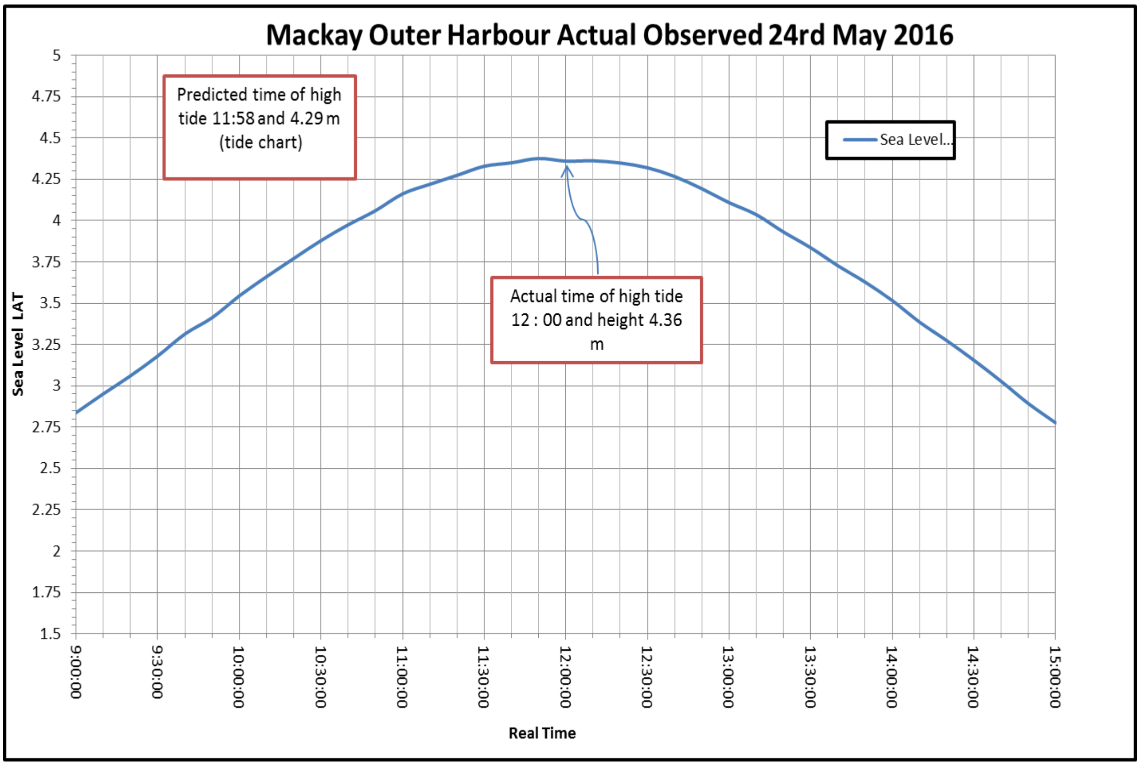


Figure 4-6 Enlargement B

4.1.4. Camila summary of variables

Table 4-I Camila measured variables

	Measured variables					Predicted variables	
Date	ELT	Ht	LRT	Mt	Ma (LAT)	M't	M'a (LAT)
S1 23/03/2016	8:29	11:04	14:24	11:00	5.44	10:51	5.51
S2 24/05/2016	9:58	12:16	14:50	12:00	4.36	11:58	4.29

And using

Window before high tide	Wb = Ht - ELT
Window after high tide	Wa = LRT - Ht
Time difference between site and MoH actual	Lag (actuals) = Ht - Mt
Time difference between site and MoH predicted	Lag' (predicted) = Ht - M't

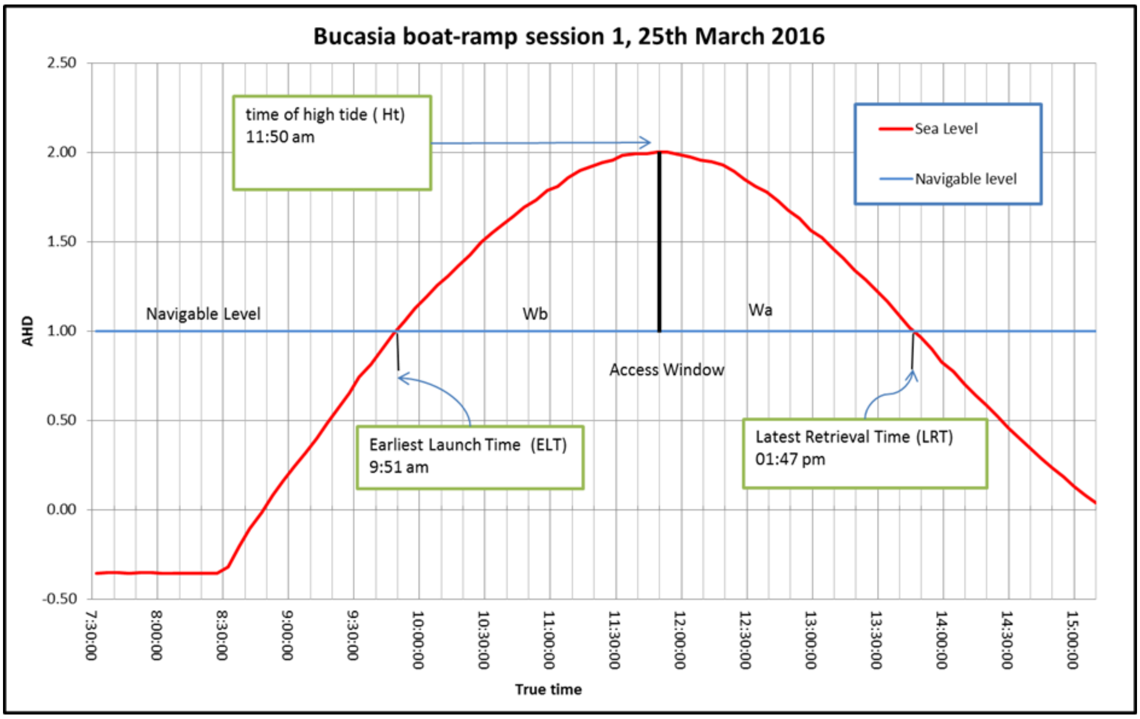
Table 4-II Session 1 and 2 summary

	Session 1	Session 2
Total window	5:55	4:52
Wb	2:35	2:18
Wa	3:20	2:34
Lag' (predicted)	0:13	0:18
Lag (actuals)	0:04	0:16

4.2. Bucasia

4.2.1. Session 1

The same process was repeated at Bucasia North boat-ramp. The site was visited on 25th March from 9:51 am to 1:47 pm. The tide was observed in 5 minute intervals. The data was downloaded and plotted and the variables extracted. The navigable level was set at 1.00 m



AHD, which was the bottom of the concrete ramp.

Figure 4-7 Bucasia sea levels 25th March

4.2.2. Session 2

The site was surveyed again on the 23rd May from 9:55 am to 1:00 pm. Data was in 1 minute intervals. The day was particularly windy with a stiff breeze blowing into the ramp from the South West. Because data was at 1 minute intervals the curve looks noisy. Wave action on the day was about 3 cm.

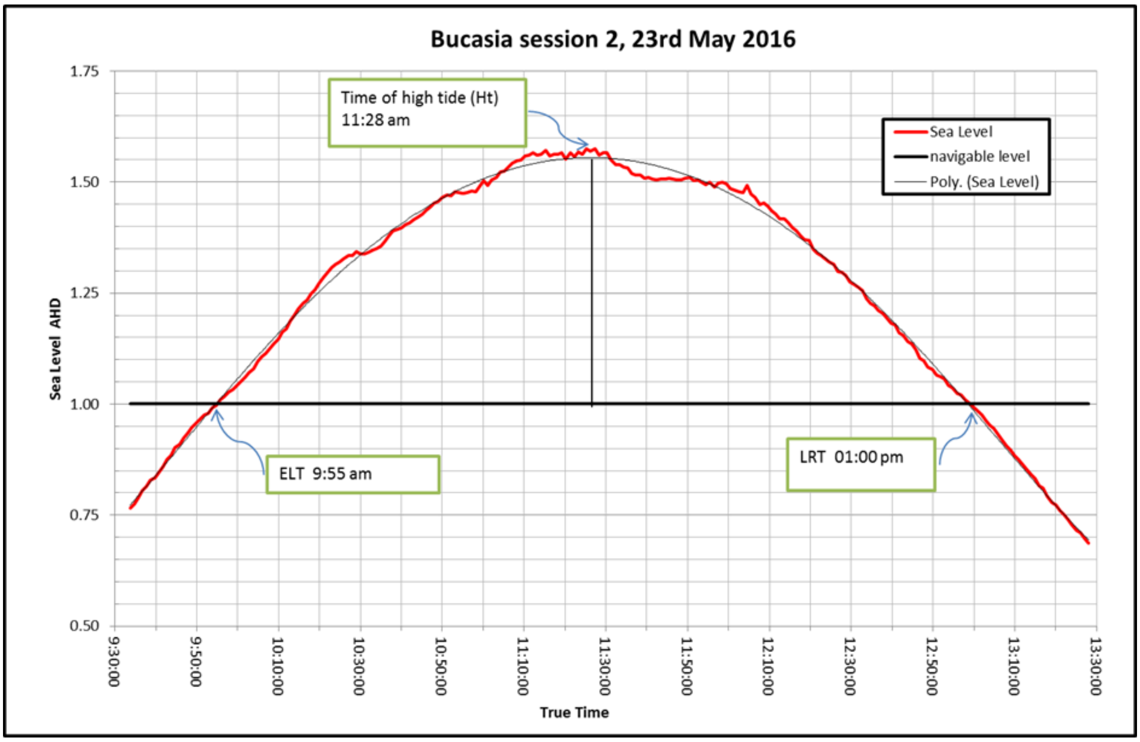


Figure 4-8 Bucasia sea levels 23rd May

4.2.3. Mackay outer Harbour

At Mackay outer harbour (MoH) the data from the automatic tide measuring device was downloaded and plotted. The height and time of the actual and predicted high tide extracted for both the 25th March and the 23rd May, corresponding to the session 1 and 2 dates.

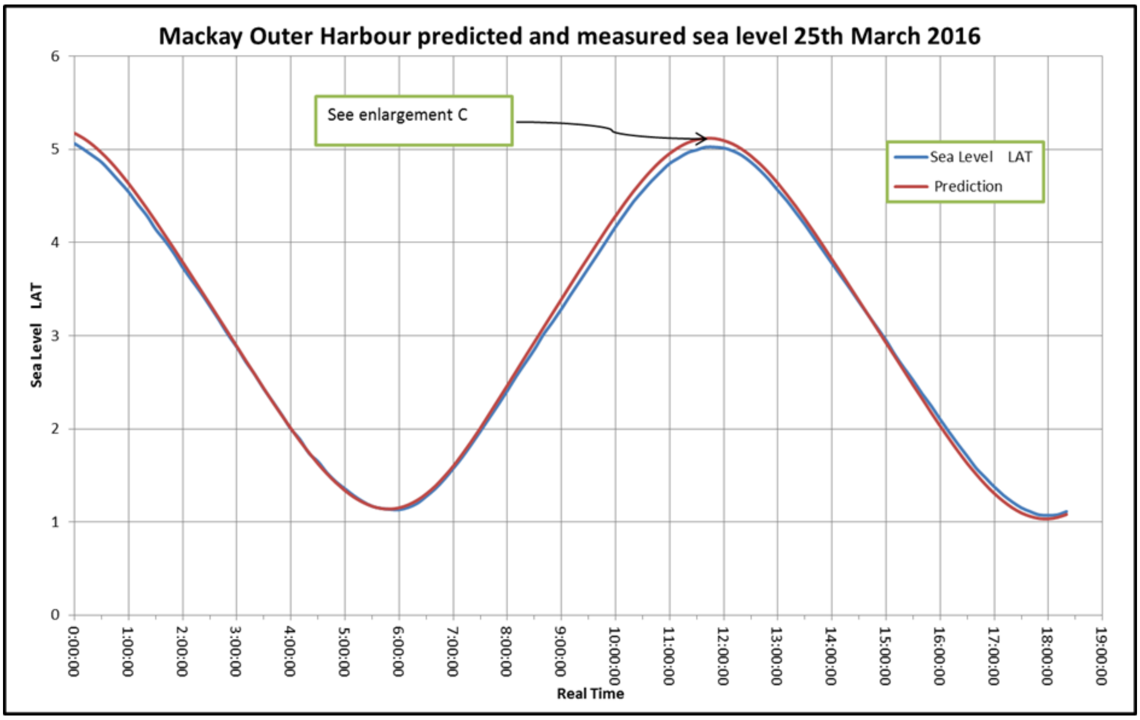


Figure 4-9 MoH sea level 25th March

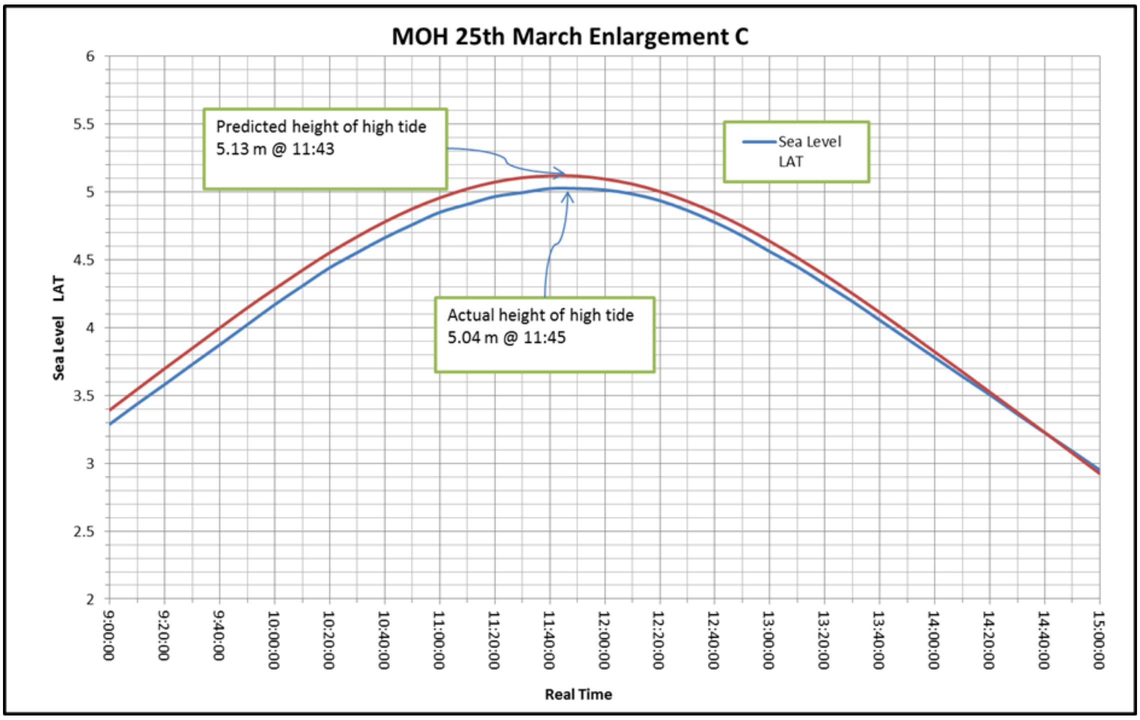


Figure 4-10 MoH sea level enlargement C

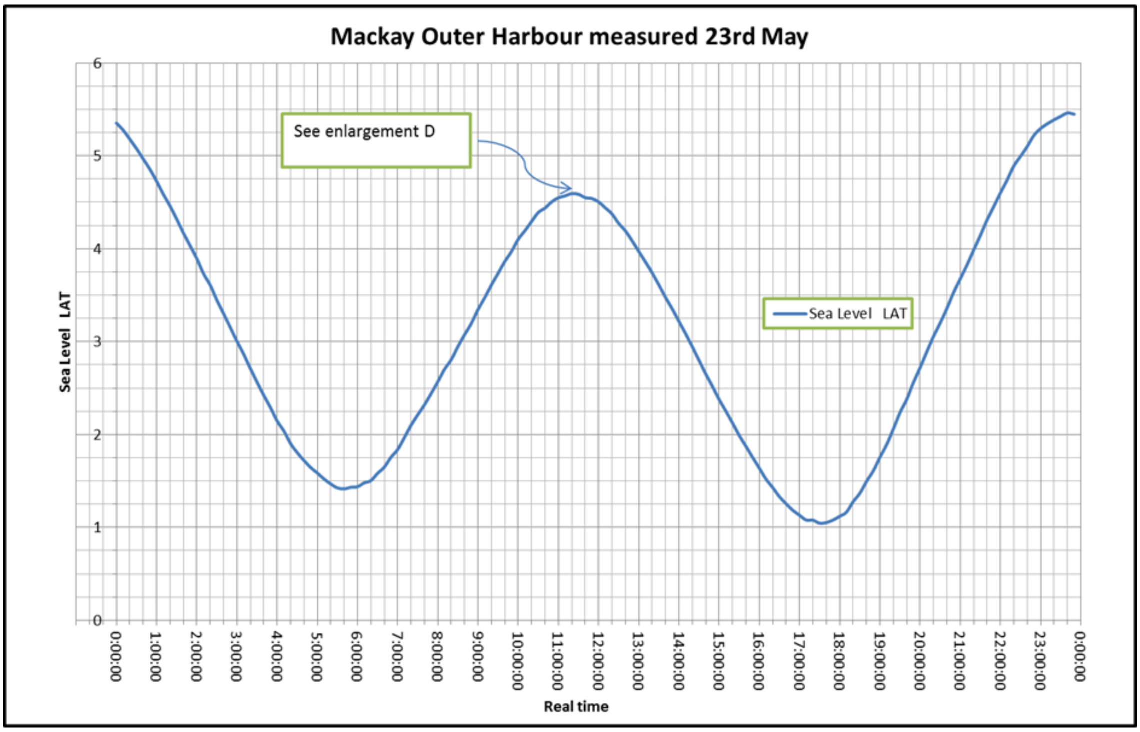


Figure 4-11 MoH sea levels 23rd May

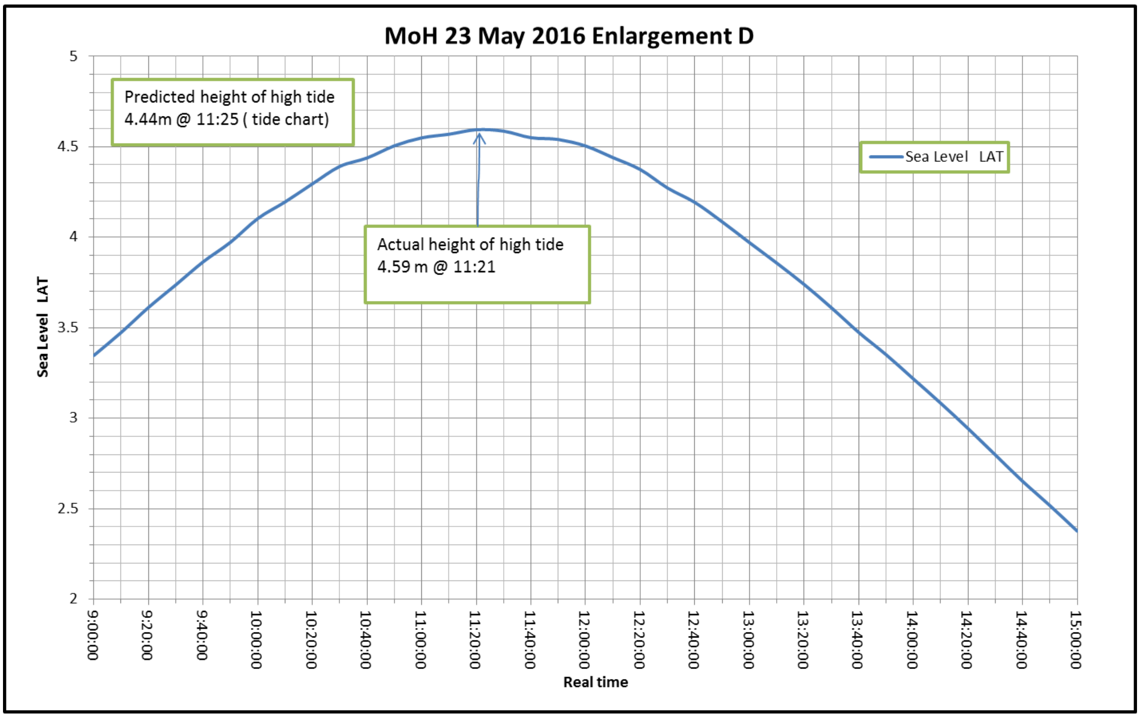


Figure 4-12 Enlargement D

4.2.4. Bucasia summary of variables

Table 4-III Summary of Bucasia variables

	Measured variables					Predicted variables	
Date	ELT	Ht	LRT	Mt	Ma (LAT)	M't	M'a (LAT)
S1 25/03/2016	9:51	11:50	13:47	11:45	5.04	11:43	5.13
S2 23/05/2016	9:55	11:28	13:00	11:21	4.59	11:25	4.44

And using

Window before high tide	Wb = Ht - ELT
Window after high tide	Wa = LRT - Ht
Time difference between site and MoH actual	Lag (actuals) = Ht - Mt
Time difference between site and MoH predicted	Lag’ (predicted) = Ht - M’t

Table 4-IV Bucasia session 1 and 2

	Session 1	Session 2
Total window	3:56	3:05
Wb	1:59	1:33
Wa	1:57	1:32
Lag (actuals)	0:05	0:07
Lag’ (predicted)	0:07	0:03

4.3. Murray Creek

4.3.1. Session 1

The same process was repeated at Murray Creek boat-ramp. The site was visited on 24th March from 8:02 am to 5:53 pm. The tide was observed in 5 minute intervals with an occasional missed data shot due to boat traffic obstructing the target. The data was downloaded and plotted and the variables extracted. The navigable level was determined to be -0.40 m AHD.

