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Roy Military Survey map of Scotland (1747-1755): mosaicing, geo-referencing, and web delivery

Keywords: military mapping; geo-referencing; web-mapping applications

Summary

This paper describes and explains a project to make available a seamed, geo-referenced version of the Roy Military Survey map of Scotland (1747-1755). The Roy map is arguably the most important map of Scotland in the 18th century, and the background to and history of the map is important to understand its value today and the priorities in making it available online. This collaborative project by the British Library and the National Library of Scotland involved seaming together 1,100 images of individual dissections of the map, and then geo-referencing these mosaics. It is suggested that for this map, geo-referencing should be subordinate to presenting the original cartographic artefact close to its original form, and considering the historical and cultural context for the item. ESRI's ArcIMS software was used as part of a customised interface to deliver the map online. The various choices made, the problems encountered, and solutions adopted are explained, along with an assessment of future planned developments.

Introduction

While using the web to present scanned collections of maps is not new, there is limited formal documentation regarding the processes for seaming together and presenting geo-referenced mapping. The authors, who undertook a joint institutional project over 2006-07, had several decisions and technical hurdles to overcome in their efforts to geo-reference and make available a culturally and historically significant manuscript map of the 18th century, the Roy Military Survey map of Scotland. It is hoped that this case study may guide others working on similar projects, particularly those involving geo-referencing of large maps, and encourage discussion and perhaps consensus on some of the methods used.

The Roy Military Survey map of Scotland is currently held as a set of 38 dissected manuscript sheets, which when placed together, measure over 9 x 6 metres (30 x 20 feet). The map is important historically, not least as the earliest comprehensive snapshot of the whole Scottish mainland at a standard scale, and it has long been popular for a range of

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historical research purposes. Because of this demand, it was a desirable item to place on the web, with our main priorities being improving access and presenting the map as close as possible to its original state as an authentic facsimile.

Some of the decisions and challenges faced are described, including seaming together the set of images, geo-referencing them, and constructing a website interface and searching capabilities within an interactive web-mapping application. Equally important to the form of the website were the social and political priorities behind the map that influenced its content, as well as the way that it was surveyed and drafted. These factors are described first below.

Background and history of the Roy Military Survey Map of Scotland

The Roy Military Survey of Scotland, known to its contemporaries as the ‘Great Map’, is uniquely important. It provides a uniform graphic snapshot of the entire Scottish mainland, at a time when the landscape was beginning an era of rapid change. For many northern areas (termed the Highlands), it is the most detailed and informative map that survives for the entire 18th century, and for all areas, the only standard topographic map prior to the Ordnance Survey mapping in the 19th century. More generally, the Roy map is a landmark of cartography, exemplifying emerging standards in military surveying and cartography, holding a seminal influence on British military mapping in the later 18th century, and not least through William Roy, holding a crucial influence on the early work of the British Ordnance Survey itself (Skelton, 1967; O’ Donoghue, 1977).

The Roy map was part of a widespread and persistent campaign to integrate Scotland into the British state, and there were political, economic and religious aspects to this effort. A key trigger, for example, was following the accession to the British throne of William of Orange in 1689. The supporters of the exiled Catholic King James II of England and the Stuart cause, who became known as Jacobites, staged a series of violent rebellions in 1689, 1715, and 1745 in Scotland and northern England. A cartographic reaction to this was the creation, by the British Board of Ordnance, of a large number of military plans of fortifications, roads, bridges, and battles. In spite of this, however, general topographic mapping of the region was very limited, and the 1745 rebellion was an acute embarrassment to British military commanders through “want of a proper survey of the country” (Moir, 1973: 105). Soon after the defeat of the Jacobites at Culloden in May 1746, the British King (George II) was petitioned to support a Military Survey of Scotland and the primary practical responsibility for this was delegated to the Assistant Quartermaster in the Board of Ordnance, William Roy.

The Roy Military Survey was significantly limited by the availability of men, equipment and time, especially when compared with the Ordnance Survey in Scotland a century later. In 1748, there were only four military engineers available for work in Scotland, all

of whom were involved in road construction. Although at this time the King approved an increase in engineers, and some practitioner engineers were appointed, the work was always one of rapid reconnaissance rather than a carefully measured topographic survey.



Figure 1. A detail from the Roy map, depicting Dundee.

According to Roy, the map was rather a “magnificent military sketch, than a very accurate map of the country” in which “no geometrical exactness is to be expected, the sole object in view being, to shew remarkable things, or such as constitute the great outlines of the Country” (Roy, 1765: 385-6). The Military Survey was not based upon triangulation, but rather upon a set of measured traverses along important features using theodolites and chains. Each surveying party consisted of an engineer with a Non-Commissioned Officer and six soldiers. The theodolites (circumferentors or surveying compasses for measuring angles) were fairly simple, of seven inches in diameter and with common sights without telescopes (see Figure 2), whilst the chains for measuring distance were 45-50 feet long. Only selected landscape features (roads, rivers and lochs) were instrumentally surveyed in this manner, with the remaining landscape features (towns and settlements, enclosures and woodland, as well as relief), sketched in by eye or copied from existing maps.



Figure 2. The simple theodolite (circumferentor) used on the Roy Military Survey.

Considerable adjustment was required to bring the separate traverses together, following discussion amongst separate surveying parties. After active surveying in the summer months, the surveyors returned in the autumn and winter to the Board of Ordnance drawing office in Edinburgh, where the composite map known as the “original protraction” was prepared. Notably, the map was not graduated for latitude nor longitude, nor presented with a standard scale, and its orientation was always towards magnetic north, the declination at this date taken to be 19 degrees west.

The Survey was conducted in two parts, first the Highlands to 1752, and then the Lowlands to 1755, and the surviving maps from these two surveys overlap. Although there were “original protractions” made of both the maps of northern and southern Scotland, various copies were made, in particular a “fair copy” of northern Scotland. (No such fair copy was made for southern Scotland).

The maps were presented to George III in 1761 and incorporated into the Royal Library in London; the King’s Library, as it became known, was offered as a gift to the British nation in 1823 by George IV, which was in turn entrusted to the British Museum in 1828. The Museum held the King’s Library, including King George III’s Topographical Collection in which the Roy map resided, until 1973, when it was transferred to the newly-founded British Library.

Sometime before 1844, the two sets of rolls were remounted as 38 sheets of unequal size (Figure 3) backed on linen and dissected into 2-7 sections, each section made up of six individual dissections. These 38 sheets were preserved in 8 slip cases to form a composite map of all of Scotland. It is the individual dissections that were photographed in 1990.

