Developing and Implementing a Large Scale Cadastral Resurvey with GPS

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ABSTRACT

Maricopa County, Arizona is the 14th largest county in area of approximately 2,950 counties in the United States. With over 10,000 public land corners, we are performing one of the largest, if not the largest, cadastral retracement surveys in the United States in recent times. This paper steps through the project from conception and justification, procedures used in the varies phases of establishing control , surveying the corners, to accessing the compiled data. The conclusion reveals an unexpected byproduct.

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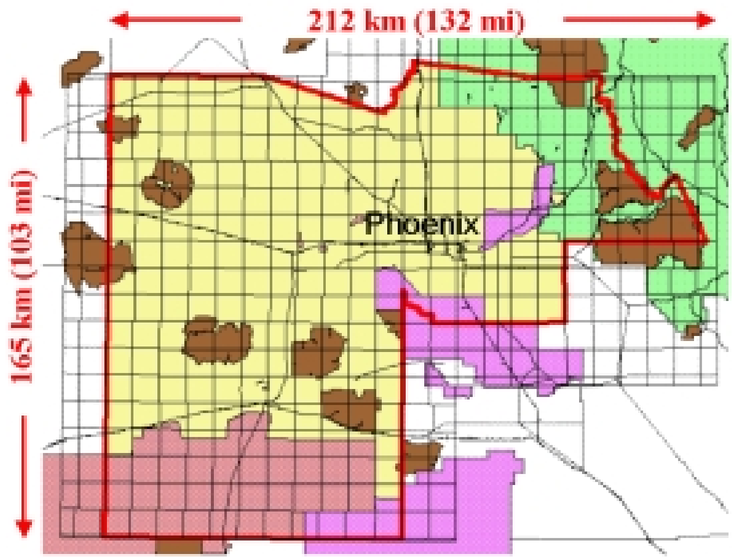


Maricopa County, Arizona, USA

1. INTRODUCTION

This project covers Maricopa County, Arizona. It is the 14th largest county of roughly 2,950 in the country covering the United States. Stretching 103 miles from north to south and 132 miles east to west, it contains some 5,904,616 acres within its bounds. It is home to 24 municipalities, including Phoenix, Scottsdale and Mesa, with over 2.8 million people.

Since Maricopa County does not have a county surveyor, the Department of Transportation (MCDOT) often satisfies such a role. MCDOT conceived, implemented, funded and continues to manage this project.

1.1 Project Goals

1. Establish a geodetic control network that will blanket Maricopa County with an approximate 6.7 km (4 mile) grid. This grid will allow a Real Time Kinematic (RTK) Global Positioning System (GPS) user to survey in nearly any location of the county all in one system.
2. From this control network, survey most the section and quarter section corners in the county. Creating a highly accurate geodetic fabric for multiple GIS coverage's throughout the county.
3. Make the information available to the public and easily accessible.

1.2 Project Overview

The project consists of four phases:
Phase A: The Primary Control Survey
Phase B: The Secondary Control Survey
Phase C: The Cadastral Survey
Phase D: The Project Maintenance

All phases of the project are being managed by MCDOT.

2. PROJECT PURPOSE / COST BENEFIT

To launch most projects, there usually is a need. For government projects, that need is generated into a cost benefit and is weighed against other projects. The following are a few of the categories that went into determining the project's cost benefit:

2.1 Geographical Information Systems (GIS)

An increasing demand for accessing accurate information, specifically from a GIS. GIS's have become a crucial tool in the managing of municipalities, utilities and miscellaneous county agencies.

In any GIS, the fundamental core is the control layer on which they are constructed. Any error that is built into this level will be directly propagated to data referencing it on other layers. Currently most GIS control layers in Maricopa County (the greater Phoenix area) contain an error of 1 to 45 meters. This project will improve that precision as much as 500 percent.

As the individual agencies convert to this project's control/datum and add and maintain their unique data, those coverages can be shared and utilized by the other agencies and private parties. Among the many disciplines affected by an increase in accuracy, the greatest beneficiaries are engineering and land boundary applications.

2.1.1 Engineering Applications

As GIS software ripens and begins to merge with Computer Aided Drafting (CAD) software the need for an accurate control layer will become even more apparent. A seamless connection between new engineering projects, existing facilities and utility projects will save considerable time for contractors and money for taxpayers.

