Infrastructure Supporting Mapping of Tidal Planes and Lines

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Abstract: Tidal lines such as Lowest Astronomical Tide, High Water Mark and so on, are used as delimiters in many spheres of activity along the inter-tidal zone. The accurate mapping of these lines is becoming more important as the use of coastal and near shore land intensifies and its value increases.

Simplistically, the mapping of a tidal line, such as the Lowest Astronomical Tide, is the intersection of the topographic surface with the elevation of the required tidal plane.

Tidal heights are known only at tidal stations and tidal range varies from place to place.

It follows that the tidal height also changes, particularly with respect to the conventional surveying reference surfaces such as the Australian Height Datum, the geoid, or the ellipsoid. Tidal planes (conveniently called tidal surfaces) are curved - not geometric planes. As a result of the changing tidal range and the curvature, tidal surfaces are not parallel to the conventional vertical datums, such as Australian Height Datum, the geoid, or the ellipsoid.

In order to represent the curved surface, the area to be mapped is divided into a number of zones. The zones are sufficiently small so that the curved surface within the zone may be regarded as a geometric plane.

In the case of hydrography, tidal heights, Lowest Astronomical Tide, and the height of the seabed relative to the Lowest Astronomical Tide surface are the fundamental entities which provide the depth of water available to shipping.

The AUSHYDROID is the reference implementation of chart datum for Australian case, Lowest Astronomical Tide) within hydrography.

The process used in the establishment of the AUSHYDROID may be applied to other tidal planes, such as Highest Astronomical Tide, Mean High Water Spring Tide, Mean High Water, etc. in order to map the tidal line at which these surfaces intersect the topography.

This paper outlines the development of the AUSHYDROID. It relates the processes to the mapping of all tidal lines.

Keywords: AUSHYDROID, chart datum, High Water Mark, Highest Astronomical Tide, Lowest Astronomical Tide, Low Water Mark, tidal lines, tidal planes.

Introduction: The ongoing development of the Global Positioning System (GPS) as an hydrographic survey tool is now at the point where it is possible to locate the survey vessel and the associated measurements (soundings) in three dimensions relative a geodetic reference frame. In the case of Australia that frame is Geodetic Datum Australia (GDA94). In the first instance, the output from a GPS based hydrographic survey is bathymetry located in terms of the GDA94.

Within calm waters, this development in GPS techniques is reducing the dependency on the water surface tidal as the height reference surface for hydrographic surveys. While it is now possible to determine heading by GPS, hydrography remains dependent on inertial systems to measure vessel motion, that is, heave, pitch, and roll when surveying waters with significant sea and swell conditions.

Navigation charts are graduated, horizontally, in terms of latitude and longitude referenced to a geodetic datum. The elevations, charted depths, are referred chart datum. All of the Australian navigation charts (the so called AUS charts) are referred to the WGS84 and Lowest Astronomical Tide (LAT) for the chart datum. Accordingly it is necessary transform the output from the survey from the GDA94 system to the WGS84 and LAT frame.

The WGS84 and GDA94 are sufficiently close together that, for practical charting purposes, they may be accepted as being co-incident. For the purposes of this paper we refer to WGS84 as the reference frame and do not consider the horizontal transformation further.

The Objective: The process reported in this paper was developed to facilitate the transformation of the elevations from the WGS84 system to LAT. It is required to create a transformation process relating chart datum (the zero elevation for charted depths) and the zero elevation ellipsoidal surface.

Constraints: It is particularly important to note that chart datum has been used for a long time and we are required to retain it at its established elevation irrespective of any technique used to realize the datum surface or used to obtain the depths to be shown on the chart.

Because of the hydrodynamic effects of the horizontal movement of the water as the tides rise and fall, the range of the tide changes from place to place.

Unfortunately there is no theory available to determine the range of tide at any place and, as a result, it is necessary to ascertain the height empirically by tidal measurement, analysis and prediction. Accordingly the height of the tide and consequently the height of the tidal planes are known with certainty only at the tidal stations where observations are available.

The AUSHYDROID: The height separation concept was introduced to achieve the transformation and to maintain the chart datum at its established elevation. The AUSHYDROID (Martin and Broadbent 1999) is the ellipsoidal height of chart datum and the parameter “L” is the height separation between the WGS84 ellipsoid and chart datum. The AUSHYDROID and “L” are the hydrographic equivalent of the geodetic AUSGEOID and “N”.

