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The 18th and 19th Century Charting of Sydney Harbour / Port Jackson

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Summary: To examine the planimetric accuracy of early nautical charts of Port Jackson (or Sydney Harbour), Australia's most important port at that time, the shorelines in four charts are compared with the modern one. The charts examined are from 1791, 1822, 1859 and 1899. Two analysis methods were used. One with ArcGIS georeferenced each of the old charts to the modern shoreline and calculated root mean square differences between a set of common control points. The other used MapAnalyst to construct a distortion grid and displacement vectors for each of the old charts as they were compared with the modern shoreline. MapAnalyst was also used to calculate root mean square differences and mean position errors (MPEs). It was found that overall, as one would expect, the achieved accuracy improved with time. The earliest chart, that of 1791, had a mean position error (MPE) of 326 m. The survey for this chart was carried out within a few weeks of first European settlement and took only nine days. In the latest chart examined, that of 1899, the MPE had decreased to 38 m. One intriguing finding was that the overall accuracy of the 1859 chart was less than that of the 1822 chart, but in the main shipping areas, where accuracy was more important, the 1859 chart was better. It seems more care was taken where it mattered.

Introduction

An often overlooked aspect of the early history of Sydney, Australia, and its harbour is that, as soon as the first European settlers entered its estuary, Port Jackson, in 1788 there was a clear need to chart its water depths. This was necessary to discover which areas were accessible to craft of various sizes and for safety of navigation. Up to the present day authorities have seen an ongoing need to survey water depths within Sydney Harbour so as to produce ever better maps of the areas safely accessible for various sizes of water craft and this was done by a variety of Royal Navy expeditions throughout the 18th and 19th centuries. As part of a project, by the writer, into early changes in water depths in the harbour it was thought desirable, first of all, to assess the planimetric accuracy of the early nautical charts. To do this the accuracies achieved in the shorelines in the 18th and 19th century charts are compared with that obtained by modern methods. Four surveys which covered the eastern part of the harbour, shown in Figure 1, are considered - those of 1788, 1822, 1859 and 1890.

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Figure 1 with place names used in text.

The Nautical Charts

The 1788 survey

The first European settlers arrived at Sydney in late January 1788. By 6th February of that same year two of the officers, Lieutenants John Hunter and William Bradley had completed a survey of the harbour from the harbour entrance to 'The Flats' (present day Homebush Bay), approximately 5.6 km inland from the western edge of Figure 1 (Bradley, 1969; Hunter, 1968). George Raper, who assisted Hunter and Bradley, made a copy of their chart in 1791 (National Library of Australia, 2007) as part of his training (Raper, 1791). (See Figure 3, later in the text, for the section of the chart analysed and http://nla.gov.au/nla.map-rm3458 for the whole chart, in scale 1:98000 approximately). Neither Hunter nor Bradley gave much detail in their writings of how they carried out the survey or the instrumentation used. Hunter wrote of making as good a survey as circumstances permitted. Both he and Bradley write of landing to take sightings and Bradley mentions measuring "another" baseline, implying that more than one was measured. The Royal Commission of 1866 (New South Wales Legislative Assembly, 1866) described it as a compass survey, that is, no theodolites nor horizontal sextants were used.

The 1822 survey

The second survey considered was carried out by John Septimus Roe, who was the assistant surveyor to hydrographer Phillip Parker King from 1818 to 1822 during the latter's extensive surveys of the Australian coast (Hordern, 1997). King had been tasked with surveying the parts of the Australian coast missed by Mathew Flinders in his circumnavigation of Australia. King worked mostly around western and north-western Australia, but used Sydney as one of his bases. Roe surveyed much of the harbour as far west as The Flats and beyond in 1822 (Roe 1822) but, for areas which he did not cover, used soundings and shorelines from the work of Hunter and Bradley, with some additions from a survey of de Freycinet in 1802 (de Freycinet, 1812). Figure 5, below, shows the section of Roe's chart analysed, with the whole chart (scale 1:35000

approximately) displayed at http://nla.gov.au/nla.map-raa5-s9. The instrumentation, including theodolites, available to Roe would have been far superior to that available to Hunter and Bradley. In addition Roe took three months to complete his survey and production of the initial chart, compared to Hunter and Bradley's nine days (Hordern, 1997). In Roe's chart shown later in Figure 5, the shaded parts of the shoreline are those resurveyed by Roe, while the unshaded portions were merely copied from the charts of Hunter and Bradley and of de Freycinet.