2.1.2 Land Boundary Applications / Assessor

This project is instrumental in creating an accurate and reliable parcel coverage (land layer). All new subdivisions in Maricopa County are submitted to the Assessors office in electronic CAD format. Once this project is completed, the Assessors office will translate those drawing onto the control layer to begin creating this parcel coverage. The Assessors office has already begun developing the workflow for rectifying old parcels to the new control system.

There are two main areas in which the Assessors office is directly affected. First, 40 to 50 percent of the current total resources of the Assessors office are devoted to appeals and corrections. The accurate land layer is anticipated to dramatically reduce such appeals and time, which will result in tax revenue savings. Second, incorrect assessment of property value due to incorrect acreage determination. Whether a particular parcel is in dispute or not, incorrect acreage is a direct factor in erroneous land valuation. Again, such a layer would help mitigate this issue.

In addition, the accurate land layer would become a staple of many professions including real estate, title and surveying companies.

2.2 Uniform Coordinate System

It is important to set a *standard* by providing the public and private agencies with a coordinate system of uniformity to aid in communication and to limit confusion. With 24 cities, numerous agencies, and countless private surveying, engineering, and construction firms in the county, facilitating a basis in which to work will save time and money in future. Currently many of the entities use different coordinate systems and units. This project will aid in bringing Maricopa County a crucial step closer to uniformity, effectiveness and efficiency.

2.3 Reduce Multiple Monumentation

Maricopa County seems to be a haven for multiple monumentation. In other words, two, three or more surveyors disagreeing with a previously established monument(s) position. This usually leads to the next surveyor setting his/her own monument leaving the public and or other surveyors confused and ultimately creating cloud of title on adjacent parcels. Given the magnitude and depth of this project, we hope to not only clear up trouble areas but set a standard for locations still uninfected with multiple monuments.

2.4 Litigation Savings

By locating and surveying an undisturbed original corners prior to their destruction, it essentially eliminates any future ambiguity and therefore extinguishing the likelihood of costly litigation over that corner's position.

2.5 Citizen Savings

Future research and retrieval of corners surveyed under this project will cost a fraction of the amount to the public. Considering the number of crews and corners recovered in Maricopa County on a yearly basis, these savings will be quite substantial to the public.

2.6 As Built Surveys

As municipalities develop workflows for surveying utilities as they are constructed, it will eliminate the need for future surface location and costly potholing when recovery is needed.

3. PHASE A – PRIMARY CONTROL

Prior to the conception of this project, Maricopa County had only had 5 "B" order and above monuments within its boundary. Due to the accuracy of GPS, using a lesser order could introduce errors into your work. As a result of the scarcity of high accuracy control, it became apparent that a densification of this primary control was needed to begin establishing a local or "secondary" control grid. MCDOT, with the support of the Arizona Department of Water Resources (ADWR), the Salt River Project (SRP), the National Geodetic Survey (NGS) and numerous other participants, performed two large surveys in late 1998 and early 1999. Following the *NOAA Technical Memorandum NOS NGS-58* entitled "Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2cm and 5cm) Versions 4.3. each monument was occupied with GPS for 3 days, 5.5 hours at a time. All the data was collected and submitted directly to the NGS for processing and the final adjustment to the surrounding CORS (Continuously Operation Reference Station) sites for inclusion into the national database. Resulting from this, a primary control network was established, adding over 50 additional monuments in and around Maricopa County (See figure below "Maricopa County, Arizona – Final Control Map" in section 4).

The average spacing of the primary control points averaged 35-40 kilometers. This facilitated conducive spacing to establish the "Secondary Control".

4. PHASE B – SECONDARY CONTROL

For this phase MCDOT released a request for proposal, in which over 40 firms submitted a response. Seven firms were short listed and five firms were ultimately chosen to perform the work. MCDOT developed the specifications/procedures for the consultants to follow, performed the quality control and was the central contact point.

The objective of the secondary control was to establish, survey and publish (into the national database (blue booking)) monuments at an approximate spacing of 7.0 kilometers. This grid spacing is the farthest distance one can utilize a RTK GPS systems optimally.

4.1 Monument Placement

Since our land parcels are based off of "townships" which are 6 miles (9.6 km) by 6 miles (9.6 km), the monuments are located in the general vicinity of the township corners and near the center. This produced a desired spacing effect of 7.0 kilometers.

