Coastline Delineation by Aerial Photography

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Abstract

This paper was originally presented to the 48th ANZAAS Conference held in Melbourne between 29th September and 2nd October, 1977.

It describes the programs undertaken by the Division of National Mapping to delineate mean low water and mean high water coastlines.

Remote sensing techniques using black and white infra-red aerial photography have been adapted to provide a means to accurately locate and identify the waterline at the instant of MLW and MHW. Ground truth testing complemented the photography to aid interpretation while the determination of the instant MLW and MHW was approximate within specified intervals which were dependent upon the physical characteristics of the tide and coastline.

Mean High Water line is the line drawn on Topographic maps to show the interface of the land and the sea whilst the Mean Low Water line is the same interface shown on Bathymetric maps. It is also used for territorial boundary purposes.

The Division of National Mapping in the Commonwealth Department of National Resources is the Australian Government's civilian mapping agency. It is responsible, in co-operation with the other members of the National Mapping Council, for the production of topographic maps over the whole of Australia. The Division's mapping program has seen the production of several map series, the International Map of the World (IMW) Series at 1:1 million scale and two topographic series at 1:250,000 and 1:100,000 scales. The 1:100,000 series is only part complete whereas the IMW and 1:250,000 series are already complete with second editions already published.

Map quality depends upon specifications and standards of accuracy and the standards applying in Australia today require depicted detail to be correct to within half a millimetre on the map. This means that detail must be fixed to within 125 m on the ground for the 1:250,000 scale topographic map but the same detail must be fixed to within 50 m of its true position on the ground for the larger scale 1:100,000 map. This is the essential requirement that dictates the ground survey techniques that must be used for compilation control.

This paper discusses how we at National Mapping have dealt with the problem of identifying and plotting the coastline on our topographic maps. The ubiquitous blue line which depicts the land/sea interface has a much lesser significance at 1:250,000 scale than it has at 1:100,000 scale, so that where there was no problem with the former series we found we were faced with a real one for the later 1:100,000 series.

The real problem resulted from the accuracy requirement which meant that a discerning survey technique would be required and, of course, an appropriate definition for the coastline would also be needed.

The Coastline Defined

There is much discussion these days upon what actually constitutes the Australian coast. A properly defined coastline is important for international boundary purposes and has become important to the Commonwealth and State Governments especially since the exploitation of offshore resources has become a reality.

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The foreshore has generally been held to be that area between high tide and low tide and Common Law has prescribed the foreshore line as being the mean high water (MHW)[1] line and this can be related to a mathematically definable value. Mean Low Water (MLW) line has some legal significance, and in Victoria prior to 1868 it was the waterline boundary for private property, however, there is a greater significance for us all because this is the line that interests the States and the Commonwealth at the present time. There are other waterlines which are used for varying purposes, for example, the lowest low water is a very useful datum line for hydrographic charts because depths shown on such a chart can be interpreted by a navigator as the minimum depth he can expect to find no matter what the state of the tide.

The requirement for the coastline to be defined for our 1:100,000 maps came at about the same time as did the need for a precise baseline for our international boundaries so that National Mapping was confronted with two similar but separate problems. Two alternative waterlines, MHW and MLW, could be used and although the technology for identifying and plotting each line is the same there is a much greater degree of difficulty with MLW than there is with MHW.

MHW was chosen as the most appropriate waterline to depict coastline on the 1:100,000 map series so that the blue line on these maps is MHW except where mangroves occur. In that case a broken blue line is shown on the seaward edge of the mangrove symbol and this line is stated to be an approximation of the coastline. This was done in order to simplify the cartographic presentation of mangroves as much as to overcome the difficulty of identification of a coastline which would otherwise be located within a stand of mangroves and could be misleading to the map-user. On open beaches MHW line is a recognisable line whilst within mangroves it is not.

MLW is the datum for baselines for territorial boundary purposes and maps with these baselines were required for negotiations between the Commonwealth and the States.

However, the accurate location of MLW presented the Commonwealth with a massive and expensive task, the extent of which only became apparent after field surveys were undertaken on the east and north-west coasts.

The decision has now been taken to prepare base maps showing MLW determined from the best available data already to hand. This will be adequate for the purpose and is expected to provide a satisfactory baseline for the determination of territorial boundaries, without any further delay.

Australian Tides, Tide Gauges and the AHD

The Australian Height Datum (AHD) is the datum for the standard benchmark network for Australia. It was established in 1971 from precise levelling throughout the mainland and connected to 30 tide gauges carefully sited around the Australian coast. The field investigations included a programme of continuous recordings at these tide gauges, mostly for the first time, over a minimum period of one year.

A value for mean sea level (MSL) was established from the tidal data and the levelling and this value is the datum defined as the AHD. However, it is worthy of note that by holding the value fixed in the mathematical adjustment of the levelling network strain was observed. This led National Mapping investigators to recommend further investigations into the mathematical models for tide gauge zeros and they recommended that this should include more observation data at the tide gauges (Roelse et al 1971).

