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AN EVALUATION OF ARCHAEOLOGICAL APPLICATIONS OF MAPPING GRADE GLOBAL POSITIONING SYSTEMS: FIELD TESTS IN NORTHEASTERN COLORADO'S PLAINS AND MOUNTAINS

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INTRODUCTION

The ability to collect and analyze spatially defined data is a core component of archaeological research. In recent years, the collection and manipulation of spatial data sets has become increasingly sophisticated and effective with the introduction of Global Positioning (GPS), computer-based mapping and Geographic Information System (GIS) hardware and software (see Kennedy 1996, Napton and Greathouse 1997: 212-215, 225-228). On the more immediate, and practical, level, the collection of precise positional information on archaeological sites, features and artifacts using GPS instruments is, hypothetically, made faster and more cost-effective (cf. Ladefoged, Graves, O'Connor and Chapin 1998). Further, collected data can then be up-loaded into computer-based software systems for mapping and simple statistical correlation analysis. The generation of quickly recorded, electronic spatial data is, potentially, both a time and money-saver in archaeological field projects, whether they are basic field inventories (involving survey and testing strategies) or major programs of archaeological research.

At the broadest (and more theoretical level) of research, spatial manipulation and analysis of complex, interrelated data sets involving multiple classes of data-archaeological, environmental, etc.-make possible sophisticated modeling of past cultural and physical landscapes. This latter research approach, landscape archaeology, is concerned with the comprehensive, analytical integration of a human (cultural) and natural ecosystem components within a well-defined geographic area (Brunswig 1996, Rossignol 1992). In applying the landscape approach, pre-modern landscapes are conceptualized within multiple, but interacting, “frames of reference” for archaeological and paleoenvironmental researchers, frames which include. 1) physical landscapes, or sets of evolving land forms over time with their associated soils, eroding and expanding (alluviation, etc) geomorphic features (streams, terraces, hills, etc); 2) biological landscapes with their associated ecosystems of plant and animal communities that are distributed in varied, and often “patchy”, patterns across the physical landscapes; and 3) archaeological landscapes or the synchronic and diachronic distribution of loci of past human activity across, and functionally defined by the characteristics of different elements of, associated physical and biological landscapes.

In 1998, this author, under contract to the U.S. Park Service’s National Center for Preservation Technology and Training undertook a preliminary field test and evaluation of emerging Global Position Systems technology for applications in archaeology. The results of that study, described below, suggest that there are a number of highly positive (and a few less positive) aspects to using GPS technology for assisting archaeologists in acquiring multiple data sets for archaeological research programs from the fundamental survey and inventory data collecting phase to providing large-scale spatial data bases for regional landscape models.

RESEARCH PROGRAM OBJECTIVES

The main objective of the GPS field testing program was to assess the utility of mapping grade GPS instruments in collecting sub-meter spatial data on archaeological sites in two environmental contexts, northeastern Colorado's high plains and mountains. The testing took place under standard field conditions at archaeological sites being documented by University of Northern Colorado survey teams working under cost-share agreements and cooperative contracts with the U.S. Forest Service and U S. Park Service, respectively GPS positions were collected at each of five sites in varying topographic contexts, position logging times, and using two different methods for achieving sub-meter spatial point precision. Altering variables of topography, collection times, and differing differential correction methods allowed better insights into factors that affect spatial data collection in field conditions. Learning about the effect of such variables in GPS data collection provided a critical test of the applicability of the technology to supporting archaeological goals.

METHODS OF TESTING AND EVALUATION

GPS Instruments, Concepts and Terms Relevant to the Research

Testing the utility of precision, sub-meter GPS data recording at archaeological sites involved the coordination of several instruments and software packages. A Trimble ProXR GPS system with a 12 channel receiver was the primary system. The ProXR has a 2 MB logging memory, capable of storing several thousand individual positions along with associated data dictionary information. The 12 channel receiver allowed the GPS to acquire and maintain lock on multiple satellites (SV's) as they transited from horizon to horizon more consistently than earlier 8 channel models. The Trimble system normally costs in the range of $12,500, although its academic price is somewhat less at $9,000.

GPS satellite signal data obtainable by the ProXR is restricted only to a signal type known as C/A code, a relatively low resolution signal type designed to be received by civilian, not military, instruments. The higher resolution P-code signal requires a classified GPS chip set not normally available to non-governmental GPS users. Further, civilian GPS units are periodically subject to selective availability or degradation of the satellite signals to C/A units by the Department of Defense (DOD). The combination of a C/A code GPS chip set and DOD selective availability commonly results in positional errors of c. 10 meters to as much as 100 meters, hardly achieving the spatial precision needed for most archaeological applications In recent years, however, civilian engineers resolved DOD restrictions to higher GPS precision by developing hardware and software “fixes” which correct for those “errors”. In doing so, they have managed to achieve a somewhat greater degree of spatial resolution than normally available in government GPS units equipped with P-code chip sets. The solution, known as *differential correction,* differential correction, involves the use of a GPS base station receiver with a known precise location and collecting satellite position signal data at the same time a field (rover) GPS unit is being used. Very simply, and simplistically, put, differential correction is a means of “determining position error at a known location and applying that determined error-correction value” to another (the rover GPS), unknown position (French 1996: 123-137, 232). At present, three methods of differential correction exist: 1) computer post-processing of field (rover) and base station data files, 2) real-time (in field, instantaneous) differential correction of satellite (SV) positional data using a broadcast signal of base station correction data from a beacon transmitter, and 3) real-time reception of “virtual” base correction data from an orbiting geosynchronous satellite (French 1996: 123-151; for information on the satellite correction signal approach-see Huff 1995 and visit the OMNISTAR web page: (http.//www.omnistar.com). A fourth and normally less viable option is use of a FM-broadcast signal from a local base station to a rover GPS unit. However, the FM method is somewhat limited in range and effectiveness with present technology.

