Applied Mobile GIS for Investigation of Arizona Surface Water Rights

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ABSTRACT

Since the 1980s, the Arizona Department of Water Resources (ADWR) has served as technical advisor in a court proceeding to determine the nature, extent, and priority of surface water rights in Arizona. Field investigations are a major part of ADWR's role in the Arizona General Stream Adjudications, and in the past, standard paper-based cartographic methods were used. New technologies are now being implemented that improve the efficiency and precision of these investigations.

Since 2005, ADWR has been using mobile GIS in its field investigation of water rights claimed by the Hopi Tribe in northeastern Arizona. ArcPad, Trimble GPS, and Windows-based tablet PCs were employed during data collection and ArcGIS methods were employed for pre- and post-field data processing. Although use of mobile GIS has not proven to be a seamless process, it is considered a success and is now being applied to other department field projects.

The Arizona Department of Water Resources GIS section is improving labor intensive field investigations through integrated deployment of mobile GIS, GPS and computer technologies. ADWR has realized a significant increase in productivity over previous investigation methods. Mobile GIS provides precise spatial data collection in the field while eliminating several data processing steps in the office.

INTRODUCTION

Per Arizona statute, ADWR must prepare and publish Hydrographic Survey Reports (HSRs) for each watershed and Indian Reservation within the two adjudication areas (Figure 1). These adjudication areas are the Gila River System and Source (Gila Adjudication) and the Little Colorado River System and Source (LCR Adjudication). These adjudication areas encompass more than half of the state of Arizona. The Gila Adjudication has nearly 30,000 parties, and the LCR Adjudication has nearly 5,000 parties who have filed one or more water rights claims (statement of claimants). Mobile GIS is used in field investigations to collect data on water right claims or uses within the adjudication areas. These data form the basis of the HSRs. HSRs are comprehensive, multi-volume documents with detailed information and maps regarding water resources, historic and current water uses, hydrologic analysis of claims and uses investigated, and ADWR's recommendations regarding water right attributes.

To date, most field investigation areas have been located in rural Arizona. Primary data features have included wells, springs, agriculture fields, irrigation ditches and impoundments (stock ponds). Spatial and various descriptive attributes of each feature are collected during the field investigation of these water right claims. Since Arizona's adjudications began, technology has made many advances. ADWR has developed new field methods to integrate this technology. The technologies deployed consist of ArcPad, Trimble GPS, and Windows-based tablet PCs. These advancements have greatly improved the efficiency of the field investigations.

Figure 1 ADWR General Stream Adjudication Areas

Past Methodologies

Former field investigations used standard paper-based cartographic mapping methods to collect data. These methods consisted of using aerial photography mounted to 3ft x 3ft foam boards with Mylar paper overlaid. The field inspector would take ten to twenty boards out to the field and hand draw the data onto the Mylar paper with colored pencils. Each data item would be recorded with its proper symbology. In addition, all of the descriptive attributes would be recorded onto the Mylar paper and within a field notebook. Although this method was an effective way to collect the field data, it was cumbersome to transport these maps in the field facing the elements of weather and rugged terrain.

After the data was collected in the field, it would be brought into the office to begin the post-processing. The first step was to have the hand-drawn features digitized. After the features were digitized, all of the field notes were entered into the attributes table for each feature. These attributes were then related to the digitized spatial feature. This data-entry process proved to be very tedious and has now been eliminated from the current field methods by combining data entry and field collection into a single process.

New Methodologies

Currently field investigations utilize new technology that increases efficiency and precision. The new technologies deployed consist of ArcPad, Trimble GPS, and Windows-based tablet PCs. A custom application was created utilizing the ArcPad software. This application collects the spatial data using GPS technologies and enters the attributes into a database directly correlated to the spatial information. With the new methods, all data is collected in electronic format. Therefore, the past methods of post field digitizing and office data entry of field notes are no longer necessary. By eliminating these processes, the field investigation is much more efficient. Based on interviews with former and current ADWR adjudication investigators, it is estimated that the efficiency is increased up to 50%. Not only is utilizing the new technologies more efficient but by utilizing GPS technologies, the precision is increased from twenty feet to sub-meter precision. This system was fully implemented during field investigations in support of a Hopi HSR.

HOPI WATER RIGHTS FIELD INVESTIGATION

In 2005, ADWR began field investigation for the Hopi HSR. The project was divided into three phases: agriculture, springs and wells, and impoundments (stock ponds). Field investigations began in September 2005 and were completed in December 2006 with each phase taking approximately one month to complete utilizing two field teams. Point, line and polygon data were collected for agriculture and impoundments; point data were collected for springs and wells phase.

