LAND USE HISTORY OF CENTRAL LULEÅ
A CASE STUDY IN THE USE OF HISTORICAL MAPS TOGETHER WITH MODERN GEOGRAPHIC MUNICIPAL INFORMATION

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The modern Luleå harbour-side dates back to 1649 when the old city was abandoned because its harbour-side and approaches had become too shallow to be useful. This shallowing, due to glacio-isostatic rebound, affects the new town also, but the results have been mitigated by coastal engineering. As a result of uplift and engineering, former harbour-side land is now far enough from the present shoreline for any maritime artifacts that might lie beneath them to be unsuspected.

We report the outcome of a successful Monash University - Luleå University project designed to identify such former harbour-side land parcels by digitizing and georeferencing a series of historical maps dating from the mid eighteenth century. The method has wide application. Typically, the spatial database built using the approach we have exemplified will be readily incorporated into official spatial datasets to be used in decision support. Thus, planning authorities charged with both re-development permit application appraisal and protection of buried heritage items can identify land parcels that would be likely to have buried artifacts, and places within the parcel that are most likely to produce “surprises”. Land re-developers would be pleased to have access to such information because of the extra scope they can derive for coping with the disruptions to excavation and building works that arise when heritage items are unearthed.

INTRODUCTION

BACKGROUND

Historic information, such as that found on historical maps, is often a neglected resource that can be very useful in certain planning activities. This project exemplifies a methodology for making such information available as part of the municipal digital spatial database.

Nine archival maps (dating from the mid-eighteenth century) depicting the city of Luleå (65° 34’ N, 22° 10’ E), northern Sweden (Figure 1), were found to be of sufficient quality for time-series geo-referencing. Thus time-series coastlines and city blocks patterns could be compared with the published (1992) coastline, and current municipal data. Information about land use history can therefore be determined for a significant number of harbour-side city blocks. Application of such knowledge refers not only to city history, but also to appraisal of potential for finding artefacts of heritage value during excavations conducted during property redevelopment.

PURPOSE AND GOALS

The purpose of this work was to investigate the possibilities of using historical maps to gather information that could be used as additional decision support for planners in a port city on an isostatically rebounding coastline.
The goals of this work were to:

- act as a pilot study in the use of comparing information contained on historical maps with that contained on modern maps;
- give some suggestions on how preparation of historical maps can be done so that it is possible to compare the information in the historical maps, both with each other and with current data;
- propose a way of handling the historical information that can be derived from the historical maps;
- show how changes in the coastline and mapped harbour-side installations in a coastal city can be tracked by using historical maps;
- illustrate how the harbour-side land parcel / city blocks history can be assembled so that the probability that land developers will find artefacts of heritage value can be known; and
- define further research questions related to the use of historical maps in modern usage.
DELIMITATIONS

This work was a pilot study, and so only maps representing recognisable ‘bench-mark’ features (mainly roads, coasts, and city blocks) were used. In that the study was designed to map land-parcel history for a limited area, many of the uncertainties mentioned by Plewe (2002) were avoided. Thus the framework for matching the spatial resolution / scale of capture (e.g. see Allen, 2000, pp. 102-103) of source data to project aims and objectives will refer to that which is sufficient to ensure that planners can assess the likelihood of artefacts referring to past land uses will be found somewhere beneath the surface of a particular land parcel.

THE LAND-UPLIFT IN SCANDINAVIA

During the last glacial maximum (circa 22,000 – 18,000BP) about 3,000 meters of ice covered the northern Gulf of Bothnia (eg see Flint, 1971, pp. 596-597). Climatic amelioration since then has caused this ice cap to retreat. The consequential isostatic rebound, or land-uplift, continues today. Currently in the northern part of Sweden there is a yearly land-uplift of approximately 8mm (Figure 2).

