

BIOGRAPHICAL INFORMATION

Elizabeth K. Burns
Professor of Geography
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Specific Responsibilities

Professor of Geography at Arizona State University since 1983. Responsible for research and teaching in urban development applications of Geographic Information Systems (GIS) and the Global Satellite System (GPS).

Past Experience

Principal investigator for research projects with the Water Services Department, Technical Services Division, City of Phoenix, Arizona since 1996, including quality assurance/quality control for GIS files, internships for qualified students, and GPS data collection pilot study started in 2002.

Educational Information

B.A. - Art History, Smith College
M.A. - Geography, University of California, Berkeley
Ph.D. - Geography, University of California, Berkeley

Professional Memberships

American Institute of Certified Planners
American Planning Association
Association of American Geographers

BIOGRAPICAL INFORMATION

Gabriel Bey
GIS/Mapping Coordinator
City of Phoenix, Water Services Department
Technical Support Division

Specific Responsibilities

Joined the Water Services Department in 1994. Responsible for the management of the Public Service Counter and its business processes, the GIS/Mapping Section and the input of pipe and appurtenance information from new construction and service related field activities, and GIS project management and application implementation as it pertains to the Water Services department.

Projects include:

- ❑ Development of the SWIMMap[®] Mobile Computer solution for Infrastructure Locators (Call Before You Dig personnel)
- ❑ Ongoing interpretation for pipe and appurtenance project acceptance and guidance to the development community as required for compliance with new system infrastructure submittals
- ❑ Spearhead inter-divisional, interdepartmental, and inter-governmental coordination for GIS related initiatives
- ❑ Oversee and manage functional requirements studies, needs assessments, and application development and systems integration projects for GIS driven activities as they relate to the Water Services department
- ❑ Manage the MAPS Project (Mobile Computing), ASU GPS (Spatial Data Collection), New Service Request Application (establish new physical and financial accounts)

Past Experience

(Period covers 1981 – present)

GIS/Mapping Coordinator, City of Phoenix, Water Services Department

Improvement District Assessment Development, City of Phoenix, Streets Department Freeway Corridor Project Coordination, City of Phoenix, Office of City Manger Project Highway Control Device Design (CADD), Arizona Department of Transportation Management (Sub-system engineer), Bechtel Power Corporation

Educational Information

Certificate of Completion - Mahoning Valley Vocational School, Youngstown Ohio

B.S. Business Management, University of Phoenix

Professional Memberships

Geospatial Information and Technology Association

Urban and Regional Information Systems Association

American Society for Public Administration

Institute of Transportation Engineers – Past member

SPATIAL TECHNOLOGIES FOR MANAGEMENT
OF WATER COLLECTION AND DISTRIBUTION

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ABSTRACT

The Water Services Department, City of Phoenix, Arizona, takes an active field verification approach to water infrastructure assets that extend across 530 square miles. A partnership between Arizona State University and the Water Services Department conducted a pilot study to provide accurate asset locations using the Global Positioning System (GPS). Two study sites are a 22 square-mile suburban community and a 19-mile downtown right-of-way in the future light rail corridor. Each site requires separate fieldwork planning, selection of data collection methods, actual GPS data collection and post-processing and data maintenance. Over 36,000 water assets now have accurate x, y, and z attributes including about 3,700 new assets not appearing on current GIS files. Over 2,800 features were shown on existing GIS files, but not found in the field. These assets must be verified before the Phoenix geodatabase can be updated. Technical standards, data collection procedures and processes, and training manuals are available to guide future GPS implementation. Accurate spatial information is expected to support the goal of improved customer service through time and cost efficiencies for field crews.

SPATIAL TECHNOLOGIES FOR WATER SERVICES

How does the City of Phoenix, Arizona conduct a baseline water asset inventory that locates visible assets spread across 530 square miles serving approximately 1.3 million people? Briefly, the city uses an incremental and systematic approach. Water Services Department (WSD) managers conduct evaluation and revisions at each stage of the location, inventory and data maintenance process.

The technical process relies on applying spatial technologies that support continuous updating of asset information for WSD management and operations (Spencer, Frizzelle, Page, and Vogler, 2003). Accurate horizontal and vertical coordinates collected using the Global Positioning System (GPS) currently enhance existing asset information in Geographic Information System (GIS) and other files. This GIS/GPS program involves numerous collaborating public partners, including Arizona State University and Maricopa County, and private engineering and GIS firms. Citywide completion is expected in five years.