Location
The Hopi Indian Reservation covers approximately 2,532 square miles (6,557 kilometers) and is located in the rugged high desert terrain of northeastern Arizona (Figure 2). Most of the roads through the reservation are primitive requiring four-wheel drive vehicles to access the features being investigated. Many features, especially springs, could only be accessed by foot.

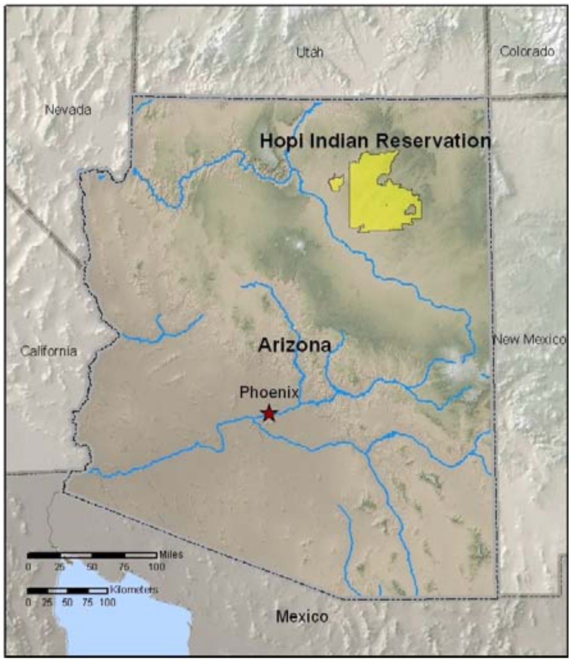

Figure 2 Hopi Indian Reservation in Arizona

Communication
The Hopi Indian Reservation has very limited cellular telephone coverage due to its remote location and sparse population. Field teams were unable to call back to the office when problems arose. Proficiency with the software and equipment by the field teams was critical to troubleshoot problems that arose. The poor means of communication also dictated that the ArcPad application developers would need to spend the first week of each phase in the field with the teams providing support.

Weather
Prior investigations have taught field crews to be prepared for all weather conditions. Temperatures on the reservation range from the upper nineties in the summer to the teens in the winter. Fortunately, rain and snow on the Hopi reservation are generally sparse. The Fujitsu tablet PCs used were not water proof, although they performed well in prior investigations where temperatures have exceeded 105 degrees Fahrenheit.

Equipment
Most of the equipment and software used in this investigation had already been purchased. However, for the final impoundments phase, the tablet PCs were upgraded from Fujitsu ST3500s (500 MHz Celerons) to Fujitsu ST5000s (1.2 GHz Pentium M). Approximate equipment cost for each piece of hardware and software are indicated in Table 1. Generally two teams were deployed during all phases of the project. Each team possessed two tablet PCs, one for data entry and navigation and the other as a backup in case the primary unit failed or was damaged.

Table 1 Equipment and software cost breakdown

	Description	Unit Cost
Field Equipment	Fujitsu Stylistic ST 5000 (1.2MHZ Pentium M, 80GB HD, 1GB Ram)	$3,300.00
	Trimble Pathfinder Pro XR GPS	$6,500.00
Field Software	ArcPad 7.x	$500.00
	Trimble GPS Correct	$500.00
Office Software	ArcPad Application Builder	$1,500.00
	Trimble Pathfinder Office	$1,800.00
Total		**$14,100.00**

ArcPad Customizations

ArcPad is very comprehensive software with tools and options to support many data collection scenarios without any customizations. In an effort to improve workflow, it was decided to perform several relatively simple but significant customizations to ArcPad's interface. Out of the box, ArcPad comes with several tools and toolbars for performing a variety of tasks; however, unused tools tend to get in the way when not needed. ArcPad Application Builder was used to develop a single, simplified toolbar that utilized only the tools needed for this investigation (Figure 3).

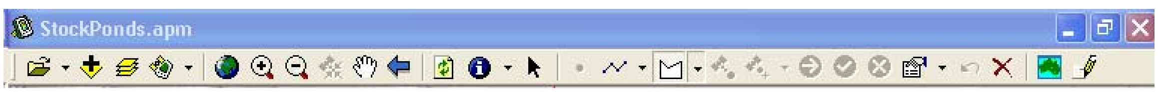

Figure 3 Simplified ArcPad toolbar with most commonly used tools displayed for quick access.

