4.8.2. Orthorectification
Kenneth L. Kvamme, University of Arkansas

The original coordinate grid at Army City was established by total station. This coordinate grid covered the entire field for purposes of the field-wide electrical resistivity survey (Hargrave et al. 2002), with a wooden stake placed every 20 m. An intensive effort was spent at the initiation of fieldwork in 2002 to relocate these datums. This was successful, and perhaps 75 percent of the badly decayed wooden stakes were found. Surveyor grade kinematic GPS units were employed to obtain real world coordinates for a suite of these datums defining the perimeter of our 100 x 160 m survey area. Permanent plastic datums (tent stakes) were sunk every 20 m around the site perimeter.

Nylon (Figure 4.51a) or metal (Figure 4.51b) crosses were placed over selected datums as ground control points (GCP) for purposes of image rectification and registration (Burrough and McDonnell 1998). The metal crosses were made of heavy-duty aluminum roof flashing and employed under the theory they would be more visible to thermal infrared imaging. They were, but so too were the nylon GCP. Both types were
placed alternately around the perimeter (Figure 4.51c) and in the interior of the study site (Figure 4.51d). Study area-wide mosaics were built using image rectification and registration techniques in Adobe Photoshop and GIS methods that “rubber-sheeted” slightly oblique imagery into a correct spatial projection in the site’s local coordinate base. This process is illustrated in Figure 4.51e where a thermal infrared frame is “fit” to the local coordinate base.

4.8.3. The Potential of Aerial Remote Sensing at Army City

Kenneth L. Kvamme, University of Arkansas

It was emphasized above that if aerial remote sensing methods do not yield useful results that point to archaeological features that it may be only a matter of poor timing. Flights in other season or climate regimes (e.g., droughts or periods of heavy rain) could yield very different outcomes. This section focuses on this issue and demonstrates that exceptional aerial imaging of Army City’s underlying structure and content would have been highly likely if aerial survey could have been undertaken at the proper time.

The summer of 2002 was a time of severe drought in much of the Great Plains, including northeastern Kansas. At the time of the July geophysical surveys, with temperatures consistently hovering near 40° C, the ground was extremely dry and parched, which made geophysical surveys difficult (see Section 4.6.1). An unforeseen consequence of the drought conditions, not fully appreciated at the time, was that the site’s surface vegetation was extremely stressed, resulting in strong negative vegetation markings that correlated with many subsurface archaeological features of Army City indicated by the geophysics. In other words, one could discern the lines of walls, streets, and even individual rooms on the surface by merely walking about the site. This was realized as an important signal at the time, and a series of surface photographs were made from a borrowed two-meter-tall stepladder of several of these markings. It was believed at this time that air or space imagery to be subsequently acquired would capture these or similar markings. It was not fully realized or appreciated that strong vegetation marks were rare at this site—they probably occur only in drought years or periods of extreme dryness. More than a half-dozen subsequent visits and an equal number of air or spaces images confirm this view (see reviews of imagery below). It is unfortunate, then, that under the premise that wet spring conditions with new plant growth might yield positive vegetation marks and a “chlorophyll response,” particularly in near-infrared bands, aerial imagery of Army City was acquired in April, 2004, and from the QuickBird satellite in a scene dating from April, 2001 (see below). At these times little anthropogenic patterning can be discerned in the imagery. As indicated by Wilson (2000) and others, vegetation markings expressed by archaeological sites have an idiosyncratic character dependent on unique site and climate conditions. At Army City it is now apparent that drought conditions must be sought to reveal the subsurface through vegetation markings. This turn of events has been a grave disappointment to the project, given the high quality of geophysical results. The following surface images demonstrate that aerial imaging could, indeed, be very productive at this site if properly timed with dry or drought conditions.

During the ground-based geophysical surveys of Army City, performed July 8-19, 2002, numerous surface features of potential interest to the interpretation and understanding of the site were observed. The field had been mowed immediately before
the survey, which facilitated the visibility of new plant growth that occurred after the brief and freak shower on the night of July 10. Some vegetation marks were made visible by new plant growth, but most were discernable as areas of stunted or wilted growth, or more often dead plants or no plants. An example of a likely cultural feature revealed by new plant growth is shown in Figure 4.52. It reveals a rectangular area measuring about 2 x 4 m, supporting a lush growth of new, green grass. It is likely caused by a moisture trap and a small region of better soil, probably within an individual room.

Figure 4.52. Rectangular cultural feature of Army City, probably a room, indicated by positive vegetation marking in the form of new grass growth. a) View to east. b) View to south.

Most cultural features at Army City were revealed by stunted or browned grasses. A good example is a portion of historic General Street, which is seen as a broad area of stunted grass (between arrows, Figure 4.53). This view is immediately south of the historic Hippodrome, and west of Washington Avenue, Army City’s principal road (see Figure 4.37e).

