Final Report

IMPROVED PROCESSING, ANALYSIS AND USE OF HISTORICAL PHOTOGRAPHY

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14. ABSTRACT

A comparative analysis of aerial photography interpretations was conducted for 8 Formerly Used Defense Sites (FUDS) using 3 methods: 1) existing USACE Archive Search Results (ASR) based on photo prints, 2) new interpretations based on film diapositives, and 3) digitally scanned and enhanced film diapositives. The focus was upon detection of munition ranges and targeting features used for WWII-era bombardier training. Improved performance was demonstrated using film diapositives instead of prints, with somewhat better results from the digital processing method. Validation efforts made effective use of expanded aerial photo searches of federal and local resources, often finding better dates of historical photos than used in the ASR studies. It was noted that future studies should carefully review prior results and conduct updated and/or expanded photo searches when needed. There is clear benefits of using historical aerial photos as a low-cost baseline for more expensive Wide Area Assessment (WAA) techniques.

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UXO, FUDS, WAA, aerial photos, image restoration, image enhancement, digital imagery, orthophoto

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ACRONYMS

AFB	Air Force Base
AOI	Area of Interest
APFO	Aerial Photography Field Office - U.S. Department of Agriculture
ASR	Archive Search Report
ATAGR	Air-To-Air Gunnery Range
BGR	Bombing and Gunnery Range
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Certificate of Clearance
DBR	Demolition Bombing Range
DEM	Digital Elevation Model
DERP	Defense Environmental Restoration Program
DIP	Digital Image Processing
DoD	Department of Defense
DOI	Department of Interior
DRG	Digital Raster Graphic
EE/CA	Engineering Estimate and Cost Analysis
EMI	Electromagnetic Induction
EPA	U.S. Environmental Protection Agency
EPIC	EPA Environmental Photo Interpretation Center
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Sites
GIS	Geographic Information System
HE	High Explosive
INPR	Inventory Project Report
LiDAR	Light Detection And Ranging
MEC	Munitions of Environmental Concern
MMRP	Military Munitions Response Program
NARA	National Archives and Records Administration
OEW	Ordnance Explosive Waste
QC	Quality Control
QR	Qualitative Reconnaissance
PA	Preliminary Assessment
PBR	Precision Bombing Range
PI	Photo Interpretation
QC	Quality Control
SAR	Synthetic Aperture Radar
SI	Site Investigation
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USGS-EDC	U.S. Geological Survey Eros Data Center
UXO	Unexploded Ordnance
WAA	Wide Area Assessment
WWII	World War II

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EXECUTIVE SUMMARY

Historical aerial photography is routinely used in support of environmental cleanup operations at many Department of Defense (DoD) sites. The broader use of current best practices for image interpretation and the application of image processing techniques can improve the amount of information extracted from the photos. This appears especially important at large Formerly Used Defense Sites (FUDS) with a history of military munitions use as practice and demolition bombing ranges for bombardier training crews during World War II. The accurate mapping of range features and the identification of sites where demolition ordnance was used is critical to the cost-effective environmental cleanup and transfer of these properties to other public and private uses. The goal of this project was to demonstrate techniques to make more effective use of historical photography for environmental cleanup support.

Eight study sites located in the Southwestern portion of the United States were selected for the demonstration project. Six of the sites were located in New Mexico and two sites were located in Texas. The sites provided a wide range in sizes, spanning from 1 to 774 square miles.

A comparative analysis of three interpretation methods was undertaken. The baseline method used existing results from photo interpretations used to develop Archive Search Reports (ASR) for Military Munitions Response Program (MMRP) sites. These interpretations were based on photographic prints and pocket stereoscopes. The second method was based on film diapositives (positive transparencies) and zoom stereoscopes. The third method was based on scanned film that was digitally processed and viewed. Both alternative methods improved upon the baseline method, with the digital processing approach systematically providing the best results. It was observed by the image analysts that routine image enhancement techniques may provide results similar to the more advanced image restoration techniques tested.

Some observations and lessons learned from the demonstration were largely tangent to the basic objectives of the project. One observation was that the all roads should be mapped and considered for their potential use as historical convoy targets. These targets appear to have been transient with no distinguishing appearances. The presence of service roads to nearly all targets was noted. The historical documents mentioned the need to develop roads for periodic maintenance of the targets.

It was recognized during the study that aerial photography archives are dynamic. Collections continue to expand and they are becoming more organized and accessible with improved finding aids. ASR photo search results should be used as a starting point for subsequent site investigations and remedial efforts, but the photo searches may need to be updated. A substantial amount of additional aerial photography was identified for the sites used for this demonstration project. It allowed the identification of several ranges that had been missed or incorrectly located in previous studies. Although some range features remain apparent on recent photography, some features were no longer evident in as little as four years after range operations were discontinued. Acquiring historical photography during or shortly after range operational periods can therefore be critical to the accurate detection and mapping of range features.

1.0 INTRODUCTION

Historical aerial photography is routinely used in support of environmental cleanup operations at DoD sites. For large World War II (WWII) sites with a history of military munitions use, such as practice and demolition bombing ranges, historical aerial photography provides a unique source of information. These ranges covered large areas, sometimes hundreds of square miles. The accurate mapping of range features and the identification of sites where practice and demolition ordnance was used is critical to the cost-effective environmental cleanup and transfer of these properties to other public and private uses.

The broader use of current best practices for image interpretation and the application of image processing techniques can improve the amount of information extracted from the photos. The goal of this project was to demonstrate how DoD and other organizations can make more effective use of historical aerial photography for environmental cleanup support by applying better processing and analysis techniques.

1.1 BACKGROUND

TerraSpectra Geomatics recently provided support to the Albuquerque District of the U.S. Army Corps of Engineers (USACE) to develop a statewide Geographic Information System (GIS) database for New Mexico FUDS. The project focused on Military Munitions Response Program (MMRP) sites. Property and range boundaries were initially developed from existing USACE ASRs. Potential limitations of the ASR historical photo reviews were noted.

Color digital orthophotos (2005) were used to verify the locations of MMRP site features. Significant offsets between the ASR range locations and their orthophoto locations became evident during quality control checks of the data. Figure 1 graphically shows the location offsets. Although ranges are broadly defined by large buffers around targets, detailed site investigations that rely on the original ASR locations could provide erroneous results.

Possible causes for the locational offsets include:

- Orthophotos were not widely available when much of the ASR work was conducted.
- Photographic prints were used rather than positive transparencies (diapositives).
- Photo interpretations were performed using pocket stereoscopes

Organizations routinely conducting historical photo analyses for environmental forensics[1] usually make use of diapositives (film positive transparencies). Diapositives have superior resolution and dynamic range compared to prints. Diapositives are preferred for direct viewing or scanning. The quality of viewing and scanning equipment can also affect interpretation results.

During quality control checks, several target features were identified that were not included in the ASRs. It was noted that some ASR interpretations were based on 1970's and later photography. A large number of FUDS used as training ranges for bombardier crews were most active during WWII. Figure 2 shows practice bombing range target features still evident on the landscape on a2005 high quality orthophoto. The range features can be accurately mapped from the orthophoto and effectively used to develop efficient field reconnaissance and ground data collection plans.

[1] Such as the U.S. Environmental Protection Agency's (EPA) Environmental Photo Interpretation Center (EPIC).

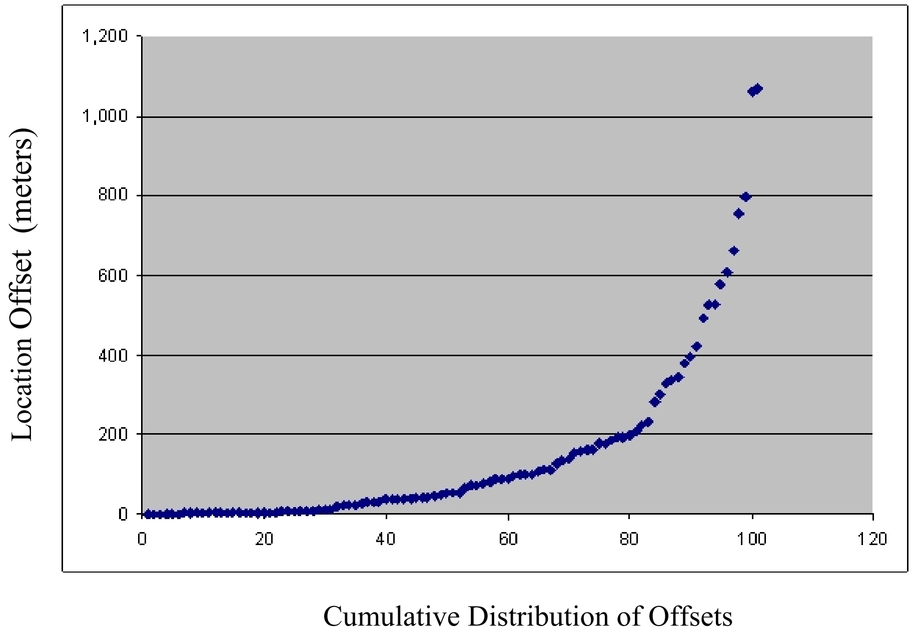

Figure 1. Range Centroid Location Offsets.

This graph presents the offset between the ASR and subsequent 2005 orthophoto-based mapping of MMRP FUDS Range centroids in New Mexico.

However, natural and man-made changes occurring on the landscape can significantly reduce, and sometimes eliminate, the surface appearance of range features. Features of interest may no longer be distinct enough to detect or identify using current aerial photography or other types of optical systems. In these cases, the use of aerial photography taken during or near the timeframe the ranges were active may be required. This is illustrated in Figures 3 and 4, which show matched sets of historical (1950) and more recent (2005) aerial photography.

Since the 1930's, there have been several national programs to collect aerial photography throughout the United States. This photography has special utility for large area studies. The demonstration of techniques for Wide-Area Assessment (WAA) was a recent focus area of the DoD Environmental Security Technology Certification Program (ESTCP, 2006). A goal of this effort was to demonstrate cost-effective methods to allocate cleanup resources. These efforts have been based on a multi-stage or layered approach (high airborne, helicopter, and ground) using a suite of sensors. These sensor systems have included orthophotography, light detection and ranging (LiDAR), synthetic aperture radar (SAR), hyperspectral imaging, magnetometer arrays, and electromagnetic induction (EMI) arrays. One limitation noted in studies using optical-based techniques is that time may obscure surface features. The more extensive use of historical photography can provide a baseline WAA methodology that can help minimize this limitation. This demonstration project addresses how DoD and other organizations could make better use of historical photography.

Figure 2. Former Walker Air Force Base (AFB) Precision Bombing Rang (PBR) #21.

WWII-era practice bombing target features that remain identifiable in this 2005 color orthophoto include outlines for a scoring circle (or “bulls-eye”) target in the center with a large (about 800 feet long) battleship, fuel storage tanks, a power plant, and other rectangular features. The faint outline of a circular outer perimeter fence or firebreak around the target area is also visible. Even after 60 years these features remain distinct and can be used to focus detailed fieldwork related to the possible presence of munitions. The orthophoto was digitally generated using a pixel resolution of 1-meter.

Figure 3. Train Engine Roundhouse and Switching Yard Target Area.

These target features are located on former Kirtland AFB PBR West Mesa site (K06NM0445). Comparison of black and white 1945 aerial photo (top) and color 2005 orthophoto (bottom) of the same area shows no distinct visual indications of the target features remaining in 2005. Note the numerous fire burn areas on the 1945 photograph. Historical documents noted that bombing range activities sometimes started brushfires. Wide firebreaks are observed around the perimeters of many ranges to contain the brushfires.

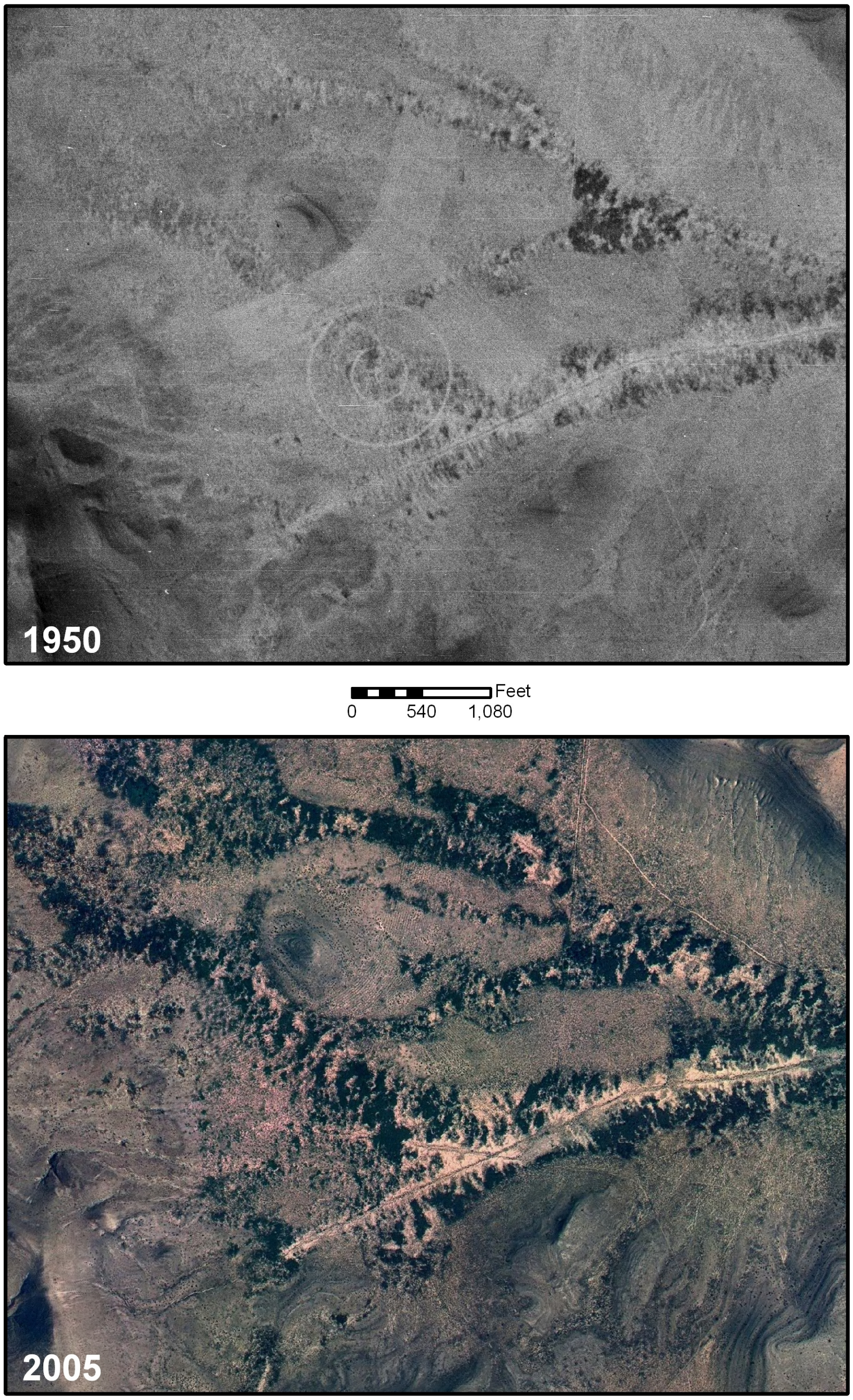

Figure 4. Guadalupe (K06NM0333) Practice Bombing Range 1.

The target features (circle and “Y”) and access road are distinct on the black and white 1950 photo, but only the road is clearly visible on the 2005 color orthophoto. Although designated as a practice bomb range, field investigations have observed high explosive bomb debris and craters on this range.

1.2 OBJECTIVE OF THE DEMONSTRATION

The primary objective of this project was to compare and evaluate results from three methods for the extraction of information from historical photography. The three methods compared were:

1. Existing ASR mapping procedures – used as a baseline.
2. Best standard practices – based on different film media and interpretation equipment.
3. Advanced digital image processing – with image restoration and enhancements.

There was a specific focus on the visual identification and mapping of WWII-era practice and demolition bombing ranges and their related target features. The improved techniques should also prove useful for other types of environmental cleanup applications where the identification and mapping of historical features could better focus efforts.

Eight project study sites were selected ranging in size from a 1-square mile site with a single target, to a site of about 774-square miles with 10 ranges. This provided a reasonable sample size in terms of the number of ranges (29) and targets (79). The sites were not randomly selected. They included four properties with several well-defined ranges and four properties for which range locations had not yet been established in the New Mexico FUDS database.[2]

A secondary objective of this project was to evaluate potential improvements in the detection and mapping of HE bomb craters. If successful, this would have provided an improved means to distinguish between practice and demolition bombing range locations. This was approached using both visual interpretation and terrain modeling methods. The high resolution terrain modeling approach was recognized as an exploratory study element. The results for both approaches, discussed in more detail later, did not demonstrate any improved performance over existing procedures.

A final objective of the demonstration was to provide for technology transfer. The development of general guidelines for the processing and interpretation of historical photography, with an emphasis on FUDS applications, supports this objective. This report and subsequent technical presentations and publications will be used to more broadly disseminate the results.

1.3 REGULATORY DRIVERS

The environmental cleanup of former DoD ranges is generally conducted under authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Detailed ground investigations and cleanup would be prohibitively expensive unless well-focused to those areas most likely to contain unexploded ordnance and/or munitions contaminants. The use of historical photography can provide a unique temporal element to large area assessments and facilitate the prioritization of other survey technologies. Aerial photography is widely understood and well accepted by the regulatory community (ITRC, 2003).

[2] During the course of this project, additional Preliminary Assessment (PA) Studies provided accurate locations for two of the four unmapped ranges.

2.0 TECHNOLOGY

Key technologies involved in this project include the application of photo interpretation, digital image processing, photogrammetry, and GIS database development. Image restoration, specifically blur removal, was systematically applied prior to standard image enhancements (e.g., brightness/contrast adjustments and image sharpening) as images were pre-processed for digital stereo-viewing and orthophoto generation.

2.1 TECHNOLOGY DESCRIPTION

The use of historical and more recent photography has proven critical for the assessment of many former DoD sites. ASRs for FUDS almost always include an examination of some historical photography. However, the methods used were not advanced, nor based on current best practices. Many of the ASRs were completed in the early to mid-1990's without the benefit of the locational accuracy that is now widely available using digital orthophotos. Much of the original ASR mapping was done by visually matching historical photographic features to topographic maps. This method is dependent upon distinct landscape features and can sometimes prove difficult and lead to large positional errors. A wealth of historical documentation and initial site reviews were developed in support of the ASR program, but the results must be carefully reviewed before proceeding with more expensive site specific field activities. It is important to recognize the potential limitations of the earlier ASR work as follow-on activities are undertaken.

2.1.1 Image Restoration and Enhancement

Until the 1960's for military systems, and much later for most commercial systems, aerial cameras lacked forward-motion compensation. This is a precise mechanical adjustment that is made to account for aircraft movement during film exposure (McDonnell Douglas, 1983). Lens quality has also been improved in newer camera systems. Lens quality and motion blur are key elements affecting image resolution and overall image quality (ASPRS, 1980). Modern digital photogrammetry systems rely on the high quality optics and automated forward-motion compensation available with newer cameras. Image restoration procedures are generally not needed nor available in these digital or "softcopy" systems. The application of image restoration techniques, however, can potentially improve the quality of historical aerial photos and provide the basis for improved interpretations. Image restoration is a well-studied field that is distinctly different from image enhancement. In certain circumstances where lens blur or motion can be well-characterized, image restoration can reveal information that cannot be obtained using routine image enhancement techniques (SWGIT, 2002; Ben-Ezra, 2004; and Simoncelli, 2005). The motion blur example shown in Figure 5 demonstrates this.

Image enhancement techniques are now widely available for digital imagery. Common functions are brightness and contrast adjustments, and edge enhancement or sharpening. It was noted during the course of this project that near real-time adjustments were often important to optimize the resulting image quality. Localized adjustments were often required to enhance specific features of interest. Two image processing software packages were used for most of the image analysis work: ERDAS Imagine and Adobe® PhotoShop®. Additional PhotoShop® plug-in modules, such as the Fovea Pro® by Reindeer Graphics®, and Kodak's® Digital GEM® were also tested.

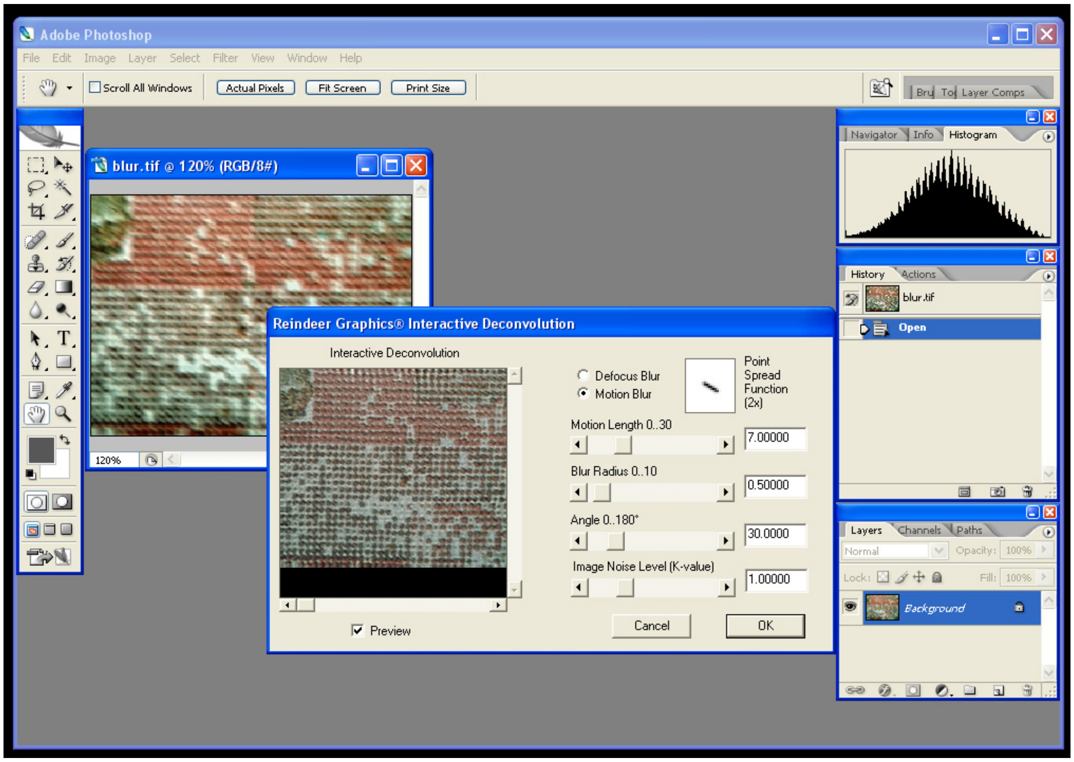

Figure 5. Example of Image Restoration.