ArcPad Project File and Navigation

An ArcPad project file (.apm) was assembled for displaying and symbolizing the layers needed for editing and navigation. Many of the features (especially springs) were located in remote canyons that could only be accessed by foot. To assist the field teams in finding the best way to a site, sixteen mosaicked, scale dependent USGS 1:250,000, 1:100,000, and 1:24,000 topographic rasters as well as mosaicked digital orthophoto quadrangles (DOQs) were included in the map file. However, it soon became apparent that it was impractical to have the user go into the table of contents and turn off a 1:24,000 topographic tile and turn on a DOQ tile. To remedy this problem, a custom tool was developed to toggle between DOQ and 1:24,000 topographic tiles without going into the table of contents. At scales below 1:50,000, the user simply pressed a button on the tool bar which executed VBScript that turns all topographic imagery on and the DOQ imagery off, or vice versa.

Feature Class Data Entry Forms

Custom data entry forms were developed for each phase of the project using Application Builder.
Drop-down list boxes with predetermined attributes streamlined data entry and VBScript was used to handle custom data validation. Figure 4 shows an example of the impoundments polygon feature class data entry form.

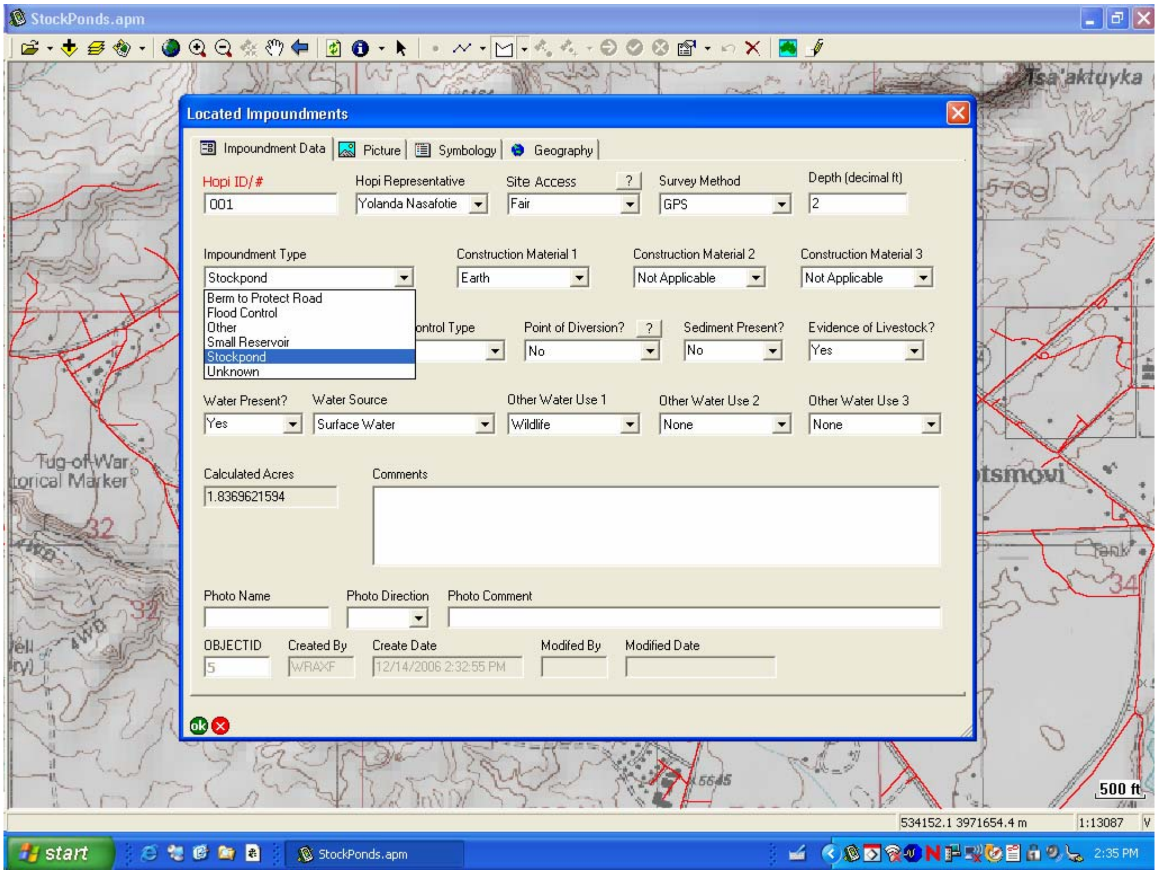

Figure 4 Impoundments polygon feature class data entry form.

