PRE-1950 HISTORIC USGS TOPOGRAPHIC MAPS
OF CENTRAL CALIFORNIA

A Project
Presented
to the Faculty of
California State University, Chico

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
In
Geography

by
Anna Hopper Clare
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ABSTRACT

PRE-1950 HISTORIC USGS TOPOGRAPHIC MAPS
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by

Anna Hopper Clare

Master of Arts in Geography
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While current USGS 7.5 minute topographic maps are available online and free to download, historic topographic maps are more difficult to locate. Hundreds have been scanned and made available online but they are scattered among various websites. The exceeding majority, are available only in hard copy and are divided among numerous map collections.

The focus of this project was to locate, digitize and georeference historic pre-1950 USGS 7.5 minute topographic maps of Central California and make them publicly available. Most maps fitting the project criteria had already been georeferenced and made available online by Matt Fox, a Google employee. Fox had created a Historic Topographic Map Project that was viewable in Google Earth. There were just sixty-seven maps needed to complete the coverage for Central California.
Forty of those maps had already been digitized but not georeferenced. Matt Fox sent them to me so that I could georeference them. I located the other twenty-seven maps at UC Davis. Unfortunately, the UC Davis map library does not allow maps to be removed from the map room and does not have a large format scanner on the premises. As an alternative I used a high-quality professional camera to photograph the maps. I then georeferenced the map images. All sixty-seven maps were sent to Matt Fox for inclusion in his Historic Topographic Map Project.
CHAPTER I

PROJECT BACKGROUND

Introduction

Prior to entering graduate school, I worked for an environmental consulting company, Foothill Associates, for four years as a GIS specialist. The majority of Foothill's clients were developers who needed environmental permits and mitigation for their projects. As one of several mitigation options Foothill produced wetland creation and restoration plans. We would investigate land parcels, either owned by the client or available for purchase, to determine if they included wetlands or contained wetlands in the past. Over the last 150 years, many areas of California have been leveled and disturbed by development or farming. Although wetlands are no longer present in these parcels, the necessary geomorphic and biologic factors for wetlands still exist. Foothill Associates both restored wetlands in their former locations and created new wetlands as nearby mitigation areas.

As a GIS Specialist, one of my work assignments was to identify land that historically held wetlands. This was a time-consuming process. Our standard methodology for identifying historic wetlands involved viewing both historic aerial photos and historic United States Geologic Survey (USGS) topographic maps. Other data sources, such as historic accounts, photographs, and field investigations were not commonly employed because of their cost or the availability of materials. Contrary to
what one might assume, aerial photographs were much easier to locate than the
topographic maps. Local United States Department of Agriculture (USDA) Natural
Resource Conservation Service (NRCS) offices generally kept hardcopy photographs of
aerial photography and maintained a cataloging system that simplified access. We were
allowed to pick up the applicable photos from the NRCS offices, scan them, and return
them. Aerial photographs, however, were not available prior to the 1940s and historic
topographic maps were used to delve further into pre-1940 landscapes.

Late 19th and early 20th century USGS topographic mapping can provide
earlier data on wetlands from an easily retrieved map format; however, old USGS
topographic maps are difficult to find. For a fee, digital scans can be requested from
USGS, but this can take several weeks. Another option is to locate digital historic
topographic maps online where they are present in a variety of image formats.
Unfortunately, only a few hundred maps are currently available online and they are
divided among many websites. The online search for historic topographic maps is time-
consuming and yields few results because no comprehensive compilation of online digital
topographic map sources exists. The other option is to locate hardcopy maps among
California’s university repositories and public agency map collections. Foothill
Associates found the topographic map collection at University of California at Davis to
be most helpful. Their library holds a nearly complete set of historic topographic maps
for California. Library policy, however, prevented the maps from leaving the library to
be scanned elsewhere. I would, therefore, travel to the UC Davis library, locate the
necessary topographic maps and photocopy the specific area of interest. A further
frustration was that the copy machines were not large enough to accommodate an entire
map sheet, so the photocopies had to be taken back to Foothill Associates where I could scan and georeference the subsetted areas.

Sadly, this convoluted process is not unique to me or the company I worked for. While current topographic quadrangles are readily available for download in high-resolution digital formats, the historic maps needed for research are not. This process would be greatly expedited by the creation of a consolidated digital archive of older USGS topographic maps. Older compilations of the quadrangles contain a cartographic record of historic (and often vanished) U.S. landscapes. One can examine the original maps and their updates to gain insight into changing landscapes over the past century. A comparison of historic topographic maps can show urban growth, hydrologic shifts, shoreline change, diminishing forests, and other changes. According to Dalia Varanka (2006, 6) in a USGS Open-file report:

The historical topographic survey has its cartographic strengths and weaknesses as a long-term topographic record of the United States, but as the only systematic, long-term cartographic depiction of the county, it can be well-leveraged for contemporary and future geographical research . . . The topographic survey has dependable information for a large number of potential applications, and to make this national resource available is of added benefit to what the value of the maps were in their contemporary time.

In this statement Varanka touches on the importance of making historic topographic maps available. In order to maximize the usefulness of these maps they need to be accessible for specific research investigations or for general examination by the public.

My graduate project is a contribution to the work of preserving and georeferencing historic USGS topographic maps. My objective for this project was to identify, locate, digitize, and georeference USGS 7.5 minute topographic maps of central California published prior to 1950 that were not yet online. Combined with the work of
others, this constitutes a complete digital coverage of central California and is currently available online at the Google Earth™ Library (http://www.gelib.com/historic-topographic-maps.html).

Topographic Maps

History of Topographic Maps

The earliest maps created contained topographic information that was the essential for specifying location in a world lacking permanent human structures. Primitive societies sketched valleys, rivers, and mountains in the sand and depicted routes and landscapes with sticks, rocks, or shells. These early peoples created representations of where they lived and traveled by symbolizing major landforms (Harvey 1980, 29-36). Slowly, as cartographic methods and instruments improved and fixed human features were placed into landscapes, topographic maps evolved and became more accurate. Features were not merely symbolized but drawn to scale. This enabled map users to measure distance, and infer elevation, slope, area, and other spatial parameters. In short, topographic maps made the transition from pictorial display to metric tool.

Types of Topographic Maps

Large scale maps that depict relief and landforms are called topographic maps. Following are descriptions of several types of topographic map. These maps are categorized according to their purpose and method of presentation.

**Contour.** USGS topographic maps are contour maps. Contour maps show relief through contour lines that connect points having equal elevation. For example, the contour line for an elevation of 2020 feet would move across a landscape on a level path.
of constant elevation. When multiple contour lines are presented on a map, a standard vertical separation is adopted between lines; this is named the contour interval. A 20 foot contour interval, for instance, represents a separation of 20 feet elevation between lines. Consideration of the relationship between adjacent contour lines shows that when contour lines are drawn close together they represent steep terrain and when the lines are far apart the terrain is more level.


**Shaded Relief.** Shaded relief maps show elevation changes through shading and perspective views. Although the eye looks vertically downward at the landscape, the shading of the terrain is based on an assumed illumination source that is generally placed in the northwest. Flat areas receive no shading while hills or mountains are shaded on one or more sides suggesting to the eye that they rise up. Shading is darker were terrain
is steeper (Collier, Forrest, and Pearson 2003, 18). While shaded relief does not give numeric elevation data, it gives the map reader a perception of heights and shapes in the landscape.