This study utilized two methods of achieving sub-meter field data; 1) post-processing of field rover data downloaded into a computer from the GPS data logger, and 2) use of a rented real-time, satellite “base station” antenna and service. The later real-time approach involved rental of an “add-on” receiver and antenna from a local Colorado surveying company who, in turn, had an annual subscription to one of the major DGPS (Differential GPS) providers-OMNISTAR. Rental of the OMNISTAR unit cost $35 per day while purchase of the system is c. $3500 and annual subscription to the service itself is $800 a year. Post processed base station correction data, early in the study, were obtained from an Internet bulletin board site operated by the U.S. Forest Service in Fort Collins, Colorado. However, early in 1998, the Forest Service opened up a base station web page which provides continuous differential correction data in FTP downloadable file formats (web address – http://www.fs.fed. us/database/gps/ftcollins.htm). The correction data at the Fort

Collins web site are kept on line for 2 months from the time of collection and collected 24 hours a day, 7 days a week. In addition to the Fort Collins facility, the Forest Service, various federal agencies, and a number of private companies maintain base stations with downloadable file sets at 47 sites in 27 states. All are accessible through the USDA Forest Service's GPS web page (http://www.fs.fed.us/database/gps/). The development of Internet base station pages has vastly simplified GPS post processing and allows sub-meter post-processed data sets to be accurately generated for rover GPS data from within a radius of 300 km of each station.

Post-processing rover GPS data collected during the study was done using Trimble's Pathfinder GPS software Pathfinder allows a number of essential functions to be performed. Field data are up-loaded from the GPS data logger and may be displayed in a generalized "flat map" form in the program. The program also allows the easy post-processing of field data using parallel time base station files (in this case, downloaded from an Internet base station web page) Multiple field or post-processed files can be combined to make up much larger, more complex, wider area (multi-site) files. Corrected and uncorrected files can then be saved in a variety of Geographic Information System (GIS), spreadsheet, or text formats, including any related field-recorded information on each recorded spatial point. Specific information can be recorded for any field-logged point using a custom designed *data dictionary* which is available in a menu or general notation (alphanumeric) format on a GPS data logger's LCD screen. The data dictionary used for this field study changed as the project evolved, but, in its final form, provided extremely useful point by point information for later analyzing and labeling GPS field data (see Appendix A for a copy of the study's final data dictionary format). Further, Pathfinder allows post-collection editing of point information before exporting the final corrected file to an external GIS or mapping program.

Computers used in processing GPS data in the study included a Pentium II 233 MHZ system with 64 MB RAM and a 42 GB Hard Drive. A 100 MB Zip Drive was used for back-up storage and data transfer between other computers. A second microcomputer, a Toshiba Pentium 133 MHZ notebook (portable) system with a 2.1 GB Hard Drive and an external 100 MB Zip Drive, was used to download GPS data while in the field and evaluate GPS performance as data were being collected. The purpose of using a portable field computer was to view uncorrected and real-time corrected data sets to determine if data collection strategies were producing the desired results and to modify collection procedures to enhance those results. For instance, one objective was to collect sufficient and correctly "spaced" positional data to create high-resolution topographic maps of archaeological sites and their surrounding terrain. The need for higher resolution topographic maps for sites and site localities represents a long-standing problem where U.S.G.S. 7.5" topographic maps commonly have contour intervals of 20 to 40 feet. Landscape archaeology modeling on the fine, micro (local) scale is based, in part, on the need to document and understand localized site location variables as the relationship of seasonal wind directions and local topographic features, water drainage patterns, etc. Successful landscape archaeology modeling, not to mention more mundane site survey mapping, on the local (micro) scale requires relatively high-resolution land surface information which, it was suggested, could be provided by high precision GPS (sub-meter) data sets. If physical gaps in GPS field data existed, then high-resolution topographic maps could not be effectively generated. Use of the viewing and initial mapping of field files on the field computer would, it was reasoned, allow subsequent, remedial data collection to fill in any gaps that might have occurred in the initial GPS survey. This proved to be the case as the study evolved.

Research Methods and Strategies

Assessing the effectiveness of sub-meter GPS data sets to archaeological applications was based on several, inter-connected approaches. First, uncorrected GPS data were compared with post-processed corrected versions of the same data. This allowed a rough evaluation in the Increase in precision for the same data sets. Second, a particular statistic generated by Trimble's Pathfinder software, the S.D. or standard deviation, provided a useful means of assessing the relative accuracy or spatial precision of each recorded GPS point. The standard deviation is a calculation of the "closeness of clustering" of a series of recorded positions for individual points. A coordinate location or specific three-dimensional spot, in GPS terms, is really an averaging of a number of locational (GPS satellite) signal readings, or positions, taken over a given period of time (French 1996. 179). Depending on a variety signal variables (number of SV's in view, earth geometry, terrain obstacles, etc.) such positions will vary somewhat in precision, but collectively are used to produce 3-dimensional coordinates for a particular point on the earth's surface. The tighter the standard deviation, the higher the statistical probability for a reliable precision point coordinate to be present. In practical terms, use of the S.D. statistic calculated automatically by the Pathfinder software allowed an effective measuring tool for comparing and evaluating relative point coordinate precision for recorded GPS data. In order to obtain comparable, measurable GPS data, standard deviations for uncorrected, real time (OMNISTAR-derived), and post-processed corrected point coordinates were compiled on an Excel spreadsheet and each column averaged at the end of each column. The resulting averaged S.D. values then provided a comparable statistic of relative spatial precision of each alternative GPS data set and the methods by which they were derived.