Figure 4.53. Stilted and browned grasses forming negative vegetation marks that indicate a segment of General Street, between arrows. This view looks east, immediately to the south of the Hippodrome and west of Washington Avenue.
Remarkably, numerous “walls,” some only 25 cm wide, were also apparent in the grassy surface of Army City. They were typically seen as linear features of browned grasses or were discerned as narrow areas lacking vegetation (Figure 4.54). Most of these walls correspond with the area of the historic Hippodrome (see Figure 3.2), and represent elements of this structure. Frequently, the patterning is clear enough such that individual rooms of this structure can be discerned. Subsequent excavations made in 2004 showed these walls to lie only 20 cm below the surface and that they were made of concrete (see Section 5.16).

Even more impressive and convincing, however, were dozens of small, circular areas of dead or browned grasses, about a half-meter in diameter (Figure 4.55). They occur in linear arrangements and clearly represent building footings. Subsequent excavations made on 2004 indicated brick and cement footings lying only 20 cm below the surface (see Section 5.16), which evidently stressed plant life growing over them.

**Figure 4.54.** Negative vegetation marks revealing linear architectural features representing walls at Army City. a-e) Views of browned and wilted grasses over the concrete walls of the Hippodrome, lying only 20 cm below surface. f) Hippodrome wall with 25 cm scale (center); Colonel Street may be seen between horizontal arrows.
Figure 4.55. Building footings revealed as negative vegetation markings at Army City. a) Two footings (arrows) with 25 cm scale. b) A linear arrangement of four footings (arrows) with geophysical survey guide ropes (each separated by 2 m) placed for survey. c) Six building footings (view to southwest, with levee in background).

It is very clear from Figures 4.52-4.55 that had the site been viewed and imaged from the air at the time of the geophysical surveys an extraordinary aerial mapping of Army City would have been achieved. In fact, such a mapping was attempted of what could be seen from the limited standpoint of the surface. It is standard practice of the ArcheoImaging Lab to systematically inspect and map the ground surface during geophysical surveys because circumstances visible on the surface (e.g., badger dens, rocks, trees, bushes) frequently explain anomalies later observed in the geophysical data.

Figure 4.56. Map of surface-visible features, many revealed by vegetation markings, made at the time of the geophysical surveys.
Maps of each 20 x 20 m survey block were therefore made throughout the 100 x 160 m study region. They depict every observable nuance or impression visible on the surface. A compilation of these maps for the full study area is illustrated in Figure 4.56. It shows much of the layout of the Hippodrome, the outline of a structure supported by footings, rocks jutting from the surface of a rectangular structure, and many depressions in the vicinity of the former Orpheum Theater (see Figure 3.2).

4.8.4. Normal-light Aerial Photographs and Imagery from Army City

Kenneth L. Kvamme, University of Arkansas

A number of aerial scenes were procured from Army City, but in the collective set few archaeological features are indicated, if any. A National Aerial Photography Program (NAPP) aerial photo dating to 1991 shows a number of large trees near the study area (appearing black from extreme contrast manipulation). The area of the hippodrome (upper left of study area) and a number of subtle linear/rectilinear anomalies may be visible (Figure 4.57a). A NAPP photo from 1996 shows a similar but less crisp view. A lineation in the upper center probably represents Washington Avenue, a square anomaly to the left possibly indicates a buried structure (Figure 4.57b). A low resolution color image made at high altitude for soil surveys in 1999, obtained from the Fort Riley Directorate of Environment and Safety, shows the trees are probably down and replaced by brush (Figure 4.57c). Heavy disturbance obscures indications of Army City’s features. A low resolution color image from 2004 (probably in late fall), also from Fort Riley, shows greener vegetation in and about the study area over the principal archaeological features of Army City, as defined by the geophysical surveys (see Section 4.6.1). This vegetation marking shows a number of linear and rectilinear patterns that probably correspond in a general way to buried elements of the town (Figure 4.57d). A high resolution color image of the study area obtained from the powered parachute in the spring of 2004 is shown in Figure 4.57e. It reveals very little about the buried town, but indicates the presence of numerous “prairie rings,” a form of grass growth on the Plains that also impacts the thermal infrared imaging (discussed below). Finally, the panchromatic band from a QuickBird satellite scene dated April 3, 2001, with 0.6 m spatial resolution, reveals a series of linear and rectilinear anomalies and clear indication of Washington Avenue (Figure 4.57f; the QuickBird imagery is again revisited in Section 4.9). Despite a variety of Army City images, it is apparent that available normal-light aerial or space views do not appear to indicate much about the town’s subsurface structure.
4.8.5. Thermal Infrared Imagery from Army City

Kenneth L. Kvamme, University of Arkansas

The thermal infrared data acquired by powered parachute at Army City were generally informative. One problem was motion blurring endemic to the Palm-IR250 thermal infrared camera. About two-thirds of the videotape was significantly blurred, but the videotapes were painstaking reviewed (at 30 frames per second) allowing extraction of hundreds of unblurred frames from throughout the study area. Several frames acquired at low altitudes yielded exceptional detail. Figure 4.58a shows a number of anomalies that represent building footings significantly warmer than the surrounding soil (white dots). This view was acquired in an evening flight immediately after sunset when dense materials like brick, concrete, or stone yet retain the day’s warmth. It illustrates sub-meter detail at a spatial resolution of approximately 6 cm. These data are enhanced through a high-pass filter in Figure 4.58b. Data from the corresponding electrical resistivity survey (Section 4.6.1) indicates similar anomalies, but these data are much coarser with a spatial resolution of only 50 cm (Figure 4.58c). The high resistivity anomalies points to brick, concrete or stone footings, consistent with thermal indications and likely footing materials.
Figure 4.58. Thermal infrared imagery from Army City showing details of building footings. a) Raw imagery. b) Enhanced through a high-pass filter. c) Corresponding electrical resistivity data.