The tides on the Australian coast have been recorded at various locations since early European settlement but only when the AHD was established were they integrated into a homogeneous system. There are about seventy-five reliable tide gauges along the coast but they are mostly located in the eastern states leaving the north and north-west with only sparsely located sites. These gauges provide the primary network but there are a large number of sites making up a secondary network. However, some of the given values for the harmonic constants for the tides there are based upon limited observations. The tidal data published in the Australian National Tide Tables has been accepted by National Mapping as the best information available for predicting tides on the Australian coast.

The Aerial Survey

National Mapping has developed a strong preference for remote sensing technology for mapping. Requirements for efficiency and for undertaking tasks within the bounds of tight budgets have led us to a heavy relience on aircraft and aerial photography and convinced us that the use of infra-red sensitive emulsions offered the best prospects for success to delineate the Australian coastline within a reasonable time.

Before considering the techniques we developed for the survey, we should firstly have a look at the physical problem we faced. The primary requirement was to produce a map with the coastline in the correct position, or at least correct within the limits of the allowed accuracy, so that we had to position the blue line of the coastline within 50 metres of its true position. Now the height of MHW can be mathematically determined so that ideally all that we needed to do was photograph the coastline at the instant the tide reached MHW level. The actual margin for error in locating the water's edge at MHW would depend upon the beach gradient, because the error in planimetric position due to a difference in tidal height is a simple multiple of the gradient.

Beach gradients vary, of course, from place to place and even between seasons at the same place whilst the instability of foreshores is a factor to be reckoned with. The gradient of the beach at around the MHW line generally is of the order of 1 in 8 easing out to 1 in 10. This value is only a rough figure and in fact under operational conditions we always tried to estimate whether the gradients varied and in some places, such as along the shore of the Gulf of Carpentaria, we found them very much different, more like 1 in 30 and more. However, it is enough to say that on the basis of this kind of estimate and with a good safety margin we always set out to locate a height to within one metre of the true MHW level.

Tide heights can be predicted from the Australian National Tide Tables but we found that we also had to monitor the actual tides by simultaneous ground work during aerial operations. This consists of reading tide gauges to determine whether the tides are behaving as predicted and it is only a simple precaution to detect whether unusual factors, such as weather, are influencing the tides. We found, however, that we needed to take observations to determine tidal factors because the secondary tidal network was not sufficiently dense for our requirement. This was especially the case in the remote north-west of Australia.

Commencing in 1970 we began testing films and film/camera filter combinations to seek an optimum operational procedure. We also used ground truth testing to build up our experience in the interpretation of the water line on the aerial photographs. The interpretation of the water's edge on aerial photography requires skill and experience, especially with infra-red films.

Field Operations

The field operations are made up of two components, namely, aerial photography and tidal observations on the ground.

Before aerial operations commence we collect as much information as we can to predict the tides in the area where the identification of the coastline is required. Such information as tidal gauges in the primary network and tidal constituents for secondary ports are published in the Australian National Tide Tables. We also seek unpublished data which may be available from a variety of sources, such as local authorities. This information is converted into hard-copy computer print-out predictions for the likely period of the survey.

If a gap in our predicted information on the coast is identified we launch field parties to make tidal observations before aerial operations commence. This additional data although only over a short duration is used to determine approximate values of tidal constituents which are then used to strengthen the secondary network to make our predictions more reliable.

Aerial operations are based upon tidal predictions, which predetermine the most suitable times for photographic sorties. The requirements for optimum quality of the aerial photography are that sorties take place during daylight hours with a sun-angle greater than 20 degrees. Therefore, operations are timed to occur when the tide is at about MHW. Field observing teams in radio contact with the aircrew are stationed at a central tide gauge and at temporary observing sites at each end of the proposed photo run. Ground parties continuously pass tidal information to the aircrew during flights.

The ideal condition for "capturing" the tide occurs when the water rises to a height just about MHW, in effect by a margin equal to the tolerance limit. However, this condition only occurs a few days each month so that it is more usual to plan a sortie when the tide is passing through MHW either on the rise or on the fall. Because a falling tide leaves a wet-mark on the sand which makes photo interpretation difficult we prefer to operate on rising water only and the range of the tide for that area becomes the limiting factor for the duration of the day's operations. During neap tides no operations may be possible and at the other extreme during spring tides the duration of operations may be as short as ten minutes, especially where large tidal ranges occur as in the region of Broome, Western Australia.

Photography operations are always planned so that the aircraft flies with the tide, that is, the flight direction along the coast is set so that it is the same as the tidal stream. For example, for tidal photography in north-west Western Australian, high tide reaches Broome later than it does at Port Hedland so that the flight would commence at Port Hedland and terminate at Broome. This is a logical approach and ensures more effective use of time.

Infra-red films are less stable than panchromatic films and must be handled carefully. We rush exposed film back to Melbourne for processing as quickly as possible.

Office Processing

Each film is processed at photographic laboratories in Melbourne then annotated and printed. Finally we prepare key diagrams of the photography for our aerial photography library.

