Computer Based Methodologies for Investigating the History of Significant Cultural Landscapes: Marsh-Billings Rockefeller National Historical Park | 2003-06

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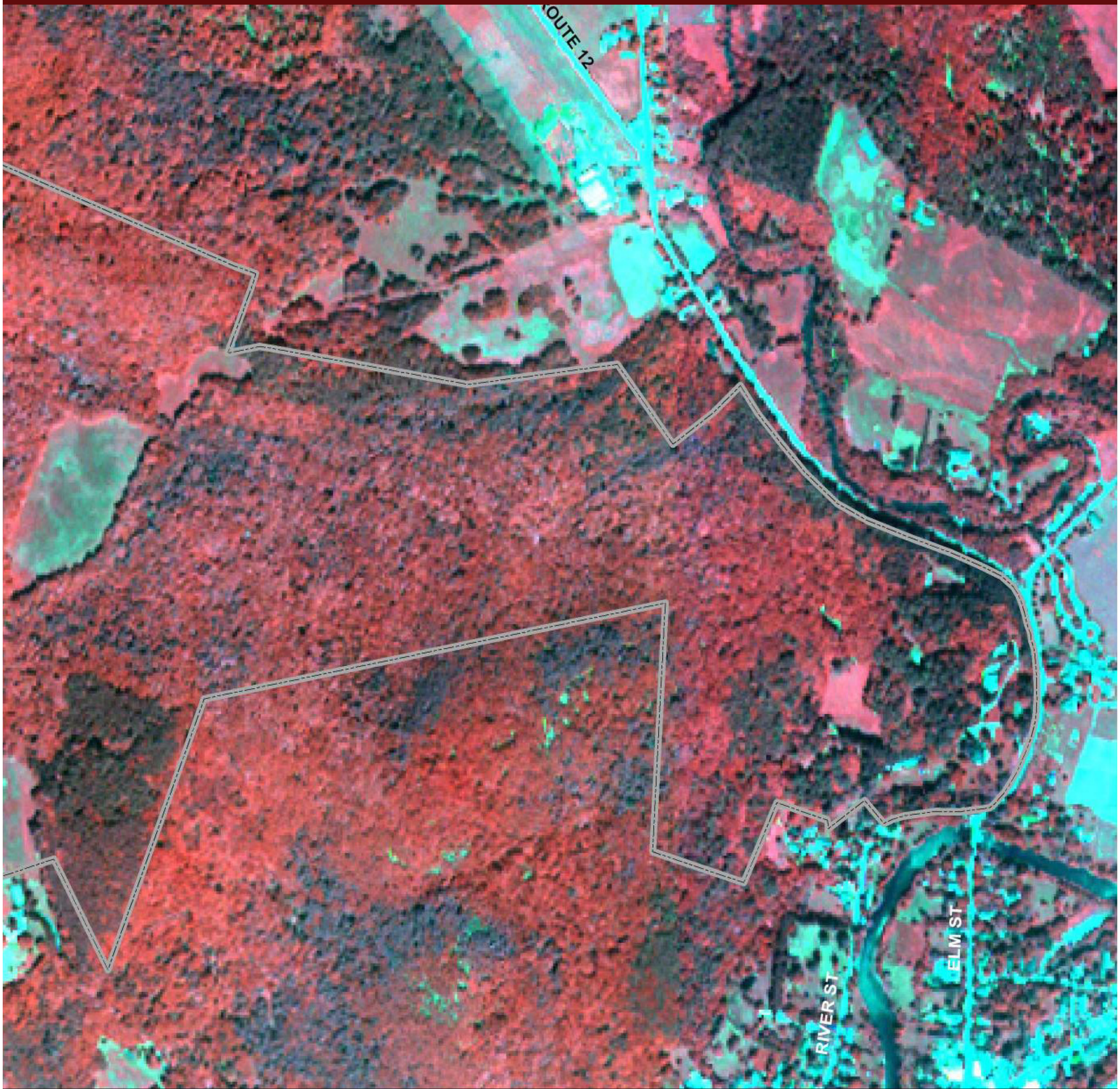

National Park Service
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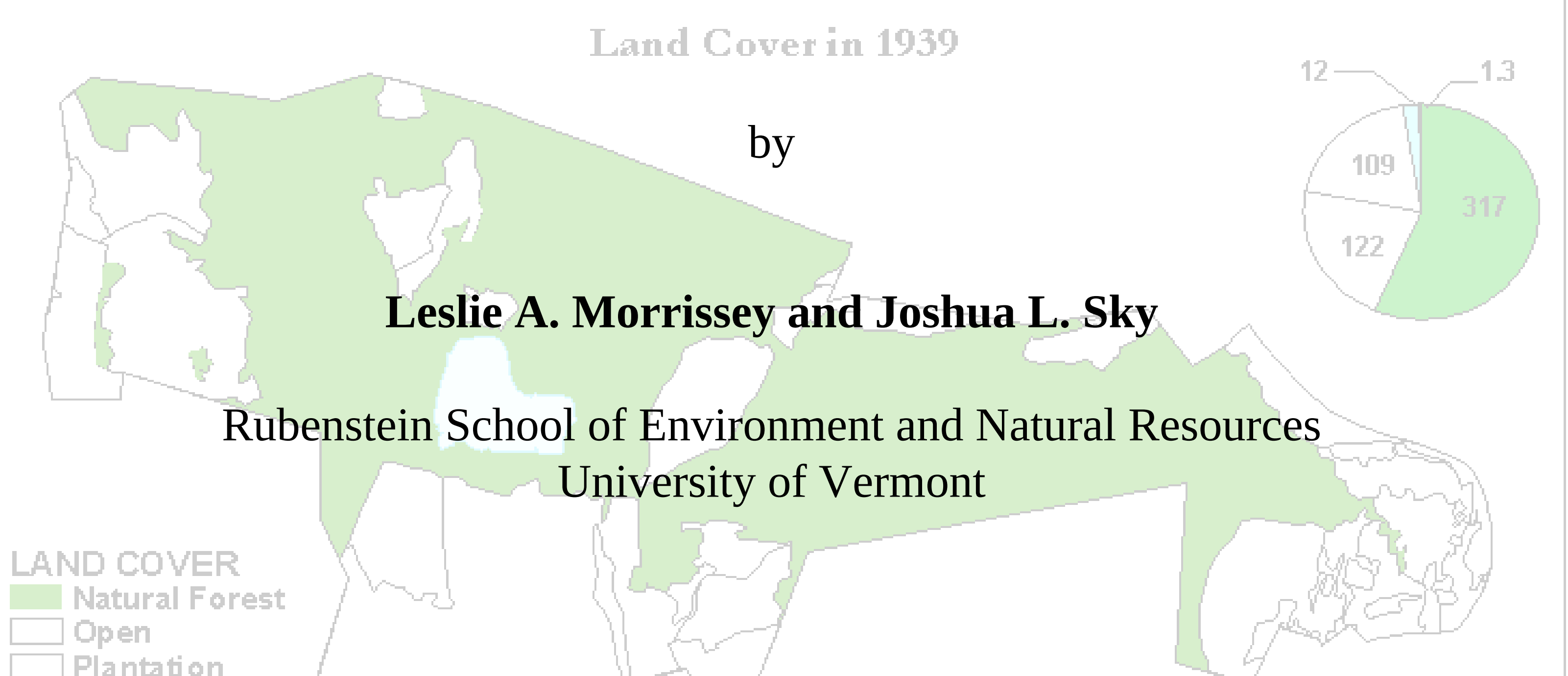

by

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Abstract

The management of culturally-significant historical landscapes is facilitated when a thorough investigation and categorization of the natural and cultural features present has been completed. Historic landscapes without sufficient archival data present a challenge to traditional methods of historic reconstruction and new methods of research are needed to provide new insights. Geographic Information Systems (GIS), Global Positioning Systems (GPS), and remote sensing (RS) were used as analytical tools for locating, identifying and analyzing significant cultural resources within Marsh-Billings-Rockefeller National Historical Park (MBRNHP). These technologies were used in combination to create a GIS database of historical aerial photographs, maps, surveys, and recent satellite data. Once in digital form, the multitemporal aerial and satellite images were analyzed, using both manual photo-interpretation and digital remote sensing techniques, to search for and document changes in the landscape over time. These methods were evaluated for their utility in reconstructing and understanding the history of both natural and cultural landscapes. GIS, GPS and remote sensing technologies provided a means to identify and verify the historic landscape features of MBRNHP such as carriage roads, stonewalls, buildings, forest plantations and surface water features visible on historic maps, aerial photographs and satellite images.

Acknowledgements

We would like to thank all those who provided invaluable assistance and support during this project. We thank Dr. Nora Mitchell, Director of the Conservation Study Institute (NPS), and Mr. Kyle Jones (NPS) for their patience and support and Mr. John Wiggin, former Mt. Tom land manager, for sharing his wealth of knowledge. The Cultural Landscape Report provided invaluable source material; we thank the authors. We would also like acknowledge the assistance of the staff of Marsh-Billings-Rockefeller NHP and the Billings Farm and Museum. Funding for this project was provided by the Center for Preservation Technology and Training, National Park Service.

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Introduction

The history of rural New England is written in the condition and character of its landscapes. The agricultural roots of European colonization are displayed in a patchwork of field, forest, pasture, road, and stonewalls that cover the hills and valleys of the region. Some of our New England landscapes reflect unique and important aspects of history, and were therefore singled out for preservation and historic research. These landscapes represent the best of rural New England and serve as a vital link to the rural culture of our past. Over time changing economies, demographics, and cultural values have swept through the New England landscape, threatening to alter or destroy some of our important historic landscapes. The pressures exerted by the rapid changes of the late 20th century have led to an increased level of awareness and a desire to better understand, protect and preserve the best of the New England landscapes.

The key to preserving historic landscape regimes is a comprehensive understanding of the landscape components and their links to the past. Traditional methods of historic landscape investigation used primary archival data such as diaries, receipts, newspaper articles, and other historic documents in combination with maps and historical photographs to document historic sites. Cultural resource professionals often study and compare historic documents for clues regarding prior activity for a given landscape. Historic maps and aerial photographs serve as a tool to locate specific landscape features and provide information on landscape conditions. In an effort to catalog and document the past conditions of the landscape, new maps and drawings of past conditions are often created. In effect, the landscape can be reconstructed, or described and documented, by the careful study of historic maps, photographs and archival data.

Historic landscapes without sufficient archival data present a challenge to traditional methods of conceptual historic reconstruction, and new methods of research were needed to provide new insights. Remote sensing, Geographic Information Systems and Global Positioning Systems (hereafter RS, GIS and GPS respectively) are the possible foundation for using innovative methods for conceptually reconstructing historic landscapes. The use of these technologies to catalog, analyze, manipulate, and maintain extensive map, photographic, and archival databases of historic landscapes adds new options for the traditional methods of historic landscape study. In the future, a combination of RS, GIS, and GPS technologies could be used by cultural resource professionals to perform much of the research and analyses that were formerly conducted manually.

The overall goal of this project is to demonstrate the utility of RS, GIS and GPS in reconstructing patterns of historical development on a rural New England cultural landscape, namely Marsh-Billings-Rockefeller National Historic Park (MBRNHP). The comprehensive and spatially-explicit analyses available through the use of these digital technologies substantially increase our knowledge and understanding of the significant features present within historic landscapes. Furthermore, the result of the demonstration of these technologies provides crucial data regarding historic resources that will aid in the management of the landscape at MBRNHP. The data generated from the use of digital technologies is presented in maps, figures, tables and text that provide insight into the historic conditions of a historic landscape.

Marsh-Billings-Rockefeller National Historical Park (MBRNHP), a historic site located in Woodstock, Vermont, was chosen as the demonstration site for this project. The landscape at MBRNHP has been altered by a progressive management regime for over a century. The forest, farm, and infrastructure management, which occurred under the guidance of the Marsh family, Frederick and Julia Billings, and Laurence and Mary Rockefeller, has transformed the area into a nationally significant cultural landscape that includes a patchwork of fields and forest as well as manicured gardens and grounds. The forest at MBRNHP has been under continuous management since the 1870s, making it one of the oldest managed forests in the United States. This site is an important cultural landscape where the interface between people and the natural environment has created a historically significant area.

MBRNHP was an excellent site for the testing of digital technologies due to its relatively small size, comprehensive archival database, and its relationship to the larger rural New England landscape. The park has been the subject of numerous historic investigations, including the Cultural Landscape Report (CLR) for the Forest at Marsh-Billings-Rockefeller National Historical Park: Site History and Existing Conditions (Wilcke et al., 2000). The CLR provides a detailed site history and a database of RS, GIS and GPS data that was used extensively in this project.

With the designation of the Rockefeller property as MBRNHP in 1992, an effort to understand the evolution of this landscape was undertaken. Traditional research methods, such as those used as the basis for the CLR for MBRNHP, documented the history of landowners and land activity at the park. Although contributing much to our understanding of the who, when, and what regarding the human use of the property, these methods were limited in describing the geographic or spatial evolution, or the where of the landscape. Spatially-explicit GIS, RS, and GPS technologies provide the opportunity to explore new and innovative methodologies for studying cultural landscapes such as MBRNHP. The spatial insights of these technologies enhance our understanding of cultural landscapes, today and in the past.

Goals and Objectives

The goals of this project were to reconstruct patterns of historical development of the landscape at MBRNHP through the use of geospatial technologies and to demonstrate the value of RS, GIS, and GPS in researching and characterizing historic landscapes. Each of the technological tools was evaluated independently and methodologies that involve the use of technologies in tandem were also reviewed. Finally, the results of the RS, GIS and GPS analyses were also compared with the existing MBRNHP archival database to assess and validate the resulting data layers and products.

In order to demonstrate the state-of-the-art digital technologies as a research tool for historical landscapes, three specific objectives guided this research:

1. Demonstrate changing landscape patterns over time
    a. Compile time series data including:
        i. Historical aerial photography
        ii. Satellite data
    b. Analyze time series data using change detection techniques including:
        i. Image subtraction
        ii. Manual photointerpretation
        iii. Historic map comparison
2. Detect, locate, and identify cultural and natural landscape features using remote sensing
    a. Demonstrate utility of edge detection techniques to detect linear features that represent significant cultural and natural resources in:
        i. Aerial photographs
        ii. Satellite scenes
    b. Demonstrate utility of IKONOS multispectral imagery in detecting significant cultural resources using:
        i. Classification of land cover
        ii. Band ratioing to highlight vegetation patterns
3. Verify the existence of historic cultural features
    a. Use GPS and GIS to locate features shown in historical data sources:
        i. Doton survey
        ii. Aerial Photographs
        iii. Satellite scenes
        iv. Historical maps
    b. Record the location and condition of historic features with GPS

Location and Setting

Marsh-Billings-Rockefeller National Historical Park is a 562-acre (227 hectares) national park located in Woodstock, Vermont (Figure 1.1). It is situated in the rolling hills above the Connecticut River Valley between the Green Mountains of Vermont and the White Mountains of New Hampshire. The elevation ranges between 660 and 1440 feet (201 – 439 meters) above sea level with generally mild topography, although there are some steep areas and small cliffs. The soils in MBRNHP are rich in limestone and support productive forest plantations and stands of northern hardwoods. In addition the landscape is divided by active agricultural fields used for hay production.

MBRNHP and the adjacent town-owned Mt. Tom property are situated to the northeast of downtown Woodstock. Woodstock is an attractive New England town on the National Register of Historic Places. The historic downtown, the Woodstock Inn, Billings Farm, and the surrounding countryside attract many visitors, providing the basis for the town’s main industry, tourism. Even when privately owned, the property currently administered by MBRNHP has been open to visitors. Since the early 1900s, guests have enjoyed such activities as walking, horseback riding, cross-country skiing and nature watching.

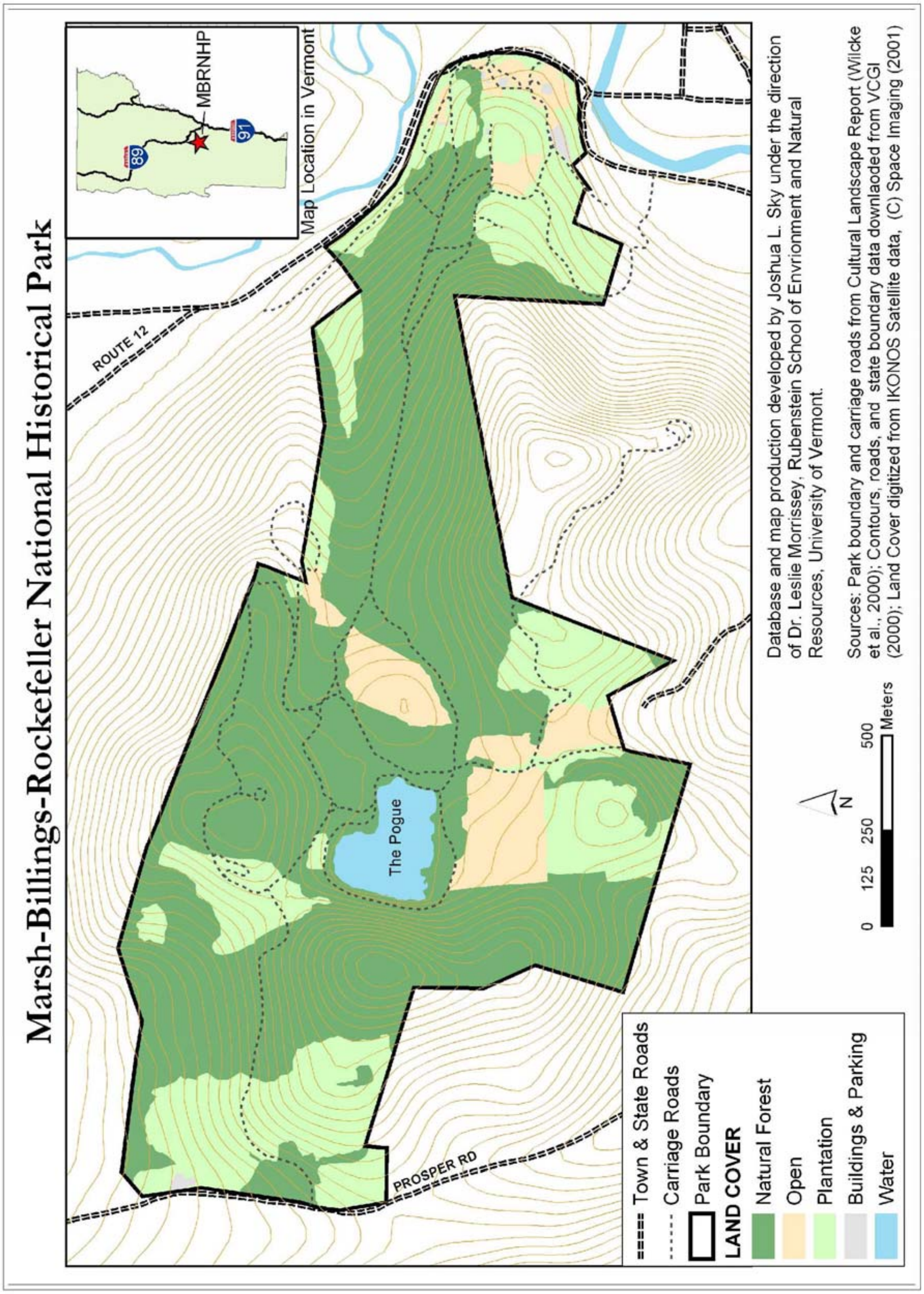


Figure 1.1 Study area and existing conditions

Site History and Significance

Marsh-Billings-Rockefeller National Historical Park derives its significance from three individuals who dramatically shaped the local as well as national landscape. George Perkins Marsh, author of *Man and Nature; or Physical Geography as Modified by Human Action (*1864) a seminal book in the environmental movement, lived on the property with his family as a young boy. Frederick Billings, a wealthy railroad tycoon, started the tradition of land stewardship on the property. Laurance and Mary Rockefeller, generous philanthropists, continued the practice of progressive management started by Billings and eventually donated the property to the National Park Service.

In addition to the tenure of the famous Vermonters, MBRNHP is a working landscape. Over time, different sections of the park have been used as a farm, forest plantation, sheep pasture and recreational site. The various uses of the property reflect the changing social and economic conditions within Vermont and New England. The changes that have occurred in the MBRNHP landscape, especially the conversion of forest to farm and then gradual return to forest has also occurred in many other areas of Vermont and surrounding New England States.

Prior to European settlement, the land that is now Marsh-Billings-Rockefeller National Historical Park was typical of that found in the Connecticut River Valley. Around 4,500 years ago and continuing through the present, the primary forest covering

Vermont was comprised of a mix of northern hardwoods stands and stands of hemlock and white pine (Klyza and Trombulak, 1999). The landform of the upper Connecticut Valley was dominated by rounded hills of glacial loess on top of rich limestone bedrock Valley. Native people found the area attractive as a summer camp and for hunting grounds and, according to Dana (1889) a group of Abenaki inhabited a meadow on the western end of the property.

The Town of Woodstock was chartered by the Province of New Hampshire in 1761. During the ensuing turbulent years (New York provincial claims, the Revolutionary War, and the Declaration of Vermont statehood), the Village of Woodstock grew to a population of about 150 with more than 1000 living within the Town boundary (Foulds, 1994). Between 1772 and 1789, few individuals were recorded as actually living within the current boundaries of the park. A Mr. Perkins (first name unknown) took up residence on the future site of the tennis courts of the Billings' estate, and a Mr. John Hoisington settled on a 20-acre parcel that later became the Billings' Farm (Dana, 1889). These two tenants were joined by an E. Thomas and Dana (first name unknown) during the1800s. Of course these settlers wanted to make the land productive and to that end, they spent a good deal of time clearing the forests of Mt. Tom and the surrounding countryside to provide wood for building and heating and to make room for agriculture. The proximity of the Village of Woodstock also makes it likely that the slopes of the western side of the property were used as a wood resource by the townspeople (Cronon, 1983).

Charles Marsh Sr., father of George Perkins Marsh, bought 50 acres of Woodstock farmland in 1789. This purchase was supplemented by several subsequent acquisitions. The Marsh family holdings provided the nucleus of the present-day park. In 1801, George Perkins Marsh (Figure 1.2) was born on the Marsh farm. He grew up during a time of widespread land conversion and clearing in New England (Fernow, 1913). Marsh left the farm in the 1820s to obtain a college education and he never lived on the Woodstock property again. In 1864 he wrote the book *Man and Nature* which speaks about the connection between a healthy forest ecosystem and the health of humankind. Forests cleared for agriculture, pasture, and by fire during the settlement of Woodstock in the late 1700s left much of the landscape, including the current MBRNHP property, devoid of large trees and contiguous forests (Wilcke et al., 2000). Although he never played a direct role in the management of the property in Woodstock, Marsh's ideas regarding land conservation were to exert a major influence over the later management of the property.

Figure 1.2 George Perkins Marsh (Courtesy of UVM Special Collections, 1820)

The Marsh family lived on the land from 1770-1869. During that time they managed the land as a conventional Vermont farm. Crops of wheat were grown adjacent to the Marsh homestead, in the area now occupied by the Billings' Farm. The future MBRNHP property was used for timber production, sheep farming, and maple sugaring by the Marsh family (Lowenthal, 1958). The remote setting of Vermont at the time made it necessary to provide food and dry goods for the family through agricultural production on the land (Wilcke et al., 2000). The Marsh clan also built a house and outbuildings on the property at the present day location of the brick mansion (Figure 1.3). The final decade of occupation by the Marsh family saw a decline in the value and productivity of the farm. By 1869, Charles Marsh Jr. was ready to sell the Woodstock property.

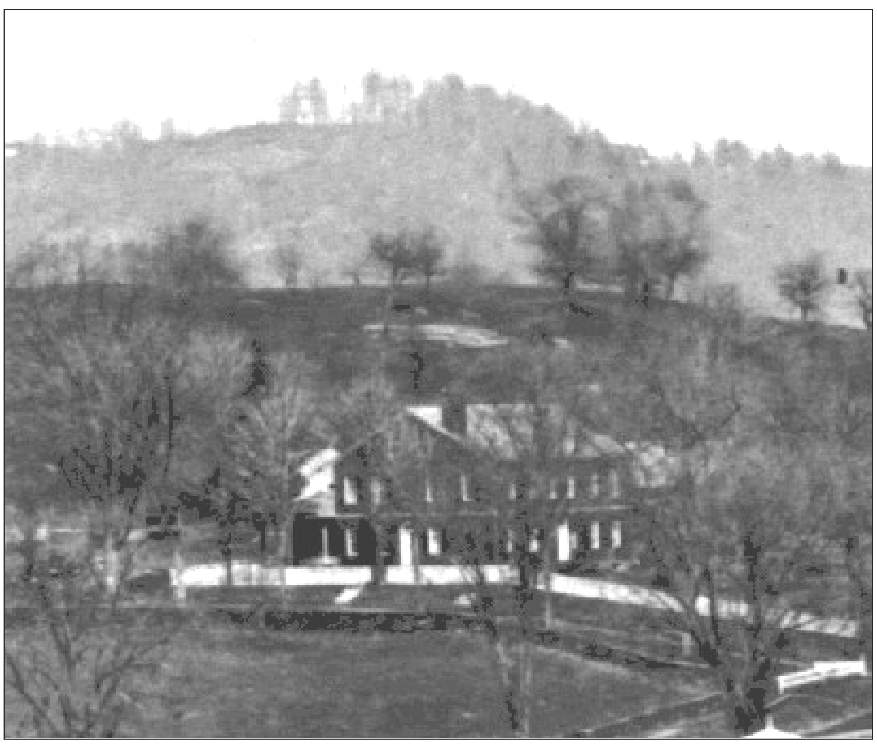


Figure 1.3 Marsh Homestead with denuded MBRNHP property in the background
(Courtesy of the Woodstock Historical Society, circa 1870)

In March of 1869, Frederick Billings (Figure 1.4) a wealthy railroad baron, purchased 247 acres of the Marsh property in Woodstock. Frederick and his wife, Julia Parmly Billings (1835 –1914), returned to the East from California and intended to use the property as a summer retreat. Billings was interested in amassing a large estate in Woodstock and set about increasing the size of his holdings by purchasing other parcels adjacent to the Marsh property during the late 1800s and early 1900s. Billings' plans to create an estate were later influenced by Marsh's writings and by his own travels to the West where he was exposed to the intense land use practices of exploitive logging and gold mining (Wilcke et al., 2000). Instead of creating a typical country estate, he decided to transform the property into a model farm and woodlot. Billings' subsequent land use management practices had a profound effect on the future character of the MBRNHP landscape.

Figure 1.4 Frederick Billings (Courtesy of UVM Special Collections, circa 1870)

The Billings era marked the beginning of forest management within the current park boundary. In the late 1800s, European forestry practices were beginning to be introduced into the United States (Fernow, 1913). A succession of farm managers, including the influential George Aitken, were responsible for importing European tree species and using European forestry techniques to create forest plantations (Wilcke et al., 2000). The archival information available from this time period includes a detailed diary of farm activity that was maintained by the Billings family (Billings Farm Memo Diary, 1880-1944). The tradition of model farming and forest management was carried out through successive generations of the Billings family. This longstanding commitment to forest management and conservation has led to the presence of unique historical resources within MBRNHP. The cultural resources of the Billings reign include native and exotic forest plantations, stonewalls, relict agricultural areas, structures, a managed watershed, carriage roads, and trails.

In 1951, Mary Montague French Billings, the last surviving child of Frederick and Julia Billings, passed away leaving the farm to her daughter and son-in-law, Mary F. Rockefeller and Laurance S. Rockefeller. The Rockefellers were dedicated philanthropists who valued conservation and continued to practice sound land management on their Woodstock property. Throughout their tenure on the property, the Rockefellers continued the practice of forest management that Mary's grandfather had started. In 1956, the forest was designated Tree Farm No. 1 in Vermont by the American Forest Institute, further recognizing the Rockefeller's commitment to exemplary management of their forest (Wilcke et al., 2000).

In 1967, The Billings-Rockefeller mansion and grounds were officially recognized as a significant cultural resource when the mansion and the surrounding 40 acres were designated as a National Historic Landmark. Six years later, the entire future site of MBRNHP was included in the Woodstock Village Historic District nomination to the National Register of Historic Places.   MBRNHP was created in 1992 when Mary and Laurence Rockefeller donated the mansion and the surrounding 562 acres to the National Park Service (NPS). In 1998, Marsh-Billings-Rockefeller National Historical Park opened to the public.

Presently the landscape at MBRNHP is under the management of the National Park Service. Presently, planted and natural forests, dominate the landscape. There are also a number of cultural features present from the long period of inhabitance and use by humans, especially over the last 150 years. These features include buildings, carriage roads, stonewalls, water pipelines, gardens, pastures, and forest plantations. The tradition of conservation and progressive management that has been practiced by the various land-owners has created a unique landscape of cultural and historical value.

Chapter II: Literature Review

Cultural Landscapes

Cultural landscapes are areas that reflect the interaction between people and their natural environment over time (Plachter and Rössler, 1995). This broad definition exemplifies the critical condition of a cultural landscape – as an area where the mark of human activity is echoed in the present state of the site. However, this definition is too encompassing and includes almost every landscape on earth. In his paper, *Functional Criteria for the Assessment of Cultural Landscapes* (1995), Plachter further defines a cultural landscape as an area where human culture and nature have truly shaped each other and where man is, or was conscious of, this influence in terms of defined aims. He also adds that some ecological mechanisms of control, reconstruction, and decomposition must still be functioning in the landscape. In the U.S., the National Park Service (NPS) narrows the definition of cultural landscapes by linking them to the important events of the past. The NPS defines a cultural landscape as ”a geographic area, including both cultural and natural resources, and the wildlife and domestic animals therein, *associated with a historic event, activity or person, or exhibiting other cultural or aesthetic values.*”(NPS, 1997, pg. 179)

The National Park Service has four categories of cultural landscapes: Historic Site, Historic Designed Landscape, Historic Vernacular Landscape (HVL) and Ethnographic Landscape (O’Donnell, 1995). These categories are not mutually exclusive and a single landscape may contain one or more of three preceding landscape types. This project focuses on the MBRNHP which is classified as an HVL, however the methods used could be used to evaluate any of the other cultural landscapes. According to the NPS, an HVL is “a landscape whose use, construction, or physical layout reflects endemic traditions, customs, and beliefs of values; in which the expression of cultural values, social behavior, and individual actions over time is manifested in the physical features and materials and their interrelationships, including patterns of spatial organization, land use, circulation, vegetation, structures and objects; in which the physical, biological, and cultural features reflect the customs and everyday lives of people” (O’Donnell, 1995, pg. 211). Put more simply, a historic vernacular landscape mirrors the culture and values, in a significant manner, of the society that created it while maintaining a fundamentally changed, but functioning ecosystem.

One goal of cultural landscape research is the assignment of integrity and significance (NPS, 1995). The features that define the landscape can be attributed to a particular period in time and a broader historical significance that is associated with their introduction or removal from the landscape. Integrity is evaluated through the verification of the existence of significant landscape features followed by an assessment of their condition. For example, Civil War battlefields throughout the U.S. are considered significant due to the role of those battles on our nation. However, these battle sites will be deemed as possessing integrity only if the land has retained the important characteristics that it had during the battle. The same type of analysis is applied to other types of cultural landscapes to determine their integrity and significance (NPS, 1997).

Criteria for the evaluation of significance and integrity are defined in the *Code of Federal Regulations, Title 36, Part 60* (C.F.R., 1996, pgs. 292-307). In this publication, landscapes are defined as "having significance if they are associated with historic events that have made a contribution to the broad patterns of our history; or are associated with important historical persons; or exemplify a type, period, or method of construction, or that are the work of a known master, or that possess high artistic values; or contain important information about history or prehistory"(36 C.F.R. Part 60, 1996). The significance of a property is determined, through historical research and existing conditions documentation, and by its compliance with the National Register of Historic Places criteria. Landscapes may contain several areas of historical significance and the careful assessment of these components, from their introduction to their present condition, is essential to determine their integrity (NPS, 1991).

Integrity is determined by the survival and condition of a property's historical features from some earlier period. A property with integrity will convey its significance, its connection to the past, through the presence of these features. The features are evaluated according to seven criteria including, location, setting, feeling, association, design, workmanship and materials (NPS, 1991; 1995). The development of integrity is a somewhat subjective endeavor which requires judgment on the evaluation and relative weight of the seven aspects. Any evaluation of historic landscape integrity must recognize its dynamic nature. Change is an on-going process and will degrade or enhance the integrity of all historic features. The challenge of preservation professionals and mangers is to combine the historic research, existing conditions documentation, and significance and integrity findings into a historic preservation management plan.

To properly discuss the process of identifying significant cultural resources, it is necessary to explain the importance of these pieces of our past. Human beings use the past as a reference point from which they base almost every decision that they make. People are reliant on their personal past for these decisions, but a more abstract past or cultural heritage is also important. Some historians argue that a link or wider sense of belonging tied to cultural history is a critical human requirement. The United Nations Educational, Social, Cultural Organization (UNESCO) describes cultural heritage as an essential human right, akin to the right to food and water. Once the past can be assembled and analyzed, it can be used to explain the present and make decisions for the future (Caple, 2000).

GIS and Historic Landscape Research

GIS expands the potential for cultural resource management, preservation planning, and documentation of resources (McCarthy, 1998). Cultural landscape research and management are, respectively, the study and administration of the component elements of a historically significant resource. The location, characteristics, and association of the historical elements are key attributes for interpretation and preservation. GIS can be used to integrate all of the natural and cultural attributes into a single georeferenced database. The GIS database can then be queried by managers and researchers to quickly provide documented information and analysis.

A powerful feature of a GIS is the ability to assign location information, or coordinates to map features, in combination with attribute data for a particular layer. Vector attributes can range from simple measurements of length or area to complex information about ownership or construction materials. The options are determined by the original source and based on the purpose of the data. For example, historical data sets might include attributes used by the National Register Information System. Raster data can be classified into several categories, each with its own unique meaning. For example, digital elevation models (DEMs) are often used to generate information on the elevation, slope, and aspect of the terrain. By combining location data with feature attribute information, one can more easily assess changing historic landscape conditions.