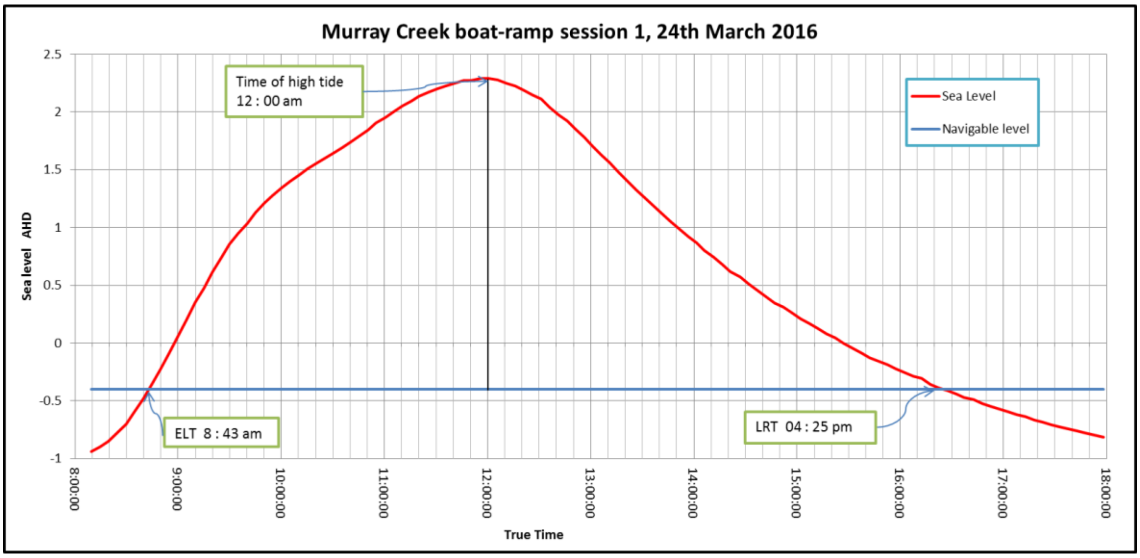


Figure 4-13 Murray Creek sea level 24th March

4.3.2. Session 2

Session 2 was on the 25th May between 7:40 am and 5:06 pm with an interval of mostly 2.5 minutes. Due to boat traffic a few data shots were missed and some extra shots taken at odd intervals.

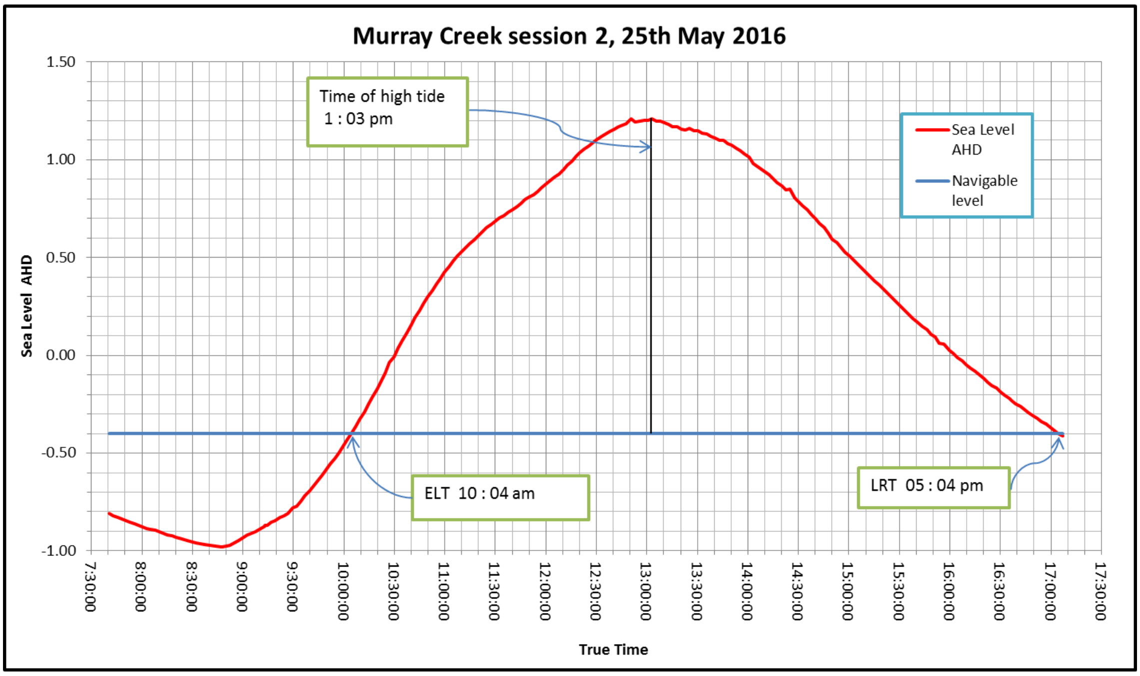


Figure 4-14 Murray Creek sea level 25th May

4.3.3. Mackay outer harbour

At Mackay outer harbour (MoH) the data from the automatic tide measuring device was downloaded and plotted. The height and time of the actual and predicted high tide extracted for both the 24th March and the 25th May, corresponding to the session 1 and 2 dates.

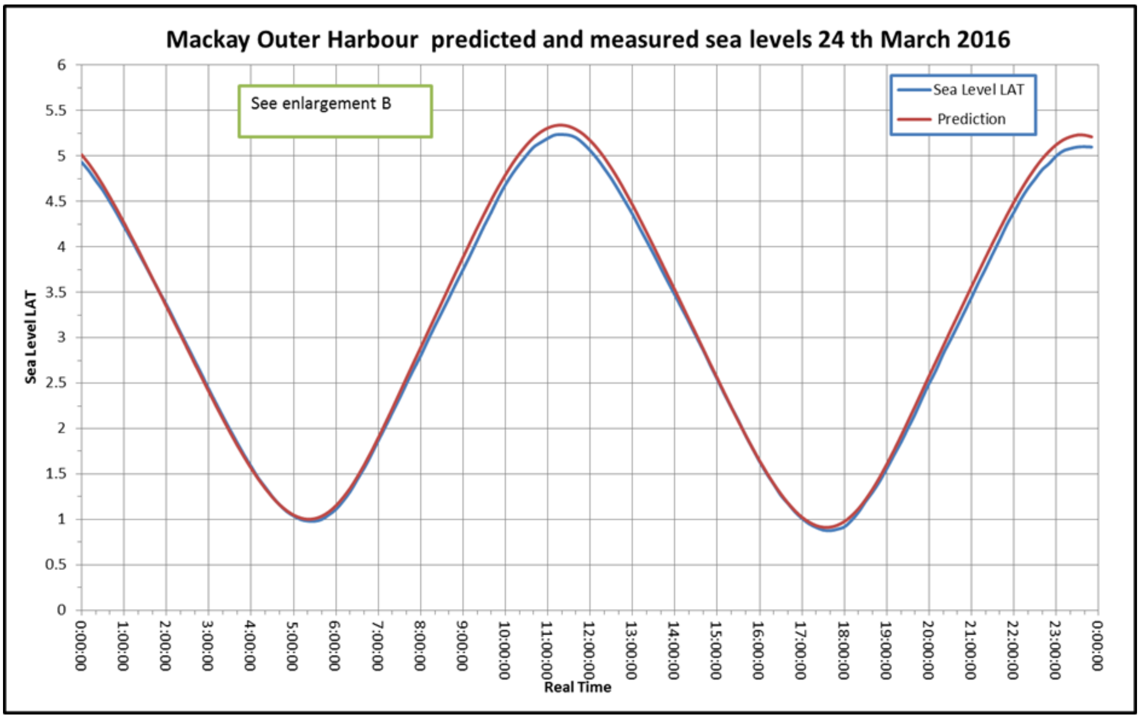


Figure 4-15 MoH sea levels 24th March

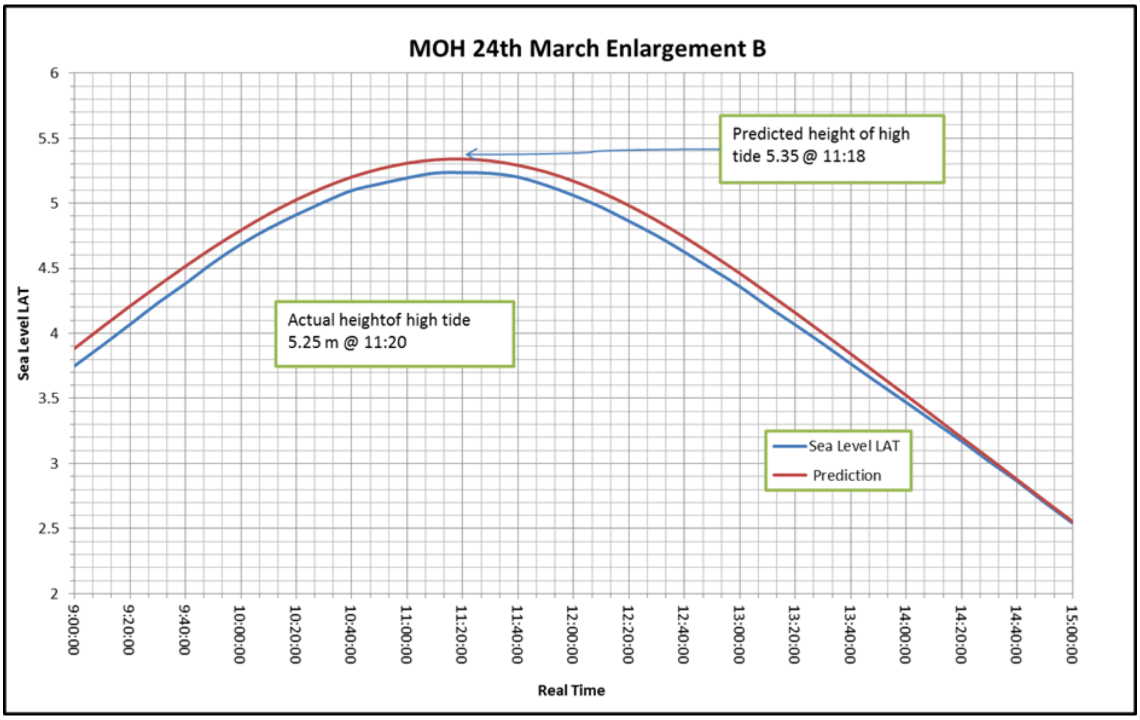


Figure 4-16 Enlargement B

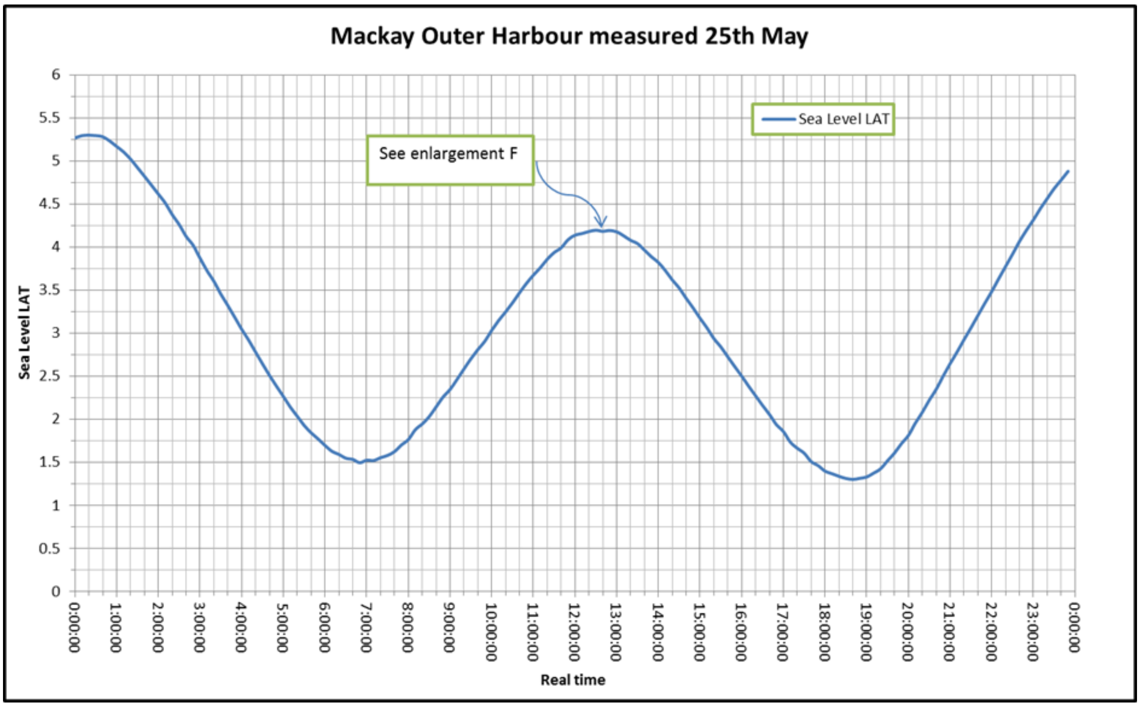


Figure 4-17 MoH sea level 25th May

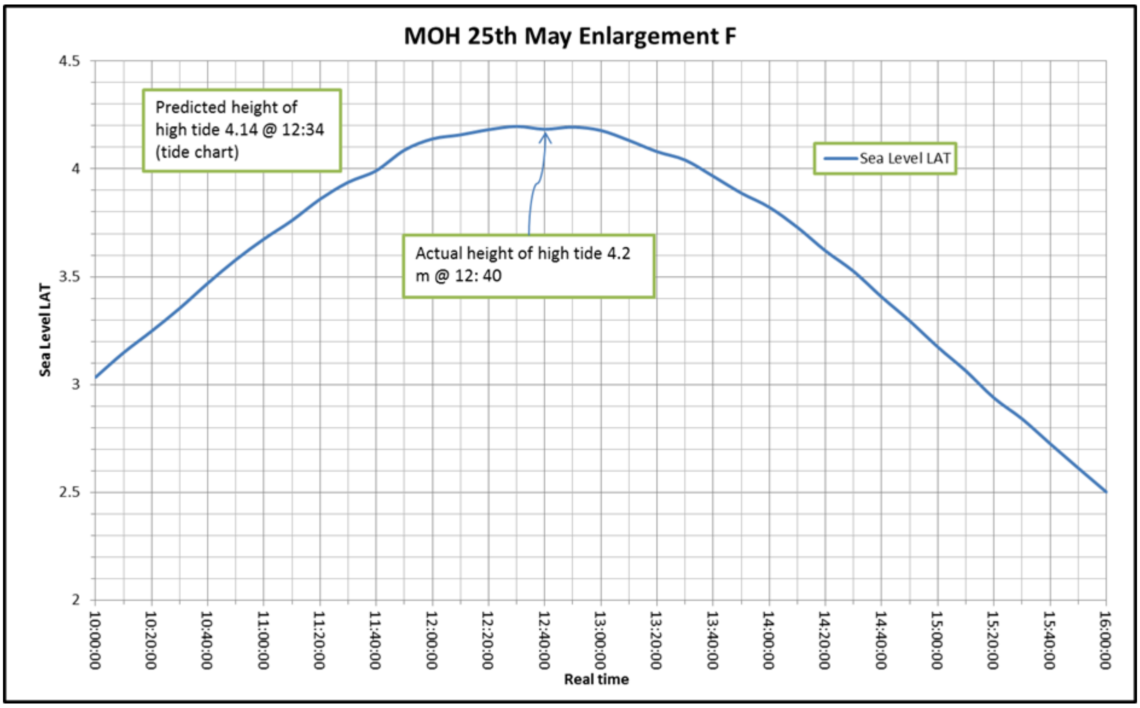


Figure 4-18 Enlargement F

4.3.4. Murray Creek summary of variables

Table 4-V Summary of Murray Creek measurements

	Measured variables					Predicted variables	
Date	ELT	Ht	LRT	Mt	Ma (LAT)	M't	M'a (LAT)
S1 25/03/2016	8:43	12:00	16:25	11:20	5.25	11:18	5.35
S2 23/05/2016	10:04	13:03	17:04	12:40	4.2	12:34	4.14

And using

Window before high tide	Wb = Ht - ELT
Window after high tide	Wa = LRT - Ht
Time difference between site and MoH actual	Lag (actuals) = Ht - Mt
Time difference between site and MoH predicted	Lag’ (predicted) = Ht - M’t

Table 4-VI Murray Creek session 1 and 2

	Session 1	Session 2
Total window	7:42	7:00
Wb	3:17	2:59
Wa	4:25	4:01
Lag (actuals)	0:40	0:23
Lag’ (predicted)	0:42	0:29

4.4. Predicted launch time (PLT) and predicted retrieval time (PRT)

4.4.1. Using Model 1

Model 1 uses the predicted amplitudes of MoH for sessions 1 and 2 to calculate the ratio. On the test day the amplitude at MoH will always be the predicted as the actual would not be available.

