

TEC-0081

An Assessment of the Horizontal Accuracy of Interim Terrain Data

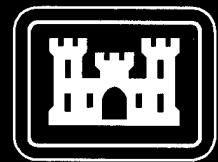
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April 1996

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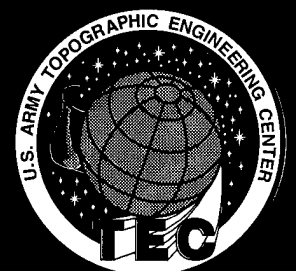


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13. ABSTRACT (Maximum 200 words) Within the U.S. Army and throughout the private sector, the accuracy of Digital Topographic Data (DTD) is often taken for granted. Users assume terrain data to be accurate merely because of its digital nature. This report describes a study that was undertaken to determine the horizontal accuracy of Interim Terrain Data (ITD), a 1:50,000-scale terrain analysis data base. ITD is composed of vector features and associated attributes representing land cover characteristics. It is produced by the Defense Mapping Agency (DMA) and provided to the U.S. Army to support near-term requirements on an interim basis until more standardized data is available. Because of its interim nature, ITD may be digitized from hard copy source ("carto-controlled") or produced solely from photography ("photo-controlled"). No definitive accuracy statement is provided with the data. This study was initiated in 1994 with the collection of ground coordinates for over 400 selected ITD features. Each feature was located in the field using a Precise Lightweight Global Positioning System Receiver (PLGR) in the Precise Positioning Service (PPS) mode (10-meter horizontal accuracy). Universal Transverse Mercator (UTM) coordinates obtained from the PLGR were annotated for each feature.(continued)				
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The UTM coordinates for coincident features in the ITD digital files were subsequently extracted by GIS query to compare statistically the digital data with the field data, calculate the offsets, and determine the horizontal accuracy of the ITD. The potential accuracy differences between the carto- and photo-controlled ITD and the variability of natural vs. manmade features are also discussed.

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PREFACE

This study was performed during the period June 1994 to September 1995 under the supervision of Mr. Jeffrey Messmore, Chief, Special Studies Division, and Mr. Richard Herrmann, Director, Digital Concepts and Analysis Center.¹

The authors would like to extend special appreciation to Mr. John Nedza, Geographic Information Lab, for the many hours of effort he provided during import of the raw Interim Terrain Data (ITD) data and subsequent conversion to Arc-Info coverages. His outstanding technical expertise greatly facilitated data analyses and played a critical role in the successful completion of this study.

The authors would also like to thank Mr. Bill Ryder, Special Studies Division, Digital Concepts and Analysis Center for his excellent terrain analysis support during the field collection; Professor Richard Scott, Rowan College, Glassboro, N.J. for advice and insight about the statistical processes used in the report; and Messrs. Robert Gormley and David Wu, Special Studies Division, Digital Concepts and Analysis Center for their work regarding research and compilation of the statistical analyses.

Mr. Walter E. Boge was Director, and Colonel Richard G. Johnson was Commander and Deputy Director of the Topographic Engineering Center at the time of publication of this report.

¹When this report was printed, Mr. Regis J. Orsinger was the Director of the Digital Concepts and Analysis Center.

AN ASSESSMENT OF THE HORIZONTAL ACCURACY OF INTERIM TERRAIN DATA

INTRODUCTION AND BACKGROUND

Interim Terrain Data (ITD) was first produced by the Defense Mapping Agency (DMA) in 1987. Production of this data was initiated to fill the Army's urgent need for a digital terrain analysis product in support of emerging topographic and Command and Control (C2) systems. Earlier, in 1984, the Army had documented a digital topographic data (DTD) requirement that encompassed all Army's known and anticipated tactical DTD requirements. However, production against this requirement, described as Tactical Terrain Data (TTD), was not scheduled to commence until 1996. In order to get similar data to Army users, DMA initiated production of a product called ITD, the goal of which was to fill the data void until TTD production came on line. Due to the interim nature of this data set and the use of more than one production method, DMA does not state a formal horizontal accuracy measure for this product.

As the center of expertise for DTD within the Army, TEC's Digital Concepts and Analysis Center (DCAC) formulated this study to characterize the horizontal accuracy of ITD. Knowledge of horizontal accuracy is important to the Army as well as other DOD users because it affects what are appropriate uses of the product. For example, is ITD as accurate as the Topographic Line Map (TLM), which may be used for targeting purposes, or is it only as accurate as a city graphic, which is not an appropriate source for targeting? Fortunately, along with the need to know ITD's horizontal accuracy, technology for rapid position determination has become available in the form of Global Positioning Systems (GPS). This technology was applied to determine the horizontal positions of well-defined ITD features.

The ITD is produced through two production processes; one is a hard-copy digitizing process, and the other is a pure photogrammetric production process. In the hard-copy process, tactical terrain analysis data base (TTADB) Mylar overlays (which are geo-registered to the corresponding 1:50,000-scale TLM's) are digitized, resulting in a "carto-controlled" ITD product. In the photogrammetric production process, imagery from DMA's feature extraction (FE) workstation is used, resulting in a "photo-controlled" ITD product. It should be noted that ITD cells from both of these widely divergent production processes are currently

distributed and in broad use. Carto-controlled cells make up the bulk of currently available ITD (≈ 840 of 1340 cells). The ≈ 500 remaining cells are photo-controlled.

PURPOSE

The purpose of this study is to provide the Mapping Charting & Geodesy (MC&G) user community with information about the horizontal accuracy of ITD features. It is intended to give the user a level of confidence regarding ITD accuracy and to establish the utility of ITD for various applications. The study also identified accuracy differences between cartographic and photogrammetrically controlled ITD.

METHODOLOGY & FIELD COLLECTION PROCEDURE

To assist with DCAC's ITD accuracy investigations, DMA provided ITD hard-copy plots, digital data, and associated TLM's for 10 cells in the continental U.S. (CONUS). The use of the hard-copy plots (from digital ITD) instead of the TTADB ensured that features identified for analysis would be represented in the digital data. Each of these plots covered approximately a 15-by-15-minute area. There were four photo-controlled cells in the Alamogordo/Las Cruces, NM area as well as six carto-controlled cells, two in the Ft. Bragg, NC area, and four in the vicinity of Ft. Hood, TX.

