The Yolo County Subsidence Network

Recommendations for Future Monitoring
May, 2000

GPS equipment set up at station HERSHEY near Colusa Basin Drainage Canal.

EXECUTIVE SUMMARY

In late 1998, a series of meetings was initiated between representatives of the Water Resources Association of Yolo County (WRA), the U.S. Army Corps of Engineers Topographic Engineering Center (the CORPS) and the National Geodetic Survey (NGS) to explore the subject of ground subsidence monitoring in Yolo County.

Subsequent meetings attended by representatives of the Corps, the California Department of Water Resources (DWR), and various Yolo County and city agencies resulted in a plan to establish a network of survey monuments throughout the county.

Partners and funding sources were identified, and the City of Davis was selected as lead agency for the project.

The network, which would serve as the framework for monitoring subsidence in the county, was installed in July 1999. Global Positioning System (GPS) observations on the network were completed in

August of 1999.

With the network now in place, we offer the following recommendations for consideration by the project participants:

Recommendation 1. Inform public and private agencies involved in construction, utilities management, public works and related activities in the county about the network and the location of all stations. Information about the project's web site should be included in this information.

Recommendation 2. Task a single county entity with visiting each monument in the network annually to assess the integrity of the individual monuments. Any discrepancies in monument description or condition should be brought to the attention of interested County parties and to the National Geodetic Survey (NGS). Follow proper formats for reporting such discrepancies.

Recommendation 3. Identify stations in imminent danger of destruction and replace them in advance, following National Geodetic Survey guidelines. (A copy of these guidelines may be obtained from the NGS California State Geodetic Advisor, Marti Ikehara - <marti_ikehara@dot.ca.gov>).

Recommendation 4. Re-observe the entire network in three years (2002).

Recommendation 5. Investigate the benefits of more frequent re-observation of particular areas of the county.

Recommendation 6. Investigate densification of the network in areas of particular interest.

Recommendation 7. Provide continuing nonfinancial support for the Continuously Operating Reference Station (CORS) at the University of California, Davis.

Recommendation 8. Investigate the establishment of a CORS site in the north county area.

Recommendation 9. Consider the merits of encouraging the Federal Emergency Management Agency (FEMA) to adopt the results of the project in its flood plain mapping efforts.

Recommendation 10. Investigate other supporting technologies as an adjunct to the GPS Subsidence Network within Yolo County. A complete list of these recommendations and their rationale is included in Section VI of this report.

Conclusion

A county-wide, unified, dense, and highly accurate network of monumented geodetic control stations sufficient to meet most spatial positioning requirements is now in place in Yolo County.

The network will support subsidence monitoring, its primary function, but will also meet most surveying, engineering design and Geographic Information System (GIS) technology needs into the future.

Full benefit from use of the network for monitoring subsidence can only be realized if the network is preserved and re-measured periodically.

Top of Page

Final Report

I. INTRODUCTION

This report outlines recommendations for capitalizing on the existence of a highly-accurate county-wide network of stations established using the Global Positioning System (GPS) in 1999.

This network provides the basis for monitoring subsidence in the county with an accuracy suitable to

meet all participating agency requirements. It further provides the basis for other spatial positioning requirements in the county including Geographic Information System (GIS) development.

The project was the culmination of a series of meetings and actions by agencies with a concern about subsidence in Yolo County. A list of the agency participants and those personnel who participated in the project is included.

Top of Page

II. BACKGROUND

The Global Positioning System is a highly-accurate, satellite-based, spatial positioning technology. It is capable of providing sub-centimeter horizontal positions (coordinates) over large distances.

Because of the nature of the GPS satellite configuration and other considerations it is not able to provide equally accurate vertical positions (elevations). Generally speaking, the accuracy of GPS-derived elevations is only one-half to one-third as accurate as GPS-derived horizontal positions (latitude and longitude), and achieving this vertical accuracy requires a greater effort than that required for horizontal accuracies.

The plan of the Yolo County network was to develop a methodology to achieve the maximum vertical accuracy in a reasonable and practical manner.