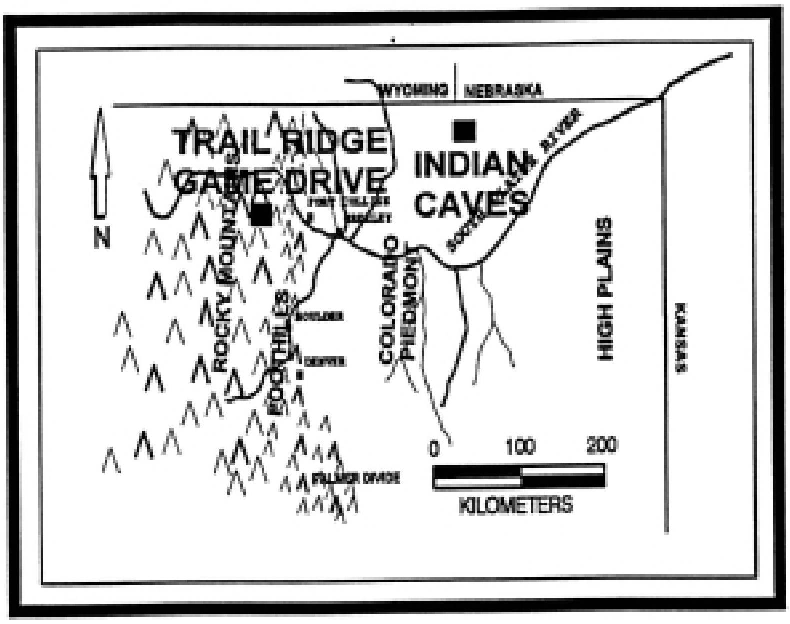
Two secondary, and somewhat informal, means of assessing the accuracy of different GPS methods were: 1) visually comparing (graphically overlaying) GPS-based maps with standard U.S.G.S. topographic maps of the same areas, and 2) comparing the deviation of selected GPS logged positions with those surveyed using a standard survey transit.

A final phase of the sub-meter GPS test program involved exporting differentially corrected data from the Trimble Pathfinder program to mapping and GIS programs. Given limitations of time, GIS analysis of the GPS data sets was explored in only a rudimentary manner using data files directly exported to Arc-View from Pathfinder, with further work to be done after the conclusion of the study. However, GPS data in Universal Transverse Mercator (UTM) coordinate system formats were exported as ASCII (test) files into the Excel Spreadsheet, then re-formatted into column and row data appropriate for use in the SURFER Mapping Program (Keckler 1995). The Excel data sheets were imported into SURFER's worksheet sub-program and' the resulting data (.DAT) files further processed into appropriate SURFER file formats for contour and surface maps and labeled feature/artifact overlays. The resulting maps provided an excellent example of the utility of sub-meter GPS in collecting high resolution spatial data and using those data to create horizontal and three-dimensional maps of smaller and larger scale archaeological landscapes.

Description of the Test Sites and Data Collection Procedures

Five archaeological sites were used in the GPS study (see figure 1 for locations). Four were located in a research area known as Indian Caves on the U.S. Forest Service' s Pawnee National Grassland (PNG) of northeastern Colorado. The Indian Caves research area was located some 90 miles east of the region's Front Range foothills in a rolling short-grass prairie terrain broken by small drainage valleys. A 50 mile long, 10-15 meter high bluff scarp, known as the Chalk Bluffs, extends along the northern boundary of the research and provided site conditions of open horizon-to-horizon exposure (on the bluff top) and restricted topography (in a small canyon valley of the bluffs). South of the bluffs were two sites on a west-facing hill slope and on a south-facing creek terrace, both locations relatively open to overhead GPS satellites from horizon to horizon. A final, fifth site used in the study was a high altitude game drive in mountainous sub-alpine terrain on the continental divide in Rocky Mountain National Park.

Figure 1
General Map Locations of the Two Test Site Areas



GPS point data were logged for the Indian Cave (PNG) sites after each had been surveyed by University of Northern Colorado field crews (cf. Brunswig 1998). Standard archaeological survey techniques were used, with each site being covered by survey crew members walking them at 3 meter intervals. All artifacts and features were marked with pin flags for mapping and collection of artifacts. Two classes of spatial points were recorded during the GPS survey: 1) artifacts, features and test units, and 2) general topographic locations designed to “fill-in” the local site topography, on-site and in adjacent non-site areas. The Indian cave sites and their general descriptions included the following:

> 5WL2304-Located on a large extension of the bluff line, this site had an excellent horizon-to-horizon perspective of the surrounding terrain and exposure to the above line of orbiting GPS satellites. The exposed bedrock and shallow soil areas of the site surface contained dozens of artifacts and nine stone ring features, the latter representing the foundations of prehistoric tipi shelters.

5WL2308-This site is located in a small, protected and partly enclosed bluff canyon/valley just below 5Wl2304 at the base of the bluffs. Archaeological components included architectural foundation and depression (pit) remains from an earIy 20th Century homestead, a small number of prehistoric stone tools, and two stone rings (tipi foundations).

5WL241 7-This is an open camp with scattered artifacts on a eroding terrace knoll on the northern margins of a small stream known as Cedar Creek. Three test pits and three shovel tests were excavated on the site, revealing two cultural units extending from c. 10 cms to 60 cms below the modern surface. Artifacts, animal bone, charcoal, and fire-cracked rock recovered from the surface and test pits and shovel tests indicated the existence of a series of short-term camps spanning several centuries. Recovery of single biface tool, characteristic of the region’s Middle and Late Ceramic culture periods, suggested that an intermediate portion of the site’s occupation likely dated to between AD 1100 and 1400.

5WL2422-This is an extensive scatter of hundreds of historic and prehistoric artifacts and features on a gently sloping west-facing hillside immediately east of site 5WL2417 Part of the site had been used as a trash dump by focal inhabitants in theearly 20th Century. The oldest culturally diagnostic artifacts from the historic period were dated to c. AD 1900. Despite the recording and recovery of more than a hundred prehistoric artifacts, no chronologically/culturally diagnostic tools were found which could be used to date the prehistoric site component Several clusters of stone tools, fire-cracked rock, and hearths were found, representing ancient short-term camps.