Similar detail is shown in Figure 4.59a. This image reveals elements of the Hippodrome, a commercial structure (see Section 3.3.4). A number of prominent walls and building footings are clearly visible (arrows), as are hints of Washington Avenue and General Street. These data, acquired in an early morning flight, show inverted thermal properties with footings and some of the walls appearing cooler than the background. Corresponding resistivity data (Section 4.6.1) are given to clarify findings (Figure 4.59b).

Figure 4.59. Thermal infrared imagery from Army City showing wall and footing details of the Hippodrome. a) Raw imagery, with arrows pointing to elements of obvious interest. b) Corresponding electrical resistivity data.

A full study-area-wide composite of mosaic thermal infrared imagery is given in Figure 4.60. The levee ditch, very wet, appears cool while the levee itself is much warmer. Of more significance, numerous anomalies and many important elements of Army City are indicated. Washington Avenue is prominently revealed and General and Colonel Streets can be discerned. Moreover, a number of prominent rectangular and
linear areas illustrate warm or cool anomalies, pointing to likely concrete, brick, or perhaps tiled areas for the former (e.g., floors), and recessed floors, gutters, or perhaps cellars filled with moist sediments for the latter. Also prominent are a number of prairie rings with the outer perimeter of new growth standing tallest and therefore cool (white arrows; see also the color view in Figure 4.57e). This data set is extensively employed in data fusions in Section 5.

4.8.6. Thermal Infrared Results from Pueblo Escondido

Eileen G. Ernenwein, University of Arkansas

Thermal data were collected at Pueblo Escondido in January 2005 using the Raytheon Palm IR 250 thermal imager, which was hand-operated from a small two-seat helicopter, rented for the occasion. The flight was planned so that data could be collected for approximately 25 minutes before and after sunset, but despite prior approval, permission for entering Fort Bliss airspace proved to be difficult once in the air and the flight was delayed for about 20 minutes. The total flight time over the site was approximately 25 minutes most of which was after sunset. During the short flight it was difficult to fly slowly enough to prevent blurring of the imagery and most of the recorded video is unusable due to inherent problems with this instrument. This was the first and only attempt to collect thermal data from this platform, and the instrument proved to be very sensitive to motion—even at the slowest speeds the helicopter pilot was willing to travel.

Several frames from the thermal video were captured as images and used to create a mosaic rectified and registered to the coordinate base of the principal geophysical
survey area (see Section 4.6.2). Twelve metal GCP were placed at grid corners every forty meters, making it possible to rectify the images to the plane coordinate system of the geophysical grid (as in Figure 4.51). The result is very similar to the much of the satellite and aerial imagery investigated by the NASA team below, which mainly show patterns of vegetation. No obvious cultural features are apparent in these data.

Figure 4.61. *Thermal infrared imagery over principal study block at Pueblo Escondido, acquired with the Raytheon PalmIR250 thermal imager.*

### 4.8.7. Relationship between Satellite Panchromatic, Aerial Thermal, Conductivity, and GPR data at Pueblo Escondido

*Eileen G. Ernenwein, University of Arkansas*

Several aerial and satellite data sets were acquired over Pueblo Escondido, including multispectral and panchromatic imagery from the QuickBird satellite, National Aerial Photography Program (NAPP) photos (Figure 4.57), and aerial thermal images acquired with CAST’s thermal camera from a helicopter (Figure 4.61). While these data have provided little direct information about Pueblo Escondido, they exhibit interesting relationships with each other and with the ground-based geophysical data. Aerial and satellite methods for archaeological site exploration rely heavily on vegetation, which, when conditions are favorable, can very clearly delineate buried cultural remains such as fortification systems, canals, roads, and prehistoric houses (Wilson 2000). No such patterns are evident in the Pueblo Escondido data, however, probably due to the lack of consistent vegetation cover on the dry desert floor (Figure 4.62a).

Although large expanses of bare soil are often a hindrance for prospecting in the visible spectrum, they can be favorable for thermal infrared sensing because the best
opportunity for detecting subsurface features may be over bare soil (Perisset and Tabbagh 1981). This could be true for Pueblo Escondido, but unfortunately the use of a helicopter caused too much motion resulting in blurred imagery and a lack of fine details (Figure 4.61). When compared against a QuickBird satellite panchromatic image of the region, acquired on March 26, 2003 (see also Section 4.9), it is clear that these data sets respond most strongly to the presence and absence of vegetation (Figure 4.62b; the spatial offset between the panchromatic and thermal image is due to small errors in georegistration). It should also be noted that the thermal data were captured some fifteen months after the vegetation had been almost entirely cleared for geophysical survey, and that some differences should likely exist.