In 1994, the National Oceanographic and Atmospheric Administration's (NOAA's) National Geodetic Survey (NGS) began testing large multi-day GPS data sets to determine a set of guidelines for achieving a few centimeters of accuracy in the vertical coordinate. The data were extracted from GPS observations obtained by the Harris-Galveston Coastal Subsidence District in Texas and over the network established near the National Institute of Science and Technology (formerly the National Bureau of Standards). This latter network served as the proving ground for GPS manufacturing companies to test their equipment against a known standard.

After over a year of testing, including a test project in the San Francisco Bay area, the guidelines were established where, with a minimum of observation time and with some more-demanding observing techniques, elevations could be determined at the two to three centimeter level (about one inch). This is

approximately consistent with older terrestrial leveling techniques over distances such as the station spacing in the Yolo County network. But terrestrial leveling techniques are more labor-intensive, require longer time to complete, and are about five times more costly.

The network in the Bay area was then extended eastward in 1996. It was further extended in 1997 and 1998 into the Sacramento-San Joaquin River delta area, including the area of Yolo County along and below the Highway 80 corridor.

These succeeding projects proved the ability of the GPS technology to meet previously unattainable levels of accuracy over reasonably short time periods and with reasonably short observation times per station (a minimum of 30 minutes).

In late 1998, representatives of the U.S. Army Corps of Engineers' Topographic Engineering Center and NGS met to discuss the use of GPS technology to measure and monitor subsidence in other areas of the Central Valley.

Water Resources Association of Yolo County (WRA) Executive Coordinator presented the information to the WRA Technical Committee. Interested WRA members (the cities of Davis, Winters and Woodland, the County of Yolo and the Yolo County Flood Control and Water Conservation District) and the California Department of Water Resources agreed to pursue the establishment of a GPS network in the county suitable for monitoring subsidence.

Reconnaissance to select existing survey monuments and sites for new survey monuments for the Yolo County project began in late May, 1999, and field observations were completed in August.

A total of 50 stations were established in the survey. After completion of the basic project stations in July, it was decided that a station near each of two extensometers, operated by the California Department of Water Resources, should also be included in the project. Observations to these extensometer sites (near Zamora and on the Conaway Ranch) were obtained in late August.

Stations observed in the project are listed here.

Top of Page

III. DISCUSSION

While the use of GPS to determine accurate elevations is becoming more widespread, subsiding areas present unique concerns.

Subsidence is generally caused by fluid withdrawal or hydro-compaction. In some areas of the country it is caused by groundwater withdrawal (e.g., California's Central Valley, Texas' Harris-Galveston Counties) and in others by oil and gas withdrawal (e.g., the Port of Long Beach). Hydro-compaction has been known to occur in some areas of the western San Joaquin Valley.

Subsidence can be extreme. In the Mendota area of Fresno County there has been over 27 feet of subsidence over the history of recorded leveling, which began in the 1920's.

In general, most of the Central Valley of California is subject to subsidence.

Subsidence is not a phenomenon that lends itself to prediction (of annual rates, for example), except in an average sense, since it is a function of several variables that vary from year to year and even from season to season.

Subsidence is not uniform over even relatively small areas. Differential subsidence (the amount a particular area subsides with respect to a neighboring area) can occur over points separated by as little as a mile, and perhaps less. For this reason, subsidence can only be monitored accurately if it is related to areas of stability, and this is where GPS technology is of particular benefit.

Prior to the mid-1990s the generally accepted method of measuring and monitoring subsidence was by conventional leveling techniques. These techniques were extremely labor-intensive and costly. Because of the differential nature of subsidence a denser network of leveling was required, driving the cost up higher yet.

By 1996 GPS had proven itself capable of achieving similar coverage with comparable accuracies at only a fraction of the cost. But it did not obviate the need to tie areas of subsidence to known areas of stability, sometimes tens of kilometers distant (as in the case of Yolo County).

A complicating factor in the use of GPS is that the

coordinates obtained, both horizontal and vertical, are related to a mathematical surface, expressed in Cartesian (x, y, and z) coordinates. These coordinates then need to be converted to the geodetic system.