This complex setting reflects the situation of other large jurisdictions where a mix of existing and emerging information must be coordinated for daily operations. The WSD uses multiple legacy databases and varied field procedures to meet increased management expectations for high-quality operations that improve personnel efficiency through appropriate information technologies. Existing GIS files are the result of an extensive citywide effort to create a single inventory of quarter-section maps. This WSD transition required combining separate sets of paper maps maintained by several divisions, confirming asset locations on GIS files compared to paper maps, and GIS operations including “edge matching” to provide seamless spatial coverage.

Field problems remained, however. Original paper maps were drawn as architectural drawings based on land development. Over time, maps showed where water and sewer lines were laid, pipe dimensions, and pipe locations (30 feet south of curb). Pipes are, in reality, laid at different depths in street rights-of-way, although the maps showed no regard for vertical dimensions. Daily maintenance incidents involve locating a unique asset in the field, knowing which valves control a specific pipe section, and avoiding buried underground structures. The accumulated number and severity of these incidents is a barrier to anticipating, preventing, and repairing line breaks across the city.

PILOT STUDY OVERVIEW

The need to minimize these continuing mapping and field issues provides strong managerial support for the current GPS data collection pilot study. Its primary goal is to add accurate x, y, and z coordinates as asset attributes in updated GIS database records. An intergovernmental agreement between the WSD and Arizona State University (ASU) provides a detailed collaborative framework for tasks and responsibilities. ASU provides project oversight using experienced faculty and staff who train student workers for GPS data collection and quality control processing. The WSD provides confidential GIS files, purchases and maintains required equipment, and staff assistance. Project deliverables include updated GIS files with supporting technical reports, asset inventory manuals, and documented GPS data collection and processing procedures.

Essential decisions must be made for every GPS project including (1) selection of data collection area, (2) determination of accuracy and error correction needs, (3) selection of mapping grade equipment, and (4) appropriate coordinate system and datum. The selected study area is the suburban community of Ahwatukee. Over 45,000 water assets appear on its quarter-section GIS files. This 22-square mile area is nearing the end of twenty years of construction. This isolated and southernmost community in Phoenix is known locally as “the world’s largest cul-de-sac.” Travel outside the area is limited to a few arterial streets that cross Interstate-10, the eastern border of the community. Daily traffic congestion results at nearby intersections. Early in 2003 GPS data collection of some 3,700 water assets in the 19-mile downtown transit corridor took precedence. This inventory is the basis for asset relocation now underway as preparation for light-rail roadbed construction by mid-2004.

Second, differential accuracy of +/- 3 International feet is the GPS standard. Field workers should identify adjacent assets, such as a series of manhole covers, by each unique WSD asset identifier in the GIS database. Locked sites contain unique types of assets. Site assets operated by radio communications control significant portions of local collection and distribution networks. After initial studies of these sites, a local engineering firm collected GPS features to sub-meter accuracy using a Trimble 5700 Series base station and rover unit.

Third, data collection uses an integrated equipment system of a Trimble Pro XRS mapping grade receiver and antenna with a pen computer running customized PenMap software (www.CondorEarth.com). Error correction in satellite signals is handled by presetting this software to ignore or “mask” satellite signals that do not meet necessary conditions (Kaplan, 1996). Signals must come from satellites above an elevation mask of 15 degrees above the horizon. Acceptable position dilution of precision (PDOP) readings are 1.5 and below to minimize ground position errors.

Fourth, WSD parameters include GPS data collection using benchmarks set by the Geodetic Densification and Cadastral Survey (GDACS) locally coordinated by Maricopa County (www.mcdot.maricopa.gov). Universal Transverse Mercator (UTM) and NorthAmericanDatum83 reflect standard local practice. This global spatial framework improves the precision of local GPS measurements and GIS infrastructure topology.

The magnitude of visible assets doubled when customer meters were added to the inventory effort. Meter data exists as unique account numbers and addresses on spreadsheets. Although geocoding this information assists field location, meter collection in the downtown corridor is slowed where parcel consolidations still use original addresses. Current addresses for new and relocated meters are not always recorded.