The following were general guidelines used in location selection:

1. Bedrock.
2. No locked areas.
3. Less than 300 meters from vehicle access.
4. Preference to city, state and federally owned or leased land.
5. As hidden from the public eye as possible.
6. Good sky visibility
7. Easy access

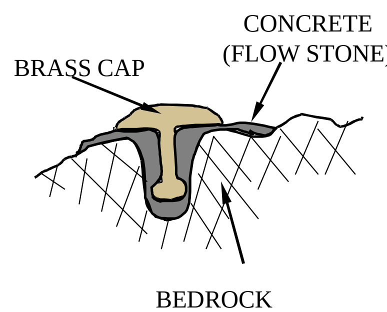
Occasionally obstructions and or logistics impeded the ideal grid space location of a monument. Depending on the severity of the movement, the surrounding monuments would need to be adjusted slightly. For an overall look at the final placement see diagram "Maricopa County, Arizona – Final Control Map" in section 5.3.

4.2 Monument Material

As a general rule two types of monuments were placed, a brass cap/disk in bedrock or a NGS 3D monument.

4.2.1 Brass Cap in Bedrock

When the situation arose and naturally occurring bedrock was exposed, a hole was made with a Punjar (gas powered drill/hammer) about 0.10 meters (0.33 feet) deep. Flow stone (aka hydraulic cement) was mixed at the site, poured into the hole and the brass cap placed. (See figure below - "Brass Cap in Bedrock") Once the cement dries the cap becomes a permanent fixture, barring vandalism.



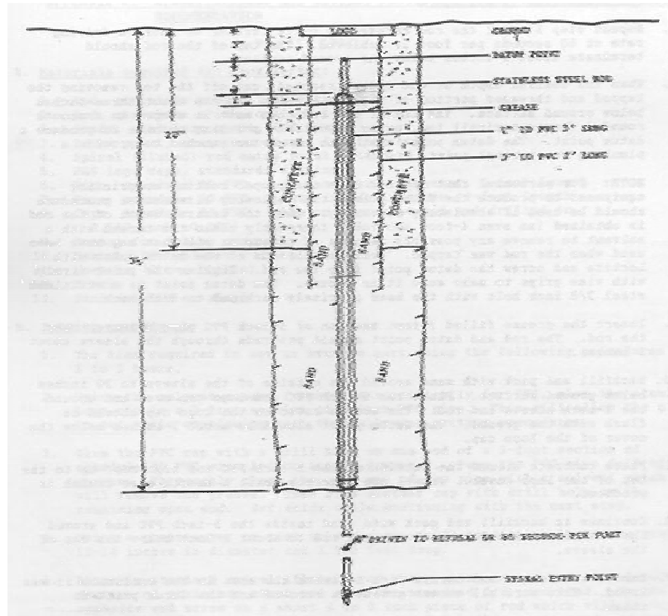
Brass Cap in Bedrock

This monument was preferred over the next type (NGS 3D monument). It is about 1/10th of the cost at approximately $20 in materials and requires much less time and energy to construct. It is also the most stable monument, less susceptible to subsidence and crustal movement.

4.2.2 NGS 3D Monument

When bedrock was not available, which was about 90 percent of the time, an NGS 3D monument was set. Referencing the figure below (NGS 3D Monument) it is a 9/16" stainless steel rod driven to refusal, which is defined by NGS as less than one foot of vertical movement in 60 seconds of impacted force. The rod is surrounded by a conglomeration of PVC pipes, sand, concrete and covered with an access cover. Although ominous at first, the monument is quite demure once installed. The only thing the casual observer might notice is the 7" access cover flush with the ground but even that could be covered with dirt if desired. For more information refer to the NGS publication "Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques", Ver. 5.0 May 11, 1988.