![Figure 2. Example of shaded relief. Source: Derived from U.S. Geological Survey. 2001. 30 meter Digital Elevation Model, Mendocino, CA.](image)

**3-Dimensional.** Elevation can also be shown through a three-dimensional (3D) perspective. This means that elevation is displayed from an oblique angle of view rather than a vertical perspective of the shaded relief image. While the map is still a flat surface, the terrain is shown as viewed from above and from a selected azimuth; this is the way we naturally see the world around us. Like the shaded relief map it does not show the numeric elevation values but it still accurately portrays landforms and their relationships. These presentations can utilize either an orthogonal or an oblique (vanishing point) perspective.
Aerial Photography. Raster imagery such as aerial photography is also considered a topographic map type because it makes a direct visual replica of the visual appearance of the earth’s surface. A map-reader sees the earth’s features as they would actually appear if one were in a balloon, airplane, or on an orbiting platform. Unfortunately, the viewpoint from an aerial photo includes unavoidable distortion due to camera optics. The image scale changes continuously from the image center. Although this visual distortion may be unnoticed by a casual viewer, it presents significant challenges if the image it to be transformed into a map having a constant scale.

Portraying relief is an ongoing problem for cartographers. Obviously there are several methods for showing terrain but a successful map would display relief information without obscuring other map data (Collier, Forrest, and Pearson 2003, 17).
Map Information

This project focuses on topographic maps, specifically USGS 7.5 minute contour maps. This particular map set is based on rectangles bounded by 7.5 minutes latitude and 7.5 minutes longitude. The scale of this series is 1:24,000, or one inch equals 2000 feet. During the first half of the century a similar scale of 1:31,680 (one inch equals one-half mile) was often used. This map series was discontinued in favor of 7.5 minute maps and are generally grouped in the same category. When people refer to historic 7.5 minute topographic maps they are often referring to both 1:24,000 and
USGS mapped the entire contiguous United States at the 1:24,000 scale. Other map scales employed on topographic maps by the USGS include 15 minute, 30 minute, and 60 minute series, that are scaled at 1:60,000, 1:100,000, and 1:250,000 respectively.

USGS topographic maps contain a significant amount of information. While the symbology on these maps is highly detailed, the data is divided into color categories to facilitate user interpretation. Green, for example, represents vegetation and blue represents water. Red lines show land division grids such as township, range and section; brown lines are contour lines as seen in Figure 5. The contour interval varies by map according to terrain but is always noted in the map margin. A contour interval of twenty feet is common on 7.5 minute topographic maps. Black is used for transportation and buildings, while pink represents built-up or urban areas. For a time purple was used to denote overlays containing updated information but this convention was abandoned (USGS 2009).

Each map also contains eight names of adjacent quadrangles, located on the four corners and four sides of the map. The latitude and longitude are printed on the four corners of each map and grid marks for latitude and longitude, UTM coordinates, and State Plane System coordinates on the map edges. USGS topographic maps also contain control points such as benchmarks and spot elevations. These points are symbolized and are labeled with their exact elevation.

Although not represented directly, there is significant information that is implicit in the map data and can be derived from it. Any map that is drawn to scale can be used to calculate distance and area. Contour elevations can be used to present a
longitudinal profile or calculate volume, slope, and aspect. Combining information from hydrologic features, a map-reader can identify flow lines and drainage basins. Large-scale maps such as 7.5 minute topographic quadrangles also have little distortion caused by the projection. At this size a map user can assume correct angles and distance, equal area, and true direction without incurring significant error (Vitek, Giardino, and Fitzgerald 2006, 238).


History of U.S. Geological Survey Topographic Maps

In the 1800s, the United States government began to recognize the importance of mapping its shorelines and territory. Accurate topographic information was essential to the development and protection of the country. In 1879, the U.S. Geological Survey (USGS) was created. The agency was tasked with documenting the minerals and
resources of the country and with uniformly mapping its entire domain. The USGS succeeded in compiling 1:24,000 scale topographic maps covering the contiguous United States in 1992. Other map series were created at 1:100,000 and 1:250,000 series, but the 1:24,000 maps remain the largest-scale complete set. The maps were and continue to be updated and revised roughly once per decade.

Prior to the establishment of the USGS, the federal government funded four western surveys under the leadership of four different men: Clarence King, F.V. Haden, John Wesley Powel, and George M. Wheeler. Only the first survey, that of Clarence King, was completed. The latter three surveys were discontinued when the United States Geological Survey (USGS) was established. Clarence King was named director of the agency and later explained that creating a single and permanent bureau was the necessary step to continuing the national geologic investigation in the most efficient and harmonious manner (Thompson 1987, 5). Under the direction of King, the USGS began a rigid scientific survey of the nation. King wanted a detailed, uniform map series that would show features and resources useful to agriculturalists, mining engineers, political economists, and timbermen (Thompson 1987, 5).

Initially, the USGS produced one degree and 30 minute map series at scales of 1:250,000 and 1:125,000 respectively. These series included individual maps bounded by roughly rectangular areas of either one degree or one-half degree (30 minutes) of latitude and longitude on a side. (A map containing one degree on each side produces a trapazoid because the convergence of longitude lines toward the poles.) Over time, more detailed maps were required. From 1864 to 1950 the most common maps produced were 15 minutes; from the 1950s onward the standard map scale was 7.5 minutes or 1:24,000.
In the beginning, the USGS surveyors used surveying chains (a steel tape) and a compass to measure distances and an aneroid barometer for measuring elevation. This was a laborious means of compiling a topographic map. These procedures were replaced by optical measurements using telescopic alidades and a plane table (Thompson 1987, 6). By 1896, the USGS was measuring elevation with engineering instruments (transits and engineer’s levels) and setting permanent bench marks for map accuracy and control. Each of these methods, however, was time-consuming, expensive, and at times dangerous. Steep and rugged areas were particularly difficult to survey. In such areas men and equipment traveled by pack train with considerable effort and accuracy was difficult to achieve. Modern compilation of topographic maps uses a combination of traditional methods, laser and radio surveying, the stereoscopic viewing of aerial photographs, and radar imaging from satellite or airborne sensors.

Literature Review

Past and Current Work

Several organizations have begun the process of preserving historic USGS topographic maps for public access. Most notably is the United States Geological Survey (USGS) itself. On the USGS website there is a link to the Historic USGS Topographic Map Project: http://infotrek.er.usgs.gov/pls/htmldb/f?p=182:1:542708055276659 where it is described as a volunteer project for the digital preservation of historic topographic maps. People with access to historic USGS topographic maps are asked to volunteer their time and resources to scan these maps and send them to the USGS. The USGS will then catalog and create metadata for the maps so that eventually the users will be able to
access the maps and search a database with place names and features. As of 2006, roughly 8,000 of the approximately 300,000 historic USGS topographic maps had been scanned and cataloged. As of the beginning of 2010, none of the 13,131 maps in California had been scanned. Scanning this collection is clearly an ambitious project and the number of unscanned maps suggests that a purely volunteer effort is unlikely to succeed in a very complete dataset. Unfortunately, the USGS does not have the funds to complete the project and must rely on a volunteer effort. In fact, the USGS is not currently georeferencing historic maps but hopes to in the future as time and funding allow.