MANAGING GPS FIELDWORK AND DATA PROCESSING

Ideally, GPS project activities are organized in major periods of fieldwork planning and preparation, actual data collection, post-processing and data verification, and data maintenance. This approach provides a comprehensive planning framework to ensure high-quality data results through careful consideration of consistent procedures and practices. In practice, this pilot study involved overlapping GPS projects that allowed rapid evaluation and revision for the next project. These incremental changes consistently simplified GPS data collection and minimized real-time field decisions.

Study fieldwork planning and preparation consumes about a third of the effort. This codification of ephemeral field knowledge on the status of each GIS asset confirms the value of electronic collection. Many WSD field workers had kept annotated quarter-section paper maps to track their field operations, such as abandoning a water valve (Burns and Burns, 1999). This information is now recorded in the field record for each asset as a comment in the Note attribute field. Other hidden record attributes include collection personnel, date and time, satellite ephemeris data, and the GPS method used.

The portable computer displays PenMap software on a transfective screen in a Windows-type format for electronic GPS data collection. Initial software customization created a set of toolbar buttons separated into distribution and collection features with symbol icons from the existing WSD glossary of features and feature symbols. The 12 different types of features found in Ahwatukee quickly expanded to 19 in the transit corridor based on local infrastructure history. This approach assumed that separate computer customizations were needed.

Figure 1. Project timeline detailing pilot study benchmarks in fieldwork planning, data collection and post-fieldwork phases

Calendar quarters											
2002				2003				2004			
1	2	3	4	1	2	3	4	1	2	3	4
<u>Ahwatukee</u> Fieldwork planning				<u>Transit Corridor</u> Fieldwork planning				<u>Finish Ahwatukee</u> Fieldwork planning			
<u>Ahwatukee</u> Fieldwork/data collection				<u>Transit Corridor</u> Fieldwork/data collection				<u>Finish Ahwatukee</u> Fieldwork/data collection			
<u>Ahwatukee</u> Post-fieldwork processing				<u>Transit Corridor</u> Post-fieldwork processing				<u>Finish Ahwatukee</u> Post-fieldwork processing			
<u>Ahwatukee</u> Data update				<u>Transit Corridor</u> Data update				<u>Finish Ahwatukee</u> data update			
								<u>City Implementation</u> Fieldwork planning			
								<u>City Implementation</u> Fieldwork/data collection			
				<u>Transit Corridor</u>				<u>City Implementation</u>			
				1	2	3	4	1	2	3	4
<u>Ahwatukee</u>					<u>Finish Ahwatukee</u>						
1	2	3	4	5	1	2	3	4			

Project phase quarters

The need for multiple data collection customizations was underestimated. Initial customization created an icon for each type of asset, using drop-down menus with selections for a specific attribute. Some GIS procedures appropriate for office settings are not ideal for GPS field collection. Initial buttons use existing feature types and feature icon symbols from the GIS glossary. This approach used feature codes organized in alphabetical drop-down lists. A hydrant button, for example, displays the hydrant icon symbol and allows the GPS worker to select from a list of “Manufacturer” names. Early field tests quickly show the value of drop-down menus that display the most-likely selection and, therefore, minimize scrolling on the field computer.