The 1857 survey

With the discovery of gold in the 1850s and the need to protect the gold shipments, the Royal Navy began to take a greater interest in New South Wales and in 1859 established a new Australian Station, a naval command separate from the East Indies Station, responsible for waters around Australia. It was initially under the command of a Commodore but upgraded in 1884 to be commanded by a Rear Admiral (Andrews, 1986). This greater naval involvement may explain the more detailed hydrographic surveys which began from about this time.

The 1857 British Admiralty survey was carried out by Hutchison et al (1859) See the analysed section of the chart in Figure 7 below and the full chart at http://nla.gov.au/nla.map-rm2813 (scale 1: 6600). It was under the direction of a Captain Henry Mangles Denham F.R.S. who had been tasked with surveying parts of the south-west Pacific in HMS *Herald.* The chart of this survey, engraved in 1859, had the high soundings density one would expect with a modern hydrographic survey and it clearly marks a significant departure from earlier mapping efforts of Sydney Harbour. The area covered was from 1.5 miles (2.4 km) seawards of the harbour entrance west to Five Dock Bay. However sounding densities were relatively sparse west of Cockatoo Island, where a new dry dock, Fitzroy Dry Dock, was opened in late 1857. A long baseline, 2780 feet long (847.344 m) was laid out at Rose Bay, from which a triangulation scheme was set up to cover all the harbour as far west as Cockatoo Island (David, 1995). Check baselines were set up at Manly Beach, approximately 3.7 km north of the harbour entrance, Darling Point and South Head. The survey and initial chart production took approximately two months.

The 1899 chart

Towards the end of the 19th century Lieutenants T. F. Pullen and G. W. Gubbins of HMS *Lark* compiled the latest information available from the New South Wales Government, whose soundings were mostly from British Admiralty soundings obtained from 1857 to 1888. (Pullen and Gubbins, 1899). Sounding densities were even greater than those in Denham's chart. Again the area covered (in scale 1:12000 approximately) was from outside the harbour entrance west to Five Dock Bay (See Figure 10, below and http://nla.gov.au/nla.map-jsc21)

Methods

To compare the shorelines in early charts with the modern one the digitally scanned early charts were obtained from the National Library of Australia. A digital version of the present day shoreline, more precisely the mean high water line (mhwl), was obtained from the Sydney Ports Corporation. This last is really a property boundary as the New South Wales government is the owner of all of Sydney Harbour below the mean high water mark. . The Projection used is GDA 1994 MGA Zone 56. (GDA = Geocentric Datum of Australia and MGA = Map Grid of Australia). Two methods of comparison were used. One used ArcGIS 10.1 from Esri and the

other used MapAnalyst, a program specifically designed for comparing older maps with more recent ones (Jenny and Hurni, 2011). The same area of the harbour was used for all analyses, so as to have valid comparisons, even though the earlier two charts extended further west than the latter two.

Using ArcGIS 10.1

Each of the older charts was georeferenced to the mhwl using a Geographic Information System (GIS), ArcGIS 10.1, from Esri. Georeferencing was done using the 22 control point spread along the harbour from South Head to near Five Dock Bay, shown in Figure 2. Points were largely taken at headlands where shoreline changes, due to reclamation, were known to be minimal, from the work of Murray (2003) and Birch et al. (2009) and aerial photographs of the New South Wales Land and Property Information Service[1]. The 22 points used in each case were not always exactly the same, because in the old charts features were sometimes hard to identify, but a feature close to one indicated in Figure 2 was always taken. The georeferencing, or warping, of the old charts was done with a first order polynomial or five parameter affine fit and the overall root mean square errors (rms) of the agreements were obtained. A first order polynomial warp allows for scale changes and translations in two perpendicular directions, a rotation and a shear. The last allows the possibility of a rectangle on the original becoming a trapezium. These changes are well described in Boutoura and Livieratos (2006) and Brovelli and Minghini (2012).