![Figure 2](image)

Map with isobases showing the land-uplift mm/year in Scandinavia. Ekman, 1996.
The cartographers who made the earlier historical maps that we have studied may have been aware of the relative fall of sea level, and perhaps also of the debates that characterised the search for an explanation. The Swedish scientist Urban Hjärne (1641-1724) was the first one to notice that the land areas were increasing along the eastern coast of Sweden. Initially this phenomenon was explained as the retreat (‘drying up’) of the water (e.g. see Charlesworth, 1957, p. 1344). During the 1740s a long debate started among scientists in Sweden (including the Swedish scientists Swedenborg (1688-1772), Linné (1707-1778), and Celsius (1701-1744)) about the reasons for the retreat of the water. The debate lasted for many decades (Frängsmyr, 1969).

Another theory, postulating that the retreat of glaciers was responsible for the land-uplift, was first presented in 1837 in reference to the Swiss Alps. The first to apply this theory to the Scandinavian land-uplift was the geologist and zoologist Otto Torell (1828-1900), in 1859 (Lundholm and Nyström 1992). The work of the geologist Gerard De Geer (1858-1943), presented in 1888 (see Anamnesis, 2003), led to a wider acceptance of the land-uplift explanation than of the retreat of the water explanation. It is glacio-isostatic rebound that is now regarded as the cause (see Gutenberg, 1941) and so it is not surprising that the ice thickness pattern of the last great ice sheet is reflected in variation in the rate of uplift. The coastline at Luleå, a location where the ice was thickest, is uplifting at a higher rate than is the case on most other Fennoscandian coasts.

**BRIEF HISTORY OF THE CITY OF LULEÅ**

The village of Luleå was founded during the 14th century on the shores of the Baltic Sea (Östersjön). Luleå was designated as a city in 1621, but by 1649 the water level in the harbour had decreased to such an extent that the whole city was moved to its current location on the ‘new’ Baltic Sea coastline, and the former site renamed Gammelstad.

Not only has continuing land-uplift affected the appearance of today’s Luleå City, but fire has also played a major part. During the 10th and the 11th June, 1887, nearly half of the city was destroyed by fire (Figure 3).

**GEOREFERENCING THE HISTORICAL MAPS**

Meeting the demand for consistency when comparing information in historical maps, both with each other and with current data, requires common georeferencing. Placing the maps in the same reference system as the modern maps requires analogue-to-digital conversion.

Sweden has a great treasury of historic maps (Flyg, 1996). The majority of the historical maps used in this project have been bought from the Swedish National Land Survey as scanned raster files in Tiff format (see Appendix). The georeferencing of the historical maps (in some cases referring only to a subset of the original) was done in ArcMap 8.2 with the Georeferencing tool, with the six-parameter affine transformation option. The Swedish National Land Survey’s digital vector-based map product ‘Fastighetskartan’ in the scale 1:10,000 was used, together with the scanned historical maps, to determine control points for calculation of the transformation parameters. Control points are common points with known coordinates in both reference systems, in the particular historical map (source reference system) and in the ‘Fastighetskartan’ (destination reference system). Through the transformation, and use of the transformation parameters, any point on one map can be converted to the reference system of the other map.
Figure 3
Bird's eye 'map' showing the area in Luleå affected by fire in 1887. The circle shows the approximate location of the source of the fire. Luleå hembygdsförening, 1987.

Figure 4
<table>
<thead>
<tr>
<th>File name</th>
<th>Date of map publication</th>
<th>Description of map</th>
<th>Scanned by</th>
<th>No. of control points</th>
<th>Root mean square (RMS) error [m] in transformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>23605249_2</td>
<td>1857</td>
<td>Luleå city; Ljunggren’s atlas; lithography (small map)</td>
<td>Swedish National Land Survey (NLS)</td>
<td>58</td>
<td>6.308</td>
</tr>
<tr>
<td>23605249_2b</td>
<td>1857</td>
<td>Luleå city; Ljunggren’s atlas; lithography (large map)</td>
<td>Swedish NLS</td>
<td>50</td>
<td>4.384</td>
</tr>
<tr>
<td>23605249_3</td>
<td>Circa 1800</td>
<td>Luleå city; Wiblingen atlas</td>
<td>Swedish NLS</td>
<td>33</td>
<td>3.772</td>
</tr>
<tr>
<td>4290011136_1</td>
<td>1750</td>
<td>Luleå city (more detailed); surveyor Esaias Hackzell</td>
<td>Swedish NLS</td>
<td>30</td>
<td>3.217</td>
</tr>
<tr>
<td>4290011136_2</td>
<td>1750</td>
<td>Luleå city (less detailed); surveyor Esaias Hackzell</td>
<td>Swedish NLS</td>
<td>29</td>
<td>3.295</td>
</tr>
<tr>
<td>4290011136_3</td>
<td>1790</td>
<td>Luleå city; surveyor Olof Clausén</td>
<td>Swedish NLS</td>
<td>25</td>
<td>3.367</td>
</tr>
<tr>
<td>4290011136_4</td>
<td>1790</td>
<td>Luleå city; a proposed city plan based on the map 490011136_3; surveyor Olof Clausén</td>
<td>Swedish NLS</td>
<td>19</td>
<td>2.893</td>
</tr>
</tbody>
</table>

