Identification of “lost” structures through satellite imagery and aerial photographs at Fort Garland, CO

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ABSTRACT: Thermography studies using airborne remote sensors have proven useful in the search for buried foundations, but the high monetary cost often forces small-scale excavations and companies to rely on aerial photographs, inaccurate historical maps, and exploratory excavation. This study tested both the appropriateness of thermography studies using free LandSat 7 ETM+ images, and digital manipulation of aerial photographs as cost effective early site-reconnaissance at a small historic site. LandSat images from the summer and early fall of 1999 and 2000 were selected to avoid bias based on differences in seasonal climate with 1950-1960s aerial photographs. Thermal anomalies were compared to landscars discernible from digitally manipulated aerial photographs, using original and current site maps as a control. ENVI 4.8 was used for processing of LandSat images and manipulation of aerial photographs. LandSat images were found to have resolution too coarse to perform studies of variations in emissivity within a site the size of Fort Garland. Stretched aerial photographs indicated that current land scars in the area are largely due to exploratory excavation, brush clearing, and other modern activities rather than the presence of a buried foundation. However, one particular area was tentatively thought to show evidence of a foundation in the general area of the original stables and corral. Further manipulation and correlated images would be needed to corroborate these findings.

Key Words: historic archaeology, emissivity, Landsat 7 ETM+, aerial photographs, ENVI 4.8, buried foundations

Introduction

In the interest of lowering the financial cost and labor intensiveness of excavations, as well as increasing the amount of information available for a site, many archaeologists are turning to the integration of remote sensing techniques to traditional archaeological excavation. Remote sensing offers the ability to perform early site-reconnaissance without much exploratory excavation, potentially meaning decreased destruction of context in the pursuit of information (Kvamme, 2005; Fowler, 2008). The analysis of aerial photographs to find landscars which could indicate archaeological features or landscape traits, is the most basic, and most used of remote sensing techniques. Newer techniques including ground penetrating radar, vegetation studies to indicate the presence of building in Mayan rainforest, and LIDAR to uncover buried foundations and lost features, have made news in the archaeological community.

One of the more interesting areas of remote sensing in archaeology is the use of variations in temperature to determine the presence of buried foundations or features. Thermography studies have been undertaken by a number of researchers, using both in situ measurements in the form of ground probes, and airborne sensors to collect thermal data.

A study in Sweden in the 1980s used a helicopter-borne sensor to measure heat emitted from a patch of stripped earth. The study determined that there was a positive relationship between higher temperatures and the presence of buried foundations/features (Lunden, 1985). More recently, studies have been done in Louisiana (Heitger, 2006), and North Dakota (Heller, 2009). Both recent studies used airborne thermal sensors to detect the presence of features. Heller used a low altitude study to determine the locations of buildings at a historic American military site, while Heitger used a higher altitude method developed by an associated researcher to determine the locations of "lost" burials in a historic American cemetery.

The use of airborne sensors provides increased accuracy through high-resolution data, but also increases the cost of the study. The intention of this study is to determine whether a free sensor, in this case Landsat7 ETM+, could be used to find buried structures at a small historic site through thermography studies similar to those undertaken by Lunden, Heitger, and Heller. As a secondary objective, the study aimed to explore the use of digital manipulation of aerial photographs, also with the intention of discovering buried structures at a small historic site.

Study Site

Fort Garland Museum is a reconstructed decommissioned 19th century military fort. Originally built in 1858 after the failure of Fort Massachusetts six miles to the north, it was intended to protect settlers in the San Luis Valley from the Ute who originally inhabited the area, the fort reached a maximum size of 2,000 soldiers. Archaeological evidence has indicated officers brought their wives and families when they stationed at the fort, enlarging the maximum number of people living on fort grounds in the 1870s. The fort was decommissioned and abandoned in 1883, serving as a private residence, a ranch, and a motel before being abandoned once more. The Colorado Historical Society bought and began reconstruction of the fort in the 1960s with the intention of establishing a museum that currently remains open to the public. The first archaeological field school was undertaken in July 2000 by Dr. Richard Goddard and was run sporadically through 2008.