While a nationwide effort relies on sporadic volunteer effort, various states and other agencies have begun the process of preserving historic topographic maps on a smaller regional scale. The North Carolina Geologic Survey (NCGS) and North Carolina State University (NCSU) libraries are collaborating to scan and georeference all historic geologic and topographic maps of North Carolina. Members of these organizations feel that these historic maps are fundamental to earth science research and want to make them digitally available for overlay with other datasets and utilization in GIS software (Essic et al. 2006). The two organizations scan the paper maps and then reference them to real-world coordinates. At the end of 2005, the North Carolina Geospatial Data Archiving Project included 165 historic USGS 15-minute topographic maps (Essic et al. 2006). This represents just a portion of historic topographic maps NCGS and NCSU plan to digitize and georeference.

The National Oceanic and Atmospheric Administration (NOAA) has also started a historic topographic map preservation project; its source maps were produced by
the National Ocean Service (NOS) rather that the USGS. The National Ocean Service is responsible for 95,000 miles of shoreline and keep updated nautical charts and hydrographic surveys. These are paper and cloth topographic maps dating back to 1834 and comprise an extensive record of the U.S. shoreline. Labeled a “data-rescue” project because of the deteriorating condition of the maps, it was vital to scan them to preserve the data from loss or damage (Daniels and Huxford, 2001). The project is committed to georeferencing the scanned maps so that they can be directly employed in GIS projects.

In an article about the project Daniels and Huxford (2001, 611) explain that, “. . . scanned maps are just images, the true value of these images will not be realized until the images are registered to a coordinate system, shorelines digitized and attribute information added.”

While the three projects mentioned above focus on historic topographic maps, the Alexandria Digital Library (ADL) Project is more encompassing (Goodchild 2004). Established in the late 1990s, the Alexandria Project is a digital geolibrary (a collection of place-based information like maps and photographs) which is administrated by the University of California (UC), Santa Barbara. The university’s map collection is extensive and includes hundreds of thousands of maps, aerial photographs, atlases, and other geographic materials (Goodchild 2004, 1-2). UC Santa Barbara is in the process of converting those materials into digital format for inclusion in the ADL.

In his article about the ADL Project, Goodchild (2004, 2) notes three problems common to all map libraries; accessibility, storage and preservation, and cataloging. The ADL Project addresses all these problems. For example, not all library systems have the space or the financing for a large map collection. Because there are few
map collections as extensive as UC Santa Barbara’s, there is an issue of accessibility. If, however, the maps are digitized and made available on the internet then virtually anyone can utilize those resources. Maps are notoriously difficult to sort and store. They can vary drastically in size and their edges and corners are easily torn. Even careful access threatens the physical integrity of the map. Digital copies preserve the maps from age and wear; they exist in the virtual space of disk arrays and non-volatile backup formats. The last issue that Goodchild notes as problematic for map libraries is cataloging. Cataloging maps simply by author, title, and subject is impractical (Goodchild 2004, 2).

In his article Goodchild (2004, 2) explains,

The most obvious basis for search and retrieval of map and related objects is geographic coverage: a user is typically looking for a map of somewhere. But geographic space is continuous rather than discrete, and an assortment of methods are used for defining geographic location, including coordinates (latitude and longitude), placenames, and various indexing schemes. Information about the City of Goleta may appear on a map titled “Santa Barbara County”, and will not by found in a title search for “Goleta” unless the nesting relationship between the two geographic entities has been coded or can somehow be inferred.

Presently a user can search maps in the ADL by coordinates or placename. A search for placename uses an online gazetteer service to convert the request into coordinates. Maps, which include those coordinates, are listed and the user can then view the maps onscreen.

UC Berkeley has a similar online avenue for historic topographic maps of the Bay Area (http://sunsite.berkeley.edu/histopo/). The site presents historic USGS topographic maps of the San Francisco Bay Area from 1895 to the present. A user can perform a gazetteer search by feature name, a quadrangle name search, or click and zoom around an interactive map. The topographic maps are both viewable and downloadable in the Multi-Resolution Seamless Image Database (MrSID) format.
The final topographic preservation project to be described in this paper is different from the others mentioned above. It was started and organized by one person, a man named Matthew Fox. Fox is an employee of Google but his historic topographic map project is an individual pursuit (Fox 2009). So far Fox has over 2,000 historic USGS topographic maps digitized and georeferenced. These maps are available online as Keyhole Markup Language files (KML), the format utilized for display in Google Earth. KML files are specifically for storing and displaying geographic data like polygons, points, lines, and images. Although these files are a means to share geographic information with users of Google Earth, KML has emerged as a standard web format for map data and is utilized by individuals, companies, and public agencies. Major GIS vendors such as ESRI also support the KML standard. Through the efforts of Fox and project volunteers, the project continues to expand. What makes this preservation project so successful is its built-in search features. While other projects require cataloging, Fox’s project makes use of tools and geographic layers already available for public access on Google Earth. As a KML file, the scanned and georeferenced historic topographic maps are overlain directly onto the earth’s surface as it is displayed in Google Earth. A user can search for road names, place names, points of interest, and even street addresses using Google Earth. The historic USGS maps will appear in their proper location along with the current aerial imagery and all other data layers available in Google Earth.

It is important to note the essential role of cataloguing in map collections. As mentioned above in the previous quote by Goodchild (2004), maps cannot be merely cataloged by title. If a library patron needs to find a particular geographic feature on a
map they might not be able to find it by searching through map titles. To make maps truly useful every feature on that map should be cataloged. This is the standard practice of the Library of Congress, California State University (CSU) Chico, and other libraries. Unfortunately, this is a time-consuming and, therefore, costly process. Most institutions that have historic topographic maps do not scan and georeference them because they lack the time and money to do so. Cataloguing requires more time than either scanning or georeferencing. The Google Earth™ Historic Topographic Map project provides historic maps and has a built-in geographic locator so that cataloguing is not required. While useful and beneficial this is not sufficient for libraries and academic institutions. Fox’s effort, however, provides a cost-effective and readily accessed resource that will bridge a very real data gap until all archival maps can be digitized and cataloged by librarians and agencies. Fox’s work is an innovative and efficient means of making historic topographic maps available to the public now.

Examples of Historic Landscape Changes

Part of the value and usefulness of historic topographic maps is that they are revised and updated through the years. When comparing several maps with different dates of the same area, a map user can see changes in roads, urban expansion, or hydrologic shifts. One example of historic landscape change captured in topographic maps is presented in an article written by Niemi and Hall (1996). They used historic topographic maps to view changes in Olema Creek and the tidal marshlands of Tomales Bay in California. The oldest map they used was a 1862 U.S. Coast Survey map. This map was compared to 1918 and 1954 USGS topographic maps, which were both 15 minute Point Reyes, CA quadrangles. Niemi and Hall georeferenced the maps and
superimposed them by using GIS techniques. Between 1862 and 1918 they saw a
dramatic change in tidal marsh of Tomales Bay, measuring over a kilometer of expansion
to the northwest. They also noted a westward migration of Olema Creek during the same
period. From 1918 to 1954 the marsh increased an additional 500 to 800 meters to the
northeast. By 1954 part of the tidal marsh had been converted to pasture after levees and
seasonal dams had been constructed. The Olema Creek also saw significant change
during this time. Several human made channels were created that changed the flow of the
lower portion of the Creek.