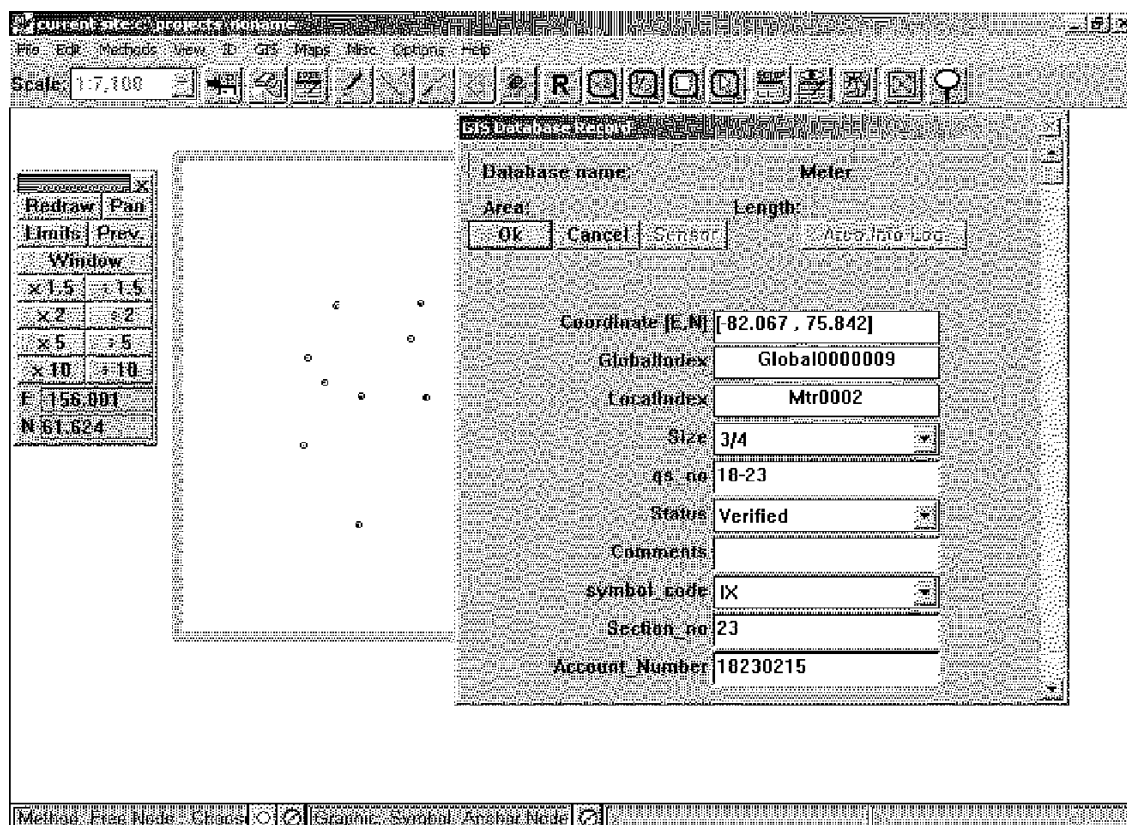
As GPS collection progressed, this approach became unwieldy. New physical assets without ID numbers as well as new types of assets were found; assets on the GIS files could also not be located. GIS files for suburban Ahwatukee were visually clear compared to dense concentrations of assets in the downtown transit corridor. The result was a steep learning curve for both ASU personnel and WSD workers with limited GIS experience.

Initiation of the WSD geodatabase in February 2003 assisted with resolution of these technical and managerial issues. A simplified customization uses generic “point, line, polygon” icons to classify every asset. Standing on the center of a valve, for example, the GPS worker collects a point location and selects from a drop-down list for the specific water or sewer valve types. GPS files are exported

to GIS file format using ArcGIS 8.3 while original GPS files are retained. GIS deliverables are *.shp files for every feature type.

Data collection formats and procedures changed to address the crucial issue of the lack of a consistent database for assets at locked sites including booster stations, wells, and storage facilities. Current tabular asset inventories vary in asset ID coding systems, naming conventions, and detail of asset identification. This discovery required on-site inventories by key managers to identify and name specific assets. A consistent database format is being developed for this crucial asset inventory in GIS file format with GPS attributes.

Figure 2. Current GPS data collection configuration showing toolbar icons and the database record fields for meters displayed in the background.



Study field GPS collection poses expected logistic problems. Four people (two teams of two workers) and their equipment often shared a vehicle. Once at a site, each GPS worker follows a step-by-step data collection sequence. First, the worker asks the satellite receiver to search for a signal. Preset parameters allow GPS collection only when a signal of "Differential GPS" accuracy is available. This approach minimizes inadvertent errors by inexperienced workers. Each field session then proceeds by creating a daily file. Background GIS files display the asset ID number in an arrow near the feature symbol. Field workers regularly

orient themselves by zooming in and out from background files showing street centerlines, street names, and parcel boundaries. Once an asset is physically located and confirmed on the GIS file, the worker completes field collection by selecting the asset type and saving the GPS attributes.

Required field equipment included a Nextel wireless phone with walky-talky capacity. This proved useful when GPS teams were nearby, perhaps on the neighboring street, but out of sight. A field comparison of phones from multiple carriers confirmed that not all local service providers have broad signal coverage, especially where prominent rocky outcrops and mountains rise to elevations hundreds of feet above the surrounding surface. Steel-tipped boots and shoe covers prevented foot injuries.