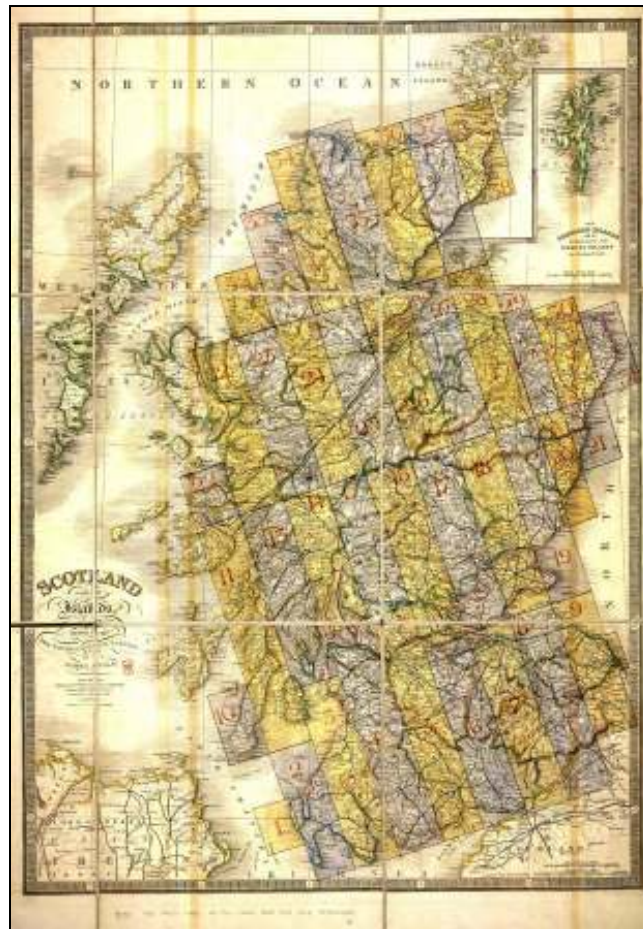


Figure 3 The “index map” showing the layout of the 38 separate strips of the Roy Map.

Project plan, digital scanning, and agreements

Both the National Library of Scotland and the British Library had long wanted to make the Roy map more accessible, due to the broad interest that the Roy map generates among visitors to the libraries as well as in the wider population. Though the NLS Map Library showcases some six thousand historical maps of Scotland between 1560 and 1928 that have already been scanned (see <http://www.nls.uk/maps>) and the BL offers many other manuscript map treasures online, there has always been a high demand for access to the Roy map, not just from family and local historians, but from anyone interested in the Scottish landscape in the 18th century, British cartographic methods at the time, and mapping before the Ordnance Survey. However, the main access to the Roy map at NLS was traditionally through surrogates in the reading room: 35 mm colour slides and black-and-white photographs, formats also used in the British Library unless the original was absolutely required.

In 2000, SCRAN (the Scottish Cultural Resources Access Network, an educational image library originally funded by the United Kingdom lottery) scanned the 35 mm slides of approximately 1,100 dissections and made them available on its website (<http://www.scran.ac.uk>). There were two main limitations of the SCRAN Roy images. First, search and retrieval was difficult, as each dissection was presented as a single separate image and searching for the right dissection and navigating from one dissection to another was difficult. Second, the SCRAN website required a fee-based subscription.

NLS led an initiative to make digital copies of the Roy map freely accessible on the Internet. This involved gaining permission to use the map, acquiring the digital images, securing funding for geo-referencing, and establishing an online resource discovery tool for the maps. A February 2006 agreement with BL brought permission to make the map available on the web in a joint NLS/BL project. While it would have been desirable to the project leaders to photograph the original map again, in order to acquire higher resolution images of larger areas so to demand less seaming, this was not an option for financial reasons. Fortunately, SCRAN agreed to supply the previously-scanned digital image files (made from the slides). Funding for the geo-referencing was obtained from NLS. The software and infrastructure for the online mapping tool was already owned by NLS, and so the Roy map could be added, without significant additional expense, to the other existing scanned and geo-referenced map collections.

Mosaicing and geo-referencing

While the original intention was to mosaic and geo-reference the images in-house, without dedicated staff, the decision was taken to sub-contract the work to a local company, the XYZ Digital Map Company. This private company had already geo-referenced Ordnance Survey mapping for NLS, and additionally, their GIS Programmer had formerly worked in the BL and had an interest in the original map and the project. Geo-referencing of historical maps is aided considerably by patience, as well as an interest and knowledge of the area, the original map, and in the end result. It was felt that would not necessarily have been achieved through sub-contracting the geo-referencing work elsewhere, or to those without a stake or direct interest in the outcome.

The basic process therefore involved:

1. Cropping the images/dissections, to remove the overlaps with adjacent dissections.
2. Seaming the images/dissections into composite strips.
3. Seaming the composite strips together into two composite maps (one for the Highlands and one for the Lowlands).
4. Geo-referencing (global, first-order affine transformation) of the composite maps.

The work was undertaken using the software ER Mapper, and was completed by January 2007.

Originally, the attempt was made to geo-reference the composite strips (ie. to skip stage 3 in the process above), to form a seamless map, but this resulted in overlapping strips, particularly because of the greater width of the linen backing in the horizontal dimension. Because the obscured detail caused by overlapping strips was felt to be unacceptable, the strips were mosaicked to form a composite map without overlaps, and this composite map was then geo-referenced (Figure 4).

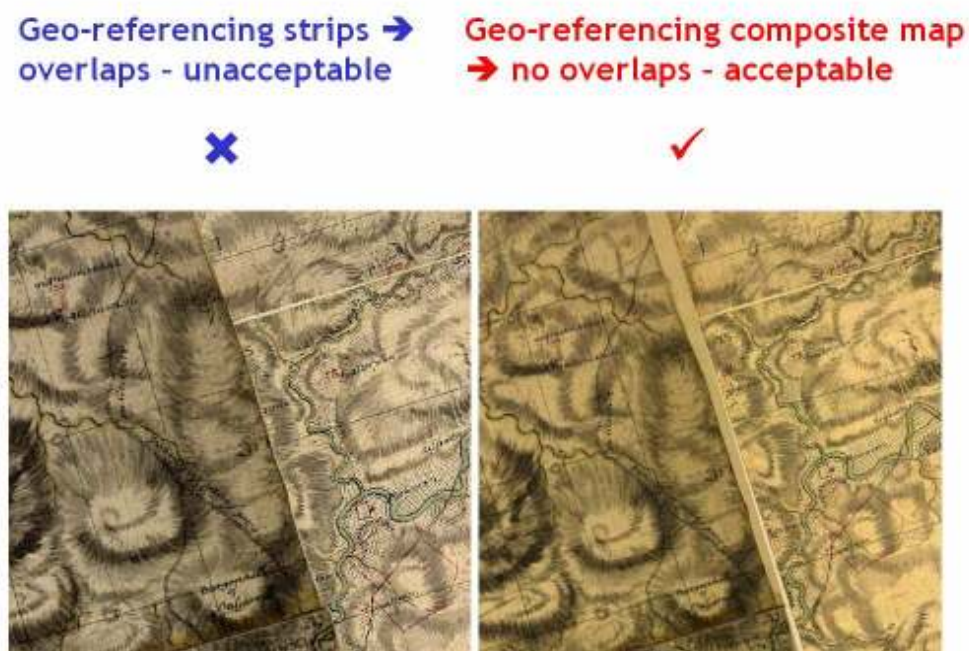


Figure 4. Two methods of geo-referencing compared. Geo-referencing strips created unacceptable overlaps, in contrast to the chosen method of geo-referencing the composite map.