Scientists at DCAC reviewed the hard-copy plots and identified appropriate features for field reconnaissance. Two factors weighed heavily in the selection of features. The first factor was the existence of a distinguishable point on the ground (e.g., a road intersection, bridge, dam, or fence line). The second factor was accessibility for measurement of its horizontal placement. No vertical accuracy criteria, such as feature height or height above mean sea level, were considered. The selected features were then annotated on the coinciding 1:50,000 TLM for field use. They comprised a representative sample from the Transportation (TRANS), Surface Drainage (SD), Obstacles (OBS), and Vegetation (VEG) overlays, since these contained point or line features that were more easily recognizable in the field (see Appendix A). Features in the Surface Configuration and Soils overlays were not used for this study. Although important for many applications, these features are not easily distinguishable on the ground and are difficult to measure accurately.

Depending on the density of the data, 14 to 73 features on each of the 10 cells in the study areas were chosen for analysis. The number and variety of features chosen were those deemed necessary to assure representative coverage throughout each cell. More than 400 features were subsequently visited in the field. Each site was located by using a Precise Lightweight Global Positioning System Receiver (PLGR) in the Precise Positioning Service (PPS) mode (≈ 10 meter horizontal accuracy). Universal Transverse Mercator (UTM) coordinates derived from the PLGR were annotated for each.

ANALYSIS

Data Preparation. The digital ITD files provided by DMA were partitioned on the provided media (9-track tape/6250 bpi) by individual sheet number and thematic layer(s). Related file header data was used to acquire descriptive information (metadata) about the individual data sets. The digital ITD files were archived in Standard Linear Format (SLF). Arc/Info (V. 7.0) was used to import the ITD-SLF files read from the tape. Upon import, the data was converted into Arc/Info coverages using the "SLFARC" command. Arc/Info's GIS functionalities enabled us to:

1. Identify and display selected features by thematic layer, feature type, and feature attributes.
2. Precisely extract UTM coordinates for selected features.

The Arc/Info coverages were geo-referenced in WGS-84 spherical geographic coordinates (LAT-LONG). Each coverage, maintained in single-coordinate precision (seven significant digits), was subsequently projected into a WGS-84 planar coordinate system (UTM) which was consistent with the GPS field collection coordinate system. Projection of coordinates from LAT-LONG to real-world UTM coordinates via the Arc/Info projection utilities was determined to be a virtually error-free process. Since both input and output coverages were stored in WGS-84 and required no additional datum transformations, the statistical significance of the root-mean-square (RMS) error was < 0.010 . [NOTE: A perfect projection with an RMS error of 0.000 is not possible with real-world data.] Customized graphical user interfaces were developed using Arc/Info's Arc Macro Language (AML) to extract digital ITD feature coordinates.

Digital ITD Coordinate Extraction. UTM coordinates for selected features were extracted in order to compare the field data to the digital data, calculate the offsets, and thereby determine the horizontal accuracy of ITD. Thematic coverages for

each cell in the study area were displayed with the features appearing as unsymbolized centerline data. Next, those ground features visited in the field were identified in the digital file. A coordinate pair was extracted and recorded alongside the coordinate pair of the coincident ground feature. Finally, a series of statistical analyses was performed on both sets of coordinates.

Statistical Analyses. Coordinates for the photo-controlled and the carto-controlled ITD features were stored in different files, which were further delineated by eastings and northings. These files were then grouped by specific feature types (e.g., "surface drainage features from photo-controlled data"). Standard statistical measures such as mean, standard deviation, 95 percent confidence interval of the mean and a t-statistic with an associated critical value were calculated for each data file. The mean and standard deviation determine the size of the error. The 95 percent confidence interval indicates the potential magnitude of that error in future measurements. The t-statistic determines whether there is a significant difference between two populations (e.g., between the field data and the photo/carto-controlled ITD). Further explanations of the individual statistics are found in Appendix B.

DISCUSSION/FINDINGS

During the field work, DCAC scientists visited 421 feature locations, collecting an easting and a northing at each for a total of 842 observations (combined photo-and carto-controlled data). A summary of statistics for this data is found in Table 1. Offsets ranged from a low of 0 meters (perfect correspondence between field & ITD coordinates) to a high of 339 meters. The average offset for all observations was 25 meters. When the GPS measurement error (Q value) of 10 meters is included, an average offset of 15 to 35 meters is established.

Table 1. Summary of ITD Feature Coordinate Offsets

# obs. (E&N)	OFFSET (m)			Std. Dev. (m)	#/% offset 50m	#/% offset 100m	Q
	Low	Mean	High				
842	0	25	339	31	73/8.67	18/2.14	10

Q - measure of GPS error (circular) in meters

E&N - Eastings & Northings

Of the 842 total observations, 769 features (91.3 percent) were within 50 meters of their expected locations. This is within the expected accuracy of the 1:50,000 Class B TLM (50 meters circular @ 90 percent confidence), which is the only related product with a formal accuracy statement. Only 73 (8.7 percent) had field/ITD offsets above the 50 meter TLM baseline. Further examination revealed that 18 (2.1 percent) of the 73 had offsets more than 100 meters. As expected, 93 percent (68 of 73) of the offsets that were more than 50 meters occurred in cartographically controlled data. These errors were especially prevalent in the SD (e.g. dams, canals), OBS, and VEG coverages where 55 of the 73 offsets were observed. Potential rationales for the higher offsets in the carto-controlled SD, OBS, and VEG coverages (vs. photo-controlled ITD) lie in DMA's collection/symbolization techniques for this data as described below.

In carto-controlled ITD, horizontal positioning is keyed to a base map. Although many features are collected from imagery, they are still subject to a potential offset of 50 meters (map accuracy). Moreover, SD features, such as dams and canals, vegetation polygons, and especially obstacles are often displaced for symbolization purposes. Obstacles such as embankments, escarpments, ditches or road cuts may be substantially displaced to ensure the correct alignment of a stream or road bed. Moreover, it is often hard to determine the exact start or end point of an obstacle in the field.

Vegetation features are inherently characterized by their natural variability. Furthermore, ITD vegetation has a minimum areal size requirement resulting in the inclusion of many different vegetation types within a single polygon. The resulting boundaries can vary in these transition areas causing offsets.

The production procedure for delineation and depiction of dams and canal end/break points (above/below ground transition) is unlike that of other SD features in which positional accuracy is strictly upheld. Dam and canal lengths are often variable since they are roughly plotted to scale to provide a relative size. More emphasis is placed on the location/axis of these features rather than on their size/length.

Figure 1 depicts the data offset for an actual point bridge as observed on the Gatesville, Texas cell, map sheet 6446-1. The ITD bridge feature is approximately 25 meters from the road/stream crossing point where the field measurement took place. However, the actual position of the bridge may be as

close as 15 meters or as far as 35 meters from its intended location depending on the GPS error introduced in the field.