Table 1: Historical maps that have been used.
However, it must be remembered that workers with historical maps are beset with many difficulties, not the least of which refers to the dimensional stability of the medium. Many historical maps are a compilation of surveys undertaken over several years, and of information from pre-existing maps. This information is seldom attributed and/or dated. Moreover, the dimensional stability of the map media (e.g. paper of various types) can be affected by factors such as temperature, humidity, and ageing.

From the book *Luleå in lågor* (Luleå in flames) (Luleå hembygdsförening, 1987) a perspective view over the pre-fire Luleå was used to map the area that was razed (Figures 3 and 4).

During initial attempts to georeference the historical maps it became clear that control points within the area affected by the fire were both difficult to find and geometrically uncertain. It therefore became necessary to seek control points outside the area affected by the fire. For change detection between the times for which we have ‘snap shots’, in the form of historical maps, it was necessary to choose control points that could be found on all the maps in the series used for the study (see Table 1).

To georeference the map 429001136_3 to Fastighetskarto, most of the control points selected were outside the area affected by the fire. Control points were mainly selected on land parcel corners along Tullgatan, Rådstugatan, Storgatan, and Smedjegatan (Figures 5 and 6).
Some of the control points in the maps 4290011136_2 and 4290011136_1, 4290011136_4, 23605249_2 and 23605249_2b were referenced against the georeferenced map 4290011136_3. Almost all of these points were within the area affected by the city fire. The purpose of doing this is to be able to compare the historical maps with each other as accurately as possible. These control points are marked with a red circle in Figures 7 – 11.

Some of the control points in the map 23605249_3 were referenced against the map 4290011136_4, (see red circles in Figure 12).

Figure 13 shows the control points used in georeferencing a map of the 1858 shoreline (Lundholm and Nyström 1992).

The map 1738-60_Luleå_Krigsarkivet was georeferenced against the georeferenced map 4290011136_1. This historical map was more of a drawing, focusing on the buildings in the city centre. The lack of geometrical accuracy within the drawing resulted in a high root mean square error in the transformation (Figure 14).

The transformation parameters are a best-fit between the source (historical map) and destination control points (Fastighetskartan). If the calculated transformation parameters are used to transform the actual source control points, then the transformed output locations will probably not match the true output control point locations. This difference is called the residual error, and it is a measure of the fit between the true locations and the transformed locations of the output control points. A root mean square (RMS) error can be calculated based on the residual error for each transformation of a known control point, and this gives an indication of how good the derived transformation parameters are/how good the transformation is.
Figure 7
Map showing the control points used in georeferencing 429001136_2.

Figure 8
Map showing the control points used in georeferencing 429001136_1.
Figure 9
Map showing the control points used in georeferencing 429001136_4.

Figure 10
Map showing the control points used in georeferencing 23605249_2.
Figure 11
Map showing the control points used in georeferencing 23605249_2b.

Figure 12
Map showing the control points used in georeferencing 23605249_3.
Figure 13
Map showing the control points used in georeferencing 1858_shoreline_Luleå (Lundholm and Nyström 1992) to Fastighetskartan.