The fort buildings, both reconstructed, standing, and "lost" were constructed of adobe bricks, with walls approximately a meter thick. Adobe is particularly adapted to the southwest and high deserts such as the San Luis Valley as it releases heat slowly, baking through out the day and keeping the interior of the structure warm through out the cold nights. This characteristic is also excellent for thermography studies as the adobe will hold heat longer than the surrounding soil. The thin topsoil and recent usage of the lost buildings at Fort Garland (recent being relative in archaeological terms) mean any buried foundations would not be deeply buried. Indeed, archaeological excavation indicated the presence of buried foundations within the first 5-10cm of earth, well with in the ideal range for thermography studies.

Figure 1. Location of Fort Garland (town and site) within the San Luis Valley, Colorado. (Google Maps, 2011)

Figure 2. Close view of town of Fort Garland, including the museum grounds, and study site, which are boxed in red. (Google Maps, 2011)

Methods

Aerial Photographs

Aerial photographs of the Fort Garland area were downloaded from glovis.usgs.gov. Photographs were selected with preference given to photographs taken prior to the mid-1960s when reconstruction of the fort grounds began. Only photographs with clear, and reasonably centralized placement of the site were selected. The photographs chosen were from the following dates: June 1954 (two views), October 1960, and July 1975.

The chosen aerial photographs were each spatial resized through ENVI 4.8 to focus on the area of the site. The subsets were then stretched through 'interactive stretching'. Manual, arbitrary, Gaussian, linear, and equalization stretches were preformed in order to determine which process yielded the more significant results. The manual and arbitrary stretching were used for the production of the final aerial photograph images.

Landsat 7 ETM+ Images

The images from Landsat7 ETM+ were also downloaded from glovis.usgs.gov. Landsat images were originally selected based on date. Images prior to July 2000 (the start date of the first field school) were chosen, and then narrowed down to months that corresponded with the months during which the aerial photographs had been taken. This was done to avoid potential bias based on seasonal climate or vegetation differences. The final images were captured on July 10, 1999; September 28, 1999; September 30, 2000.

All images selected were downloaded as separate TIF files, and the selected image files were combined using the "layer stacking" function of ENVI. The images compiled, the data was then spatially resized to include the area of the site and town of Fort Garland.

These subsets were then processed with emissivity normalization, a function of ENVI. This required editing the header of the file to change both the band names to the appropriate band number, changing the wavelengths to the numbers appropriate to each band of Landsat 7 ETM+, and changing the unit of measurement to micrometers (http://landsat.usgs.gov). Without these changes, ENVI produces an error message concerning the unit of measurement.

The emissivity normalized images were outputted, and analyzed for thermal anomalies in the area of the site. A red temperature color palette was applied through the “color mapping” function of ENVI in order to make thermal anomalies more obvious. The images were saved in ENVI and Jpeg format. A zoom of the site area including the reconstructed fort was saved in Jpeg format. Both the emissivity normalized images and the zoom of the site area within the subset were analyzed for thermal anomalies in geometric shapes or patterns which would indicate purposeful human influence in the area (Kvamme, 2005).

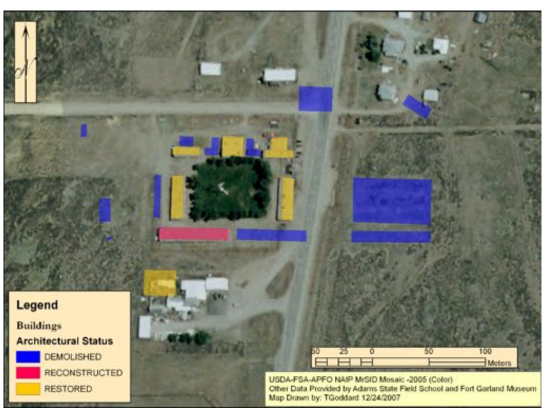

Figure 3a. Current site map for Fort Garland Museum Site, as drawn by Tim Goddard. Large (legible) map included in appendix.