![Figure 4.62. Comparison between satellite and aerial data over the principal Pueblo Escondido study area. a) QuickBird panchromatic image at 0.6 m spatial resolution. b) Aerial thermal image with vegetation based on QuickBird panchromatic data shown with yellow contours. c) Color aerial photograph of the site looking south with approximate location of geophysical survey area shown in red.](image)

The QuickBird panchromatic and thermal infrared data sets also relate to some of the ground-based geophysical data. Figure 4.63a illustrates the areas of high EM conductivity in black, with vegetated areas indicated by the QuickBird panchromatic band outlined in yellow. Although the relationship is not consistent throughout the entire study area, it is clear that the majority of the vegetated areas are associated with regions of very low conductivity, whereas areas lacking vegetation exhibit high and low conductivity. Vegetation draws moisture from the ground. It may also promote low conductivity by loosening up soil with root systems, thereby increasing porosity and allowing it to dry out more thoroughly. In the right moisture conditions this could make root zones less conductive. The satellite and aerial data have therefore aided the interpretation of the ground-based conductivity data. What the conductivity data are showing remains unclear, but it appears that some anomalies are related to the distribution of vegetation.
Patterns in the QuickBird, thermal, and conductivity data are also related to the ground-penetrating radar response. When the vectorized interpretations, which are based largely on GPR, are compared to the conductivity image (Figure 4.63b), it is clear that areas of high conductivity contain fewer and less distinct archaeological features. This is more apparent in Figure 4.63c where high conductivity and vegetated areas are shown overlaid on a 31-47 cm deep GPR slice. It is not surprising that areas of high conductivity, which attenuates GPR signals (Conyers 2004), are associated with few GPR reflections. Vegetated areas, generally associated with greater ground disturbance, are also associated with poorer GPR results. In fact, the panchromatic and conductivity data could be used in the future as a means of predicting GPR success.

It is clear that GPR responds much better in areas of low conductivity lacking vegetation, but the exact causes are still unknown. Vegetated regions might be associated with poor preservation, as could high conductivity areas. Alternatively, preservation may be similar across the site, but imaging with GPR is simply compromised by the presence of vegetation and high conductivity. These questions were not addressed during the archaeological excavation program, but no major differences in preservation were found to be associated with vegetation or conductivity. Although aerial and satellite data do not appear to be highly successful methods of locating archaeological features at Pueblo Escondido, they have proven useful when used together with ground-based geophysics. The QuickBird panchromatic image shows that the thermal data responded primarily to vegetation cover, which is also associated with low conductivity. In addition, the GPR data are much improved in areas of low conductivity and little or no vegetation, suggesting that aerial images and conductivity could help predict the success and reliability of GPR over a survey area.
4.9. AERIAL AND SPACE MULTI-SENSOR REMOTE SENSING BY NASA

Thomas L. Sever and Burgess F. Howell, NASA Marshall Space Flight Center

4.9.1. Introduction
Kenneth L. Kvamme, University of Arkansas

This section summarizes aerial and space-based remote sensing activities conducted by the NASA Marshall Space Flight Center at the SERDP project sites. The NASA team performed an extensive array of aerial remote sensing and additionally conducted research using high resolution QuickBird satellite imagery. Sever and Howell (2005) present this work in a summary report. This team chose to perform their analyses “with little a priori knowledge of specific cultural features on the ground in order to determine the ability of aerial remote sensing to locate and map unknown archeological features without the benefit of ground verification.” Because it offers a “blind” appraisal of the SERDP project sites, the following material is very different from the content of foregoing sections. Much focus and many interpretations were consequently made outside of the study boundaries of the geophysical surveys, for example. Some of this interesting material cannot be presented here, where focus continues on the specific project areas and multidimensional remote sensing findings within them. Project study areas have been superimposed on the NASA imagery to maintain that focus in this report. Comparisons of these findings should be made against geophysical and aerial remote sensing materials given in Sections 4.6 and 4.8 to aid in the interpretation of these results. In particular, some of the remote sensing interpretations given at the various sites point to disturbed brushy ground where trees were once located at Army City, to known pipelines at Kasita Town, and geophysical survey grid lines (that impacted plant growth from repeated walking) at Silver Bluff and Kasita Town.

The following sections describe data sources, modes of acquisition, processing and enhancement methods, and analytical techniques. Several problems encountered while collecting and processing the data are enumerated, as well as lessons learned that may be applied to future projects of this nature.

4.9.2. Sensor Instrumentation

4.9.2.1. QuickBird
QuickBird is a high-resolution commercial earth observation satellite owned by DigitalGlobe, launched in 2001. It collects panchromatic (black and white) imagery at 60-70 centimeter resolution and multispectral imagery at 2.4- and 2.8-meter resolutions. Bands and band widths are given in Table 4.5. The satellite orbits the earth every 93.4 minutes at an altitude of 450 km in a 98 degree sun synchronous inclination. It acquires data over an area of interest either in a single area (16.5 km by 16.5 km) or in a strip (16.5 km by 165 km) and revisits the same location on the earth every 1 to 3.5 days, depending on latitude at 70 cm resolution.