Another example of historic change documented by topographic maps can be
found in the article “Historic and Future Land Loss for Upland and Marsh Islands in the
Chesapeake Bay, Maryland, U.S.A.” published by the *Journal of Coastal Research*
(Wrayf, Leatherman and Nicholls, 1995). The study used historic NOS T-sheets
(National Ocean Service Topographic Sheets), USGS topographic maps, and aerial
photography to assess the land loss of eight islands in the Chesapeake Bay between the
years 1848 to 1987. The researchers noted dramatic land loss due to erosion on the
northern and western parts of the islands but little change on the eastern sides of the
island where land is more protected from the elements. All eight islands have
experienced more than a seventy-six percent land loss during the time period.

A third example comes from a study of the Alaskan coastline. Researchers
used historic aerial photographs and historic USGS topographic maps to calculate
modern rates of erosion along a section of the Alaska Beaufort Sea coast called the
Teshekpuk Lake Special Area. This 140 km stretch of coast is hunting grounds for
Inupiant Eskimos and is thought to contain large stores of petroleum (Jones et al. 2008,
Using historic topographic maps, researchers found that some cultural and historical sites along the coastline no longer exist. Kolovik, for instance, was an abandoned village mapped on a 1955 USGS topographic map. In a visit to the site in July of 2007 researchers found only a single standing structure. (Jones et al. 2008, 369). Any other buildings or structures existing in 1955 were lost with the eroding coast. Also, an Esook trading post was identified on a 1951 US Coast and Geodetic Survey topographic map. Subsequent aerial photographs in 1979 and 2002 show the loss of all five of the trading post structures and the land beneath them (Jones et al. 2008, 367-368).

Historic USGS topographic maps have also been used to document urban growth. Lora Richards (1999) used 7.5 minute USGS maps created between 1889 and 1992 along with aerial photographs, satellite images and existing land use to create a historic geographic information system for Truckee, CA. From these sources Richards was able to create a timeline of historic changes and make conclusions about trends, impacts and rates of change.
CHAPTER II

PROCESS

Methodology

Early Steps

The purpose of my project was to complete a digitized, georeferenced, pre-1950 USGS 7.5 minute topographic map coverage of Central California. The majority of these maps had already been digitized and georeferenced and were included in the Google Historic Topographic Map Project. My objective was to identify the maps that were missing from the coverage and then locate, digitize and georeference them. Figure 6 is a flowchart of my process and illustrates the steps taken.

I began by contacting the USGS and requesting a list of all 7.5 minute topographic maps published for California prior to 1950. Once I had received the list I compared it to a digital 7.5 minute quadrangle index map in ESRI’s ArcMap software. (See appendix map 1) This step allowed me to see the spatial distribution of maps created in this time period. The USGS map coverage prior to 1950 was focused on the Bay Area, Central California, and Southern California around Los Angeles and San Diego. Using ArcMap, I selected all the quadrangles in Central California that matched the list I had received from USGS. These maps represented a continuous coverage from Chico south to Bakersfield and constituted a master list for my project.
Figure 6. Process Flowchart.
My next step was to identify all the maps within my project area that had already been
digitized and georeferenced as part of the Google Earth™ Historic Topographic Map
Project. I contacted Matt Fox, the author of the project, and had him send me a list of all
the 7.5 minute maps he had already georeferenced. Once these maps were eliminated
from my list I was left with sixty-seven maps that needed to be located, digitized, and
georeferenced. I then investigated the digital collection of regional libraries in agencies
and universities. Of the sixty-seven maps, forty had already been scanned by various
libraries throughout California and are made available online. Prior to the start of my
project, Fox had downloaded the scanned images but had not georeferenced the maps.
He sent me the forty images so that I could do so.

The other 27 maps had not yet been digitized and were found at the UC Davis
Library. (See appendix map 2) According to library policy I was not permitted to remove
the maps for scanning off-site. As an alternative, I photographed the maps using a high
quality camera.

**Digital Map Compilation**

The digital scanning of maps is the preferred method for compiling a digital
map archive. Although my project did not include scanning, it is an essential part of
historic map preservation. The following methodology contains recommendations for
scanning with best results and a discussion of scanning options. The following sections
on resolution, file format, delivery and storage are relevant to photographing maps as
well as scanning and include the methods I personally employed.

**Scanning Device.** There are a vast number of scanners on the market but they
can generally be divided into four categories: hand-held scanners, sheet scanners, drum
scanners, and flatbed scanners. Hand-held scanners are small and are used by moving the scanner slowly and steadily over the document. At most they can scan images approximately four inches wide and are most often used for logos or signatures. A sheet scanner requires the document to be fed into the machine and digitized as the paper moves past the scanning head, not unlike a fax machine (Pal, 2010). In a drum scanner the document is placed in a glass cylinder that rotates around a sensor at high speeds. Flatbed scanners which are the most common type are sometimes called desktop scanners. As with a copy machine the document is placed face down on a glass plate. The scanning head then moves across the document and creates a digital image.

When scanning, it is universally accepted that documents are digitally represented best when scanned in full; therefore, drum scanners, sheet scanners and large flatbed scanners are most suitable for large documents like maps (Pal, 2010). Most libraries use large-format sheet scanners similar in appearance to the printers used for poster and map production.

**Mosaic.** Although it is preferable to scan maps in full they can also be scanned in sections and then mosaicked together. This greatly increases the project workload and may result in introducing distortions that did not exist in the original.

A mosaic is a single image file created from multiple files. It can be done in a variety of ways. For example, map sections can be stitched together in Adobe Photoshop or other graphics applications in the same manner that a series of photographs can be mosaicked into a single panoramic scene. There is little control, however, over matching at edges and undesirable artifacts are often produced by this process. These artifacts are unnoticed by casual examination but are unacceptable for quantitative map work.
Map sections can also be georeferenced and mosaicked in dedicated map software such as ESRI’s ArcMap. This application provides for detailed control along edges and “rubber sheeting”. While more sophisticated, it still allows the introduction of artifacts. Mosaicking a historical topographic map is not ideal and should be avoided if possible. It is difficult to match up and align multiple scans perfectly. The final product might have contour lines that do not align evenly along seams or features that are warped from stretching the image.

**Color.** Maps, particularly USGS topographic maps, should be scanned in color in order to retain the previously mentioned color-coded information types. Some scanners only create grayscale digital files. Topographic maps use color as part of their symbolization and it is essential to maintain those colors so the map can be accurately read and interpreted. It is also important to use a scanner with color matching so that the fidelity of the colorset is preserved.