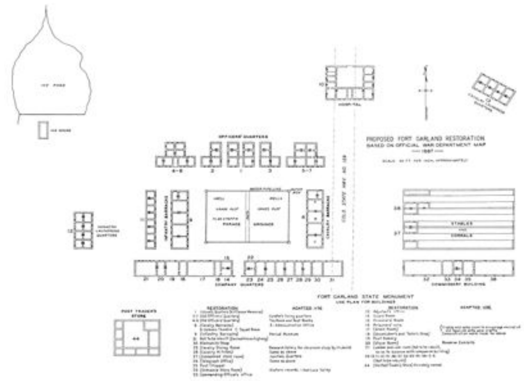
Figure 3b. Colorado State Historical Society reconstruction map based on 1867 military map. N-S alignment is fairly correct (off by less than 1m), however, E-W alignment is severely compressed. Larger (legible) map included in appendix.

Comparison

The digitally manipulated aerial photographs were side-by-side compared with the emissivity normalized images. Images were compared across the board, and by closest month. All images were then compared to the current site map as well as E-W compressed military map from 1867 (Figures 3a-b).

Results and Discussion

Aerial Photographs

The arbitrary and manual stretches applied to each aerial photograph (Figures 4-7) enhanced the shadows and tones of the aerial photographs, making it easier to note changes in elevation, ground coverage, and landscars.

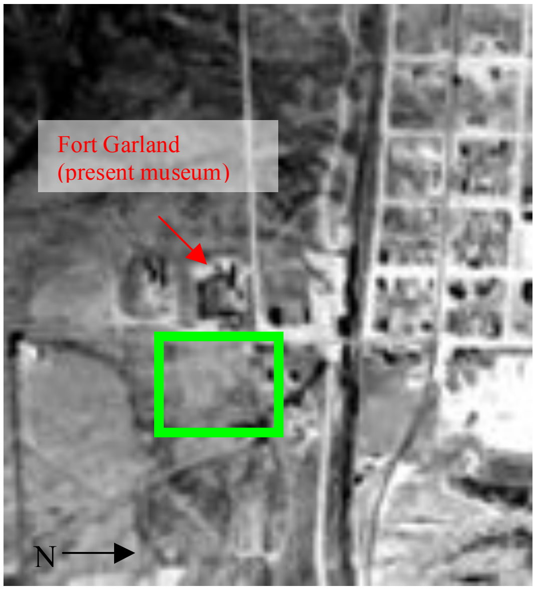

Figure 4. Arbitrary and manually stretched aerial photograph from June 1954 (flight path E-W). The location of the current museum grounds is labeled in red. The slight variation in color in the general area of the former corrals and stables is marked in green. Note that the lighter area forms a vaguely straight line.

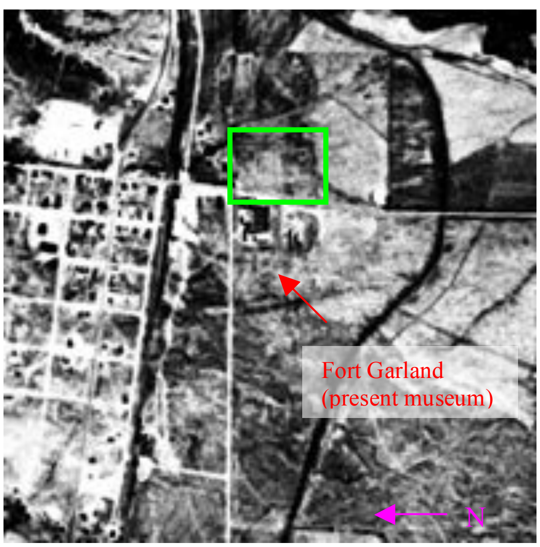

Figure 5. Linear and manually stretched aerial photograph from June, 1954 (flight path W-E). This image includes the clearest view of the lighter tones in the area of the former corrals and stables which form a rectangle to the west of the current museum grounds (boxed in green).

Figure 6. Linear and manually stretched aerial photograph from October 1960 (flight path N-S). Note the parade grounds are visible at the center of Ft. Garland (current museum site), but the lightness in the area of the former corrals and stables is not. Area of expected lightness is marked in green.

