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Interfaces: Mobile GIS in archaeological survey

MOBILE GIS IN ARCHAEOLOGICAL SURVEY

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You are surveying a broad, featureless plain and the planned coverage area is delimited in a Geographic Information System (GIS), but how do you rapidly locate your starting position and line up your survey crew with few landmarks? Your Global Positioning System (GPS) will get you to the survey area, but figuring out the coordinates is time consuming. Ideally, local maps and imagery, the survey coverage area, and yesterday's coverage are available on a screen with your current GPS position indicated.

You have discovered a site consisting of lithic concentrations of different material types, and each looks like a distinctive reduction event, but you only have 45 minutes to record and collect at the site. Using common GPS methods, you can map each concentration as a polygon feature, assign an ID number to it, document and collect it, and attribute it later. Alternately, you open the "lithic locus" geometry in a mobile GIS and map in each concentration. The GIS assigns a new ID number to the locus, and the collection bag from that locus is labeled accordingly. After mapping the locus, a digital form appears and requests summary information about the locus, the environmental context, digital photo numbers, and other relevant information. These data accompany the locus polygon back to your laboratory GIS system, where the feature geometry, data tables, digital photos links, and laboratory results from the analysis of the collection are integrated into a single GIS record by the unique ID number assigned to that artifact concentration.

Enter Mobile GIS

These capabilities are available in present-day mobile GIS. Affordable mobile GIS technology is the result of a convergence between personal electronics, satellite navigation systems, and new GIS software integrated across various scales of hardware from workstations to handheld units. And for data-intensive field studies like archaeology, future improvements hold even more possibilities. For example, if digital calipers and scales had a local wireless (e.g., Bluetooth) connection, rapid analysis in the field for non-collection studies would be possible. Spatial statistics in the field would allow users to explore digital spatial data in real-time and improve their methodology in an iterative manner. There are notable limitations, however, to adopting a mobile GIS approach in 2004, and therefore what follows is a summary of both the successes and the obstacles encountered during recent survey work conducted using mobile GIS.

Archaeologists have long realized benefits from using GIS to manage, analyze, and summarize regional archaeological survey data. Whether the survey design is targeting specific environmental contexts or attempting to meet statistical sampling goals, existing GIS approaches play strongly to the scale and data-management needs of many archaeological survey projects (Banning 2002; Kvamme 1999; Wheatley and Gillings 2002). However, after several decades of GIS applications in archaeology, it is recognized that a principal limitation is in the acquisition and assimilation of new digital data into a GIS structure.

GPS technology considerably simplified the spatial positioning of archaeological resources. Many recent low-cost GPS units provide approximately 5-m accuracy, so a trained user can record a variety of geometry types associated with archaeological phenomena and bring those data back to a lab-based GIS system with a minimum of costs and complications. Given the accuracy of a simple GPS approach, why would archaeologists want to bring a miniature GIS computer into the field?

The potential contribution of mobile GIS to survey fieldwork should be considered in three categories: data acquisition, management, and analysis. First, mobile GIS offers a faster, more flexible, and potentially comprehensive data-attribution method compared with the existing GPS "data dictionary" approach. For managers and researchers, the ability to query and explore large digital datasets while in the field is useful for resource management and field data checking. Finally, in-field spatial statistics of new data combined with existing datasets are still at a nascent stage, but this technology promises to empower field researchers and improve the available information for conduct-