The last archaeological site investigated using GPS survey methods was 5LRI 15-Trail Ridge Game Drive. 5LR15 is located on the eastern side of the continental divide immediately south of Trail Ridge road approximately 3 miles before it crosses the divide at Trail Ridge Pass. The site, with elevations ranging between 3465-3500 meters, was recently documented as part of a study of high altitude game drive sites in north central Colorado’s Front Range mountains (Benedict 1996: 7-20). It consists of three loose-masonry rock walls and five rock-lined game blind pits designed to funnel game from lower sub-alpine wooded areas up a steep saddle between two mountain knolls Radiocarbondating of charcoal, granite weathering studies, and recovered, culturally diagnostic projectile point types provided evidence that elements of the drive complex date from at least 3000 BC to as late as AD 1000. Discovery of a Paleoindian tool thought to date c. 6000 BC suggests drive construction may have begun as early as 8000 years ago.

A GPS survey of 5LR15 was undertaken as part of a multi-year archaeological inventory of selected study areas within Rocky Mountain National Park under contract with the U.S. Park Service. The survey provided important baseline information on the applicability of sub-meter GPS spatial data collection and precision topographic and archaeological feature mapping in high elevation mountain territories, in contrast to the above described high plains site locales.

ANALYSIS AND RESULTS OF GPS FIELD TESTS

As noted above, five archaeological sites in varying terrains were surveyed using GPS data logging. Table 1 summarizes key information on total areas covered (square meters and acres), number of points recorded, and number of positions per acre for each site. A total of 74.16 acres, or 301,118 meters^2, were surveyed at the five test sites. Areas for each site were determined by use of a Pathfinder software function which calculates both distances between points and physical areas covered by a site's recorded points-a useful tool for archaeologists.

Table 1
GPS Surveyed Area Data (per site and cumulatively), Number of Positions Recorded & Positions Recorded per Unit Area (by Site)

Site	$meters^2$	Acres	Points Recorded	Points per Acre	Total Recording Time	Recording Time per Point (Avg)
5LR15	150,100	37.09	144	3.9	184 min	1 min 17 sec
5WL2304	24,322	6.01	90	14.98	118 min	1 min 19 sec
5WL2308	28,409	7 02	69	9.81	57 min	50 sec
5WL2417	22,703	5.61	58	10 34	64 min	1 min 6 sec
5WL2422	75,584	1843	193	10.47	388 min	2 min 1 sec
Totals	301,118	74.16	111(Avg)	9.9(Avg)	-----------	1min19 sec

Spatial points recorded for the sites ranged between 193 and 58, with an average of 111 per site Data logging times per site varied from 388 to 57 minutes. Average recording times per point for individual sites ranged from as high as 2 minutes 1 second to as low as 50 seconds. Point logging times, however, were intentionally varied from site to site to determine if longer or short collection times (number of positions recorded per point) would affect position precision. Data logging times were also affected by travel time between logging points (a terrain-dependent variable, rougher terrain required more travel time) and time involved in recording data dictionary information for each point. It was, however, concluded that point data logging times in most terrains could easily average well under a minute per point, depending on the relative size and topographic complexity of the site being surveyed. This logging time compares favorably with standard transit and Electronic Distance Measure (EDM) methods used by the author. Further, the GPS approach only requires a single operator where other methods require two or more personnel. Another advantage to using

GPS over more conventional surveying instruments is that, in extremely rough or vegetated (forest, etc.) terrain, conventional instruments, requiring line-of-sight contexts, have to be re-positioned frequently using valuable field time. The GPS operator simply moves over the landscape wherever topographic or archaeological feature and artifact points need to be recorded.

Table 2 shows data comparing coordinate point standard deviation (δ) averages for uncorrected and differentially corrected data sets for three of the study's test sites.

Table 2
Experimental Data on Uncorrected vs. Differentially Corrected GPS
Site Position Data Sets

Site	Positions Per Point	No of Points	S.D. (δ)* Uncorrected (meters)	S.D. (δ) Dif. Cor # (meters)	2 S.D (δ) Dif. Cor.# (meters)
5LR15	3.3	144	3.817	.21817	.4393
5WL241	41	58	3.2621	.0844	.1689
5WL242	54	193	3.9582	.0784	.1568

***S.D. refers to standard deviation, a calculated value representing the "widest" cluster of spatial values per position provided by the Trimble Pathfinder GPS software. S.D. provides a close statistical approximation of the accuracy of GPS positions and a means of evaluating each position's relative precision. S.D. precision is best for horizontal coordinates, although field tests suggest that vertical (elevation) data seldom exceed a doubling of the actual position values, and, in most cases, are nearly identical with those values.**
****Standard deviations for these sites are based on an averaging of real-time corrected GPS data logging using the OMNISTAR differential correction satellite uplink system. OMNISTAR corrected positions were also "re-corrected" using a regional base station correction data set to determine if further precision could be gained by using post-processing differential correction.**
#Single, one sigma, standard deviation averages based post-processed, differentially corrected position data.
##Doubled, or two sigma, standard deviation averages based on post-processed, differentially corrected position data.

Comparison of the three sites with uncorrected (raw) GPS data with their subsequent post-processed results indicates a significant gain in positional precision. The high elevation mountain site's (5LR15) average of uncorrected, field point values was ±3.817 meters. That site's differentially corrected standard deviation average (at 1δ) of the same points was ±.21817 meters, achieving an accuracy of under a half meter. Two plains sites, 5WL2417 and 5WL2422, had even more impressive increases in post-processed accuracy. Site 5WL2417, situated on a low terrace along a shallow creek, had an averaged uncorrected standard deviation of ±3.2621 meters. Its differentially corrected average was an impressive ± .0844 meters, or less than 17 cm. Site 5WL2422, located on the mid to lower, west-facing slope of a large hill, produced an uncorrected average of ±3.9582 meters, but when its GPS points were differentially corrected, yielded an even more impressive average of ±.0784 meters-under 16cm.

Results of the above field tests compare favorably with other studies using roughly comparable GPS systems, although not in similar topographic contexts. U.S. Forest Service researchers working in the northwest coast's Mount Hood National Forest used an earlier model Trimble ProXL unit which produced horizontal positions averaging ±1.34 meters under a forest canopy (Jasumback 1996: 4). A recent study of sub-meter GPS surveying at archaeological sites in Hawaii reported levels of accuracy between 20 and 70 cm, although precision was severely diminished in conditions of thick vegetation (Ladefoged, Graves, O'Connor and Chapin 1998). The overall higher precision of spatial data generated by this study, however, is largely attributable to the use of a more advanced Trimble GPS unit (the 12 channel ProXR) and more open, horizon-to-horizon environments of northeastern Colorado's high plains and high mountains.