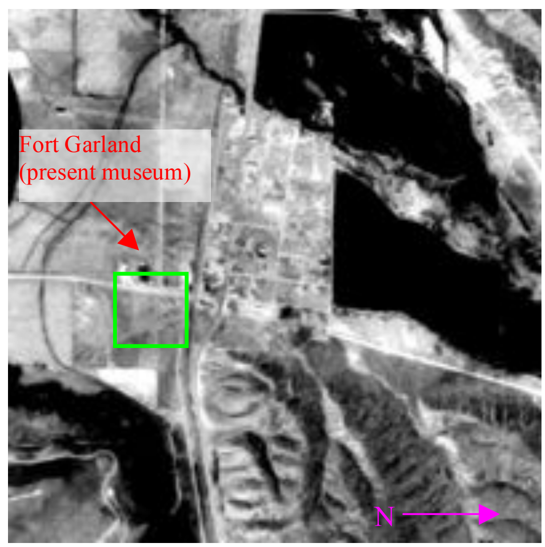

Figure 7. Linear and manually stretched aerial photograph from July 1975. Image shows lower spatial resolution as well as little to no anomalous lightness in the area west of the current museum grounds (highlighted in green).

Land scars were visible in both images from June 1954, which were taken the same day along reversed flight paths (W-E, E-W). However, these landscars, in this case areas of lightness is otherwise homogenously gray areas, are not seen in the later aerial photographs from 1960 and 1975. This could be indicative of the landscar being vegetation based, or of clearing of the area in 1954. However, further data would be needed to reach any conclusion on the matter.

The aerial photograph from October 1960 shows scarring within the site map-established site boundaries, but without the geometric pattern necessary to indicate purposeful human creation. The aerial photograph from July 1975 is typical of the period in this location. The several aerial photos downloaded from the period of the late 1960s-1970s showed very low spatial resolution. It's almost as though airplanes had the capacity to fly higher, but cameras (at least those used for these photographs) did not yet have the capacity to capture images at that altitude.

Aerial photographs of in between, or more consistent, dates were not included due to low resolution or the near exclusion of the study area. Numerous aerial photos included Fort Garland site at the every border of the photograph, where the geometry was skewed, and the tones/shadows were extremely light. As there were too many possible errors and biases, the photographs were excluded from this study.

Landsat 7 ETM+

The images for Landsat 7 ETM+ were chosen as companions to the aerial photographs seen Figures 8-13. The interest was to lower the potential bias caused by seasonal vegetation and climatological changes. However, this selection was limited by both cloud and snow cover in a large number of images. Images prior to the beginning of the first Fort Garland field school were chosen to minimizes thermography anomalies caused by exploratory excavation which leads to the compaction and loosening of soil in key areas. One of the images chosen for this study, taken September 30, 2000 is outside of this ideal window, however, it was included in order to have more images as images from earlier that year (2000) has severe cloud or snow coverage which completely inhibited visibility and thermography studies.

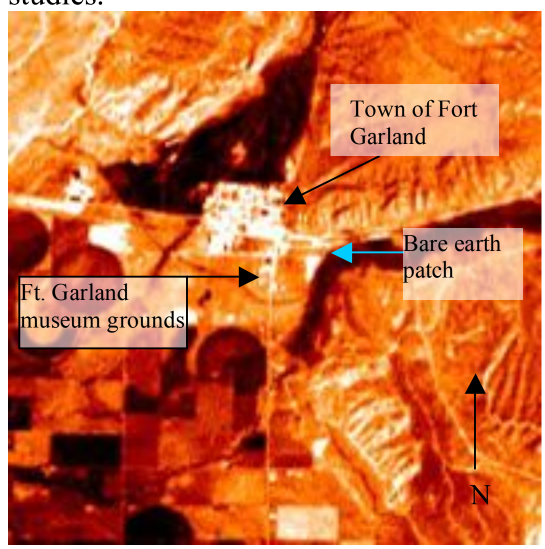

Figure 8. Emissivity normalized image from July 10, 1999. Brighter/closer to white colors indicate higher emissivity, dark colors/closer to black indicate lower emissivity. Note that the town, the museum and patch of bare earth have high emission while the area where landscars were previously seen in aerial images (west of museum grounds) are without higher emissivity.