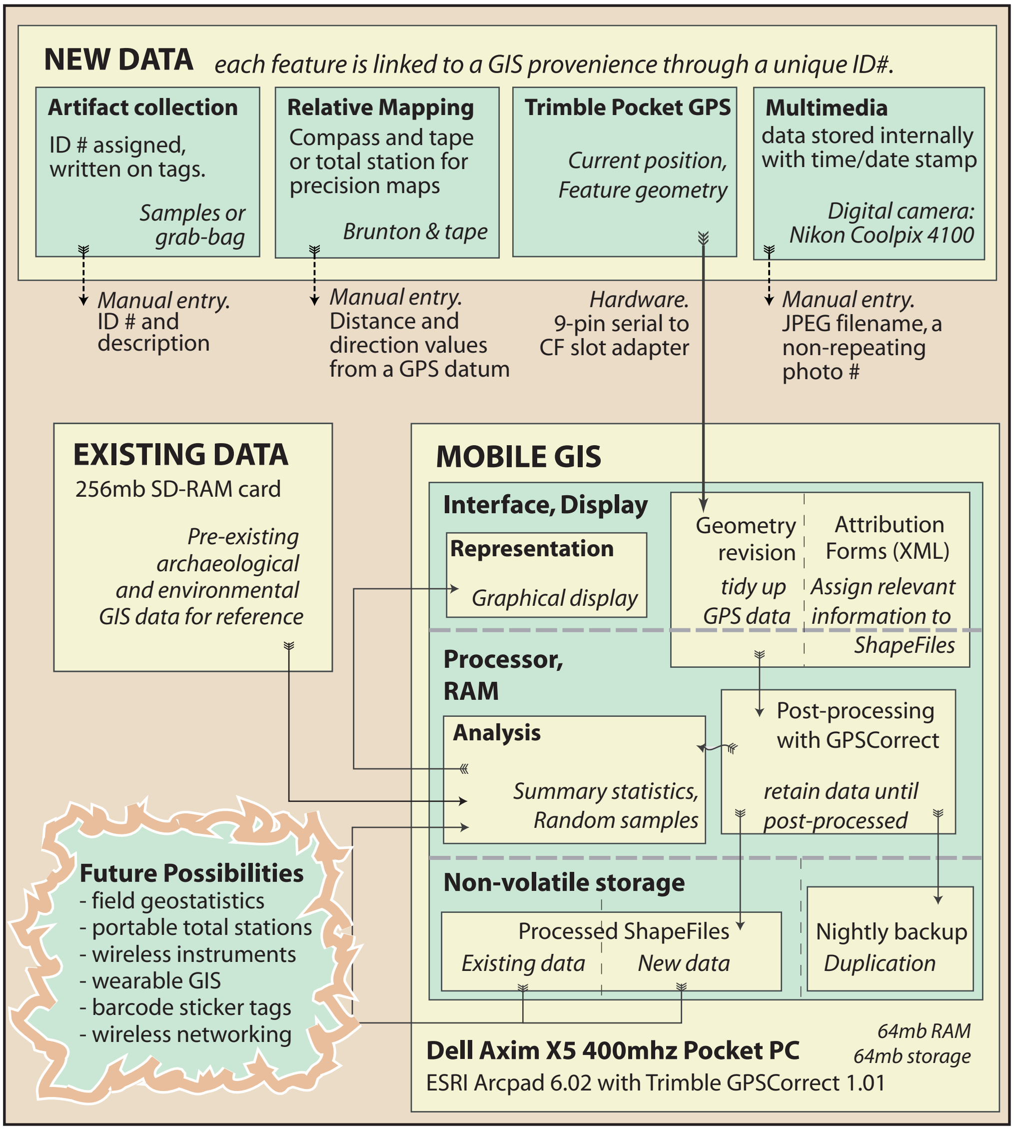

Figure 1: Mobile GIS implementation with ESRI Arcpad 6. New data sources are shown in top row, but currently only the GPS has a direct connection to Pocket PC; other values are entered manually. Where post-processing is needed, new data are not integrated with other data until later. New and existing data can be summarized and displayed together.

ing high-quality fieldwork.

In our implementation of mobile GIS on archaeological survey, the system was primarily intended to record lithic and ceramic artifact concentrations, but the survey also encountered ancient architecture, roads, and other forms of cultural remains that all had to be accommodated. The research software and hardware consisted of ESRI Arcpad 6.02 running on a Dell Axim x5 400 MHz PocketPC (Figure 1). GPS data were provided by a Trimble Pocket GPS connected via a Serial-Compact Flash adapter and were post-processed using Trimble GPSCorrect 1.01 and Pathfinder Office 2.9 software. Hardware costs amounted to $800. If the budget permits, a pair of more rugged, one-piece systems offered by Trimble (the GeoXM/XT) is recommended, although these begin at $2500 apiece.

A mobile GIS such as Arcpad will also run on a laptop or a tablet PC, and the larger screen area would be beneficial. However, there is an important distinction to be made between PCs that are hard-drive based and those that run the operating system and data from RAM. Hard drives provide more megabytes of space and the hard drive will retain saved data even if all power is lost, but they also require booting up and consume much more power. Most handheld computers do not contain hard drives and in addition to being energy efficient, they can start up very quickly. For applications where extremely lightweight equipment isn't demanded, such as excavation, intensive mapping, or geophysical survey, a tablet PC or laptop running a complete GIS may be preferable. Mobile GIS has limitations; for example, feature editing is rudimentary, and a tabular view of data sets is unavailable in the current version of Arcpad. If the data need extensive reviewing or editing in the field, a full-blown GIS is more suited to the job. The emphasis with mobile GIS is on data acquisition and limited analysis coupled with portability and efficiency.