Table 2 illustrates various comparisons between the carto- and photo-controlled ITD at the thematic level. Carto feature offsets are acceptable, with some coverages performing better than others. For example, offsets for the carto transportation features averaged approximately 24 meters, while obstacles offsets approached 70 meters. The mean offset for the carto vegetation features ($\approx 23\text{m}$) was comparable to transportation but exhibited a much higher 95 percent confidence interval (≈ 22.5 vs. $\approx 4.5\text{m}$). This indicates increased variability for the vegetation features and a potentially lower correlation with subsequent field observations.

Overall confidence intervals for the carto-controlled features ranged from $\approx 4\text{m}$ (transportation) to $\approx 53\text{m}$ (obstacles). The mean offset for the carto data is 28.8 meters. Conversely, the mean offsets of the photo-controlled features were very low across all thematic layers. They ranged from a low of 10-12 meters (vegetation, surface drainage, and transportation features) to a high of 21 meters (obstacles). The 95 percent confidence intervals are fairly consistent across features ranging from $\approx 6\text{m}$ (transportation) to ≈ 22 meters (obstacles). The mean offset for the photo data is 13.7 meters. This is directly attributable to the increased fidelity provided by a solely photogrammetric production technique.

It is recognized that statistics/comparisons for several feature groupings in Table 2 are based on small sample sizes (<30 observations). However, in each case the t-statistic exceeds the critical value, indicating that random error cannot explain the variance observed between the field data coordinates and those of ITD. Therefore, there is a significant difference between the populations at the 95 percent confidence level.

It should be noted that all of the ITD data used for this study was collected over CONUS areas with relatively reliable source materials. Assuming the availability of comparable sources, findings in this report should be extensible to any location. However, it is unknown to what extent, if any, foreign or other ancillary source materials may affect the results herein.

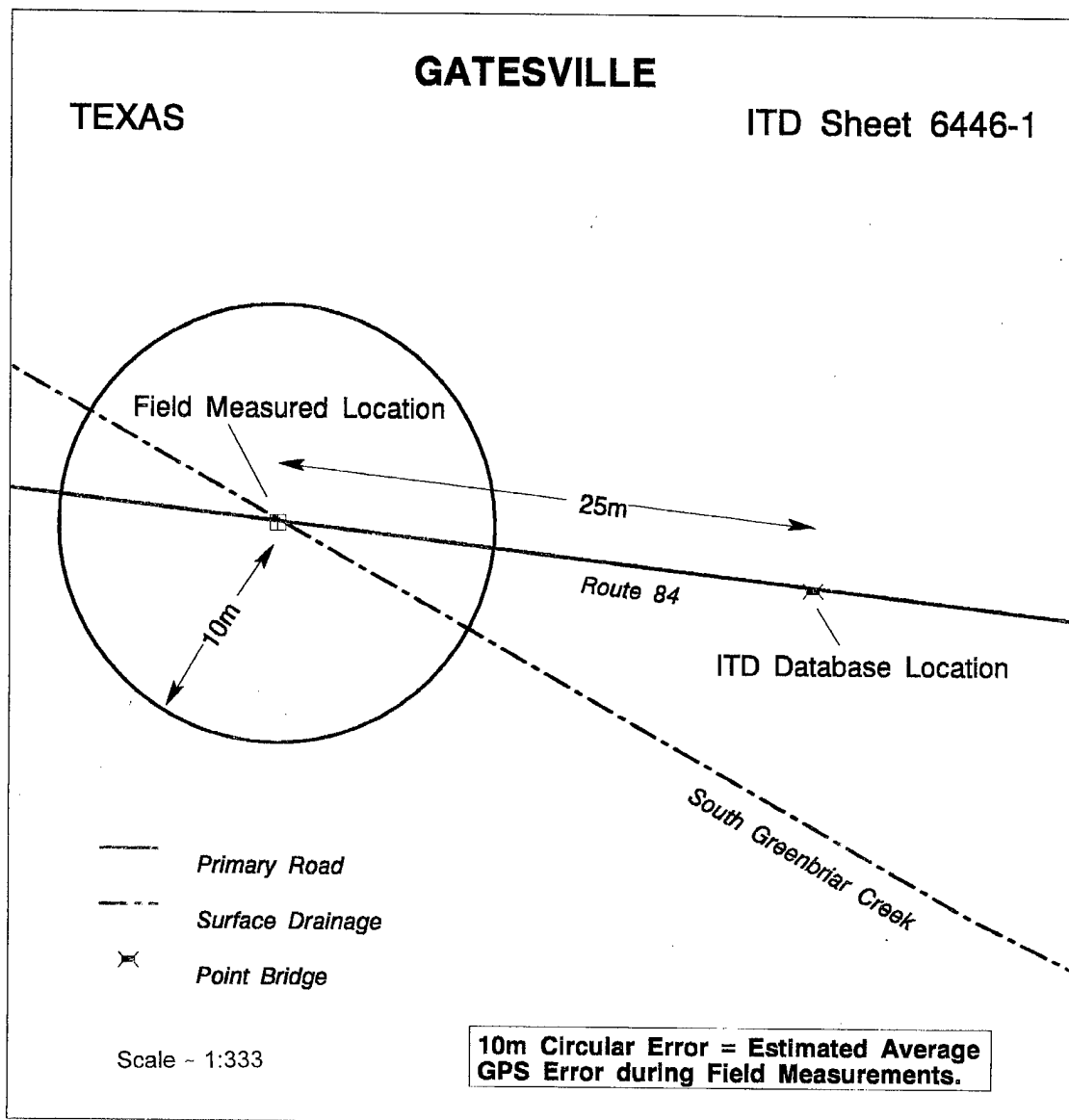


Figure 1. Data Point vs Field Point Offset

Table 2.—Carto/Photo ITD vs. Field Data Offsets by Feature & Associated Statistics

Photo-Controlled Data in meters

<i>Measurement Type</i>	<i>Average (Mean)</i>	<i>Std. Dev.</i>	<i>95% Confidence Int. Of Mean</i>	<i>T Stat.</i>	<i>Crit. Val.</i>	<i>Sample Size</i>
All features	13.72	19.49	10.98 - 16.47	9.8	1.65	196
Transportation features	12.69	17.29	9.69 - 15.69	8.37	1.66	130
Obstacle features	21.31	30.85	10.19 - 32.44	3.91	1.70	32
Surf. Drainage features	11.00	11.57	5.25 - 16.75	4.04	1.74	18
Vegetation features	10.00	9.56	4.91 - 15.09	4.19	1.75	16

Carto-Controlled Data in meters

<i>Measurement Type</i>	<i>Average (Mean)</i>	<i>Std. Dev.</i>	<i>95% Confidence Int. Of Mean</i>	<i>T. Stat.</i>	<i>Crit. Val.</i>	<i>Sample Size</i>
All features	28.76	32.25	26.27 - 31.25	22.67	1.65	646
Transportation features	24.43	24.97	22.20 - 26.65	21.61	1.65	488
Obstacle features	69.68	75.57	43.30 - 96.05	5.38	1.69	34
Surf. Drainage features	37.04	30.05	31.14 - 42.94	12.45	1.66	102
Vegetation features	23.27	25.42	12.00 - 34.54	4.29	1.72	22

CONCLUSIONS

1. The offset of well-defined ITD features taken as a whole was approximately 25 meters. Approximately 90 percent of these features were within 50 meters of their expected locations. This meets the accuracy specification of 50 meters for a Class B, 1:50,000-scale TLM, a traditional source for targeting information.