Original image (left) and motion-blur corrected image (center) of aerial imagery of an orchard. Image enhancement techniques cannot recover the imagery detail apparent in the restored image. The amount of motion blur in this image is severe and not typical of historical aerial photography.

2.1.2 Photogrammetry Using Historical Photos

Another area addressed during this project was the lack of camera calibration reports for some sets of older historical aerial photography. Digital photogrammetry systems rely upon calibration reports to correct for some lens distortions. The lack of this information requires the use of non-standard procedures for generating digital orthophotos. While simple registration techniques are widely applied, a very limited number of examples of historical orthophotos have been reported in the literature (Slonecker, 2009). The ERDAS Leica Photogrammetry Suite® and Mira Solutions' photogrammetry suites were used for the photogrammetric processing.

2.1.3 Geographic Information Systems

The use of a GIS framework for organizing site imagery and other data can significantly improve interpretation and analysis results. Geospatially organized collateral data and information can often assist interpretation and analyses. The Environmental Systems Research Institute (ESRI)® ArcGIS® software was used to provide this functionality and organize interpretation results.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

A primary advantage of historical photography is that it can provide the appropriate temporal element for past activities of concern. Aerial photographs are unique in providing a visual record or "snapshot in time" of historical site conditions. When suitable photography is available it can prove extremely cost-effective, since no mission deployment costs are involved. Only data search and reproduction or digital scanning costs from existing archives are involved.

A primary limitation of aerial photography and other optical-based techniques is that they are not directly sensing the presence of munitions, but must make use of a surrogate or indicator. Aerial photography requires a surface expression such as visually distinct range target features or bomb craters as an indicator for the likely presence of munitions. The use of historical photography is also limited by the type and quality of photography available. Obviously there are no retroactive options to change the original acquisition parameters. As observed for the set of sites used for this study, the appearance of target features may persist for decades, but they may also disappear in a relatively short timeframe due to environmental conditions (e.g., sandy soil) or developmental activities (e.g., conversion from open range to cropland).

A key observation of this study is that photographic archives are continuing to expand as historical photos are added to the collections. With new finding aids, especially those based on geographic coordinate based databases, they are also becoming easier to search. One result of this is that prior search results cannot be relied upon as complete, since new searches may identify additional sets of historical photos. Prior ASR photo searches generally made use of the primary government archives of historical photos: the National Archives and Records Administration (NARA), the U.S. Geological Survey EROS Data Center (USGS-EDC), and the U.S. Department of Agriculture Aerial Photography Field Office (APFO). Additional photography is often available from other federal organizations and especially state and local resources. These region specific resources are more numerous and sometimes more difficult to readily identify. Primary regional sources include private aerial photo firms, university libraries, and state and local governmental organizations. Transportation departments are often a good source at the state and local level. The validation effort for this project made effective use of state and local resources to obtain selected copies from their photographic holdings.

The shelf-life of film is limited and a concern of all archives. Shelf-life can vary significantly, from a few years to many decades, dependent upon environmental factors such as temperature and humidity. Early film was nitrate-based, which had the drawback of decomposing after several decades and being extremely flammable. Acetate-based "safety film" was subsequently developed, but cellulose triacetate degradation was reported within a decade of its introduction in 1948. As it became better understood, this problem became known as the "vinegar syndrome".

Conversion to digital format is one option for long-term storage. The USGS-EDC no longer provides film copies of their extensive holdings of over 8 million frames of aerial photography. Only digital scans of their film are now available as a standard product. Moving towards digital imagery is a requirement in order to continue to use some historical archives, and this conversion trend is expected to continue.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for this demonstration project are summarized in Table 1, followed by descriptions for each of the objectives.

Table 1. Performance Objectives.

Performance Objective	Metric	Data Required	Success Criteria
Quantitative Performance Objectives			
1. Visual identification of all bombing range areas	Percent detected	Location of ranges	100% detection
2. Limited false alarms for bombing range areas	Percent of areas incorrectly identified as ranges	Location of ranges	< 50% false identifications
3. Identify all range target features (e.g., outlines of ships, docks, airstrips, etc.)	Percent detected	Location of range targets	> 90%
4. False alarm rate for range target features (above)	Percent of features incorrectly identified as range target features	Location of range targets	< 50% false identifications
5. Identification of ranges with craters (inferred use of HE munitions)	Percent detected	Location of craters within or near ranges	> 75% detection
6. Feature Mapping Location accuracy	Average range and target feature mapping location error	Feature centroid location mapped from historical photos onto their corresponding orthophoto locations	< 10 meters distance offset
7. Interpretation Production rate	Time required to analyze each stereo-pair of photos	Log of analysis time accurate to 10 minutes	Analysis time: < 1 hour per photo pair
8. Orthophotos from historical photos	Average tie and check point location offset errors	Location accuracy of distinct features compared to USGS (or similar) orthophoto	< 10 meter distance offset for tie points < 15 meter offset for distinct check point features
9. Digital Elevation Models from historical photos	Percent correct detection of craters	Demolition bomb crater feature locations	Improved crater detection performance using restored imagery versus non-restored imagery
Qualitative Performance Objectives			
10. Ease of use and technology transfer	(Not applicable)	Feedback from analysts on the usability of the different procedures and products developed	Completion of general guidelines or protocols for use of historical photos and professional publication(s) of results

3.1 OBJECTIVE 1 – IDENTIFICATION OF ALL BOMBING RANGE AREAS

This was considered a primary project objective and involved the detection and identification of all validated practice and demolition bombing ranges. The ranges were developed to be visually distinctive, as the WWII bombardier training was based on visual targeting. It was anticipated that all ranges would be accurately detected and identified when the comparative analysis or validations involved suitable dates and scales of photography. Some of the original ASR site analyses, however, involved photography acquired over 30 years after range operations had ended. The results from these sites were anticipated to be more problematical and dependent upon site specific conditions. Potential differences between interpretation results for the different analysis methods were considered more likely for these sites.

Some sites had individual targets or clusters of target features that were significantly distant from previously defined range locations. For the purposes of this project, these individual targets or clusters of features were defined as new ranges whenever they were located farther than 1,500 feet from another range centroid. Large navigation markers developed at Site #1 (Guadalupe) were not considered as ranges unless there was evidence they were further developed and used as a practice or demolition range. The identification of these markers as range features was included in the range feature analysis (see Objectives #3 and #4).

Comparisons were made to the best available sources of range locations. This included a combination of site specific historical records, field survey results, and additional historical aerial photographs. The one potential range area that could not be confidently validated by existing records or distinct photo appearance (located on Site #8, Dalhart) was confirmed by a project field survey.

The baseline for assumed locations of practice and demolition ranges was established from the maps provided in the Defense Environmental Restoration Program (DERP) Annual Report to Congress for Fiscal Year 2008 (DERP, 2008). This source provides a listing of all MMRP sites with ASR maps[3] and data that is specified "current as of September 30, 2008". Suitable historical photography (1940's to early 1950's) was used in conjunction with historical documentation and field survey results to identify additional range locations. Locations were transferred onto recent digital orthophotos. A total of 29 "range areas" were defined within the eight study sites.

Success for this criterion required no range omission errors, meaning this objective was considered to be met if 100% of the validated range locations were properly detected and mapped. Only the digital image processing (DIP) method fully met this objective, although the photo interpretation (PI) method missed only one range (97%). The timeframe of the photographs used (1971) was clearly a major factor for this omission; the range circle target is distinctive on earlier 1954 and 1946 photography that was acquired for the validations.

[3] Two PA studies and one Site Investigation (SI) were used where ASRs were not available or did not use aerial photos. Subsequent references to ASR products will be inclusive of the PA and SI studies.

3.2 OBJECTIVE 2 – LOW FALSE ALARM RATE FOR BOMBING RANGE AREAS

This objective addressed interpretation commission errors, or false alarms, for the identification of ranges. A relatively low number of features were expected to be incorrectly interpreted and classified as bombing ranges. The number of false targets was based upon the assessment of verified range locations. This objective was considered met if less than 50% of the features mapped were incorrectly identified as bombing ranges. The potential number of false alarms was expected to be relatively low, so the preferred bias was towards including any questionable features that might prove to be undocumented ranges. Due to the distinctive appearance of the ranges, it was not considered likely that any field verification would be required should any “new” ranges be identified.

There was only one feature identified by the PI and DIP as a potential range that was subsequently validated as something else (i.e., an incorrect interpretation). Overall performance of this objective was a false alarm rate of only 3%, well below the success criteria of 50%.

3.3 OBJECTIVE 3 – IDENTIFY ALL RANGE TARGET FEATURES

This objective involved the detection and identification of range target features established by plowing, bulldozing, constructing, and/or painting simulated target features. Examples of these include ship outlines, docks, power plants, fuel storage tanks, and other features routinely used for bombing practice targets. The most common type of target features were concentric targeting circles (such as shown earlier in Figures 2 and 4) that were used for scoring the accuracy of bomb drops.

Correct identification of all munitions response site target features was the metric for this criterion. Although a descriptive classification of the different feature types (e.g., ships, docks, etc.) was used for the interpretations, the final metric assessment was evaluated on a binary basis (i.e., target feature or not).

Verified target features from existing ASRs, selected PA and SI investigations, or new field checks were used as a basis for comparisons. Although not as critical as the initial identification of ranges, at least 90% of the verified range targeting features should be detected and mapped to facilitate more focused field investigations. The results for this objective fell somewhat short of expectations: 42% for ASR studies, 75% for PI, and 84% for DIP. All results were below the success criteria of 90% detection. Additional historical photos of better dates and scales, acquired for validations, allowed 13 additional target features to be identified. The availability and use of appropriate dates of photography was considered the most significant factor in these results.

3.4 OBJECTIVE 4 – FALSE ALARM RATE FOR RANGE TARGET FEATURES

Most bombing ranges were developed in remote locations. Prior land use practices could still create the appearance of potential targeting features and result in false alarms. A large number of false alarms – i.e., the incorrect identification of other landscape features as target features – would limit the utility of target feature maps.

Verified target features from existing studies were used as a basis for comparisons. Additional features identified with high confidence from additional photos or other sources were included in the analyses. This objective was considered met if less than 50% of the features mapped were incorrectly identified as range target features (false alarms). The potential number of false alarms was expected to be relatively low, so the bias was towards including features that might prove to be undocumented target features. Visually distinct features did not require field validation. Only two possible target features required field validation for a definitive assessment.

Only three features were considered false alarm target features by the PI and DIP methods, a 4% error rate substantially below and meeting the success criteria of less than 50% false alarms.

Features that could not be field or otherwise validated were identified as "Open" (unresolved) in the summary of interpretation results (Appendix A-2) and not included in the comparative analyses. There were seven "Open" features, two of which were potential radar targets that were not considered visual targets.

3.5 OBJECTIVE 5 – IDENTIFICATION OF RANGES WITH CRATERS

The historical designation of bombardier training ranges as either practice or demolition ranges has not always proven accurate. Several instances have been noted where HE bomb materials (as well as unexploded bombs) have been found on ranges designated as practice only. The identification of craters on a range would, therefore, be useful information. HE craters tend to degrade in appearance over time, so the improved use of historical photography was considered of potential value for this application.

The metric for this objective was the percent of ranges correctly identified as containing craters within or nearby the designated ranges. Verified documentation of the use of HE bombs – and the field recognized presence of the resulting craters and HE fragments – was used to establish designated areas as demolition ranges.

A moderate goal of better than 70% correct identification of bombing ranges with visible craters was considered the success criteria for this objective. Although it was believed likely that appropriate dates of historical photography would generally provide a good basis for detecting and mapping HE craters, the sites selected for assessment included a variety of environmental conditions (e.g., sandy soils) and a range of photo scales and dates that hindered accurate identification of craters. In addition, some ranges had limited HE usage for secure (classified) testing that may have involved only a small number of HE bombs.

None of the 3 methods fully met the success criteria: ASR performance was 70%, PI performance 60%, and DIP performance was 70%. The validation effort required field investigation inputs to validate an additional 4 ranges with craters.

3.6 OBJECTIVE 6 – LOCATION ACCURACY

Feature location mapping accuracy affects the utility of photo-interpretation results to be readily used in conjunction with other data. This is especially true when using viewing and analysis tools available in a GIS framework. Location accuracy was established for the various methods via comparison of centroid coordinates for range and target features.

The existing ASR range locations were based on the sometimes difficult transfer of photo-interpreted features from historical photos to topographic maps in Digital Raster Graphic (DRG) format. The new interpretations for this demonstration were mapped onto digital orthophotos as a base. This approach (image to image) is easier and more accurate, but was not generally available when the initial ASR mapping efforts were undertaken.

Ground distance offsets for range and target feature centroid locations were used as the basis for comparison among the different mapping methods. Feature locations were transferred to digital orthophotos. Range and target feature centroids were then compared among the methods. A mapping accuracy of less than 10 meters offset between mapped and verified locations was considered a requirement for mapping the large range and range target features. Both the PI and DIP approaches met the locational accuracy goal, with comparable average results of 2.4 meters and 2.2 meters average offsets. The prior ASR offset results, without the benefit of orthophotos, was substantially larger at 28.6 meters for the specific set of ranges in this comparative analysis.

3.7 OBJECTIVE 7 – PRODUCTION RATE

A standard production rate factor for photo-interpretation is the amount of time required to visually analyze the imagery and document the interpretation results. Based on prior professional experience, a reasonable estimate of 1-hour per stereo-pair of photography was used as the production rate goal.

The time required to complete each stereo-pair analysis and document interpretation results was used to establish an average production rate. The photo-interpreters and digital image analysts logged analysis times accurate within 10-minute intervals. An average analysis time of less than 1-hour per stereo-pair of photos was considered the goal for this criterion. The PI method averaged 49 minutes per stereo pair, inclusive of both initial photo interpretations and subsequent senior analyst review. The DIP method took longer, averaging 57 minutes per stereo pair. Times for the original ASR interpretations were not available, but were assumed to be similar to the PI results.

3.8 OBJECTIVE 8 – ORTHOPHOTOS FROM HISTORICAL PHOTOS

Most photogrammetric applications require the use of special calibration reports to characterize and account for aerial camera and lens distortions that affect photograph geometric quality. The lack of historical camera calibration reports requires the use of non-standard procedures. This objective was the successful demonstration of such procedures. Existing digital elevation models (DEMs) and control from existing orthophotos were used to generate second generation orthophotos from the historical photographs. Any errors in the current orthophotos are propagated forward using this approach, but no field survey ground markers are necessary (nor feasible with the historical photos) and new DEMs are not required. Orthophotos were generated using pixel resolutions of 1-meter and smaller, depending upon input photo scales and quality.

Standard assessments of average check point errors for well defined features were used to measure the resulting orthophoto quality. The comparative locations of distinctive features that were visually apparent on both the historical photography and more current USGS (or similar quality) orthophotos were used as a basis to determine locational accuracy.

Average check point offsets of <10 meters, based on full frame photo assessments, was used as the success criteria for this performance objective. Results did vary by the specific type of camera systems used for various sets of historical photography, but averaged 3.6 meters, substantially better than the <10 meter criteria.

3.9 OBJECTIVE 9 – DIGITAL ELEVATION MODELS

Generation of improved digital elevation models suitable for the detection of craters (indicating the use of HE bombs) was investigated using the image restoration techniques. This objective was considered exploratory in nature, as it was recognized that historical photographs do not meet standard specifications for DEM generation at the spatial detail (2-3 meter postings) that was expected to be needed for this application. Sample site specific DEMs were generated from the historical photos and compared with DEMs based on the same photos after digital motion and lens blur restoration were applied.

The metric for this objective was an improved crater detection performance using the processed (blur corrected) imagery versus the unprocessed imagery. However, the poor DEM performance did not warrant pursuit of this objective.

3.10 OBJECTIVE 10 – EASE OF USE AND TECHNOLOGY TRANSFER

This objective addressed technology transfer of improved procedures and an assessment of their usability. It was based on feedback from analysts using the procedures and products developed. As a qualitative objective, there was no specific metrics for evaluating this objective. Feedback from the photo interpreters and image analysts involved in the various project elements was used to evaluate ease of use. General guidelines for the improved use of historical photos in support of DoD munitions range management were established. Feedback from the interpreters and analysts has been incorporated into the final report. Technology transfer will also be facilitated by planned technical conference presentations and the publication of a professional article summarizing key elements of the project.

4.0 SITE DESCRIPTIONS

The emphasis of this technology demonstration project was upon large practice and demolition bombing ranges. These ranges were originally developed and operational during WWII and shortly thereafter to support bombardier crew training. The target features constructed on these ranges were generally large and distinct, as the training missions were based on visual target identifications.

4.1 SITE SELECTIONS

Eight FUDS MMRP sites were selected for the demonstration. Six of the sites are located in New Mexico, and two are in Texas. Figure 6 presents a map of the study site locations. These sites are believed to be generally representative of environmental and bombing range conditions and target features present in the Southwest region of the United States. Several criteria were used in the selection of the test sites, including: range size, availability of WAA data for validation, and sites where target features had not been previously photo verified or unexpected HE debris had been encountered during field investigations (see Table 2). The following sections briefly describe the site histories, characteristics and rationale for the eight FUDS MMRP sites that were selected for this study.

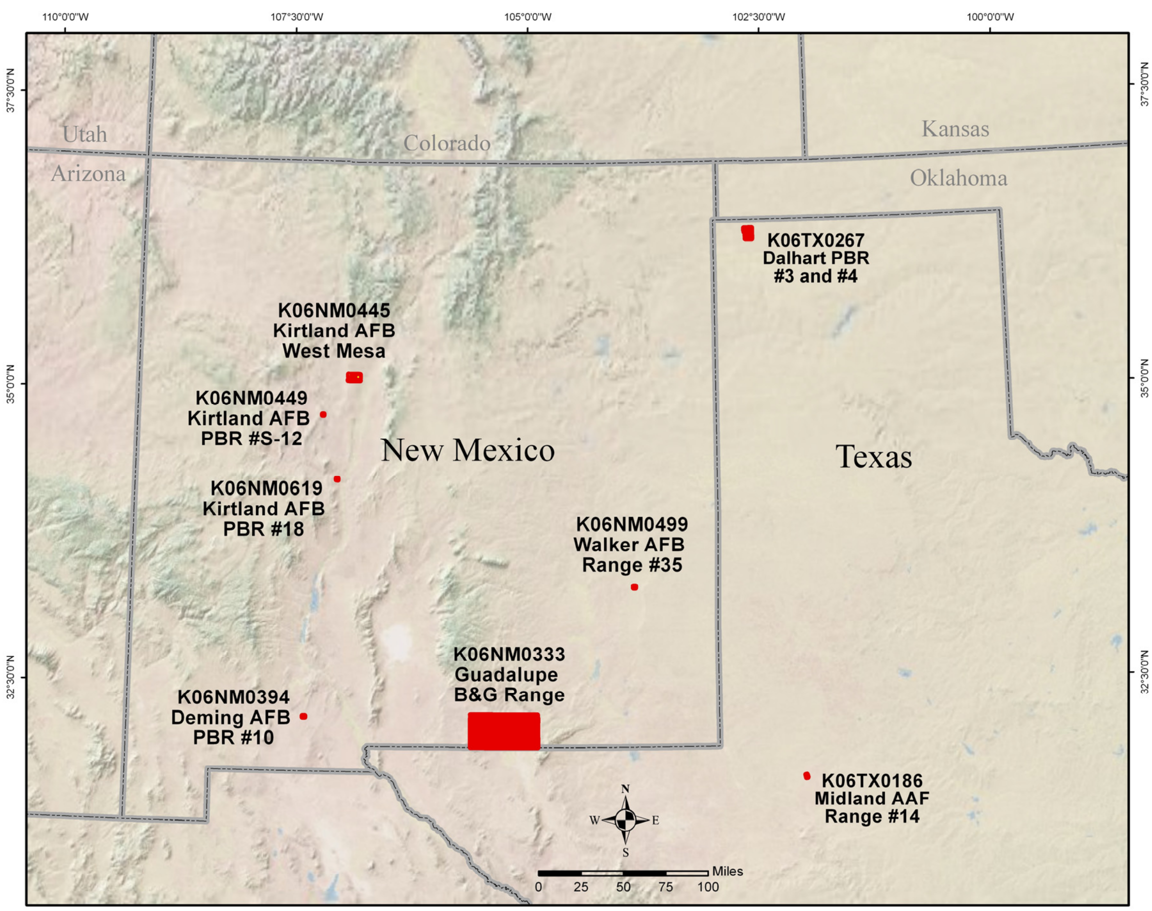

Figure 6. New Mexico and Texas Study Site Locations.

Table 2. Project Study Sites.

PROJECT # - FUDS ID STUDY DATE	RAC [(1)] SCORE	SITE NAME	ACTIVE PERIOD	RANGE ACRES	PROPERTY ACRES	COMMENTS
NEW MEXICO SITES						
#1 - K06NM0333 2001	4	Guadalupe Bombing and Gunnery Range	1943-1956	12,539	495,053	Combination of several practice and demolition ranges, with several unmapped navigation markers
#2 - K06NM0394 1997	4	Deming AFB PBR #10	1943-1947	649	960	Practice bombing range; no features evident in photos used for original ASR; range considered "missing" [(2)]
#3 - K06NM0445 1994	2	Kirtland AFB Ranges – West Mesa	1941-1945	1,298	15,246	Combination of multiple practice and one demolition range; WAA site
#4 - K06NM0449 2005	4	Kirtland AFB PBR #S-12	1942-1946	649	640	Considered "missing" practice range at project start; range found off-site of original property inspected
#5 - K06NM0499 1998	4	Walker AFB Demolition Bombing Range #35	1944-1945	649	1,000	Considered "missing" demolition range; ASR field mapped location, not evident in ASR photo set
#6 - K06NM0619 2004	4	Kirtland AFB PBR #18 Target S-5	1943-1946	649	640	Considered "missing" practice range at project start – range found off-site of original property field visited
TEXAS SITES						
#7 - K06TX0186 2000	3	Midland AAF Target Range #14	1942-1947	1,646	1,646	Unexpected HE debris found during Site Investigation; several practice range target features and crater area
#8 - K06TX0267 2009	4	Dalhart Precision Bombing Ranges #3 and #4	1943-1945	16,581 [(3)]	16,581	Combination of two practice and one demolition range, with several target features present; unmapped HE range

(1) RAC: Risk Assessment Code assigned for site during initial assessment (1=highest risk, 5=lowest risk).

(2) When this ESTCP project was proposed, four New Mexico FUDS-MMRP sites were not mapped via photo interpretation in the available FUDS related documents; all four were included as project sites with a secondary project goal of locating the "missing" ranges; preliminary assessment (PA) documents for two of the sites (K06NM0449 and K06NM0619) were subsequently made available that correctly locate the range locations (but miss the battleship target on K06NM0449).