In North America the geodetic system is composed of two parts; the horizontal part is the North American Datum of 1983 (NAD83) and the vertical part is the North American Vertical Datum of 1988 (NAVD88). It is a relatively straightforward process to translate the GPS-derived Cartesian coordinates into the NAD83 and NAVD88 geodetic coordinates.

The accuracy of this translation depends on the physical stability of the points being measured. Subsiding areas present unique problems that make accurate coordinate conversion problematic. To overcome these problems it is necessary to perform simultaneous GPS observations in the subsiding area and stations with known NAVD88 elevations in non-subsiding (stable) areas. This was accomplished in the Yolo County network.

View the results of terrestrial leveling that was performed between some of the network stations.

The use of GPS eliminates the need for significantly more expensive and labor-intensive terrestrial leveling techniques.

Top of Page

IV. THE YOLO COUNTY NETWORK

The Yolo County network consists of 47 stations inside the county and three stations outside the County.

The stations outside the county serve to connect the network to areas of stability to the east and to the north. An existing stable site in western Yolo County was also used. Two of the stations in the network are Continuously Operating Reference Stations (CORS). These two stations are part of the Bay Area Regional Deformation (BARD) network monitored by the University of California, Berkeley Seismological Laboratory in cooperation with the University of California, Davis. The BARD network provides monitoring of the network of CORS sites throughout northern California. Coordinates (latitude, longitude and elevation) for these sites are monitored continuously.

The Yolo County network, a combination of existing and new survey monuments, was observed according to guidelines established by the National Geodetic Survey. The GPS observations took place in July and August, 1999.

A copy of the project map is included in the envelope at the back of the printed report. For a more complete discussion of the network observations and related information see "The Yolo County 1999 GPS Subsidence Project: Field Operations Report", also by Don D'Onofrio and Jim Frame.

The network, for its county-wide coverage and accuracy, is still only a combination of discrete points. It is simply the framework to which other stations, perhaps more dense and employing other technologies, can be related.

It is also important to note that the network coordinates represent positions at the time of the observation. Since subsidence is a dynamic process, differing from location to location, the coordinates are susceptible to change over time. These issues are discussed in the recommendations, (Section VI).

The Yolo County project was accomplished under contract with Frame Surveying & Mapping, a Davis-based firm, which retained Don D'Onofrio for his geodetic expertise. All observations were performed with support from a number of participating public agencies. These agencies included:

- U.S. Bureau of Reclamation
- California Department of Transportation
- Yolo County Planning and Public Works Department
- City of Woodland

Personnel from these agencies were provided at no cost to the project.

This support accounted for about 70 person-days of effort. This is both a significant contribution and an outstanding example of cooperative effort among different levels of government.

The overall project was managed and administered by the City of Davis Public Works Department. The value of these staff contributions is approximately $25,000.

In addition, GPS survey equipment-usage

contributions were provided for the duration of the project by the following agencies:

· U.S. Bureau of Reclamation
· California Department of Transportation
· University of California, Davis

The GPS and related equipment was provided to the project at no cost. The value of the equipment contributions is approximately $15,000.

Top of Page

V. SUBSIDENCE IN OTHER AREAS

At least two areas of the United States have established ongoing GPS monitoring of subsidence: the Harris-Galveston Coastal Subsidence District in Texas and the Port of Long Beach in California.

In both cases their monitoring efforts go back to the 1950s. The former began GPS monitoring in 1995 and the latter about 1998.

Other areas in California have been surveyed for subsidence, including the Santa Clara Valley, Coachella Valley and the California Aqueduct.

Representatives involved in these efforts have been contacted for subsidence monitoring recommendations. Appendix D features a list of those contacted and a sample of the letter sent to each. A review of the responses combined with input from county and local agencies should help to develop a sound policy for future monitoring of the Yolo County network.

Any policy developed for these monitoring efforts must include the ability to relate Yolo County survey monuments to those stable survey monuments outside the County.