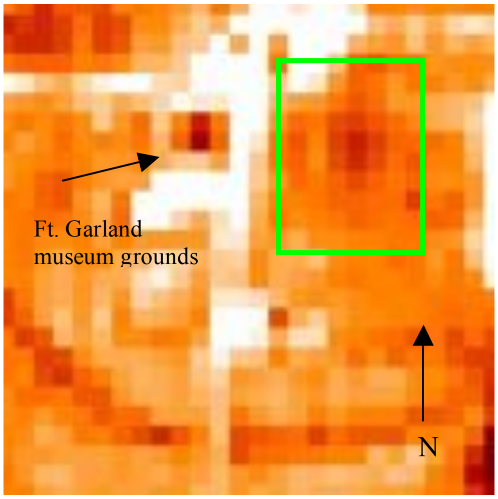

Figure 9. Zoom of Ft.Garland museum area and field to the east from Figure 8. Highly vegetated parade grounds of fort/museum are shown in dark colors due to high vegetation and low emissivity. Note thermal anomalies are visible, but do not form a pattern.

Figures 8 and 9 show the Landsat 7 ETM+ image from July 10, 1999 with normalized emissivity. The towns, roads, and fort/museum grounds all appear to be high emitters, and are shown in white. Vegetation is shown in darker colors for lower emissivity. Upon zooming into the specific area of the fort/museum (Figure 9), it is possible to distinguish the parade grounds of the fort, which are lushly vegetated and shown in dark colors. Note the adobe buildings surrounding the parade grounds do not seem to have an impact on the emissivity. This could be due to coarse resolution that is grouping the high emissivity adobe with low emitting surrounding soils. It is possible to note an area of low emissivity in the Figure 9, but no pattern or particular shape is indicated, potentially due to coarse resolution.

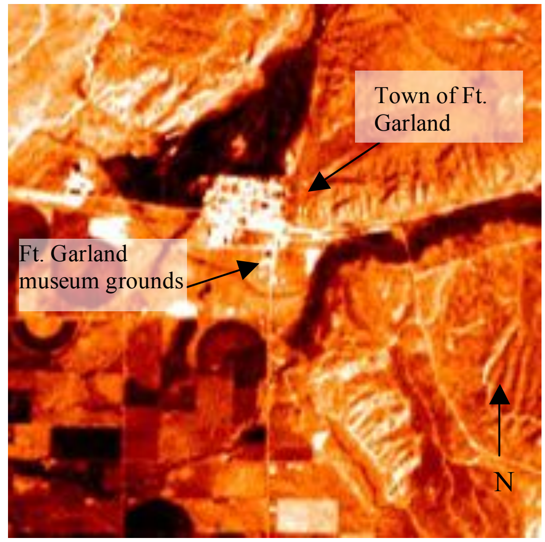

Figure 10. Emissivity normalized image of the town of Fort Garland, including the museum grounds, and field to the east of the museum. Lighter colors indicate high emissivity, darker colors indicate lower emissivity.

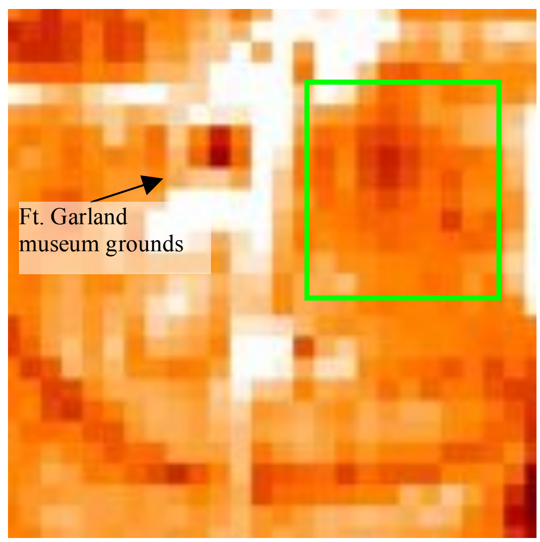

Figure 11. Zoom of Figure 10. Note area of low emissivity in same area as in Figures 8-9. Lighter colors indicate higher emissivity, darker colors indicate lower emissivity.

Much as is seen in Figures 8-9, Figures 10-11 also show an area of low emission to the east of the fort/museum grounds. The area is particularly clear in the zoomed images (Figures 9 and 11). However, in Figure 11, the area still does not indicate a pattern or definite shape. The same issue of 'bleeding' between the parade grounds, the adobe of the reconstructed fort, and the surrounding soil is an issue. This is due to the averaging of signal value and coarse resolution.