(3) The original 1998 ASR did not examine aerial photos, so individual ranges were not mapped and the entire property area was considered a range; results from the 2009 SI were used for the comparative analyses.

4.1.1 Site #1 – K06NM0333 – Guadalupe Bombing and Gunnery Range (BGR)

Guadalupe BGR is located in Otero County, New Mexico immediately north of the New Mexico and Texas state line. The site encompassed over 495,000 acres, forming a rectangle nearly 20 miles by 40 miles. The large size was needed for heavy bombers flying at high altitude to safely fire at targets towed by other planes on both sides of the aircraft. Use of the Air-To-Air Gunnery Range (ATAGR) began in November 1943. To support this use, a series of 24[4] location markers were planned along four east-west rows and five north-south columns in the shapes of letter or geometric shapes up to 4,000 feet in size.

Beginning in 1944, the site established 4 high-altitude practice bombing targets (PB-1, PB-2, PB-3, and PB-4) that were placed on previously established ATAGR markers (2A, 2B, 4A, and 4B). Five more bombing targets were constructed after 1948 for practice (P-3 and P-7), HE demolition (D-4 and D-6), and radar bombing (R-5). Table 3 provides a summary of the ranges and field investigation results (ASR and SI) related to munitions debris.

The release of lands occurred in phases as target abandonment and land clearances allowed (1951, 1956, 1959, and 1960). Following the last land clearance in 1960, the lease and suspension agreements for the remaining area of the range were allowed to expire and on December 19, 1961 the withdrawal of the lands for the Air Force completely ended (USACE, 2008).

The site was chosen for this study for its large size, and the presence of several known and suspected practice and demolition targets. Numerous features were seen on historical aerial photographs that were not mapped in the 2001 ASR, most of which were subsequently identified as ATAGR markers.

Table 3. Munitions Debris at Confirmed and Possible Targets.

TARGET	MUNITIONS DEBRIS [5]
PB-1	Practice bombs, flares, rockets and small arms
PB-2	HE fragments, practice bombs and small arms
PB-3	HE fragments, practice bombs and small arms
PB-4	HE fragments, practice bombs and small arms
P-3	HE fragments, practice bombs and small arms
P-7	Practice bombs and small arms
D-4	HE fragments, practice bombs and small arms
D-6	HE fragments (bomb/rockets), practice bombs and small arms
ATAGR 3B	Practice bomb and small arms; verbal account of other test drops.
R-5	Not visited – bombing target in historical documentation
"+" Target	Not visited – possible target based on aerial imagery
P-0	Not visited – possible target based on aerial imagery
ATAGR Markers	1A, 1B, 1C, 2C, 2D, 3A, 3C, 3D, 4C, 4D, 5A, 5B, 5B/C, 5C, 5D Markers only, not used as targets.

[4] 23 of the ATAGR markers were interpreted on the aerial photography, and a 24th possible marker was found.
[5] Munitions debris found during ASR and Site Investigation field inspections.

4.1.2 Site #2 – K06NM0394 – Deming AFB PBR #10

Deming PBR #10 is located in Doña Ana County, New Mexico, approximately 28 miles east of the city of Deming, New Mexico. The site consists of approximately 960 acres of open land that was used by the Deming Army Flying School for training activities based at Deming Army Airfield between 1943 and 1947. This site was one of 24 bombing ranges associated with Deming Army Airfield (USACE, 1992a) and was used for both day and night bombing practices. Planning documents stated that the day target consisted of standard concentric circles with a 350-foot square superimposed upon the circles, a mock battleship target and an oil refinery. The night target was stated to be a target that consisted of four strings of lights on the ground, forming a cross or grid, used as an illuminated truck convoy (Parsons, 2009a). The Lease and Suspension Agreement (320 acres) was terminated June 1947 and the remaining 640 acres was returned to Department of Interior (DOI) June 1949. The site is currently administered by the Bureau of Land Management and the State of New Mexico and is used for livestock grazing (USACE, 1992a).

The munitions datasheets in the 2004 ASR Supplement lists the Munitions and Explosives of Concern (MEC) that may be found at the former Deming PBR No. 10 as M38A2 and M85 100-pound practice bombs fitted with spotting charges. Letters of decontamination dated 1945 and 1949 state that the land was searched and neutralized of all dangerous explosive materials (USACE, 2004a).

The Deming PBR #10 site is located on broad alluvial fans of alluvium soils. The soils are sand-silt/sand clay and presented a chief difficulty for dedudding crews as "it often happens that the bomb is completely buried in the sandy soil prevalent in the area." The soils have a moderate erosion hazard as runoff is very slow and also have a high hazard of soil blowing erosion. Due to the nature of the environment and the terrain, the area undergoes severe erosion/deposition. These environmental conditions clearly affected the visibility of bombing target remnants over time (USACE, 1997).

The site was selected because no target features were mapped from historical aerial photos in the ASR. The ASR examined aerial photography from 1974, 1975, 1980, 1986 and 1989. Remnants of the bombing target were not visible on any of the ASR dates of photography (USACE, 1997).

4.1.3 Site #3 – K06NM0445 – Kirtland AFB PBRs West Mesa

This site, designated as Kirtland AFB PBR N-1, N-3, N-4, & "New Demolitions" in the ASR, is located approximately 2 miles west and 18 miles northwest of Albuquerque, New Mexico. The site encompassed 15,246 acres. The U.S. Army Air Corps used this range for bombing practice during the period 1941-1945 (USACE, 1992b). The 1994 ASR report stated "there were at least five targets, including sites identified as N-1, N-3, N-4, "NEW" Demolitions, and a target site to the west of "NEW" Demolitions called Bomb Target N-2."[6] Targets included numerous "simulated targets," including an oil refinery, battleships, a large bridge, heavy artillery emplacements, a railroad roundhouse, and a strip of road with a realistic truck transport convoy painted on it (USACE, 1994a).

[6] The INPR did not name Bomb Target N-2, but referred to it as one of two target areas north of the Double Eagle Airport. The INPR stated there were six known practice bombing ranges, and identified a "Tank Farm Target Area" (USACE, 1992b).

On October 23, 1946 the War Department declared this site as surplus to its mission. The Lease from the city of Albuquerque for 10,456 acres was canceled on March 31, 1947. The remaining 4,790 acres were transferred back to the DOI by October 26, 1949 (USACE, 1992b).

In 1952 Certificates of Clearances (COC) were issued for target areas N-l, N-3 and N-4. The COC issued for target area N-l states that the site was cleared, but recommends that the site, consisting of approximately 960 acres, be restricted to surface use. The COC issued for target area N-3 states that 17, 000 pounds of metal and military scrap were stockpiled at the center of the target and that the target area, consisting of approximately 320 acres “is safe and free of dangerous and/or explosive material.” The COC issued for Target N-4 states that the area was cleared, but recommends that the 1,280 acres be restricted to surface use. There are no clearance records for the approximately remaining 12,686 acres of the range (USACE, 1992b).

During February 1-5, 1994 the ASR team conducted a field visit to the following target impact areas: N-1, N-2, N-3, N-4, “NEW” Demolitions and Area F Range land. The ASR identified the types of ordnance dropped on the targets as including 100 pound concrete bombs and 100 pound sand-filled bombs, aircraft flares, and 250 pound general purpose HE bombs (USACE, 1994a).

PBR N-4 impact area is located within the boundaries of the Petroglyph National Monument. Since the bombing range is over 50 years old, the Park Service also considers it to be of historical significance and wants ordnance explosive waste (OEW) that is deemed safe to remain on-site (USACE, 1994a).

The site was selected as it has been used for detailed studies by WAA projects and provided good ground data and cross-checks between the technologies. Although there were multiple ASR references to target features being present on aerial photography, it is not clear if K06NM0445 ever had a systematic PI study completed. There was no formal listing of photos dates in the ASR. Mention was made about photos believed to have been taken in 1971. Archive searches for this project identified only partial eastern coverage in 1973 and earlier sitewide coverage in 1967. The 1967 photography was acquired and used for the comparative analysis.

4.1.4 Site #4 – K06NM0449 – Kirtland AFB PBR #S-12

Kirtland PBR #S-12 is located in Valencia County, New Mexico approximately 31 miles southwest of Albuquerque. The site encompassed 640 acres for use as an auxiliary PBR for Kirtland Army Airfield from 1942 to 1946. A concentric circle bull’s-eye target, 1,000 feet in diameter was identified.

On October 23, 1946 the property was declared surplus and the process of disposal was initiated. The acreage was transferred back to the DOI on January 13, 1948. A COC was issued on October 7, 1953 recommending surface use only on the site (USACE 2005). On March 23, 2004 the PA site survey team observed ground surface evidence of the past use as a practice bomb target, finding M38 fuze caps, metal skin and similar practice bomb parts, and a few crushed bomb bodies from M38A2 bombs scattered about the property.

The site was selected because no MMRP maps were available in the DERP Annual Report to Congress, Fiscal Year 2008.

4.1.5 Site #5 – K06NM0499 – Walker AFB Demolition Bombing Range DBR #35

Walker DBR #35 is located in Chaves County, New Mexico approximately 37 miles east of Roswell, New Mexico. The site is comprised of 1,000 acres of public domain lands that were transferred to the War Department February 10, 1944 for use with the establishment of the Roswell DBR[7] for Roswell Army Flying School. The Army Air Corps used the site as a demolition bombing range from 1944–1945 (USACE, 1991a). Normal training procedures required a student bombardier to drop about 100 practice bombs and two HE bombs. This range was designated a demolition (HE) bombing range.

The site was reported excess on June 18, 1945 and was transferred to the DOI by the War Department on March 27, 1947. The letter stated that the area had been inspected and cleared of all dangerous or explosive material that was reasonably possible to detect.

On June 4, 1998 a site research team visited the site. The soil is sandy and the terrain consists of sand dunes and wind blow-outs resembling craters. The team did find evidence of the past usage of the site as a demolition range, including a number of arming vanes from M100 series tail fuzes. No UXOs were observed on the ground surface during the site visit; however, the soft-sandy soil conditions may have enabled penetration of aerial bombs to several feet below the surface.

This site was selected because no target features were mapped from historical aerial photos in the ASR.

4.1.6 Site #6 – K06NM0619 – Kirtland AFB PBR #18 Target S-5

Kirtland AFB PBR #18, Target S-5 is located in Socorro County, approximately five miles northwest of San Acacia, New Mexico. The Kirtland AFB PBR No. 18, Target S-5 was acquired by the U.S. Army in 1942 for precision bombing practice. The 640-acre FUDS was one of 24 precision bombing ranges associated with the Air Forces Advanced Flying School at Kirtland Field. The target is known to have been used from 1943 to 1946 for the training of pilots and bombardiers, as both a day and night target (Parsons, 2010).

In October 1945 the War Department changed Kirtland Field's status to "temporarily inactive." On October 22, 1946 the property was declared surplus and the process of disposal was initiated. A COC was issued on 22 January 1953 for "Kirtland AFB Bombing Target No. S-5", and stated, "All lands…have been given a careful search and have been cleared of all dangerous and/or other explosive materials possible to detect." Sub-surface use of the land, however, was not recommended (USACE, 2004b).

On March 24, 2004 a site visit was conducted. The team observed evidence of past use as a practice bomb target (M38 fuze caps, metal skin and similar practice bomb parts).

The site was selected because no MMRP maps were available in the DERP Annual Report to Congress, Fiscal Year 2008.

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[7] Renamed to Walker Air Force Base, Demolition Bombing Range No. 35

4.1.7 Site #7 – K06TX0186 – Midland Army Air Field (AFF) Target Range #14

Midland Target Range #14 is located in Midland County, approximately 19 miles southwest of Midland, Texas and comprised approximately 1,259-acres. The War Department leased the land from 1942 to 1953 for use as the Midland AAF Target Range #14. It was one of 23 practice bombing target ranges for training bombardiers and navigators stationed at the Air Corps Advanced Twin Engine and Bombardier Training Center at Midland AAF (Parsons, 2008).

Six target areas with various target structures were used at the site: a circular day bombing target, an elliptical "battleship" bombing target, three combat targets that resembled transportation and industrial features, and a possible HE target area with visible cratering.

Midland AAF TR14 remained in use by Carswell AFB until September 15, 1953, when the lease on the land expired and it was returned to the previous landowner (Parsons, 2008). The ASR did not find any COC. The ASR site visit team found several munitions debris items present on site, including heavy fragments from what appeared to be AN-M30 general purpose munitions bombs, M47 100-lb. "chemical practice" bombs (sand-filled), M26 parachute flares, and M85 100-lb. concrete bombs.

This site was selected because HE debris was unexpectedly found in the middle of the Midland AAF Target Range during 2008 field investigations.

4.1.8 Site #8 – K06TX0267 – Dalhart PBR 3 and 4

The Dalhart PBR 3 and 4 site is located in Dallam County, approximately 22 miles northwest of Dalhart and 20 miles east of Texline, Texas. The site encompassed a total of approximately 16,581 acres. The site was used to train pilots and bombardiers stationed at Dalhart AAF between 1943 and 1945. The site included both bombing ranges and an air-to-ground gunnery range.

Bombing targets were located in the northeast and southwest corners. The area through the center of the property was used for air-to-ground gunnery practice. A demolition bomb range was also located in the center of the gunnery range. South of the demolition target were several targets that were used for bombing practice. Practice bombs were used in areas except the demolition range where demolition bombs were used. The ground gunnery targets were probably limited to .30 caliber and .50 caliber ammunition. However, toward the end of the war, Dalhart Army Air Base did conduct training with 20 mm cannons and these weapons may have been fired on this range.

The Dalhart Army Air Base was placed on temporary inactive status on November 2, 1945. This status was changed to surplus on November 20, 1945 (USACE, 1998a). The 15,901 permit acres were disposed of on November 29, 1946 by letter of transfer to the Department of Agriculture. The remaining 680 acre lease from the private landowner was canceled in 1948 (USACE, 1991b).

This site was added as a study site because the 1998 ASR stated that "no historical aerial photography was obtained for these ranges, so no interpretations were conducted." A photo verified target map was therefore not available.

5.0 TEST DESIGN

Existing range maps developed in support of prior ASRs (or the selected PA and SI studies noted earlier) were used as the baseline source of range feature information. It was anticipated that some "new" locations for unmapped bombing range features might be identified. Most of these features were expected to be self-evident upon detailed visual inspection. Only a few questionable features were expected to require field checks to verify their correct classification.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The basic experimental design for this demonstration was to compare interpretation results from existing maps (ASR or subsequent studies) with those obtained using "best practice" photo interpretation procedures and digital image analysis procedures. The new photo interpretations made use of standard procedures developed by the EPA and other organizations involved in environmental forensics. An experienced analyst made use of visual interpretation procedures and film diapositive products. A separate review of the results by another senior analyst was used to provide a quality control (QC) check. All differences in interpretations were resolved by a visual review with discussion and consensus. The potential influence of differences among different professional interpreters and the amount of time available to conduct the analyses was recognized but was not addressed as part of this study. All interpreters had at least 10 years professional experience.

The digital processing alternative involved similar interpretation procedures, but was based on digitally pre-processed imagery rather than film products. There are many potential photo scanning resolutions, image enhancement and image restoration algorithms, and parameter settings possible for the digital processing. It was not practical to quantitatively test the numerous permutations possible. As such, an experienced analyst selected an appropriate set of algorithms and settings to apply. Additional interactive enhancements were applied "on-the-fly" by the analysts to assist any specific feature interpretations (e.g., a locally different contrast) that was required to best interpret a specific feature. As with the film-based alternative, the initial analyst's results were reviewed by another senior analyst and any differences in interpretations resolved by review with discussion and consensus for final interpretations.

To avoid possible cross-over influence among the analyses, different pairs of analysts were involved for the photo interpretation and digital image analyses. The analysts were not provided with any site specific identification or descriptive information. The historical imagery was provided without any site location or descriptions other than film date and scale. A statement was signed by each analyst attesting to their independent and unbiased analyses of the imagery without the use of any collateral sources of information or prior knowledge regarding site details.

In addition to the primary objectives of range and feature identification and mapping, the locational accuracy of orthophotos developed from the historical photography was tested using USGS and similar quality orthophotos. Recent orthophotos were assumed geometrically correct and used as the basis for control of the historical orthophotos that were developed. Location accuracy was estimated by evaluating offsets between matched pairs of visually distinct feature locations in the orthophotos.

5.2 EQUIPMENT SPECIFICATIONS

The specifications for historical aerial photography are inherently pre-defined and not subject to change. Available metadata information is often limited to obvious statements of film type (e.g., black and white versus color), scale, and area of coverage.

For the digital analyses, a large range of film scanning resolutions are possible. Photogrammetric applications generally require higher resolutions and geometric fidelity compared to many other image processing applications. Preliminary photo scanning for this demonstration project used a photogrammetric scanner with a true optical resolution of 7 microns or 3,629 pixels per inch. This results in large data files (over 1GB per 9-inch black and white photo), but was considered most likely to benefit from the planned image processing. Initial results, however, indicated no significant quality difference between a 7 micron and 14 micron scanned photos. Analysts conducting the initial image assessments generally preferred the larger scan resolution as it was less grainy. As there appeared no visual interpretation benefit to the finer resolution, even after blur removal processing, the 14 micron scan resolution was adopted as the project standard.

Figure 7 provides an example of the four different standard scan resolutions used by USGS-EDC. On October 1, 2009, the USGS initiated a program to systematically scan their aerial photo archive collections to a standard format of 25 microns. They have also discontinued the production of film or print hardcopies for aerial photo products. All USGS-EDC photo products are now delivered in digital format only.

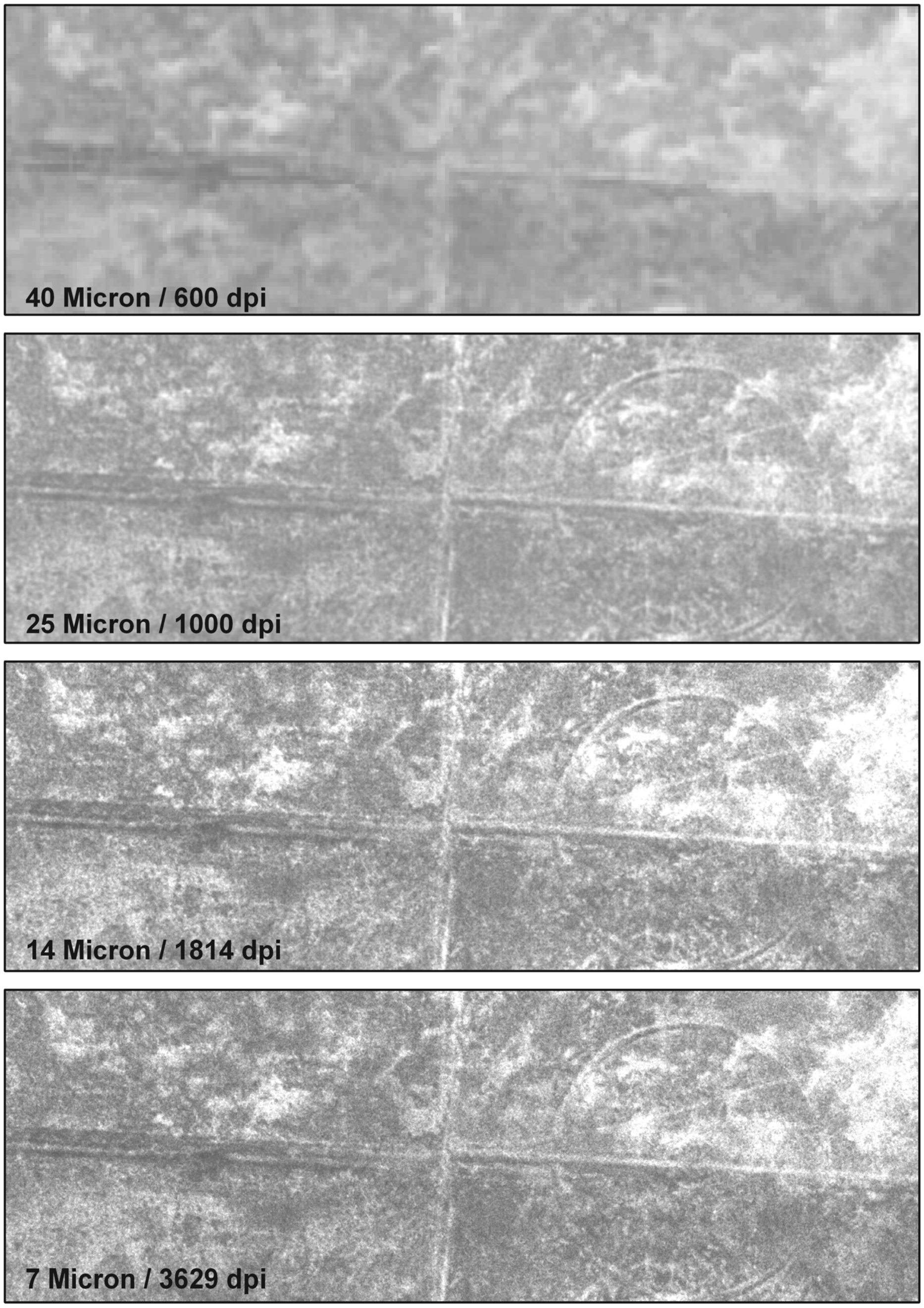


Figure 7. Comparison of Film Scanning Resolutions.

Northeastern circular target range on Site #8 (Dalhart). The bottom three images were from a high quality photogrammetric scanner, while the top image is from a graphics scanner used to generate browse images. All four image scans are from the USGS-EDC. The target circle appears slightly degraded on the 25 micron scan and would not be identified on the 40 micron scan without prior knowledge of its location. The original photograph was acquired in 1954 at a film scale of 1:60,000. The outer target circle is 1,000 feet in diameter.

5.3 DATA COLLECTION

Historical photography was acquired to match the corresponding set of photography acquired for the ASR studies. Table 4 provides a summary of the photo years and scales acquired for the baseline studies. Detailed citations (mission identifiers, frame numbers, etc.) are available from the citied studies.

Table 4. Photo Data Sets Used for the Comparative Analysis.