2. Overall, carto-controlled ITD feature offsets (29 meters) were higher than photo-controlled ITD feature offsets (14 meters). Our expectations were that the photo-controlled ITD would perform very well, as it did; however, performance of the carto-controlled ITD was also suprisingly good.

3. The positional accuracy of ITD features was determined to be compatible with the positional accuracy of hand-held precise GPS equipment currently used in the field. This accuracy compatibility will lessen the chance for confusion and correlation problems, such as could occur when features are located close to one another on the ground and GPS-derived locations do not match data base locations. This problem may be more of a concern with lower accuracy data sets, such as VMap Level 1 (1:250,000 scale) and DCW (1:1,000,000 scale).

LIST OF ACRONYMS

AML	Arc Macro Language
C ²	Command and Control
CONUS	Continental United States
DCAC	Digital Concepts and Analysis Center
DCW	Digital Chart of the World
DMA	Defense Mapping Agency
DOD	Department of Defense
E & N	Easting and Northing
FE	Feature Extraction
GPS	Global Positioning System
ITD	Interim Terrain Data
LAT/LONG	Latitude/Longitude
MC&G	Mapping, Charting, and Geodesy
OBS	Obstacles
PLGR	Precise Lightweight Global Positioning System Receiver
PPS	Precise Positioning Service
RMS	Root-Mean-Square
SD	Surface Drainage
TEC	Topographic Engineering Center
TLM	Topographic Line Map
TRANS	Transportation
TTADB	Tactical Terrain Analysis Data Base
TTD	Tactical Terrain Data
UTM	Universal Transverse Mercator
VEG	Vegetation
VMap	Vector Smart Map
WGS 84	World Geodetic System 1984