In 1998, the NPS Cultural Resources GIS (CRGIS) Facility partnered with the Historic American Engineering Record (HAER) in an effort to expand the capabilities of cultural research with GIS. The Colonial National Historical Park constructed a GIS database for The Colonial Parkway. The project combined architectural drawings, maps, photographs, as well as HAER and CRGIS data into a single GIS database for the park. The purpose of the GIS database was to provide an inventory of park holdings and to develop an understanding of the historic landscape. Furthermore, the researchers intend that the database be used by managers and planners as a resource. For example, a developer may wish to find all historic sites that fall within a 1000 meter radius of a proposed construction site (McCarthy, 1998). In addition, a GIS database of 39 current and historical database layers of MBRNHP was developed by Morrissey (UVM) in collaboration with the National Park Service (Wilcke et al., 2000). This GIS database was used extensively as part of this research project.

Other projects involving the integration of historical landscape information into a GIS range from large to small scale. Public Land Survey (PLS) records from the late 1700s have been used to create pre-settlement vegetation maps of large sections of the Midwestern, Mountain, Great Plains and Western US States (Schulte & Mladenoff, 2001; Maines et al., 2001; Anderson et al., 1996). These projects involved the conversion of PLS data into GIS coverages that map forest cover types from the 1700s. Zybach, Barrington, and Downey (1995) developed a methodology for mapping the historical range of Douglas fir (*Pseudotsuga menziesii*) of the Pacific Northwest using historic logging records. This project was undertaken with the goal of understanding the cumulative effect of biological and cultural impacts of the human presence in the forested river basins of this region.

GIS provides a suite of tools for conducting landscape change analysis. In Rhode Island, researchers used GIS to map landscape change over 100 years at an old farm site (Simeoni, 2000). The researchers georeferenced historic survey data from 1885 with existing orthographic photographs and then used the 1885 data to create historic data layers. Taylor et al. (2000) expanded previous GIS studies by using grid analysis of land cover data. Their research of English and Welsh national parks highlights areas of change and quantifies the amount of land cover conversion over a 20-year period.

Cultural Resource Management (CRM) and landscape analysis have also realized the potential benefits of GIS over the last decade. While the analytical capabilities of GIS are often stressed by users, the majority of projects have focused on the creation of a single database of georeferenced and textual material. However, the wide array of data sources, variable formats, and different scales often hinders subsequent spatial analysis. Recently, improvements in digital image processing software and GIS technology have improved the quality and functionality of historic GIS research. Taylor et al. (2000), state that their spatial analyses yielded practical results that were of great utility in CRM and landscape analysis.

Remote Sensing of Cultural Landscapes

Remote sensing is the science of obtaining useful information about the Earth's surface with instruments located at a distance from the target (Lillesand and Kieffer, 1997). The preservation community has used aerial photography as a research tool for decades (Williamson and Warren-Findley, 1991). Aerial photography and satellite imagery have proven effective in recording the location of historical sites and analyzing them within an environmental context (Lightfoot, 1989; Crumley, 1983). More recently, computer-aided recitifcation techniques have increased the utility of aerial photographs and other remotely sensed data by removing distortions caused by cameras, film processing, elevation differences, atmospheric attenuation, and sensor error.

The United States has had an active aerial photography program since the 1930s and has been collecting satellite imagery since the 1960s. Satellite scenes were initially captured on film, but digital instruments became available in the 1970s. Medium resolution Landsat multispectral data is available from the mid 1970s and high resolution (e.g. 1 m pixel size, IKONOS and Quickbird satellite systems) multispectral data have recently become available. Satellite remote sensing systems have been launched by the French, Canadian, German, Indian, Japanese and U.S. governments to collect data on the Earth from space. As a result, there are several million satellite images covering the United States and other parts of the world. A given study area will often have many photographs and satellite scenes from various eras available for purchase. It is also possible to have aerial photography or satellite imagery collected by a vendor upon request. However, the sheer volume of archived data and its relatively low cost, when compared to custom ordered imagery, make it an attractive option for historical research.

The National Park Service advises the use of aerial photography as a preliminary research tool when beginning a cultural resource inventory (Birnbaum, 1994). The aerial photography or satellite scenes can be reviewed to orient the researcher to the landscape. These images are useful for locating and identifying geographic features, landscapes, vegetation types, structures, and other cultural features (Jensen, 1986). Sometimes large landscape features that are not obvious from the ground can be found by photointerpretation of images that provide a more areal or regional context (Lillesand and Kiefer, 1997).

Aerial photographs have been used by archeologists to find and evaluate historic sites. Lillesand and Keifer (1997) offer several examples of the use of aerial photographs to aid archeological research. Surface features, ruins, earthen mounds, and rock formations have been identified. Subsurface features, such as the buried city of Spina in the Po delta of Italy and the foundations of ancient Roman villas in Burgundy, France have been discovered as well. Chohfi (1988) presents a dramatic example of archeological use of aerial photographs with the discovery of the food supply area for the ancient city of Machu Picchu. The utility of aerial photographs in landscape interpretation has increased with the addition of color infrared (CIR) films as well as instruments that record data in digital format. In Chaco Canyon, NM a Thermal Infrared Multispectral Scanner (TIMS) sensor was flown over the landscape in 1982 and several prehistoric roads, dating from 900 to 1000 AD were discovered (Wagner, 1991).

The addition of satellite imagery to the arsenal of remote sensing products has increased the utility of remote sensing as an historic research tool. Landsat Thematic Mapper and Landsat Multispectral Scanner (Landsat TM and Landsat MSS) data have been used to examine historic sites and differentiate details that are not visible through other means. For example, ancient Mayan temples and causeways were discovered in The Petèn, Guatemala by analyzing Landsat TM imagery (Sever, 1998). Recently declassified military satellite photos from the US CORONA spy program and the Russian military were analyzed in a study of the cultural resources of the Stonehenge area in Great Britain (Fowler, 2001).

Remote Sensing and Forestry

Forestry professionals traditionally rely on aerial photography for off-site forest classification, although the emergence of high-resolution satellite imagery may some day overtake aerial photographs as the base layer of choice. Aerial photographs are widely available in the US, through both public and private sources, and provide a comprehensive record of the ground conditions for their acquisition date. Hershey and Befort (1995) offer a comprehensive guide to classification of New England forests using color infrared (CIR) aerial photography. The techniques used to identify forest cover types rely on the basic principles of manual photointerpretation, which can be time consuming and are often limited by the quality and acquisition date of the photography. Increasingly, researchers are using image processing of high resolution satellite images and low altitude color photography to automate forest classification and create more accurate forest cover maps (Key et al., 2000; Brandtberg, 1998).

Forest classification and mapping is based on dominant species or species groups. In 1980 forest cover types of the United States were defined by the Society of American Foresters and these groupings are widely used by resource professionals today (Eyre, 1980). The actual division of forest cover types on a map is a subjective endeavor due to the often gradual shift from one type to another that must be defined discretely. The use of automated image classification can aid the process of cover typing by producing a continuous picture of the cover types over large regions. However, the results may be difficult to interpret and varies from the standard practice of drawing a line dividing forest cover types; the method used by most foresters.

Image Processing Techniques

The only constant in a landscape is change. The features on the surface of the Earth are in constant flux from both natural and human forces. The nature of this change can be local to worldwide. Scientists, land managers, and the general public are interested in how these changes take effect and what the greater impact of these changes might be. One way to document and understand landscape change is through the use of change detection techniques in remote sensing.

Change Detection

Change detection is the comparison of two or more multitemporal data sets to determine change in land cover between the image dates (Lillesand and Keifer, 1997). Change detection results are most effective when comparing data sets that are captured using the same sensor, same resolution, during the same time of the year (season), and even the same hour of the day. That way, natural factors such as vegetation differences, shadows, and ground conditions are consistent through successive date imaging.

Furthermore, each image should be registered to within one pixel of each other, so that features on corresponding images or photographs will align properly (Lillesand and Keifer, 1997). Anything greater than 1 pixel misregistration will result in spurious results, due to the misalignment of landscape features from one image to another.

Due to the constraints of automated change detection analysis, most change detection projects have been limited to satellite imagery. Landsat TM data has been used to detect change in forest cover over time (Rock et al., 1986, 1990; Leckie, 1990; Sader et al., 1994; Nyerges and Green, 2000). These studies focused on the comparison of forest cover types influenced by cultural practices and natural disturbance mechanisms. The New Jersey Pine Barrens was the site of a particularly interesting project using Landsat TM data to assess the natural and anthropogenic disturbance regimes in the Pitch-Pine forest ecosystem (Luque, 2000). Carlotto (1997) gives an example of Landsat TM change detection over a wide area to detect new building sites and Ehlers et al. (1990) used Systeme Probatorie de la Observation de la Terre (SPOT) satellite imagery to detect change at the urban/suburban interface.

Aerial photography has also been used in change detection analysis. A project documenting landscape change from the mid 1970s to 1985 was conducted for the National Parks of England using aerial photography (Taylor et al., 2000). The process was hindered by the researcher's inability to co-register the different photos, but produced acceptable results. The final solution was to present geographic data at a coarse scale and to produce statistics that calculated overall landscape change, rather than local specified change (Taylor et al., 2000).

Change detection of aerial photographs is often hindered by image displacement and the introduction of error due to inherent differences in the source images. Seasonal variations, different film emulsions, different elevations, and errors in registration combine to confound the change detection algorithm (Lillesand and Kieffer, 1997). To minimize these differences, band ratioing has been used by researchers to remove atmospheric distortion and topographic shadowing prior to change detection analysis to provide more accurate results (Song et al., 2000). Rowe and Grewe (2001) gave an example of an alternative technique for change detection of linear features such as buildings and roads in aerial photographs. Instead of registering photographs to a common map base, digital scans of the photographs were convolved with the "Canny" edge detection algorithm and the resultant images were registered to each other. These images were then compared to locate areas where edges, which often corresponded to buildings and roads, differed. This technique attempted to minimize displacement error by eliminating edges within a 2-pixel radius and the use of a minimum threshold edge length for final analysis.

Edge Detection of Linear Features

Edge detection algorithms can be used to exaggerate the differences between highly contrasted neighboring pixels to detect landscape features such as boundaries, roads, and other linear features. The process, termed convolution, uses a kernel or matrix window to detect differences in contrast. Edge detection, a convolution process, is often used in agricultural and urban studies where linear features dominate the landscape. Specific edge detection algorithms can be used to detect horizontal, vertical or non-directional edges (e.g. the edge of forest stands).

The Sobel edge detection algorithm uses two kernels to perform a non-directional edge detection (Figure 2.1). The Sobel operator performs a 2-D spatial gradient measurement on an image which emphasizes regions of high spatial gradients that correspond to edges (Rencz and Ryerson, eds., 1999). The term non-directional is somewhat misleading because the Sobel algorithm actually performs a zero sum edge detection in the horizontal direction followed by edge detection in the vertical direction.

-1	**0**	**1**
-2	**0**	**2**
-1	**0**	**1**

Kernel 1

1	**2**	**1**
0	**0**	**0**
-1	**-2**	**-1**

Kernel 2

Figure 2.1 Example of Sobel kernels for edge detection

Cultural landscape studies have relied on manual analysis of imagery to highlight linear features (Taylor et al., 2000; Sever, 1998; Wagner, 1991). In these studies, the investigators used photointerpretation to identify linear features, such as ancient roads (Sever, 1998; Wagner, 1991) and cultural landscape patterns (Taylor et al., 2000). Each of these studies incorporated multispectral digital data, and could have used edge enhancement as an additional method of discovering linear features.

Global Positioning Systems

GPS technology is an efficient, accurate method for navigating to and recording the location of landscape features. A constellation of geostationary satellites orbiting the Earth provides the basis for geolocating ground features. A GPS receiver, in contact with at least four GPS satellites, uses a series of mathematical calculations to pinpoint its location on the surface of the Earth. Initially, GPS technology was used as a navigational tool by the nautical world. However, as the locational accuracy of the technology has increased, GPS is increasingly being used as a terrestrial measurement tool (Hurn, 1993).

The accuracy of GPS has improved since the introduction of differential GPS. A reference GPS receiver, in addition to a roving GPS unit, is the key to differential GPS. The reference receiver is stationary, located in a known geographic position. This receiver is continuously processing satellite data and any recorded deviations from the known geographic location are used to correct for atmospheric and signal errors. This reference data is made available, usually through the WWW, to make corrections on the data collected by the roving receiver. Differential GPS coordinates are considered to be some of the most accurate field measurements available.

Several cultural landscape projects have used GPS technology for mapping and map registration purposes. Burns (1998) organized a team of GPS users to record the locations of historic monuments, military pieces, and field edges of the Chickamuga battlefield. This data was later incorporated into a GIS database used to assist park management. McCarthy and Stein (1999) tested the efficacy of GPS technology for architectural surveys and map registration at Fort Washington, MD. The effort to record the location of buildings was hindered by interference from the building itself, but they were able to register the architectural drawings with GPS reference points.

There is relatively little research published on the use of GPS technology to navigate to features identified on historic maps. In fact, there is little to suggest that investigators have been using GPS technology as anything more than a location recording device. However, aircraft pilots, ocean vessel captains, and the U.S. military have relied heavily on this technology to navigate to known locations. The basic idea of GPS navigation is the waypoint. The waypoint is a set of geographic coordinates stored in the GPS unit. Distance and bearing from the waypoint are displayed and updated as you move to or away from the desired location. The Trimble GeoExplorer III expands waypoint capability by displaying GIS data layers on screen, allowing the user to view his/her location on-screen during while working in the field. The background layers provide context and directional aid for navigating to potential historical features that have been identified on maps, aerial photographs or other remote sensing data.

Chapter III: Methodology

Overview

The historical reconstruction of the MBRNHP landscape using geospatial technologies was accomplished through the acquisition, compilation, and analysis of remotely sensed and map-based data. Remote sensing technology was used to analyze a variety of historical and current data sources including panchromatic and color infrared (CIR) aerial photographs as well as panchromatic and multispectral satellite images. USGS topographic maps, survey maps, other historic maps, and historic ground photographs were collected to provide the basis for subsequent analyses. A sequential process (summarized in Figure 3.1) was used to collect, integrate, analyze and present the material required for this project.

The outline for completing the historical analysis of MBRNHP involved six key steps:

- Step 1 – <u>Data Acquisition</u>
    - Search historical and contemporary sources for geographic and archival data
    - Obtain a digital or "hard" copy of the data
- Step 2 – <u>Integrate Data into a GIS Database</u>
    - Scan paper or film-based data
    - Register and rectify geographic data to a common map base

- Step 3 – Historic Feature Identification
  - Use edge enhancement, band ratioing, and classification to detect and identify historic features on the images
  - Photointerpret and digitize historical features and land cover found in digital images
- Step 4 – Change Detection
  - Conduct digital change detection
  - Perform manual photointerpretation of landscape change
- Step 5 – Historic Feature Verification
  - Use GPS technology to verify the existence of features identified through analysis of historical data sets
  - Use archival material to verify the lineage/existence of features identified through historical analysis
- Step 6 – Products of Analysis
  - GIS database of data layers (with metadata)
  - Thematic maps of selected historic data layers
  - Report on "How to Search for Historic Maps and Aerial Photographs"
  - Web page
  - This report

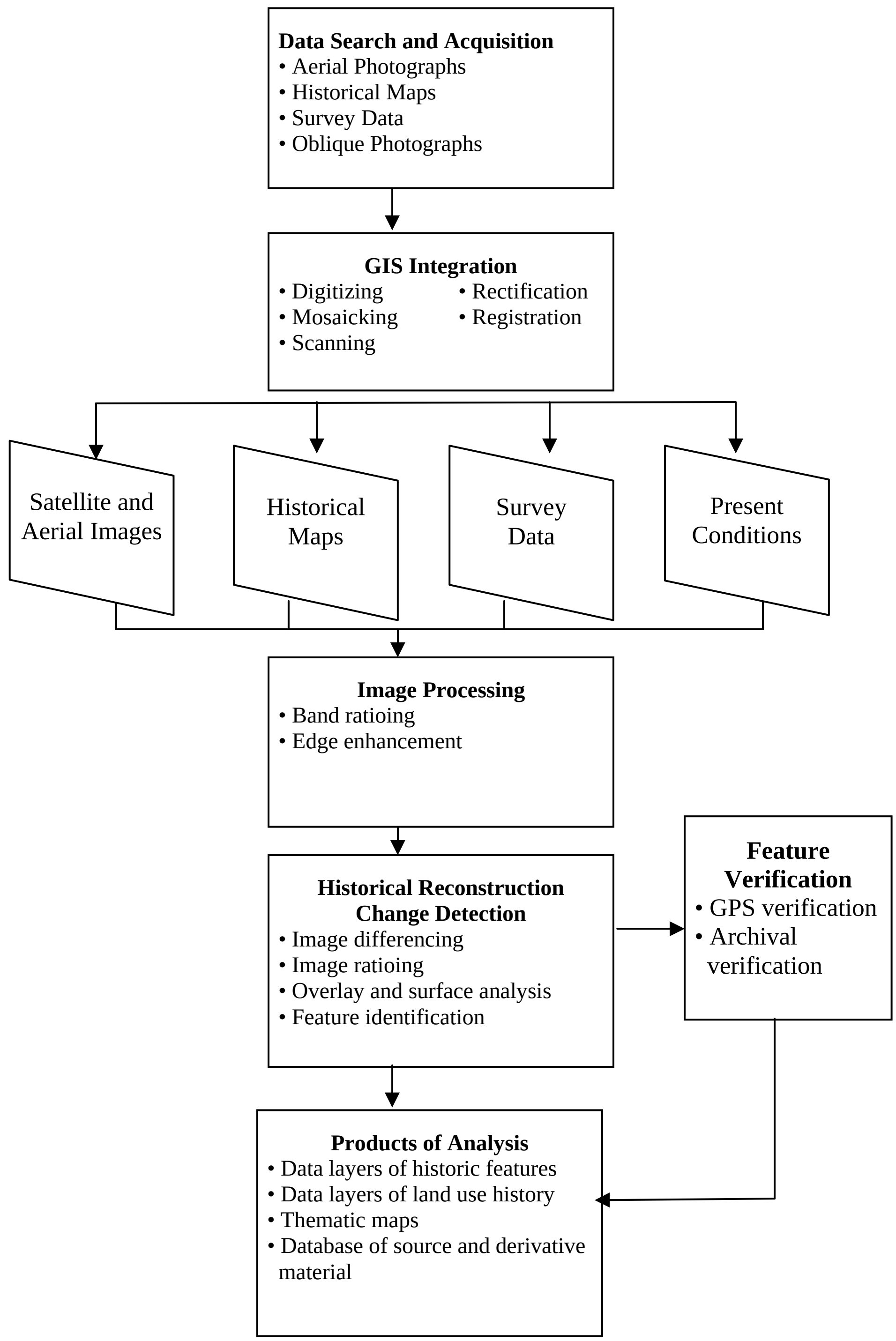


Figure 3.1 Methodology for Analysis of Historical Vernacular Landscape at MBRNHP

Data Acquisition

The first step in the reconstruction of the historic landscape was to search for and acquire historical data. Specifically, this project focused on the collection of spatially-explicit materials that included both historical and current aerial photographs, maps, and ground surveys. To facilitate a comprehensive yet productive search, a number of agencies and sources for historical material were searched for historic aerial photography, historic maps, and satellite imagery.

Research was conducted at the UVM Bailey-Howe Library, on the World Wide Web, and by letter and personal contact with personnel at state and federal agencies. The Woodstock Historical Society, Vermont Historical Society, Billings' Archives, UVM Special Collections, UVM Bailey-Howe Map Room, Dartmouth University Map Room, Cartographic Division of the Library of Congress, and the Northeast Branch of the National Archives and Records Administration were contacted for the purpose of obtaining historical data layers. Other agencies and facilities were also contacted by personal visit, telephone, e-mail or letter. Those groups, agencies and their respective data archives are summarized in Table 3.1.

Table 3.1 Sources for historical maps, aerial photographs, satellite data, and surveys for MBRNHP

Agency	Aerial Photographs	Maps	Other
UVM Special Collections	None	Beers Atlas, Sanborn Fire Insurance	Historical Photographs
UVM Map Room	1962, 1968, 1974, 1977 (CIR), 1994 DOQ	USGS Topographic Maps 1911, 1982 (Paper)	
Dartmouth Map Room	1969 Orthophoto	1832 Woodstock Map, 1934 Woodstock Map	
UNH Diamond Library	None	1911, 1913, 1943 USGS Topographic Maps (Digital)	
National Archives and Records	None	None	Historical Photographs
Library of Congress	None	1756, 1761, 1795, and 1826 Vermont Maps	Historical Photographs, Panoramic Photographs
United States Geological Survey (EROS Data Center)		1855, 1856 Woodstock Maps, Beers Atlas, Sanborn Fire Insurance Maps	
United States Department of	1992 CIR & DOQ	1977 USGS Topographic Maps	
Billings' Archives	1980 B&W photo	None	
Woodstock Historical Society	1939 and circa 1954 aerial photographs	Doton Surveys, Other Maps and Renderings	Farm Journal, Historical Photographs, Correspondence and other memorabilia

Data acquired to document the current condition of the landscape are summarized in Table 3.2. An IKONOS high-resolution satellite scene was obtained to map current landscape conditions for MBRNHP. The Vermont Center for Geographic Information (VCGI - web address http://www.vcgi.org/,) is a clearinghouse for Vermont spatial data. Map layers downloaded from this site include roads, town boundaries, USGS digital elevation model (DEM) data, USGS digital line graphics (DLGs), and USGS Digital Raster Graphics (DRGs) 1:24,000 and 1:100,000 topographic map series from the 1980s. Digital orthophotographic quadrangles, and DEM data (AutoCad format) were obtained from the Vermont Mapping Program (VMP). GPS data were collected with a Trimble GeoExplorer III model GPS receiver during the summer and late fall of 2001.

Table 3.2 Sources of current conditions data for MBRNHP

Source	**Data Type**	**Date Acquired**
Space Imaging Corporation	1 meter panchromatic and 4 meter multispectral IKONOS satellite scene	6/19/2001
Trimble Pathfinder GPS	GPS data files of roads, boundaries, monuments, buildings and other historic features	Summer / Fall 2001
Vermont Center for Geographic Information	Arc/Info coverages/grids of Vermont roads, DEMs, DLGs, town, county and state boundaries	4/22/2001
Vermont Mapping Program	Digital orthographic quadrangle # 148124 and corresponding point DEM coverage	Fall 2000

Data layers from the *Cultural Landscape Report* (*CLR*) *for the Forest at Marsh-Billings-Rockefeller National Historical Park* (Wilcke et al., 2000) were also obtained and used in subsequent analysis. CLR data represent both historical and current conditions of the park. The data layers were created by Mr. James Morrissey under the direction of Dr. Leslie Morrissey (no relation) and are referenced as CLR layers in the subsequent discussion (Table 3.3).

Table 3.3 CLR data layers used for MBRNHP analysis

CLR Data Layer	**Description**	**Coverage Type**	**Original Source**
Propbnd	MBRNHP Boundary	Polygon	Survey (1995)
Hbuilds	Historic Buildings	Polygon	Doton Survey (1887- 1888)
Stands	Land Cover Including Forest Type	Polygon	John Wiggin (1993)
Hparcel	Historic land ownership within MBRNHP	Polygon	Doton Survey (1887-1888)
Carriage	Carriage roads	Line	Doton Survey (1887- 1888)
Hbound	Historic boundary markers	Point	GPS data (1999)
1939 Aerial Photograph*	Paper print of a panchromatic aerial photograph	Raster	Natural Resource and Conservation Service (NRCS, 1939)
1954 Aerial Photographs**	Two paper prints of panchromatic aerial photographs	Raster	Unknown (Circa 1954)

* The 1939 aerial photograph was rescanned and rectified for this report.
**The 1954 aerial photographs were obtained for use in the CLR, but were not converted into a GIS data layer during that project.

Sixteen aerial photographs were collected for the purpose of creating georeferenced digital images that cover a time period of fifty-five years. A CORONA spy satellite scene, which is actually a black and white aerial photograph taken from space, was acquired. This image was treated as though it were a black and white aerial photograph for processing. These images were subsequently processed to enhance edge features, illustrate change, or create land cover maps through photointerpretation and digitization of the MBRNHP study area. Historical maps and surveys were also collected and scanned for inclusion in the MBRNHP database.

Satellite data scenes were collected for the purpose of demonstrating change by documenting the current landscape conditions of the MBRNHP property. An IKONOS satellite scene was purchased from the Space Imaging Corporation to serve as the most recent data layer and to test the capabilities of high-resolution multispectral data in historic research (Figure 3.2). The IKONOS satellite (Scene ID: 2001061915451880000011612472), was acquired on June 19, 2001. For this project one meter panchromatic and four meter multispectral (red, green, blue and near infrared) images, georeferenced to Vermont State Plane Zone 4400, North American Datum 1983, were captured by the IKONOS satellite platform on June 19, 2001. These images were captured as GeoTiff image files (11-bit data - 2^{11} or 2048 potential digital number values per pixel) for each band. A nearest neighbor convolution was used to rectify the data, and the data were resampled to 1 and 4 meters respectively. Root mean squared error (RMS error) of 25 meters is reported for this data (Space Imaging Corporation, 2001).

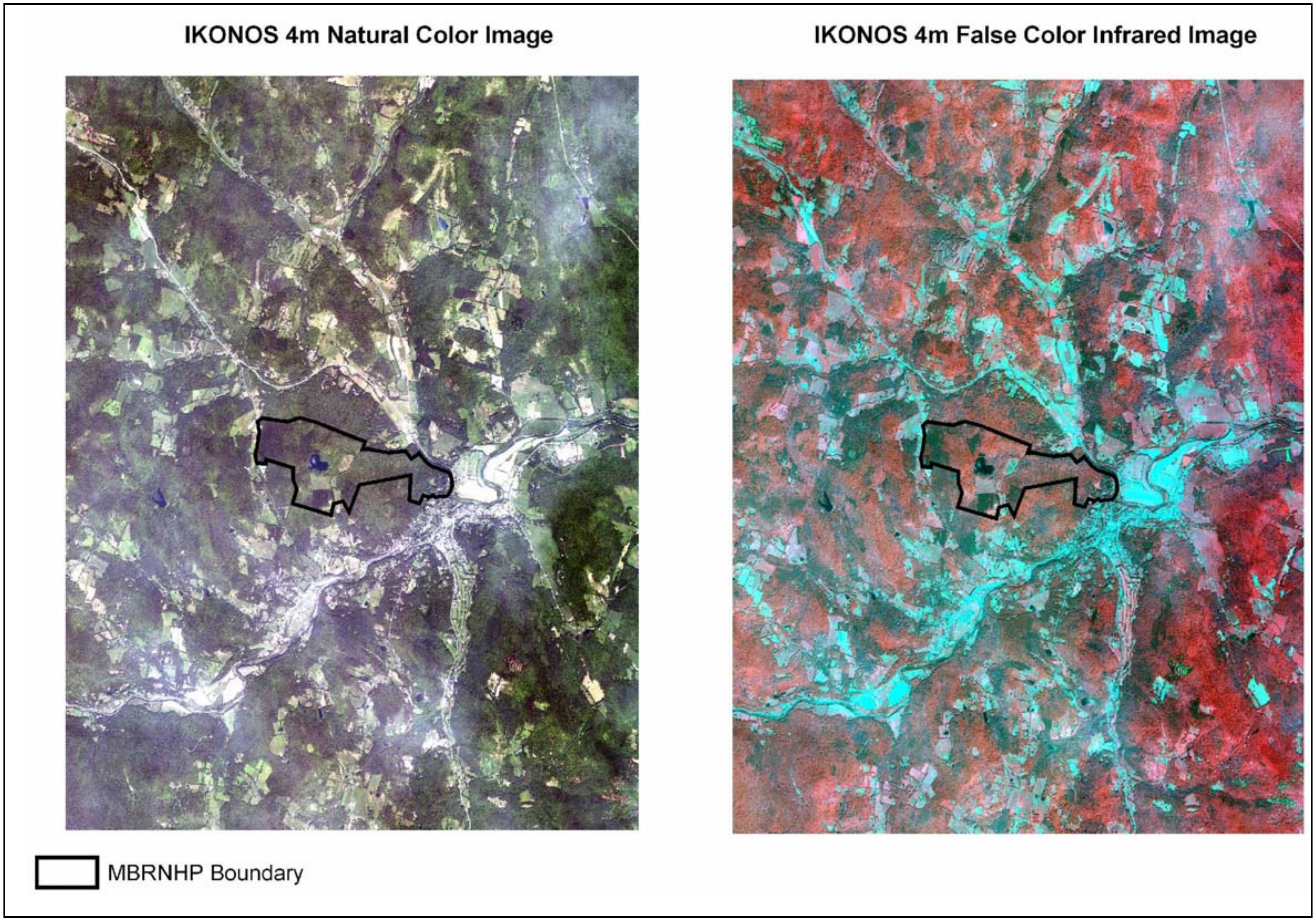


Figure 3.2 IKONOS satellite scene of MBRNHP and surrounding area (© Space Imaging, 2001). Haze and cirrus clouds are evident in the two images.

The results of the search for, and acquisition of, historical and current conditions data for MBRNHP were compiled and summarized. Sources for historic data sources were identified and are described in a report (Appendix F). Historical aerial photography, digital orthographic photography, historical maps, USGS topographic maps, the CORONA satellite image, and IKONOS satellite imagery were assessed for their potential historic research application.

Data Capture

Aerial photography, maps, ground surveys, and historical photography of MBRNHP were converted to digital format using several different techniques. Each data category (paper maps, aerial photographic prints, photographic film positives, digital GIS data and satellite data) required a different method of capture and preprocessing for integration into the GIS database. However, in general, scanning and digitizing were used to convert analog data into a digital format for inclusion in the MBRNHP digital database. Raster files were created from scanning the data and vector coverages were created from digitizing. The unregistered scanned raster data sets were stored as TIFF (*.tif) files in the GIS database. The vector coverages created were stored as Arc/INFO coverages and Arc Interchange (*.E00) files.

Black and white aerial photographs were scanned using available optical flatbed scanners (either UMAX PowerLOOK 2100 XL or Hewlett Packard ScanJet ADF) and stored on CD-R media. Black and white aerial photographs were captured in 256 shades of gray (8-bit) and were scanned at a resolution selected to provide sub-meter pixel size. According to Welch and Jordan (1996), an average aerial photograph has a resolution of 15 to 30 line pairs per millimeter (lpr/mm) or 762 to1524 DPI.   Using this assumption, the aerial photographs were scanned to produce a final pixel size of less than 1 meter. For example, the 1968 black and white aerial photographs, originally acquired at 1:20,000 scale, were scanned at 600 dpi yielding an image with a pixel size of 0.85 meters and a corresponding ground resolution of 1.7 to 3.4 meters (because 2 to 4 pixels are required to discern ground objects).

The 1969 and 1975 orthophotographs were scanned from poor quality, large format prints and the resulting images were grainy and over 300 megabytes (MB) in size. As a result, these two images are not included in the MBRNHP digital database. Two CIR aerial photographs, a 1977 and 1992 CIR set, were scanned (1200 and 600 DPI respectively) as true color images (red, green, blue) with 64,000 colors. The 1968 CORONA satellite scene and 1977 CIR photograph were acquired in film negative and film positive format correspondingly. The CORONA scene and 1977 CIR were scanned on a flatbed scanner (Hewlett Packard ScanJet ADF) at 1200 DPI, using a transparency adapter. The quality of 1977 CIR image was affected by the transparency adapter and the resulting scanned image contains some stripping or banding.

Historical maps were also scanned using an optical scanner or were downloaded directly from their source in digital format (Table 3.1). Historical maps presented a challenge to traditional scanning due to their large physical size. The large maps included in the database (i.e. 1832 and 1934 Woodstock maps) were scanned at 300 dpi on a large format scanner in the Dartmouth University Map Room. Other maps were scanned in the UVM Spatial Analysis Lab on an 11" x 17" medium format (UMAX PowerLOOK 2100 XL) scanner. The 1911, 1913, and 1942 topographic maps were downloaded from the UNH Diamond Library website (http://docs.unh.edu/nhtopos/nhtopos.htm). The 1983 topographic map (DRG) was obtained from the NPS. The Doton Survey (originally scanned and rectified for the CLR) offered a wealth of detail of the MBRNHP property for the 1887-1888 time period. Property boundaries, roads, building locations, the Pogue, Pogue pipeline and well locations digitized from this layer for the CLR were used in this project. The 1942 and 1977 USGS topographic maps include vegetation and road detail and this data was digitized as well.

Digital Image Processing

Digital image processing was used to facilitate image analysis and to create georeferenced map layers to facilitate historical reconstruction of MBRNHP. Registering, rectification, and mosaicking were used to create seamless aerial mosaics that approximate digital orthographic photographs. Layer stacking was used to create multi-band satellite images. Band ratioing was used to generate satellite images that minimize atmospheric attenuation and topographic shadowing. Change detection was used to document landscape evolution over time. Edge detection was used to detect and identify linear features on the landscape that may possess historic value. ERDAS Imagine 8.4 and 8.5 software was used for all digital image processing.

Preprocessing

Preprocessing images for the MBRNHP project involved rectification and registration of aerial photography and satellite images as well as mosaicking of select aerial photographs to create aerial mosaics. Preprocessed images including maps, aerial photography and satellite images were registered and rectified to Vermont State Plane (NAD 83) and Universal Transverse Mercator (UTM) projections using Vermont Digital Orthophoto Quadrangle # 148124 as the master layer (1:5000 Scale). This master image was chosen because it has the highest resolution (0.5 meter) of all the database layers and conforms to National Map Accuracy Standards (NMAS) at 1:5,000 scale (90% of points tested are within 4.2 meters of their true position).

Three of the map layers (excluding VT DOQ # 148124) included in the MBRNHP database were acquired with rectification already performed. Of these three, the 1982 USGS DRG (1:24000) and 1992 DOQ (Nominal Scale 1:40,000) were obtained in UTM format and were subsequently re-projected to VT State Plane (NAD83). The spatial accuracy for the 1983 USGS DRG and 1992 DOQ are stated to conform to NMAS for 1:24,000 scale (+/- 20.3 meters) and rectified 1:12,000 scale (+/- 10.2 meters) respectively (Federal Metadata for USGS Map Products). The third image, the IKONOS satellite scene, was projected to VT State Plane (NAD83) by Space Imaging®. Due to a larger spatial disparity (+/- 25 meters) with other layers in the MBRNHP digital database, the IKONOS image was re-registerd and rectified to the DOQ master to allow for more accurate spatial comparison.