Fieldwork Preparation

ESRI Arcpad 6 can be used straight out of the box for a suite of basic features akin to those available in a more elaborate GPS unit. However, making the most of Arcpad requires a significant amount of pre-fieldwork preparation. First, GIS data covering regional cultural and environmental themes should be assembled. Projects using GIS probably already have such data. Local topographic data, such as a digital elevation model and derived data such as contour lines, high-slope areas, and hydrology, are particularly helpful. Other digital reference data might include satellite imagery, scanned local maps, and scanned data from prior archaeological research. Updating everything to a modern map datum such as NAD83 or WGS84 is recommended.

Mobile GIS computers are limited in both processing power and data storage, so a local subset of both the raster and the vector layers is commonly cropped out of the larger GIS database so that just the data for the research area are loaded into the mobile GIS. Additionally, the vector datasets that will be edited and later re-integrated into the larger database must be "checked-out," a process that gets significantly more complex when multiple mobile GIS units are in use during a single day. Fortunately for ESRI users, the Arcpad Tools for ArcMap takes care of the data cropping and check-out/check-in issues.

Prior to beginning fieldwork, digital data forms should be thoughtfully designed with the larger goals of the project in mind, just as is done with the paper forms used in conventional survey methods. However, because mobile GIS forms are limited by small screen size and slow typing speeds, fast and space-efficient interface controls, such as pull-down menus, are widely used (Figure 2). In Arcpad, digital forms are based on XML and VBScript. In preparation for recent fieldwork, it took me over a month, as a reasonably experienced GIS end-user, to design the forms and to learn how to control the behavior of forms reliably using VBScript. Arcpad Application Builder 1.01 facilitates the layout of forms, but this release is still relatively unpolished. Ultimately, third-party XML and VBScript editors were the most useful tools for form scripting, and the most valuable script material was modified from code available on the Arcpad user-group website. Because it is often difficult for archaeologists to anticipate the kinds of data that will be recorded, a challenge in preparing digital forms is making them general enough to accommodate wide variability in phenomena, yet narrow enough to be attributed quickly and to generate relevant and comparable data categories.

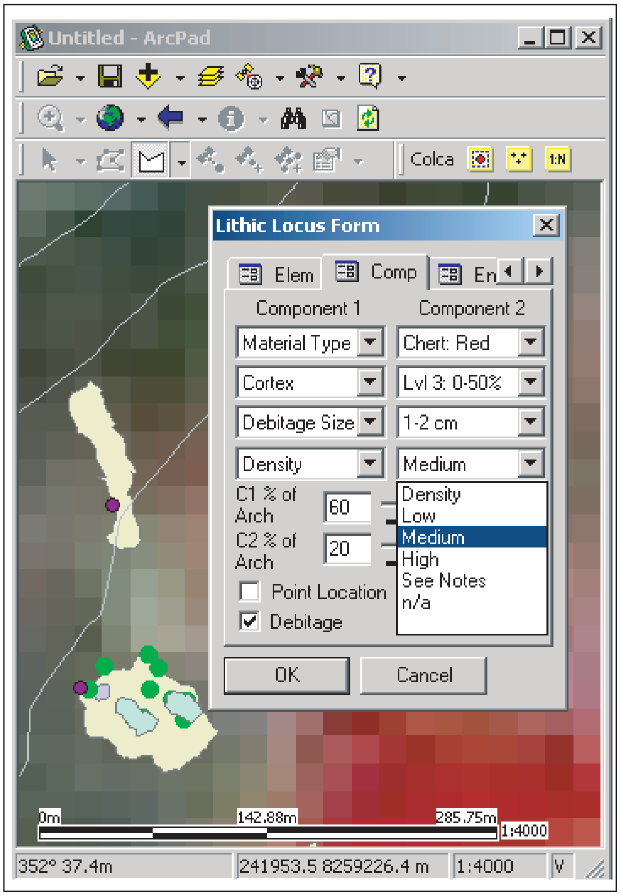

Figure 2: Example of a lithic locus form in Arcpad. In the background, two sites and contour lines are displayed on top of an ASTER scene.