Each GPS worker received classroom and field training to become familiar with field set-up steps using a manual with photos and with the customized data collection software described in Condor Earth Technologies, Inc. PenMap training manuals). ASU and WSD staff normally started their days at 7 a.m. and earlier to avoid mid-day heat. The transit corridor presented daily local traffic hazards of congestion, dust, and emissions. WSD workers collected right-of-way GPS assets at night using backlit computer screens.

Scheduling data collection occurred one to two weeks in advance when separate preparation, fieldwork, and post-processing tasks were assigned. ASU staff and students had checklists for personal health and safety. Items covered include including water intake, sunscreen use, regular breaks in shaded area, and training for heat exhaustion. Seasonal air pollution conditions vary in metropolitan Phoenix. High ozone and particulate warnings were checked the day before scheduled. Field teams always responded to phone alerts when nearby lightning storms shift and when local pollution accumulations rose.

Study post-fieldwork processing and maintenance follows a predictable pattern. Processing of GPS files verifies GPS data before conversion to GIS file format. Occasionally, GPS files were corrupted or overwritten. GPS files were downloaded weekly at an ASU GIS laboratory where all files are backed up nightly. GPS files were then converted to GIS file format. Actual GPS points collected could then be compared to original GIS asset points to identify missed, mislabeled, or new features. Quarter-section manuals of the original GIS files and telephone communication with project staff resolved most field questions. The next field collection trip was scheduled to collect any water features that were initially missed. The final step of transferring revised GIS files with added GPS attributes is still underway. GPS fields and formats now exist in the WSD geodatabase.

DISCOVERIES

This study makes a measurable contribution to the citywide effort to collect verified GPS data for all water assets. Over 45,500 suburban assets include 20,000 water features - primarily hydrants and valves – plus 25,000 meters and about 500 assets on locked sites and in dangerous intersections. The 3,800 transit right-of-way assets include 2,000 assets - primarily hydrants, valves, and sewer manholes - plus 1,800 meters.

Table 1. Status of GPS features collected

	GPS Features *	
	Number	Percentage
Total	42,570	100.0%
Verified	36,052	84.7%
Not Found	2,766	6.5%
New	3,680	8.6%
Removed Meters	72	0.2%

* As of December 31, 2003

Verified, *Not Found*, and *New* categories of mapped assets provide unexpected results. City of Phoenix GIS and other files were initially expected to be sufficient and accurate for all assets (Burns, Bey, and Reynolds, 2003). The GPS collection study now includes an additional fieldwork task. *Not Found* assets must be verified as buried, removed, or abandoned or as built in a location than differs from the original “as-built” record. *New* assets reflect the rapid pace of local building that outstrips the updating of GIS files with current construction records.

Distribution assets, excluding meters, are about 66% of the suburban inventory compared to 80% of the transit inventory. *Not Found* and *New* distribution assets are 33% of the suburban inventory compared to 18% downtown.

- Suburban assets are 72% *Verified* (14,750) compared to 82% for downtown assets (2,300).
- *Not Found* assets include 2,021 suburban features (16%) versus 144 (7%) in the transit corridor.
- *New* features are 16% of suburban assets (3,283) and 11% of downtown assets (204).
- About 99% of suburban meters and 90% of downtown meters are *Verified*.

WHAT HAVE WE LEARNED?

GPS data collection experience from the pilot study process sets the current direction for citywide implementation.

- A public-private collaboration between the local engineering and GIS community, Arizona State University, and the Water Services Department is the management model for future mapping.
- Needed flexibility in data collection procedures, field scheduling, and software customization will be better anticipated in the citywide effort.
- Improved WSD business practices now use experienced locators to locate *Not Found* water assets.
- City development permit standards are under review to address the *New* assets. The WSD may recommend that all future construction permits locate water assets to differential GPS accuracy as confirmed by a registered land surveyor.

REFERENCES

Burns, E., G. Bey, and D. Reynolds, 2003, Urban Water Infrastructure Maintenance Using GPS and GIS: Universities Council on Water Resources Proceedings of the Water Security in the 21st Century conference, 1-3.

Burns, E. and J. Burns, 1999, Mapping from Memory: Surveying Underground Utilities: GeolInfoSystems, 22-29.

Kaplan, E. (ed), 1996, Understanding GPS: Principles and Applications: 1-554.

Spencer, J., B. Frizzelle, P. Page, and J. Vogler, 2003, Global Positioning System: A Field Guide for the Social Sciences: 1-218.