The purpose of geo-referencing was to facilitate access, not to employ cartometric analysis or examine the map's geometric accuracy. The authors felt too that there is a danger in geo-referencing and integrating a map such as this with modern maps or satellite imagery, which could arguably misrepresent its geometric accuracy, or misuse the informational content of the map, finding it deficient in ways its original creator and users would never have appreciated or intended. The way we should present an Ordnance Survey map of the 1930s is not the same as a county map or a military sketch map of the 18th century. In making available historical maps we have a responsibility to their creator and time period. Crucially, we did not want to degrade the original images (which were relatively low resolution by 2006 standards) through transformation, and this also weighed against the

use of rubber-sheeting methods, or higher-order polynomial transformations. One of the disadvantages of this was that the Roy map was only approximately geo-referenced, a first-order affine transformation, shifting and rotating the map to best fit a modern geography (Boutoura and Livieratos, 2006). Due to geometric inaccuracies in the original map, in some cases the placing of the Roy map location was up to five miles distant from the real geographical location (Figure 5), creating some difficulties in the website of more accurate gazetteer point location queries, and locational differences in zooming between the index map and the more detailed Roy map. However, these disadvantages were felt to be overcome in this project by making the Roy map available as an authentic facsimile and not degrading the original images.

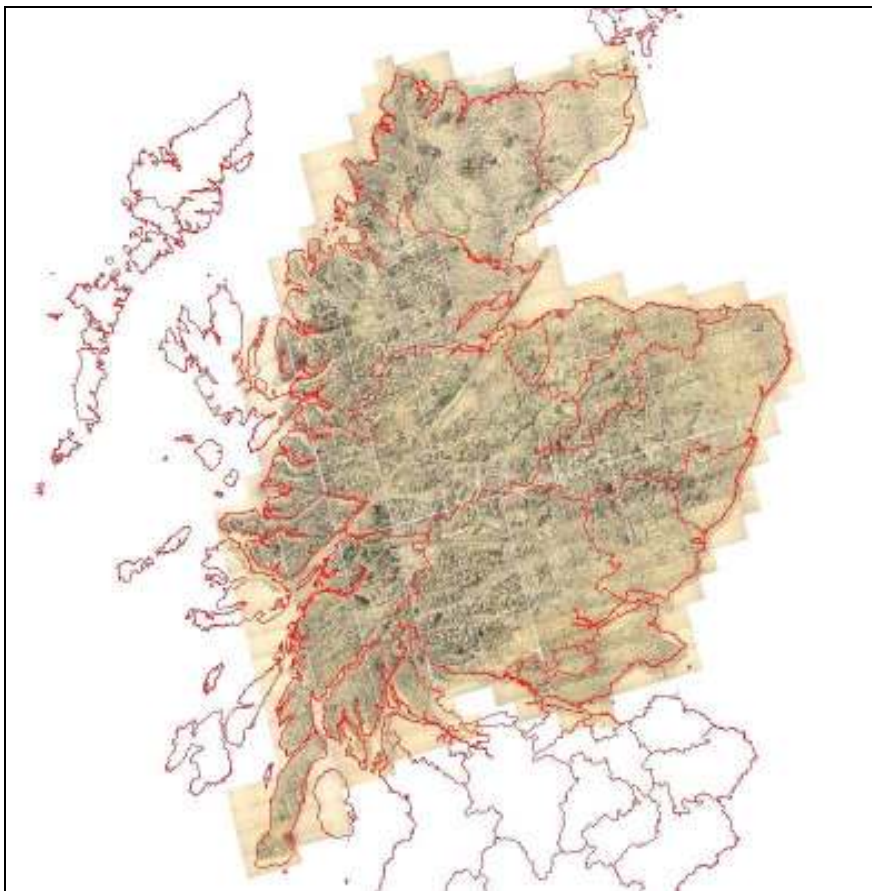


Figure 5. The Roy map for the Highlands overlaid with a modern coastline and county boundaries. Geo-referencing through a basic first-order affine transformation lead the acceptable disadvantage of some map locations being up to five miles distant from their true location, particularly in the north.

Another difficulty was the size of the composite images - some 26 Gb in total. We also needed to retain them as 24 bit colour (rather than reduce them to 8-bit colour at one third of the image size) to allow the use of a transparent or no-data colour in ArcIMS so that

the white pixels beyond the edge of each of our two composite maps could be set as transparent and not obscure the other map.

The geo-referencing of the index map sheet (a marked up version of James Wyld's *Scotland with its islands drawn from the topographical surveys* (1843) was undertaken with ArcGIS in NLS - with control points scattered across the map, and a basic first-order affine transformation.

Website Delivery

Although we were aware of the growing value and use of open source solutions, mashups, Google Earth and Google Maps for delivering geo-referenced mapping, our initial perception was that they would be more complicated and risky than existing, tried and trusted commercial software. Within NLS, ArcIMS had been used successfully from 2004 for delivering geo-referenced information, with two main public applications: OS National Grid mapping indexes, and Bathymetrical Survey of the Fresh Water Lochs of Scotland (Fleet, 2005 - see <http://geo.nls.uk/>). From 2006, there had also been an intention to use ArcSDE for delivering large quantities of geo-referenced raster images relating to the Ordnance Survey six-inch mapping (1840s-1880s).

The existing ArcIMS applications were based around an easily customisable interface using Macromedia Coldfusion and Javascript, and given this existing code, it was relatively simple to adapt for the Roy Map application. The ArcIMS application requires no downloads or plug-ins, and the Coldfusion connector translates requests from web browser clients into ArcXML for the ArcIMS image server to then generate a map as an HTML page, with all processing done on the server side. Coldfusion also allows tools for querying databases of geo-referenced units, including polygons of counties and parishes, and gazetteer points, and zooming the map to these chosen locations. The application also uses dynamic HTML for generating red zoom box extents and map panning.

However, in spite of these advantages, there were a number of problems experienced with the ESRI (ArcIMS / ArcGIS / ArcSDE) software, including:

- Complexity - multiple software modules and sophisticated functionality
- Bugs - refreshing ArcIMS services, ArcSDE import hanging
- Difference between literature and reality
- Slow and inadequate support
- Unhelpful error messages
- Regular and difficult upgrades

We persevered through several setbacks. The original attempts to load JPEG2000 images and ECW images into ArcIMS failed. We were advised by ESRI that version 9.2 of ArcGIS / ArcIMS would handle these formats better, but version 9.2 didn't. ESRI then advised the use of ArcSDE, which was acquired and installed, but attempts to load the im-

ages again failed. It subsequently appeared that the NLS network and caching on the server was a problem, which we were told movement to a Storage Area Network would solve, but by early May 2007, we were still awaiting. So the solution we adopted was to abandon using ArcSDE and tile the original TIFF images into 20 x 20 km chunks, each about 70 Mb in size each, and load these as a layer with their accompanying TIFF World Files (see Appendix 1) into ArcIMS. The ArcXML map configuration file, with its basic <IMAGEWORKSPACE> layers, and the ability to set scale ranges and transparent colours, is reproduced in Appendix 2.