Top of Page

VI. RECOMMENDATIONS FOR MONITORING AND USE OF THE YOLO COUNTY NETWORK

A first step in capitalizing on the county-wide network is to ensure that the survey monuments that make up

the network are preserved.

Survey monuments are susceptible to destruction from construction activities, inadequately planned or improperly executed maintenance activities, and vandalism. Occasionally a monument will be in the way of highway construction and cannot be preserved. Establishment of a new station monument and transfer of elevation prior to the destruction of the original will preserve the value of the monument to be destroyed and the associated subsidence history.

Recommendation 1. Inform public and private agencies involved in construction, utilities management, public works and related activities in the county about the network and the location of all stations. Information about the project's web site should be included in this information. There is no cost, per se, associated with this recommendation. Information about the network, including station listing, description, and a variety of related information are included in the project web site.

Recommendation 2. Task a single county entity with visiting each monument in the network annually to assess the integrity of the individual monuments. Any discrepancies in monument description or condition should be brought to the attention of interested County parties and to the National Geodetic Survey (NGS). Follow proper formats for reporting such discrepancies.

We estimate that Recommendation 2 will require about one person-week of effort per year. This includes visiting all sites and preparing reports on any discrepancies noted.

Recommendation 3. Identify stations in imminent danger of destruction and replace them in advance, following National Geodetic Survey guidelines. (A copy of these guidelines may be obtained from the NGS California State Geodetic Advisor, Marti Ikehara - <marti_ikehara@dot.ca.gov>). A station destroyed before replacement represents a permanent break in the

subsidence history of that station.

We estimate that Recommendation 3 will require about three person-days of effort for each station destined to be destroyed plus the cost of materials to establish the new station. This includes selecting the location of the new site (in the vicinity of the destroyed station), resetting the new station monument, performing a terrestrial leveling tie between the two monuments, and preparing the necessary documentation.

NOTE: Recommendation 4. Re-observe the entire network in three years (2002). Depending on the results of this re-observation the county can better determine the time period for subsequent re-observations.

We estimate that Recommendation 4 will require somewhat less time and cost than the original (1999) project since there will be few, if any, new survey monuments to be set. This assumes the project will be accomplished in the same manner as the 1999 project, i.e., observation personnel and equipment provided by participating agencies. It is possible that changes in the use of the GPS technology may allow the project to be accomplished in a shorter time frame, and thus at a further reduced cost.

Recommendation 5. Investigate the benefits of more frequent re-observation of particular areas of the county. We have no estimate for the cost of such a project because of the uncertainty of the size and scope of such a project. Subsidence rates and amounts differ throughout the county. Areas where smaller amounts of subsidence are critical to infrastructure maintenance might lend themselves to more frequent re-observation.

We can provide estimates if there is interest in considering a project in a

particular area.

Recommendation 6. Investigate densification of the network in areas of particular interest. We have no estimate for the cost of such a project because of the uncertainty of the size and scope of the project. As discussed above, differential subsidence can occur over relatively small areas. The basic network, which provides an excellent framework for the county as a whole, might not provide the spacing and location of monuments for a more in-depth investigation in concentrated areas, e.g., the cities of Davis or Woodland or, the levees along Cache Creek.

Using modified GPS observing techniques, specifically Real Time Kinematic (RTK), can provide a reasonably cost-effective and timely means to accomplish an accurate survey over city-sized areas. Conventional terrestrial leveling techniques might also be suitable over these short distances.

Recommendation 7. Provide continuing nonfinancial support for the Continuously Operating Reference Station (CORS) at the University of California, Davis. This site can be of significant value in ongoing subsidence measurement operations.

The UCD CORS site is referenced to other CORS outside the county and can help to provide real-time elevations at the site in the NAVD88 reference frame. County agencies can use this site in ongoing subsidence measurement operations.

Recommendation 8. Investigate the establishment of a CORS site in the north county area. We estimate the cost of a CORS installation to be about $30,000 plus annual monitoring and maintenance costs; there are entities outside the county that may be willing to cooperate with the

county in sharing these costs.