Figures 12-13 show the emissivity normalized image of the study area on September 30, 2000. This is after the first Fort Garland field school. The images show no area of low thermal emission east of the museum grounds, which could be interpreted as a product of exploratory excavation. However, given that the parade grounds of the fort, which have appeared as a 2-pixel unit of low emission is not clearly visible in the zoomed image (Figure 13), it is likely that there is an issue with the sensor or signal, not with the actual site. The field to the east of the museum grounds does show variation of emissivity, but there is no indication of pattern or shape, which would indicate purposeful human influence.

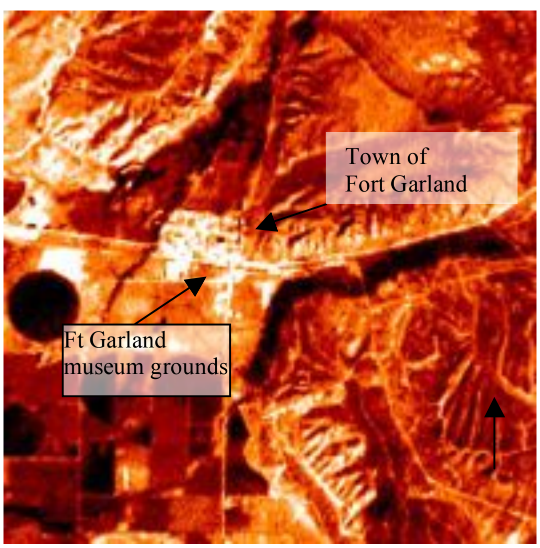

Figure 12. Emissivity normalized image of the town of Fort Garland, including the museum grounds and field east of the

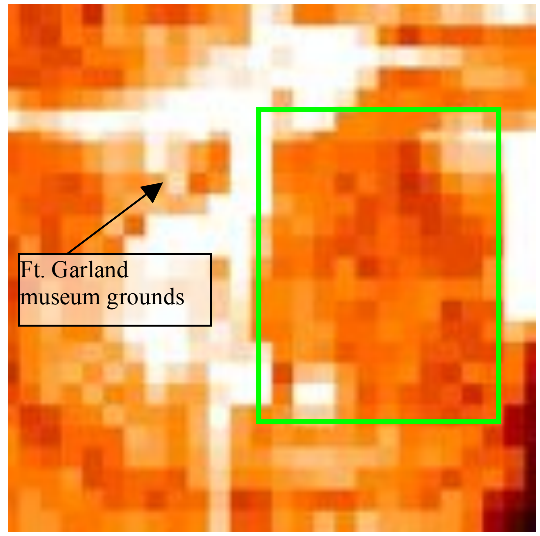

Figure 13. Zoom of site area from Figure 10. Note that in this image, the area of low thermal emission is not as clearly visible, nor is the parade ground as a single, dark unit.

Comparison

Aerial photograph images and Landsat 7 emissivity normalized images were compared to each other and the site maps for the area (Figure 3a-b). The comparison is not imaged in this paper as the images in question have already been used and no positive data was drawn from the comparison, other than as already noted.

Conclusions

The Landsat 7 ETM+ image resolution was too coarse to determine building-sized thermal anomalies on a site the size of Fort Garland. While the resolution was fine enough to determine site boundaries at a site this size, there was no compelling evidence for the determination of site boundaries based on thermal or moisture retention anomalies. The variation and consistency of temperature from pixel to pixel within the study site is indicative of the viability of this study, given finer spatial resolution.

Despite the established use of aerial photographs as a remote sensing tool in archaeology only two aerial photographs showed a small shadow that could indicate a landscar in the vicinity of the former corrals and stables. While the land scar is seen in two images, this cannot be considered definitive given that both images were taken on the same day, under the same conditions and equipment. The lack of land scars visible in the pre-reconstruction/ pre-field school aerial photographs indicates that current land scars as seen in Google Maps images (used in the site map) are most likely caused by exploratory excavation and preparatory land clearing (Figure 3a).

Recommendations

As the cost of airborne sensors decreases, and the resolution of freely acquired satellite sensors increases, this project should have more positive results in the future. If more recent aerial photographs (prior to the first field school) could be obtained, the comparison of pre-field school land scars and post-field school land scars could be analyzed to the benefit of the localization of buried structures at small sites like Fort Garland.