Figure 14
Map showing the control points used in georeferencing 1738-60_Luleå_Krigsarkivet to Fastighetskartan. The ends of the blue lines identify each pair of control points. The nature of failure in congruence is seen to refer to a range of orientations and distances. Lundholm and Nyström 1992.
When georeferencing historical maps for use with modern spatial data it should be remembered that:

- the geometrical quality of the historical maps varies between the different maps and also within the maps, and
- the historical data/map (designated ‘source map’) will be georeferenced to the destination data/map which will be a modern digital map with under-pinning metadata with a high quality.

It is generally recommended to keep the order of transformation as low as possible. An affine transformation (a first order transformation) can differentially scale the data, skew it, rotate it, and translate it. This means that with an affine transformation straight lines on the raster will still be straight lines after the transformation. Parallel lines will be parallel after the transformation. Squares and rectangles on the raster, however, can be changed into parallelograms of arbitrary scaling and angle orientation. Using a higher order transformation than the affine transformation may result in straight lines, eg straightened streets, emerging from the transformation.

Adding more control points will not necessarily yield a better georeferencing. More important is to spread the control points over the entire source data (eg the historical map) rather than concentrating them in one area. When possible, it is normally recommended to have at least one control point near each corner of the raster image to be georeferenced and a few throughout the interior. In general, the greater the overlap between the source data and destination data, the better the alignment results because more widely spaced points can be used to georeference the source data. In these terms, the status of areas outside the overlapped area can only be assumed unless there is independent check.

The residual errors for the control points should be acceptably small, but some difference between the actual and calculated coordinates of the control points should be both expected and accepted. Acceptance avoids introducing artificial distortions into the data in any effort to ‘improve’ the result. A low root mean square (RMS) error does not automatically mean an accurate georeferencing. The transformation may still contain significant errors, for example due to a poorly entered control point data.

In this project, the control points were selected so that they mainly could be found in all the historical maps. This increases the possibility to compare the root mean square (RMS) errors between the different transformations and this in turn can be used as an indication of the relative geometrical quality between the historical maps used.

**THEMATIC CLASSIFICATION AND VECTORISATION OF GEOREFERENCED HISTORICAL MAPS**

The thematic information can vary between and within the historical maps, similar to the variations in geometric quality. Also, cartographic representation can vary between historical maps. The features that have been included on the historical maps, and the degree of detail with which they are represented, gives an indication of the relative importance of those features in terms of the purpose of the map. For example in 4290011136_3 the jetties were shown in detail, but in 23605249_2 it was difficult to separate the jetties/wharves from the coastline.
Further processing of the georeferenced historical maps was necessary to be able to evaluate and combine the historical information with other data sources, such as modern municipal geographic information. Such data integration increases the value of the information because in offering scope to deploy the data for a range of applications it supports spatial query and modelling by different kinds of users.

Thematic classification involves an evaluation of what features to include and what to omit. For example, several of the historical maps showed the bell tower (then separate from the church) of the pre-fire church. In order to depict the bell tower as a tower, it was drawn on a far larger scale than the other features on the map (Figure 15). This made it impossible to determine its exact location on the ground. In such instances the feature was either omitted or was represented by a point.

In the process of thematic classification and vectorisation it is nevertheless possible to create a common classification and representation (graphic features such as points, lines or polygons, and use of visual variables) for similar geographic features in the various historical maps.

![Figure 15](image)
The bell tower represented as a symbol in the historical map 4290011136_1.

**WHAT IS VECTORISING, HOW WAS IT DONE, AND WHAT WAS THE RESULT?**

The scanned historical maps are in raster format (square picture elements) much like digital camera output. Vectorising is the process of converting raster format information into vector format (the digital equivalent of line-maps).

The vectorising of the historical maps was done in ArcMap 8.2 with the on-screen Editor tool.
The coastline and tracks were vectorised as lines, and the city blocks, buildings, church, and jetties were vectorised as polygons.