This coastline photography is at a scale of approximately 1:34,000 and has a forward overlap of 60%. Skilled interpreters, using stereoscopic inspection

Fig. 1

Fig. 2

LEGEND

A: Mangroves
B: Land above tidal influence
C: Sea water
D: Inter-tidal)

Photographs taken in the Exmouth Gulf area of north-west Western Australia.

Plate 1: Infra-red film **Plate 2: Panchromatic film**

Note the different tones of the topographic detail and the vegetation. The *panchromatic film records the different* species of mangrove while the distinction is hardly visible on the infra-red. The water boundary is clearly delineated on the infra-red with very little water penetration but note the difference in panchromatic.

Fig. 3

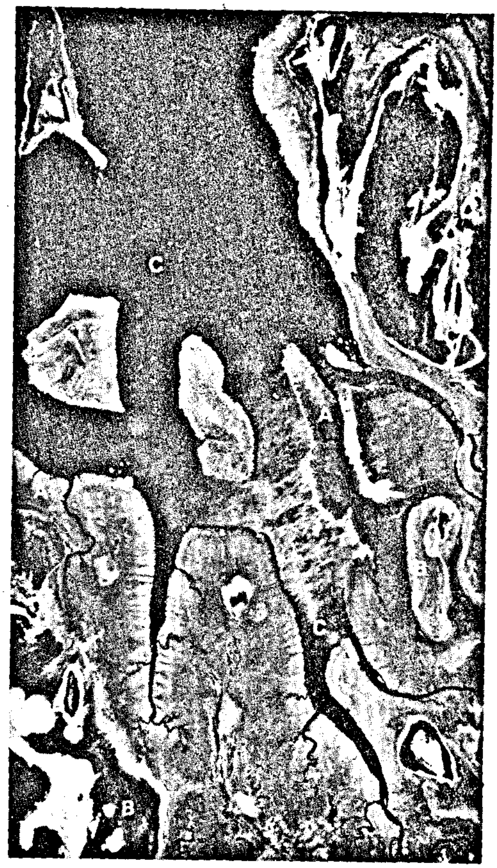

Fig. 4

Photographs also taken in the Exmouth Gulf area.

Both films are infra-red.

Plate 3: Mean Low Water **Plate 4: Mean High Water**

The water line is clearly delineated and there is evidence of water penetration where the outline of the inter-tidal flat on Plate 3 is just visible on Plate 4. However, the water line is clearly identifiable, cf. the western edge of the island in the north-west corner of the plates.

techniques to view the coastline in three dimensions, identify the waterline on the photography then they transfer this identified line on to manuscript compilations of the 1:100,000 map using photogrammetric plotting equipment.

The transfer is usually carried out with simplified plotting equipment such as the Bausch and Lomb Zoom Transferscope (ZTS) which has been specifically designed for the plotting of additional detail on existing maps. Our compilations are usually compiled from mapping photography, using panchromatic aerofilm designed for high altitude photography and not, therefore, suitable for waterline identification and in any case it is impracticable to schedule mapping photography to coincide with MHW. In consequence MHW photography is flown so that it is ready to be used when the compilation has been completed.

Summary

The techniques described above have been used to photograph the Australian coastline between Geraldton in Western Australia clockwise around the coastline as far as Fraser Island. This coastline included the areas where tidal ranges are the greatest as distinct from Southern Australia where the tidal ranges are least. In terms of significance for our mapping then this is the region where it is important and it does coincide with the Division's prime responsibility for mapping.

In order to improve the accuracy of the interpretation of the MHW mark we have used the technique of flying photography when the waterline is at a level just above and also just below MHW, the MHW is identified by interpolation. However, for all intents and purposes, field surveys for MHW have been completed.

The field work for MLW is the same as for MHW except that the beach gradients in the vicinity of MLW are of the order of 1 in 30 to 50 so that tighter limits on predicting tide heights are necessary. The requirements for ground support for aircraft operations is a major consideration so consequently the field parties on this work are larger than those for MHW work. However, for the sake of efficiency we have tried to undertake both MHW and MLW surveys simultaneously.

MLW has been determined by the techniques described in Western Australia from Geraldton to Darwin and on the southern coast of New South Wales but no more field work is proposed for the reasons given earlier in this paper.

We found Wild RC9 and RC10 cameras with their superwide angle lenses ideal but we have also used Hasselblad 70mm format cameras and found them quite suitable. We have also used red as well as yellow filters and found better results came with red filters.

We have found that the techniques have been highly effective especially for delineation of MHW. It seems to be the best and most effective method for delineating MLW but it is more expensive in terms of both money and the Division's resources than for MHW. However, it will be the method used in the foreseeable future if National Mapping is required to delineate MLW with greater precision than has been done.

References

1. Commonwealth of Australia: *Specification for Topographic Map Series, Vol. 1, 1:100,000 Scale.*

2. Kenardy, A. M., *Tidal Boundaries,* Paper read to The Institution of Surveyors (Australia), 19th Australian Survey Congress, May, 1976.

3. Roelse, A., Granger, R. W. and Graham, J. W., *The Adjustment of the Australian Levelling Survey, 1970-1971,* Technical Paper No. 12, Division of National Mapping, June, 1971.