Site #	Site	Study	Photo Year (1)	Photo Scale
1	Guadalupe Bombing & Gunnery Range K06NM0333	ASR 2001	1950	1: 44,000
			1972-74	1: 32,000
			1996-98	1: 40,000
2	Deming AFB PBR#10 K06NM0394	ASR 1997	1974	1: 40,000
3	Kirtland AFB PBR – West Mesa K06NM0445	ASR 1994	1967 (2)	1: 26,000
4	Kirtland AFB PBR #S-12 K06NM0449	PA 2005 (3)	1951	1: 28,400
			1997	1: 40,000
5	Walker AFB DBR #35 K06NM0499	ASR 1998	1971-72	1: 24,000
6	Kirtland AFB PBR #18 Target S-5 K06NM0619	PA 2004 (4)	1946	1: 35,000
			1971	1: 40,000
			1996	1: 40,000
7	Midland AAF Target Range #14 K06TX0186	ASR 2000	1946	1: 20,000
			1966	1: 20,000
8	Dalhart PBR Ranges #3 and #4 K06TX0267	SI 2009 (5)	1954	1: 60,000

(1) Photo mission campaigns can span months to a few years; the ranges for three multiyear missions are shown.
(2) The ASR notes several photo-based observations but does not provide a detailed photo date listing. There is one reference to photos taken approximately 1971. The only sitewide photo availability near this timeframe was 1967, which was used as the basis for the comparative analysis. It is possible that the ASR used a combination of other unspecified dates of photography.
(3) No ASR was available at the start of this project. The 2005 PA was used as the source.
(4) No ASR was available at the start of this project. The 2004 PA was used as the source.
(5) The ASR (1998) for this site did not examine any site photography. The 2009 SI was used as the source.

Standard overlapping sets of photos were acquired to allow stereo viewing. Stereo viewing proved less important than anticipated, as the range features were generally located on flat terrain. Stereo coverage did prove useful to eliminate the possible misinterpretations of several film artifacts, which are more common in some of the older sets of photography. Figure 8 provides an example of a circular film processing artifact that might be misinterpreted as a bombing range target feature if only the one frame of photography was examined.

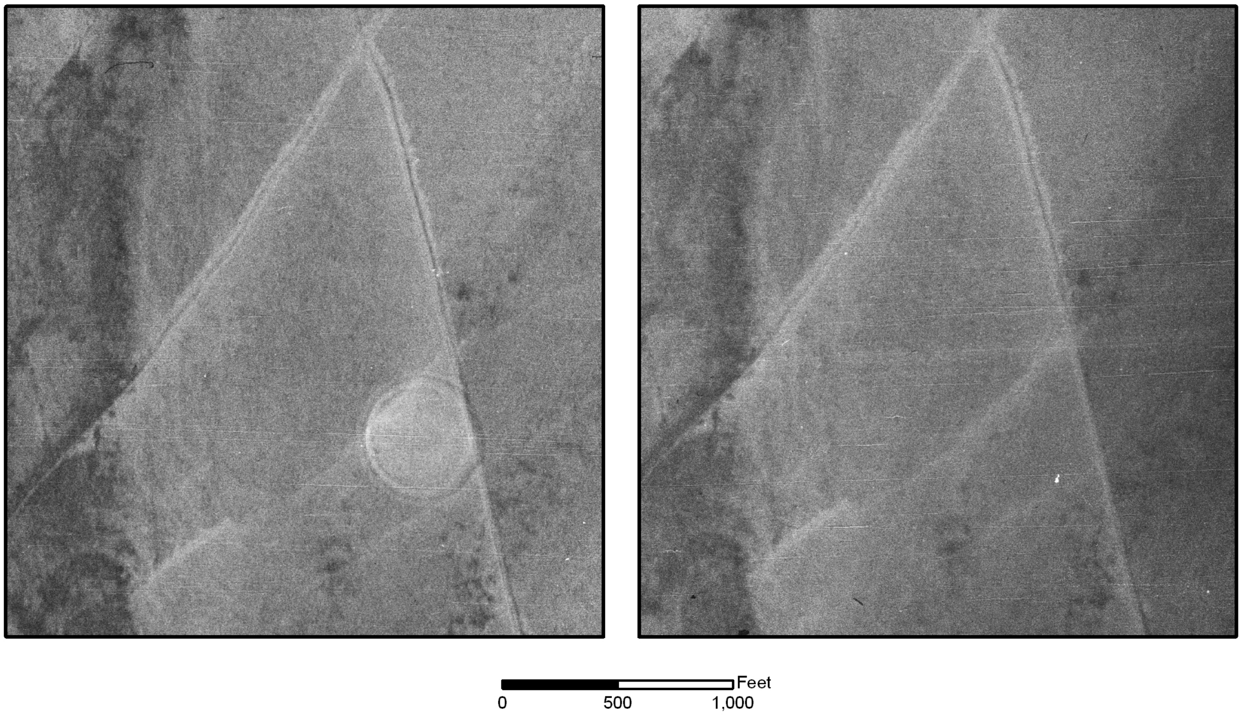


Figure 8. Stereo Pair of 1950 Photography

The 500-foot circular feature on the photo (enlarged from frame 58-VV) is a film processing artifact. Based on its circular shape, size, and intersection with a road that could have been used for site access, it could easily be misinterpreted as a target feature. The feature is missing in the overlapping photo (frame 57-VV), which proves that the feature is a film processing artifact. The photos are from Site #1 (Guadalupe).

Photos were acquired in both diapositive (film transparency) and scanned digital format. The USGS-EDC has transitioned to a digital-only distribution policy for copies of aircraft and satellite imagery from their archives. This makes the future capability to handle digital imagery mandatory for some photography. Vendors supporting the NARA currently support both film duplicate and digital scans of the archive holdings. High resolution digital scans are currently available from both USGS-EDC and NARA sources. These and other sources were used to acquire additional photography that was used for validations. Scanning options available from other sources are highly variable in terms of scanning resolution and quality of equipment. In some instances, validation photos were only available as digital scans of photographic prints using graphic scanners. Although significantly less optimal in terms of image quality, the specific dates and scales were generally observed to be more important for the validations than the media or type of scanner.

5.4 VALIDATION

Possible interpretation errors can be categorized into two classes – errors of omission (Type I) and errors of commission (Type II). In the context of this project, an error of omission would be to miss the detection of a range feature. An error of commission would be to misidentify a non-range feature by calling it a range feature. Although both interpretations would be considered errors, for this application an omission error would be considered more significant than a commission error – i.e., missing a range would be more significant than calling a non-range feature a range feature. Similarly, missing sites where HE bombs were used would be considered more significant than missing sites used for only practice bombs.

It is not practical to establish 100% confidence in the validations, due to cost constraints related to the large areas involved in this study. Significant effort was extended to validate all features to the maximum extent that cost considerations allowed. Validation efforts used a variety of sources and methods and a "convergence of evidence" approach to determine if a feature was considered validated. The primary and most productive method was to conduct updated and more extensive searches of historical photo archives and to acquire better dates and/or scales of photography.

Three sites had marginal dates of photography used for the ASR photo interpretations:

- Site #2 (Deming) – 1974
- Site #3 (Kirtland) – 1967
- Site #5 (Walker) – 1971/1972

Scale concerns were noted for three sites:

- Site #1 (Guadalupe) – 1: 44,000
- Site #2 (Deming) – 1: 40,000
- Site #8 (Dalhart) – 1: 60,000

More suitable dates and scales of photography were identified and selected photographs were acquired for all five of these sites. In addition to more suitable dates of photography, selected sets of photographs taken prior to range developments were acquired to assist the interpretation of specific features of interest (see Table 5).

Table 5. Additional Photography Acquired to Assist Range and Feature Validations.

Site #	Site	Photo Year	Photo Scale
1	Guadalupe Bombing & Gunnery Range K06NM0333	1943	1: 50,000
		1946	1: 24,000
		1948	1: 27,230
		1958	1: 17,200
2	Deming AFB PBR#10 K06NM0394	1942*	1: 56,000
		1951	1: 20,000
		1953	1: 54,000
		1956	1: 31,680
3	Kirtland AFB PBR – West Mesa K06NM0445	1935*	1: 44,000
		1945	1: 21,400
		1951	1: 24,000
5	Walker AFB Demolition Bombing Range #35 K06NM0499	1946	1: 31,680
		1954	1: 63,000
8	Dalhart PBR Ranges #3 and #4 K06TX0267	1941*	1: 20,000
		1953	1: 20,000

* Photo dates prior to range operational periods.

The additional photography provided sufficient source material to validate nearly all of the photo interpreted features. It also identified several features that had been missed by later dates and/or smaller scales of photography. After review of the additional photography, validation problems did persist for two sites: Site #2 (Deming), and Site #8 (Dalhart). The ASR for Site #2 (Deming) identifies four range target features (ship, cross-hairs, industrial, and convoy) that were discussed in planning documents. The planning documents included a map of the site with proposed target locations. These four features did not appear on any of the photography reviewed The site documentation indicates the range was operational between 1943 and 1947. Available imagery included 1942 photographs that show the site under partial development and 1951 photographs on which the specified features were not apparent (although surface disturbances and the standard nature of the site layout suggest likely locations). Assuming the target features were developed, it appears likely that the sandy environment of the site quickly (within 4 years) degraded the target appearances.

Convoy targets were considered the most problematical type of target feature to interpret. Collateral documentation noted that these occurred on specific road or trail segments, sometimes with features painted on the ground (Kirtland Field, 1943). No features could be confidently identified as convoy targets on any of the photography examined. Several bridge features, potentially used as convoy targets, were noted on Site #3 (Kirtland – West Mesa). One road segment with no apparent destination was interpreted as a possible convoy target at this site. Field investigations by the USACE for an Engineering Estimate and Cost Analysis (EE/CA) found several ordnance related items in this area, suggesting the presence of a target (EODT, 2006).

A related observation from the validation effort is that historical roads and trails should be mapped during site investigations. Nearly all target features had distinct access roads for target maintenance. Road segments should also be reviewed as potential convoy target areas. Historical roads and trails should be considered for systematic field investigation during standard SI Qualitative Reconnaissance (QR) walk-around surveys. A potential "road bias" in this case may prove beneficial.

Site #3 (Kirtland – West Mesa) had three features that do not appear to have been related to the bombing ranges. This included a building complex with a unique hexagon layout pattern that was constructed after the site was no longer used as a bombing range, and two hillside markers that were similarly developed after the bombing range was discontinued. The markers were located on the Petroglyph National Monument and their probable nature was confirmed by site personnel.

There were two distinct features present on the Site #8 (Dalhart) photography that required field validations (Figure 9). The field effort for these features identified several munitions debris items that confirmed the features as range target areas (HydroGeoLogic, 2010).

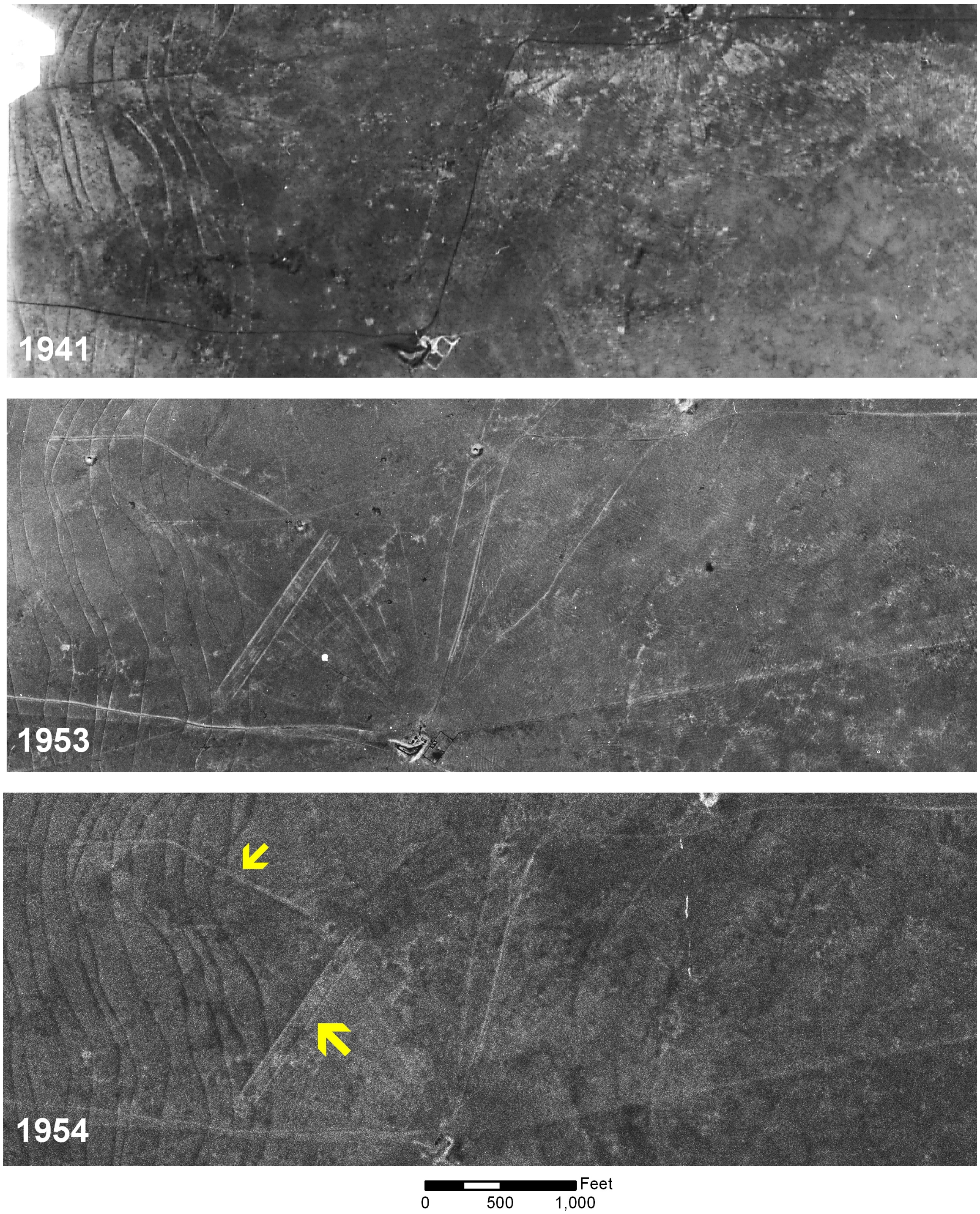


Figure 9. Field Validation Features.

The features indicated by yellow arrows were noted on the 1954 photos used in the comparative analyses as possible target features by the PI and DIP analysts. They could not be confidently identified on the earlier and better scale 1953 photos acquired for validations. The features were not present on the earlier 1941 (pre-WWII) photos, thus bracketing the construction as between 1941 and 1953. Field validation identified possible wood target debris on the upper feature and bomb debris was found at both sites. Three craters were also found at the lower site. The original film scales were 1:20,000 for both 1941 and 1953, and 1:60,000 for the 1954 photos.

6.0 DATA ANALYSIS AND PRODUCTS

Existing FUDS range maps were used as a baseline for comparison with the two alternative analysis methods. These maps are available online from the MMRP SI section of the 2008 DERP Annual Report to Congress. ASR documentation for the maps describes their development as based on the photo interpretation of photographic prints using pocket stereoscopes and, where available, range planning maps for specific sites. The first alternative method involved best practices for photo interpretation – using different film media and viewing equipment than used for the baseline. The second method involved various types of digital image processing and image analysis. The specific processing and analysis steps that were be used for the comparison of baseline and alternative methods are discussed in the following sections.

6.1 PHOTO ACQUISITIONS AND PREPROCESSING

Both alternative methods of data analysis began with the acquisition of historical aerial film diapositives (positive transparencies) for the study sites. For direct photo interpretation there was no preprocessing of the imagery required. Standard film quality checks were used to document the aerial film characteristics (correct coverage, general brightness and contrast, presence of haze, clouds, or cloud shadows, general sharpness, any film processing streaks, etc.).

For digital processing, the photographs were scanned using photogrammetric quality scanners at high resolution. Initial scanning was performed at the highest available resolution of 7 microns (3,629 pixels per inch). The results of the highest resolution scans presented at full pixel resolution were considered too noisy with no observable benefit to the restoration and enhancements. An empirical comparison of different scanning results led to the selection of 14 microns as providing a more practical resolution for scanning the historical photography. The film resolving power of more recent photography may benefit from the higher resolution scanning. A detailed assessment of optimal scanning resolutions for different films and flight acquisition parameters was beyond the scope of this project.

Selective image enhancements and restoration procedures were applied to the imagery to develop the comparative products. These included routine procedures such as brightness/contrast and edge enhancement, as well as the more advanced blur correction, and photogrammetric procedures for orthophoto and DEM generation.

6.2 TRAINING KEYS

Image training keys that provided examples of range features present at other bombing ranges (sites not involved in this study) were used to familiarize the analysts with the types of features to be identified. A classification scheme was developed for the basic types of recognized range features (e.g., target circles, cross-hairs, HE bomb craters, outlines of ships, docks, fuel storage tanks, airfield, train, etc.). An "Area of Interest" (AOI) feature type was included to identify other features that might have been range related but could not be reasonably defined as a range target feature.

6.3 TARGET DETECTION AND IDENTIFICATION

The two sets of imagery (film and digital) were interpreted by two sets of experienced image analysts for the visual detection and identification of features comprising a bombing range. Stereo-pairs of imagery were examined for both types of interpretations. The analysts recorded the type and location of each feature and included a basic confidence factor for each feature mapped: confident, probable, or possible. Additional AOIs, such as towers and building structures, were also annotated but not incorporated into the comparative analyses. Film analysis results were initially annotated onto photo overlays and then transferred into GIS format using orthophoto bases. Digital interpretations were directly mapped onto orthophotos using GIS techniques to record the location and attributes of range features.

6.4 DATA PRODUCTS

Comparative data sets of photography for the PI and digital scans for DIP were prepared for each site. These sets matched those that were used for the specified ASR studies. Figure 10 provides an example of a photo frame acquired in 1951 that covers Site #4 (Kirtland AFB PBR #S-12). Figure 11 provides an enlargement of the range area in both raw scan and processed form. Figure 12 provides a further enlargement of the targets.

Additional photography and other collateral data were collected to assist the validation effort. Figure 13 provides an example of four dates of imagery for the N-1 Range area of Site #3 (Kirtland – West Mesa). It was noteworthy in this time series that in six years from 1945 to 1951 the range features had already become less distinct. A bridge and/or convoy target, distinct on the 1945 photo, was no longer apparent by 1951. The much later 1967 photography was used for the comparative analysis. By that timeframe, only the primary target circle and cross-hairs remained evident.

Some validation photography was acquired from sources that only had duplicate prints and no photogrammetric quality scanners available. Although less than optimal, in many instances this photography covered critical time periods and provided useful information for the validations. Photos were also acquired for two sites for dates prior to range operations: 1935 photos of Site #3 (Kirtland – West Mesa) and 1941 photos for Site #8 (Dalhart). These photos were acquired to help validate specific site features that were considered possibly pre-existing conditions that were not range activity related. NARA estimates that 85% of the continental U.S. has such photography available (NARA, 1973).

Validation data sets included ASR maps and any site descriptions available from historical documents. Site related maps that were pertinent to possible interpretations were usually georeferenced to facilitate examination using GIS techniques. Any subsequent analyses conducted, such as SI results, were also examined and used when appropriate. These more recent studies usually included GIS datasets that could be readily incorporated into the site dataset used for validations.

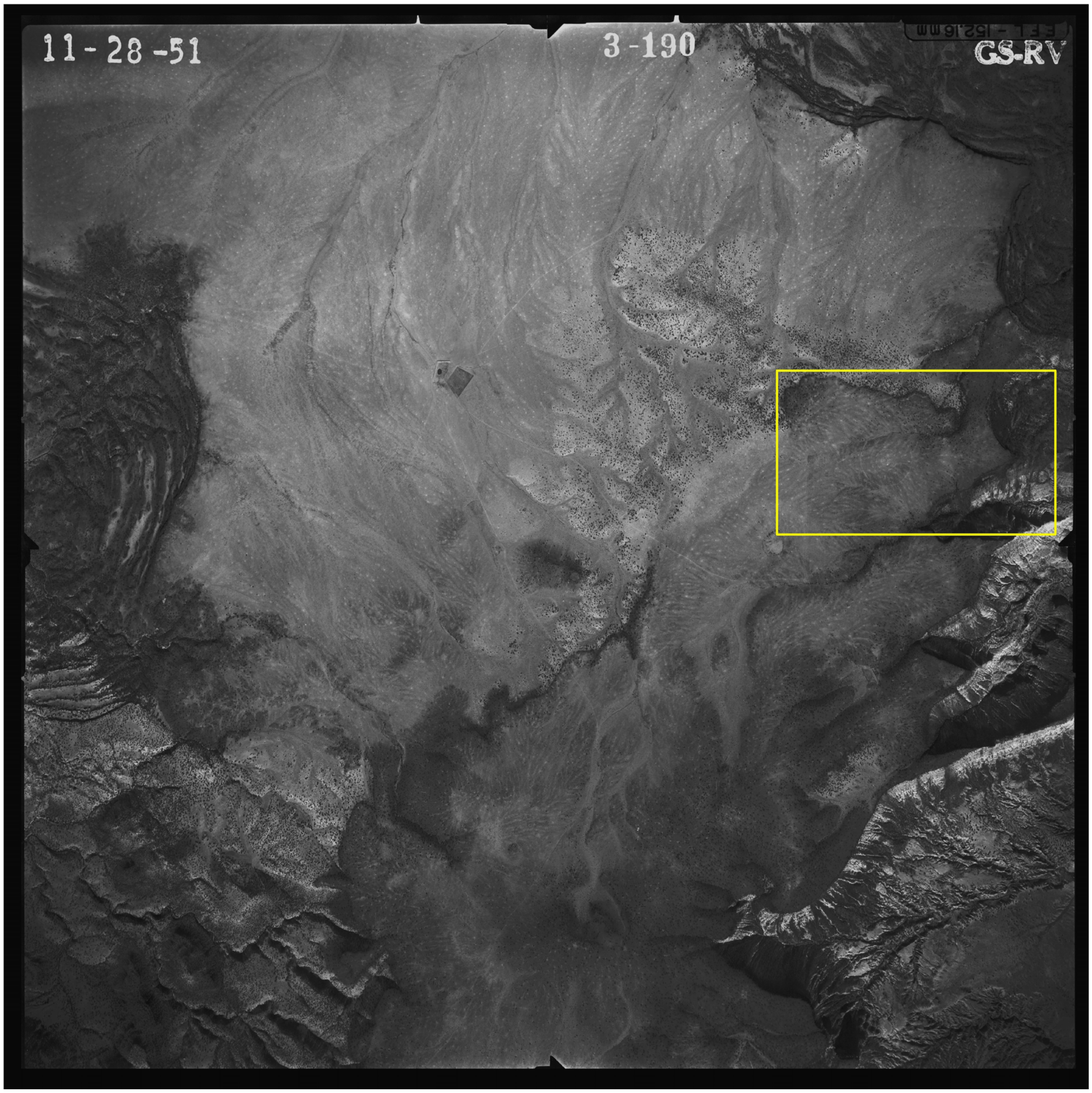
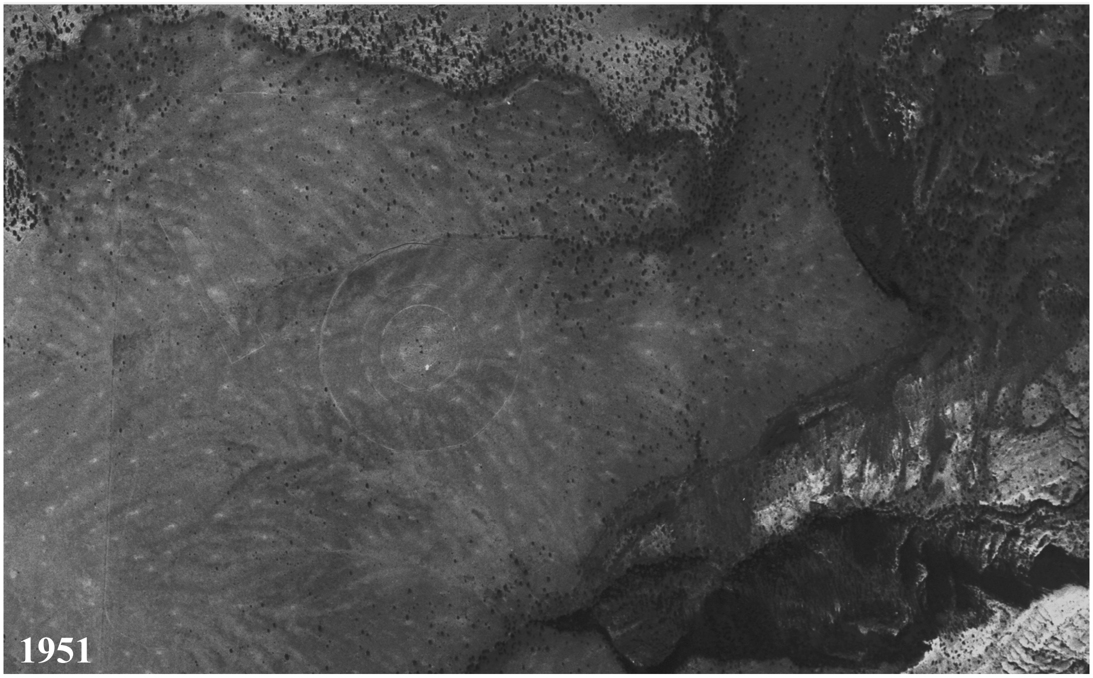


Figure 10. Site #4 (Kirtland AFB PBR #S-12) 1951 Scanned Photograph.