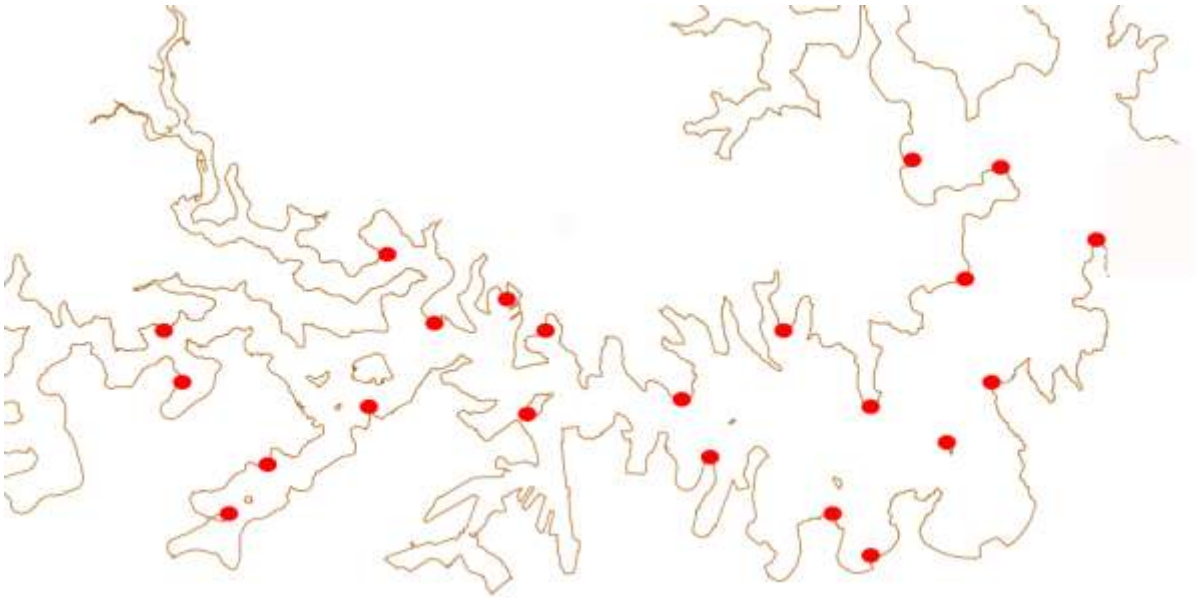

Figure 2: Present shoreline of Sydney Harbour, showing the 22 points used for georeferencing.

In comparing early with modern shorelines one must bear in mind that the shoreline has been much altered in many locations by reclamation, especially in the side bays on the south side of the harbour, west of Darling Point. (Murray, 2003; Birch et al. 2009), which is why there are few

[1] See website at maps.six.nsw.gov.au, viewed 20 March 2014.

control points in these areas. The changes at headlands are generally minor. None of the charts specify what they are using for the shoreline – mean high water mark, mean sea level or something else. Because most of the features used as control points are at headlands where the topography has a reasonable slope this should not matter, as the size of the differences in position, resulting from vagueness in specifying shoreline, would be too small to detect at the scale of the figures in this paper.

Because this GIS technique only compares shapes the distance between South Head and the south-west corner of Goat Island (See Figure 1) was compared in the early charts with the same distance off the modern shoreline. These distances were obtained off the charts, before georeferencing, to avoid distortions. Positions off the charts could be obtained to approximately ± 10 m, so that differences with the modern shoreline were accurate to ± 20 m.