4.9.2.2. Raytheon PalmIR 250
The PalmIR 250 is an inexpensive, lightweight portable thermal unit that was mounted on a fixed wing aircraft flying at high altitude for complete coverage of the study area and environs in single scenes. It is a single, broad band (7-14 microns) thermal system that detects slight temperature differences between objects and people in its field.
of view and uses this information to create real-time “thermal landscapes” of the area on display. It uses a 320 X 240 barium strontium titanate detector with a spatial resolution of 1.0 mrad and a thermal sensitivity of less than 0.10 at 30 degrees Centigrade. Thermal data are direct results of target and temperature. Due to the low altitude at which the PalmIR 250 data were acquired, the atmospheric component was negligible and no atmospheric corrections were made. Emissivity, temperature, and reflectance are therefore features that influence the radiation detected.

**Table 4.5. QuickBird bands and band widths.**

<table>
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<tr>
<th>Channel 1</th>
<th>pan</th>
<th>450-900 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel 2</td>
<td>blue</td>
<td>455-516 nm</td>
</tr>
<tr>
<td>Channel 3</td>
<td>green</td>
<td>506-595 nm</td>
</tr>
<tr>
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<td>630-690 nm</td>
</tr>
<tr>
<td>Channel 5</td>
<td>NIR</td>
<td>760-900 nm</td>
</tr>
</tbody>
</table>

**4.9.2.3. DuncanTech MS4100 Digital Multispectral Camera**

The DuncanTech MS4100 camera is a digital, progressive scan, multispectral camera mounted on a fixed wing aircraft. It employs a color separating prism and three imaging channels that allow simultaneous image acquisition in 3-5 spectral bands through a common aperture. Image sensors are charge coupled device (CCD) array sensors (Table 4.6).

**Table 4.6. DuncanTech MS4100 bands and band widths.**

<table>
<thead>
<tr>
<th>Channel 1</th>
<th>green</th>
<th>520-590 nm</th>
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</thead>
<tbody>
<tr>
<td>Channel 2</td>
<td>red</td>
<td>630-690 nm</td>
</tr>
<tr>
<td>Channel 3</td>
<td>NIR</td>
<td>760-900 nm</td>
</tr>
</tbody>
</table>

**4.9.2.4. Advanced Thermal and Land Applications Sensor (ATLAS)**

Six thermal bands from ATLAS were analyzed over Pueblo Escondido at Fort Bliss, Texas. The data were provided by personnel from Ft. Bliss who had previously acquired extensive ATLAS data for interdisciplinary research at 5 m spatial resolution. Only a subset of the data, the area over Escondido Pueblo, was provided to this project. The ATLAS airborne sensor acquires high spatial resolution multispectral and thermal infrared data and is flown on board a Lear 23 jet aircraft operated by the NASA Stennis Space Center. The ATLAS is a 15-channel multispectral scanner that basically incorporates the bandwidths of the Landsat TM (along with several additional channels) and six thermal IR channels similar to that available on the airborne Thermal Infrared Multispectral Scanner (TIMS) sensor (Table 4.7). Only the thermal channels, bands 10-15, were provided and used in this study.
### Table 4.7. *ATLAS* sensor system specifications.

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<th>Channel NUMBER</th>
<th>Bandwidth Limits (µm)</th>
<th>NER mW/cm² µm</th>
<th>NE T °C</th>
<th>MTF @ 2 mrad</th>
<th>Cooling</th>
</tr>
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<td>0.5</td>
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</tr>
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<td>0.5</td>
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<td>0.5</td>
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</table>

#### 4.9.3. Image Analysis Software

Image processing software utilized for this study included ERDAS Imagine (1999), RSI-ENVI, and Z/I Imaging Image Analyst. ERDAS Imagine is the industry standard for processing remotely sensed data and includes a powerful graphical modeling capability to develop customized models and streamline routine tasks. RSI-ENVI is a competitive image processing product that was utilized for specific tasks that were problematic in Imagine. For example, RSI offers improved capabilities for post classification and spectral mapping. Also, ENVI color tables are generally superior to ERDAS. Image Analyst was utilized for digitizing areas of interest. It is particularly well suited to this task because of its flexible and powerful image display tools that allow interactive real-time modification of image display characteristics. ELAS is a sophisticated image processing and remote sensing package that allows the user great flexibility in modifying the operations and parameters at a very fundamental level.

#### 4.9.4. Processing Techniques

##### 4.9.4.1. Georeferencing

All data sets used in site analysis were projected (or reprojected, where necessary) to a common workspace on a per site basis using the Universal Transverse Mercator system. Since QuickBird data were common across all sites, each of those scenes was arbitrarily chosen as being in the “correct” orientation, and every other data set of interest was registered to its respective QuickBird analog.
4.9.4.2. Resolution enhancement

In order to enhance the spatial resolution of the multispectral QuickBird data used in this project, a data fusion process known as pan sharpening was performed. In pan sharpening one of several techniques is employed to generate new data sets which combine the high frequency spatial domain data of the panchromatic band with the higher information content, but lower spatial resolution data of the multispectral bands. For the data in this study, we used a process known as a Principal Components Transformation (PCT). PCT transforms the multispectral data from spectral space into a feature space where one of the resulting bands is correlated with the high resolution data. The high resolution band is then substituted for the correlated band and a reverse transform applied to translate the bands back to spectral space. In the PCT, information content common across the multispectral bands is mapped to a single output data set called the Principal Components Image (PCI). The content of this image is typically highly correlated to brightness or intensity (Jensen 1996; Chavez et al. 1991). The high resolution QuickBird panchromatic data are contrast matched to the PCI, then substituted for the PCI in an inverse PCT operation that transforms the data back into spectral space (Schott 1997).