So Ratio $R = (M'a_3 - M'a_2)/(M'a_1 - M'a_2)$

	$PLT = M't_3 + Lag - W'b$
And	$PRT = M't_3 + Lag - W'a$
Where:	$W'b = (Ht_1 - ELT_1) - (Ht_2 - ELT_2) * R + (Ht_2 - ELT_2)$
	$W'a = (Ht_1 - LRT_1) - (Ht_2 - LRT_2) * R + (Ht_2 - LRT_2)$
With	$Lag = ((Ht_1 - M't_1) - (Ht_2 - M't_2)) * R + (Ht_2 - M't_2)$
and	Ratio $R = (M'a_3 - M'a_2)/(M'a_1 - M'a_2)$

From the tide charts for Mackay Outer Harbour

Table 4-VII MoH tide times and heights

	$M't_3$	$M'a_3$
Murray Creek 23rd July	13:04	4.60
Camila 24th July	13:53	4.53
Bucasia 25th July	14:52	4.48

Table 4-VIII Camila model 1 predictions

Using model 1 predicted MOH amplitudes			
	Site 1 Camila	**Site 2 Bucasia**	**Site 3 Murray Creek**
Ration R	0.196721	0.057971	0.380165
Wb'$_3$	2:21:21	1:34:30	3:05:51
Wa'$_3$	2:43:03	1:33:27	4:10:07
Lag'$_3$	0:17:21	0:02:57	0:34:17
PLT	**11:49**	**13:20**	**10:32**
PRT	**16:53**	**16:28**	**17:48**

4.4.2. Using Model 2

Model 2 tries to reduce meteorological influences on the calculation of the ratio by using the actual measured amplitudes at MoH instead of the predicted.

So Ratio R = $(M'a_3 - Ma_2) / (Ma_1 - Ma_2)$

And from the tide charts

Table 4-IX MoH tide times and heights

	$M't_3$	$M'a_3$
Murray Creek 23rd July	13:04	4.6
Camila 24th July	13:53	4.53
Bucasia 25th July	14:52	4.48

Table 4-X Camila model 2 predictions

Using model 2 the actual MOH amplitudes			
	Site 1 Camila	**Site 2 Bucasia**	**Site 3 Murray Creek**
Ration R	0.157407	-0.24444	0.380952
Wb'$_3$	2:20:41	1:26:39	3:05:51
Wa'$_3$	2:41:14	1:25:53	4:10:09
Lag'$_3$	0:14:27	0:07:08	0:29:49
PLT	**11:47**	**13:32**	**10:28**
PRT	**16:49**	**16:25**	**17:44**

4.5. Testing the prediction

4.5.1. Camila

The test for Camila was the 24th July. The predicted amplitude and height of the Mackay tide was input into both model 1 and model 2 and a predicted launch and retrieval time calculated. At site, two datum pins were placed at the navigable datum level 0.3 m AHD. The tide was observed and the time the actual water enveloped the pins recorded and photographed. This was repeated when the water retreated some hours later.

Model 1 results

Table 4-XI Camila model 1 result

Using model 1 predicted MOH amplitudes		
	Site 1 Camila	
Ration R	0.196721	Test 24th July measured
Wb'₃	2:21:21	
Wa'₃	2:43:03	
Lag'₃	0:17:21	
PLT	**11:49**	11:49
PRT	**16:53**	16:50

Model 2 results

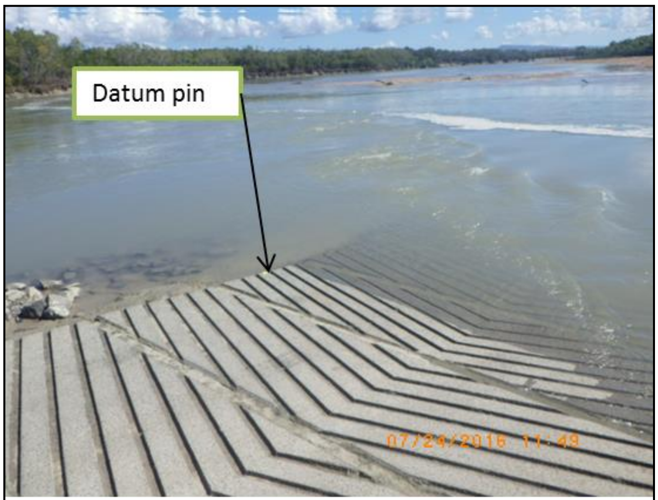
Table 4-XII Camila model 2 results

Using model 2 the actual MOH amplitudes		
	Site 1 Camila	
Ration R	0.157407	Test 24th July measured
Wb'₃	2:20:41	
Wa'₃	2:41:14	
Lag'₃	0:14:27	
PLT	**11:47**	11:49
PRT	**16:49**	16:50

On the test day, 24th July, using model 1 the earliest launch time was predicted to be at 11:49 am and was recorded at 11:49 and the latest retrieval time was predicted at 4:53 pm and recorded at 4:50 pm.

Model 2, using the actual measured amplitudes instead of the predicted for MoH showed a similar result with a predicted launch time of 11:47 am and a retrieval time of 4:49 pm, being 2 minutes early and 1 mins early respectfully. In this case the difference between the two models was insignificant. Both model predicted the ELT and LRT to within a few minutes.

The times recorded for ELT and LRT on the test day varied from one side of the ramp to the other due to different water levels on either side of the ramp.



Camila earliest launch time
left side of ramp

Photo 4-A Camila datum pin

Camila earliest launch time
right side of ramp

Photo 4-B Camila datum pin

Camila latest retrieval time

4.5.2. Bucasia

The test day was 25th July. The same method as Camila was used.

Table 4-XIII Bucasia model 1 results

Using model 1 predicted MOH amplitudes		
Site 2 Bucasia		
Ration R	0.057971	Test 25th July measured
Wb'$_3$	1:34:30	
Wa'$_3$	1:33:27	
Lag'$_3$	0:02:57	
PLT	**13:20**	13:32
PRT	**16:28**	16:29

Table 4-XIV Bucasia model 2 results

	Using model 2 the actual MOH amplitudes	
	Site 2 Bucasia	
Ration R	-0.24444	Test 25th July measured
Wb'$_3$	1:26:39	
Wa'$_3$	1:25:53	
Lag'$_3$	0:07:08	
PLT	**13:32**	13:32
PRT	**16:25**	16:29

Model 1 ELT prediction was 12 minutes early but the LRT was within a minute of the actual time. Interestingly when model 2 was used the result improved, with the ELT being spot on and the LRT being 4 minutes later than expected.

The differences between the two models was because session 1 Mackay data was lower than predicted but the session 2 data (one month later) was the opposite, with sea levels at Mackay significantly higher than predicted. This altered the ratio factor and hence the predicted window.

Bucasia earliest launch time

Photo 4-C Bucasia datum pin

Bucasia latest retrieval time

Photo 4-D Bucasia datum pin

4.5.3. Murray Creek

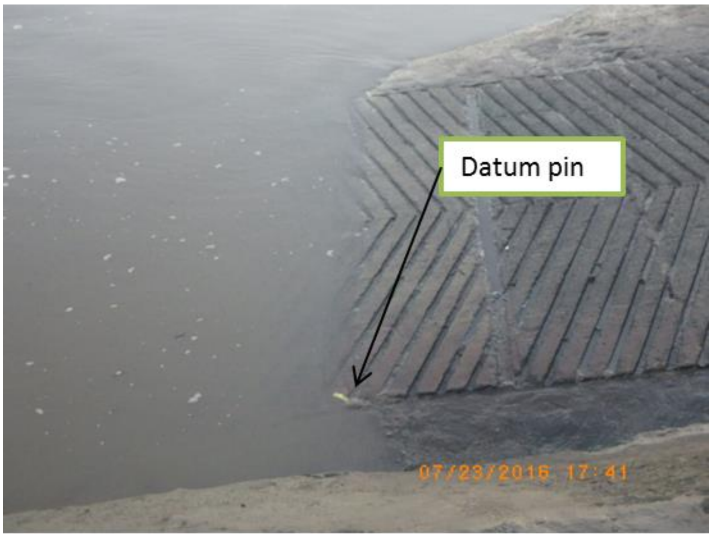
This site was tested on 23rd July.

Table 4-XV Murray Creek model 1 results

Using model 1 predicted MOH amplitudes		
	Site 3 Murray Creek	
Ration R	0.380165	Test 23rd July
Wb'_3	3:05:51	
Wa'_3	4:10:07	
Lag'_3	0:34:17	
PLT	**10:32**	10:58
PRT	**17:48**	17:42

Table 4-XVI Murray Creek model 2 results

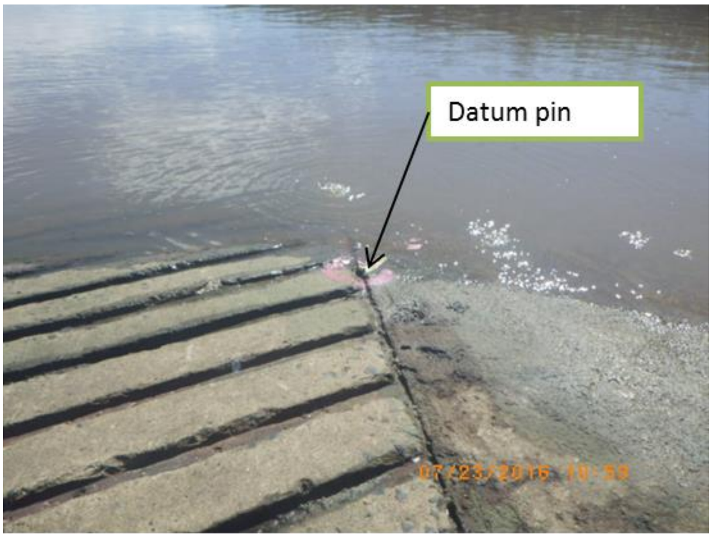
Using model 2 the actual MOH amplitudes		
Site 3 Murray Creek		
Ration R	0.380952	Test 23rd July
Wb'$_3$	3:05:51	
Wa'$_3$	4:10:09	
Lag'$_3$	0:29:49	
PLT	**10:28**	10:58
PRT	**17:44**	17:42



Murray Creek latest retrieval time

Photo 4-E Murray Creek datum pin

Murray Creek after heavy
rain on test day.



Murray Creek earliest launch
time

Murray Creek was the most complex of all three sites. This was reflected in the results.

In model 1 the tide was 28 minutes late arriving and then left 4 minutes early. This pattern was repeated with model 2, with the tide 33 minutes late and spot on for retrieval time. Of particular note here was the evidence of recent heavy rain in the constant creek catchment in the week leading up to the test day. This flood flow was evident by the colour of the water, normally during the smaller tides of the month the water would be a green colour, but can be seen to be quiet discoloured. Logs and other debris was scene floating with the tide. Model 2 used the assumption that the meteorological impacts would impact equally at MoH and each site for any given day. This did not occur here as the floods don't impact on the open ocean levels.

The increase in downstream flows may have the effect of delaying the in-coming tide, and therefore reducing the access window at that site.

4.6. Summary

At Camila model 1 predicted the launch time exactly, and was 3 minutes late of its retrieval time prediction. Model 2 only made a slight improvement, with the launch time being 2 minutes early and the retrieval time within a minute.

At Bucasia model 1 launch time prediction was 12 minutes early, but the retrieval time was within a minute. Model 2 showed some improvement with launch time spot on and the retrieval time 4 minutes early.

Murray Creek was not as clear cut with a delay of 26 minutes or so for the launch time and interestingly, the retrieval time only early by 6 minutes. Model 2 did not improve things, but made the launch time blow out to 30 minutes and the retrieval time 2 minutes late. Possible reasons will be discussed in the next chapter.

Summary of measured variables

Table 4-XVII Summary of variables - all sites

		SESSION 1											
	MOH				**Site 1 Camila**			**Site 2 Bucasia**			**Site 3 Murrys**		
	Predicted		Actual		measured variables			measured variables			measured variables		
Date	M't	M'a	Mt	Ma	ELT	Ht	LRT	ELT	Ht	LRT	ELT	Ht	LRT
23/03/2016	10:51:00	5.51	*11:00*	*5.44*	8:29:14	11:04:14	14:24:14						
24/03/2016	11:18:00	5.35	*11:20*	*5.25*							8:43:00	12:00:00	16:25:00
25/03/2016	11:43:00	5.13	*11:45*	*5.04*				9:50:54	11:49:54	13:46:54			
			Total Window		5:55:00			3:56:00			7:42:00		
			Wb_1		2:35:00			1:59:00			3:17:00		
			Wa_1		3:20:00			1:57:00			4:25:00		
			Lag'_1		0:13:14			0:06:54			0:42:00		
	using MoH actuals		Lag_1		0:04:14			0:04:54			0:40:00		
		SESSION 2											
	MOH				**Site 1 Camila**			**Site 2 Bucasia**			**Site 3 Murrys**		
	Predicted		Actual		measured variables			measured variables			measured variables		
Date	M't	M'a	Mt	Ma	ELT	Ht	LRT	ELT	Ht	LRT	ELT	Ht	LRT
23/05/2016	11:25:00	4.44	*11:21*	*4.59*				9:54:42	11:27:42	12:59:42			
24/05/2016	11:58:00	4.29	*12:00*	*4.36*	9:58:21	12:16:21	14:50:21						
25/05/2016	12:34:00	4.14	*12:40*	*4.2*							10:04:33	13:03:33	17:04:33
			Total Window		4:52:00			3:05:00			7:00:00		
			Wb_2		2:18:00			1:33:00			2:59:00		
			Wa_2		2:34:00			1:32:00			4:01:00		
			Lag'_2		0:18:21			0:02:42			0:29:33		
	using MoH actuals		Lag_2		0:16:21			0:06:42			0:23:33		

Table 4-XVIII Summary model 1 results

Using model 1 predicted MOH amplitudes						
	Site 1 Camila		**Site 2 Bucasia**		**Site 3 Murray Creek**	
Ration R	0.196721	Test 24th July	0.057971	measured	0.380165	measured
Wb'$_3$	2:21:21	measured	1:34:30	measured	3:05:51	measured
Wa'$_3$	2:43:03		1:33:27		4:10:07	
Lag'$_3$	0:17:21		0:02:57		0:34:17	
PLT	**11:49**	11:49	**13:20**	13:32	**10:32**	10:58
PRT	**16:53**	16:50	**16:28**	16:29	**17:48**	17:42

Table 4-XIX Summary model 2 results

Using model 2 the actual MOH amplitudes						
	Site 1 Camila		**Site 2 Bucasia**		**Site 3 Murray Creek**	
Ration R	0.157407	Test 24th July	-0.24444	measured	0.380952	measured
Wb'$_3$	2:20:41		1:26:39		3:05:51	
Wa'$_3$	2:41:14		1:25:53		4:10:09	
Lag'$_3$	0:14:27		0:07:08		0:29:49	
PLT	**11:47**	11:49	**13:32**	13:32	**10:28**	10:58
PRT	**16:49**	16:50	**16:25**	16:29	**17:44**	17:42

Chapter 5: Discussion

5.1. Model 1

This model used the relationship between each sites two observed access windows and the predicted times and amplitudes of the same tides at Mackay. The basic assumption was that tides are the result of a combination of forces that result in a tidal envelope (National Ocean and Atmospheric Administration 2015b). This includes the gravitational, centrifugal forces and local bathymetric conditions. These forces, while ever changing, are repeatable. This means for each site with the local bathymetric conditions being constant, a tide should react the same way as any other tide under the same forces. This is referred to as the tidal envelope. Layered over this envelope are meteorological influences. It has been shown that prolonged wind, barometric pressure, salinity, flood waters can influence sea level (Bureau of Meteorology 2016).

Model 1 used the simple relationship that if for example a 5 metre high tide at Mackay resulted in an access time of 8 hours at a nearby site, then every other 5 metre tide will result in a similar window. It also used the idea that if another tide of 4 meter amplitude at Mackay resulted in a measured window of, say 7 hours, than a tide somewhere in-between would have a window in-between 7 and 8 hours. Model 1 used a linear relationship so that a 4.5 m tide would be half way between the two so have a window of 7.5 hours.

To predict the access times the lag (the time difference between the MoH tide and each site) has also to be predicted. Model 1 used the same linear proportion used above to interpolate the lag for a predicted tide. So if the 5 metre tide arrived 20 minutes late, and the 4 metre tide was only 10 minutes late, than a 4.5 metre tide would be 15 minutes late.

As tides move into shallow water the tidal form can be distorted (Blanton et al. 2002). The means the shape of the tide is no longer symmetrical, like it would be in the open ocean. The level of the distortion or asymmetry depends on the local bathymetry and the amplitude of the tide. For this reason the access window has been divided into two parts, the access time from earliest launch time (ELT) to the high tide (Ht) and from Ht through to the latest retrieval time (LRT). These are Wb and Wa respectfully.

Formulae for predicted launch time (PLT) and predicted retrieval times (PRT)

Table 5-I Model 1

Model 1	PLT = M'_{t3}+Lag-W´b
And	PRT = M'_{t3}+Lag-W´a
Where:	W´b = (Ht_1-ELT_1)-(Ht_2-ELT_2)*R+(Ht_2-ELT_2)
	W´a = (Ht_1-LRT_1)-(Ht_2-LRT_2)*R+(Ht_2-LRT_2)
With	Lag = ((Ht_1-M'_{t1})-(Ht_2-M'_{t2}))*R+(Ht_2-M'_{t2})
	Ratio R = (M'_{a3}-M'_{a2})/(M'_{a1}-M'_{a2})

5.2. Model 2

As mentioned in the section above, meteorological influence impact of sea level. Model 2 attempted to negate some of these influence in the two data sets from each site. Model 1 used a relationship between the windows at each site and the predicted amplitudes at Mackay for the same tide. Those predicted amplitudes were surmised to be the underlying force behind the resultant window at each site. From the MoH data set, the actual and predicted levels area available. The difference is called the residual. These residuals are regularly up to 100 mm during normal weather conditions.

Example of data from MoH automatic tide measuring device

Table 5-II Example MoH actual sea level data

Date / Time	Actual	Predicted	Residual
2016-03-24T10:40	5.098	5.202	-0.104
2016-03-24T10:50	5.149	5.264	-0.115
2016-03-24T11:00	5.195	5.308	-0.113
2016-03-24T11:10	5.232	5.334	-0.102
2016-03-24T11:20	5.236	5.34	-0.104
2016-03-24T11:30	5.23	5.326	-0.096
2016-03-24T11:40	5.201	5.292	-0.091

The example above recorded at 11:00 on the 24th March, 2016 and shows the sea level around 100 mm lower than predicted.

The forces that cause this residual are more regional than local. This means the wind conditions will be similar at MoH and each site on any given day. It would be reasonable to assume that if the tide was 100 mm lower than predicted, than the window at a nearby site would be affected.

Model 2 uses the actual recorded amplitudes in the calculation of the ration R instead of the predicted MoH amplitudes as in Model 1.

Table 5-III Model 2

Model 2	**PLT = M'_{t3}+Lag-W′b**
And	PRT = M'_{t3}+Lag-W′a
Where:	W′b = $(Ht_1-ELT_1)-(Ht_2-ELT_2)*R+(Ht_2-ELT_2)$
	W′a = $(Ht_1-LRT_1)-(Ht_2-LRT_2)*R+(Ht_2-LRT_2)$
With	Lag = $((Ht_1-M't_1)-(Ht_2-M't_2))*R+(Ht_2-M't_2)$
	Ratio R = $(M'a_3-Ma_2)/(Ma_1-Ma_2)$

Both models do not use the actual measured amplitudes $M'a_3$ on the test day. Obviously the measured amplitudes are not available until after the test day, so they can’t be included in the prediction. Never the less, variation on the test day between the measured and predicted MoH amplitudes can have a significant influence on predicted launch and retrieval times. Particularly on retrieval times as 100 mm may mean time difference of 15 minutes. See section 5.7 below.