Using MapAnalyst

In MapAnalyst a georeferenced jpeg image of the mean high water mark (mhwm) was mapped on to each of the old charts using the same 22 control points as above. The resulting distortion grids, (see Figures 4, 6, 8, 9 and 10) showed how much a rectangular grid on the mhwm image had to be distorted in order to obtain a least squares minimisation of the differences in positions of the 22 points. Also displayed on each of these figures are "displacement vectors" and "circles of displacement". A displacement vector runs from a point in the old map to the position of the corresponding point on the map of the mhwm. However in many cases the lengths of the displacement vectors were multiplied by five or ten, to make them easily visible in the figures. The displacement circles each have an area proportional to the length of its corresponding displacement vector. It shows the same information, but without the direction. Both are used here to aid visualisation. MapAnalyst also calculates the root mean square (rms) difference in position of the 22 control points and a mean position error (MPE) and an overall rotation of the mhwm image to achieve best fit. In MapAnalyst a Helmert or four parameter affine fit was used which allowed for translations and scaling in two perpendicular directions plus a rotation. Using a five or six parameter fit made little difference. With both the ArcGIS and MapAnalyst analyses error estimates only apply to the goodness of fit of the 22 control points and are not a measure of goodness of fit in areas without control points.

Results

Figures 3 and 4 compare Raper's copy of Hunter's and Bradley's chart with the modern shoreline, using the ArcGIS and MapAnalyst methods, respectively. One can see that the match is quite inaccurate. Rms errors with ArcGIS and MapAnalyst are 273 m and 230 m, respectively, and MPE, from MapAnalyst is 326 m. (Data on the accuracies achieved with all the charts are compared in Tables 1 to 3). Also a pronounced overall shear was required in ArcGIS on Raper's chart to achieve even this match. From Figure 4 the position errors appear to be random with no systematic trends or groupings. Some of the differences in the bays on the south side of the harbour, west from Darling Harbour are due to extensive reclamation (Birch et al, 2009), but there are also large surveying inaccuracies. Nowhere around the harbour has land been removed except in a small number of docks. All shoreline changes have been caused by filling in parts of the harbour. However this chart appears to have been adequate for the practical purposes of the early settlers because the survey was not significantly upgraded till 1822.

Figure 3: Raper's 1791 chart of Sydney Harbour, with modern mean high water mark (red line).