<table>
<thead>
<tr>
<th>File name</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>23605249_2</td>
<td>The scale of the map was such that it was difficult to separate the coast line from the jetties/wharves</td>
</tr>
<tr>
<td>23605249_2b</td>
<td>The scale of the map was such that it was difficult to separate the coast line from the jetties/wharves</td>
</tr>
<tr>
<td>23605249_3</td>
<td></td>
</tr>
<tr>
<td>4290011136_1</td>
<td>The scale of the map was such that the coastline was generalised</td>
</tr>
<tr>
<td>4290011136_2</td>
<td>The scale of the map was such that the coastline was generalised</td>
</tr>
<tr>
<td>4290011136_3</td>
<td>The scale of the map was such that there was good detail, particularly with the jetties</td>
</tr>
<tr>
<td>4290011136_4</td>
<td></td>
</tr>
<tr>
<td>1858_shoreline_Luleå</td>
<td>The jetties and wharves were included in the coastline</td>
</tr>
<tr>
<td>1738-60_Luleå_Krigsarkivet</td>
<td>The scale of the map was such that the coastline was generalised</td>
</tr>
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</table>

Table 2 Comments about vectorising the historical maps.

<table>
<thead>
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<th>File name</th>
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<th>Church</th>
<th>Tracks</th>
<th>Buildings</th>
<th>Jetties</th>
<th>Other</th>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>-</td>
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<tr>
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<td>✓</td>
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<td>✓</td>
</tr>
<tr>
<td>23605249_3</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
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<td>✓</td>
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<td>✓</td>
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<tr>
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<td>-/✓</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>1738-60_Luleå_Krigsarkivet</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

(✓ = feature/s vectorised)  

Table 3 Categories that were vectorised in the historical maps.

The category ‘City blocks’ in some historical maps includes individual land parcels. The category ‘Church’ sometimes includes the church grounds where they have been indicated on the historical maps.
The category ‘Buildings’ may include:

- school,
- mill,
- town hall,
- cottages,
- boat houses, and
- cemetery.

The category ‘Other’ may include:

- toll stations, and
- toll jetty.

**COASTLINE CHANGES AND THE OLD HARBOUR-SIDE OF THE CITY OF LULEÅ**

On-going glacio-isostatic uplift has ensured gradual change in the coastal landscape. Figures 16 and 17 show the time-series of coastlines that can be derived from the historical maps that we have brought to a common georeferencing system.

![Time-series coastlines](image)
Figure 17
City blocks with immediate potential for harbourside heritage significance (not only wharves, but, for example, piles, ship skeletons, groynes, docks, anchors, and so on).

Despite the spatial accuracy issues mentioned earlier, it is clear that harbour-side artefacts from the 18th and 19th centuries are likely to be preserved under the surface of particular modern land parcels. Clearly those land parcels can be attributed for potential heritage significance when redevelopment appraisals are conducted by municipal authorities. Thus foundation excavation can be planned to meet current legal requirements (Kulturminneslagen, 1988). Together with the advent of new dredging and earth movement equipment, the glacio-isostatic rebound has increased scope for coastal reclamation. Figures 16 and 17 also include the modern coastline. The extent to which it does not reflect the alignment of the previous coastlines is a measure of the degree to which the modern coastline is engineered.

The depiction of changes between 1857 and 1992 could probably be relied on during spatial query designed to be supported by access to historical data. The 1750 coast as depicted here is probably not reliable enough for quantitative change detection, despite the congruence between the 1857 and 1750 street grid that was achieved during time-series database building. To some extent, the difference in reliability will reflect the relative ease with which the map makers of earlier times could distinguish the rather more engineered harbour shoreline of, say 1857 and
later compared with the less-engineered 1750 coast. This would be especially so where the more natural littoral zone was of lowest gradient.

**CITY RENEWAL BEFORE AND AFTER THE 1887 FIRE**

A comparison between the pre 1887 street alignments and those of the modern (post 1887) city central area shows that the post-conflagration city planners took the opportunity to re-align the streets. As a result, some major coastal changes also occurred. For instance, between 1790 (4290011136_3) and 1857 (23605249_2b) the town expanded to the east and north-east. The new city blocks were constructed on a grid plan, following the alignments already in place. One notable change is the removal of the track which gave direct access from the country side to the open area of the centre of Luleå, which housed the church, the market place, and various official buildings as shown on the 1790 map. This is in line with a 1791 proposal (4290011136_3) to regulate ‘buildings, market places, and streets and alleys in the city’ (Figures 18 and 19).