Color matching is essential because monitors, printers and scanners use different methods to portray color. For example, monitors vary the strength of electron beams to make the red, green, and blue phosphors in its screen glow different colors. Printers, however, use cyan, yellow, magenta, and black inks (CYMK system) in various combinations to print (Hagadorn 2004). The two mediums, light (additive color) and pigment (subtractive color), are conceptually different and produce image characteristics that are difficult to reconcile. Scanners have the difficult job of creating a RGB (red, green and blue) image for display from a CYMK printout. Color matching is a process first addressed in 1993 by the International Color Consortium (ICC), a group comprised of companies including Apple, Microsoft, Kodak, and Adobe (International Color
Consortium 2010). The ICC provides open, cross-platform, vendor-neutral device profiles for use in color management software (International Color Consortium 2010). Every device produces color differently. For example, an RGB color model (R=205, G=46 and B=28) tells a device numerically how much red, green and blue light or other colorant to use in order to produce a color. Even though the color model is numeric the actual color produced is dependant on the behavior of the device. An ICC profile is file created for a device that matches its particular color behavior with a recognized color model. Color matching software uses ICC profiles to produce matching color throughout input, display and output (Hagadorn 2004). Calibrating a device to duplicate an ICC profile is difficult and must be repeated as the device ages or inks are renewed.

Another issue involving color is bit (binary digit) depth. Binary numbers (bits) are used to represent shades of color. A higher number of bits supports more shades. A 1-bit document has just two values, black and white. An 8-bit grayscale file represents 256 possible shades, or $2^8$ shades (Wentzel 2007, 9). A color file requires bits for red, green and blue to produce color combinations. A 24-bit color file contains 8-bits of red, 8-bits of green, and 8-bits of blue. This represents 16.7 million ($2^{24}$)possible colors (Wentzel 2007, 9). It is important to note that file size increases with bit depth. The Digital Library Federation recommends scanning images at 300dpi in 24-bit color (Wentzel 2007, 8). One square inch at 300dpi includes 90,000 bytes (8 bits) of information for each of the red, green, and blue color planes, or a total of 270,000 bytes. At 600 dpi the file size would be 1,080,000 bytes. Thus, as the scanning resolution doubles, the file size rises by a factor of four.

**Resolution (DPI).** Along with scanner size and color capability, resolution is
important to consider. Resolution is measured in dots per inch (dpi) of scanners and printers or the pixel grid of optical output devices. Wide format scanners accept maps form 24” to 72” in width and have selectable resolution in the range of 120 – 2400 dpi (newsprint quality to glossy magazine quality). The USGS requires that maps be scanned at a minimum of 400 dpi for inclusion in its historical map project; however, USGS Digital Raster Graphics, or DRGs, have been created by scanning USGS topographic maps at 500 dpi since October of 2001. Prior to this time the USGS made DRGs by scanning at 250 dpi (Shawa 2006, 257).

The Library of Congress has a historic map collection of American maps called American Memory. For inclusion in this collection the Library of Congress scanned the historic maps at 300 dpi and stored them as uncompressed TIFFs (Library of Congress 2010). For map preservation, a digital map should be at least as clear at the same scale as the original map. One can zoom into a digital map and view features much larger than they appear on a hardcopy map but if a 1:24000 digital map cannot be viewed legibly at 1:24000 then the resolution is not high enough.

File Format. Another issue when scanning historic maps is file format. The three most commonly used image files are Tag Image File Format (TIFF), Joint Photographic Experts Group (JPG), and Graphic Interchange Format (GIF). TIFF is generally the best choice for archiving maps. TIFFs can capture all major color models (such as RGB and CMYK) and is supported by all platforms (Fulton 2010). TIFF images are also “lossless”; any compression of the image data does not cause a loss in information (quality). Whenever a TIFF image is viewed, it appears exactly as it did when it was saved (Fulton 2010). A JPG image is an example of a “lossy” compression
file. This means that the image loses quality when compressed. In Adobe Photoshop the degree of compression for JPG output can be selected at one of thirteen levels. At low levels of compression, the lost information does not alter the visual appearance of the image, but the loss of data is unacceptable for preservation or quantitative work. JPG files are often used for web sites and email where small file size is important and high quality is not required. GIF files are used for simple images and graphics like logos. While GIFs are lossless they only use indexed colors and are limited to a palette of 256 colors (Fulton 2010). So of the three formats all maps are best preserved as TIFF files which retain both quality and a full range of colors.

On the other hand, if a scanner is not available then photographing the map is another option. The common digital camera only produces JPG files, however, professional-grade cameras can offer TIFF or RAW files in addition to JPG. RAW files contain the intrinsic (“raw”) values and are uncompressed and unprocessed. They are the equivalent to a film negative and must be converted to another format to be printed or edited (HP 2010). RAW files offer maximum quality but the file size is often enormous (between 30MB to 40MB per image (HP 2010)).

I photographed twenty-seven of the maps I needed for my project. I used a Canon EOS 40D camera that offered just two formats, RAW and JPG. I choose to save the map photographs as JPGs because a large number of photographs were needed and RAW files take up considerable space in a camera’s memory. While it would have been preferable to have the digital photographs as TIFF images to ensure high quality that option was not available. Since my map images were destined for inclusion in Fox’s Google Earth™ based archive, perfect archival preservation was not required and the
JPG format is perfectly suited to web access. Librarians and any source seeking a permanent archive, however, would not use the JPG format.

**Metadata.** Metadata is described simply as “data about data”. It is an information file, often an XML document, that describes a data file’s content and quality. The International Organization for Standardization (ISO) created the ISO 19115 “Geographic Information – Metadata” in 2003 which is the considered the current standard in geospatial metadata. Table 1 below shows ISO core elements.

<table>
<thead>
<tr>
<th>Mandatory Elements</th>
<th>Conditional Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dataset title</td>
<td>Dataset responsible party</td>
</tr>
<tr>
<td>Dataset reference data</td>
<td>Geographic location by coordinates</td>
</tr>
<tr>
<td>Dataset language</td>
<td>Spatial resolution</td>
</tr>
<tr>
<td>Dataset topic category</td>
<td>Distribution format</td>
</tr>
<tr>
<td>Abstract</td>
<td>Spatial representation type</td>
</tr>
<tr>
<td>Metadata point of contact</td>
<td>Reference system</td>
</tr>
<tr>
<td>Metadata date stamp</td>
<td>Lineage statement</td>
</tr>
<tr>
<td></td>
<td>On-line resource</td>
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<td></td>
<td>Metadata file identifier</td>
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<td></td>
<td>Metadata standard name</td>
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<td>Metadata standard version</td>
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<td></td>
<td>Metadata language</td>
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<td>Metadata character set</td>
</tr>
</tbody>
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The FGDC was tasked with creating the U.S. version of this standard. According to the FGDC geospatial metadata should include the following sections: Identification, Data Quality, Spatial Data Organization, Spatial Reference, Entity and Attribute Information, Distribution and Metadata Reference (FGDC 2000).
The Identification section includes a brief description of the data along with its limitations and intended uses. It should include a citation for how the data should be referenced in other documents, key words, and the time period for which the data is current and relevant. The Data Quality element addresses attribute accuracy. In other words, how accurate was the assignment of names and values? This section should also address the completeness of the data and whether there were omissions or generalizations. Lineage and the source for the data should also be included here.