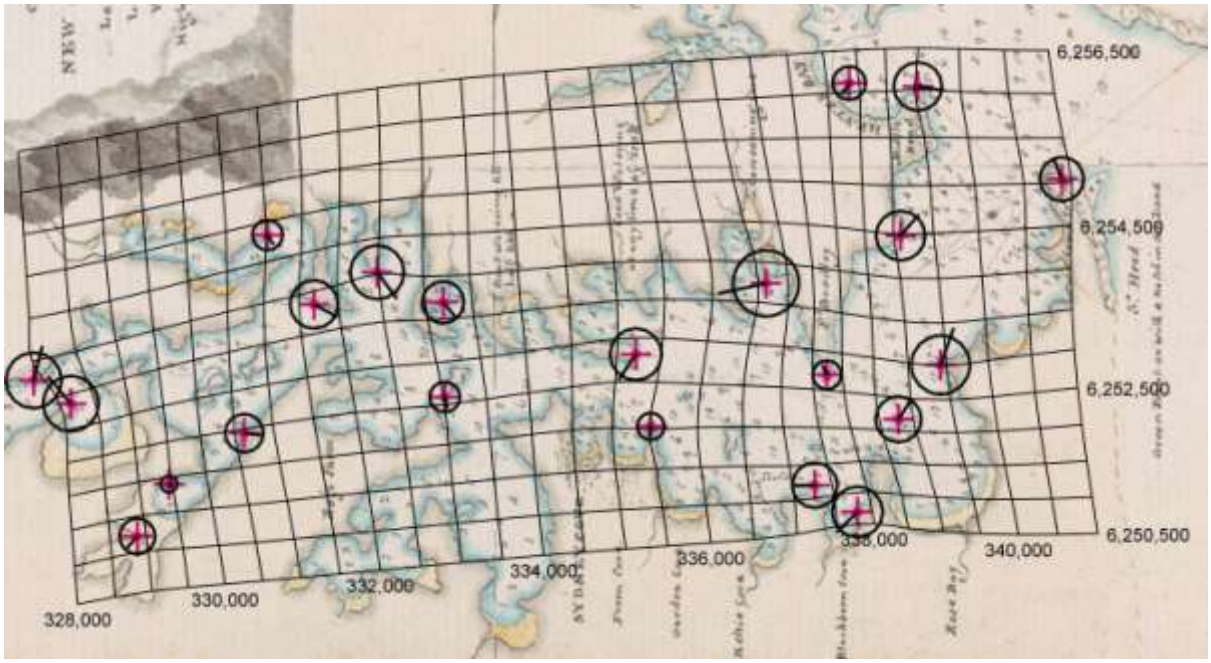

Figure 4: Distortion grid, displacement vectors and circles of displacement for Raper's 1791 chart.

Comparing Roe's 1822 chart with the modern shoreline (Figures 5 and 6) the match is better in the eastern part of the harbour than in the west but goes astray further west. The fit is better than with the Raper chart with rms errors of 118.8 m and 79 m from ArcGIS and MapAnalyst, respectively, and an MPE of 112 m from MapAnalyst.

Figure 5: J. S. Roe's chart of Sydney Harbour, with modern mean high water mark superimposed.

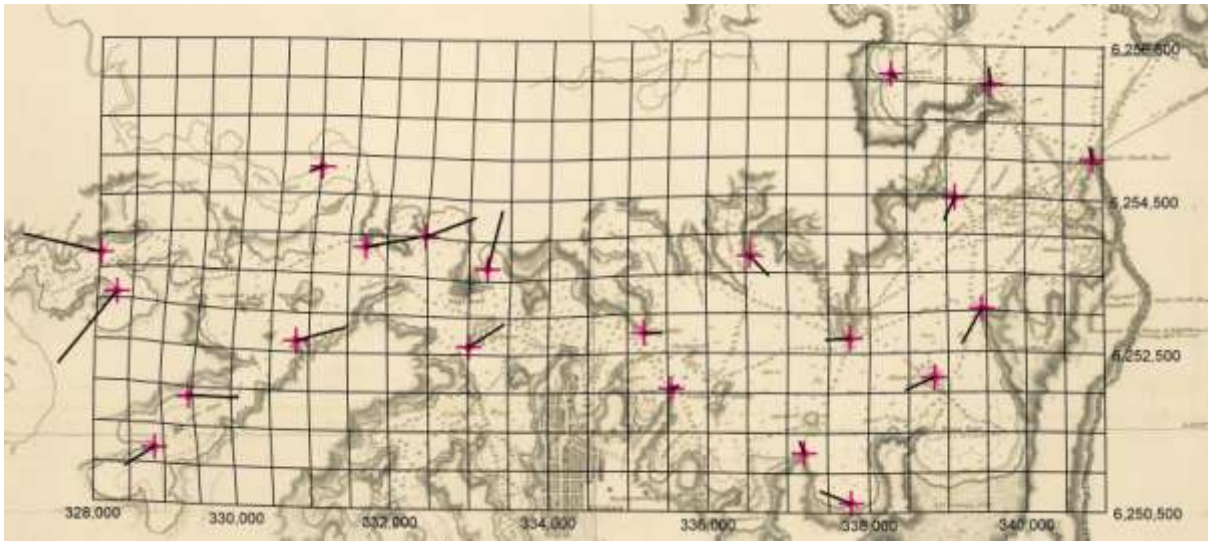

Figure 6: Distortion grid, with displacement vectors x 5 on Roe's 1822 chart.

Despite the greater care taken in the survey of Hutchison et al. (1859) there are still discrepancies between its shoreline and the modern one, especially west of Darling Harbour (See Figure 7 and 8). In fact overall rms errors and MPE are worse than with Roe's. (See Tables 1 and 2). Note that at this time Garden Island was still separated from the mainland and stayed separate until World War II.

Figure 7: 1859 chart of Hutchison et al, compared with modern mean high water mark, using 22 points.

Note in Figure 8 how a group of six points in the western part of the harbour are displaced to the south west, while in the eastern part a group of five are displaced to the north east.