APPENDIX A. LIST OF FEATURES USED FOR ITD ACCURACY ANALYSIS

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
6446-3	Ft Hood, TX	Enbankment	612236E	612211E	Carto
			3439270N	3439299	
		Dam	601152E	601138E	
			3440698N	3440711N	
		Canal	615675E	615713E	
			3444048N	3444142N	
		Canal	618715E	618703E	
			3445428N	3445472	
		Dam	614521E	614502E	
			3447867N	3447927N	
		Dam	600534E	600551E	
			3451879N	3451932N	
		Dam	603833E	603806E	
			3457106N	3457133N	
		Bridge	612461E	612473E	
			3443791N	3443782N	
		Bridge	602949E	602916E	
			3441761N	3441715N	
		Bridge	596393E	596349E	
			3438843N	3438820N	
		Intersection	598382E	598416E	
			3437559N	3437602N	
		Intersection	603169E	603139E	
			3434389N	3434362N	
		Bridge	603771E	603780E	
			3430498N	3430492N	
		Bridge	606084E	606078E	
			3430848N	3430860N	
		Intersection	608351E	608352E	
			3435176N	3435157N	
		Intersection	610708E	610677E	
			3441426N	3441406N	
		Bridge	611441E	611453E	
			3441161N	3441160N	
		Bridge	614365E	614392E	
			3433882N	3433891N	
		Intersection	618432E	618392E	
			3438905N	3438916N	
		Intersection	617649E	617663E	
			3445778N	3445792N	
		Intersection	610652E	610677E	
			3445582N	3445620N	
		Bridge	612829E	612871E	
			3447389N	3447448N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
6646-3	Ft Hood, TX	Intersection	610243E	610210E	Carto
			3452197N	3452218N	
		Intersection	610278E	610266E	
			3448437N	3448446N	
		Intersection	609292E	609296E	
			3444767N	3444794N	
		Bridge	606925E	606910E	
			3446290N	3446331N	
		Bridge	606958E	606944E	
			3445267N	3445289N	
		RR Crossing	604570E	604552E	
			3447927N	3447966N	
		Bridge	601837E	601825E	
			3454347N	3454364N	
		RR Crossing	600230E	600251E	
			3457508N	3457491N	
		Intersection	599383E	599335E	
			3456696N	3456773N	
		Intersection	596695E	596680E	
			3454347N	3454364N	
		Bridge	601679E	601688E	
			3451879N	3457491N	
		Intersection	603913E	603896E	
			3456696N	3456773N	
		Bridge	603648E	603632E	
			3455382N	3455381N	
		Veg	614601E	614492E	
			3443070N	3443068N	
		Veg	614659E	614672E	
			3443335N	3443378N	
		Veg	618071E	618133E	
			3438827N	3438838N	
		Veg	618014E	617999E	
			3438659N	3438658N	
5154-3	S. Pines, NC	Hedgerow	647612E	647589E	Carto
			3883884N	3883900N	
		Hedgerow	654834E	654598E	
			3875056N	3875104N	
		Escarpment	653902E	653909E	
			3901450N	3901480N	
		Escarpment	653318E	653398E	
			3901582N	3901468N	
		Hedgerow	639646E	639651E	
			3888422N	3888474N	
		Dam	658618E	658673E	
			3895060N	3894973N	
		Dam	658491E	658440E	
			3895058N	3894969N	
		Dam	647793E	647825E	
			3885606N	3885555N	
		Dam	638742E	638710E	
			3885007N	3884974N	
		Dam	638067E	638022E	
			3876549N	3876521N	
		Dam	637986E	637946E	
			3876802N	3876738N	
		Dam	655077E	655096E	
			3895868N	3895795N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
5154-3	S. Pines, NC	Dam	644347E	644297E	Carto
			3897558N	3897527N	
		Dam	641612E	641590E	
			3899349N	3899308N	
		Dam	645541E	645530E	
			3890682N	3890644N	
		Culvert	655308E	655308E	
			3892756N	3892730N	
		Bridge	653375E	653381E	
			3891897N	3891897N	
		Intersection	650815E	650811E	
			3891228N	3891202N	
		Intersection	647444E	647475E	
			3890524N	3890497N	
		Intersection	648608E	648634E	
			3884290N	3884284N	
		Culvert	646803E	646825E	
			3882437N	3882409N	
		Intersection	649561E	649581E	
			3876123N	3876123N	
		Culvert	651602E	651598E	
			3875322N	3875352N	
		Intersection	654536E	654547E	
			3875182N	3875148N	
		Bridge	646894E	646886E	
			3875818N	3875800N	
		Bridge	644370E	644388E	
			3879661N	3879625N	
		Bridge	640181E	640164E	
			3883193N	3883166N	
		Bridge	639308E	639293E	
			3883724N	3883706N	
		RR Bridge	637964E	637950E	
			3879795N	3879776N	
		Intersection	637041E	637045E	
			3880440N	3880401N	
		Intersection	643237E	643240E	
			3882771N	3882740N	
		Bridge	642069E	642059E	
			3876720N	3876650N	
		RR Crossing	640897E	640904E	
			3875525N	3875545N	
		RR Crossing	639850E	639821E	
			3875450N	3875448N	
		Bridge	638787E	638764E	
			3877334N	3877365N	
		RR Crossing	637723E	637743E	
			3877627N	3877592N	
		RR Crossing	637251E	637260E	
			3879071N	3879021N	
		RR Crossing	637106E	637139E	
			3879120N	3879108N	
		RR Crossing	637722E	637762E	
			3877315N	3877290N	
		Intersection	651349E	651380E	
			3882662N	3882656N	
		RR Crossing	657343E	657359E	
			3883748N	3883713N	
		Intersection	657709E	657703E	
			3880950N	3880941N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
5154-3	S. Pines, NC	Bridge	649989E	649982E	Carto
			3891562N	3891533N	
		RR Crossing	646665E	646684E	
			3893685N	3893630N	
		RR Bridge	645701E	645722E	
			3892795N	3892759N	
		Intersection	658668E	658662E	
			3898187N	3898177N	
		Culvert	657110E	657113E	
			3899111N	3899107N	
		Intersection	654251E	654265E	
			3900762N	3900776N	
		Bridge	654991E	655002E	
			3901200N	3901185N	
		Intersection	648893E	648890E	
			3901028N	3901013N	
		Bridge	649381E	649334E	
			3898330N	3898362N	
		Intersection	649467E	649481E	
			3896655N	3896623N	
		Bridge	646070E	646048E	
			3898360N	3898381N	
		Intersection	641145E	641161E	
			3896577N	3896535N	
		Intersection	640958E	640955E	
			3899258N	3899221N	
		Bridge	641272E	641253E	
			3900515N	3900472N	
		Bridge	637627E	637601E	
			3899910N	3899853N	
		Culvert	638452E	638471E	
			3898448N	3898393N	
		Intersection	638789E	638785E	
			3895800N	3895780N	
		Bridge	643040E	643026E	
			3893622N	3893651N	
		Bridge	637160E	637101E	
			3891736N	3891732N	
		Intersection	639767E	639766E	
			3890356N	3890313N	
		Culvert	641248E	641229E	
			3888409N	3888388N	
		RR Bridge	643012E	643006E	
			3888869N	3888860N	
		RR Bridge	643626E	643592E	
			3889215N	3889191N	
		Veg	643250E	643227E	
			3896449N	3896392N	
6446-1	Gtsville, TX	Embankment	636020E	635832E	Carto
			3474037N	3474032N	
		Embankment	623743E	623750E	
			3469601N	3469537N	
		Embankment	623335E	623336E	
			3470156N	3470120N	
		Dam	620569E	620544E	
			3483618N	3483606N	
		Dam	632108E	632133E	
			3480786N	3480787N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
6446-1	Gttsville, TX	Dam	621354E	621382E	Carto
			3475762N	3475745N	
		Intersection	619358E	619373E	
			3478498N	3478474N	
		Intersection	620154E	620186E	
			3483541N	3483519N	
		Bridge	619546E	619525E	
			3484672N	3484708N	
		Bridge	625009E	625002E	
			3485357N	3485309N	
		Culvert	630407E	630387E	
			3482051N	3482057N	
		Bridge	627952E	627927E	
			3477804N	3477791N	
		Bridge	633273E	633281E	
			3477574N	3477550N	
		Bridge	637903E	637918E	
			3478469N	3478474N	
		Culvert	639389E	639421E	
			3481077N	3481101N	
		Intersection	639745E	639758E	
			3482187N	3482189N	
		Bridge	637139E	637128E	
			3485114N	3485125N	
		Intersection	642206E	642217E	
			3484883N	3484848N	
		Bridge	642108E	642124E	
			3485294N	3485254N	
		RR Crossing	641872E	641891E	
			3476955N	3476904N	
		Intersection	640600E	640617E	
			3472100N	3472072N	
		Bridge	639334E	639379E	
			3472937N	3472957N	
		Bridge	636034E	636102E	
			3472727N	3472772N	
		Bridge	633134E	633145E	
			3474033N	3474058N	
		Bridge	633344E	633357E	
			3474034N	3474054N	
		Intersection	631370E	631425E	
			3473751N	3473750N	
		Bridge	627608E	627610E	
			3474296N	3474310N	
		RR Crossing	624019E	624032E	
			3475633N	3475665N	
		Bridge	623346E	623365E	
			3473061N	3473055N	
		Bridge	623469E	623491E	
			3472803N	3472751N	
		Intersection	623801E	623848E	
			3472078N	3472044N	
		Bridge	620781E	620780E	
			3470228N	3470200N	
		RR Crossing	625162E	625151E	
			3470791N	3470705N	
		RR Crossing	626392E	626363E	