Spatial Data Organization includes names of geographic features, the data type (such as vector, point or raster), and the number of spatial objects. Spatial Reference encompasses coordinate system, map projection, and map projection parameters such as longitude of central meridian, latitude of projection origin, false easting, and false northing. The Entity and Attribute element of the metadata provides descriptions of attribute fields if tabular data is associated with the data file. The Distribution section covers where and how the data can be obtained, information about the distributor, a resource identifier like a catalogue number, ordering instructions and fees, and a statement of liability. The final section is the Metadata Reference. This includes the person or group responsible for the metadata and their contact information. It would provide the date the metadata was written, if and when it was updated, and possibly a date when the metadata would be reviewed in the future (FGDC 2000).

When the USGS creates its DRGs it also creates an ASCII text metadata file for each DRG. USGS uses the FGDC metadata standard described above. Metadata is an essential part of a digital archive. As data files are distributed outside of the archive’s institution users need to have information about where that data came from, how it was
produced, and limitations are inherent in it.

I did not create metadata files for the map images in my project. Fox is assembling a timely database for web users and not a library resource. Only map images will be viewable through Google Earth™ and not metadata. The only metadata viewable to the public is in the errata on the map edges.

**Delivery.** Sending digital files is all about digital space and time. One or two small files can be sent through email but large files or large numbers of files require a better method. When I needed to send Matt Fox all my georeferenced TIFF and JPG files I used a File Transfer Protocol (FTP) site. An FTP site is a password protected website that facilitates file transfer over the internet. Matt gave me the password to his FTP site and I uploaded all my historic map files to this location. Matt was then able to download those files from the FTP site at his convenience. My other option was to burn the files to DVDs and send them in the mail. Using a FTP site, however, was faster and easier.

**Storage and Preservation.** For libraries, companies, and institutions who store and preserve large amounts of digital data a document created by The Consultative Committee for Space Data Systems (CCSDS) at NASA is becoming the standard conceptual framework for digital archives. NASA, burdened with the responsibility of archiving the huge data sets of remote sensing and astronomy, is a leader in this field. The *Reference Model for an Open Archival Information System*, published by NASA, discusses key digital data management responsibilities. These include receiving data, managing data hierarchy, refreshing the media, error checking, and disaster recovery capabilities (CCSDS 2002). When the data is received, whether it is downloaded, sent via email, or arrives on a DVD, data needs to be placed in a hierarchy within the digital
archives. Data can be stored on DVD, hard drive, server, or in a data cloud (remote storage site accessed over the web). Over time, storage methods can become obsolete and data needs to be moved and re-stored according to current technology. It should be periodically checked for errors and a second copy should be housed in an off-site location in case of disaster.

Georeferencing

Once a map is in digital form it can be georeferenced into its real world location or space relative to other locations on the earth’s surface. A digital file is considered georeferenced when it has been moved to and assigned a coordinate system. The initial coordinate system does not matter; once a file has an assigned projection it can be easily converted to any other projection using appropriate mapping applications such as ESRI’s ArcMap.

For this project I georeferenced sixty-seven scanned historic maps. Forty of those maps I received from Matt Fox in Multi-Resolution Seamless Image Database (MrSID) format and converted to TIFF files. The other twenty-seven maps were JPGs taken with a digital camera. Each of the sixty-seven maps I processed were georeferenced by numerical input of control coordinates. (Images can also be georeferencing visually without numerical input but this method would not be recommended for USGS topographic maps) The process is described below. When the USGS creates its Digital Raster Graphics (DRG), it georeferences by numerical input. While I used just four control points, the four map corners, the USGS uses a control point for every graticule tick on the map. On the 7.5 minute topographic map there are sixteen graticule tick marks (USGS 2001). My use of four control points is appropriate to the
The designed accuracy level of Keyhole Markup Language (KML) presentation on Google Earth™.

The georeferencing process is fairly straightforward using ArcMap, a GIS software application created by ESRI. As mentioned above, it can either be referenced visually or by numerical input. In the initial step, the TIFF or JPEG file is added to an ArcMap project. If the file is being referenced by numeric input then no other files are needed. Using the control point tool in the georeferencing toolbar, the user clicks the first point to be referenced. As the user then right clicks the mouse, a small window appears where the x and y coordinate data is entered for that point as shown in Figure 7 below. The process is then repeated at least three more times using points evenly distributed around the image. The most successful georeferencing is done with four or more control points distributed in a diamond or rectangle formation on the image, therefore my use of the coordinate data for the four corners meets these requirements. Once all the control points and coordinate data are entered, the user chooses to “update the georeferencing” and the coordinate information is permanently attached to the file. This image rectification process successfully moves the image from a local coordinate system to a map projection.

The main concern when georeferencing is to avoid unnecessary distortion. In other words, the relationship between control points on the digital image should match closely to their real world location. In ArcMap distortion is calculated as Root Mean Square (RMS) error. RMS is the distance of the georeferenced control point from the vector coordinate given to it. In numerical terms, if your RMS error was 1.0 and your pixel size represents 30m then your georeferenced point is accurate within 30m. The
lower the RMS error, the lower the amount of distortion. ESRI recommends no more than 0.004 RMS error for accurate maps and 0.008 RMS error for less accurate maps (Sprague, Iwasaki, and Takahashi 2007, 93). In ArcMap, no RMS values appear in the control point table until the fourth point is entered, then, each control point is given a RMS value. From the control point table viewable in ArcMap, the user can identify which points are more likely to be accurate. If a particular point has a high RMS error it can be deleted and the user can create a new, more accurate control point.

Figure 7. Screen shot of georeferencing process.

When I georeferenced the maps I received from Matt Fox, the RMS error was extremely low. All 40 files had a RMS error of approximately 0.0001 to 0.00009 which is below the maximum 0.004 RMS error recommended by ESRI. When I georeferenced
the photographs, however, my RMS error results were extremely high. Some maps had an RMS error as large as 80. Unfortunately, the photographing process warped the map boundaries. The wide angle lens captured the center well but the edges are distorted. Many of the map corners appear to be greater than 90°. As a result of this warping the photographed map images cannot be accurately georeferenced. While my maps are suitable to be viewed on the internet they unfortunately have limited value and cannot be used for rigorous academic inquiry.

CSU Chico Digitization Process

At CSU Chico, Deborah Besnard of Meriam Library Special Collections oversees the digitizing of maps. During an interview (Besnard 2010) she described the library’s digitizing methods and standards. Special Collections uses a Widecom drum scanner acquired in 2000 for large documents and an Epson flatbed scanner for small documents like photographs. Their documents are scanned in full color. According to the library, standard historic maps are scanned at 400 dpi and photographs are scanned at 600dpi.

All of the library’s digitized materials are put into TIFF format. Their historic topographic maps, however, are also converted into MrSID format using GeoExpress, an application from Lizard-tech, for inclusion on their website. The MrSID format is a proprietary format of Lizard-tech and routinely achieves compressed factors of 10-20 while also creating subset images for rapidly accessing large files. Each map is also made into a JPG thumbnail. Users of the library’s website (http://cricket.csuchico.edu/maps/topo_search.html) can click on a thumbnail and view the MrSID image of a
historic map. MrSID files are easy to view, pan, and zoom.