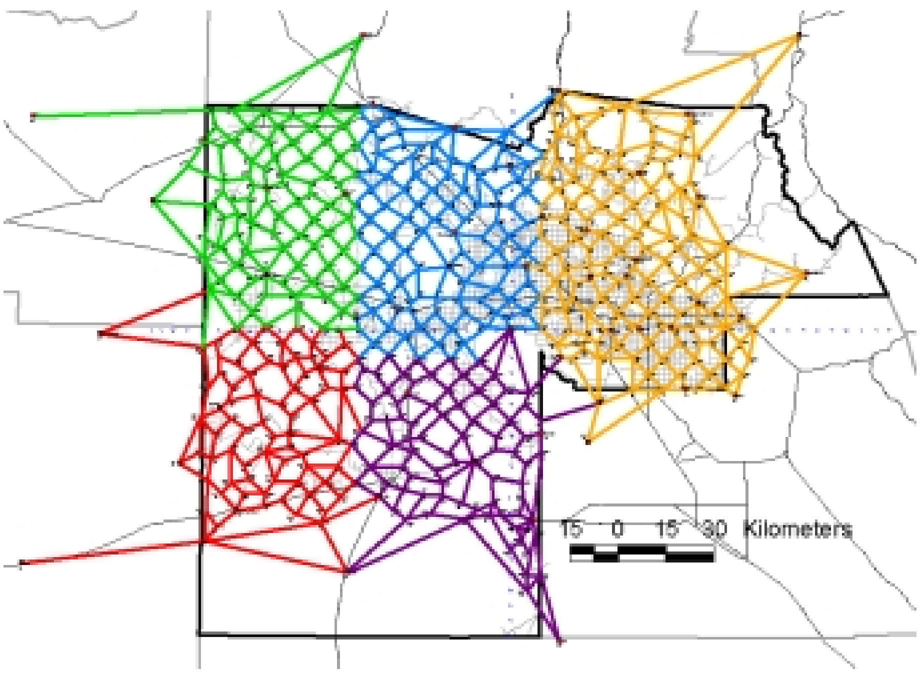
This particular monument costs about $200 for an average rod depth of 7.6 meters (25 feet). Depths vary pending on soil compaction and content. The longest rod in this project was driven 91.4 meters (300 feet) deep, the shortest was 1.2 meters (4 feet). Once at the installation site the monument requires 1-3 hours to install depending on soil conditions and experience.


NGS 3D Monument

In the immediate vicinity of both types of monuments, a forged steel eye bolt was installed permanently to secure equipment. There were 407 total monuments set for the secondary control phase. The average labor cost of all the monuments including on the job training, preparation each day (acquiring materials) and drive time to and from the site was $1,277.20 per monument (this does not include MCDOT management time).

4.3 Network Design and Management

Utilizing the *NOAA Technical Memorandum NOS NGS-58 (2cm – 5cm)* guidelines, MCDOT developed a static control network (see diagram - "Secondary Control Network"), and disseminated the vectors to the consultants. MCDOT held numerous classes on occupation, management and work flow procedures. Each consultant had a minimum of 4 GPS receivers running, totaling 20 receivers operating daily.