In anticipation of fieldwork, the entire hardware and software workflow should be tested in hypothetical recording scenarios, battery consumption should be studied, and data-backup strate-

(a) Shapefiles and XML forms appropriate to data type

Type \ Data	Point Position	Line / Polyline	Polygon / Area
Sites *Site-level features*	**Site-P** *Site datum, mapping sub-data.*	~	**Site-A** *Site boundaries.*
Lithics *Stone artifacts*	**Lithic-P** *Diagnostic projectile point locations.*	~	**Lithic-A** *Lithic locus boundaries.*
Ceramics *Pottery*	**Ceramic-P** *Diagnostic ceramic locations.*	~	**Ceramic-A** *Ceramic locus boundaries.*
Structures *Architecture or natural shelters*	**Structure-P** *Diagnostic structural features, structure map sub-data.*	**Structure-L** *Terraces, walls, rockshelter entrances, rock art panels.*	**Structure-A** *Enclosures, structures.*

(b) ID# Provenience System

105	- **Site-A "Mayemeja"**
106	- Ceramic-A, locus in 105
106.1	- *7 black on red sherds*
106.2	- *13 undecorated sherds*
106.3	- *5 chert flakes*
107	- Struct-A, locus (corral) in 105
107.1	- *4 undecorated sherds*
107.2	- *7 obsidian flakes*
108	- Lithic-P, Isolated Proj. Pt
109	- **Site-A "Taukamayo"**
110	- Struct-L, rock shelter in 109
111	- Ceramic-P, fine rim sherd
112	- **Site-A "Pokomoko"**
112.1	- *5 cortical obsidian flakes*

Figure 3: (a) Archaeological Shapefile names and descriptions. Each of the Shapefiles had a form associated with it that prompted the user with fields appropriate to that data type. (b) An example of a part of the ID # system that prioritizes spatial provenience in the field. Inventory numbers for collections (after the decimal) were assigned later in the laboratory.

gies considered. In the field, Arcpad data can be backed up to non-volatile Flash RAM cards or synched to a laptop. As an extra safety precaution, we backed up all data from each field outing to a new folder named for the date. A CD containing digital photos, Arcpad data, and other new digital datasets was burned weekly.

Surveying

The data-display capabilities on a mobile GIS can facilitate survey in a variety of ways. Although the capabilities aren't necessarily new, they are simpler and faster than was previously possible with a GPS and a paper map. A survey team can have field access to the equivalent of many kilograms of paper survey reports and maps in the new digital, searchable form as layers in their GIS. It is also advantageous that updated data layers can be easily brought into the field, so Team A can have Team B's site data and survey coverage from the previous day available as a layer in their mobile GIS. Eventually, wireless networking might bring real-time progress updates to all teams in the survey.

If the budget permits, a pair of GPS units like the Trimble GeoXM could be carried on either end of the survey line. The units could be mapping the entire survey coverage into line geometry in Arcpad and the display could simultaneously be used by each end-person for guiding the survey progress. The two mapped lines could be joined later into polygons, and if the number of surveyors is also recorded with each line record, real quantification of the thoroughness of survey coverage is possible—coverage rates are a statistic that is frequently overestimated.

Site and Locus Recording

The data-management capacity of mobile GIS makes "siteless" survey more feasible than ever before, although the time commitment required in handling and mapping large numbers of individual artifacts in the field still seems prohibitive. While doing recent survey work, we recorded isolated artifacts, but the emphasis was placed on recording loci that, by definition, fell inside of sites.

Archaeological distributions were mapped using a suitable GIS geometry type (Figure 3a). Individual artifacts and concentrations smaller than 2 m, the average accuracy of our GPS after post-processing, were recorded as points, linear features were recorded as lines, and two-dimensional phenomena were recorded as polygons. As an example, the two hypothetical sites in Figure 4 both could have been recorded in less than one hour, but greater intra-site structural detail becomes possible through mobile GIS recording in an equivalent amount of time.

A single ID number system transcended all nine files (Figure 3b), which simplified keeping track of the provenience of collections and photographs. As compared with traditional, more descriptive forms of proveniencing, this system can make it a little more difficult to figure out what kind of data a given provenience refers to. For example, a fieldworker writing tags might ask "was this rim sherd we found #110, or was #110 the rock shelter?", and someone would have to refer to the mobile GIS to find out. In practice, site names also were assigned simply because names are more memorable. However, computer databases work best with unique ID numbers, and so if archaeologists can record their data into a single number series, then all