![Comparison between the street alignments of 1790 and 1857](image)

*Figure 18*

City blocks and street re-alignments. The arrow points in the direction from which the church, the market place, and various official buildings were approached along the pre-fire track.
Rebuilding the city after the fire marked the beginning of modern Luleå, with wide streets and rectangular blocks (see Figure 20). Almost half of Luleå city was burned down in 1887, and new city blocks were formed thereafter as part of street re-alignment during city reconstruction. 23605249_3 appears to be based on 429001136_4 (a proposed city plan), but updated to show current features (city blocks). The coastlines are much the same.

**PROTECTION OF ANCIENT REMAINS IN SWEDEN**

According to Swedish law *Lag (1988:950) om kulturminnen m. m.*, change or damage to, or removal of, fixed ancient remains is not permitted without official sanction. Nor is the re-burial of accidentally exhumed remains. If plans for bigger building projects mean that a fixed ancient remain will be affected, then a permit must be granted from the County Administrative Board. The said Board is the authority responsible for making sure that the law protecting fixed ancient remains is obeyed. It also decides in matters related to fixed ancient remains within the County. The County Administrative Board must first decide if any exhumed and hitherto undocumented fixed ancient remains are significant. Factors such as the importance of the fixed ancient remain, possibilities to avoid damage, etc are considered during such appraisal. Thereafter a permit can
be granted, under the condition that the changes are documented by archaeologists. The building developer must pay for the archaeological work and this could lead to change or cancellation of plans for development. In this way the law can be seen as a tool to protect fixed ancient remains.

The County Administrative Board of Norrbotten has a spatial database containing details of more than 10,000 fixed ancient remains located in the County Norrbotten.

The ‘Board of Antiquity’ supervises the protection of ancient remains in Sweden.

Clearly planning for city development projects would be well served by access to information that allows probability of unearthing artefacts to be assessed.

**CONCLUSIONS**

It has been shown that despite a range of geometrical properties encountered among the historical maps, planimetric differences between the maps used in this study can be classified into those that can be reconciled by use of affine transformation using well-placed common ground control points, and those that were probably not well-enough surveyed in the first instance for transformation to yield results useful in quantitative work.
Overlay of the cadastrale on the time-series coastline map allows the most likely maximum age of artefacts to be predicted, city block by city block. Overlay of historical wharves/jetties allows presently overlaying city blocks to be attributed as likely to yield harbour-side artefacts during property redevelopment.

With regard to the evolution of city form in Luleå (the post-1649 site), the time-series database we have built can be queried to reveal changes in street alignment, especially with regard to the post-conflagration period. Again, city block histories can be compiled/elucidated and historical landscape reconstruction/interpretation better facilitated.

Clearly there are cartographic archives referring to Norrbotten (and surely many other places) that can yield much fiscal information if subject to the kind of data handling exemplified in this study. There is, therefore, scope to argue that digital state spatial data infrastructure should include time-series cartographic data.
Appendix figure 1 23805249_2 (1857)
Appendix figure 2 23605249_3 (1800)
Appendix figure 3 4290011136_1 (1750)
Appendix figure 5 4290011136_3 (1790)
Appendix figure 6 4290011136_4 (1790)

FOTO: KRIGSARKIVET, STADS- OCH FÄSTNINGSPLANER NR 5. NBMS BILDARKIV.

Appendix figure 7 krigsarkivet_1738-60_lulea
En karta över stadshalvön med niväkurvor inlagda visar med heldragen linje 6 m (egentligen 7 meter) samt med strecklinje 5 m (egentligen 6 m). I det förra fallet framträder Güllzauudden som en egen ö liksom även höjdområdet Svarholmen vid dagens järnvägsstation. I det senare fallet får vi en halvö med ett antal utskjutande uddar. Prickad linje visar strandlinjen 1858.


**Appendix figure 8** 1858, shoreline, Luleå (1858/1992)

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