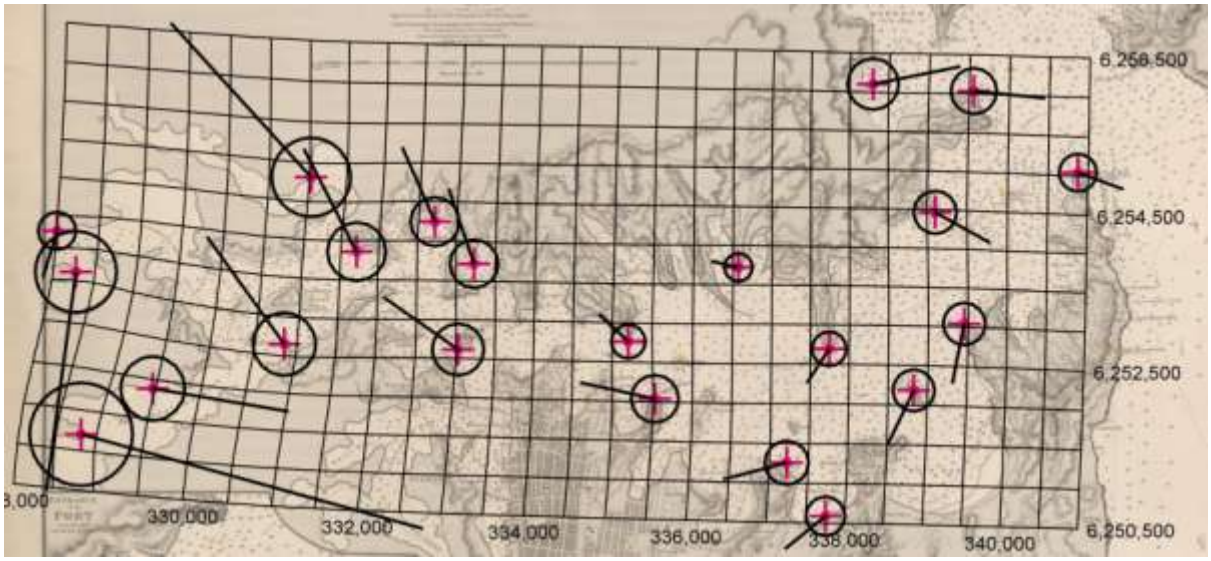

Figure 8: Distortion grid, displacement vectors and circles of displacement for chart of Hutchison et al (displacement vectors x 10). 22 points

However if the western part of the survey is excluded from the analyses, these grouped displacements disappear and the accuracy, over the sixteen remaining control points, is much better than Roe's, as shown in Figure 9, with rms errors of 27.5 m and 20.0 m, respectively, and an MPE of 28 m. In the ArcGIS analysis (not shown) over these sixteen points the modern mhwm in the area between Rozelle Bay and Darling Harbour still overlaps the land in the old chart, in the same way as in Figure 7. It seems that care was focussed on the main shipping areas with much less attention being paid to other areas.