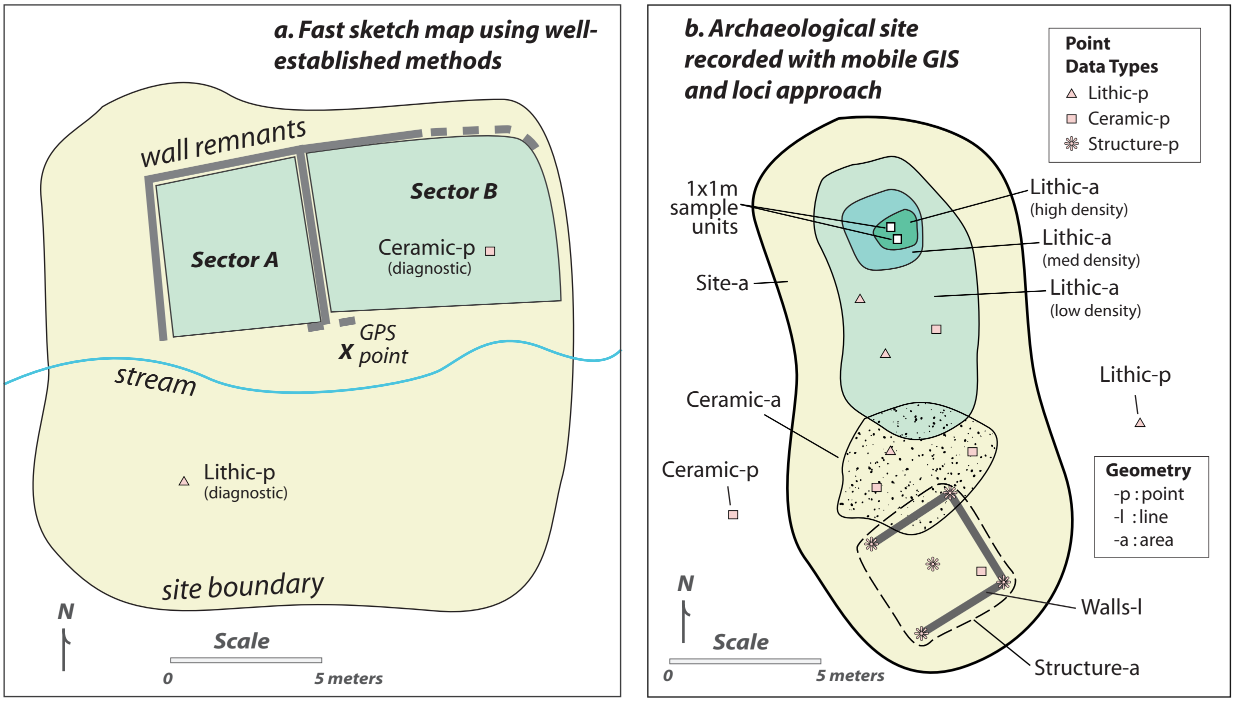

Figure 4: Maps for hypothetical sites recorded in less than one hour. (a) A conventional sketch map showing only general site features and site sectors in their approximate positions (b) Mobile GIS site map with 1–2-m dGPS error. Internal distributions, such as the fried-egg density gradient model shown here, can be assessed and rapidly mapped.

the advantages of a database system become available for subsequent analytical tasks. During the ensuing laboratory analysis, individual artifacts and groups of like artifacts were assigned inventory numbers for tracking them through later analysis and labeling, shown after the decimal in Figure 3b. In this system, spatial provenience is paramount, regardless of geometry type, so that data can be moved around easily during analysis and provenience is not lost. This system leaves the task of maintaining spatial relationships to the GIS.

During survey work, when a newly found site was initially evaluated, team members would fan out with pin flags and review the archaeological materials. The site boundary would be mapped first by walking around it with the GPS running, and the site would receive the next available ID# in the series with data from within the site receiving successive numbers (Figure 3b). Next, the mobile GIS user would visit each feature with the person who documented it and record it. For a lithic locus, this would involve first mapping it to create a GIS polygon, and then a custom Arcpad form would appear that permitted the user to describe the feature primarily using pull-down menus. Each team member also had a field notebook and he/she could take notes about features using the same ID# reference system. These personal notes were available as a complement to the form-based recording system.

On the whole, the mapping accuracy is not greater than was formerly possible with merely a GPS. A rapid but detailed map can be made with a GPS using ID numbers, but in the long run, in-field attribution saves an enormous amount of time and reduces errors. In addition, users are forced to reconcile the archaeological data with the GIS classification system while they are still in the field, improving the link between the original data and the GIS datasets. A "Comments" form was available with every record for unanticipated descriptive text, with a button linking the Comments form to an independent text editor. Voice comments could be recorded as small MP3 files by the PocketPC and linked to individual GIS records by the ID#, although in practice this still demanded too much from the processor of the handheld computer.