An important issue we face collectively for making available series mapping is the mechanics of tiling large images and sets of large images so that subsets of them can be delivered in a swift online application. The ArcSDE approach uses a database to manage reduced resolution subsets of rasters, also compressing the data, whilst ArcGIS and ArcIMS use reduced resolution data files (*.rrd files). KML files allow SuperOverlays with hierarchies of Regions and Network Links. In our case, sufficiently small quantities of Roy map images, each as a relatively small tile, allowed sufficiently fast results using *.rrd files without the use of a database, but for larger volumes of imagery, we know that this would not be suitable.

In spite of these constraints, we were able to design an interface that presented the Roy map in a way we felt was reasonably true to its original state, intuitive and easy to navigate as seamless layers. Contextual and historical information on the map was presented on the main home pages (<http://www.nls.uk/maps/roy/index.html>) with details of the scope of the survey, field survey methods, and cartographic style and content. By deliberately avoiding the use of modern mapping in the search interface, we did not overemphasize the geometric inaccuracies of the original map, nor allow fallacious comparisons between old and new with overlays that were not geographically “true”. An index map, based on a marked-up 1840s map of Scotland provides a basic smaller scale overview, and the use of historical counties and parishes as geo-referenced units for searching, is more appropriate than using modern jurisdictions (Figure 6 and <http://geo.nls.uk/roy>).

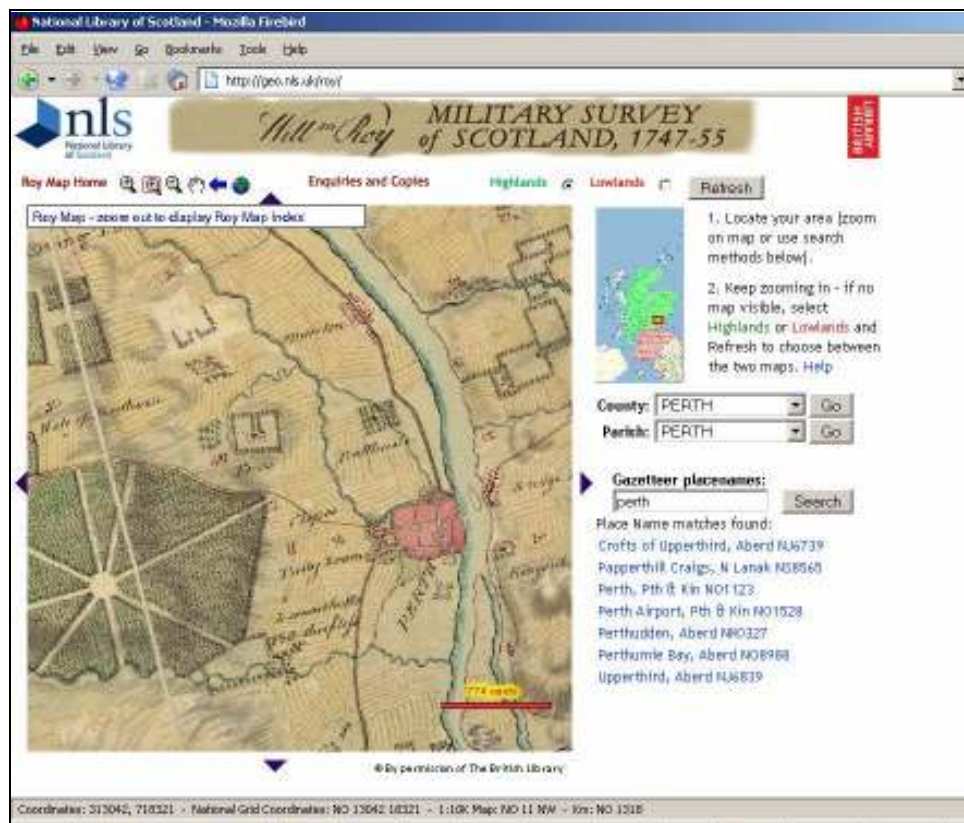


Figure 6. The Roy Map website, illustrating a zoomed map detail on Perth.

Note the colour-coded overview map, the ability to search by County / Parish, as well as gazetteer search.

See <http://geo.nls.uk/roy/> to view the Roy Map application.

That said, we are aware too of problems. There is no gazetteer of place names taken directly from the Roy map, and yet we know that users often prefer to search by place name. The modern gazetteer of names from 1:50,000 mapping provides a method of locating the Roy map, but the place name is often not there on the original, or does not appear in its modern gazetteer form. Similarly, places named on the Roy map that have since disappeared do not appear in the modern gazetteer. Another difficulty is the overlap between the maps of the Highlands and Lowlands. It is possible to choose between these two maps, and refresh the map to display the chosen map (with the coloured overview map attempting to indicate the coverage of each) but this is not intuitive, and in spite of online help, can create confusion. Web mapping technology is changing very fast, and this application looks rather limited compared to more flexible, non-frame-based interfaces, with streamed, AJAX-based mapping, exemplified particularly by Google Earth and Google Maps. Programming the application to work in all web browsers and operating systems has required more resources than we have available, and at present the application only works completely in Mozilla Firefox, Netscape 6 or higher, or Internet Explorer version 5.5 or higher. Obviously, the seamed geo-referenced Roy maps could be

made available in different software in a new application overcoming the present limitations, without needing to completely repeat the whole project, an important principle for all digital mapping applications. Due to the rate of technological change, interfaces are most ephemeral, but the effort of scanning and geo-referencing should not require repetition.

Conclusion

By far the largest proportion of paper mapping in libraries forms part of a set or series, yet in terms of online availability as records or as images, it is least available. There are a number of reasons for this, not least the greater costs involved in recording or scanning sets of maps rather than single items. However, another important reason is that series mapping often requires additional work to crop, seam, and geo-reference the individual parts as the most effective way of making them available. The process is therefore more time-consuming and costly, and the tools and software for doing this and making them available are less well understood (Fleet, 2006). It is hoped that case studies such as this that illustrate relatively simple and cheap methods for doing this could have value in furthering the broader availability of this important category of mapping.

This project illustrates a number of advantages offered by geo-referencing historic manuscript maps for use in web mapping applications. It enables:

- Improved searching via the use of gazetteers of related geo-referenced content
- Accurate presentation of scale and locational information
- Easy creation of overview map, in this case by colour-coding to distinguish the two maps (the “fair copy” for the Highlands, and “original protraction” for the Lowlands)
- Viewing and panning across a seamed, composite map

In the future, further advantages will hopefully be realised, such as:

- Integration with other geo-referenced historical mapping within this application.
- Linkage, via OGC Web Mapping Services in this case, with other geo-referenced historical maps
- Creation of appropriate metadata for better retrieval

This paper also suggests that presenting historical maps should try to take account of the background context of the original map, and that any geo-referencing and integration of historical maps with modern maps or geospatial information should be sensitive to the problems this can cause if done inappropriately. A distinction can usefully be made between geo-referencing for access and geo-referencing for cartometric / geometric analysis.