The original scale of the 9-inch photograph is 1: 28,400. It is shown here at approximately 1:40,000 scale (70% of the original). The yellow box area is the location of the practice bombing range that is shown enlarged in the next figure.



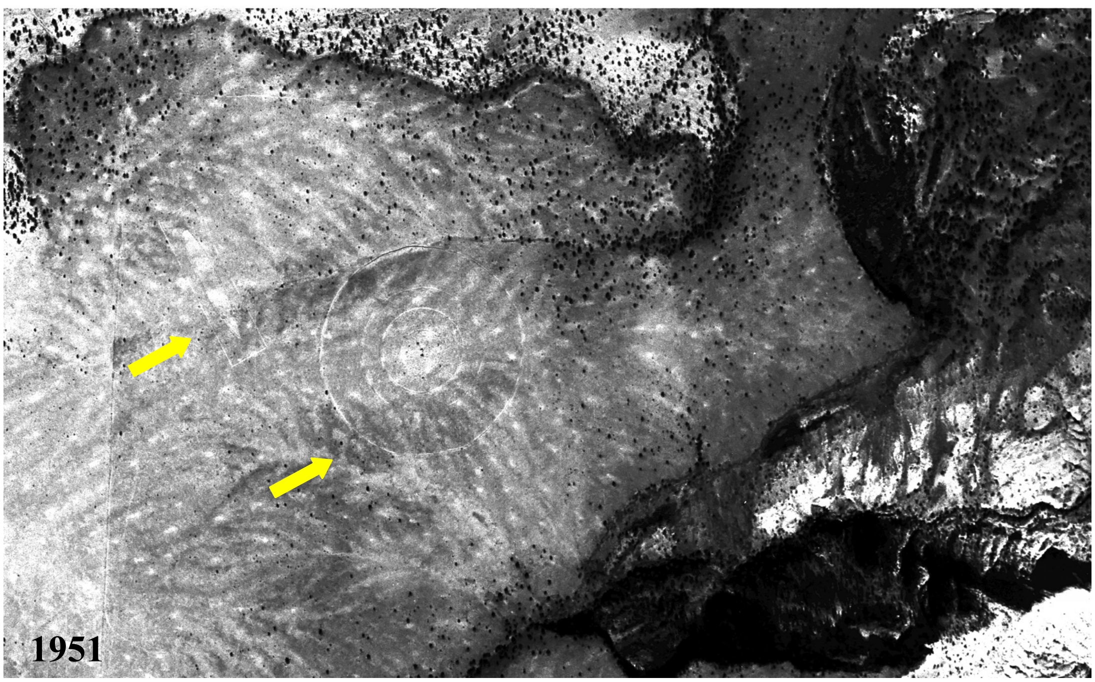


Figure 11. Site #4 (Kirtland AFB PBR #S-12).

Comparison of raw scanned 1951 photograph subscene (top) and processed version of same area (bottom). Processing involved blur removal and simple brightness and contrast enhancements, followed by sharpening. Circle and ship targets are more distinct in the processed imagery. The ship target was not identified in the 2005 PA report photo interpretation that was based on a film print copy of the same photograph. Photo scale as shown is approximately 1: 10,000.

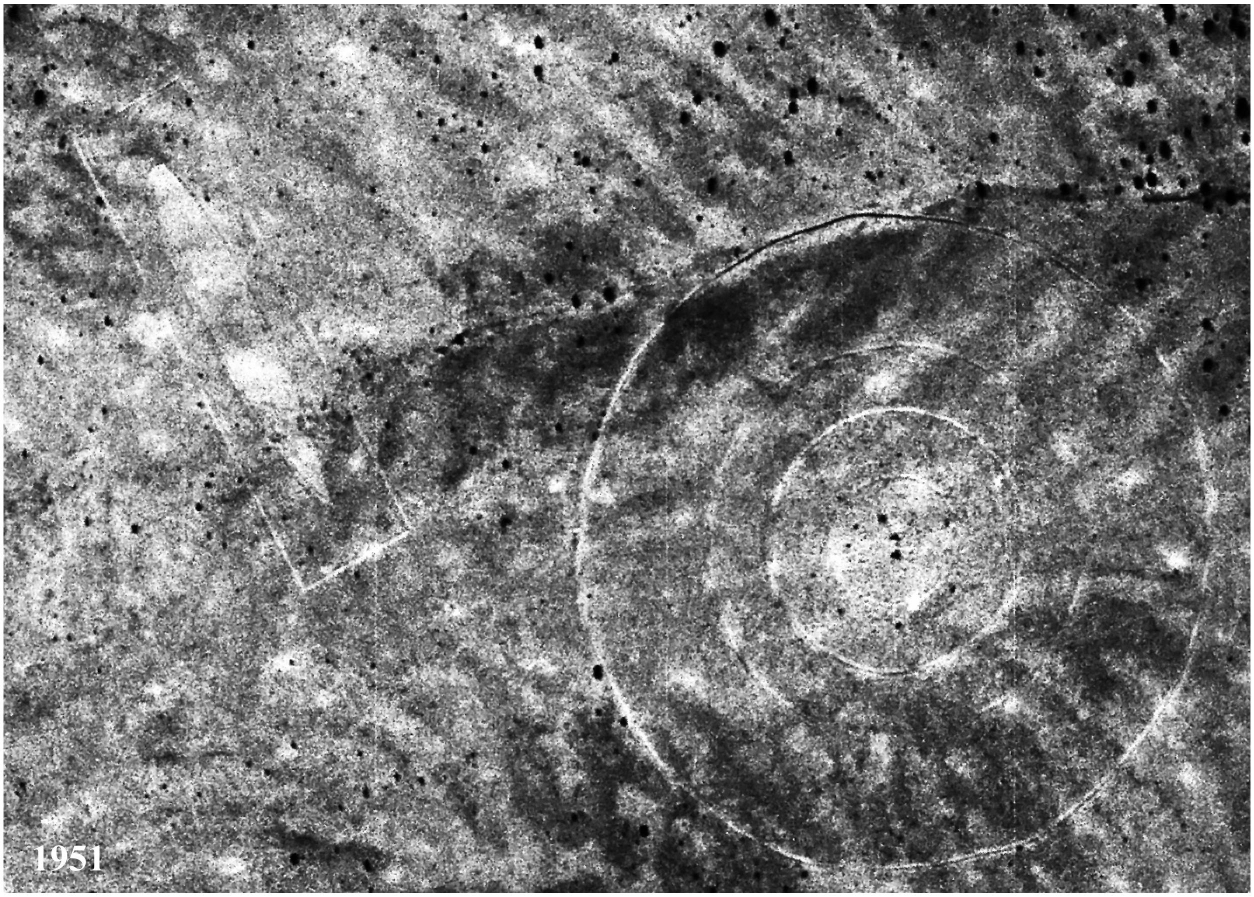


Figure 12. Further Enlargement of Ship and Circle Target Area.

This close view of the range area shows a distinctive rectangle outline encompassing the ship target. The outer target circle diameter measures 1,000 feet and the rectangle measures 800 feet in length. Photo scale as shown is approximately 1:3,500.

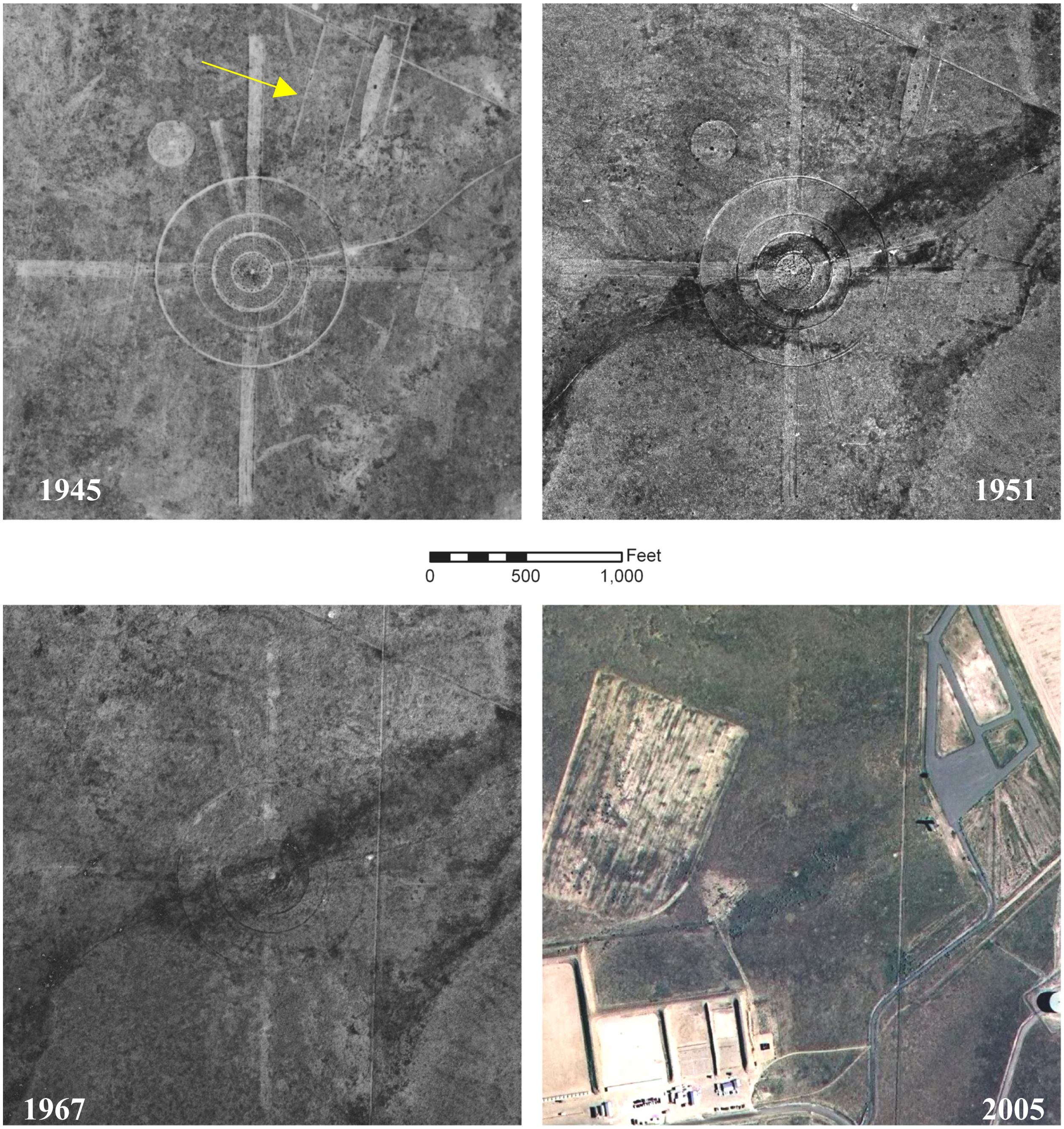


Figure 13. Time Series of N-1 Range Area.

This range has a bridge or convoy target that is evident in the 1945 photograph (yellow arrow) but no longer apparent by the 1951 timeframe. The comparative image analyses in this study were based upon the 1967 photography. In the 1967 photograph the target circles and cross-hairs are still evident, but the other targets are no longer apparent. By 2005, the target features are barely discernable, or have been obscured by development. Historical documents noted that the original cross-hairs were developed using magnetic north instead of true north and had to be redone for correct usage by navigators, thus the offset shorter cross-hairs. The nominal presentation scale shown here is 1:10,000.

7.0 PERFORMANCE ASSESSMENT

Summaries of the validated interpretation results are presented below. A more extensive tabular listing of feature interpretation results is provided in Appendix A-2, which identifies specific features.

7.1 OBJECTIVE 1 – IDENTIFY ALL DESIGNATED BOMBING RANGES

As shown in Table 6, a total of 29 munitions range areas were considered validated (see Appendix A-2). Both the PI and DIP approaches identified significantly more ranges (7 and 8, respectively) than the ASR mappings. The only difference between the PI and DIP approaches was the DIP addition of the Site #4 (K06NM0499) demolition range, where access roads and the possible presence of craters suggested the presence of a demolition range. Distinct targeting features were not visible on the 1971 photography used by the ASR and the comparative analyses. Digital enlargement and processing assisted this interpretation of a possible range. Additional 1954 and 1946 photography was acquired for validation purposes. Both HE craters and a targeting circle are distinct on the earlier photos.

Table 6. Results for Objective #1.

Objective #1 - Visual Identification of All Bombing Range Areas						
#	FUDS ID	FUDS Name	ASR(1)	PI(2)	DIP(3)	Validation
1	K06NM0333	Guadalupe B&GR	9	10	10	10
2	K06NM0394	Deming PBR #10	0	1	1	1
3	K06NM0445	Kirtland AFB PBR – West Mesa	5	8	8	8
4	K06NM0449	Kirtland AFB PBR #S-12	1	1	1	1
5	K06NM0499	Walker Demolition Range #35	0	0	1	1
6	K06NM0619	Kirtland AFB PBR #18 Target S-5	1	1	1	1
7	K06TX0186	Midland AAF Target Range #14	3	3	3	3
8	K06TX0267	Dalhart PBR Ranges #3 and #4	2	4	4	4
		Totals	21	28	29	29
	Success Criteria: 100% detection		72%	97%	100%	100%

Note: The 2005 Preliminary Assessment (PA) for Site #4 and the 2004 Preliminary Assessment (PA) for Site #6 were used in place of ASRs, which were not available for these sites. The 2009 Site Investigation (SI) for Site #8 was used as the 1998 ASR did not examine any photography for the site.

Only the DIP and validation provided complete identification of all 29 range areas, although the PI approach was close at 97% (one omission). The 72% level of performance for the existing ASR documents missed visual identification of 8 ranges. Probable locations for two of these ranges (located in Sites #2 and #5) were reasonably inferred, based on planning maps and other documents, even though visual assessments of aerial photography prints could not identify any range features.

7.2 OBJECTIVE 2 – LOW FALSE ALARM RATE FOR BOMBING RANGE AREAS

Only one feature was interpreted as a bombing range and later validated as incorrect. This was a building complex with a hexagon layout pattern (see Figure 14) located on Site #3 (K06NM0445) between the N-2 and New Demolition ranges. The building complex is visible on 1967 photography, but not visible on 1951 or recent photography. The bombing range was documented as only being operational between 1943 and 1947, so for validation purposes the building complex is not considered a visual-based bombing range. The geometric layout of the complex is very suggestive of a potential military target range. The location between the N-2 and New Demolition ranges also supports this interpretation. The interpreters noted the possible sequential use of the different range areas, which could not be resolved without additional dates of photography that were not part of the comparative analysis. The function of the building complex, which is no longer present, was not determined.

The one false alarm represents a rate of 3% (1 of 30 range area identifications), which was lower than anticipated. False alarms (commission errors) are much less significant than omission errors. The success criterion was set at less than 50% in anticipation of more false alarms. It may be desirable to provide interpreter guidance that encourages a lower threshold for interpretation of "potential" and especially "possible" identifications.

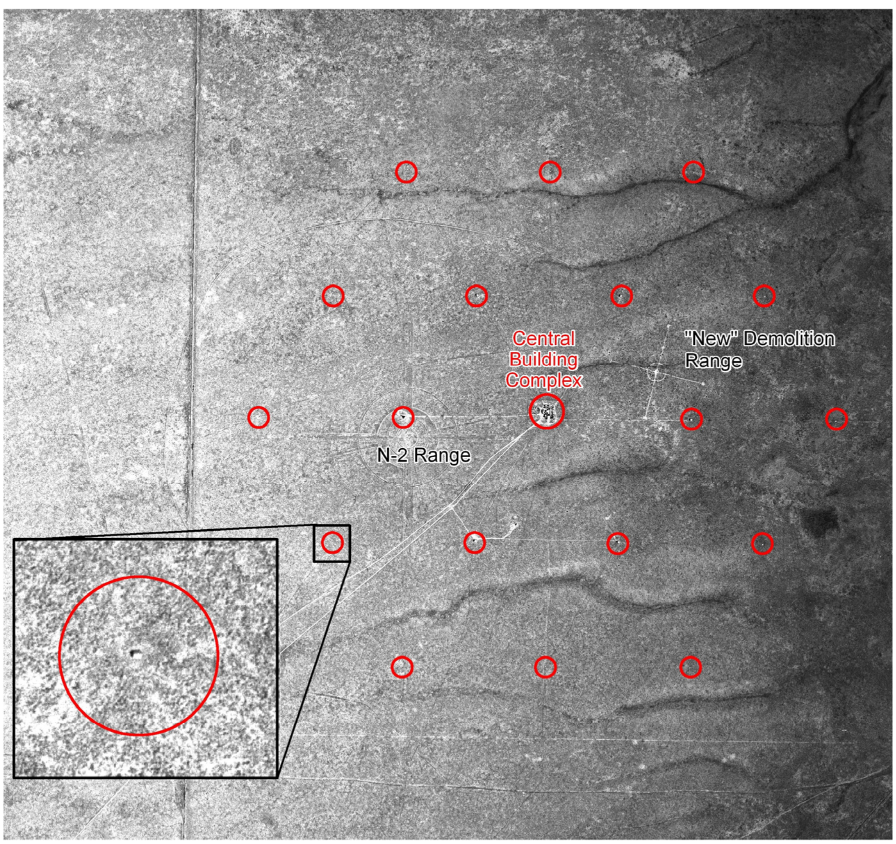


Figure 14. Hexagon Building Layout.

Small buildings around a central building complex were noted on 1967 photos. The complex was located between the inactive N-2 and New Demolition Ranges. Small buildings or sheds are noted in each of the circled areas.

7.3 OBJECTIVE 3 – IDENTIFY ALL RANGE TARGET FEATURES

Range target features include both primary and secondary targets, plus related features such as perimeter fence lines and/or firebreaks. Some ranges involved a single target, while others had groups of targets. The performance tabulations include all of the features and are summarized in Table 7. None of the comparative methods fully met the 90% criteria for target features.

Table 7. Results for Objective #3.

Objective #3 - Identify All Range Target Features						
#	**FUDS ID**	**FUDS Name**	**ASR(1)**	**PI(2)**	**DIP(3)**	**Validation**
1	K06NM0333	Guadalupe B&GR	15	24	27	28
2	K06NM0394	Deming PBR #10	0	1	1	2
3	K06NM0445	Kirtland AFB PBR – West Mesa	5	17	19	26
4	K06NM0449	Kirtland AFB PBR #S-12	1	1	2	2
5	K06NM0499	Walker Demolition Range #35. Range	0	1	1	3
6	K06NM0619	Kirtland AFB PBR #18 Target S-5	2	2	2	2
7	K06TX0186	Midland AAF Target Range #14	8	8	8	8
8	K06TX0267	Dalhart PBR Ranges #3 and #4	2	5	6	8
		Totals	33	59	66	79
	Success Criteria: > 90% detections		42%	75%	84%	100%

Notes: The two potential radar targets at Site #1 (one believed to not have been built (USACE, 2008) are not included in the above summary as they are not considered visual range targets. In addition, no visible evidence of one "T" ATAGR marker shown on planning maps was found on suitable photography. The planned location was assessed as inappropriate (too hilly) for target construction. The project validation review concluded that this planned marker was most likely never developed. Five other feature validations remain unresolved (shown as "open") and are not included in the above summary (see Appendix A-2). Future field investigations or additional documentation will be necessary to close the unresolved validations. Four of these are located at Site #2 and are presumed to have been constructed.

Performance results for the PI and DIP methods were both higher than the ASR results, mapping up to twice as many range related features. The DIP method proved 9% better than the PI method, correctly identifying seven more features. Three of these were faint ATAGR markers at Site #1, where image contrast enhancements and sharpening proved useful. The remaining five features included two Bridge and/or Convoy targets at Site #3, a ship target at Site #4, and a HE target circle at Site #8. The use of older dates and better resolutions of photography allowed the validation of an additional 13 range features. The availability of these older dates of photography was considered the most significant factor for the validations.

The validation of the four "open" features presumed to have been constructed at Site #2 would lower the performance scores for PI and DIP to 70% and 78%, respectively. Figure 15 shows the comparative analysis (1974) and validation (1951) photos used for Site #2.