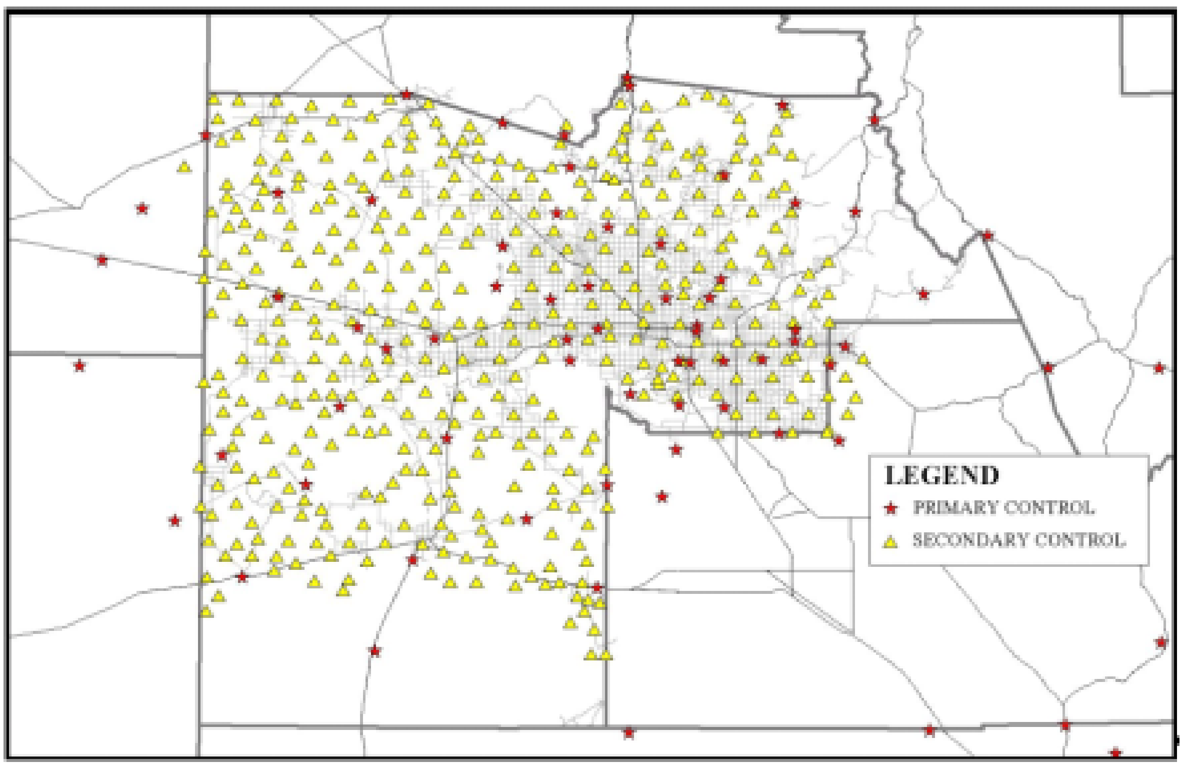
Secondary Control Network

Using Static GPS procedures, each monument was occupied a minimum of 2 times and often 4 to 5 times for one-half hour intervals. The average vector length was approximately 7.0 km in length. Vectors stretching farther required longer occupation times.

All the data collected by the consultants was transmitted to MCDOT for quality control, processing and adjustment. MCDOT followed all the "Blue Book" specification from NGS for inclusion into the national database system.

Altogether there were 1644 vectors occupied at an average cost of $371.34 per vector. Completion of this network gave Maricopa County nearly 500 B order (1:1,000,000) or better control points. See diagram - "Maricopa County, Arizona – Final Control Map".

Utilizing the final accepted geodetic positions (latitude, longitude and ellipsoid height), MCDOT derived vertical adjustment parameters utilizing least squares and 26 NGS first order vertical benchmarks. The maximum and average residuals were .027m (0.09 ft) and .014m (0.046 ft) respectively. This enables anyone to use RTK anywhere in Maricopa County and produce elevations within approximately 0.027m (0.09ft) with respect to other stable NGS first order benchmarks (barring any anomalies in the geoid and standard errors associated with the RTK system).



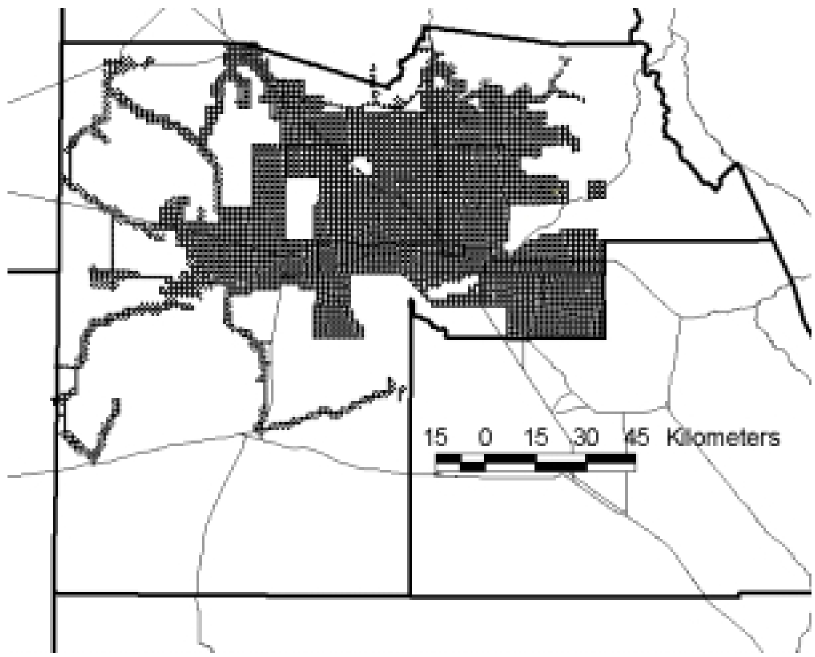
Maricopa County, Arizona – Final Control Map

The large open area to the south is Barry M. Goldwater Gunnery Range. It is an active range used for military bombing and miscellaneous tests. The large area open to the northeast is the Tonto National Forest which is federal land and densely wooded. The open circular areas in the middle are various federal wilderness areas.