The objective is to be able to determine “L” at any point on a chart.

Discussion: It is clear from the following tabulated examples that the spatial variation in the elevation of LAT is large enough to warrant making an estimate of it (and therefore of “L”) at places between tidal stations.

Table 1: Tidal Heights and Ranges at Selected Tidal Stations in Queensland Waters.

Place	HAT (m)	MHWS (m)	MSL (m)	AHD (m)	LAT (m)	Range (m)
Brisbane Bar	2.71	2.16	1.22	1.243	0.00	2.71
Mooloolaba	2.13	1.60	0.95	0.990	0.00	2.13
Noosa Head	2.18	1.74	1.05	1.123	0.00	2.18
Waddy Point Fraser Island	2.26	1.68	1.04	1.007	0.00	2.26
Bundaberg (Burnett Heads)	3.58	2.86	1.71	1.693	0.00	3.58
Gladstone	4.69	3.91	2.32	2.268	0.00	4.69
Hay Point	7.14	5.78	2.36	3.340	0.00	7.14
Mackay	6.41	5.28	3.00	2.941	0.00	6.41
Shute Harbour	4.26	3.24	1.90	1.907	0.00	4.26

Table 2: Tidal Heights and Ranges at Selected Tidal Stations in Morton Bay.

Place	HAT (m)	MHWS (m)	MSL (m)	AHD (m)	LAT (m)	Range (m)
Brisbane Bar	2.71	2.16	1.25	1.243	0.00	2.71
Manly Boat Harbour	2.78	2.21	0.95	1.290	0.00	2.78
Wellington Point	2.82	2.25	1.26	1.330	0.00	2.82
Victoria Point	2.93	2.36	1.39	1.410	0.00	2.93
Cabbage Tree Creek	2.60	2.07	1.19	1.310	0.00	2.60
Woody Point	2.58	2.05	1.15	1.230	0.00	2.58
Scarborough Boat Harbour	2.41	1.92	1.12	1.170	0.00	2.41
Bongaree - Bribie Island	2.33	1.86	1.06	1.100	0.00	2.33
Tangalooma	2.49	1.99	1.15	N/A	0.00	2.49
Caloundra Head	2.04	1.62	0.95	0.990	0.00	2.04
Mooloolaba	2.13	1.60	0.95	0.990	0.00	2.13

HAT/LAT - Highest/Lowest Astronomical Tide. MHWS – Mean High water Spring Tide
MSL – Mean Sea Level. AHD – Australian Height Datum

Because of the lack of theory concerning the height of LAT, we are left with the following choice of technique used to undertake the estimation:-

1. Create an analogue of the natural system, i.e. a carefully validated hydrodynamic model; or
2. Use an arbitrary mathematical process, such as interpolation or extrapolation.

Hydrodynamic Models: An hydrodynamic model links the physics of the water movement induced by the rise and fall of tide and the bathymetry to derive the height of the water level at any point in the waterway. Based on those water levels, the elevation of LAT may then be deduced for any point.

Detailed, high precision hydrodynamic models are costly to build and validate. Although they are becoming more commonly available, there are very few models available for coastal streams and estuaries where high resolution is required in order to provide a reasonable level of certainty in the derived water levels. Accordingly there are so few available that to consider them further does not advance our cause in realizing LAT.

As a result is has become necessary to fall back and rely on the mathematical processes of either extrapolation and or interpolation.

Mathematical Processes: In the absence of any attempt to relate cause and effect, the arbitrary nature of extrapolation is intuitively dangerous - interpolation seems a little less so, particularly for a system that has no discontinuities. Although concerned with tidal boundary lines Nichols (1989) writes:- "Consequently, even interpolation between Reference Ports or Secondary Ports with known reference surface heights only yields an approximation of the elevation at intermediate survey sites."

Accordingly it is the contention of the present authors that the interpolation process is a necessary component of the estimation of the height of the tidal planes, and "L".

Tidal Planes: We have shown that the tidal range varies spatially. It follows that the elevation of the tidal planes also changes, particularly with respect to the conventional surveying vertical reference surfaces such as the Australian Height Datum (AHD), the geoid, or the ellipsoid.

All tidal planes, including chart datum, are curved surfaces that are not parallel to the conventional vertical reference surfaces. They are not geometric planes.

Further it is important to recognize that tidal plane heights are known only at tidal stations.