The tools and software for geo-referencing historical maps and making them available over the Internet are becoming steadily more widespread and easy to use. That said, there are a large and growing number of ways of geo-referencing maps, tiling large images, and customising interfaces to present these online, and so a growing need for shared solutions and collaborative approaches to these tasks.

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Appendix 1

Example of a TIFF World File, a six-line text file accompanying a TIFF raster image to provide basic locational information, with an explanation of each element

```
5           (the dimension of a pixel in map units in the x direction)
0.000      (rotation term for row)
0.000      (rotation term for column)
5           (the dimension of a pixel in map units in the y direction)
180003.97377323595 (the x coordinate of the centre of upper-left pixel)
759998.01272738166 (the y coordinate of the centre of upper-left pixel)
```

Appendix 2

The ArcIMS map configuration file, written in ArcXML for the Roy map application. This illustrates the basic <IMAGEWORKSPACE> properties, and the ability to set scale ranges (maxscale="1:150000") and transparent colours <IMAGEPROPERTIES transcolor="255,255,255" /> for individual layers

```
<?xml version="1.0" encoding="UTF-8"?>

<ARFXML version="1.1">
  <CONFIG>
    <ENVIRONMENT>
      <LOCALE country="GB" language="en" variant="" />
      <UIFONT color="0,0,0" name="dialog" size="12" style="regular" />
      <SCREEN dpi="96" />
    </ENVIRONMENT>
    <MAP>
      <PROPERTIES>
        <ENVELOPE minx="100000.0" miny="600000.0" maxx="500000.0" maxy="1000000.0"
name="Initial_Extent" />
        <MAPUNITS units="meters" />
        <IMAGEGENERALIZATION mode="false" />
      </PROPERTIES>
      <WORKSPACES>

        <SHAPEWORKSPACE name="shp_ws-3" directory="e:\data\Databases" />
        <IMAGEWORKSPACE name="img_ws-2" directory="e:\data\OS\Mini" />
        <IMAGEWORKSPACE name="img_ws-4" directory="e:\data\Roy\Lowlands" />
        <IMAGEWORKSPACE name="img_ws-5" directory="e:\data\Roy\Highlands" />
        <IMAGEWORKSPACE name="img_ws-6" directory="e:\data\Roy\Index" />

      </WORKSPACES>

      <LAYER type="image" name="Mini" visible="true" id="0" minscale="1:200000">
        <DATASET name="MiniScale (with grid) R5.tif" type="image" workspace="img_ws-2" />
      </LAYER>
    </MAP>
  </CONFIG>
</ARFXML>
```

```
</LAYER>

<LAYER type="image" name="RoyIndex" visible="true" id="2" minscale="1:150000" >
  <DATASET name="*ImageDirectory" type="image" workspace="img_ws-6" />
</LAYER>

<LAYER type="image" name="Level7" visible="true" id="4" maxscale="1:150000" >
  <DATASET name="*ImageDirectory" type="image" workspace="img_ws-4" />
  <IMAGEPROPERTIES transcolor="255,255,255" />
</LAYER>

<LAYER type="image" name="Level8" visible="true" id="5" maxscale="1:150000" >
  <DATASET name="*ImageDirectory" type="image" workspace="img_ws-5" />
  <IMAGEPROPERTIES transcolor="255,255,255" />
</LAYER>

</MAP>
</CONFIG>
</ARXML>
```

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The Roy map was part of a widespread and persistent campaign to integrate Scotland into the British state, and there were political, economic and religious aspects to this effort. A key trigger, for example, was following the accession to the British throne of William of Orange in 1689. The supporters of the exiled Catholic King James II of England and the Stuart cause, who became known as Jacobites, staged a series of violent rebellions in 1689, 1715, and 1745 in Scotland and northern England. A cartographic reaction to this was the creation, by the British Board of Ordnance, of a large number of military plans of fortifications, roads, bridges, and battles. In spite of this, however, general topographic mapping of the region was very limited, and the 1745 rebellion was an acute embarrassment to British military commanders through “want of a proper survey of the country” (Moir, 1973: 105). Soon after the defeat of the Jacobites at Culloden in May 1746, the British King (George II) was petitioned to support a Military Survey of Scotland and the primary practical responsibility for this was delegated to the Assistant Quartermaster in the Board of Ordnance, William Roy.

The Roy Military Survey was significantly limited by the availability of men, equipment and time, especially when compared with the Ordnance Survey in Scotland a century later. In 1748, there were only four military engineers available for work in Scotland, all

of whom were involved in road construction. Although at this time the King approved an increase in engineers, and some practitioner engineers were appointed, the work was always one of rapid reconnaissance rather than a carefully measured topographic survey.



Figure 1. A detail from the Roy map, depicting Dundee.

According to Roy, the map was rather a “magnificent military sketch, than a very accurate map of the country” in which “no geometrical exactness is to be expected, the sole object in view being, to shew remarkable things, or such as constitute the great outlines of the Country” (Roy, 1765: 385-6). The Military Survey was not based upon triangulation, but rather upon a set of measured traverses along important features using theodolites and chains. Each surveying party consisted of an engineer with a Non-Commissioned Officer and six soldiers. The theodolites (circumferentors or surveying compasses for measuring angles) were fairly simple, of seven inches in diameter and with common sights without telescopes (see Figure 2), whilst the chains for measuring distance were 45-50 feet long. Only selected landscape features (roads, rivers and lochs) were instrumentally surveyed in this manner, with the remaining landscape features (towns and settlements, enclosures and woodland, as well as relief), sketched in by eye or copied from existing maps.



Figure 2. The simple theodolite (circumferentor) used on the Roy Military Survey.

Considerable adjustment was required to bring the separate traverses together, following discussion amongst separate surveying parties. After active surveying in the summer months, the surveyors returned in the autumn and winter to the Board of Ordnance drawing office in Edinburgh, where the composite map known as the “original protraction” was prepared. Notably, the map was not graduated for latitude nor longitude, nor presented with a standard scale, and its orientation was always towards magnetic north, the declination at this date taken to be 19 degrees west.

The Survey was conducted in two parts, first the Highlands to 1752, and then the Lowlands to 1755, and the surviving maps from these two surveys overlap. Although there were “original protractions” made of both the maps of northern and southern Scotland, various copies were made, in particular a “fair copy” of northern Scotland. (No such fair copy was made for southern Scotland).

The maps were presented to George III in 1761 and incorporated into the Royal Library in London; the King’s Library, as it became known, was offered as a gift to the British nation in 1823 by George IV, which was in turn entrusted to the British Museum in 1828. The Museum held the King’s Library, including King George III’s Topographical Collection in which the Roy map resided, until 1973, when it was transferred to the newly-founded British Library.

Sometime before 1844, the two sets of rolls were remounted as 38 sheets of unequal size (Figure 3) backed on linen and dissected into 2-7 sections, each section made up of six individual dissections. These 38 sheets were preserved in 8 slip cases to form a composite map of all of Scotland. It is the individual dissections that were photographed in 1990.