One of the project requirements was to have a user ID and date and time automatically tagged to each feature created or modified. To accomplish this, Application Builder was used to develop a login form which prompted users to login when ArcPad first opened. Script then assigned the user ID to the user properties of the application object. Every time a feature was created or modified, VBScript would update created by, create date, modified by and modified date fields. Having this information proved invaluable for tracking other information tied to a feature (like pictures) and to troubleshoot data problems.

Picture Data

Pictures were taken of each feature collected, which required a system for associating a given picture to a specific feature. Associating a picture to a given feature in a one-to-many relationship through a field application was and still is a cumbersome process. To accomplish this, script for generating a unique ID per feature was incorporated from the San Diego sample files included with ArcPad. The script sequentially populates an object ID field by finding the maximum value contained in the field object ID, increments it by one, and then assigns that value to the new feature. Usually, one member of a two person team was responsible for taking pictures and recording on paper (and to a spreadsheet at the end of the day) the object ID of the feature and the file name of the picture taken. This system works well when only one tablet PC is deployed, but creates duplicate records when using two or more tablet PCs. To get around this problem, the user ID combined with the object ID creates a composite unique key for each record in the feature class. However, in order for records to remain unique, field crews were required to use the same tablet PC throughout a project phase. It is inevitable though, that someone might use two different tablet PCs and create two features with duplicate object ID and user IDs. In these situations, primary key conflicts were resolved by comparing the date and time that the picture was taken to date and time of the duplicate features.

Tablet PC Setup and Configuration

After the custom tools, toolbar and data entry forms were developed, the final step was to distribute the map file and data to the four project tablet PCs. A typical setup routine would include:

1. Copy custom ArcPad.apx to ArcPad's System directory. This is where the toolbar and login form are stored.
2. Create project directories and copy data (~ 6GB).
3. Open ArcPad and configure Trimble's GPS Correct extension. This extension allowed the shapefiles to be post-processed to half meter as well as control the Pathfinder Pro XR.
4. Test application and GPS for function and connectivity.

Deployment

Important lessons learned from this project included the need to properly train field personnel on software and equipment and consistency in data collection. Testing equipment and software for code and logic errors was also critical. A couple of weeks before deploying to the Hopi Reservation, field crews spent one to two days training and testing the equipment at various springs, wells and impoundments around Phoenix, AZ. These testing and training sessions significantly increased productivity and the precision of data collection. Code, logic and equipment bugs were much easier to correct in the office than in the field. Below is a list of proficiencies that the field personnel were required to learn.

1. **Windows Tablet PC:** Microsoft has developed special features specifically for stylus driven pen PCs. Most people find using a stylus to control a computer a little tricky at first but quickly adapt.
2. **GPS Theory:** GPS systems are relatively new and most personnel had little to no knowledge of how a GPS works. This is critical knowledge that field personnel must have to collect accurate and precise data. Percent dilution of position (PDOP), differential correction, and multi-pathing in canyons, batteries and connectivity were all issues that crews routinely considered.
3. **GIS and ArcPad:** Just like GPS theory, many personnel had limited knowledge of desktop GIS and no knowledge of mobile GIS. Point, line, poly, vertices and other terms combined with editing features through a GPS and stylus were all skills that needed to be learned.
4. **Troubleshooting:** Calling the Support Desk for assistance was not possible due to very limited cell phone coverage on the Hopi Reservation. Therefore, the field crews had to possess basic troubleshooting skills to debug minor problems like GPS connectivity through a serial port. Additionally, the application developers spent the first three to four days of each phase with the field crews giving further training and fixing any problems with software and equipment. Having the developers in the field meant problems were fixed quickly getting each phase off to a smooth start.
5. **Data Knowledge:** Beyond equipment and software, the field crews and developers also needed to understand the data being collected. Each phase required knowledge of the following
    a. Agriculture – Plant types, agricultural methods, irrigation systems and hydrology.
    b. Springs and wells – Groundwater hydrology, geology, and well construction.
    c. Impoundments – Dam construction materials, methods and terminology.