While the following discussion refers to chart datum, the principles apply equally to the estimation of the height of any other tidal plane.

Chart Datum: In order to represent the curved chart datum surface, the chart is divided into a number of zones (polygons) which we call co-tidal zones. The zones are created small enough for the curved surface within each zone to be regarded as a geometric plane. This approximation simplifies the estimation of the elevation of chart datum and thus "L" value at any point.

Traditionally the tidal heights relative to chart datum are based on:-

1. The observed the tidal readings at one or more tidal stations and; and
2. Some interpolating techniques together with the associated assumptions.

Because of the requirement to retain chart datum at its established elevation, and our contention that the interpolation process is a necessary component of the estimation of the height of LAT, chart datum, we make use of the traditional tidal assumptions to estimate "L".

Tidal Assumptions: Because the tidal times and heights are not the same everywhere, i.e., tidal times and heights are site specific - they apply only at the place where they were recorded.

Accordingly it is usual to observe the tide at one place (at least) and to make an assumption about the times and heights at other places nearby. There are two usual assumptions made:-

1. Accept that the tide is the same at all places in the immediate vicinity of the tidal observation station (Assumption - there is no appreciable change in the tidal times or range); or,
2. Interpolate the tidal time and height from observations at a number of stations. There are two commonly accepted techniques. They are:-
    a. Linear -The tidal height at a point along the line joining the tidal stations is interpolated by distance from simultaneous readings from each station. All points on a line at right angles to this point are assumed to have the same tidal height. The tidal stations are situated at the ends of the survey area along the line of the tidal flow (Assumption - the change in tidal time and range (and the related elevation of the datum) occurs along the line of flow and that the cross flow (and cross slope in the datum) is minimal); and,
    b. Planar - The water surface is assumed to be a geometric plane between three tidal stations. In this way any cross slope incorporated into the interpolation.

Interpolation of tidal heights implies that the height of the chart datum is also interpolated - necessarily in the same manner as the tidal heights. Accordingly the interpolation method used to interpolate the tidal heights defines the height of chart datum at places in between the tidal stations. Unfortunately this important fact has not always been recognized in the past.

Co-Tidal Zones: The traditional techniques for the tidal interpolation are de facto co-tidal zoning. The tidal height with in each zone is known by observation or estimated using known relationships to the recorded tides at some adjacent, reference, tidal station. Zones may have more than one reference station in which case the interpolation method to be used within a zone is a mandatory component of the co-tidal information.

At this stage, the information attached to each co-tidal zone is:-

1. The spatial extent;
2. The chart datum in use (always LAT);
3. The applicable tidal station or stations; and,
4. The applicable interpolation technique.

Selection of Zones: For those areas without a previous survey or in which we wish to establish different tidal stations or tidal reduction techniques, the zones are selected so that zone boundaries fall along the banks where little of no flow exists. Tidal stations are placed so that the flow is along the line joining the stations. In this way we capture any slope in the water surface or in the chart datum.

Because of the requirement to maintain chart datum at its established elevation in areas with an established datum, the spatial extent of each zone is selected to reflect the tidal stations previously used. The stations and the tidal reduction technique used are adopted for the zone.

In this way the ability to continue surveying using the traditional tidal reduction techniques is maintained.

Example Zone Definitions:

Zone 0301 Interpolate the tides linearly between the Victoria Point tidal station 007007A (Latitude 27^o 35 S and Longitude 153^o 19’ E) and the Redland Bay Jetty tidal station 007005A (Latitude 27^o 37 S and Longitude 153^o 19’ E)
Datum is LAT

Zone 0302 Interpolate the tides linearly between the Toondah Harbour Jetty tidal station 007002A (Latitude 27^o 32 S and Longitude 153^o 17’ E) and the Wellington Point tidal station 007204A (Latitude 27^o 28 S and Longitude 153^o 14’ E)
Datum is LAT

Zone 0304 The Manly Boat Harbour - use tides as recorded at the Manly Boat Harbour tidal station 007105B.
The datum is LAT
(27^o 30’ - 153^o 21), (27^o 30 S - 153^o 25), (27^o 35’ - 153^o 25’), (27^o 35’ - 153^o 21’), (27^o 34.5 - 153^o 20’)

Shape of waterway.	**Example.**	**Tidal Reduction Technique.**
Small rectangle	Zone 304	Tides at a single station (accept that the tide is the same at all places in the immediate vicinity of the tidal observation station)
Channels	Zone 301	Linear - Interpolate the tidal time and height from observations at a two tidal stations, one at each end of the channel;
Non-channelized	Zone 302	Planar - Interpolate the tidal time and height from observations at three stations. Note: - the example zone is presently defined by reference to two stations. However with the implementation of the AUSHYDROID three tidal stations will be used.