Data for the study's remaining two test sites, 5WL2304 and 5WL2308, are shown in table 3. As in Table 2, differentially corrected values are shown at both one and two standard deviations. The second and third columns show real-time (OMNISTAR) differentially corrected data for those sites while the last two columns in the table show a second set of *post-processed* averages at one and two standard deviations. In short, the initially field-logged, real-time (OMNISTAR) corrected data for the sites were differentially corrected a second time to determine if a second post-processed differential correction would improve the initial real-time corrected values.

Table 3
Comparison of Real Time (OMNISTAR) and
Post-Processed Averaged Position Accuracy

Site	R.T-1 S.D. (δ) (meters)	R.T-2 S.D. (δ) (meters)	PP-1 S.D. (δ) (meters)	PP-2 S.D (δ) (meters)
5WL2304	.2853	.5706	.2092	4183
5WL2308	.1340	.2679	.1258	.2516

Real-time position averages for the bluff-top site, 5WL2304, were sub-meter at ±.2853 meters, but that value was not as precise as post-processed averages for the other two Indian Cave's sites cited above. Post-processing 5WL2304's real-time data set resulted in an increase in accuracy to ±.2092 meters, an improvement of 27%. For some reason, possibly the time of day (related to satellite orbit variables) when logging took place, the site with the poorer horizon-to-horizon perspective at the base of the bluff line, 5WL2308, produced a more precise real time data set average. That standard deviation average, at ±.1340 meters (1 δ), was less than half that calculated for 5WL2304.

Further, post-processing of the site's real-time data resulted in only a marginal increase in averaged point precision to ±.1258 meters.

Remote real-time differential correction using the OMNISTAR "virtual base station" service compares favorably with results documented elsewhere. Huff (1995) notes that earlier OMNISTAR-corrected GPS position logging yielded accuracy on the order of ±.30 meters for horizontal coordinates and ±.60 meters for elevations. Forest Service researchers reported similar sub-meter results of ±.48 meters (horizontal) and ±.62 meters (elevation) for surveys in Louisiana's Kisatchie National Forest using a differential correction broadcast beacon at Vicksberg (Jasumbuck and Luepke 1996).

A broad comparison of the relative accuracy of the OMNISTAR real-time correction method with uncorrected GPS data is illustrated in Table 4 which shows standard deviation averages for both types of data from the Colorado test sites. The table lists single standard deviation values for maximum (the highest S.D. of each data set) and minimum (the lowest S.D. in each data set) S.D. positions and the average value of all positions in each data set. Uncorrected averages ranged between ±3.262 and ±3.958 meters while real time averages using OMNISTAR were ±.2853 and ±.1339.

Table 4
Comparison of Unprocessed vs. Real Time (OMNISTAR) Differential Corrected GPS Data Sets (Averages)

Site	GPS Data Class	Maximum-1 S.D. (meters)	Minimum-1 S.D. (meters)	Data Set Avg. (meters)
5WL2417	Uncorrected	22.16	.379	3.817
5WL2304	Real Time Corrected	13.685	.076	.2853
5WL2308	Real Time Corrected	.369	.037	.1339
5WL2417	Uncorrected	9.087	.8	3.262
5WL2422	Uncorrected	31.161	183	3.958

Mapping and Landscape Modeling of Archaeological Sites Using GPS Data

A final method of assessing the utility of sub-meter GPS data for archaeological purposes was the export of differentially corrected data sets to mapping and GIS programs. Although all the sites in the study were experimentally mapped and analyzed using the SURFER computer program, only two of the sites, one in the mountain research area and one in the plains research area, are discussed here. Probably the most impressive example of the utility of sub-meter GPS data in an archaeological application was that of the high altitude Trail Ridge game drive site. Sub-meter coordinate data for the game drive site were exported and processed into appropriate ASCII text (or data) files for conversion and display in the SURFER mapping program-a program commonly used by archaeologists. Two types of data files were constructed; one containing *all differentially corrected points* for the site (an X,Y,Z data set), and three-dimensional (X,Y,Z) point data on specific archaeological and environmental features. Each feature type (i.e. walls, game blind pits, etc.) was given a pre-set symbol number in one of the data worksheet columns. Individual features were also labeled in another data worksheet column. SURFER employs these types of data sets to generate contour and 3-dimensional surface maps which can then be overlaid (posted) with feature symbols and labels.

Results of the game drive mapping exercise are shown in figures 2 and 3. The resulting contour and 3-dimensional surface maps of the game drive site (5LR15) were generated by SURFER from sub-meter GPS point data collected during a 184 minute survey period by a single individual. The maps in the figures represent two-meter contour intervals, although, given the sub-meter precision of the GPS data, the maps could have been created with resolutions under a meter. Both maps were overlaid with analytical information such as locations and orientations of archaeological game drive features (walls, blinds, etc.), environmental conditions (krumholz or sub-alpine fir forest areas), portions of an ancient game trail, and location of the site's primary datum. With minor modifications, graphic symbols could added to show water drainage and seasonal wind flow patterns, all factors useful for interpreting the function and conditions surrounding the use of the game drive system over the past several thousand years.