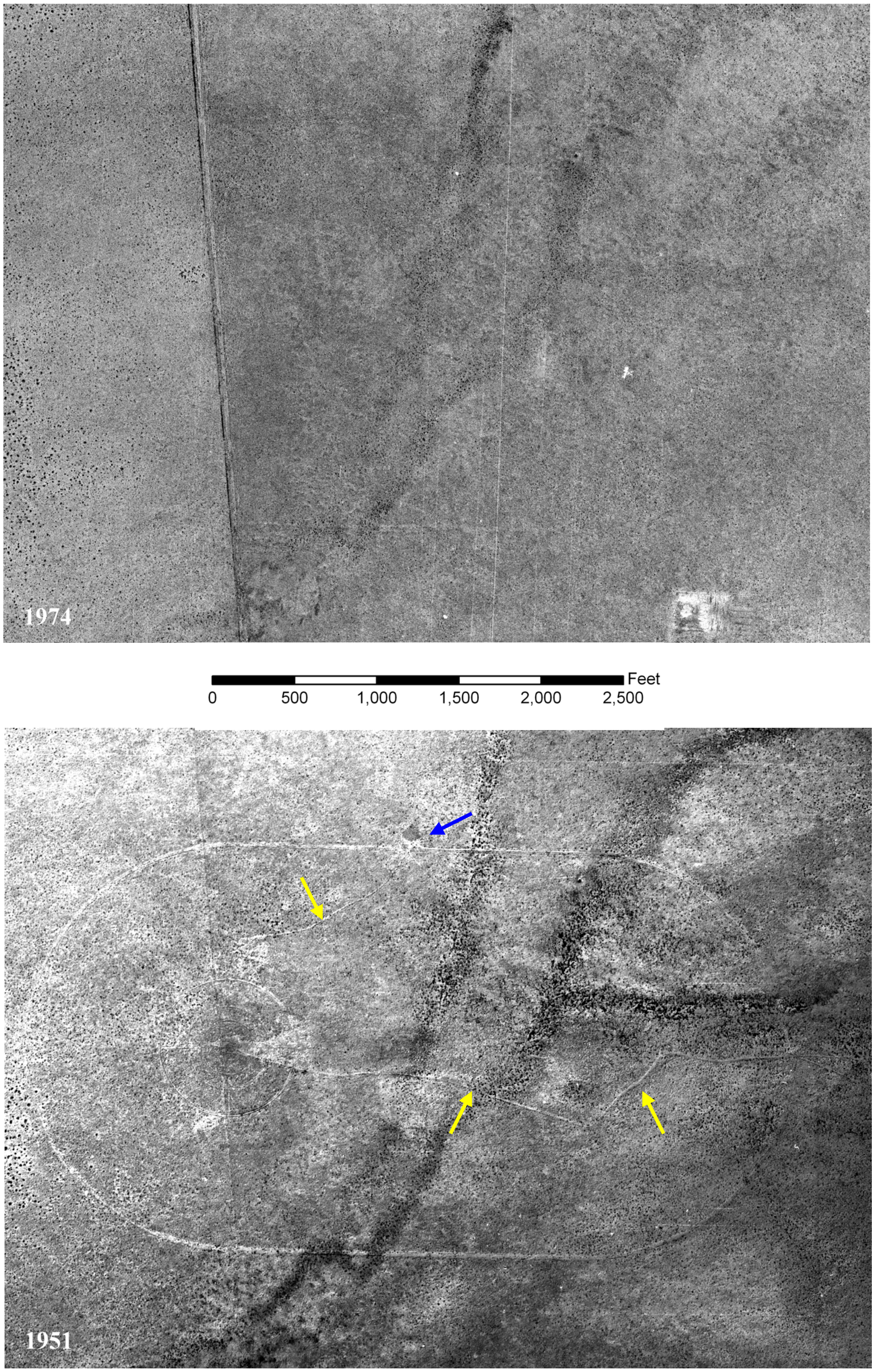


Figure 15. Site #2 (Deming AFB PBR #10)

The 1974 photo (top) was used in the ASR where no features could be mapped. The 1951 photo (bottom) was acquired for validation purposes. Although the range perimeter, circular target, and access roads are distinct, four other target features noted in site documentation, and presumed constructed, could not be identified. Any segment of the site trails, indicated by the yellow arrows, could have been used as a convoy target. A potential generator location to power the night targets is indicated by the blue arrow.

A majority of the interpretation omissions occurred at the Site #3 (Kirtland – West Mesa), where the 1967 timeframe of the photography was not suitable for identifying many of the features. Similar problems were encountered at Site #2 and Site #5, where the earliest dates of photography used for the ASR investigations were 1974 and 1971, respectively. Less common as a limiting factor was photography scale; the DIP results for 1954 photography of Site #8 (scale 1:60,000) missed two features that were distinct on better resolution (scale 1:20,000) photography acquired just one year earlier (1953).

7.4 OBJECTIVE 4 – FALSE ALARM RATE FOR RANGE TARGET FEATURES

Only three features were validated as range feature commission errors. All of these features were located on Site #3 (Kirtland – West Mesa). One of these was the hexagon building complex previously discussed, which had been interpreted as a probable range (Figure 14). Two other features at this site were subsequently validated as local ethnographic markings, rather than navigation markers (Figure 16). Personnel of the Petroglyph National Monument confirmed that there was good evidence to support the "J" marker being placed by members of St. Joseph's College, which was founded nearby in 1951. The "JA" marker, which was developed later sometime between 1959 and 1967, is presumed to be related to the nearby John Adams Middle School. As both markers were developed after the property was released from use as a bombing range, these features are considered validated as not related to bombing range activities.

Three false alarms and a total of 79 validated features results in a commission error rate of 4%, which is substantially less than the < 50% criteria for success. As noted earlier for Objective 2, false alarms (commission errors) are less significant than omission errors, so interpreter guidance should encourage a lower threshold for interpretation of "potential" and especially "possible" identifications.

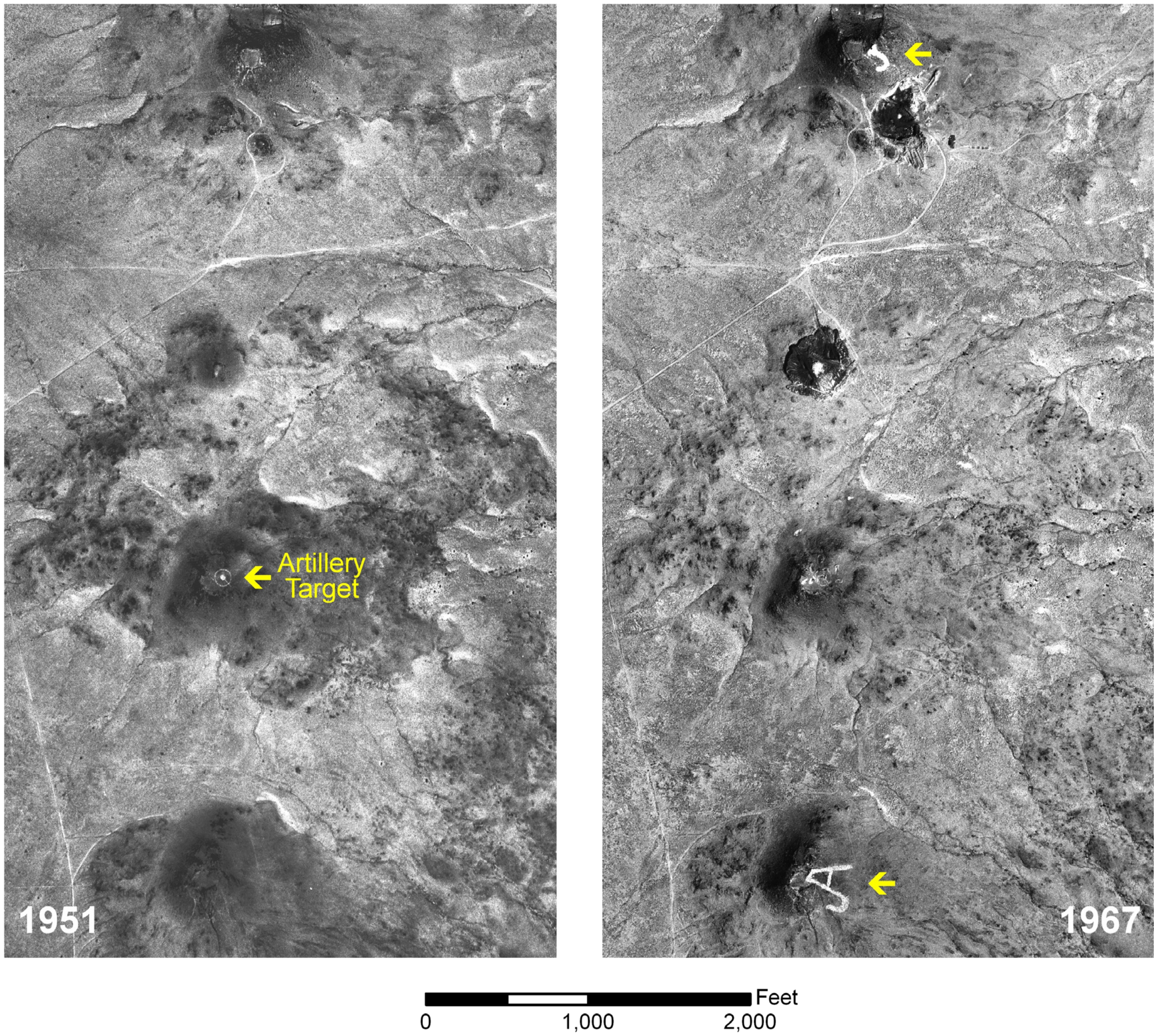


Figure 16. Markers on JA Volcano and Vulcan Volcano.

The artillery target is distinct on the 1951 and faintly visible on the 1967 photo. The markers are not visible in 1951. They were clearly developed after the bombing range was released from use in 1947.

7.5 OBJECTIVE 5 – IDENTIFICATION OF RANGES WITH CRATERS

The accurate identification of HE bombing ranges was considered a high priority, due to the potential safety hazard of any UXOs. The identification of craters is considered a useful surrogate for identifying areas where HE bombs were used. Table 8 provides a summary of the results for identifying range areas with craters.

Table 8. Results for Objective #5.

Objective #5 – Identification of Ranges with Craters						
#	FUDS ID	FUDS Name	ASR(1)	PI(2)	DIP(3)	Validation
1	K06NM0333	Guadalupe B&GR	5	3	3	6
2	K06NM0394	Deming PBR #10	-	-	-	-
3	K06NM0445	Kirtland AFB PBR – West Mesa	1	1	1	1
4	K06NM0449	Kirtland AFB PBR #S-12	-	-	-	-
5	K06NM0499	Walker Demolition Range #35. Range	-	1	1	1
6	K06NM0619	Kirtland AFB PBR #18 Target S-5	-	-	-	-
7	K06TX0186	Midland AAF Target Range #14	1	1	1	1
8	K06TX0267	Dalhart PBR Ranges #3 and #4	-	-	1	1
		Totals	7	6	7	10
	Success Criteria: > 75% detections		70%	60%	70%	100%

Overall, the results for identification of craters were comparatively similar among the methods. Both the ASR and DIP approaches found 7 of 10 areas with craters, which at 70% is below the success criteria of 75%. The DIP and PI approach did not identify three crater sites on Guadalupe, but the PI approach identified one additional crater area on another site (Site #5) and the DIP approach identified additional crater areas on two other sites (Sites #5 and #8).

Based on available ASR documentation it was anticipated that HE ranges would be readily distinguished by the presence of numerous craters. This proved true for the four heavily used demolition ranges examined in this project. However, several instances of very limited HE use occurred on ranges found on Site #1 (Guadalupe). Documentation indicates that some practice ranges had limited HE usage for secure (classified) testing that may have involved only a small number of HE bombs. Figures 17 and 18 show a comparison of the Guadalupe Demolition Range IV with numerous HE craters and the Practice Range 2 with only a few HE craters.

Site #7 (Midland) presented another limited HE range situation; according to ASR (2000) documentation the Army Air Corps invited local residents to a July 4th 1944 demonstration air show that involved the use of HE bombs over a formation of vehicles, the remnants of which were noted during field investigations. The relatively uniform landscape conditions of this site and availability of timely (1946) and excellent scale (1:20,000) aerial photography allowed ready identification of the HE craters. The more variable landscape conditions and later (1950) photography at a smaller scale (1:44,000) that was used for Site #1 (Guadalupe) made similar identifications more problematic. Figure 19 and 20 shows the HE Range area on Site #7.

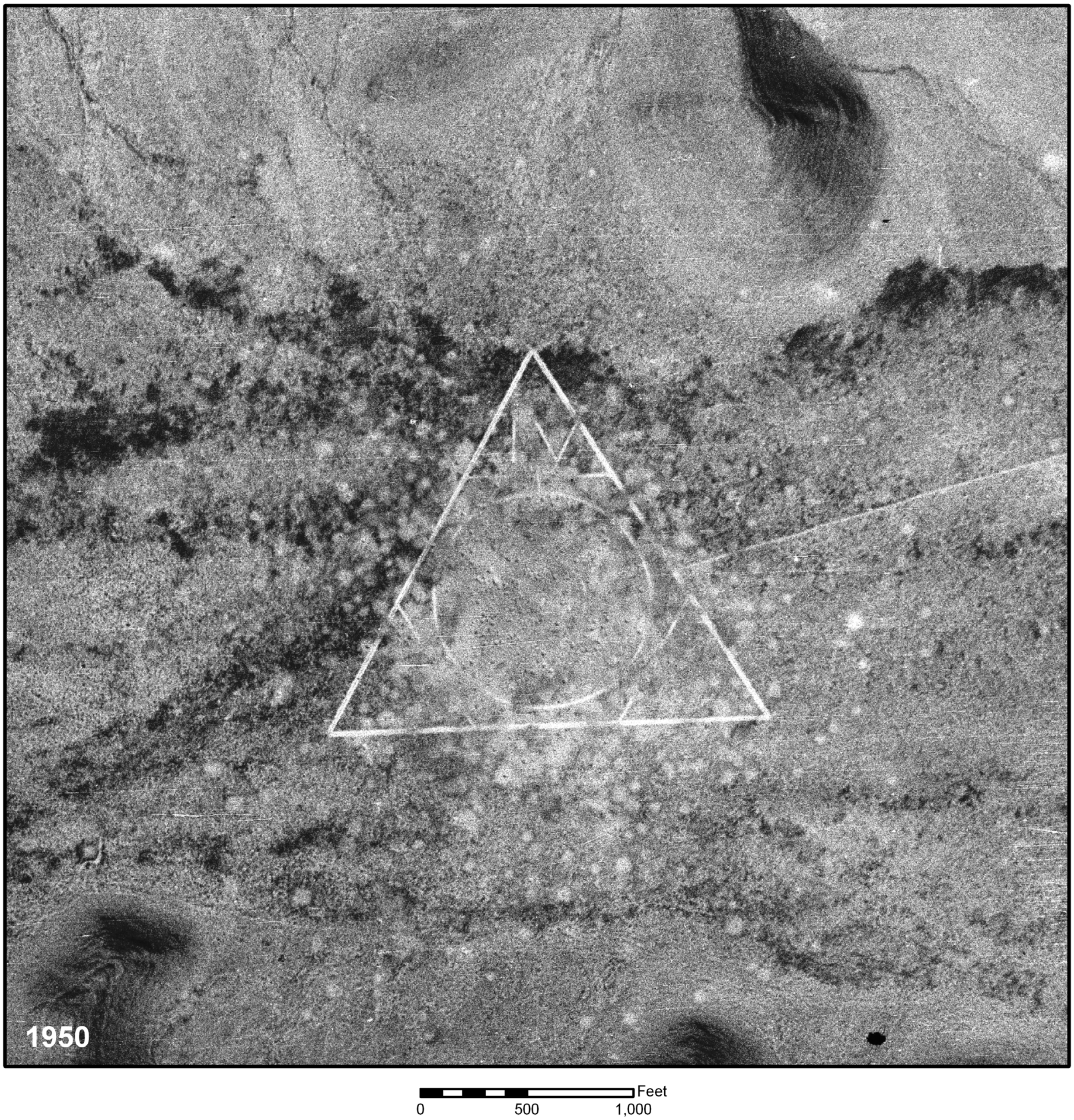


Figure 17. Site #1 (Guadalupe) Demolition Range IV.

Distinct craters are visible throughout the range area. The crater ejecta also create lighter-toned circular patches that readily identify this site as a demolition range. The scale as shown of this enlargement is approximately 1:10,000. The original film scale was 1:44,000.

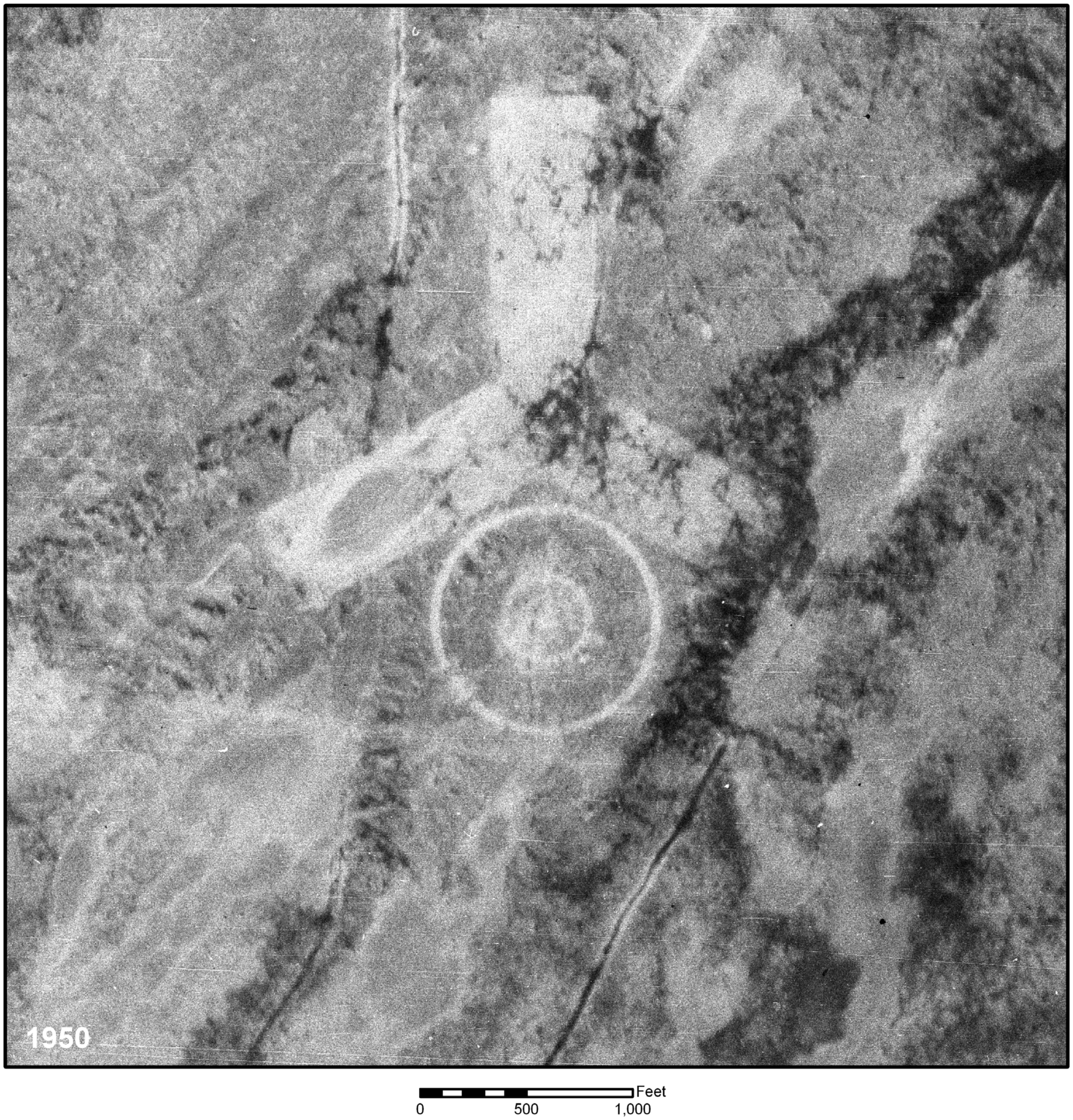


Figure 18. Site #1 (Guadalupe) Practice Bombing Range 2.

This site was apparently used to a limited extent for testing HE ordnance. The ASR image analyses, which made use of stereo viewing, identified possible HE cratering in the circular target area. The possible cratering that was noted in the ASR photo interpretation in the north end portion of the target appears very limited and is not as distinctive as on the previous figure of a demolition range; neither the PI nor DIP interpretations identified craters for this range. ASR field investigations did find a row of shallow craters (2 to 4 feet deep) and HE fragments near the target. The scale as shown of this enlargement is approximately 1:10,000. The original film scale was 1:44,000.

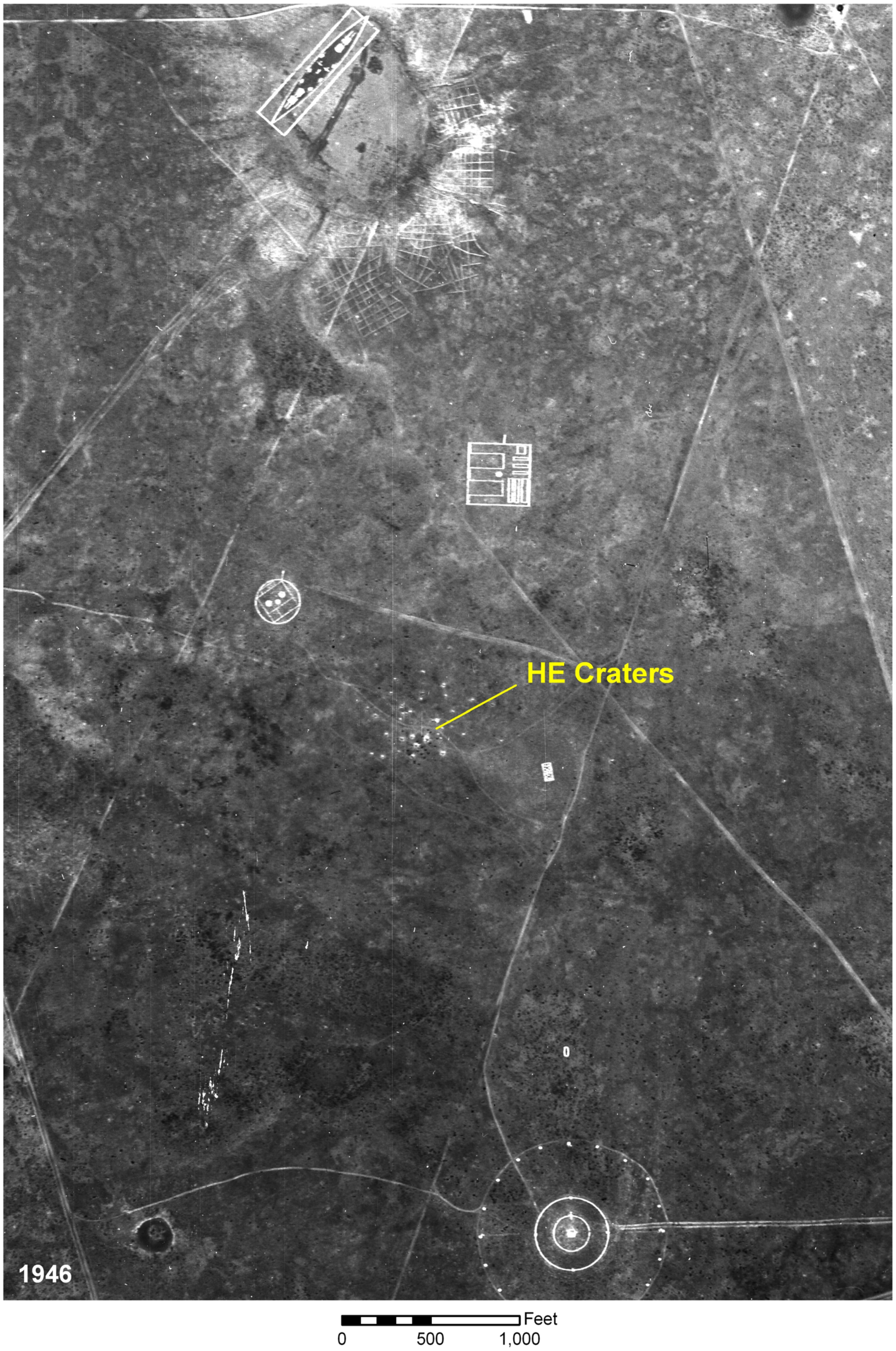


Figure 19. Site #7 (Midland) Overview.