			3470036N	3470048N	
		RR Crossing	626091E	626037E	
			3470600N	3470645N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
6446-1	Gtsville, TX	RR Crossing	627009E	627054E	Carto
			3471319N	3471307N	
		RR Crossing	626559E	626572E	
			3472283N	3472256N	
		Intersection	628417E	628471E	
			3466272N	3466246N	
		Bridge	629100E	629136E	
			3467627N	3467650N	
		Intersection	629588E	629617E	
			3469356N	3469327N	
		RR Crossing	629864E	629840E	
			3464385N	3464390N	
		Intersection	631809E	631833E	
			3463629N	3463621N	
		Bridge	633558E	633508E	
			3460735N	3460726N	
		Intersection	635882E	635901E	
			3458878N	3458832N	
		Intersection	641192E	641155E	
			3460735N	3460789N	
6446-2	Kileen, TX	Bridge	632954E	632966E	Carto
			3469163N	3469164N	
		Intersection	635168E	635197E	
			3468303N	3468295N	
		Bridge	639842E	639826E	
			3469409N	3469390N	
		Bridge	639694E	639680E	
			3469618N	3469578N	
		Veg	620448E	620457E	
			3478827N	3478835N	
		Fence	621510E	621606E	
			3445934N	3446019N	
		Dam	640448E	640382E	
			3433611N	3433555N	
		Dam	640033E	639989E	
			3432615N	3432595N	
		Dam	623227E	623202E	
			3437054N	3437098N	
		Dam	632025E	631960E	
			3448194N	3448164N	
		Dam	636824E	636817E	
			3445119N	3445130N	
		Dam	634618E	634648E	
			3438880N	3438823N	
		Dam	633533E	633558E	
			3442258N	3442222N	
		Dam	626060E	626031E	
			3439811N	3439792N	
		Dam	625992E	625963E	
			3439862N	3439834N	
		Dam	625924E	625875E	
			3439894N	3439889N	
		Canal	621810E	621691E	
			3444471N	3444570N	
		Dam	623546E	623579E	
			3445851N	3445841N	
		Intersection	640647E	640614E	
			3434695N	3434707N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
6446-2	Kileen, TX	Intersection	633937E	633905E	Carto
			3436873N	3436973N	
		Intersection	629191E	629161E	
			3436217N	3436221N	
		Bridge	628739E	628721E	
			3431566N	3431590N	
		Bridge	629368E	629394E	
			3431225N	3431229N	
		Bridge	627409E	627354E	
			3434251N	3434228N	
		Intersection	624917E	624898E	
			3433549N	3433540N	
		Intersection	620823E	620807E	
			3433556N	3433539N	
		Intersection	619490E	619474E	
			3436219N	3436224N	
		Intersection	622900E	622930E	
			3447695N	3447690N	
		Intersection	631809E	631786E	
			3448350N	3448355N	
		Intersection	630910E	630895E	
			3450406N	3450380N	
		Culvert	629653E	629598E	
			3452862N	3452741N	
		Bridge	629913E	629838E	
			3453300N	3453181N	
		Bridge	632545E	632548E	
			3447583N	3447578N	
		Intersection	641494E	641497E	
			3441626N	3441617N	
		Bridge	640503E	640474E	
			3440679N	3440665N	
		RR Crossing	639165E	639176E	
			3439701N	3439680N	
		Bridge	635613E	635664E	
			3437928N	3437906N	
		Bridge	635528E	635387E	
			3437969N	3438032N	
		RR Bridge	633503E	633458E	
			3438800N	3438828N	
		Bridge	634536E	634510E	
			3440113N	3440074N	
		Bridge	625171E	625192E	
			3441837N	3441821N	
		Bridge	625085E	625084E	
			3441773N	3441761N	
		Bridge	623935E	623894E	
			3442572N	3442573N	
		Bridge	622830E	622848E	
			3443032N	3443087N	
		RR Crossing	621484E	621384E	
			3443444N	3443498N	
		RR Bridge	619344E	619345E	
			3443784N	3443804N	
		Bridge	639590E	639593E	
			3456637N	3456613N	
		RR Crossing	641437E	641457E	
			3456560N	3456642N	
		Bridge	642220E	642236E	
			3456627N	3456551N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
6446-2	Kileen, TX	Culvert	642376E	642360E	Carto
			3456891N	3456854N	
		Veg	623892E	623904E	
			3436271N	3436241N	
		Veg	624085E	624080E	
			3436352N	3436333N	
6446-4	Purmela, TX	Escarpment	614325E	614357E	Carto
			3459098N	3459074N	
		Dam	611342E	611279E	
			3462480N	3462665N	
		Dam	598636E	598624E	
			3470160N	3470168N	
		Dam	618222E	618225E	
			3472729N	3472777N	
		Dam	597188E	597165E	
			3482222N	3482238N	
		RR Crossing	611766E	611800E	
			3460071N	3460079N	
		Intersection	612071E	612098E	
			3461831N	3461799N	
		Intersection	603726E	603739E	
			3459003N	3459025N	
		Intersection	597701E	597673E	
			3461129N	3461123N	
		Bridge	606178E	606141E	
			3461767N	3461710N	
		Bridge	606239E	606216E	
			3461871N	3461846N	
		Intersection	605810E	605780E	
			3461088N	3461103N	
		Intersection	601294E	601295E	
			3467052N	3467060N	
		Bridge	595896E	595905E	
			3467660N	3467660N	
		Bridge	602910E	602964E	
			3471970N	3471972N	
		Bridge	602994E	603073E	
			3471984N	3471992N	
		Bridge	610876E	610892E	
			3474273N	3474292N	
		Intersection	613390E	613364E	
			3474034N	3474044N	
		Intersection	608913E	608904E	
			3468643N	3468636N	
		Culvert	616790E	616829E	
			3469255N	3469245N	
		Intersection	615598E	615618E	
			3468910N	3468933N	
		Bridge	618213E	618238E	
			3466087N	3466071N	
		Intersection	617535E	617561E	
			3462579N	3462561N	
		RR Crossing	614417E	614400E	
			3476328N	3476383N	
		Bridge	615053E	615049E	
			3478377N	3478380N	
		Intersection	611844E	611749E	
			3478834N	3478787N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
6446-4	Purmela, TX	Culvert	608495E	608500E	Carto
			3478687N	3478675N	
		Bridge	601335E	601358E	
			3475281N	3475301N	
		Intersection	604494E	604445E	
			3480033N	3480036N	
		Culvert	603191E	603199E	
			3480475N	3480468N	
		Culvert	603640E	603636E	
			3480307N	3480301N	
		Bridge	596928E	596888E	
			3479897N	3479909N	
		Intersection	598572E	598555E	
			3483744N	3483754N	
		Bridge	598511E	598528E	
			3483850N	3483843N	
		Bridge	605711E	605677E	
			3484555N	3484559N	
		Bridge	608088E	608040E	
			3485626N	3485561N	
		Intersection	609356E	609317E	
			3483656N	3483660N	
		Bridge	614235E	614253E	
			3483123N	3483110N	
		RR Crossing	613555E	613511E	
			3483499N	3483533N	
		Intersection	617119E	617115E	
			3478496N	3478477N	
		Bridge	617687E	617759E	
			3478481N	3478487N	
		Bridge	617983E	618053E	
			3478483N	3478481N	
		Veg	602766E	602784E	
			3476602N	3476574N	
		Veg	602524E	602520E	
			3475830N	3475851N	
5254-3	Fayetteville, NC	Hedgerow	698560E	698527E	Carto
			3902238N	3902260N	
		Hedgerow	698828E	698767E	
			3902418N	3902433N	
		Embankment	688976E	689046E	
			3887458N	3887404N	
		Hedgerow	690583E	690505E	
			3882709N	3882788N	
		Hedgerow	695243E	695301E	
			3881569N	3881688N	
		Escarpment	701409E	701070E	
			3885266N	3885043N	
		Dam	687376E	687369E	
			3890552N	3890577N	
		Dam	687378E	687361E	
			3890408N	3890435N	
		Dam	685796E	685824E	
			3901018N	3901008N	
		Dam	687228E	687217E	
			3901251N	3901230N	
		Dam	688213E	688235E	
			3902275N	3902272N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
5254-3	Fayetteville, NC	Dam	691884E	691885E	Carto
			3899280N	3899222N	
		Dam	692141E	692149E	
			3899452N	3899395N	
		Dam	698946E	698907E	
			3900134N	3900074N	
		Dam	698892E	698876E	
			3900002N	3899957N	
		Canal	686771E	686641E	
			3881603N	3881644N	
		Dam	684201E	684195E	
			3878045N	3878042N	
		Dam	684091E	684101E	
			3878069N	3878080N	
		Dam	684195E	684193E	
			3875250N	3875266N	
		Dam	689552E	689512E	
			3881090N	3881160N	
		RR Crossing	684338E	684342E	
			3888530N	3888511N	
		RR Bridge	686700E	686703E	
			3890292N	3890319N	
		RR Crossing	687316E	687653E	
			3889569N	3889590N	
		RR Crossing	688731E	688709E	
			3889699N	3889692N	
		Intersection	683262E	683238E	
			3889916N	3889901N	
		Intersection	684994E	684962E	
			3891858N	3891890N	
		RR Crossing	684729E	684704E	
			3892798N	3892772N	
		Intersection	684620E	684601E	
			3893506N	3893596N	
		Bridge	683239E	683215E	
			3896469N	3896468N	
		Bridge	683398E	683384E	
			3896352N	3896312N	
		Bridge	686364E	686401E	
			3897405N	3897505N	
		Bridge	687778E	687773E	
			3899046N	3899042N	
		Intersection	684902E	684890E	
			3901451N	3901481N	