4.9.4.3. Image stacking

A simple but effective technique to examine the data content of dissimilar data sets is to use them as constituents of an image stack. In much the same way that a GIS system allows examining multiple database layers at a common location, an image stack allows computational and visual analysis of multiple spectral datasets over a common area. We created image stacks for each study area utilizing input bands from 2 or more sensors. In each case, the site’s QuickBird scene was chosen as the “master” data set, with the other data sets being resampled such that their pixels were dimensionally identical to, and spatially coincident with, their QuickBird counterparts.

4.9.4.4. Band ratioing

Over most sites, one or more synthetic data sets were produced by ratioing pairs of image bands. In most instances, the purpose was to generate a normalized difference vegetation index for inclusion in an image stack. Where coincident Duncan and QuickBird data were available, a ratio of the NIR bands from those data sets highlighted changes in vegetation vigor and density between the two data acquisition dates.

4.9.4.5. Filtering

For the thermal data, the appearance of a target varies from image to image across a sequence of frames. When a sequence is put together as a mosaic the variation is manifested as noise that obscures the target signal. To reduce the impact of this noise, a simple 3x3 low pass convolution kernel was passed over the mosaic of thermal data. To regain lost detail from this operation, the output of the low pass kernel was subjected to a Laplacian edge enhancement filter. Those filtered data were then used as final input for stacking, ratioing, and other processing.

4.9.4.6. Principal components analysis (ATLAS thermal)

Each of the ATLAS thermal channels was reviewed individually and various band combinations created in an attempt to detect the ruins of Pueblo Escondido. In addition,
principal component analysis was performed to circumvent noise problems in the data. In this technique a set of axes is selected so that the maximum amount of a data set’s variation is accounted for by a minimum number of perpendicular axes. The first principal component can be equated to target brightness and constitutes the majority of the data, while the remaining components contain logarithmically decreasing proportions of the data. Principal components analysis provided a crisp image of the study area, as noted in the scrub vegetation and other surface features, but did not reveal walls, rooms, or other features associated with the pueblo structure. One explanation is that the data was acquired at mid-morning when thermal temperatures are balancing rather than at thermal maximum (solar noon) or minimum (pre-dawn.). Although there might be concern that the 5 m resolution of the data precluded the detection of these feature, this is not the case. Five meter aerial thermal data was successfully used at pueblos in Chaco Canyon, New Mexico, which did in fact reveal walls, trash middens, gates, and emerging and exiting roads (Sever 1990; 1983).

4.9.5. Data Analysis

Processed data sets for each site were interpreted by a variety of manual and automated means. Multispectral datasets were subjected to supervised and unsupervised classifications based on spectral characteristics of component bands. Individual bands were “stretched” (contrast enhanced) by density slicing (application of a continuous color table to a grayscale image based on the relative magnitude of constituent pixel values), thresholding (application of a binary color table to a grayscale image based on the relative magnitude of constituent pixels), and stretching (remapping some or all of the range of pixel values to increase the apparent brightness difference between consecutive values). Contrast stretching techniques included simple linear (remapping some or all of an image’s constituent pixel values—chosen by specific values—across the dark-to-bright range of a display system), linear percent (remapping a portion of an image’s constituent pixel values—chosen as a percentage of all possible values—across the dark-to-bright range of a display system), and linear piecewise (remapping various segments of constituent pixel values to several non-linear and/or non-contiguous segments of the range of a display system).

Because stretch operations are performed utilizing parametric statistics based on a sample of the total pixels for a band or image, the output appearance can be varied almost infinitely by changing the input sample. In particular, sampling a specific spatial extent on the ground causes the stretched output to enhance small differences across that area. Differences outside that area are minimized to the extent that, when a very small or spectrally homogeneous area is sampled, gross features may appear highly generalized and monotone. Both highly enhanced and highly generalized portions of a stretched image can be used to extract information about a scene. Features of interest within the various data sets were noted by creating a set of overlying bounding or delineating vectors using Bentley MicroStation CAD software. Georeferencing information in the form of UTM and geographic coordinates was attached to those vectors by Z/I Imaging Coordinate System Operations. The vectors were then exported as ESRI shapefiles for incorporation with the project overall GIS.
4.9.6. Features of Interest

In general, other than the geographic coordinates of a central point for each site, all data were acquired, processed, and analyzed without benefit of \textit{a priori} knowledge, with two notable exceptions. At Army City, placement of positional reference markers was accomplished with the assistance of other team members, and utilizing a grid originally devised during the course of previous investigation. At Silver Bluff, similar markers were placed at the site alongside and obvious archeological excavations already in progress. Primarily because of this lack of an existing knowledge base upon which to base specific conjecture, most instances of significant or interesting features found in the imagery of the four study sites are noted simply as “features” or “anomalies.” Only in cases where feature characteristics make identification obvious do we label targets as to particular type.