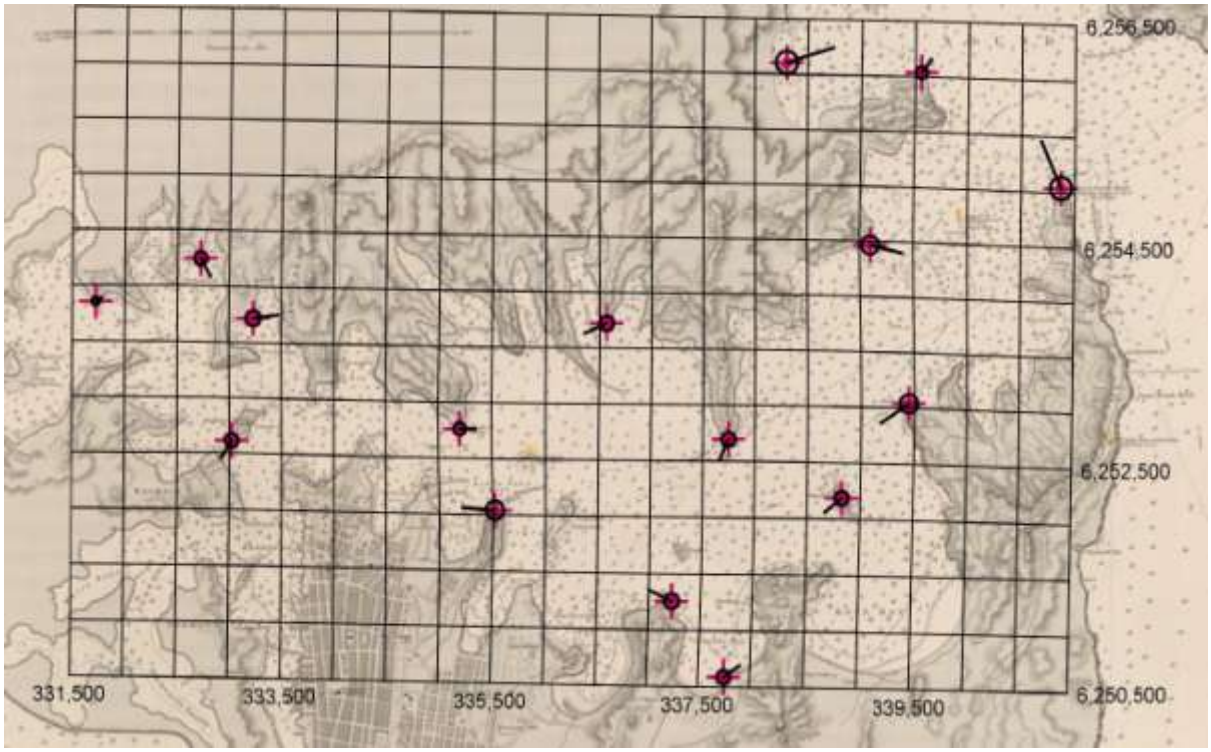

Figure 9: Distortion grid, displacement vectors and circles of displacement for chart of Hutchison et al (displacement vectors x 10). 16 points.

Comparing the Pullen and Gubbins chart's shoreline with the modern one (figure 10) the overall correspondence is improved throughout the harbour, with rms errors of 15.5 m and 27 m, using ArcGIS and MapAnalyst, respectively and an MPE of 30.4 m . As Tables 1 and 2 show these overall rms errors and the MPE (over 22 points) for the Pullen and Gubbins chart are less than those for the previous charts. Even in the west and in the side bays in the south of the area studied the modern shoreline no longer overlaps the land in the old chart (ArcGIS analysis not shown). The Pullen and Gubbins chart went through many revisions right up to 1945.