		Intersection	687929E	687918E	
			3900666N	3900664N	
		Intersection	692663E	692689E	
			3901641N	3901635N	
		Bridge	693068E	693090E	
			3900799N	3900774N	
		Intersection	689555E	689558E	
			3894894N	3894873N	
		Intersection	695794E	695811E	
			3897946N	3897963N	
		Intersection	699284E	699270E	
			3900244N	3900248N	
		RR Crossing	702077E	702057E	
			3897360N	3897339N	
		Intersection	696830E	696836E	
			3895386N	3895374N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
5254-3	Fayetteville, NC	RR Crossing	694982E	694960E	Carto
			3893758N	3893761N	
		Intersection	696860E	696859E	
			3892900N	3892911N	
		RR Bridge	695196E	695214E	
			3891817N	3891849N	
		Intersection	691516E	691536E	
			3886491N	3886483N	
		Bridge	689225E	689228E	
			3884899N	3884890N	
		Intersection	685145E	685154E	
			3885782N	3885806N	
		Intersection	683336E	683345E	
			3883675N	3883685N	
		Bridge	684484E	684491E	
			3883110N	3883103N	
		Intersection	684609E	684584E	
			3879853N	3879842N	
		Bridge	684470E	684435E	
			3875250N	3875266N	
		Intersection	685474E	685518E	
			3875462N	3875502N	
		RR Bridge	689469E	689511E	
			3876917N	3876932N	
		Intersection	688309E	688355E	
			3879937N	3879907N	
		Intersection	688481E	688491E	
			3882056N	3882070N	
		Intersection	693415E	693417E	
			3882420N	3882320N	
		Bridge	695736E	695661E	
			3881689N	3881649N	
		Bridge	695442E	695513E	
			3881606N	3881603N	
		Bridge	695343E	695359E	
			3880735N	3880736N	
		Bridge	695514E	695543E	
			3880658N	3880654N	
		Bridge	698873E	698861E	
			3876023N	3876071N	
		Bridge	701832E	701843E	
			3877111N	3877130N	
		Intersection	703153E	703142E	
			3875945N	3875956N	
		Intersection	703734E	703697E	
			3883561N	3883595N	
		Intersection	704652E	704593E	
			3889022N	3889016N	
		RR Crossing	700507E	700524E	
			3888062N	3888038N	
		Intersection	702567E	702564E	
			3891612N	3891625N	
		Bridge	704579E	704576E	
			3894461N	3894457N	
		Intersection	696703E	696694E	
			3888154N	3888157N	
		RR Crossing	696189E	696203E	
			3884635N	3884614N	
		Veg	687869E	687881E	
			3889309N	3889315N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
4649-3	Sn Diego Mt, NM	Embankment	319694E	319669E	Photo
			3602811N	3602917N	
		Embankment	319902E	319986E	
			3602289N	3602169N	
		Dam	312677E	312693E	
			3601301N	3601267N	
		Bridge	318908E	318897E	
			3597557N	3597589N	
		Bridge	313092E	313098E	
			3601316N	3601324N	
		Bridge	312608E	312608E	
			3602266N	3602260N	
		RR Bridge	312551E	312559E	
			3610308N	3610307N	
		Intersection	314258E	314234E	
			3618851N	3618851N	
		Intersection	315469E	315426E	
			3618890N	3618900N	
		Intersection	318688E	318660E	
			3618948N	3618974N	
		Intersection	316283E	316278E	
			3611107N	3611093N	
		Intersection	318512E	318488E	
			3606332N	3606327N	
		Intersection	320260E	320250E	
			3602535N	3602550N	
		Intersection	320868E	320871E	
			3601240N	3601236N	
		Bridge	320620E	320595E	
			3600195N	3600185N	
		Veg	317143E	317127E	
			3605719N	3605715N	
4648-3	Afton, NM	Canal	330578E	330575E	Photo
			3567167N	3567161N	
		Intersection	334762E	334753E	
			3563269N	3563267N	
		Intersection	334604E	334599E	
			3563591N	3563595N	
		Bridge	334246E	334242E	
			3563617N	3563605N	
		RR Crossing	333868E	333862E	
			3561458N	3561455N	
		Bridge	334169E	334167E	
			3564683N	3564678N	
		Bridge	334250E	334250E	
			3565450N	3565450N	
		Bridge	334260E	334261E	
			3565560N	3565569N	
		Bridge	334302E	334301E	
			3566048N	3566053N	
		Intersection	334400E	334388E	
			3567184N	3567199N	
		Intersection	333706E	333713E	
			3568456N	3568454N	
4648-1	Organ Peak, NM	Fence	348364E	348391E	Photo
			3595868N	3595854N	
		Embankment	336249E	336255E	
			3576812N	3576807N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
4648-1	Organ Peak, NM	Embankment	336390E	336407E	Photo
			3576960N	3576951N	
		Embankment	335877E	335894E	
			3576752N	3576736N	
		Embankment	337332E	337333E	
			3574594N	3574599N	
		Canal	338617E	338621E	
			3595980N	3595963N	
		Canal	338639E	338629E	
			3596409N	3596409N	
		Dam	338854E	338854E	
			3577645N	3577660N	
		Dam	342513E	342515E	
			3579290N	3579298N	
		Dam	339300E	339287E	
			3579062N	3579063N	
		Dam	339865E	339872E	
			3582598N	3582595N	
		Culvert	357102E	357110E	
			3589906N	3589890N	
		Bridge	355954E	355968E	
			3589884N	3589868N	
		Bridge	354952E	354975E	
			3589866N	3589849N	
		Bridge	350363E	350376E	
			3588951N	3588962N	
		Intersection	348340E	348325E	
			3588354N	3588366N	
		Culvert	348322E	348338E	
			3594259N	3594252N	
		Intersection	341697E	341703E	
			3585625N	3585601N	
		Intersection	337347E	337310E	
			3583917N	3583881N	
		Intersection	337717E	337693E	
			3586795N	3586772N	
		Bridge	337324E	337327E	
			3590839N	3590825N	
		Bridge	337042E	337034E	
			3593026N	3593054N	
		Bridge	336905E	336922E	
			3593917N	3593917N	
		Intersection	336721E	336724E	
			3595366N	3595367N	
		Bridge	335389E	335416E	
			3576897N	3576905N	
		Intersection	338398E	338408E	
			3577631N	3577616N	
		Intersection	341626E	341626E	
			3578993N	3578987N	
		Intersection	336695E	336700E	
			3573853N	3573836N	
		Intersection	343152E	343276E	
			3575268N	3575286N	
		Intersection	346998E	347040E	
			3577994N	3577887N	
		RR Crossing	350275E	350265E	
			3578157N	3578121N	
		Veg	342194E	342202E	
			3592762N	3592755N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
4648-1	Organ Peak, NM	Veg	342586E	342600E	Photo
			3592754N	3592752N	
		Veg	340689E	340689E	
			3584703N	3584715N	
		Veg	340522E	340487E	
			3584706N	3584716N	
		Veg	340494E	340484E	
			3584325N	3584311N	
4749-1	Hollomn AFB, NM	Veg	340686E	340681E	Photo
			3584316N	3584308N	
		Veg	335375E	335373E	
			3569766N	3569762N	
		Embankment	394613E	394605E	
			3634347N	3634334N	
		Embankment	394745E	394737E	
			3633743N	3633746N	
		Escarpment	394647E	394648E	
			3639836N	3639797N	
		Fence	397025E	397033E	
			3638228N	3638228N	
		Fence	397514E	397516E	
			3638265N	3638267N	
		Fence	398544E	398552E	
			3637871N	3637868N	
		Fence	398544E	398562E	
			3638334N	3638324N	
		Escarpment	397616E	397603E	
			3640263N	3640247N	
		Escarpment	401876E	401945E	
			3644321N	3644316N	
		Canal	397784E	397827	
			3633706N	3633713N	
		Bridge	400204E	400208E	
			3633233N	3633205N	
		Intersection	399103E	399088E	
			3634194N	3634186N	
		Bridge	398656E	398657E	
			3632375N	3632373N	
		Intersection	398680E	398684E	
			3632334N	3632334N	
		Intersection	393443E	393443E	
			3629277N	3629255N	
		Intersection	390214E	390209E	
			3627364N	3627345N	
		Intersection	387538E	387540E	
			3628968N	3628960N	
		Intersection	405318E	405350E	
			3635535N	3635571N	
		Bridge	397268E	397270E	
			3632966N	3632961N	
		RR Crossing	393571E	393577E	
			3634483N	3634476N	
		Intersection	395407E	395409E	
			3637829N	3637828N	
		Bridge	392789E	392797E	
			3640877N	3640877N	
		Bridge	392581E	392575E	
			3644460N	3644457N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates		Control Source
			Field	Digital File	
4749-1	Hollomn, NM	Bridge	392524E	392522E	Photo
			3645393N	3645393N	
		Bridge	392365E	392367E	
			3648006N	3648006N	
		RR Crossing	392435E	392441E	
			3639098N	3639104N	
		Intersection	393792E	393792E	
			3642802N	3642818N	
		Intersection	393802E	393804E	
			3645964N	3645919N	
		RR Crossing	398914E	398943E	
			3634658N	3634722N	
		RR Crossing	400107E	400111E	
			3635825N	3635831N	
		Intersection	397853E	397858E	
			3641726N	3641736N	
		RR Bridge	406519E	406516E	
			3651646N	3651642N	
		Intersection	404539E	404538E	
			3646317N	3646318N	