4.9.6.1. Army City

A full QuickBird scene of the region around Army City, including much of Fort Riley, is illustrated in Figure 4.64. It is presented in a true color format, with bands 3,2,1 assigned to red, green, and blue, respectively. The general region of interest is illustrated in the yellow box.

![Figure 4.64. Full scene, true color QuickBird image, band 3,2,1 (RGB) showing the general area of study at Army City in yellow.](image)

Composite imagery is illustrated in Figure 4.65a-d. It shows QuickBird band 4 (NIR) on the red channel, PalmIR thermal on the green channel, and QuickBird band 2
(green) on the blue channel. Figure 4.65b highlights some of the major bright anomalies (in yellow). In addition, much of the area in the left half of the image (particularly in the geophysical study area, is shown to be disturbed ground (in purple). That purple signature extends throughout the image. This scene emphasizes many anomalies outside the geophysical survey area. A close up view of five of the highlighted anomalies is given in Figure 4.65c,d, enhanced to show greater detail.

Figure 4.65. Composite Army City imagery showing QuickBird band 4 (NIR) as red, PalmIR thermal as green, and QuickBird band 2 (green) as blue. a) View of processed region with b) bright anomalies indicated in yellow. c,d) Enhancements focused on specific anomalies. The focal study area of 100 x 160 m is outlined in black.

The PalmIR thermal infrared data show temperature variations throughout the region (Figure 4.66a). (These data were acquired at relatively high altitude from a fixed wing aircraft, compared to low-altitude results given in Figure 4.60.) The anomalies from Figure 4.65 have been overlaid onto the image. Several small, dark dots in the image are from the thermal reflectance of the aluminum markers used for georeferencing. The data of Figure 4.65 are again illustrated in Figure 4.66b, but with a different enhancement.
Many linear and surface anomalies are superimposed on this image. The linear features represented by red are speculated to be of recent origin.

Figure 4.66. Army City imagery. a) PalmIR thermal temperature variations with anomalies superimposed. b) Enhancement of previous RGB imagery showing linear and surface anomalies. The focal study area of 100 x 160 m is outlined in black.

4.9.6.2. Pueblo Escondido

The full, true color, QuickBird scene is illustrated in Figure 4.67. This image shows band 3,2,1 as red, green, and blue, respectively. The general area of study is given in yellow.
A pan sharpened and contrast enhanced QuickBird image is given in Figure 4.68a. This image shows bands 4,2,1 as red, green, and blue (RGB). Unfortunately, no QuickBird data band combinations, processing methods, or enhancement techniques were able to indicate any probable archeological features at this site. This circumstance is apparently true of the other forms of remote sensing data. A contrast enhanced first principal component image of ATLAS thermal data (bands 10-15) is given in Figure 4.68b; a contrast enhanced RGB image of ATLAS thermal principal components 1, 2, and 3 is illustrated in Figure 4.68c; a contrast enhanced RGB image of ATLAS thermal bands 15, 13, and 11 is portrayed in Figure 4.68d. No evidence of cultural features was seen in these data sets.
Figure 4.68. Enhanced imagery of the Pueblo Escondido study region. a) Pan sharpened and contrast enhanced QuickBird image, bands 4, 2, 1 (RGB). b) Contrast enhanced first principal component image of ATLAS thermal data (bands 10-15). c) Contrast enhanced RGB image of ATLAS thermal principal components 1, 2, and 3. d) Contrast enhanced RGB image of ATLAS thermal bands 15, 13, and 11. The project study areas are outlined in black with the largest rectangular space measuring 100 x 120 m.

4.9.6.3. Silver Bluff

The full QuickBird scene, a true color image showing bands 3, 2, and 1 as red, green, and blue, respectively, is given in Figure 4.69. The general area of study in outlined in yellow.
The QuickBird multispectral bands were pan sharpened and contrast enhanced. Bands 4, 2, and 1 are illustrated in Figure 4.70a as an RGB color composite with current excavations visible at lower left (in white and cyan). Interpretations are given in Figure 4.70b. Linear features are outlined in green and two anomalous rectangular areas are defined in yellow. Other anomalies appear in the field as bright red, which are related to vegetation differences.
Figure 4.70. a) QuickBird image, bands 4,2,1 (RGB) with current excavations at lower left (in white and cyan). b) Linear anomalies are defined in green and two rectangular anomalies in yellow. The project study area is outlined in white.

The DuncanTech MS4100 camera yielded several clear images of the study area. Band 2 (green) shows excavated areas toward the left of the image and anomalous areas in the clearing near the center of the image (Figure 4.71a). Band 3 (near infrared) shows the enhanced capability of the NIR to detect linear features within the excavations, which may be related to excavation depth or the location of previous structures.

Figure 4.71. Duncan multispectral data. a) Duncan image band 2 (green). b) Duncan image band 3 (NIR). The project study area is outlined in white.
4.9.6.4. Kasita Town

The full QuickBird scene, a true color image showing bands 3, 2, and 1 as red, green, and blue, respectively, is given in Figure 4.72. The general area of study in outlined in yellow.