Figure 2
Contour and Feature Overlay Map of 5LR15

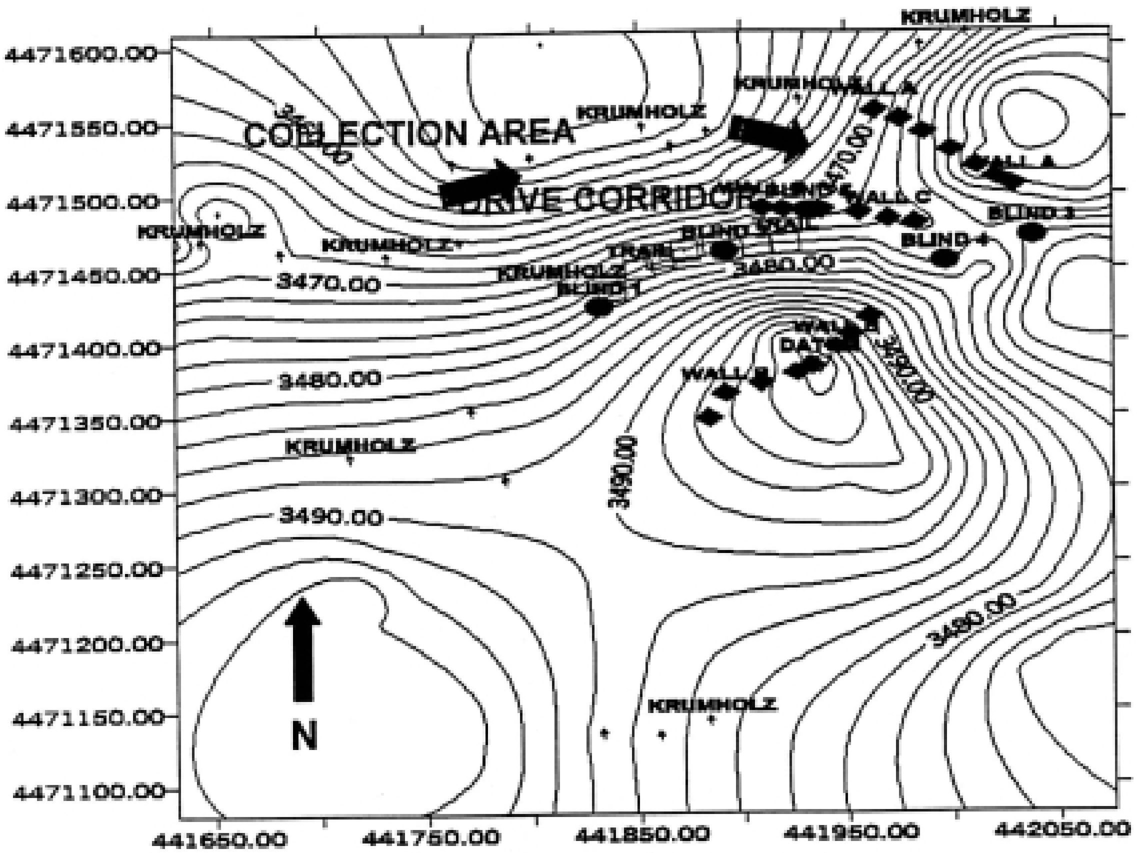
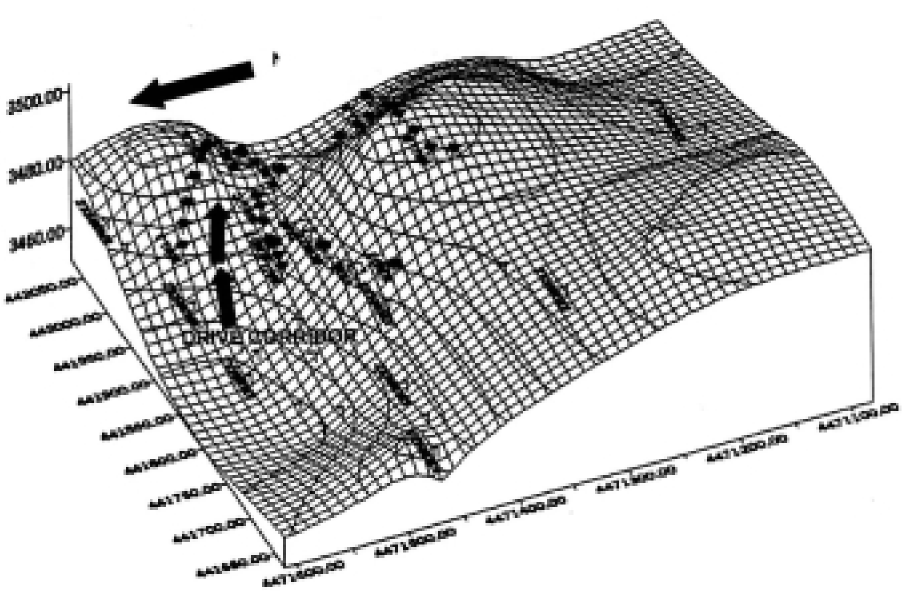


Figure 3
Surface 3-Dimensional and Feature Overlay Map of 5LR15



The current U.S G.S. 7.5 minute topographic map of the 5LR15 site area provides a topographic map resolution of 1:24,000 with 40 foot contour lines. A Digital Electronic Map (DEM) version of the same map has the same low 40-foot contour resolution and provides insufficient accuracy and resolution for reconstructing (mapping) terrain subtleties needed to better define environmental factors related to the construction and operation of the drive system. However, sub-meter GPS-based maps, as shown in the above figures, clearly provide superior graphic evidence of factors involved in the drive's operation as they are related to local topographic and environmental conditions. Even greater accuracy could be achieved using EDM laser surveying instruments, but at much greater cost in time and convenience. However, it suggested that spatial resolution higher than the ± .218 meter average acquired in the 5LR15 GPS survey is unnecessary for quality landscape research at such sites.

Figures 4 and 5 are contour and 3-dimensional surface maps generated from sub-meter data sets for site 5WL2417 in the Indian Caves research area. The site, as described previously, consists of shallow, multiple deposits and scattered surface remains of several centuries of seasonal hunter-gatherer camps on a terrace knoll and creek bank. The SURFER maps show both horizontal contours and a 3-dimensional projections of the site and its immediately surrounding area with superimposed locations and symbols of artifacts, test pit (T1..) and shovel test (ST..) locations, and the site's primary datum Data logging of feature, artifact, and topographic points was done in slightly more than an hour (64 minutes) and the differentially corrected data made possible a site map in two and three dimensions with .5 meter contour resolution. Standard transit and laser EDM methods could have been done in the relatively open site terrain in an equivalent amount of time with greater precision, but with slightly more effort since those methods would have required at least a two person survey team. However, the GPS maps provide more than adequate spatial resolution and quality mapping data for all but the most demanding archaeological survey documentation needs. In fact, given that most site surveys involve the drawing of simple sketch maps, usually made with Brunton compasses and measuring tapes, sub-meter GPS data logging and computer mapping is considered by this author to be a faster and more efficient means of documenting the vast majority of sites encountered in standard archaeological survey projects.