APPENDIX B. STATISTICAL EXPLANATIONS

Sample Size/Mean - For this study, sample size is the number of northings and eastings in a given data grouping. A single sample represents the difference in meters between the field coordinates and the photo/carto-controlled ITD coordinates at a specific point. Mean was determined by taking the sum of all errors and dividing by the sample size.

Standard Deviation - A measure indicating the extent to which the data values are distributed about the mean. In a normal distribution, 68 percent of all values should fall within one standard deviation of the mean. The standard deviation is proportional to the sum of the difference between each value and the mean squared.

95 Percent Confidence Interval - Indicates, with 95 percent certainty, the range in which the mean is situated.

T-statistic/Critical Value - This statistic is dependent upon sample size and determines the probability that the actual variance observed can be solely explained by random error. The critical value is the threshold that the T-statistic must exceed, at a given confidence level and sample size, to ensure rejection of the null hypothesis (i.e., for this study, that there is no difference between the field data coordinates and those of the ITD data). Therefore, for a given sample size of >30 observations, a t-statistic of ≈ 1.65 represents a 0.05 probability that the measured error is solely random. A t-statistic of 2.58 represents a 0.005 probability of random error and a t-statistic of 6.90 represents a 5.48×10^{-10} probability. For smaller sample sizes (15 to 30 observations), a t-statistic of ≈ 1.75 will yield similar probabilities. A large t-statistic indicates that the error found is real (not random) and ensures the validity of comparisons between varying sample sizes.