The multispectral IKONOS data were provided in separate GeoTIFF (*.tif) files, one file for each band. After rectification, the four bands (red, green, blue and near infrared, aka R, G, B and NIR) were combined into a single four-band ERDAS Imagine image file. The resulting four-band image can be manipulated to display as a true color image, color infrared image, as well as other combinations. The IKONOS scene was clipped to a region encompassing MBRNHP.

The series of aerial photographs were rectified using ERDAS Imagine 8.5 software. Each image was transformed using a 3^{rd} order polynomial, cubic convolution resampling algorithm, and a minimum of 35 ground control points (GCPs) located within and around the MBRNHP property. Aerial photographs that offered entire coverage of the site were assigned at least 40 ground control points. Output pixel size was set to match the scale of the original data and is a function of the scan resolution. Due to the small pixel size of the scanned images and 3^{rd} order polynomial resampling algorithm, the RMS error computed by ERDAS was computed at less than 0.1 pixels. The RMS error reflects the registration parameters (3^{rd} order, cubic convolution algorithm) rather than the actual locational accuracy of the output data.

An additional check for RMS error was conducted on all rectified data layers to ascertain their spatial accuracy. The testing methodology is specified in the *Positional Accuracy Handbook: Using the National Standard for Spatial Data Accuracy to Measure and Report Data Quality* (Governor's Council on Geographic Information, 1999). Twenty control points were selected for each layer and compared to a layer of higher accuracy, in this case, the 1:5,000 Vermont digital orthographic quadrangle (VT DOQ# 148124). The x and y error (i.e. distance between the same points in the master and image tested) was computed for each point and the RMS error was calculated for the entire image. For an example see Appendix B (Manual RMS Assessment of Registered Images).

Sixteen aerial photographs were processed to produce 10 rectified images of the MBRNHP property (Figure 3.3). Of the 10 images, 9 were used to perform spatial analysis and are displayed as paper maps (Appendix C). The 1977 CIR photograph, with a nominal scale of 1:80,000, had streaks caused by polarized light emitted from the transparency adaptor. This layer was not used to create any vector data, but is included in the digital database. Each photomap offers complete coverage of the MBRNHP property and is a snapshot of the landscape at a specific point in time.

Figure 3.3 1962 B&W aerial photographs, scanned registered and rectified

Mosaicking was used where aerial photographic coverage of the MBRNHP spanned two images. Rectified images were overlain and a cutline was placed in the area of overlap. The images were then combined into a single image file, resampling again using cubic convolution. During mosaicking an area of interest (AOI) was used to clip the file to a rectangular area corresponding to the extent of MBRNHP. Eight scanned images (1954, 1962, 1968 and 1974 black and white photographs) were mosaicked to provide nearly seamless images. Spectral differences between the matching photographs were minimized by histogram matching during mosaicking.

IKONOS and CORONA satellite scenes were also registered to VT DOQ # 148124 to produce rectified data layers. The 1-meter panchromatic IKONOS scene was matched to the DOQ to create a transformation matrix. This matrix was then used to rectify both the 1-meter panchromatic and 4-meter multispectral scenes. The transformation matrix used to register this data was also used to transform the results of classification, band ratioing, and edge enhancement created using the IKONOS scene. The re-registered IKONOS data had an RMS error of 5.9 meters based on a manual assessment (see Table 4.6, pg. 70). To date, it is the most current satellite data available for MBRNHP. The CORONA satellite scene (analog/ film negative format) was preprocessed as though it was an aerial photograph resulting in an RMS of 12.7 meters (based on a manual assessment, see Table 4.6, pg. 70). The satellite scenes are shown in Appendix D.

The 1992 CIR photograph was orthographically corrected using camera data from the USGS camera calibration website (http://mac.usgs.gov/mac/tsb/osl/dbfiles.html) and the Vermont Mapping Program DEM for tile # 148124. This layer was the only one with camera calibration data available and the orthographic correction shows an improved spatial accuracy when compared to the polynomial method of rectification (see Table 4.6, pg. 70.) RMS error is not computed by ERDAS for this type of rectification but it was assessed manually by comparison with independent point locations.

The aerial photographs, IKONOS and CORONA satellite scenes, and rectified maps were formatted as a series of ERDAS Imagine image (*.img) files and GeoTIFF files (*.tif). To comply with NPS standards for GIS data, each of the rectified images were re-projected into Universal Transverse Mercator format. Satellite scene and aerial photographic images included in the MBRNHP database are summarized in Appendix E.

Selected maps were registered and rectified using a first order polynomial, nearest neighbor convolution with a minimum of 20 ground control points (GCPs). The Sanborn fire insurance maps, USGS topographic maps, 1832 Woodstock Map, 1869 Postal Atlas Map, and the F.W. Beers Windsor County Map were rectified in this manner. The Doton Survey data was originally registered for the CLR using a 3rd order transformation and 40 control points (Wilcke et al., 2000). The manual assessment method (Appendix B: Example RMS Assessment for Registered Images) for computing RMS error was used for estimating locational accuracy for all maps registered for this project and the results can be found in Table 4.6. The historic maps contained information regarding transportation, building, surface water, vegetation and topography. Many of the older maps included owner names for residences around the MBRNHP property. Rectified map layers are also included in the MBRNHP digital database as ERDAS Imagine 8.5 image and GeoTIFF files. A summary of the rectified map layers is included in Appendix E.

Edge Detection

Edge detection was performed on aerial photographs and satellite images to enhance linear features in the MBRNHP landscape. The purpose was to highlight roads, stonewalls, buildings, and plantation boundaries within the historical and recent images. These features were then verified in the field using GPS or compared with historic map layers and archival data to determine their origin. To test the results of edge detection, images were compared with other historic data layers (e.g. CLR and GIS database) layers of stonewalls, roads, plantation boundaries and buildings. These analyses are presented in the results section.

The aerial photographs, CORONA satellite scene and IKONOS data were digitally enhanced using the Sobel edge detection algorithm prior to registration (ERDAS, 1994). The resulting images were then registered, rectified, and/or mosaicked if necessary. Edge detection was performed prior to registration and rectification to minimize the smoothing effect of registration resampling on the DN values of the image and to increase the identification potential for linear features. Each edge detection image was examined for the presence of linear features that might represent historic landscape features (e.g. stonewalls, plantation boundaries, field boundaries, roads and building locations). To aid in interpretation, a threshold operation was used to divide the edge detection digital values into two to twelve categories to enhance contrast. For example, the 1939 black and white aerial photograph was convolved using the Sobel filter and the resulting image had 97 DN levels. These 97 DN values were divided into 2 classes along Jenks Natural Breaks to highlight lines and minimize background noise (ERDAS, 1994).

Band Ratioing

Band ratioing was preformed on the multispectral IKONOS data to remove atmospheric attenuation and topographic shadowing, thus allowing for improved image interpretation. Two ratio images were created for the purpose of differentiating vegetated and non-vegetated areas. A near-infrared over red (NIR/R) ratio image and the Normalized Vegetation Index (NDVI) $\frac{\text{NIR - R}}{\text{NIR + R}}$ ratio image were used to highlight vegetation differences (e.g. conifer forest plantations, hardwoods, meadows, and fields) and non-vegetated areas (e.g. roads, buildings, parking lots, and water).

The images created through band ratioing were photointerpreted in much the same fashion as the aerial photography and other IKONOS satellite scenes. The resulting interpretation was used to refine classification of land cover rather than create an independent layer. An example of the IR/R image is presented in the results section and the NDVI image is presented in Appendix D (Satellite Scenes).

Change Detection

Change detection was performed to detect and document differences in the MBRNHP landscape over time. Digital change detection was conducted based on a time series of aerial photographs. Manual change detection was conducted by comparing land cover map layers created through manual photointerpretation. For both techniques, the 1939 aerial photograph was used as a base image and each subsequent aerial photograph was compared with this image. Image differencing was conducted using rectified aerial mosaics/photographs of the original images. In image differencing, each successive raster data set (e.g. 1954 aerial mosaic, 1962 aerial mosaic, etc.) was subtracted from the 1939 aerial photograph. The resulting images were presented using three classes; increased DN values indicated the reduction of vegetated areas, decreased DN values indicated an increase of vegetation, and DN values that remained the same over time. The vegetation (i.e. forest, field, meadow, etc) that dominates most of MBRNHP allowed for an interpretation of the change detection results that excluded most urban type changes (i.e. vegetated area to road, field to building, and etc).

Inherent differences in the pixel DN values of source data with different scale, photographic processing methods, time of acquisition, and season of acquisition mandated the testing of several change detection thresholds. Three threshold limits were tested for change detection; 10%, 25% and 40% change. The percentage value represents a comparison of the absolute value of the subtraction of the DN of corresponding pixels in each image divided by the number or values in the base image histogram. To correct for baseline differences in the DN values, the images used in change detection were histogram matched (ERDAS, 1995). Areas of change highlighted in each change detection image were evaluated by comparing them with the original image. Through this technique, each area of change was identified and documented.

The second technique used for change analysis of the aerial photographs and satellite images was conducted using manual photointerpretation of land cover. Land cover layers were screen digitized in ArcGIS 8.2 and were summarized in maps and charts that describe the landscape condition of MBRNHP at several different points in time. Land cover charts for each aerial photomap and satellite image were created using acreage values generated with the ArcGIS Field Calculator. Taken in sequence, the land cover maps and charts provide an evolutionary picture of the MBRNHP landscape from 1939 to 2001.

Land Cover Classification

A supervised classification was conducted using the 4-band IKONOS satellite image. The image was sectioned into 5 classes: natural forest, open land, water, forest plantation and urban features. Classes were chosen to represent the most common land cover types found in MBRNHP. The classified image was compared with the land cover layer created from manual photointerpretation of the 2001 IKONOS satellite scene by comparing acreage of each class.

Spectral signatures were created from training areas within the satellite image to generate statistics for the digital classification algorithm. For example, the Pogue and other known water features were selected and their DN values were used to derive a water spectral signature. Seven training sites were chosen for each class and a total of 35 spectral signatures were derived for each land cover class based on the training site data. Each of these signatures was evaluated for potential problems, such as the presence of a bimodal histogram distribution which would indicate the presence of two distinct spectral patterns (i.e. two different classes). The spectral signature provided the basis for digital image classification using the maximum likelihood rule (ERDAS, 1995).

Photointerpretation and Digitizing of Digital Images

Aerial photographs, satellite images, and maps were digitized after scanning to create vector data layers of current and historic landscape features. Building, transportation, hydrographic, and other features were screen digitized from the maps and aerial photographs. Land cover layers were also created from the photointerpretation of aerial photographs and satellite images. Summary explanations and an example of federally-compliant metadata files for each coverage were also generated (Appendix G). The coverages were projected in both Universal Transverse Mercator and State Plane (NAD 83) coordinates.

Manual photointerpretation was used to classify land cover of the aerial photography and satellite images of MBRNHP. Land cover layers were created by screen digitizing land cover polygons from the registered images. Five land cover classes were used to categorize the remotely sensed images and they include: natural forest, plantation, open land, open water, and developed. Traditional photointerpretation techniques based on shape, size, pattern, tone, and texture were used to determine feature types and boundaries. Photointerpretation was used because computer-based classification methods were not able to distinguish different landscape features with panchromatic aerial photographs.

Historic map features identified on registered map images were digitized to produce transportation, water, and building layers. The 1832 Woodstock map, 1869 Postal Atlas map of Woodstock, and 1869 Postal Atlas map of Windsor County were used to create transportation infrastructure, surface water, and building layers for their respective time periods. In the case of these maps, some of the building features were identified by owner and this information was included in the building attribute table. Similarly, USGS Quadrangle maps from 1911, 1913, 1943 and 1983 were digitized to create transportation, building, and surface water layers.

Global Positioning Systems and Field Checking

A Trimble GeoExplorer III handheld GPS receiver and Pathfinder 2.0 software were used to collect and process GPS data. Landscape features detected on satellite data, historic aerial photography, and on the Doton Survey (CLR data) were downloaded to the GeoExplorer III as ArcView shapefiles. The coordinates of these features were then used to navigate to those features on the ground. Once the coordinates were located in the field, the presence or absence of the expected landscape feature was noted. Additional attribute information was collected for features that were present include the: type, condition, and the presence of other historically significant properties.

The purpose of field verification was to test the utility of locating historical features in the field using registered geographic data acquired from historic sources. Point, line and polygon features representing monuments, carriage roads, stonewalls, buildings, plantations, and water features were verified using GPS. GPS for all features were recorded with a minimum of five satellites in view and position dilution of precision (PDOP) less than 6. For point features (i.e. survey markers, rock outcrops), the GPS was held stationary over the object until at least 60 data points were recorded. Linear features, such as roads and stonewalls were sampled at a rate of 1 point per 3 seconds while walking along the feature. RMS error was recorded for each GPS location.

Chapter IV: Results and Discussion

The landscape, both current and historic, of MBRNHP was recreated using computer-based tools and analytical techniques. Remotely sensed and map data for MBRNHP were analyzed to demonstrate the utility of GIS, GPS and RS techniques in documenting and understanding historic landscape change in the park. Remote sensing techniques were used to analyze aerial photographs, maps, and satellite data and the resulting images were then examined for the presence of historic features and landscape change. Landscape features detected through this process were located and verified in the field using GPS technology. GIS provided a framework for managing the RS, GPS and map products that were the result of this research.

The results of this RS, GIS and GPS-based investigation were compared with the findings of previous studies: *Cultural Landscape Report for the Forest at Marsh-Billings-Rockefeller National Historical Park*, (Wilcke et al., 2000); *Land Use History for Marsh-Billings National Historical Park*, (Foulds et al., 1994) and archival material from the park. A discussion of the utility of each technique and how it relates to cultural landscape research is included in each of the following sections.

Historic Data Acquisition

The challenge presented to any historical researcher is where to find data. The search for historical data can be aided by a definitive research plan and prior knowledge of the expected materials available. Deciding when the search for material is complete is more problematic. Clear project goals can help to decide when to terminate a search, but the temptation to look for additional data is ever present. A report summarizing sources of historic data and methods for the acquisition of historical maps and aerial photographs can be found in Appendix F.

When searching for historical maps or aerial photographs, a Land Grant State University library map room is a good place to begin looking. There are usually a number of aerial photographic sets, complete with an index and historical maps. Also, universities can often provide access to scanning equipment so that digital copies of materials found can be made. In addition, many libraries have “Special Collections” of historic photographs, maps and land records. Another excellent source of free information is the Internet, where historic data from federal, university and private collections is available for research. State agencies and public libraries often have digital copies of maps, aerial photographs and even Digital Orthophoto Quadrangles (DOQs) available for perusal and download. When researching an area outside of your home region, federal government sources provide coverage of the United States in aerial photographic or map format. Historical societies, although limited to specific sites, are excellent sources of hard-to-find or rare maps and aerial photographs. Commercial companies can be contracted to acquire up-to-date (current conditions) aerial photographs (digital or paper) and high-resolution digital images of specific project areas, but can be quite costly. Satellite imagery can be purchased from federal and commercial sources. Table 4.1 summarizes the sources of data for this project.

Table 4.1 Summary of data sources for this project

Data Type	Sources	Historical Research Application	Best Source
Historical Aerial Photographs	US agencies State agencies Library Map Rooms Historical societies Commercial services	Landscape mapping Feature identification Change detection	University Library Map Rooms
Digital Orthographic Photographs	US Agencies State Agencies Library Map Rooms Historical Societies Commercial services Internet	Landscape mapping Feature identification Change detection	State agencies Library Map room
Historical Maps	US agencies State agencies Library Map Rooms Historical societies Commercial services Internet	Feature identification	Historical societies
USGS Topographic Maps	US agencies Library Map Rooms Historical societies Internet	Feature identification Landscape mapping (Forest cover & surface water)	USGS and the Internet
CORONA Satellite Image	US agencies Internet	Landscape mapping Feature identification	USGS website
IKONOS Satellite Image	Space Imaging Corp.	Landscape mapping Feature identification Change detection Band ratioing Classification	Space Imaging Corporation

The search for and acquisition of historic data for MBRNHP resulted in the collection of six ground-based historical photographs, 16 aerial photographs, 15 maps, a CORONA satellite scene, and an IKONOS satellite scene. The six historical photographs are documented (Table 4.2) and displayed in full in Appendix G – Historical Photographs of MBRNHP and Vicinity. A series of historical black and white aerial photographs, at least one per decade with the exception of the 1940s, and color infrared aerial photographs make up the aerial photograph collection (Table 4.3). Historic maps, ranging from a hand drawn explorers map (1756) to a modern USGS topographic map (1983) comprise the map collection (Table 4.4). A high-resolution IKONOS scene and a CORONA spy scene were collected for the satellite database (Table 4.5).

Table 4.2 Historical ground-based photographs of MBRNHP and vicinity

Photograph Description	Photographer	Source	Date
Panoramic Photograph of Woodstock from Mt. Peg	Henry Barreuther	Library of Congress	8/6/1914
Panoramic Photograph of Woodstock from the South	Henry Barreuther	Library of Congress	8/6/1914
Hillside on northeast edge of MBRNHP	Marian Post Wolcott	Library of Congress	3/1940
The Pogue, looking southeast	Unknown	Woodstock Historical Society	Circa 1890
Bridge over the Ottaquechee with Mansion in background	Unknown	Woodstock Historical Society	Circa 1910
Bridge over the Ottaquechee with Mansion in background	Unknown	Woodstock Historical Society	Circa 1910

Table 4.3 Aerial photography acquired for MBRNHP

Type	**Agency**	**Scale**	**Coverage***	**Date**	**Roll/Frame**	**Media**
B&W	NRCS**	1:30,000	Entire	11/20/39	C 4-141	Film Print
B&W	Billings' Archives**	1:40,000	East	Circa 1954	Unknown	Film Print
B&W	Billings' Archives**	1:40,000	West	Circa 1954	Unknown	Film Print
B&W	VT Dept. Highways	1:18,000	East	1/9/62	62-36-13	Film Print
B&W	VT Dept. Highways	1:18,000	West	1/9/62	62-36-220	Film Print
B&W	VMP	1:24,000	East	1968	6824-3-46	Film Print
B&W	VMP	1:24,000	West	1968	6824-3-115	Film Print
B&W	VMP	1:5,000	Entire	1969	(Ortho 148124)	Paper Print
B&W	State of Vermont	1:20,000	East	5/15/74	7420-10-212	Film Print
B&W	State of Vermont	1:20,000	West	5/15/74	7420-10-193	Film Print
CIR	US Army	1:80,000	Entire	1977	4193-13	Film Positive
B&W	VMP	1:5,000	Entire	1978	(Ortho 148124)	Paper Print
B&W	USDA	1:40,000	Entire	9/12/80	50027-180-99	Film Print
B&W	NAPP	1:40,000	Entire	4/27/92	4193-12	Digital Ortho
CIR	USGS	1:64,000	Entire	4/27/92	4193-12	Film Print
B&W	VMP	1:30,000	Entire	1994	(VT 148124)	Digital Ortho

*Coverage refers to the portion of MBRNHP shown in the aerial photograph

** Indicates that data was originally acquired from the CLR (Wilcke et al., 2000)

Table 4.4 Historic and current maps compiled for the MBRNHP database

Name	**Date**	**Format**	**Scale**	**Coverage**	**Author**
Province of New Hampshire	1756	Digital	1:633,600	Northern New England	Samuel Langdon
Province of New Hampshire	1761	Digital	1:633,600	Northern New England	Joseph Blanchard
Vermont, from actual survey	1795	Digital	1:696,960	Vermont	Amos Doolittle
Vermont	1826	Digital	1:633,600	Vermont	Lucas Fielding
Woodstock, Town Map	1832	Paper	~1:24,500*	Woodstock, Township	Woodstock Institute
Woodstock Land Ownership	1856	Paper	~1:600**	Woodstock, Village	Unknown
Postal Atlas	1869	Paper	~1:42,240*	Windsor County	F.W. Beers
Postal Atlas	1869	Paper	~1:6,930*	Woodstock, Village	F.W. Beers
Doton Survey***	1888	Paper	1:1,200	Billings, Property	Hosea Doton
Sanborn Fire Insurance	1904	Paper	1:1,200	Woodstock, Village	Sanborn Company
Sanborn Fire Insurance	1910	Paper	1:1,200	Woodstock, Village	Sanborn Company
USGS Woodstock 15’ Quadrangle	1911	Paper	1:62,500	43°30’- 43°45’ N, 72°30’- 72°45’ W	R.B. Marshall
USGS Woodstock 15’ Quadrangle	1913	Paper	1:62,500	As Above	R.B. Marshall
USGS Woodstock 15’ Quadrangle	1943	Paper	1:62,500	As Above	US Army Map Service
Woodstock North USGS 7.5, Quadrangle	1983	DRG	1:24,000	43°37’30”- 43°45'0" N 72°30'0" - 72°37’30”W	USGS
Woodstock South USGS 7.5, Quadrangle	1983	DRG	1:24,000	43°30’0”- 43°37'30"N 2°30'0" - 72°37’30”W	USGS

*Scale converted from rods or chains
**Approximate scale calculated from map measurement
*** Indicates data originally acquired for the CLR (Wilcke et al., 2000)

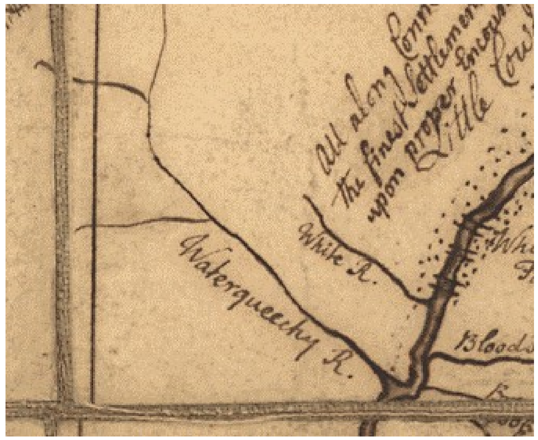
Table 4.5 Satellite imagery compiled for MBRNHP database

Name	**Date**	**Format**	**Coverage**	**Nominal Scale/ Resolution**	**Source**
CORONA DS1104-2127DA004	8/15/1968	Film Positive	6 Mile Wide Strip from Glens Falls, NY to Lake Sunapee, NH	1:247,500 / 2.75 m	CORONA Spy Satellite
IKONOS 1-meter panchromatic PO #: 73597_pan	6/19/2001	11-bit GeoTIFF	43.58° - 43.68° N, 72.48° - 72.59° W	1:50,000 / 1 m	IKONOS Satellite, Space Imaging
IKONOS 4-meter Multispectral PO #s: 73597_red, 73597_grn, 73597_blu, 73597_nir	6/19/2001	11-bit GeoTIFF Red ,Green ,Blue, and Near Infrared Bands	43.58° - 43.68° N, 72.48° - 72.59° W	1:50,000 /4 m	IKONOS Satellite, Space Imaging

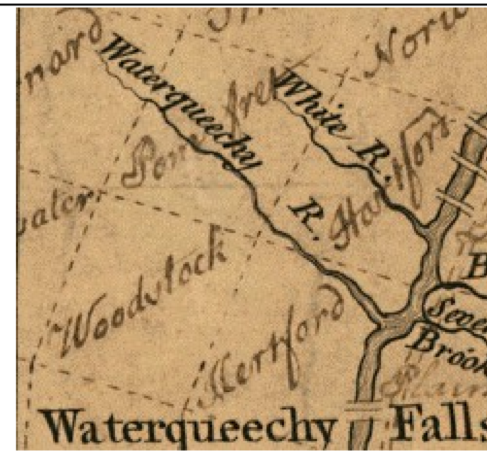
Early Maps of the MBRNHP Area

Native Abeneki, who were assumed to have had camping grounds on the banks of the Ottaquechee, were the first inhabitants of the future MBRNHP. Unfortunately, they left no written record or maps of their occupation. In fact, the first map that shows the MBRNHP area in any detail was published in 1756 by Samuel Langdon for "His Excellency Benning Wentworth, Esqr., His Majesty's Governor." (Figure 4.1 and Appendix E - Selected Historical Maps). Woodstock, and the area to become MBRNHP, remained largely unmapped and uninhabited by Europeans until the mid 1700s.

After 1756, the Woodstock area was mapped with some regularity by the colonial explorers and the new American government workers. Several of these maps and charts are available through the Library of Congress American Memories Website (http://memory.loc.gov/). Each map of the area shows continuous advancement in mapping and surveying techniques that improves the accuracy in representing ground features. The maps also document the continuing development of the natural and human landscape of Vermont including the landscape of MBRNHP. Several maps have been linked together in Figure 4.1 to illustrate the evolution of map quality and development of Woodstock, Vermont and the future MBRNHP property.



Portion of 1756 Map
(Samuel Langdon, ~1:630,000)



Portion of 1761 Map
(Joseph Blanchard, ~1:630,000)

Portion of 1795 Map
(Amos Doolittle, ~1:700,000)

Portion of 1826 Map
(Lucas Fielding, ~1:630,000)

Figure 4.1 Portions of historical maps of New England 1756 – 1826, displaying Woodstock and the area currently occupied by MBRNHP (downloaded from the Library of Congress American Memories Website)

The Ottaquechee River, shown in each of the four maps, provides a good example of the improvement in map accuracy over a 70-year period. In the Samuel Langdon map of 1756 the Waterqueechy makes its first appearance on a New England map (Figure 4.1). The river is shown incorrectly flowing from northwest to southeast where it joins the Connecticut River. In the 1761 map, the incorrect course remains and the addition of town boundary lines depicts the river lying almost entirely outside of the Town of Woodstock. The 1795 map corrects the course of the Ottaquechee River, depicting it flowing through the town of Woodstock. Finally, the 1826 map shows the Ottaquechee River flowing in a west to east direction through the center of Woodstock, closely resembling modern depictions of the path traveled by the river today. In addition, roads appearing in the 1985 and 1826 maps indicate the colonization of the area by European settlers.

The 1832 map of the Town of Woodstock, published by the Woodstock Institute at 1:24,500, scale shows the future MBRNHP property identified as Roger's Tract (Figure 4.2). The Pogue is identified as the Pogue Hole and a stream can be seen flowing from it to a tributary of the Ottaquechee River. Henry C. Marsh and Charles Dana (Hen. C. Marsh and Dana) are identified as property owners on either side of the Pogue stream in what is now the eastern edge of MBRNHP. An "E. Thomas" is shown as the owner of the area South of the Pogue that later became the Hilltop farm. In addition, the map provides the layout of the roads and hachure depicting hills and Mt. Tom.

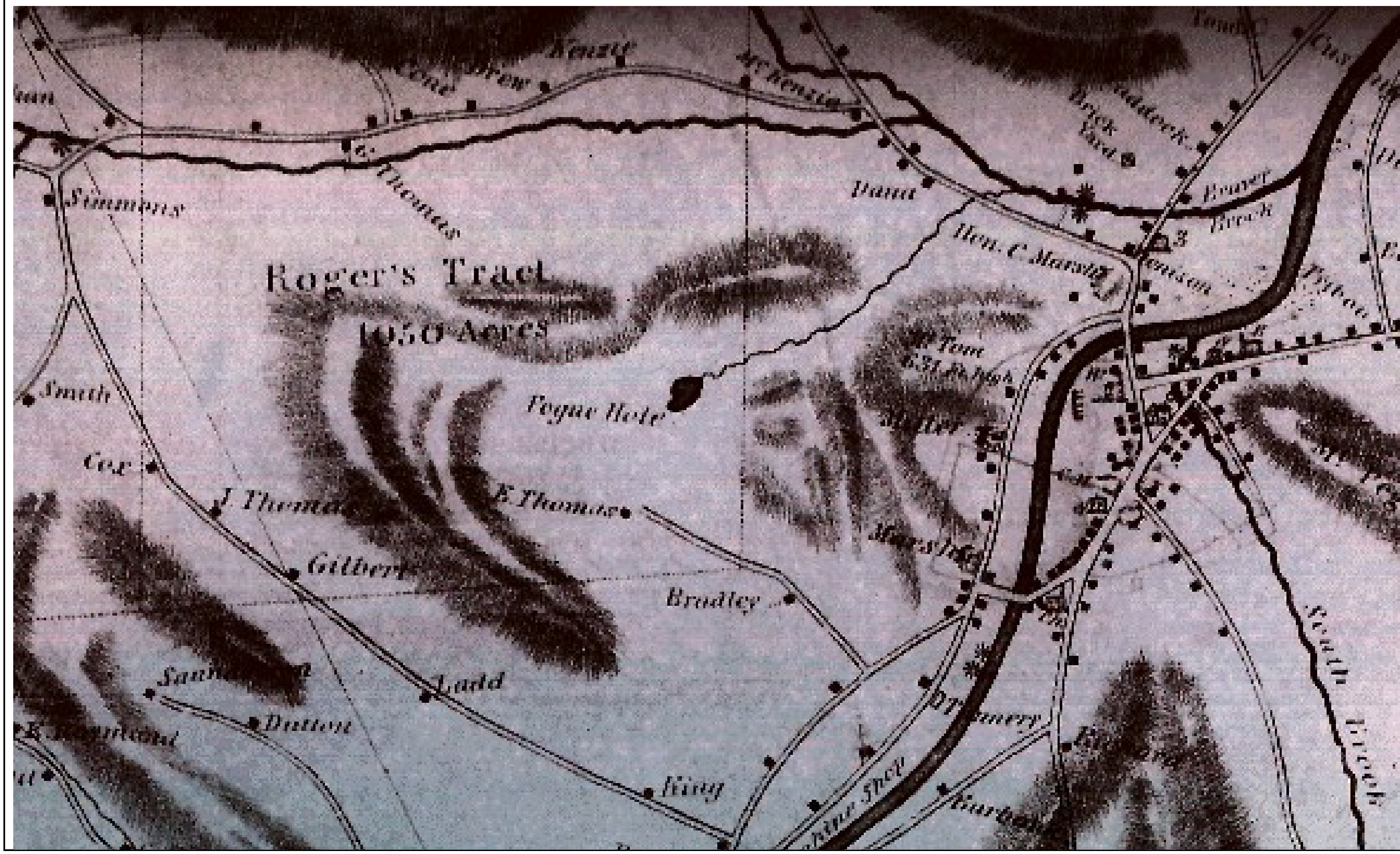
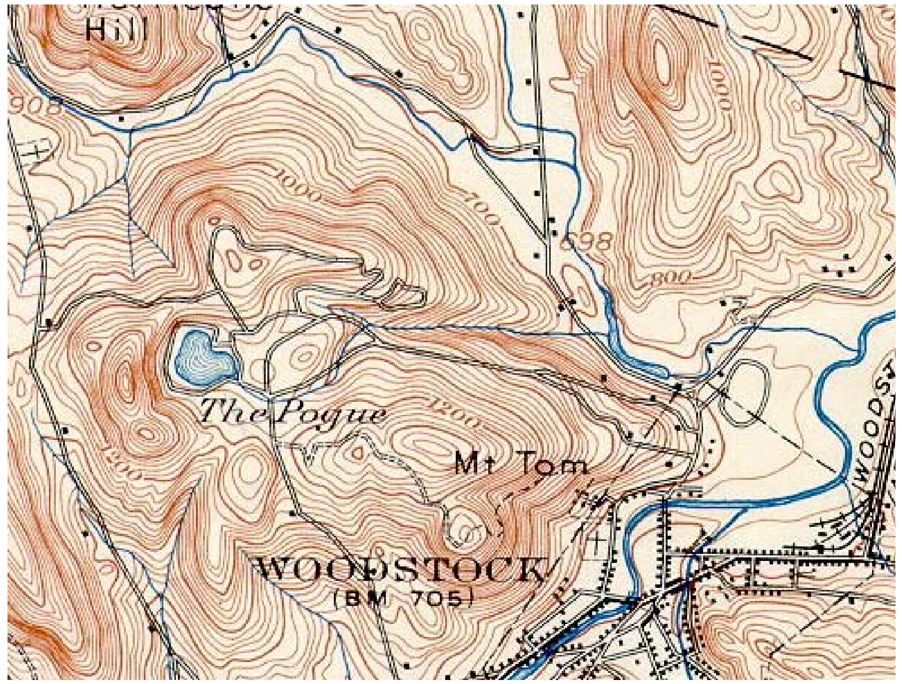


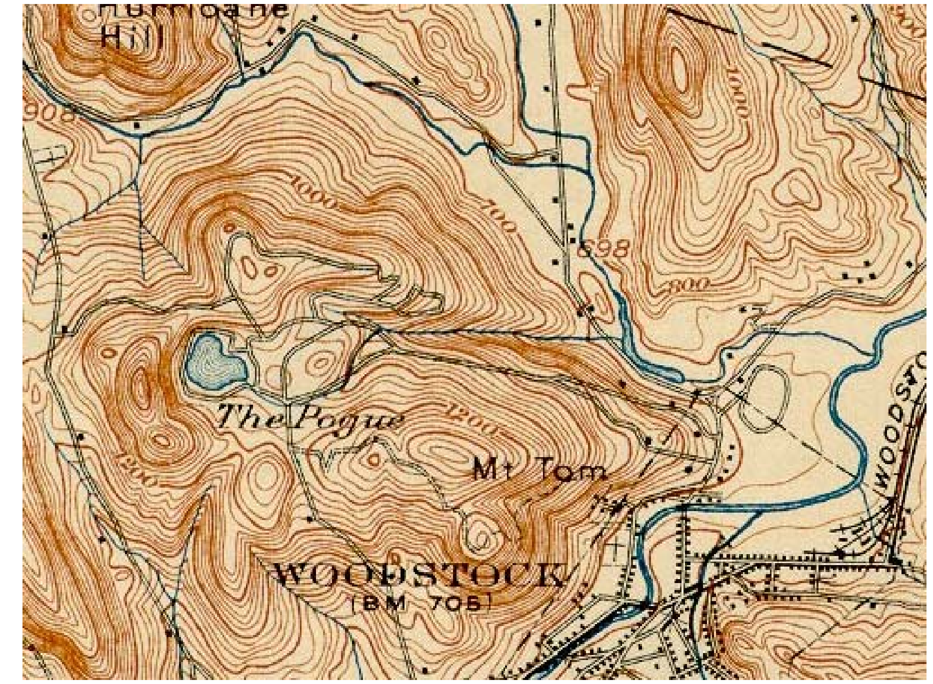
Figure 4.2 1832 Map of the Town of Woodstock and Roger's Tract (Published by the Woodstock Institute, ~ 1:24,000)

Beginning in 1911, the United States Geologic Survey published a series of topographic maps that cover the MBRNHP study area (Figure 4.3). As a part of this project, these maps were interpreted like other historical maps, as well as rectified to the Vermont State Plane coordinate system and incorporated within a GIS database. Presented in series, the maps tell the story of the MBRNHP landscape in much the same way as the older historical maps. The USGS topographic quadrangles also had the advantage of having some degree of consistency between map editions.