What the model 2 does not do is allow for localised meteorological factors. This includes locate runoff or flooding. It also does not allow for differences between the impacts of a phenomenon at MoH and at each site. While the wind may be the same at both locations, causing a 100 mm deflection at MoH, the result may not be the same at a particular site because of variations in geometry of the coastline, water depth and local bathymetry.

5.3. Results at Camila

The models 1 and 2 were tested on 24th July 2016. Both models very similar and the Predicted Launch time (PLT) and Predicted retrieval time (PRT) was within a few minutes of the actual measured time.

Model 1: PLT and measured time were the same. The tide was 3 minutes earlier than the PRT

Model 2: The tide was 2 minutes later the PLT, and 1 minute later than the PRT.

Both models did not change the prediction significantly.

5.4. Results at Bucasia

Model 1: the tide was 12 later than the PLT but the PRT was within 1 minute.

Model 2: Improved the result, with the PLT spot on and the PRT 4 minutes late.

5.5. Results at Murray Creek

Model 1: The tide was 26 minutes later than the PLT and 6 minutes earlier than the PRT.

Model 2: Did not really improve. The tide was 30 minutes later the PLT and 2 minutes early for the PRT.

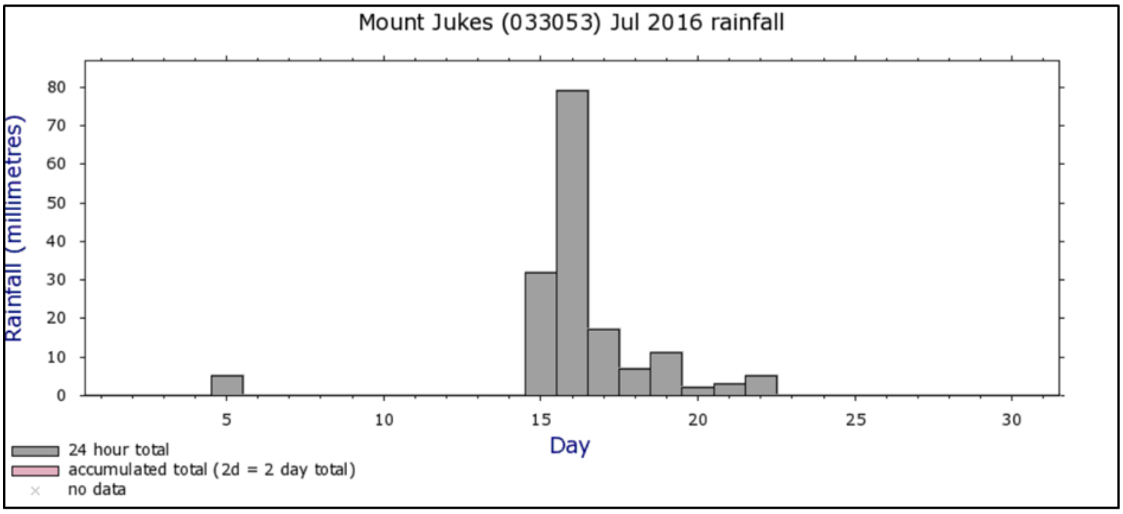
One of the reasons Murray Creek was chosen as a test site was its complexity. The ramp is further away from the coast than the other two test sites. This may be a contributing factor.

It was shown that localised meteorological factors can delay and reduce the amplitude of the tide (Dronkers 1975). The correction in model 2 can only work if the meteorological factors are general in nature. This means that the wind speed and direction needs to be about equal at both sites. Also the impact of those prolonged winds may change amplitude differently due to changes in the depth of water and the shape of the land (Bureau of Meteorology 2016). The correlation between the heights of the tide at Mackay, being say 100 mm higher than predicted, may not mean that the same 100 mm change will be applied at 50 km up the coast.

The impact of the local bathymetry on the estuary can also impact on the result at Murray creek. The boat-ramp was located much further upstream than the other two sites. Several shallow rock bars are located downstream of the ramp that act as barriers. A small change in sedimentation levels or tide amplitudes may attenuate as the tide moves up the estuary.

Model 2 also does not allow for localised meteorological influences, like freshwater runoff.

In the week leading up to the test day, heavy unseasonal rain fell in the catchment of the Constant creek. Mt Charlton to the north of Murray Creek received 102 mm 16th July. On the test day 23rd July, the river appeared to in ‘flood’ with lots of debris and colour observed in the river. The increase in downstream flows has been shown to distort the timing and height of a tide



Rainfall data at Mt Jukes, near the headwaters of Constant creek.

Climate Data Online, Bureau of Meteorology
Copyright Commonwealth of Australia, 2016

Figure 5-1 Rainfall near Murray Creek

However the magnitude of the differences in this case doesn’t support the flooding as a sole reason for this discrepancy. 30 minutes on an incoming tide at Murray Creek equates to about 500 mm in height change. If the river was significantly in flood, the water level would have been elevated not reduced.

Even with these factors the result is not conclusive. The data sets for the model 1 and 2 for all sites have not been validated. This means an error in the data sets, while every effort was made to limit these, cannot be totally dismissed. The fact that the total window on the test day was 6 hours 44 minutes, less than session 2 window on 7 hours even though the MoH amplitude being greater during the test day. In the authors opinion the data set for session 2 needs to be revisited.

To make any strong statement about the results for Murray Creek would be unjustified and more work is required at that site.

5.6. Adequate prediction times

The aim of this paper is to adequately predict launching and retrieval times at three case study locations in Central Queensland. To adequately predict depends on the consequence for an over ambitious prediction. If the prediction for launching a vessel is 10 minutes early, there is no real consequence. The operator would simple have to wait for the incoming tide for a few (10) minutes. If the same prediction was late, the vessel could be launched straight away, since the water level would have already risen above the ramp navigable level.

If the predicted retrieval time (PRT) was late the water level still maintains access. If on the other hand the PRT occurred earlier than stated, the boat may be stranded. This may mean a long wait until the tide returns. A prudent seaman would not cut critical retrieval to the last minute, unless the fishing was red hot.

5.7. Time vs height

Variations in predicted amplitudes mean variation in time. This depends on the rate of change of the tide. I will call this the vertical speed. This vertical speed varies depending on location, the shape of tidal curve and the overall amplitude of the tide. Each site in the study has different navigable elevation on the boat-ramp and hence the vertical speed of the tide varies. In the open ocean, the vertical speed is normally at its maximum at the mid-point of the high and low tides. During the ebb (change in tide), the tide slows down, stops than speeds back up. The size of the tide also impacts on the vertical speed. Obviously a larger tide has to move further in the same period as a smaller tide, so the rate of change is greater. Lastly the individual site characteristics cause larger or smaller tides than at other locations. Areas to the south of Mackay, like Camila, have larger overall amplitudes than MoH.

Rate of change for each site at the navigable level (NL)

Table 5-IV Rate of change of sea level

	Rate of change mm / 10 minutes					
	Bucasia NL 1.00		Camila NL 0.3		Murray Creek NL -0.4	
	ELT	LRT	ELT	LRT	ELT	LRT
Session 1	150	120	270	150	260	60
Session 2	90	90	200	130	140	60
Session 3*	102	96	204	130	185	60

*Session 3 values have been interpolated from the ratio R obtained in chapter 4.

The rate of changes values vary with location, amplitude, elevation of the measuring point, and for incoming and outgoing tides (ELT, LRT).

5.8. Vertical resolution of site data

The method used to gather the session 1 and 2 tide data has some inherent errors. The innovative method used standard surveying equipment to obtain heights and times of sea level. A bench mark was established at close proximity to each site. Since all measurements at each site a relative to that bench mark the absolute elevation does not impact on the results. Also the length of each measurement was relatively short, normally less than 20m. The system use automatic target locking and from the author's personal experience the errors in each measurement from the bench mark to the prism would be less than 5 mm.

The locations were all in protected waters, with no ocean waves, but localised wave action caused by wind and some boat activity was considered as the most significant of vertical random errors. This ripple error was between 15 to 25 mm.

Using the rate of change table above, 20 mm equates to about 1 m for incoming tide and 2 m for dropping tide.

The time was recorded on a TSC 3 data recorder, the time stamp was checked and reset manually from a smart phone time clock. The time was recorded and downloaded digitally so the total resolution for the time stamp was 1 minute. The combination of the two means about 2 minute's resolution in the model predictions.

5.9. Vertical resolution of MoH data

In this study we also used the automatic tidal data from Mackay outer Harbour. It was shown that the actual height and high water (HW) regularly deviated by 100 mm both above and below predicted HW. This residual is the result of meteorological impacts, like prolonged wind and barometric pressure. The weather conditions during the project could be considered normal, with no extreme events. This means that during normal weather difference of 100 mm are likely. 100 mm equates to about 4 minutes at Camila on an incoming tide or about 6 minutes at Bucasia and more than 15 minutes during the outgoing tide at Murray Creek. Of course during more extreme weather this could be much larger.

The total predicted resolution combining the model resolution and the meteorological influence would be say 7 minutes for incoming tide and 15 minutes for the outgoing tide. It would be prudent to allow a safety margin of 7 minutes on incoming tide and 15 minutes on outgoing tide.

It is worth noting to stakeholders that the precision of predictions need to be fit for the purpose. If for example the tide is 10 minutes later than expected when you are launching a boat, it just means waiting 10 minutes or so. On the other hand, if the tide leaves 10 minutes earlier than predicted, you could be left stranded and wait until the next incoming tide some hours away.

5.10. Data acquisition

The methods used to obtain the data for this paper were constrained by what was available. Improvement in efficiency and techniques are required if this is to be rolled out over a larger number of sites. The author invested a considerable amount of field time in gathering the data for this paper. With 3 days on control site establishment, 6 days on session 1 and 2 data gathering, and 3 days on testing predictions. Travel time was also significant with Camila being 1:45 hours one way, and Murray’s creek 1 hour one way.

The role of government agencies like Maritime Safety Queensland (MSQ) could be included as a partner in future expansion. One of MSQ roles is hydrographical mapping, and part of that is the determination of a local datum (LAT) or port datum. To do this measurements are made using a portable tide logging device that is suspended on the sea floor. This equipment is expensive and was not available for this research. Some unsuccessful inquiries were made to a colleague at MSQ for a loan of this equipment. Access to an archived data base with time stamped tide levels at different locations may be able to be used in further work. If for example, the tide was observed during a larger tide (normal practice for local LAT determination I have been told) then it would only need the smaller tide observation to complete the data for the access predictor.

Other ways to obtain the data may include Satellite imagery. Boat-ramp images at regular intervals over a period of time could give sea level estimations. If the grade of the ramp is known, then the distance from the top of the ramp to the water level would give a height of sea level relative to the top of the ramp. If the resolution of imagines is 250 mm they height resolution would 30 mm on a grade of 1 in 8.

5.11. Justification

Many reasons exist for tidal research. The precise knowledge of tidal movements is critical for coastal navigation, operation of ports, marine boundaries and creation of charts. The determination of a Lowest Astronomic Tide (LAT) is used on hydrological charts.

Determination of the highest astronomical tide (HAT) is needed for engineering works associated with the coastal zone, like construction of bridges, wharfs, walk-ways and boat-ramps all require tidal knowledge. The HAT is also critical in determining some legal boundaries including international economic zones.

Professional fishermen rely on knowledge of tides for improving their catch. Even recreational users, surfers, fishers and beach walkers all need information about tides. Scientists are also concerned with tides, sea level changes, currents and a mirage of other related phenomenon. The Mean Sea level (MSL) is used in geodesy and datum establishment.

Real time sea level measurements are used in many major ports to provide safety and efficiency (National Ocean and Atmospheric Administration 2015b). With shipping and international trade placing increasing pressure on infrastructure, under keel clearance and access times are being used to increase port efficiency. The Dynamic UKC system (DUKC) uses real-time tide data to calculate safe drafts and maximise access times.

Many of these stakeholders need absolute values, like the highest tide value or the lower tide value or time of high tide. This paper looked at access times at a particular elevation at a specific location.

5.12. Future work

With the increase in recreational boating in Queensland the demand for marginal ramps has increased (Boon et al. 2011). This paper has attempted to develop a cheap and efficient method to provide reliable and adequate predictions for access times at tide dependant boat-ramps. This method, with a two data gathering sessions at each site, and corresponding simultaneous standard port observations may provide a database of access time predictions.

An online or phone application could be developed with corresponding weather and Moon information to be a one stop shop for the small boat operator. With a data base of all tide dependant ramps in the region, the users would select the date and location of planned excursions and the access times output in a simple graphical format.

Chapter 6: Conclusion

Since time began humans have had a fascination with understanding and predicting natural phenomenon. Tides are no exception. The aim of this research was to adequately predict access times at several test sites in central Queensland.

In chapter 2, a review of the literature defined tides, and what forces influence them and how they are measured and predicted. Even with this depth of knowledge a gap was identified for a simple, fit for purpose, method for predicting access times at specific locations.

In chapter 3, a concept was developed for an innovative method to obtain tide data from just two observed cycles of the tide. This was relating to a nearby standard port data, and access windows predicted using the standard port's predictions. This is a method that fits the requirements of the solution. This method does not try to derive all the components of a tide, just the time element as the water passes over a specific elevation at a specific location.

In chapter 4 results show that model 2 predicted access times at both Camila and Bucasia to within a few minutes. The results at the third site, Murrays Creek was not as conclusive. This was discussed in Chapter 5.

The hypothesis that

- *That different tidal amplitudes impact on access time duration (windows).*

Has been shown to be true for my test locations, with the access windows variations measured during different amplitude tides.

- *Adequate access time predictions at specific locations can be made using the relationship between the simultaneous measured amplitudes at a nearby standard port and the sites corresponding access times.*

Using Model 2 the access times were predicted at two of the three sites.

There are 137 tide dependant boat-ramps just in Queensland (Maritime Safety Queensland 2015b). A reliable access window predictor at these sites could open up a valuable resource. A phone application that includes an access predictor for Queensland boat-ramps would be popular among recreational boat uses, especially travelling tourists without the local knowledge. Tourism is an increasing trend in reginal economies (Planning Information and Forecasting Unit 2006). Net free areas recently introduced into Queensland reflects the Government intent in relation to recreational fishing.

Future work could involve other methods of quickly and efficiently obtaining the two observed cycles per site needed for the prediction. A review of information held by government agencies may be a shortcut for some of these locations. Government agencies like Maritime Safety

Queensland already obtain data at many of these sites for boating and navigation purposes. Access to and adapting this data may be an option.

Finally other remote methods of obtaining the data though new satellite imagery could also be investigated.

LIST OF REFERENCES

Blanton, JO, Lin, G & Elston, SA 2002, 'Tidal current asymmetry in shallow estuaries and tidal creeks', *Continental Shelf Research*, vol. 22, no. 11–13, pp. 1731-43.

Boon, C, Dwyer, E, Hooper, T & Williams, M 2011, *Recreational Boating Facilities Demand Forecasting Study*, Queensland Government, Brisbane, QLD. viewed 20th May,2016, <http://www.gladstone.qld.gov.au/documents/1570002/9662715/G_5.2.02_Attachment_A_-_Recreational_Boati.pdf>.

Bureau of Meteorology 2016, *About Tide Predictions*, Australian Governent, viewed 31st July, <http://www.bom.gov.au/australia/tides/about/index.shtml>.

Doodson, AT 1921, 'The harmonic development of the tide generating potential', *Royal Society Of London*, vol. 100, no. 704, pp. 305-29.

Dronkers, JJ 1975, 'Tidal theory and computations', in VT Chow (ed.), *Advances in Hydroscience*, Elsevier, Hydraulic Department of Deltaworks, The Hague, The Netherlands, vol. Volume 10, pp. 145-230.

Foreman, MGG 1977, *Manual for Tidal Heights Analysis and Prediction*, Canada Institute of Ocean Sciences, Patricia Bay,Canada. viewed 26th October, <https://books.google.com.au/books?id=3qPNGwAACAAJ>.

Friedrichs, CT & Aubrey, DG 1988, 'Non-linear tidal distortion in shallow well-mixed estuaries: a synthesis', *Estuarine, Coastal and Shelf Science*, vol. 27, no. 5, pp. 521-45.

Hibbert, A, Royston, SJ, Horsburgh, KJ, Leach, H & Hisscott, A 2015, 'An empirical approach to improving tidal predictions using recent real-time tide gauge data', *Journal of Operational Oceanography*, vol. 8, no. 1, pp. 40-51.

Hicks, SD 2006, *Understanding tides*, manuscript, guide for professionals to understand tides., Center for Operational Oceanographic Products and Services, 1305 East-West Hwy Silver Spring, MD 20910, December 2006, <.

Karimi, S, Kisi, O, Shiri, J & Makarynskyy, O 2013, 'Neuro-fuzzy and neural network techniques for forecasting sea level in Darwin Harbor, Australia', *Computers & Geosciences*, vol. 52, pp. 50-9.

Lee, TL & Jeng, DS 2002, 'Application of artificial neural networks in tide-forecasting', *Ocean Engineering*, vol. 29, no. 9, pp. 1003-22.

MacMahan, J, van de Kreeke, J, Reniers, A, Elgar, S, Raubenheimer, B, Thornton, E, Weltmer, M, Rynne, P & Brown, J 2014, 'Fortnightly tides and subtidal motions in a choked inlet', *Estuarine, Coastal and Shelf Science*, vol. 150, Part B, pp. 325-31.

Makarynskyy, O, Makarynska, D, Kuhn, M & Featherstone, WE 2004, 'Predicting sea level variations with artificial neural networks at Hillarys Boat Harbour, Western Australia', *Estuarine, Coastal and Shelf Science*, vol. 61, no. 2, pp. 351-60.

Maritime Safety Queensland 2012, *Notes and definitions*, Department of Transport and Main Roads, viewed 20th October, <http://www.msq.qld.gov.au/Tides/Notes-and-definitions.aspx>.

Maritime Safety Queensland 2014, *Tidal planes*, Department of Transport and Main Roads, viewed 4 th October, <http://www.msq.qld.gov.au/Tides/Tidal-planes.aspx>.

Maritime Safety Queensland 2015a, *Calculating secondary port tide times*, Department of Transport and Main Roads, viewed 10th October, <http://www.msq.qld.gov.au/Tides/Calculating-secondary-port-tide-times.aspx>.

Maritime Safety Queensland 2015b, *Tide book report*, Queensland governement, viewed 11 September, <.

Maritime Safety Queensland 2016a, *Calculating secondary port tide times*, Queensland Governemnt, viewed 15th March, <http://www.msq.qld.gov.au/Tides/Calculating-secondary-port-tide-times>.

Maritime Safety Queensland 2016b, *Tidal datum information*, Department of Transport and Main Roads, viewed 24th August, <http://www.msq.qld.gov.au/Tides/Tidal-datum-information>.

Matthäus, W 1972, 'On the history of tide gauges', *Proceedings of the Royal Society of Edinburgh, Section B.Biology*, vol. 73, pp. 26-34.

McCully, JG 2006, *Beyond the Moon : A Conversational, Common Sense Guide to Understanding the Tides*, WSPC, Singapore, SG.

Meena, BL & Agrawal, JD 2015, 'Tidal level forecasting using ann', *Procedia Engineering*, vol. 116, pp. 607-14.

National Ocean and Atmospheric Administration 2015a, *Tides and Currents Harmonic analysis*, Center for Operational Oceanographic Products and Services, viewed 20th October, <http://tidesandcurrents.noaa.gov/harmonic.html>.

National Ocean and Atmospheric Administration 2015b, *Tides and water levels*, U.S department of commerce, viewed 5 th October, <http://oceanservice.noaa.gov/education/kits/tides/>.