Feature 4
Contour Feature & Artifact Overlay Map of 5WL2417

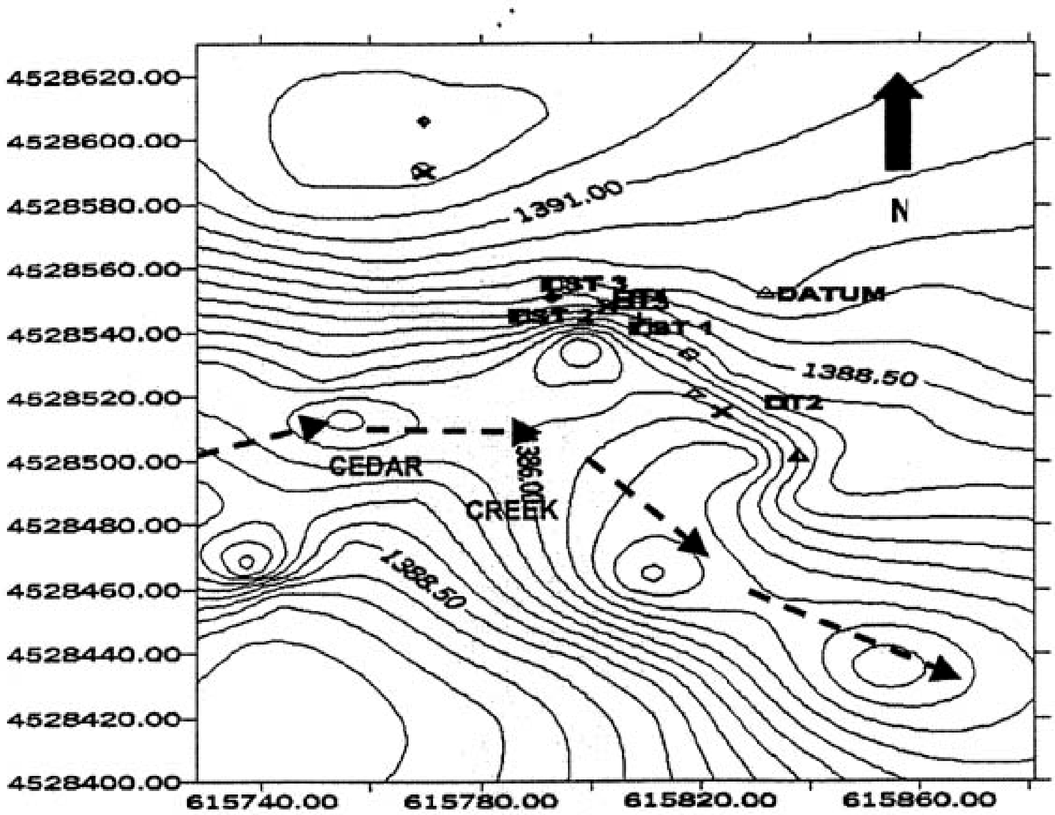
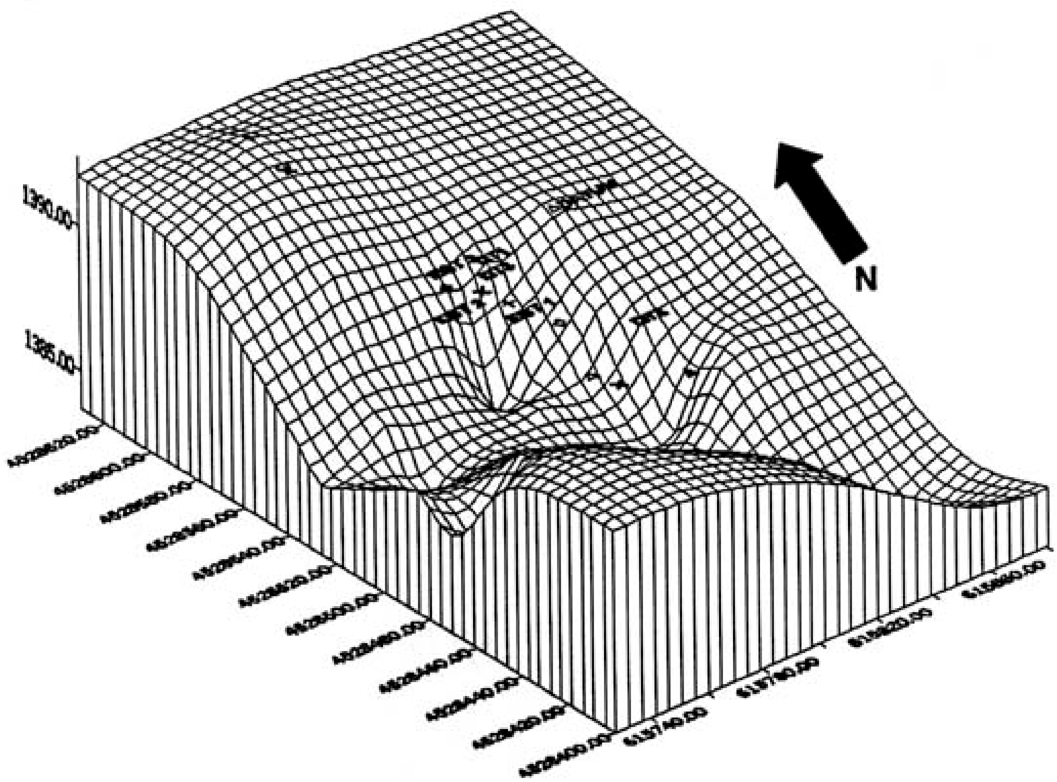