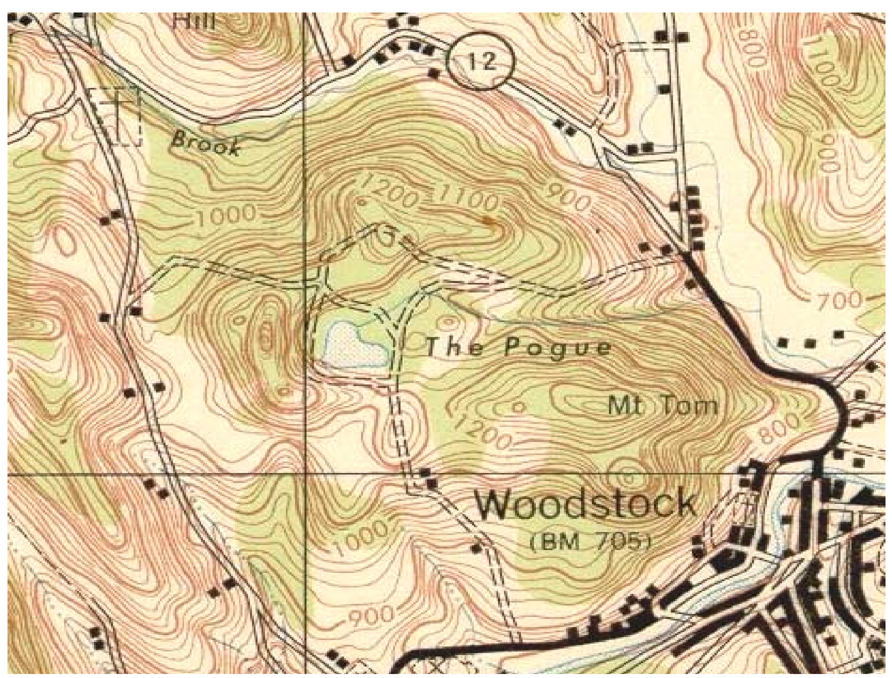
The 1911 and 1913 USGS quadrangles (1:62,500 scale) depict surface water, roads, and buildings in the MBRNHP area (Figure 4.3). Although the publication of two USGS series maps so close together in time would indicate a problem with the first edition, no changes were documented in and around the MBRNHP area. The 1943 (1:62,500) and 1983 (1:24,000) quadrangles show these same features with the addition of forest cover shown with green shading. A lack of development is evident for the MBRNHP area in these maps. For example the carriage roads are shown as double parallel lines, the same symbol as town roads in the 1911 and 1913 edition maps. In the 1943 and 1983 editions the carriage roads are shown as double hashed lines, different from the symbols for town and state roads, and there is less interior detail for the carriage roads. Four buildings disappear from the interior of the park by 1983; the McKenzie Farm, on the western border of the park at the intersection of Prosper Road with the carriage roads as well as three buildings that are shown along the split carriage road in the eastern section of MBRNHP. From 1911 to 1983 there was a net loss of roads and buildings shown in the MBRNHP area (despite an increase in map scale).



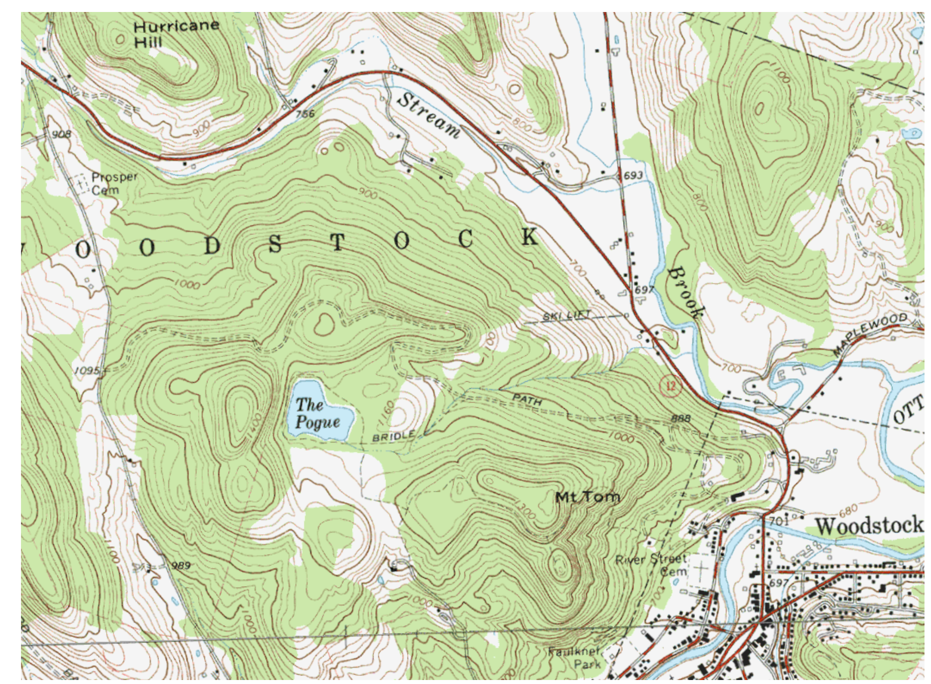
USGS Topographic Map 15’ Quadrangle
Woodstock 1:62,500 (1911)



USGS Topographic Map 15’ Quadrangle
Woodstock 1:62,500 (1913)



USGS Topographic Map 15’ Quadrangle
Woodstock 1:62,500 (1943)



USGS Topographic Map 7.5’ Quadrangle
Woodstock North 1:24,000 (1983)

Figure 4.3 USGS Topographic maps clipped to the area surrounding MBRNHP (1911 – 1983)

Accuracy of Registered and Rectified Data Sets

Rectification of aerial photography, maps and satellite images was required for GIS database compilation, analyses, and interpretation. The process of rectification and registration to a master map projection, combined with the inherent distortions and errors in remotely sensed data and maps resulted in varying degrees of locational error. In addition, the rectification process altered the original DN values of the digital images with the possible effect of reducing the effectiveness of digital enhancement techniques. The impact of registration and rectification of the historic source data (maps, aerial photography and satellite images) was assessed and is described in the following sections.

Positional Accuracy

Following registration and rectification, positional accuracy was determined for each data layer by comparison with the master image, VT DOQ # 148124 (1:5,000). Positional error of all aerial photographic images that were registered to VT DOQ # 148124 averaged ±8.5 meters (Table 4.6). Aerial mosaics tended to have a somewhat lower root mean squared (RMS) value (mean ~8.4 meters) than single image aerial photographs (mean ~8.7 meters). However, the minimum RMS error of 6.4 meters for the 1939 aerial photograph suggests that the higher (e.g. more positional error) RMS value of single image scenes was to large degree, a reflection of the original scale of the photograph. It should be noted that only four aerial photographs and four aerial mosaics were compared in the above analysis. The 1992 CIR, 1992 DOQ and 1994 DOQ images in Table 4.6 were not registered to the master image and were excluded from the above analysis

Table 4.6 RMS error for registered and rectified aerial photographs and satellite scenes

Image	**Roll/Frame**	**Raster Cell Size (Pixels/m)***	**RMS Error (m)**
1939 Aerial Photograph	CIW 4-141	0.8	6.4
1954 Aerial Mosaic	Untitled	0.7	10.4
1962 Aerial Mosaic	62 36-139 62 36-220	0.9	7.8
1968 Aerial Mosaic	6824 3-46 6824 3-115	1.0	7.0
1974 Aerial Mosaic	7420 10-212 7420 10-193	0.8	8.2
1977 CIR	4193-13	1.6	10.8
1980 Aerial Photograph	50027 180-99	1.4	6.6
1992 CIR Photograph	4193-13	2.0	11.0
1992 CIR Photograph **	4193-13	1.0	4.8
1992 DOQ*** Mosaic	4193-13 4193-14	1.0	6.4****
1994 DOQ	148124	0.5	Master
1968 CORONA Spy Scene	DS1104- 2127DA004	5.2	12.7
2001 Panchromatic IKONOS scene	73597_PAN	1.0	5.9
2001 4-Band IKONOS scene	73597_R, G, B, NIR	4.0	5.9*****

*Based on scanning resolution - dots per inch
**This image was orthorectified using NAPP camera calibration files
***This image was rectified by the USGS NAPP program
****Based on USGS National Mapping Program Technical Instructions, 1996
*****The transformation matrix and RMS value for the panchromatic and 4-band IKONOS image were identical

Historic maps that were registered to the master image or to geographic coordinates (e.g. USGS Topographic Quadrangle) resulted in digital map images. The positional error of registered and rectified map images is summarized in Table 4.7. Since the main purpose of a map is to "read" its information, the impact of misregistration does not necessarily negatively impact the utility of the map as with aerial photographs or satellite images.

Table 4.7 RMS error for registered maps of MBRNHP

Historic Map	**Registration Process**	**Raster Cell Size (pixel/m)**	**RMS Error (m)**
Sanborn Fire Insurance Maps (1904 & 1910)	Registered to Master Image	0.1	36.2
1832 Town of Woodstock map	Registered to Master Image	2.0	65.4
1869 Windsor County map	Registered to Master Image	1.8	81.7
1869 Town of Woodstock map	Registered to Master Image	1.5	37.0
1911 USGS Quadrangle	Registered to geographic coordinates	1.0	24.3
1913 USGS Quadrangle	Registered to geographic coordinates	1.0	24.5
1943 USGS Quadrangle	Registered to geographic coordinates	1.0	26.4
1983 USGS Digital Raster Graphics	Registered by the USGS	4.0	20.3*

* Meets National Map Accuracy Standards for 1:24,000 scale

Effects of Image Registration and Resampling on DN Values

Preprocessing digital images fundamentally alters the characteristics of the original images which may impact subsequent analyses. Perhaps the most insidious impact of digital image processing is the effect of resampling on the digital number (DN) values of individual pixels in the data. Resampling, which results from registration and rectification of digital images, averages DN values, thus reducing image contrast and utility. Although these altered DN values may not be visible on an image, the image statistics have nonetheless been altered impacting subsequent digital analysis. A typical photo-mosaic in the MBRNHP database was subject to two resampling algorithms, as well as an original scan. The effect of registration resampling (cubic convolution) is documented in the histograms on the next page (Figure 4.4).

Resampling due to the geometric correction process iteratively averages DN values when based on the cubic convolution algorithm. Scanning of the original paper photographs produced a digital image that was stored as digital numbers in a computer. Scanning software, depending on the manufacturer, grouped DN values into DN bins that appear as spikes in the left hand side of the 1962 scanned data histograms (Figure 4.4). The human eye is not able to differentiate the 256 shades of gray in a grayscale image, so these images displayed on a computer monitor appear continuous. However, this grouping og DN values during scanning reduces the information content of the imagery.

With rectification resampling, data values are averaged. As a result of averaging, DN values lower than the median increase, while DN values higher than the median generally decrease. This results in fewer outliers and more intermediate DN values, as is evident in Figure 4.4.

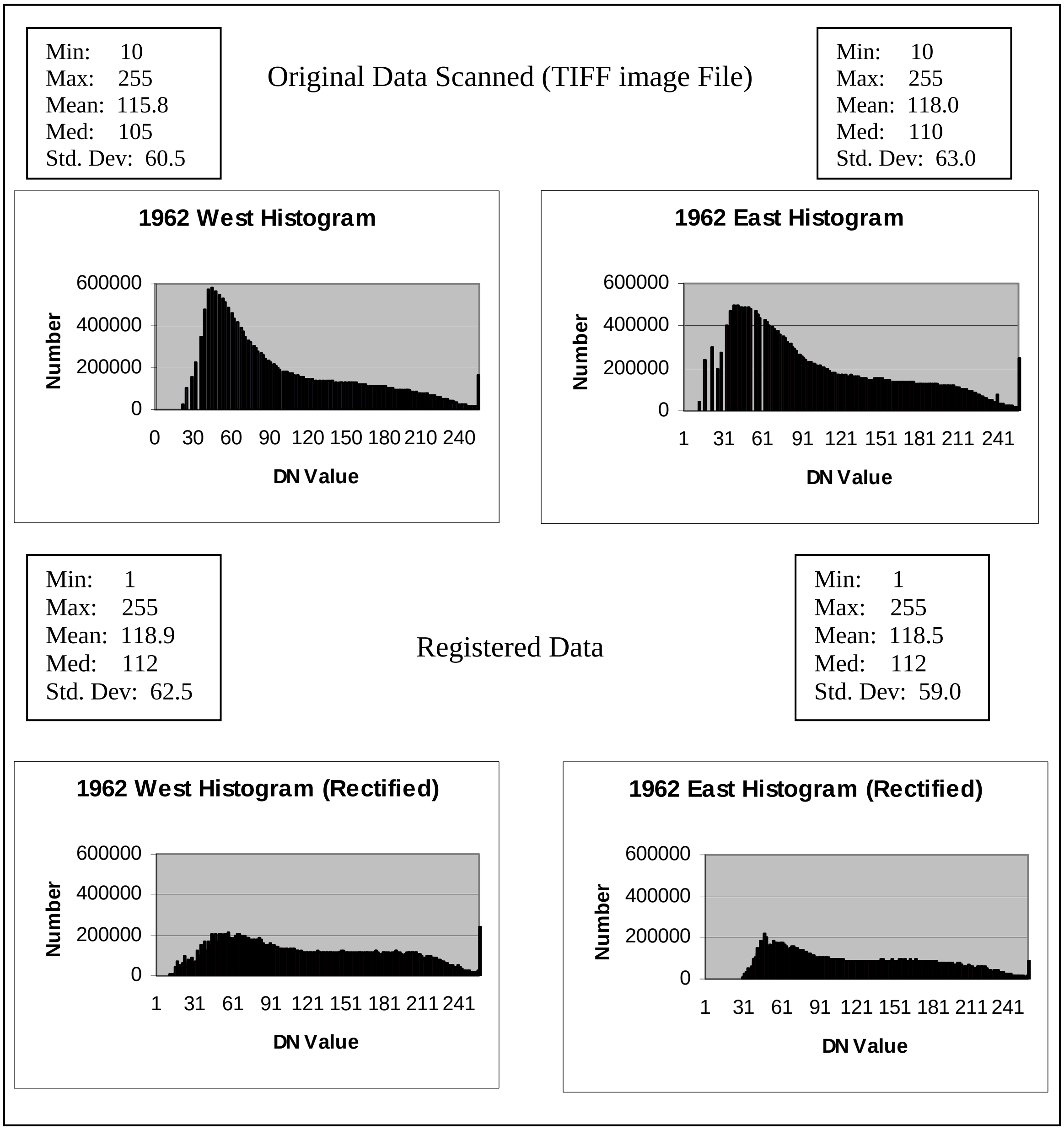


Figure 4.4 The impact of rectification on DN values for two 1962 aerial photographs. The resampling process leads to reduced image contrast.

Also the number of median DN values decreases, due to the filling in of the empty DN bins, and the median value is shifted upward. For example, following resampling, the average DN value (of all B&W aerial photographs) for the Pogue increased from 54.7 to 60.1 and the average standard deviation (± 1 S.D.) increased from 13.6 to 20.6 (Table 4.8). The mean DN values of the Pogue trend upwards, unlike the downward trending mean DN values of entire images (Figure 4.4), because the initial DN values of water were low. The low DN values of the Pogue are "pulled" toward the mean value due to the averaging of the image histogram. The impact of the DN changes for analysis (manual or digital) of the photograph might include the confusion of water areas with other dark areas such as shadows cast by topography or tree cover. Digital image processing of remote sensing images is base on the assumption that features on the surface of the Earth have unique spectral signatures or reflectance. Any processing that reduces the inherent differences in these spectral signatures reduces will reduce the chance of success during subsequent digital analyses.

The IKONOS scene, acquired pre-rectified by Space Imaging (bilinear interpolation) statistics for the Pogue provided more insight into the unpredictable results of resampling multispectral images (Table 4.8). The mean value of the NIR band decreased from 344.0 to 200.2 and the standard deviation dropped from 32.6 to 15.1 following resampling. Resampling the R, G, and B bands produced an increase in the means and a reduction in the standard deviation. The results are surprising since the common assumption is that the relatively low DN values of the Pogue would produce similar effects to those seen in the statistics of the panchromatic aerial photographs.

Table 4.8 Digital Images – DN values for the Pogue prior to and following registration and rectification

Image	**Pogue statistics for Digital Images, prior to rectification process.**				**Pogue Statistics for Registered, Rectified and Mosaicked Images**			
	± 1 S.D	Mean	Max	Min	± 1 S.D	Mean	Max	Min
1994 VT DOQ # 148124	4.6	45.7	144	20	⇓ 4.4	45.3	144	20
1992 NAPP DOQ	64.5	162.8	244	20	⇑67.5	⇑168.2	⇓236	⇓ 13
1980 Aerial Photograph	5	31	94	21	⇑7.21	⇑ 33.2	⇑173	⇓ 20
1974 Aerial Photograph	18.9	101.7	187	63	⇑19.3	⇑104.0	⇑188	⇑ 64
1968 Corona	5.9	64.9	91	43	⇑ 7.2	⇑ 66.2	⇑115	43
1968 Aerial Photograph	9.5	29.3	250	0	⇑26.4	⇑ 23.0	⇑255	0
1962 Aerial Photograph	3.9	48.7	81	34	3.9	⇓ 42.6	⇑127	⇓ 29
1954 Aerial Photograph	26.4	14.5	153	1	⇑38.2	⇑ 26.0	⇑214	⇑ 3
1977 CIR Photograph (Red Band)	0.9	0	48	0	⇑ 2.1	⇑ 0.1	⇑ 52	0
1977 CIR Photograph (Green Band)	29.4	35.6	125	0	⇑29.8	⇑ 53.7	⇑217	0
1977 CIR Photograph (Blue Band)	25.9	52.1	153	0	25.9	⇑ 53.5	⇑222	0
1992 CIR Photograph (Red Band)	1.9	9.5	54	4	⇑ 2.7	9.5	⇑ 80	⇑ 5
1992 CIR Photograph (Green Band)	2	8.5	64	3	⇑ 2.2	8.5	⇑ 73	3
1992 CIR Photograph (Blue Band)	1.7	11.3	53	5	⇑ 1.9	⇓ 11.2	⇑ 60	5
2000 IKONOS (Pan)*	17.8	272.5	457	248	⇓17.7	⇑273.0	⇑472	⇓247
2000 IKONOS (NIR)*	32.6	344	494	306	⇓15.1	⇓200.2	⇓298	⇓182
2000 IKONOS (Red)*	15.2	199.8	297	183	⇓11.0	⇑315.8	⇑396	⇑290
2000 IKONOS (Green)*	15.2	315.6	395	295	⇓11.0	⇑336.1	⇑398	⇑319
2000 IKONOS (Blue)*	11.2	336.1	398	319	⇓11.0	⇑347.3	⇓393	⇓300

* CIR aerial photographs not included in the evaluation of image statistics

Edge Enhancement to Detect Historic Landscape Features

The examination of edge-enhanced images, created by processing aerial photographs and satellite imagery, resulted in the detection and identification of linear features on the MBRNHP landscape. Digital aerial photographs, after edge enhancement, highlighted stonewalls, field boundaries, and forested areas. IKONOS satellite imagery, where individual spectral bands could be analyzed, was useful in identifying building locations. Edge-enhanced CIR photography resulted in the differentiation of forest plantation areas. The completion of land cover maps was also aided by using edge-enhanced images to help locate developed areas and changes in vegetation.

The 1939 aerial photograph, which lacked extensive forest cover, provides an excellent example of the utility of edge detection in locating historic landscape features (Figure 4.5). Following digital edge detection (using the Sobel algorithm) the image was displayed in a GIS using Jenks natural breaks to separate the results into two categories; edge indicated and edge not indicated (ERDAS, 1995). Stonewalls appeared as a single or double line along a field edge. The straightness of the line and the abrupt angles and turn indicated that this was a human-constructed feature. The field area at the center of this image appeared nearly devoid of linear features indicating that vegetation covering this field was uniform (Figure 4.5). The forested area around the field appears as somewhat mottled mass of interconnected black and white lines that reflect the canopy openings and variations in forest density and type.

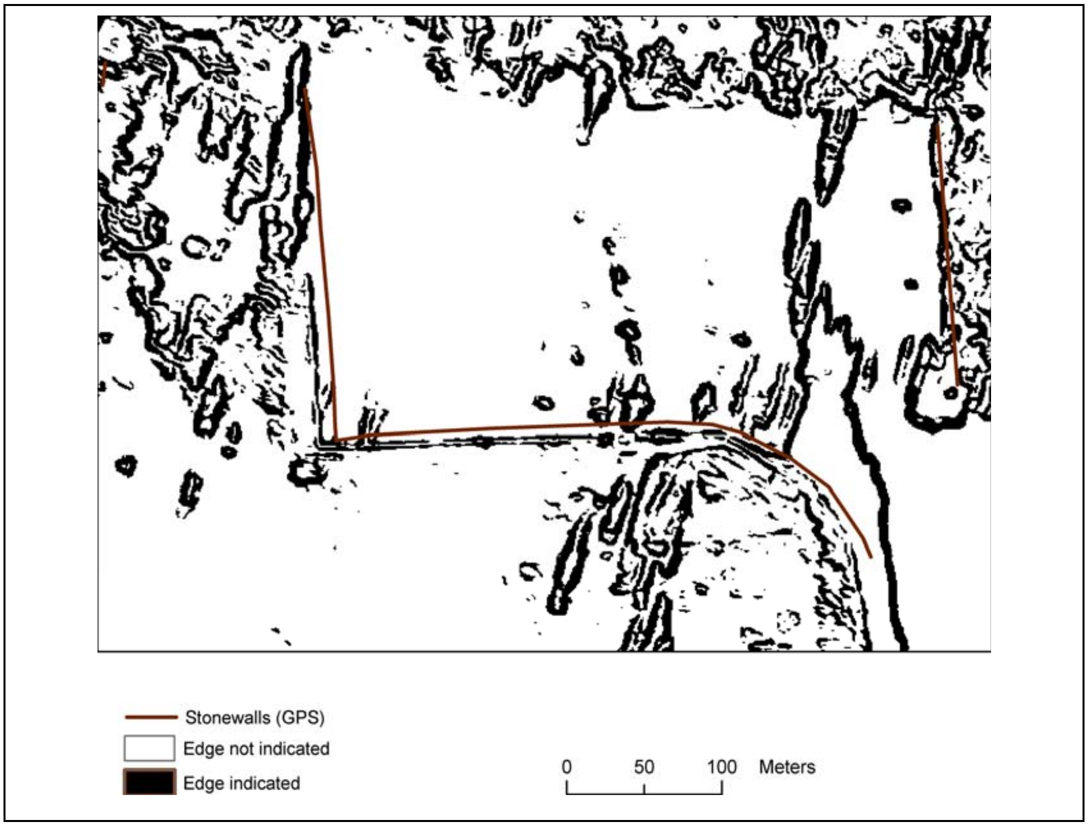


Figure 4.5 Edge detection of a portion of the 1939 aerial photograph highlighting linear features such as stonewalls (shown in brown).

Textural enhancement of the CIR photography was especially useful for differentiating conifer plantations, hardwood forests, and fields in MBRNHP (Figure 4.6). This image was created by displaying an edge-enhanced image of the 1992 CIR photograph in grayscale. The forest plantation areas appeared dark and featureless in the edge-enhanced image due to their uniform cover of conifer trees. In contrast, the hardwoods forests appeared as a mottled mass of edge and non-edge features similar to the forest in Figure 4.5. A notable exception was the European larch (*Larix decidua*) plantation, located in the lower right hand corner of Figure 4.6. This conifer plantation appearance was similar to that of hardwood forest due to the trees leaf-off condition at the time of photograph (*Larix decidua* shed their needles in the winter).

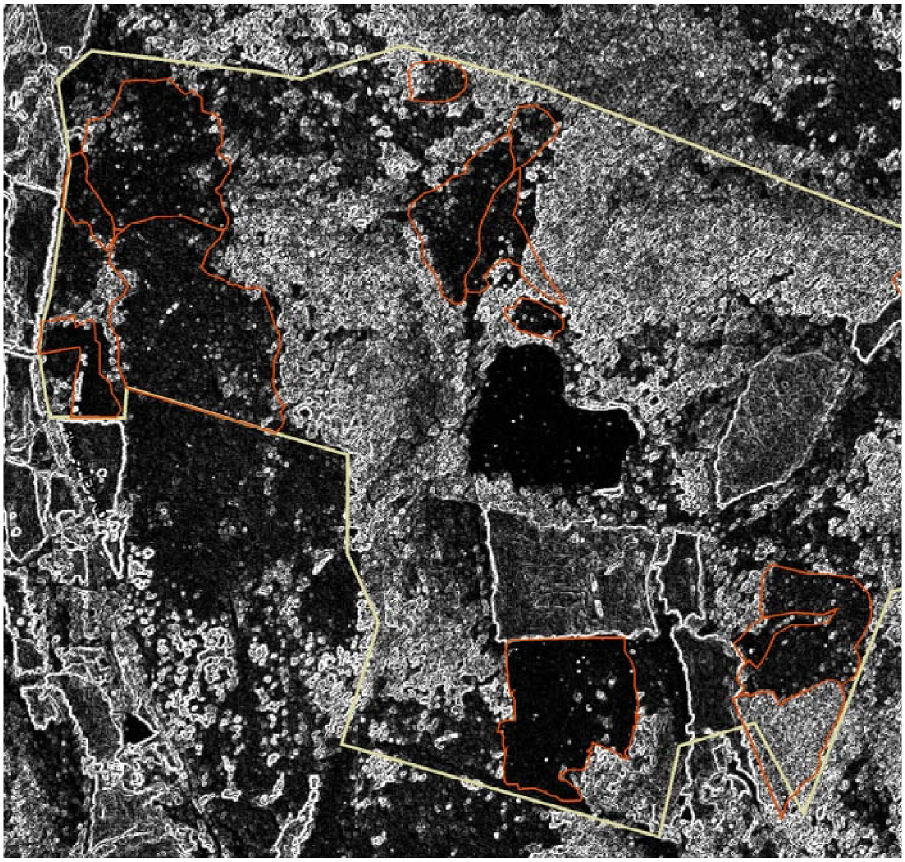


Figure 4.6 Image of 1992 CIR photograph of western half of MBRNHP highlighting conifer plantations and fields following texture analysis. Conifer plantations (CLR layer, Wilcke et al., 2000) are outlined in red, and fields are outlined in white.

Edge enhancement of the red band of the IKONOS satellite scene with the Sobel algorithm resulted in the identification of developed or built features (Figure 4.7). This continuous raster image displays low DN values as black, indicating a lack of edges, and high DN values as white indicating an edge. The buildings of the “gardens and grounds” area of MBRNHP as well as buildings and roads outside the park to the south and west were highlighted white (i.e. edges) in this image, while vegetated areas appeared uniformly dark. The edges of the paved roads that encircle the park boundary appeared as a double white line encircling the eastern edge of the park in this image.

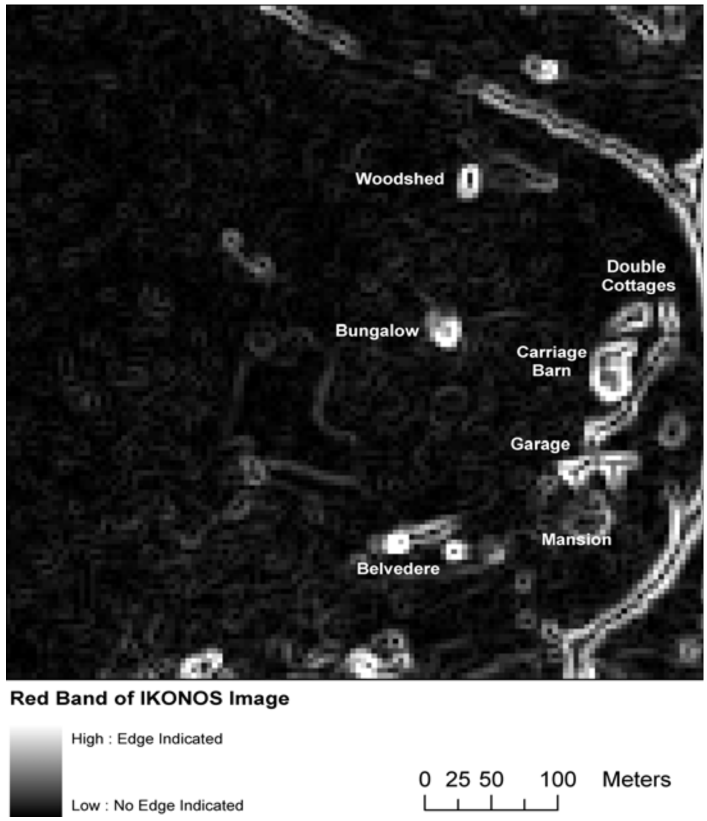


Figure 4.7 Sobel edge enhancement of the red band of the IKONOS satellite scene detailing the roads and developed area around the mansion at MBRNHP. Buildings are identified by name.

Band Ratioing for Historic Feature Detection

The images produced through band ratioing (NDVI and NIR/R) were useful in differentiating between vegetated and non-vegetated features. Because band ratioing is a technique developed for use with multispectral satellite imagery, the process was only conducted on the IKONOS satellite imagery collected for MBRNHP. Overall reductions in atmospheric attenuation and topographic shadowing were also accomplished through band ratioing

The NIR/R (Figure 4.8) image shows urban areas and water as black areas and was sensitive enough to detect a small (50 x 30 m) dirt parking lot on the western edge of the park. The NDVI image is presented in Appendix B and shows different vegetation types across MBRNHP. In the case of MBRNHP there was not a substantive difference in features highlighted by the NDVI and NIR/R images.

The NDVI and NIR/R images were useful in differentiating between vegetation types. For example, in both images the coniferous trees, both planted and naturally occurring, appeared dark gray, compared to the light gray of hardwood forest indicating the high reflectance of broadleaf forests during the growing season. In addition, the open areas of the park are differentiated by a medium gray without the texture of the tree crowns present in forested sections. The images were also useful distinguishing vegetated from human-constructed features. Non-vegetated areas, including water and human-constructed feature appear black in these images.

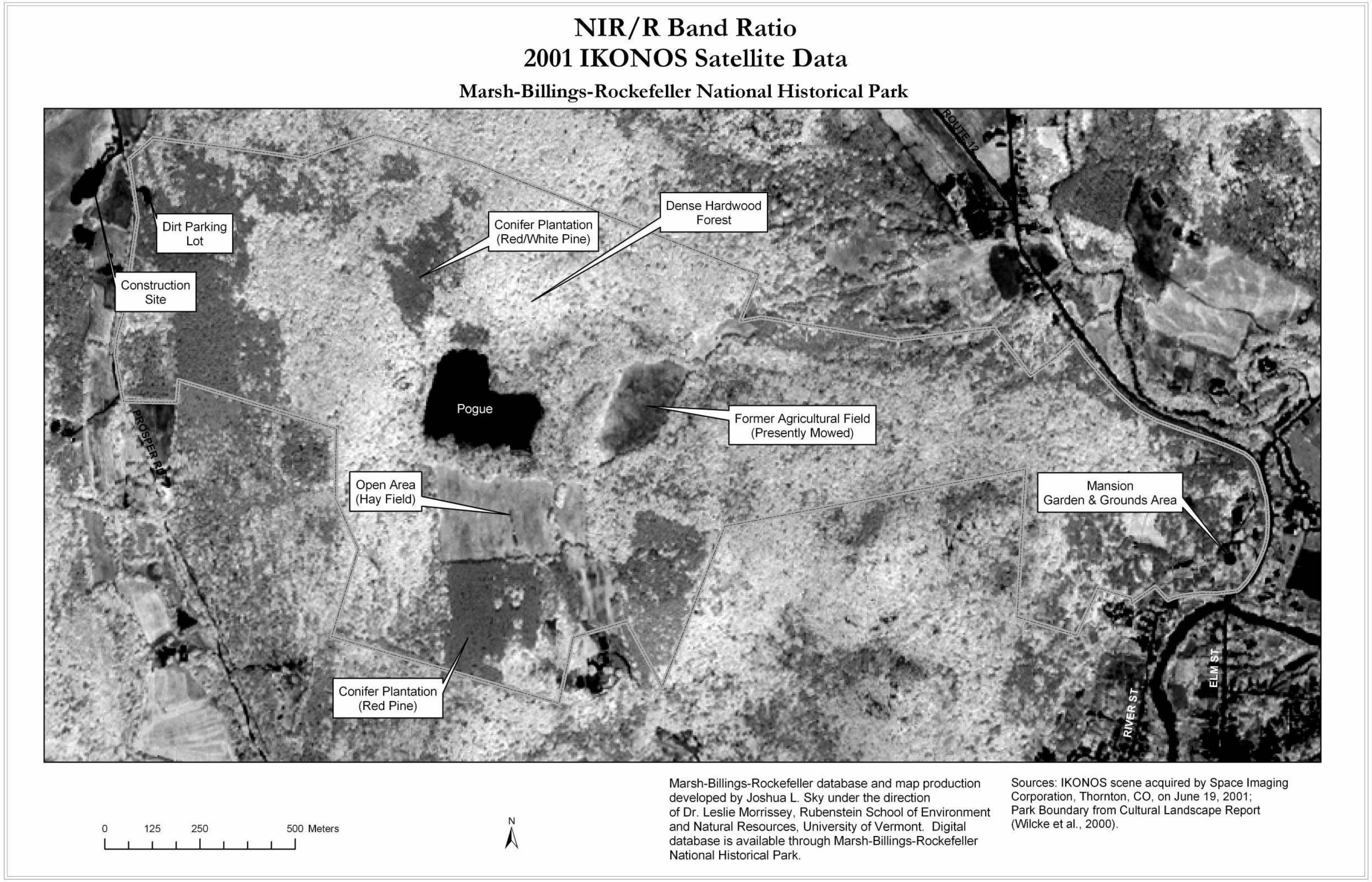


Figure 4.8 NIR/R IKONOS scene showing differences in vegetated communities and vegetated vs. non-vegetated areas (shown in black)

Creating GIS layers from Historic Data Sources

GIS provided the framework for the incorporation, management, and analysis of the historic data for this project. GIS data layers were created from maps, aerial photographs and satellite scenes, and provided a means for analyzing the evolution of the landscape through time. Some data were provided in digital format as raster grid cells (e.g. scanned aerial photographs, scanned maps and satellite data), while other data were provided in vector format (points, lines and polygons that represented a landscape feature of MBRNHP). In preparation for analysis in a GIS, the raster data were digitized to "trace" particular landscape features such as carriage roads, stonewalls, buildings and other features identified in Table 4.9.