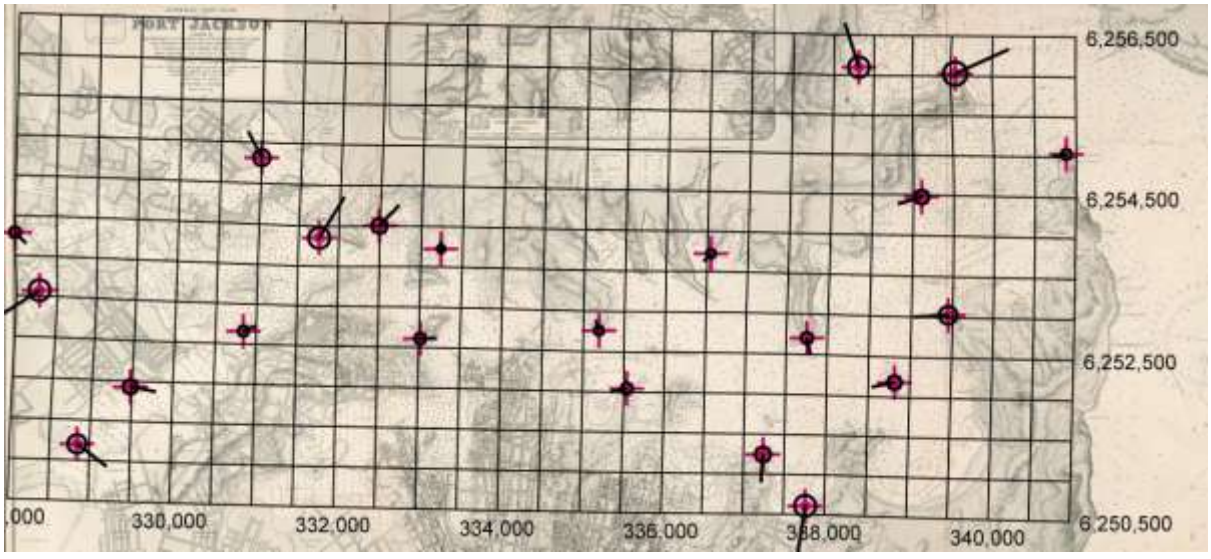

Figure 10: Pullen and Gubbins chart with distortion grid etc. (Displacement vectors x 10).

From Tables 1 and 2 it can be seen that agreements between each chart and the modern shoreline tended to improve over time with the exception of the chart of Hutchison et al. This seems to be because the latter were little concerned with the very western part of their survey, as in the eastern part their results agree well with the latest data.

To obtain a measure of the positional accuracy achievable with the present methods in matching the mhwl to another chart, a tiff image of recent Royal Australian Navy chart of the harbour, Aus200, (Australian Hydrographic Service, 1992) was georeferenced against the mhwl image. The shoreline in the Aus200 was very close to the modern one, with an rms error and an MPE, using MapAnalyst, of 11 m and 16 m, respectively. If the shoreline in Aus200 were the mean high water line agreement should be exact but, as discussed previously, charts do not exactly define their shorelines, so this is an indication of achievable accuracy with the methods used.

Chart	rms difference (m) (22 points)	Worst fit (m)
Raper, 1791	273.3	406.3
Roe, 1822	118.8	231.7
Hutchison et al., 1859	163.1	473.6
Hutchison et al (western points excluded, 16 points used)	27.5	55.4
Pullen & Gubbins, 1899	15.5	32.2

Table 1: Rms errors in fits with mhwm using ArcGIS 10.1, using 22 points unless stated otherwise.

Chart	Rotation (°)	Standard deviation (m)	Mean position error (m)
Raper, 1791	5 (ccw)	230	326
Roe, 1822	1 (cw)	79	112
Hutchison et al., 1859	2 (cw)	114	161
Hutchison et al. (western points excluded, 16 points used)	1 (cw)	20	28
Pullen & Gubbins, 1899	1 (cw)	27	38
AUS200, 1992	1 (cw)	11	16

Table 2: Rotations, standard deviations and mean position errors from MapAnalyst, using 22 points unless stated otherwise, (cw = clockwise, ccw = counter clockwise).

The GIS technique used so far compares shapes rather than actual distances. As a check on the actual distances between points in the various charts an example was taken of the distances between Long Nose Point and South Head off the charts before georeferencing. See Table 3. As one would expect the Raper chart shows the greatest difference and the Pullen and Gubbins the least.

Chart	Distance km)	Difference from mhwm (km); %
Raper, 1791	9.030	+0.795; 9.7%
Roe, 1822	8.181	-0.054; 0.7%
Hutchison et al, 1859	8.041	-0.221; 2.7%
Pullen & Gubbins, 1899	8.185	-0.050; 0.6%
mhwm	8.235	

Table 3: Distance from south-west corner of Goat Island to tip of South Head from different charts.

Concluding Remarks

Although the basic instruments available, e.g. theodolite, horizontal sextant and lead line, did not change over the course of the 19th century the improvements in mapping the shape of the harbour shoreline is clear. This is most likely due to steady improvements in both instrumentation and techniques. Two very helpful innovations introduced to British surveyors, during the term of Captain Thomas Hurd as hydrographer, 1808-1823, were high quality sextants and station pointers (Ritchie, 1978). It is not clear if these were available for Roe's survey of 1822, but they would have been available for subsequent surveys. By the time of the Pullen and Gubbins chart of 1899 the accuracies achieved were very close to modern ones and in the 1859 chart of Hutchison et al. accuracies were high were this was believed to matter.

Acknowledgements

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