Problems Encountered

Overall the software and equipment worked well; however, there were several minor but significant problems which needed to be overcome. Battery life was an issue for the four year old Fujitsu 3500 tablet PCs used during the agriculture and springs/wells phases. Some batteries would last less than an hour which required the computer be put to sleep if a long hike was involved. This sometimes led to connectivity problems with the GPS when the computer was restarted. The Trimble GPS Pro XR's battery life was not much better and would get at most four hours out of a good battery set. Unfortunately, battery failure on the Pro XRs was quite common with some battery sets lasting less than an hour. The only way around these battery problems was to have everything plugged into the vehicles power supply and charging at all times. This sometimes overloaded the vehicle's circuit leading to a blown fuse. A typical field vehicle would have two tablet PCs (one operational and one for battery charging), and a power inverter charging the two sets of GPS batteries all plugged in simultaneously.

Outdoor screen visibility on the older Fujitsu Stylistic 3500 tablet PC was another problem. In order to see the screen, users had to shade the tablet PC with their bodies and could not wear sunglasses. Even simple computer tasks were challenge during the first days of the investigation because of poor screen visibility, limited familiarity with the software and equipment plus hot or cold windy weather.

New tablet PCs were deployed in the third and final phase of the investigation. Fujitsu Stylistic 5100s replaced the outdated and dim ST3500s with screens that were highly visible in the sun and had a long battery life. Unfortunately, migrating to the new tablet PCs was not trouble free. The Trimble Pro XRs uses a serial port to connect to a computer, and like most new computers, the new 5100 tablet PCs did not have serial ports. This problem was anticipated and all tablet PCs came with USB to serial adapters. The adapters worked well during the testing and training; however, on the first day in the field, the Pro XRs began having difficulty connecting to the tablet PCs. By the second day of phase three, the developers had narrowed the problem down to failed USB to serial adapters. Some of the cables failed outright while others lasted for days, but they all eventually failed. Fields crews carried backup cables for the remaining three weeks of phase three.

Data Management

During each field phase, crews typically returned from the Hopi Reservation to ADWR's Phoenix office on Friday afternoon and departed from Phoenix on the following Monday to return to the field. On Monday mornings, the developers would download the previous week's shapefiles and GPS correctional data onto ADWR's network. At the end of each phase, all shapefiles were post processed to half meter precision using Trimble Pathfinder Office. A table was developed to relate all picture data to its appropriate feature using the feature's object ID and user ID.

Data Compilation and Reports

The data was compiled into maps and reports using ArcGIS and Microsoft Access. ADWR's Adjudication team will analyze the field data and incorporate their findings in an HSR to be submitted to the Adjudication Courts.

RESULTS AND DISCUSSION

Advantages

Utilizing mobile GIS has improved data collected to sub meter precision, and also improved navigation. The real-time GPS navigation incorporated into an ArcPad project allowed field crews to navigate with a precise position on both topographic map and aerial photography.

The custom ArcPad application also has increased productivity by eliminating post-field data entry and digitizing. This post-field work was not only time consuming but also increased the probability of human error from data entry and by not correlating the correct spatial data to the attribute data. Collection of spatial and attribute data digitally in the field allowed users to quickly review how their final data would look while still in the field. This allowed for edits on the spatial and attributes information to be made before returning to the office.

The application also allowed the field crews to utilize custom tools such as polygon acreage or distance to a feature in the field. These tools allowed the user to make quick interpretations of the data they were collecting.

Disadvantages

Utilizing new technologies has not been a seamless process. Implementing new GPS equipment, tablet PCs and software is a large investment. Deploying this new technology also requires additional training prior to field work. It requires not only a programmer to customize the application for each field project, but additional training for the field crews. In many cases, traditional field crews have limited computer experience and exposure to technology. In order to deploy this technology, they need to be competent in GIS, GPS and computer technology. Their competency is not just utilizing the application, but also how to troubleshoot problems they may encounter in the remote locations. GPS, software and tablet PC equipment are complex, which makes it difficult for field crews to troubleshoot in the field. This causes projects delays while office IT staff corrects the issues.

CONCLUSION

Throughout the Hopi Water Rights Field Investigation, it has been determined that technical support must be combined with knowledge of the field subject matter to have a successful application. The application must be designed with consideration of both the users' project and their technical capabilities. Field crews will need to be able to troubleshoot technical software and/or hardware issues as they arise in the field. This may require having a developer and/or technical support in the field, or in close communication, to the field crew during deployment of the application.

Utilizing the new technologies of GPS, tablet PCs and ArcPad have improved the efficiency and precision of ADWR's Arizona Surface Water Rights field investigations. The past paper-based cartographic methods were successful for field work for many years; however, new technologies have provided field crews with improved navigation, precision on spatial data, and efficiency with reduced data post processing. ADWR considers mobile GIS a successful field method and it is now being applied to other Department field projects.

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