The photointerpretation and digitization of the aerial photographs and satellite scenes produced land cover GIS layers of forest, forest plantation, open, developed and surface water (Table 4.9). In addition, where possible, individual landscape features, such as roads, stonewalls and buildings were also identified and digitized from the aerial photographs and satellite scenes. The land cover and other GIS layers created from these images span 62 years, from 1939 to 2001, providing the basis for quantifying change in the MBRNHP landscape.

Table 4.9 GIS vector data layers created for MBRNHP database

Base Image(s)	**Date Range**	**GIS Coverages**
Aerial Photographs	1939, 1954, 1962, 1968, 1977, 1980, 1992, 1994 and 2001	land cover, buildings, surface water and stonewalls*
USGS Topographic Maps	1911, 1913, 1943, 1983	roads, streams, buildings, and surface water
Doton Survey**	1880s	carriage roads, buildings, monuments, streams, surface water, and the Pogue pipeline
Sanborn Fire Insurance Maps	1904, 1910	roads and buildings

* 1939 and 1954 aerial photographs only.
** Data originally created for the CLR

An example of the process of converting historical map data into GIS data layers is illustrated in Figure 4.9. A 1911 USGS topographic map that was scanned and registered to the 1994 DOQ was used as a background image for digitizing important landscape features. The carriage roads as well as buildings, streams, and water bodies were screen digitized and converted to GIS data layers. These layers were then compared with other GIS layers that were digitized in the same way to determine the presence or absence of landscape features over time (Table 4.10). In the case of the Doton Survey digitized features were used for GPS navigation for field verification.

Table 4.10 Features within the present MBRNHP boundary

	Doton Survey	**USGS Topographic Map**		
Feature	**1880s**	**1911/13**	**1943**	**1980**
Buildings (Count)	13	6	1	9
Streams (Count - Length)	2 5100 Ft	4 9400 Ft	1 4600 Ft	1 4600 Ft.
Pogue (Area)	4.8 Acres	11.9 Acres	9.8 Acres	12.8 Acres
Carriage Roads (Length)	7.8 Miles	6.0 Miles	3.2 Miles	5.8 Miles

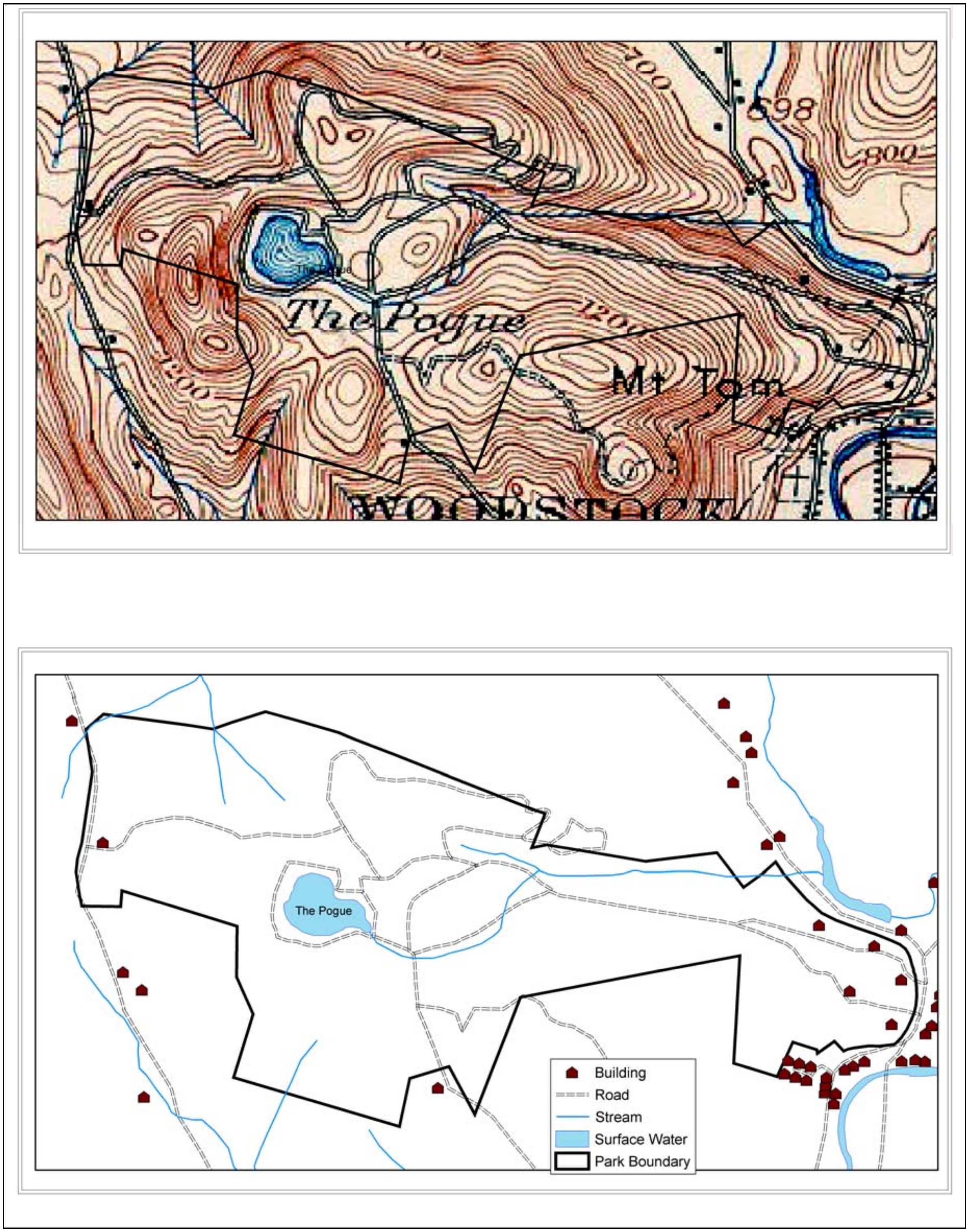


Figure 4.9 An example of digitization of map features from a 1911 USGS topographic map

Land Cover Classification of the Landscape

The 2001 IKONOS 4m multispectral scene was classified using the Maximum Likelihood rule to identify five land cover types. The result was a land cover image, in raster format, of the MBRNHP area. This layer was used to compute land cover acreages for comparison with land cover maps created from older aerial photographs to document landscape changes. The process of digital image classification is usually accompanied by a formal accuracy assessment involving ground truthing and the construction of an error matrix. While a formal assessment of accuracy was beyond the scope of this analysis, a simple analysis of error, including an examination of transformed divergence and a comparison with other land cover layers was conducted.

Transformed divergence (TD) was used during the classification process to determine if class separability was sufficient for differentiation among the five classes. At a score of 1700 and above (out of 2000) a class is considered to be distinct and spectrally separate from other classes, and between 1400 and 1700 the separation is borderline but can still be used in classification (Jensen, 1996). Table 4.10 is a matrix of TD scores for the five classes chosen for MBRNHP. This table shows that the open and developed classes of MBRNHP are most likely to be mistaken for one another by the classification algorithm.

Table 4.10 Transformed divergence matrix for the supervised classification of IKONOS satellite image (4m multispectral)

Class	**Plantation**	**Developed**	**Water**	**Open**	**Natural Forest**
Plantations	0	1959	1734	1950	1985
Developed	1959	0	2000	*1497**	1798
Water	1734	2000	0	1999	2000
Open	1950	*1497**	1999	0	1854
Natural Forest	1985	1798	2000	1854	0

*Transformed divergence scores below 1700 are considered to have poor separation between classes

The land cover classification results for the IKONOS satellite image provided a current conditions snapshot of the MBRNHP landscape (Figure 4.10). The resulting classified image illustrated the use of existing image classification techniques used to classify high resolution imagery. Based on a comparison with the land cover classification provided by the CLR the classes match the actual landscape conditions quite well. Where conditions were homogeneous (e.g. conifer plantations with closed canopies, open fields, and open water) the classification results were correct. In other areas, such as the natural forest and narrow country lanes the classification was more prone to error. This was probably due to canopy openings in the natural forest and tree crown covering the narrow roads.

High spatial resolution multispectral satellite imagery has only recently become available. Therefore, much of the existing body of research that deals with digital image processing is still catching up with this advance in technology. Traditional image classification software for images was based on per pixel classification of medium resolution (30 - 60 meter grid cells) satellite data such as Landsat. New software packages specifically designed for high resolution data such as eCognition© have the potential to improve the process by which high-resolution satellite imagery is classified and analyzed.

When ordering satellite imagery, different degrees of radiometric and geometric correction are offered by satellite vendors. The specific choice of data selected depends on the user's level of expertise and access to digital image processing software. To avoid potential problems using high-resolution satellite data the degree of correction should be carefully considered. Uncorrected data should be selected by users trained in image processing, who can then rectify the data to a specific coordinate system, and remove atmospheric anomalies. This option avoids the need to re-rectify images that are not accurately registered. For users with limited knowledge of, or access to, image processing software the best option would be to order data with the highest positional and radiometric accuracy possible.

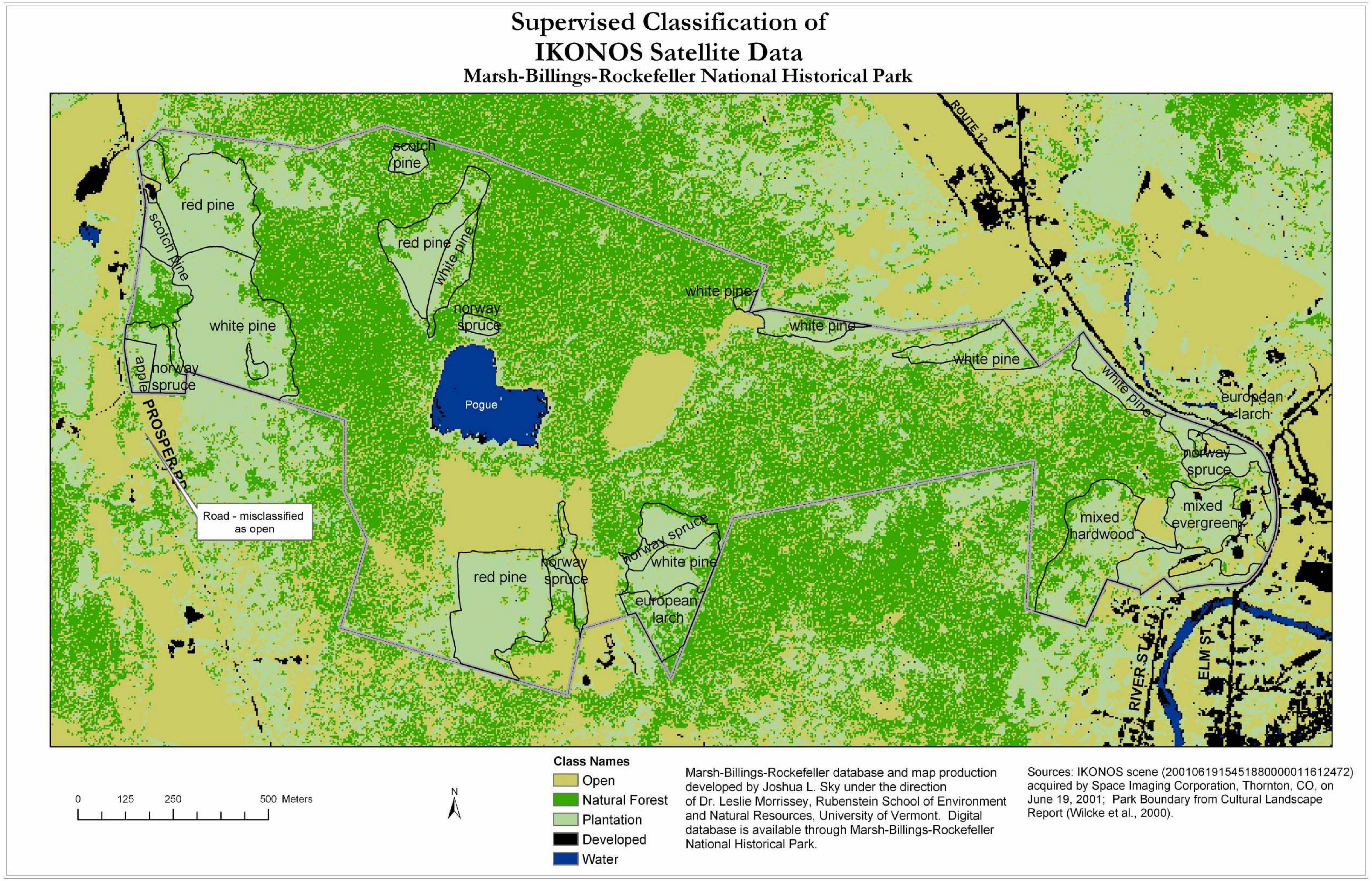


Figure 4.10 Supervised classification of IKONOS satellite scene (2001)

Detecting Changes on the Landscape

Landscape change at MBRNHP captured in aerial photographs and satellite images was documented through digital change detection and manual photointerpretation methods. Digital change detection, or the comparison of DN values for images of aerial photographs acquired during different time periods resulted in the identification of areas of potential change within the MBRNHP landscape. The land cover layers that were created by photointerpretation were compared with each other to quantify the area, amount, and type of change occurring on the MBRNHP landscape.

Digital Change Detection Results

Two areas highlight the use of digital change detection to identify conversion of pasture and agricultural fields to forest (Figure 4.11 and 4.12). Area A is located in the southwestern corner of the park along Prosper Road and Area B is located between the Pogue and the southern border of the park. Area A is the site of the old McKenzie Farm where former open fields, an apple orchard, and an old homestead have been converted into plantation and natural forest. Area B is the site of the former Hilltop Farm where a significant portion of open land has reverted to forest and a historic agricultural field was planted with a red pine plantation.

Digital change detection results worked best where there was a marked difference in DN values between the 1939 base image and more recent aerial photography, such as areas where open fields converted to forest. This occurred in areas that were open in the 1939 aerial photograph and were then converted to forest plantations or left to regenerate naturally as time went on. The rest of the park, where forest dominates from 1939 to the present and remained basically unchanged, produced somewhat inconsistent results. In some imagery, the DN values for the forest was much higher (lighter) when compared to the 1939 aerial photograph. To correct for baseline differences in the DN values, the images used in change detection were histogram matched. However histogram matching does not remove all of the spurious effects of change detection.

In the 1939 aerial photograph, Area A is primarily meadow, nearly devoid of trees or other shrubby vegetation (Figure 4.11). Some darker areas represent the remnants of an old apple orchard planted in the late 1800s and some ornamental black locust trees associated with the McKenzie Farm (Wiggin,1993). In subsequent aerial photographs, the growth of forest in Area A is observed. Change detection results of these aerial photographs also show a progression from meadow and open field in 1939 to a mature forest in 1994. Between 1939 and 1994, the DN values in Area A steadily decrease (shown as red) until there is uniform forest cover over the entire region. One notable exception to the steady decrease in DN value occurs in the 1974 image. The 1974 aerial mosaic shows an area where misregistered data, along the southern boundary of the park, is identified as change. Comparison of the change detection results in Area A with a forestry survey reveals that a Norway spruce plantation was planted in 1950 and that a white pine stand and black cherry stand have regenerated naturally after the abandonment of the McKenzie farmstead in the late 1880s (Wiggin, 1993).

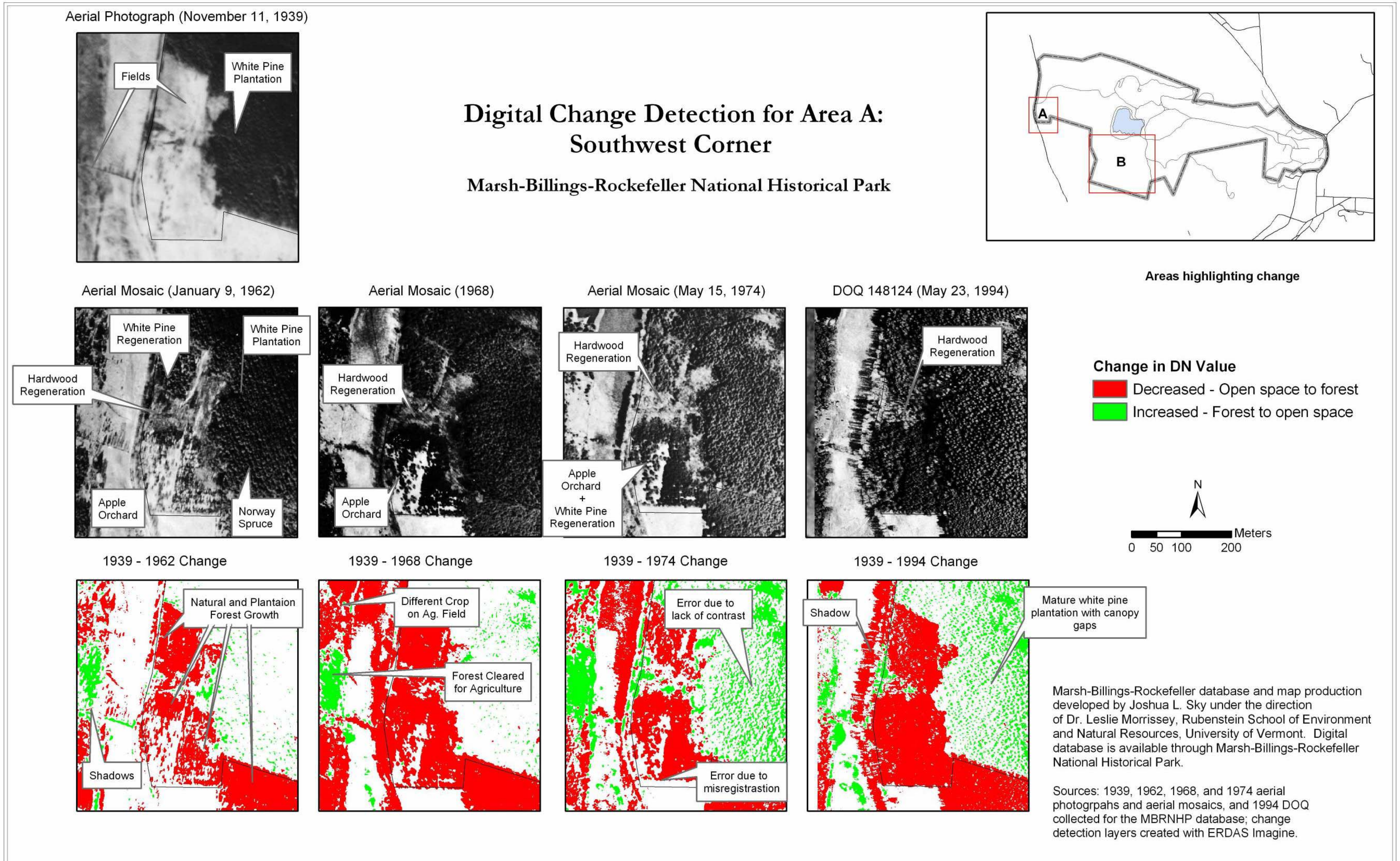


Figure 4.11 Change Detection results documenting forest cover change in the southwest corner of MBRNHP (1939 – 1994)

Landscape change south of the Pogue (Area B) shows the growth of a forest plantation and natural forest regeneration (Figure 4.12). From the southern boundary of the park to the edge of the field, the steady increase of red pixels (i.e. decreasing DN values) charts the development of red pine plantation planted in 1952. The western region of Area B and a smaller region to the southwest of the red pine plantation indicate a progression from an old open field to a natural forest dominated by mixed hardwoods. Change detection analysis for the red pine plantation is consistent for all of the photographs presented and progresses continuously throughout the time series. The area of hardwood development appears mottled with dark and light values consistent with an immature hardwood stand. Due to seasonal differences in the photographs, the DN values of the developing hardwoods area do not increase steadily through the progression of aerial photographs.

Shadows cast by trees in the 1939 aerial photograph also create spurious results in comparison with other layers during change detection (Figure 4.11 – 4.12). The 1974 aerial photographic mosaic and 1994 DOQ erroneously document areas of change from forest to meadow indicated to the immediate southwest of the Pogue; due to shadows cast by tall conifer trees growing alone in a meadow in the 1939 aerial photograph. Due to differences in the date, season, and time of day of the acquisition of the various aerial photographs, the shadow effect is evident in all of the automated change detection results. Finally, due to image speckle, acreage summaries of land cover change have not been computed.

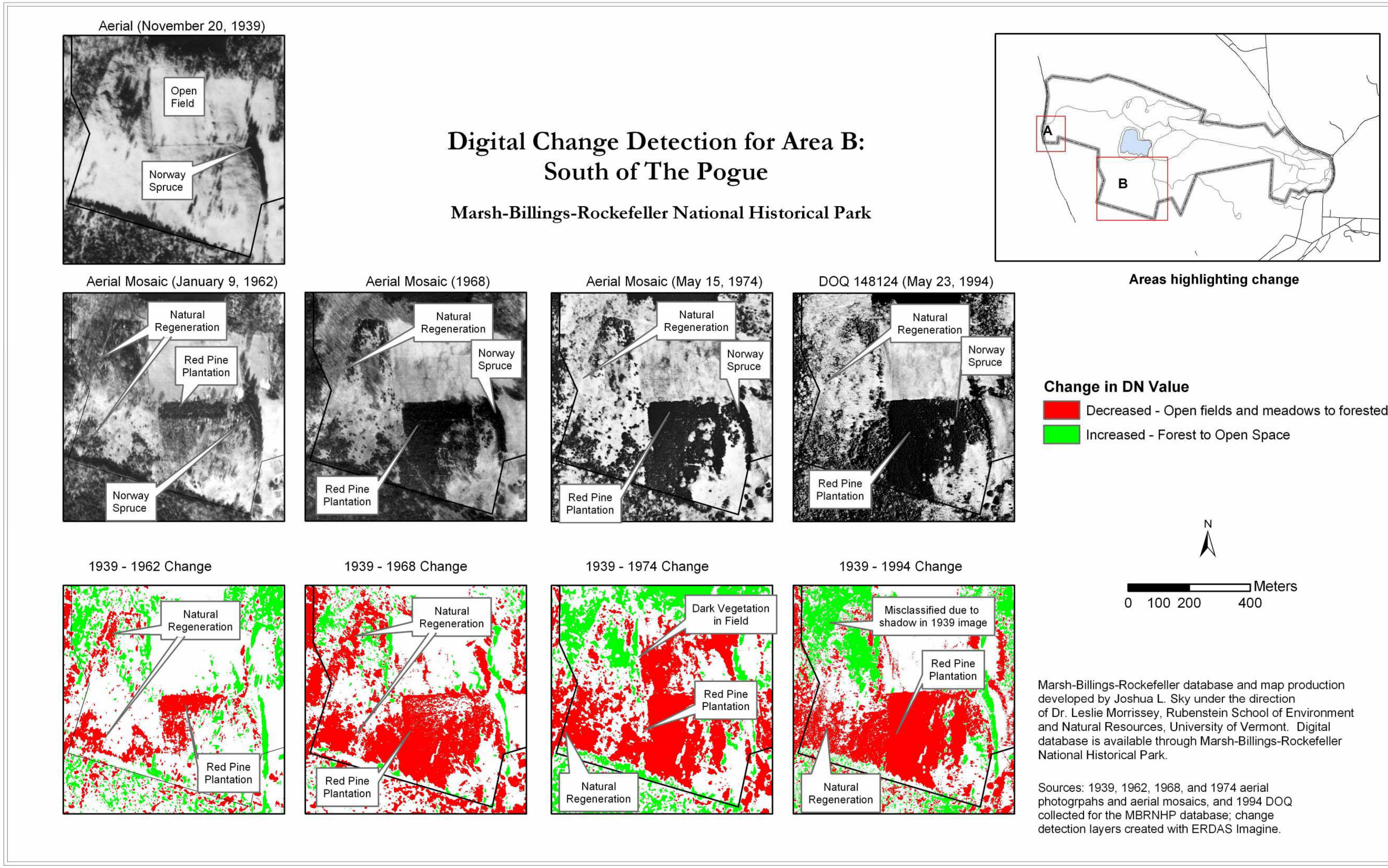


Figure 4.12 Change detection results documenting the development of a red pine plantation, and natural forest regeneration south of the Pouge (1939-1994)

The digital change detection results shown here indicated that this technique was useful for locating potential areas of change. In large study areas, where many aerial photographs would have to be examined manually, the technique could be used to efficiently target areas where change may have occurred. Subsequently, the aerial photographs would undergo visual analysis of the areas identified through digital change detection. Another aspect to consider when using digital change detection techniques is that knowledge of the pixel values of the cover types in the study area is required. Change detection merely detects a potential change in DN value of each image's corresponding pixels. If a study area were, for example, a hardwood forest with the initial image taken in the fall with leaf-off conditions, and the comparison image from the high summer, or leaf-on conditions, digital change detection techniques would erroneously indicate that a change had occurred. Conversely, coniferous forest are not as likely to be affected by seasonal differences because the needles are retained throughout the year.

Change Detection through Manual Photointerpretation

Land cover layers created through manual photointerpretation were compared for aerial images (1939 –2001) to quantify landscape change in MBRNHP. This process yielded summary information on the amount, type, and location of change within the MBRNHP boundary. This method was labor intensive and required somewhat subjective decision making during the initial classification process. However, the results are site specific and indicate not just areas of potential change but the type of change.

Based on the results of manual photointerpretation, water and developed areas remained essentially unchanged over the past 62 years, while natural forest and plantations increased at the expense of open areas. MBRNHP experienced an 11.5% decrease in the area of open fields and meadows from 1939 to 2001 (Figure 4.13-14). The open areas of the park were converted to natural forest and forest plantation. Natural forest extent increased by 6.9% from 1939 to 2001 and forest plantation increased by 4.8% from 1939 to 1994. In 2001, the forest plantation area appears to shrink by 3 acres from that of 1994. Any number of factors, including forest mortality or natural forest regeneration within the forest plantations, may account for this change. However, the change is most likely attributable to registration error or photointerpretation error.

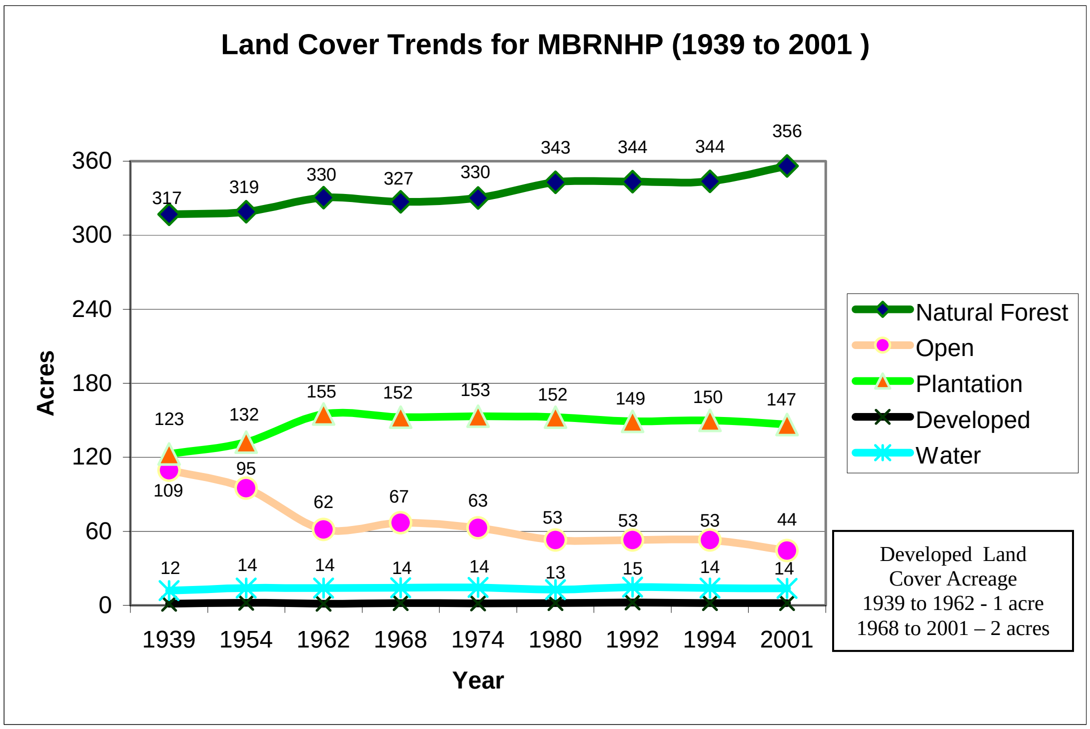


Figure 4.13 Change in land cover for MBRNHP (1939 – 2001) as determined through manual photointerpretation of aerial photographs and satellite imagery.

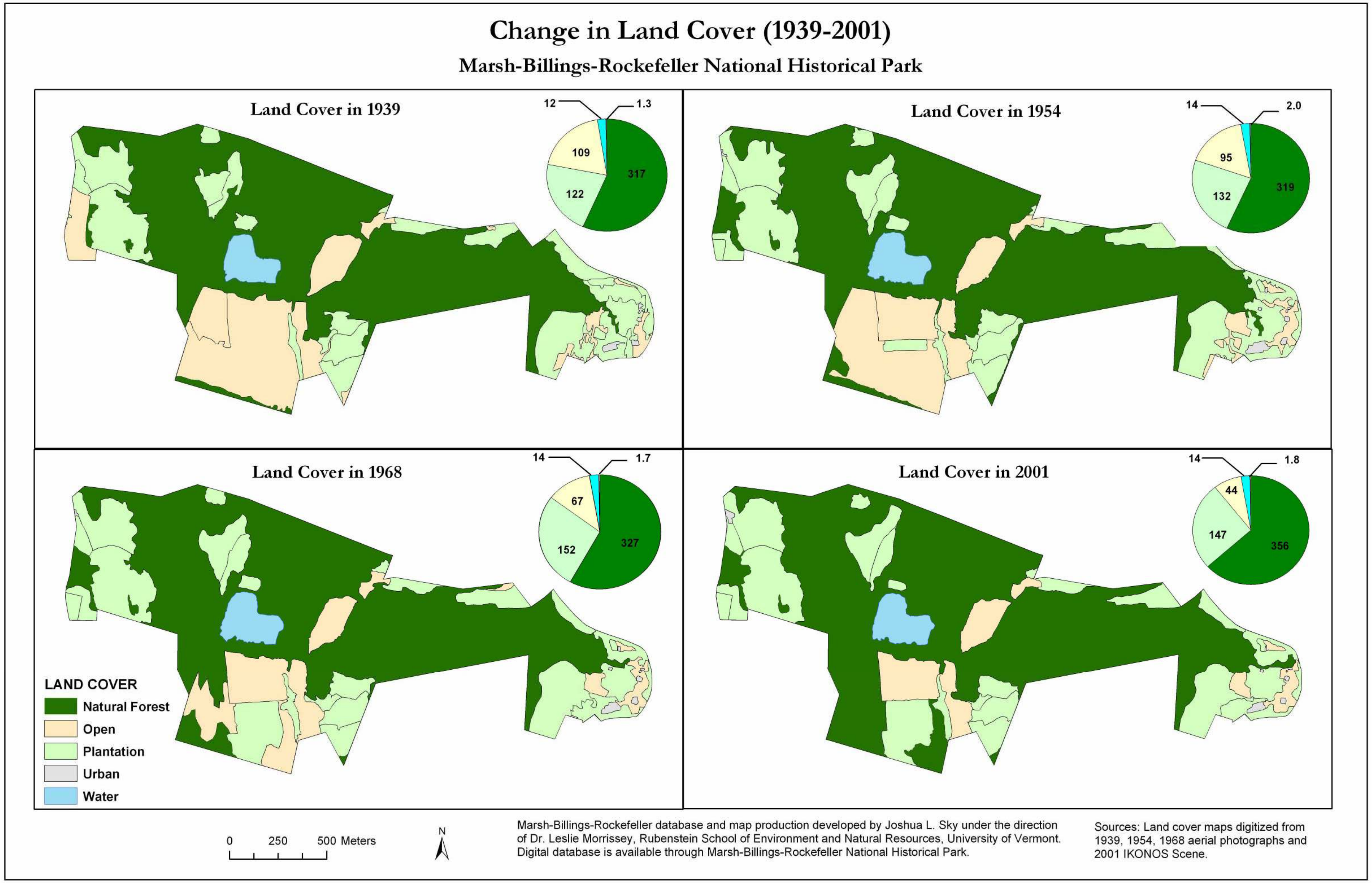


Figure 4.14 Manual photointerpretation of aerial photography and satellite images was used to document land cover change (1939 – 2001). Two key area of change (A and B) are outlined. Pie charts show acreage for each land cover type.

Comparison of Digital and Manual Change Detection Techniques

The use of change detection techniques to analyze landscape change over time is dependent on the size and type of landscape. In this case, two techniques for change detection (digital and manual) were used to document the MBRNHP landscape over time. Both techniques were similar in that they required that the remote sensing images be registered to a common map base. However, the practical application of each technique turned out to be quite different.

For the relatively small landscape of MBRNHP, the use of manual change detection analysis produced results that were quantifiable and easy to interpret. The technique can be duplicated by a novice remote sensing user and is relatively inexpensive. However, manual change detection is very labor intensive and requires that the practitioner have some basic photointerpretation skills. In contrast, digital change detection produced results that were not easily quantifiable (due to error and image speckle) and often required additional manual photointerpretation. The digital technique also requires the use of expensive image processing software and knowledge of the characteristics of digital images. However, over large areas where manual photointerpretation would be impractical, digital change detection would identify target areas of potential change that may be missed through manual inspection. These areas can then be targeted for a more in-depth manual analysis.

Verification of Historic Landscape Features with GPS

GPS navigation technology was used to verify the existence of historic landscape features identified on historic maps, aerial photographs, and satellite images (Table 4.11). This method of research was a departure from the traditional use of GPS to record the location of known features in the field. Although historic features that were located in the field were also recorded using GPS technology, GPS was used here to verify the existence of historic features that may have existed previously as indicated on historic source materials such as the Doton Survey. The result was a data set of GIS layers that represented the presence of historic landscape features (Figure 4.15).