At Kasita Town the data were pan sharpened and contrast enhanced. QuickBird bands 4, 2, and 1 were assigned red, green, and blue (Figure 4.73). The field is bounded by a runway to the east (in cyan), and a roadway (cyan with truck convoy) to the west. Two major influences complicated image interpretation: artifacts from mowing and disturbances attributable to current and past runway construction and maintenance.
Figure 4.73. Pan sharpened and contrast enhanced QuickBird image with bands 4, 2, and 1 as RGB. The project study area is outlined in white.

Several interpretations are offered for these data (Figure 4.74). Multiple linear features and surface anomalies are highlighted in yellow. A variety of other unmarked anomalies are obvious in the image. The longest linear feature extending generally east-west through the scene is a drainage feature. Evidence of this feature continues westward to the river (white area to far left). Many of the anomalies are probably attributable to the ongoing runway construction and maintenance.
Figure 4.74. Pan sharpened and contrast enhanced QuickBird image with bands 4, 2, and 1 as RGB. Interpretations are given in yellow. The project study area is outlined in white.

The DuncanTech MS4100 camera yielded several images of the study area. In Figure 4.75a, a composite image composed of Duncan band 3 (IR) as the red channel, QuickBird band 4 (IR) as the green channel, and QuickBird band 2 (green) as the blue channel is given. This composite highlights changes in the infrared signature, primarily attributable to vegetation changes, between times of collection of the QuickBird and Duncan data. Figure 4.75b gives the same data with several linear features highlighted in yellow.
Figure 4.75. Composite imagery at Kasita Town. a) Image composed of Duncan band 3 (IR) as red, QuickBird band 4 (IR) as green, and QuickBird band 2 (green) as blue. Interpretations are given in yellow. The project study area is outlined in white.

4.9.7. Lessons Learned

4.9.7.1. Data acquisition

Acquiring airborne data using fixed-wing aircraft over the study areas proved to be a challenge. The optimum time for data acquisition is in the spring when the ground cover is clear and the leaves have not emerged from the trees (leaf-off conditions). The contractor responsible for the data acquisition, GEOTEK, is located at Bay St. Louis, Mississippi. The distance from there to Ft. Riley, Kansas, Fort Benning, Georgia, and Silver Bluff, South Carolina proved to be difficult as rainy spring weather conditions often interrupted the data acquisition schedule. Sometimes the study area was cloudy or rainy. Other times the study area was clear but weather conditions in Bay St. Louis prevented take off. Most frustrating was when the study area was clear, the airport in Bay St. Louis was clear, but a severe band of storms between the two locations prevented data acquisition since the pilot could not navigate around the storms. The best approach for future acquisition missions would be to make use of local military aircraft, local contractors, or to acquire the data from a powered parachute (Section 4.8.1).

4.9.7.2. Time of acquisition of thermal data

Although it has been documented that, in general, the optimum time for thermal data acquisition is at thermal maximum and minimum (solar noon and pre-dawn) (Sever 1983, 1991; Luvall et al. 2005; Gonzalez 2005), it is recommended that before thermal data is acquired from the air, ground truth measurements be made to determine the optimum time for the data acquisition. All materials emit energy at different rates and are affected by temperature, pressure, and humidity. By comparing the emissions of known archeological features (such as ditches, hearths, kilns, and refuse areas) with the adjacent ground cover throughout the course of a 24 hour period, the optimum time to detect these features could be determined.
4.9.7.3. **Mode of acquisition of thermal data**

In large part due to the physical characteristics of the PalmIR 250, collection of clean, consistently usable data sets from an airborne platform proved to be problematic. Thermal data were recorded in the form of an image sequence by feeding the sensor signal to a frame grabber operating at 15 frames per second. The thermal instrument has both a relatively slow scene integration time and a relatively high sensor latency. These characteristics combine to cause a smearing artifact in the individual data frames. The severity of the artifact depends to a large extent on the aircraft’s altitude and ground speed—slower speeds and higher altitudes lessening the effect—and, to a smaller extent, the level of thermal contrast through the target scene.

In light of this situation, the PalmIR 250 would probably be better utilized on a fixed boom, a tethered balloon-borne platform, or a potentially slower moving aircraft such as a powered parachute or helicopter (assuming a stable, vibration-free mount could be devised).

4.9.7.4. **Site preparation**

The grass was mowed at the study areas in order to allow better conditions for the ground-based geophysical surveys. It was also thought that this condition would be optimal for detecting archeological features through emerging springtime vegetation. This phenomenon, known as vegetation outcropping, has been used to detect archeological features throughout the world (Sever 2000, 1990; Deuel 1969; Crawford and Keiller 1928). This approach was successful in locating the 1910 hangar of the Wright Brothers at Wright Patterson Air Force Base (Sever 1998). In our analysis of the aerial remote sensing imagery for this study, however, we could see the effects of the mowing process and have not yet concluded if this improves or confuses the signal response to the aerial platform. A future investigation, that compares imagery over an area before mowing and after mowing, would resolve this issue.