National Ocean and Atmospheric Administration (NOAA) 2013, *Our restless tides*, NOAA / National Ocean service, viewed 26th October, <http://www.co-ops.nos.noaa.gov/restles1.html>.

Ocean motion and surface currents 2015, *Types of tides*, Nasa, viewed 5 th October, <http://oceanmotion.org/html/background/tides-types.htm>.

Permanent committee on tides and mean sea level (PCTMSL), *Australian tides manual,* 2014, Intergovernmental Committee on Surveying and Mapping (ICSM), Commonwealth of Australia, Australia, <http://www.icsm.gov.au/tides/SP9_Australian_Tides_Manual_V4.1.pdf>.

Planning Information and Forecasting Unit 2006, *The economic and social impacts of tourism in the Far North Queensland planning region*, Department of Infrastructure and Planning, viewed 9th August, <.

Quinn, N, Atkinson, PM & Wells, NC 2012, 'Modelling of tide and surge elevations in the Solent and surrounding waters: The importance of tide–surge interactions', *Estuarine, Coastal and Shelf Science*, vol. 112, pp. 162-72.

Tang, YM & Grimshaw, R 2003, 'The effect of barriers on the tidal range in estuaries', *Estuarine, Coastal and Shelf Science*, vol. 58, no. 1, pp. 57-66.

Zetler, BD & Cummings, RA 1967, 'A Harmonic Method for Predicting Shallow-Water Tides', *Journal of Marine Research U. S. A.*, vol. 25, no. 1, pp. 103-14.

Appendix A

ENG4111/4112 Research Project

Project Specification

For: Patrick McFadden

Title: Tidal predictions in ungauged estuaries for boat ramp access windows.

Major: Surveying

Supervisors: Zhanyu Zhang

Enrolment: ENG4111 – EXT S1, 2016

ENG4112 – EXT S2, 2016

Project Aim: To use a simplified method to predict access times of several tide dependant boat ramps in central Queensland.

Programme: Issue A. 16th March 2016

1. Research methods for tide predictions.
2. Design method for getting tidal data at each site.
3. Choose 3 locations that have limited access at low tide.
4. Collect data over on tide from low through to high and back to low.
5. Obtain simultaneous data of tide movement at Mackay outer harbour gauge.
6. Use a simplified method to predict the times of usable access at each ramp.
7. Visit each site again to test these predictions.
8. Evaluate the results and discuss reason why this method has worked or not worked

If time and resources permit:

9. Create an easy to use phone application that the user can input location of ramp and date of intended use – and output a nice graph showing clearly the times that the boat ramp is accessible.

Appendix B

Site session 1 and 2 raw data

Camila sea levels Session 1

date	True Time	Sea Level AHD	date	True Time	Sea Level AHD	date	True Time	Sea Level AHD
2016.0323	8:23:14	0.307	2016.0323	12:14:35	2.781	2016.0323	16:25:23	-0.138
2016.0323	8:28:15	0.436	2016.0323	12:19:37	2.707	2016.0323	16:30:25	-0.145
2016.0323	8:33:17	0.576	2016.0323	12:24:39	2.611	2016.0323	16:35:27	-0.154
2016.0323	8:38:18	0.708	2016.0323	12:29:04	2.530	2016.0323	16:40:28	-0.159
2016.0323	8:43:02	0.860	2016.0323	12:34:42	2.443	2016.0323	16:45:03	-0.169
2016.0323	8:48:22	0.999	2016.0323	12:39:44	2.332	2016.0323	16:50:32	-0.178
2016.0323	8:53:23	1.168	2016.0323	12:44:45	2.236	2016.0323	16:55:34	-0.184
2016.0323	8:58:26	1.349	2016.0323	12:49:47	2.149	2016.0323	17:00:35	-0.191
2016.0323	9:03:27	1.511	2016.0323	12:54:49	2.063	2016.0323	17:05:37	-0.196
2016.0323	9:08:29	1.664	2016.0323	12:59:51	1.968	2016.0323	17:10:39	-0.205
2016.0323	9:13:31	1.804	2016.0323	13:04:53	1.843	2016.0323	17:15:41	-0.209
2016.0323	9:18:33	1.925	2016.0323	13:09:55	1.748	2016.0323	17:20:43	-0.212
2016.0323	9:23:34	2.032	2016.0323	13:14:57	1.657	2016.0323	17:25:45	-0.221
2016.0323	9:28:36	2.147	2016.0323	13:19:59	1.564	2016.0323	17:30:47	-0.226
2016.0323	9:33:38	2.221	2016.0323	13:25:01	1.456	2016.0323	17:35:49	-0.230
2016.0323	9:38:04	2.344	2016.0323	13:30:03	1.358	2016.0323	17:40:51	-0.237
2016.0323	9:43:42	2.405	2016.0323	13:35:05	1.262	2016.0323	17:45:53	-0.240
2016.0323	9:48:43	2.531	2016.0323	13:40:06	1.159	2016.0323	17:50:55	-0.244
2016.0323	9:53:45	2.598	2016.0323	13:45:08	1.048	2016.0323	17:55:56	-0.248
2016.0323	9:58:47	2.683	2016.0323	13:50:01	0.960	2016.0323	18:00:58	-0.249
2016.0323	10:03:48	2.734	2016.0323	13:55:11	0.865			
2016.0323	10:08:05	2.789	2016.0323	14:00:13	0.770			
2016.0323	10:13:52	2.885	2016.0323	14:19:37	0.480			
2016.0323	10:18:54	2.964	2016.0323	14:24:39	0.467			
2016.0323	10:23:56	3.009	2016.0323	14:29:04	0.409			
2016.0323	10:28:58	3.068	2016.0323	14:34:42	0.359			
2016.0323	10:34:00	3.106	2016.0323	14:44:46	0.273			
2016.0323	10:39:02	3.149	2016.0323	14:49:48	0.240			
2016.0323	10:44:03	3.164	2016.0323	14:54:49	0.206			
2016.0323	10:49:05	3.204	2016.0323	14:59:51	0.172			
2016.0323	10:54:07	3.248	2016.0323	15:04:53	0.143			
2016.0323	10:59:09	3.267	2016.0323	15:09:55	0.117			
2016.0323	11:04:11	3.306	2016.0323	15:14:57	0.092			
2016.0323	11:09:12	3.276	2016.0323	15:19:59	0.071			
2016.0323	11:14:14	3.258	2016.0323	15:25:01	0.047			
2016.0323	11:19:16	3.289	2016.0323	15:30:03	0.029			
2016.0323	11:24:18	3.260	2016.0323	15:35:05	0.008			
2016.0323	11:29:02	3.276	2016.0323	15:40:07	-0.008			

2016.0323	11:34:21	3.214	2016.0323	15:45:09	-0.028			
2016.0323	11:39:23	3.202	2016.0323	15:50:01	-0.045			
2016.0323	11:44:25	3.171	2016.0323	15:55:12	-0.066			
2016.0323	11:49:27	3.100	2016.0323	16:00:14	-0.082			
2016.0323	11:54:29	3.051	2016.0323	16:05:16	-0.090			
2016.0323	11:59:03	2.985	2016.0323	16:10:18	-0.106			
2016.0323	12:04:32	2.923	2016.0323	16:15:02	-0.116			
2016.0323	12:09:34	2.838	2016.0323	16:20:21	-0.126			

Camila sea levels Session 2

date	**True Time**	**Sea Level AHD**						
2016.0524	8:10:21	-0.505	2016.0524	11:22:30	1.777	2016.0524	12:08:46	1.964
2016.0524	8:12:51	-0.506	2016.0524	11:23:31	1.785	2016.0524	12:09:47	1.968
2016.0524	8:15:22	-0.506	2016.0524	11:24:31	1.787	2016.0524	12:10:47	1.974
2016.0524	8:17:53	-0.507	2016.0524	11:25:31	1.788	2016.0524	12:11:47	1.976
2016.0524	8:21:35	-0.513	2016.0524	11:26:32	1.803	2016.0524	12:12:47	1.980
2016.0524	8:26:36	-0.514	2016.0524	11:27:32	1.811	2016.0524	12:13:48	1.984
2016.0524	8:31:37	-0.517	2016.0524	11:28:32	1.813	2016.0524	12:14:48	1.986
2016.0524	8:36:39	-0.520	2016.0524	11:29:33	1.823	2016.0524	12:15:48	1.987
2016.0524	8:41:41	-0.524	2016.0524	11:30:33	1.832	2016.0524	12:16:17	1.986
2016.0524	8:46:42	-0.527	2016.0524	11:31:33	1.842	2016.0524	12:21:18	1.992
2016.0524	8:51:44	-0.530	2016.0524	11:32:34	1.843	2016.0524	12:26:20	1.983
2016.0524	8:56:45	-0.532	2016.0524	11:33:34	1.855	2016.0524	12:31:21	1.951
2016.0524	9:01:47	-0.534	2016.0524	11:34:34	1.867	2016.0524	12:36:23	1.924
2016.0524	9:06:48	-0.516	2016.0524	11:35:35	1.875	2016.0524	12:41:24	1.883
2016.0524	9:11:50	-0.483	2016.0524	11:36:35	1.886	2016.0524	12:46:26	1.840
2016.0524	9:16:52	-0.454	2016.0524	11:37:35	1.895	2016.0524	12:51:28	1.827
2016.0524	9:21:53	-0.406	2016.0524	11:38:36	1.901	2016.0524	12:56:29	1.793
2016.0524	9:26:55	-0.337	2016.0524	11:39:36	1.901	2016.0524	13:01:31	1.743
2016.0524	9:31:56	-0.244	2016.0524	11:40:36	1.909	2016.0524	13:06:32	1.685
2016.0524	9:36:58	-0.135	2016.0524	11:41:37	1.907	2016.0524	13:11:34	1.640
2016.0524	9:41:59	-0.024	2016.0524	11:42:37	1.919	2016.0524	13:16:35	1.580
2016.0524	9:47:01	0.074	2016.0524	11:43:37	1.926	2016.0524	13:21:37	1.527
2016.0524	9:52:02	0.180	2016.0524	11:44:38	1.923	2016.0524	13:26:38	1.470
2016.0524	9:57:04	0.284	2016.0524	11:45:38	1.949	2016.0524	13:31:40	1.404
2016.0524	10:02:06	0.379	2016.0524	11:46:38	1.940	2016.0524	13:36:41	1.329
2016.0524	10:07:07	0.483	2016.0524	11:47:39	1.943	2016.0524	13:41:43	1.262
2016.0524	10:12:09	0.583	2016.0524	11:48:39	1.947	2016.0524	13:46:45	1.188
2016.0524	10:17:10	0.705	2016.0524	11:49:39	1.951	2016.0524	13:51:46	1.123
2016.0524	10:22:12	0.833	2016.0524	11:50:40	1.954	2016.0524	13:56:48	1.046
2016.0524	10:27:13	0.959	2016.0524	11:51:40	1.948	2016.0524	14:06:51	0.883
2016.0524	10:32:15	1.071	2016.0524	11:52:40	1.960	2016.0524	14:11:52	0.809
2016.0524	10:37:16	1.171	2016.0524	11:53:41	1.960	2016.0524	14:16:54	0.732
2016.0524	10:42:18	1.265	2016.0524	11:54:41	1.960	2016.0524	14:21:55	0.655
2016.0524	10:47:20	1.366	2016.0524	11:55:41	1.958	2016.0524	14:26:57	0.590

2016.0524	10:52:21	1.432	2016.0524	11:56:41	1.960	2016.0524	14:31:58	0.522
2016.0524	10:57:23	1.508	2016.0524	11:57:42	1.964	2016.0524	14:37:00	0.460
2016.0524	11:02:24	1.579	2016.0524	11:58:42	1.963	2016.0524	14:42:02	0.392
2016.0524	11:07:26	1.629	2016.0524	11:59:42	1.965	2016.0524	14:46:35	0.338
2016.0524	11:12:27	1.686	2016.0524	12:00:44	1.968	2016.0524	14:56:38	0.233
2016.0524	11:15:29	1.716	2016.0524	12:01:44	1.968	2016.0524	15:01:39	0.180
2016.0524	11:16:29	1.717	2016.0524	12:02:44	1.966	2016.0524	15:06:41	0.135
2016.0524	11:17:29	1.726	2016.0524	12:03:45	1.961	2016.0524	15:11:42	0.094
2016.0524	11:18:29	1.734	2016.0524	12:04:45	1.963	2016.0524	15:16:44	0.056
2016.0524	11:19:30	1.746	2016.0524	12:05:45	1.963	2016.0524	15:21:45	0.022
2016.0524	11:20:30	1.756	2016.0524	12:06:46	1.961	2016.0524	15:26:47	-0.008
2016.0524	11:21:30	1.761	2016.0524	12:07:46	1.963	2016.0524	15:31:49	-0.038

Camila sea levels Session 2

date	True Time	Sea Level AHD
2016.0524	15:36:50	-0.065
2016.0524	15:41:52	-0.091
2016.0524	15:46:53	-0.114
2016.0524	15:51:55	-0.135
2016.0524	15:56:56	-0.154
2016.0524	16:00:19	-0.167
2016.0524	16:05:20	-0.188
2016.0524	16:10:21	-0.204

Bucasia sea levels Session 1

date	True Time	Sea Level AHD						
2016.0325	7:31:54	-0.355	2016.0325	10:33:14	1.549	2016.0325	13:29:28	1.225
2016.0325	7:36:56	-0.354	2016.0325	10:38:16	1.597	2016.0325	13:34:29	1.166
2016.0325	7:41:57	-0.354	2016.0325	10:43:18	1.641	2016.0325	13:44:34	1.017
2016.0325	7:46:59	-0.355	2016.0325	10:48:02	1.694	2016.0325	13:49:36	0.963
2016.0325	7:52:01	-0.354	2016.0325	10:53:23	1.734	2016.0325	13:54:38	0.896
2016.0325	7:57:03	-0.354	2016.0325	10:58:25	1.785	2016.0325	13:59:04	0.828
2016.0325	8:02:05	-0.356	2016.0325	11:03:28	1.810	2016.0325	14:04:42	0.774
2016.0325	8:07:07	-0.357	2016.0325	11:08:03	1.858	2016.0325	14:09:43	0.703
2016.0325	8:12:09	-0.355	2016.0325	11:13:32	1.897	2016.0325	14:14:45	0.641
2016.0325	8:17:11	-0.357	2016.0325	11:18:34	1.919	2016.0325	14:19:47	0.586
2016.0325	8:22:13	-0.357	2016.0325	11:23:36	1.943	2016.0325	14:24:49	0.523
2016.0325	8:27:15	-0.354	2016.0325	11:28:38	1.956	2016.0325	14:29:51	0.456
2016.0325	8:32:17	-0.320	2016.0325	11:33:04	1.982	2016.0325	14:34:53	0.400
2016.0325	8:37:27	-0.205	2016.0325	11:38:42	1.991	2016.0325	14:39:55	0.344
2016.0325	8:42:03	-0.107	2016.0325	11:43:43	1.992	2016.0325	14:44:57	0.284
2016.0325	8:47:33	-0.015	2016.0325	11:48:45	2.003	2016.0325	14:49:59	0.234
2016.0325	8:52:35	0.080	2016.0325	11:53:47	2.002	2016.0325	14:55:01	0.182
2016.0325	8:57:37	0.164	2016.0325	11:58:49	1.988	2016.0325	15:00:02	0.128

2016.0325	9:02:39	0.240	2016.0325	12:03:51	1.974	2016.0325	15:05:04	0.081
2016.0325	9:07:41	0.319	2016.0325	12:08:54	1.956	2016.0325	15:10:06	0.036
2016.0325	9:12:43	0.400	2016.0325	12:13:56	1.946			
2016.0325	9:17:45	0.485	2016.0325	12:18:58	1.928			
2016.0325	9:22:47	0.568	2016.0325	12:24:00	1.891			
2016.0325	9:27:48	0.650	2016.0325	12:29:02	1.849			
2016.0325	9:32:05	0.740	2016.0325	12:34:03	1.809			
2016.0325	9:37:52	0.815	2016.0325	12:39:05	1.778			
2016.0325	9:47:56	0.982	2016.0325	12:44:08	1.728			
2016.0325	9:52:58	1.054	2016.0325	12:49:01	1.675			
2016.0325	9:58:00	1.125	2016.0325	12:54:12	1.631			
2016.0325	10:03:02	1.188	2016.0325	12:59:14	1.563			
2016.0325	10:08:04	1.256	2016.0325	13:04:16	1.524			
2016.0325	10:13:06	1.311	2016.0325	13:09:19	1.460			
2016.0325	10:18:08	1.366	2016.0325	13:14:21	1.407			
2016.0325	10:23:01	1.426	2016.0325	13:19:23	1.339			
2016.0325	10:28:12	1.495	2016.0325	13:24:26	1.288			

Bucasia sea levels Session 2

date	**True Time**	**Sea Level AHD**	**date**	**True Time**	**Sea Level AHD**	**date**	**True Time**	**Sea Level AHD**
2016.0523	9:33:42	0.766	2016.0523	10:19:57	1.271	2016.0523	11:06:13	1.535
2016.0523	9:34:42	0.775	2016.0523	10:20:57	1.286	2016.0523	11:07:13	1.544
2016.0523	9:35:42	0.789	2016.0523	10:21:58	1.297	2016.0523	11:08:14	1.547
2016.0523	9:36:42	0.804	2016.0523	10:22:58	1.307	2016.0523	11:09:14	1.551
2016.0523	9:37:43	0.815	2016.0523	10:23:58	1.315	2016.0523	11:10:14	1.559
2016.0523	9:38:43	0.829	2016.0523	10:24:59	1.320	2016.0523	11:11:14	1.561
2016.0523	9:39:43	0.835	2016.0523	10:25:59	1.327	2016.0523	11:12:15	1.566
2016.0523	9:40:44	0.847	2016.0523	10:26:59	1.335	2016.0523	11:13:15	1.561
2016.0523	9:41:44	0.859	2016.0523	10:28:00	1.335	2016.0523	11:14:15	1.562
2016.0523	9:42:44	0.875	2016.0523	10:29:00	1.344	2016.0523	11:15:16	1.572
2016.0523	9:43:45	0.885	2016.0523	10:30:00	1.339	2016.0523	11:16:16	1.559
2016.0523	9:44:45	0.902	2016.0523	10:31:01	1.339	2016.0523	11:17:17	1.562
2016.0523	9:45:45	0.909	2016.0523	10:32:01	1.341	2016.0523	11:18:17	1.562
2016.0523	9:46:46	0.924	2016.0523	10:33:01	1.348	2016.0523	11:19:17	1.565
2016.0523	9:47:46	0.934	2016.0523	10:34:02	1.350	2016.0523	11:20:17	1.552
2016.0523	9:48:46	0.946	2016.0523	10:35:02	1.356	2016.0523	11:21:18	1.567
2016.0523	9:49:47	0.956	2016.0523	10:36:02	1.367	2016.0523	11:22:18	1.558
2016.0523	9:50:47	0.966	2016.0523	10:37:03	1.380	2016.0523	11:23:18	1.569
2016.0523	9:51:47	0.976	2016.0523	10:38:03	1.390	2016.0523	11:24:19	1.562
2016.0523	9:52:48	0.979	2016.0523	10:39:03	1.394	2016.0523	11:25:19	1.574
2016.0523	9:53:48	0.991	2016.0523	10:40:04	1.398	2016.0523	11:26:19	1.569
2016.0523	9:54:48	0.998	2016.0523	10:41:04	1.405	2016.0523	11:27:20	1.575
2016.0523	9:55:49	1.009	2016.0523	10:42:04	1.409	2016.0523	11:28:20	1.560
2016.0523	9:56:49	1.017	2016.0523	10:43:05	1.415	2016.0523	11:29:21	1.566