Point features, including monuments, boundary markers, wells, and building locations, identified on historical maps and surveys were verified in the field. A total of 23 monuments and boundary markers located on the corners of property boundaries in the Doton Survey were located on the ground. Two wells and a wooden cistern, also from the Doton Survey, were also located. In addition, three rock outcrops (not shown) and two rock piles were located based on the edge enhanced 1939 aerial photograph.

Table 4.11 GPS verification of historical landscape features of MBRNHP

Feature	Type	Existing	Verified	Detection Source	Original Source
Boathouse	Polygon	Ruin	Possibly	Doton Survey	Doton Survey
Carriage roads	Line	Yes	Yes	1911 USGS Topographic Map	Portions of carriage roads are present in all maps and aerial photographs after 1832
Forest Plantations	Polygon	Yes	Yes	1992 CIR photograph	All aerial photography and satellite images
Rock Outcrop	Point	Yes	Yes	1939 photograph Edge enhanced data	1939 aerial photograph
Mansion and surrounding buildings	Polygon, Point	Yes	Yes	2001 IKONOS image, edge enhanced data	Doton Survey
Markers (23)	Point	Yes	Yes	Doton Survey	Doton Survey
McKenzie Farm, Sugarhouse	Polygon, Point	Ruin	Yes	1911 USGS Topographic Map	Doton Survey
Pogue pipeline	Line	Ruin	Yes	Doton Survey	Doton Survey
Pogue wells	Point	Yes	Yes	Doton Survey	Doton Survey
Stonewalls	Line	Yes	Yes	1939 and 1954 photographs, edge enhanced data	1939 and 1954 aerial photograph

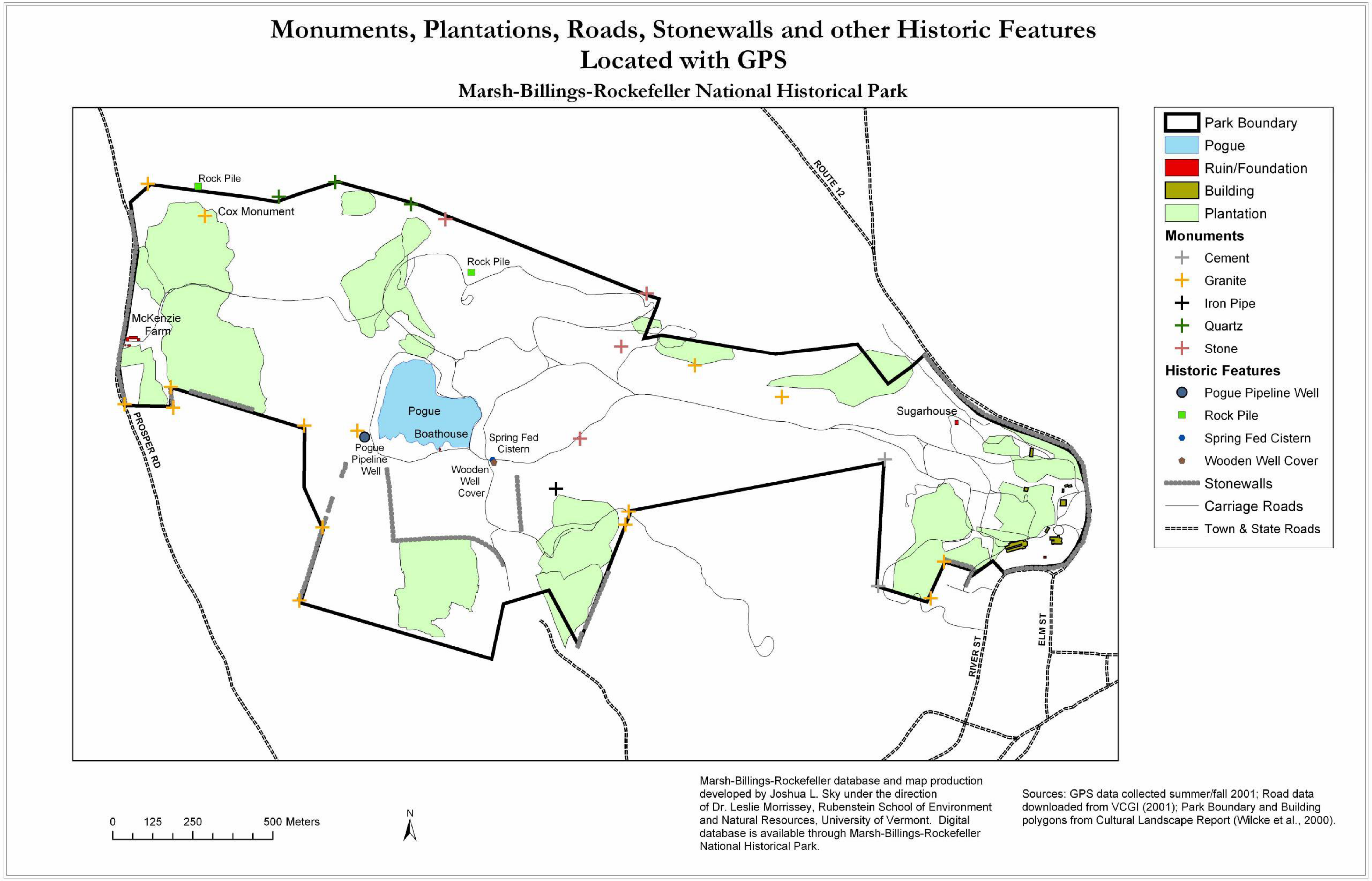


Figure 4.15 Historic and modern landscape features located and verified in the field using GPS

The existence of linear features, such as carriage roads, stonewalls, and the Pogue pipeline was also verified using GPS. The carriage roads appeared on each historic map from 1856 through current USGS maps and in number of the remotely sensed images. Since the roads are well maintained today, it was a simple matter to "verify" their existence. Six intact and one relict stonewalls were identified in the1939 and 1954 edge-enhanced aerial photographs and were successfully located and mapped using GPS. The Pogue pipeline is an underground pipe running from the Pogue to the mansion area of MBRNHP. Using GPS technology to walk above the underground pipeline resulted in the location of exposed piping in two eroded streambeds.

Building features, like roads, were found in a number of historical documents. The most complete source for building types and their location was the Doton survey (1887-1888). GPS technology was ideally suited for navigation to intact buildings, such as those in the "gardens and grounds" section surrounding the mansion. GPS and the Doton Survey data were also useful in navigating to and locating the suspected ruins of the boathouse on the Pogue, the McKenzie Farm on Prosper Road, and sugarhouse located to the northwest of the mansion. Forest plantations, which were identified in aerial photographs and satellite images, were also easily located using GPS.

Archival material such as the ecological survey (John Wiggin, 1993), the Billings farm diary, and even some of the historic map documents were used to confirm some of the findings of the historic research. The ecological survey contained a detailed forest inventory that helped to confirm the land cover type in different portions of the park. The Billings diary contained detailed information about early forest planting in MBRNHP. Many of the map documents had notations or text that described property owners, acreages, and sometimes even property transfers. This study was aided by the prior research conducted for the CLR in that much of the archival verification of landscape features in MBRNHP had already been conducted. These early archival documents provided information that supported the change detection analyses which mapped historic cover types and landscape features. Without this archival material photointerpretation of the aerial images would have been more difficult and the class identifications questionable.

Summary of GIS, Remote Sensing and GPS as Historic Preservation Tools

The three technologies used to examine the landscape at MBRNHP proved to be useful historical documentation tools (Table 4.12). GIS, RS, and GPS provided a technological lever that was used to extract a wealth of data from the archival material. However, the technological tools were not without limitations. In many cases the success of one or more of the analyses was limited by the quality of the source data. This section of the results will document the relative strength and weakness of the various technologies and data sources.

GIS was used to create, store, and manipulate data layers for MBRNHP. It was also used to create maps and other visual aides that appear in this report. GIS was

Table 4.12 Pros and cons of GIS, remote sensing and GPS

	PROS	CONS
	GIS Technology	
• Storage • Creation • Mapping	• GIS allows historical data to be created, displayed, and stored in one efficient platform • GIS layers can be transferred to GPS for navigation and GPS data can be stored in a GIS • RS Images can be stored in a GIS	• Users must have some proficiency in software to effectively manipulate the data • Manual layer creation and documentation is time intensive
	Remote Sensing Images & Digital Image Processing	
• Registration • Rectification • Mosaicking • Band Ratioing • Change Detection • Image Classification	• Remote sensing tools allow for the creation of map accurate aerial photographs and satellite scenes that can be stored in a GIS • Digital copies of maps can be registered to geographic coordinates and stored in a GIS Additional analyses can be conducted on digital images to highlight important features	• Digital remote sensing requires a sophisticated hardware/ software setup with large amounts of hard disk space • Proper processing and analysis is limited to a specific data type (e.g. Band ratioing cannot be conducted on historic maps)
	GPS For Historic Feature Verification	
• Navigation • Data Collection	• Accurate and efficient tool for navigating to features in the field • GPS can be customized to make field data collection more efficient	• GPS satellite reception is poor on north facing slopes, or under heavy tree canopy

essential to the success of the project, and served to integrate the RS and GPS data. Remote sensing, or the use of remote sensing software, was used to manipulate the digital versions of maps, aerial photographs, and satellite images. The resulting analyses conducted using RS were stored and displayed in GIS. GPS was used to navigate to, and catalog the various features identified during the RS process. These tools were used synergistically, and the absence of any one of them would have stymied the progress of the research project.

Over the course of this project an evaluation of the maps, aerial photographs, and satellite imagery used to examine landscape conditions at MBRNHP was conducted. After conducting historic analysis tasks it became apparent that certain digital evaluation techniques were better suited to different types of data. The evaluation focused on two main factors of spatial data: positional accuracy and potential use. Positional accuracy was evaluated earlier in this chapter (see Accuracy of Registered and Rectified Sets, pg. 69). Potential uses for the data will focus on the digital evaluation techniques, and the relative strengths and weakness for historic landscape research.

The historic maps of the MBRNHP area were difficult to evaluate as a single data set. For the purpose of discussion, the maps will be broken into three categories: maps prior to 1880, the Doton Survey, and maps from 1900s to the present. Maps of the MBRNHP area that were created prior to 1880 were most useful for identifying small scale features, such as roads and town boundaries, and identifying the spatial relationships between features (e.g.. the Pogue lies to the northeast of the Village of

Woodstock). The small scale and poor spatial accuracy in these base maps resulted in misaligned images. The Doton Survey was perhaps the single most useful layer for historic landscape analysis. The level of detail and accuracy of this layer made it well suited to rectification and subsequent conversion into GIS layers. Maps from the 1900s to the present, including Sanborn Fire Insurance maps and USGS topographic maps were also well suited to registering/rectification and GIS layer creation. In general large scale maps provided the best rectification results.

Aerial photographs of the MBRNHP area were particularly well suited to the historic landscape investigation in this project (Table 4.13). For a proper discussion the aerial photographs must be separated into two data types: panchromatic and CIR. Panchromatic photographs were rectified, and in some cases mosaicked to create digital photomaps. This process proved to be most successful when the original medium was a 10” by 10” print. Larger images (e.g. the 36” x 36” VT orthophotos) were more difficult to process due to the large file size and poor image quality. Panchromatic photographs were most useful for change detection analyses, and were successfully used to show differences in forest vegetation on the MBRNHP property (See Figures 4.11 and 4.12). CIR images were also successfully rectified to create digital photomaps. Once again, the medium determined the overall success of this process; the 1992 film print image was able to be used for further RS analyses, while the 1977 transparency produced an image with streaks and artifacts (See Appendix C). Due to the enhanced differences in vegetation types, the 1992 CIR image was useful for manual photointerpretation and digital edge detection. In addition the CIR photographs were taken at a higher elevation resulting in a smaller nominal scale than most of the panchromatic images.

Table 4.13 Strength and weaknesses for aerial photographs of MBRNHP

Aerial Photographs	Strengths	Weaknesses
Panchromatic	• Available from the 1930s to the present • Manual photointerpretation • Change detection • Large scale	• Different mediums • Edge detection between different vegetation types
Color Infrared	• Available from the 1970s to the present • Manual photointerpretation • Edge detection	• Different mediums • Limited number of photographs • Change detection • Medium scale

There were two satellite scenes collected for the MBRNHP property: a CORONA satellite photograph from 1968 and an IKONOS satellite scene from 2001. The CORONA photograph was, in almost all respects, similar to a panchromatic aerial photograph. The exception is that it was taken from an extremely high altitude and that the medium was long strip negative. This image was successfully georeferenced, but due to the small scale it was not useful for change detection, edge detection or photointerpretation. The IKONOS satellite scene was the only image collected that was appropriate for advance digital image processing such as band ratioing and digital land cover classification. However, the IKONOS scene was the most expensive product used, costing 30 to 40 times as much as the other data sources and requires the costly image processing software.

Overall, the results of this project show that maps, aerial photographs, and satellite scenes can be used to document changes on a historic landscape such as MBRNHP. The interpretation of the information contained within these data can be used to reconstruct the historic landscape and. Older maps, those created before adequate survey control, are less useful for GIS layer creation and digital image processing. Ground surveys, if available, are excellent resources for accurate GIS layer creation that can be used in GPS navigation and historic feature documentation. More recent maps, at least those created with survey control, are useful for documenting the presence or absence of constructed features on the landscape. Aerial photographs serve as good resource for land cover layer creation through various digital image processing techniques, and for automated change detection. Finally, high-resolution digital satellite images unlock the power of advanced RS techniques to investigate the landscape, but at a high cost.

Chapter V: Conclusion

This study offered a unique opportunity to demonstrate the utility of RS, GIS, and GPS technology for historic research. These technologies were used to explore, define, and reconstruct the historic landscape of the MBRNHP. One of the additional benefits of this study was that it served practical as well as research-oriented purposes. In addition to testing new approaches and methods for historic analyses, a GIS database of historical maps and photographic layers was created for future planning and management of park resources. The study and its associated database will aid those who wish to conduct further research at MBRNHP.

The remote sensing techniques including edge enhancement, band ratioing, change detection and classification, as well as manual photointerpretation, were used to examine and reconstruct the landscape at MBRNHP. Edge enhancement of aerial photographs and satellite images improved detection of historic linear features such as stonewalls, roads, plantation boundaries, and conifers vs. hardwoods in MBRNHP. Band ratioing provided images where vegetation types and developed vs. vegetated areas were easily differentiated. Digital change detection highlighted potential areas of change that were then verified on the respective source images. Manual change detection worked well to identify and quantify areas that were converting from agricultural fields or pastures to natural forest or forest plantations. Classification of the IKONOS satellite scene provided a systematic method for creating a current conditions land cover map of MBRNHP.

GIS was used as the vehicle to store, display and manipulate spatially-explicit data for this study. Environmental Systems Research Institute's GIS software proved to be an efficient platform for managing the large amount of data required. Spatial data was easily stored, maintained, and updated within a customized framework that allowed for map generation, and ancillary data creation. Registration of the GIS data layers provided the basis for a comparison of landscape features over time. The GIS database, created as part of this research in addition to the previously available CLR database, will provide MBRNHP with a substantial and valuable resource for future historic research and resource management of the park.

The process of identifying historic map features, entering the data into a GIS, and navigating to the field site was a new application for GPS technology. At MBRRNHP, features found on historic maps (e.g. buildings and roads), aerial photographs, and satellite images (e.g. forest plantations and stonewalls) were successfully located in the field using GPS navigation. In addition to the confirmation of features previously located on historic maps and photography, GPS was also used to record the location of new features found while in the field. Overall GPS success was due in some part to the availability of high quality historic base map data (e.g. Doton Survey) and the well-preserved landscape of MBRNHP.

In combination, GIS, RS and GPS provide historic preservation practitioners with a powerful management and research tool. GIS and RS allows investigators to document landscape change over time through digital change detection and manual photo-interpretation, identify potential historic landscape features using edge enhancement and band ratioing, and to verify the existence of landscape features using GPS technology. The results of historic research are readily presented as maps and charts, through the use of a GIS illustrating the condition of the historic landscape at MBRNHP.

Today, as the human population expands, understanding and preserving our cultural heritage becomes more and more important. Marsh-Billings-Rockefeller National Historical Park has served as a test area for the demonstration of Geographic Information Systems, remote sensing and Global Positioning Systems as historic research tools. Cultural resource professionals and historic preservation practitioners have been provided with a demonstration of the techniques and tools, presented in this paper, to help better understand their utility in the study of landscape evolution.

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Appendix A: Digital Database for Marsh-Billings-National Historical Park

This digital database contains the images and coverages that were obtained and created during the course of this project. Each data layer is provided in both Vermont State Plane and UTM projection. Vermont State Plane layers are zone 4400, meters, NAD 1983. UTM layers are zone 18, meters. State Plane projection layers were provided to allow for ease of use with most of the GIS data available covering the state of Vermont. UTM layers were provided to comply with federal standards for geospatial data. All layers are available through MBRNHP.

Aerial Photographs and Satellite Scenes

Table A1 MBRNHP digital database file names for remotely sensed images

Original Data (Filename)	MBRNHP Database Name (Imagine 8.5 Image File)	MBRNHP Database Name (GeoTiff file)
1939 Aerial Photograph (aerial1939.tif)	1939ae_sp.img 1939ae_u.img	1939ae_sp.tif 1939ae_u.tif
1954 Aerial Photographs (aerial1954_a.tif) (aerial1954_b.tif)	1954aemos_sp.img 1954aemos_u.img	1954aemos_sp.tif 1954aemos_u.tif
1962 Aerial Photographs (aerial1962_a.tif) (aerial1962_b.tif)	1962aemos_sp.img 1962aemos_u.img	1962aemos_sp.tif 1962aemos_u.tif
1968 Aerial Photographs (aerial1968_a.tif) (aerial1968_b.tif)	1968aemos_sp.img 1968aemos_u.img	1968aemos_sp.tif 1968aemos_u.tif
1974 Aerial Photographs (aerial1974_a.tif) (aerial1974_b.tif)	1974aemos_sp.img 1974aemos_u.img	1974aemos_sp.tif 1974aemos_u.tif
1977 Aerial CIR (cir1977.tif)	1977cir_sp.img 1977cir_u.img	1977cir_sp.tif 1977cir_u.tif
1980 Aerial Photograph (aerial1980.tif)	1980ae_sp.img 1980ae_u.img	1980ae_sp.tif 1980ae_u.tif
1992 Digital Orhtomosaic (vmpdoq_utm83.gis)	1992aemos_sp.img 1992aemos_u.img	1992aemos_sp.tif 1992aemos_u.tif
1994 Digital Orthophoto: (VT148124.lan)	1994ae_sp.img 1994ae_u.img	1994ae_sp.tif 1994ae_u.tif
1968 Corona Satellite Scene corona.tif	1968corona_sp.img 1968corona_u.img	1968corona_sp.tif 1968corona_u.tif
2001 IKONOS Pan. (po_73597_pan_0000000.tif)	ikpan_sp.img ikpan_u.img	ikpan_sp.tif ikpan_u.tif
2001 IKONOS Multispectral (po_73597_blu_0000000.tif) (po_73597_grn_0000000.tif) (po_73597_red_0000000.tif) (po_73597_nir_0000000.tif)	ik4bnd_sp.img ik4bnd_u.img	ik4bnd_sp.tif ik4bnd_u.tif

Historical Maps

Table A2 MBRNHP digital database file names for historical maps

Historical Map (Filename)	MBRNHP Database Name (Imagine 8.5 Image File)	MBRNHP Database Name (GeoTiff file)
Woodstock, Town Map (woodstock1832.tif)	1832wdinst_sp.img 1832wdinst_u.img	1832wdinst_sp.tif 1832wdinst_u.tif
Woodstock Town Map (woodstock1856.tif)	1869windsor_sp.img 1832windsor_u.img	1869windsor_sp.tif 1832windsor_u.tif
Postal Atlas – Windsor Co. (Windsorco1869.tif)	NA	NA
1904 Sanborn Fire Insurance (Sanborn1904.tif)	1904sand_sp.img 1904sand_u.img	1904sand_sp.tif 1904sand_u.tif
1910 Sanborn Fire Insurance (Sanborn1910.tif)	1910sand_sp.img 1910sand_u.img	1910sand_sp.tif 1910sand_u.tif
1911 USGS 15' Quadrangle (wood11ne.jpg)	1911topo_sp.img 1911topo_u.img	1911topo_sp.tif 1911topo_u.tif
1913 USGS 15' Quadrangle (woodne13.jpg)	1913topo_sp.img 1913topo_u.img	1913topo_sp.tif 1913topo_u.tif
1943 USGS 15' Quadrangle (wood43ne.jpg)	1943topo_sp.img 1943topo_u.img	1943topo_sp.tif 1943topo_u.tif
1983 Woodstock North and South USGS 7.5, Quadrangle (woodstock north.tif) (woodstock south.tif)	1983topo_sp.img 1983topo_u.img	1983topo_sp.tif 1983topo_u.tif

Coverages

Table A3 MBRNHP digital database file names for polygon files

Date	**Coverage Description**	**Source**	**MBRNHP Database Name**
1939	Land Cover	Aerial Photograph	Ae_lc1939
1954	Land Cover	Aerial Photographs	Ae_lc1954
1962	Land Cover	Aerial Photographs	Ae_lc1962
1968	Land Cover	Aerial Photographs	Ae_lc1968
1968	Land Cover	CORONA Image	corona_lc1968
1974	Land Cover	Aerial Photographs	Ae_lc1974
1977	Land Cover	CIR Aerial Photograph	cir_lc1977
1980	Land Cover	Aerial Photograph	Ae_lc1980
1992	Land Cover	Aerial Photographs	Ae_lc1992
1992	Land Cover	CIR Aerial Photograph	cir_lc1992
1994	Land Cover	1994 DOQ	Ae_lc1994
2001	Land Cover	2001 IKONOS Image	ikon_lc2001

1832	Pogue Hole	Woodstock Map	wd1832pogue
1888	Buildings	Doton Survey	Dotbuild
1888	Lilly Pond	Doton Survey	Dotlily
1911	Pogue Pond	USGS Topo Quad	wd1911pogue
1913	Pogue Pond	USGS Topo Quad	wd1913pogue
1943	Pogue Pond	USGS Topo Quad	wd1943pogue
1980	Pogue Pond	USGS Topo Quad	wd1980pogue

Table A4 MBRNHP digital database file names for linear and point features

Date	**Coverage Description**	**Source**	**MBRNHP Database Name**
1939	Stone Walls	Aerial Photograph	ae1939stwall
1962	Stone Walls	Aerial Photographs	ae1962stwall
1962	Roads	Aerial Photographs	ae1962rds
1968	Stone Walls	Aerial Photographs	ae1968stwall
1974	Stone Walls	Aerial Photographs	ae1974stwall
1832	Buildings	Woodstock Map	wd1832build
1832	Roads	Woodstock Map	wd1832rds
1832	Streams	Woodstock Map	wd1832strm
1888	Pogue Pipeline	Doton Survey	dotpline
1888	Carriage Roads	Doton Survey	dotroad
1888	Streams	Doton Survey	dotstrm
1869	Buildings	Windsor County Map	win1869build
1869	Roads	Windsor County Map	win1869rds
1869	Streams	Windsor County Map	win1869strm
1869	Railroad	Windsor County Map	win1869rr
1911	Buildings	USGS Topo Quad	wd1911build
1911	Roads	USGS Topo Quad	wd1911rds
1911	Streams	USGS Topo Quad	wd1911strm
1913	Buildings	USGS Topo Quad	wd1913build
1913	Roads	USGS Topo Quad	wd1913rds
1913	Streams	USGS Topo Quad	wd1913strm
1943	Buildings	USGS Topo Quad	wd1943build
1943	Roads	USGS Topo Quad	wd1943rds
1943	Streams	USGS Topo Quad	wd1943strm
1980	Buildings	USGS Topo Quad	wd1980build
1980	Roads	USGS Topo Quad	wd1980rds
1980	Streams	USGS Topo Quad	wd1980strm

Table A5 MBRNHP digital database file names for raster layers

Description	**Source**	**MBRNHP Database Name**
IR/Red Band Ratio	IKONOS Scene	ik_ir_red
Normalized Differnce Vegetative Index	IKONOS Scene	ikndvi
Classed Satellite Scene	IKONOS Scene	ik_class

Appendix B: Example RMS Assessment for Registered Images

The resampling technique used to georeference historical aerial photographs and maps tended to underestimate the positional error present in finalized GIS layers. Contributing factors to the underestimation were the small pixel size (around 1 meter) and the cubic convolution resampling algorithm. Rather than relying on the error estimate produces while georeferencing the aerial photographs, a manual method was used. In the case of aerial photographs, where multiple resampling of the base image occurred, the manual method of RMS calculation was used on the finalized image and not intermediate images.

The method used to test the positional error (RMS error) of georefeerenced aerial photographs is endorsed by the Federal Geographic Data Committee (FGDC). The FGDC is an interagency committee that combine senior and cabinet level members of 19 federal agencies and is responsible for developing the National Spatial Data Infrastructure for the United States. This committee sets the rules and standards for geospatial data.

For this research project the RMS testing was conducted by comparing known points of registered aerial photographs with matching points on the most accurate data available (VT DOQ # 148124). RMS was then calculated using the simple formula: $(x_{reg} - x_{DOQ})^2 + (y_{reg} - y_{DOQ})^2$. An example of the process is shown for the 1968 Aerial photographic mosaic.

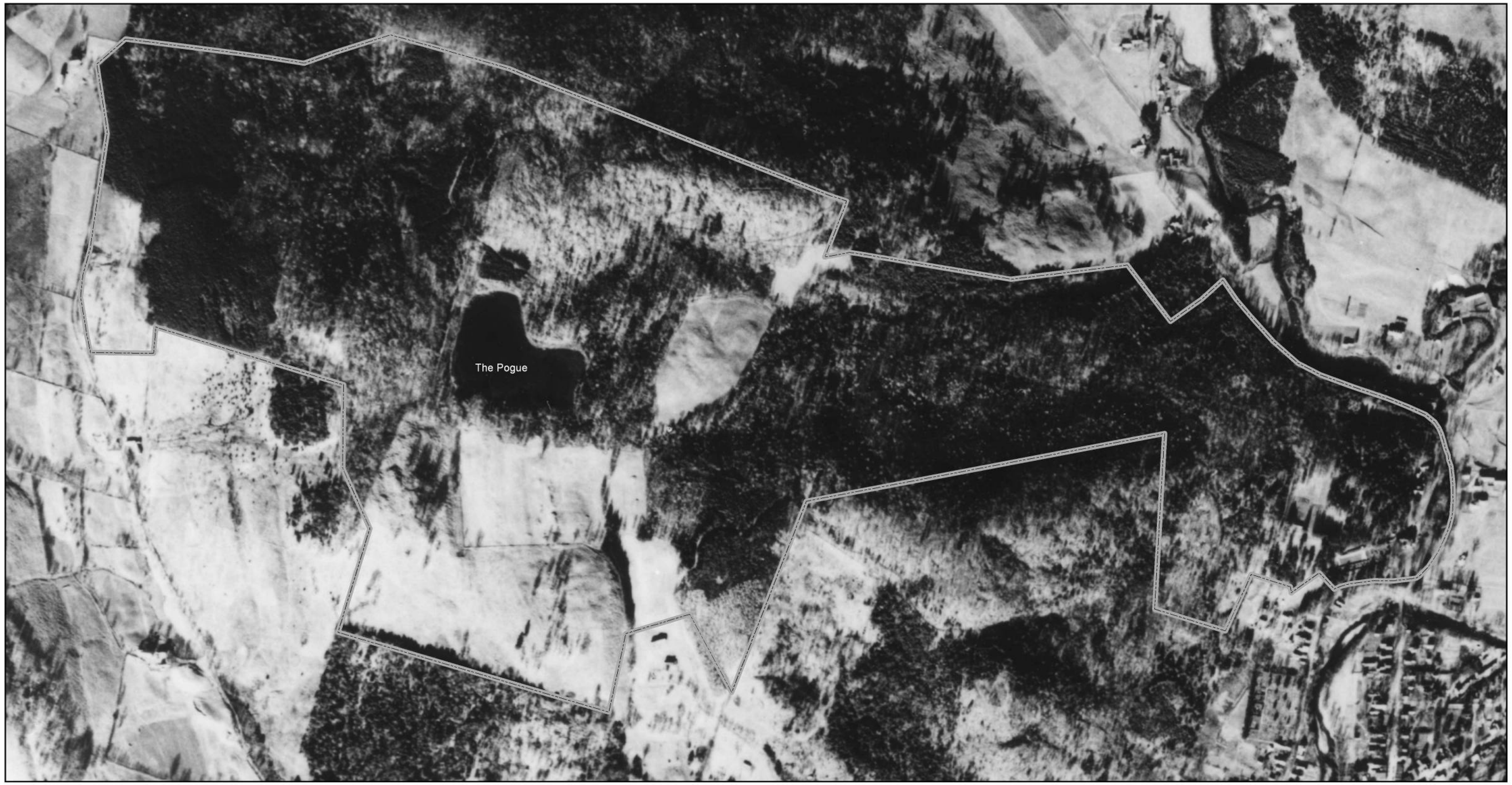
Table B1 Example of accuracy assessment for the 1968 aerial photographic mosaic using the 1994 DOQ as the master image

Point number	Point description	x (independent)	x (test)	diff in x	(diff in x) ^{2}	y (independent)	y (test)	diff in y	(diff in y) ^{2}	(diff in x) ^{2} + (diff in y) ^{2}
1	greenhouse_se	498444.29	498443.27	1.02	1.04	125513.97	125514.49	-0.52	0.27	1.31
2	bridge1_nw	498514.19	498520.31	-6.12	37.45	125418.48	125427.78	-9.30	86.49	123.94
3	billingsbarn_nw	498689.82	498693.86	-4.04	16.32	125692.15	125691.93	0.22	0.05	16.37
4	landing_ne	498453.82	498454.36	-0.54	0.29	125831.03	125830.42	0.61	0.37	0.66
5	bridge2_nw	497580.64	497572.37	8.27	68.39	126932.70	126932.12	0.58	0.34	68.73
6	pogued_sw	496653.79	496652.14	1.65	2.72	125836.82	125832.87	3.95	15.60	18.32
7	larch_nw	496917.43	496913.59	3.84	14.75	125434.14	125433.97	0.17	0.03	14.77
8	stwall_corner	496458.31	496468.06	-9.75	95.06	125539.06	125543.82	-4.76	22.66	117.72
9	farm_east	495604.98	495605.63	-0.65	0.42	126615.91	126617.05	-1.14	1.30	1.72
10	sw_corner1	495761.02	495761.26	-0.24	0.06	125966.14	125960.94	5.20	27.04	27.10
11	hayfield_s	496883.22	496884.59	-1.37	1.88	125792.14	125793.50	-1.36	1.85	3.73
12	farm2_n	497972.36	497972.99	-0.63	0.40	126705.46	126713.52	-8.06	64.96	65.36
13	bridge3_sw	497939.14	497939.32	-0.18	0.03	126853.72	126872.99	-19.27	371.33	371.37
14	hayfield2_w	497180.72	497179.54	1.18	1.39	126155.73	126152.67	3.06	9.36	10.76
15	road_int	497967.54	497965.66	1.88	3.53	126466.73	126461.76	4.97	24.70	28.24
16	farm3_n	498724.58	498730.50	-5.92	35.05	125927.33	125922.93	4.40	19.36	54.41
17	dtown1_nw	498513.71	498516.38	-2.67	7.13	125062.09	125061.64	0.45	0.20	7.33
18	covbridge_nw	498329.10	498329.70	-0.60	0.36	124945.40	124949.92	-4.52	20.43	20.79
19	sw_corner2	495625.88	495630.85	-4.97	24.70	125967.94	125967.85	0.09	0.01	24.71
20	wpine_rd	496563.00	496564.12	-1.12	1.25	126161.58	126160.53	1.05	1.10	2.36
									sum	979.70
									average	48.98
									RMSE	7.00
									NSSDA	12.11

Appendix C: Aerial Photography Map Prints

1939 Aerial Photograph

Marsh-Billings-Rockefeller National Historical Park



0 125 250 500 Meters

N

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: Aerial Photograph (CIW 4-141) acquired by Natural Resources Conservation Service, Nov. 20, 1939 (Nominal Scale - 1:30,000) print located in the Billings Family Archives, Woodstock, VT; Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure C1 1939 Aerial photograph map