Figure 5
Surface 3-Dimensional Feature & Artifact Overlay Map of 5WL2417



ASSESSMENT OF THE APPLICABILITY AND POTENTIAL OF MAPPING GRADE GPS TO ARCHAEOLOGICAL DATA COLLECTION

This study's investigation into archaeological field applications of GPS hardware and software suggests that mapping grade resolution (sub-meter) GPS instruments can rapidly collect large numbers of spatial data points three-dimensional precision of ±10-30 centimeters for topographic, environmental, and archaeological site variables. Open environmental conditions, such as the rolling plains and unforested mountains and valleys of northeastern Colorado, are particularly amenable to the use of mapping grade GPS systems for archaeological applications. Both post-processed and real-time differentially corrected GPS data sets in such environments provide reliable sub-meter point data for use in advanced computer mapping and graphics-based analysis (i.e. GIS) programs. Resulting mapping grade spatial data sets, downloaded into mapping programs such as SURFER or GIS programs such as IDRIS or ARC-INFO, provide the basis for graphical and statistical analysis and modeling of archaeological, and associated natural, landscapes of both small and large archaeological sites. Two particularly outstanding benefits of mapping grade GPS technology in archaeology are time savings in mapping sites during large-scale surveys and quickly (and more easily) collecting high resolution mapping data in remote and rugged terrain.

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APPENDIX A:
ASCII PROGRAM CODE SUMMARY OF THE FINAL ARCHAEOLOGICAL DATA DICTIONARY VERSION

The data dictionary can be edited in any word processor program and downloaded into GPS software and subsequently downloaded into the GPS data logger for field use It is present for logging each position and, using the pull-down menus, be used to record specific information for those positions Individual notations can also be recorded for each position in addition to selection of the pre-programmed menu items.

```
"UNC Archaeology GPS", Dictionary

"site primary datum", point

    "remarks", text, 100

   "date", date, auto, mdy, not_permitted
   "time of data collect', time, auto, 24, not_permitted
"site type", point
   "site type", menu, "open camp"
      "sheltered camp"
      "rockshelter/cave"
      "lithic quarry"
      "sandstone quarry"
      "lithic scatter"
      "ceramic scatter"
      "ridge game drive"
      "cliff jump"
      "arroyo/canyon kill"
      "animal/plant processing"
      "burial"
      "look-out"
      "other see remarks"
   "remarks", text, 100
   "date", date, auto, mdy, not_permitted
   "time of data collect", time, auto, 24, not_permitted
"site feature", point
   "site feature", menu,
      "gen tool concentration"
      "bone concentration"
      "simple hearth"
      "pit hearth"
      "rock lined hearth"
      "storage pit"
      "boiling pit"
      "rock wall"
      "rock alignment"
           "game blind"
           "vision quest"
      "work table"
      "post hole"
      "stone ring"
```

"pitstructure"
"burial"
"plant process tools"
"butchering toots"
"flaking debris concentration"
"rock cairn"
"footers pit"
"burrow"
"natural erosion profile"
"tree/bush"
"other see remarks"
"remarks", text, 100
"date", date, auto, mdy, not_permitted
"time of data collect", time, auto, 24, not_permitted
"site artifacts", point
"artifact types", menu,
"full projectile point"
"partial projectile point"
"metate"
"mano"
"scraper"
"pottery"
"chopper"
"hammerstone"
"biface knife"
"drill"
"spokeshave"
"graver"
"abrader"
"flake"
"core"
"fire cracked rock"
"bone, general"
"bone tool"
"other see remarks"
"remarks", text, 100
"date", date, auto, mdy, not_permitted
"time of data collect', time, auto, 24, not_permitted
"test pit nw corner", point
"test or grid designation", menu,
"test pit number see remarks"
"excavation grid see remarks"
"remarks", text, 10
"date", date, auto, mdy, not_permitted
"time of data collect", time, auto, 24, not_permitted
"gen topo cont pt", point
"remarks", text, 100
"date", date, auto, mdy, not_permitted
"time of data collect", time, auto, 24, not_permitted
"origin point water source", point
"remarks", text, 100
"date", date, auto, mdy, not_permitted
"time of data collect", time, auto, 24, not_permitted
"mod cultural feature", point
"remarks", text, 100
"date", date, auto, mdy, not_permitted

“time of data collect”, time, auto, 24, not_permitted
“primary vegetation”, point
“remarks”, text, 100
“date”, date, auto, mdy, not_permitted
“time of data collect”, time, auto, 24, not_permifted
“stream”, line
“order classification”, menu,
“first order”
“second order”
“third order”
“fourth order”
“fifth order”
“other see remarks”
“date”, date, auto, mdy, not_permitted
“road”, line
“remarks”, text, 100
“date”, date, auto, mdy, not_permitted
“time of data collect”, time, auto, 24, not_permitted
“fence line”, line
“remarks”, text, 100
“date”, date, auto, mdy, not_permitted
“time of data collect’, time, auto, 24, not_permitted
“rock alignment”, line
“remarks”, text, 100
“date”, date, auto, mdy, not_permitted
“time of data collect”, time, auto, 24, not_permitted
“vegetation”, area
“vegetation zone”, menu,
“short grass prairie”
“medium & tall grass”
“brush”
“woodland”
“pine forest”
“aspen forest”
“spruce/fir forest”
“riparian”
“tundra”
“other see remarks”
“date”, date, auto, mdy, not_permitted
“time”, time, auto, 24, not_permitted
“site polygon”, area
“site id number”, menu
“see remarks”
“remarks”, text, 100
“date”, date, auto, mdy, not_permitted
“time of data collect’, time, auto, 24, not_permitted
“water feature”, area
“water type”, menu
“spring basin”
“playa”
“permanent pond”
“permanent lake”
“other see remarks”
“remarks”, text, 100
“date”, date, auto, mdy, not_permitted
“time of data collect”, time, auto, 24, not_permitted