2016.0523	9:57:49	1.027	2016.0523	10:44:05	1.421	2016.0523	11:30:21	1.566
2016.0523	9:58:50	1.034	2016.0523	10:45:06	1.429	2016.0523	11:31:21	1.550
2016.0523	9:59:50	1.042	2016.0523	10:46:06	1.436	2016.0523	11:32:22	1.539
2016.0523	10:00:50	1.051	2016.0523	10:47:06	1.444	2016.0523	11:33:22	1.540
2016.0523	10:01:51	1.060	2016.0523	10:48:07	1.453	2016.0523	11:34:22	1.534
2016.0523	10:02:51	1.071	2016.0523	10:49:07	1.456	2016.0523	11:35:23	1.531
2016.0523	10:03:51	1.080	2016.0523	10:50:07	1.465	2016.0523	11:36:23	1.519
2016.0523	10:04:52	1.095	2016.0523	10:51:08	1.472	2016.0523	11:37:23	1.515
2016.0523	10:05:52	1.106	2016.0523	10:52:08	1.469	2016.0523	11:38:24	1.516
2016.0523	10:06:52	1.115	2016.0523	10:53:08	1.477	2016.0523	11:39:24	1.508
2016.0523	10:07:53	1.125	2016.0523	10:54:09	1.477	2016.0523	11:40:24	1.511
2016.0523	10:08:53	1.135	2016.0523	10:55:09	1.475	2016.0523	11:41:25	1.506
2016.0523	10:09:53	1.146	2016.0523	10:56:09	1.477	2016.0523	11:42:25	1.505
2016.0523	10:10:54	1.163	2016.0523	10:57:10	1.479	2016.0523	11:43:25	1.507
2016.0523	10:11:54	1.170	2016.0523	10:58:10	1.479	2016.0523	11:44:26	1.507
2016.0523	10:12:55	1.188	2016.0523	10:59:10	1.491	2016.0523	11:45:26	1.508
2016.0523	10:13:55	1.200	2016.0523	11:00:11	1.503	2016.0523	11:46:26	1.507
2016.0523	10:14:55	1.214	2016.0523	11:01:11	1.492	2016.0523	11:47:27	1.504
2016.0523	10:15:56	1.226	2016.0523	11:02:11	1.504	2016.0523	11:48:27	1.506
2016.0523	10:16:56	1.234	2016.0523	11:03:12	1.511	2016.0523	11:49:27	1.509
2016.0523	10:17:56	1.248	2016.0523	11:04:12	1.523	2016.0523	11:50:28	1.510
2016.0523	10:18:57	1.258	2016.0523	11:05:13	1.525	2016.0523	11:51:28	1.504

Bucasia sea levels Session 2

date	**True Time**	**Sea Level AHD**	**date**	**True Time**	**Sea Level AHD**	**date**	**True Time**	**Sea Level AHD**
2016.0523	11:52:28	1.506	2016.0523	12:40:45	1.179			
2016.0523	11:53:29	1.500	2016.0523	12:41:45	1.161			
2016.0523	11:54:29	1.495	2016.0523	12:42:46	1.155			
2016.0523	11:55:29	1.500	2016.0523	12:43:46	1.141			
2016.0523	11:56:30	1.489	2016.0523	12:44:46	1.135			
2016.0523	11:57:30	1.498	2016.0523	12:45:47	1.123			
2016.0523	11:58:30	1.499	2016.0523	12:46:47	1.103			
2016.0523	11:59:31	1.496	2016.0523	12:47:47	1.098			
2016.0523	12:00:31	1.486	2016.0523	12:48:48	1.084			
2016.0523	12:02:32	1.478	2016.0523	12:49:48	1.078			
2016.0523	12:03:32	1.477	2016.0523	12:50:48	1.065			
2016.0523	12:04:33	1.493	2016.0523	12:51:49	1.061			
2016.0523	12:05:33	1.473	2016.0523	12:52:49	1.057			
2016.0523	12:06:33	1.466	2016.0523	12:53:49	1.043			
2016.0523	12:07:34	1.449	2016.0523	12:54:50	1.036			
2016.0523	12:08:34	1.454	2016.0523	12:55:50	1.025			
2016.0523	12:09:34	1.445	2016.0523	12:56:50	1.021			
2016.0523	12:10:35	1.435	2016.0523	12:57:51	1.010			
2016.0523	12:11:35	1.427	2016.0523	12:58:51	1.002			

2016.0523	12:12:35	1.418	2016.0523	13:01:52	0.976
2016.0523	12:13:36	1.418	2016.0523	13:02:52	0.963
2016.0523	12:14:36	1.408	2016.0523	13:03:53	0.953
2016.0523	12:15:36	1.398	2016.0523	13:04:53	0.945
2016.0523	12:16:37	1.390	2016.0523	13:05:53	0.933
2016.0523	12:17:37	1.380	2016.0523	13:06:54	0.920
2016.0523	12:18:37	1.371	2016.0523	13:07:54	0.906
2016.0523	12:19:38	1.369	2016.0523	13:08:54	0.896
2016.0523	12:20:38	1.350	2016.0523	13:09:55	0.883
2016.0523	12:21:38	1.340	2016.0523	13:10:55	0.876
2016.0523	12:22:39	1.335	2016.0523	13:11:55	0.864
2016.0523	12:23:39	1.327	2016.0523	13:12:56	0.854
2016.0523	12:24:40	1.320	2016.0523	13:13:56	0.841
2016.0523	12:25:40	1.316	2016.0523	13:14:56	0.833
2016.0523	12:26:40	1.299	2016.0523	13:15:57	0.816
2016.0523	12:27:41	1.297	2016.0523	13:16:58	0.810
2016.0523	12:28:41	1.289	2016.0523	13:17:58	0.792
2016.0523	12:29:41	1.276	2016.0523	13:18:59	0.778
2016.0523	12:30:42	1.270	2016.0523	13:19:59	0.772
2016.0523	12:31:42	1.262	2016.0523	13:20:59	0.760
2016.0523	12:32:42	1.256	2016.0523	13:22:00	0.751
2016.0523	12:33:43	1.238	2016.0523	13:23:00	0.741
2016.0523	12:34:43	1.227	2016.0523	13:24:00	0.728
2016.0523	12:35:43	1.221	2016.0523	13:25:01	0.716
2016.0523	12:36:44	1.211	2016.0523	13:26:01	0.709
2016.0523	12:37:44	1.204	2016.0523	13:27:01	0.697
2016.0523	12:38:44	1.192	2016.0523	13:28:02	0.686
2016.0523	12:39:45	1.182			

Murrys Creek sea levels Session 1

date	True Time	Sea Level AHD	date	True Time	Sea Level AHD	date	True Time	Sea Level AHD
2016.0324	8:09:32	-0.942	2016.0324	12:21:02	2.192	2016.0324	16:32:39	-0.442
2016.0324	8:14:34	-0.899	2016.0324	12:26:04	2.149	2016.0324	16:37:04	-0.468
2016.0324	8:19:35	-0.848	2016.0324	12:31:05	2.112	2016.0324	16:42:42	-0.490
2016.0324	8:29:39	-0.700	2016.0324	12:36:07	2.041	2016.0324	16:47:43	-0.524
2016.0324	8:34:41	-0.595	2016.0324	12:41:09	1.976	2016.0324	16:52:46	-0.546
2016.0324	8:39:43	-0.484	2016.0324	12:46:11	1.922	2016.0324	16:57:47	-0.572
2016.0324	8:44:45	-0.352	2016.0324	12:51:13	1.851	2016.0324	17:02:49	-0.593
2016.0324	8:49:47	-0.225	2016.0324	12:56:15	1.782	2016.0324	17:07:51	-0.617
2016.0324	8:54:48	-0.084	2016.0324	13:01:16	1.704	2016.0324	17:12:52	-0.638
2016.0324	9:04:53	0.198	2016.0324	13:06:18	1.625	2016.0324	17:17:54	-0.665
2016.0324	9:09:54	0.352	2016.0324	13:11:02	1.559	2016.0324	17:22:56	-0.686
2016.0324	9:14:56	0.478	2016.0324	13:16:22	1.480	2016.0324	17:27:58	-0.707
2016.0324	9:19:58	0.614	2016.0324	13:21:24	1.404	2016.0324	17:33:00	-0.725
2016.0324	9:24:59	0.736	2016.0324	13:26:26	1.327	2016.0324	17:38:01	-0.743

2016.0324	9:30:01	0.854	2016.0324	13:31:27	1.259	2016.0324	17:43:03	-0.763
2016.0324	9:35:03	0.951	2016.0324	13:36:29	1.189	2016.0324	17:48:05	-0.781
2016.0324	9:40:04	1.032	2016.0324	13:41:31	1.117	2016.0324	17:53:07	-0.798
2016.0324	9:45:06	1.129	2016.0324	13:46:32	1.049	2016.0324	17:58:08	-0.817
2016.0324	9:50:08	1.213	2016.0324	13:51:34	0.984			
2016.0324	9:55:01	1.279	2016.0324	13:56:36	0.922			
2016.0324	10:00:11	1.344	2016.0324	14:01:38	0.867			
2016.0324	10:05:13	1.399	2016.0324	14:06:04	0.804			
2016.0324	10:10:15	1.454	2016.0324	14:11:42	0.743			
2016.0324	10:15:17	1.506	2016.0324	14:16:48	0.678			
2016.0324	10:20:18	1.553	2016.0324	14:21:05	0.620			
2016.0324	10:30:22	1.644	2016.0324	14:26:52	0.575			
2016.0324	10:35:24	1.691	2016.0324	14:31:54	0.510			
2016.0324	10:40:25	1.738	2016.0324	14:46:59	0.346			
2016.0324	10:50:29	1.845	2016.0324	14:52:01	0.312			
2016.0324	10:55:03	1.906	2016.0324	14:57:03	0.262			
2016.0324	11:00:32	1.952	2016.0324	15:02:05	0.213			
2016.0324	11:05:34	2.003	2016.0324	15:07:06	0.170			
2016.0324	11:10:36	2.052	2016.0324	15:12:08	0.126			
2016.0324	11:15:38	2.094	2016.0324	15:17:11	0.081			
2016.0324	11:20:04	2.138	2016.0324	15:22:13	0.046			
2016.0324	11:25:42	2.173	2016.0324	15:27:14	-0.001			
2016.0324	11:30:43	2.201	2016.0324	15:32:16	-0.046			
2016.0324	11:35:45	2.227	2016.0324	15:37:18	-0.088			
2016.0324	11:40:47	2.251	2016.0324	15:42:02	-0.124			
2016.0324	11:45:48	2.271	2016.0324	15:52:23	-0.188			
2016.0324	11:50:05	2.275	2016.0324	15:57:25	-0.223			
2016.0324	11:55:52	2.288	2016.0324	16:07:29	-0.286			
2016.0324	12:00:54	2.287	2016.0324	16:12:31	-0.305			
2016.0324	12:05:56	2.280	2016.0324	16:17:33	-0.355			
2016.0324	12:10:58	2.252	2016.0324	16:22:35	-0.385			
2016.0324	12:16:00	2.224	2016.0324	16:27:37	-0.414			

Murrys Creek sea levels Session 2

date	True Time	Sea Level AHD	date	True Time	Sea Level AHD	date	True Time	Sea Level AHD
2016.0525	7:40:33	-0.810	2016.0525	10:09:35	-0.327	2016.0525	12:05:14	0.912
2016.0525	7:43:03	-0.821	2016.0525	10:12:06	-0.287	2016.0525	12:07:44	0.927
2016.0525	7:45:34	-0.831	2016.0525	10:14:37	-0.250	2016.0525	12:10:15	0.950
2016.0525	7:48:05	-0.839	2016.0525	10:17:08	-0.212	2016.0525	12:12:46	0.974
2016.0525	7:50:36	-0.846	2016.0525	10:19:39	-0.172	2016.0525	12:15:17	0.995
2016.0525	7:53:06	-0.855	2016.0525	10:22:09	-0.131	2016.0525	12:17:48	1.017
2016.0525	7:55:37	-0.863	2016.0525	10:24:40	-0.090	2016.0525	12:20:19	1.038
2016.0525	8:02:48	-0.886	2016.0525	10:27:11	-0.036	2016.0525	12:22:49	1.053
2016.0525	8:05:19	-0.890	2016.0525	10:29:42	-0.007	2016.0525	12:25:20	1.072

2016.0525	8:07:49	-0.895	2016.0525	10:32:13	0.036	2016.0525	12:27:51	1.089
2016.0525	8:10:20	-0.904	2016.0525	10:34:44	0.075	2016.0525	12:30:22	1.105
2016.0525	8:12:51	-0.909	2016.0525	10:37:14	0.114	2016.0525	12:32:53	1.118
2016.0525	8:15:22	-0.918	2016.0525	10:39:45	0.152	2016.0525	12:35:24	1.132
2016.0525	8:17:52	-0.924	2016.0525	10:42:16	0.191	2016.0525	12:37:54	1.146
2016.0525	8:20:23	-0.930	2016.0525	10:44:47	0.229	2016.0525	12:40:25	1.159
2016.0525	8:22:09	-0.935	2016.0525	10:47:18	0.265	2016.0525	12:42:56	1.169
2016.0525	8:27:10	-0.947	2016.0525	10:49:48	0.299	2016.0525	12:45:27	1.179
2016.0525	8:32:11	-0.959	2016.0525	10:52:19	0.332	2016.0525	12:47:58	1.184
2016.0525	8:37:13	-0.969	2016.0525	10:54:50	0.363	2016.0525	12:50:28	1.210
2016.0525	8:47:16	-0.982	2016.0525	10:57:21	0.392	2016.0525	12:52:59	1.193
2016.0525	8:52:18	-0.972	2016.0525	10:59:52	0.426	2016.0525	12:58:01	1.200
2016.0525	8:57:19	-0.947	2016.0525	11:02:23	0.456	2016.0525	13:00:32	1.203
2016.0525	9:02:21	-0.920	2016.0525	11:04:53	0.481	2016.0525	13:03:03	1.210
2016.0525	9:07:22	-0.902	2016.0525	11:07:24	0.507	2016.0525	13:05:33	1.198
2016.0525	9:12:55	-0.873	2016.0525	11:09:55	0.530	2016.0525	13:08:04	1.199
2016.0525	9:13:05	-0.871	2016.0525	11:12:26	0.554	2016.0525	13:12:51	1.181
2016.0525	9:14:17	-0.868	2016.0525	11:14:56	0.572	2016.0525	13:15:21	1.170
2016.0525	9:16:48	-0.855	2016.0525	11:17:27	0.593	2016.0525	13:17:52	1.170
2016.0525	9:19:19	-0.845	2016.0525	11:19:58	0.613	2016.0525	13:20:23	1.156
2016.0525	9:21:49	-0.830	2016.0525	11:22:29	0.634	2016.0525	13:22:54	1.153
2016.0525	9:24:20	-0.820	2016.0525	11:25:00	0.653	2016.0525	13:25:24	1.159
2016.0525	9:26:51	-0.809	2016.0525	11:27:30	0.672	2016.0525	13:27:55	1.149
2016.0525	9:29:22	-0.782	2016.0525	11:30:01	0.687	2016.0525	13:30:26	1.147
2016.0525	9:31:53	-0.770	2016.0525	11:32:32	0.703	2016.0525	13:32:57	1.138
2016.0525	9:34:24	-0.745	2016.0525	11:35:03	0.717	2016.0525	13:35:28	1.134
2016.0525	9:36:54	-0.717	2016.0525	11:37:34	0.731	2016.0525	13:37:59	1.121
2016.0525	9:39:25	-0.693	2016.0525	11:40:04	0.745	2016.0525	13:40:29	1.111
2016.0525	9:46:58	-0.613	2016.0525	11:42:35	0.761	2016.0525	13:43:00	1.101
2016.0525	9:49:29	-0.585	2016.0525	11:45:06	0.778	2016.0525	13:45:31	1.098
2016.0525	9:51:59	-0.556	2016.0525	11:47:37	0.796	2016.0525	13:48:02	1.085
2016.0525	9:54:30	-0.526	2016.0525	11:50:08	0.811	2016.0525	13:50:33	1.074
2016.0525	9:57:01	-0.496	2016.0525	11:52:39	0.822	2016.0525	13:53:04	1.060
2016.0525	9:59:32	-0.464	2016.0525	11:55:10	0.840	2016.0525	13:55:34	1.046
2016.0525	10:02:03	-0.431	2016.0525	11:57:40	0.859	2016.0525	13:58:05	1.032
2016.0525	10:04:34	-0.397	2016.0525	12:00:12	0.878	2016.0525	14:00:36	1.015
2016.0525	10:07:04	-0.362	2016.0525	12:02:43	0.894	2016.0525	14:03:07	0.981

Murrys Creek sea levels Session 2

date	True Time	Sea Level AHD	date	True Time	Sea Level AHD	date	True Time	Sea Level AHD
2016.0525	14:12:33	0.925	2016.0525	16:20:03	-0.118			
2016.0525	14:15:03	0.902	2016.0525	16:22:34	-0.140			
2016.0525	14:17:34	0.884	2016.0525	16:25:05	-0.154			
2016.0525	14:20:04	0.867	2016.0525	16:27:35	-0.168			

2016.0525	14:22:35	0.847
2016.0525	14:25:06	0.850
2016.0525	14:27:37	0.804
2016.0525	14:30:08	0.785
2016.0525	14:32:39	0.765
2016.0525	14:35:10	0.745
2016.0525	14:37:41	0.720
2016.0525	14:40:11	0.698
2016.0525	14:42:42	0.674
2016.0525	14:45:13	0.653
2016.0525	14:47:44	0.627
2016.0525	14:50:15	0.591
2016.0525	14:52:46	0.575
2016.0525	14:57:47	0.528
2016.0525	15:00:18	0.506
2016.0525	15:02:49	0.485
2016.0525	15:05:20	0.465
2016.0525	15:10:22	0.420
2016.0525	15:12:53	0.399
2016.0525	15:15:23	0.382
2016.0525	15:17:54	0.361
2016.0525	15:20:25	0.339
2016.0525	15:22:56	0.319
2016.0525	15:25:27	0.295
2016.0525	15:27:58	0.275
2016.0525	15:30:28	0.254
2016.0525	15:32:59	0.231
2016.0525	15:35:30	0.210
2016.0525	15:38:01	0.190
2016.0525	15:40:32	0.172
2016.0525	15:43:45	0.149
2016.0525	15:46:16	0.132
2016.0525	15:48:47	0.106
2016.0525	15:51:17	0.093
2016.0525	15:53:48	0.064
2016.0525	15:56:19	0.056
2016.0525	15:59:41	0.026
2016.0525	16:02:12	0.008
2016.0525	16:04:43	-0.011
2016.0525	16:07:14	-0.027
2016.0525	16:09:44	-0.047
2016.0525	16:12:15	-0.066
2016.0525	16:15:02	-0.082
2016.0525	16:30:06	-0.187
2016.0525	16:32:37	-0.206
2016.0525	16:35:08	-0.221
2016.0525	16:36:48	-0.232
2016.0525	16:39:18	-0.247
2016.0525	16:41:49	-0.262
2016.0525	16:44:20	-0.279
2016.0525	16:46:51	-0.294
2016.0525	16:49:22	-0.309
2016.0525	16:51:52	-0.324
2016.0525	16:54:23	-0.337
2016.0525	16:56:54	-0.352
2016.0525	16:59:25	-0.368
2016.0525	17:01:56	-0.383
2016.0525	17:04:27	-0.398
2016.0525	17:06:57	-0.411