The AUSHYDROID: In order to accommodate bathymetry referenced to the ellipsoid, we now extend the co-tidal information for each zone to include the details required to determine “L”

In accordance with the concept that the AUSHYDROID is curved surface, we establish a grid of points, each with its own “L” value and a specified interpolation technique for the calculation of intermediate points. All that is necessary is to ascertain the “L” value at each tidal station and to interpolate it for every point using the interpolation technique applicable to the co-tidal zone.

This is analogous with the AUSGEOID in which a grid of points were generated from the gravity observations and model. The height of the geoid at any point is obtained by use of the interpolation technique is provided as a part of the published AUSGEOID package.

Table 3: AUSHYDROID "L" Values at Selected Tidal Stations in Morton Bay.						
Place	HAT (m)	MHWS (m)	MSL (m)	AHD (m)	"L" (m)	LAT (m)
Brisbane Bar (Whyte Island Gauge)	2.71	2.16	1.25	1.243	40.253	0.00
Wynnum Creek	2.78	2.21	1.27	1.29	40.159	0.00
Manly Boat Harbour	2.78	2.21	1.27	1.290	40.107	0.00
Toondah Harbour	2.77	2.21	1.29	1.25	40.041	0.00
Redland Bay	2.95	2.35	1.35	1.41	N/A	0.00
Amity Point	2.22	1.77	1.09	1.02	40.485	0.00
Chain Banks					N/A	0.00
Hanlon Light					N/A	0.00
Dunwich	2.68	2.13	1.22	1.30	39.964	0.00
Potts Point	2.85	2.27	1.32	N/A	N/A	0.00
Wellington Point	2.82	2.25	1.26	1.330	40.037	0.00
Tingalpa Creek	2.92	2.33	1.29		40.087	0.00
Victoria Point	2.93	2.36	1.39	1.410	39.733	0.00

It has not yet been decided whether to create a regular grid of "L" values at such a density that a simple linear interpolation between grids will suffice or to simply adopt the co-tidal zone parameters including the "L" value and interpolation technique applicable to the zone. In this respect, experience with the publication of and use of the AUSGEOID will be sought before adopting either approach.

Treatment of other Tidal Planes: Finally we point out that LAT is a tidal surface (tidal plane) the elevation of which is statistically determined at each tidal station. It follows that the elevation of any tidal plane may also be interpolated in the same way as is being established for the AUSHYDROID.

Determination of Tidal Lines: Once the elevation of a tidal plane can be determined for any point, it becomes a relatively trivial matter to intersect the tidal surface with the bathymetry or topography to obtain a tidal line (mark). It this way it is possible to map the MHWS (high water mark HWM), low water mark, highest astronomical tide line, or lowest astronomical tide line.

Figure 4 MHWS line illustrates this development of our proposal. It depicts the intersection of the HAT and the MHWS (high water mark in Queensland) tidal planes with the topography surveyed by high precision airborne laser scanner.

Comments: It is implicit in the foregoing that the AUSHYDROID and the tidal planes are referred to geodetic frame. The Queensland implementation of the AUSHYDROID is linked to the Australian geodetic network (GDA94) by means of the Queensland Tidal Reference Frame. The frame consists of the 22 permanent tidal stations operated by the Queensland state agencies and incorporates the tidal datum epoch concept to monitor sea level changes that are being attributed to the green house effect. Broadbent G. J., (2003).

Concluding Remarks: The tidal interface is becoming a zone of great interest administratively, economically and environmentally.

As the population rushes to the coastal towns and cities, the demand for and the value of our coastal land is increasing rapidly. The administrators are continually frustrated by the paucity of mapping of the tidal lines used to delineate littoral boundaries to private and public property and the various administrative zones.

Once a mapping of the elevations of the various tidal planes is implemented, and detailed, precise topography and bathymetry are available from such sources as airborne laser scanning, then the precise mapping of the tidal lines, high water mark, HAT etc., becomes feasible and practicable.