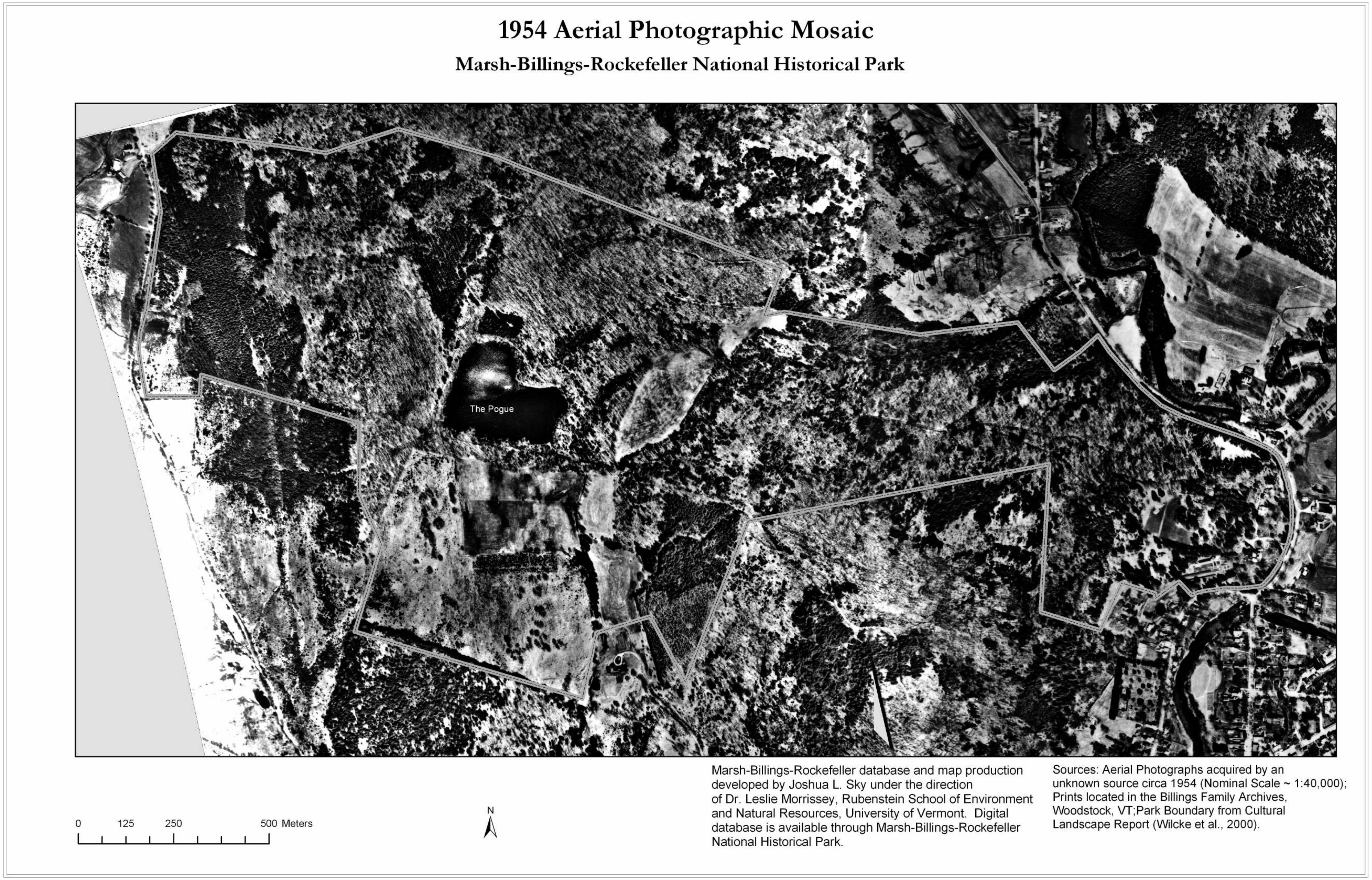
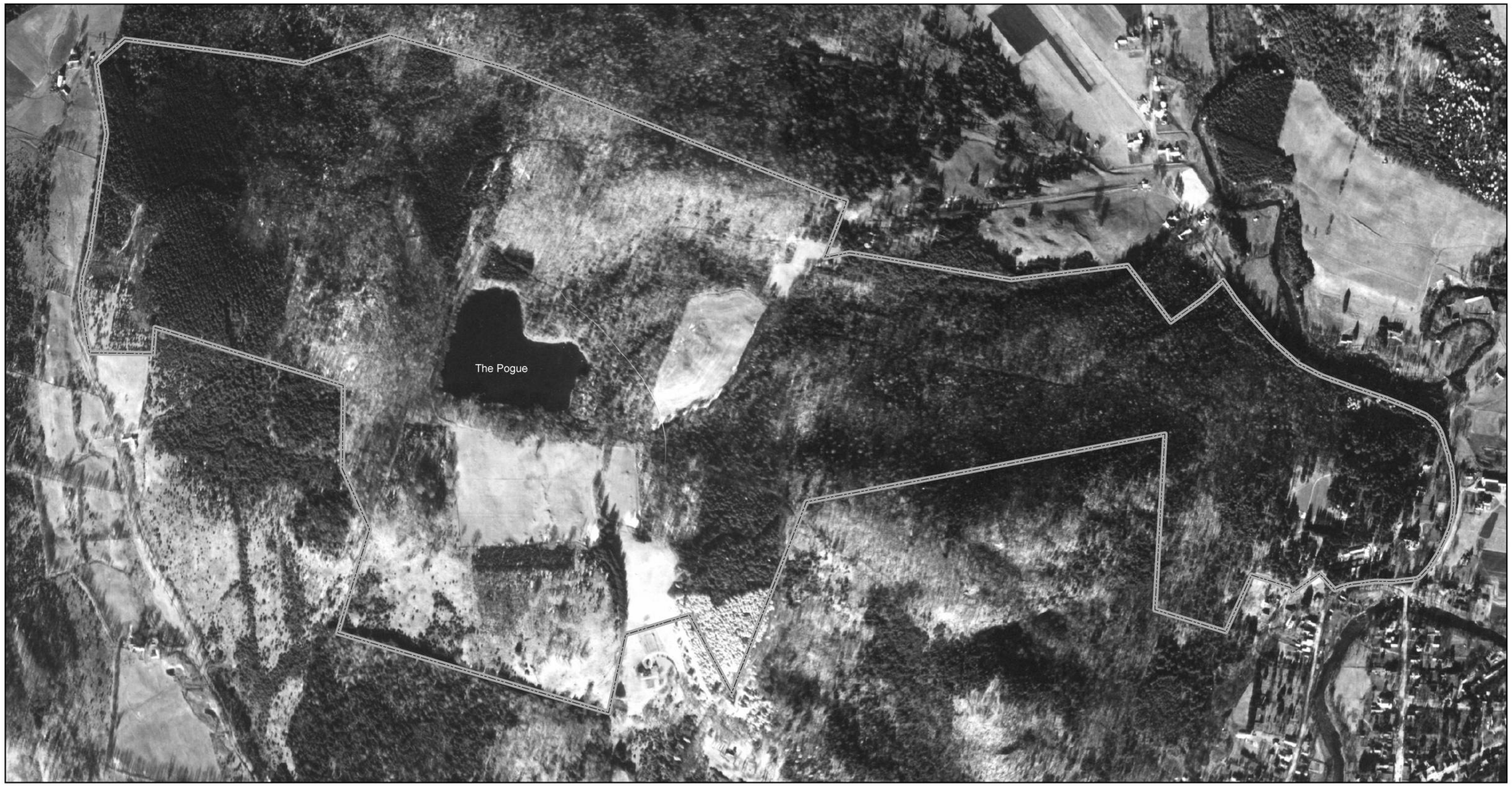


Figure C2 1954 Aerial photograph map

1962 Aerial Photographic Mosaic

Marsh-Billings-Rockefeller National Historical Park



0 125 250 500 Meters

N

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, School of Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: 1962 Aerial Photographs (62-36-139 & 62-36-220) acquired by Vermont Department of Highways. Print located in Bailey Howe Library Map Room, University of Vermont;Park Boundary from M-B-R Cultural Landscape Report (Wilcke et al., 2000).

Figure C3 1962 Aerial photograph map

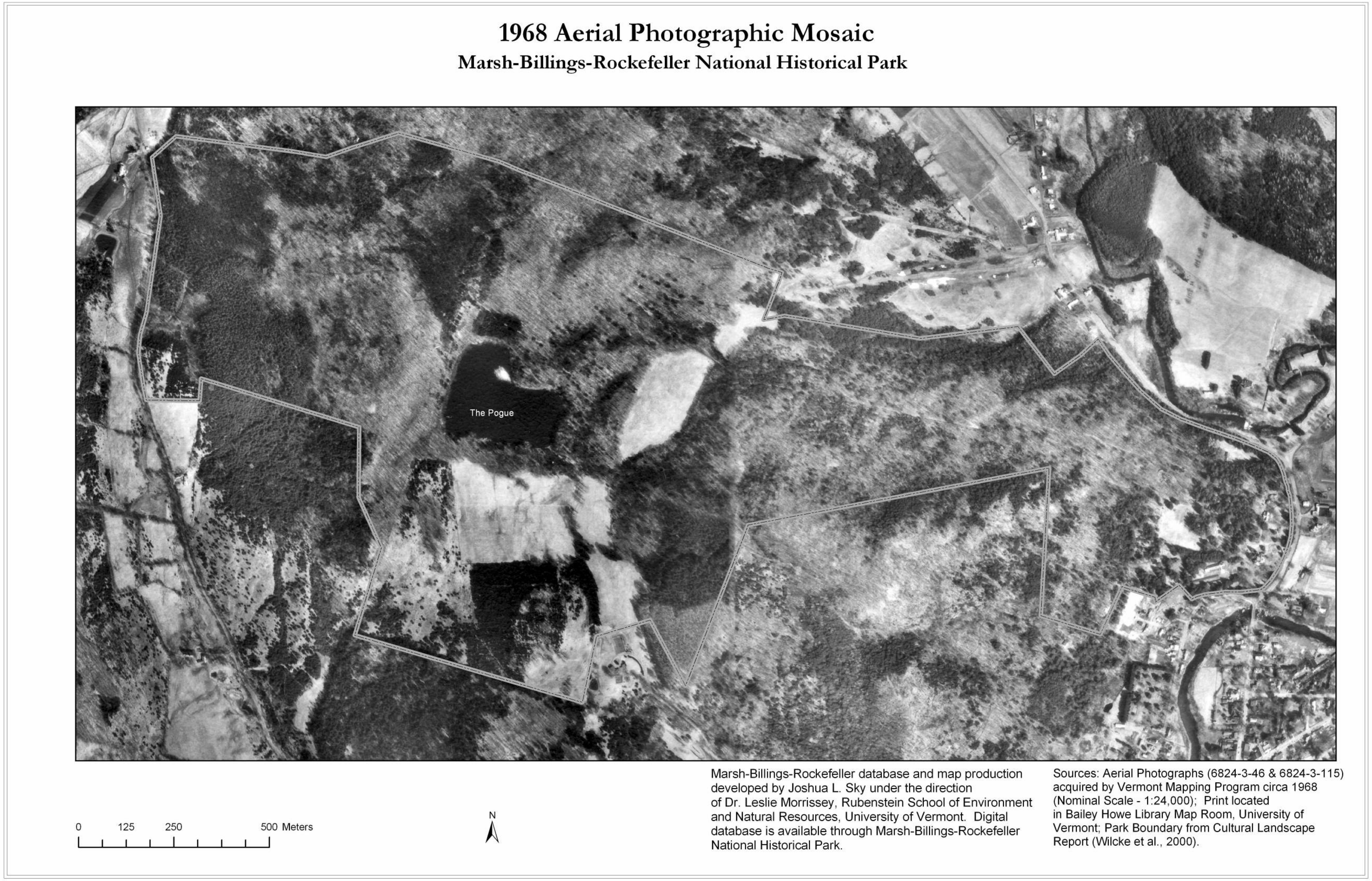


Figure C4 1968 Aerial photograph map

1974 Aerial Photographic Mosaic

Marsh-Billings-Rockefeller National Historical Park

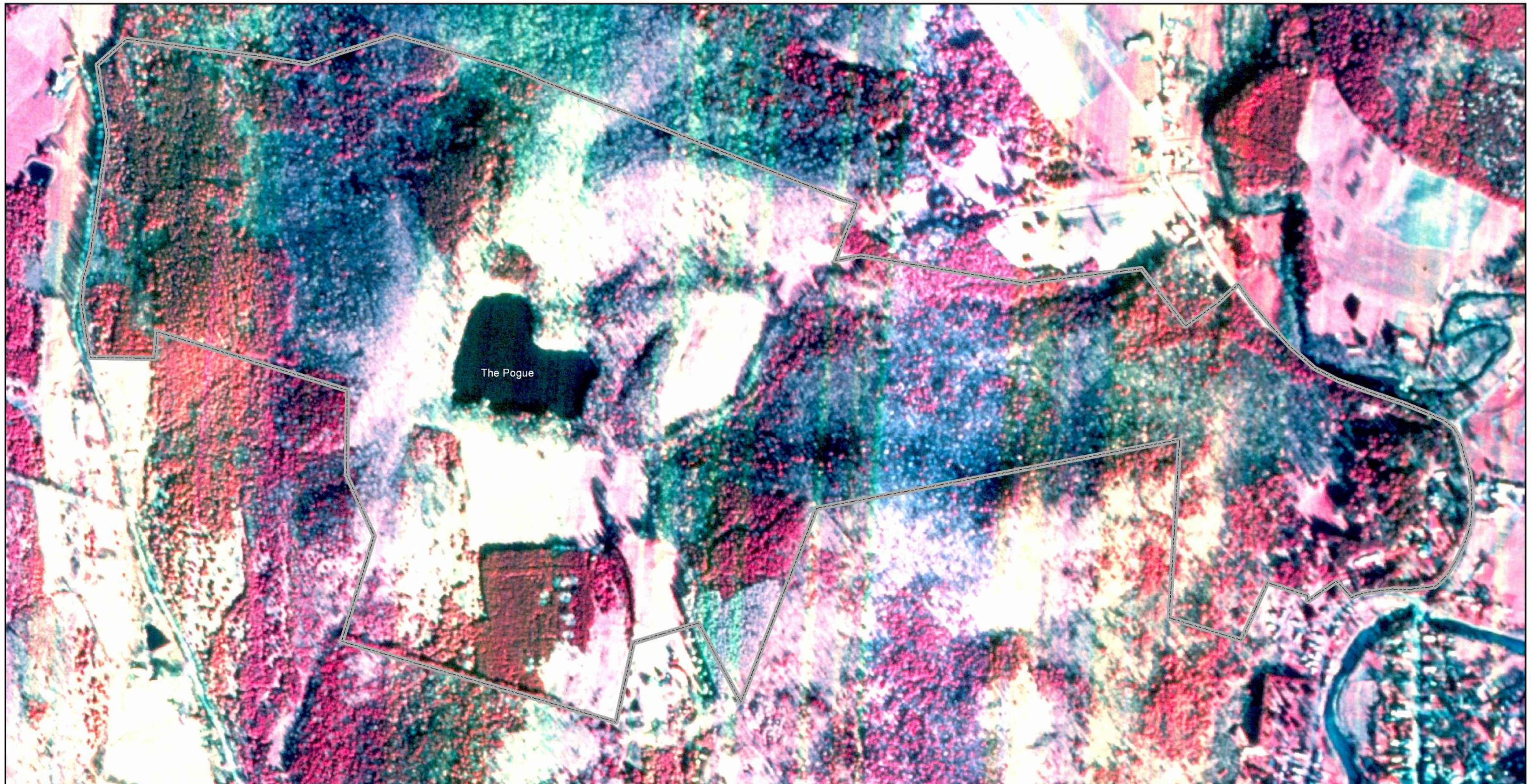
Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: Aerial Photographs (7420-10-212 & 7420-10-193) acquired by the State of Vermont May 15, 1974 (Nominal Scale - 1:20,000). Prints located in Bailey Howe Library Map Room, University of Vermont; Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure C5 1974 Aerial photograph map

1977 CIR Aerial Photograph

Marsh-Billings-Rockefeller National Historical Park



Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: CIR Aerial Photograph (4193-13) acquired by US Army circa 1977 (Nominal Scale - 1:80,000); Print located in Bailey Howe Library Map Room, University of Vermont; Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

0 125 250 500 Meters

N

Figure C6 1977 CIR Aerial photograph map

1980 Aerial Photograph

Marsh-Billings-Rockefeller National Historical Park

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: Aerial Photograph (40 50027 180-99) acquired on September 12, 1980 by USDA APFO, Salt Lake City, UT (Nominal Scale -1:40,000); Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure C7 1980 Aerial photograph map

1992 CIR Aerial Photograph

Marsh-Billings-Rockefeller National Historical Park

0 125 250 500 Meters

N

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: CIR Aerial Photograph (NAPP 4193-13) acquired on April 27, 1992 by the USGS NAAP (Nominal Scale - 1:40,000); Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure C8 1992 CIR Aerial photograph map

Figure C9 1992 Aerial photograph map

1994 Digital Orthophotography Quadrangle

Marsh-Billings-Rockefeller National Historical Park

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: DOQ (148124) acquired on April 20, 1994 by the Vermont Mapping Program Waterbury, VT (Nominal Scale - 1:30,000, Projection - VT State Plane); Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure C10 1994 Aerial photograph map

Appendix D: Satellite Scene Map Prints

1968 CORONA Satellite Photograph

Marsh-Billings-Rockefeller National Historical Park

0 125 250 500 Meters

N

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: CORONA film negative (DS1104-2127DA004) acquired on August 8, 1968 was purchased from the EROS Data Center, Sioux Falls, SD (Nominal Scale - 1:247,500, Resolution - 2.5 meters); Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure D1 1968 CORONA satellite photograph map

2001 IKONOS (1-Meter) Panchromatic Satellite Scene

Marsh-Billings-Rockefeller National Historical Park

0 125 250 500 Meters

N

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: IKONOS scene acquired by Space Imaging Corporation, Thornton, CO, on June 19, 2001; Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure D2 2001 IKONOS panchromatic satellite scene

Normalized Difference Vegetative Index
2001 IKONOS Satellite Data

Marsh-Billings-Rockefeller National Historical Park

0 125 250 500 Meters

N

Value

High : 0.67

Low : 0.02

Marsh-Billings-Rockefeller database and map production developed by Joshua L. Sky under the direction of Dr. Leslie Morrissey, Rubenstein School of Environment and Natural Resources, University of Vermont. Digital database is available through Marsh-Billings-Rockefeller National Historical Park.

Sources: IKONOS scene acquired by Space Imaging Corporation, Thornton, CO, on June 19, 2001; Park Boundary from Cultural Landscape Report (Wilcke et al., 2000).

Figure D3 2001 IKONOS NDVI satellite scene

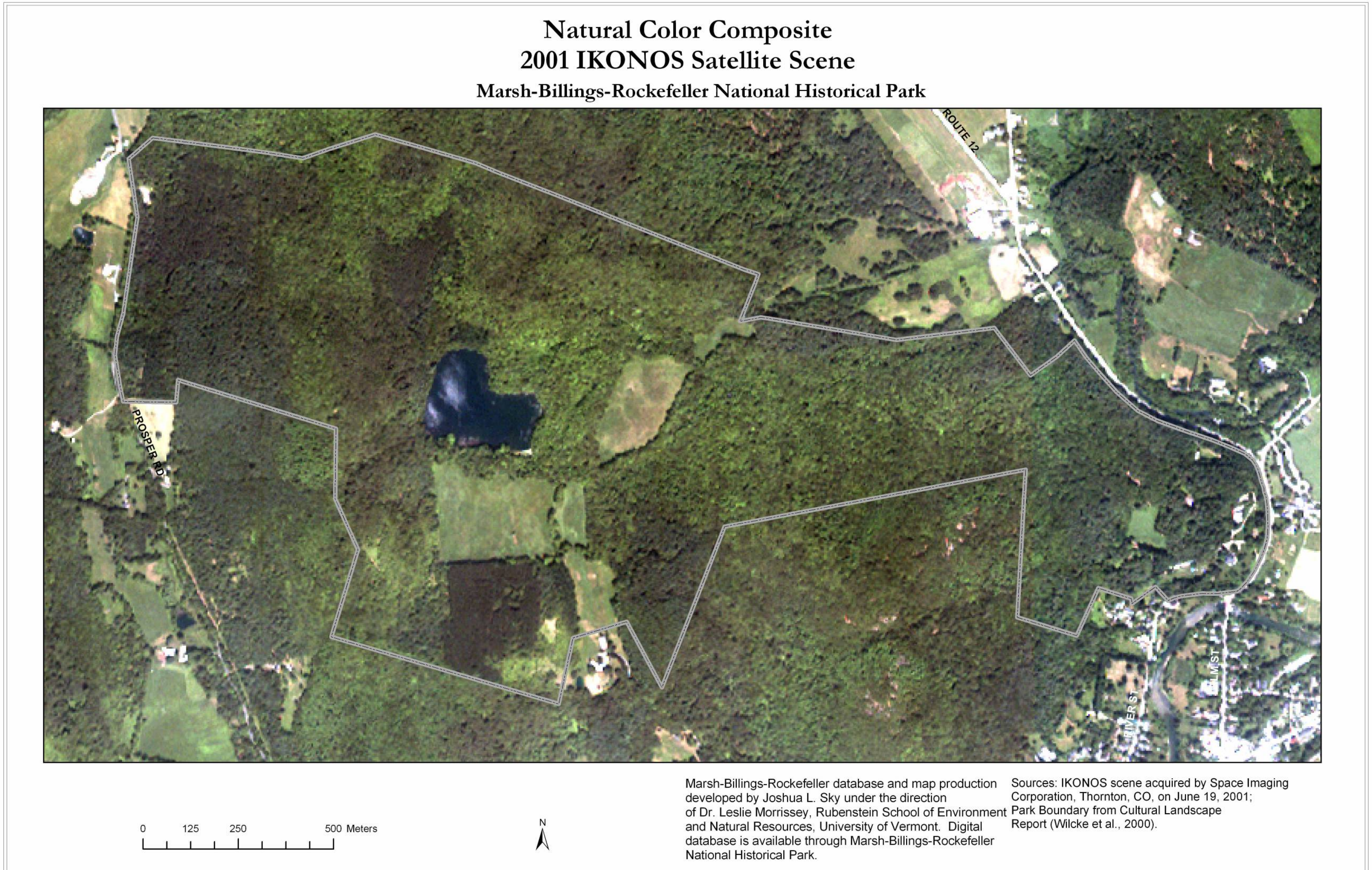


Figure D4 2001 IKONOS natural color satellite scene

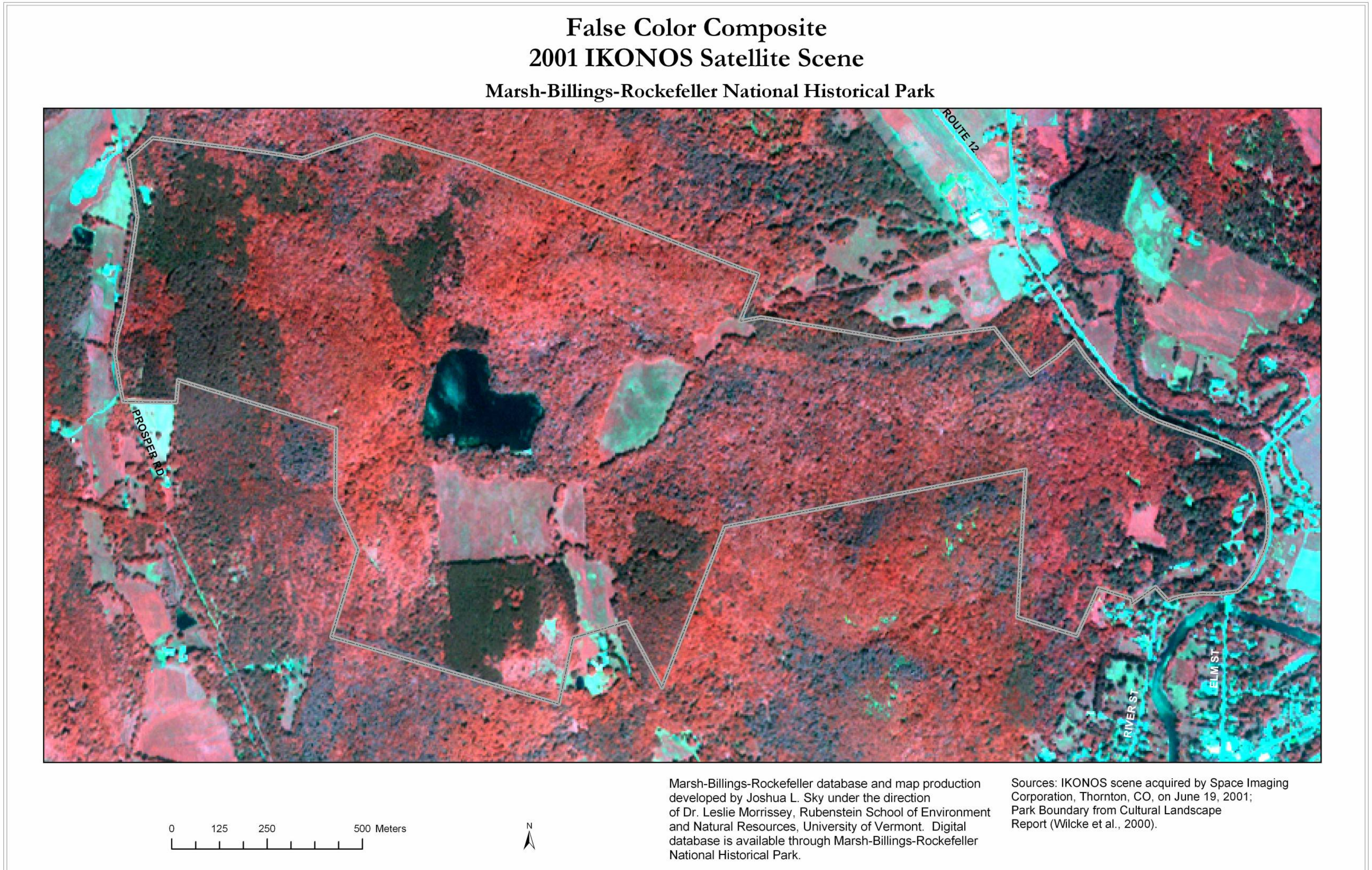


Figure D5 2001 IKONOS false color composite satellite scene

Appendix E: Selected Historic Maps

Figure E1 Map of New England, Published in 1756
(Courtesy of Library of Congress, American Memories Web Site)

Figure E2 Map of Vermont, Published in 1826
(Courtesy of Library of Congress, American Memories Web Site)

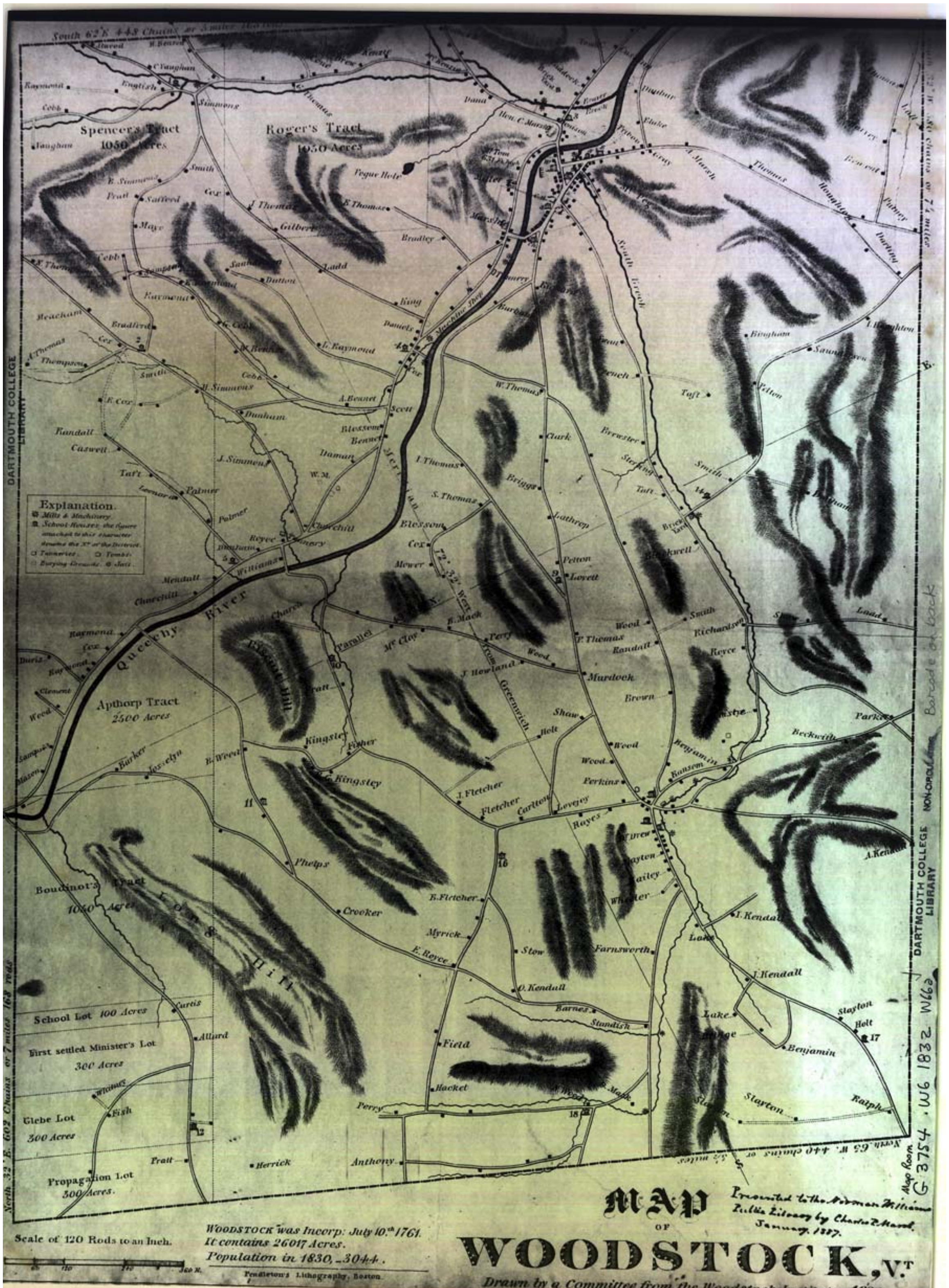


Figure E3 Map of Woodstock, VT Published in 1832
(Courtesy of Dartmouth University Map Room)

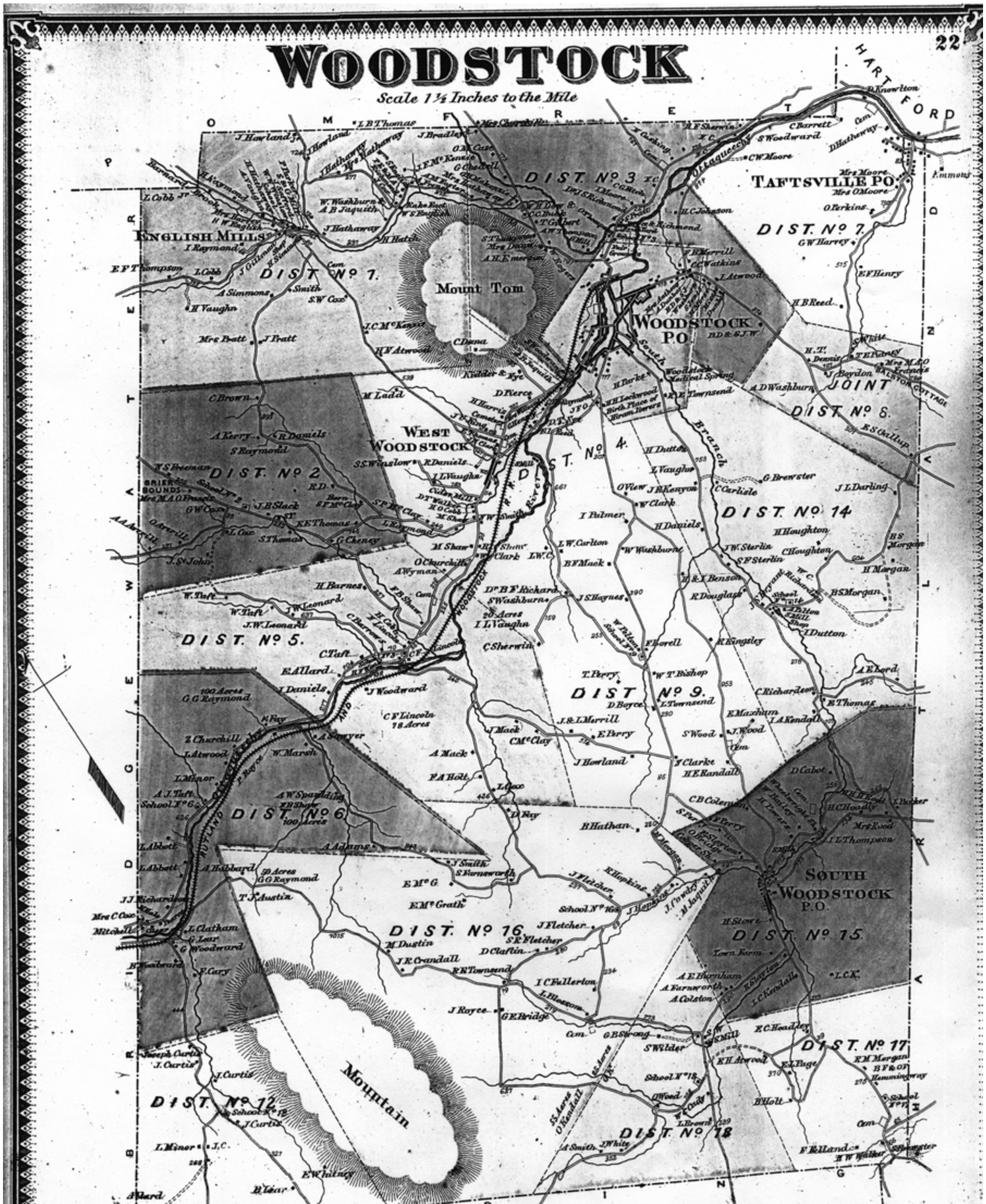


Figure E4 1869 Map of Windsor County from Burr Postal Atlas
(Courtesy of University of Vermont Special Collections, Bailey-Howe Library)