All of the TIFF files for digitized documents are stored on DVD. One copy of the DVD is kept at Meriam Library and one copy is kept in a vault in Butte Hall on campus. Metadata is also kept on each file through a software program called Portfolio by Extensis. The program stores and manages files and keeps metadata. According to Besnard, the library will shortly be switching to a new software program called ContentDM. At that time more detailed metadata will be kept.

Digitized historic USGS topographic maps are cataloged the same as those in the Main Collection. Every word and coordinate that appears on the map is entered into a database and searchable in the library catalogue. This level of information entry is extremely valuable because it allows a search to be made on any map feature. Compiling of this data, however, cannot be automated and is highly time-consuming. Libraries and agencies are unable to digitize their map collections quickly because the cataloging process is so labor intensive. Matt Fox’s project does not require cataloging and can therefore proceed at a rapid rate making it an excellent intermediate source of information.
CHAPTER III

PROBLEMS AND CONCLUSIONS

Results

As mentioned in my introduction, my project objective was to identify, locate, digitize and georeference USGS 7.5 minute topographic maps published prior to 1950 of Central California that were not yet available online. I identified sixty-seven maps that met my criteria, located and georeferenced digital versions of the maps and sent them to Matt Fox for inclusion in the Google Historic Topographic Map Project. Forty of the maps I georeferenced were also provided to the Meriam Library at CSU Chico for cataloguing and inclusion in the map collection.

Although I met my objective in completing historic topographic coverage for Central California, the process did not go smoothly. The first problem I encountered was in identifying the topographic quadrangles I needed. Before the USGS focused its efforts on creating 7.5 minute topographic maps for the entire continental U.S. many maps were created at a scale of 1:31680. These maps are often referred to as historic 7.5 min topographic maps although they are at a slightly smaller scale. Current 7.5 min USGS maps correlate directly to the 1:31680 scale maps but they have been given different names. It was difficult and time consuming to find a source that listed the historic quadrangle name along with the current name. However, Cathie Benjamin from the CSU
Geography Department located a book by Peter Stark (1989) that proved to be invaluable. She sent me the reference and I was able to find it at the CSU Hayward library. With the information provided in that book I was able to identify the maps I need for my project.

Forty of the sixty-seven maps I needed were provided by Matt Fox already in digital form. I had great difficulty, however, gaining access to the other twenty-seven maps. I contacted the USGS and UC Berkeley about maps I needed but they both required $20 per map to scan them. UC Berkeley does allow maps to be checked out of the library but a library card for a non-UC student costs $100 and interlibrary loan could not be arranged. I took a trip to the Berkeley Earth Science Library and located ten of the twenty-seven maps I needed but did not check them out. I also contacted the UC Davis map librarian, Kathy Stroud. She verified, via e-mail message received on July 28, 2009, that all twenty-seven of the maps I needed were housed at the UC Davis Library. Unfortunately, UC Davis does not allow its historic maps to be removed from the library and it was impossible to scan them.

An 11”x17” size color Xerox machine was available onsite for a small fee but I feared that photocopying the maps in sections and then scanning and mosaicking the copies would produce unsatisfactory results. Each map would need to be copied in six sections which would create twelve matched seams for each map. In a telephone conversation with the author on July 24, 2009, Kathy Stroud recommended that I take digital photographs of the maps and indicated that other people had used the method successfully in the past. I knew that photograph map images would be inferior to scanned maps but scanning the maps was not feasible for the reasons stated above.

In early August of 2009, I traveled to the UC Davis Library to photograph the
historic topographic maps I needed. I first went through the map drawers and pulled out
the maps I needed. I then found a bright corner of the map room and borrowed a ladder
from the library. One by one I laid the maps on the ground, got up on the ladder and shot
multiple photographs of each map. The camera was roughly four to five feet from the
map when each photograph was taken. I hoped that at least one photo would be suitable
for each map. I used a hand-held Canon 100 zoom lens camera and set it to maximum
resolution (3072 x 2304 pixels). For most of the maps I used a flash but I turned the flash
off for maps that were laminated. Unfortunately, because I was standing over the maps
and the light source was above me a slight shadow was cast on all the maps.

At home I sorted through the photographs but found that the quality was not
good. Although the maps were in focus the resolution was not high enough and the
words appeared fuzzy. I brought the best photos into Adobe Photoshop and attempted to
sharpen the images. The maps were slightly improved. I georeferenced the maps and
sent them to Matt Fox. In an e-mail message to the author on September 16, 2009, he
explained that the quality was not good enough to include in the project. On September
23, 2009 Matt Fox sent an email indicating that photographed maps might be suitable for
inclusion in his historic topographic map project if they were taken with a high quality
camera so that the map lines and features are clearly visible.

A month later I returned to the UC Davis library to make a second attempt at
photographing the maps. This time I used a high quality digital camera (Canon EOS
40D, 3888 x 2592 pixels) and a wide-angle lens. The most difficult problem was getting
enough light while avoiding glare. Dawn Collings, one of the university map librarians,
was kind enough to spend over an hour helping me find the best location to take
photographs. We tried closing the blinds, opening the blinds and turning off the lights, putting the maps on the floor, setting the maps on an easel, and so on. I finally set up in an area slightly removed from the map collection near the restrooms. There was a bright light directly overhead and the location was shielded from any glare caused by sunlight entering through the windows. I rotated each map on its side so that it was oriented lengthwise and clipped it to the easel. I took 5-6 photographs of each map in its entirety. The wide angle lens allowed me to hold the camera approximately 1 foot from the center of the map when I took the photographs. The camera I used had an automated focusing feature that showed small red dots in the viewfinder at each point of focus when I held the button down halfway. My goal was to get as many red dots as possible in an evenly distributed pattern. Afterwards I was able to view all the photographs and choose the best one for each map. In an e-mail message to the author on December 8, 2009, Matt Fox says that the new photographs are significantly improved over the last set. Still, the photographs are markedly inferior to scanned images.

In Figure 8 below you can clearly see that the light source is overhead. The map is lighter at the top and darker towards the bottom. Unfortunately, all the maps I photographed have this same characteristic. If I had laid the maps on the floor or on a table they would have had consistent lighting but I would have cast a shadow when I leaned over them to take the picture. High quality images might have been obtained in the studio of a professional photographer, but these facilities could not be duplicated in a university library.

In Figure 9 you can see how the maps were put on the easel. I placed a large poster board on the easel for support and I clipped the maps in two locations to the top of
the board. This method kept the maps relatively flat.


Figure 10 is an example of a laminated map. Although I did not use a flash you can see that my image is reflected by the plastic. You can even see that I was wearing a pink shirt.

Figure 11 is an example of the legibility of the marginalia. Figure 12 is a photograph of the same map taken with a point and shoot camera on my first visit to the UC Davis Library. The contrast between figure 11 and figure 12 is obvious. Figure 12 is fuzzy and several words and numbers are illegible. As mentioned earlier Matt Fox did not accept the photographs from my first trip to the UC Davis library because of their poor quality.