VARIABILITY WITHIN LOCI. We defined loci as areas of higher densities of like artifacts, but these areas were rarely homogeneous. Documenting the variability within a locus quickly is particularly difficult and is an issue that is usually addressed through sampling. However, even limited sampling is time-consuming. We were looking for a method of describing variable artifact concentrations that were not worth sampling but that should be recorded nonetheless. A compromise solution was devised whereby the principal and secondary components of a locus were defined, and the variability was described by estimating Component 1 and Component 2. For example, suppose that the main "axis" of variability within a lithic locus is Material Type, with mostly obsidian flakes and some chert. The locus will be mapped, and in the locus form (Figure 2), Component 1 will be Obsidian, Component 2 will be Chert, and then an estimate of the representation described by Component 1 or Component 2 is made. For analytical clarity, if there was also variability in average size of flakes, for example, that contrast would be documented by recording a wholly different polygon. This method lacks statistical reliability; different analysts are likely to record the same concentration differently. However, given the time constraints on survey and the oft-mentioned weaknesses of surface data, such as poor temporal control, visibility bias, and other limitations, we felt that this expedient method was justified.

SAMPLING. Time permitted sampling only at high-density loci. Cluster sampling was accomplished by using 1x1-m collection units within which 100% of artifacts were collected. After a locus was mapped, the polygon size (m^2) was available in Arcpad and, depending on the size of the polygon, a number of random 1-x-1-m sample locations were generated using the Arcpad script "Sample Design," which offers an unaligned grid method.

HIGHER-RESOLUTION SPATIAL DATA. The limited accuracy of GPS becomes evident with any measurements under a few meters apart, and the limitations of these data are especially obvious when mapping architectural features. As a full Total Station could not be carried on survey, a provisional datum point was recorded with GPS and relative measures with Brunton and tape were taken from that datum. However, fields like geology have created a market for portable total stations. Ideally such equipment could communicate directly with Arcpad so that features mapped from a datum could be attributed just as those mapped with GPS using the same forms interface.

DIGITAL PHOTOGRAPHY. The clock in a digital camera can be used to link photographs with other forms of digital data. GPS units must have accurate clocks in order to function, so the camera clock should be synced regularly with the GPS clock. A time and date stamp, as well as other information, such as the light metering, is hidden inside a JPEG file from a digital camera. Software can retroactively link photographs with GPS-derived geometry through the time/date stamps.

STATISTICAL SUMMARIES. Summaries of new data, such as feature sizes and counts, are available in the field. These summaries are useful for sampling purposes and for guiding fieldwork. Statistics from new data can also be compared with those of pre-existing data sets. More sophisticated exploratory data analysis tools, such as the spatial statistics available in ArcMap 8, are not currently available in Arcpad, but such capacities may eventually allow fieldworkers to make more informed data-gathering decisions.

Conclusion

Just when archaeologists thought that survey fieldwork was their last refuge from computers, along comes mobile GIS. Although mobile GIS software like Arcpad is still undergoing improvements, the interface is functional, the link with larger databases is reliable, and customizable forms can be tailored to meet the needs of archaeologists. The ability to document archaeological resources on survey dramatically lowers the time investment required to get new data into a GIS.

Archaeologists who already are using GIS and are familiar with digital data management will benefit from mobile GIS because their principal GIS database will become available to them in the field. Land managers will particularly appreciate the ability to revisit recorded sites and evaluate previous work. However, there are significant drawbacks to adopting this technology. Mobile GIS requires a lot of preparation so that valuable field data are securely acquired. The potential complexities of such a system mean that archaeologists may be forced to troubleshoot elaborate computer problems a long way from technical support services. Finally, the most important hazard of implementing mobile GIS is that the technical intricacy and new ability to map an abundance of features might detract from research because of the focus on large quantities instead of the quality and relevance of field-gathered data.

Mobile GIS holds a lot of promise for archaeologists. Wearable computers are becoming available at affordable prices, and real-time GPS positioning is much more accurate than it was in the 1990s. Mobile GIS may remain something of a gadget in archaeology for a few more years, but inevitably it will become widely used because the technology is so well-suited to the data-management tasks faced by archaeologists.

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