The global positioning system (GPS) technology employed in modern hydrographic surveying has developed to the point where it is possible to measure the position of the sounding platform in height as well as the horizontal dimensions. This development of the GPS surveying techniques is reducing the dependency on the water surface tidal as the height reference. Martin R.J., Broadbent G. J., (1999), and Castalanelli C., (2003). Reduction of GPS derived elevations to chart datum is however dependent on a knowledge of the height of chart datum relative to the zero ellipsoidal surface. The AUSHYDROID provides that link.

The work reported here is very much "work in progress". The principles to establish the elevation of the tidal planes have been set out. All that remains is to implement these principles and build the infrastructure to support the mapping of the tidal planes and lines.

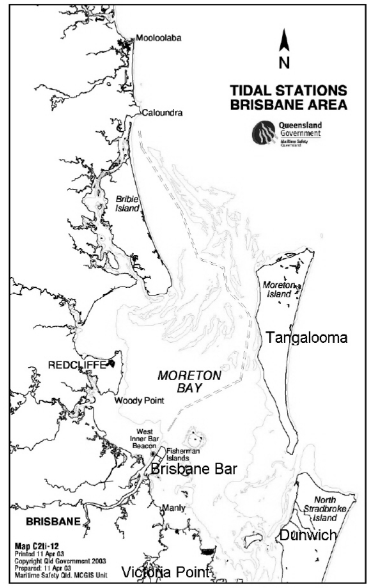

Figure 1 Queensland

Figure 2 Moreton Bay

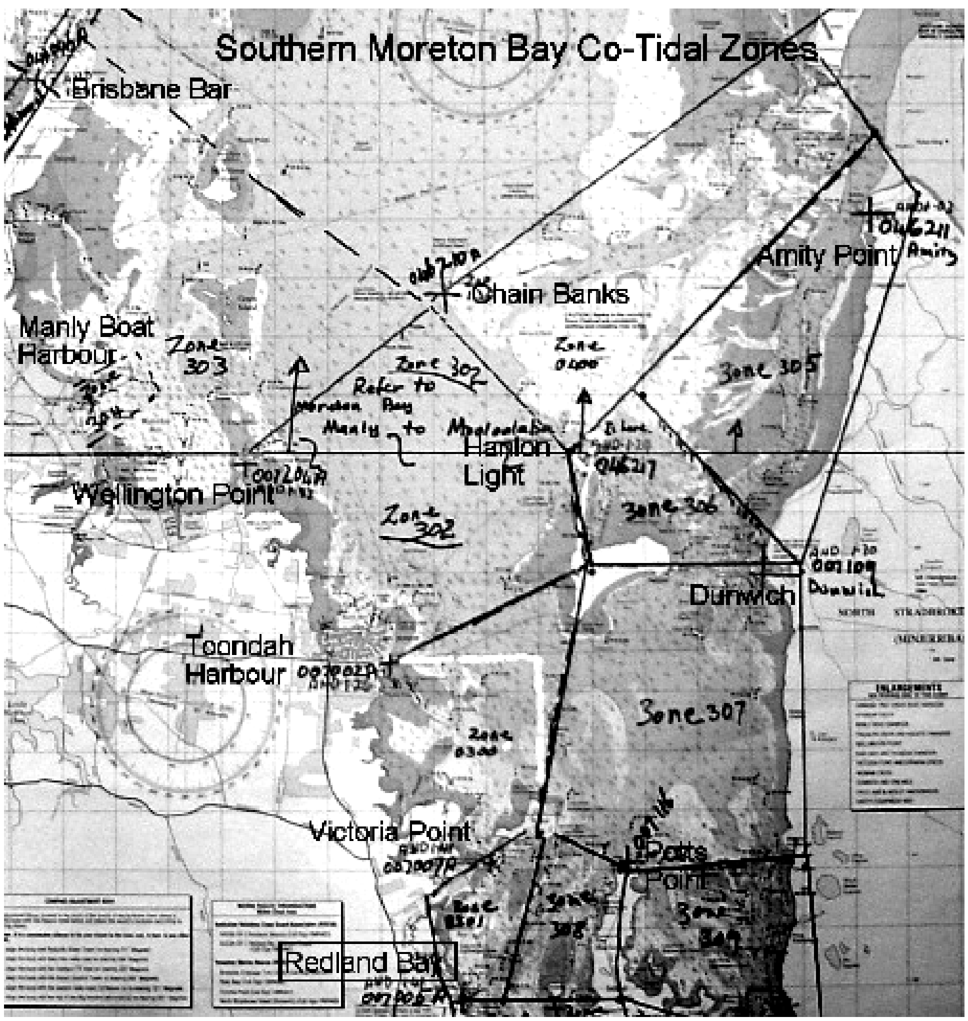

Figure 2 Southern Moreton Bay Co-Tidal Zones

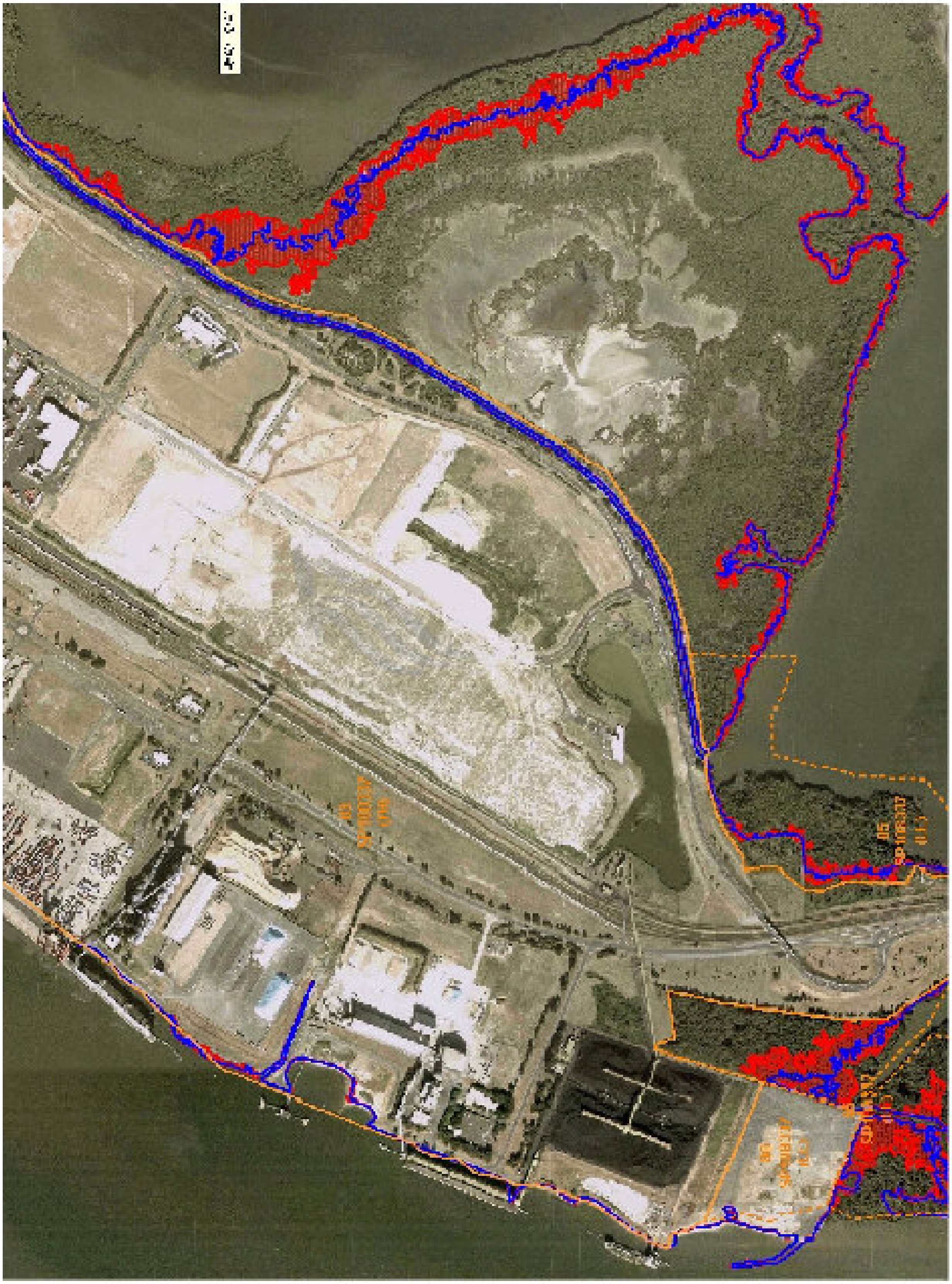

Figure 4 MHWS line derived from Airborne Laser Scan Topography

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