Figure 13 is another example of an acceptable photograph of a topographic map.

Once I had chosen the best photograph for each topographic map I brought the images into Adobe Photoshop and cropped the images so that the map was shown but the easel, wall and unnecessary background were removed. I also made a slight adjustment to the brightness. I georeferenced the maps and uploaded them to a Google Historic Topographic map FTP site for Fox.

For the forty scanned images I received from Matt Fox, I first had to convert them from MrSID files to TIFF files. MrSID is proprietary format that can be viewed
(but not manipulated) with Internet browser plug-ins or public domain applications and MrSID files cannot be viewed or manipulated in Adobe Photoshop. I used the GeoViewer program from Lizardtech to make the conversion. GeoViewer is free to download from the Lizardtech website.

Once the files were converted I brought each scanned image into Adobe Photoshop and optimized it. Because these historic maps were roughly one hundred years old, many were faded or yellowed with age. In Photoshop, I ran an automated color adjustment, that brought the map background as close to white as possible. Next, I used the program to sharpen the images, which made the lines and text brighter and crisper. Several of the maps had library stamps or writing in the margins. I erased these marks so that the maps would look as close to their original state as possible. Figures 10 and 11 show before and after comparisons.

While I was viewing each map in Photoshop I took the opportunity to enter coordinate information (longitude, latitude) for the four corners into my master list of topographic maps. These coordinates were then converted to decimal degrees for use in georeferencing.

For georeferencing, I added one optimized map image at a time to an ArcMap project. As mentioned above, each map corner is labeled with coordinates. I referenced each map corner to its labeled coordinates by using control points. Initially, when a non-georeferenced image is brought into ArcMap it is displayed simply floating in space. I moved the map to its true location by manually placing a control point on a map corner and then inputting where the control point should be in coordinate space. I entered the locations in decimal degrees. Once I had four control points, one at each map corner, I

updated its georeferencing and permanently moved the map to its real world location. The image now had spatial data associated with it. In other words, anytime the file is opened it will appear in the proper spatial location. This georeferencing process was repeated for each map.

Once all forty maps were georeferenced I uploaded them to a Google Earth™ Library FTP site for Matt Fox. He has received the maps and has included them in the Google Historic Topographic Map Project. I also used a CSUC Geography Department FTP site to send the maps to CSU Chico Meriam Library in the care of Cathy Benjamin.

In order to view the Google Earth™ Historic Topographic Map Project one must download the KML file available at the Google Earth™ Library website (http://www.gelib.com/historic-topographic-maps.html). That KML file (historic-topographic-maps.kml) can be opened in Google Earth™. Once opened, the user will see index grids with names in the western and eastern portions of the United States. The user can zoom in and choose a USGS quadrangle by name or use the Google Earth™ search function to locate a specific place or feature. When the desired quadrangle is identified the user double clicks on the point in the center of the quadrangle and a box is opened that lists all available historic USGS maps by year as shown in Figure 16. The user clicks on a year and that historic topographic map will appear in the window as in Figure 17. The map appears in its entirety with all marginalia.

The Google Earth™ Historic Topographic Map Project is both innovative and user-friendly. My contribution, although small, adds to this important resource. I was disappointed in the results of the map photographs but they are useful in the interim until digital scans of those maps are made available.
Figure 16. Example of index grids and display box. Source: Copyright 2010 TerraMetrics®, Inc. www.terrametrics.com, Copyright 2009 Google™. Google Earth™ screen shot. (captured July 22, 2010)

Conclusion

We have an amazing resource that is not being utilized because it is largely unavailable. Historic topographic maps are beautiful and are filled with information about how the world looked at the time they were made. Studying these old maps can show us how the world around us has changed over time. We can use them to answer questions about land use and the natural environment. When these maps are scanned they are preserved from age and damage. In digital form and when placed on the Internet, they are available to everyone with computer access.

The main purpose of my project was to complete a digitized, georeferenced, historic topographic coverage of central California that would be available to the public. I completed my goal and added sixty-seven maps to the Google Earth™ Historic
Topographic Map Project and can be viewed in **Google Earth**™.

My results, however, were not what I had hoped for. I had difficulty accessing the maps. There were fees to get maps scanned and fees to check maps out. The maps that were freely accessible could not be moved from their locations. As a result I photographed twenty-seven maps of the maps need to complete my project. The photographed maps are suitable for inclusion in the Historic Topographic Map Project on **Google Earth**™ but are not library quality and limit their use as research tools. Photographs distort the maps and make accurate georeferencing impossible. They are also subject to the effects of light and shadow.
Digital scanning is the only suitable choice for preserving historic maps. Several organizations and libraries, including CSU Chico, are in the process of scanning their historic topographic maps but others lack funding, time and man-power. There is also a lack of collaboration. Digital historic topographic maps are scattered among many websites and cannot be easily located.

The work needs a cohesive vision and single repository accessible to the public. If there were a single online location for historic topographic maps then there would be no duplication of effort. The world does not need ten scanned images of the same topographic map available on ten different websites. With time and funding in demand organizations cannot afford to duplicate the work of others.

The most logical options for a single online repository are the USGS Historic Map Project, the Google Earth™ Historic Topographic Map Project and the Alexandria Digital Library Project. The USGS is the most obvious choice. If someone were searching for a historic USGS map they would undoubtedly go to the source first. The Google Earth™ Historic Topographic Map Project has the advantage of a built-in search feature so that processed maps could be viewable immediately and cataloguing could be done as time allows. The Alexandria Digital Library Project is attractive in that it is well funded and has a sizable collection.

If organizations collaborate their efforts then the work of preserving historic topographic maps could increase rapidly. For example, UC Davis has an extensive collection of USGS topographic maps but lack the equipment to scan them. UC Berkeley has a limited collection but high quality scanning equipment. If UC Davis could be persuaded to make an exception to library policy and allow maps to leave campus UC
Berkeley staff could scan them and some significant progress could be made. The scanned images could be sent to university GIS classrooms where students could practice georeferencing skills.

More than 300,000 historic USGS topographic maps need to be preserved. The work needs to continue with greater effort, positive collaboration and increased vision. The problem is access. We need a central online repository for historic topographic maps. We need organizations to work together. But most importantly, we need a leader.

I think a graduate student from the CSU Chico geography department should organize a collaborative effort to digitize and georeference historic topographic maps in California. As a graduate project that student could contact map librarians throughout the state and moderate a discussion and a plan for completion.
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APPENDIX A
Map 1
Pre-1950 USGS 7.5 Minute Topographic Quadrangles

Legend
- Orange: 7.5 Minute Topographic Maps Created Prior to 1950
- Green: 1:31680 Scale Topographic Maps Created Prior to 1950 in Central California

Note: 1:31680 scale maps are often referred to as historic 7.5 min topographic maps. The geographic area contained in a 1:31680 map correlates to current 7.5 min maps and can therefore be represented on a 7.5 min index map.
Map 2
Pre-1950 USGS 7.5 Minute Topographic Quadrangles within the Project Area

Legend
- Maps housed at UC Davis Library
- Maps provided by Matt Fox (not georeferenced)
- Maps georeferenced by Matt Fox
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