A portion of the photograph (frame DAR-3C-85) is presented here at the same scale (1:10,000) as Figure 17. The original scale of 1:20,000 (versus 1:44,000 for the previous Guadalupe photos) and more uniform grasslands background allows craters to be readily identified.

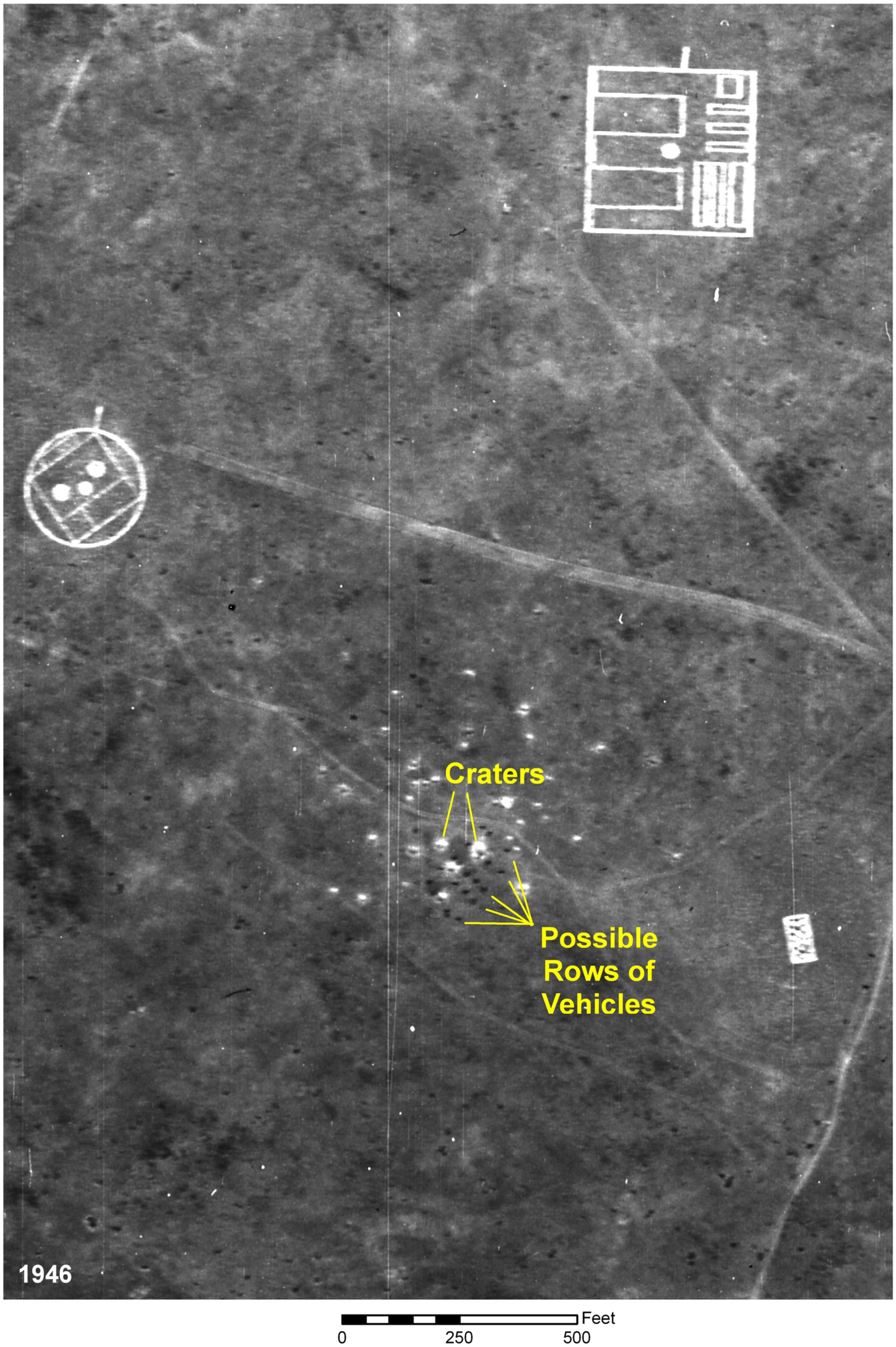


Figure 20. Site #7 (Midland) Further Enlargement.

Targets and crater features are distinct at this site (selected features indicated by yellow lines). Note the row pattern of objects that was interpreted as a possible vehicle formation used as the HE target.

7.6 OBJECTIVE 6 – LOCATION ACCURACY

The ASR documents provided only approximate locations of range centroids. It was explicitly stated in some ASR reports that the measurements used in the analyses were made using analog instrumentation and should only be considered approximate. The locational offsets discussed earlier (Figure 3) included both interpretation and mapping errors; for the location accuracy assessment only mapping errors were compared.

After removing interpretation errors, range locational offsets were then compared using current orthophotos for each site. It should be noted that the orthophotos themselves have an allowable map accuracy error of about 10 meters, although most recent orthophotos are usually less than 3 meters from true positions.

The PI and DIP methods both involved the use of the digital orthophoto as a final mapping base, so their performance was similar. As expected, their performance was better than the analog ASR method that did not have the benefit of orthophotos.

For the range locations that could be compared, the average ASR offset was 28.6 meters. The average PI offset was measured at 2.4 meters and the average DIP offset was 2.2 meters. Both the PI and DIP methods met the criterion for location offsets of less than 10 meters.

7.7 OBJECTIVE 7 – PRODUCTION RATE

The production rates for the PI and DIP methods were relatively similar. The PI method averaged 49 minutes per stereo pair to interpret and check, while the DIP method averaged 57 minutes per set-up, interpretation, and check. The DIP method was based on a non-oriented digital stereo view, which is more expedient for a simple interpretation than a full orientation set-up. A full orientation approach would roughly double the DIP time factor. Both methods met the success criteria threshold of less than one hour per stereo pair for interpretations. Interpretation production rates for the ASR's were not available for comparison.

7.8 OBJECTIVE 8 – ORTHOPHOTOS FROM HISTORICAL PHOTOS

The orthophoto production process proved successful. Figure 21 shows a 1951 orthophoto mosaic developed for Site #3 (Kirtland AFB PBR – West Mesa). Figure 22 provides an enlargement of two target features. The orthophoto was generated using a 30-cm pixel ground resolution. The quality of the original 1:24,000 scale photography allowed good spatial accuracy. Ground control for this and the other New Mexico sites used the statewide 2005 digital orthophoto. The two Texas sites used 2008 orthophotos for control.

The offset between checkpoints on the historical orthophotos and the more recent orthophotos used for control averaged 2.3 meters, substantially less than the 10 meter criteria that was set for success.

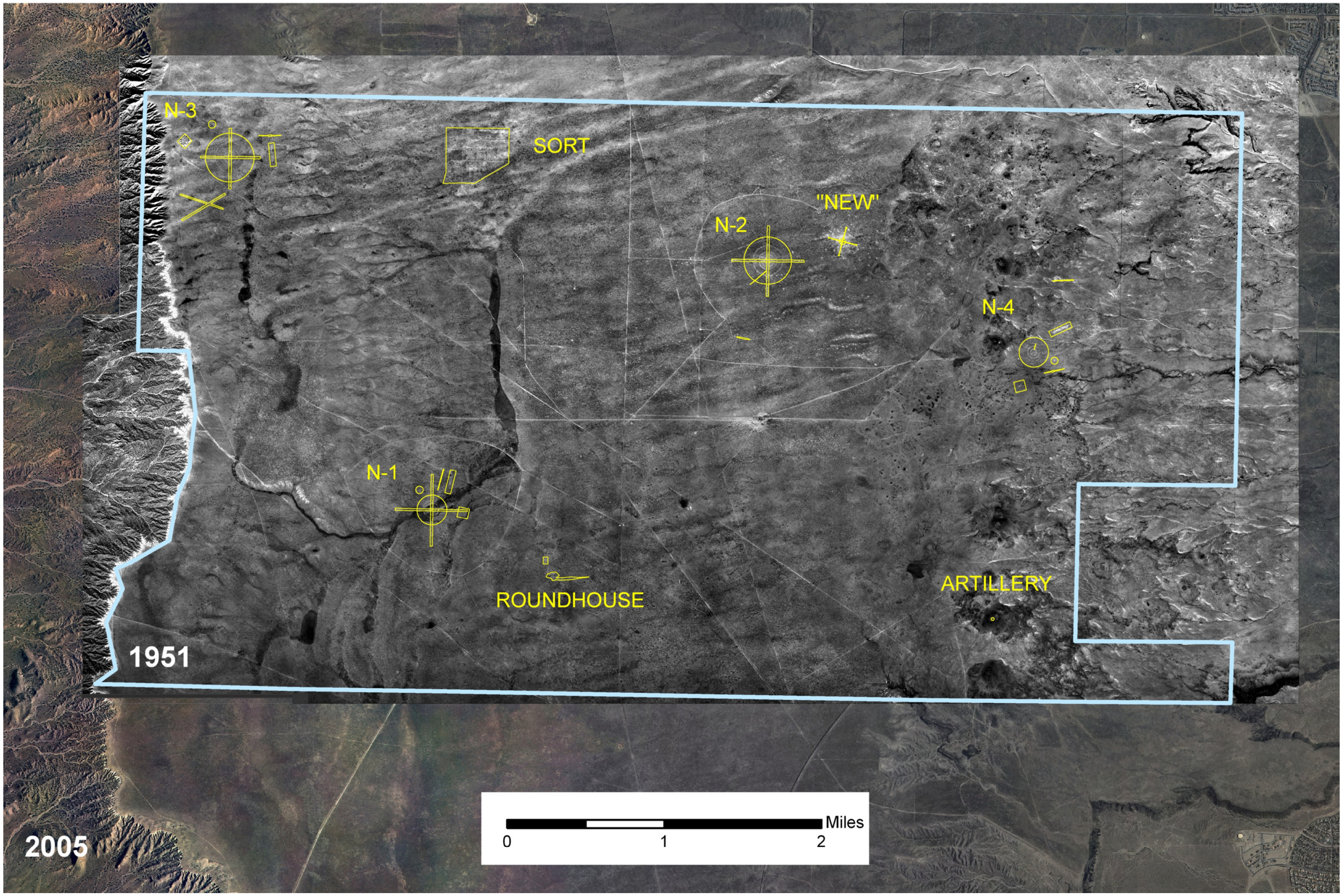


Figure 21. 1951 Digital Orthophoto Mosaic of Site #3 (Kirtland – West Mesa).

The background image is the 2005 color orthophoto used for control. Munitions ranges are outlined and labeled in yellow. The 1951 black and white orthophoto mosaic was developed from 11 photos. The overall FUDS outline is shown in light blue.

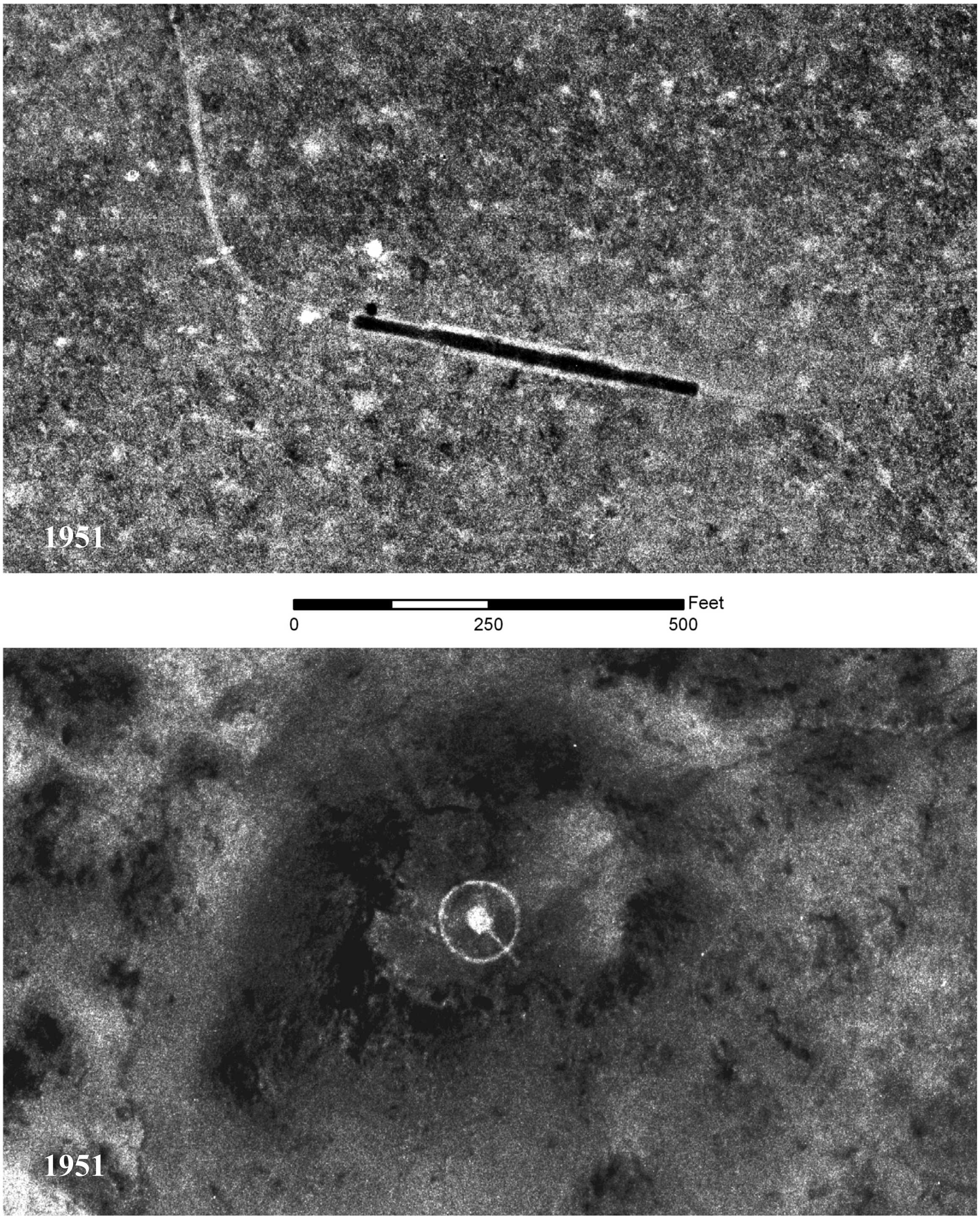


Figure 22. Enlargement of Site #3 Orthophoto.

Two Kirtland AFB PBR target features are shown. The top target is a bridge and/or convoy target feature located southeast of the N-2 target circle. The bottom photo shows a heavy field artillery target that was developed on top of Black Volcano.

7.9 OBJECTIVE 9 – DIGITAL ELEVATION MODELS

Results of the DEMs were marginal and showed no significant improvement over standard processing. It was not possible to achieve higher density elevation postings that provided any useful crater details. Figure 23 below shows a hillshade of one of the DEMs for Site #3 (Kirtland New Demolition Range) and suggests there is some relationship between the craters and elevation postings. More detailed postings would be required to support crater detection based on elevation differences.

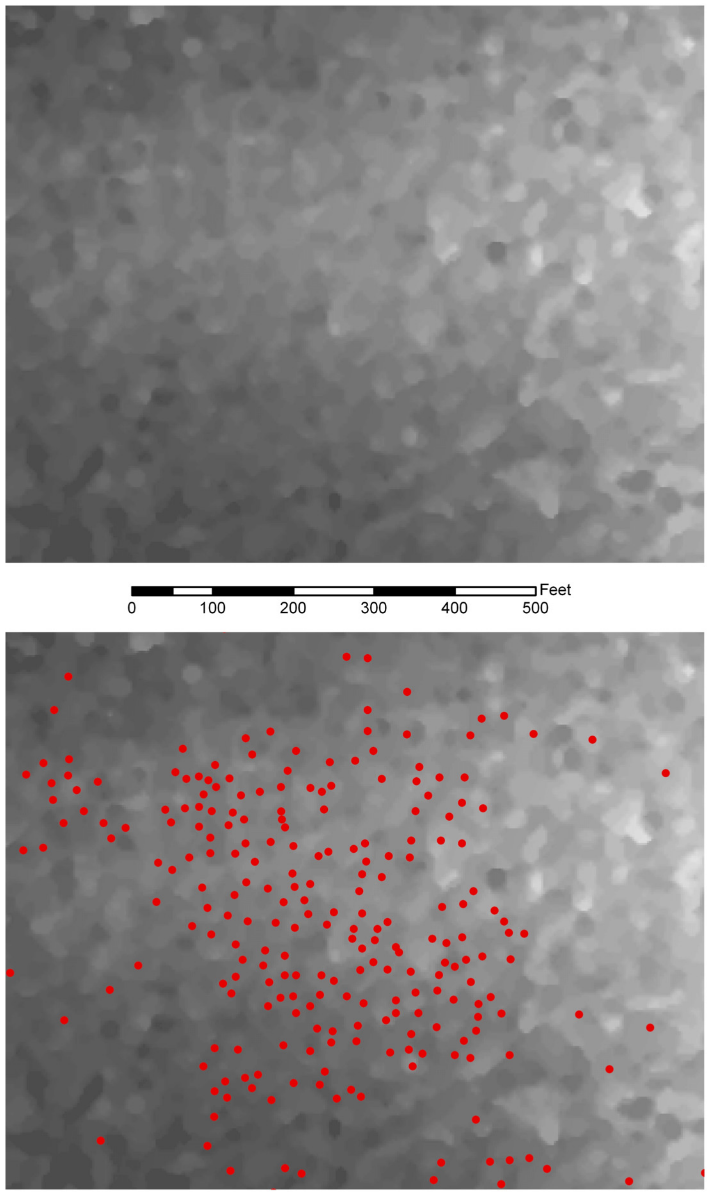


Figure 23. High Resolution DEM of Site #3 (Kirtland New Demolition Range).

The top image is a DEM-based hillshade of the site. The bottom image is the same hillshade with an overlay of visually mapped crater locations. Although there is evidence of a spatial correlation between elevation postings and the crater locations, the posting density proved insufficient to discern any crater details.

7.10 OBJECTIVE 10 – EASE OF USE AND TECHNOLOGY TRANSFER

Manual photo interpretation of aerial photography requires a limited amount of specialized equipment to ensure optimal results. The ASR procedures involved only pocket stereoscopes and used photographic prints. Professional level equipment such as zoom stereoscopes require limited training to use properly. The learning curve for photo interpretation skills is generally not considered very steep, but it can require a substantial period of time to achieve professional skill levels. A basic understanding of environmental and cultural factors affecting the appearance of the landscape is needed, along with regional and application specific knowledge.

Digital image processing requires more specialized equipment, especially for stereo viewing. Stereo viewing equipment is more specialized and expensive compared to standard non-stereo equipment for both hardware and software components. This also results in a steeper learning curve. It involves all of the technical training aspects pertinent to photo interpretations, plus the additional knowledge required for digital image processing. With the ongoing conversion of photographic archives into digital format it is also becoming a mandatory requirement for making use of some datasets.

One observation noted during this project was the value of continuous near real-time enhancement and scrolling options. Analysts saw this as a major advantage of some viewing packages versus those that allow enhancements but require several inputs before viewing the results.

Digital image restoration techniques for blur removal were found useful but too tedious to optimize on a per frame basis. Basic setup parameter defaults were often found adequate. As noted above, image analysts found immediate access to simple tools most useful. These included brightness and contrast adjustments and smoothing (for noise reduction) and edge enhancements.

Additional technical training is required to make full use of digital photogrammetry and GIS technology. Both fields have substantial learning curves and, like image processing, several specialty areas.

8.0 COST ASSESSMENT

Cost information for the demonstration project was tracked for several key activities. A substantial amount of prior experience on similar historical photo interpretation projects was also available and reviewed. Based on this information a basic cost model was developed for operational costs of the recommended DIP approach. Capital costs were also collected for the necessary hardware and software needed.

8.1 COST MODEL

Table 9 summarizes estimated operating costs of photo interpretations for two site sizes:

- 1 square mile sites, such as Site #6 (Kirtland AFB PBR #18 Target S-5)
- 20 square mile sites, similar to Sites #3 (Kirtland – West Mesa) and #8 (Dalhart)

It was assumed that a minimum of three dates of stereo photography would be acquired for each site. Additional dates of photography would increase costs proportionately. It was also assumed that one historical orthophoto would be prepared and used as a base for mapping interpretation results. Simpler georeferencing techniques were assumed for the other dates.

The historical photo scales examined for this project ranged from 1:20,000 to 1:63,000. At the preferred 1:20,000 scale, each frame covers about 8 square miles (2,090 ha). Each frame at 1:63,000 scale covers about 80 square miles (20,741 ha). Smaller scale photography (e.g., 1:63,000) can sometimes prove inadequate for small features, but may still be useful if it is the only photography available for a critical timeframe.

Figure 24 provides an example of 1:20,000 versus 1:60,000 scale photos for Site #8 (Dalhart). The 2009 SI made use of the 1:60,000 scale photos (1954) and did not identify the HE range location at this site. The PI and DIP interpretations both identified a probable HE range in this area from the same photos. The 1:20,000 scale photo (1953) was used to validate the HE range and also allowed two additional range features to be identified.