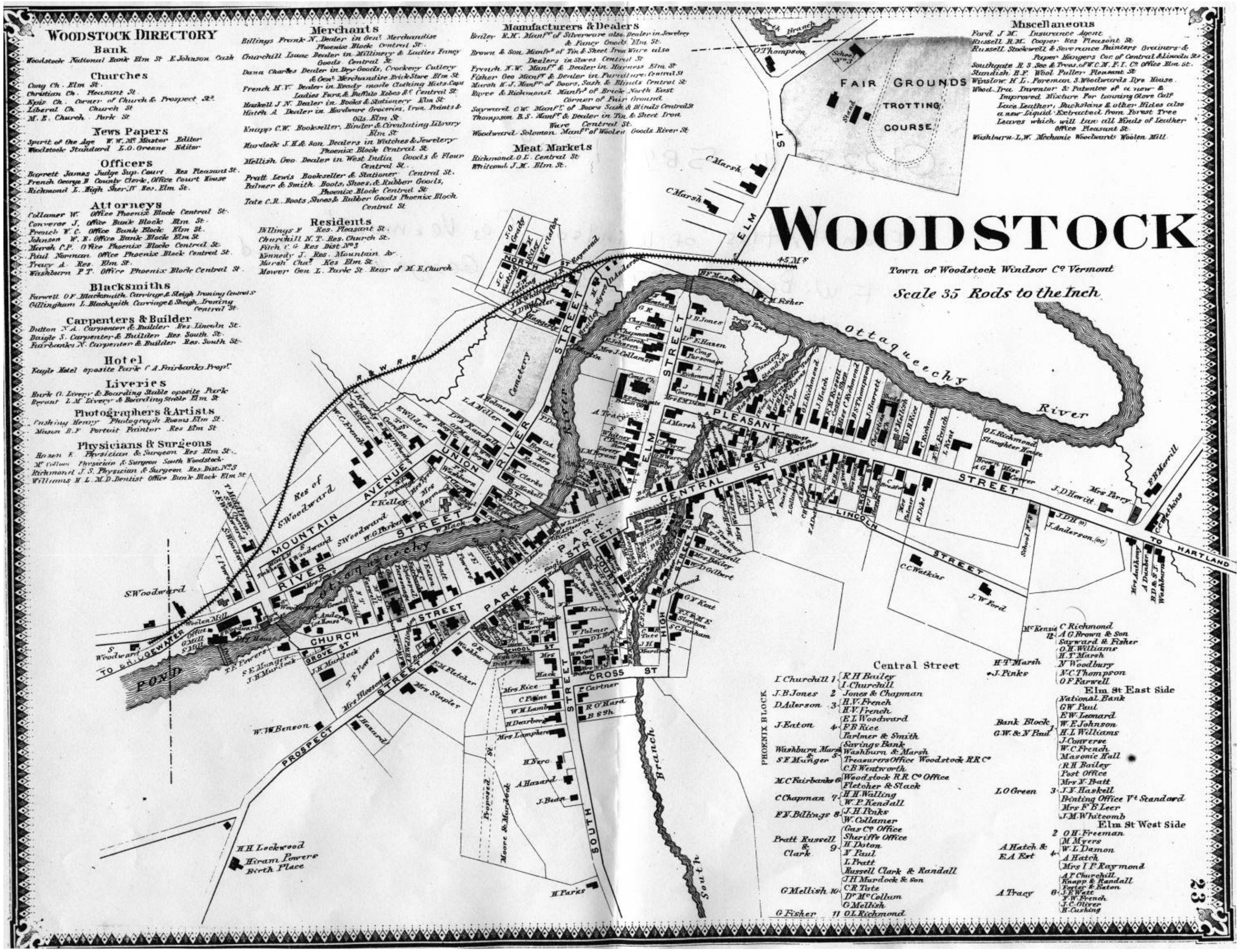


Figure E5 1869 Map of the Town of Woodstock from the Burr Postal Atlas
(Courtesy of Library of Congress, Cartographic Division)

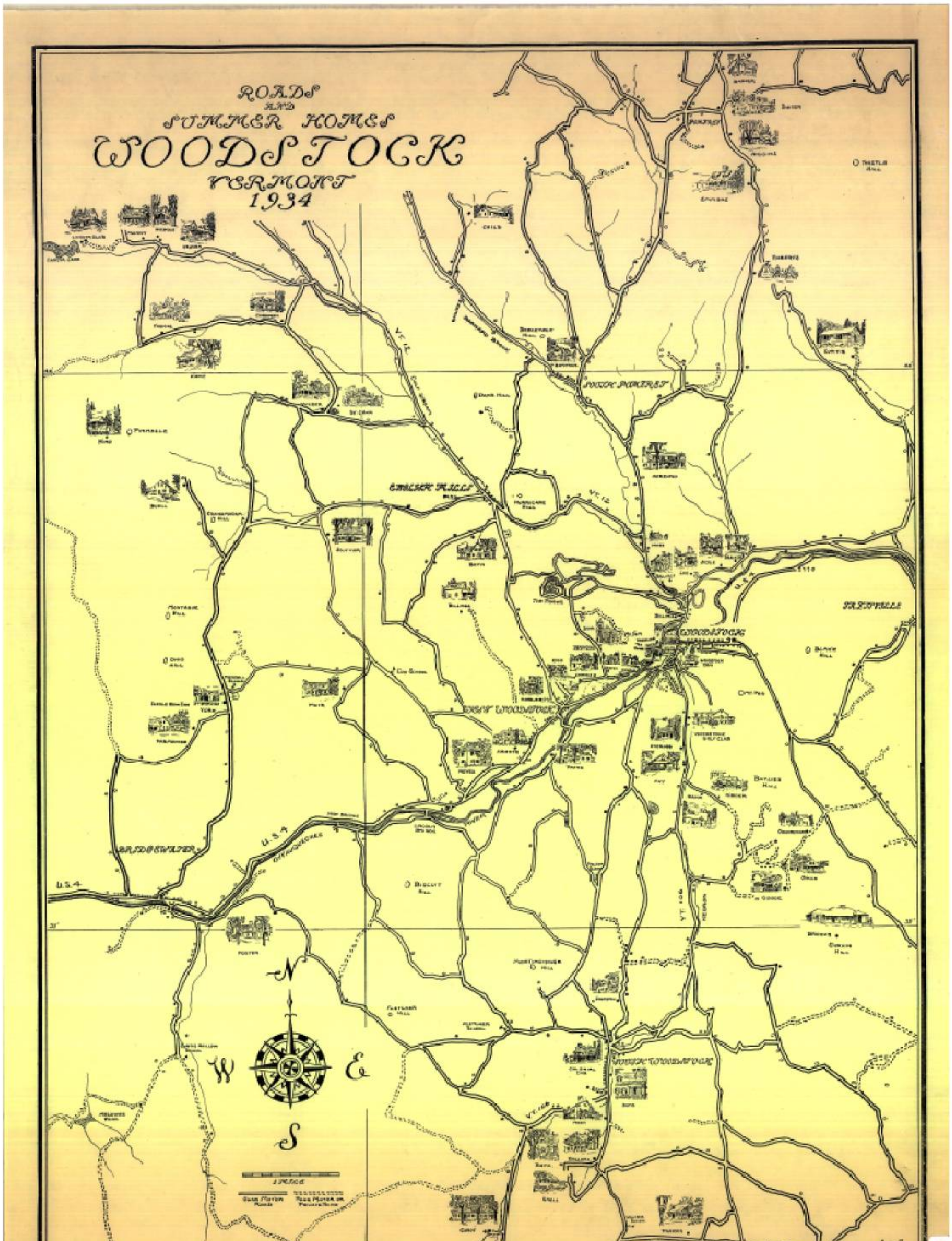


Figure E6 1934 Town of Woodstock Map
(Courtesy of Dartmouth University Map Room)

Appendix F:

A Guide to Sources for Historic Aerial Photography and Maps of the United States

Sources for Historic Aerial Photography and Maps of the United States

Introduction

Historical maps and aerial photographs provide insight into the condition of landscapes at a given point in time. Understanding and interpreting historic maps and aerial photographs helps researchers document the evolution and changes that have shaped our important historical landscapes. The search for and procurement of maps and aerial photographs of a given location is a daunting task. This document summarizes the key historic map and aerial photography archives in the United States. Ideally, this document will serve as a starting point from which historic preservationists and other cultural resource professionals can launch a search for historic maps and aerial photographs.

Fig F1: 1860 Aerial View of Boston from a hot air balloon, taken by James Wallace Black

Historic Aerial Photography

The first aerial photographs were created when photography pioneers first mounted hot air balloons and took photography to the skies in the late 1850's. Although this technique was first pioneered in France, the oldest photograph in existence is one taken of Boston by James Wallace Black in 1860 (Fig 1.) The availability and coverage of these photographs is very limited and the serve as a footnote to the more comprehensive sources of aerial surveys conducted by the U.S. government. Since the mid 1930's comprehensive photographic surveys of the entire U.S. have been conducted. These resources are stored within the various agencies of the government and are discussed in detail in the following sections.

Fig F2: Vertical Aerial Photograph, Golden Gate Bridge, San Francisco, Calif., National Aerial Photography Program, August 1993.

Aerial photographs are images captured on film from an airborne platform and are usually reproduced as photographs. These images are further defined by their perspective, oblique or vertical. Vertical aerial photographs (Fig. 2) are created when the camera is aligned perpendicular to the horizon and are the focus of this paper. Aerial photographs are also categorized by the photographic medium they are captured on, black and white, natural color or color infrared (CIR) film. Black and white photographs, also called panchromatic, are the most common type of historical aerial photography. Natural color images are less common, but provide an inexperienced observer with an easily understandable view. CIR images, which are available from the 1960s, are especially suited to differentiating vegetated and non-vegetated areas (Fig 3) because the infrared wavelength that is captured on this film is sensitive to green vegetation and soil moisture.

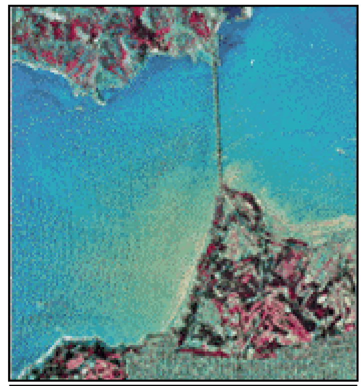


Fig F3: Golden Gate Bridge, San Francisco, Calif., National Aerial Photography Program color-infrared aerial photograph, June 1987

Scale is the property of an aerial photograph that determines ground coverage and the ability to resolve landscape features. The scale of an aerial photograph is determined by dividing the focal length of the camera by the altitude of the flight platform. An aerial photograph, although it will come complete with scale information, can not be used like a paper map. The differences in elevation, displacement of features toward the edges of the photograph, and the angle of capture contained in the photograph will cause linear distortions between points on the ground. An orthophoto is an aerial photo that has had the distortions removed by a photogrammetric process. Given this warning, the original scale of an aerial photograph is important in deciding what application it is most suited for. A large tract of land such as a National Forest or major watershed may be best served by a small scale, above 1:40,000, photograph that will provide good coverage and adequate detail. Conversely, a large scale photograph (e.g. 1:5000) is ideally suited to small study areas, like historic battlefields or managed historic landscapes.

Aerial photographs are available in a number of formats that specify the type of medium and size of the finished product. Common mediums are paper print, film positive, film negative and digital data. Many photographs are presented as 9-by-9 inch prints, or 4.5-by-4.5 inch and 9-by-18 inch prints. However, more and more photographs are being transferred to and acquired in digital format. When selecting a format, the final use of the product should be considered. For example, if you are interested in using digital image processing or GIS to evaluate your image you should select a digital format. In summary, when searching for and acquiring aerial photography, criteria for selection should include scale, film type, and format

Historic Maps

The United States has been mapped consistently since the first European explorers ventured across the Atlantic. Since that time, everything from Native American maps drawn on the earth to advanced orthographically-corrected color aerial photographs have been used to capture the landscape. Historic maps come in many different shapes, scales and formats, and the USGS has some excellent references to help map hunters to quickly find information on potential sources for maps. These three are a good starting point:

Map Collections in the United States and Canada: A Directory compiled by David K. Carrington and Richard W. Stephenson and published by the Special Libraries Association, New York, c1985. 188p. 4th ed.

Antique Map Reproductions: A Directory of Publishers & Distributors of Antique Map, Atlas & Globe Facsimiles & Reproductions edited by Gregory C. McIntosh and published by Plus Ultra Publishing Company, New York. October 1, 1998. 56p. 1st ed.

Guide to U.S. Map Resources edited by David A. Cobb and Published by the American Library Association, 1990. 2nd ed.

Starting a Search

The first step in a search for historic aerial photographs and maps is to define a study area. Identify latitude and longitude, or geographic coordinates, for the four corners of a rectangle surrounding the area of interest. A paper map, preferably from a USGS topographic series, with the study area outlined is also very useful. Make several copies of this map, as you will probably have to send it out to several different parties during the search process.

The second step is deciding where to begin searching. If your study area is located nearby it is good idea to begin your search using local resources. However, if your study area is located far away or in a remote area the federal sources are a good starting point. In either case the Internet can also be an excellent starting point from which to see what types of information might be available for your study area. Many local, state and federal sources provide descriptions of the type of data available on their websites. It is even possible to order photographic prints or maps from many Government Webpages.

After finding several potential sources for historical data the third step in the search for historic maps and photographs is to record all of the bibliographic information available. This information, which is often overlooked, can save hours of wasted research time. Record as much information about the data source as possible, such as the flight information of an aerial photograph, or the cartographer and publisher of an historical map. Often this information is only available on-site and even small details can prove to be very useful at some point during subsequent research.

After actually locating historic maps and aerial photographs it is necessary to obtain an adequate reproduction. Many sources for historic documents offer on site reproduction in analog or digital format. However, certain facilities, offer almost no means to reproduce an image and it is advisable to pre-arrange a method for obtaining a copy of the desired map or photograph.

The Local Level: State, County, Town, and Other Sources

The search for historic maps and aerial photographs through local channels is different for each location. However, some general strategies and tips are suggested here. Perhaps the best advice is to start with a broad search and then focus your efforts when you begin to find where the best repositories are. State agencies responsible for taxation, transportation, natural resources, and general geographic information often conduct mapping programs and are excellent places to begin a search. Often these agencies will have contact information available on the WWW. Another excellent resource for historical material is to locate the State Historical Archive or Records Depository.

Most state agencies will have several map and aerial photographic sets that offer very good coverage of their state. When attempting to find an individual photograph for a particular study area, it is useful to use an index (composite of several aerial photographs). State agencies are not usually equipped to produce large quantities of photographic prints or map reproductions to the general public, so ingenuity is often necessary to obtain copies of important historical documents. Whenever possible it is best to visit a specific agency with a recording or reproduction device (e.g. scanner and laptop, or digital camera and tripod) for the map or photograph of interest.

Many states are modernizing the collection and distribution of their geographic resources into a computerized Geographic Information System (GIS). Access to a description of the holdings and often free data layers can be found through most states

WWW portal. The information available varies from state to state, with Massachusetts providing full color, ½ meter pixel size, digital orthographic photographs online and Colorado providing a link to several federal government sources for GIS archives. The major drawback to finding historical data in a state GIS is that the organizations are relatively new. Therefore much of the information in these GIS archives focuses on the current rather than historical conditions of the landscape.

Another source of historical imagery is a college or university map room. Map rooms are repositories for all of the spatial data contained within a particular library and often contain a variety of maps and aerial photographs. Map rooms are often repositories for state agency, federal agency, and commercial materials. All of these data types can be found in an array of formats, conditions, and completeness. A preview of the map and photograph collections stores within map rooms is often listed in the University or College Web Site. Map rooms are best approached through the WWW and then by a site visit. If a visit is impractical then contacting the administrator and requesting a detailed description of specific holdings may be necessary first step. This will usually determine whether a site visit is practical or not. It is important to remember to ask what type of hardware is available to make reproductions of the various maps and aerial photographs as the originals generally do not circulate to the public.

Town and county offices can also be good sources for historical maps and aerial photographs. Many study areas, especially those of historical importance, have been selected due to interesting characteristics that have long been known by local inhabitants.

Consequently, some of these areas are associated with a museum or local historical society. A few select areas may even have privately funded archives dedicated to maintaining a complete historical record of the area. Historical societies, museums and private archives will often have unique or hard to find maps and imagery that may not be available elsewhere. The geographic coverage of these materials is often very limited, but it will often include a portion, if not complete coverage of specific study areas.

A major problem associated with maps and aerial photographs found in smaller institutions is the lack of resources to adequately reproduce of the material. It is advisable to call ahead when approaching these sources and obtain permission to reproduce any images you may need. Often this will require that photographic reproduction or large format scanning be used to capture the images. Usually an outside source (e.g. reprographic service) is needed to scan or digitize large base images and it can be quite expensive.

Federal Sources of Historic Aerial Photographs and Maps

The U.S. Government is the largest single repository for aerial photography. Federal agencies have been photographing the U.S. since the mid 1930's. Six major agencies (summarized in Table 1) hold the majority of photographs and maps and they can be searched in a variety of different ways. The holdings of each of the major federal agencies will be discussed in the following section.

Table F1: Summary of federal sources for historic aerial photographs and maps

Agency	Aerial Photograph Availability Range	Film Format	Product Format	Map Availability Range	Map Holding Highlights
United States Geological Survey	1940s-Present	B&W CIR Color	Print Negative Positive Digital	1884 – Present	Topographic
United States Department of Agriculture	1940s –Present	B&W CIR	Print Negative Positive	1900s – Present	Agricultural Census Data
Library of Congress	1900s-Present	B&W CIR Color	Print Digital	1500s- Present	Early American Maps
National Archives and Records Administration	1935-1960s	B&W	Print	1774 – Present	Public Land Survey Records
National Ocean Service	1940s-Present	B&W CIR Color	Print Negative Positive	1700s - Present	Nautical Charts, Early Topographic Maps
Tennessee Valley Authority	1935 – Present	B&W CIR	Print Negative Positive	1933 – Present	Historic City Maps

United States Geological Survey

The U.S. Geological Survey (USGS), established in 1879, has a large number of historical topographic maps and aerial photographs available for public use. Maps dating to 1879 as well as aerial photographs from 1939 to the present are available. The USGS preserves out-of-print maps on microfilm and photographs are preserved as negatives. In this way, the USGS can limit its vast inventory to the most current data and still provide copies of older maps and photographs. Out-of-print maps are available for purchase as black-and-white photographic paper reproductions and photographs are available in a variety of formats.

To obtain a reproduction of a particular topographic map from the USGS, send a research inquiry to a regional USGS Earth Science Information Center (ESIC). The letter of inquiry should give as much information as possible, including the State, county, and town or township; year of interest or range of years; as well as the type of information you are seeking on the map. For example different types of information might include, streams and rivers, railroad lines, roads, or geographic or cultural features. Map reproductions are approximately 24 by 30 inches in size at a cost of $6-7 dollars a sheet.

Select USGS Earth Science Information Centers

Reston - ESIC
USGS
507 National Center
Reston, VA 22092
(703)648-6045

Rolla - ESIC
USGS
1400 Independence Road
Rolla, MO 65401
(314)341-0851

Lakewood - ESIC
USGS
Box 25046, Federal Center
Denver, CO 80225
(303)236-5829

Salt Lake City - ESIC
222 West 2300 South, 2nd Floor
Salt Lake City, UT 84119
(801)975-3742

Menlo Park - ESIC
USGS
Room 3128, Bldg. 3
345 Middlefiled Road
Menlo Park, CA 94025
(415)329-4390

Anchorage - ESIC
USGS
4230 University Drive, Room 101
Anchorage, AK 99508-4664
(907)561-5555

Nationwide Information Number: (888) ASK-USGS

Historic USGS maps are available from the Historical Map Archives of the National Mapping Division Reference Collection. In addition digital versions of USGS topographic quadrangles of New England and New York are available online through the Diamond Library at the University of New Hampshire. The online collection of over 1500 topographic maps (http://docs.unh.edu/nhtopos/nhtopos.htm) includes complete geographical coverage of New England and New York from the 1890s to 1950s. The database of historical maps is searchable by state and town and map images can be downloaded in JPEG image format at no cost.

U.S. Geological Survey
NMD Reference Collection
Historical Map Archives
522 National Center
Room 2B125
12201 Sunrise Valley Drive
Reston, VA 20192 USA
E-mail: rbier@usgs.gov
Phone: 703-648-6207
Fax: 703-648-6373
http://library.usgs.gov/

The U.S. Geological Survey (USGS) is searchable via mail, phone, fax or the internet. A basic search of the USGS for aerial photos involves accessing the Aerial Photographic Summary Record System (APSRS). The APSRS is a record of aerial photographic coverage of the U.S. from federal and participating state, regional, and commercial sources. ASPRS is available on CD-ROM or the USGS will search the database for a fee. If the CD-ROM is not available, the search must be performed by contacting an Earth Science Information Center. Photographs can not be ordered from APSRS results, the sources listed in the results must be contacted directly.

An APSRS search will undoubtedly list the Earth Resource Observation Systems (EROS) Data Center as a source for many aerial photographs. The EROS Data Center holds millions of aerial photographs from the 1940s to the present. Photographic holdings are summarized at the USGS EROS Data Center web page, http://edc.usgs.gov/products/aerial.html. The main holdings of the EROS data center are the National High Altitude Program (NHAP), and the National Aerial Photography Program (NAPP) photographs.

USGS
EROS Data Center
Sioux Falls, SD 57198
(605)594-6151
http://edcwww.cr.usgs.gov/

The NHAP was enacted in 1980 to acquire aerial photography of the entire U.S. The NAPP, successor to the NHAP program, systematically collects 1:40,000 scale CIR photography of the entire U.S. every five years. These aerial photographs provide high quality inexpensive products dating back 20 years. The general characteristics of these photographs are summarized in Table 2.

Table F2: NHAP vs. NAPP

	NHAP	**NAPP**
Collection Dates	1980-1987	1987-Present
Scale	1:58,000 and 1:80,000	1:40,000
Ground Area	8 x 8 miles and 11 x 11 miles	5 x 5 miles
Film Types	black & white, CIR	black & white, CIR

Obtaining aerial data from the EROS Data Center can be a difficult process, but there are some shortcuts that can expedite the process. Historical searches, that don't necessarily focus on NAPP and NHAP photos, can be accomplished by filling out the "Inquiry Form: Geographic Search for Aircraft Data" to the best of your ability. This form is available upon request from EROS Data Center. Another way to search the EDC database is through the WWW. This method is preferable because secure online ordering of photographs is available as soon as you find them. The EROS Data Center website provides links to several other searchable databases; these are detailed in Table 5. The USGS is continually updating and refining the process by which aerial photographs are archived and reproduced, please visit http://ask.usgs.gov/photos.html to see the most recent updates.

Table F3: USGS aerial photograph websites

Site	**Web Address**	**Products**
EarthExplorer	http://edcsns17.cr.usgs.gov/EarthExplorer/	A complete search and order tool for aerial photos and other USGS products.
PhotoFinder	http://edc.usgs.gov/Webglis/glisbin/finder_main.pl?dataset_name=NAPP	USGS National Aerial Photography Program (NAPP) Photos.
Global Land Information System*	http://edcsns17.cr.usgs.gov/EarthExplorer/	A search and order tool for aerial photos and other products distributed by the USGS.

* Replaced by EarthExplorer

United States Department of Agriculture

The U.S. Department of Agriculture (USDA) stores all of its aerial photography in its Aerial Photography Field Office (APFO) in Salt Lake City, Utah. This agency has been acquiring aerial photography since the 1930s and can generally reproduce pictures from the1940s to the present. APFO can be contacted directly and will perform a search for photos. Three agencies within the department, the Consolidated Farm Service Agency, the Natural Resources Conservation Service and U.S. Forest Service use a great deal of the USDA aerial photography. It is worth contacting a local office to locate photographs that may not be stored at the APFO location. NAPP and NAHP photographs are also available through the APFO.

USDA
Consolidated Farm Service Agency
Aerial Photography Field Office
P.O. Box 30010
Salt Lake City, UT 84130-0010
(801)975-3505
Fax:(801)975-3532
http://www.apfo.usda.gov/

Historic maps created by the USDA are available through the National Cartography and Geospatial (NCG) Library. A computerized database exists in which the maps produced by NRCS are cataloged. This catalog of products, listing both in-house and Federal Records Center files is comprised of over 12,000 entries and is growing continuously. It may be searched by old and new identifying numbers, type of map, geographical or political location, title, and scale. Specialized printouts may be created. Manual records (cards) are kept on materials archived prior to 1979.

USDA/NRCS
NCG Library
P.O. Box 6567
Fort Worth, Texas 76115-0567
Phone: (817) 509-3394 or(817) 509-3411
Email: dgaster@ftw.nrcs.usda.gov or
rvenable@ftw.nrcs.usda.gov

National Archives and Records Administration

The National Archives and Records Administration (NARA) holds over 9 million aerial photographs and more than 2 million maps produced by civilian and military branches of the U.S. government in its Cartographic Archives and Architectural Division. Photography records date from 1935 to the mid 1960s and maps are available from 1774 to the present. The scale of the photography varies (generally from 1:15,000 to 1:56,000). NARA will process a written request for information and has indexes available to the public in the research room of the Cartographic Archives Division. NARA has published a useful document entitled *Aerial Resources in the National Archives*: Special List Number 25. NARA also has an online database called NARA Archival Information Locator (NAIL), http://www.nara.gov/nara/nail.html, which is described as a working prototype of a future database. It contains information about aerial photography and map holdings, but does not provide specific geographic details in the search results. The following publications, which can be viewed online, may prove useful in conducting historical map research through NARA:

Cartographic and Architectural Branch (NWDNC)
National Archives
8601 Adelphi Road
College Park, MD 20740-6001
Reference Inquiries 301-713-7040
Fax Number 301-713-7488
http://www.nara.gov/

General Information Leaflet No. 26
Cartographic and Architectural Records
http://www.archives.gov/publications/general_information_leaflets/26.html

Special List No. 29
List of Selected Maps of States and Territories
http://www.archives.gov/publications/general_information_leaflets/29.html

Library of Congress

The Library of Congress serves as the research arm of Congress and is recognized as the national library of the United States. As the world’s largest library, it is a great resource for scholars and researchers. In the Geography and Map Division Reading Room of the Library of Congress, researchers can find the largest cartographic collection in the world, including more than 4.5 million maps and 60,000 atlases, as well as cartographic materials in other formats. These cartographic materials date from 14th century portolan charts through recent Geographic Information System data sets. The Geography and Map division also houses seven million aerial photographs and other remotely sensed images of the earth taken by National Aeronautics and Space Administration and USDA. Additional aerial photography can be found in the Prints and Photographs Division of the Library. These images are from various sources and date from the 1900's to the 1940's.

Geography and Map Division
Library of Congress
101 Independence Ave. SE
Washington, D.C. 20540-4650
Phone: 202-707-6277
Fax: 202-707-8531
E-mail: maps@loc.gov

Prints and Photographs Division
Library of Congress
101 Independence Ave. SE
Washington, D.C. 20540-4730
Phone: (202) 707-6394
Fax: (202) 707-6647
E-mail: “Ask a Librarian”

The best option for searching the Library of Congress is to pay a visit to Washington, DC and look through the card catalog or the Reading Room of the Geography and Map Division. The *Library of Congress Geography and Maps: An*

Illustrated Guide (lcweb.loc.gov/rr/geomap/guide) is a useful publication for becoming familiar with the resources available in the Geography and Maps division. Library staff will also accept specific research requests via phone, fax or e-mail. Once a photograph or map is located, a reproduction can be produced and mailed out to a researcher.

Recently, the Library of Congress has made its card catalog available online at http://catalog.loc.gov/ and records for aerial photography can be retrieved. At present, the search interface is somewhat difficult to understand and the search results lack specific geographic coordinates. The Library of Congress webpage, http://www.loc.gov/, has a feature called "Ask A Librarian", where specific research requests are accepted. "Ask a Librarian" results are usually returned within 5 business days and are conducted by the library’s professional staff. A dedicated search of the Library will often result in the location of some of the oldest and rarest historical data of a particular study area.

National Oceanic and Atmospheric Administration

National Ocean Service

The U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) maintains a branch called the National Ocean Service (NOS). NOS is charged with making nautical charts for U.S shorelines in the Atlantic, Pacific and Great Lakes regions. The creation of these charts is conducted by the Remote Sensing Division of the NOS National Geodetic Survey. Since the late 1930s, NOS has been conducting aerial surveys of the U.S. coastline and airports. There are 500,000 photographic negatives indexed and archived from 1945 through the present. As of October 2002, NOS had roughly 45,000 of these images scanned and available online at the NOS MapFinder web site (http://oceanservice.noaa.gov/dataexplorer/welcome.html) The agency has plans to add all 500,000 photographic records to MapFinder, so the site is worth repeated visits. NOS photographic records differ form many of the other federal sources because the agency has experimented with natural color film.

Special Projects Office
National Ocean Service - NOAA
9th Floor, SSMC4 1305 East West Hwy. Silver Spring, MD 20910
(301)713-3000 x132
mapfinder@noaa.gov

NOS also maintains a collection of over 20,000 maps and charts from the late 1700s to the present day in the Office of Coast Survey's Historical Map and Chart Collection. Some of the nation’s earliest nautical charts, hydrographic surveys, topographic surveys, geodetic surveys, city plans and Civil War battle maps are housed in the NOS collection. The Historical Map and Chart Project has scanned each map or chart and offers the images free to the public through the Coast Survey web site (http://historicals.ncd.noaa.gov/historicals/histmap.asp). The Project is managed by the Cartographic and Geospatial Technology Program of the Coast Survey Development Laboratory.

Tennessee Valley Authority

In 1933 President Roosevelt created the Tennessee Valley Authority (TVA) through the New Deal program. Over 400,000 square miles of land in Alabama, Mississippi, Georgia, Kentucky, Virginia, North Carolina and Tennessee were put under the management of the federal government to ensure that agricultural and industrial development would be coordinated and the natural resources conserved. Maps and aerial photographs of the region can be purchased through the TVA map store. At present, a searchable database of current products is under construction, but a map store representative will respond to specific requests.

Tennessee Valley Authority – Map Store
1101 Market St.
Chattanooga, TN 37402-2801
(432)751-MAPS
(800)MAPS-TVA
Fax:423-751-6216
E-mail:mapstore@tva.gov
https://maps.tva.com/

Maps of the TVA lands are available in a wide variety of formats and tend to focus on the dams, locks, towns, and other constructed features. Topographic maps of the area are also available through the map store. Aerial photography products include black and white, color, and CIR photographs. Most of these photographs were produced from low altitude flights and range in scale from 1:8,000 to 1:24,000. Reprints from the TVA map store are available in many sizes (18x18, 27x27 or 36x36 inches).

Conclusion

There are many different sources for historical maps and aerial photographs in the United States. From the small historical society, run by a single person and holding a single map, to state and federal archives, staffed by thousands and maintaining millions of map and photographic documents, the amount information available is staggering. This information is accessible, and with a little planning, the different search options can be prioritized.

This document provides recommendations on a process. Start with a broad search in the federal archive, and then narrow down your options by looking in local sources such as University map rooms, town offices, and historical societies. In addition this document provides a summary and contact information for major archives. The information provided should be an excellent starting point for a search for historical maps and photographs.

Appendix G:

Historical Photographs of MBRNHP and Vicinity

Figure G1: Panoramic photograph of Woodstock from Mt. Peg, Henry Barreuther, 1914 (Courtesy of the Library of Congress).
A portion of MBRNHP is visible to the right and left of Mt. Tom (Center).

Figure G2 Panoramic Photograph of Woodstock from the South, Henry Barreuther, 1914 (Courtesy of the Library of Congress).
Mt. Tom and MBRNHP are visible through the haze in the right hand side of the photograph.

Figure G3 The Pogue, looking southeast, Unknown Photographer (Woodstock Historical Society, Circa 1890)
The Pogue is shown prior to the construction of the dam and pipeline.

Figure G4 Hillside on northeast edge of MBRNHP showing a relatively open landscape, Marion Post Wolcott, 1940 (Courtesy of the Library of Congress)

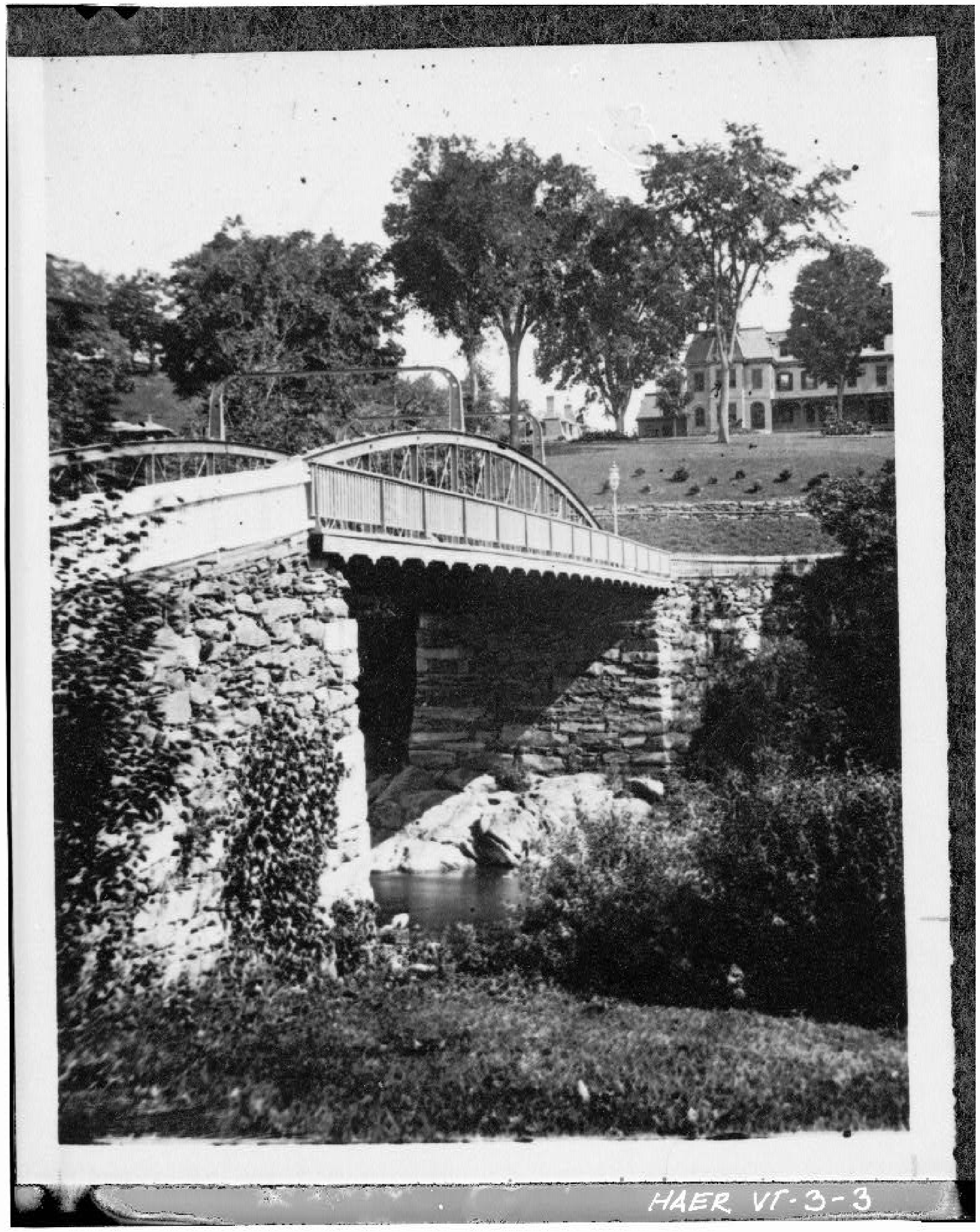


Figure G5 Bridge over the Ottaquechee with Mansion in background, Unknown Photographer. Circa 1910, (Woodstock Historical Society) Elm Trees are visible in the foreground landscape.

Figure G6 Bridge over the Ottaquechee with Mansion in background, Unknown Photographer. Circa 1910, (Woodstock Historical Society) Elm trees and a stonewall , and a rock outcrop are visible in the foreground landscape.