Appendix C

Mackay Outer Harbour session 1 sea levels

Mackay Outer harbour data from 23rd March to 25th March

DateTime	Water Level	Prediction	Residual
2016-03-23T00:10	4.548	4.548	0
2016-03-23T00:20	4.426	4.408	0.018
2016-03-23T00:30	4.286	4.262	0.024
2016-03-23T00:40	4.139	4.116	0.023
2016-03-23T00:50	3.987	3.963	0.024
2016-03-23T01:00	3.839	3.809	0.03
2016-03-23T01:10	3.686	3.656	0.03
2016-03-23T01:20	3.539	3.501	0.038
2016-03-23T01:30	3.382	3.343	0.039
2016-03-23T01:40	3.228	3.188	0.04
2016-03-23T01:50	3.069	3.031	0.038
2016-03-23T02:00	2.908	2.872	0.036
2016-03-23T02:10	2.755	2.717	0.038
2016-03-23T02:20	2.602	2.56	0.042
2016-03-23T02:30	2.447	2.404	0.043
2016-03-23T02:40	2.295	2.25	0.045
2016-03-23T02:50	2.152	2.101	0.051
2016-03-23T03:00	2.004	1.952	0.052
2016-03-23T03:10	1.855	1.808	0.047
2016-03-23T03:20	1.72	1.671	0.049
2016-03-23T03:30	1.597	1.539	0.058
2016-03-23T03:40	1.479	1.416	0.063
2016-03-23T03:50	1.355	1.303	0.052
2016-03-23T04:00	1.259	1.201	0.058
2016-03-23T04:10	1.152	1.111	0.041
2016-03-23T04:20	1.091	1.037	0.054
2016-03-23T04:30	1.021	0.98	0.041
2016-03-23T04:40	0.984	0.941	0.043
2016-03-23T04:50	0.944	0.922	0.022
2016-03-23T05:00	0.953	0.925	0.028
2016-03-23T05:10	0.963	0.949	0.014
2016-03-23T05:20	0.998	0.995	0.003
2016-03-23T05:30	1.059	1.064	-0.005
2016-03-23T05:40	1.155	1.153	0.002
2016-03-23T05:50	1.251	1.26	-0.009
2016-03-23T06:00	1.385	1.386	-0.001
2016-03-23T06:10	1.518	1.527	-0.009

2016-03-23T06:20	1.662	1.676	-0.014
2016-03-23T06:30	1.812	1.837	-0.025
2016-03-23T06:40	1.979	2.004	-0.025
2016-03-23T06:50	2.154	2.173	-0.019
2016-03-23T07:00	2.322	2.347	-0.025
2016-03-23T07:10	2.494	2.522	-0.028
2016-03-23T07:20	2.667	2.693	-0.026
2016-03-23T07:30	2.843	2.868	-0.025
2016-03-23T07:40	3.006	3.042	-0.036
2016-03-23T07:50	3.175	3.212	-0.037
2016-03-23T08:00	3.339	3.386	-0.047
2016-03-23T08:10	3.501	3.559	-0.058
2016-03-23T08:20	3.662	3.731	-0.069
2016-03-23T08:30	3.836	3.904	-0.068
2016-03-23T08:40	4	4.076	-0.076
2016-03-23T08:50	4.172	4.244	-0.072
2016-03-23T09:00	4.334	4.411	-0.077
2016-03-23T09:10	4.503	4.573	-0.07
2016-03-23T09:20	4.652	4.726	-0.074
2016-03-23T09:30	4.802	4.872	-0.07
2016-03-23T09:40	4.928	5.006	-0.078
2016-03-23T09:50	5.059	5.128	-0.069
2016-03-23T10:00	5.152	5.234	-0.082
2016-03-23T10:10	5.251	5.325	-0.074
2016-03-23T10:20	5.33	5.399	-0.069
2016-03-23T10:30	5.386	5.452	-0.066
2016-03-23T10:40	5.417	5.486	-0.069
2016-03-23T10:50	5.433	5.499	-0.066
2016-03-23T11:00	5.437	5.49	-0.053
2016-03-23T11:10	5.408	5.461	-0.053
2016-03-23T11:20	5.364	5.411	-0.047
2016-03-23T11:30	5.299	5.342	-0.043
2016-03-23T11:40	5.204	5.254	-0.05
2016-03-23T11:50	5.105	5.149	-0.044
2016-03-23T12:00	4.998	5.03	-0.032
2016-03-23T12:10	4.876	4.899	-0.023
2016-03-23T12:20	4.74	4.758	-0.018
2016-03-23T12:30	4.598	4.61	-0.012
2016-03-23T12:40	4.457	4.455	0.002
2016-03-23T12:50	4.298	4.295	0.003
2016-03-23T13:00	4.148	4.135	0.013
2016-03-23T13:10	3.991	3.97	0.021
2016-03-23T13:20	3.835	3.806	0.029
2016-03-23T13:30	3.671	3.642	0.029
2016-03-23T13:40	3.512	3.475	0.037
2016-03-23T13:50	3.354	3.31	0.044

2016-03-23T14:00	3.189	3.145	0.044
2016-03-23T14:10	3.02	2.979	0.041
2016-03-23T14:20	2.856	2.813	0.043
2016-03-23T14:30	2.693	2.651	0.042
2016-03-23T14:40	2.526	2.486	0.04
2016-03-23T14:50	2.37	2.323	0.047
2016-03-23T15:00	2.204	2.165	0.039
2016-03-23T15:10	2.053	2.007	0.046
2016-03-23T15:20	1.894	1.854	0.04
2016-03-23T15:30	1.745	1.708	0.037
2016-03-23T15:40	1.599	1.567	0.032
2016-03-23T15:50	1.463	1.434	0.029
2016-03-23T16:00	1.33	1.311	0.019
2016-03-23T16:10	1.214	1.198	0.016
2016-03-23T16:20	1.109	1.097	0.012
2016-03-23T16:30	1.024	1.012	0.012
2016-03-23T16:40	0.942	0.941	0.001
2016-03-23T16:50	0.892	0.889	0.003
2016-03-23T17:00	0.858	0.856	0.002
2016-03-23T17:10	0.836	0.844	-0.008
2016-03-23T17:20	0.835	0.853	-0.018
2016-03-23T17:30	0.861	0.885	-0.024
2016-03-23T17:40	0.917	0.937	-0.02
2016-03-23T17:50	0.973	1.011	-0.038
2016-03-23T18:00	1.076	1.106	-0.03
2016-03-23T18:10	1.189	1.217	-0.028
2016-03-23T18:20	1.307	1.345	-0.038
2016-03-23T18:30	1.442	1.488	-0.046
2016-03-23T18:40	1.588	1.637	-0.049
2016-03-23T18:50	1.745	1.797	-0.052
2016-03-23T19:00	1.904	1.962	-0.058
2016-03-23T19:10	2.067	2.127	-0.06
2016-03-23T19:20	2.233	2.296	-0.063
2016-03-23T19:30	2.403	2.466	-0.063
2016-03-23T19:40	2.581	2.632	-0.051
2016-03-23T19:50	2.74	2.8	-0.06
2016-03-23T20:00	2.908	2.969	-0.061
2016-03-23T20:10	3.062	3.133	-0.071
2016-03-23T20:20	3.226	3.3	-0.074
2016-03-23T20:30	3.389	3.466	-0.077
2016-03-23T20:40	3.549	3.63	-0.081
2016-03-23T20:50	3.715	3.796	-0.081
2016-03-23T21:00	3.873	3.96	-0.087
2016-03-23T21:10	4.046	4.12	-0.074
2016-03-23T21:20	4.21	4.276	-0.066
2016-03-23T21:30	4.368	4.428	-0.06

2016-03-23T21:40	4.511	4.57	-0.059
2016-03-23T21:50	4.652	4.706	-0.054
2016-03-23T22:00	4.769	4.829	-0.06
2016-03-23T22:10	4.875	4.939	-0.064
2016-03-23T22:20	4.966	5.036	-0.07
2016-03-23T22:30	5.037	5.117	-0.08
2016-03-23T22:40	5.096	5.18	-0.084
2016-03-23T22:50	5.139	5.226	-0.087
2016-03-23T23:00	5.172	5.253	-0.081
2016-03-23T23:10	5.179	5.261	-0.082
2016-03-23T23:20	5.169	5.249	-0.08
2016-03-23T23:30	5.148	5.217	-0.069
2016-03-23T23:40	5.095	5.167	-0.072
2016-03-23T23:50	5.026	5.099	-0.073
2016-03-24T00:00	4.931	5.014	-0.083
2016-03-24T00:10	4.839	4.915	-0.076
2016-03-24T00:20	4.727	4.803	-0.076
2016-03-24T00:30	4.622	4.679	-0.057
2016-03-24T00:40	4.495	4.546	-0.051
2016-03-24T00:50	4.365	4.408	-0.043
2016-03-24T01:00	4.223	4.263	-0.04
2016-03-24T01:10	4.086	4.113	-0.027
2016-03-24T01:20	3.94	3.965	-0.025
2016-03-24T01:30	3.798	3.81	-0.012
2016-03-24T01:40	3.651	3.655	-0.004
2016-03-24T01:50	3.503	3.502	0.001
2016-03-24T02:00	3.365	3.344	0.021
2016-03-24T02:10	3.21	3.187	0.023
2016-03-24T02:20	3.053	3.032	0.021
2016-03-24T02:30	2.901	2.874	0.027
2016-03-24T02:40	2.746	2.716	0.03
2016-03-24T02:50	2.595	2.563	0.032
2016-03-24T03:00	2.433	2.407	0.026
2016-03-24T03:10	2.281	2.253	0.028
2016-03-24T03:20	2.132	2.106	0.026
2016-03-24T03:30	1.987	1.96	0.027
2016-03-24T03:40	1.846	1.82	0.026
2016-03-24T03:50	1.709	1.688	0.021
2016-03-24T04:00	1.582	1.562	0.02
2016-03-24T04:10	1.456	1.445	0.011
2016-03-24T04:20	1.353	1.34	0.013
2016-03-24T04:30	1.25	1.245	0.005
2016-03-24T04:40	1.163	1.163	0
2016-03-24T04:50	1.089	1.098	-0.009
2016-03-24T05:00	1.04	1.048	-0.008
2016-03-24T05:10	0.999	1.016	-0.017

2016-03-24T05:20	0.983	1.002	-0.019
2016-03-24T05:30	0.981	1.009	-0.028
2016-03-24T05:40	1.001	1.036	-0.035
2016-03-24T05:50	1.052	1.083	-0.031
2016-03-24T06:00	1.112	1.152	-0.04
2016-03-24T06:10	1.201	1.239	-0.038
2016-03-24T06:20	1.306	1.343	-0.037
2016-03-24T06:30	1.436	1.465	-0.029
2016-03-24T06:40	1.566	1.599	-0.033
2016-03-24T06:50	1.711	1.744	-0.033
2016-03-24T07:00	1.868	1.898	-0.03
2016-03-24T07:10	2.021	2.06	-0.039
2016-03-24T07:20	2.178	2.222	-0.044
2016-03-24T07:30	2.333	2.39	-0.057
2016-03-24T07:40	2.497	2.558	-0.061
2016-03-24T07:50	2.653	2.726	-0.073
2016-03-24T08:00	2.802	2.892	-0.09
2016-03-24T08:10	2.969	3.058	-0.089
2016-03-24T08:20	3.129	3.225	-0.096
2016-03-24T08:30	3.282	3.389	-0.107
2016-03-24T08:40	3.438	3.556	-0.118
2016-03-24T08:50	3.597	3.721	-0.124
2016-03-24T09:00	3.75	3.885	-0.135
2016-03-24T09:10	3.907	4.049	-0.142
2016-03-24T09:20	4.069	4.21	-0.141
2016-03-24T09:30	4.233	4.365	-0.132
2016-03-24T09:40	4.383	4.516	-0.133
2016-03-24T09:50	4.543	4.66	-0.117
2016-03-24T10:00	4.685	4.793	-0.108
2016-03-24T10:10	4.806	4.917	-0.111
2016-03-24T10:20	4.912	5.027	-0.115
2016-03-24T10:30	5.01	5.122	-0.112
2016-03-24T10:40	5.098	5.202	-0.104
2016-03-24T10:50	5.149	5.264	-0.115
2016-03-24T11:00	5.195	5.308	-0.113
2016-03-24T11:10	5.232	5.334	-0.102
2016-03-24T11:20	5.236	5.34	-0.104
2016-03-24T11:30	5.23	5.326	-0.096
2016-03-24T11:40	5.201	5.292	-0.091
2016-03-24T11:50	5.139	5.241	-0.102
2016-03-24T12:00	5.06	5.17	-0.11
2016-03-24T12:10	4.97	5.084	-0.114
2016-03-24T12:20	4.862	4.982	-0.12
2016-03-24T12:30	4.751	4.867	-0.116
2016-03-24T12:40	4.625	4.74	-0.115
2016-03-24T12:50	4.493	4.603	-0.11

2016-03-24T13:00	4.359	4.461	-0.102
2016-03-24T13:10	4.208	4.31	-0.102
2016-03-24T13:20	4.065	4.158	-0.093
2016-03-24T13:30	3.919	4.001	-0.082
2016-03-24T13:40	3.766	3.842	-0.076
2016-03-24T13:50	3.616	3.682	-0.066
2016-03-24T14:00	3.469	3.523	-0.054
2016-03-24T14:10	3.32	3.361	-0.041
2016-03-24T14:20	3.172	3.198	-0.026
2016-03-24T14:30	3.014	3.039	-0.025
2016-03-24T14:40	2.864	2.876	-0.012
2016-03-24T14:50	2.699	2.713	-0.014
2016-03-24T15:00	2.542	2.554	-0.012
2016-03-24T15:10	2.38	2.393	-0.013
2016-03-24T15:20	2.232	2.234	-0.002
2016-03-24T15:30	2.087	2.078	0.009
2016-03-24T15:40	1.925	1.93	-0.005
2016-03-24T15:50	1.781	1.783	-0.002
2016-03-24T16:00	1.635	1.644	-0.009
2016-03-24T16:10	1.503	1.514	-0.011
2016-03-24T16:20	1.387	1.391	-0.004
2016-03-24T16:30	1.266	1.28	-0.014
2016-03-24T16:40	1.176	1.181	-0.005
2016-03-24T16:50	1.084	1.095	-0.011
2016-03-24T17:00	1.011	1.024	-0.013
2016-03-24T17:10	0.952	0.97	-0.018
2016-03-24T17:20	0.913	0.932	-0.019
2016-03-24T17:30	0.883	0.914	-0.031
2016-03-24T17:40	0.877	0.915	-0.038
2016-03-24T17:50	0.892	0.936	-0.044
2016-03-24T18:00	0.919	0.977	-0.058
2016-03-24T18:10	0.989	1.039	-0.05
2016-03-24T18:20	1.081	1.119	-0.038
2016-03-24T18:30	1.198	1.219	-0.021
2016-03-24T18:40	1.302	1.334	-0.032
2016-03-24T18:50	1.422	1.464	-0.042
2016-03-24T19:00	1.56	1.606	-0.046
2016-03-24T19:10	1.706	1.757	-0.051
2016-03-24T19:20	1.848	1.915	-0.067
2016-03-24T19:30	2.005	2.08	-0.075
2016-03-24T19:40	2.159	2.244	-0.085
2016-03-24T19:50	2.333	2.411	-0.078
2016-03-24T20:00	2.497	2.58	-0.083
2016-03-24T20:10	2.648	2.743	-0.095
2016-03-24T20:20	2.825	2.909	-0.084
2016-03-24T20:30	2.973	3.074	-0.101

2016-03-24T20:40	3.128	3.236	-0.108
2016-03-24T20:50	3.286	3.399	-0.113
2016-03-24T21:00	3.444	3.563	-0.119
2016-03-24T21:10	3.609	3.723	-0.114
2016-03-24T21:20	3.763	3.884	-0.121
2016-03-24T21:30	3.924	4.043	-0.119
2016-03-24T21:40	4.08	4.196	-0.116
2016-03-24T21:50	4.244	4.347	-0.103
2016-03-24T22:00	4.382	4.492	-0.11
2016-03-24T22:10	4.525	4.626	-0.101
2016-03-24T22:20	4.647	4.752	-0.105
2016-03-24T22:30	4.747	4.866	-0.119
2016-03-24T22:40	4.849	4.968	-0.119
2016-03-24T22:50	4.918	5.053	-0.135
2016-03-24T23:00	5.001	5.124	-0.123
2016-03-24T23:10	5.057	5.178	-0.121
2016-03-24T23:20	5.082	5.212	-0.13
2016-03-24T23:30	5.099	5.231	-0.132
2016-03-24T23:40	5.102	5.23	-0.128
2016-03-24T23:50	5.099	5.211	-0.112
2016-03-25T00:00	5.063	5.174	-0.111
2016-03-25T00:10	5.002	5.12	-0.118
2016-03-25T00:20	4.934	5.049	-0.115
2016-03-25T00:30	4.862	4.963	-0.101
2016-03-25T00:40	4.76	4.865	-0.105
2016-03-25T00:50	4.652	4.753	-0.101
2016-03-25T01:00	4.543	4.633	-0.09
2016-03-25T01:10	4.412	4.503	-0.091
2016-03-25T01:20	4.292	4.369	-0.077
2016-03-25T01:30	4.142	4.228	-0.086
2016-03-25T01:40	4.022	4.083	-0.061
2016-03-25T01:50	3.887	3.938	-0.051
2016-03-25T02:00	3.733	3.789	-0.056
2016-03-25T02:10	3.596	3.64	-0.044
2016-03-25T02:20	3.463	3.49	-0.027
2016-03-25T02:30	3.319	3.34	-0.021
2016-03-25T02:40	3.171	3.188	-0.017
2016-03-25T02:50	3.015	3.037	-0.022
2016-03-25T03:00	2.877	2.885	-0.008
2016-03-25T03:10	2.719	2.732	-0.013
2016-03-25T03:20	2.582	2.583	-0.001
2016-03-25T03:30	2.427	2.432	-0.005
2016-03-25T03:40	2.29	2.285	0.005
2016-03-25T03:50	2.148	2.143	0.005
2016-03-25T04:00	1.998	2.003	-0.005
2016-03-25T04:10	1.887	1.869	0.018