Acknowledgements

The author would like to thank Dr. Fernando Gilbes Santaella for use of the GERS laboratory, and for his patience in helping with missing color ramps, ENVI error messages and (last minute) problems. The author would also like to thank Tim and Dr. Dick Goddard for facilitating the current site maps as well as numerous 19th century military maps, and discussions on the history of Fort Garland.

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Appendix

Figure 3a in larger, legible size. Site map based on Google Maps, and provided courtesy of Tim and Dr. Dick Goddard.

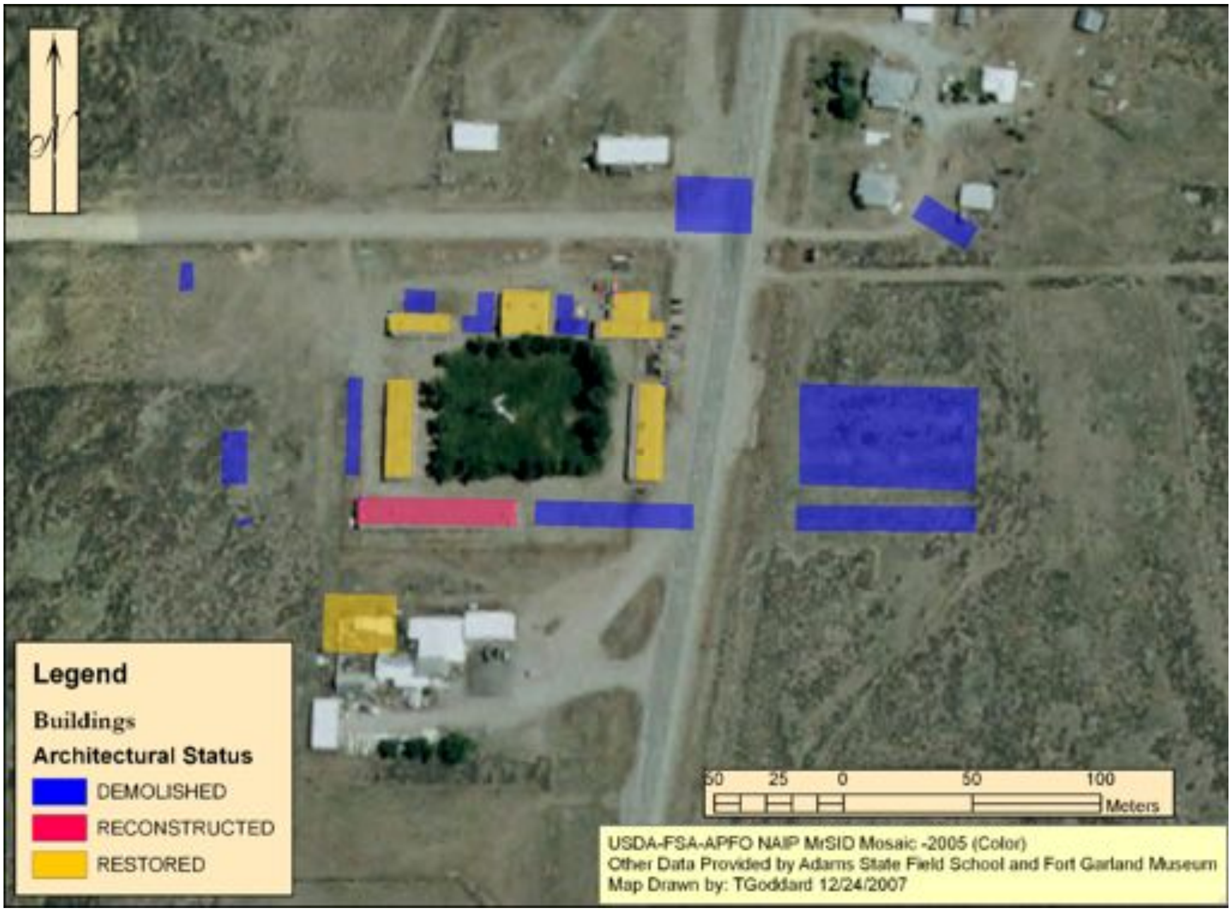

Figure 3b, in a larger, more legible size. Map courtesy of Dr. Dick Goddard, property of the Colorado Historical Society.