Figure 3 The “index map” showing the layout of the 38 separate strips of the Roy Map.

Project plan, digital scanning, and agreements

Both the National Library of Scotland and the British Library had long wanted to make the Roy map more accessible, due to the broad interest that the Roy map generates among visitors to the libraries as well as in the wider population. Though the NLS Map Library showcases some six thousand historical maps of Scotland between 1560 and 1928 that have already been scanned (see <http://www.nls.uk/maps>) and the BL offers many other manuscript map treasures online, there has always been a high demand for access to the Roy map, not just from family and local historians, but from anyone interested in the Scottish landscape in the 18th century, British cartographic methods at the time, and mapping before the Ordnance Survey. However, the main access to the Roy map at NLS was traditionally through surrogates in the reading room: 35 mm colour slides and black-and-white photographs, formats also used in the British Library unless the original was absolutely required.

In 2000, SCRAN (the Scottish Cultural Resources Access Network, an educational image library originally funded by the United Kingdom lottery) scanned the 35 mm slides of approximately 1,100 dissections and made them available on its website (<http://www.scran.ac.uk>). There were two main limitations of the SCRAN Roy images. First, search and retrieval was difficult, as each dissection was presented as a single separate image and searching for the right dissection and navigating from one dissection to another was difficult. Second, the SCRAN website required a fee-based subscription.

NLS led an initiative to make digital copies of the Roy map freely accessible on the Internet. This involved gaining permission to use the map, acquiring the digital images, securing funding for geo-referencing, and establishing an online resource discovery tool for the maps. A February 2006 agreement with BL brought permission to make the map available on the web in a joint NLS/BL project. While it would have been desirable to the project leaders to photograph the original map again, in order to acquire higher resolution images of larger areas so to demand less seaming, this was not an option for financial reasons. Fortunately, SCRAN agreed to supply the previously-scanned digital image files (made from the slides). Funding for the geo-referencing was obtained from NLS. The software and infrastructure for the online mapping tool was already owned by NLS, and so the Roy map could be added, without significant additional expense, to the other existing scanned and geo-referenced map collections.

Mosaicing and geo-referencing

While the original intention was to mosaic and geo-reference the images in-house, without dedicated staff, the decision was taken to sub-contract the work to a local company, the XYZ Digital Map Company. This private company had already geo-referenced Ordnance Survey mapping for NLS, and additionally, their GIS Programmer had formerly worked in the BL and had an interest in the original map and the project. Geo-referencing of historical maps is aided considerably by patience, as well as an interest and knowledge of the area, the original map, and in the end result. It was felt that would not necessarily have been achieved through sub-contracting the geo-referencing work elsewhere, or to those without a stake or direct interest in the outcome.

The basic process therefore involved:

1. Cropping the images/dissections, to remove the overlaps with adjacent dissections.
2. Seaming the images/dissections into composite strips.
3. Seaming the composite strips together into two composite maps (one for the Highlands and one for the Lowlands).
4. Geo-referencing (global, first-order affine transformation) of the composite maps.

The work was undertaken using the software ER Mapper, and was completed by January 2007.

Originally, the attempt was made to geo-reference the composite strips (ie. to skip stage 3 in the process above), to form a seamless map, but this resulted in overlapping strips, particularly because of the greater width of the linen backing in the horizontal dimension. Because the obscured detail caused by overlapping strips was felt to be unacceptable, the strips were mosaicked to form a composite map without overlaps, and this composite map was then geo-referenced (Figure 4).



Figure 4. Two methods of geo-referencing compared. Geo-referencing strips created unacceptable overlaps, in contrast to the chosen method of geo-referencing the composite map.

The purpose of geo-referencing was to facilitate access, not to employ cartometric analysis or examine the map's geometric accuracy. The authors felt too that there is a danger in geo-referencing and integrating a map such as this with modern maps or satellite imagery, which could arguably misrepresent its geometric accuracy, or misuse the informational content of the map, finding it deficient in ways its original creator and users would never have appreciated or intended. The way we should present an Ordnance Survey map of the 1930s is not the same as a county map or a military sketch map of the 18th century. In making available historical maps we have a responsibility to their creator and time period. Crucially, we did not want to degrade the original images (which were relatively low resolution by 2006 standards) through transformation, and this also weighed against the

use of rubber-sheeting methods, or higher-order polynomial transformations. One of the disadvantages of this was that the Roy map was only approximately geo-referenced, a first-order affine transformation, shifting and rotating the map to best fit a modern geography (Boutoura and Livieratos, 2006). Due to geometric inaccuracies in the original map, in some cases the placing of the Roy map location was up to five miles distant from the real geographical location (Figure 5), creating some difficulties in the website of more accurate gazetteer point location queries, and locational differences in zooming between the index map and the more detailed Roy map. However, these disadvantages were felt to be overcome in this project by making the Roy map available as an authentic facsimile and not degrading the original images.

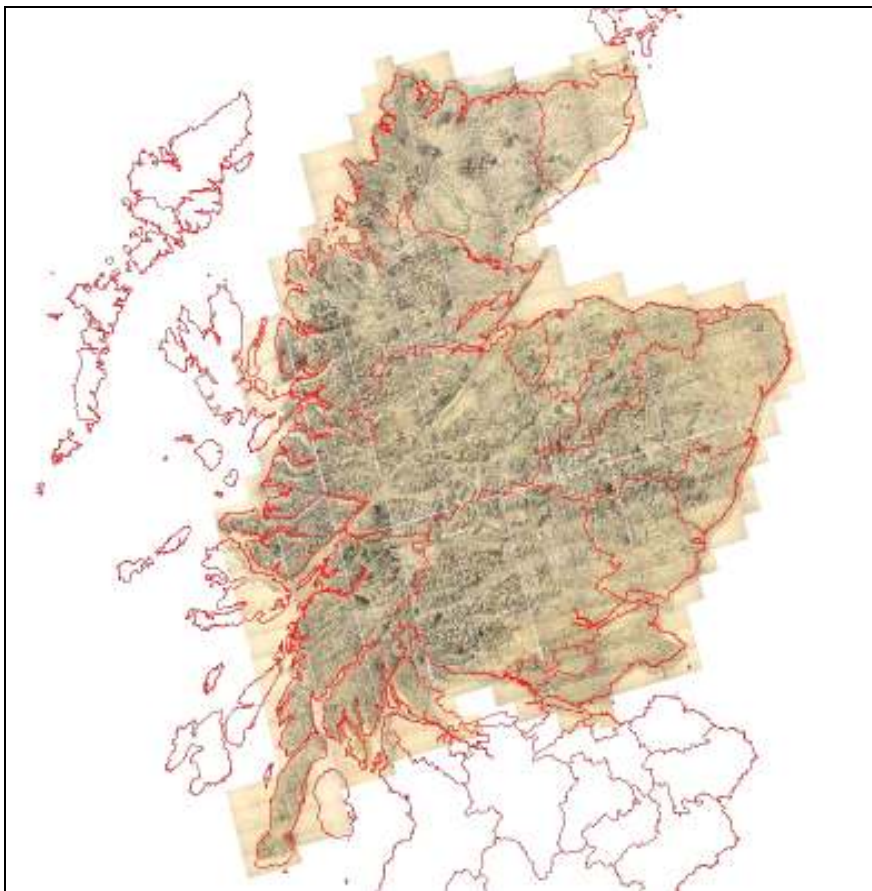


Figure 5. The Roy map for the Highlands overlaid with a modern coastline and county boundaries. Geo-referencing through a basic first-order affine transformation lead the acceptable disadvantage of some map locations being up to five miles distant from their true location, particularly in the north.

Another difficulty was the size of the composite images - some 26 Gb in total. We also needed to retain them as 24 bit colour (rather than reduce them to 8-bit colour at one third of the image size) to allow the use of a transparent or no-data colour in ArcIMS so that

the white pixels beyond the edge of each of our two composite maps could be set as transparent and not obscure the other map.

The geo-referencing of the index map sheet (a marked up version of James Wyld's *Scotland with its islands drawn from the topographical surveys* (1843) was undertaken with ArcGIS in NLS - with control points scattered across the map, and a basic first-order affine transformation.

Website Delivery

Although we were aware of the growing value and use of open source solutions, mashups, Google Earth and Google Maps for delivering geo-referenced mapping, our initial perception was that they would be more complicated and risky than existing, tried and trusted commercial software. Within NLS, ArcIMS had been used successfully from 2004 for delivering geo-referenced information, with two main public applications: OS National Grid mapping indexes, and Bathymetrical Survey of the Fresh Water Lochs of Scotland (Fleet, 2005 - see <http://geo.nls.uk/>). From 2006, there had also been an intention to use ArcSDE for delivering large quantities of geo-referenced raster images relating to the Ordnance Survey six-inch mapping (1840s-1880s).

The existing ArcIMS applications were based around an easily customisable interface using Macromedia Coldfusion and Javascript, and given this existing code, it was relatively simple to adapt for the Roy Map application. The ArcIMS application requires no downloads or plug-ins, and the Coldfusion connector translates requests from web browser clients into ArcXML for the ArcIMS image server to then generate a map as an HTML page, with all processing done on the server side. Coldfusion also allows tools for querying databases of geo-referenced units, including polygons of counties and parishes, and gazetteer points, and zooming the map to these chosen locations. The application also uses dynamic HTML for generating red zoom box extents and map panning.

However, in spite of these advantages, there were a number of problems experienced with the ESRI (ArcIMS / ArcGIS / ArcSDE) software, including:

- Complexity - multiple software modules and sophisticated functionality
- Bugs - refreshing ArcIMS services, ArcSDE import hanging
- Difference between literature and reality
- Slow and inadequate support
- Unhelpful error messages
- Regular and difficult upgrades

We persevered through several setbacks. The original attempts to load JPEG2000 images and ECW images into ArcIMS failed. We were advised by ESRI that version 9.2 of ArcGIS / ArcIMS would handle these formats better, but version 9.2 didn't. ESRI then advised the use of ArcSDE, which was acquired and installed, but attempts to load the im-

ages again failed. It subsequently appeared that the NLS network and caching on the server was a problem, which we were told movement to a Storage Area Network would solve, but by early May 2007, we were still awaiting. So the solution we adopted was to abandon using ArcSDE and tile the original TIFF images into 20 x 20 km chunks, each about 70 Mb in size each, and load these as a layer with their accompanying TIFF World Files (see Appendix 1) into ArcIMS. The ArcXML map configuration file, with its basic <IMAGEWORKSPACE> layers, and the ability to set scale ranges and transparent colours, is reproduced in Appendix 2.

An important issue we face collectively for making available series mapping is the mechanics of tiling large images and sets of large images so that subsets of them can be delivered in a swift online application. The ArcSDE approach uses a database to manage reduced resolution subsets of rasters, also compressing the data, whilst ArcGIS and ArcIMS use reduced resolution data files (*.rrd files). KML files allow SuperOverlays with hierarchies of Regions and Network Links. In our case, sufficiently small quantities of Roy map images, each as a relatively small tile, allowed sufficiently fast results using *.rrd files without the use of a database, but for larger volumes of imagery, we know that this would not be suitable.

In spite of these constraints, we were able to design an interface that presented the Roy map in a way we felt was reasonably true to its original state, intuitive and easy to navigate as seamless layers. Contextual and historical information on the map was presented on the main home pages (<http://www.nls.uk/maps/roy/index.html>) with details of the scope of the survey, field survey methods, and cartographic style and content. By deliberately avoiding the use of modern mapping in the search interface, we did not overemphasize the geometric inaccuracies of the original map, nor allow fallacious comparisons between old and new with overlays that were not geographically “true”. An index map, based on a marked-up 1840s map of Scotland provides a basic smaller scale overview, and the use of historical counties and parishes as geo-referenced units for searching, is more appropriate than using modern jurisdictions (Figure 6 and <http://geo.nls.uk/roy>).

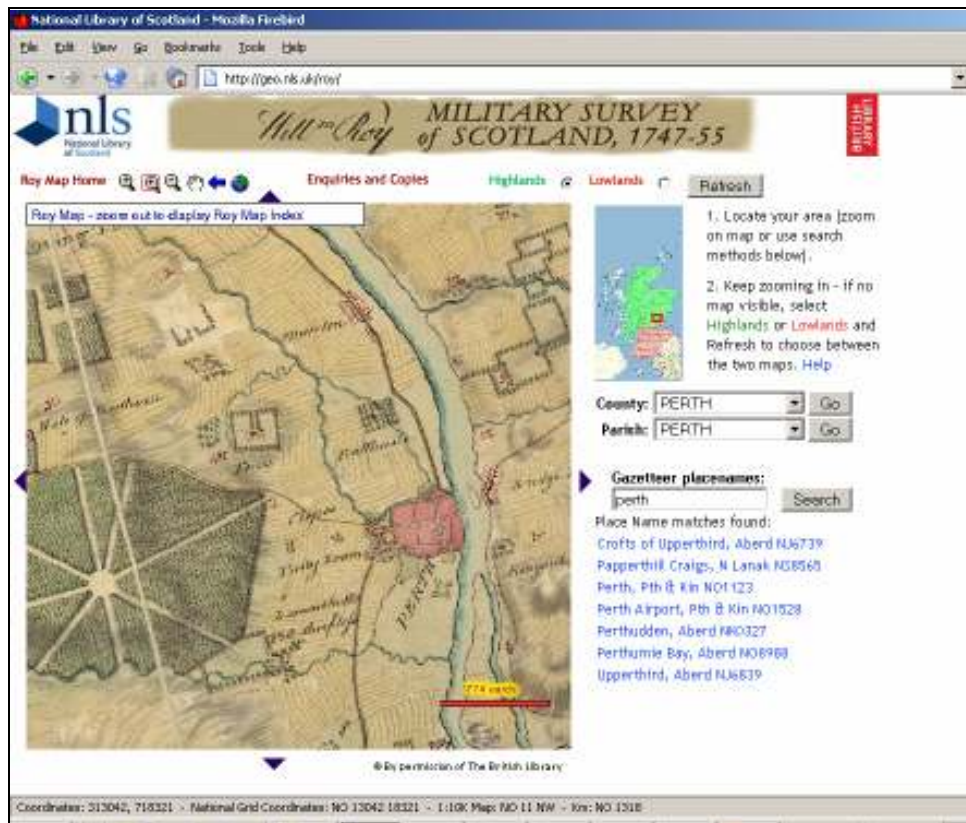


Figure 6. The Roy Map website, illustrating a zoomed map detail on Perth.

Note the colour-coded overview map, the ability to search by County / Parish, as well as gazetteer search.

See <http://geo.nls.uk/roy> to view the Roy Map application.

That said, we are aware too of problems. There is no gazetteer of place names taken directly from the Roy map, and yet we know that users often prefer to search by place name. The modern gazetteer of names from 1:50,000 mapping provides a method of locating the Roy map, but the place name is often not there on the original, or does not appear in its modern gazetteer form. Similarly, places named on the Roy map that have since disappeared do not appear in the modern gazetteer. Another difficulty is the overlap between the maps of the Highlands and Lowlands. It is possible to choose between these two maps, and refresh the map to display the chosen map (with the coloured overview map attempting to indicate the coverage of each) but this is not intuitive, and in spite of online help, can create confusion. Web mapping technology is changing very fast, and this application looks rather limited compared to more flexible, non-frame-based interfaces, with streamed, AJAX-based mapping, exemplified particularly by Google Earth and Google Maps. Programming the application to work in all web browsers and operating systems has required more resources than we have available, and at present the application only works completely in Mozilla Firefox, Netscape 6 or higher, or Internet Explorer version 5.5 or higher. Obviously, the seamed geo-referenced Roy maps could be

made available in different software in a new application overcoming the present limitations, without needing to completely repeat the whole project, an important principle for all digital mapping applications. Due to the rate of technological change, interfaces are most ephemeral, but the effort of scanning and geo-referencing should not require repetition.

Conclusion

By far the largest proportion of paper mapping in libraries forms part of a set or series, yet in terms of online availability as records or as images, it is least available. There are a number of reasons for this, not least the greater costs involved in recording or scanning sets of maps rather than single items. However, another important reason is that series mapping often requires additional work to crop, seam, and geo-reference the individual parts as the most effective way of making them available. The process is therefore more time-consuming and costly, and the tools and software for doing this and making them available are less well understood (Fleet, 2006). It is hoped that case studies such as this that illustrate relatively simple and cheap methods for doing this could have value in furthering the broader availability of this important category of mapping.

This project illustrates a number of advantages offered by geo-referencing historic manuscript maps for use in web mapping applications. It enables:

- Improved searching via the use of gazetteers of related geo-referenced content
- Accurate presentation of scale and locational information
- Easy creation of overview map, in this case by colour-coding to distinguish the two maps (the “fair copy” for the Highlands, and “original protraction” for the Lowlands)
- Viewing and panning across a seamed, composite map

In the future, further advantages will hopefully be realised, such as:

- Integration with other geo-referenced historical mapping within this application.
- Linkage, via OGC Web Mapping Services in this case, with other geo-referenced historical maps
- Creation of appropriate metadata for better retrieval

This paper also suggests that presenting historical maps should try to take account of the background context of the original map, and that any geo-referencing and integration of historical maps with modern maps or geospatial information should be sensitive to the problems this can cause if done inappropriately. A distinction can usefully be made between geo-referencing for access and geo-referencing for cartometric / geometric analysis.

The tools and software for geo-referencing historical maps and making them available over the Internet are becoming steadily more widespread and easy to use. That said, there are a large and growing number of ways of geo-referencing maps, tiling large images, and customising interfaces to present these online, and so a growing need for shared solutions and collaborative approaches to these tasks.

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Appendix 1

Example of a TIFF World File, a six-line text file accompanying a TIFF raster image to provide basic locational information, with an explanation of each element

```
5           (the dimension of a pixel in map units in the x direction)
0.000      (rotation term for row)
0.000      (rotation term for column)
5           (the dimension of a pixel in map units in the y direction)
180003.97377323595 (the x coordinate of the centre of upper-left pixel)
759998.01272738166 (the y coordinate of the centre of upper-left pixel)
```

Appendix 2

The ArcIMS map configuration file, written in ArcXML for the Roy map application. This illustrates the basic <IMAGEWORKSPACE> properties, and the ability to set scale ranges (maxscale="1:150000") and transparent colours <IMAGEPROPERTIES transcolor="255,255,255" /> for individual layers

```
<?xml version="1.0" encoding="UTF-8"?>

<ARFXML version="1.1">
  <CONFIG>
    <ENVIRONMENT>
      <LOCALE country="GB" language="en" variant="" />
      <UIFONT color="0,0,0" name="dialog" size="12" style="regular" />
      <SCREEN dpi="96" />
    </ENVIRONMENT>
    <MAP>
      <PROPERTIES>
        <ENVELOPE minx="100000.0" miny="600000.0" maxx="500000.0" maxy="1000000.0"
name="Initial_Extent" />
        <MAPUNITS units="meters" />
        <IMAGEGENERALIZATION mode="false" />
      </PROPERTIES>
      <WORKSPACES>

        <SHAPEWORKSPACE name="shp_ws-3" directory="e:\data\Databases" />
        <IMAGEWORKSPACE name="img_ws-2" directory="e:\data\OS\Mini" />
        <IMAGEWORKSPACE name="img_ws-4" directory="e:\data\Roy\Lowlands" />
        <IMAGEWORKSPACE name="img_ws-5" directory="e:\data\Roy\Highlands" />
        <IMAGEWORKSPACE name="img_ws-6" directory="e:\data\Roy\Index" />

      </WORKSPACES>

      <LAYER type="image" name="Mini" visible="true" id="0" minscale="1:200000">
        <DATASET name="MiniScale (with grid) R5.tif" type="image" workspace="img_ws-2" />
      </LAYER>
    </MAP>
  </CONFIG>
</ARFXML>
```

```
</LAYER>

<LAYER type="image" name="RoyIndex" visible="true" id="2" minscale="1:150000" >
  <DATASET name="*ImageDirectory" type="image" workspace="img_ws-6" />
</LAYER>

<LAYER type="image" name="Level7" visible="true" id="4" maxscale="1:150000" >
  <DATASET name="*ImageDirectory" type="image" workspace="img_ws-4" />
  <IMAGEPROPERTIES transcolor="255,255,255" />
</LAYER>

<LAYER type="image" name="Level8" visible="true" id="5" maxscale="1:150000" >
  <DATASET name="*ImageDirectory" type="image" workspace="img_ws-5" />
  <IMAGEPROPERTIES transcolor="255,255,255" />
</LAYER>

</MAP>
</CONFIG>
</ARXML>
```