The 20-plus CORS sites that have been established in northern California have been established in areas to support earthquake hazard research. The site at UC Davis is the only one that adequately serves Yolo County for subsidence purposes. Our experience with establishing CORS sites as part of California's Earthquake Hazards Reduction Program indicate that obtaining land use permits for CORS establishment can be very time-consuming.

Experience in southern California has shown that educational institutions frequently make good partners for such an installation. A CORS site established in Dunnigan, couple with the two existing extensometers monitored by the California Department of Water Resources (in Zamora and on the Conaway Ranch), would provide an excellent basis for indications of general subsidence trends in the county.

Recommendation 9. Consider the merits of encouraging the Federal Emergency Management Agency (FEMA) to adopt the results of the project in its flood plain mapping efforts.FEMA flood plain maps are required to be based on NAVD88 elevations supplemented by data from other Federal, state and local agencies.

The 1999 YOLO County GPS Subsidence Network will provide the most accurate and up-to-date NAVD88 elevations in the county. Affected personnel and agencies will have to fully understand the issues of flood plain mapping in subsiding areas. Subsidence could place previously unaffected properties in the flood plain, and could similarly result in the removal of some currently affected areas from requiring flood plain insurance.

Recommendation 10. Investigate other supporting technologies as an adjunct to the GPS Subsidence Network within Yolo County. (See Section VII.)
Top of Page

VII. OTHER SUPPORTING TECHNOLOGIES

There are additional technologies that can provide information about change detection (subsidence).

These are: Synthetic Aperture Radar (SAR) and Light Detection And Ranging (LIDAR). Both technologies provide areal coverage, rather than discrete point coverage as with GPS. Both LIDAR and SAR have other uses beyond those for use as detectors of vertical changes.

Synthetic Aperture Radar (SAR) is a technology suited for change detection. The technology employs aircraft- or satellite-based sensors that monitor the ground and in successive passes can determine the change in elevation over large areas to about five centimeter accuracy. There are some issues that need to be resolved, especially in agricultural areas. The technology cannot distinguish between the ground and the tops of vegetation. In an extreme case, successive passes over a field lying fallow at the first observation and with a full mature crop of corn at the second would indicate the change of perhaps a couple of meters!

Light Detection And Ranging (LIDAR) is the optical analog of radar. The energy source for the system is laser. The system serves as a range finder, measuring the distance from the LIDAR platform, generally an aircraft, to the ground. It otherwise provides information and data similar to SAR for the purposes of monitoring vertical changes.

It should be remembered that both SAR and LIDAR are change detection technologies. They can apparently record the relative differences in an area over time, but cannot measure the absolute change without some ground-truth mechanism. That is where GPS is needed, whether or not SAR or LIDAR are employed. There are costs associated with each of these technologies (SAR and LIDAR).

In the early phases of their development and use, there may be opportunities for further partnering efforts and cost-sharing.

Top of Page

VIII. CONCLUSION

A county-wide, unified, dense, and highly accurate

network of monumented geodetic control stations sufficient to meet most spatial positioning requirements is now in place in Yolo County.

The network will support subsidence monitoring, its primary function, but will also meet most surveying, engineering design and Geographic Information System (GIS) technology needs into the future.

Full benefit from use of the network for monitoring subsidence can only be realized if the network is preserved and re-measured periodically.

The coordinates (latitude, longitude and elevation) determined in the 1999 GPS Subsidence Project are consistent with those used by other Federal and State agencies.

Accurate measurements of subsidence can only be achieved if the network is related to stable (non-subsiding) areas, which are primarily outside the county. Densification (closer spacing of monitoring points) in some critical areas in the county is recommended.

Participating agencies should also keep abreast of emerging technologies, i.e., SAR and LIDAR, to determine how they might be used in the subsidence monitoring process.

Respectfully submitted:

Don D'Onofrio, Geodetic Consultant
7228 Willowbank Way
Carmichael, CA 95806
(916) 944-7879

Jim Frame, Frame Surveying & Mapping
609 A Street
Davis, CA 95616
(530) 756-8584

Top of Page

Entrance Participating Organizations
Monitoring Stations Links

Web Site by: