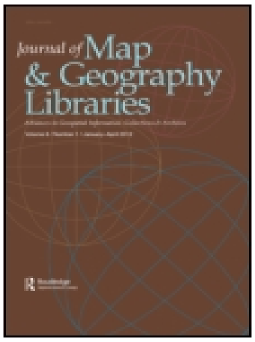

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The Long-Term Preservation of Digital Historical Geospatial Data: A Review of Issues and Methods

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For quite some time, librarians and archivists have been concerned with the long term preservation of all manner of digital objects in their collections. More recently, scholars who have often spent years developing Geographic Information Systems for historical analysis have come to the realization that the more information technology evolves, the less likely it is that the historical geospatial data which they have painstakingly created will be accessible for many years to come. Further complicating the issue is the multiplicity of data structures that can make up the collection of geospatial information necessary for the instantiation of a map view. While there are currently no permanent solutions to these issues, there are a number of prudent steps that can be taken to preserve such data past the short-term, thus making it more likely that these valuable cultural resources can be migrated in step with advancing technologies well into the future.

KEYWORDS *archives, data preservation, geospatial data, geographic information systems (GIS), historical geographic information systems (HGIS)*

INTRODUCTION

Scholars in history and geography have been using GIS research methods for decades now (Gregory and Geddes 2014; Knowles 2008; Knowles 2002). This has generated a considerable amount of historical geospatial data, only some of which is being curated in any sort of formal digital collection. With

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the passage of time, the risk of losing these digital resources continues to grow, and planning for long term preservation can no longer be ignored (Downs 2015, 117). This article aims to address the needs of researchers producing this specialized geospatial data and librarians and archivists who are just beginning to implement solutions to the problems of archiving digital geospatial data in general.

The historical geospatial data referred to is often generated by researchers using Historical Geographical Information Systems (HGIS), a methodology used across many disciplines, often under the umbrella "the spatial humanities" (Gregory and Geddes 2014; Bodenhamer et al. 2010). A distinction should be drawn between geospatial data acquired or created from primary sources in the course of historical research and that geospatial data which is "historical" in the sense that it represents geographical features recorded sometime before the present. It is the former which will be referred to here as historical geospatial data.

The article introduces some of the issues unique to the preservation of historical geographical information in both the abstract realm of information science as well as in the more concrete realm of archiving and curating digital information objects. This will be accomplished by first looking at the problems of preserving geographic information at the logical level of digital representation, and second by discussing the challenges to preserving geospatial data at the physical level, addressing issues such as the multiplicity of geospatial data formats. Such objects can include geodatabases, cartographic representations, and web services, as well as the underlying data content itself. After outlining these issues, we will turn to archival practices and how researchers can work with librarians and archivists to ensure that their data is preserved beyond the short term and in such a manner that it can be migrated in step with advancing technologies into the foreseeable future.

CHALLENGES TO PRESERVING GEOSPATIAL INFORMATION

As a librarian and researcher whose HGIS work dates back over a decade, I am increasingly concerned by the large amount of geospatial data that continues to grow on my workstation[1]. A brief survey of my files reveals a hodge-podge of different data structures and file formats, among them Shapefiles, GeoTiffs, World Files, and KML documents, as well as myriad images of paper maps and data tables with record locations, all ready for georeferencing. Some of this data is sitting unstructured within a simple folder tree, other data is held in various geodatabases, most of them proprietary. Visualizations of this data, in varying degrees of cartographic refinement, are sometimes held as snapshots in different types of image formats or are stored more loosely as symbolized data layers in Esri map documents. The preservation of this research material appears to be a daunting prospect.

However, before addressing the challenges presented by the multiplicity of geospatial data structures, let us consider the nature of geographical information in general. By starting with an abstract concept of geographical information and some models for representing such information digitally before considering the physical structures of geospatial data, the focus will be on the overlapping and contradictory ways in which geospatial data can be stored in a digital environment. Framing the problems this way should help identify paths through the thicket of choices facing the researcher and archivist, allowing them to choose an approach to preservation based on a full conceptualization of the problem rather than merely attempting to minimize the shortcomings presented by today's technology.

So what is meant by "geographic information?" As Longley and his colleagues (2006, 4) have noted: "Almost everything that happens, happens somewhere." Therefore the "location" of an "event" is a useful generalization. Furthermore, a "location" must be referenced to somewhere on the surface of the earth at a particular scale. While location cannot stand alone from scale, it can remain independent of the location of other objects. Nonetheless, another key aspect of an object's location can be its spatial relationship to or with other objects. Thus, at this logical level of abstraction, geographic information must have a geographical reference, scale, and, optionally, topology.

Moving from that simple abstraction to the level of representing geographic information in a digital environment we can observe three important variations in geospatial data: 1) such information can be continuous or discrete, 2) it can be topological or unstructured, and 3) it can be stored in vector or raster data structures. Considering these variations illuminates a key problem in the preservation of geospatial data. Different geospatial data formats can capture subsets of these elements but not all of them. Therefore, there is no way to treat geospatial data as a single type of data the way an archivist might treat "textual" data (McGarva et al. 2009).

Another critical aspect of representing geographical information is visualization. At a logical level, we can consider such visualizations as maps consisting of a variety of data layers, all of which may be held in different types of digital representation. In the case of linked data some of these layers may be represented by ephemeral web-services that present serious challenges to preservation. Researchers and archivists must think carefully about which visualizations in a research project need to be preserved, what collection of digital objects will be necessary to instantiate a particular visualization, how to maintain the fixity of these objects, and how to preserve the context of the collection itself.

GEOGRAPHICAL INFORMATION AND HISTORICAL INFORMATION

Creating geospatial information from historical sources further complicates its representation, adding to the challenges of preservation. As Baker (2003, 210) has observed, any geographical information discovered from historical sources cannot be considered factual. Instead, it represents the assessment of a researcher, and such scholarly judgments must be contextualized. In the case of historical geospatial data this includes the critical choices made by researchers for the physical representations of space and time in a GIS environment.

For the creation of geospatial data from contemporaneous observations, researchers have the luxury of defining the spatial and temporal dimensions of the data before they collect it. However, scholars creating historical geospatial data must work with whatever implicit representations of time and space existing in the primary sources they are investigating.

Furthermore, because GIS technology handles time and space as separate entities, the instantiation of historical events must be represented in discrete spatial and temporal terms. Not only is this true for vector datasets, but raster representations of continuous data must also have an explicit ground distance.

That said, location information obtained from historical sources is rarely that straightforward. Instead, one of the principal challenges to conducting HGIS research is that sources are often incomplete, inaccurate, or otherwise ambiguous (Gregory and Ell 2007, 17). Therefore the explicit geospatial definition of historical locations must be determined by the researcher, often based on an assessment of limited information. This contextual information must be preserved as a part of any historical geospatial data.

Likewise, representing time in GIS does not always lend itself to a clear interpretation of historical sources. GIS generally holds time as single discrete values, either in a snapshot model where all objects in a map are presumed to exist at the exact same time, or in a space-time composite model where objects in a map are given multiple time-stamps. However, neither model can handle historical sources in which time occurs at multiple granularities. Such temporal ambiguity in historical sources is illustrated by Yuan (2014, 46) with the case of the *Carte de Cassini* (see Figure 1), the pioneering topographic mapping project in 18th century France. While it provides researchers with a single geographical snapshot of physical and cultural features, it was actually compiled over the course of thirty plus years and therefore it is not always possible to tell which features existed contemporaneously.

In the case of a space-time composite picture of historical geographical information, such as the GIS representation of demographic information contained in administrative units, the research problem to be contextualized is more complex. Given changes in the spatial boundaries of the administrative reporting units, spatial interpolation functions must be utilized to allow comparisons of geospatial data over time.

FIGURE 1 An inset view from the Cassini's *Carte de France levee par ordre du Roy* [*No. 1 (Paris)*]. Source: David Rumsey Historical Map Collection. http://www.davidrumsey.com/

PRESERVATION OF GEOSPATIAL DATA

Of course, the specialized problems considered here are part of the much larger problem of preserving all forms of digital information. In the United States, the Library of Congress has taken a lead role in addressing these issues through the National Digital Information Infrastructure and Preservation Program (NDIIPP), authorized by Congress in 2000. The Geospatial Data Preservation Resource Center provides a clearinghouse for information on the subject. Among a broad array of initiatives, NDIIPP has funded efforts aimed specifically at geographic information preservation and a brief review of this work, as well as similar efforts in Europe, will serve as an introduction to the current state of the art.

Among the earliest NDIIPP-sponsored geospatial programs was the National Geospatial Digital Archive (NGDA), a joint effort by Stanford University and the University of California at Santa Barbara built upon the previous work of the Alexandria Digital Library Project (ADL). From 2004 to 2009 the project created digital geospatial archives at both universities with attendant protocols and collections policies, as well as producing a geospatial format registry (Erwin and Sweetkind-Singer 2009).

While NGDA was aimed primarily at digital library preservation, NDIIPP also funded an effort to boost the capabilities of state and local government agencies to host and archive collections of their GIS data. Originally piloted in a single state as the North Carolina Geospatial Data Archiving Project, led by North Carolina State University Libraries, this project was expanded to include government agencies from Kentucky, Montana, and Utah in the Geospatial Multistate Archive and Preservation Project (Morris, et al. 2010; GeoMAPP 2011a). Based on work from 2007 to 2011, GeoMAPP's findings have served as a widely followed guide among GIS professionals (Locher and Temens 2012; Rönsdorf et al. 2013). Of particular interest are project reports on archival metadata elements and content packaging for geospatial data (GeoMAPP 2011b; GeoMAPP 2011c).

In Europe, the Swiss Federal Archives (SFA) and the Federal Office of Topography (swisstopo) conducted a study of geospatial data management among various government agencies. The study concluded that existing data storage models were inadequate for the long term preservation of geospatial data and a project was initiated to find appropriate alternatives. The result was a prototype archival system for data transfer and proposals for file formats and metadata standards for long term archiving (Locher and Temens 2012). This work evolved into Project Ellipse, a conceptual model for archiving geospatial data (SFA 2013).

Building on both the U.S. and Swiss efforts, the European Spatial Data Research (EuroSDR) Archiving Working Group was formed with representatives from eleven national mapping agencies (NMAs) and state archives and tasked with providing recommendations for archival best practices for European NMAs. The result was the GI+100 Report (Rönsdorf et al. 2013), a compilation of sixteen essential principals for archiving geospatial data.

Some of the most recent information on the preservation of geospatial data can be found in volume 11 of this journal, a special issue on *Geospatial Data Management, Curation and Preservation* (Downs 2015).

CHALLENGES TO PRESERVING GEOSPATIAL DATA

Investigators at the National Geospatial Digital Archive have identified a number of other characteristics of geospatial data that are relevant to this discussion of preservation. One of the most salient is the proprietary nature of many GIS formats. Not only do these formats pose a preservation risk over the long run given technological uncertainty, but because of commercial considerations they are often not backwardly compatible between versions in the short term (Janée 2008, 1).

Furthermore, geospatial data can be produced at multiple granularities. Single thematic features may have multiple geometries, or homogenous thematic features might be contained within heterogeneous databases. The many ways that geospatial data can be assembled and disassembled and the multiple operations involved in its production make it impossible to organize at uniform granularities (Janée 2008, 1).

In addition, much geographic information is dependent on the context of relating multiple datasets together. This context is often held in relational data systems and the preservation of these relationships must be accomplished within the digital object being preserved quite apart from whatever contextual information can be maintained in an archival management system. Trying to preserve individual data layers inevitably results in critical data loss.

Finally, there can be contextual information that is not explicitly represented in geospatial data. Ultimately, the true nature of geospatial information lies in unconstrained combinations of geospatial information at multiple granularities (swisstopo 2010, 3). There is contextual information about these combinations of data objects which is implicit, and may be restricted to the specialized knowledge of a small group of practitioners (Janée 2008, 1). This seems especially appropriate to bear in mind while considering the preservation of historical geospatial data.

PRINCIPLES OF LONG TERM GEOSPATIAL DATA PRESERVATION

Over the long run digital preservation relies on the "relay" principle. As stated by the NGDA, ". . . a preservation system should support handoff of its archival content to the next preservation system in succession; that is, the preservation system should support its own migration" (Janée 2008, 3). No one can predict how a particular information system or physical data model will fare over time. The only thing predictable is that hardware and software will become obsolete. Scholars producing historical geospatial information need not concern themselves with the migration of entire systems; however they, and the librarian's assisting them, must produce data management plans that ensure the successful migration of that part of the system which allows the historical geographic information they have produced to be stored, accessed, and used within a new and unknown preservation system.

In order to do this, certain preservation principles must be considered. The GI + 100 Report lists sixteen such principles to draw upon for this discussion (Rönsdorf 2013). However, the authors of the principles were concerned with the preservation and migration of entire archival systems and therefore what follows will cull from their list those principles most useful for data management planning from an information producer's point of view (see Figure 2)[2]:

First, archiving begins at the point of data creation. While many researchers are considering the preservation of data retroactively, clear documentation of how they have produced information is essential to successful

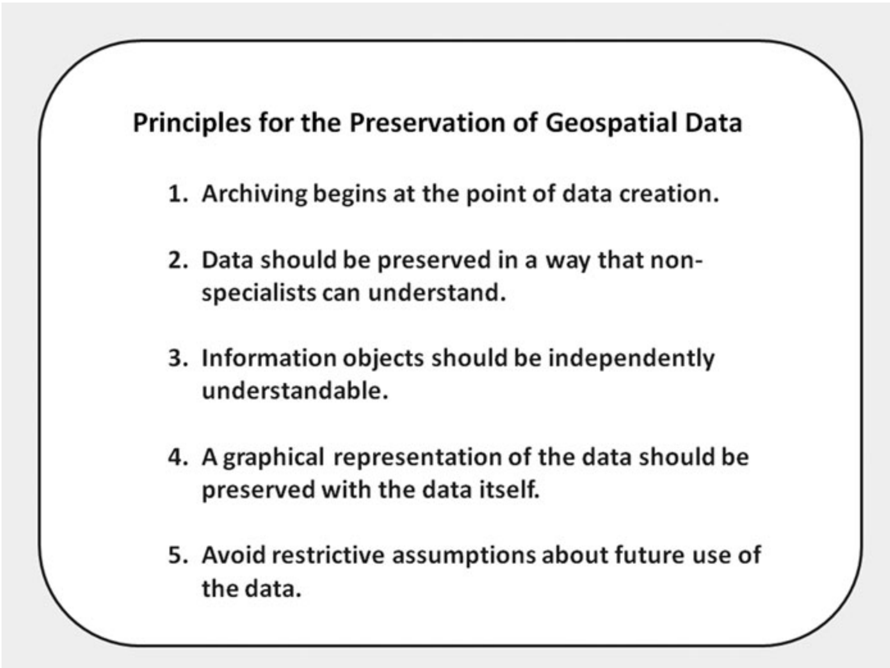

FIGURE 2 Five principles for the preservation of geospatial data.

preservation. At the very least, scholars must create geospatial metadata while they create data.

Second, historical geospatial data should be preserved in a way that non-specialists can understand. This means more than having a fully populated geospatial metadata scheme. Data producers should keep in mind that future users and future archivists will need to understand the context of the entire information package that will be migrated. Therefore, even metadata require contextualization.

Third, information objects should be self-contained and independently understandable. While this principle may be considered an ideal rather than a practical objective in all cases, nonetheless completeness and simplicity should be the watchwords for data management planning.

Fourth, a graphical representation should be kept in tandem to a logical representation of the geospatial data. Preserving a cartographic representation of the geospatial data is useful in two ways. Obviously, it provides context for future users of the preserved data. But in addition, the act of designing this graphical representation during the data management planning phase should assist the scholar (and archivist) to better understand what elements of context should be considered for preservation as part of a larger information package. Nothing concentrates the mind like a map.

Fifth, do not be too restrictive in the assumptions made about the future use of the data. In this regard, it might be useful to archive both the original geospatial data in its current data format but also attempt to reproduce the essential information in a more loosely structured data object that can be transformed into data structures not yet anticipated.

CHALLENGES TO PRESERVING GEOSPATIAL DATA ITEMS

Many of the challenges to preserving geospatial data can be overcome if they are stored in open, rather than proprietary, file formats (Morris 2011). Many tools exist to do this such as Quantum GIS[3] and those provided by the Geospatial Data Abstraction Library (GDAL)[4]. Complications can arise, however, when geospatial information is converted from proprietary to more open and sustainable formats, including the loss and distortion of data. These caveats should be considered as we examine particular data structures and formats.

One of the most difficult problems, from a preservation standpoint, is the cartographic representation of geospatial data. In order to preserve the instantiation of a map, one must be prepared to preserve many different types of datasets as well as a host of descriptive and display information. Much of this information is contained in project files such as the proprietary Esri Map Document .mxd file, or the Map Info Workspace .wor file. There are open source project files such as Quantum GIS Project Files .qgs, but here too one must be concerned by a data structure that relies on particular software architecture for future access and use.

One preservation case that falls between the aggregation of data layers and the single dataset is the homely and ubiquitous Esri Shapefile. While this file format has been designated an open format by the Open Geospatial Consortium, it presents archivists with a challenge. The fact is that a Shapefile is not strictly speaking a file. Rather it is a collection of files which must be preserved as a whole in order to function. The loss of a single item, or subfile, can render the entire Shapefile collection useless. Furthermore, the Shapefile is not a truly standardized data structure insofar as there are thirteen recognized subfile formats, only three of which are mandatory (OGC). In practice, Shapefiles exist in a variety of configurations without a uniform set of properties, beyond feature geometry and a data table. For preservation purposes it is highly desirable that two non-mandatory subfiles be included in a Shapefile: one containing the dataset's spatial reference system (.prj format) and another containing a formal geospatial metadata schema (e.g., FGDC or ISO 19115) in .xml format.

Georeferenced raster datasets may also be stored in more than one data format. Following the proprietary practice of Esri's ArcGIS software a .tif or .jpeg file can be georeferenced by storing an associated world file (.tfw or .jpw) with the raster image. More desirable from a preservation point of view is the GeoTIFF format which stores the georeferencing information in the header of an otherwise standard .tif formatted image. In addition to the objects holding the georeferenced raster data, it is desirable to preserve additional information about the georeferencing process. Including the referencing GIS data layer and control points (in an associated text file) will allow future users to understand the choices made in registering the image to a spatial reference system. The root mean square deviation is a measure estimating errors resulting from the choice of control points, and should be included in the horizontal accuracy element of the geospatial metadata stored with the raster dataset.

Finally, there is the challenge to preserving the context of the geospatial features and data tables contained in a geodatabase. There are many relational database management systems (RDBMs) with spatial extensions, and many of them are proprietary. While preserving a snapshot of a geodatabase regardless of its structure is important, it may not be sufficient for long term preservation given the inevitable evolution of technology. Two approaches might enhance the longevity of historical geospatial information contained in a particular RDBMS. First, relevant geospatial datasets might be identified and exported from the database for preservation as individual data layers. In these cases, data management planning should configure these associated datasets as an immutable collection with a considerable amount of contextual information derived from the original RDBMS structure. A second approach would be to migrate the original geodatabase to a more flexible and open-source RDBMS such as PostgreSQL or MySQL. This would also require preservation of contextual information including explanations of any data loss resulting from such a migration.

CONTENT PACKAGING for DIGITAL ARCHIVES

The Open Archival Information System (OAIS) reference model is used by many digital libraries as a conceptual framework for preservation efforts (CCSDS 2012; Lavoie 2000). While libraries and archives rely on a number of different digital repository architectures, both proprietary and open source, the OAIS reference model provides a useful overview to their commonalities (see Figure 3). This functional model defines the flow of information from producers to consumers within information packages. These packages include the information itself, contextual information for the management, discovery and use of the information, as well as a standardized framework for organizing and storing the packages.

Content packaging has both a logical and a physical component which can be implemented independently or together. The physical component delivers data objects in a consolidated file, while the logical component uses

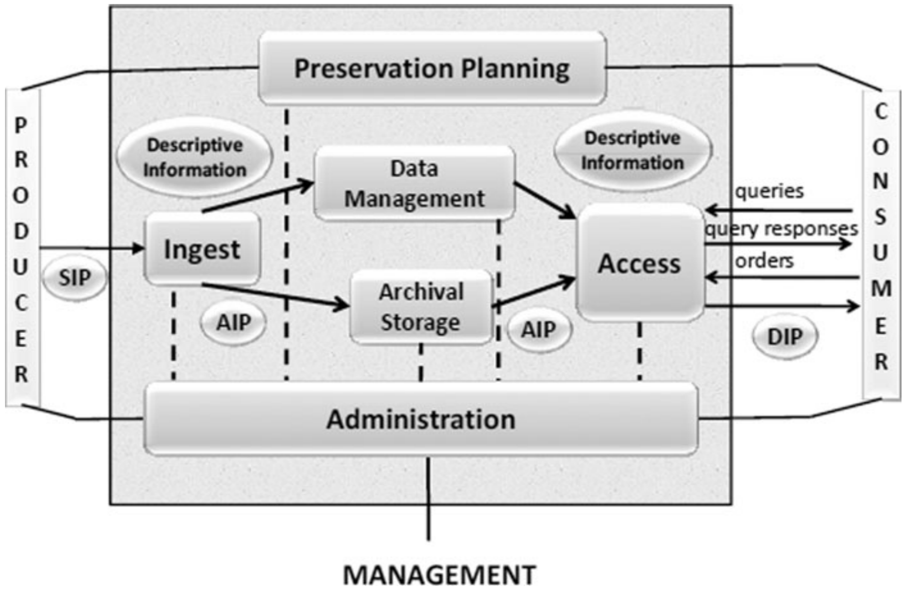

FIGURE 3 Functional elements of the Open Archival Information System (OAIS) reference model. Source, Wikipedia website, https://en.wikipedia.org/wiki/Open_Archival_Information_System#/media/File:OAIS-.gif

a document structure (such as XML) to organize the data files for transfer. Physical packaging often uses a ZIP or TAR format to ensure that subdirectories are maintained, a common example being the transfer of Shapefiles in zipped folders. Logical packaging usually takes the form of an XML wrapper that maintains relationships between data objects and may include additional metadata elements. The GeoMAPP report *Emerging Trends in Content Packaging for Geospatial Data* is a helpful reference for understanding the choices available for a variety of current geospatial data formats (GeoMAPP 2011c). It is also a good jumping off point for understanding more recent developments in content packaging, notably those implemented at the Stanford Digital Repository (Hardy and Durante 2014; Durante and Hardy 2015).

CONSIDERING WHAT TO PRESERVE

When it comes to preservation, context is everything. That context can be physically preserved in three ways. First, by finding looser, alternative data structures to represent the information held in the original geospatial data set; second, by collecting multiple objects, such as those required to instantiate a cartographic representation, in a single content package; and third, by finding efficient and meaningful ways to capture and transfer metadata.

In the first case, scholars and archivists should consider preserving more than one instantiation of the original data in different formats. This might apply to preserving geodatabases as snapshots while simultaneously preserving individual feature classes embedded in the database. Another case might involve preserving a data object in its original proprietary format as well as a copy of the same data transformed into open data formats. In both of these instances, care should be taken to include metadata fully describing the transformation and a description of any data lost through transformation.

The second case, collecting multiple objects, presents many problems. For example, online mapping projects that require external web services are an especially tricky problem to solve. In fact, all spatial humanities projects that rely on service oriented architecture (SOA) will require sophisticated archival management planning. And, regardless of a project's digital environment, data management planning should consider much of the implicit context inherent in the project data. For example, choosing which cartographic representations of the data might be necessary for others to understand the research.

Finally, metadata will be required throughout the geospatial data curation life cycle. This includes metadata objects associated with the research data itself, such as those held in formal geospatial metadata schemas like FGDC or ISO 19115. It also includes the project's preservation metadata which will generally be embedded in the various archival content packages, often within an XML wrapper. Preservation metadata standards such as PREMIS will include the elements necessary for archivists to manage the geospatial data over the long term.

CONCLUSION

Ideally, the preservation of historical geospatial data should begin before any research project commences. The archival process begins with data management planning. Librarians and scholars should conceptualize the data management problem by first considering the structure and content of an archival information package and then working backwards towards the research goals and data needs of the research project itself. The structure of the archival information package in turn will require consideration of funding agency requirements as well as a more general understanding of possible data use—cases at short, medium, and long term planning horizons. When a good conceptual outline of the archival needs of the research project are in place, then all of the parameters for data creation will be clarified.

The preservation of historical geospatial data will require particular attention to preserving contextual information which links many data layers into a cartographic representation of historical geospatial information. This is especially important as it relates to the use of primary source material.

Some of this information may be contained in formal geospatial metadata schemes, while in some cases it might be desirable to include enhanced metadata objects such as detailed data articles describing methods and the resolution of issues related to the historiography of the research project. Additional contextual information might be preserved in ancillary cartographic representations of geospatial datasets.

These are early days in the preservation of digital geospatial data, and there is much to be learned as archival practices deepen and lessons learned can be disseminated. In the subdiscipline of historical geospatial data preservation there is plenty of room for innovation. In particular, there is a need for research and the development of practices in the formal structuring of contextual information unique to historical GIS research. This could take the form of enhancements to existing metadata schemas, as well as in more loosely structured data article configurations that might contain a fuller exposition of research methods. Hopefully, this brief review of issues and methods will be a useful starting point for data management planning as historical geographic research results continue to accumulate in the spatial humanities.

NOTES

1. Examples include "Electrification" [Plate 44] in *Historical Atlas of Maine*, Hornsby S.J. and R.W. Judd, eds. (2015) Orono, ME: University of Maine Press, and Clark J.H. and D.W. Holdsworth, "Wood pulp and the new industrial landscape of Maine, 1880 to 1930" *Maine History* (forthcoming).
2. The five principles paraphrased and elaborated on correspond to the GI+100 principles numbered 1, 8, 9, 11, and 16, respectively (Rönsdorf 2013, 1)
3. Quantum GIS Project, http://www.qgis.org
4. http://www.gdal.org/

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