5. PHASE C – THE CADASTRAL SURVEY

Maricopa County has approximately 160 townships, which contain 5760 sections, monumented by 17,000 or more section and quarter section corners. Utilizing the consultants, MCDOT is surveying approximately 10,000 of these corners in and around the metropolitan and suburban areas, along with designated county roads and highways. MCDOT decided not to survey the center of sections due to the additional cost, in addition they were not set by the original surveys that subdivided the land.

Some areas, as discussed previously, are in remote locations in which construction is prohibited or are highly unlikely for quite some time. The diagram below displays the corners being surveyed.



Selected Cadastral Corners

MCDOT has developed a 37 page specifications manual for all the consultants to follow to insure consistent, quality data. The cadastral phase is broken up into numerous sub phases. Each sub phase contains two townships of corners for each consultant, approximately 250 corners. Even tackling just one sub phase is difficult to estimate the cost without spending quality time in the area. For this fact, each sub phase is split one more time into two surveys. The first is called an ”inventory” survey. The purpose of the inventory survey is to locate and survey all of the monuments that are fairly apparent in the area. Completing this portion gives MCDOT a chance to decide whether to proceed with a particular township. This also helps to estimate the completion cost of the particular area. If it is decided that the area should be completed the second survey is commenced. This is called the ”boundary” survey. So far only one township has stopped after the ”inventory” survey due to the high probability of litigation in completing the boundary portion.

5.1 Occupation Procedure

MCDOT dictates that RTK GPS be utilized whenever possible to survey monuments. To date, only 2 monuments required taping out of the approximate 3000 surveyed. RTK provides superior searching abilities, accurate position retrieval and thorough attribute gathering.

Due to the cost, a reoccupation of each monument under a significant change of satellite geometry (later time) is impractical. To insure a solid integer solution, two moving independent On-The-Fly (OTF) initializations are performed at each monument with a minimum of two occupations of at least 90 epochs each. The chances of obtaining two identical independently obtained erroneous OTF initializations are highly unlikely. Once a bad initialization is detected it is discarded. All acceptable initialization will produce a resultant position within a quarter of the L1 wavelength or 0.0475 meters. To help minimize field error (i.e. bubble adjustment, occupation of the same punch mark, etc) the tolerances are set and not to exceed 0.021 meters (0.07 feet) horizontally and vertically. If either component is breached, reoccupation until compliance is required.

A mean is determined from the positions with a weighted average resulting in a final coordinate for each monument.

Monument attribute gathering is performed by a series of detailed prompts which change depending of the physical monument encountered. Attributes include items such as material type, orientation of monument (above, flush or below ground) and by how far, identification, and many more. This extremely reduces the chances of missed attributes and keeps the consultants consistent amongst themselves and to each other.

In addition, digital images are required of each monument. The MCDOT specifications outline the procedure on obtaining the images to insure quality and consistency between the consultants.

5.2 Results of Survey

Each consultant is tasked with producing a results of survey for each portion of a phase.

The inventory survey only requires minimal detail and consists of the following:

1. A cover sheet depicting the entire township with all the found monuments.
2. An extensive coordinate list including point name, latitude, longitude, ellipsoid height, northing, easting, elevation, convergence, state plane scale factor and an in-depth monument description.

The boundary survey is quite comprehensive, requiring the items from the inventory survey plus the following:

1. The cover sheet containing the entire township with bearings and distances to all accepted monuments.
2. Details when necessary.
3. An extensive coordinate list, however this one includes a column called location which denotes the United States Public Lands code (i.e. T1N R1E 36 NE)
4. A historic time line of the particular township, outlining when it was established and any significant surveys between then and now.
5. A document index/records table, indexing all the documents (surveys, deeds, etc), recorded or not, utilized by the consulting registered land surveyor in determining whether to reject, accept or re-establish a new corner.

6. Corner Determination Table. This is a detailed account of the methods and records used by the consulting registered land surveyor when rejecting, accepting or re-establishing a new corner.