2016-03-25T04:20	1.738	1.744	-0.006
2016-03-25T04:30	1.649	1.626	0.023
2016-03-25T04:40	1.528	1.518	0.01
2016-03-25T04:50	1.432	1.422	0.01
2016-03-25T05:00	1.356	1.337	0.019
2016-03-25T05:10	1.281	1.266	0.015
2016-03-25T05:20	1.219	1.211	0.008
2016-03-25T05:30	1.17	1.17	0
2016-03-25T05:40	1.147	1.146	0.001
2016-03-25T05:50	1.136	1.14	-0.004
2016-03-25T06:00	1.133	1.153	-0.02
2016-03-25T06:10	1.157	1.185	-0.028
2016-03-25T06:20	1.201	1.234	-0.033
2016-03-25T06:30	1.276	1.302	-0.026
2016-03-25T06:40	1.358	1.386	-0.028
2016-03-25T06:50	1.459	1.488	-0.029
2016-03-25T07:00	1.576	1.601	-0.025
2016-03-25T07:10	1.698	1.729	-0.031
2016-03-25T07:20	1.834	1.865	-0.031
2016-03-25T07:30	1.975	2.009	-0.034
2016-03-25T07:40	2.118	2.16	-0.042
2016-03-25T07:50	2.262	2.313	-0.051
2016-03-25T08:00	2.412	2.467	-0.055
2016-03-25T08:10	2.568	2.623	-0.055
2016-03-25T08:20	2.711	2.78	-0.069
2016-03-25T08:30	2.854	2.932	-0.078
2016-03-25T08:40	3.014	3.087	-0.073
2016-03-25T08:50	3.147	3.241	-0.094
2016-03-25T09:00	3.289	3.393	-0.104
2016-03-25T09:10	3.438	3.546	-0.108
2016-03-25T09:20	3.582	3.699	-0.117
2016-03-25T09:30	3.729	3.848	-0.119
2016-03-25T09:40	3.874	3.998	-0.124
2016-03-25T09:50	4.022	4.146	-0.124
2016-03-25T10:00	4.17	4.286	-0.116
2016-03-25T10:10	4.307	4.423	-0.116
2016-03-25T10:20	4.442	4.553	-0.111
2016-03-25T10:30	4.554	4.671	-0.117
2016-03-25T10:40	4.663	4.78	-0.117
2016-03-25T10:50	4.759	4.876	-0.117
2016-03-25T11:00	4.85	4.957	-0.107
2016-03-25T11:10	4.909	5.023	-0.114
2016-03-25T11:20	4.966	5.073	-0.107
2016-03-25T11:30	4.995	5.105	-0.11
2016-03-25T11:40	5.025	5.119	-0.094
2016-03-25T11:50	5.025	5.117	-0.092

2016-03-25T12:00	5.015	5.095	-0.08
2016-03-25T12:10	4.985	5.058	-0.073
2016-03-25T12:20	4.936	5.003	-0.067
2016-03-25T12:30	4.864	4.931	-0.067
2016-03-25T12:40	4.777	4.846	-0.069
2016-03-25T12:50	4.676	4.747	-0.071
2016-03-25T13:00	4.56	4.636	-0.076
2016-03-25T13:10	4.449	4.515	-0.066
2016-03-25T13:20	4.321	4.387	-0.066
2016-03-25T13:30	4.193	4.251	-0.058
2016-03-25T13:40	4.054	4.111	-0.057
2016-03-25T13:50	3.916	3.967	-0.051
2016-03-25T14:00	3.778	3.82	-0.042
2016-03-25T14:10	3.64	3.674	-0.034
2016-03-25T14:20	3.505	3.524	-0.019
2016-03-25T14:30	3.362	3.375	-0.013
2016-03-25T14:40	3.224	3.226	-0.002
2016-03-25T14:50	3.088	3.075	0.013
2016-03-25T15:00	2.95	2.923	0.027
2016-03-25T15:10	2.792	2.773	0.019
2016-03-25T15:20	2.653	2.621	0.032
2016-03-25T15:30	2.521	2.47	0.051
2016-03-25T15:40	2.377	2.324	0.053
2016-03-25T15:50	2.247	2.174	0.073
2016-03-25T16:00	2.102	2.03	0.072
2016-03-25T16:10	1.964	1.892	0.072
2016-03-25T16:20	1.832	1.757	0.075
2016-03-25T16:30	1.706	1.629	0.077
2016-03-25T16:40	1.577	1.513	0.064
2016-03-25T16:50	1.478	1.404	0.074
2016-03-25T17:00	1.377	1.307	0.07
2016-03-25T17:10	1.289	1.224	0.065
2016-03-25T17:20	1.216	1.153	0.063
2016-03-25T17:30	1.153	1.098	0.055
2016-03-25T17:40	1.112	1.061	0.051
2016-03-25T17:50	1.077	1.038	0.039
2016-03-25T18:00	1.072	1.034	0.038
2016-03-25T18:10	1.078	1.05	0.028
2016-03-25T18:20	1.113	1.082	0.031

Appendix D

Mackay Outer Harbour session 2 sea levels

Mackay Outer Harbour from 23rd May to 25th May

Date	Time	actual Reading			
23/05/2016	00:00	5.352	23/05/2016	07:50	2.442
23/05/2016	00:10	5.278	23/05/2016	08:00	2.57
23/05/2016	00:20	5.18	23/05/2016	08:10	2.704
23/05/2016	00:30	5.078	23/05/2016	08:20	2.807
23/05/2016	00:40	4.967	23/05/2016	08:30	2.949
23/05/2016	00:50	4.855	23/05/2016	08:40	3.077
23/05/2016	01:00	4.727	23/05/2016	08:50	3.198
23/05/2016	01:10	4.587	23/05/2016	09:00	3.347
23/05/2016	01:20	4.461	23/05/2016	09:10	3.474
23/05/2016	01:30	4.32	23/05/2016	09:20	3.612
23/05/2016	01:40	4.17	23/05/2016	09:30	3.737
23/05/2016	01:50	4.033	23/05/2016	09:40	3.864
23/05/2016	02:00	3.895	23/05/2016	09:50	3.972
23/05/2016	02:10	3.732	23/05/2016	10:00	4.103
23/05/2016	02:20	3.609	23/05/2016	10:10	4.195
23/05/2016	02:30	3.447	23/05/2016	10:20	4.295
23/05/2016	02:40	3.301	23/05/2016	10:30	4.391
23/05/2016	02:50	3.153	23/05/2016	10:40	4.438
23/05/2016	03:00	3.004	23/05/2016	10:50	4.505
23/05/2016	03:10	2.865	23/05/2016	11:00	4.549
23/05/2016	03:20	2.711	23/05/2016	11:10	4.569
23/05/2016	03:30	2.563	23/05/2016	11:20	4.594
23/05/2016	03:40	2.422	23/05/2016	11:30	4.586
23/05/2016	03:50	2.291	23/05/2016	11:40	4.55
23/05/2016	04:00	2.145	23/05/2016	11:50	4.54
23/05/2016	04:10	2.039	23/05/2016	12:00	4.504
23/05/2016	04:20	1.903	23/05/2016	12:10	4.44
23/05/2016	04:30	1.805	23/05/2016	12:20	4.374
23/05/2016	04:40	1.721	23/05/2016	12:30	4.272
23/05/2016	04:50	1.645	23/05/2016	12:40	4.192
23/05/2016	05:00	1.586	23/05/2016	12:50	4.085
23/05/2016	05:10	1.521	23/05/2016	13:00	3.97
23/05/2016	05:20	1.468	23/05/2016	13:10	3.857
23/05/2016	05:30	1.425	23/05/2016	13:20	3.739
23/05/2016	05:40	1.415	23/05/2016	13:30	3.61
23/05/2016	05:50	1.432	23/05/2016	13:40	3.474
23/05/2016	06:00	1.438	23/05/2016	13:50	3.351
23/05/2016	06:10	1.48	23/05/2016	14:00	3.217
23/05/2016	06:20	1.504	23/05/2016	14:10	3.083

23/05/2016	06:30	1.583	23/05/2016	14:20	2.943
23/05/2016	06:40	1.649	23/05/2016	14:30	2.797
23/05/2016	06:50	1.756	23/05/2016	14:40	2.651
23/05/2016	07:00	1.839	23/05/2016	14:50	2.517
23/05/2016	07:10	1.968	23/05/2016	15:00	2.376
23/05/2016	07:20	2.101	23/05/2016	15:10	2.251
23/05/2016	07:30	2.214	23/05/2016	15:20	2.123
23/05/2016	07:40	2.321	23/05/2016	15:30	1.988

23/05/2016	15:40	1.873	23/05/2016	23:50	5.448
23/05/2016	15:50	1.753	24/05/2016	00:00	5.432
23/05/2016	16:00	1.637	24/05/2016	00:10	5.402
23/05/2016	16:10	1.519	24/05/2016	00:20	5.349
23/05/2016	16:20	1.429	24/05/2016	00:30	5.297
23/05/2016	16:30	1.33	24/05/2016	00:40	5.212
23/05/2016	16:40	1.254	24/05/2016	00:50	5.124
23/05/2016	16:50	1.183	24/05/2016	01:00	5.03
23/05/2016	17:00	1.131	24/05/2016	01:10	4.909
23/05/2016	17:10	1.079	24/05/2016	01:20	4.788
23/05/2016	17:20	1.078	24/05/2016	01:30	4.643
23/05/2016	17:30	1.045	24/05/2016	01:40	4.534
23/05/2016	17:40	1.052	24/05/2016	01:50	4.411
23/05/2016	17:50	1.079	24/05/2016	02:00	4.265
23/05/2016	18:00	1.12	24/05/2016	02:10	4.139
23/05/2016	18:10	1.164	24/05/2016	02:20	4.003
23/05/2016	18:20	1.277	24/05/2016	02:30	3.86
23/05/2016	18:30	1.367	24/05/2016	02:40	3.728
23/05/2016	18:40	1.496	24/05/2016	02:50	3.59
23/05/2016	18:50	1.608	24/05/2016	03:00	3.441
23/05/2016	19:00	1.755	24/05/2016	03:10	3.3
23/05/2016	19:10	1.891	24/05/2016	03:20	3.138
23/05/2016	19:20	2.059	24/05/2016	03:30	2.99
23/05/2016	19:30	2.237	24/05/2016	03:40	2.849
23/05/2016	19:40	2.379	24/05/2016	03:50	2.711
23/05/2016	19:50	2.56	24/05/2016	04:00	2.563
23/05/2016	20:00	2.721	24/05/2016	04:10	2.413
23/05/2016	20:10	2.891	24/05/2016	04:20	2.29
23/05/2016	20:20	3.056	24/05/2016	04:30	2.166
23/05/2016	20:30	3.202	24/05/2016	04:40	2.043
23/05/2016	20:40	3.358	24/05/2016	04:50	1.923
23/05/2016	20:50	3.53	24/05/2016	05:00	1.822
23/05/2016	21:00	3.677	24/05/2016	05:10	1.742
23/05/2016	21:10	3.825	24/05/2016	05:20	1.65
23/05/2016	21:20	3.988	24/05/2016	05:30	1.561
23/05/2016	21:30	4.144	24/05/2016	05:40	1.508
23/05/2016	21:40	4.311	24/05/2016	05:50	1.464

23/05/2016	21:50	4.455	24/05/2016	06:00	1.444
23/05/2016	22:00	4.603	24/05/2016	06:10	1.414
23/05/2016	22:10	4.742	24/05/2016	06:20	1.399
23/05/2016	22:20	4.892	24/05/2016	06:30	1.443
23/05/2016	22:30	4.995	24/05/2016	06:40	1.444
23/05/2016	22:40	5.102	24/05/2016	06:50	1.499
23/05/2016	22:50	5.221	24/05/2016	07:00	1.543
23/05/2016	23:00	5.295	24/05/2016	07:10	1.619
23/05/2016	23:10	5.346	24/05/2016	07:20	1.701
23/05/2016	23:20	5.388	24/05/2016	07:30	1.801
23/05/2016	23:30	5.425	24/05/2016	07:40	1.893
23/05/2016	23:40	5.462	24/05/2016	07:50	2.009

24/05/2016	08:00	2.123	24/05/2016	16:10	1.919
24/05/2016	08:10	2.232	24/05/2016	16:20	1.807
24/05/2016	08:20	2.351	24/05/2016	16:30	1.701
24/05/2016	08:30	2.464	24/05/2016	16:40	1.594
24/05/2016	08:40	2.582	24/05/2016	16:50	1.497
24/05/2016	08:50	2.699	24/05/2016	17:00	1.412
24/05/2016	09:00	2.838	24/05/2016	17:10	1.324
24/05/2016	09:10	2.952	24/05/2016	17:20	1.258
24/05/2016	09:20	3.061	24/05/2016	17:30	1.203
24/05/2016	09:30	3.181	24/05/2016	17:40	1.155
24/05/2016	09:40	3.314	24/05/2016	17:50	1.132
24/05/2016	09:50	3.413	24/05/2016	18:00	1.108
24/05/2016	10:00	3.545	24/05/2016	18:10	1.132
24/05/2016	10:10	3.661	24/05/2016	18:20	1.148
24/05/2016	10:20	3.771	24/05/2016	18:30	1.208
24/05/2016	10:30	3.879	24/05/2016	18:40	1.264
24/05/2016	10:40	3.975	24/05/2016	18:50	1.344
24/05/2016	10:50	4.06	24/05/2016	19:00	1.427
24/05/2016	11:00	4.162	24/05/2016	19:10	1.542
24/05/2016	11:10	4.22	24/05/2016	19:20	1.653
24/05/2016	11:20	4.274	24/05/2016	19:30	1.786
24/05/2016	11:30	4.329	24/05/2016	19:40	1.916
24/05/2016	11:40	4.35	24/05/2016	19:50	2.056
24/05/2016	11:50	4.376	24/05/2016	20:00	2.222
24/05/2016	12:00	4.36	24/05/2016	20:10	2.365
24/05/2016	12:10	4.362	24/05/2016	20:20	2.518
24/05/2016	12:20	4.349	24/05/2016	20:30	2.665
24/05/2016	12:30	4.32	24/05/2016	20:40	2.823
24/05/2016	12:40	4.267	24/05/2016	20:50	2.973
24/05/2016	12:50	4.193	24/05/2016	21:00	3.106
24/05/2016	13:00	4.109	24/05/2016	21:10	3.257
24/05/2016	13:10	4.036	24/05/2016	21:20	3.414
24/05/2016	13:20	3.931	24/05/2016	21:30	3.564

24/05/2016	13:30	3.836	24/05/2016	21:40	3.72
24/05/2016	13:40	3.727	24/05/2016	21:50	3.872
24/05/2016	13:50	3.628	24/05/2016	22:00	4.033
24/05/2016	14:00	3.516	24/05/2016	22:10	4.18
24/05/2016	14:10	3.386	24/05/2016	22:20	4.331
24/05/2016	14:20	3.274	24/05/2016	22:30	4.49
24/05/2016	14:30	3.155	24/05/2016	22:40	4.618
24/05/2016	14:40	3.028	24/05/2016	22:50	4.743
24/05/2016	14:50	2.893	24/05/2016	23:00	4.858
24/05/2016	15:00	2.777	24/05/2016	23:10	4.965
24/05/2016	15:10	2.655	24/05/2016	23:20	5.067
24/05/2016	15:20	2.522	24/05/2016	23:30	5.125
24/05/2016	15:30	2.386	24/05/2016	23:40	5.193
24/05/2016	15:40	2.269	24/05/2016	23:50	5.238
24/05/2016	15:50	2.154	25/05/2016	00:00	5.269
24/05/2016	16:00	2.033	25/05/2016	00:10	5.295

25/05/2016	00:20	5.301	25/05/2016	08:30	2.032
25/05/2016	00:30	5.296	25/05/2016	08:40	2.145
25/05/2016	00:40	5.282	25/05/2016	08:50	2.26
25/05/2016	00:50	5.233	25/05/2016	09:00	2.347
25/05/2016	01:00	5.169	25/05/2016	09:10	2.463
25/05/2016	01:10	5.106	25/05/2016	09:20	2.585
25/05/2016	01:20	5.022	25/05/2016	09:30	2.703
25/05/2016	01:30	4.923	25/05/2016	09:40	2.81
25/05/2016	01:40	4.823	25/05/2016	09:50	2.907
25/05/2016	01:50	4.72	25/05/2016	10:00	3.034
25/05/2016	02:00	4.616	25/05/2016	10:10	3.148
25/05/2016	02:10	4.512	25/05/2016	10:20	3.248
25/05/2016	02:20	4.377	25/05/2016	10:30	3.354
25/05/2016	02:30	4.262	25/05/2016	10:40	3.47
25/05/2016	02:40	4.125	25/05/2016	10:50	3.579
25/05/2016	02:50	4.022	25/05/2016	11:00	3.675
25/05/2016	03:00	3.872	25/05/2016	11:10	3.761
25/05/2016	03:10	3.728	25/05/2016	11:20	3.86
25/05/2016	03:20	3.603	25/05/2016	11:30	3.938
25/05/2016	03:30	3.454	25/05/2016	11:40	3.992
25/05/2016	03:40	3.323	25/05/2016	11:50	4.087
25/05/2016	03:50	3.185	25/05/2016	12:00	4.139
25/05/2016	04:00	3.046	25/05/2016	12:10	4.158
25/05/2016	04:10	2.921	25/05/2016	12:20	4.182
25/05/2016	04:20	2.781	25/05/2016	12:30	4.197
25/05/2016	04:30	2.644	25/05/2016	12:40	4.184
25/05/2016	04:40	2.511	25/05/2016	12:50	4.194
25/05/2016	04:50	2.386	25/05/2016	13:00	4.178
25/05/2016	05:00	2.266	25/05/2016	13:10	4.132

25/05/2016	05:10	2.143	25/05/2016	13:20	4.08
25/05/2016	05:20	2.036	25/05/2016	13:30	4.041
25/05/2016	05:30	1.929	25/05/2016	13:40	3.966
25/05/2016	05:40	1.844	25/05/2016	13:50	3.888
25/05/2016	05:50	1.773	25/05/2016	14:00	3.822
25/05/2016	06:00	1.697	25/05/2016	14:10	3.729
25/05/2016	06:10	1.629	25/05/2016	14:20	3.62
25/05/2016	06:20	1.593	25/05/2016	14:30	3.525
25/05/2016	06:30	1.549	25/05/2016	14:40	3.406
25/05/2016	06:40	1.535	25/05/2016	14:50	3.295
25/05/2016	06:50	1.497	25/05/2016	15:00	3.174
25/05/2016	07:00	1.526	25/05/2016	15:10	3.063
25/05/2016	07:10	1.522	25/05/2016	15:20	2.938
25/05/2016	07:20	1.555	25/05/2016	15:30	2.841
25/05/2016	07:30	1.581	25/05/2016	15:40	2.726
25/05/2016	07:40	1.625	25/05/2016	15:50	2.613
25/05/2016	07:50	1.703	25/05/2016	16:00	2.502
25/05/2016	08:00	1.766	25/05/2016	16:10	2.385
25/05/2016	08:10	1.88	25/05/2016	16:20	2.274
25/05/2016	08:20	1.947	25/05/2016	16:30	2.162

25/05/2016	16:40	2.057
25/05/2016	16:50	1.939
25/05/2016	17:00	1.859
25/05/2016	17:10	1.736
25/05/2016	17:20	1.665
25/05/2016	17:30	1.607
25/05/2016	17:40	1.51
25/05/2016	17:50	1.463
25/05/2016	18:00	1.399
25/05/2016	18:10	1.369
25/05/2016	18:20	1.339
25/05/2016	18:30	1.314
25/05/2016	18:40	1.303
25/05/2016	18:50	1.315
25/05/2016	19:00	1.331
25/05/2016	19:10	1.376
25/05/2016	19:20	1.426
25/05/2016	19:30	1.52
25/05/2016	19:40	1.609
25/05/2016	19:50	1.718
25/05/2016	20:00	1.813
25/05/2016	20:10	1.956
25/05/2016	20:20	2.081
25/05/2016	20:30	2.222
25/05/2016	20:40	2.348

25/05/2016	20:50	2.501
25/05/2016	21:00	2.646
25/05/2016	21:10	2.781
25/05/2016	21:20	2.924
25/05/2016	21:30	3.062
25/05/2016	21:40	3.205
25/05/2016	21:50	3.347
25/05/2016	22:00	3.485
25/05/2016	22:10	3.633
25/05/2016	22:20	3.776
25/05/2016	22:30	3.919
25/05/2016	22:40	4.067
25/05/2016	22:50	4.197
25/05/2016	23:00	4.317
25/05/2016	23:10	4.448
25/05/2016	23:20	4.565
25/05/2016	23:30	4.682
25/05/2016	23:40	4.78
25/05/2016	23:50	4.881