In addition to scale, the specific number of frames required for stereo coverage of a site also varies by the alignment of the photo mission flightlines and camera stations. Film acquisition, scanning, pre-processing, and some other costs do not become linear until site sizes are larger than the frame coverage for the scale involved. As shown in Table 9, the costs per unit area are estimated to be lower for the 20-square mile site versus the 1-square mile site. Sites larger than 20 square miles would scale in a more linear fashion, especially for larger scale photos.

The operating cost model does not include costs to develop a report documenting interpretation results. Nor are costs to develop appropriate training keys and train personnel in procedures included. Training costs can vary significantly depending upon the prior qualifications of the personnel involved.

Table 9. Operating Cost Model for Digital Image Processing and Interpretations.

Cost Element	Data Tracked During Demonstration	Estimated Costs Small Site 1 Square Mile (259 Hectares) (640 Acres)	Estimated Costs Medium Site 20 Square Miles (5,180 Hectares) (12,800 Acres)
Archive Search And Data Management	Hours required Personnel required NARA search subcontract	$ 1,150	$ 1,150
Photo Scanning	Cost per frame Number of frames	$ 900	$ 1,800
Pre-processing of imagery	Hours required Personnel required	$ 1,300	$ 2,340
Image Interpretation and Review	Hours per stereo pair Number of stereo pairs Personnel required	$ 1,040	$ 1,820
Data Compilation and QC	Time required Personnel required	$ 260	$ 520
Project Management	Time required Personnel required .	$ 640	$ 640
TOTAL COST PER SITE Cost Per Hectare (Cost Per Acre)		$ 5,290 $ 20.42 per Hectare ($ 8.27 per Acre)	$ 8,270 $ 1.60 per Hectare ($ 0.65 per Acre)

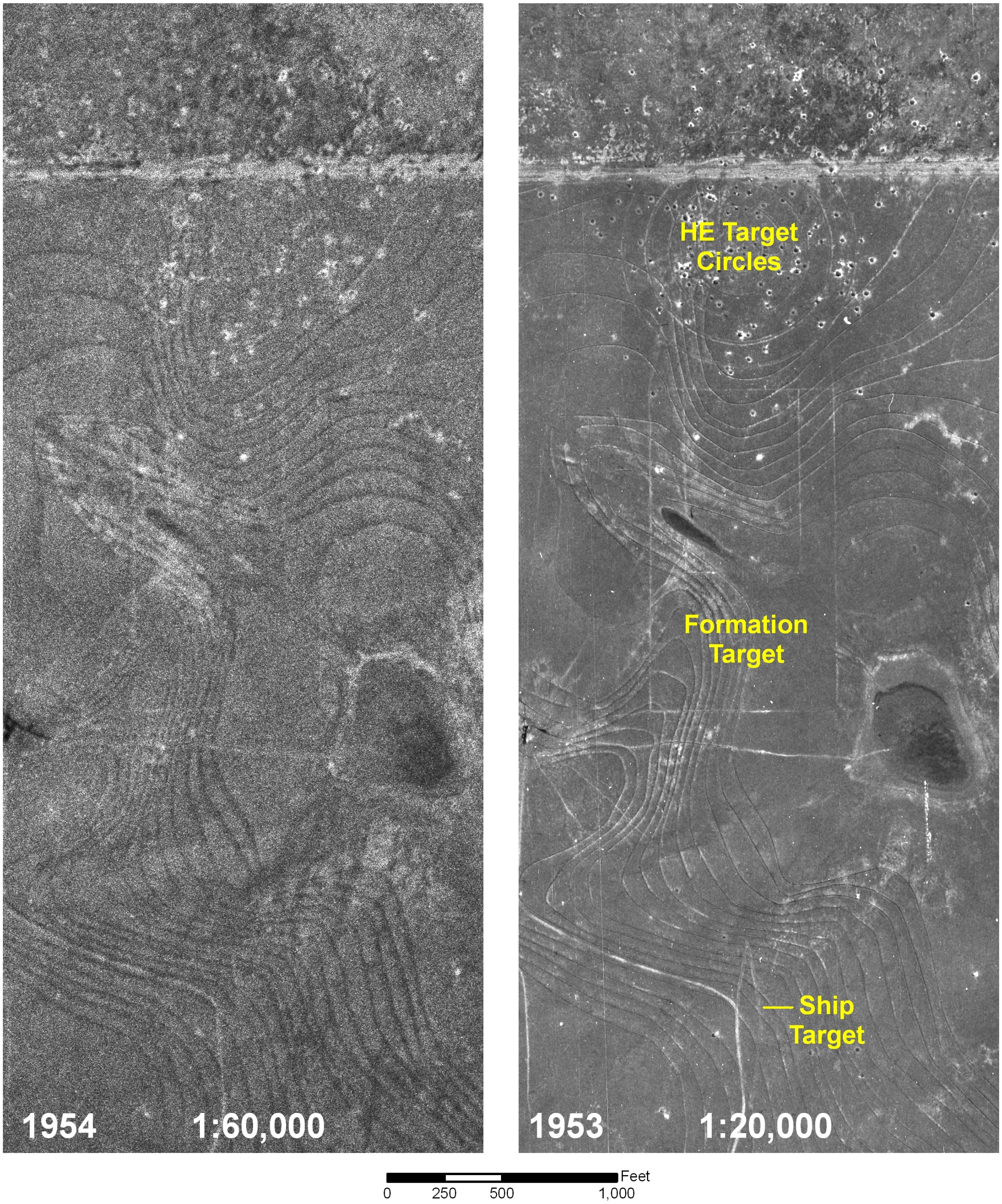


Figure 24. Photo Scale Comparison.

Although the photos were taken only one year apart, the difference between the scales results in substantially better target detection on the larger scale (1:20,000) photos. The contour farming practice made interpretations difficult. The ship target feature was not initially validated until a target layout map included in the ASR documentation was reviewed. The layout map included target shapes, sizes, and distances between the targets, but incorrectly located the series of targets as being in the middle of the site, about one third of a mile east of their actual location.

Capital costs for appropriate hardware and software are summarized as follows:

• High capacity computer workstation:	$5,000
• Stereo viewing display monitor	$4,500
• Image processing software with 3-D photogrammetry modules	$8,500
• Basic GIS software package	$1,500
Total	$19,500

A high capacity workstation is recommended due to the substantial image file sizes and processing requirements for advanced image processing algorithms. Such workstations have multipurpose uses and are relatively common for technical analysts. Appropriate image processing and GIS software are also relatively standard and have multipurpose uses. The stereo viewing display monitors that are integrated with specific image processing and photogrammetry software, however, are relatively specialized.

8.2 COST DRIVERS

As indicated by Table 9, the primary cost drivers for historical photo interpretations are related to photo searches, scanning and pre-processing of digital imagery, and the image analyses. The results of this demonstration project indicate that the historical documentation and aerial photography used for existing range definitions should always be reviewed to ensure their adequacy before expensive field activities are undertaken.

8.3 COST BENEFIT

Earlier photo interpretations of 2005 digital orthophotos to support the New Mexico statewide FUDS GIS database development identified several mislocated ranges and additional range target features. These photo interpretations helped focus SI efforts and avoided potentially costly rework for several MMRP sites. The results of the photo interpretations greatly reduced the required area to be traversed and sampled during the SI, resulting in a much more satisfied regulatory community as pertains to the attainment of the Data Quality Objectives in the MMRP SI program. A more systematic review and use of historical photography as demonstrated in this project can potentially provide more benefits.

A detailed cost benefit assessment was not possible for this demonstration. Several missing or mislocated range target features were observed within the selected study areas for this demonstration project. These features included an HE range that was not identified in a recent 2009 Site Investigation (Site #8, Dalhart). In addition, five distinct bombing ranges that do not appear in the current FUDS MMRP inventory, and not related to the selected study sites, were identified during the course of photo reviews for this project. The coordinates for these sites have been forwarded to the USACE for a review of their potential FUDS status.

9.0 IMPLEMENTATION ISSUES

The use of film diapositives instead of prints for historical photo interpretations is a relatively straightforward step with only modest cost impacts for specialized equipment. Much of the benefits can most likely be obtained using intermediate level equipment (light boxes and mirror stereoscopes with magnifying optics in lieu of more expensive stereo zoom equipment). However, photographic film archives are steadily moving towards a digital future that already requires the use of digital image processing for data from some primary archive sources.

Digital image products have also become a standard element of GIS databases. This project demonstrated that DIP results generally surpassed standard optical PI results. Implementation of DIP for improved analysis of historical aerial photographs is therefore recommended as the preferred method of analysis for this application.

Based on this and similar projects, some basic general guidelines for improved use of historical photography for FUDS projects are summarized below.

- Collect available archive data and define expectations for the site. Prior knowledge, in the form of maps and text descriptions can significantly benefit the photo interpretation process.
    - Previous reports often provide substantial insights about a site's history and what type of features are to be expected.
    - Analysts need to be flexible and open to finding unexpected features, but blind photo interpretation unnecessarily hinders efficient analyses.
- Review available analysis results, such as:
    - Visibility of distinct features on available photos.
    - Timeframe of available photos; ideally these would be during the operating period or shortly thereafter. If needed, earlier photography can sometimes help identify pre-existing features.
    - Suitable resolution (primarily scale) to see detail; a scale range of 1:15,000 to 1:25,000 is preferred, when available, although scales up to 1:60,000 have been found useful when better scales are not available.
    - Stability of landscape; sandy environments may obscure range features, as can agriculture or urban development.
- Conduct extended photo search (if needed):
    - Review National and Regional Photo Sources.
    - Recommend pre-activity period and post-activity photos; decade intervals may be adequate for post-activity review (to avoid unrelated false alarms).

- Acquire diapositive copies or digital scans (preferred) from original source materials.
- Preprocess imagery for basic brightness/contrast, blur, noise, and edge enhancements.
- Georeference all photos (minimally) and create orthophotos if terrain conditions are a significant factor (i.e., hilly or mountainous).
- Develop a set of training keys with descriptions.
- Develop a suitable classification scheme:
    - Include confidence criteria (e.g., confident, probable, possible).
    - Include open “area of interest” for additional items, with comments.
    - Map transportation features (roads and trails).
- Monoscopic viewing may be adequate for some features, but stereo viewing is recommended and sometimes required.
- Use a GIS data collection framework to record and attribute interpretation features.
    - This approach allows other datasets to be viewed in context and supports the “convergence of evidence” required for some interpretations.

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APPENDICES

Appendix A-1: Points of Contact

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APPENDIX A-2. Summary of Interpretation Results

Site #1 - KO6NM0333 - Former Guadalupe Bombing and Gunnery Range						
RANGE	**Feature**	**ASR(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
P-0	**Rough circle with line target**	Noted	Yes	Yes	Yes	Feature was noted during photo analysis, but not included in ASR summary map.
PB-1	**"Y" and circular target**	Yes	Yes	Yes	Yes	Practice bomb debris found during field investigations.
PB-2	**"Y" and circular target**	Yes	Yes	Yes	Yes	Secure/Practice range - HE munition debris found during field investigations.
PB-3	**"Y" and circular target**	Yes	Yes	Yes	Yes	Practice range - HE munition debris found during field reconnaissance.
P-3	**Circular target and III (3)**	Yes	Yes	Yes	Yes	HE framents found during field reconnaissance; Roman Numeral range identifier (III).
PB-4	**"Y" and circular target**	Yes	Yes	Yes	Yes	HE framents found during field reconnaissance.
D-4	**Triangle w/circles and IV (4) target**	Yes	Yes	Yes	Yes	Demolition range - distinct HE craters visible on photography. Range identifier (IV).
D-6	**Triangle w/circles target and VI (6)**	Yes	Yes	Yes	Yes	Demolition range - distinct HE craters visible on photography. Range identifier (VI).
P-7	Circular target and VII (7)	Yes	Yes	Yes	Yes	
Target +	**Line with cross near end**	**No**	Yes	Yes	Yes	Special Projects target feature; believed to had limited usage.
*** Radar V**	**Radar range - reported operational**	**No**	**No**	**No**	**Open**	Nothing visible on photos reviewed; decontamination field teams indicated site abandoned with no need for cleanup.
*** Radar VI**	**Radar range - presumed not built**	**No**	**No**	**No**	**Open**	Probably not built; nothing visible on photos; one possible marker feature 3 miles distant needs validation

ASR (1): Archive Search Report results
PI (2): Photo Interpretation results
DIP (3): Digital Image Processing results
VAL (4): Validation results based on additional photography; "yes" indicates feature is validated, "no" indicates it is not believed to have been developed, and "open" indicates validation effort is inconclusive

*** Radar Ranges:** No visual expression of the potential radar ranges were found on any photography examined; they are shown here but exclued from the performance assessment as they are not visual-based ranges.

Blue responses indicate feature was not photo interpreted by method used (column heading).
Red indicates range involved use of high explosive (HE) munitions.

Appendix A-2. Summary of Interpretation Results (continued).

Site #1 - KO6NM0333 - Former Guadalupe Bombing and Gunnery Range (continued)						
Markers	**Feature**	**ASR(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
1A	Angle (inverted "L")	**No**	Yes	Yes	Yes	
1A (west)	Triangle	**No**	Yes	Yes	Yes	
1B	"A"	**No**	Yes	Yes	Yes	
1B/C	2 dashes (" - -")	**No**	**No**	Yes	Yes	
1B/C	Siteways "T"	**No**	Yes	Yes	Yes	
1C	"D"	**No**	Yes	Yes	Yes	
1C (south)	"I"	**No**	**No**	**No**	Yes	Distinct feature matches planning map location.
TBD	"I"	**No**	Yes	Yes	**Open**	Possible marker; also interpreted as possibly related to agricultural activity.
2C	"Y"	**No**	**No**	**No**	Yes	Feature is distinct on 1946 and 1948 photography.
2D	"Y"	**No**	**No**	Yes	Yes	
3A	Rotated "L" with extra leg	**No**	**No**	Yes	Yes	
3B	"Y"	Yes	Yes	Yes	Yes	
3C	"Y"	Yes	Yes	Yes	Yes	
4C	"Y"	Yes	Yes	Yes	Yes	
4D	"Y"	Yes	Yes	Yes	Yes	
5A	Triangle	Yes	Yes	Yes	Yes	
5B	"A"	**No**	Yes	Yes	Yes	Appears reworked from "Y" to "A"; possible clearing activity over area evident on later dates; offsite airfield nearby.
5C (north)	"T" on planning map	No	No	No	**No**	Nothing visible on photos; assumed not constructed as hilly terrain appears inappropriate for target at planned location.
5C	"D"	**No**	Yes	Yes	Yes	
5D	"O"	Yes	Yes	Yes	Yes	

Markers: Large Air-to-Air Gunnery Range (ATAGR) course markers features were unique to this site; designations are from 1944 ATAGR feature grid (numbers and letters) map in draft SI Addendum (2008).
Four circular range targets were developed immediately adjacent to "Y" course markers; these markers are noted in the range feature descriptions and not separately shown as markers.

Appendix A-2. Summary of Interpretation Results (continued).

Site # 2 - KO6NM394 - Deming PBR #10						
RANGE	**Feature**	**ASR(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
Range #10	**Range Perimeter "racetrack" outline**	**No**	Yes	Yes	Yes	Developed from planning documents for ASR; no features photo interpreted.
	Concentric Circles Scoring Target	**No**	**No**	**No**	Yes	Confirmed on validation photos (1956 and earlier).
	Crosshair Target	**No**	**No**	**No**	**Open**	Standard location can be estimated given "racetrack" perimeter; but no distinct target feature evident on photos examined.
	Battleship Target	**No**	**No**	**No**	**Open**	ASR has layout from planning documents; presumed built, but not visible on photos examined.
	Oil Refinery Target	**No**	**No**	**No**	**Open**	ASR has layout from planning documents; presumed built, but not visible on any photos examined.
	Truck Convoy illuminated Target	**No**	**No**	**No**	**Open**	Possible convoy target area evident in validation photos (1951); however, different trail segments could have been used

Site # 3 - KO6NM445 - Kirtland AFB Precision Bombing Ranges N1, N3, N-4 and "New" Demolition						
RANGE	**Feature**	**ASR(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
Range N-1	**Range Perimeter outline**	**No**	Yes	Yes	Yes	Perimeter fenceline and/or fire breakline; ASR mapped a rectangular area.
	Cross-hair/Circles Target	Noted	Yes	Yes	Yes	Not specifically mapped in ASR.
	Battleship Target	**No**	**No**	**No**	Yes	
	Square Target	**No**	**No**	**No**	Yes	
	Circular Target	**No**	**No**	**No**	Yes	
	Bridge and/or Convoy Target	**No**	**No**	**No**	Yes	
Range N-2	**Range Perimeter outline** (partial)	**No**	Yes	Yes	Yes	Partial Perimeter fenceline and/or fire breakline; ASR mapped a rectangular area for the range.
	Cross-hair/Concentric Circles Target	Noted	Yes	Yes	Yes	Not mapped in ASR; small number of HE craters noted in 1951 validation photos (possible New range outliers.)
	Bridge and/or Convoy Target	**No**	**No**	Yes	Yes	
"New" Range	**Cross-hair/Circle Target**	Noted	Yes	Yes	Yes	ASR mapped a rectangular area for range; HE craters visible in 1967.
Range N-3	**Concentric Circles Target**	Noted	Yes	Yes	Yes	ASR mapped a rectangular area for range.
	Battleship Target	**No**	Yes	Yes	Yes	
	Airfield Target	**No**	Yes	Yes	Yes	
	Square Target	**No**	Yes	Yes	Yes	
	Circular Target	**No**	Yes	Yes	Yes	
	Bridge and/or Convoy Target	**No**	**No**	Yes	Yes	
Range N-4	**Concentric Circles Target**	Noted	Yes	Yes	Yes	ASR mapped a rectangular area for range.
	Battleship Target	**No**	Yes	Yes	Yes	
	Circular Target	**No**	Yes	Yes	Yes	
	Square Target	**No**	Yes	Yes	Yes	
	Bridge and/or Convoy Target	**No**	**No**	**No**	Yes	
	Bridge and/or Convoy Target	**No**	**No**	**No**	Yes	Feature area is designated OOU-6 in USACE EE/CA.
SORT	**Simulated Oil Refinery Target (SORT)**	**No**	Yes	Yes	Yes	Target discussed in ASR but location not mapped; incorrectly attributed to N-3 area.
Railyard Area	**Railroad Roundhouse/Switchyard**	**No**	Yes	Yes	Yes	
	Rectangular Industrial Target	**No**	**No**	**No**	Yes	Located near railroad roundhouse feature.
Artillery	**Circular Artillery Target**	**No**	Yes	Yes	Yes	Unusual compared to other target locations; placed on top of volcanic mountain.
	Marker: Combined J and A	**No**	Yes	Yes	**No**	Feature is visible in 1966 but not 1959 photos; similar to a branding mark.
	Marker: J	**No**	Yes	Yes	**No**	Feature is visible in 1959 but not 1951 photos.
Unknown	**Hexagon Building Complex**	No	Yes	Yes	**No**	Complex was developed after 1951 photo date.

Appendix A-2. Summary of Interpretation Results (continued).

Site #4 - KO6NM449 - Kirtland AFB Precision Bombing Range #S-12						
RANGE	**Feature**	**ASR(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
Range #S-12	**Concentric Circles Target**	Yes	Yes	Yes	Yes	Range location was identified off-site of original property description investigated for INPR.
	Battleship Target	**No**	**No**	Yes	Yes	

(1) 2005 PA with 1951 photos was used for comparative analysis as no ASR or MMRP maps were available when this site was selected for analysis.

Site #5 - KO6NM499 - Walker AFB Demolition Bombing Range #35						
RANGE	**Feature**	**ASR(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
Range #35	**HE Crater Area**	**No**	Yes	Yes	Yes	Possible HE crater field identified at likely location for target feature.
	Range Perimeter	**No**	**No**	**No**	Yes	Range perimeter fence and/or firebreak (distinct on 1954 and 1946 photos).
	Circle Target	**No**	**No**	**No**	Yes	Distinct target circle and HE craters visible on 1954 and 1946 photos.

Site #6 - KO6NM619 - Kirtland AFB Precision Bombing Range #18 Target S-5						
RANGE	**Feature**	**PA(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
Range #18	**Range Perimeter**	Visible	Yes	Yes	Yes	Perimeter outline is visible on photography that was used for the PA but was not specifically mapped.
	Concentric Circle Target	Yes	Yes	Yes	Yes	Target was located off-site of original property location that was field investigated for INPR .

(1) 2004 Draft PA with 1946 photos was used for comparative analysis as no ASR or MMRP maps were available when this site was selected for analysis.

Site #7 - KO6TX0186 - Midland AAF Target Range #14						
RANGE	**Feature**	**ASR(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
Northern Area	**Battleship Target**	Yes	Yes	Yes	Yes	
	Coastal Street Network	Noted	Yes	Yes	Yes	ASR identified feature as "Unusual polygonal patterning."
Central Area	**HE Crater Area**	Yes	Yes	Yes	Yes	Small number of distinct HE craters visible on 1946 photos; possible vehicle targets.
	Square Dock or Industrial Target	Yes	Yes	Yes	Yes	
	Circular Industrial Target	Yes	Yes	Yes	Yes	
	Small rectangular Target	Yes	Yes	Yes	Yes	
Southern Area	**Concentric Circles Target**	Yes	Yes	Yes	Yes	Inner rings have ordinal markers; outer ring had periodic dot features, assumed to be lights for night use.
	Small Circular Feature	Yes	Yes	Yes	Yes	ASR identified feature as range marker designation of zero ("0") for N10 1 feature is visible in circular target

Site #8 - KO6TX0267 - Dalhart Precision Bombing Ranges #3 and #4						
RANGE	**Feature**	**SI(1)**	**PI(2)**	**DIP(3)**	**VAL(4)**	**Comments**
Northeast Range	**Cross-hair/Concentric Circles Target**	Yes	Yes	Yes	Yes	Northeast bombing target.
Gunnery Range	**HE Concentric Circles Target**	**No**	**No**	Yes	Yes	Central site area; distinct HE craters visible on photos, including recent dates (2008).
	Formation Target	**No**	**No**	**No**	Yes	Identified later when given description and distance from HE target; visible on 1953 validation photos.
	Battleship Target	**No**	**No**	**No**	Yes	Identified later when given description and distance from formation target; visible on 1953 validation photos.
Southwest Range	**Cross-hair/Concentric Circles Target**	Yes	Yes	Yes	Yes	Southwest bombing target.
	Range Perimeter	**No**	Yes	Yes	Yes	Range perimeter fence and/or firebreak.
Southeast Range	**Rectangular Feature**	**No**	Yes	Yes	Yes	Field validated as target area.
	Airfield and/or Convoy Target	**No**	Yes	Yes	Yes	Field validated as target area.

(1) 2009 Site Investigation (SI) based on 1954 photos was used for comparative analysis because 1998 ASR did not use any photos.