Once again, MCDOT has generated strict guidelines to follow insuring consistency between the consultants. Each drawing set covers one township (6 miles by 6 miles) and is plotted on 24 x 36 inch paper at 1" = 1500'. All horizontal data is represented in the North American Datum of 1983 (NAD 83), 1992 epoch, and the vertical is in the North American Vertical Datum of 1988 (NAVD 88). All distances and coordinates are displayed in international feet.

5.3 The Database

MCDOT has spent over a year in customizing a database to warehouse all the collected information.

5.3.1 Populating the database

The consultants can directly import all of the data collected form the surveying software resulting in minimal hands on editing thus reducing blunders from keyboard entry. Once a particular sub phase is completed by a consultant the data is transmitted to MCDOT where it is added to the main database.

5.3.2 Accessing the data

The data will be accessible via the internet. Instead of MCDOT developing a web site, the data will be transmitted to the Arizona State Cartographers (ASC) site (http://sco.az.gov/website/geoserver/default.htm) for graphical interactive data retrieval. As more counties, municipalities and utility agencies add to this database, taxpayer savings will be realized by negating the need to develop multiple web sites. In addition, it will keep the data localized insuring greater accuracies and create a one-stop-shop for the public.

Given all the tasks for the cadastral phase, an average cost including consultant field labor, office time and delivery is approximately $450 to $550 per corner. This does not include MCDOT management time.

6. PHASE D – PROJECT MAINTENANCE

As maintenance is needed, internal MCDOT survey crews will complete the tasking and take the appropriate steps to inform the public.

6.1 Control (Primary or Secondary)

As Continually Operating Reference Station (CORS) sites that broadcast RTK frequencies become more prevalent, the need to re-establish control will become less and the remaining existing control will become vital check points for assuring quality control for data collection.

Thanks to SRP and City of Scottsdale, Maricopa County has two and soon to be four CORS sites that broadcast RTK frequencies. MCDOT is planning to install a fifth later this year.

6.2 Cadastral Corners

As the surveying communities becomes more familiar with geodetic positions and state plane coordinates the need to re-establish a physical monument at the locations we are currently collecting will become obsolete.

7. CONCLUSIONS AND RECOMMENDATIONS

The overall cost of this project is estimated to be about $7.6 M. It started in the middle of 1998 and is scheduled to be completed the end of 2004.

More than a few lessons have been learned tackling a project of this magnitude. Although the project is technically and logistical very difficult, one of the hardest issues to overcome is funding. Nothing happens without the capital. Even if you currently have some funds allocated, spend some quality time brain storming, writing and justifying all the benefits for such a project. It is a difficult project to quantify the saving because the end users are usually other government agencies or far removed from the actual project (i.e. a private person contracting the services of a land surveyor, that private person will begin to save money and the more time that goes by, the more money is saved). Doing this will create a better understanding among your staff and assist in selling the project to non-technical funding sources.

It is imperative that there is a competent, dedicated, extremely well organized project manger in charge, whether in-house or a consultant. Unlike a bridge, a road or any other physical object you can walk up to and touch, you will be collecting information. The quality and accessibility of the data is <u>everything</u>! Tracking everything from the budget to work performance will lead to a successful project.

For current updates and additional project information please visit, <u>www.mcdot.maricopa.gov/survey</u>.

A byproduct that resulted from this project is an indexing of all of the Maricopa County recorded plats. Up until 2 years ago, there was no real way to query the Recorders Office for survey and subdivision plats performed in a given area. The closest venue that existed was the county assessors map which only contained large subdivision plats. Internal MCDOT personnel, with the help of outside volunteers, indexed over 29,000 survey plats by plat name, date, township, range, section, quarter section, quarter-quarter section, registered land surveyor, recordering number, book and page. The search engine is on the web (<u>http://www.mcdot.maricopa.gov/ apps/2plat/</u>) and has become a staple in every surveyors tool bag.

Good Surveying.

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BIOGRAPHICAL NOTES

Brian Dalager graduated from California State University, Fresno with a B.S. in Surveying Engineering. He moved to Phoenix and worked in the private sector for three years until taking a position at Salt River Project (SRP), Phoenix's power company. During the next 2 years at SRP he managed the Global Positioning Systems (GPS) section in the survey department. Maricopa County Department Of Transportation(MCDOT) then hired Mr. Dalager to develop and manage the county wide Geodetic Densification and Cadastral Survey (GDACS) project. He has been working at MCDOT since 1998.